API RP-552

Signal Transmission

2nd Edition

Contents

1 Scope 14
2 Acronyms and Definitions 14
2.1 Acronyms 14
2.2 Definitions 18
3 Signal Transmission Methods 30
3.1 Design Considerations 30
3.2 Pneumatic Transmission 31
3.3 Electronic Signals 32
3.3.1 Standard Signal Types 32
3.3.2 Signal Isolation 41
3.3.3 Single Ended Inputs and Outputs 42
3.4 Serial Data 44
3.4.1 Serial Data Transmission Types 44
3.4.2 Floating Point Data 51
3.4.3 Isochronous Operation and Time Synchronization 52
4 Transmission Standards and Protocols 52
4.1 Communication Protocols 52
4.2 Serial Interfaces 53
4.2.1 RS-485 53
4.2.2 RS-232 56
4.2.3 ASCII 57
4.3 Fieldbus Networks 59
4.3.1 General 59
4.3.2 Modbus RTU 60
4.3.3 HART FSK 61
4.3.4 H1 Foundation™ Fieldbus 62
4.3.5 PROFIBUS 65
4.3.6 FOUNDATION™ Fieldbus H1 vs PROFIBUS 67
4.3.7 Manchester Encoding 68

4.4 Discrete Logic Networks 72
4.4.1 Actuator Sensor Interface (ASi) 72
4.4.2 DeviceNet 72
4.5 Industrial Ethernet 73
4.5.1 Foundation™ HSE 74
4.5.2 EtherNet/IP™ 74
4.5.3 PROFINET 75
4.5.4 Modbus/TCP 76
4.5.5 HART-IP 77
4.5.6 IEEE 802.3cg Ethernet 77
4.5.7 OPC UA (Open Platform Communication United Architecture) 79
4.5.8 Ethernet Switches 82
4.6 Wireless Protocols 85
4.6.1 Proprietary Protocols 85
4.6.2 WirelessHART 86
4.6.3 ISA 100.11a 86
4.7 SCADA 87
5 Cybersecurity 87
5.1 Physical Security 88
5.2 Serial Data Security 88
5.2.1 Data Encryption 88
5.2.2 Data Port Security 89
5.2.3 OPC UA 89
5.3 Network Access Security 89
5.3.1 Firewalls 89
5.3.2 Virtual Private Networks 90
5.3.3 Zero Trust 90

5.4 Wireless Security 91
5.5 Cybersecurity References 92
6 Device Definition Software 92
6.1 Introduction 92
6.2 Device Description Languages 92
6.3 FDI/EDDL 93
6.3.1 EDDL 93
6.3.2 FDI 94
6.3.3 FDI Host 94
6.3.4 Product Certification 95
6.4 FDT/DTM 95
6.4.1 FDT 95
6.4.2 DTM 96
6.4.3 DTMS Types 96
6.4.4 FDT Frame 97
6.4.5 PACT*ware* 97
6.5 EDDL and DTM Comparison 97
7 Electrical Hardware 99
7.1 NEMA/IEC Handswitches 99
7.1.1 Pushbuttons 99
7.1.2 Selector Switches 101
7.1.3 Pilot Lights 102
7.1.4 Contact Blocks 102
7.1.5 Contact Types 104
7.2 Wire Terminals 105
7.2.1 IEC vs. NEMA Terminal Blocks 105
7.2.2 Terminal Block Bodies 106
7.3 Horns and Beacons 106
7.3.1 Audible Signals 106
7.3.2 Visual Beacons 107
7.3.3 Beacons and Audio Signals Wiring 108

7.4 Control Enclosures 108
7.4.1 Enclosure Construction 108
7.4.2 Enclosures Materials 110
7.4.3 Content Protection 112
7.4.4 Terminal and Outlet Boxes 114
7.4.5 Junction Boxes 115
7.4.6 Local Panels 116
7.4.7 System Cabinets 117
7.4.8 Cabinet Colors and Lighting 118
7.4.9 Marshalling 118
7.4.10 Field Mounted I/O Cabinets 119
7.5 Tagging and Nameplates 120
7.5.1 Instrument Label Fabrication and Attachment 120
7.5.2 Nameplate Fabrication 120
7.5.3 Nameplate Color Codes 120
7.5.4 Nameplate Service Descriptions 120
7.6 Shock and Vibration 121
8 Electrical Signal Installation 121
8.1 Wire and Cable Selection 122
8.1.1 Cable Types 122
8.1.2 Wire Type 126
8.1.3 Applications 126
8.1.4 Wire and Cable Specification 127
8.2 Raceway and Cable Tray Installation 140
8.2.1 Comparison of Cable and Conduit Systems 140
8.2.2 Conduit 141
8.2.3 Cable Trays 142
8.2.4 Channel Tray 144
8.2.5 Underground Installations 144
8.2.6 Flexible Wiring 146
8.2.7 Messenger Cable 147

8.2.8 Access Floors 148
8.3 Wire Termination 150
8.3.1 Terminal Strip Installation 150
8.3.2 Wire Installation 150
8.3.3 Wire and Terminal Identification 151
8.4 Electrical Noise 152
8.4.1 Noise Resistant Equipment 153
8.4.2 Shield Application 153
8.4.3 Signal and Power Separation 159
8.4.4 Noise Minimization Techniques 162
8.5 Grounding 163
8.5.1 System Grounding 163
8.5.2 Conduit and Tray Grounding 164
8.5.3 Grounding Networks 165
8.5.4 Cathodic Protection Systems 173
8.6 Surge Protection 174
8.6.1 Surge Protection 174
8.6.2 Inductive Spike Suppression 177
8.7 Ethernet Installation 179
8.7.1 Installation Practices for Ethernet 179
8.7.2 Ethernet and Fieldbus Connectors 179
8.8 Close Circuit Television 180
8.8.1 Analog Cable Transmission 180
8.8.2 Analog Cable Types 181
8.8.3 Internet Protocol (IP) Transmission 182

9 Fiber Optic Cable 182
9.1 Fiber Optic Planning 183
9.2 Multimode vs Single-Mode Fibers 184
9.3 Fiber Optic Cable Types 184
9.4 Typical Fiber Optic Cable Specification 185
9.5 Fiber Optic Cable Routing 186
9.6 Fiber Terminations 187
9.7 Fiber Connectors 188
9.8 Patch Panels and Outlet Boxes 188
9.9 Fiber Cable Installation 189
9.10 Fiber Optical Testing 189
10 Wireless Installation 190
10.1 Frequencies 190
10.2 Wireless Plant Networks 190
10.3 Wireless Sensor Networks 191
10.4 ISA 100.11a vs WirelessHART 191
10.4.1 Wireless Layout 192
10.4.2 Wireless Device Installations 193
10.4.3 Wireless Gateway Installation 194
10.4.4 Repeaters and Wireless Backhaul 194
10.4.5 Antennas 194

10.5 Power Considerations 195
10.6 Host Interfaces 196
10.7 Wireless System Management 196
11 Electrical Power Supply 196
11.1 AC Power Distribution 196
11.2 DC Power Distribution 197
12 Electrical Code Application 198
12.1 Codes and Standards 198
12.2 Zone Classifications 199
12.3 National Recognized Testing Laboratories 200
12.3.1 OSHA 1910.303 200
12.3.2 OSHA 1910.307 201
12.4 Field Labeling 201
12.5 IEC Standards 202
12.5.1 IEC 60364 202
12.5.2 IEC 60079 202
12.5.3 IECEx 202
12.6 Class I, Division 1 Areas 202
12.7 Class I, Division 2 Areas 203
12.7.1 Division 2 Installation Requirements 203
12.7.2 General-Purpose Assemblies 203
12.8 Wiring Methods for Class I Locations 205
12.9 Conduit and Cable Seals 206
12.9.1 Conduit Seal Fittings for Enclosures 207
12.9.2 Transition from Classified Locations 207
12.9.3 Pressure Piling 208
12.9.4 Exceptions to Sealing 208
12.9.5 Vapor Seals 208
12.9.6 Cable Glands 208
12.9.7 Process Seals 209

12.10 Maximum Surface Temperatures 210
12.11 Explosionproof Enclosures 211
12.12 Pressurized and Purged Enclosures 212
12.13 Combustible Gas Detection 216
12.14 Optical Fiber in Classified Areas 217
12.15 Intrinsically Safe and Nonincendive 217
12.15.1 Intrinsically Safe Installations 218
12.15.2 Nonincendive Installations 227

13 Fire Protection 233
13.1 Fire Resistant Cable and Tray 233
13.2 Fire Resistant Junction Boxes 233
13.3 Fires Stops 234
14 Future Growth 234
15 Standards 235
15.1 American Petroleum Institute (API) 235
15.2 ASTM International (ASTM) 235
15.3 British Standard (BSI) 236
15.4 European Standard (EN) 236
15.5 FOUNDATION™ Fieldbus Standards 237
15.6 International Electrotechnical Commission (IEC) 237
15.7 Institute of Electrical and Electronics Engineers (IEEE) 240
15.8 International Society of Automation (ISA) 241
15.9 Joint ISO/IEC Standards (ISO/IEC) 245
15.10 National Electrical Contractors Association (NECA) 245
15.11 National Electrical Manufacturer's Association (NEMA) 246
15.12 User Association of Automation Technology in Process Industries (NAMUR) 246
15.13 National Fire Protection Association (NFPA) 247
15.14 Process Industry Practices (PIP) 247
15.15 Telecommunications Industry Association (TIA) 248
15.16 Underwriters Laboratories (UL) 248

Tables

Table 1 Standard Signals 32
Table 2 Example Calculation for the Maximum Distance of a 4-20 mA Signal 34
Table 3 Resistance of Seven Strand Class B Copper Conductors 35
Table 4 NAMUR mA signal Levels 36
Table 5 Example Calculation for the Maximum Distance of a 24 VDC Discrete Signal 39
Table 6 Comparison of Common Wired Fieldbuses 58
Table 7 Fieldbus Comparisons 59

Table 8 Modbus Data Types 61
Table 9 FOUNDATION™ Fieldbus Standards 63
Table 10 PROFIBUS Standards 67
Table 11 EtherNet/IP™ Standards 74
Table 12 PROFINET Standards 76
Table 13 Modbus/TCP Standards 77
Table 14 Standards Based SCADA Protocols 87
Table 15 IPSec VPN vs OpenVPN 90
Table 16 EDDL vs FDT/DTM 98
Table 17 NFPA 79/IEC 60073 Color Coding for Handswitches and Pilot Lights 102
Table 18 Switch Identifications 104
Table 19 Sound Loudness and Frequency for Audible Notifications 107
Table 20 Daylight Viewing Distances for Clear Beacons 108
Table 21 Color Transmission Effectiveness 108
Table 22 Selection of IEC 60529 IP Enclosures to meet NEMA Requirements 108
Table 23 NEMA Enclosure Selection 113
Table 24 Wire and Cable Types 122
Table 25 Typical Data Cables 123
Table 26 Standard PIP Instrument Cables 126
Table 27 Cable Jackets and Insulators 129
Table 28 Standard Cable Jacket Colors 129
Table 29 NEMA Instrument Cable Temperature Ratings 130
Table 30 UV Testing Specifications for Cables 131
Table 31 Cable Armor Types 131
Table 32 NEC Table 310.104(A) UL 83 600V Standard Wire Types 132
Table 33 UL Wire Code Breakdown 134
Table 34 NEC Instrument and Communication Cables 135
Table 35 EMI Reduction with Twisted Wire 140
Table 36 Standard Wire Color Codes 152
Table 37 Tray to Tray Separations (mm) 160
Table 38 Noise and Transient Effects on Equipment Failures 164

Table 39 Network Planning and Installing Specifications 179
Table 40 Typical Analog Video Cables 181
Table 41 Fiber Optic Cable Types 185
Table 42 Fiber Optic Cable Specifications 185
Table 43 IECA Standards for Cable Fabrication 186
Table 44 Function Comparison of ISA 100.11a and WirelessHART 191
Table 45 Recommended spacing for IEEE 802.15.4 Wireless Devices 193
Table 46 Division and Zone Classifications 198
Table 47 Gas Classifications 200
Table 48 Field Wiring in Class I Locations 206
Table 49 NFPA 496 Purging Types 212
Table 50 Intrinsically Safe Barrier Types 219
Table 51 Entity Markings for Intrinsically Safe Devices 221
Table 52 Truth Table for an Entity Pair Calculation 222
Table 53 Acceptable Intrinsically Safe Ground Electrodes 225
Table 54 Entity Markings for Nonincendive Field Wiring 230
Table 55 Truth Table for a Current Regulated NIFW Device 231

Figures

Figure 1 Maximum Distance for a 4-20 mA Signal 35
Figure 2 Four Wire Transmitter with Signal Isolator 41
Figure 3 Current Source to Current Sink Wiring 43
Figure 4 Current Source Output to Current Source Input Wiring 43
Figure 5 Current Sink I/O with a Pull Resistor 43
Figure 6 Styles of Wireless Networks 47
Figure 7 Shunt Protection of RS-485 Signal Reference 54
Figure 8 Installation of Multi-Drop RS-485 Signal 55
Figure 9 Manchester Encoding 69
Figure 10 Redundant FOUNDATION™ Fieldbus Link 71
Figure 11 PROFIBUS OSI Model 76
Figure 12 Combined HSR and PRP Networks 84

Figure 13 Graphic Presentation of Switch Forms 103
Figure 14 Typical Junction Box 111
Figure 15 GUA Outlet Box 115
Figure 16 Shielding Effectiveness 139
Figure 17 EMI Noise Resistant Cable Tray 143
Figure 18 Example of Access Floor 149
Figure 19 Hybrid Ground with Capacitor 156
Figure 20 Typical Impedance versus Frequency 166
Figure 21 TIA 607-C Isolated Grounding Busbar 166
Figure 22 Typical Equipment Noise Frequency Ranges 168
Figure 23 Building Bonding MESH 170
Figure 24 Surge Protector Schematic 175
Figure 25 Field Device Surge Protector 175
Figure 26 Connection of Surge Devices 175
Figure 27 Spike Limiters Across an Inductive Load 178
Figure 28 Zone Marking 199
Figure 29 Electrical Hazard Reduction through Purging or Pressurization 214
Figure 30 Interconnected Intrinsically Safe Barriers 224

1 SCOPE

This document describes methods used to transmit process measurement and control commands as well as diagnostic information between field devices and control systems.

This document is limited to the transmission of measurements, diagnostic statuses, and control data between field devices and control systems or data acquisition systems. It does not cover communications within control systems. See API RP-554 for discussions of these systems.

The communication technologies included in this document are:

a. Electronic signals that communicate values on an analog or discrete circuit
b. Transmission of values using pneumatic signals
c. Serial data transmission over wire, fiber optic or wireless media
d. Industry fieldbus systems that supply communications among devices using digital communications
e. Measurements using wireless communication to control systems or data acquisition systems.

2 ACRONYMS AND DEFINITIONS

2.1 Acronyms

AAC	Amp Alternating Current
AES	Advanced Encryption Standard
AHJ	Authority Having Jurisdiction
ANIFW	Associated Nonincendive Field Wiring Apparatus
ANSI	American National Standards Institute
API	American Petroleum Institute
APL	Advance Physical Layer
ASi	Actuator Sensor Interface
ASTM	ASTM International
BPCS	Basic Plant Control System
BRC	Bonding Ring Conductor
BSI	British Standards Institute
CAN	Controller Area Network
CBN	Common Bond Network
CCTV	Close Circuit Television
CIP™	Common Industrial Protocol
CPF	Communication Protocol Family
CSA	Canadian Standards Association
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
CT	Current Transformer

DAN	Dual Access Node
DART	Dynamic Arc Recognition and Termination
DCOM	Distributed Component Object Model
DCS	Distributed Control System
DD	Device Description
DDL	Device Description Language
DIP	Dust Ignition Proof
DLR	Device Level Ring
DMZ	Demilitarized Zone
DNP	Distributed Network Protocol
DP	Decentralized Peripherals
DSS	Digital Satellite Signal
DSSS	Direct Sequence Spread Spectrum
DTM	Device Type Manager
EDD	Electronic Device Description
EDDL	Electronic Device Description Language
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference/Radio Frequency Interference
EN	European Standard
ER	Exposed Run
ERP	Ethernet Ring Protection Switching
FB	Function Blocks
FDI	Field Device Integration
FDT	Field Device Tool
FEP	Fluorinated Ethylene Polymer
FF	FOUNDATION™ Fieldbus
FISCO	Fieldbus Intrinsic Safe Concept
FNICO	Fieldbus Non-Incendive Concept
FR-EPR	Flame Retardant Ethylene Propylene Rubber
FSK	Frequency Shift Keying
GSD	General Station Description
GSM	Global System for Mobile Communication
HART	Highway Addressable Remote Transducer
HMI	Human Machine Interface

HSR	High-Availability Seamless Redundancy
HTTPS	Hypertext Transfer Protocol Secure
HV	High Voltage, 69kV to 230kV
I/O	Input/Output
ICCP	Inter-Control Center Communications Protocol
ICEA	Insulated Cable Engineers Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IPTV	Internet Protocol Television
IS	Intrinsically Safe
ISA	International Society of Automation
ISO	International Standards Organization
IPSec	Internet Protocol Security
IT	Information Technology
ITC	Instrument Tray Cable
Kb/s	kilobit per second
LAN	Local Area Network
LFL	Lower Flammable Limit
LV	Low Voltage, 1000V and below
M.I.C.E.	Mechanical, Ingress, Climatic/Chemical and Electromagnetic
M2M	Machine to Machine
mA	Milli-Amperes
MAC	Media Access Control
MBP	Manchester Based Power
MRP	Media Redundancy Protocol
MTTR	Mean Time to Repair
MV	Medium Voltage; 1000V to 69kV
NAMUR	User Association of Automation Technology in Process Industries
NEC	National Electrical Code
NECA	National Electrical Contractors Association
NFPA	National Fire Protection Association
NI	Nonincendive

NIFW	Nonincendive Field Wiring
NIFW	Nonincendive Field Wiring Apparatus
NIST	National Institute of Standards and Technology
NRTL	Nationally Recognized Testing Laboratory
NTP	Network Time Protocol
NZDS	nonzero dispersion shift
ODVA	Open DeviceNet Vendors Association
OLE	Object Linking and Embedding
OPC	Open Platform Communications
OPC UA	OPC Unified Architecture
OSI	Open Systems Interconnection model
OT	Operation Technology
PA	Process Automation
PC	Personal Computer
PE	Polyethylene
PEC	Parallel Earth Conductor
PID	Proportional Integral Derivative Control
PIP	Process Industry Practices
PLC	Programmable Logic Controller
PLTC	Power Limited Tray Cable
PMI	Positive Material Identification
PNO	Profibus Nutzerorganisation
POE	Power over Ethernet
PRP	Parallel Redundancy Protocol
PTP	Precision Time Protocol
PTZ	Pan, Tilt and Zoom
PVC	Polyvinyl Chloride
RAL	Reichsausschuß für Lieferbedingungen (National Committee for Delivery)
RF	Radio Frequency
RoHS	Restriction of Hazardous Substances
RP	Recommended Practice
RSTP	Rapid Spanning Tree Protocol
RTD	Resistant Temperature Device
RTPS	Real Time Publish Subscribe

RTU	Remote Terminal Unit
SAMA	Scientific Apparatus Makers Association
SAN	Single Access Node
SCADA	Supervisory Control and Data Acquisition
SMTP	Simple Mail Transfer Protocol
SPDT	Single Pole Double Throw
STP	Shielded Twisted Pairs
STP	Spanning Tree Protocol
SWA	Steel Wire Armor
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access.
TSN	Time Sensitive Network
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver-Transmitter
UID	User interface descriptions
UIP	Interfaces Plug-Ins
UL	Underwriters Laboratories
UPS	Uninterruptable Power Supply
UTP	Unshielded Twisted Pair
VAC	Volts, Alternating Current
VDC	Volts, Direct Current
VLAN	Virtual Local Area Network
VPN:	Virtual Private Network
VSAT	Very Small Aperture Terminal
VSD	Variable Speed Drives
VT	Voltage Transformer
WAN	Wide Area Network
WDS	Wireless Distribution System
WPF	Windows Presentation Foundation
WSN	Wireless Sensor Network
XLPE	Cross-linked Polyethylene

2.2 Definitions

Advance Physical Layer: an Ethernet based loop power two-wire physical layer intended for data transmission up to 1000 meters.

Approved: acceptable to the Authority Having Jurisdiction.

Arcing Device: a device during normal operation, produces an arc with enough energy to cause ignition.

Associated Apparatus: a device where the circuits are not necessarily intrinsically safe but affects the energy in the intrinsically safe circuits and is relied on to maintain intrinsic safety.

Associated Nonincendive Field Wiring Apparatus: a device where the circuits are not necessarily nonincendive but that affect the energy in Nonincendive Field Wiring and are relied upon to maintain nonincendive energy levels.

Authority Having Jurisdiction: an organization, office, or individual responsible for enforcing a code or standard, or for approving equipment, materials, an installation, or a procedure. When public safety is primary, the Authority Having Jurisdiction can be a federal, state, local, or other regional department. For insurance purposes, an insurance inspection department or rating bureau can be the authority. In other circumstances, the property owner or a designated agent can assume the role of the Authority Having Jurisdiction.

Backhaul Network: a part of the network forms the intermediate link between the core network, or backbone network and the fieldbus subnetworks.

Balanced Line: a cable having two identical conductors which carry voltages with opposite polarities but are equal in magnitude with respect to ground.

Balun: a balanced to unbalanced (Bal-Un) transformer used to connect an unbalanced transmission line; i.e. coaxial cable, to a balanced system or cable. It also supplies impedance matching, such as a 300 Ω balanced cable to a 75 Ω unbalanced cable.

Baud: a measure of symbol rate that express the communication speed over a data channel. Baud is related to, but not equivalent to, gross bit rate, which is expressed as bits per second.

BNC Connector: a quick connector used with coaxial cable. It features two bayonet lugs in the female connector; mating is fully achieved with a quarter turn of the coupling nut. The BNC has been often used with control networks, BNC connectors match the impedance of the 50 ohms or 75 ohms cables. They are used at frequencies below 4 GHz and voltages below 500 V.

Bridge: a verb to refer to passing information transparently from one interface to another on the same device without that device being a destination or source during the transmission

Bus Topology: each node is connected by a single cable using connectors or terminals. This cable is the backbone and is known as the bus. When a signal is broadcast on the bus, the data is accepted if the signal has the device address. In this topology data can be read by any node. The number and length of drops allowed depend on the bus.

Cable Gland: a device assists in cable transition into an electrical apparatus or enclosure.

Cable Tray: a prefabricated structure consisting of sides connected at the bottom by transverse members for supporting and routing cables within a structure. Usually fabricated according to NEMA VE 1 and installed according to VE 2 requirements.

Category 6 cable: often referred to as Cat 6, is a standard twisted pair cable for Ethernet and is backward compatible with other twisted pair Ethernet cables. It has effective performance up to 250 MHz and a maximum length of 55 meters when used for 10GBASE-T protocol. With 10/100/1000BASE-T the maximum length is up to 100 meters (328 ft). They often are terminated using 8P8C; i.e. RJ-45, modular connectors. The connectors use TIA T568A or T568B pin assignments. Category 6A cable is characterized to 500 MHz and allows 10GBASE-T to be run up to 100 m.

Cellular Telemetry: used when remote I/O needs to be replicated at another site using the wide area cellular network and is designed for few discrete or analog points.

Channel Tray: a fabricated structure consisting of a one-piece ventilated-bottom or solid-bottom channel section with three, four and six inch widths.

Circuit Integrity Cable: is used ensure survivability for continued circuit operation for a specified time, typically two hours, under fire conditions for remote-control, signaling, or power-limited systems that supply critical circuits; e.g. fire alarms, gas detectors, and the like.

Class I, Division 1: a location (1) where ignitable concentrations of flammable gases, flammable liquid-produced vapors, or combustible liquid-produced vapors can exist under normal operating conditions, or (2) where ignitable concentrations of flammable gases, flammable liquid–produced vapors, or combustible liquids above their flash points can exist frequently due to repair or maintenance operations or leakage, or (3) where breakdown or faulty operation of equipment or a processes can release ignitable concentrations of flammable gases, flammable liquid–produced vapors, or combustible liquid–produced vapors and can also cause simultaneous failure of electrical equipment so as to directly cause the electrical equipment to become an ignition source.

Class I, Division 2: a location (1) where volatile flammable gases, flammable liquid–produced vapors, or combustible liquid–produced vapors are handled, processed, or used, but where the liquids, vapors, or gases are normally confined within closed containers or a closed system from which they only escape in an accidental rupture or breakdown of the containers or systems or abnormal equipment operation the, or (2) where ignitable concentrations of flammable gases, flammable liquid–produced vapors, or combustible liquid–produced vapors are normally prevented by positive mechanical ventilation and can become hazardous through failure or abnormal operation of the ventilating equipment, or (3) adjacent to a Class I, Division 1 location, and where ignitable concentrations of flammable gases, flammable liquid produced vapors, or combustible liquid produced vapors above their flash points can occasionally be communicated unless such communication is prevented by adequate positive-pressure ventilation from a clean air source and effective safeguards against ventilation failure are provided.

Classified Location: a hazardous (classified) area where fire or explosion hazards can exist due to the presence of flammable gases, vapors, or liquids, combustible dust, or ignitable fibers.

Coaxial Cable: an unbalanced cable with a cylindrical transmission line composed of a conductor centered inside a metallic tube or shield, separated by a dielectric material, and covered by an insulating jacket.

Combustible Dust: a solid material composed of distinct particles or pieces, regardless of size, shape, or chemical composition, which presents a fire or deflagration hazard when suspended in air or some other oxidizing medium.

Combustible Flyings: solid particles, including fibers, greater than 500 µm in nominal size that can be suspended in air and can settle out of the atmosphere under their own weight.

Common Bond Network: metallic components that are interconnected to form the principle means for effectively bonding equipment to the grounding electrode system. It includes such items as grounding cables, conduit, cable tray, structural steel, rebar, and the like.

Common-mode (CM) noise: the unwanted noise voltage and current that appears equally and in phase with each victim signal, control, or power conductor to ground, or between grounds or grounding conductors. CM noise is also referred to as longitudinal-mode (LM) noise.

Conduit Seal: a sealing fitting, filled with a potting compound, designed to contain an explosion in the enclosure to which it is attached and minimizes flammable gases or vapors passage from one location to another.

Conduit: a threadable raceway made of aluminum or galvanized steel with a circular cross-section designed for the physical protection and routing of conductors and used as an equipment grounding conductor.

Conformal Coating: a thin polymeric film that conforms to the circuit board contours to protect the components. It is applied to electronics to protection against moisture, dust, chemicals, and temperature extremes.

Contact or Connector Fretting: a wearing away of the conductor surfaces by rubbing or vibration gnawing, frequent operation, or temperature cycling.

Continuous Process: one of the three forms of production, the others are batch processing and continuous flow manufacturing. A continuous process is where either dry bulk or fluids are continuously in motion, undergoing reactions or subject to mechanical treatment. Continuous processes usually run 24 hours per day, seven days per week with infrequent scheduled shutdowns.

Control Center: An equipment structure, or group of structures, from which a system is measured, controlled, and monitored with a combination of the services, enclosures, and environmental treatment for the long-term operation.

Control Drawing: A drawing or other document provided by the supplier of intrinsically safe apparatus, associated apparatus, Nonincendive Field Wiring apparatus, or associated Nonincendive Field Wiring apparatus, which details the interconnections between the intrinsically safe and associated apparatus or between the Nonincendive Field Wiring apparatus and associated Nonincendive Field Wiring apparatus.

Control Equipment: factory assembled devices intend for monitoring and control including items as motor controls, DCS's, PLC's, panel meters, etc.

Control Panel: (1) A structure with a unique designation that has a group of instruments mounted on it and houses an operator-process interface. The panel consist of one or more sections, cubicles, consoles, or desks. (2) A section of an equipment cabinet, enclosure or a metallic or nonmetallic sheet where the operating controls, dials, instruments, or subassemblies of an electronic device or other equipment are mounted. (3) the flat mounting surfaces of a control center.

Controller: a device, usually electronic, which governs an apparatus in a predetermined manner.

Core: a term for a conductor in a cable.

Corrosion Resistant: a term used to describe material or finish that meets the testing requirements of NEMA 250 section 5.10, ASTM B117 or Test Kb in IEC 60068-2-52 for 200 hours and does not show pitting, cracking, or other deterioration more severe than that resulting from a similar test on passivated AISC Type 304 stainless steel.

Coupling: the mechanism by which a near-field interference source of voltage, current, or both produces interference in a victim circuit without a conductive path being involved. In general, coupling occurs through stray or parasitic reactive means

Crosstalk: the unwanted transfer of signals or electrical noise by near-field inductive and capacitive coupling between electrically separated, but physically adjacent conductors. Crosstalk problems vary inversely with the spacing between the circuit conductors.

Daisy Chain: a wiring scheme where multiple devices are wired together in linear fashion to form either a sequence or a ring. Each system retransmits the message along the chain until it reaches the destination.

DB-25 Connector: used with RS-232 serial communications, but this is not mandatory. RS-232 devices originally used the DB-25, but for many applications the uncommon signals are omitted, allowing a DE-9 to be used. The standard specifies that male connector attaches to the terminal equipment.

DB-9 Connector: a subset of the RS-232 serial signals with the unused signals being omitted. See DB-25

Demilitarized Zone (DMZ): a screened subnet that is a physical or logical subnetwork which contains and exposes an organization's external-facing services to an untrusted network, such as the enterprise business systems or in the case of some SCADA systems the Internet. It is sometime referred to as Level 3.5 in the Purdue Model or the security zone. The purpose of a DMZ is to add an additional layer of security to an organization's local area network (LAN). It is usually located between two firewalls.

Device Description Language: A standard programming language used to write the Device Description for field devices to allow them to operate on a fieldbus with other devices such as a host or another field device.

Device Description: a program file written in the applicable Device Description Language. Describes a device’s parameters and functions needed by a host application or other devices to communicate with the device

DeviceNet: a non-redundant, four-wire network protocol that is an extension of CAN (Controller Area Network) technology. It uses the Common Industrial Protocol (CIP™) over a Controller Area Network layer and has an application layer to cover a range of device profiles. ODVA maintains specifications of DeviceNet. Additionally, ODVA ensures compliance to DeviceNet standards by supplying conformance testing and supplier conformity.

Digital Signal: a signal created to transmit data using a pattern of bits.

Discrete Signal: a bi-stable signal that is used to indicate status, open/close, on/off, true/false, etc.

Distributed Component Object Model: a proprietary Microsoft software component that allows COM objects to communicate with each other over the network.

Drop: a cable between the trunk cable and a device, also called a spur.

Earthed: See Grounded.

Electromagnetic interference (EMI): the weakening of a wanted signal by an electromagnetic disturbance. Also, applied to equipment whose operation is impaired by conducted, coupled, or radiated electrical interference (EMI).

Enclosure: A confined volume such as; a panel, marshalling cabinet, control rack, or junction box, intended for the protection of wiring or components.

Encryption Key: a piece of information or parameter that determines the output of a cryptographic algorithm. For encryption algorithms, a key specifies the transformation of plain text into cipher text, and vice versa for decryption algorithms.

Entity Concept: a method that allows intrinsically safe apparatus interconnection to associated apparatus not specifically examined for in such a combination. The requirement for interconnection is that the voltage (V_{max}) and current (I_{max}) which intrinsically safe apparatus receive and remain intrinsically safe, considering faults, should be equal to or greater than the voltage (V_{oc} or V_t) and current (I_{sc} or I_t) levels which are delivered by the associated apparatus, considering faults and other applicable factors. In addition, the maximum unprotected capacitance (Ci) and inductance (Li) of the intrinsically safe apparatus, including interconnecting wiring, should be equal to or less than the capacitance (C_a) and inductance (L_a) that can safely be connected to the associated apparatus. If these criteria are met, then the combination can be connected without compromising intrinsic safety.

Ethernet: a physical and data link layer defined by IEEE 802 standards using Carrier Sense Multiple Access/Collision Detection (CSMA/CD) for access management. Various media; e.g. Category 6 balanced lines and fiber optic cables are used for the physical layer.

Explosionproof Equipment: equipment in an enclosure that can withstand an explosion of a specified gas or vapor that can occur within it while preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosion of the gas or vapor within it, and has an external temperature that a surrounding flammable atmosphere does not ignite.

Explosive Atmosphere: A mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapor, mist, or dust where, after ignition, combustion spreads throughout the unconsumed mixture.

F Connector: a threaded coaxial connector used for broadcast television, CCTV, and some data networks. Usually used with RG-6 and RG-59 cables. The male connector is fitted to the cable, and the female to the equipment or the static interface.

Fieldbus: digital communications by instruments or manufacturing equipment.

Firewall: a network security system that monitors and controls incoming and outgoing network traffic based on predetermined security rules. A firewall establishes a barrier between two networks such as between a trusted internal network and the Internet.

: Fieldbus Intrinsic Safe Concept, a method to power an MBP fieldbus IS segment with approved FISCO devices.

Flammable Mixture: a gas/air, vapor/air or dust/air combination that is combustible or explosive.

FNICO: Fieldbus Non-Incendive Concept, a method to power a fieldbus segment in a Division 2 or Zone 2 Location.

FOUNDATION™ Fieldbus: a digital, serial, two-way communications system that serves as the base level network in an industrial environment. It is an open architecture, developed and administered by the FieldComm Group.

Fresnel zone: prolate ellipsoidal region of space between and around a transmitting antenna and a receiving antenna.

Full-Duplex Signaling: data transmission in two directions simultaneously, this is in contrast with half-duplex signaling and simplex signaling.

Gateway: a network device that enables other devices on the network to communicate with a second network using a different protocol

Gateway: an application interface between a fieldbus network and the plant network.

General Purpose Equipment: this is electrical equipment according to the NEC that has no specific requirements; such as being explosion proof and does not need to be identified, marked, listed, labeled, or approve beyond an evaluation for electrical safety.

Ground Loop: a completed circuit between shielded pairs created by random contact between shields. Also, an undesirable circuit condition where interference is created by ground currents when grounds are connected at more than one point.

Grounded: an intentional connection to earth through a connection or connections of sufficiently low impedance whose value is specified by recognized standards and having enough current-carrying capacity to prevent the voltage buildups that can result in hazards to the connected equipment or to persons.

Grounding Electrode: a conducting object through which a direct connection to earth protentional is established.

Group: A designation for electrically hazardous materials and is included in area classification.

GUA terminal box: a type of location rated conduit outlet box with a screw on cap between three to five inches in diameter.

Half-Duplex Signaling: a bidirectional signaling method where data transfer takes place in either direction, but only in one direction at a time, this is in contrast with full-duplex signaling, and simplex signaling.

Hermetically Sealed: equipment sealed against the entrance of an external atmosphere where the seal is made by fusion, for example: soldering, brazing, welding, or glass fused to metal.

Home run: the installation of a multi-conductor cable or serial data cable from where it originates; e.g. the rack room, and the first distribution point such as a junction box.

Host System: any networked multi-user computer that furnishes services to other systems or users. These services include printers, database access, device management or computing resources.

Identified: equipment according to the as NEC that is suitable for a specific purpose, function, use, environment, application, and the like. Some examples to determine equipment suitability for a purpose or environment include investigations by a qualified testing laboratory, an inspection agency, or other organizations concerned with product evaluation.

Instrument Tray Cable (ITC): a factory cable defined by NEC Article 727 with two or more 300V insulated copper conductors, 22 through 12 AWG, with or without grounding conductors, and enclosed in a nonmetallic sheath, with or without armor.

Intelligent Instrument: a device that can be programmed, has memory, can perform calculations and self-diagnostics and reporting faults, and can be communicated with from a remote location.

Interoperable: the ability to use multiple devices in the same system, independent of the supplier, without functionality loss.

Intrinsic Safety Barrier: a component having a circuit designed to limit the energy available to the protected circuit in the hazardous (classified) location under specified fault conditions.

Intrinsic Safety Ground Bus: A grounding system that allocates a conductor separate from the power system that ground currents do not normally flow and is reliably connected to a grounding electrode.

Intrinsically Safe Apparatus: a device where the circuits are intrinsically safe; i.e. the stored energy is below the ignition threshold for the hazard.

Intrinsically Safe: protection for a Division 1, Zone 0 or Zone 1 location as well as being suitable for Division 2 and Zone 2 locations that only have intrinsically safe apparatus, circuits, and wiring that is incapable of causing ignition in the surrounding atmosphere. Except for battery-operated, self-contained apparatus, no device or wiring is intrinsically safe by itself but is intrinsically safe when employed in a correctly designed system.

IP address: is a numerical label assigned to a device that uses the Internet Protocol for communication. An IP address serves two main functions, host or network interface identification and location addressing. It is used at layer 3 of the OSI model.

Isochronous timing: A sequence of events that occur regularly at equal intervals.

Jitter: the difference between the expected and actual time of a bit arrival.

Jumper: an individual conductor usually short used to connect two terminal points together. It can be permanent or temporary.

Junction Box: a protective enclosure for wire or cable connections usually provided with terminals.

Labeled: equipment or materials acceptable to the Authority Having Jurisdiction that have a label, symbol, or other identifying mark of an organization that is concerned with product evaluation and maintains periodic inspection of the labeled equipment or materials production where labeling by supplier indicates compliance with the appropriate standards or performance.

Latency: the delay before data transfer begins following an instruction for the transfer.

LC Connector: a standard ceramic ferrule connector, easily connected with any adhesive. It has a small form factor with a 1.25 mm ferrule and is half the SC connector size. It has superior optical performance and is favored for single-mode cables.

LFL.m (Lower Flammable Limit meter) is a unit of measure for a flammable gas being detected over an open path. For example, 1 LFL.m can represent a 1 meter wide gas cloud whose concentration is at the explosive level (100% LFL) of the target gas.

Link Active Scheduler (LAS): a deterministic, centralized bus scheduler that keeps a list of transmission times for device data buffers that need to be cyclically transmitted.

Listed: Equipment, a list of materials or services published by an organization that is acceptable to the Authority Having Jurisdiction, which is concerned with evaluation of products or services, maintains periodic production inspection of the listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate standards or has been evaluated and found suitable for the specified purpose.

Logic Solver: A generic term for devices that perform real time calculations or discrete logic. For instance programmable controllers, DCS multi-loop controllers, embedded controllers in vendor packages are examples of logic solvers.

Loop: devices or instruments along with the associated wire and tubing that make a system which is designed to measure, manipulate, or control a process.

M.I.C.E.: classification system that describes the environment conditions that effect a data channel based upon the following factors: Mechanical, Ingress, Climatic/Chemical and Electromagnetic

Macrocycle: the time it takes for a fieldbus segment to execute the Link Active Scheduler sequence one time.

Marshalling Panel: a cabinet that houses terminals for the field cables and supplies the cross wiring between the field instruments and the control system cables.

Master-Slave Protocol: a communication system where transactions are started by a master device and are received and responded to by a slave device

Media Access Control Address: a permanent address that is assigned by the device manufacturer. It is used at OSI layer 1; that is the lowest level, for network communication.

Medium Voltage: voltages in an electrical distribution network that are between 600V and 6,900V.

Mesh Network: a wireless network made up of radio nodes organized in an ad hoc multi-connected lattice topology.

MESH-BN: a grounding grid or mat where associated equipment frames, racks, and cabinets and usually the DC power return conductor, are grounded to plus at multiple points to the facility Common Bond Network. Consequently, the MESH-BN augments the Common Bond Network.

Modbus: an open, simple serial protocol developed for use with Modicon® programmable controllers. It is standard communication protocol and is used to connect industrial devices. Modbus protocols updates are managed by the Modbus Organization.

Modem: **(**modulator/demodulator) a data communications equipment (DCE) device that assists a data terminal equipment (DTE) device, such as a personal computer, in communicating across a wide-area link.

Modems: a device that connects network nodes using ordinary non digital capable wire or connects wireless nodes. Carrier signals are modulated digitally to produce an analog signal with properties for transmission.

Multi-drop Network: a network system that allows devices to be wired together on a single cable.

Multi-Mode Optical Fiber: an optical fiber used for communication over short distances, such as in a building or on a campus. It has 10 Mbps to 10 Gbps data rates at lengths up to 600 meters (2000 feet). Multi-mode fiber has a large core diameter propagating multiple light modes. The modal dispersion limits the maximum transmission distance. (See Single-Mode Optical Fiber)

National Recognized Testing Laboratory: a term used by the United States Occupational Safety and Health Administration to indicate third-party organizations that have the qualifications to perform safety testing and certification of products within OSHA and the organization's scope.

Nationally Recognized Testing Laboratory: Third-party organizations identified by OSHA perform safety testing and certification of products covered within OSHA’s scope. The testing and certification are conducted according to standards issued by U.S. standards organizations.

NEMA enclosure: a system of enclosure protection levels for electrical apparatus with protection against contact with live or moving parts inside the enclosure, and protection against solids and liquids ingress. The enclosure rating is in addition to the protection necessary to ensure security against ignition in hazardous locations.

Network Switch: a device that filters and forwards OSI layer 2 frames between ports based on the destination address. Switches have several ports that support a star topology and switch cascading in a tree topology. The term switch is often used loosely to include devices such as routers and bridges. A switch is distinct from a hub in that it only sends the frames to the physical ports involved in the communication rather than every port.

Nonincendive Equipment: equipment having electrical or electronic circuitry that is incapable, under normal operating conditions, igniting specified flammable gas–air, vapor–air, or dust–air mixture due to arcing or thermal means in a Division 2 or Zone 2 location.

Nonincendive Field Wiring Apparatus: Nonincendive Equipment intended to be connected to nonincendive field wiring.

Nonincendive Field Wiring: wiring that enters or leaves an equipment enclosure and equipment under normal operating conditions, is not capable, due to arcing or thermal effects, of igniting the flammable gas-, vapor-, or dust-air mixture. Normal operation includes opening, shorting, or grounding the field wiring. See also nonincendive circuit.

Normal-Mode (NM) Noise: the noise voltage or current that appears in the same mode as the desired signal or power waveform on the victim circuit. Normal mode noise is also referred to as transverse noise and differential mode noise

Open Systems Interconnection (OSI) Reference Model: A seven-layer architecture developed by the International Organization for Standardization that serves as the foundation for standards development for network communications. The seven layers are the physical, data link, network, transport, session, presentation, and application.

Plenum: a compartment or chamber where one or more air ducts are connected to form an air distribution system.

Polymeric Material: substances composed of large molecules, called macromolecules usually synthetic. UL certified materials are GRP (glass fiber reinforced polyester); Polycarbonates; ABS; Polyesters. However, ABS is not UL or CSA certified.

Power limited tray cable (PLTC:) intended for Article 725 Class 2 and 3 Remote-Control, Signaling, and Circuits. It is used with a listed power-limited power supply and is a legacy method of industrial cabling prior to its required use with listed devices. Its use been replaced by Article 727 ITC cable in industrial facilities.

Process Seal: a seal between electrical systems and flammable or combustible process fluids where a failure can allow the process fluid migration into the wiring system.

PROFIBUS: a standard for fieldbus communication in automation technology. PROFIBUS DP (Decentralized Peripherals) manages sensors and actuators using a centralized controller in production or manufacturing automation applications. PROFIBUS PA (Process Automation) is used to supervise measuring equipment with a control system in process applications.

Protocol: a set of rules used for generating or receiving a message.

Provisioning: supplying devices with the configuration required for operation within the network.

Purdue Enterprise Reference Model: Is a model for describing layers of an organization with Level 0; the physical process, Level 1; the instruments and effectors, Level 2; Process Controllers; Level 3; manufacturing operation systems and Level 4; the business systems. It has been extended to incorporate network security concepts and partitions one of which is Level 3.5 or the DMZ.

Purged or Pressurized Enclosure: an enclosure supplied with clean air or an inert gas at enough flowing capacity and positive pressure to reduce to a safe level any flammable gas or vapor concentration initially present, and to keep this safe level by positive pressure with or without continuous flow.

Raceway: an enclosed channel designed for holding wires, cables, or busbars. Conduit is a raceway, but cable tray is not.

Rack Room: a room, usually air-conditioned and equipped with a UPS, devoted to the continuous operation of controllers and control system servers usually mounted in standard cabinets arranged in rows.

Radio Frequency (RF): electromagnetic frequencies greater than 9 kHz.

Real Time: hardware and software systems subject to real-time constraints. Real-time programs guarantee response within specified time constraints. These systems depend on their chronological aspects as well as their functional aspects. Real-time responses are understood to be within milliseconds.

Repeater: a device that regenerates a digital signal. A repeater receives a signal from one source, generates an identical signal, and then transmits it to the next destination.

Restriction of Hazardous Substances (RoHS): refers to the EU directive 2002/95/EC which bans certain substances. Of primary concern in cables are: Asbestos and its compounds, Cadmium and its compounds, Chromium VI and its compounds, Lead and its compounds, Mercury and its compounds, and Polybrominated Biphenyls (PBBS) and their ethers/oxides (PBDE’s, PBBE’s).

Riser: a system of pathways that allow cables to run from one floor to another.

RJ-45 Connector: an 8P8C modular connector. Commonly referred to incorrectly as an RJ-45 when used in the context of Ethernet and Category 6 cables. A true RJ-45 is a keyed connector intended for phone use. TIA/EIA-568 is the standard for data circuits wired installed with modular connectors.

Router: An internetworking device used to direct packets from one network to another. In ISA 100.11a networks routes messages for other devices operating in the wireless subnet. See Repeater

Safe location: Depending the associated device, is the unclassified location or in a Division 2 location when it is rated for installation in that location.

SC Connector: a subscriber connector and is the TIA and IEC standard-duplex fiber-optic connector with a square molded plastic body and push-pull locking features.

Simple Apparatus: an electrical component or combination of components of simple construction with well-defined electrical parameters that does not generate more than 1.5 volts, 100 milliamps, and 25 milliwatts, or a passive component that does not dissipate more than 1.3 watts. Examples are non-inductive resistive devices, switches, thermocouples, light-emitting diodes, connectors, and resistance temperature detectors.

Simplex Signaling: a unidirectional signaling method where data transfer takes place in only one direction, with no capabilities to change directions, this contrasts with full-duplex signaling, and half-duplex signaling.

Single-Mode Optical Fiber: an optical fiber where only one mode propagates. The fiber has a small core diameter of eight micrometers. It allows signal transmission at high bandwidths and longer distances. (See Multi-Mode Optical Fiber)

ST Connector: a straight tip, a high-performance fiber-optic connector with round ceramic ferrules, a metal shell and bayonet locking features. Use primarily for multimode networks. Seating can be an issue.

Star Topology: each device is connected to a central hub with a point-to-point connection. Every device is indirectly connected to every other node with the support of the hub. The nodes on the network connect to a central device. The traffic passes through the central hub and the hub acts as a signal repeater.

Supervisory Control and Data Acquisition: a control system using communications such as phone lines, microwaves, radios, or satellites to link remote terminal units (RTU's) with a central control system

Synchronous timing: A relationship between two or more events that have simultaneous or near-simultaneous constant phase relationship.

System Manger: Manages the network devices through controlled configurations based on desired performance parameters.

T Code: A classification system where a temperature class is allocated to a device. The temperature class represents the maximum surface temperature of any part of the device that can encounter a flammable or ignitable mixture.

Temperature Identification Number (T Code/Temperature Class): a classification system where one of fourteen temperature identification numbers (for zones, six temperature classes) can be given to an apparatus. The temperature identification number stands for the maximum apparatus surface temperature that can contact the flammable gas or vapor mixture.

Transmitter: in the process control context, an instrument which responds to a measured variable with a sensing element and converts it to a standardized transmission signal which is a function of the measured variable. It also refers to equipment used to generate and send electromagnetic signals. Likewise refers to the electronics that converts electrical signals into light in a fiber optic system.

Tree Topology: a collection of star networks arranged in a hierarchy. The tree has individual peripheral nodes; i.e. the leaves, which send to and receive from another node and are not needed to function as repeaters or regenerators.

Triaxial Cable: a cable having a conductor and two isolated braid shields, which are insulated from each other. A coaxial cable with a second braid applied over an inner jacket and an outer jacket applied over the outer braid.

Tropicalized: to adapt or make fit for use in a tropical climate with humidity >95%, using measures intended to combat the effects of fungi, and moisture or saline atmospheres using conformal coatings as well as using anti-fretting lubricants, fungus resistant plastics and insulation, etc.

Tunneling: also known as port forwarding, is the transmission of data for use only within a private, network through a public network in such a way that the routing nodes in the public network are unaware that the transmission is part of a private network.

Unclassified Locations: locations determined to be neither Class I, Division 1; Class I, Division 2; Class I, Zone 0; Class I, Zone 1; Class I, Zone 2; Class II, Division 1; Class II, Division 2; Class III, Division 1; Class III, Division 2; Zone 20; Zone 21; Zone 22; nor in any combination.

Universal Asynchronous Receiver-Transmitter: is a device for asynchronous serial communication in which the data format and transmission speeds are configurable. The electric signaling levels and methods are managed by a driver circuit. It is usually an integrated circuit used for serial communications over a peripheral serial port.

Virtual Private Network: a network created by encrypting traffic between two endpoints that are connected to one another across an insecure network, such as the internet. Security and tunneling protocols, are used to create a secure channel for the traffic to traverse.

Water-Tight: Equipment that it meets at least a NEMA 250 Type 4 or 4X or an IEC IP 55 or 56 rating.

3 SIGNAL TRANSMISSION METHODS

3.1 Design Considerations

Several factors are involved with installing and operating a data gathering network. The following items are to be considered:

a. Time response requirements [1]

b. Personnel required as well as skills and training needed

c. Fault tolerance needs as well as mean time to repair

d. Expandability and spare capacity

e. Complexity complications

f. Provisions for maintenance and testing including equipment exchange

g. Compatibility with legacy facilities

h. Life cycle requirements including decommissioning
i. Equipment and cable locations [2]
j. Protection from electrical and radio-frequency interference
k. Facility environment concerns
    i. Marine, tropical, desert, or artic locations
    ii. Atmospheric corrosion issues
    iii. Solar ultraviolet radiation effects
l. Electrical hazardous location compatibility
m. Diagnostic and predictive maintenance needs
n. Asset management and documentation requirements
o. Instrument air and electric power access, capacity, and reliability
p. Effects of regulations and codes

Note 1: Process time constants and system latency influence a control system performance. A deterministic response is necessary for effective close loop control. At the device level this is associated with input analog to digital conversion and digital to analog conversion of outputs. At the fieldbus level this is associated with the time it takes to request data, process it, and return a response.

Note 2: The equipment should be accessible. The equipment as well as the routing of cables, optical fibers, and pneumatics should be located to avoid fire damage, overheating and mechanical abuse. Also, underground transmission systems should not affect below ground infrastructure.

3.2 Pneumatic Transmission

Pneumatic transmission uses air pressure or similar gases to communicate analog signals using tubing. Remote control started in refineries in the 1950's with pneumatic transmitters and controllers. It has the advantages of simplicity and reliability. Pneumatics are deemed safe because they use air rather than electrical power. This is especially useful for operating in Zone 0 locations and Group A; i.e. acetylene, environments which have especially strict requirements for electrical equipment.

The Scientific Apparatus Makers Association originally established 3 to 15 psig as the pneumatic signal pressure. Pneumatic systems operate according to IEC 60382 or ISA 7.0.01-1996 Table B.2 respectively use a 20 to 100 kPa or a 3 psig to 15 psig signals.

Copper or stainless steel tubing is used for pneumatic lines. The preferred size is ¼ inch diameter (OD) with a minimum wall thickness 0.030 inches. Larger tubing is used with control valves when higher flow rates are needed.

The tube runs, and multi-tube bundles should be tagged at both ends. Also, where one end of a tube is obscured from the other, both ends should be tagged but runs less than 10 ft that can be easily followed, do not require tagging. Tubes that pass through a wall or a bulkhead should be tagged on both sides.

Most control systems based entirely upon pneumatic technology are legacies. Few suppliers now exist for pneumatic transmitters with ranges and features being unavailable. Also, pneumatic transmitters take a long lead time to obtain.

Outside of control valve actuators and their accessories, pneumatic systems based upon pneumatic signals are limited to remote valve and metering stations associated with gas pipelines, gathering systems, etc. that do not have a reliable electrical power system and use pipeline gas to operate the logic and measurement devices. When using gases other than air, proper venting is required to prevent asphyxiation. Besides being a pollutant, the components of natural gas are Group D electrical hazards, so it has the additional problem creating a Division 1 environment when it is released.

See API RP 551 for pneumatic instruments controllers and API RP 553 for further discussion of pneumatic valve actuators and positioners.

3.3 Electronic Signals

3.3.1 Standard Signal Types

Analog transmissions are used to transmit measurements and commands using conductor pairs or triads. The signal can be a value using current or voltage. Alternatively, a discrete signal is a bit level indication that denotes a binary status or a logic command. See Table 1 for signals that can be encountered.

Table 1
Standard Signals

Code	Signal Type	Wire Qty	Volt Level	Application
A01	4-20 mA, 2-Wire	2	2	Standard Analog Signal
A02	4-20 mA, 2-Wire HART	2	2	Standard Analog Signal
A03	4-20 mA, 3-Wire 24 VDC	3	2	Standard Analog Signal; e.g. Point Gas Detector
A04	4-20 mA, 4-Wire 24 VDC	4	2	Standard Analog Signal
A05	4-20 mA, 4-Wire HART 24 VDC	4	2	Standard Analog Signal
A06	4-20 mA, 4-Wire 120V	2+2	2	Standard Analog Signal
A07	4-20 mA, 4-Wire 120V HART	2+2	2	Standard Analog Signal
D01	24 VDC	2	2	Discrete Logic
D02	NAMUR Discrete	2	2	Not detected (<1 mA), detected (>2.2 mA)
D03	120 VAC	2	3	Discrete Logic
D04	Square Edge Pulse	2	2	Positive displacement, turbine, vortex meters
E01	Ethernet, 4-Wire	4	2	10BaseT and 100VBaseT
E02	Ethernet, 2-Wire	2	2	APL 10BASE-T1L
F01	Foundation™ Fieldbus H1	2	2	MBP Digital Fieldbus
F02	PROFIBUS PA	2	2	MBP Digital Fieldbus
F03	PROFIBUS DP	3	2	Digital Fieldbus, Multidrop
F04	RS-485	3	2	Digital Fieldbus, Modbus RTU, Multidrop
F05	ASi Bus	2	2	Digital Fieldbus, Multidrop

Code	Signal Type	Wire Qty	Volt Level	Application
F06	DeviceNet	4	2	Digital Fieldbus, Multidrop
M01	API Std 670	3	1	0 to -22V Machine Sensor Signals
M02	mV	2	1	pH, ORP
M03	Sinusoidal	2	1	Turbine, magnetic meters, speed probes
M04	Fiber	1	NA	Special transducers; e.g. temperature
M05	75Ω Coaxial Cable	1	1	Analog CCTV
R01	RTD	3	2	Temperature
R02	Full Bridge	4	1	Weigh cells, strain gauges, pressure transducers
R03	Half Bridge	3	1	LVDT, potentiometers, inductive transducers
R04	Quarter Bridge	2	1	Rheostats, resistors, thermistors
T01	Type B Thermocouple	2	1	Temperature
T02	Type E Thermocouple	2	1	Temperature
T03	Type J Thermocouple	2	1	Temperature
T04	Type K Thermocouple	2	1	Temperature
T05	Type N Thermocouple	2	1	Temperature
T06	Type R Thermocouple	2	1	Temperature
T07	Type S Thermocouple	2	1	Temperature
T08	Type T Thermocouple	2	1	Temperature
T09	Type C Thermocouple	2	1	Temperature
V01	0-1 mA	2	1	Power System Transducers
V02	0-10 VDC	2	1	HVAC, temporary instruments; e.g. voltmeters
V03	0-120 VAC	2	3	Voltage Transformers
V04	1-5 VDC	2	1	Data or TTL logic
V06	0-5 AAC	2	3	Current Transformers

3.3.1.1 4-20 mA Signals

The analog 4–20 mA signal is common in process control. The lower value 4 mA stands for the zero value while 20 mA is 100% of the signal. These signals carry both information from the field instruments and send control signals to a valve or other modulating control device.

The characteristics of a 4-20 mA signal should meet the requirements of ISA 50.00.01 “Compatibility of Analog Signals for Electronic Industrial Process Instruments” or IEC-60381-1 “Analogue Signals for Control systems Part 1: Specification for Direct Current Signals”

These signals have the advantages of simplicity and noise immunity with a large user and supplier base. Often 4–20 mA field devices are powered by the wire pair, removing the need for a separate power supply. Further, it is possible to superimpose a signal; i.e. HART, which transmits the device condition or added measurements over the analog signal wire.

The advantages of the current loop are:

a. Because it is a regulated current signal it has excellent noise immunity

b. Live zero detection which can differentiate between true zero signal vs power off.

c. The signal accuracy is not affected by the conductor voltage drop

d. It can be sent long distances [1]

e. The elevated nominal 4 mA zero powers the remote device, so power conductors are not needed

f. It is self-monitoring; currents less than 3.8 mA or more than 20.5 mA reveal a fault

g. Low impedance loop powered displays can be inserted in the circuit.

h. Simple conversion to a voltage with a 250 Ω resistor [2]

Note 1: A two-wire transmitter with a 650 Ω nominal impedance can send a signal upwards of 21,000 ft with a 24 VDC power source over an 18 AWG wire with a 250 ohm input. See section 3.3.1.1.1 on how to determine the allowed distance.

Note 2: Signals should be terminated with 250 Ohms, 0.1%, ¼ W conversion resistors. Normally, these are precision wire wound resistors.

3.3.1.1.1 Resistive Loading

Instrument suppliers publish the resistive load or burden that a transmitter can drive at specified voltages. Typically, this is between 500 and 600 ohms for a two-wire transmitter with 24 VDC power supply.

The maximum transmission distance for a loop can be determined by using values from Table 3, the input resistance (typically 250Ω), 24 VDC power supply impedance (if any), and the two-wire maximum resistive loading (550Ω) and the burden of any accessories. Half the resistance from the calculation should be used to include both conductors in the pair. See Table 2 for an example calculation.

Table 2
Example Calculation for the Maximum Distance of a 4-20 mA Signal

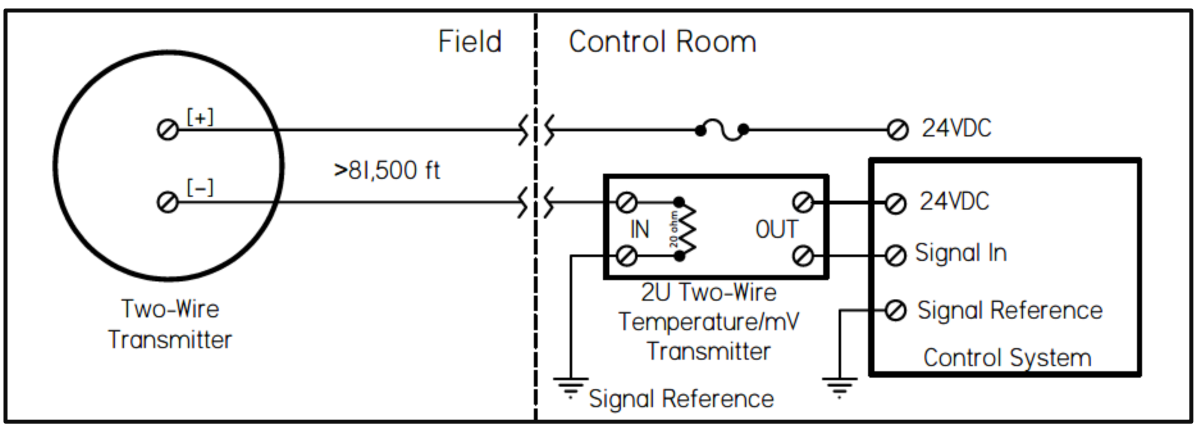
A	Allowed transmitter burden at 24 VDC	550	ohm	By Instrument Supplier
B	Power Source impedance [1]	-145	ohm	By Control System Supplier
C	Input resistance	-250	ohm	By Control System Supplier
D	Accessories (e.g. milli-amp indicator)	-10	ohm	By Instrument Supplier
E	Remaining wire pair burden	145	ohm	=A-B-C-D
F	Resistance per single conductor	72.5	ohm	=E/2
G	18 AWG resistance/1000ft	6.67	ohm/1kft	From Table 3
H	Max Distance	10,870	ft	=F/G*1000

Note 1: The power supply impedance is a resistor that is sometimes used by the control system supplier to protect the DC supply from a low resistance short. It limits the amount of current to ground. The other approach is to provide an active current limiting circuit that regulates the maximum current that can be drawn but does not add significantly to the loop resistance. The latter can be wired in series to two 250 ohm inputs while the former cannot.

Table 3
Resistance of Seven Strand Class B Copper Conductors

American Wire Gauge (AWG)	Ohm/1000 feet	Ohm/km
24	27.7	90.9
22	16.7	54.8
20	10.5	34.4
18	6.67	21.9
16	4.18	13.7
14	2.63	8.63
12	1.66	5.45
10	1.04	3.41
Resistance for 10 to 22 AWG is from NEMA WC 57-2014. These values are based upon 20°C. With an increasing temperature the resistance increases by .004/°C		

Figure 1
Maximum Distance for a 4-20 mA Signal



The distance to a transmitter can be increased significantly with 18 AWG wire up to 81,500 ft by using an isolated two-wire temperature/mV transmitter and a precision 20 Ω conversion resistor.

3.3.1.1.2 4-20 mA Format Variations

According to ISA 50.00.01 the 4-20 mA signals can be provided in several formats. There are two, three, and four wire configurations. There are three levels of load impedances (L, H, and U) that a device should be capable of driving. The lowest acceptable value is ISA Class L impedance, which is 300 ohms. The standard impedance for an input is 250 ohms. This leaves 50 ohms for wire and a possible low impedance local meter or test instrument. However, most instruments can drive 550 ohms or more with a 24 VDC power supply. This enables the instrument to work with two devices in series, each with a 250 ohm resistance.

Two wire instruments receive their power from the signal wires. Three and four wire instruments use the third and fourth wires for power. Most pressure transmitters and EMF/electrical transducers as well as several types of inline flow meters and liquid level transmitters are “Full Isolated” ISA 2U devices according to ISA S50.00.01. They are two wire devices using a 24 VDC nominal power supply with its power, output, and electrical signal input terminals electrically isolated from each other and ground.

A thermal bridge gas detector is an example of an isolated, three wire device. The third wire is needed to provide the additional power required by the sensor circuit. Other examples include zero speed pickups and area flame monitors.

Four wire devices are used for measurements that need more than the nominal ten milliwatts that are provided to two wire devices by the signal wires. These typically are ISA 4H devices; i.e. they can drive more than 800 ohms and have an active output. However, many of these devices are not isolated. This is frequently not acceptable, so further signal conditioning is necessary. See Figure 2 for an example of a four-wire device with a two-wire isolator.

There is a four-wire configuration that is not covered by ISA S50.00.01 that avoids the use of an isolator or the alternative of wiring to the signal input and signal ground terminals. To reduce space the former terminal is not provided on some termination assemblies. The instrument output is a regulated open collector that operates like a two-wire 4-20 mA device. The four-wire instrument transmitter is wired to the 24 VDC and signal input terminals. If the device is powered by 24 VDC that needs to be supplied separately.

If not taken care of by a signal conditioner, different connections are necessary when terminating the conductors to the facility control system. See section 3.3.1.3 concerning the methods for terminating a current signal.

3.3.1.1.3 NAMUR NE 43

NAMUR NE 43 has extended the standard 4-20 mA signal to supply diagnostic information. Table 4 shows the signal level interpretations for devices that conform to NAMUR NE 43 requirements. Typically, transmitter failures are shown by one signal level that is often user selectable. To indicate failure the signal is either less than 3.8 mA or greater than 20.5 mA. However, for this to be effective the analog input much be ranged from 3.6 mA to 22.0 mA.

Table 4
NAMUR mA signal Levels

Level	Signal (mA)
Normal	4.0 to 20.0
Normal under range	3.8 to 4.0
Normal over range	20.0 to 20.5
Transmitter Failure [1]	3.6 to 3.8
Transmitter Failure [2]	20.5 to 22.0
Probable open field wire	0 to 3.6
Probable shorted field wire	≥22.0
Note 1: The usual setting to indicate transmitter failure Note2: The alternate setting to indicate transmitter failure	

3.3.1.2 Voltage Signals

IEC 60381-2 defines the values for analog voltage signals. A frequently used voltage signal is 0-10 VDC. It is the standard signal used in HVAC systems and is used in the machine tool industry for position measurement. A -10 VDC to +10 VDC voltage can represent values that have an inherent bipolar nature. These are useful for position measurements that have both a positive and negative displacement. The two other voltage signals are 0-5 VDC and 1-5 VDC. The latter is used internally with 4-20 mA input conversion resistors in control systems.

Voltage signals are four-wire signals needing a separate power supply. Since they are voltage signals, they are not recommended for long distances. They can have differential inputs for common noise canceling. Regardless, they should be kept isolated from AC power and other noise sources.

For rotating machinery API Std 670 uses a 0 to -20 VDC signal to measure shaft position. A three wire system is used: -24 VDC power, Voltage Signal and Signal Reference. The negative signal voltage indicates the XY probe trace at a positive 45° slope on oscilloscopes. This allows spot measurements along the trace using the oscilloscope cursor.

3.3.1.3 Power Monitoring

Electrical load readings are a useful process indication. They can supply pump flow indication allowing controls such minimum flow protection. Compressor load and efficiency can be determined. The motor thermal capacity, a measurement of the heat in the windings, can be determined by integrating the current. They can also indicate a failure of the drive train for a cooling tower fan or similar device. Small, molded case current switches can be used to augment the number of motor starter auxiliary run contacts without directly revising the started wiring.

There are two types of instrument transformers, current transformers (CT’s) and voltage transformers (VT’s). They are the primary sensors for monitoring electrical systems.

3.3.1.3.1 Current Measurement

A Current Transformer (CT) converts the load current into values suitable for standard protective relays and meters while isolating the instruments from line voltages.

The most common current transformer is the toroidal or donut type. The toroidal current transformer has the advantage that it is non-intrusive. The insulated primary conductor is run through the window of the current transformer.

There is not a direct connection to the power circuit. The only link between the circuit being monitored and the current transformer is the magnetic field developed by the primary conductor. This allows toroidal current transformers rated at 600V to measure Medium Voltage loads.

The transformer is selected as a ratio of the primary current to the secondary current such as 100:5 ratio. Standard CT’s have a five amp secondary current rating or output. C57.13 lists thirty-three single ratio CT’s and a similar number of multi-ratio current transforms. However, the lower practical range limit is 50:5 for donut type transformers.

It is possible by looping the primary through the donut window to adjust the ratio so that a 100:5 ratio in effect become a 50:5 ratio. A second loop creates a 25:5 ratio. Also looping the secondary around the core adds or subtracts from the current ratio. So, the 25:5 ratio can be further reduced to 20:5 with a subtractive loop of the secondary lead. Additive loops are used to improve the accuracy and burden capability of a CT.

The indicators and protective devices are connected in series in the five amp secondary current loop. Each device imposes a burden on the transformer. Depending on the primary and required accuracy the allowed burden can vary from 1 VA to more than 8 VA.

The higher the ratio the greater the allowed burden on the transformer. Conversely, the lower the connected burden the higher the accuracy of the reading. The burden with non-metering grade CT's less than 100 A tends to be 2 VA with 2% accuracy.

Analog transducers, protective relays, and conventional ANSI 4½" analog switchboard meters have an average burden about 0.35 VA. With the wiring burden included this allows about three devices to be wired in series with a CT rated for 2 VA. A microprocessor based device with combined indication and protective functions can have an overall burden of 0.1 VA or less.

For safety, the measurement converters should be mounted in the electrical enclosure with the current transformer. If the current transformer secondary is disconnected from the signal converter while operating dangerous voltages occur in secondary.

The use of shorting-type terminal blocks in CT circuits is recommended. It is normal practice to provide test switches or blocks in CT circuits to allow connection of test equipment without having to disconnect CT wiring. Unused CTs should be shorted and grounded.

3.3.1.3.2 Voltage Measurement

Though current is a good indication of equipment energy usage, voltage can be added to determine the actual power usage or give an indication of the power factor or VARS. Since a CT output does not change sign when the current reverses, a watt measurement is required to monitor a device like a motor generator.

A voltage transformer (VT) transforms primary voltage into values suitable for meters and standard protection relays while isolating them from the stresses associated with the main power system. A simple VT has two windings, designated as primary and secondary, which are insulated from each other. It is common for VT secondaries to be tapped to allow flexibility in how the secondary is connected. VTs are available with multiple primary and secondary windings, which allow changing their ranges.

VT's have a rated primary voltage, which is the line voltage and a ratio. This combination results in a nominal open circuit secondary voltage of 120 V.

The allowed burden is specified but tends not to be a concern. The thermal burden on a VT is more of a concern than its saturation. In medium-voltage applications, VTs are always applied in the three-phase wye connection. the wye-wye connection of VTs produces a faithful replica of primary voltage with no phase shift.

See IEEE 3004.1 for further information on instrument transformers.

3.3.1.3.3 0-1 mA Signals

Due to wide availability of analog panel meters, power transducers provide a 0-1 mA output. Analog panel meters that read 0-1 mA have been a ubiquitous display device for decades. They are reasonably accurate, typically 2%, and are robust. The electromechanical movement filters out most noise. The current signal is also noise resistant. Depending on the internal impedance and signal source this signal can be transmitted several miles.

3.3.1.4 Discrete Signals

3.3.1.4.1 24 VDC

The standard signal voltage for bi-stable control devices is low power 24 VDC. Discrete 24 VDC signals have the following characteristics:

a. No exposure to hazardous touch voltages
b. Hot work possible
c. Intrinsically safe circuits available
d. Used in 4-20 mA multi conductor cable acceptable
e. More I/O per card
f. Operates with redundant 24 VDC power supplies
g. Voltage drop limits the output run length [1]
h. Leakage current issues with low power solenoids

Note 1: The voltage losses in long runs can be below the pull in voltage of solenoid valves and relay coils. See the calculation for a 24 VDC hydraulic solenoid valve in Table 5. Instead low power pilot solenoid valves, ≤2 watts, are recommended. Similar issues occur with providing 24 VDC power to four-wire instruments. It is recommended that appropriate calculations be made to ensure proper operation.

Table 5
Example Calculation for the Maximum Distance of a 24 VDC Discrete Signal

A	Hydraulic Solenoid Valve Power at 24 VDC	12	watts	By Supplier
B	Hydraulic Solenoid Valve Current	500	milliamps	=A/24*1000
C	Valve Coil Voltage Tolerance	10	%	By Supplier
D	Allowable Voltage Loss	2.4	volts	=C*24
E	Allowable Circuit Resistance	0.208	ohms	=B/D*1000
F	Resistance per Single Conductor	0.104	ohms	=E/2
G	16 AWG Resistance/1000 ft	4.18	ohms/Kft	From Table 3
H	Max Distance	25	ft	=F/G*1000

3.3.1.4.2 120 VAC

Discrete AC signals have the following characteristics:

a. Marking and protection are needed as well as tag/lock out procedures required
b. NFPA 70E arc flash concerns
c. Inductive coupling with contact with long cable runs
d. Faster stroke with solenoid valves
e. Higher leakage currents with triac outputs
f. More energy to drive solenoid and contactor coils
g. Polarity insensitive
h. Coil holding current is lower
i. Coil burnout if the plunger does not fully stroke

3.3.1.4.3 AC Inductive Coupling

With discrete circuits, capacitive coupling limits run lengths for AC signal pairs. Distributed line capacitance presents a problem in AC signal circuits that use high impedance inputs with low drop out voltages. Long AC signal circuits can have enough conductor-to-conductor capacitance to prevent de-energizing of an input when the contact opens.

The line capacitance is the total capacitance between signal wires as well as cable to conduit. Factors that determine line capacitance include the insulation type, conductor diameter, the distance between conductors and run length. Humidity and liquid filled conduits add to this effect.

The capacitance prevents inputs and coils from dropping out. The coupled capacitance increases with the square of the signal voltage. Using DC eliminates the effect since coupling is only possible with continuous varying voltages.

PVC cable is twice as prone to continuous AC coupling with distances as short as 600 ft being the limit. PVC is not a good insulation for long distance runs. It has a large capacitance with a high variability. Cable with polyethylene insulation can be run twice as far.

Initially a circuit can work properly, but changes due to wear, aging, deteriorating insulation, humidity, or other factors can result in coupling. A monitored contact signal cannot drop out at a critical moment.

The following are solutions for AC cable coupling:

a. Use a coil with a higher sealing power
b. Use DC operated inputs [1]
c. Use local power at the switch to supply the signal voltage
d. Use the NC contact on the SPDT switch to locally ground the returning signal
e. Placing a power resistor in parallel with the input low input impedance
f. Use XLPE insulation rather than PVC [2]

Note 1: DC signals can be used with wire sized for the current and distance. A NAMUR solid state self-contained switch can monitor mechanical contacts at up to 5750 ft using 16 AWG wire. It usually has the added advantage of providing wire monitoring.

Note 2: Polyethylene insulation has half the capacitance per than PVC.

3.3.1.4.4 Discrete Output Leakage Current

The effects for output leakage current should be evaluated with low power devices. A DC output uses transistor while an AC output employs a triac. Solid state outputs leak a small amount of current in the off state. This is an inherent characteristic of solid state devices. Also, some outputs use supervisory currents to monitor the circuit. Voting type outputs can have up to 1 mA of leakage current.

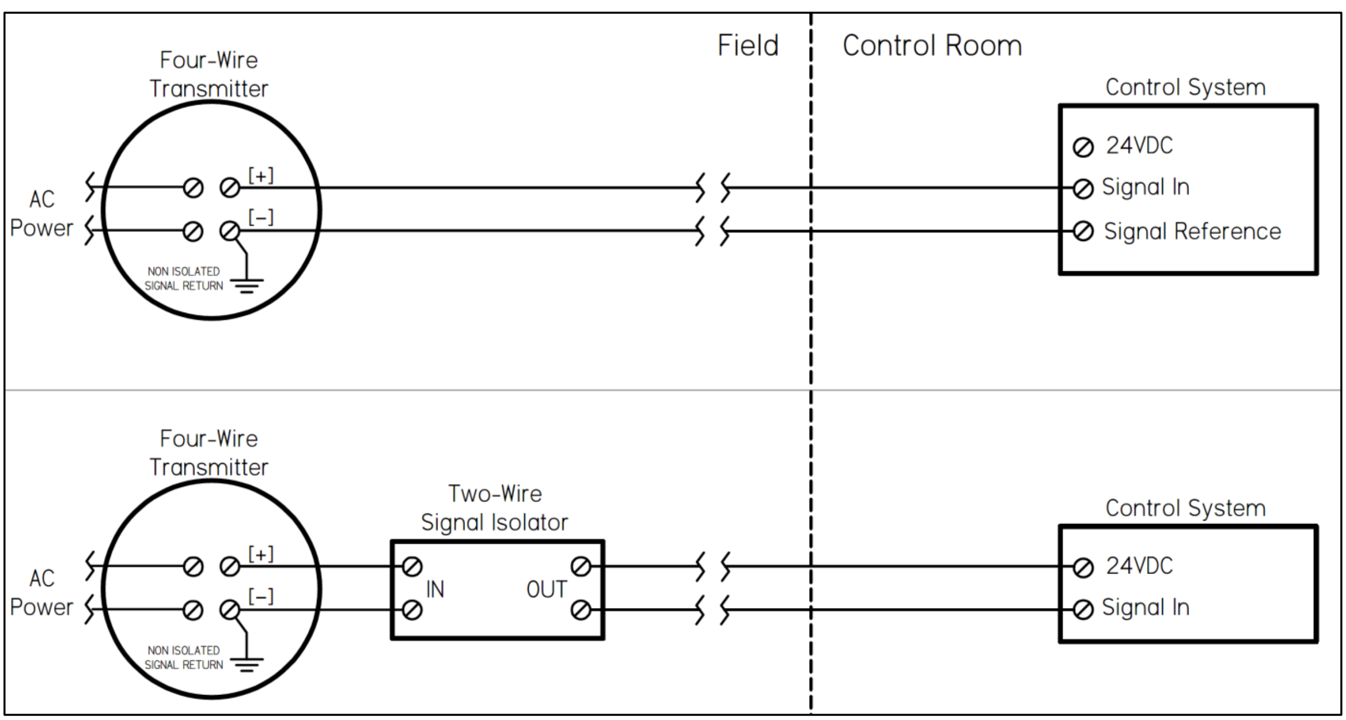
These leakage currents can cause sensitive relays and low power solenoids not to drop out. Also, leakage current can cause pilot lights to glow. The solution is to match the output leakage to the dropout current of the device. A buffer relay between the device and the output can be required.

In some cases, with triac outputs the load, such as a pilot light, can be too small to cause it to switch off. A 30K, 1 watt resistor can be used to shun current across the output, allowing it to shutoff.

3.3.2 Signal Isolation

Instruments and other devices need to be protected or isolated from stray electrical potentials. They should be fully isolated according to ISA S50.00.01 requirements. Electrical isolation is an absence of a connection among signals, power, earth ground and any other terminals. It is usually defined in terms of voltage.

Figure 2
Four Wire Transmitter with Signal Isolator



A minimum dielectric strength of 500 VAC from ground and between isolated circuits is recommended. The requirements of IEEE C37.90-2005 Section 8.2 should be met or pass IEC 61298-2-2008 Sections 6.3.2 and 6.3.3 testing with no measurable loss of resistance or a flash over.

A dielectric strength of 1500 V can be required in locations of high electrical activity such as switch yards or surge protectors can be provided.

When employing four-wire instruments, two-wire electrical isolators; i.e. loop power, mount in the field with the instrument are recommended to avoid termination issues with the control system while ensuring adequate isolation. For instance, if a current source input is used then an isolator should be used.

A typical system termination assembly has three terminals: 24 VDC, Signal Input and Signal Reference. The Signal Reference is used instead of the 24 VDC power source with four wire instruments. A two-wire isolator elements the need for the infrequently used Signal Reference terminal so a simpler, space saving two connection termination assembly can be used. A third fewer input terminals are needed with the control system as shown in the lower illustration of Figure 2.

3.3.3 Single Ended Inputs and Outputs

When connecting 4-20 mA or 24 VDC discrete signals to a control system single-ended inputs are often provided. For DC circuits the power source is important in selecting the input or output type. DC inputs and outputs can sink current or source current. Conversely, current flows in both directions with an AC circuit so there is only one input or output type.

Current sources and current sinks have the following characteristics:

a. Sinking input is a grounded connection for the signal [1]
b. Sourcing input is a power source to the signal transmitter
c. Sinking output is a grounded connection for the load
d. Sourcing output is a power source to the load [2]

Note 1: The most typical signal input for a control system is a current sink with a 250 ohm conversion resistor. In a two-wire instrument the other terminal is a 24 VDC power supply.

Note 2: The most common output is a 4-20 mA signal driving the load from a current source.

Both a voltage source and a ground reference are needed to create a circuit. The distinction for a control system input between sourcing and sinking depends on whether the inputs are associated with the +24 VDC power or the ground terminals. If the input A/D is in series before the signal ground, the inputs are sinking, and it pulls the signal from the sensor. If the input A/D is in series with +24 VDC power, the control system supplies power to the sensor while reading the signal. The former is the more common.

Figure 3
Current Source to Current Sink Wiring

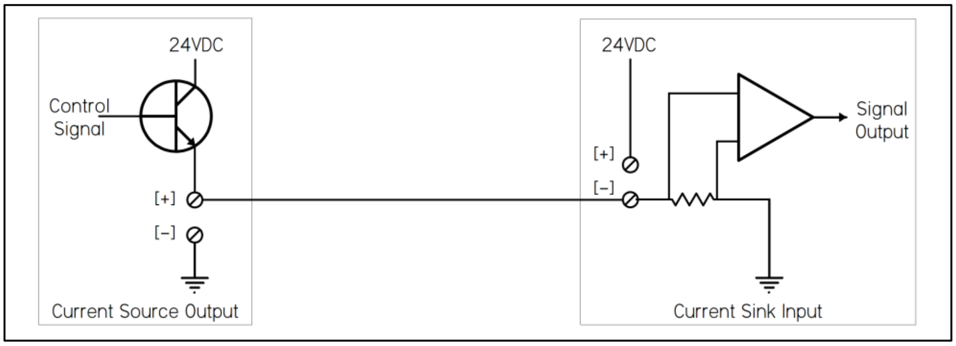


Figure 4
Current Source Output to Current Source Input Wiring

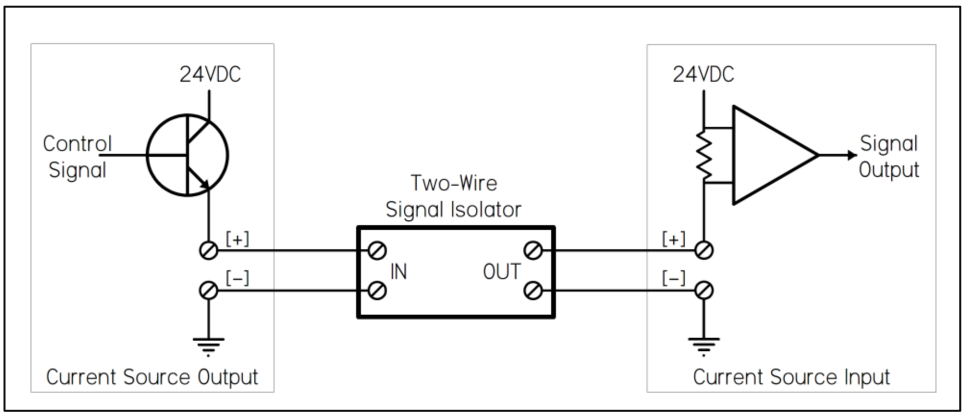
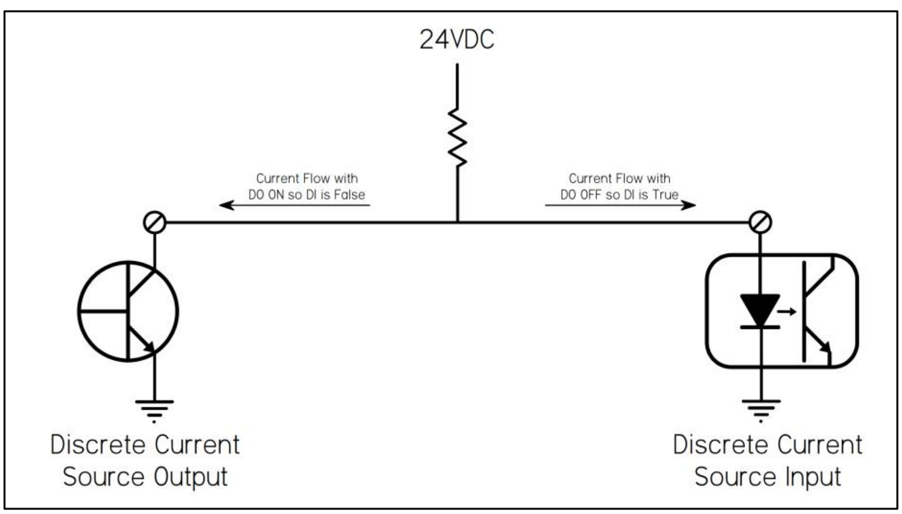


Figure 5
Current Sink I/O with a Pull Resistor



For inter system connections a sourcing input or output is connected respectively to a sinking output or input. Inputs and outputs should be matched with their opposite type, for example, a sourcing output should be connected to a sinking input.

If it is necessary to connect a sourcing input to a sourcing output or a sinking input to a sinking output, a relay is used for discrete circuits and for analog circuits a signal isolator is employed.

A less frequent practice for discrete circuits is to use a pull-up or pull-down resistor but this has the disadvantage of inverting the signal going between the two systems.

Isolated differential inputs are another input type. Similarly, isolated, or floating outputs are available. Differential Inputs are two signal wires that run from each signal source to the receiving device. One goes to the (+) input and one to the (-) input. This allows the receiving device to measure the signal against its internal reference.

When using differential inputs, the sensor can float that has no ground connection. Still it is preferred to connect the negative (-) signal wire to the control system signal reference. Otherwise, the circuit build a harmful voltage charge.

3.4 Serial Data

Serial communication sequentially transmits data a bit at a time. Serial communication covers a variety of methods to transfer information.

3.4.1 Serial Data Transmission Types

Serial data acquisition uses copper wire, fiber optic media or wireless methods. These data transmission methods consist of hardware standards and data protocols. Further, power can be supplied over the same wires when using Manchester MBP encoding, ASi and POE Ethernet systems.

With instruments serial communication can be used in the following ways:

a. Transmit process variables between an instrument to the control system
b. Transmit device health status and diagnostics to the control system or an asset management system
c. Transmit configuration data between the instrument and configuration tools; such as handheld communicator, the control system, or a personal computer.
d. Interaction by an operator using a system display to manipulate the process.

Serial communication methods used in refining applications typically include:

a. Two or four-wire serial communications using RS-485
b. Fieldbus serial communications
c. Ethernet communications over a Category 6 cable or an optical fiber pair
d. Wireless communication
e. Proprietary Networks; e.g. machinery monitoring

3.4.1.1 Wired Data Transmission

Wired communication systems transfer data using copper cables. Wired serial communications have to comply with the electrical area hazard classifications. Also, grounding, electrical surge, and electrical safety considerations apply to wired systems.

In general, wired communications are considered to be the most stable type of communication services. It is usually easier to install than fiber. Compared to wireless communications it is comparatively impervious to bad weather. They are not as prone to signal blockage due to crowding as wireless systems. Unlike fiber, wired data transmission can be corrupted by electrical noise. Wired communications are almost always connected to the electrical grid unlike many forms of wireless fieldbus communications, which rely on depletable batteries. This reliability has allowed wired data transmission to remain widespread even as wireless and fiber solutions grow.

3.4.1.2 Fiber Optic Transmission

Fiber-optic communication transmits information by sending light pulses across a glass fiber. There are different technologies, so optical electronics has to be compatible at both ends.

Fiber optic media has advantages such as:

a. Fiber optic cable is insensitivity to electromagnetic interference
b. Fiber optic cable can run longer distances than serial cables
c. Fiber optic data rates are higher and can support multiple data streams

Disadvantages fiber optic transmission are as follows:

a. Depending on the transmission method different cable types are needed.
b. Fiber is more difficult to install.
c. Terminations need special equipment and training.
d. Fiber terminations can require more space.
e. Fiber cannot transmit power with the data.
f. Interfaces with their power supplies add complexity.
g. Dual fibers are needed to supply duplex communication. [1]

Note 1: A loss of one fiber out of the pair can cause unforeseen results for systems that are not designed for that type of failure.

3.4.1.3 Wireless Transmission

Wireless systems use electromagnetic signals to communicate the data. Wireless devices can lower installation effort, facilitate expansion, and enable faster commissioning.

Wireless applications should use suitable practices to ensure robust and reliable operation. The full functionality defined by a communication standard is not necessarily provided by a supplier. Users should evaluate what functionality and features are available to meet their needs.

Wireless systems typically use unlicensed frequencies. Most process wireless technology depends on frequency-hopping to supply reliability and security. Frequency hopping technologies minimize interference and improves system security. Frequency hopping and system join technologies allow wireless applications to overlap without affecting one another.

3.4.1.3.1 Wireless Sensor Networks

Wireless sensor networks (WSN) based on industry standards are encrypted and secure. Mesh networks are preferred for robustness, reliability, and scalability. They use lower data rates than wired plant networks.

Wireless sensors are mostly battery powered with the occasional externally powered device. In some cases, solar, thermal generators and other forms of energy scavenging are used.

Application of these wireless sensor networks (WSN) include:

a. Continuous Process Monitoring

b. Sending Manual Commands

c. Closed Loop Control

d. NFPA 72 Fire Alarms

One of the advantages of wireless sensor networks is that many devices are intrinsically safe. So besides eliminating the need for signal wires maintenance is simplified in that hot work permits are not necessary.

3.4.1.3.2 Process Wireless Network Applications

Wireless communication can be used for monitoring and controlling plant variables. Wireless signal transmission is effectively used for the following non-time critical services:

a. Diagnostic messages for valves and measurement instruments
b. Machinery monitoring for low voltage pumps and fans
c. As a substitute for inaccessible local temperature and pressure gauges
d. Temperature and other indications used for process studies
e. Non-time critical alarms and indicators
f. As a local flow indictor for large lines
g. As redundant indication of an essential process variable
h. Temperature monitoring of systems with a large thermal capacity
i. Monitoring of cooling tower level, vibration, and blowdown
j. Level measurement in tanks with a long residence
k. Utility packages that have a stored buffer or continuous operation is not critical
l. Level indication and motor control for remote sumps and ponds
m. Battery limit flow, pressure, and temperatures
n. Substitute for local recorders and pneumatic instruments
o. Monitoring pump seal pot pressure and level
p. Pressure measurement at the end of headers
q. Pressure indication for regulators [1]
r. Safety shower monitoring
s. Monitoring of heat traced lines
t. Monitoring Electrical Hazard Reduction Purges
u. Temporary measurements for process studies commissioning and startups
v. Replace grade level mounted draft gauges and pipe

w. Flare control system monitoring
x. Remote valve position indication

Note 1: This can be a substitute for facility control system pressure control loop. An example is a tank blanketing system.

With modified feedback algorithms designed for nondeterministic updates and long sample time, it has been shown that it is possible to control process variables with battery powered wireless devices. Even fast loops like flow can be controlled.

3.4.1.3.3 Process Wireless Characteristics

Wireless instrument networks fall into four basic topologies.

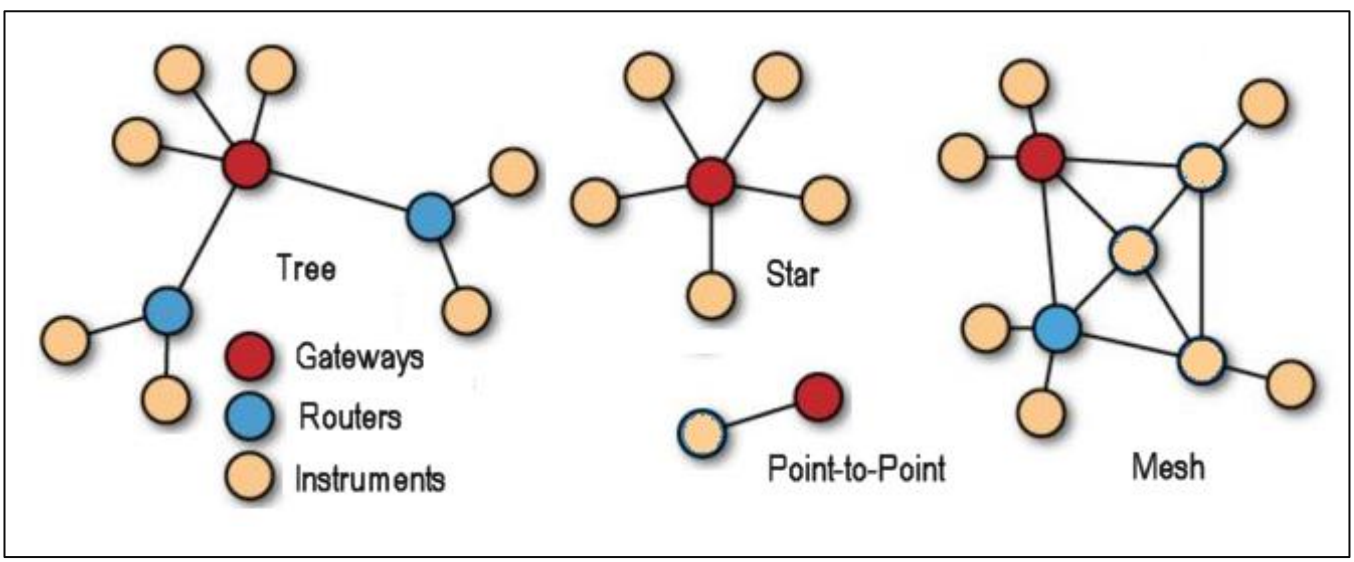
3.4.1.3.3.1 Point-to-Point Network

A version of the point-to-point system is an instrument, such as temperature sensor that has a communication path to a dictated readout. Another alternative is a handheld controller that energizes a contact to operate a device such as an access gate.

The point-to-point configuration is also used where multiple signals are wired into a wireless multiplexer. The multiplexer accepts conventional signals with analog or discrete inputs and repeats them to a central gateway using a dedicated path. The values are demultiplexed to the equivalent wired signals at the output end. Outputs can be sent in the other direction.

This type of system is used with microwave radios on pipelines to control pumping and compressor stations. A high speed version of this type of system is also used as a bridging system to tie two control systems together in a plant.

Figure 6
Styles of Wireless Networks



3.4.1.3.3.2 Star Network

The star network has multiple measurement devices sending the data to a central gateway. The gateway then transmits the values to a host system. Discrete control is often sent to remote relays to start pumps and the like. This configuration is common with proprietary networks.

3.4.1.3.3.3 Tree Network

Tree systems where individual wireless instruments communicate with routers along a fixed path to a gateway. An instrument has one communication path to the gateway. This is one of the allowed ISA 100.11a topologies. Otherwise this configuration is limited to hardwired networks.

3.4.1.3.3.4 Mesh Network

This wireless network consists of sensors that self-organize into a mesh. The wireless sensors do not need to communicate directly with the gateway. To communicate sensors or repeaters near the gateway, retransmit the signal until it reaches the gateway.

The wireless sensors determine the nearest sensors and pass messages through them. They pass on the received messages as well as their own. There are multiple paths in the network, so they are self-healing, and a loss of a few devices does not affect the messages getting through. Redundant gateways are common with this type of network.

3.4.1.3.4 Wireless Plant Networks

Wireless plant networks supply Wi-Fi or IEEE 802.11a/b/g/n wireless access points for multiple applications and preferably use the Ethernet protocol. They can also be part of the business systems network. These networks supply standard security mechanisms and high data bandwidth. Applications include:

a. Transmission of video and occupancy signals for monitoring and security
b. Staff time tracking and access control
c. On-site access to the control system, calibrations, real time data, etc.
d. Tracking equipment, material, and chemicals
e. Data backhaul or bridging for control systems and wireless networks

3.4.1.3.5 Backhaul Wireless Backbone

A backhaul wireless backbone typically is a point-to-point wireless connection, usually at a higher power and speed, to supply communications between multiple wireless gateways or other wireless devices to a host.

A mesh of Ethernet devices can be created using IEEE 802.11n access points. The IEEE 802.11n access points that can form their own mess networks and can be managed remotely. The wireless access points can function as gateways for both WirelessHART and ISA 100.11a devices and simultaneously perform the role of repeaters. These devices can also function as access point for the IEEE 802.11a/b/g/n plant network as well as operate digital CCTV cameras and other security devices.

3.4.1.3.6 Cellular Networks

Cellular routers are available that use mobile phone technology to transmit data over the public telecommunications network. This can be as simple as an individual location telemetering a few data points to a large integrated, packet switching SCADA network.

A problem with cellular technology, as they evolve legacy technologies are discontinued. Older networks such as GSM, EDGE, UMTS and CDMA are now unavailable, and the associated cellular hardware no longer functions.

Standardization is another problem with these systems. Each application has to be programmed with the interface which is outside the normal control system. A simple approach used with a single point cellular device is sending commands employing SMS messages. These devices use a simple script language. The device should be configured to accept commands from designated phone numbers and the correct password has to be transmitted to start a session. Conversely they can be configured to call-in status changes and measurements.

PLC suppliers supply cellular interfaces so a micro PLC can be configured as RTU that communicates with a companion PLC in the control center. Then a standard serial protocol can be used to communicate with the central control system or business system.

For larger networks security is ensured by using AES 128 bit or better encryption with FIPS 140-2 physical protection on top of a VPN for data transmission. Since public networks are used, these connections should be protected with stateful firewalls intended for SCADA service. See the relevant ISA and NIST recommendations for fuller and more specific requirements.

3.4.1.3.6.1 LTE Networks

LTE and 4G data transmission are the same thing. To transition to LTE and LTE+, carriers shutdown the 2G and 3G networks to make that spectrum available for it.

NB-IoT and LTE-M (CAT-M) are used for data transmission on 4G/LTE networks. NB-IoT can be deployed on 4G (LTE) and legacy GSM networks, while LTE-M is a 4G protocol. However, LTE-M is compatible with the existing LTE network, while NB-IoT uses a different modulation scheme, which requires additional network hardware

3.4.1.3.6.2 Fifth Generation Networks

The radio access technology beyond LTE is 5G-NR (New Radio). Adoption of 5G technology doesn't replace 4G/LTE, it works in conjunction with 4G's spectrum. It uses spectrum in the mid-band or high-band ranges.

Standalone mode is the core 5G that brings improvements for consumers and IoT/M2M deployments. The core system brings three prominent use cases eMBB, URLLC and MMTC. URLLC (Ultra-Reliable Low Latency Communications) is the most appropriate deployment for SCADA but eMBB was deployed prior to URLLC

3.4.1.3.6.3 SIM Cards

Specialist SIM card vendors to suppler cellular modem are available to provide network connections worldwide. Cellular network carriers distinguish IoT data usage from other cellular usage with SIM cards designed specifically for IoT and M2M use.

Wide-range of connectivity compared to traditional cell SIMs for remote deployments and stable connection. Simply put, IoT SIMs get better connectivity range.

IoT SIMs and data plans can be used to accommodate custom data needs such as high-data usage from video cameras and streaming.

IoT devices that do not pull a lot of data from the network use IoT SIMs to limit power strain, data consumption, and cost.

IoT SIMs are designed to match the rugged environments in which they are deployed - extreme temperatures, impact, vibration, humidity and corrosion.

Multi-carrier IoT SIMs: Some IoT SIMs can access multiple networks and switch to the carrier with the strongest signal. Learn more about SIMETRY's multi-carrier services here.

IoT SIMs have better remote access and security capabilities, which allows businesses to protect and access their data from IoT platforms designed for easy device management.

1.1.1.1.1 Satellite Communications

Satellite terminals allow control of assets operating in remote areas. VSAT, BGAN and Certus are common satellite terminal types. The amount of data you plan to send or receive is one of the key considerations when deciding which technology to choose. Small amounts of satellite bandwidth are available for individual sites.

A typical terminal has the ability to transmit four analog signal or use Modbus protocol to connect to a PLC based RTU. The terminals use a scripting language for configuration. Satellite transmission can be more secure than other forms of wireless since signal is directed only at the satellite. Still similar security provided with cellular data transmission is recommended for satellite communications.

Satellites are subject to specific considerations that affect their ability to transmit signals, namely latency and rain fade.

VSATs orbit 35,000 kilometers above the earth. Because of this physical distance, there is a delay of about 250 milliseconds as communications travel from the earth to the satellite and come back. Protocol processing adds another 300 to 500 milliseconds.

These add up to create latency, which is the time lag between a signal’s broadcast and when it is received at the destination.

There are ways to mitigate latency, such as TCP processing or spoofing. Spoofing means that instead of running TCP acknowledgements all the way across the satellite, the TCP protocol is terminated at the remote terminal and the gateway station. This offers a better user experience for web browsing and transferring data.

Rain fading is caused by rain or moisture in the atmosphere, which can lead to the loss of strength or degrade the quality of the satellite signal at higher Ku and Ka-band frequencies.

To mitigate rain fading on the forward channel, adaptive coding and modulation can increase the power of the signal. On the return channel, adaptive coding and changing the return channel symbol rate increases the signal quality.

It is also possible to increase the uplink power available at the remote location to avoid rain fading.

For backup communications modems are available that combine satellite and cellular capabilities.

1.1.1.1.1.1 BGAN

BGAN can be sufficient for your needs. It also supports telemetry and short-term video broadcasts. The BGAN can transmit data at speeds of up to 500 kbps and is generally designed for single users or a small team that has sporadic data usage throughout the day.

1.1.1.1.1.2 VSAT

The VSAT is a better choice for those who need high bandwidth to transmit high levels of data on a long term basis. It can carry data as well as latency-sensitive applications and IP based multicast applications like audio and video streaming. The VSAT can provide point-to-point WAN links and is capable of “always on” broadband internet services; it also supports bandwidth on-demand services, encrypted data transfers between two or more sites, and VPNs. The VSAT platform supports dozens of users with upload speeds of up to 5 Mbps and download speeds of up to 20 Mbps. The VSAT terminal can back up to terrestrial networks or can utilize customized plans to backup exclusively with satellite service providers. The VSAT is extremely reliable and not affected by natural disasters, making it an excellent option for mission-critical applications. Rain attenuation can affect its performance, so larger antennas and amplifiers are usually recommended for some applications.

IEC Telecom’s VSAT satellite add-on services are important enhancements to your custom solution that provide network continuity when the VSAT link is down or weakened due to rain fade. This way, business-critical applications can continue to perform their intended functions until the issue is resolved.

1.1.1.1.1.3 Certus

Certus offers high throughput L-band data speeds for simultaneous connections of data access, multiple phone lines, and location-based applications. Its low-latency network provides consistent smartphone use anywhere around the globe. Certus allows you to automatically route data connection through an external cellular modem when networks are available to help reduce the cost and provide a seamless user experience. It initially launches with speeds of up to 352 kbps but can be upgraded to 704 kbps and potentially reach a maximum 1408 kbps. Certus can be used as primary broadband or as a backup to an existing VSAT. The Certus terminal features a low-frequency I-band signal that is unaffected by weather conditions.

3.4.2 Floating Point Data

Digital data communication makes it possible to transmit IEEE 754 floating point values. The entire measurement capability of the transmitter is realized by sending floating point data. Transmitter spanning is not necessary since the entire available range is transmitted. The only time a span is applied is for the display of analog values like bar graphs and pointer indicators

3.4.3 Isochronous Operation and Time Synchronization

Continuous processes need a real time communication protocol that transmits time constrained messages; i.e. the data arrives at fixed time periods in an isochronous manner. This is necessary since control algorithms use time averaged data in their calculations. Depending on the process the data update rates can be between 0.1 seconds and 3 seconds.

On the other hand, discrete logic used in manufacturing production lines can need faster data update rate in the one milli-second or less range to react to a changing state. For instance, if a belt conveyor goes off track it should be shut down before a catastrophic failure occurs. In manufacturing exact time synchronization is unnecessary if the sequence of events stays the same and within the required window.

Consequently, communications protocols intended for manufacturing operations can be inadequate for a process controller that needs consistent periodic updates. Alternatively, process control communication networks can be too slow for a manufacturing production line, such as a bottling plant.

Standard Ethernet is not truly deterministic but can be configured to deliver information down to the one milli-second range with a high degree of certainty.

A true deterministic network, such as Foundation Fieldbus requires the use of fixed cycles where the time sensitive information receives priority. These cycles are rigidly scheduled. IEEE 802.1AS and IEC/IEEE 60802 among other standards apply to the specification to TSN networks.

Still with Ethernet separating the traffic into priority classes makes it possible to ensure bandwidth is available for mission-critical protection applications so eliminating congestion and providing a firmer guarantee for high-priority traffic delivery.

The number of supported priority queues varies among switches, with the minimum of two needed to claim IEEE Std 802.1D support. Queuing strategy is usually configurable, with “strict priority” being one of the options. Low-priority messages are not forwarded until the high-priority traffic has been processed.

Separation of traffic into multiple priority classes makes it possible to calculate and control the worst-case latencies encountered by the highest priority real-time traffic, thus creating the true determinism needed for real-time network operation.

See IEEE 2030.101 for specifics on designing time synchronized networks and time distribution across networks.

4 TRANSMISSION STANDARDS AND PROTOCOLS

4.1 Communication Protocols

Communicating systems use well-defined formats or protocol for exchanging messages. A communication protocol has rules that allow two or more devices to interchange information. The protocol defines the rules syntax and synchronies communication as well as determine the error recovery methods. Protocols can be implemented by hardware, software, or both.

Modern protocols are a total package based on the seven layer ISO 7498 OSI model. This model breaks down communications into seven layers starting with the physical interface and ending with the application interface. Fieldbus protocols do not necessarily support every aspect of this model, but it did inspire a total systems approach towards developing communication standards. It even facilitates a degree of operability between protocols.

Prior its introduction in 1984 suppliers independently created communication systems using various off-the-self components such the ASCII character set, UART chips and RS-232/RS-485 drivers. With the exception of Modbus, the various devices from different vendors where proprietary and had almost no interoperability.

4.2 Serial Interfaces

4.2.1 RS-485

RS-485 or TIA- 485 signals are used in a wide range of systems using a tristate differential balanced signal over a twisted pair. RS-485 is often used in continuous process automation to transfer data between two devices. It can transmit data synchronously using two wire pairs or more commonly asynchronously with one pair.

RS-485 also supports simple local networks and multidrop communications. Depending on the RS-485 transceiver impedance can support as few as 32 nodes and 128 or more nodes before a repeater is required. The actual number of nodes is limited by the addressing space of the higher layers of the specific protocol being used.

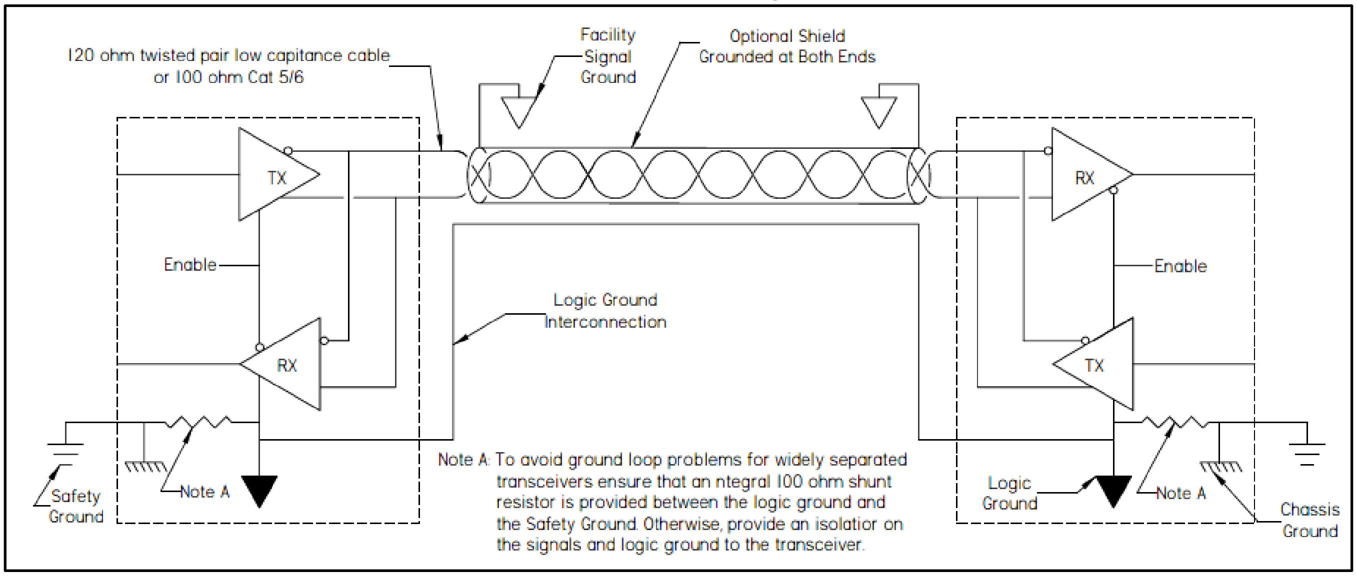
RS-485 has speeds up to 12 Mb/s but it is used at lower speeds when interconnecting distant field devices. It can be used with maximum data rates for lengths less than forty feet and distances up to 1,200 m (4,000 ft) at 100kb/s. A 120Ω terminator is needed at the end of the line.

RS-422 is a similar standard that proceeded the introduction of RS-485. The electrical specifications and the wiring requirements of RS-422 correspond mostly with the RS-485 standard. RS-485 are compatible with legacy RS-422 networks but the opposite is not true.

The tristate capabilities of RS-485 allow a single wire pair and ground to share transmit and receive signals for half-duplex communications. Conversely a RS-422 system requires a dedicated pair of wires for each signal, a transmit pair, a receive pair and when needed an additional pair for each handshake/control signal used.

RS-485 is not a protocol; it is simply an electrical interface. Although many applications use RS-485 signals, the speed, format, and protocol of the data transmission is not specified. The standard does not define character encoding, such as ASCII, character framing; that is start bits, stop bits, etc., the bit transmission order, or error detection. Interoperability with similar devices from different suppliers is not assured by compliance with the signal levels alone.

Figure 7
Shunt Protection of RS-485 Signal Reference



RS-485 is still used as the physical layer underlying many standard and proprietary automation protocols including the most common versions of Modbus and PROFIBUS. It allows industrial processors to communicate with a master/slave protocol or using a token passing access control. Since it is a differential signal, it resists electromagnetic interference from motors and other electrical equipment.

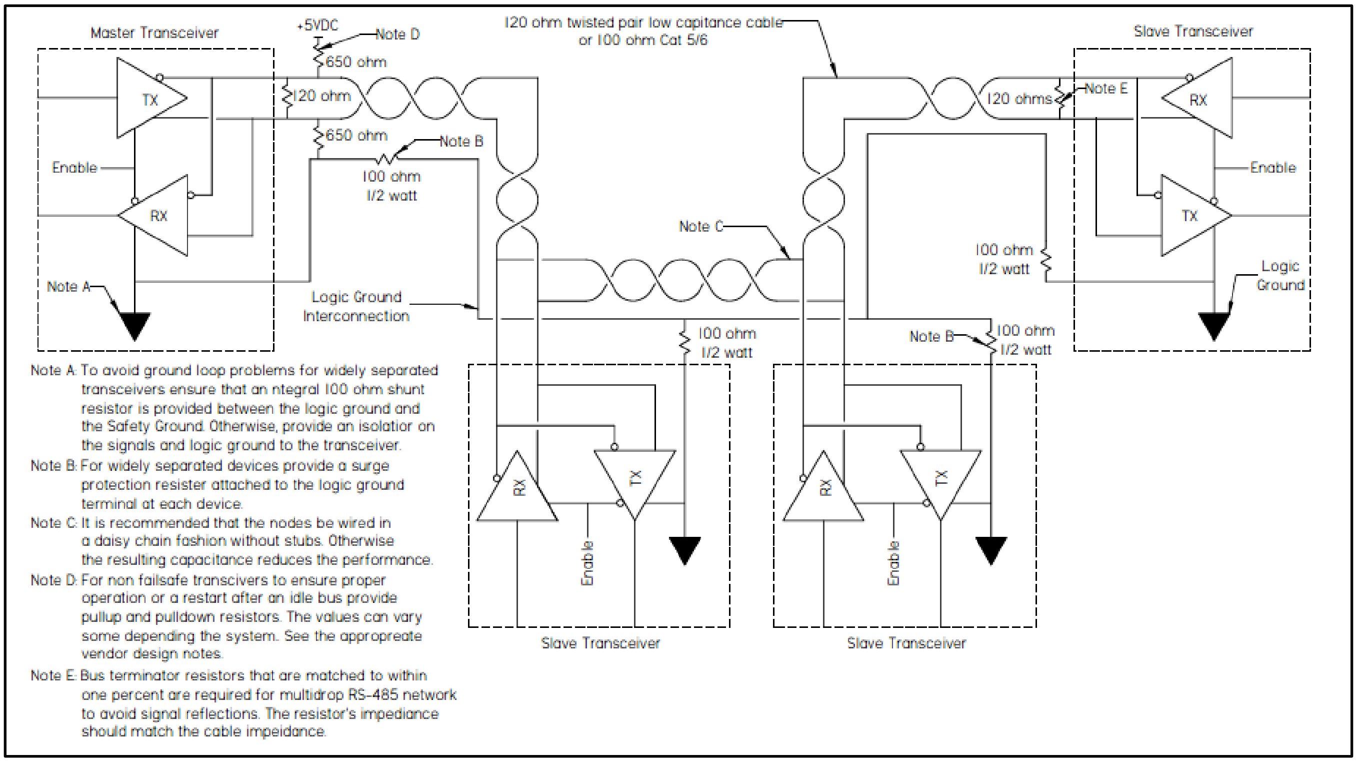
RS-485 is also used in building automation as the simple wiring and long cable length is ideal for joining remote devices. It is used to control video surveillance systems or to interconnect security panels.

Unless external security protection is provided, RS-485 based protocols often have minimal security protection, which makes it problematic for SCADA applications where the communication path is not controlled or under user observation.

Since it uses minimal wiring, RS-485 communication is typically half-duplex, using a low capacitance, twisted pair combined with a logic ground wire. Three conductors of a Cat 6 UTP or similar cable with a 100 ohm impedance can be used. The RS-485 specification is based on 100 ohm cable. For industrial applications, a shielded communication cable with a 120 ohm impedance is preferred and it transmits the signal a bit more effectively. Other than short distances and low speeds the characteristics of ordinary instrument cable is inadequate for transmitting RS-485 signals.

Since it has balance inputs, RS-485 is noise resistant so that unshielded cables can be used. Additionally, with a simple bus topology RS-485 can supply bi-directional communication.

Figure 8
Installation of Multi-Drop RS-485 Signal



Stubs influence the system capacitance. They require special calculations to implement and are generally avoided. A simple daisy chain installation is the most effective. Still, nodes should not be placed too close together. A high network lumped capacitance can require a separation of half a meter between nodes. Without special provisions, star and ring topologies are not feasible due to signal reflections as well as issues with termination impedances.

Though differential balanced inputs; such as RS-485, can operate without a common signal reference the excessive difference in ground potentials that can occur over long distances is not acceptable. The shield is sometimes used as the common ground between the nodes. However, this practice allows noise to bypass the protection in MESH grounding systems and should not be used.

When there is no data activity, the lines are not driven so they are susceptible to external noise or interference. If not provided internally to the RS-485 interface to ensure that a device stays in a constant state, pull-up and pull-down resistors are recommended to bias the network.

One practice is to use a separate ground reference wire with a shunt. The shunt limits ground currents. The TIA/EIA-485 specification recommends a 100 ohm resistor as shown in Figure 7 in series between each signal ground connection. This provides a signal ground sufficient to overcome common mode potential differences well enough for RS-485 to work in most cases. However, in areas prone to high ground differentials signal isolates should be considered.

Also, surge protectors should be considered. When using a signal reference ground wire, surge protectors specific for RS-485 systems offer the best solution by holding the voltage spikes to less than seven volts.

The inherent fault tolerance of a RS-485 network is nominal. However, to address this problem, RS-485 device servers with self-healing ring topologies have been developed by several suppliers. The RS-485 device is connected to a transceiver that sends the data over a bidirectional ring using a fiber, Cat 6 cable or similar wire. Upon failure detection, the traffic that is downstream of the break is rerouted in the reverse direction to the disconnected nodes.

Some of these devices are designed for the master/slave type protocol and its data flow control. One transceiver is intended to operate as the master. They are operable with Modbus and similar protocols.

Intelligent motor protection relays are used for motor remote control and advanced monitoring using either non fault tolerant Modbus RTU or Profibus DP. A fault tolerant remote motor control can be achieved using an RS-485 self-healing ring.

Star topology is useful for installation such as intelligent motor operated valves in a tank farm where the valves are distributed over a wide area. By using a cluster of DIN rail mounted repeaters at a central location a star network can be formed that can individually reach out to the remotely located valves. Each repeater can transmit signals up to 4000 ft.

4.2.2 RS-232

RS-232 is an older standard introduced in 1960 for serial data communications. ITU-T V.24 is the international version of RS-232. Due to its simplicity and past ubiquity, RS-232 interfaces are used in industrial equipment, networking hardware, and instruments where a short-range, point-to-point, low-speed wired data connection is satisfactory. Like RS-485 it is not a protocol; it is simply an electrical interface.

The standard defines the electrical characteristics and signal timing, and the signal meaning, as well as the physical size and pinout of the DB-25 connector. The current version of the standard is TIA-232-F "Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange."

The character format and transmission bit rate are set by the hardware. It is intended for bit rates of 9,600 Kb/s or lower. RS-232 uses an unbalanced circuit which makes them prone to common mode interference and ground loop problems. By using low-capacitance cables, communication runs can be 300 m (1,000 ft.)

Like RS-485 the RS-232 standard does not define character coding, framing, bit transmission, or the error detection protocols. Pins in the DB-25 connector are intended for transmission control.

Many RS-232 connections are not configured correctly. The standard did not foresee devices such as computers, printers, test instruments, etc. designers have freely interpreted the standard. The result is non-standard connector pin assignments and incorrect or missing control signals.

Frequently, a DB-9 connector is supplied because most of the signals in a DB-25 go unused. An advantage of a full RS-232 port is it has the ability to provide power to an auxiliary device such as isolator or converter.

4.2.3 ASCII

ASCII stands for the American Standard Code for Information Interchange. It is a seven bit character encoding standard for electronic communication. It was originally developed for teletypewriters and is still used today. It is used with RS-485 and RS-232 devices. It is also used for programming configurable devices using terminal emulation software.

ASCII encodes 128 characters into seven-bit integers. Out of the 128 characters 95 are printable. The initial characters of Unicode UTF-16, 16-bit, and UTF-32, 32-bit, is based on ASCII. For transmission control the character set includes “Start of Message” (SOM) and “End of Message” (EOM) characters.

ASCII is transmitted with the least significant bit first. Since a byte is eight bits this allows adding a parity bit for error checking. This type of error checking is not considered robust enough for control applications so other forms of error checking are used by the IEC fieldbus standards.

ASCII is an American based character set. Using the full byte allows the use of international characters. ISO 8859-1 or Latin-1 is an eight-bit character set and is an extension of ASCII which contains an additional 96 printable characters that is sufficient to express the most common Western European languages. It has some additional symbols as well, but it has shortcomings such as not having the € symbol for the Euro. UTF-8 is used for encoding more complex characters and uses between one and four bytes. However, standard fonts just support a small subset possible with a four byte word. For instance, the standard Arial font has 2818 characters and 3419 glyphs so a 16-bit word can portray the basic Arial character set.

Table 6 Comparison of Common Wired Fieldbuses

Physical Layer								
Technology	FF H1	PROFIBUS PA	FF HSE	PROFINET	PROFIBUS DP	HART	MODBUS RTU	ASi
Standards	IEC 61158	IEC 61158	IEC 8802 IEEE 802.3	IEC 8802 IEEE 802.3	TIA-485	Bell 202 4-20 mA	TIA-485	IEC 62026-2
Power w/Comm	Yes	Yes	No	No	No	Yes	No	Yes
Fault Tolerance	High	High	High	High	Moderate	Low	Low	Low
Comm Type	Digital	Digital	Digital	Digital	Digital	Digital on Analog	Digital	Digital
Comm Speed	31.25 Kb/s	31.25 Kb/s	100 Mb/s 1 Gb/s	100 Mb/s 1 Gb/s	9.6 Kb/s to 12 Mb/s	1.2 Kb/s to 9.6 Kb/s	9.6 Kb/s to 12 Mb/s	167Kb/s
I.S. Possible	Yes	Yes	No	No	No	Yes	No	No
Max Distance	1.9km to 9.5km	1.9km to 9.5km	100m	100m	1512m	3.0km	1512m	100m to 200m
No. Devices	32 per seg	32 per seg	Unlimited	Unlimited	247 per seg	1 w/Analog, 62	247 per seg	62
Data Link Layer								
Standards	IEC 61158	IEC 61158	IEC 8802	IEC 8802	IEC 61158	IEC 61158	None	IEC 62026-2
Data Link Type	Token Passing	Token Passing	Token Passing	Token Passing	master/slave address scheme	Flat Addressing	master/slave address scheme	master/slave address scheme
Error Detection	16-bit CRC	16-bit CRC	16-bit CRC	16-bit CRC	Check Sum	CRC	CRC	Check Sum
Deterministic	Yes	Yes	No	No	No	No	No	Yes
Comm Relationship	client/server pub/sub	Master/slave	client/server pub/sub	Master/slave	Master/slave	Master/slave	Master/slave	Master/slave
Real Time Mgt	TM distributes	None	TM distributes	None	None	None	None	None
Application Layer								
Standards	IEC 61158 Function block IEC 61804	IEC 61158	IEC 61158	IEC 61158	IEC 61158	IEC 61158	IEC 61158	IEC 62026-2
Data Transfer	AI, AO, DI, DO, PID, PD, CS, MIO, etc.	AI, AO, DI, DO	AI, AO, DI, DO, PID, PD, CS, MIO, etc.	AI, AO, DI, DO	AI, AO, DI, DO	Commands	Registers	DI, DO or AI, AO
Control in Field	Yes	No	Yes	No	No	Yes	No	No
Peer to Peer Comm	Yes	No	Yes	No	No	No	No	No
Alerts and Trends in Devices	Alarm Trend	Alarm Trend	Alarm Trend	Alarm Trend	Alarm	Alarm	No	No
Time Features	Single sense of time	Event time stamping	Single sense of time	Event time stamping	Event time stamping	None	None	None
IEEE 754 Floating Point Data	Yes	Yes	Yes	Yes	Yes	Yes	No	No

Table 7
Fieldbus Comparisons

Fieldbus	Max Devices	Isochronous	Bus Power	Cable Redundancy	≤ 1ms Cycle
AS-Interface	62	No	Yes	No	No
DeviceNet	64	No	Yes	No	No
ControlNet	99	No	No	Yes	No
EtherNet/IP™	3.4×10^{38}	Yes	No	Optional	Yes
Modbus RTU	246	No	No	No	No
PROFIBUS DP	126	Yes	No	Optional	No
PROFIBUS PA	126	No	Yes	No [1]	No
PROFINET IO	3.4×10^{38}	No	No	Optional	No
PROFINET RT	3.4×10^{38}	Yes	No	Optional	Yes
FOUNDATION™ Fieldbus H1	240	Yes	Yes	No [1]	No
FOUNDATION™ Fieldbus HSE	3.4×10^{38}	Yes	No	Yes	No
Note 1: Redundancy links to a device is not available but a redundant trunk between the host and the local distribution block are offered by some suppliers using device couplers					

4.3 Fieldbus Networks

4.3.1 General

Digital communication enables improved accuracy, better reliability, and a reduced checkout effort. Also, upgrades are facilitated. Common fieldbuses in the refining and petrochemical industry are described in this section. API RP-554 discusses higher level communications within control systems. This section does not list every fieldbus, nor does it endorse a particular technology.

Fieldbus systems require the following features:

a. Communicate one or more measurements from an instrument.

b. Communication of information and commands from one instrument to another.

c. Enable control functions, both continuous and discrete, among devices.

d. Communicate device status and diagnostics.

e. Allows operator interaction with the control functions.

f. The upload and download of configurations.

Fieldbus systems allow devices to share communication media. Also, fieldbus support multiple functions. The functions vary with the application and the protocol.

Fieldbuses have standards, application recommendations and qualification testing. Their developed and managed by a governing body, usually a trade association or user group.

Fieldbus standards enable interoperability between different suppliers' hardware. There are several systems, and the choices are based upon the data, transmission distance, update speed and the host's capabilities. IEC 61158 lists standards for various fieldbuses. See **Error! Reference source not found.**.

4.3.2 Modbus RTU

Modbus was the first open protocol available for industrial control. It was first published in 1979. It is a master/slave protocol and has a simple data structure and command set.

It was designed for use with discrete logic systems such as programmable controllers. Due to its simplicity and its almost universal support it is still widely used especially in SCADA applications and as a means of transferring information between dissimilar systems such as a DCS and a chromatograph.

Modbus ASCII also exists but it is infrequently used because of its less efficient data transmission. This mode is used when the physical communication link or the capabilities of the device does not allow conformance with RTU mode requirements regarding timer management. Then Modbus ASCII is used to avoid time outs.

Limitations of serial Modbus are as follows:

a. The number of data entities is limited to four. Large binary objects are not supported. [1]

b. The address space limits its data storage capabilities. With the traditional standard the number of addresses is limited to 9,999 for each entity and are mapped to specific locations. [2]

c. No standard way exists for a node to find the description of a data object. Mata data such as engineering units are not supported.

d. There is no way for a field device to "report by exception" The master node polls each device and looks for data changes.

e. It is limited to addressing 247 slave devices. [3]

f. Modbus transmissions have to be contiguous. The receiving devices have to buffer the data to avoid gaps. [4]

Note 1: Typically this is not a problem. The standard convention is to store 32-bit IEEE floating point data in two adjacent registers. Enron/Daniel Modbus Extensions have a 32-bit unsigned integer and 32-floating registers. Still with the former there can be compatibility issues with the byte or word order between systems. It is also common practice to use groups of 16 bit registers to hold two ASCII characters for model numbers and the like.

Note 2: Modbus V1.1 has done away with these two limits. The register addresses range can be from 0 to 65535. The pre-mapping between the Modbus data model and the device application can be totally device vendor defined.

Note 3: RS-485 is limited to 32 nodes before a repeater is required to address additional devices. On the other hand, Modbus/TCP can address a vast number of slaves using Ethernet, but switches are needed to create the network.

Note 4: The maximum size of a Modbus packet is 100 registers

Table 8 lists the data types provided from a slave device to a Modbus master device.

Table 8
Modbus Data Types

Data Type	Access	Size
Coil	Read-Write	1 bit
Discrete input	Read	1 bit
Input register	Read	16 bits
Holding register	Read-Write	16 bits

Due to the limited data types the transferring data between systems requires some external coordination either with the user programs or system vendor software to create negative numbers, real numbers, etc.

There are alternate proprietary versions of Modbus such as Enron/Daniel Modbus, developed to expand its set of simple data types such as IEEE floating point numbers, but is not widely enough supported to ensure interoperability in every regard. None of these extensions were evaluated by an independent agency such as Modbus.org for interoperability.

Enron/Daniel Modbus, which is the most common variant, returns 4-bytes per register instead of the 2-bytes per holding register of the Modbus specification. For instance polling registers 5001 and 5002 in Enron/Daniel Modbus returns 8-bytes or two 32-bit integers, while Standard Modbus would only return 4-bytes, or one 32-bit integer treated as two 16-bit integers. In addition, polling register 5010 in Enron Modbus returns the tenth 32-bit long integer, where Standard Modbus would consider this half of the fifth 32-bit long integer in this range.

When relying on system software to convert the data to other formats, the inter-operability between the two systems needs to be carefully evaluated using all the extended data types.

See the "MODBUS over serial line specification and implementation guide" from Modbus.org for details on installing and operating a serial Modbus system. Also supported by Modbus.org is the Modbus Conformance Testing Program and device directory listing the certified devices.

4.3.3 HART FSK

The HART FSK Protocol is widely used for communicating with individual 4-20 mA transmitters. Further HART is the basis of a widely used wireless protocol. It is a master slave type protocol. It allows device parameter adjustment from the control room by the control system or using a portable communicator where there is access to the device wiring.

HART has Universal Commands that every device needs to recognize to be certified by the FieldComm Group. Optional are the Common Practice Commands. Lastly there are Device Specific Commands which are unique to the device. The last two are defined in the Electronic Device Description (EDD) file used by the control system to recognize and communicate with the device.

The protocol is widely used as a point-to-point protocol for instrument configuration. Also, it is a convenient method for transferring additional data to the control system. For instance, a multi-variable flow transmitter can send the temperature and pressure as 12-bit data using FSK signals at 1200 BPS.

Furthermore, HART has evolved from being a Bell 202 FSK signal multiplexed on a signal 4-20 mA signal. It is used in RS-485 multi-drop networks and transmitted wirelessly.

HART multi-drop uses a single wire pair and an auxiliary power supply. It is a multi-drop network that can be used with supervisory control installations that are widely spaced such as pipelines, custody transfer stations, and tank farms. Depending on the mode, fifteen or sixty-one devices are supported. It is usually wired in a daisy chain fashion.

The usual HART communication rate is about two to three updates per second but can take more than twenty seconds. The HART protocol allows two masters, primary and secondary with the secondary usually being a handheld configurator.

The installation for HART communicating devices is the same as a conventional 4-20 mA installation. The theoretical distance is ten thousand feet. The cable capacitance characteristics as well as the device affects it, so the distance can be fewer than three thousand feet. Ordinary shielded twisted pair cable is acceptable but for maximum distance a cable with 20 pf/ft. (65 pf/m) capacitance is recommended. Also, good shield practices are needed to effectively receive the HART signal.

Special equipment can be needed in the marshaling cabinet. Galvanic barriers or isolators need to be HART capable, so the signal can be carried through into the control system. For control systems that cannot read HART data, modules are available that read the HART FSK signals and convert them into analog or discrete signals.

In some instances, the FSK signal interferes with the control equipment. Filter modules are needed prior to system I/O to ensure reliable operation. The filter isolates the control system from modulated HART signals.

Further, filters can be needed when a 4-20 mA instrument is not designed for HART communication, such as a valve, which is connected to a HART capable control system. The HART filter is a passive device that is inserted in line with the 4-20 mA loop.

4.3.4 H1 Foundation™ Fieldbus

FOUNDATION™ Fieldbus has two protocols, H1 and HSE and is maintained by the FieldComm Group. The former, H1, uses Manchester encoding that can supply power to field devices. The latter is Ethernet TCP/IP based and is used for high speed communication and serves as a backbone for the lower speed H1 fieldbuses.

H1 FOUNDATION™ Fieldbus is a local area network. FOUNDATION™ Fieldbus creates an automation infrastructure by using a bi-directional, multi-drop, digital communication link among field devices and control systems.

H1 FOUNDATION™ Fieldbus operates at 31.25 Kbps and connects field devices and host systems. H1 FOUNDATION™ Fieldbus can supply communication and power over standard stranded twisted-pair wire for both conventional and intrinsic safety applications. Prior to use it is recommended that the existing wire be evaluated for attenuation at 39 kHz as well as other electrical properties. For new installations, cable that conforms to FF-884 H1 or IEC 31158-2 Type A requirements is used.

The segment is the basic unit in FOUNDATION™ Fieldbus network. A segment links transducers and valves together to form a control network. The segment is powered by a power supply designed to feed the connected devices. The devices are programmed using control blocks which reside in the devices as well as the host. Also, it can distribute control applications across the wider network.

The segment supports peer to peer isochronous communication still there is a Link Active Scheduler to manage the segment and the communications with host and other segments. This is normally an ordinary device that is assigned this role when the segment is formed. To ensure continuity if the Link Active Scheduler fails another device automatically assumes this role.

H1 Foundation™ Fieldbus has technical and performance requirements to insure isochronous operation. Segment loading is dependent upon the number of devices, the types, and the degree of control. This ensures that time dependent functions such as controllers and their tuning operate consistently. To fit within the macrocycle, the segments should be analyzed for power and execution time requirements.

As many as 31 devices are allowed on a segment but because the cycle time or macrocycle can be unacceptable long, a limit of about twelve simple, non-control devices is applied. When high performance is necessary, three or less devices with one final control element is the usual limit.

An average loop with three level or temperature control valves can have a macrocycle time of 1000 ms. While faster loops can have a 250 ms macrocycle. The macrocycle time is broken up into scheduled communication and unscheduled communication for acyclic information; e.g. alarms, display updates, etc. The latter initially should be 70% of the macrocycle.

Another limit that applies is power consumption. A non-intrinsically safe supply can supply up to 500 mA, which needs to be budgeted between the active devices, short circuit protectors and temporary diagnostic tools as well as a 20% safety margin for growth.

Lastly, the cables trunk and spurs lengths need to be budged. The maximum distance is 1900m when using an FF-844 Type A cable. The actual allowed cable length is determined by three calculations to determine first the allowed length and second the voltage drop to the furthers point. Lastly, an attenuation calculation is necessary to account for the spur capacitance. See AG-181 FOUNDATION™ Fieldbus System Engineering Guidelines for recommendations. IEC 61784-5-1 for installation requirements for CPF-1 are applicable to the two forms of FOUNDATION Fieldbus.

Fortunately, these calculations have been automated and several tools are available to design segments using standard rules and known values for the cables and devices.

Power requirements and execution time for similar devices differ among suppliers. Modifications require that the segment be re-analyzed. To ensure an operating margin the number of devices and control are frequently set more conservatively than those allowed by the FOUNDATION™ Fieldbus specification.

Table 9
FOUNDATION™ Fieldbus Standards

IEC 61784-3-1	Industrial communication networks - Profiles - Part 3-1: Functional safety fieldbuses - Added specifications for CPF 1
IEC 61784-5-1	Industrial communication networks - Profiles - Part 5-1: Installation of fieldbuses - Installation profiles for CPF 1

4.3.4.1 H1 FOUNDATION Fieldbus Features

H1 FOUNDATION Fieldbus has the following features:

a. Reduced EMI noise and ground loop issues

b. Better resolution than analog signals without digital to analog conversion errors

c. Values are transmitted as an IEEE 754 floating point value

d. The processors and communication interfaces need a smaller rack room

e. Field device parameters are adjustable from the control room

f. Field devices can be tracked and managed from a central location

g. Reduce commissioning time [1]

h. Advanced device status and diagnostic data provided

i. Multiple variable communication between devices

j. Fieldbus segments are protected from failure by redundancy [2]

k. Advanced functions can be added to field devices [3]

l. Control functions can be executed by field devices. These functions continue to run if the host fails, or communication is lost. [4]

Note 1: There is a learning curve which can affect commissioning time during the first installations.

Note 2: Redundant power supplies, redundant segment couplers and the automatic transfer of the Link Active Scheduler (FF) / Bus Master Controller (PA) to alternative devices.

Note 3: Publisher/subscriber communications, a form of peer to peer data exchange can be used for signal selectors, characterizers, PID control, custom calculations, mass flow calculation, etc.

Note 4: PID control on the segment has better dynamic performance than PID control in the host.

4.3.4.2 FOUNDATION™ Fieldbus Issues

H1 FOUNDATION Fieldbus has the following issues:

a. When using single point grounding, it is less tolerant of shielding and grounding errors than standard analog cables

b. FOUNDATION™ Fieldbus segment design needs more design effort to ensure that the time cycles, wire lengths, drops, etc. are correct

c. The device count and their criticality in a segment needs to be carefully evaluated

d. The control loop latency needs to be considered in the design [1]

e. Power supplies, which meet the FOUNDATION™ Fieldbus specification, are required

f. The system, field device and segment testing are more complex than analog checkout

g. Although devices are interoperable, the devices cannot be interchangeable [2]

h. Maintenance personnel need training to perform service and replacement

i. Existing analog wire cannot be reusable for FOUNDATION™ Fieldbus applications. The wire should be evaluated for length, shielding, and electrical properties

j. Device file version management is necessary since FOUNDATION™ Fieldbus uses Device Descriptor files

Note 1: Latency is introduced if the input and output devices are not on the same segment. When the field devices perform control functions, the input and output devices should be on the same segment. Still the device location can make this impractical.

Note 2: Replacing a device with a different model or software means that the segment has to be re-analyzed. Also, its information display can be affected.

4.3.5 PROFIBUS

4.3.5.1 General

PROFIBUS has many of the same strengths as FOUNDATION™ H1 Fieldbus. PROFIBUS functions are more orientated towards discrete industries and non-continuous operations such as sequence manufacturing and motor controllers.

It does not support independent control in the field, so the segments cannot run in a stand-alone mode. FOUNDATION™ Fieldbus has stronger determinism that is intended for continuous control.

PROFIBUS DP and PA have different physical and data link layers, but they share application layer functions. PROFIBUS DP usually runs faster than PROFIBUS PA. They interfaced with one another using approved DP/PA interfaces. PROFIBUS PA does not connect directly to the host but passes through a coupler or gateway. A PROFIBUS DP network connected to a PA network is held to the slower PA speed.

A device can send 244 bytes of input data and 244 bytes of output data. For PROFIBUS PA, the typical number of bytes is two for discrete variables and five for analog variables.

See IEC 61784-5-3 for installation requirements for CPF-3 which are applicable to PROFIBUS DP, PROFIBUS PA, and PROFINET IO Fieldbuses.

Only one master can control the network at a time. Control passes between the masters using token passing, with Class I Masters; i.e. the PLC's, having priority. After the Class 1 Masters polls every field device, for a fixed time it passes the token to Class 2 Masters; i.e. engineering and operator stations. Once this time ends, the token reverts to the Class 1 Masters. If the asynchronous data cannot be sent in the defined time, the remaining data transfers in succeeding cycles.

PROFIBUS technology is developed and administrated by PROFIBUS & PROFINET International (PI).

4.3.5.2 PROFIBUS DP

PROFIBUS DP is based on RS-485 and was originally developed for discrete manufacturing. PROFIBUS DP-V2 supports time stamps and clock synchronization. It networks discrete devices such as solenoid, pressure switches sensors, motor control and analog devices; e.g. RTD's, variable speed drives, etc.

4.3.5.2.1 PROFIBUS DP features

PROFIBUS DP has the following features:

a. Fewer EMI noise and ground loop problems
b. The digital data supplies better resolution than analog signals as well as avoiding analog to digital conversion errors
c. Process data sent as IEEE 754 floating point values
d. The processors and communication interfaces need a smaller rack room
e. Field devices are managed from a central location
f. Reduce commissioning time [1]
g. NAMUR 107 device status and diagnostic data available
h. Multiple variable communication between host and devices
i. The field devices parameters can be adjusted from the control room.

j. If instructed by the master, variables can be communicated between devices such as a controller and a valve or transmitter.

k. Devices that conforms to the PROFIBUS Trade Organization standards is interoperable with another supplier's certified devices.

l. Multiple baud rates with longer segment lengths or faster data transfers than PROFIBUS PA [2]

m. Time synchronization, isochronous real-time functionality with time-stamping

Note 1: There is a learning curve which can affect commissioning time with the first installations.

Note 2: Due to its ability to send long distances it works well with motor operated valves in tank farms and pipelines. Using RS-485, PROFIBUS DP can control devices over a twisted pair cable that can be several kilometers long in a multidrop topology.

4.3.5.2.2 PROFIBUS DP Limitations

PROFIBUS DP supports devices such as limit switches, encoders and similar devices found in discrete manufacturing applications. PROFIBUS DP has been extended to support more complex controls such as servo stepping motors and variable speed drives used in industrial type manufacturing but has fewer continuous control functions than FOUNDATION™ Fieldbus.

a. Logic and control functions only in the system master, peer to peer control not practical

b. PROFIBUS DP does not power devices

c. PROFIBUS DP does not offer configurations that can be used readily in electrically classified environments. [1]

d. File version management is necessary since PROFIBUS uses GSD files to define the device type. PROFIBUS is often supplemented by EDD or DTM files

Note 1: Typically, PROFIBUS DP devices are not electrical area certified but can be used in Class I, Division 2 and Class II, Division 2 area when conforming section 12.7 requirements.

4.3.5.3 PROFIBUS PA

PROFIBUS PA networks use a Manchester encoding physical layer like Foundation™ Fieldbus. The PROFIBUS PA is a communication system that uses polled field devices using a physical layer operating according to IEC 61158-2, clause 21. The primary intent of PROFIBUS PA is to supply an intrinsically safe control network.

A PROFIBUS DP/PA coupler, link or a PROFINET gateway is needed as an interface to the control system. The more common interface PROFIBUS DP/PA coupler or link uses RS-485 as a backhaul network to the control system.

4.3.5.3.1 PROFIBUS PA Features

Except for a single data transmission rate and does not support isochronous operation, PROFIBUS PA has the same features as PROFIBUS DP. PROFIBUS PA also has the following added features:

a. Has redundant communication and redundant master abilities. However, the slave devices are not redundant

b. PROFIBUS PA networks supply power and data on a single wire pair

c. One twisted wire pair from the PROFIBUS link to the device coupler

d. Intrinsically safe operation of the devices and signals
e. Configuration through the network
f. System oriented asset management for the field devices
g. Provides enhanced device diagnostics
h. A transducer block implementation compatible with the HART serial protocol
i. Allows spurs up to 120m from the trunk
j. Supports a ring topology

4.3.5.3.2 PROFIBUS PA Limitations

PROFIBUS PA has the following limitations:

a. Control functions reside in the system master
b. Time stamping, and time synchronization is inconsistent
c. Peer to peer communication occurs only when directed by the master
d. PROFIBUS PA does not have a direct interface to a master. A backhaul network is needed [1]
e. PROFIBUS PA needs intrinsically safe barriers between the PROFIBUS coupler, and the network installed in electrically hazardous locations

Note 1: There is no direct interface for PROFIBUS PA. There is a PROFIBUS coupler that translates the IEC 61158 MBP to RS-485 or ProfiNet. This adds to the configuration effort and vulnerable interface device.

Table 10
PROFIBUS Standards

IEC 61784-3-3	Industrial communication networks - Profiles - Part 3-3: Functional safety fieldbuses - Added specifications for CPF 3
IEC 61784-5-3	Industrial communication networks - Profiles - Part 5-3: Installation of fieldbuses - Installation profiles for CPF 3

4.3.6 FOUNDATION™ Fieldbus H1 vs PROFIBUS

Applications which are controlled by PLC's (Programmable Logic Controllers) tend to employ PROFIBUS, and applications which are controlled by a DCS (Distributed Control System) are inclined towards FOUNDATION™ Fieldbus use.

The following are the difference between FOUNDATION™ H1 vs PROFIBUS:

a. At the physical level FOUNDATION™ H1 and PROFIBUS PA use Manchester bus powered (MBP) for data transmission and power. They do use different link-layer and application layer protocols.
b. PROFIBUS is fast and suited to a manufacturing environment. Isochronous operation has been added to PROFIBUS for synchronization of motion control applications and closed loop operation. Still, FF has stronger determinism suited for continuous process automation.
c. PROFIBUS uses master-slave communication, while Fieldbus uses peer-to-peer communication. The message formats in PROFIBUS PA are identical to PROFIBUS DP.

d. PROFIBUS utilizes a hybrid media access technique using token bus between masters and a master slave protocol to the devices. FOUNDATION™ Fieldbus uses peer to peer communications where devices publish and subscribe to information.

e. PROFIBUS DP and PA use the same communication protocol and are thus fully interoperable and a good fit for hybrid industries where discrete e.g. variable frequency drives, limit switches as well as continuous tasks e.g. analog continuous process values, closed loop control, are needed.

f. FOUNDATION™ Fieldbus has been designed as an interoperable system. It was set up with strict guidelines for operability between field devices. The FieldComm Group has proved two tests; "The Stack Conformance Test" and the "Device Interoperability Test" to ensure that certified devices work together.

g. Since PROFIBUS is a master-slave protocol, effective control exists in the host. Theoretically PROFIBUS can support control in the field, but it needs a master device to supply the instructions for a slave to continuously process a function block, communicate the result back to the master which makes it available to the other slaves

h. FOUNDATION™ Fieldbus, on the other hand, is a peer-to-peer protocol. Devices can communicate with each other without a host, and they can start communications without a host command.

i. There is no clocking structure within the PROFIBUS PA protocol to synchronize measurements with sample data controller demands. PROFIBUS runs without timed execution because it was designed initially for discrete control strategies. As a result, PROFIBUS-PA has experienced controller tuning problems.

j. H1 FOUNDATION™ Fieldbus provides explicit synchronization of control and communication for precise periodic (isochronous) communication and execution of control functions that minimized dead-time. It synchronizes clocks in the fieldbus devices for Function Block scheduling and alarm time-stamping at the point of detection.

4.3.7 Manchester Encoding

H1 Foundation™ Fieldbus and PROFIBUS PA use Manchester bi-phase encoding. It was chosen to enable digital communications between multiple devices while transmitting enough power for intrinsically safe operation.

The devices communicate with a synchronous serial rectangular waveform modulated on the power supply by alternating the segment 9 mA current at a frequency of 31.25 kHz. The Manchester Based Power (MBP) supply can furnish up to 30 VDC. The minimum voltage a device needs is 9 VDC.

4.3.7.1 Signal Level

The communication signal voltage is $0.75V_{pp}$ to $1.0V_{pp}$ (peak-to-peak), at 50Ω resistance. To suppress signal reflections a terminator that corresponds to the cable impedance (100 Ω) is mounted at both ends of the line

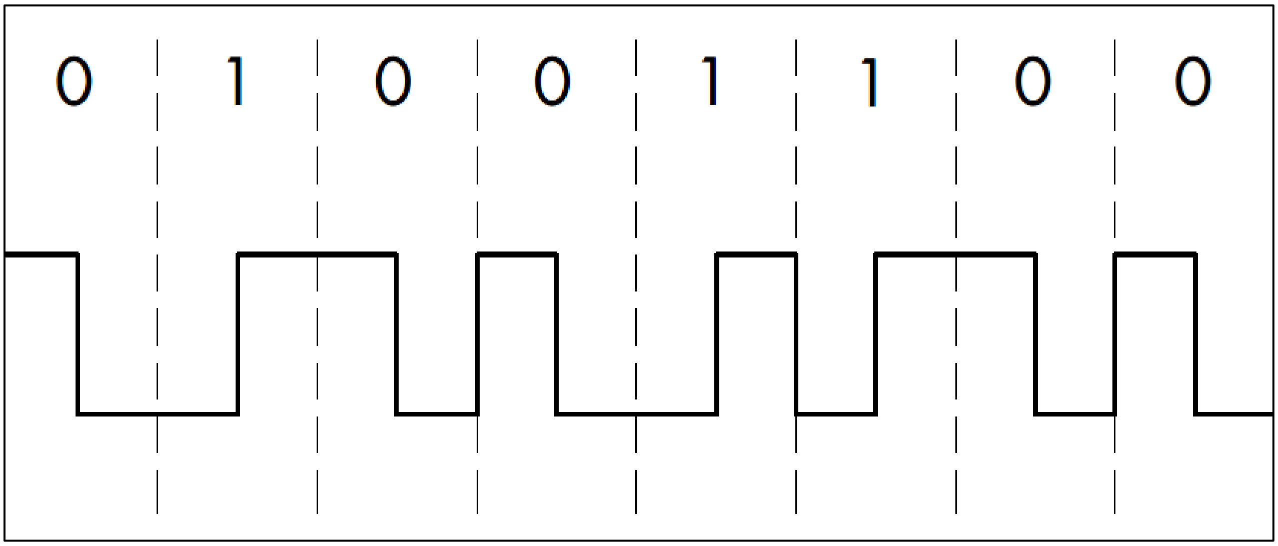
4.3.7.2 Transmission of 1's and 0's

The data is phased encoded. Transitions crossing the zero line; i.e. the voltage supply level, determine a one or zero. A positive transition at the phase transition point indicates a zero and a negative transition designates a one. Within a limited window the transition is expected at the bit time midpoint. If the crossing does not happen within this window, the bit is lost. Network clocking is contained in the waveform.

4.3.7.3 Jitter

Jitter is the difference between the expected and actual time of a bit. It is measured in milliseconds. Jitter is sensitive to any change in the physical layer. A change in inductance, capacitance, or resistance changes the jitter. It is a good diagnostic, if the jitter is okay, then the installation is satisfactory.

Figure 9
Manchester Encoding



4.3.7.4 Infrastructure

Since both FOUNDATION™ Fieldbus and PROFIBUS PA use MBP for their physical layer they share a lot of the same accessories and topology.

4.3.7.4.1 Device Coupler

Initially MBP fieldbus systems were daisy chained; cables looped from field device to field device. Working on fieldbus devices was a challenge. The standard now is chicken foot or tree topology. This topology is a bus topology with a trunk extended to a field junction box with varying length spurs or drops to the field instruments.

A trunk line goes to one or more junction boxes that contain couplers. The spurs or drops fan out from the couplers. The spur connections can be terminals or quick disconnects. The coupler and spur topology is easier and safer to maintain. Devices are added or removed by simply connecting or disconnecting its spur from the coupler.

Between four and twelve field devices are connected to a coupler. The spur connection to a device is a simplex hookup.

There are several coupler types available. The most basic is a simple terminal block or tee connector. It has connections for trunk in, trunk out, and field spurs. This option does not provide short circuit protection.

The second option is a short circuit limitation module called a segment protector, device coupler, or brick. This protection ensures that a short circuit on one spur does not affect the segment. Short circuit protection also eliminates complex, dynamic faults, including contact bounce. This option supplies diagnostics feedback. Segment protectors have LED’s that show power, communication, and short circuits.

Signal noise, ground faults, and other measured values from the fieldbus communication can be monitored online. Diagnostics evaluate the signals and creates maintenance messages. Problems can be corrected before failure occurs.

4.3.7.4.2 Fieldbus Power Supplies

A FOUNDATION™ H1 or PROFIBUS PA fieldbus power supply consist of DC bulk power supplies and conditioners. MBP fieldbus power supplies should be designed to FF831-1 requirements. Depending on the electrical location protection bulk power supplies sizes can range from 17 V to 30 V with 350 mA or 500 mA being furnished. The higher voltage allows longer cables while the higher current permits more devices on a segment.

To support the higher voltage power supplies with a nominal 24 VDC output voltage are adjustable to as high a 30 VDC to operate with an MBP fieldbus. It recommended that the overall system voltage including 4-20 mA devices be standardized at the higher voltage. This is not a problem for 4-20 mA I/O or transmitters and even most control system DC regulators are flexible enough to work with the additional five volts.

The MBP fieldbus power supply consists of a module carrier and power conditioner plugin modules. The motherboard or module carrier consists of failure resistant passive components. The bulk power supplies, the fieldbus input from control system and the output to the field devices terminate on the module carrier. For PROFIBUS PA, the module carrier also holds the link module to the PROFIBUS DP network.

The MBP conditioner furnishes impedance matching and the control system interface. Impedance matching prevents overloading of the regulated power supply by the variable Manchester voltage levels. Power conditioners, at their simplest, are inductive loads of five millihenry and a 50 Ω resistor on one side of the power supply. This prevents the regulated power supply from reacting to the voltage variations on the fieldbus network.

Power conditioner redundancy is normally used since between five and twenty devices are attached. The power conditioners are hot swappable. For redundant power conditioners, one to four networks are connected to the module carrier. For non-redundant power modules twice as many networks can terminate on the module carrier.

The power conditioner also provides other capabilities. It can supply load sharing between the two DC power feeds as well as galvanic isolation and surge protection. It provides current limiting to meet the needs of Intrinsic Safety, FISCO, or Division 2 installations FNICO. It also incorporates a network terminator.

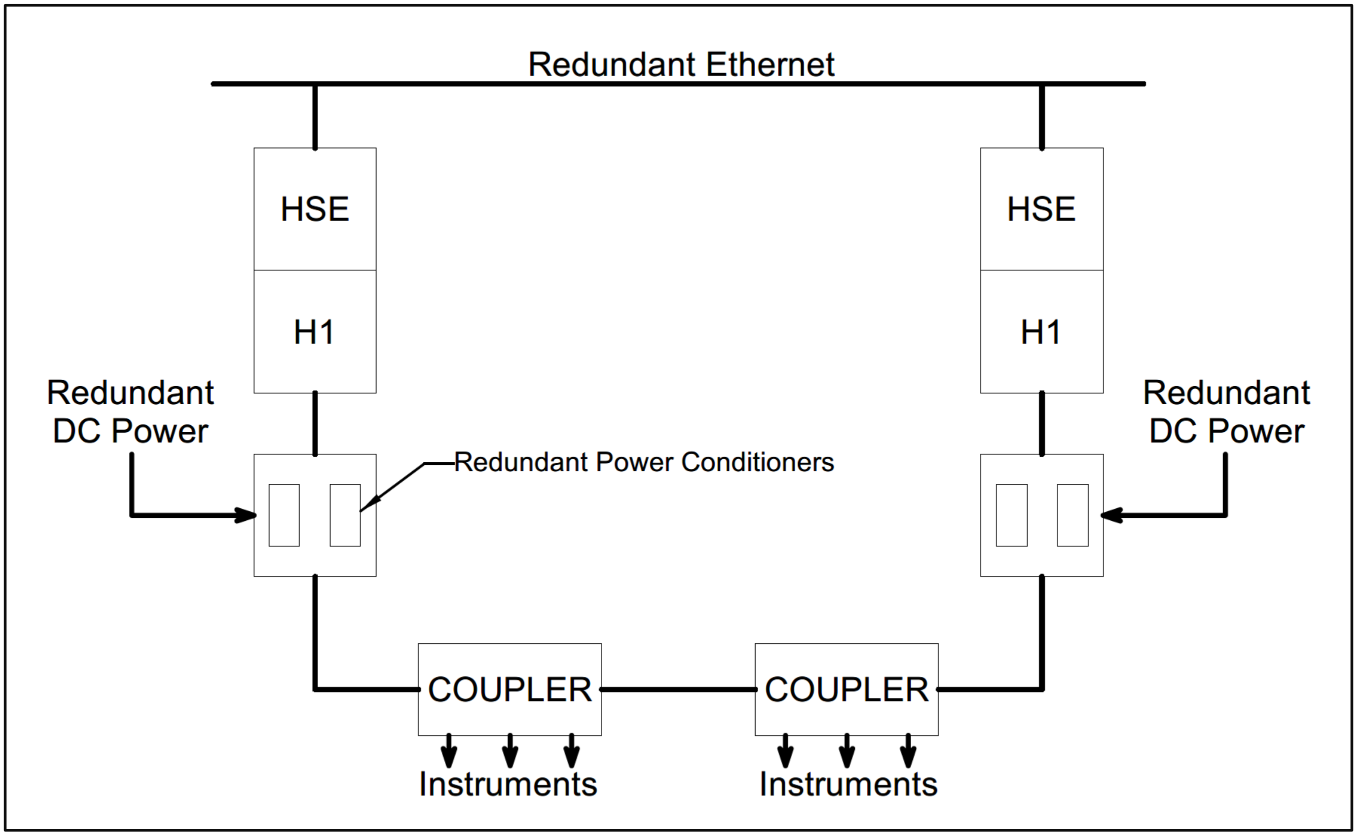
Module carriers are also equipped with diagnostic modules. At a minimum, these modules provide an alarm contract with LED's which communicate a detailed status; such as high current, low voltage, and carrier failure, about the physical layer. Some suppliers can network these modules together and send quantitative diagnostic data to the system asset manager.

4.3.7.4.3 Trunk Cable and Spurs

The trunk is the main cable which runs along the entire segment joining the power supply conditioners and one or more couplers together. The trunk has the same cable characteristics as the spurs. A heavier wire gauge can be used to lower the voltage drop over the longer distance to the coupler.

A spur is the cable connecting the field device to the trunk. The spur length is limited based on the number of participants connected to the segment and the number of instruments per spur. It is recommended that just one field device be connected to a spur, this optimizes the coupler short circuit protection.

Figure 10
Redundant FOUNDATION™ Fieldbus Link



MBP wiring should be designed and installed according to FOUNDATION Fieldbus Guide AG-140 "Wiring and Installation 31.25 Kbits/s, voltage Mode, wire Medium." This document is a complete guide for the successful installation of MBP systems. It illustrates the various installation alternatives such as multi-point grounds or single point ground.

FOUNDATION Fieldbus Guide AG-163 31.25 Kbits/s Intrinsically Safe Systems covers the use of MBP wiring in electrically hazardous areas.

4.3.7.4.4 Terminators

Segments need two terminators. The terminators are the equivalent of a 1 pF capacitor and a 100Ω resistor in series. The terminators are placed at the ends of the segment.

The primary function of the terminator is to function as a current shunt for the control network. The other purpose of the terminator is to reduce electrical reflections. These reflected signals cause distortions and jitter.

4.3.7.4.5 Repeaters

The fieldbus power repeater is a device for extending fieldbus segments. It repeats the fieldbus signal, with restored waveform and signal level. The two interconnected segments are separate physical layers for the cable distance and device count. However, they need a separate power input and are used when connection to a distant location is needed. It should not be used to augment the power in an existing segment instead another segment is recommended.

4.3.7.4.6 Redundant MBP links

A solution for fault tolerant fieldbus wiring is to terminate both ends of the segment in the equipment room. This configuration is shown in Figure 10.

An automatically-terminating device coupler makes this segment redundant. When cable break occurs, the auto-terminating device coupler detects a communications failure and that it is the end of a functioning leg, so it activates a local terminator. The segment has now split into two pieces, which continue to function.

4.4 Discrete Logic Networks

4.4.1 Actuator Sensor Interface (ASi)

ASi is an industrial networking technology used in PLC, DCS and PC based systems. It is designed for industrial applications and is extremely noise resistant. It offers a simple remote I/O solution. A typical module has four discrete inputs and four discrete outputs. It operates at 167 kb/s.

ASi is an alternative to hard wired field devices. It can be combined with higher level fieldbus networks such as PROFIBUS, DeviceNet, and Industrial Ethernet. It is used in conveyor control, packaging machines, continuous process valves, bottling plants, and electrical motor control systems.

Using a single two-conductor cable it is designed for connecting and supplying power to simple devices e.g. discrete devices, continuous sensors, rotary encoders, push buttons, and valve position sensors. ITC cable suitable for 167 Kb/s is available so it is suitable for Class I, Division 2 areas.

Though it is mostly associated with discrete control applications it does have 12-bit and 14-bit analog I/O modules. It has deterministic communication with a cycle time ≤5 ms while supplying up to eight amps at 30 VDC.

An ASi valve top controller has two sensors showing the open and closed positions and one or two outputs that drive the valve position. Since it supplies power as well as control, a valve top ASi module can effectively control automated quarter turn valves over a twisted pair.

One interface scanner/gateway module can address up to 62 modules. It uses a flexible trunk and drop system. The module layout can be an unstructured tree topology using tee connectors. With the master at one end the maximum cable length is 300m. With the master in the middle, 500m is possible. Distances can be increased by using line powered repeaters.

A module’s I/O mix and device type are stored in its profile. The I/O code is used to define the module’s inputs and outputs and other features. The ASi specification is managed by AS-International.

4.4.2 DeviceNet

DeviceNet is a protocol designed for discrete industrial operations such as sawmills or packaging machines. It is often used in a motor control center to connect motor starters as well as variable speed drives into a network. A standard DeviceNet cable has four conductors plus a shield drain wire, but shielded ITC wire pairs can be used for DeviceNet installations.

It is also used to control automated quarter turn block valves. Unlike ASi, DeviceNet has modules that combine analog and discrete I/O that allows monitoring of the entire automated block valve travel. This information can be used to analyze the valve operation for sticking, partial closure, etc.

DeviceNet does not support intrinsically safe wiring. Nor does it allow a ring topology or other types of backup.

DeviceNet is an open network standard and is a flexible trunk/drop topology. The communication link is based on CAN which is a broadcast protocol. CAN was developed to replace automobile wire harnesses. It has proven to be a robust protocol and is widely available.

DeviceNet does not need a host computer. DeviceNet can run in a master/slave, multi-master, or peer-to-peer configuration. In a typical DCS network, the DeviceNet interface acts as the master. The nodes communicate to each other through a CAN two-wire bus using polling. DeviceNet supports DO, DI, AI, and AO data. It has data rates of 125 Kbps, 250 Kbps and 500 Kbps.

DeviceNet addressing has the following addressing requirements:

a. A maximum of 61 active nodes are supported

b. Address 62 is used for diagnostic devices

c. Address 63 is reserved for adding devices and network recover

A DeviceNet device has five terminals, one pair for the CAN signal, another pair for the device power and a shield drain. There are five cable types defined in the DeviceNet standard; thick round, medium round, thin round, flat and unshielded drop. DeviceNet also allows an independent pair to power the devices.

The CAN wires are a twisted pair with a 120 Ω impedance and a nominal 12 pF/ft conductor to conductor capacitance. When using ITC cables according to NEC article 727, the power wires have a five-amp limit.

Terminator resistors should be placed at both ends of the cable. The terminators reduce communication reflections on the network.

DeviceNet specifications allow a 100m trunk line length at the maximum speed of 500 Kbps. Experience shown some devices are unstable at the highest speed. With a mixture of devices, at 500 Kbps, a 60m longest trunk length should be considered for stability or operating at a lower data rate. For instance, at 125 Kbps trunk lines with distances of 1640 ft are possible.

ODVA is the organization that supports network technologies built on the Common Industrial Protocol which includes DeviceNet. See “The Common Industrial Protocol (CIP™) and the Family of CIP™ Networks” Publication PUB00123R1 for further information.

4.5 Industrial Ethernet

Ethernet has been extended into the industrial environment and supports real time operations. It is used for device communications i.e. Level 0 of the Purdue Reference Model.

There are deterministic Ethernet protocols. With the communication speeds that Ethernet supports and the addition of the IEEE 1588 synchronization, Ethernet is acceptable for real time control. Further, Ethernet networks are certified for safety applications according to IEC 61508.

Ethernet is based on the master-slave principle. Modules controlling the processes are slaves. However, the slaves can communicate with each other. This reduces the load on the central control system.

Troubleshooting is facilitated with readily available tools, such as Ethernet sniffers, for maintenance, checking, and repair. Reliability is ensured by using device rings, meshes and other IEEE recognized technologies. Also, power can be transmitter to device; such as CCTV's, temperature sensors, etc. using power over Ethernet (POE) technology with UTP Ethernet cable.

The maximum distance using a copper Cat 6 Ethernet cable without POE powered repeaters is 100m which is a concern for use in petrochemical facilities. The distance limitation is not an attenuation problem, it is caused by propagation delay. The length is limited by the time allowed for collision sensing. There are several proprietary inline devices that extend that limit.

Also the maximum distance for a Cat 6 Ethernet cable is reduced by insertion loss from the connectors and the cables themselves. See TIA-1005-A and IEC 61918 to calculate the actual lengths.

4.5.1 Foundation™ HSE

FOUNDATION™ HSE (High Speed Ethernet) is a control backbone. HSE enables the integration and information exchange needed by a process facility. HSE is one of the IEC 61158 protocols. It has a linking device gateway and a communication protocol. It integrates FDT frame applications with the fieldbus interface module. (See section 6.4 for the use of FDT.) This creates transparent access to FDT field devices connected to the H1 FOUNDATION™ Fieldbus networks.

Running at 100 Mbps, HSE is designed for device, subsystem, and enterprise integration. It supports all the fieldbus capabilities, including function blocks and Device Descriptions (DD's), as well as application Flexible Function Blocks (FFB's) for discrete and advanced applications.

HSE has H1 features at the subsystem level. It supports interoperability between dissimilar controllers and gateways. Flexible Function Blocks (FFB's) can be created by using IEC 61131-3 style programming languages.

HSE also supports analyzers, gateways, and logic by PLCs to other networks. It supplies communication to high-speed devices and hybrid batch applications.

HSE uses standard Ethernet wiring, including fiber optics to supply effective electrical isolation between plant areas as well as offer EMI immunity.

All or some of the HSE network and its devices can be made redundant to achieve the fault tolerance level desired. Hardware redundancy is supplied using standard Ethernet equipment.

4.5.2 EtherNet/IP™

For industrial applications EtherNet/IP™ supplies a network using standard Ethernet technology. It is a CIP™ network. EtherNet/IP™ with DLR (Device Level Ring) it is a communications protocol suitable for secure motor control automation. It is robust and uses a ring topology so there are two paths to the devices.

CIP™ enables cyclic and time-critical data traffic. CIP™ networks, such as DeviceNet, are interoperable with each other. EtherNet/IP™ also is supports CIP™ Safety which meet the requirements of IEC-61508. EtherNet/IP™ development is governed by ODVA. See IEC 61784-5-2 installation and planning of EtherNet/IP™.

Table 11
EtherNet/IP™ Standards

IEC 61784-3-2	Industrial communication networks - Profiles - Part 3-2: Functional safety fieldbuses - Added specifications for CPF 2
IEC 61784-5-2	Industrial communication networks - Profiles - Part 5-2: Installation of fieldbuses - Installation profiles for CPF 2

IEC PAS 62413 Real-time Ethernet - EtherNet/IP™ with time synchronization

4.5.3 PROFINET

PROFINET is a further development of the PROFIBUS DP technology. PROFINET is part of the PROFIBUS group of standards. PROFINET is an industrial Ethernet standard that was managed by PROFIBUS & PROFINET International (PI). See IEC 61784-5-3 installation and planning of PROFINET.

There are various protocols defined within the PROFINET context. Below is a list of these protocols along with their intended use:

a. PROFINET CBA: It is a protocol associated with applications distributed in industrial automation environments. This component permits data communication between intelligent devices using Ethernet TCP/IP. It is not suited for real-time applications. Control is conducted with a small number of signals. Building on the Microsoft DCOM model, PROFINET CBA provides a seamless system from the sensor-actuator network to the controller and enterprise networks.

b. PROFINET DCP: It is a discovery and configuration protocol based on the link layer and is used to configure device names and IP addresses. It is restricted to a network and principally used in small and medium applications that have no DHCP server.

c. PROFINET IO: It applies to communication of decentralized peripheries. The provider-consumer model is used to support the data exchange. The provider does not require a "request to send" to forward data. Parameters, diagnostics, and alarms plus other functions are transmitted by PROFINET IO.

d. PROFINET MRP: Is a media redundancy protocol using a ring topology. The network is restructured in the event of a fault.

e. PROFINET PTCP: Precision Time Control Protocol is based on the link layer, to synchronize clock time signals in various PLC's.

f. PROFINET RT: It is used to transfer data in real time. It is intended for applications with cycle times as low as 10 ms.

g. PROFINET IRT: It applies to isochronous data transfer in real time and is used for cycle times as low as 1 ms.

h. PROFINET MRRT: Its objective is to provide media redundancy for PROFINET RT.

PROFINET provides fast data exchange. It is based upon Ethernet, and it supplements existing PROFIBUS technologies.

PROFINET IO uses cyclic data transfer to exchange data with Programmable Controllers and field devices. PROFINET IO describes the data exchange and the communication between the control unit and the field devices.

PROFINET IO information is always transmitted as real-time communications, so the data exchange only takes a few milliseconds. The provider can send data without a request, which makes it continuously available. Providing parameters and diagnostics are included.

The PROFINET RT and IRT versions supply bus cycle times within a few hundred microseconds. The information is treated with a higher priority than regular TCP/IP data. With PROFINET RT, process data and alarms are transmitted in real time. PROFINET RT is based on IEEE and IEC requirements, which limits the time for real-time services to a bus cycle.

Figure 11
PROFIBUS OSI Model

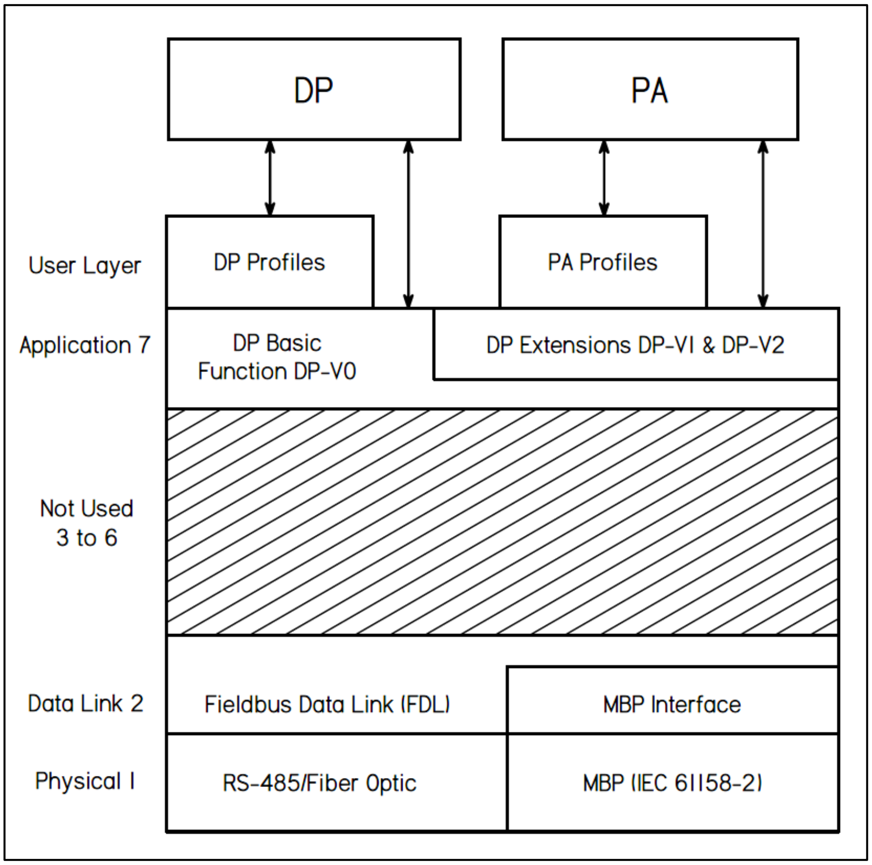


Table 12
PROFINET Standards

IEC 61784-3-3	Industrial communication networks - Profiles - Part 3-3: Functional safety fieldbuses - Added specifications for CPF 3
IEC 61784-5-3	Industrial communication networks - Profiles - Part 5-3: Installation of fieldbuses - Installation profiles for CPF 3

4.5.4 Modbus/TCP

Modbus TCP is available in every industrial device; such as machinery monitors and multi-component analyzers with an Ethernet connection. Certified devices are listed in the Modbus catalogue. See IEC 61784-5-15 installation and planning of Modbus TCP.

Modbus/TCP is extended using Modbus RTPS which enables faster data return and more deterministically. It can supply a ring topology so there are two paths to every device. Also, it supports a redundant ring network topology according to IEC 62439-2.

Modbus independent of the transmission medium. The Modbus TCP object model and services are the same as the other Modbus protocols. It uses the client-server principle. The client initializes a call by sending a request telegram. It is answered by the server with a response telegram.

Modbus/TCP has identical data and command set of Modbus RTU and Modbus ASCII. Modbus TCP uses the same data types: discrete inputs, coil outputs, input registers and holding registers. See section

4.3.2 for specifics. To obtain more advanced data types like IEEE floating point values, requires using one of the various Modbus extensions.

The Modbus TCP protocol uses TCP for data exchange in Ethernet networks. The data is embedded into the TCP telegram by encapsulation. With the embedding, the client generates a Modbus application header. This supplies an explicit statement of the parameters and commands.

With Modbus RTU communication, a CRC checksum and the slave address are transmitted in addition to the data. With Modbus TCP, these functions are performed by the TCP protocol.

Later releases of Modbus/TCP include provisions for security in the communication stack. It incorporates the use of X.509 digital certificates and common encryption algorithms.

For existing Modbus systems, a Modbus/OPC UA gateway allows passing Modbus commands through the gateway, which secures then with the OPC UA services and turns them back into Modbus at the other end. A third approach is to set up an encrypted IPSec VPN to transmit the data.

Modbus TCP network depends on the device processors as well as Ethernet network type. The efficiency of the Modbus TCP protocol is high. In an ideal case, 3.6 million 16-bit register values per second can be transmitted in a 100 Mbps switched Ethernet network. In practice, it is less than that.

Table 13
Modbus/TCP Standards

IEC 61784-5-15	Industrial communication networks - Profiles - Part 5-15: Installation of fieldbuses - Installation profiles for CPF 15

4.5.5 HART-IP

A HART-IP network is used connect to the HART gateways together. This technology uses the HART application protocol over common Ethernet or Wi-Fi media using the TCP/IP transport protocols. HART-IP shares the same Ethernet hardware as other industrial Ethernet protocols such as Modbus/TCP and EtherNet/IP™.

A HART-IP backhaul network enables software to have direct access to information in WirelessHART devices without having to perform data mapping through Modbus or OPC. So time consuming and error prone data mapping is eliminated. Also hardwired 4-20 mA/HART multiplexers are available using a HART-IP backhaul.

4.5.6 IEEE 802.3cg Ethernet

4.5.6.1 Single Pair Ethernet

10BASE-T1L version of IEEE 802.3cg, allows field devices to connect with Ethernet systems over a wire pair at 10 Mb/s. IEEE 802.3cg extends Ethernet pairs beyond the 100 m limit while providing 50W of device power. 100BASE-T1 and 1000BASE-T1 can provide faster data speeds and manage large data quantities but over much shorter distances.

The IEEE 802.3cg architecture is based on the Ethernet physical standard. This ensures compatibility with common Ethernet protocols such as EtherNet/IP™ and PROFINET. However, different connectors from Category 5 and 6 cables are used. The switches use IEC 63171-6 connectors and deliver upwards of 50 watts at 48 volts according to IEEE 802.3bu, the Power over Dataline (PoDL) standard.

Single Pair Ethernet cable should be fabricated and installed according to IEC 61918 AMD1 2022 Annex Q. Single pair Ethernet cable is available with a PLTC rating so it can be installed in Class 1 Div 2 areas.

The single pair ethernet shielded connector is provided with a simple field termination to 18 AWG 1-pair shielded copper cable that is compliant with TIA-568.5 SP1 or IEC 61918 AMD1 2022 standards. The plug complies with the IEC 63171-6 “Type 6” standard and is provided with an IP20 shell for indoor use and an IP67 for outdoor connections.

It uses media access layer (MAC) addresses. IP and TCP addresses respectively are provided with layers three and four. This makes possible direct, end-to-end, communication to the field level. It is a protocol neutral, physical layer that control protocols such as Foundation Fieldbus HSE or HART-IP can ride on. Ethernet/IP has been enhanced to enable two wire Ethernet

This allows a field device to communicate directly with an OPC/UA server. When permitted by security policies a field device can communicate to Purdue Model Level 3 and higher layers. The plant status including floating point values can be shown at higher sampling frequencies and approaching virtual real time conditions for key variables.

4.5.6.2 Ethernet APL Extensions of IEEE 802.3cg for Classified Areas

IEEE 802.3cg APL extension (2-WISE) supports the trunk and spur technology that is used in process automation. It is the intrinsically safe version of 10BASE-T1L. It is installed according to IEC TS 60079-47 “Explosive atmospheres - Part 47: Equipment protection by 2-wire intrinsically safe Ethernet concept (2-WISE)” requirements.

Migration from MBP based fieldbus networks is part of the APL concept. Since IEEE 802.3cg specifies standard fieldbus cable, Type A, the facilities can use their existing MBP cabling. In a 2-WISE system, two-wire 18 AWG IEC 61158 (FF-844) Type A can be used as single pair Ethernet (SPE) wire. That can range up to 1000 m provides data at 10 Mbit/s and 500 mW of power to a field device. The transfer rate of 10 Mb/s is about 10,000 times faster than HART.

The cable used in a 2-WISE system complies with the following parameters:

cable resistance	Rc : 15 Ω/km to 150 Ω/km
cable inductance	Lc : 0,4 mH/km to 1 mH/km
cable capacitance	Cc : 45 nF/km to 200 nF/km

Trunk requirements:

a. The data exchange are based upon standard Ethernet 802.3 specifications.
b. A range of 1000 m from a Power Switch located in a safe area (Division 2/Zone 2 or unclassified) to a Field Switch that is located in a hazardous area (Division 1/Zone 1).
c. A maximum of ten inline connectors are allowed over this distance. This allows the cable to be laid in sections and joined.
d. Since the trunk goes into the Division 1/Zone 1 hazardous areas, the trunk ports of the Switch and the Field Switch, as well as the cable met the appropriate Division 1/Zone 1 protection requirements.
e. The Safe Area Power Switch provides trunk power for the connected Field Switches and Field Devices. The support of 50 field devices from a Switch, where each field device requires less than 500 mW of power.

Spur requirements:

a. The data exchange is based on the IEEE 802.3 specification.
b. A reach of 200 m from the Field Switch to the Field Device.
c. A maximum of five inline connectors are allowed to reach this distance.

d. Since the spur can goes into Division 1/Zone 0 hazardous areas, the spur ports of the Field Switch and the Field Device, and the cable meets the appropriate Division 1/Zone 0 protection requirements.
e. Each port of the Field Switch provides up to 500 mW to a Field Device.

The Power Switch is installed in a control room or on a skid in a junction box. In turn a Field Switch connects to the field devices using a chicken foot topology.

The APL Power Switches provide connectivity between the standard Ethernet networks and field devices and include a power supply that provides power to the APL Field Switches and field devices. Switches as well as and power supplies can be provided with redundancy.

The APL Field Switches are designed for installation and operation in hazardous areas, which are typically Zone 1 and 2 or Division 2. Normally, they are loop-powered by the APL Power Switch and distribute both communication signals and power using spurs to the field devices.

Similar to a FISCO installation, the field devices in hazardous areas using two-wire spurs from the Field Switch are connected using intrinsically safe methods. Each spur has a range of 200 m.

Some Field Switches can support both field devices with an IEEE 802.3cg interface as well as existing fieldbus devices. For instance it detects if a PROFIBUS PA device is connected instead of an Ethernet field device, the switch can then adapt the baud rate and protocol to the corresponding port and convert the data to Ethernet.

4.5.7 OPC UA (Open Platform Communication United Architecture)

OPC UA is a data exchange standard for the industrial environment. It is a multi-faceted communication method with options for data organization and cross platform data exchange. It provides secure and reliable exchange of data. Besides providing diagnostics, configuration, process displays, maintenance etc. to the local network this information can also be presented at the enterprise level.

OPC UA operates in a broad technology space, so it supports multiple transports. This variety makes OPC UA scalable.

It is a platform independent. It promotes interoperability of various devices and systems by allowing them to exchange data. It mostly uses the Client/Server model but peer to peer communication between Servers is also supported. In terms of complexity OPC UA is at one end and MODBUS RTU is at the other.

A mutual understanding of implemented OPC UA profiles is necessary to ensure interoperation between applications. Using secure communication it provides interoperability and data exchange from sensors up to enterprise management. To guarantee interoperability, standard data modeling is key. A device OPC Server provides the same methods and data definitions for Clients as any other Server. The profiles can be confirmed by third party conformance testing and certification.

A typical application is an HMI Client talking to a PLC Server. Once a PLC manufacturer has developed an OPC Server, any Client can access the device. Similarly once the SCADA or HMI supplier has developed their OPC Client, it is possible to access devices such as a PLC with an OPC Server.

OPC UA technology provides the following features:

- OPC UA has a Service Oriented Architecture (SOA). It uses a mechanism for Client devices to find and identify Server devices.

- OPC UA uses Object models. OPC UA connects Objects so that Information can be shared between Clients and Servers. It also allows relationships to other Objects. The OPC UA Address Space is organized around Objects. Objects are entities that consist of Variables and Methods. They are a standard way for Servers to transfer information to Clients. Open source reference implementations. Standard Object models are freely available for dozens of types of equipment.
- The extensible data model has an extensive tool set. Software Development Kits (SDK) and stacks are available for developing applications.
- OPC UA provides a suite of services for events, alarms, reading, writing, discovery and more to applicable Clients.
- OPC UA uses standard transport and encoding to ensure that connectivity is achieved with both embedded and enterprise environments. Support for both Client/Server and Publish/Subscribe communication. Communication protocols such as TCP/IP, UDP/IP, WSS, AMQP and MQTT are available. OPC UA is capable of moving data over the Internet.
- Cross platform abilities that are not tied to one operating system or programming language. OPC UA is scalable and platform independent. It supports high end Servers to low end sensors. Server profiles are discoverable regardless of size.
- OPC UA implements a Security Model that ensures the authentication of Client and Servers. It has extensible security profiles, including authentication, authorization, encryption, checksums, and security key management.

When it was first released as OPC DA its purpose was to convert industry protocols; such as Modbus, Profibus, etc. into a standard interface which allowed various HMI and SCADA systems to interface with a "middleman" that converted generic OPC read/write requests into device-specific requests and vice-versa. OPC DA along with two other legacy modules for historization and alarming versions are still used and are now known together as OPC Classic.

It offers a variety of agnostic solutions to allow platform interaction. It is more than a communication protocol. It is an environment that determines how data is obtained and stored as well as how platforms interact with each other.

OPC UA describes the interactions between Servers and Clients as well as the services offered by Servers. OPC UA defines nodes address spaces that represent physical or virtual objects reachable by an application process. An application can function as a Server, Client, Publisher, or Subscriber or in any combination.

Typical OPC UA applications include:

- Human Machine Interface (HMI)
- Supervisory Control and Data Acquisition (SCADA)
- Data Acquisition/Process Data
- Online Process Analyzer Stream Compositions
- Device Diagnostics and Asset Management
- Production Monitoring and Inventory Management
- Quality Control and Analytical Laboratory Information (LIMS)
- Condition Monitoring
- Reporting Systems
- Manufacturing Execution System (MES)

- Enterprise Resource Planning (ERP)

Besides the standardized mapping defined by the core specifications an industry specific companion specifications are available. These were developed by diverse organizations such as Industrial Association for House, Heating and Kitchen Technology and the FieldComm Group.

OPC UA uses different communication stacks with between four and eight layers to manage data interchange. See the diagram below:

OPC UA Transportation Stacks

<table>
<tr><td></td><td>OPC UA Client Server</td><td colspan="4">OPC UA Publish/Subscribe</td></tr>
<tr><td rowspan="2">OPC Application</td><td colspan="5">OPC UA Device Object Models</td></tr>
<tr><td colspan="5">Device Information</td></tr>
<tr><td>Encoding</td><td>UA Binary, JSON, XML</td><td colspan="4">UADP, JSON</td></tr>
<tr><td>OPC Security</td><td>UA Secure Conversation</td><td colspan="4"></td></tr>
<tr><td>Protocol</td><td>UA TCP, UA HTTPS, WSS</td><td colspan="2">MQTT, AMQP</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Security</td><td colspan="2">TLS</td><td></td></tr>
<tr><td>4
Transport</td><td colspan="3">TCP</td><td>UDP</td><td rowspan="2"></td></tr>
<tr><td>3
Network</td><td colspan="4">IP</td></tr>
<tr><td>2
Data Link</td><td colspan="5">Ethernet
IEEE 802.1, IEEE802.3 incl IEEE P802.3cg, IEC/IEEE 60802</td></tr>
<tr><td>1
Physical</td><td colspan="5">POE Coax, Cat 6, OS2 Fiber, IEC 31158-2 Type A Cable</td></tr>
</table>

OPC UA is object oriented. Its Object orientation lets Servers model data, information, processes, and systems as Objects and presents them to Clients. The standard describes the semantics, relationships, and syntax. A OPC UA information model is defined by a schema to represent semantic dependencies between objects.

To achieve this OPC UA defines abstracted data models, communication scenarios and mapping to underlying transport protocols. Performance depend on implementation choices. OPC UA itself does not restrict the kinds of applications. It can support any device platform.

OPC UA is designed to be flexible and not bound to a particular transport protocol or messaging system. Documentation define mappings to selected protocols. Transport of messages between Clients and Servers can occur using UA binary, XML, or JSON coding.

There are two means for exchanging data with OPC UA:

- The Client/Server model where the UA Clients use the facilities of a UA Server over TCP HTTPS or WSS links
- A Publisher/Subscriber model can use a broker-based or non-broker depending on the underlying protocol. The UA Server makes subsets of information available to a number of recipients using UDP, AMQP or MQTT links.

Messages transport between Publishers and Subscribers can run over UDP with IP multicast, MQTT, or AMQP messaging middleware. PUB/SUB communication is defined by OPC UA with mapping to either binary or JSON representation. The binary representation is called UA Datagram Protocol (UADP), which operates over Ethernet.

OPC UA provides a profile mechanism for the description, classification, and discovery of implemented features. The mechanism allows contact between different devices like programmable logic controllers (PLC) communicating to Server devices. A Discovery Server can be used to optimize the discovery process. The Local Discovery Server (LDS) profile provides infrastructure to expose the available OPC UA Servers.

Another feature is the ability to make remote procedure calls which allow one machine to call a procedure, function, or method on another. As the Server processes the call, the Client waits for the Server to finish before resuming its process. Remote procedure calls use software modules called proxies and stubs, which makes them look like local procedure calls.

4.5.8 Ethernet Switches

Switches are the building blocks of Ethernet networks. Ethernet was introduced in 1980 as a masterless business oriented protocol. It used CSMA/CD or collision detection technology to determine which device gets to transmit data over a simple coaxial bus network. This technology can become locked up during high traffic volumes.

It has evolved over the subsequent years with increased speed and additional features such as redundancy and time synchronization. Other types of media were added employing full-duplex transmission. The introduction of Ethernet switches with dedicated ports for each device changed the topology of Ethernet making it suitable for critical industrial applications by eliminating the requirement for CSMA/CD to manage data exchange between devices.

Now each device can be connected to a switch port. This allows the devices freely transmit data without restriction. It is up to the switch to manage the data interchange between devices and other switches.

Switches are either managed or unmanaged. The unmanaged switches are devices that simply pass the data on to the attended address. Managed switches have an array of features.

A managed industrial Ethernet switch intended for real time critical services has the following features:

a. EMI hardening and extended temperature operation
b. 100 Mb/s or better port speed with auto negation
c. Wire-speed switching
d. Redundant power supplies

e. Alarm contacts
f. Collision-free environment and full duplex port operation (IEEE Std 802.3)
g. IGMP snooping and queriers for multicast propagation control
h. Port mirroring
i. Priority queuing support (IEEE Std 802.1D)
j. VLAN support (IEEE Std 802.1Q)
k. Device loss-of-link management
l. Link aggregation (IEEE 802.1AX)
m. Ethernet ring protection (IEC 62439-3 HSR) [1]
n. Dual homing (IEC 62439-3 PRP) [2]
o. Flow control (IEEE 802.1Qbb)
p. Supports NTP or PTP time protocols (IEEE 1588)
q. Has SNMPv3 or higher for switch management
r. Remote monitoring, port mirroring, and diagnostic support
s. Support for MAC address filtering and port lockout

Note 1: EtherNet/IP has DLR for providing backup signals. PROFINET also has its own redundancy features. Still, HSR implements its redundancy at OSI layer 2 and is transparent to the upper layer protocols such as EtherNet/IP and PROFINET.

Note 2: Other types of path redundancy existed prior to PRP such as Rapid Spanning Tree but they have latencies while PRP is bumpless. Also, the major systems vendors use proprietary redundancy methods that rely on custom switches.

This type of switch is special and not like a typical information technology (IT) device. Several of these features are necessary to tune the network for a proper time response to priority information.

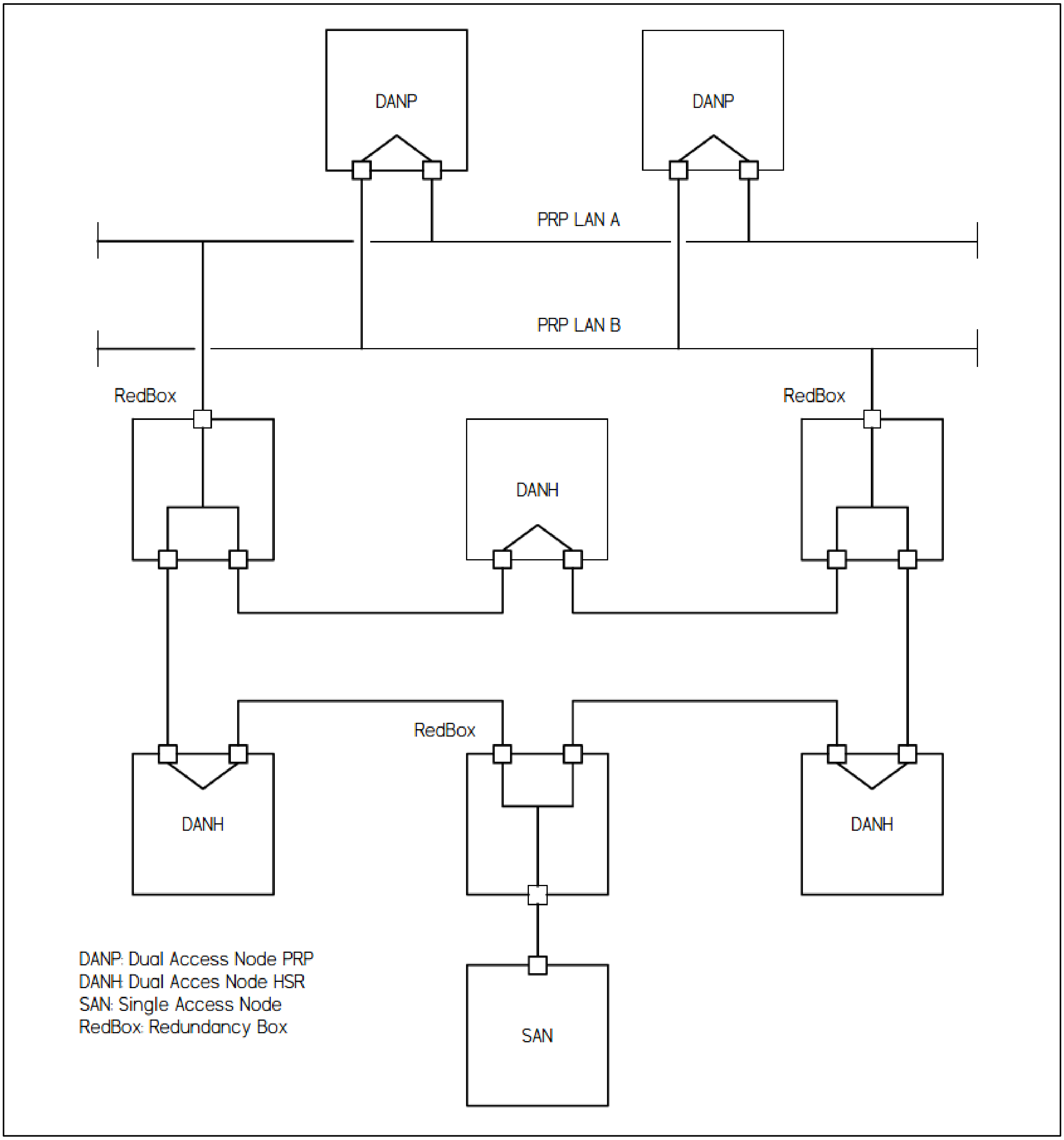
Industrial switches universally use 8P8C, which is a RJ-45 type connector for device connections. Most have a pair of fiber optic jacks or plugin connections (Small form-factor pluggable devices, or SFP) for various transceiver modules for linking to the higher level networks. Transceiver modules allow the use of fiber or copper media in a slot. The use of interchangeable plugin transceiver modules is common with centrally mounted rack switches.

A network switch is a multiport network bridge that uses media access control addresses to forward data at the data link layer (layer 2) of the OSI model. Some switches can also forward data at the network layer (layer 3) by additionally incorporating routing functionality. Such switches are commonly known as layer 3 switches or multilayer switches. Since protocols, such as EtherNet/IP and Profinet, do not use SMTP or HTTPS in the session layer, switches with higher layer functions should be evaluated for proper functionality with the network. For instance for performance in some Ethernet industrial applications the IP layer 3 protocol is replaced with PROFINET RT/IRT or IEEE TSN

Ethernet switches are not hardware redundant. One means to achieve redundancy is by creating parallel networks using dual ported nodes with proprietary technology and custom switches. This approach is common with DCS networks and other trunkey control systems.

The IEEE 802 standards specified several forms of fault tolerant protocols. Initially this was the Spanning Tree Protocol (STP), then Rapid Spanning Tree Protocol (RSTP), G.8032 ERP and Media Redundancy Protocol (MRP). The problem with these is that they had latencies from several milli-seconds to seconds.

Figure 12
Combined HSR and PRP Networks



Networks using PRP and HSR redundancy protocols have no latency and are recommended for new applications. Both these protocols are flexible and can operate together. When used together the PRP parallel network typically operates on top of an HSR ring network. See The IEEE 802 standards specified several forms of fault tolerant protocols. Initially this was the Spanning Tree Protocol (STP), then Rapid Spanning Tree Protocol (RSTP), G.8032 ERP and Media Redundancy Protocol (MRP). The problem with these is that they had latencies from several milli-seconds to seconds.

Figure 12.

Dual port devices or DAN's provide the most secure connection to a switched network. An HSR network is a loop while a PRP is a true dual path network. In a PRP network both ports can have the same MAC address. Nevertheless, that is not the case with some forms of network redundancy. Single port devices or SAN's can be provided with a RedBox or redundancy box to allow connection to fault tolerant networks such as HSR and parallel networks such as PRP.

Link aggregation, where a switch can transmit a nodes signal through two or more ports can also provide some signal path redundancy. A small dedicated managed switch can be used like a redundancy box.

4.6 Wireless Protocols

a. WirelessHART (IEC 62591) [1]

b. ISA 100.11a (IEC 62734) [1]

c. IEEE 802.11 Wi-Fi [2]

d. Wireless WAN [3]

e. Unlicensed ISM band proprietary protocols [4]

Note 1: WirelessHART and ISA 100.11a use the 2.4 GHz frequency band. They are both based upon IEEE 802.15.4 standard.

Note 2; IEEE 802.11 is used for Wi-Fi access and only covers the lower layer of the OSI communication stack. For full implementation, a protocol such as Modicon/TCP or EtherNet/IP™ needs to be incorporated in the upper layers of the stack.

Note 3: Wireless WAN services only furnish the physical layer, but mobile or cellular radios intended for continuous process data transfer, i.e. SCADA and Cellular Telemetry are available. They typically have RS-232/485 and Ethernet ports as well some discrete I/O for resetting the attached equipment and similar actions.

Note 4: Many propriety solutions use the IEEE 802.15.4 standard using the 2.4 GHz band which is license free in most of the world. Also, the 915 MHZ band is popular in the Western Hemisphere while 869 MHz is used in Europe. The 2.4 GHz band has the advantage that it supports the highest data rates.

Items c through e are recommended for onetime applications where it is not effective to install a complete wireless infrastructure.

4.6.1 Proprietary Protocols

There are propriety wireless transmission solutions which use the unlicensed ISM bands. These bands vary across the world's three ITU regions, but they are generally either 400MHz, 600MHz, 900 MHz and 2.45GHz. These frequencies can be subject to local regulation.

These systems use architectures and communications protocols that have been developed for specific equipment. These solutions mostly pre-date the development of WirelessHART and ISA 100.11a solutions but are useful for applications that are suited for small systems that do not need much effort to startup.

Proprietary solutions fall in one or more of the following system types:

a. Field device and gateway: This solution involve sensors furnished by a wireless supplier that communicate with the supplier's gateway. Wireless communications typically use supplier protocols. Often these systems are star configurations with the field devices communicating directly with the gateway.

The gateway communicates with a host system using Windows based data acquisition software, Modbus, or similar interface to a host control system module. A wired connection is used between the gateway and host.

b. Point-to-Point multiplexers: These typically are a cable replacement system that consists of multiplexers at both ends of the communication path. Input and output devices are wired to the multiplexers and the values are wirelessly transmitted.

c. Network extenders: These applications use wireless repeaters. These systems are a wireless segment in an otherwise wired network. They are useful when long distances are involved but latency can be an issue.

Network extenders often have architecture requirements and data transmission speed limitations. Some systems use general-purpose Ethernet wireless extenders that allow connecting modules to an ordinary Ethernet network.

Proprietary wireless networks have been developed to transmit standard wired protocols such as DeviceNet. These are often network extenders, but star networks are also available where the gateways are attached at various points along the trunk cables. Many Ethernet based protocols are compatible with wireless systems.

4.6.2 WirelessHART

WirelessHART uses the IEEE 802.15.4 specification and runs on the 2.4 GHz band. It uses the basic wired HART protocol to create a self-organizing mesh network. The WirelessHART protocol has the same functionality, messages, and data.

The WirelessHART standard was created by the HART Communications Foundation. Further, WirelessHART was adopted by IEC in IEC 62591. For added information on WirelessHART technology, see the FieldComm Group's publications.

4.6.3 ISA 100.11a

ISA 100.11a also uses the IEEE 802.15.4 specification and runs on the 2.4 GHz band. The ISA 100 committee was formed to develop an industrial wireless communications standard that would support many device types and functions.

An ISA 100.11a network has devices with the following abilities:

a. Receive and pass on signals from other devices including non-routing devices
b. Communicate with authorized routers
c. Implement general network services

ISA 100.11a supports tunneling so other protocols can be transmitted using its services. This allows HART and similar protocols to be transmitted over an ISA 100.11a wireless network.

Since ISA 100 encompasses a wide set of features, interoperability between devices from different suppliers needs to be evaluated with testing by the 100S Wireless Compliance Institute.

4.7 SCADA

SCADA or remote telemetering is used to monitor remote locations such as metering stations, tank farms, well heads and gathering systems, pipeline pumping stations, power substations and the like. Typically several sites are monitored from one site located several miles away.

Table 14
Standards Based SCADA Protocols

Protocol	Standard	Remarks
DNP3	IEEE 1815	
Profibus DP	IEC 61158-5-3	
DDS	OMG	Security Plugins Recommended
Modbus	IEC 61158-5-15	
MQTT	ISO/IEC PRF 20922	Messaging
T101	IEC 60870-5-101	Power
RS-485 HART	IEC 61158-5-20	
ICCP	IEC 60870-6/TASE.2	Power
ELCOM-90	IEC 60870-6/TASE.1	Power
IEC 104	IEC 60870-5-104	Power
UCA	IEC 61850	Power, Gas, Water
MMS	ISO 9506/61850	Messaging
DLMS	IEC 62056	Power Metering
OPC UA	IEC 62541	Integral Cyber Security
BACnet	ISO 16484-5	Building Operations
LonTalk	ISO/IEC 14908	Building Operations

SCADA is transmitted by many means; public switched telephone network (PSTN), the Internet, dedicated fiber optic pairs and wireless networks. For wireless communications satellite, microwave and cellular networks are used. Also, cloud based services are available for SCADA operations.

There are dozens of SCADA protocols. They are frequently industry specific and proprietary. There are also several standards based protocols. See Table 14. Some of the more common standards based protocols started as vendor specific products.

A lot of work has been put into protocol development by IEEE and IEC committees. Most of these are oriented towards power utilities and substation control. Pipelines also use SCADA for control and metering. Modbus RTU is widely used for this purpose.

Standard protocols have significant advantages. Some systems can communicate with them directly without an interface or I/O chassis. When an interface is required, creating a connection is simplified. However, different interpretations of a standard can lead to difficulties. With the advent of the certification process, newer devices and competing devices from other manufacturers are more likely to be interoperable.

Most SCADA sites involves just a few I/O so can operate on low band width channels. This is why Modbus RTU, despite its legacy security issues, is popular.

5 CYBERSECURITY

Detailed implementation of Cyber security is a topic that is beyond the scope of this document. Regardless, listed below are some measures to consider when designing and operating a plant network. NIST SP 800-2 "Guide to Industrial Control Systems (ICS) Security" and API Standard 1164 "Pipeline SCADA Security" provide guidelines for developing and assessment of cyber security in a facility.

5.1 Physical Security

The physical protection of the plant control networks should be addressed as part of the overall security of a plant. For industrial networks, wired fieldbuses are within a secured plant perimeter, so security is primarily assured by physical isolation. The primary goal is to keep people away from sensitive areas both physically and virtually without stopping them from carrying out their duties or responding to emergencies.

NIST SP 800-53 "Security and Privacy Controls for Information Systems and Organizations" provides policy and procedures for physical access to an information system including entry, transmission media, and display media. Controls for monitoring physical access, maintaining logs, and handling visitors are described. This includes management of emergency controls such as shutdown systems.

Physical security controls are measures that limit access to information assets in the plant control network environment. These measures prevent undesirable effects, including:

- Unauthorized access to sensitive locations.
- Physical modification, manipulation, theft or other removal, or destruction of existing systems, infrastructure, communications interfaces, personnel, or physical locations.
- Unauthorized observation of sensitive informational assets through visual observation, note taking, photographs, or other means.
- Prevention of unauthorized introduction of new systems, infrastructure, communications interfaces, or other hardware.
- Prevention of unauthorized introduction of devices intentionally designed to cause hardware manipulation, communications eavesdropping, or other harmful impact.

5.2 Serial Data Security

5.2.1 Data Encryption

Since RS-485 is extensively used on external networks to unattended tank farms, valve stations and the like, cyber security is an issue. Data encrypters can be added to the communication line. They are a bump-in-the-wire device that adds security to serial links. They are available for point-to-point links, multidrop SCADA networks, and dial-up configurations. These devices are available with NIST approved AES 256 bit encryption. One issue with these devices is they add latency to the message transmission.

In addition to the use of AES encoding algorithm FIPS 140-2 physical security should apply. Level 2 or higher is recommended. Security Level 2 require features that show evidence of tampering, including tamper-evident coatings or seals that are broken when attaining physical access to the plain text cryptographic keys and critical security parameters within the module. Also, the use of a true hardware random number generator is recommended.

Compact standalone devices are available that function as gateways. They provide an elevated level of protection data integrity and authenticity when transmission latency is not a problem. With strong data authentication they are designed to protect against spoofed, altered, spliced, reordered, or replayed data. They use AES-128 or AES-256 data encryption for protection against eavesdropping. They also prevent unauthorized device access by rejecting communication session requests from sources that cannot pass cryptographic session authentication.

Devices with public access should be secured with strong identity-based access controls. Also, logs should be generated that can be analyzed to identify persistent attacks and their pattern.

These measures should be augmented with the physical security of the control device. Robust locked enclosures and anti-climb fencing as well as motion detectors and CCTV should be considered.

5.2.2 Data Port Security

Many devices have multiple ports. They can provide an interface to a higher level system or be used for configuration. These ports can be used to force I/O or attach USB memory flash drives. Modifications can be made that have not undergone the Management of Change process.

The use of device data ports should be managed. Devices have been compromised with the attachment of uncontrolled configuration devices. Devices that are not in an access controlled facility such as the central control center but are located in the processing units are vulnerable.

Once a system is commissioned it is recommended that only those ports required to operate the system be active. No more than one backup port should be used. The ability to use memory flash drives should be disabled. Memory flash drives attached by innocent users are a leading vector for infecting systems with malware.

Tightly held, strong passwords should be used and changed according to a schedule. Also, parodic copies of the configuration should be made using a secure device and compared to the Controlled original. See ISA 62443-3-3 and its companion standards. NIST SP 800-82 “Guide to Industrial Control Systems (ICS) Security” also provides several practical recommendations for protecting equipment.

5.2.3 OPC UA

OPC UA Secure Conversation in particular provides strong protection and is designed for use with industrial networks and fieldbuses as well as the business environment and cloud services. It is interoperable with many of the standard industrial protocols.

5.3 Network Access Security

Firewalls, VPN tunneling, Secure Socket Layer (SSL), remote authentication and the like should be employed. See NIST SP 800-77, IEC 62443-4-2 and ISO/IEC 27033-5 for the implementation of VPN’s. See NIST SP 800-41 “Guidelines for Firewalls and Firewall Policy” plus recommendations concerning firewalls.

5.3.1 Firewalls

To provide defense in depth, it is recommended network hardware stateful firewalls intended for IACS protection be provided at the various network levels. Some of the more sophisticated switches can function as firewalls to prevent undesirable communication to access the network. For security purposes it is recommended that devices tested by recognized third parties be used for gateways and firewalls. Also network segmentation using firewalls can be in order.

Access Control Lists (ACL’s) should be carefully applied to maximize security while maintaining the flexibility needed for integrated operations. The security system should support a robust VPN environment. The security system should be evaluated with the protocols being used in the system to ensure interoperability.

Firewalls should not hinder the control of the facility. Its capabilities should exceed the network requirements so when the facility experiences an upset a firewall does not throttle the network. Network modeling should be considered using methods such as Monte Carlo simulation. These simulations should be kept in an ever green state so that updates and changes can be managed properly.

Firewall protection can involve hundreds of rules and should be configured by a specialist familiar with the selected device. See NIST SP 800-41 “Guidelines on Firewalls and Firewall Policy” recommendations for fuller and more specific requirements.

Firewalls and switches configuration should be backed up online using a transferable memory card or other means so that the MTTR is minimized.

5.3.2 Virtual Private Networks

Many SCADA protocols have weak or no security features. In these cases IPsec VPN or TSL (Transport Layer Security) is should be used with Internet based communications.

At the beginning of a session these services establish authentication between the agents and negotiation of cryptographic keys used during the session. VPN’s supports network-level peer authentication, data origin authentication, data integrity, data encryption, and replay protection.

IPsec VPNs operate at the network layer while TSL operates at the higher session layer of the OSI model. IPsec VPN’s connect hosts or networks to the private network, while TLS, formerly SSL, securely connects a user's session to specific services inside the protected network. Working at the network layer gives IPsec wider and long lasting access to network devices and resources. While, without custom development TLS connections support only browser based applications. See ISA TR99.00.01 and NIST SP 800-77 concerning the security of IPSec VPN’s and their use.

An alternative to IPsec VPN’s is OpenVPN. OpenVPN is regarded as being more secure and flexible. As a non-stop, site-to-site solution OpenVPN is easier to implement with field devices, particularly with SCADA. OpenVPN, as a point-to-point solution, is effective for troubleshooting field devices.

Table 15
IPSec VPN vs OpenVPN

	IPSec VPN	**OpenVPN**
Remote access	Site-to-Site	Point-to-Point
Authentication by password	YES	YES
Authorization by certificate	YES	YES
Authentication by server	YES	YES
Support for point-to-multipoint tunnels	YES	NO
Transmission Protocols	TCP	TCP or UDP
Supported by networking devices	YES	Partial
Tunnel dynamic routing	YES	YES
NAT traversal	YES	YES
Documentation	Complete	Complete

5.3.3 Zero Trust

Zero-trust cybersecurity assumes that every user, network segment and their resources are hostile. Traditional cybersecurity assumes segments within the security perimeter are safe. With IPsec VPNs, any user connected to the network is an unrestricted member of the network. ZTN go deeper than VPNs down to the application, device and user level.

The business network is considered hostile when planning ICS access. The security between the business network and the ICS by applying policies based on the combination of user identity, source device and the intended workload. Network architects define the absolutely necessary traffic, and block everything else. In the implementation of a zero-trust network there is a risk of making the system cumbersome and inefficient to the point where an organization is unable to operate effectively or in a timely manner.

The network is implemented without public IP addresses or open ports. Authentication and authorization is performed prior to opening a route to a specific service. Granular controls are employed.

Zero-trust execution begins with micro-segmentation. Micro-segmentation creates security zones based on risk. These zones have stronger access controls than those traditionally seen.

Access is managed by a policy administrator component. Continuous monitoring and logging are vital.

Identity authentication is an essential component to this process. Multi-factor authentication to access operational zones is required. The following principles apply:

- Remove visibility applications from the public internet
- Multi-factor authentication use
- Eliminate privileged network segments and security zones
- There should be no direct database access
- Shrink the application boundaries to as close as possible to the workload
- Grant access to the application, not the network
- Ever device is explicitly authenticated
- Before allowing application access, the device and user identities, device state, and the session context are evaluated
- Limits are provided for every session based upon the user, the device, where they are located, as well as information about the circumstances.
- Encrypt the communication as well as inspecting and logging the traffic
- Monitoring of the user and device for anomalous behavior

Abnormal behavior changes the trust that was created during the initial authentication and authorization process. Re-authentication is required if the behavior deviates too far from established baselines. Inhouse certificate authority is recommended. Trusting external certificate authorities creates an unnecessary vulnerability. See NIST SP 800-207 “Zero Trust Architecture” for additional information.

5.4 Wireless Security

if an unsecured or mildly protected industrial protocol is used beyond the plant perimeter such as the Internet or if it “spills over the fence” when using IEEE 802.11 Wi-Fi, then measures should be employed to protect data. For example Modbus, Profibus, wired HART and HART-IP are among protocols that incorporate little or no systemic protection.

Security is a concern about wireless communication in process automation. Wireless systems are subject to attacks in a similar manner to wired communications. Because a wireless system can be attacked without physical intervention, it is perceived as being less secure. Still, the vulnerabilities are known, and protection technologies are available. For instance the signals are routinely encoded using a strong cypher, spread spectrum and frequency hopping are used so they are hard to intercept. See ISA TR100.14.01 for further information on wireless security.

Wireless security parameters are treated as confidential information according to plant and corporate security policies.

5.5 Cybersecurity References

IEC TR 62443-3-1	Industrial Communication Networks - Network And System Security - Security
IEC/PAS 62443-3	Security for industrial process measurement and control - Network and system security
IEC 62443-4-2	Security for industrial automation and control systems, Security requirements for IACS components
ISA TR84.00.09	Cybersecurity Related to the Functional Safety Lifecycle
ISA TR99.00.01	Security Technologies for Industrial Automation and Control Systems
ISA TR100.14.01	Trustworthiness in Wireless Industrial Automation, Information for End Users and Regulators
ISA 62443-3-3	Security for control systems, Security requirements and levels
ISO/IEC 27033-5	Network security Securing communications across networks using Virtual Private Networks (VPNs)
NIST SP 800-41	Guidelines for Firewalls and Firewall Policy
NIST SP 800-53	Security and Privacy Controls for Information Systems and Organizations
NIST SP 800-77	Guide to IPsec VPNs
NIST SP 800-82	Guide to Industrial Control Systems (ICS) Security
NIST SP 800-207	Zero Trust Architecture

Furthermore, see the ISA 62443 standard suite for additional requirements.

6 DEVICE DEFINITION SOFTWARE

6.1 Introduction

Configurable field devices have options that need to be selected. An advantage of fieldbus systems is that besides feeding back process data and diagnostics, they enable remote configuration and central management of the field devices. A device information file and related software provides access to the device attributes and functions.

Configuration tools at a minimum should:

a. Be device neutral
b. Support the applicable protocols
c. Enable device calibration
d. Modify tunable parameters
e. Simulate functions
f. Assist diagnosis
g. Generate documentation

6.2 Device Description Languages

Device Description Languages (DDL) are formal languages that enable configuration of field devices.

The DDL describes:

a. Addressing Information
b. Data or Parameters
c. User Interfaces
d. Operations e.g. Calibration

The DD (device description) tells the system what function blocks are present in a supplier's device type, what parameters are available, their data type, the default values, and the permitted ranges. This information enables a system to recognize a device when it is present in the system.

There are two tools based on standards available for device description; FDI/EDDL and FDT/DTM. The following standards apply:

a. IEC 61804 Electronic Device Description Language (EDDL)
b. IEC 62769 Field Device Integration (FDI)
c. IEC 62453 Field Device Tool (FDT/DTM)

FDI or FDT technology provides supplier, protocol, and host independence. See Table 16 comparing the two technologies. OPC UA information server models have been developed for both FDI and FDT, ensuring system wide interoperability and security when used.

6.3 FDI/EDDL

6.3.1 EDDL

EDDL (Electronic Device Description Language) was created as a way to describe devices across different systems. EDDL is a text based language for describing the parameters, diagnostic information, and configuration details in a system neutral environment.

The DDL removes the requirement to write a new tool for a new device type. The creation of a DDL description takes less effort than programming a new software tool.

EDDL is a declarative technology, not a compiled software program. EDDL files are interpreted using a common engine. They are encapsulated and secure.

The features of EDDL are as follows:

a. It is a text file that is operating system independent
b. Each device requires an EDD
c. Only functions described in IEC 61804-2 are allowed
d. EDDL instruments have the same look and feel
e. Additional functionality requires proprietary plugins

The EDD file provides a standard form and structure for host systems, laptops, handheld communicators, and other devices to access and display information in field instruments independent of the system, or the communication protocol.

The EDDL structured text files describe:

a. Device parameters and their dependencies
b. Device functions, such as Simulation, Calibration or Configuration Modes
c. Graphics, such as Menus, Calibration Plots
d. Control device Interactions
e. Graphical representations
f. Persistent data storage

EDDL allows a host to both configure as well as monitor devices online. EDDL's provides data, alarms and diagnostic status for operator displays. The diagnostic status tend to conform to NAMUR 107 requirements. The style or "look & feel" comes from the host. This ensures that colors are consistently used, and that buttons and other controls function uniformly.

The EDDL provides the following services:

a. Identification
b. General Information

c. Diagnostics
d. Performance Analysis [1]
e. Operational Statistics
f. Parameterization and Ranges [2]
g. Simulation and Override
h. Calibration Trim
i. Monitoring
j. Device Security
k. Reset

Note 1: Valve signature, hysteresis, step response, etc.
Note 2: Advanced setup such as a radar echo curve are available

The FieldComm Group and PROFIBUS have merged their dialects of DDL. The result became IEC 61804 “Electronic Device Description Language (EDDL).”

EDDL also supports Methods, a scripting language based on a subset of ANSI C. This allows step-by-step, interactive setup and calibration procedures.

Using EDDL, a supplier can develop support for advanced applications or a “Snap-On” for valve signatures and other diagnostics that are compatible with the host system. All versions of EDDL are backwards compatible with existing devices.

6.3.2 FDI

The FDI (Field Device Integration) Device Package is a software module that contains the tools, device information, and user interface plug-ins. Field device suppliers define within the FDI Device Package what data, functions and user interfaces stored on the FDI Server. It includes the IEC 61804 Electronic Device Description (EDD), which has the device definition, business logic, communication server and the user interface description (UID). It goes beyond EDDL,

The device definition communicates the field device data, and the internal structure e.g. blocks in EDDL. Business logic is the descriptive element of an FDI Device Package that specifies device behavior and mapping logic for communication.

User interface descriptions (UID) and user interfaces plug-ins (UIP) define the user interface. EDDL UID ensures a consistent look and feel, because the supplier configures one version that each system use to create its interface. A simple and clear user interface standardizes activities to configure a field device reducing set-up time and configuration errors.

Further an optional UIP offers a programmable FDT user interface that is based on Windows Presentation Foundation (WPF). This allows a more complex implantation but requires a Windows based device.

The FDI also can contain the certifications, user manuals, installation instructions and data sheets. Product documentation, protocol-specific files, such as GSD, can be added as attachments to the FDI Package.

6.3.3 FDI Host

FDI hosts use an OPC UA client-server architecture. The FDI Device Packages are stored within the FDI Server resident in the host. The FDI Server interacts with the FDI Device Package. Using the information from the FDI Server, the FDI client runs either the UID or UIP from the package to provide the interface display.

The FDI Server also contains the EDD Engine which interprets the EDD and passes it to the communication service. The communication services include HART, PROFIBUS, and FOUNDATION Fieldbus. Besides supporting the protocols developed by the FieldComm Group; e.g. HART, IEC 62769-100 "Field Device Integration (FDI), Part 100: Profiles – Generic Protocols" enables the use of a wider set of protocols; such as EtherNet/IP™ while IEC 62769-115-2 specifically supports Modbus RTU.

Hosts are scalable and include handheld communicators, laptops, device management software, plant asset management systems, and historians.

6.3.4 Product Certification

Product registration providers, like the FieldComm Group, furnishes conformance testing, registration, and FDI Device Package distribution services. Products bearing the FDI Registered mark undergo a series of tests ensuring a consistent functionality and interoperability regardless of the host system.

Future enhancements of the EDDL and FDI are governed by the FieldComm Group, Profibus Nutzerorganisation (PNO), OPC Foundation and the FDT Group.

6.4 FDT/DTM

FDT/DTM stands for Field Device Tool and Device Type Manager. It is supported by the FDT Group. Initially FDT used the Windows Component Object Model (COM) technology and is the basis of FDT 1.X versions. The .NET Framework platform is used with FDT 2.X versions which provides some platform independence while enabling backward compatibility with the older COM software. Operation within the OPC UA environment is also possible with various FDT 2.X and higher implantations allowing better platform independence.

6.4.1 FDT

FDT technology uses programs known as Device DTM's. FDT is designed to be a software receptacle into which a DTM for a field device is inserted. DTM's provide an interface, a common database, history, audit trail and security. Further special applications are supported by DTM's.

FDT can interface to the control system or become an integral part of it. FDT provides access to underlying services, such as display, keyboard, database, digital communication interfaces, and other control system features.

FDT use is not limited to field devices. It is used with network switches, PLC I/O and other devices anywhere in the overall network.

FDT/DTM technology requires following parts:

a. An FDT Frame Application
b. Device DTM for each field device type
c. A CommDTM for each protocol

A Device DTM can be specific to a device or a family of devices as well to a protocol. It contains the user interface and any diagnostics plus processing functions.

The device supplier develops a Device Type Manager for its devices. The DTM encapsulates the device specific data, functions, and business rules, such as the device structure, its communication capabilities, internal dependencies, and the HMI interface structure.

DTM’s require an FDT/FRAME system to run. The DTM is launched in the FDT Frame Application using a host system. To allow device management a DTM is represented within the Frame Application as a graphic display.

The displays are not designed by the HMI provider or the control system supplier. The FDT/DTM architecture, the field device display is the responsibility of the device supplier.

Still unlike the more ridged EDDL UID displays depending on the application needs the displays are more flexible but newer implantations are required to follow the FDT Style Guide.

The initial FDT 1.X displays were not governed by a style document. In later implantations they are based upon FDT Group’s Common Components and Style Guide. Conformance to these requirements is part of the certification process. FDT 2.X displays are the basis of UIP displays included in the FDI package.

6.4.2 DTM

Device DTMs are created by the device supplier. DTM's are executable software drivers. The DTM’s provide functions for accessing parameters, configuring, and operating the devices plus diagnosing problems.

A DTM can range from setting parameters with a simple graphical user interface (GUI) to a complex application performing intricate real-time diagnosis calculations and supporting asset management.

The DTM includes graphical interface for device configuration, maintenance, diagnostics, and troubleshooting. DTM’s conforming to the FDT Style Guide provide a commonly appearing graphical interface across suppliers.

6.4.3 DTMS Types

There are different types of DTM’s:

a. Supplier Specific DTM – These DTM’s offer the highest functionality. A single device DTM can support one or a group of a common device types of such as family of pressure transmitters. These DTM’s can be provided with features such as extended configuration and diagnostic capabilities as well as furnish networking analysis or display calibration curves.

b. Interpreter DTM – These DTM’s are not developed for a specific device. Instead, they interpret device descriptions. Device Descriptions (DD’s), Electronic Device Descriptions (EDD’s), and Field Device Integration (FDI) Device Packages, can be used within an FDT/FRAME enabled system.

c. Generic DTM – A Generic DTM supports devices that comply with specific protocol parameters. For instance with a generic HART DTM, a HART device that can be accessed with the “Universal and Common Practice Commands.”

d. Communication DTM (CommDTM) – The Comm DTM provides the connection to the device. It is provided by the communication cards and linking devices suppliers. The CommDTM establishes the communication channel. The communication DTM can function as a standard driver for one or multiple protocols.

e. Gateway DTM’s – Gateway DTM’s allow communication to transition cross various gateways and switches in the FDT architecture. Gateway DTM’s link the communication DTM and device DTM. Unlike EDDL’s they allow nested communication across several levels.

6.4.4 FDT Frame

FDT/FRAME provides a common runtime environment. FDT/FRAME manages instances and retains their data. This ensures uniform data organization at the enterprise level throughout its life cycle. FDT/FRAME provides an interface for data retrieval. The data can be backed up and restored from a central data store. It provides change management through the use of logs.

The Frame Application holds the Comm DTM's and the Device DTM's. Available as stand-alone device such as a laptop, the Frame Application is also used with larger systems, such as engineering tools, operator interfaces or asset manager.

FDT/FRAME can be embedded in system hosts such as asset management tools, Programmable Logic Controllers (PLC's), HMI's and Distributed Control Systems (DCS's). The Frame Application works with multi-workstations or a single workstation.

FDT/FRAME performs network scans for new devices. Providing single-point access to the network, the FDT/FRAME, provides access to devices, gateways, switches, and other configurable components.

An online connection is not required for configuration. Topology planning with gateways and links as well as system structuring and configuration can be developed off-line.

A Frame Application typically renders one device type at a time. Still most Frame Application support multiple windows, allowing interaction with several devices.

The information in the field is accessible in real-time. However, unlike EDDL's, the DTM's do not provide real time data and alarms to operator stations.

Process control system suppliers can embed the Frame Application, and the Comm DTM into their system management tools. FDT Technology is often used without the user aware of the underlying technology which promotes focus on device configuration.

6.4.5 PACT*ware*

PACT*ware* is a widely used freeware FDT/DTM program. It runs on a Windows computer for parameter adjustment and configuration of field instruments, remote I/O systems and communication modules in fieldbus systems and networks. It is useful for installations and facilities with limited resources.

It is a development of the PACT*ware* Consortium. It allows members to offer full FDT/DTM packages without the burden of maintaining their own FDT/Frame and CommDTM applications. Individual member companies distribute PACT*ware* together with their DTM's.

Also the basic PACT*ware* package enables control of generic HART instruments. It contains a communication driver for standard HART FDK modems and a basic HART instrument DTM that enables control of the basic parameters of the instrument.

6.5 EDDL and DTM Comparison

Though these two standards nearly serve the same purpose, they are based on dissimilar technologies and have significant differences. For instance FDT/DTM doesn't provide continuous alarm monitoring and status to the operator stations. Table 16 below summarizes these differences.

Only functions described in IEC 61804-2 are possible in EDDL. There are cases where EDDL is not sufficient. For instance for initial device setup some devices require calculations beyond what EDDL provides. DTM's can meet this need.

EDDL and FDT/DTM are complementary technologies, important to open integration of control systems and instrumentation in multi-supplier environments. It is common to use both technologies especially when a protocol such as EtherNet/IP™ which is not support with EDDL is used.

Table 16
EDDL vs FDT/DTM

	EDDL	**FDT/DTM**
Structure	Text, data	Program
Control	Yes, provides information to the control system	No, a DTM is an independent program that is not used in control
Alarming and status	Yes	No
Application integration	Yes, where control data is used	Yes, within the DTM
Installation	Addition of a file to the host program, one install per system	Installation of a single or package DTM per client
Distribution	Fieldbus organizations and suppliers	Instrument and device suppliers
Communication interface support	No	Yes
Operating system	Interpreted by the host or DCS	Windows, version specific, Some OPC UA
Supported protocols	HART, FOUNDATION Fieldbus, PROFIBUS, PROFINET, ISA 100 Modbus RTU	HART, IO-Link (IEC 61131-9), Modbus, EtherNet/IP™, EDDL, DeviceNet, Profibus, et al
Flexibility for adding functionality	Low for device manufacturers	High for device manufacturers, None for host system manufacturers
Presentation of device functionality	Has to be supported by a DCS vendor. Common look and feel. Restricted functionality for more complex device types	Is determined by DTM so full functionality for device types
Installation procedures	Yes, copy file	Yes, software installation, some restart required. No registry changes
Dependency on operating system	No, but the application (EDDL interpreter) can depend on the host operating system	Yes, FDT frame and DTM must be verified against operating system
User interface	Determined by host system	DTM style guide
Certification process	FieldComm Group, Profibus Nutzerorganisation (PNO)	Certified test facilities by the FDT group
International standard	IEC 61804-3	IEC 62453

7 ELECTRICAL HARDWARE

7.1 NEMA/IEC Handswitches

A handswitch is a device that can interrupt a circuit. Closing the contacts completes the circuit allowing the current to flow, and opening the contacts discontinues the current flow. It can have one or more sets of contacts. This discrete device turns on lights, and equipment; such pumps, as well as trigger process operations.

Handswitches can be momentary; i.e. pushbuttons or can maintained; i.e. selector switches. They can have different contact variations such as single-pole, double-pole double-throw, etc. See Figure 13

A handswitch is an assembly of individual components that can consist of the following items:

a. Actuator [1]
b. Contact Blocks [1]
c. Basil ring or Mounting Bracket [1]
d. Gasket
e. Enclosure [2]
f. Legend plates [3]
g. Name tag [3]

Note 1: Minimum components required for a functioning switch.

Note 2: Handswitches can come preassembled in a control station that holds one or more switches and pilot lights. See section 7.4.1and section 7.4.2 for construction features. As an option punched holes for attaching cables and conduits can be included. NEMA 7 enclosures should come with predrilled threaded holes.

Note 3: Supplier metal legend plates are available with standard wording; e.g. stop, on/off, etc. Custom laminated nameplates can be added to the above switches to further describe the service or used instead of a supplier's metal legend plate. See section 7.5.4 for the design and language for nameplates.

There are three standard handswitch sizes based upon the mounting hole. The following is their nominal designations:

a. 30 mm
b. 22 mm
c. 16 mm

Handswitches are often designated as NEMA or IEC style. The NEMA style switches are the 30 mm devices while the IEC style mostly is supplied in the 22 mm nominal size, but IEC also recognizes a 16 mm size. Both types have similar features and robustness. Both types offer metallic and nonmetallic components. The contacts are usually rated to both standards.

IP 66, NEMA 4X and NEMA 12 construction is available with both types. NEMA/IEC handswitches are mechanically and electrically rated for 200,000 to 1,000,000 operations. Selecting a proven supplier is the main factor in a successful application.

7.1.1 Pushbuttons

Pushbuttons are primarily biased switches. They return to their initial position when the actuator is released. Pushbuttons are usually associated with a device such as relay, motor contactor or other form of memory that is set to the latched, sealed-in, or on state. This state is reset by logic or another pushbutton.

Pushbuttons can be connected together by a mechanical linkage so that the act of pushing one pushbutton causes the other pushbutton to be released. In this way, a stop pushbutton forces a start pushbutton to be released. The mechanical linkages are used with equipment that has no control circuits; such as an overhead door.

Emergency mushroom heads can be used for tripping equipment or a process. Other accessories for pushbuttons include guard rings and covers. An extended guard ring is used to recess a pushbutton, so it is not accidentally bumped causing a spurious trip. Guard rings are also used in lockout-tagout procedures to hold a stop button in the depressed state with a locking device. Safety covers perform the same function that an extended guard ring in that protects the pushbutton or selector switch from unintended use.

Options for pushbutton actuators:

a. Standard Spring Return Action
    i. Color Coded Caps
    ii. Legend Caps
b. Flush or Extended Button
c. Push/Pull Action
d. Keylock Reset
e. Integral Pilot Lights [1]
    i. Incandescent
    ii. LED
    iii. Neon
    iv. Xenon Strobe
f. Mushroom Heads [2]
g. Twist to Release Action
h. Recessed Guard Rings [2]
i. Lockable Safety Covers [3]
j. Safety Lockout Rings [4]
k. Lockout Attachments [4]
l. Two button mechanical Interlock
m. Pushbutton with selector basil ring
n. Protective Boots
o. Push-On, Push-Off Action
p. Time Delay Action
q. Sealing well [5]

Note 1: LED lights last for 100,000 hours while a full voltage incandescent bulb has a 5000 hour life.

Note 2: Red mushroom heads are used for emergency trips. Conversely, recess guard rings can be used for emergency trips. This protects the button from accidental contact. Some mushroom buttons are equipped with late break contacts to reduce the occurrence of accidental trips.

Note 3: Covers with plastic hinges have tend to fail over time.

Note 4: Safety rings and lockout-tagout attachments have padlock hasps that when installed holds the stop or trip button in the depressed position.

Note 5: Sealing wells are sub-compartments that eliminate the need to Class 1, Division 1 conduit and cable seals.

7.1.2 Selector Switches

Selector switches are available in a variety of styles including illuminated, non-illuminated, and key operated. Styles range from maintained or spring return and available in up to four positions.

The selector switch has a rotation knob on the front with the various contact types on the back where the wire is terminated. The major difference between the selector switch and the pushbutton is that, while a pushbutton has a plunger that activates the contacts at the same time, a selector switch has a rotating cam that independently actuates the switches.

Selector switches are available in two, three, or four-position versions. Usually, the center position of the selector switch is the starting position. The left position presses the left plunger and activates a set of contacts. Turning clockwise the selector switch activates the contacts on the right side. Returning the switch to the center can activate a middle set of contacts. Rotation between the positions are distinct break-make steps; i.e. non-shorting.

Spring return action to center allows biased pushbutton type operation. This enables start/stop momentary control with one switch. In this case the middle position does not have active contacts.

Also, cams can be organized to activate contacts in more than one position. Cam reduce the need to add contact blocks and jumpers to create functionality. The selector switches use cams in combination with contact blocks to provide a range of circuit openings and closings. The different cams are selected using a truth table, which show the state of the contact at the various positions.

Options for selector switches:

a. Two, Three, or Four Positions [1]
b. Color Coded Knobs
c. Standard, Lever, or Coin Slot Knobs
d. Keylock [2]
e. Integral Pilot Light
f. Spring Return [3]
g. Lockable Safety Covers [4]
h. Lockout Attachments [5]
i. Sealing well [6]

Note 1: Cams can be provided so that a contact can be active in more than one position. For more than four positions, rotary cam switches, which are used with switch gear, can be employed. Gold plated contacts are needed for low voltage circuits with rotary cam switches.

Note 2: Selector switch keys can be removable or trapped. With a trapped key, the key can only be removed at one position.

Note 3: Spring action is selectable for clockwise and counter-clockwise action from the far left hand position and the far right hand position. Clockwise and counter-clockwise action together on three-position switch can provide the same logic as a dual set of pushbuttons.

Note 4: Covers with plastic hinges have tend to fail over time.

Note 5: Lockout attachments can freeze the selector in place or in case of three-position switch the use of one position is restricted. Other lockout attachments are available that allow any maintained position to be chosen.

Note 6: Sealing wells are sub-compartments that eliminate the need for Class 1, Division 1 conduit seals or cable seals.

7.1.3 Pilot Lights

A pilot light is used to furnish a status and provide feedback. The pilot light can be an independent device or can be part of a handswitch. In the case of selector switches independent pilot lights have to be used to indicate more than one status. As a result, the use of integral pilot light with selector switches is not common.

The energy to illuminate the pilot light is not wired to the pushbutton contacts but operates off the action of the logic of the controls. A start pushbutton when depressed causes the process or equipment to start and an independent contact that is part of the operation or process turns on the light. This feedback indicates that the process or action has occurred.

LED lights have the advantage that they last for 100,000 hours while a full voltage incandescent has a 5000 hour life. LEDs are also vibration and shock resistant. Some LEDs are not as bright as incandescent bulbs. Blue and white are the dimmest colors.

DC pilot lights also can be furnished with dual inputs to enable a common test function that is independent of the control circuit. For a pilot light that is not integral to a pushbutton a push to test feature can be added.

Incandescent lights require 70 mA at 24 VDC. LED require 21 mA or less enabling them to operate over at a longer distance. Some LED and neon bulbs can need a shunt power resistor because of excess leakage currents from solid state outputs.

Pushbuttons are often color coded to associate them with their function. Common colors are red for stopping a motor or tripping a process and green for starting them. See Table 17 for standard color assignments.

Table 17
NFPA 79/IEC 60073 Color Coding for Handswitches and Pilot Lights

Color	Description	Light	Switch
Green	Normal Operation, Motor Running, Valve Open	Yes	Yes
Red	Fault, Danger, Motor Stopped, Valve Closed, Electrically Energized, Stop	Yes	Yes
Amber	Caution, Equipment in Motion	Yes	
Blue	Mandatory Action	Yes	
White	Ready, Status, Pause, State, Transitory Condition; e.g. valve in motion, test in progress	Yes	
Black	Start, Open, Reset, Select		Yes

7.1.4 Contact Blocks

Dual circuit contact blocks save space and add functionality. Standard handswitch contact blocks have four terminals with two contacts. This allows two circuits to a contact block.

When the contacts are open in the normal or unoperated condition the switch is designated as Normally Open (NO). The combination when the contacts are closed in the de-energized or unoperated position is characterized as normally closed (NC).

The most common NEMA/IEC handswitch contact block is a Form Z configuration which is a double break form with one normally open (NO) paired and one normally closed (NC) contact. Multiple contact blocks are stacked to increase functionality. Subject to space availability four dual circuit blocks can be mounted in a pushbutton for a total of eight circuits.

Standard NEMA and IEC rated contacts require some electrical arcing for cleaning high resistant sliver oxide coatings that form on the surface. Standard signal circuits do not possess enough energy for this purpose. The alternative used with NEMA/IEC handswitches is to use Rhodium hermitically sealed contacts that are rated to operate as low as 5V and 1 mA. Non-hermitically switches use gold plated contacts that resist oxidation but completely lose their gold plating when used with higher voltages.

Figure 13
Graphic Presentation of Switch Forms

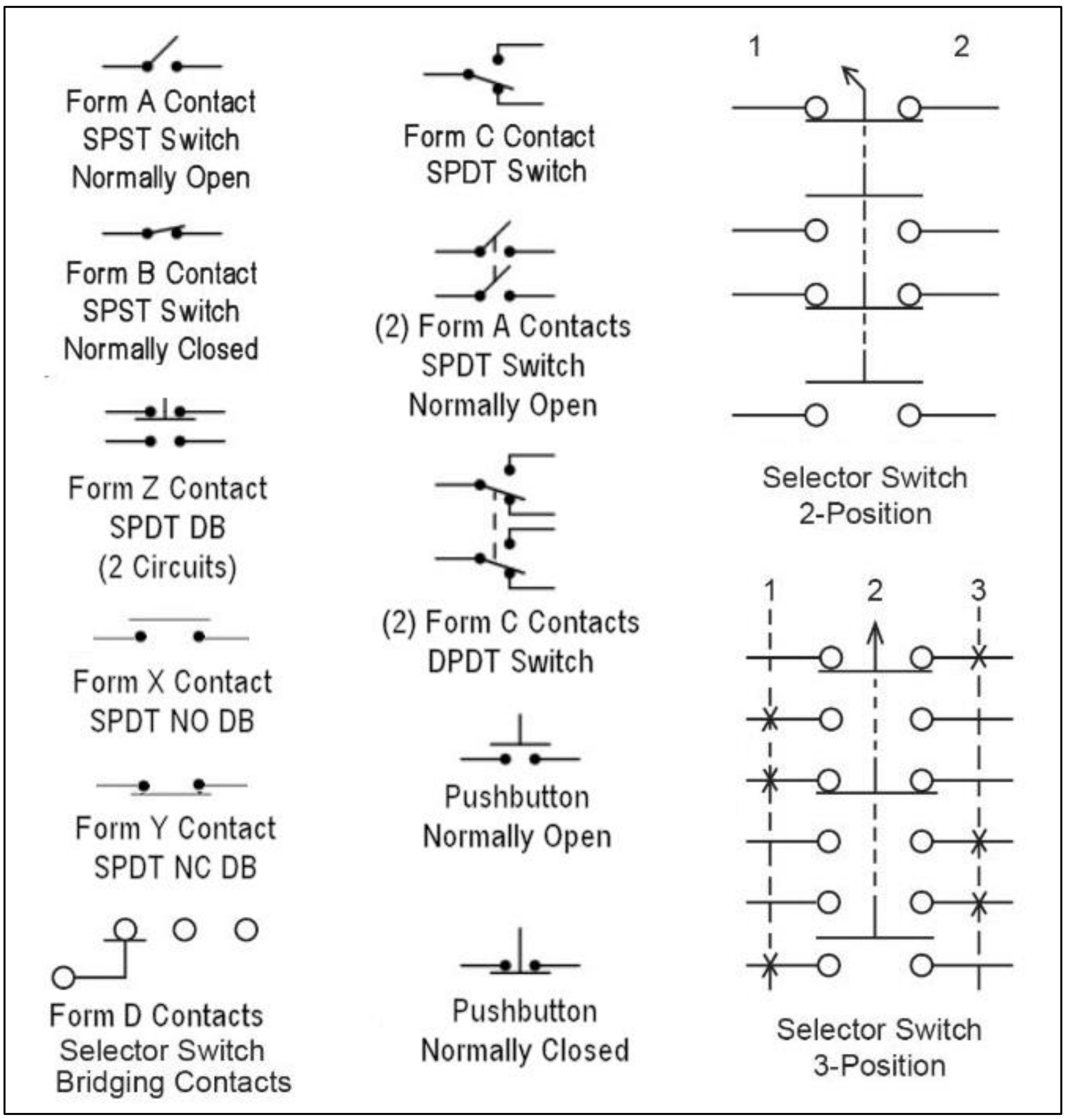


Table 18
Switch Identifications

Term	Description
B	Break
DB	Double Break
DM	Double Make
DP	Double Pole
DT	Double Throw
M	Make
NC	Normally Closed
NO	Normally Open
TP	Triple Pole

7.1.5 Contact Types

There are several types of contacts used in handswitches:

a. NEMA/IEC Silver Alloy [1]
b. Hermetically Sealed [2]
c. Hermetically Sealed, Low Energy [3]

Note 1: Contact rating varies with voltage, the continuous current rating ranges between 2A to 10A at 120VAC depending on the contact. The continuous current DC rating is significantly less than the AC rating. Also, the load allowed for the contact break action is significantly less than the contact make action.

Note 2: Tungsten hermitically sealed contacts suitable for five amps and a Class I, Division 2 location.

Note 3: Rhodium hermitically sealed PLC rated contacts are rated down to 1 mA.

7.1.5.1 Sequence of Abbreviations

The contact switching combinations are defined in terms of number of poles, number of throws (single or double), normal position (open or closed), and the sequence to make and break. The various combinations have been given form letter symbols as shown in Contact NEMA/IEC block combinations include the following:

a. 1 Normally open and 1 normally closed contact [1]
b. 2 Normally open contacts
c. 2 Normally closed contacts
d. 1 Early closing contacts [2]
e. 1 Delayed opening contacts [3]
f. Make-before-break contact pair [4]

Note 1: Unlike toggle switches, SPDT or Form C contacts are not available for NEMA/IEC style handswitches. The NO and NC terminals on the contact block has to have jumpers tying them together to create a common terminal.

Note 2: Contact action occurs prior to the operation of a normal contact.

Note 3: Contact action occurs after the operation of a normal contact. Used on trip switches.

Note 4: Make-before-break allows transfer operations such as bypassing a UPS circuit for maintenance. Make-before-break or shorting Form D contacts are not available with standard

NEMA/IEC selector switches. A rotary cam type change-over switch intended for power management can be configured to provide this function by using slip contacts.

Abbreviations are used for a contact assembly; the following order is used: (1) Poles (2) Throws (3) Normal position (4) Double make or break, if applicable. For example: SPST NO DM refers to single pole, single throw, normally open, double make contacts. Table 18 provides the contact functional identification.

7.2 Wire Terminals

7.2.1 IEC vs. NEMA Terminal Blocks

Wire terminal blocks are categorized as IEC or NEMA style depending on their mounting and design characteristics.

NEMA style terminal blocks contain self-lifting pressure plates, binder head screws or box lug connectors. The rail designs are normally not interchangeable between suppliers. Frequently, they are screw directly to the mounting surface without mounting rails.

NEMA blocks use more panel space and offer fewer terminations per linear foot. The traditional spade 600V terminal block is more than twice the width of IEC terminal block.

They are frequently used for heavy-duty operations. They are useful for elevated temperature and high current applications. They are typically made from a phenolic material. They are still widely used in motor control centers. Since they are easier to wire, they are the terminal type supplied with most field instruments where only a few terminations are needed.

NEMA terminal blocks are:

a. More options for high current applications
b. Open construction, which allows for easier wiring

IEC screwed compression blocks are the most common terminal block. They are rated for 300V or 600V. Typically, the 300V version is 5 mm wide and accepts 12 to 22 AWG wire sizes.

The terminals have steel clamping components plated with a tin alloy. They are modular, and the contacts use pressure plates with the live parts recessed into the insulation.

IEC design offers more terminations per linear foot. IEC 60947-7-1 blocks are easier to mount than NEMA style blocks. They come in a wide variety of styles and features.

Rails are used to hold the terminals and are offered in 15mm, 32mm and 35mm widths. Because the rail is standardized IEC blocks are compatible between suppliers and often have the same shape and dimensions.

The most widely used mounting rail is a 35 mm IEC 60715 Type O rail, which is the Top Hat style and is the preferred type. The C and G cross section rails a mostly used in legacy installations. Also, small electronic devices; such as transducers and power supplies are designed to mount on 35 mm Top Hat rails.

IEC terminals have the following advantages:

a. Compact design
b. Extensive variety
c. Wide acceptance

IEC spring-clamp terminal blocks are another form of terminal. They are screwless and are intended to be vibration resistant. They mount on a 35 mm IEC 60715 Type O rail. Some organizations have standardized using them while others are concerned about the longevity of the spring mechanism.

7.2.2 Terminal Block Bodies

Terminal block bodies are constructed from Polyamide, Melanie, or Ceramic. They have a high tracking resistance and are non-hydroscopic.

Polyamide, also known as Nylon, is the material used for terminal block construction. Polyamide is a thermoplastic and remains elastic from -40°C to 105°C. This material is a good insulator with low flammability. It has an IEC 60112 tracking resistance of ≥600 Volts ensures they have non-hydroscopic properties.

Polyamide also has high impact strength and is halogen-free as well as being UV-resistant. It is fungus and termite resistant plus it is impervious to chemical attack and has good aging attributes.

Melamine is a resin-based thermoset plastic with an organic filler. It is a more fragile material than Polyamide. Melamine provides an elevated level of resistance to heat. It is recommended where the continuous temperature is between 110°C and 140°C.

Ceramic is a rugged but brittle material that can be utilized at temperatures approaching 250°C. Ceramic blocks are used in plants with excessive dust deposits and corrosive atmospheres. They are used with thermocouples and around furnaces and boilers.

7.3 Horns and Beacons

Alarm horns and beacons are elements in a notification system to warn of a hazardous situation. These systems can be two to three levels deep. The highest level is the plant or community mass notification alarm that is audible over a large territory. These systems are used to trigger an evacuation from an area. In the case of a large facility such as a refinery sound sequence codes are used to designate the area to be evacuated. The lower level alarms are local alarms within a unit. It warns of toxic gas, affixation, and machinery trouble. These alarms consist of an audio and a visual component.

7.3.1 Audible Signals

In selecting auditory signals for alarms it is preferable to pick tones which carry a pre-established cultural association distinct from the tones from other emergency conditions. An upper limit of five tones should be used for local alarms but none of these should be the same as used by the facility wide alarm.

In particular building fire alarms are distinctive from other sounds and this sound is not used for any other function. A three pulse temporal pattern followed by a pause over a four second period is usually assigned and is recommended by NFPA.

The sound level should be appropriate for the location’s background noise. A signaling system should produce a sound level at least 15 dB above the ambient sound level or 5 dB above the maximum sound level having a duration of at least 60 seconds. Every time the distance from the source doubles, the sound level decreases by about 6 decibels (dB). Without special support the maximum sound pressure level permitted is 110 dBA.

The larger the area, the louder the signal required or the greater the number of units required. Better coverage is frequently obtained by using several signals of lower dB rating than one very loud signal. The effective masked threshold can be calculated in accordance with ISO 7731 “Danger Signals for Work Places - Auditory Danger Signals.”

Table 19
Sound Loudness and Frequency
for Audible Notifications

Condition	Recommendations
If the distance to the listener is great	Use increased loudness and low frequencies
If the sound is to be heard around obstacles and pass through partitions	Use low frequencies
If background noise is present	Select frequencies lower than those of the background noise. Use several tones differing by an octave
To demand personnel attention	Modulate the signal to give intermittent beeps or modulate the frequency to make pitch rise and fall at rate of 1 to 3 Hertz.
To distinguish between different alarms	Use different sound waveforms, with pulse frequency between 0.5 to 2.0 Hz. Consistently use the same waveform for the same function or purpose. Use no more than three or four different forms.

7.3.2 Visual Beacons

For beacons to be in the normal cone of vision, mounting heights of less than 96 in. (2.44 m) and greater than 80 in. (2.03 m) are recommended. Different light sources can offer significantly different effective light intensity and ability to attract attention, particularly while flashing. Table 17 should be used to select the colors.

Below are the common illumination sources for beacons:

Incandescent / Filament bulb: The incandescent light bulb has modest performance, which is enhanced with a Fresnel lens. It has a short life and is further shortened when exposed to even low levels of vibration. Incandescent bulbs require the most energy to operate which makes them the least suitable for direct operation from a logic system. A typical incandescent beacon uses 1.0 Amp at 24 VDC for a 15 cd output.

Halogen bulb: A more efficient beacon than an incandescent bulb. Its life is up to three times longer. A halogen can produce an increase of 80% in luminous efficiency. A typical load for halogen beacon is 1.0 Amp at 24 VDC for a 21 cd output.

LED: Emits only one frequency of light. it offers a long lifetime, being an effective solution where an indication or status is required. Requires 130 mA for a 19 cd output. However, the lower operating temperature is -25°C (-13°F) which limits its application.

Xenon Strobe: Operates at high voltage with xenon tube being ignited to create an instantaneous flash of light. This can further be enhanced with a Fresnel lens. The tube life is typically 5 to 8 million flashes. Uses 82 mA at 24 VDC for a 50 cd output and 270 mA at 24 VDC for a 250 cd output. The lower operating temperature is -35°C (-31°F).

Table 20
Daylight Viewing Distances for Clear Beacons

Effective Candela (cd)	Warning Distance (m)	Warning Distance (ft)	Viewing Distance (m)	Viewing Distance (ft)
10	5	16	22	73
50	11	37	50	164
100	16	52	71	232
200	22	73	100	328
300	27	90	122	401

Table 21
Color Transmission Effectiveness

Clear	Yellow	Amber	Green	Blue	Red
100%	93%	70%	25%	24%	23%

The effective Candela range is calculated using the Illuminating Engineering Society of North America Handbook. The actual distances tend to be less.

7.3.3 Beacons and Audio Signals Wiring

Beacons and audio signals can require a great deal of current to operate. Depending on the noise generator up to 1.3 amps at 24 VDC can be required for an outdoor audio alarm to produce 120 dBA at one meter. In some cases, auxiliary power can be required if these signals are transmitting more than a dozen feet. One option is to use a pneumatic alarm with a low power solenoid valve.

However, by careful device selection and by using independent signals it is possible to operate a 116 dBA electronic horn at 275 ft and a 250cd strobe light at 220 ft using 18 AWG wire fed directly by a logic processor output.

7.4 Control Enclosures

7.4.1 Enclosure Construction

NEMA 4 enclosures combined with oil-resistant gaskets are used outdoors for junction boxes and instrument housings. They are unaffected by a high pressure water spray from a hose. Similarly, IP65, IP66 and IP67 enclosures, according to IEC 60529, are rated as hose resistant. See Table 22 and Table 23 for a description of the enclosure ratings.

Table 22
Selection of IEC 60529 IP Enclosures
to meet NEMA Requirements

NEMA	Description	IP	Description
1	Indoor General Purpose	20	Protected from solid objects ≥12.5 mm dia.
2	Suitable where severe condensation present	22	Protected from solid objects ≥12.5 mm dia. and against dripping water, spillage (not rain) when tilted up to 15°

NEMA	Description	IP	Description
3	Weather-tight against rain and sleet	55	Dust-proof, Protected against water jets
3R	Rain-tight, less than NEMA 3	24	Dust-tight, Protected from splashing water
4	Water-tight. Resistant to direct water jet spray	66	Dust-tight, Protected from powerful water jets
4X	Same as NEMA 4. but corrosion resistant		
5	Dust-tight	53	Dust-tight, Protected against spraying water
6	Limited submersion in water	67	Protected against immersion effects ≤1 m
7	Explosionproof, contains internal gas ignitions		
12	Dust-tight and Drip-proof	54	Dust-tight, Protected against splashing water
13	Oil-tight and Dust-tight. Constructed with gaskets to resist oil and liquid chemicals	54	Dust-tight, Protected against splashing water
NOTE: Used this table to determine IP rated enclosures that meet NEMA enclosure designations			

Further, refinery environments are corrosive due to the materials being processed and their frequent proximity to marine waters. Sulfur recovery, and hydrofluoric alkylation units as well as cooling towers are especially corrosive.

Outdoor equipment should be able to withstand an ISO 9223 C4 environment. In C4 mild, untreated steel loses up to 650 g/m³ per year. This is equivalent to an ISA 71.04 G3 environment.

NEMA 4X is suitable for corrosive locations. There is no similar IEC rating, so construction material needs to be specified. See NEMA 250 section 3.5.2 for further information on allowed enclosure materials.

An IP 65, IP66 or IP67 enclosure is considered corrosion resistant if it is fabricated Type 304 or 316 stainless steel. It is also considered corrosion resistant if it passes NEMA 250 Section 5.10, ASTM B117 or Test Kb in IEC 60068-2-52 testing for 200 hours without showing pitting, cracking, or other deterioration that is more severe than a similar test on passivated ASTM A240 314SS (UNS S30400) plate.

Besides NEMA 4 other enclosure types exists. See Table 23. A NEMA 12 or IP52 junction box design is suitable for indoor use. NEMA 1 or IP20 enclosures or better are used as system cabinets. NEMA Type 12 enclosures are not suitable for outdoor use but can be modified to meet Type 3 outdoor requirements with the addition of a drip shield. Enclosures carrying both a NEMA 3 and 12 rating superior to those carrying just a NEMA 3 rating.

The NEMA 250 specification covers the construction of the entire enclosure while IEC 60529 just addresses ingress protection. The following is covered by NEMA 250:

a. Mechanical impact
b. Gasket aging
c. Material finish
d. Latching
e. Flammability
f. Ventilation

g. Mounting
h. Grounding

7.4.2 Enclosures Materials

Corrosion resistant enclosures can be polyurethane painted, galvanized, or aluminized carbon steel; painted, galvanized, or aluminized cast iron; low copper aluminum (less than 0.4%); austenitic stainless steel; or acceptable polymeric materials.

7.4.2.1 Austenitic Stainless Steel

Austenitic stainless steel is the most used material in exterior locations. It is resistant to solvents, alkalis, and acids. When using stainless steel in a marine environment steps need to be taken to ensure that the Molybdenum content is ≥2.5 %. Standard 316SS (UNS S31600) can be between 2% and 3%. Instead, i316LM (W. Nr. 1.4404) or 317SS (UNS S31700) should be considered or PMI material certifications are obtained to ensure that the Molybdenum content is met.

7.4.2.2 Aluminum

Aluminum enclosures are also effective in outdoor environments and suitable for marine environments. Aluminum is lighter than other metals and is easy to fabricate. The aluminum should have 0.4% or less copper. For instance, 5052-H32 plate has less than 0.1% copper and welds without difficulty. Aluminum can be cast into transmitter housings and other small enclosures.

7.4.2.3 Polymeric Materials

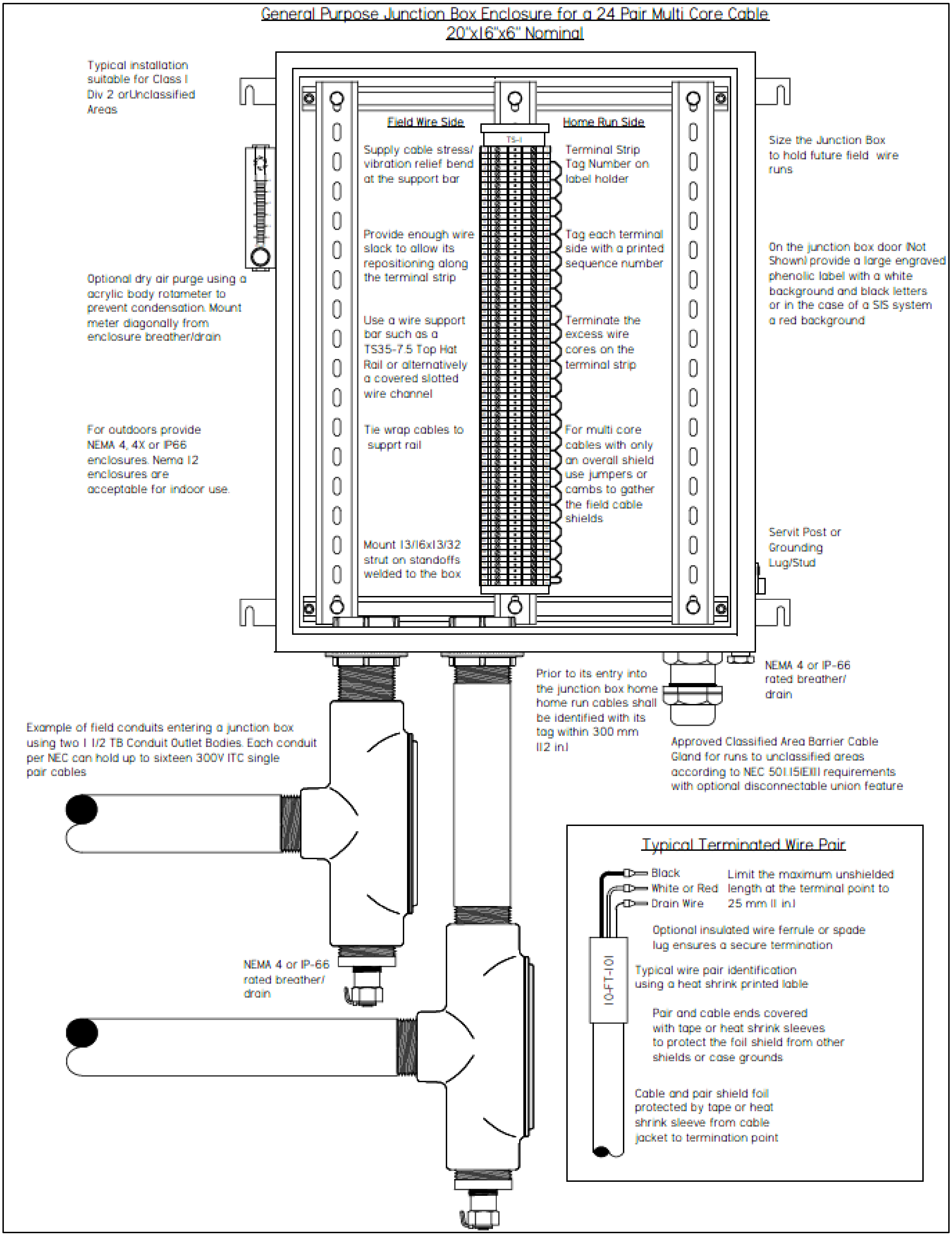
Polymeric boxes require ultraviolet resistance and long term strength. According to UL 746C, an acceptable polymeric material meets F1 tests for UV and water immersion, the 5VA flammability tests, and the impact test as well as the other requirements.

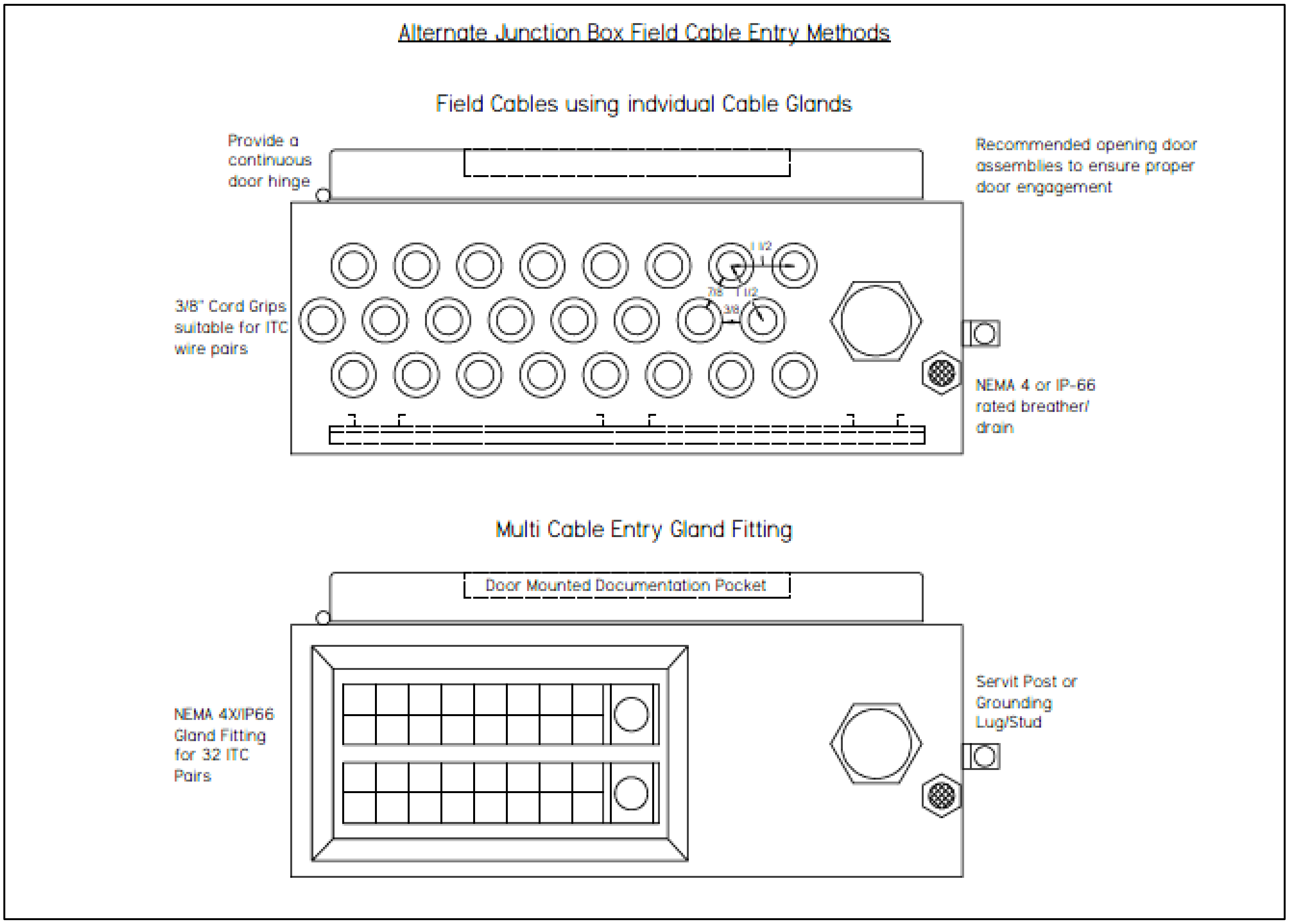
One limitation is that the distance between cutouts in polymeric boxes are less than an equivalent metal box. Also for EMI resistance, polymeric materials need conductive coatings or additives.

7.4.2.4 Enclosure Hardware

The material for the hardware; e.g. hinges, fasteners, and the like, can be the same material or a comparable one. Stainless steel hardware is usually the most effective, but thread galling should be considered. Using a molybdenum disulfide lubricant can be necessary.

Figure 14
Typical Junction Box





7.4.3 Content Protection

In highly corrosive or tropical environments techniques to protect the contents; such as air purges or tropicalization can be necessary. Also, cooling towers, regardless of geographical latitude, and marine loading facilities are prone to environmental issues.

The goal is to reduce the formation of fungus and prevent oxide and sulfide coatings forming on a switch or the electrical connections; e.g. a terminal or a conductor. Keeping humidity under control reduces the impact of both fungus and surface corrosion.

7.4.3.1 Environmental Purges

Environmental purges are an effective technique to protect equipment. NEMA 4 or IP66 enclosures should be used to obtain the necessary tightness. To limit the air consumption the penetrations and door seams of the enclosures should be equipped with oil resistant, neoprene gaskets.

To set the flow rate, the purge connection should have a rotameter with needle valve. A standard, single door junction box would have an air consumption of about 1.0 SCFM. Depending on the size, panels can need a flowmeter with a 0-10 SCFM range. Exact ranges have to be determined by testing.

Also, for safety the enclosure requires a pressure relieving breather. A few inches of pressure can slam open a door with the force of several hundred pounds. If the enclosure is being purged to meet an electrical hazardous location, then a purge kit with an alarm should be supplied according to NFPA 496 requirements. See section 12.12 for electrical hazard reduction purges.

In extreme cases where dry air is not available; e.g. a jetty, a miniature heatless air drier that delivers less than one SCFM can be used. A small oilless air compressor can be needed to supply the compressed air. Heatless dryers do not create condensate so wet surfaces are not a problem.

Using nitrogen for a purge is not recommended due to the possibility of oxygen deprivation. Unconsciousness can occur within seconds.

7.4.3.2 Space Heaters, Air Conditioners and Dehumidifiers

Besides air purges, electric space heaters using a humidistat, or a differential temperature controller is an acceptable solution for moisture control if the location classification is met. The surface temperature should be less than 80% permitted by the area T code at 120% of the applied voltage. The latter requirement can be deleted if a temperature controller is provided.

For larger enclosures, a circulating fan can be necessary to ensure even distribution of warm air. Another method for ensuring a uniform temperature would be to use several smaller heaters and place them throughout the enclosure.

Class I, Division 2 thermoelectric coolers are available to reduce enclosure temperatures. Temperature control should be used to prevent external surface condensation.

Unless a connection to a storm water sewer is supplied, air conditioners and dehumidifiers are not recommended for humidity control. The condensed water promotes algae formation on pavement which becomes a slip hazard.

Polymer electrolysis dehumidifiers have been developed for small enclosures; e.g. CCTV cameras. They exhaust the water as molecules of hydrogen and oxygen. Care should be taken to ensure that these gases do not accumulate inside the enclosure.

Table 23
NEMA Enclosure Selection

	Outdoor Use									
Protection Provided	3	3R	3S	3X	3RX	3SX	4	4X	6	6P
Contact with the enclosed equipment	●	●	●	●	●	●	●	●	●	●
Rain, snow, and sleet	●	●	●	●	●	●	●	●	●	●
Sleet	—	—	●	—	—	●	—	—	—	—
Windblown dust	●	—	●	●	—	●	●	●	●	●
Hose down	—	—	—	—	—	—	●	●	●	●
Corrosive agents	—	—	—	●	●	●	—	●	—	●
Temporary submersion	—	—	—	—	—	—	—	—	●	●
Prolonged submersion	—	—	—	—	—	—	—	—	—	●

	Indoor Use									
Protection Provided	1	2	4	4X	5	6	6P	12	12K	13
Contact with the enclosed equipment	●	●	●	●	●	●	●	●	●	●
Falling dirt	●	●	●	●	●	●	●	●	●	●
Falling liquids and light splashing	—	●	●	●	●	●	●	●	●	●
Circulating dust, lint, fibers, flyings	—	—	●	●	—	●	●	●	●	●
Settling airborne dust, lint, fibers, flyings	—	—	●	●	●	●	●	●	●	●
Hose down and splashing water	—	—	●	●	—	●	●	—	—	—

Protection Provided	Indoor Use									
	1	2	4	4X	5	6	6P	12	12K	13
Oil and coolant seepage	—	—	—	—	—	—	—	●	●	●
Oil or coolant spraying and splashing	—	—	—	—	—	—	—	—	—	●
Corrosive agents	—	—	—	●	—	—	●	—	—	—
Temporary submersion	—	—	—	—	—	●	●	—	—	—
Prolonged submersion	—	—	—	—	—	—	●	—	—	—

7.4.3.3 Contact Lubricants

Contact lubricants such as dialectic grease, like those used in vehicles, supply protection for electrical connections and switches. Fluoroether grease is an example but there are several compounds that have been formulated specifically for contact materials, current loads, etc. These lubricants also protect against contact fretting, which is metal transfer and wear.

Volatile corrosion inhibitors are not recommended with electronic equipment or other devices that have solder or lead. They have a limited life that is suitable only for the construction phase. Instead a conformal coating can be used which is a permanent finish that protects the components.

7.4.3.4 Sun Shields

Consideration should be given to sunshades in deserts and other locations where temperature and solar radiation combine to heat the enclosure interior above the long term operating limits of the device. This occurs in Australia, the Arabian Peninsula and Africa as well as many areas within a 15° from the equator.

Temperature rise of 30°F is possible from solar effects alone. When designing a sunshade for a large enclosure the shade orientation compared to the sun should be considered. The peak temperature inside an enclosure occurs at 2:00 PM. So, the shade width should be such that the lower portion of the enclosure should be shaded between 10 AM to 6 PM. The enclosure surface should be reflective even under a shade since the underside of the shade reradiates solar energy.

7.4.4 Terminal and Outlet Boxes

GUA type outlet boxes provide a convenient means for making a few terminations or mounting small transducers. They are small enough that they can be mounted in-line with the conduit. Their openings range in size from 3¾ inches to 5¾ inches. It can be ordered with threaded connections on any of the four sides and the bottom. They are rated for Class I, Division 1, Group B,C,D and Class II, Division 1, Groups E,F,D locations as well as being NEMA 4 enclosures.

For instance, for making thermocouple terminations a DIN B format transducer with a diameter of 44.5mm fits inside a standard round thermocouple head or a GUA conduit outlet box. By adding a small terminal strip, they are also used for terminating devices that have potted leads like limit switches and solenoid valves.

Figure 15
GUA Outlet Box

7.4.5 Junction Boxes

7.4.5.1 Junction Box Use

Wire pairs take signals from instruments to a junction box. Junction boxes are used to gather and connect cables. Junction boxes allow identification and the interconnection of wires as well as permitting conductor testing and repair. The signals leave the junction box and run to the rack room using a multi-pair cable.

7.4.5.2 Junction Box Selection

The following factors should be considered in junction box application:

a. Location indoor or outdoor
b. Electrical classification
c. Terminal type, gauge size and marking
d. Nameplates and labels
e. Environmental corrosion
f. Moisture, humidity and splashing liquids
g. Enclosure size [1]
h. Insect, rodent, and general vermin protection
i. Box mounting
j. Access requirements
k. Number, type, and location of doors
l. Door hardware
    i. Butt or continuous hinge
    ii. Fast opening or screw down clamps
    iii. Key locks, hasps
    iv. Gasket material
m. Gland and cover plates
n. Gland fittings, cable transition frame
o. Door pockets
p. Sub panels, internal brackets
q. Grounding connection and door strap

r. Drain, purge connections
s. Fire and blast protection

Note1: Allow enough terminals to terminate the wires, including the shields as well as 20% spare terminals. The enclosure size should be based on the number of terminal strips; the wire space around the terminal strips plus the side or bottom area needed for the entry of cable or conduit.

7.4.5.3 Junction Box Mounting

Junction boxes should be mounted at an accessible height with the top mount six feet (1.8 meters) above grade.

Low point conduit drain fittings should be supplied and for exposed cable supply drip loops should be used prior to the enclosure. Bottom entry is recommended with side entry acceptable. To reduce leak possibilities entry through the top is discouraged.

7.4.5.4 Drainage

If an enclosure is likely to trap liquid or condensed moisture, a drain fitting should be supplied. Combination breathers/drains are recommended. Drains, with screens to discourage insects, to eliminate water accumulation are recommended.

7.4.6 Local Panels

The panels should be fabricated and wired to meet the requirements of NFPA 79 or IEC 60204-1. Outdoors panels should use NEMA 4X or corrosion resistant IP-65 enclosures. Panels and cabinets inside environmentally controlled areas can be NEMA 1 or IP-10 enclosures. Electronic indicators, controllers and auxiliary devices mounted in racks or panels should operate using a 4-20 mA signal or a standard digital communication signal.

7.4.6.1 Electrical Hazardous Locations

Most panels can be fabricated to meet Class I, Division 2 requirements without needing a hazard location reduction purge. Handswitches, circuit breakers, annunciators, power supplies and the like are available that make hazardous location purging unnecessary.

Redundant power supplies are available with a T4 code which is suitable for normal ignition hazards. Additionally, battery backup options are available.

Unprotected contacts; such as used by a boiler flame scanners can use NAMUR relays. Using an intrinsically safe NAMUR switch module with an integral hermetically sealed contact that are suitable for Class I, Division 2 allows using ordinary non-rated contacts in a hazardous location. See section 12.7.2 for addition information.

When an instrument enclosures cannot meet the electrical area classification then they shall be purged according to IEC 60079-15 or NFPA 496. Otherwise for environmental protection outdoor panels can be provided with an air purge and a relief device.

7.4.6.2 Environmental Protection

Field panels containing relays or electronic devices should be equipped with rain shields large enough to protect personnel using and maintaining the panel. The panels should also be designed to protect the internal equipment from ambient conditions including any solar gain. The maximum enclosure interior temperature should be calculated, and steps taken to ensure that the maximum operating temperature for the devices is not exceeded. Continuous temperature monitoring of the panel interior is recommended

In extreme cases a Class I, Division 2 thermoelectric cooler can be used to protect the contents. See section 0 for additional information of content protection of enclosures.

7.4.6.3 Panel Wiring

Wire, including shields, should land on terminal blocks. The wires and terminals should have markers that are labeled according to the termination drawings and schematics.

Cabinet and panel wires should be routed inside covered channels. The terminals and channels should be segregated according to signal type.

7.4.6.4 Local Panel Alarming

Local alarms which use hardwired logic or non-networked proprietary embedded controllers should have voltage free, isolated SPDT (Form C) contacts for the common trouble alarms and other statuses sent to the plant control system.

A backlit engraved annunciator can provide visual and audible alerts for critical process conditions or the occurrence of unacceptable hazards. The annunciator should have laminated windows engraved with Medium Helvetica or similar sans-serif font that is at least 5 mm (3/16 in.) high. The service description should be according to section 7.5.4 requirements. The bulbs should be bright enough to light the windows to be seen from fifty feet. Some bulb configurations are not bright enough at this distance, especially red colored windows.

Outputs from a logic system can be used to operate the annunciator and these outputs should open to alarm. Outputs from annunciator cards should not be used as an input to logic processors.

Annunciator sequences should be according to ISA 18.1 requirements. The normal annunciator sequence can be an ISA Sequence A. Alarm systems associated with equipment shutdowns can use a “First Out” sequence F3A-3 to indicate the triggering event.

7.4.6.5 Local Panel HMI’s

Class I, Division 2 HMI with touch screen can be provided to assist in startup and provide diagnostic information such as the readouts from API Std 670 machinery monitors and annunciators. Key controls such as manual equipment trips should be independently wired to the appropriate protection system.

The display should have an IP65 enclosure rating. Solid state hard drives should be provided. Convection cooling is recommended.

To be readable in sunlight conditions the screen should have a brightness of 1000 nits, and 200:1 contrast ratio or better. A display with a 700 nits screen brightness can be read when shaded from direct sun light with a hood. The screen surface should be solvent and UV resistant.

7.4.7 System Cabinets

The de facto standard for system cabinets is the 800mm by 800mm footprint. For access, it is recommended that both sides be equipped with half width doors. 400mm doors enables personnel passage even with minimum width aisles.

System cabinets should be equipped with fans and dust filters. Fans remove heat that can otherwise shorten equipment life. Over time dust has been known to create high resistance shorts or overheating.

The cable penetrations should have seals so that tramp air does not bypass the filters and bring in dust. Modular multi-hole transition fittings offer the advantage that cables with pre-terminated connectors can pass through the opening prior to installing the cable seals.

For best EMI noise reduction, it is recommended that the cable enter the cabinet through a common gland plate. The control system metal racks should be RF grounded for noise resistance. Segregation systems by cabinet is a beneficial EMC practice. This prevents EMI cross contamination besides preventing maintenance on the wrong hardware. For these reasons as well as avoiding the spread of fire, common baying of the cabinets should be avoided.

7.4.8 Cabinet Colors and Lighting

Rack room cabinets typically are RAL 7035, light gray inside and out. A RAL 9016 glossy white enamel is often used for custom enclosure interiors. This improves visibility within the box by illuminating the contents. Also Junction boxes and other outdoor enclosures are light colors or are bare metal such as stainless steel or aluminum. This reduces solar gain and keeps the contents cool.

Ideally, the rack room's lighting is adequate to illuminate the cabinet interior. In outdoor locations or rooms with minimal light the addition of LED cabinet lighting strips should be considered.

LED lights have a long life, are bright, are compact and are damage resistant. A lighting level of 320-500 lux with a color temperature of 4000K or higher should be provided. Positioning the strips down the sides ensure that the light reaches all corners.

7.4.9 Marshalling

Signal conductors can be connected directly to the system terminals or on an intermediate terminal strip. The system terminals can be incorporated in the electronic chassis or be on an intermediate termination assembly which then connects to the system with prefabricated cables.

The following are locations for marshalling the cables from the field junction boxes:

a. Control System Cabinets
b. Rack Room Marshalling Cabinets
c. Remote I/O System Cabinets

Marshalling cabinets can achieve the following:

a. Allows for cross wiring; where the field signals are re-arranged with jumpers to match the control system terminals.
b. Independent fuses and disconnects can be supplied.
c. Supplies a location for intrinsically safe apparatus, surge barriers, isolators, and other signal conditioners.
d. Shield pigtails can be kept short and segregated. See section 8.4.2.2 for details.
e. Protects the system electronics during construction and commissioning.

A common method to attach the signals is to use intermediate terminal strips mounted in mounted in the marshalling cabinet. Individual jumpers are used to connect to the control system terminals. This simplifies the field connections because they can be land in wire pair order, which mirrors the connections in the field junction box. Prewiring the jumpers offers further efficiency.

The problem with using jumper wire is that two more terminations are needed as opposed to landing directly on the system I/O point. This increases the failure possibilities and needs more space and hardware.

Electronic marshalling eliminates intermediate terminal strips and jumpers. The field signals still land in the same order as the home run cable from the junction box. Instead the jumpering is done electronically and the signal selection is done either electronically or with single channel pluggable modules.

This has been found to be more efficient than conventional cross wiring since wiring changes can be accommodated programmatically. There are limitations on the quantity of I/O that can be bussed together, but it can easily manage the equivalent of fifteen junction boxes each with twenty signals. For less common signals, electronic configuration is not practical, while pluggable modules can be tailored to any signal.

An advantage of using electronic marshalling is that enclosure can be released for to the site prior to completing the system design.

7.4.10 Field Mounted I/O Cabinets

Remote I/O cabinets can be used to eliminate home run cables and reduce the need for electrical trays.

The following benefits are possible remote I/O cabinets:

a. Elimination of multi-conductor home run cable
b. Decrease of cable tray in pipe racks
    i. Smaller pipe racks
    ii. Foundation reduction
c. Elimination of junction boxes
    i. Boxes and related terminals not needed
    ii. Ten to twenty cubic feet of space recovered
d. Redundant communications
e. Less EMI noise picked up due to shorter cable runs

Below is a list of issues to be faced with remote I/O:

a. Longer conduit runs
b. A larger box replaces several junction boxes with twenty to thirty cubic feet needed
c. Power distribution and backup
d. Heat and humidity management
e. Maintenance in electrically hazardous locations

Remote field cabinets can also be used to contain controllers and similar equipment. This practice allows the expansion of control systems without having to enlarge existing buildings.

7.5 Tagging and Nameplates

7.5.1 Instrument Label Fabrication and Attachment

An instrument should be labeled with the full ANSI/ISA 5.1 tag number including applicable unit prefixes. To avoid wind flutter, the field instruments at the time of shipment the tag should be permanently banded with an austenitic stainless steel tag with a thickness that is ≥ 0.5mm (20 Gauge.)

The tag should be uniformly and deeply stamped, engraved, or etched to a minimum depth of 0.02 mm (0.008 in.) with 3 mm (⅛ in.) high letters using Medium Helvetica or a similar sans-serif font.

The tag should be attached to the instrument with either 18 AWG (1 mm^2) UNS N04400 (Monel®) tie wire, austenitic stainless steel screws, austenitic stainless steel cable ties or similar banding.

7.5.2 Nameplate Fabrication

Junction boxes, disconnect switches, bulkhead plates, and blind enclosures should be provided with nameplates that show their device code.

Laminated nameplates for outdoor services should be fabricated from UV resistant HPDE or PMMA marine-grade plastic; such as UVA acrylic. Nameplates should be attached with two austenitic stainless steel drive screws. The nameplate lettering should be engraved using Medium Helvetica or a similar sans-serif font.

Panel instruments and pneumatic penetrations should have laminated nameplates with a white background and black letters at least with 5 mm (3/16 in.) high engraved black letters high showing the instrument tag number and service description.

Panels, junction boxes and blind enclosures should be provided with a laminated nameplate with 25 mm (1 in.) high letters. ISA 60.6 Appendix A should be used to determine letter heights for viewing distances greater than 500 mm (20 in.)

7.5.3 Nameplate Color Codes

Nameplates using black backgrounds are not acceptable. Nameplate colors should be as follows:

General Purpose:	White with Black lettering
Fire & Gas Systems:	Red with White lettering [1]
Process Emergency Systems:	White with Red lettering [1]

Note 1: Codes tend to restrict the use of red nameplates and signage to fire alarms and manual alarm initiating devices; such as pull stations.

7.5.4 Nameplate Service Descriptions

The nameplates should fully describe their service. This should include the following:

a. The tag number of the point
b. The number and name of the equipment being controlled
c. The variable, its general location and purpose
d. Further, hand switches and pushbuttons should have their positions or action described; e.g. “Normal-Bypass.” Rotary hand switches should indicate spring return action with a (M) e.g. “Normal-Reset(M)” The state descriptor use should be consistent and kept to the smallest practical set of words.
e. Scale factors should be provided for meters and recorders when appropriate.

Items “a” through “c” should preferably be on separate lines according to the example below. When applicable either Item d or e should occupy the last line. For hand switches and push buttons the last line can be inscribed on a legend plate that is integral to the switch.

Example Nameplate

a	1-HS-12001
b	P-1201 HYDRAULIC PUMP A
c	HIGH PRESS S/D XMTR #1 ALARM
d	NORMAL RESET(M)

Index service descriptions and control system descriptions should be a combination of Item b and c.

Abbreviations should be used only when an inadequate description results due to space limitations. The following are sources of recognized abbreviations:

a. Plant Standards
b. P&ID Legend Sheets
c. ISA 60.6 Appendix B
d. ANSI/ISA 5.1 Table 5.2.2
e. ANSI/ISA 5.1 Section A.14.2
f. PIP PIC001 Table A3
g. PIP PIC001 Table A1
h. NFPA 79 Table E
i. PIP PNC00002
j. ASME Y14.38

7.6 Shock and Vibration

The hardware and material should be mechanically robust and should be able to withstand shock and vibration. Below are some typical requirements:

Evaluated for shock resistance according to IEC 60068-2-27 with the following conditions:

a. Six shocks in each direction along three mutually perpendicular axes for a total of 36 shocks
b. Pulse shape: half-sine
c. Peak acceleration: 15 gn
d. Duration of the pulse: 11 ms

Evaluated for vibration resistance according to IEC 60068-2-6 with the following conditions, along three mutually perpendicular axes:

a. Frequency range: 10 Hz to 55 Hz
b. Amplitude: 0.5 mm
c. Sweep cycle duration: 5 min
d. Duration at resonant frequency or at 55 Hz: 30 min in the three axes for 90 min in total

8 ELECTRICAL SIGNAL INSTALLATION

This section describes the practices used for wired instrument signals and digital communications. Wire communications require installation practices that avoid distortion and attenuation. Factors include regulatory codes, equipment requirements, and the environment which the wires pass through.

Electrical workmanship is further described in NECA 1. Also see the technical bulletins from the Cable Tray Institute.

8.1 Wire and Cable Selection

8.1.1 Cable Types

8.1.1.1 Electronic Cables

Table 24 lists the cable types used with for standard measurement and control systems.

Table 24
Wire and Cable Types

Type	Description
I	Untwisted copper wire single conductors, 600V, TFFN [1]
II	Unshielded, twisted copper wire, 300V, AWM UL Style 1007 [1]
III	Shielded, twisted copper wire, 300V, ITC-ER [2]
IV	Multiconductor unshielded, twisted copper wire, 300V, ITC-ER [2]
V	Multiconductor Type II wire with an overall shielded, 300V, ITC-ER [2]
VI	Multiconductor Type III wire with an overall shielded cable, 300V, ITC-ER [2]
Note 1: Non-tray rated conductors, use with enclosed raceway only Note 2: PLTC can only be used with list power sources. ITC tray cable is required for the non-listed power sources that process instruments use. The exposed run or ER designation allows it to be installed outside of trays if it is continuously supported and protected from damage using dedicated protection such as struts, structural angles, or channels. It is secured at intervals not exceeding 1.8 m (6 ft).	

8.1.1.2 High Temperature Cables

NEMA HP 100, High Temperature Instrumentation and Control Cables offer an extended temperature operating range. See Table 29.

8.1.1.3 Serial Data Cables

Serial data cables have higher performance requirements than analog wire. Specifications such as allowable capacitance, Impedance, shielding, and other characteristics are important.

Impedance (Ohms) is the resistance that the cable presents to the electrical current passing through it. At low frequencies, the impedance is a function of the conductor size, but at higher frequencies, conductor size, insulation material and insulation thickness also affect the cable's impedance. Matching impedance is important. If the system is designed for 100 Ohms, then the cable should match that, otherwise error-producing reflections are created by the mismatch.

Attenuation is a ratio comparing power input to output. It is measured in decibels per unit length (db/ft) and is a measurement of the signal loss along the cable. Attenuation is dependent on signal frequency. A cable that works well with low frequencies can perform inadequately at higher data rates.

Shielding is part of the cable construction. For example, the cable can be unshielded, have shielded pairs, have an overall aluminum/mylar tape and drain wire or a double shield.

Shielding effectiveness is complex and depends on the data frequency within the cable and the shield design. A shield can be effective in one frequency range, but at a different frequency another design can be needed. See section 8.1.4.5 for further information.

Capacitance in cable is measured in picofarads per foot (pf/ft). It shows how much electrical charge the cable can store. If a voltage signal is being transmitted on a twisted pair or coaxial cable, the wire insulation becomes charged by the circuit voltage. Since it takes time for a cable to reach its charged level, the signal being transmitted is slowed down.

Digital data pulses are a string of square waves with near-vertical rise and fall transitions. A cable with a high capacitance distorts these transitions so that they become saw-teeth, which the signal circuitry cannot process. The lower the cable capacitance, the better the performance at higher frequencies.

A PLTC shielded twisted pair (STP) Cat 6 cable tends to be the best choice for most industrial serial communications. Its EMI resistance, low capacitance, 14 pF/Ft and 100 Ω input impedance allows data transmission up to 250 MHz with attention of 32.1 dB/100m. See Table 25 for common cables used in data transmission. See TIA-1005-A and IEC 61918 to determine the cable characteristics necessary for the area IEC 29106 M.I.C.E. electrical noise rating.

For shielded cables with bi-directional signals where the device at the ends of the cable are mirror images, the shield should be grounded at both ends.

8.1.1.4 Coaxial Cables

Coaxial cables have conductor centered inside a shield separated by a dielectric material with a jacket covering the shield. They were developed to transmitter radio signals in the 1930's. The center conductor is typically solid copper. The copper conductor can be bare, tinned or silver coated. The conductor is typically 18 to 22 AWG. The dielectric is typically made from polyethylene or fluoropolymer. It can be either a solid or a foam dielectric.

Coaxial cable is useful for signals above 300 kHz. Upper limits on frequency are in the range of a few-hundred megahertz where cable losses become the limiting factor.

Since the two signal conductors have the same axis, the magnetic flux created externally to the cable by the signal current is zero and similarly the net voltage induced in each conductor due to an external magnetic field is zero.

Table 25
Typical Data Cables

Protocol	Cable Construction	Shield DC Resistance ohms/km	Shield and Percent Coverage	Operating Frequency Kb/s
Modbus RTU	RS-485 Half Duplex, Twisted Pair, 100-120 Ω/ft and ≤16 pF/ft [1]	11	Individual twisted pair, Aluminum foil 100%, tinned copper braid 100%	10 to 100
PROFIBUS DP		<15		9.6 to 12,000
DeviceNet	Signal pair plus power pair, like RS-485	6 to 11		125 to 500
ASi	Twisted pair, PVC PLTC/ITC	N/A	Not Needed	167

Protocol	Cable Construction	Shield DC Resistance ohms/km	Shield and Percent Coverage	Operating Frequency Kb/s
PROFIBUS PA	FF-884 Type A with data and power on the pair	<51	Individual pair 100% Al foil	31.25
FF Fieldbus				
ControlNet	RG-6 Coax	12 to 14	Quad Shield (Al foil/Al foil/braid)	500
Note 1: For long distance transmission a third wire can be necessary. See Section 4.2.1				

At low frequencies coaxial cables do not supply the best EMI suppression because the return current uses the same conductor; i.e. the shield, as the noise currents. The frequency below which a shield offers no useful attenuation is the cable cutoff frequency.

Cutoff frequencies for coaxial cables range from 0.5kHz to 10kHz. This range is related to the cable length as well as its construction. For example, a short coaxial cable with heavy-wall copper shielding works at a lower frequency than a longer one with thin-wall shielding.

As the frequency increases above the cutoff frequency, the shield offers increasing noise attenuation. The improvement results from the reduction in loop area caused by current returning on the shield. The inner-surface of the shield, is a conductor for the signal. It supplies an EMI path on its outer surface by taking advantage of skin-effects to keep the signal and EMI current separate in the shield's cross-section.

So, at higher frequencies, a coaxial cable begins to look like triaxial cable when the skin depths on the inner and outer surface of the shield do not overlap and the signal current flows exclusively on the inner surface of the cable's shield. This is the ideal operation point for coaxial cable.

The shield is usually a woven metallic braid or wrapped foil shield. Woven braid shields are normally copper. Foil shields are often aluminized mylar. For more effective shielding, combinations of a braid shield over a foil shield or a second braid shield are used. Some trunks or broadband network coaxial cables have solid aluminum shields.

There are many jackets available with PVC being the most common, but polyethylene, CPE, and fluoropolymers are used as well. According to MIL-C-17T the PVC jacket should be a non-contaminating Type II material.

Coaxial cable nominal impedance can vary with 50 Ω, 75 Ω, and 95 Ω being the most common. Frequency specific coaxial cables are used for wireless, satellite, and mobile phone RTU's.

The Mil-C-17 specification broadly defines the coaxial cable types and has replaced the old RG based system. The RG number designations are still popular, so manufacturers use both; e.g. M17/2-RG6 or M17/15-RG11.

The RG system is core size specific which determines the connector size. ANSI/SCTE 74 is a widely used fabrication specification for Series 59, 6, 7 and 11 cables. While TIA-568-C.1 and TIA-568-C.4 cover the installation and testing of coaxial cables. NEMA WC 63.2 is used for Ethernet cables.

RG6 and RG11, which are 75 Ω cables are used for most services with the larger 10.3mm RG11 used for trunk services. RG59 is still used with CCTV systems. Some computer networks use 50 Ω Ethernet cables but these have been mostly replaced with fiber optic cable or UTP low capacitance cable.

For coaxial shielding to be effective, the shield should be properly terminated, and the conductor should be centered. the braid should be soldered, or connector terminated so that it completely and symmetrically encloses the inner conductor with a minimum impedance change.

Pigtail terminations function as an antenna which can radiate and receive EMI. Also, asymmetrical cable termination causes an impedance bump, which generate signal reflections. Standing wave resonance can lead to dielectric failures with some higher power circuits.

Coaxial cables were used extensively in control networks, but they are mostly legacy technology. Overall, for networking and control systems, coaxial cables are being replaced with fiber optic cables and low capacitance twisted pair cables. They are still used for CCTV systems, and security systems.

8.1.1.5 MI Cables

MI cable is an assembly of conductors in compressed mineral insulation enclosed in a metal sheath. The sheath is seamless, liquid and gas tight made from drawn copper, stainless steel, or Alloy 825.

Due to its construction, it has the intrinsic ability to block gases, vapors, and liquids. With the proper fitting MI cable can withstand 2000 psig and can be used as a secondary process seal. MI cable withstands high temperatures so it is used for thermocouple sheathes and can be used in critical services due to its flame resistance.

It is approved for installation in Class I, Division 1 and Division 2, and Zone 1 and Zone 2 hazardous locations without the use of conduit and conduit seals. For installation in a hazardous location an approved fitting is needed for the cable ends.

The cable can be bent around obstacles, but a minimum bend radius has to be maintained. MI is not suitable for vibrating services. Expansion loops should be provided, and long unsupported lengths avoided.

MI cable is hygroscopic, and moisture is a short circuits the exposed ends. The MI cable has to be protected from moisture until it has been terminated. Sealing the end fittings as soon as possible is imperative in preventing moisture accumulation. Otherwise, it should be kept in a heated enclosure until properly terminated. Sometimes, the moisture can be driven off by heating the cable according to the supplier's instructions.

A pinhole in the copper sheathing can allow moisture into the insulation leading to eventual failure of the circuit. A PVC jacket or sheaths of other metals such as Alloy 825 can be used if chemical damage is possible.

Termination can be labor intensive. It is best to use a factory supplied termination. Otherwise, it requires stripping back the copper sheath and attaching a gland fitting. The conductors are insulated with plastic sleeves. Insulating putty or epoxy resin is then poured into the gland fitting to provide a watertight seal.

The assembly should be checked with 500 V mega-ohm meter to ensure that moisture has not compromised it. Typically, readings are made prior to start-up at 25 mega-ohms or higher.

8.1.2 Wire Type

Although a pair of untwisted, unshielded, stranded copper wires (Type I) can be used to interconnect most instruments, it is not recommended due to EMI noise.

Single, unshielded, twisted-pair wires(Type II) is used in control system cabinets to save space. The RFI noise is screened out by the metal enclosures.

Shielded, twisted Type III pairs are recommended for analog and low power discrete signals. It is the most common type for outdoor services. Due to electrostatic coupling, shielded Types III, V, or VI should be used.

Table 26
Standard PIP Instrument Cables

PIP Type[1]	Table 24	Description
SPISCO	III	Single pair instrument signal cable (16 AWG minimum) with overall shield
SPTECO	III	Single pair thermocouple cable (16 AWG minimum) with overall shield
STISCO	III	Single triad instrument signal cable (16 AWG minimum) with overall shield
MPISCO	V	Multi-pair instrument signal cable (20 AWG minimum) with overall shield
MPTECI	VI	Multi-pair thermocouple cable (20 AWG minimum) with individual and overall shields
MPISCI	VI	Multi-pair instrument signal cable (20 AWG minimum) with individual and overall shields
MTISCO	V	Multi-triad instrument signal cable (20 AWG minimum) with overall shield
MTISCI	VI	Multi-triad instrument signal cable (20 AWG minimum) with individual and overall shields
Note 1: See ELSWC05 “300-Volt Instrumentation Tray Cable Specification” for specifics on PIP cable requirements.		

8.1.3 Applications

8.1.3.1 Instrument Power

For an externally power instrument a 24 VDC power source should be selected over an AC source if the device can be powered through a standard multi-pair instrument cable. This is typically seven watts at 200 meters (650 ft.) Otherwise, it should be fed from an AC field power panel.

8.1.3.2 Voltage Signals

Voltage signals should not be used for long-distance transmission due to susceptibility to voltage induced by electromagnetic interference. It is recommended that a thermocouple/mV transmitter be used in the field to convert the signal to 4-20 mA.

8.1.3.3 Non-Standard Signals

Electronic transmitters such as ultrasonic, magnetic, etc. flow transmitters, analyzer elements etc. have non-standard cables between the sensor and the transmitter electronics. In some instances, such as flame rods, the signal level can be in the Pico amp range. The installation and length of these cables should follow supplier’s recommendations. Since they are not tray, rated non-standard cables should not be used for long distances and require the use of an approved raceway or conduit. The transmitter should be mounted close to the device.

8.1.3.4 Thermocouples

For thermocouples, the extension lead wire should consist of shielded, twisted pairs. The extension wire should conform to ASTM E230 and IEC 60584-3 (ANSI MC96.1 has been withdrawn)

Grounded thermocouples should have no other grounded point than that at its tip. See API RP-551 for a discussion of grounded vs. ungrounded thermocouples.

8.1.3.5 Magnetic Probes

A magnetic reluctance pickup is a common speed pickup used with rotating machinery. The voltage output is a sine wave. Amplitude is a function of the frequency and the material being sensed. At the lowest frequency, the voltage can be few millivolts, typically, about 10 mV. As the frequency increases to 32 kHz the voltage increases to as much as 10 volts. When large diameter, multi-tooth gears are used except for the lower speeds these voltages can be detected for several hundred feet without amplification in standard twisted shield cables

8.1.3.6 Pulse Outputs

Unlike speed probes, two wire signals from turbine meters have a lower amplitude. This is due to the low magnetic permeability and speed use with turbine stainless steel blades. These signals can be susceptible to EMI when connected to high impedance inputs.

The supplier's recommendations concerning the pre-amplifier and the wire installation should be considered. Also, the supplier's recommendation should be consulted on the cable choice and recommended installations. See API 551 Section 6.5.5.2 concerning turbine meter pickup installation.

8.1.4 Wire and Cable Specification

Instrument cables are fabricated according to NEMA WC 57, UL 2250 and UL 1277 are most commonly used in North America. They are tray rated accord NEC to meet Class I Division 2 electrical area hazard classifications. In ATEX and IEC regulated areas, cables fabricated according to PAS BS 8308-2, EN 50288-7 and IEC 60227 requirements are typical.

Regardless of the fabrication specification chosen the cable should be rated for "Sunlight Resistance." These standards either do not mention this requirement or it is an option. In the case of exposed cables installed outdoors a Sunlight Resistance rating is mandatory.

It is best to standardize cables on one or two types per voltage and application. Otherwise, when many small quantities are used, mix-ups become common and the likelihood of running out a specific cable increases. For instance, a twenty-four pair PVC cable is the optimum size for area junction boxes and is the most available type in North America.

8.1.4.1 Wire Size

Twisted wire pairs are preferred for both analog and discrete signals. Normally, single twisted pair cable is 16 or 18 AWG and for multi-pair cables 18 or 20 AWG is employed. Power feeds less than seven watts should be 24 VDC that is feed from the same junction as the signals. Other larger wire gauges should be selected due to voltage drop with non-low power solenoid valves and other devices that use more than 300 mA.

The size recommended for 120VAC single conductors is stranded 14 AWG with THWN insulation according to UL 83 requirements. Three conductor 16 AWG cable with TFFN insulation is recommended to supply 120VAC to remote mounted instruments.

8.1.4.2 Number of Conductors

Instrument cables are stocked with a standard number of pairs or triads. One of the most common cables is an 18 AWG, twenty-four, shielded pair cable with an overall shield. It has 73 conductors including the overall shield drain. Common sizes are cables with six, twelve, eighteen, twenty-four and thirty-six pairs or triads. When the twenty percent reserved conductors are subtracted this works out to five, ten, fifteen, twenty and thirty pairs or triads available for use.

Thermocouple and signal cables often included an insulated 22 AWG communication wire for a sound power telephone to coordinate terminations and checkout.

Cables with individual conductors or control cables are used for services such as motor operated valves and motor control stations. With five conductor un-shield cable being among the most common.

8.1.4.3 Stranded Wire

Stranded wire is recommended due to its flexibility and resistance to breakage. Seven strand wire is standard. Nineteen strand wire can be used in panels and other locations for its increased flexibility. Thermocouple wire is normally a solid conductor.

8.1.4.4 Insulation and Jacket Materials

This section is written to provide guidance in the selection of jackets and insulation. It provides properties and characteristics of cable jackets. See IEEE 532 IEEE “Guide for Selecting and Testing Jackets for Power, Instrumentation, and Control Cables for further information.”

8.1.4.4.1 Insulation

Wire with 300V insulation is normally satisfactory for instrument signals. ITC cable (Instrument Tray Cable) is typically used fabricated according to NEMA WC 75 and UL-2250. The 300V ITC cable has a small cross-sectional area, so more cables can be used in a conduit or a cable tray. The area of a 300V cable is 71% of a 600V cable. This is about a third more cables in a conduit or cable tray.

However ITC cable cannot be installed in circuits operating more than 150 volts or more than 5 amperes. Also ITC cable cannot be installed with not power limited circuits such as power, lighting, Class 1 signal circuits. ITC has to be segregated from TC cable or other 600 volt and above wiring

It is common practice to have multiple ratings on cables so that one cable specification can be used in many situations. For instance, ITC instrument cable is rated PLTC as well. However, PLTC and ITC circuits cannot be run together in that same raceway or tray. However, this would be an unusual circumstance since ITC wiring practices can encompass certified and uncertified power limited devices if they are installed in an industrial establishment that use qualified maintenance personnel.

The use of ER rated cables can eliminate installing conduit between the tray and the electrical device. Cables with an ER rating can extend beyond 1.8 meters outside a tray if protected from damage with structural angle or similar material. It has to be supported every 1.8 meters (6 feet).

The NEC requires wires that are in the same raceway to have insulation rated for the highest voltage present. For example, if 480V is present as found in a motor starter compartment, 600V insulation is needed for instrument cables. Otherwise, a metal separation barrier or a liquidtight flexible conduit should be used.

When wire is run near hot surfaces; e.g. fired heaters, moisture resistant, elevated temperature insulation according to NEMA HP 100 requirements should be used. See Table 29. When away from the heat source, a junction box can be installed to allow the use of standard wire for the remaining distance.

8.1.4.4.2 Overall Jacket

The overall jacket material should be resistant to moisture, abrasion, flames, ultraviolet, and chemicals as well as being compatible with the environment. See Table 27 for typical material used for insulation and jackets.

When necessary, the cable should be impervious to termites and rodents. This issue is not limited to underground cables. The cable, a proven method, intended specifically for the pests being encountered, should be used.

Table 27
Cable Jackets and Insulators

Material	Temperature		Flexibility	Resistance to:					
	Max. (°C)	Min. (°C)		Abrasion	Acid	Base	Solvent	Moisture	Flame
PE	75	-62	Excellent	Good	Good	Good	Fair	Excellent	Poor
FR-EPR	105	-40	Excellent	Good	Good	Good	Fair	Excellent	Good
XLPE [1]	90	-62	Excellent	Good	Good	Good	Fair	Excellent	Good
PVC [1]	90	-10	Excellent	Good	Good	Good	Fair	Good	Good
Nylon [1]	125	-54	Good	Excellent	Poor	Good	Good	Fair	Poor
FEP	200	-166	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Aramid	250	-73	Good	Excellent	Excellent	Excellent	Excellent	Poor	Excellent
Glass	450	-73	Good	Poor	Excellent	Excellent	Excellent	Poor	Excellent
Note 1: Most commonly used jacket and insulator materials for cables									

PVC is not a good insulation for data transmission. It has a large capacitance with a high variability. The mutual capacitance it not controlled during its manufacture. Polyethylene cable, especially Cat 6, is better suited for data communication.

Table 28
Standard Cable Jacket Colors

Jacket	Purpose	Pair Colors
Black	General Purpose	Black/Red [1]
Light Blue	Intrinsically Safe	Black/Red [1]
Red	Fire and Gas	Black/Red
Purple	RS-485/Profibus DP	Green/Blue
Orange	MBP Fieldbus	Orange/Blue
Blue	IS MBP Fieldbus	Orange/Blue
Note 1: A red conductor is recommended as opposed to white. The colors white, grey, and green have specific designations according to the NEC and should be voltage free.		

8.1.4.4.3 Fire Resistant Jackets

Unless preventive measures are taken, cable going through buildings cannot bypass fire barriers. The NEC requires that indoor cables be resistant to the spread of fire and be self-extinguishing.

The NEC has four levels for rating fire resistance cables in buildings: Dwelling, General Purpose, Riser, and Plenum. The highest fire-resistant power-limited data cable is CMP which is the Plenum cable.

The NEC has tables for Power Limited Circuits, Fire Alarm, Fiber Optic, Communications, Antenna Systems, Broadband. The most fire-resistant fiber optic cables are OFNP and OFCP which are all-dielectric and conductive cables, respectively.

These cables contain flame retardants. Most retardants are halogens. In North America halogens are added to improve the fire resistant of insulation. Halogen-based flame retardants are effective in reducing insulation ignitability. Fluorine, chlorine, bromine, iodine, and astatine are halogens, however once burning they can create toxic gases.

Jurisdictions outside North America, primarily those governed by IEC type codes, have mandated that their cables be halogen free. Similarly, marine and offshore facilities also stress low smoke and toxicity in cable insulation. Controlling smoke density and toxicity is believed to be as important as preventing flame propagation so other flame retardants have to be used. As result these cables carry a LSZH designation.

The main difference between IEC 60332-1 versus UL 1581, UL 1666 and UL 910 is that the under the IEC cable can continue to burn while emitting very few gases. The UL specs require that cable self-extinguish the flame, but it still can emit toxic gases.

Locations that apply IEC codes or for maritime facilities, halogen free XLP cables are used rather than halogen based polyvinyl chloride (PVC) cables. On the other hand, being a halogen compound PVC has an inherently better flame retardance.

8.1.4.4.4 UV Resistance

The NEC requires that outdoor cables be UV or sunlight resistance. Adding 2% carbon black to a cable jacket is the most common method to make UV resistance. Other compounds are available which permit cable jacket colors other than black. The major advantage of carbon black is the stabilization effect does not decrease with time.

Below are standard tests for UV testing of cables. IEC specifications do not have the same emphasis on UV or sunlight resistance as the NEC. So, UL 1581 is the recommended procedure for UV testing.

8.1.4.4.5 Temperature Rating

The wire or cable insulation should have a temperature rating suitable for the lowest and highest expected temperature. It is recommended that 90°C be used at a minimum as the temperature specification. NEMA HP 100 insulation should be used in elevated temperature locations such as near furnaces.

Table 29
NEMA Instrument Cable Temperature Ratings

Insulation	Maximum [1] Temperature (°C)	Location
NEMA WC 57 Cables		
XLPE [2]	90	Wet

Insulation	Maximum [1] Temperature (°C)	Location
EP [2]	90	Wet
SR [2]	125	Dry
CSPE	90	Wet
PVC	75	Wet
PVC/Nylon	75/90	Wet/Dry
PE	75	Wet
SBR	60/75	Wet/Dry
TFE	75/90	Wet/Dry
FR-EPR/CPE	90	Wet/Dry
NEMA HP 100 Cables		
FEP Tin Plated	150	Dry
FEP Silver Coated	200	Dry
ETFE	150	Dry
XLPO	150	Dry
ECTFW	150	Dry
Note 1: These temperature ratings are for multi-conductor NEMA cables with an overall jacket. Individual UL conductors can have different ratings. See Table 33 Note 2: 125°C cable rated for dry locations also available.		

The lower cable temperature rating should be considered when selecting a jacket material. The jacket can have a cold bend test temperature of as low as -40 °C. When the temperature is below -10°C, it is recommended that the cable be installed with the supplier’s concurrence.

Table 30
UV Testing Specifications for Cables

Specification	**Description**
HD 605	“Electric cables - Additional test methods” (use Spec Section 2.4.20 and 2.4.23 for UV testing)
EN 50289-4-17	“UV Cable Testing” (Acceptable is ≤20% Elongation and ≤20% Tensile)
ISO 4892-2	“Plastics - Methods Of Exposure To Laboratory Light Sources - Part 2: Xenon-Arc Lamps”
UL 1581	“Standard for Safety Reference Standard for Electrical Wires, Cables, and Flexible Cords.” (Use Spec Section 1200 " Xenon-Arc Tests" for UV)

Table 31
Cable Armor Types

Armor Types	**Features**
Continuous Corrugated Welded Sheath	Continuously welded. Supplies a gas tight sheath with a solid metal wall. With an UL 2225 MC-HL listing can be used in Class I, Division I hazardous locations.

Armor Types	Features
	Excellent electromagnetic shielding and superior performance on harmonics problems associated with pulse-width-modulated variable-frequency drives. Continuously corrugated sheath without a jacket is suitable for plenum and other air handling spaces use according to the NEC.
Smooth Sheath	Rigid and supplies a gas/vapor tight sheath with a solid metal wall. Can be used as the equipment grounding conductor. Excellent electromagnetic shielding and superior performance with problems associated with pulse width variable frequency drive harmonics.
Aluminum Interlocked Armor	Flexible but does not have a gas tight sheath. When MC rated it is suitable for Class I, Division 2 installations.
Round Wire or SWA	High tensile strength for submarine cable, applications with long vertical drops or other high tensile strength applications. Not approved by UL as Type MC. Still internationally it is used for IEC Flameproof installations.
Basket-Weave Armor	Consists of wire laid closely together, flat, and parallel, and forming a basket weave that firmly grips the cable and is fabricated according to IEEE 1580. The armored layer as a side function provides some electromagnetic shielding. Not approved by UL as Type MC.
Flat Metal Tape	Double or single wrapped. Widely used internationally for direct burial. Not approved as Type MC.

Table 32
NEC Table 310.104(A) UL 83 600V Standard Wire Types

Type	Temp. °C/°F	Moist.	AWG	Sunlight Res.	Typical Insulation
THHN	90/194	Damp	1-14	No	PVC
THWN	75/167	Wet	1-14	No	PVC
THWN	90/194	Dry	1-14	No	PVC
THWN-2	90/194	Wet	1-14	No	PVC
THW	75/167	Wet	1000-14	Yes	PVC
THW-2	90/194	Wet	1000-14	Yes	PVC
TW	60/140	Wet	1000-14	-SR	PVC
RHW	75/167	Wet	4/0-6	No	Polyethylene
RHW-2	90/194	Wet	4/0-6	No	Polyethylene
RHH	90/194	Damp	4/0-6	No	Polyethylene
XHHW	90/194	Dry	8-14	Yes	Polyethylene
XHHW	75/167	Wet	8-14	Yes	Polyethylene
TFFN	90/194	Wet	16-18	No	PVC
SIS	90/194	Dry	2-18	No	Polyethylene

Type	Temp. °C/°F	Moist.	AWG	Sunlight Res.	Typical Insulation
MTW	90/194	Dry	2-18	No	PVC
MTW	60/140	Wet	2-18	No	PVC

AWM*	80/176	Dry	16-32	No	PVC

* Allowed by NFPA 79 with added requirements. In panels UL-508a allows 300V insulation; e.g. UL Style 1007 cable

The yellow cells show conductors most by control systems.

Table 33
UL Wire Code Breakdown

UL Wire Codes	
T	As first letter - Thermoplastic insulation
H*	75°C
HH*	90°C
N	Nylon jacket
W	Moisture resistant
R	Thermoset insulation
X	Cross-linked polymer insulation
S	Silicone (Thermoset) insulation
FEP	Fluorinated ethylene propylene insulation
PFA	Perfluoroalkoxy alkane insulation
TFE	Polytetrafluoroethylene
Z	Modified ETFE insulation
FF	Fixture wire, flexible stranding
MTW	Machine Tool Wire
B	Braid
U	Underground use
-LS	Low Smoke
-SR	Sunlight Resistant
* Wire designations without suffix H is limited to 60°C	

Table 34
NEC Instrument and Communication Cables

Legend	Installation Type	Description	Area Class	NEC Article	Standard	Copper Wire Sizes
MI	Mineral Insulated	– Cable rated 600V or 300V – Metal sheath with magnesium oxide insulation – Metallic sheath suitable for ground – Outdoor use – With or without nonmetallic jacket – Nonmetallic jacket sunlight resistant if so marked – Direct burial – Nonmetallic jacket suitable for tray use if so marked – Nonmetallic jacket suitable for buildings if so marked – Seven conductors maximum	Class I Div 2 Class II Div 1	332	UL 504	>1-18 AWG
MC	Metal Clad	– Cables are rated 600V or 2 kV – Interlocking or continuously corrugated welded armor (CCW) – Exposed Run – Wet Locations if so marked – Outdoor Use – Oil Resistant if so marked – Direct Burial if so marked – Optional jacket sunlight resistant if so marked – Optical fiber marked MC-OF – Low Smoke if marked -LS – Armor is grounding path when so marked – Class II, Division 1 with polymeric jacket	Class I Div 2 Class II Div 1	330	UL 1569	>1-18 AWG
MC-HL	Metal Clad Hazardous Locations	– As specified as above – Continuously corrugated welded armor (CCW) – Certified for Hazardous (Classified) Locations	Class I Div 1 Class II Div 1	330	UL 2225	

Legend	Installation Type	Description	Area Class	NEC Article	Standard	Copper Wire Sizes
TC	Tray Cable	– Cables are rated 600V – For use in Cable Tray and Raceway – Flame Rating: Vertical-Tray (UL 1685) or FT4/IEEE1202 – Sunlight Resistant if so marked – Wet Locations if so marked – Low Smoke if marked -LS – Halogen Free if marked -HF – Low Smoke and Halogen Free if marked -LSHF – Has Fiber Optics been so marked or marked -OF – Thermocouple use only if marked THCPL EXTN – Vapor blocked if so, marked plus Class and Group marking – Gas and vapor tight continuous jacket – Oil Resistant if so marked – Direct Burial if so marked	Class I Div 2 Class II Div 2	336	UL 1277 NEMA WC57	8-18 AWG
TC-ER	Tray Cable – Exposed Run	– As specified above – Protected runs supported at intervals not exceeding 1.8m (6ft)				
TC-ER-HL	Tray Cable Hazardous Locations	– As specified above – Continuously corrugated welded armor (CCW) – One inch or less – Certified for Hazardous (Classified) Locations	Class I Div 1 Class II Div 1	505	UL 2225 NEMA WC57	
ITC	Instrument Tray Cable	– For use in 150V Cable Tray and Raceway – Cables are rated 300V – Wet Locations if so marked – Flame Rating: Vertical-Tray (UL 1685) or FT4/IEEE1202 – Sunlight Resistant – Gas and vapor tight continuous jacket – Optical fibers if marked -OF – Thermocouple use only if marked THCPL EXTN	Class I Div 2	727	UL 2250 NEMA WC57	12-22 AWG

Legend	Installation Type	Description	Area Class	NEC Article	Standard	Copper Wire Sizes
		– Oil Resistant if so marked – Direct burial is so marked				
ITC-ER	Instrument Tray Cable Exposed Run	– As specified above – Protected runs supported at intervals not exceeding 1.8m (6ft)				
ITC-HL	Instrument Tray Cable Hazardous Locations	– As specified above except for the following – Oil Resistant – Direct burial – Jacket sunlight resistant if so marked – Continuously corrugated welded armor (CCW)	Class I Div 1	505	UL 2225 NEMA WC57	
PLTC	Power Limited Tray Cable	– For use in 300V Cable Tray and Raceway – Approved devices only – Cables are rated 300V – Flame Rating: Vertical-Tray (UL 1685) or FT4/IEEE1202 – Sunlight Resistant if so marked – Wet Locations if so marked – Low Smoke if marked -LS – Halogen Free if marked -HF – Low Smoke and Halogen Free if marked -LSHF – Has Fiber Optics if marked -OF – Thermocouple use only if marked THCPL EXTN – Oil Resistant if so marked – Direct Burial if so marked	Class I Div 2	725	UL 13	
PLTC-ER	Power Limited Tray Cable Exposed Run	– As specified above – Protected runs supported at intervals not exceeding 1.8m (6ft)				
CMP	Communications Cable Plenum	– Flame Rating: Plenum (NFPA 262/UL 910) or CSA FT7 – For use within buildings – Dry locations – Has Fiber Optics if marked -OF		800	UL 444 NEMA WC66	22-24 AWG

Legend	Installation Type	Description	Area Class	NEC Article	Standard	Copper Wire Sizes
		– Low Smoke if marked -LS – Halogen Free if marked -HF – Sunlight Resistant if so marked – Oil Resistant if so marked				
CMR	Communications Cable Riser	– Flame Rating: Riser (UL 1666) – For use within buildings – Dry locations – Has Fiber Optics if marked -OF – Low Smoke if marked -LS – Sunlight Resistant if so marked – Oil Resistant if so marked				
CMG	Communications Cable General Purpose	– Flame Rating: CSA FT4 – For use within buildings – Dry locations – Has Fiber Optics if marked -OF – Low Smoke if marked -LS – Halogen Free if marked -HF – Sunlight Resistant if so marked – Oil Resistant if so marked				
CM	Communications Cable General Purpose	– Flame Rating: Vertical-Tray (UL 1685) – For use within buildings – Dry locations – Has Fiber Optics if marked -OF – Low Smoke if marked -LS – Halogen Free if marked -HF – Sunlight Resistant if so marked – Oil Resistant if so marked				

8.1.4.5 Shielding

The type of shielding required is dependent upon the signal interference encountered from outside sources or between the signal conductors. Steel shielding is effective to 100 kilohertz at higher frequencies, aluminum or copper shielding is more effective. See Figure 16 for shielding effectiveness at higher frequencies

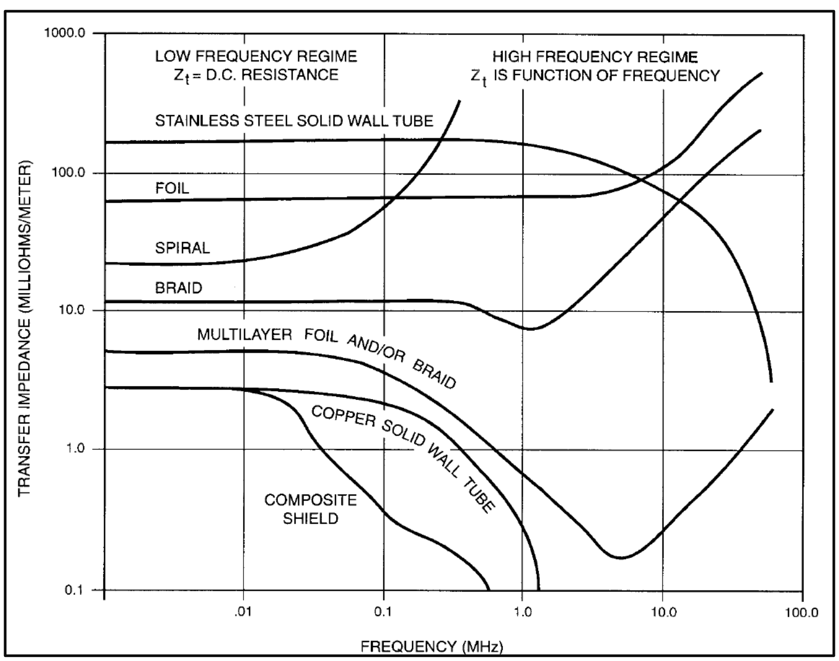
Shielding for instrument and thermocouple cable is aluminum foil tape bonded to a polymer film that is in continuous contact with a stranded drain wire. This shield supplies full coverage using a 25% overlap. See IEEE Std 1143 for descriptions of the other shielding types for low-voltage cables.

Services using 4-20 mA current are less subject to this interference. Low voltage, pulse or high frequency communications are more susceptible to interference and cross-talk. With high frequency signals the shield's other purpose is to keep the RFI interference in the cable.

The shield should be electrically insulated both inside and outside. For multi-pair cables, overall shielding should have the same specifications and should also be insulated both inside and outside.

Shielding for instrument and thermocouple cable is aluminum foil tape bonded to a polymer film that is in continuous contact with a stranded drain wire. This shield supplies full coverage using a 25% overlap. See IEEE Std 1143 for descriptions of the other shielding types for low-voltage cables.

Figure 16
Shielding Effectiveness



8.1.4.6 Number of Crossovers

Shielding is not effective against electro-magnetic noise. Added twisting supplies some protection from electro-magnetic disturbances. Twisted wire should have a of six crossovers per foot, which is a two-inch lay. See Table 35.

8.1.4.7 Wire and Pair Identification

For identification either alphanumeric coding every three inches or color coding is needed for multi-conductor cables. Refer to Appendix E ANSI/NEMA WC 57-2014/ICEA S-73-2014 tables.

Tables E-2 and E-4 supply color sequences are recommended since they do not include white or green conductors. The NEC stipulates that white and grey wire are only used as neutral conductors and that green or green/yellow is used only as a ground.

Table 35
EMI Reduction with Twisted Wire

Type	Nosie Reduction	
	Ratio	**dB**
Parallel wires	1:1	0
Parallel wires in 1 in steel conduit	22:1	24
Twisted Pair		
102 mm (4.0 in) lay	14:1	23
76 mm (3.0 in) lay	71:1	37
51 mm (2.0 in) lay	112:1	41
25 mm (1.0 in) lay	141:1	43
Frequency 60 Hz, Length 1.0 m (3.3 ft)		

8.2 Raceway and Cable Tray Installation

8.2.1 Comparison of Cable and Conduit Systems

Conduit systems are used to supply physical and environmental protection for conductors in hazardous and nonhazardous locations. Conduit prevents transmission of an insulation fire within one conduit from spreading to an adjacent conduit. Conduits are self-supporting. For smaller gauge wire conduit allows the installation of several wires in a single pull. Also, conduits can accommodate changes; old wiring can be removed and new installed.

Both ferrous and aluminum conduit supply magnetic shielding and a low resistance path to ground. At 60 Hz, steel is about ten times more effective than aluminum as an EMI shield. Still, conduit does not supply shielding against electromagnetic fields from ground currents.

Galvanized steel conduit is prone to internal condensation and corrosion, which compromises the protection, especially in offshore or near shore locations. Aluminum conduit is less corrosion prone, but its magnetic shielding is not as effective at lower frequencies normally encountered.

Conduit is a closed system that allows gas transmission from one location to another. Conduit can be a passageway to send hazardous substances to other enclosures, control rooms and electrical equipment buildings. Conduit use in line seals to create system integrity.

A cable tray is an alternative to conduit. Cable tray needs less effort to install. Threading and joining conduit is labor intensive. With cable fewer types of fittings are needed. Overall, less fittings are needed per cable run. Cable is visible, which allows for inspection and simplifies circuit tracing.

Cable has better corrosion resistance. Cables need support and depending on the material it can be more corrosion prone than steel conduit.

Cable tray is classified by NEC as a support system and not as a raceway. A raceway completely encloses the conductors. Cable in tray has a greater risk and can be an ignition source or supply fuel to a fire. Use of armor cable reduces this risk.

A third more flexible means of support uses crush resistant cable and dedicated protection such as struts, structural angles, or channels. This includes armored MC, TC-ER-HL, and ITC-HL cable as well as non-armored TC-ER and ITC-ER cable. When it is supported and secured at intervals less than 1.8 m (6 ft), these cables can be installed without using trays, conduit, or other listed raceways. For shielding for EMI, deep struts and heavy gauge steel angle are effective PEC's.

8.2.2 Conduit

The conduit material should be suitable for the environment. Galvanized steel and aluminum are the most commonly used materials. Steel conduit coated with polyethylene or PVC is also used when chemical resistance is needed in hazardous locations.

Galvanized steel has the best shielding properties. The magnetic shielding supplied by enclosing a 60 Hz power cable in rigid, galvanized, steel conduit has a factor shielding between 10 to 100 (-20 dB to -40 dB) for frequencies below 1 kHz.

Nonmetallic conduit is seldom used aboveground and is not recommended unless there is a significant corrosion problem. Galvanized steel conduit around cooling water towers and other locations subject to continuous contact with water vapor should be avoided. Aluminum or fiberglass works well in moist environments. The latter is not suitable for hazardous locations.

The support and arrangement of conduit systems should be as follows:

a. Allow for thermal expansion and equipment movement.
b. Fastening conduit to supports with clamps or U-bolts.
c. Install conduit with bend and offset angles totaling ≤180° [1]
d. Supply conduit drains at low points.
e. Due to differential expansion and vibration, conduit should not be supported by pipe.
f. Supply junction boxes where the wire or insulation type changes.
g. Junction boxes should be used to terminate multi-pair cables.
h. Install a conduit seal within eighteen inches of an enclosure [2]
i. Conduit should not be over filled [3]
j. The quantity and size of pull points should be adequate for cable installation.
k. Supply a solid ground connection between the conduit and the junction box or tray.
l. Terminals and GUA terminal boxes should be used for individual splices

Note 1: See NECA 101 “Installing Steel Conduit” and NECA 102 “installing Aluminum Conduit for further information on workmanship related to conduit.

Note 2: See section 12.9 as well as API-14F-2008 Section 6.8 and ANSI/ISA-12.01.01 for alternatives.

Note 3: Uses the cross-sectional area, the number of conductors permitted in a conduit is determined by NEC Table 1, Chapter 9. These quantities should be reduced depending on the conduit run length and the number of bends or turns.

8.2.3 Cable Trays

Cable trays can be used where allowed by the NEC and other applicable codes. Ladder trays are widely used in industrial facilities. They are built to NEMA VE 1 requirements and installed according to NEMA VE 2. Instrument cable tray size should be determined according to NEC 392.22(A)(2) which limits the fill to half the tray depth.

Cable tray covers should be considered for cables exposed to intense sunlight and dropped objects. Also tray covers improve the EMI cable resistance.

8.2.3.1 Cable Tray Types

There are three types of cable trays used with instrument and data transmission systems:

a. Ladder Tray
b. Wire Mesh Tray
c. Slotted or Perforated Trays

8.2.3.1.1 Ladder Tray

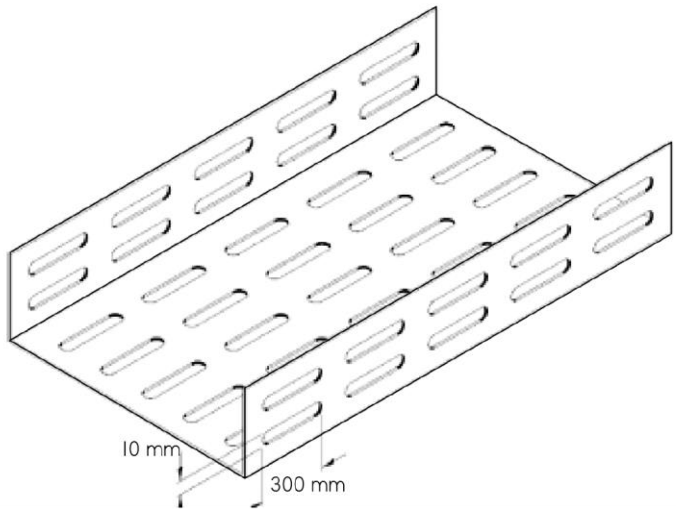
NEMA style ladder tray rung spacings are from six to twelve inches. The tray is made from galvanized steel, aluminum, and other materials. It is available in seven standard widths from six to thirty-six inches with lengths up to twenty-four feet. With just side rails it is the least capable of serving as a PEC. Supplying dividers does help some in creating a stronger protective magnetic flux. Also, covers can be retrofitted, if necessary, to deal with excessive noise.

8.2.3.1.2 Wire Mesh Tray

Wire mesh tray is also covered by NEMA VE 1. It is made from galvanized steel or stainless-steel wire. It is available in nine standard widths from six to twenty-four inches with depths from one to six inches. It does not fail when subject to fire.

It is not as robust as ladder tray since it can be deformed with less effort. The section lengths are ten feet. Its adoption as an outdoor central trunk has been limited. It can be used as a PEC, but its transfer impedance is a quarter of perforated tray.

Figure 17
EMI Noise Resistant Cable Tray



8.2.3.1.3 Perforated Tray

Slotted or perforated trays are fabricated according to IEC 61537 requirements. They formed by punching obround holes in galvanized steel, aluminum and stainless-steel sheets with the long axis running parallel with the tray long axis. They are available in sizes up to 160mm x 600mm x 6000mm. Their transfer impedance is only exceeded by metal conduit or a solid tray with a cover.

8.2.3.2 Cable Tray EMI Noise Rejection

Cable tray reduces EMI in two ways. By adding to the system mass, the tray improves the equipotential system. The induced current is drained from the cable trays. Second, a reductive effect is generated by a field that is in phase opposition to the noise. This weakens the EMI original disturbance.

Running cables down the middle of a ladder tray, though neat, provides minimal shielding. Cables are best routed on the tray side walls. Rather than uniformly stacking the cables across the tray, placing the cables in the corners supplies the best protection. This improves cable shielding and helps prevent ground loop problems. With a ladder tray a PEC conductor which supplies protection up to 100 kHz or a cover should be considered for noisy environments.

Non ladder cable tray can supply shielding up to 200 MHz when using a low RF impedance connection to the cabinets; such as plate spot welded along the seam. Steel tray supplies effective shielding at frequencies up to 100 KHz, in the megahertz range, aluminum or copper shielding is more effective.

8.2.3.3 Cable Placement in Trays

The following should be considered in using cable trays:

a. Multi conductor cables rated 600 volts or less, with the same voltage, can be installed together without a solid barrier between them.
b. ITC and TC cable in tray is only suitable for Division 2 locations.

c. Fire-stops should be supplied when cable trays penetrate floors and walls according to the applicable codes.

d. Cable trays should be accessible for maintenance and inspection.

e. Except when separated by a barrier or sleeve, ITC cables should not be placed in a tray, compartment, enclosure, box with Class I non-power limited or power circuits.

f. Intrinsically safe signals should not be placed in a cable tray with ordinary circuits except when they are kept apart by separation of 50 mm and secured or a grounded metal partition.

g. Metallic cable trays with electrical conductors should be grounded according to NEC Article 250.

8.2.3.4 Tray Routing

The following should be also considered when routing cable tray:

a. Tray routing should minimize fire exposure

b. Hot surfaces and piping should be avoided.

c. Avoid locations where hydrocarbon, corrosive or wash down fluids can fall into the trays.

d. Trays should not be in locations with high electrical interference

e. Trays should not be located where there is the possibility of physical damage such as collisions. [1]

Note 1: It is recommended when crossing roads that trays be elevated to allow cranes and new process equipment to pass under them or by placing the raceways below ground.

8.2.4 Channel Tray

A channel tray is a small form of cable tray. They are effective in supporting cable drops from the trunk tray to run to the instrument. Channel tray is convenient for runs involving a small number of cables. Channel tray is available in three, four and six-inch widths. They are used for running both armored and unarmored instrument cables. Channel trays are useful when cable glands are used. At the instrument they eliminate between five to ten threaded conduit fittings. Conduit tees, drain fittings, unions and the like are got rid of. This simplifies material management and the installation effort.

Unarmored cables can exit through the bottom ventilation holes, out the top or at the end. Where the cables exit through the openings it is advisable to use bushings for abrasion protection.

8.2.5 Underground Installations

Underground installations protect cables from fire, detonations, hurricane winds, sandstorms, and collisions. It also eliminates overhead obstructions and frees pipe rack space.

The installation effort is higher than what is needed for overhead systems. Similarly, the effort of repairing and replacing cables is higher than equivalent overhead systems. Expansion is eventually an issue regardless of the provisions made for spare ducts or cables.

Further, it is exposed to groundwater and chemical spills. The cables should be solvent resistant. Underground installations also have the drawback of being a barrier to other underground services, such as fire water, sewers, and the like.

The three basic methods for installing cables underground are as follows:

a. Underground Conduit Banks
f. Direct Burial Cable
g. Removable Top Trenches

Soil loading is a concern with underground cable, especially if piling is needed to prevent damage from uneven soil settling. Systems in seismic zones should be designed for earthquakes as well.

The current caring ability of conductors is reduced with underground installations. Higher soil temperatures can cause the need for further capacity derating.

The most widely used method is cables pulled into PVC or aluminum conduit banks. The use of galvanized conduit should be considered for signal cables that are within 150mm of power cables. See section 8.4.3 for recommended separations.

The banks are protected by either a concrete slab or a complete envelope. For identification, the concrete is dyed red.

Conduit banks should be installed which is greater: two feet below grade, twelve inches below drainage ditches, or below the frostline. The minimum spacing between conduits is 1½ inches. Three to five inches thick slabs reinforced with steel mesh are used to cover the cables. Typically, the envelope thickness around a conduit bank is three inches. Also, the cables can also be installed in precast cement duct banks.

Direct burial of sheathed armored cables is another method for installing underground cable. The installation would have the sheathed armored cable lying in a two-inch bed of sand, covered with another inch of sand, and then protected with two inch thick precast red colored concrete slabs or tiles. Damage is likely to occur during installation, so, jacketing with suitable abrasion resistance and physical strength is needed.

Precast removable top trenches are another method for protecting cables. Precast trenches offer advantages similar to above ground cable trays in that new cables can be installed easily. Being on the surface they occupy space that can be used otherwise. Still with reinforcement, precast trays can be incorporated into walkways and roads.

Precast trenches should be installed in stable soil that does not settle or shift horizontally. Also, it is recommended that the trenches should be sloped so that they can drain into a storm system.

Where conduit changes from underground to overhead, stub-ups are needed. They extended six feet above grade. To survive a fire the stub-ups are encased in concrete or other fire-resistant material.

Pull boxes locations should be selected using appropriate calculation methods based upon the strength of the selected cable. Adequate space should be provided inside the pull box for the equipment that tugs the cable through the conduit.

Above ground pull boxes are preferred but if an underground pull box or vault is required, it should be made from reinforced concrete with a removable cover designed to support vehicles. The covers should be labeled with their load limit.

Conduit runs should slope and drain toward the pull box. The pull box should have a drain or a sump suitable for a portable pump.

Underground pull boxes or vaults are confided spaces and can accumulate hazardous materials. To lower the risk of filling the vacant space temporarily with sand or other material should be considered.

Road crossings design needs care to prevent shearing, crushing, or damage from uneven settlement. Locations with heavy vehicle traffic need reinforced structures or pipe sleeves to prevent settling and damage over time. Underground conduit banks that cross under roadways, railways, or other locations that have heavy loads or poor soil should be given added support or have a reinforced envelope.

The installations should have accurate, well maintained documentation. The underground runs should be clearly indicated. The runs should be marked with robust, UV resistant, visible signs, as well as red dyed concrete or otherwise below ground warning tape or tile. A pointer and the service should be included on the signs. They should be mounted on posts set in concrete or fixed into the paving at each turn and every hundred feet along straight runs.

See API 540, PIP ELSGL01 and NEMA TCB 2 for more specifics on underground installations. IEEE C2 sections 32, 34 and 35 provides detailed recommendations for underground systems.

8.2.6 Flexible Wiring

1.1.2 Flexible Wiring

To prevent physical damage the NEC discourage the use of extended flexible connections and primarily views them as an accommodation for vibrating equipment or to facilitate equipment removal for maintenance.

The length of unsupported cable outside conduit, and cable tray plus other raceways is limited. According to the NEC Liquid tight flexible metal conduit (LFMC) unsupported length is 900 mm (3 ft) from the last securely fastened point for sizes less than 1½ in. while the unsupported length of ITC-ER and TC-ER cable is 1.8m (6 ft.)

To allow extended movement refineries and other process facilities need longer cable lengths. Coke cutting drill stems, rail car loading facilities, equipment lifts, and floating roof tanks are examples. Further in petrochemical plants high cycle packaging machines are common for bagging products.

When necessary to install flexible connections in Class I locations, the following is permitted:

a. Listed flexible fittings, such as an explosion flexible proof coupling
b. Extra-hard usage flexible cord such as SOOW with location approved connectors
c. For applications up to 600 volts, jacketed, protected TC-ER-HL cable installed using a separate ground conductor and location approved fittings. This method is limited to controlled access facilities where qualified persons service the installation.

Where provision has to be made for flexibility in Division 2 areas, the following is permitted:

a. Listed flexible metal fittings.
b. Flexible metal conduit with listed fittings.
c. Interlocked armor Type MC cable with listed fittings.
d. Liquidtight flexible metal conduit and Liquidtight flexible nonmetallic with listed fittings[1]

e. Flexible cord listed for extra-hard usage and terminated with listed fittings. A conductor for use as an equipment grounding conductor has to be included in the flexible cord.

Note 1: According to NEMA RV 3 "Application and Installation Guidelines for Flexible and Liquidtight Flexible Metal and Nonmetallic Conduits." in lengths longer than 1.8 m (6 ft), except where a longer length is approved as essential for flexibility. NEMA RV 3 support requirements when flexibility is necessary after installation.

Installations should avoid torsion on flexible cable/conduits. Torsion considerably reduces their life. Experiencing a continuous 5° twist motion, a braided coupling can have its reduce service life by 70%, and 7° of twist can reduce service life up to 90%. Similar effects can be expected with Liquidtight conduit.

For stress minimization flexible cable/conduits should be connected according to the requirements of Section 3 of NEMA RV 3. There is two configurations, straight lengths which are govern by tables and traveling vertical half loops. These two configuration allows two stress free degrees of freedom when installed according to NEMA RV 3. Torsion is introduced when there is movement in the third plane. When torsion is unavoidable it is best to distribute the rotation out over a long straight length of cable.

Flexible conduit should not be used for rapid movements unless specifically designed for that purpose. Standard UL wire and cable, such as TFFN or TC-ER, are non-flexing conductors, with time they will fail when continuously bent by movement. Thinner insulation and highly stranded wire is recommended. For extreme continuous motion, cable rated for $5x10^6$ cycles is available.

Flexible cables that move should be supported so that there is neither mechanical strain at the connection points nor sharp flexing. The cables should be supported with cable grips, guides or similar devices prior to the connections. Downward facing elbows should be used with hanging flexible cable/conduits.

Static bends in cables should be made so as not to cause unnecessary stress. For a static bend, the radius of the curve, measured from the inside edge of the bend, is not less than five times the cable diameter.

When this is achieved by a moving a loop, it should have a bending radius of at least 10 times the diameter of cable. See NFPA 79 "Electrical Standard for Industrial Machinery" for further information on installing cable and conduit subject to movement.

In extreme examples of flexing or rotation an explosion proof slip ring or a unclassified slip ring with intrinsically safe circuits might be necessary.

Nylon spiral wrap can be used to protect moving cables from wear. For large cable movements flexible enclosed cable carriers are recommended. A suitable guard would be a drag chain cable carrier. A cable drag chain is a basically a joined cable tray that secures cables or hoses that keeps them separated while permitting movement. These are commonly used on drilling rigs.

8.2.7 Messenger Cable

A messenger is an aerial cable that a signal line is fastened to with lashings. It is a high-strength, corrosion resistant, stranded wire rope that does not carry current. It is supported at intervals by poles or other structures. NEC 225.18 provides the minimum installation heights for overhead cables and conductors. In locations, such as tank farms, messenger cables are useful where long spans need to be bridged or it is not practical to install cable tray.

Messenger cables should be grounded at intervals. The ground connection should be suitable for faults and lightning protection. Lightning protection is limited due to messenger's proximity to the signal cable.

Power lines on the pole should be as far as possible from the signal cable and when possible, should be transposed periodically. Electrical facilities and communication cable facilities should be according to the National Electrical Safety Code (NESC) IEEE C2. Diagonal measurements do not apply to electrical clearances. Added vertical clearance on the pole can be needed to achieve the necessary clearances.

8.2.8 Access Floors

Access flooring is used in rack and control rooms for routing signal cables and power conduits. It is available in combustible, non-combustible and composite panels.

The access floor layout should be determined prior to the installation of any equipment or cabling. Care should be taken to ensure there is enough clearance below the access floor surface to prevent crosstalk among signal cables. Typically, the floor is between twelve and eighteen inches deep. This also allows enough room to meet the bending radius requirements of most multiconductor cables.

Since process control instrument cable is not plenum rated, the access floor should not be used to provide cooling air to the cabinets. Instead the floor is classified as a raceway.

The openings have floor seals, sealing grommets and edging to minimize the entrance of debris. Also, the space under the floor should be protected from the entrance of water during floods or pipe leaks. Level switches can be installed to provide a layer of protection. Cables should be stacked on higher than six inches. Consideration should be given to creating two or more layers under the floor using tray to allow cable segregation.

The floor system should meet local conditions including seismic. The panels should be 2 ft by 2 ft and should have a welded steel construction. The laminate should be a NEMA LD3, high wear HW120 type. Floor panels should have anti-static properties according to IEC 610000-4-2 requirements. The frame grounding grid should maximize the equipotential performance of the access floor.

A panel supported by the understructure system should carry a point load of 1250 psi at any location without a permanent set as defined by the Ceilings & Interior Systems Construction Association. The ultimate load should be three times the point load. Stringers should be used to interconnect pedestals in a 2 ft by 2 ft grid for stability and to support the panels. See TIA-589 "Telecommunications Pathways and Spaces" for added design requirements for access floors

Control system rack rooms are not classified as Information Technology Equipment Rooms. It is recommended that the applicable parts of NEC article 645 be used to design rack rooms.

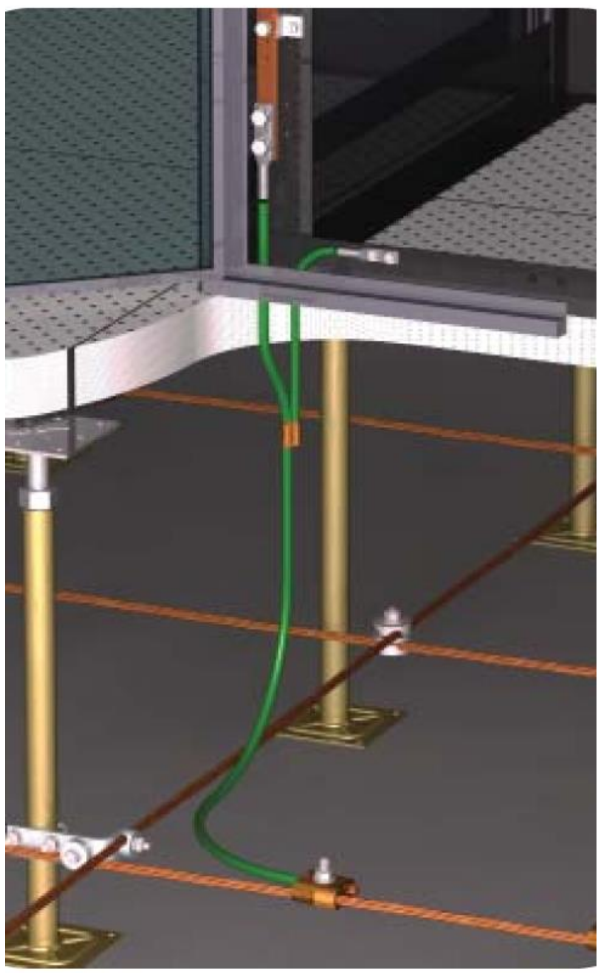
In new construction, the access floor should be built with a recessed area with the top of the floor even with the other floors in the facility. Where the slab is not recessed, ramps or steps are needed. Building codes including ADA requirements should be followed for both the ramp and step dimensions.

Consideration should be given to the following:

a. Cable quantities
b. Secondary pathways
c. Cable runs crossings
d. Cable bend radius limitations [1]
e. Access space

Note 1: The bend radius should be considered for the horizontal and vertical axes. Too shallow a floor cannot have enough depth to redirect a multiconductor into a cabinet.

Figure 18
Example of Access Floor



The shielding from an access floor is a combined equipotential performance of the frame grounding grid and the access floor. If either flooring panels do not contact; such as when using anti-static seals, or stringer contact is not assured, a bonding grid should be added to the metal uprights, as shown in Figure 18.

The copper frame grounding grid is installed with the largest cell size of 2 m in any horizontal direction. The conductor minimum cross-sectional area for the frame grounding grid is 10 mm².

If the access floor is installed with a surface that is intended to supply protection against electrostatic discharge, the DC resistance between the access floor upper surface and the grounding grid should be between 1 MΩ to 10 MΩ. The location and values of DC resistance measurements should be recorded for comparison following repairs.

8.3 Wire Termination

8.3.1 Terminal Strip Installation

Feed through terminals should be used to tie conductors together. Crimp splices and wire nut connections are not recommended. Only two wires to the terminal side should be used. Jumpers such as combs, internal bridge, etc. should be intended for the terminal selected.

Due to ergonomic issues, double deck terminals are not recommended for feed through terminals and fuse holders.

A fuse terminal block should be supplied for the field circuits. It is recommended that fuse blocks have a lever, so they can also function as a disconnect.

It is recommended that the wires depending on the thermal type be terminated with a ferrule or insulated spade lug. They should be attached with a compression tool designed for this purpose.

The 35 mm Top Hat rails should be mounted on sub plates or strut to improve access for construction and maintenance while supplying protection for surface condensation.

Terminal blocks should be arranged in vertical rows with adequate separation to allow clear wire identification. Terminal blocks for the field wires should have the field conductors on one side of the terminal rows and internal panel wires on the other.

Unused sides of terminal blocks should not be left uncovered and exposed but provided with end plates which clamp the terminals in place. At the end of each terminal block assembly, wherever a change in terminal block size occurs or when a side of a terminal block is not used, an end plate should be provided.

Isolation partitions should be provided for visual separation or to contain current creepage within the terminal assembly. Partitions should indicate where there is a different voltage.

8.3.2 Wire Installation

Terminal strips should be logically arranged and clearly labeled. Spare wires should be organized and managed. The wire should be routed around and between terminal strips and not over strips.

The wire should have adequate slack to allow re-termination anywhere within the enclosure. Typically, an incoming cable is wrapped once around the interior of the enclosure before being landed.

Spare wires and drain wires in multi-conductor cables should be terminated at both ends and grounded. See section 8.4.2.2 concerning recommendations for terminating shields.

Coiling should be avoided otherwise an inductor is formed. Instead the excess wire should be Z folded and secured.

8.3.3 Wire and Terminal Identification

8.3.3.1 Terminal Identification

The terminal blocks and terminal strips should be uniquely numbered, and they should be numbered on both sides. Using a common letter to label grounds, power source, etc. is not recommended and complicates trouble shooting.

8.3.3.2 Wire Identification

Individual signals and signals in multi-conductor cable need permanent tags that are affixed to the pairs or triads on either side of the terminal strip. Labels should be waterproof, smear resistant, and impervious to solvents, etc. In addition, the label material should be UV resistant.

Wire should be identified with legible tags at the terminals. The wire end should be supplied with a heat shrinkable sleeve marker. Clip-on type markers should not be used since they fall off.

Excluding signals going to system I/O, wire tagging inside panels and systems should conform to the requirements of IEC 62491 section 6.4 “Both-End Connection Labelling” with the far end device having an ANSI/ISA S5.1 tag or circuit breaker number.

Field wire tagging and color codes should follow established procedures. For new systems it is recommended that wire tags be the same as the instrument tag or signal tag to which they are related. The tagging starts at the signal origination point and continues to the destination. Single pair cable can be numbered by adding pre-fix “IC-” to the instrument tag. Example: flow transmitter 12-FT-001 can be IC-12-FT-001. Other prefixes can be used to designate power conductors, secondary signals, nonincendive field wiring, etc.

Based on ICEA Table E-1 signal wire pairs are often black and white. There is little consistency between users on how these wires are used with respect to polarity. Some plants employ wiring practices adopted from electronic equipment for DC power circuits that uses black as the negative or the lower voltage.

Other plants use black as positive or the power source since NEC article 200.5 for AC circuits restricts the use of white to neutral circuits. According to NFPA and UL requirements with white or gray are the AC current carrying grounded conductors with black being the unground conductor or positive. See Table 36 for wire color codes that have designated services according to various codes and standards.

Using ICEA Table E-2 or E-4 color sequences avoids these issues. The first two colors out of the 36 conductors assign are black and red. White, gray and green conductors are not used. NEC reserves last for safety grounds. Still consistency with safe past practices should be the governing principal according to the fundamentals of human factors.

However, neither conductor in a two-wire loop is voltage free. The positive wire of the transmitter operates at a nominal 24 VDC while the negative terminal which is the signal output has a nominal five volt value.

Table 36
Standard Wire Color Codes

Solid	**Tracer**	**Purpose**	**Origin**	**Label**
NFPA and UL Color Codes				
White		Ground/Neutral	NEC	N
Black		Control at Supply Voltage	UL 508A	
Black		Ungrounded DC Negative	NEC	**–**
Black		AC or DC Power	NFPA 79	
Blue		Unground DC Control	NFPA 79	
Blue		Unground DC Control	UL 508A	
Red		AC Control	NFPA 79	
Red		Ungounded DC Positive	NEC	**+**
Grey		Ground/Neutral	NEC	N
Green		Safety Ground	NEC	G
Green	Yellow	Safety Ground	NEC	G
Yellow		Excepted Circuits	UL 508A	
Orange		Excepted AC Power [1]	NFPA 79	
White	Orange	Excepted AC Ground [1]	NFPA 79	
White	Yellow	Excepted AC Ground [1]	UL 508A	
White	Blue	Grounded DC Control	NFPA 79	
IEC Color Codes				
Lt Blue		Neutral	IEC 60445	N
Brown		Line	IEC 60445	L1
Black		Line	IEC 60445	L2
Grey		Line	IEC 60445	L3
Green	Yellow	Protective Ground	IEC 60445	PE
Black		AC and DC Power Circuits	IEC 60204-1	L
Red		AC Control Circuits	IEC 60204-1	
Blue		DC Control Circuits	IEC 60204-1	
Orange		Excepted Circuits [1]	IEC 60204-1	
Note 1: Excepted circuits remain live when the main power disconnect is open. This color is used with external power control circuits. This color is also used for cabinet lighting and convenience outlets that remain powered for maintenance.				

8.4 Electrical Noise

Cables had functioned as filters for EMI noise because they had high mutual capacitance. With digital communication; e.g. HART and MBP fieldbus, cables with high frequencies capabilities are used so shielding and grounding practices are essential.

EMI has increased significantly with the addition of Wi-Fi, mobile phones, ubiquitous use of two-way radios, and wireless networks plus non-intentional radiators such as, variable frequency drives, arc welding, uninterruptable power supplies, desalters, electric heat exchangers, switching power supplies, Ethernet switches, etc.

Though these items are designed to meet C.F.R. Title 47, part 18 they are often incorrectly reassembled, or their wiring becomes defective. Also, equipment has been grandfather; e.g. as motors, prior to these rules. The result is that RF noise levels are high enough to cause unprotected systems to malfunction.

This is a continuous problem. Systems in noisy environments slowdown with data retransmissions caused by failed error checks. This leads to premature and unnecessary system obsolescence. Slow data can cause operator personnel to lose focus and adds disproportionately to their reaction time. Also, it increases the chance for an inappropriate action or non-action.

Interference enters an electronic system by the following means:

a. Electromagnetic coupling from alternating current (AC) fields and radio-frequency (RF) fields.

b. Electrostatic or capacitive coupling with other circuits.

c. Direct coupling with other circuits by leakage current paths, or a common return lead for more than one circuit. [1]

Note 1: For instance, spurious signals by current leaking from one circuit to another can be caused by moisture. Water filled conduits can also lower the capacitance between circuits leading to noise transmission. This can be reduced by using properly insulated wire and terminal strips.

8.4.1 Noise Resistant Equipment

It is important the equipment used should be resistant to EMC noise. The transmitter and other field devices should meet the requirements of NAMUR NE-21 with the addition that the device be assessed at 60 Hz as well. IEC 61326-3-1 and IEC 61326-3-2 should be met as well regardless of if the application is safety related or not.

The control system hardware should meet the EMC requirements of either IEC 61131-2 (NEMA IA 2.2) “Programmable controllers – Part 2: Equipment requirements and tests” or IEC TS 62603-1 “Industrial process control systems – Guideline for evaluating process control systems – Part 1: Specifications.”

8.4.2 Shield Application

Shielding is used to reduce electrical and magnetic noise picked up by the circuits either between signals inside a pair or triad cable or from outside interference. See section 8.1.4.5 about the selection of cable shields.

8.4.2.1 Shield Grounding

There are various approaches to grounding shields:

a. Single Point Shield Grounding
b. Two Point Grounding
c. Multi-Point Grounding

The conventional method uses twisted shield cables grounded at one point to eliminate low frequency hum caused by coupling from the power cables.

The other methods use at least two grounded connections. Because of increased electrical noise as well as electrical hazards, International Standards and IEEE now tend to favor multi-point shield grounding. For instance, cloud-to-cloud lightning within 2 miles radius couples well with horizontally-run cable shields and can inject 10kV over a 100m length. Un-terminated shields on the ends of long cables have observed arcs during thunderstorms. Physical damage occurs, with the possible risk of electric shock and fire.

IEEE 1143 “Guide on Shielding Practice for Low Voltage Cables” provides a detailed discussion applying cable shield.

8.4.2.1.1 Shields Grounded at a Single Point

Single-point grounding and wiring cable shields at one end evolved when elevated RF levels were rarely seen. With low-frequency circuits, customarily, shielded twisted pairs grounded at a single point protect against capacitive coupling. This system is easy to install but it does not supply comprehensive protection.

The shield grounding at the signal source minimizes low-frequency noise caused by ground currents. Ground currents are often DC, 60 Hz, or the lower harmonics of 60 Hz.

At low frequencies since the shield is held at the same relative voltage as the grounded reference, external voltage sources cannot couple to the shielded. The interference current is conducted along the shield to the common ground point.

Connecting the cable shield to ground at one end is enough to ensure that both ends are at the same voltage as the circuit common. While the location of this ground connection is normally not critical. It is preferred to make this connection at the same place where the circuit common is connected to the safety ground.

With thermocouples dissimilar metals cause common mode interference to transform into differential mode interference which is not easy to filter out. Grounding the thermocouple at the measurement point; i.e. close as possible to the noise source, minimizes the distance that the induced current travels. So, the differential-mode interference voltage error is limited.

If the shield has a high capacitance to ground, this allows circulating currents to flow at low frequencies. It is best to make the ground connection at the high capacitance point. The highest capacitance is often at the signal source. A grounding strap or low-inductance jumper shorts-out this capacitance.

When functioning properly single point shield grounds are good at preventing ground loops, however they are not effective when high-frequency interference occurs. With long cables both ends of the shield cannot be kept at the same voltage as the circuit common. Further, due to jacket deterioration it is common for unintended grounds to develop allowing ground loops to arise during rainstorms and the like.

Grounding the shield at one end creates a capacitive voltage divider between the distributed capacitance of the shield and the conductors. External EMI is coupled capacitively to the shield in a distributed fashion. So, the shield impedance to the grounded end is a prime factor in determining how well the voltage divider performs.

Because the shield voltage varies, noise is capacitively coupled to the conductors. If the circuit length becomes a significant fraction of the EMI frequency, the shield starts to fail. With added length the shield gains impedance. For lengths exceeding 1/20th of the noise wavelength, the shield is no longer at a constant voltage along its length. Shields start to lose their effectiveness at 1/20λ and begins to become an unintentional antenna. When it reaches 1/4λ the protection is gone.

With high interference frequencies, the shield inductive properties add a series impedance. So, the ground voltage noise directly couples through distributed capacitance with the shield and then through the shield capacitance with conductors to the signal.

8.4.2.1.2 Shield Grounded at Both Ends

It is recommended by IEC 61000-5-2 that the shield be grounded at both ends. This is especially true if the cable is electrically long at interference frequencies. The shielded twisted pair grounded at both ends has the same potential which is a wide spectrum installation that is noise resistant. It also essential is that every signal has its own circuit return for proper noise management.

The design of two-wire field transmitters, galvanic isolation amplifiers, and differential amplifiers suppress ground loop noise. Prone to ground loop noise are low voltage analog measurements from strain gages, thermocouples, audio cables and the like. Grounding a shield at both ends can allow interference of a few kHz into a cable unless the preventive methods; such as using a PEC (Parallel Earthing Conductor) are used.

Ground loop noise is managed by keeping the signal cable tight to its parallel equipotential ground system. This minimizes their total loop or enclosed antenna area which lowers the interference amplitude.

Safety considerations call for the far end of the shield to be grounded. Otherwise, the floating end of the shield becomes the receiving tip of a monopole antenna, causing it to be noisy. During high energy disturbances, the voltages were measured as high as 2 kV and arced over. So, both shield ends should be bonded to the equipotential ground system.

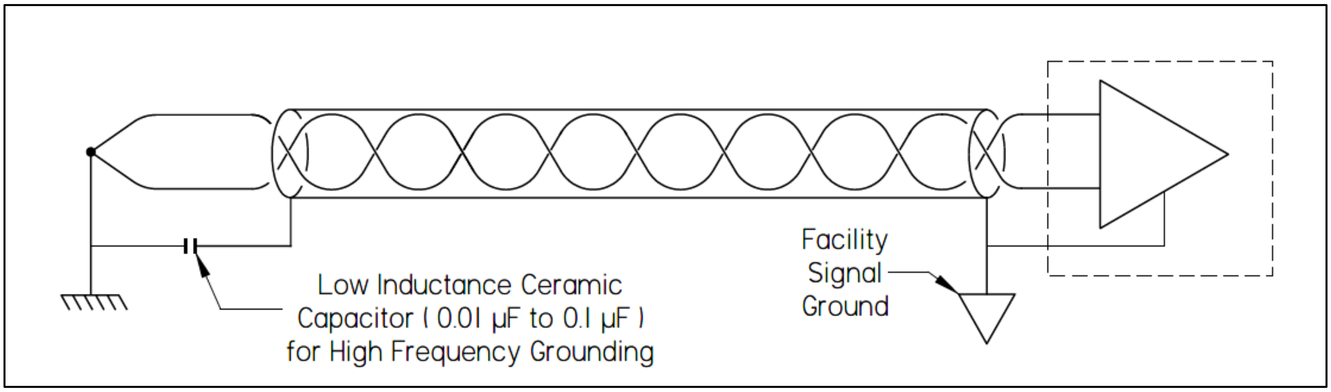
Still when a shield is grounded widely at two points, there is a risk that potential gradients in the ground system during faults can cause large currents. Potentially, the cable shield currents can overheat a cable.

Nevertheless, if facility has been correctly grounded as a low impedance system that is needed for safety, the current flows in the cable shields, which have higher impedances, cannot be high enough to damage them. Despite this, grounds at multiple points should be considered for exposed cable runs with foil shields since it eliminates this issue and is more effective in noise reduction.

The grounding structure in legacy installations can be poor. Cables can be routed to where there is no common low-impedance grounding system. Adding a low impedance parallel PEC protects the shield from overcurrent damage and helps protect the electronics from damage during thunderstorms.

Another solution is a hybrid ground where the receiving end shield is grounded with a low inductance ceramic capacitor (0.01 µF to 0.1 µF), which provides high frequency grounding. The capacitor acts as a ground to RF signals on the shield but blocks low frequency line current from ground loop to flow in the shield. For convenience, the capacitor can be mounted in a component type terminal block.

Figure 19
Hybrid Ground with Capacitor



Connecting the spare conductors in a cable to ground at both ends also increases the shielding effectiveness. The spare conductors become part of the PEC. This increases the grounded metal appearing as a shield, as well as reducing the EMI from parasitic oscillations occurring in the radiating dipoles that these ungrounded conductors create from the stray inductor-capacitor products. This is important because of their proximity to the active signal conductors in the cable. Evenly distributing the grounded spares achieves the best results.

8.4.2.1.3 Shield Grounded at Multiple Points

Where the cable length approaches 1/20λ of the EMI frequency, it can be necessary to add ground connections along the cable's path. To break it up into shorter lengths based upon the EMI's frequency. In locations where there is a significant noise source, make the connection as close as possible to the noise source.

At high frequencies, connecting the shield to ground at multiple points rather than just at the ends can prevent resonance effects. Using many small ground loops is a method for EMI mitigation. This enhances the equipotential ground system. FOUNDATION™ Fieldbus Class B and C grounding does this for the 31.25 kHz signals.

For long distances, added connections to the facility ground network are desirable at irregular distances between the devices. These added connections form a shorter return path for the noise currents in the PEC. For U-shaped trays, the connections should be made externally to maintain separation from the interior.

Effective low-frequency magnetic field shielding is more difficult to obtain than electrostatic shielding. Prior practice was to avoid ground loops by using single point grounds, still ground loops can supply EMI protection and solve problems that cannot be solved otherwise.

The larger the loop the more interference. Creating many small ground loops reduces the total interference. Numerous small ground loops mitigate EMI if the transfer impedance with respect to nearby circuits is low. An equipotential system uses many low impedance bonds to the plant ground bed. Systems installed this way suppress ground loops. The shield should be grounded at any splice and at both ends so that there are no random paths established through the components.

Meshing with a low reference grid impedance, lowers the voltage differences between the equipment grounds so ground loops are suppressed. This is accomplished successfully in professional audio systems where a detectable hum from ground loops is unacceptable.

Conversely, accidental high impedance ground loops are quite common in existing systems due to deterioration and improper modifications. Since continuous process control devices are designed to reject 50 Hz and 60 Hz noise this problem is undetected until a significant noise surge occurs.

A weatherproof grounded junction box gland connector protects the intermediate ground points. Also, a connector can be mounted on a grounded bulkhead plate inside the junction box.

8.4.2.1.4 PEC's

PECs are metal conductors that carries the largest part of the disturbance current and diverts it from the signal cables. PEC can be conduit, cable tray, structural steel, another wire, or any metal component that can shade the signal cable along its length.

The shield resistance divided by the PEC resistance is the estimate shield current reduction at 1kHz. For example, a typical small diameter shielded cable that is 100 m long a has shield resistance of 2Ω, so a PEC using a 6mm diameter copper wire would reduce the shield current to 3% of its original value or by 30dB.

To be effective a PEC should be correctly sized. A PEC should have a low resistance when compared with the cable shield resistance. The cable should be strapped to it along its length. Also, the loop area of the signal conductors and the PEC should be minimal. The PEC and the signal cable should be in intimate contact without gaps. Shields and armor should be 360° grounded prior to leaving a cable tray or other PEC. The PEC can be the following and are shown in ordered with conduit being the best:

a. Conduit
b. Strut or narrow duct [1]
c. Perforated cable tray [2]
d. Corners of structural angle, I beam or C channel
e. Wire mesh cable tray [2]
f. Surface of a structural member, solid lightning tape or flat bar
g. A grounding conductor [3]

Note 1: Providing a lid significantly improves the effectiveness of the strut as a PEC. The Height/Width ratio also influences the effectiveness of the struct as a PEC. A ratio of 2 is five times more effective than a ratio of 1 for a strut.

Note 2: For best results locate the cable in the tray corners. Stacking the cables in the middle of the tray on top of other cables provides minimal noise protection.

Note 3: Ground conductors are effective up to 60 Hz

To maximize shielding effect, the signal cables should be routed in corners when possible. The strut channel with its U shape is particularly effective, second only to steel conduit. For a PEC, the more enclosed sides the better. Adding a cover or closure strip that is conductively bonded to the main element maximizes the PEC effectives.

Armored cable can be a PEC at low frequencies depending on the armor construction and the quality of its 360° bonding at its terminations. However, armor cable e.g. steel wire armored (SWA) or continuously welded MC-HL does not provide much protection above 1MHz. A problem with using armored cable as a PEC is that it is vulnerable modifications, if it perceived as providing just mechanical protection, the continuity can be compromised during maintenance.

8.4.2.2 Shield Termination Methods

The shield wire is an antenna that radiates high frequency interference. It is important that the wires used to terminate a shield are as short as possible, if not eliminated. A poor shield ground conductor location causes coupling to instrument conductors.

The practice of using pigtails or jumper wires to ground shields should be avoided since they supply unwanted coupling points to signal conductors that are parallel to them.

For cables that run internal to the cabinet, the shields should have a low-inductance bond to the circuit common inside the cabinet.

It is normal practice to use the drain wire to ground foil-shielded cables, but this limits the cable EMC performance. Shields that use pigtails start to lose effectiveness above a few hundred kHz. Pigtails longer than 30mm eliminates shielding protection above 1MHz. Combining pigtails together further adds to the degradation.

A 360° shield ground can reduce the emission level by 20 dB. To be effective the cable RF grounding device needs a tight fit around the cable's shield. Shield ground fittings that rely on compression springs or shield clamps tied to a bus bar do not supply 360° coverage, so the higher frequencies can leak out. Up to 50 MHz, P-clips, saddle clamps or stainless-steel cable ties tie to a ground plate supply better coverage. Enclosure entry seals that incorporate conductive braids and gland fittings supply the most complete high frequency 360° ground path.

The shield ground fitting should be attached directly to the BRC Main Grounding Terminal. A grounding strap or braid attached to the 360° connection defeats its purpose. The best practice is for every cable including power is to enter from one side of the cabinet and that the shields are fully circumferentially grounded to the cabinet outside surface.

Braid shielded cables are straight forward to 360° RF ground. On the other hand, spiral-wrapped foil-shielded cables are more difficult. The foil is a plastic film that is metalized on one side. For protection at higher frequencies it is important that the foil metal makes a 360° contact with the equipotential system. Making 360° contact is not difficult if aluminum coating is on the outside surface.

Where the internal surface is coated which the more typical construction, the foil needs to be cut and folded or rolled back to expose the aluminized surface. The aluminum coating is thin, less than 0.5 mil, and can eventually oxidize, becoming an insulator.

Foil tape that has a 4.5 mil aluminum coating and a conductive adhesive with a shield effectiveness above 1MHZ can be used to protect the cable ends by covering the backwards fold. Also, when combined with 360° cable glands it enables cable mid-point grounding, so mesh zones can be created along the cable's path.

The less desirable alternative to 360° grounding is for each pair to have individual shield ground points. When pigtails are used, they should be terminated individually to prevent crosstalk. The terminal assignments of shields and signal conductor scan have a major effect on crosstalk problems. The shield should be terminated with its signal pair. If a shielded pair is in a multi conductor cable, the pair shields should have individual terminals and the terminals should be arranged to balance the coupling from the shield to each signal conductor, so the net effect is zero.

8.4.3 Signal and Power Separation

8.4.3.1 Recommended Separations

An effective method to prevent noise transmission is to space the circuits by signal or power level. Circuits are normally run in common raceways, such as cable trays, according to their group classification with no mixing between groups. In determining the separation between the cables, the raceway affects the separation distance. Those with less effective shielding are spaced further apart.

There are recommendations in IEEE 1050, IEC 61000-5-2, and NAMUR NE 98 for separating cables. IEC 61918 supplies guidelines for separating balanced data cables from other circuit types. TIA-569-C supplies also supplies a detailed table for separating balanced twisted pair data cables from power circuits.

The following are groupings for signal separation based upon IEC 61000-5-2 guidelines:

Level 1 Measurement Signals

a. Signals with full-scale readings ≤10 volt or ≤1ma
    i. Thermocouples
    ii. Thermistors
    iii. Strain Gauges
    iv. Load Cells
    v. Microphones and Telephones
    vi. Receiving Antennas
    vii. Optical Encoders
    viii. Magnetic Sine Wave Signals
b. Voltage Source Impedances ≥1kΩ
c. Signal-to-Noise Ratio ≥72db
d. Signal digitization ≥12-bit [1]
e. Analog CCTV
f. Ethernet and other low voltage digital transmissions [2]

Note 1: Greater than 1 part in 4000 resolution required
Note 2: See IEC 61918 "Installation of communication networks in industrial premises" and TIA 1005-A "Telecommunications Infrastructure Standard for Industrial Premises" for detailed determination of cable selection and separation requirements for Ethernet and other fieldbuses.

Level 2 Control Signals

a. Standard 4-20 mA Analog Signals [1]
b. DC Discrete Circuits ≤3.0W
c. 0-10V with a Source Impedance ≤1kΩ
d. Three or Four Wire RTD's
e. API Std 670 0 to -22V Signals
f. 5V TTL Digital Communications, ≤9600 Kb/s
    i. RS-232

ii. RS-422
iii. RS-485

g. Signal-to-Noise Ratio ≤60dB
h. Signal Digitization ≤10 bit [2]
i. MBP fieldbus; i.e. PROFIBUS, H1 Foundation™ Fieldbus

Note 1: Intrinsically safe signals are separated according to HEC section 504.30 or IEC 60079
Note 2: Greater than 1 part in 1000 resolution required

Level 3 Auxiliary Circuits

a. 120VAC Discrete Signals
b. AC Circuits ≤5 kVA
c. DC Solenoid and Relay Coils >2.8W and ≤45W [1]

Note 1: Solenoid and relay coils should have snubber circuits to suppress inductive spikes. See section 8.6.2 for recommended circuits.

Level 4 Low Voltage Circuits [1]

a. ≤480VAC or 1000V peak
b. ≤ 800 DC
c. Across-the-Line Started Motors
d. AC circuits >5 kVA and ≤810 kVA
e. Unsuppressed resistive and inductive loads e.g. solenoid, relay, and contactor coils

Note 1: The following should be separated by least 600mm from Level 1 cables: DC or AC variable speed motor drives, arc welders, transmitting antennas, as well as SCR controlled heaters, switched power converters or UPSs with excessive harmonic content.

Level 5 Medium Voltage Circuits [1]

a. Medium Voltage AC cables
b. AC circuits ≥800 kVA and ≤1.50 MVA

Note 1: This formula can be used to determine the separation for circuits above 1.50MVA

$y = \frac{\sqrt{x}}{2}$ where x is load in VA and y is the separation in mm

Table 37
Tray to Tray Separations (mm)

	Level 1	Level 2	Level 3
Level 1	0	150	300
Level 2	150	0	150
Level 3	300	150	0
Level 4	450	300	150
Level 5	600	450	300

Group the cable by type and level with low level signals to the farthest from power, then mA circuits, then alarms; closest are 120VAC control circuits such as solenoid valves. The transmission line length affects the electrical interference magnitude. The longer the distance the greater the EMI interference possibilities.

If each level is contained in a galvanized metal conduit the spacings between them can be disregarded. An enclosed metal duct can be as good as conduit, if the cover makes a reliable direct metal-to-metal contact to both of the duct’s sides at least every $30/f_{max}$ along its length.

The minimum cable spacings are based upon circumstantial data. These distances have been shown to be effective for industrial installations. Actually separations are dependent upon emissions and the immunity characteristics of the interconnect equipment, and the signal-to-noise ratios needed.

Some sensitive electronic equipment spacings can need to be increased otherwise extra shielding or filtering can be added. Where cables are not routed using a PEC, the minimum spacings to other classes of cables should be increased. Each case has to be analyzed mathematically or by trial and error.

8.4.3.2 Separation by Stacking Trays

If cable trays are stacked vertically, the high-voltage feeders should be in the top tray, and signal cables should be in the bottom tray. The circuits can be arranged from bottom to top as follows:

a. Level 1 & 2 Control and low voltage signals
b. Level 3 Lighting circuits and LV lines
c. Level 4 MV lines with AC or DC
d. Level 5 HV lines

8.4.3.3 Separation from Radio Transmitters

A building can give attenuation between 0 and 20db from commercial broadcast signals. Portable transmitters; such as two-way radios do not have high radiated power, but they can be brought close to susceptible equipment. Typical field strengths from a 1W UHF handheld transmitter are from 5 V/m to 7 V/m at a half meter.

IEC 61326-3-2 recommends a protective distance of 1.8 m for 5W two-way radios. Mobile phones transmit less than 200 mW, so a minimum distance is not relevant. Equipment tests are conducted according to EN 61000-4-3 over a frequency range of 80 to 1,000 MHz and 1.4 to 2 GHz at 10 V/m. The protective distances from radios are determined at these frequencies. Transmitters operating at higher frequencies; e.g. LAN at 2.4 GHz, rarely cause problems because they use low power signals.

8.4.3.4 Proximity to AC Fields

Although direct routing is desirable, the signal sensitivity to electrical magnetic interference calls for added precautions. Magnetic field interference occurs when signal wires pass through strong AC fields. This occurs near large motors, generators, electric heaters, desalters, and transformers. Do not lay cables immediately next to reactor inductors and single-phase transformers.

Signal leads should enter at right angles to AC equipment's magnetic field. When power and signal wires cross near one another, the crossover should be made at right angles. They should be no closer than 12 inches (0.3 meters); however, 24 inches (0.6 meters) is recommended. To further suppress electrical noise interference consideration should be given to shielding MV and HV power cables.

8.4.3.5 Similar Signals

The signals in a raceway or tray should have a comparable voltage. For instance, it is common to mix 4-20 mA and 24 VDC discrete signals including low power solenoid valves as well as NAMUR proximity probes together.

Wires from some sensors or systems should be isolated from standard circuits. Some examples are listed below:

a. Turbine meters and other pulse signals (up to 2000 Hz)

b. Machinery speed pickups (up to 32 kHz)

c. API Std 670 (0 to -22V)

d. Weigh Cells and Strain Gauges

e. RTD's and Thermistors

f. Flame Rods

g. Thermocouples

h. Shutdown Signals and Critical Alarms [1]

i. Intrinsically Safe Circuits [1]

j. Circuit Integrity and Fire Protection Cables [2]

k. AC signals e.g. solenoid valve, relays, and discrete switches

l. Larger DC solenoid coils and contactors, ≥100 mA.

Note 1: Required to meet safety standards and codes.

Note 2: Besides isolation the tray fill can be limited to one layer. Often required to meet safety standards and codes.

To avoid special cables and noise problems the following devices should use local two-wire or four-wire converters to produce an isolated 4-20 mA signal:

a. Magnetic flow meters

b. pH and ORP electrodes

c. Acceleration transducers

d. Nuclear gauges

e. Radiation Pyrometers

Also, two-wire temperature transmitters are more effective than using thermocouple extension wire.

8.4.4 Noise Minimization Techniques

Inputs that accept a two wire 4-20 mA signal are not differential inputs. Standard two-wire 4-20 mA inputs are not balanced due to the internal conversion resistor so there is no common mode noise rejection. Since it is a current signal common mode voltage noise has almost no effect on the measurement.

Spurious noise can be managed using by the following techniques:

a. Use shielded, twisted signal cables

b. Installing signals in equipotential grounded conduit and covered trays [1]

c. Eliminate or mitigate the nearby noise source

d. Route signal wires away from high voltage lines and equipment with strong electric fields
e. Minimize parallel runs of different voltages
f. Shielding the power line, install it in grounded conduit or a separate tray [1]
g. Using twisted conductors for the power circuits [2]
h. Crossing high voltage wires at right angles while maintaining separation
i. Keep the signal plus and minus together [3]
j. Install surge protectors, EMI filters or galvanic isolates circuits on unshielded circuits [4]
k. Eliminate common return leads [5]
l. Install an isolated power supply by using a UPS or shielded isolation transformer [6]
m. Avoid spooling or looping cables [7]

Note 1: For low frequencies aluminum conduit is less than half as effective as steel, while plastic conduit has no shielding effect. Still, it is more important when using the raceway as a PEC that has a low impedance continuous path rather than selecting the material for its magnetic permeability.

Note 2: The twist or lay of the power cable should be different from the twist used with the signal cables.

Note 3: Having single conductor daisy chained between devices increases the unintended antenna area which significantly increases the noise voltage. Low power discrete signals; such as limit switches, are commonly run this way.

Note 4: For instance, use galvanic barriers for intrinsically safe circuits.

Note 5: The current causes a resistive voltage loss that appears as an addition signal when using the differential voltage inputs. Signal pairs are critical when using a PEC to manage signal noise. Further, this puts the associated signals at risk from a single point failure.

Note 6: A shielded isolation transformer can attenuate noise by 60 dB at frequencies up to 1 MHz.

Note 7: Spooling causes coupling problems since the loops act like transformer windings. To make the connection cut it to the length needed. Otherwise, to reduce this effect fold the excess cable back and forth and tying it in place.

8.5 Grounding

8.5.1 System Grounding

Grounding should conform to the NEC article 250 and local regulations. Reliable instrument grounding ensures personnel safety, signal integrity and equipment protection.

Control systems are faster and more capable. Advances have resulted in dense integrated circuits with low signal voltages. While the decrease in voltage allows for increased circuit density and higher operating speed, they are susceptible to damage due to overvoltage and transients. Proper grounding is essential in preventing transient over voltage.

Personnel safety, equipment protection, and signal accuracy are the three reasons for grounding. Electrical safety is essential in the grounding design; the NEC article 250 requirements for grounding need to be satisfied. Isolated grounds are not allowed and are a safety hazard with lightning.

Table 38
Noise and Transient Effects on Equipment Failures

Equipment	**Transient**		**Continuous EMI**
	2 x Normal	**4 x Normal**	
Circuit Board Failure		●	●
Data Transmission Error	●	●	●
Power Supply Failure	●	●	●
Memory Loss	●	●	●
Hard Disk Crash		●	
Program Lockup	●	●	●
SCR Failure		●	

It has been found that 28% of industrial electronic failures was overvoltage, which is the highest source of failures. Low impedance grounding or bonding is the simplest protection method and is key to overall performance.

The ground system needs careful planning from the beginning of the control system design. Distributed control system and programmable controller suppliers furnish installation manuals which address their basic grounding requirements. The system and equipment grounding design should meet or exceed the requirements of the instruments and control system suppliers. A detailed grounding diagram should be developed and reviewed with the equipment suppliers.

8.5.2 Conduit and Tray Grounding

The physical interface between a conduit, a wireway, a cable tray, or equivalent is accomplished by a direct connection or by jumpers. Protecting control equipment from noise and transients needs a suitable grounding design and installation procedure.

Creating a ground path along the raceway is a useful tool for electrical noise reduction. Cable tray and raceways should be continuously grounded their entire length with parodic attachment to the plant ground grid using low impedance bonds. Care should be taken to assure that cathodic protected equipment is electrically isolated.

Conduit should be connected to the facility ground system even if it is used for enclosing power circuits. The conduit should use clamps and brackets attached to the structural steel and grounded to plant ground grid. The brackets and hangers should be securely grounded to the conduit and the structural members. The screws on the cover plates of pull boxes, junction boxes, and outlet boxes should be tight and in place. Grounding locknuts should penetrate the paint or other nonconductive finishes.

The joints between conduit sections, fittings, and boxes should be electrically continuous. The conduit and locknut threads should be treated with an oxide inhibiting electrical joint compound before they are engaged and tightened. This applies to Al-Al, Al-Cu and Al conduit threads as well as galvanized conduit.

Similarly, the cable tray and supports should be electrically continuous. The cable tray joints that are not inherently continuous should be bonded with jumpers sized for the conductors contained in the cable tray.

For higher frequency protection full bonding plates should be supplied. The tray grounding to enclosures should be like the method used to join the trays together. The following are bond types between trays in the order of desirability with the last being the best for high frequencies:

a. Short bonding wire; ≤100kHz
b. Multiple short braid straps; ≤100MHz
c. Plates bolted or spot-welded across the seams

8.5.3 Grounding Networks

Grounding or Bonding networks are key to reliable system operation. IEEE 142 and IEEE 1100, covers grounding in depth. There are two grounding system types used in control systems:

a. Single-Point Grounding
b. MESH Grounding

8.5.3.1 Single-Point Grounding

The single-point grounding system was developed several decades ago to deal with low frequency ground loop noise while resolving conflicts with the electrical code. The electronic equipment ties together at the same point at the plant grounding system. This overcomes NEC violations that were created by using independent grounding electrodes.

When the electronic equipment grounding electrode and the electrical power system grounding electrode are connected, a transient voltage rise into the building steel results in the entire electronic equipment system rising and falling with the building steel. So, overvoltage is not induced into the electronic circuits.

Single-point grounding systems should be designed according to supplier or NEMUR NE 98 Section 14 standards. NAMUR NE 98 requirements often exceed supplier standards in that it considers the RF frequencies of the noise, and it incorporates utility piping.

Star Grounding is a form of single-point grounding. The different grounds are segregated according to their function with the more noise prone devices isolated on their individual branches. In particular, power grounds should not be used as instrument grounds. The star points are joined together at the main busbar.

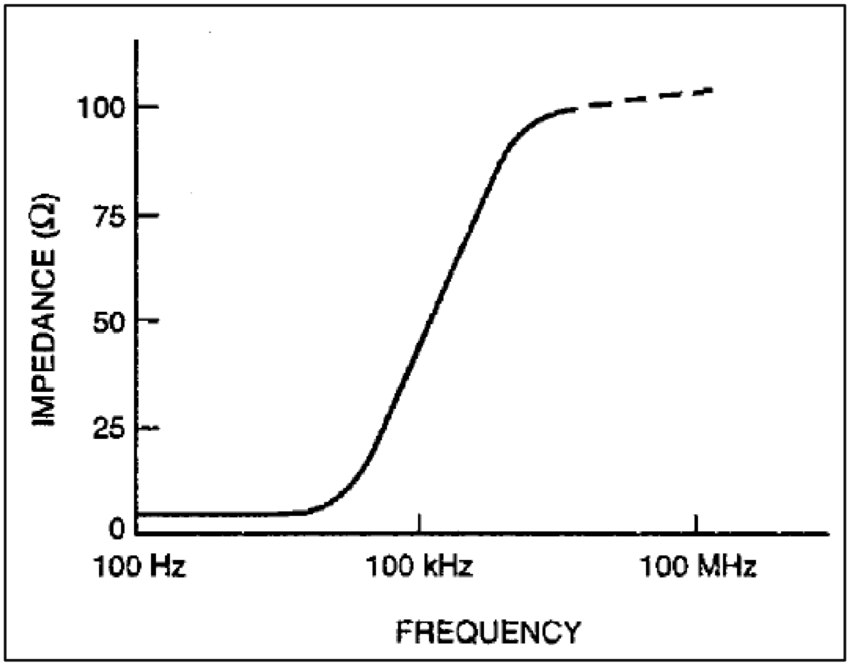
The star ground branches are:

a. Safety/Case/Shield [1]
b. Instrument Signal Reference
c. Zener Barrier Intrinsically Safe Ground
d. Electrical Power Supply
e. Lightning Protection

Note 1: For safety, connect nearby conductive items to the cabinet ground system.

A single-point ground system is appropriate for systems operating under 300 kHz. Once the signal ground cable begins to approach 0.15 of the signal's wavelength, the ground cable can no longer be considered a low impedance path. Ten feet of 12 AWG wire with standard insulation has an impedance of 90.8 ohms at 300 KHz while 6 AWG wire of the same length would have an impedance of 17.4 ohms. The graph below impedance versus frequency for a circuit shows how impedance increases logarithmically with frequency.

Figure 20
Typical Impedance versus Frequency



At low frequencies, if the cabinets are separated by distances more than 150 meters (500 feet), a ground cable cannot be considered a low impedance path. In both cases, multiple-point grounding techniques become necessary.

Interconnections between buildings should use isolators at both ends of the cables. This overcomes the capacitive induced voltages between the buildings caused by separate grounding. The alternative is isolation of the interconnected signal cables using fiber-optic cables or supplying surge protectors.

Figure 21
TIA 607-C Isolated Grounding Busbar

Single-point grounds need frequent rigorous inspection. They are a point where its failure affects the entire system and can put it out of commission. There have been instances where the connection become corroded and suddenly fails.

To lower the impedance between systems the distances to the local ground bus should be kept short using a low impedance, heavy gauge, highly-stranded copper cable that is at least a 6 AWG wire. Braided straps in RF applications should be at least one inch wide and fabricated from a fine wire that is tinned to resist oxidation. The cable should be secured with a two-hole compression lug. Solid copper TIA 607-C busbars with tin plating are recommended.

8.5.3.2 Equipotential Bonding

8.5.3.2.1 MESH-BN Concept

With digital systems and data processing the separate ground concept has been abandoned and international standards now prescribe an equipotential combined ground system. There is no such thing as clean and dirty ground as practiced with a star single-point ground system.

With the advent of Ethernet APL high frequency field signals will be the norm. The “Ethernet-APL Engineering Guideline” sponsored by the FieldComm Group, ODVA, OPC Foundation and Profibus & Profinet International uses the mesh equipotential grounding system. NAMUR NE 98 grounding system is based upon high frequency equipotential Mesh bonding. Mesh BN or MCBN are recognized by IEEE 1100 the Green Book. Ethernet Switch providers also recommend a common Mesh bonding system.

A multiple-point ground or MESH-BN system should be considered for equipment that function above 30 kHz and certainly when operating over 300 kHz. A MESH-BN is a grid of grounding conductors based upon IEC 61000-5-2, TIA-607-B and the Bisci™ Telecommunications Distribution Methods Manual. The advantages are grounding is easier and standing wave effects at high frequencies are avoided.

A MESH-BN augments the normal facility CBN (Common Bond Network) by increasing the local density of the conductors and functions by diversifying and limiting the radio frequency (RF) capture-loop area of the current paths. The current density on any conductor or conductive loop is reduced to an acceptable level.

A consideration with a multiple-point ground system is that the system can create multiple low-frequency ground loops that can cause common-mode noise in low-frequency circuits, but the signal reference structure (SRS) design used to create the multi-point ground reference alleviates this problem. A meticulously designed system is free of ground loop issues.

The intent of the MESH-BN grid is to create a low impedance ground with the facility CBN to control the noise voltage amplitude regardless of its frequency. It is not an isolated ground but bonds the ground points together. Its easiest application is in new installations. It has the advantage that its operation does not need tight monitoring of unintentional grounds as needed for a single-point ground system and does not have a single failure point.

8.5.3.2.2 Frequency Requirements

The first step in designing a MESH-BN is to determine the immunity level need and the maximum noise frequencies that need to be managed. The frequency of both the noise source and the victim electronic needs to be considered. For victim circuits, the associated equipment clock frequency indicates its susceptibility.

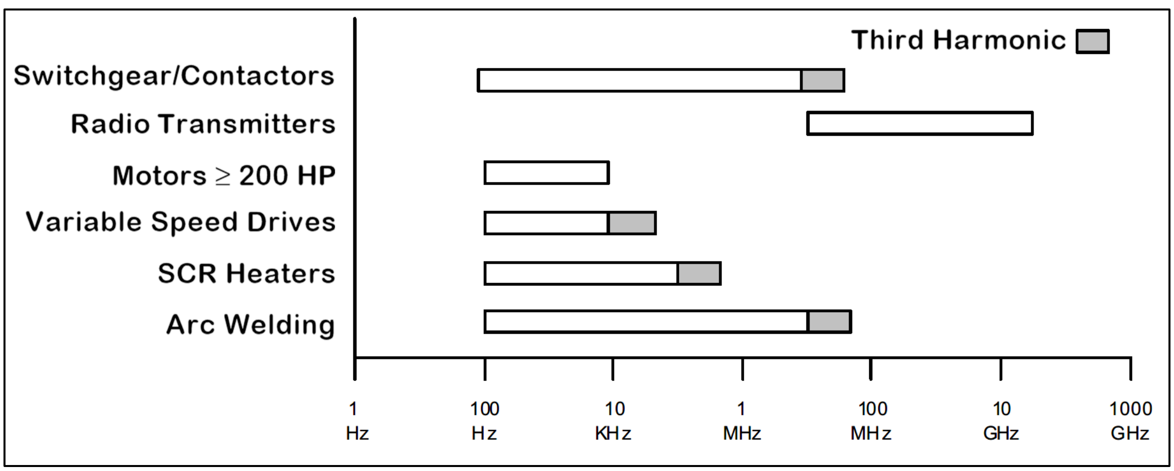
Eighty percent of the electrical noise and transients is generated within the plant. The rest is caused by sources, such as lightning and electrical switching.

Current chopping by an electrical contractor can be as high as 2 MHz. The frequency when opening a circuit breaker is about 100 kHz. VFD's and some higher voltage motors can produce noise up to 10 MHz.

Lightning is known to emit significant electromagnetic energy in the frequency range from below 1 Hz to nearly 300 MHz. There are many processes in lightning flashes. For an idealized lightning impulse, about half the energy is in the first 7 harmonics, or below 120 kHz. The peak occurs around 10kHz and there is little energy above 1 MHz. More information concerning lightning protection is covered in depth by IEC, NFPA and IEEE standards.

The transient amplitude tends to fall significantly as they approach 10 MHz. Systems intended for protection greater than 10 MHz needed bonding such as wide flat conductors or many short (100mm) conductors.

Figure 22
Typical Equipment Noise Frequency Ranges



8.5.3.2.3 Design

Different density meshes are used depending on the equipment being protected. The MESH supplies multiple paths for the resonance frequencies. The MESH is created using a grid structure with the frequency determining its size. Loose meshes being used for ordinary electrical equipment with tighter meshes for high speed processors and telecommunication systems.

These meshes are not isolated but grounded to the building steel and facility ground system at multiple points so that incoming major current spikes are diffused and drain away without the current re-concentrating. Multiple interconnections creating a three-dimensional mesh, are desirable. Increasing the CBN conductor quantity and their interconnections increases the shielding capability and extends the system upper frequency limit.

Wall and concrete column reinforcing rods as well as steel structural frames should be used as "natural" down-conductors where conveniently possible. The intent is to create a Faraday cage. A well designed grid can keep the local ground plane within a few volts of the true ground despite severe high frequency spikes.

For instance, for protection from lightning surges a MESH-BN with a mesh size less than 4 meters in any dimension including the diagonal is used. As installed as square it would have four 2.8-meter sides.

High-frequency equipment such as computers, Ethernet switches, or telecommunications systems need a small mesh size 600 mm or less. Many Ethernet switches need high frequency protection so multiple connections are necessary to a dense grid. For instance, tighter meshes are recommended when high speed Ethernet switches since switch backplane speeds can exceed 800 MHz.

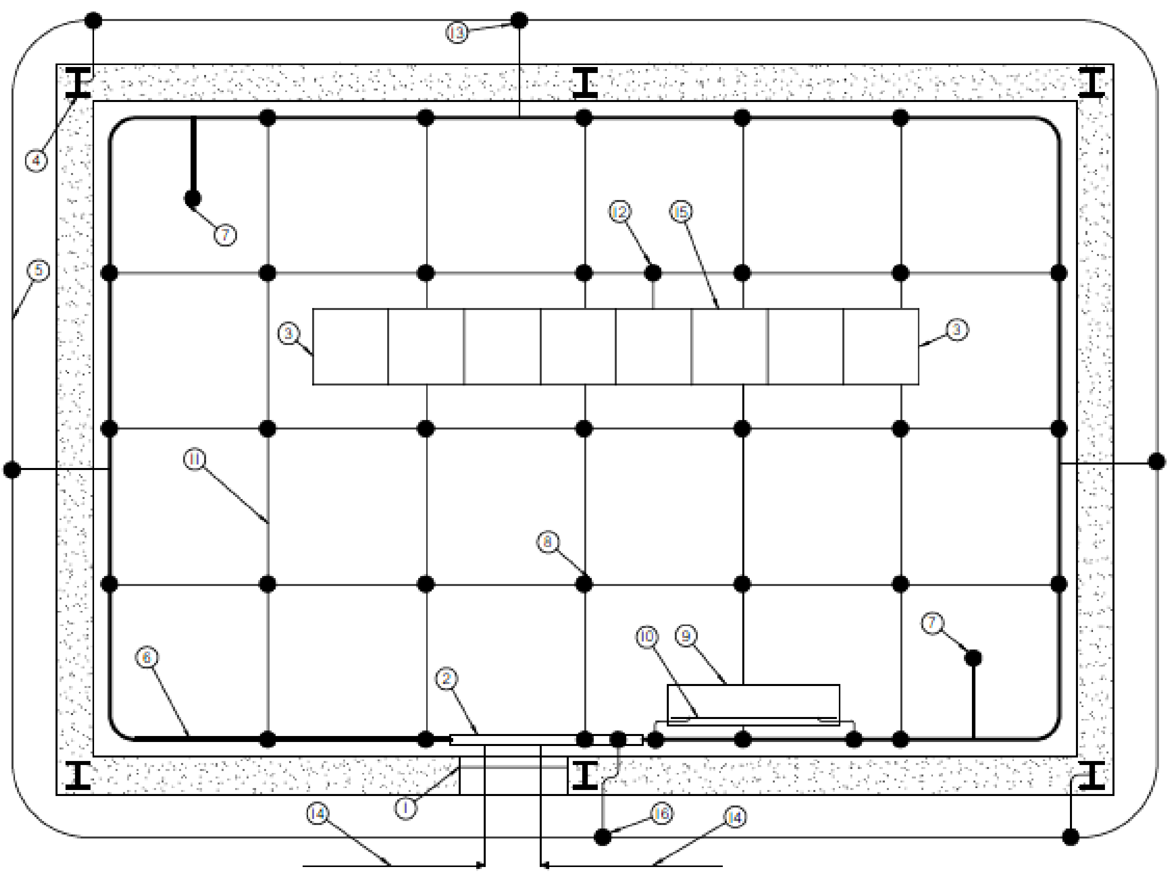
MESH grids can be nested to supplied successively higher protection. Transition from one MESH zone to another follows the same practices, see section 8.4.1, that would apply going from an unprotected location to one that is protected. Another alternative is setting up different MESH islands, each is intended for a specific protection level. The latter needs shield grounding only once instead of the successive shield grounding that the former would need as the signal cable moves in turn into each zone.

The mesh or grid is typically laid out in a raised access floor using a low impedance, multi-strain, or braided copper cable. Overhead meshes are an alternative when raised access floors are not used. Flat copper strips can supply protection up to 100 MHz and can be more effective in new construction.

Figure 23
Building Bonding MESH

MESH BN

1. Facility Electrical and Utility Entrance
2. Shields, surge protectors and RF filters for cables bonded at the main grounding bar
3. Individual cabinets with noise sensitive equipment
4. Bond to the building steel and concrete rebar
5. Ground ring with ground rods as needed
6. Bonding Ring Conductor (BRC) 50 sq mm minimum cross section
7. Grounding pad in floor connected to concrete rebar
8. Bond Underfloor Grid with clamps with welded connections else where
9. Field Signal Termination Cabinet
10. To serve as a ground plane bond Termination Cabinet back panel to BRC two places
11. AWG #2 Conductor Suppemental Bonding Grid
12. Typical cabinet bond to grid at least one per cabinet
13. Ground ring bonded to BRC at 5m spacing or less
14. Signal, power and utility pipes enter and are bonded at a common entry point
15. Bond Each Electronic Cabinet to Suppemental Bonding Grid Grid
16. Place an earth electrode near the main ground busbar



The bonding grids are exothermic welded or joined together with heavy-duty compression connectors intended for ground systems. Bolt type clamps are not recommended and should be limited to revamp work.

Round cables are less effective for bonding where frequencies are above 10 MHz. Due to surface current flows at high frequency, a round conductor, has a higher impedance than a flat conductor with the same material cross-section. Still, the use of a flat conductor for grounding rather than a round cable can be overstated. Lower impedances are achieved by multiple bonds using short round connectors.

8.5.3.2.4 Bonding Ring Conductor

The Bonding Ring Conductor (BRC) should encircle the MESH-BN. It should be a round copper conductor with a cross-sectional area ≥50 sq. mm such as a perimeter electrical grounding busbar or lightning tape. The lighting tape should be at least 25mm x 2mm. An alternative is a round conductor with at least 8mm diameter. The BRC should be solidly bonded together and to the MESH-BN.

8.5.3.2.5 Main Grounding Terminal

A Main Grounding Terminal, which is a copper busbar or plate, should be placed in series with the Bonding Ring Conductor so that it is integral with it. The Main Grounding Terminal should be wide enough to accept several two-hole lugs as well as 360° shield grounds. It should be plated or stainless steel for corrosion resistance. Where many instrument signals are routed the main grounding terminal can be a grounded backplane in a marshalling cabinet. The cables should enter from one side of the Marshalling Panel. See ISO/IEC-30129 “Telecommunications Bonding Networks for Buildings and Other Structures” for details on cabinet grounding and bonding to MESH networks.

The AC power entrance, signals cables and the grounding conductor entry should be close together and grounded on the Main Grounding Terminal. It is desirable that the egress points for the conductors entering the facility, including the grounding conductor to be placed close together by the Main Grounding Terminal. This includes metal pipes and conductive fluids. Conductive fluids in plastic or other non-conductive pipe should be supplied with a grounding ring like those used for a magnetic meter.

The conductors and conductive utilities e.g. metal pipes for gas, water, and air, entering at a detached area should be RF-grounded, either directly, or indirectly through filters or surge protection devices (SPDs), at the Main Grounding Terminal where they cross the Bonding Ring Connector (BRC).

The Main Grounding Terminal should connect to the following:

a. With a short conductor, the closest grounding electrode [1]

b. When an isolation transformer or UPS is not supplied, the AC electrical service ground. Also, the PEN or PE in IEC TN electrical systems should be connected.

c. The incoming measurements and outgoing control signal shields [2]

d. EMI filters and surge protector grounds

e. Metallic pipes and conducting fluids in non-conducting plastic pipe [3]

f. Other elements of the facility CBN such as rebar and the structural steel

g. The lightning protection system down conductor

Note 1: Supply added grounding electrodes as necessary to achieve the desired true earth ground resistance. A control system is considered a critical facility so a 5 ohm or less DC ground resistance is recommended. The resistance should be measured according to IEEE 81 methods.

Note 2: Conductors without shields; such as power cables or UTP Ethernet cables, should be supplied with an EMI filter or surge protector mounted on the Main Grounding Terminal.

Note 3: Corrosive restraint ground rings should be provided for plastic pipe that contact the fluid. Ground rings for magnetic meters serve this purpose.

The facility CBN should be connected to the Main Grounding Terminal. Multiple conductors between the CBN and the Main Grounding Terminal are recommended.

The facility CBN should have a ring conductor that surrounds the building between three and six feet with the ground rods and building steel attached to it. The Main Grounding Terminal of the CBN should be extended by a Bonding Ring Conductor around the building interior. In effect this is an internal bonding ring within an exterior grounding ring.

8.5.3.2.6 Shielding Effects of the CBN

As contributors to the shielding capability of the CBN. Interconnection of the following CBN elements is important:

a. Metal building parts including I-beams and concrete reinforcement where accessible
b. Cable supports, trays, racks. raceways, and AC power conduit

It is best to avoid routing signal cables in the protected area periphery. When this is unavoidable, for sensitive high-speed data circuits a conduit or enclosed tray can be needed.

In steel frame buildings, the shielding effects that the steel frame supplies against lightning strikes helps. For cables extending between floors. Maximum shielding is obtained by placing the cables near the building center.

The CBN facilitates shielding by supplying a low impedance path in parallel that is close to the shields. The current driven by the potential difference is carried by the CBN. Disconnection of a cable shield for inspection negligibly affects the current distribution in the CBN. See section 8.4.2.1.2 for further information.

8.5.3.3 Isolated Bonding Network (IBN)

An isolated bonding network (IBN) has a single-point connection or single point ground to either the MESH-BN or another isolated bonding network. Typically, this is a system-level grounding topology required by an original equipment supplier (OEM). The IBN uses a single-point connection interface to the rest of the MESH-BN.

8.5.4 Cathodic Protection Systems

Impressed current systems for cathodic protection can erode conduit, tray, shields, and signal grounds. Eventually the single point ground connection fails. NEC article 250 allows the isolation of DC ground currents from cathodic protection systems.

An AC coupling/DC isolating device is permitted in the equipment grounding conductor path to provide an effective return path for AC fault current while blocking the DC current. Also, instrument signal cables should not be tied directly to cathodic protected equipment unless isolators or fiber optics are used.

8.6 Surge Protection

8.6.1 Surge Protection

Induced surges on signal lines are characterized by a rapid, high intensity rise of short duration. A sustained surge can occur when power lines fall across a signal line.

Installations should be evaluated to determine potential surge sources and durations. Instrument cables subjected to high voltages from lightning, electrostatic phenomena, or power-line transients need surge protectors and isolators.

There are several high-voltage electrical surge sources. Lightning can strike the cable directly, but more commonly it is caused by a nearby strike that becomes electromagnetically coupled to the line. Surges can also occur from switching transients in nearby power lines.

Long runs to remote locations; such as tank farms, as well as transmitters and valves found at the top of towers and other high points are surge prone. Also signal runs on marine jetties are exposed to lightning surges. Also, certain regions such northwest Australia and centrical Africa experience severe lightning storms.

8.6.1.1 Methods of Surge Protection

An effective method to avoid electrical surges in electrical active zones is to use fiber-optics or digital wireless devices to carry analog, digital or control signals. The fiber optic cables do not behave like antennas, they supply galvanic isolation that disregards electromagnetic disturbances, and they can manage high data rates. Wireless devices with digital signals supply similar isolation and are incapable of transmitting unwanted noise.

Lightning effects can be reduced with a grounded protection wire above the signal cable. The shield wire supplies a triangular shield wedge. This triangular area has a base that is twice its height so if the shield wire is one foot above the cable, the cable is protected by foot on either side of its centerline. These are often used in power transmission. Power wires above a signal cable provide protection like a shield wire. For added installation information see ANSI/NFPA 78, Lightning Protection Code.

To ensure reliability methods other than surge protectors are desired. If fiber optics or wireless is not a choice, nor routing along shielding such as steel pipe, structures, or conduit, then consideration can be given to installing surge protectors. Surge devices are available for analog and data transmission circuits. See IEEE 1100 for detailed information on further information on surge protection.

Figure 24
Surge Protector Schematic

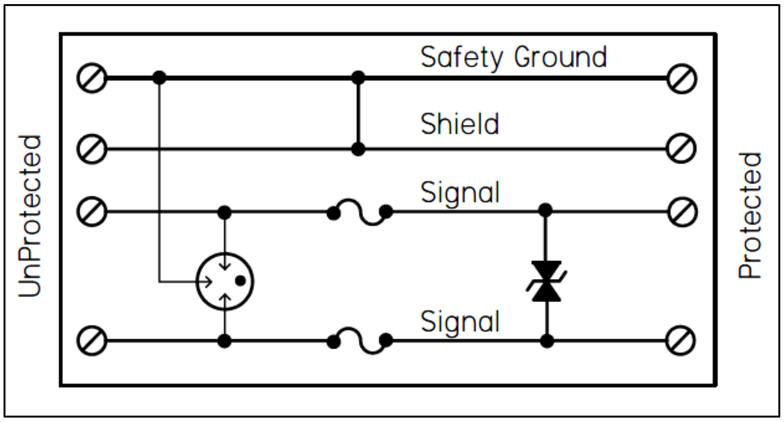


Figure 25
Field Device Surge Protector

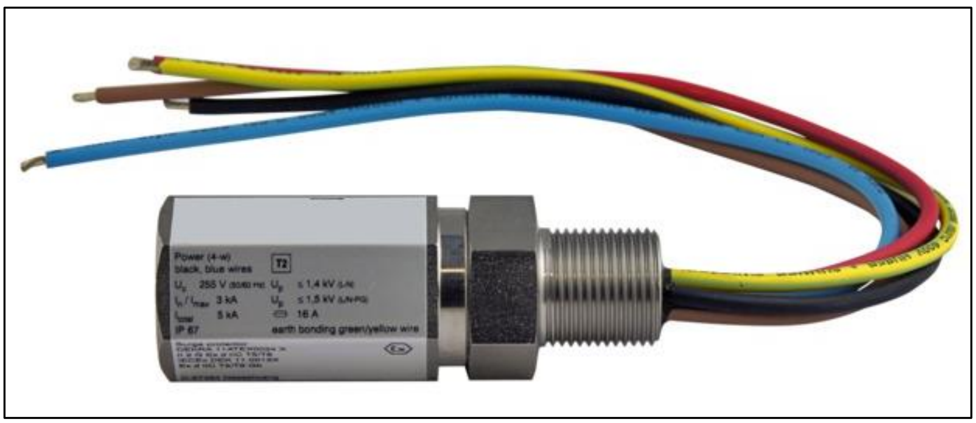
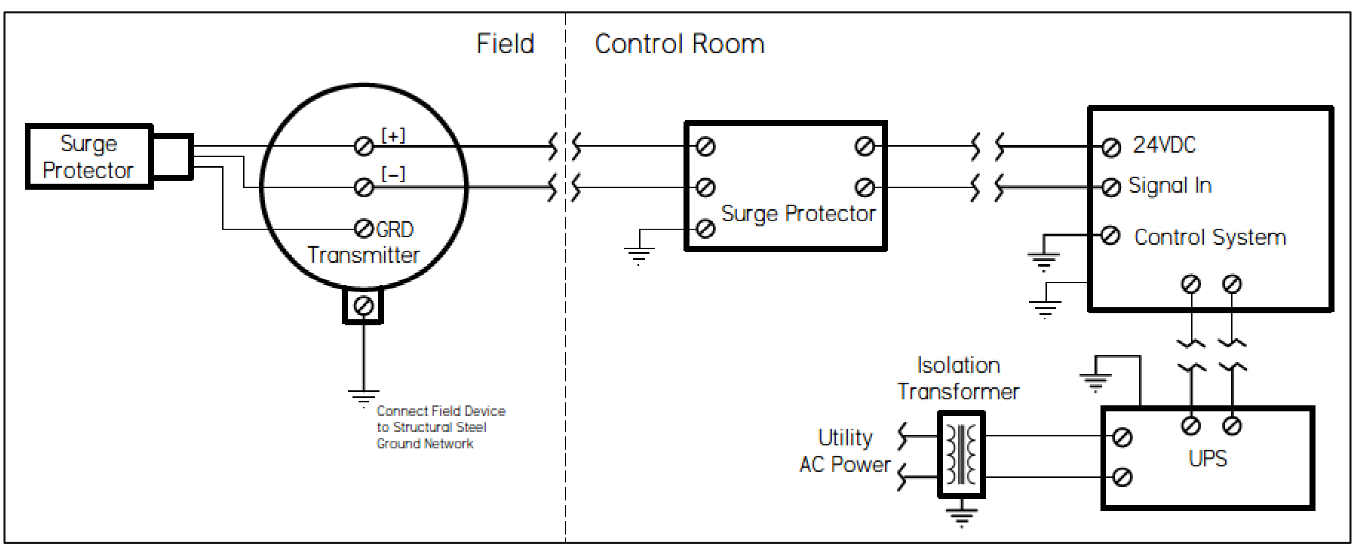


Figure 26
Connection of Surge Devices



8.6.1.2 Electrical Surge Protectors

The surge protection devices should not sacrifice fidelity or availability. For current loops, the two signal wires are isolated from the ground. See Figure 24. See IEEE 1100 for detailed information on further information on surge protection.

To protect them from transients, surge protectors are needed at both end points. See Figure 26. Field devices are protected by threading a surge protector onto the field device housing. See Figure 25.

Transient normal-mode voltages between signal wires and common-mode voltages to ground are limited at both end points. Also, the surge protector should be equipped with a multi-stage protective circuit.

Surge protection systems need inspection and maintenance to be dependable. Since surge protection can fail covertly, IEC 62305-3 requires testing. The time interval, is between one and four years, depending on the service.

Status detection is available for protective devices. For instance, there are LED indicators and contacts. A yellow status shows that the protective device is nearing the end of its life. This makes it possible to plan an early replacement before failure. Immediate replacement is needed when the red LED is illuminated.

8.6.1.3 Surge protector types

Surge protectors are classified into the two following types:

a. A filter serves as barrier to high frequency noise current, while allowing the low frequency power or signal current to pass through unaffected.
b. A transient diverter is a device that has a low impedance to ground whenever the voltage exceeds its trigger value preventing the high voltage going to the equipment.

The device should match the service. The surge protectors listed below have a range of current and voltage limiting capacities.

8.6.1.3.1 Spark Gap Arrestors

Gap arrestors divert the excess current from the line to ground using inert gas as conductor between the signal or power line and ground. Normally, the inert gas is a poor conductor, but when the voltage is above the trigger level, the inert gas ionizes becoming a conductor stays that way until the voltage returns to a normal level.

Unless they are properly matched DC voltages can be a problem for spark gap protectors. Some spark-gap arrestors do not turnoff after being triggered. The circuit operating voltage should be below the extinguishing voltage.

8.6.1.3.2 Solid-State Devices

Solid state devices such as Metal Oxide Varistor (MOV) or Silicon Avalanche Diodes, are used to protect DC circuits. However, solid-state devices are normally not used alone. These devices conduct rapidly, but do not have the energy capacity necessary to fully protect the instruments. These components are normally used with other protection devices, such as gap arresters, inductive devices, and resistors.

8.6.1.3.3 Inductive and Resistive Limiters

Resistive and inductive Impedance is used to limit the surge current to prevent the destruction of devices such as shunt diodes.

8.6.1.3.4 Hybrid Devices

Semiconductor devices are often used in conjunction with fuses or gap arrestors devices for limiting low transient voltages as well as high surge currents. See Figure 24 for a typical circuit. Refer to IEEE 1100 for detailed information on surge protection and snubbing circuits.

8.6.2 Inductive Spike Suppression

Inductive spikes occur from the collapsing field when the current is switched off to an electrical coil. Spikes can damage electrical contacts and circuits and should be mitigated with a bypass circuit.

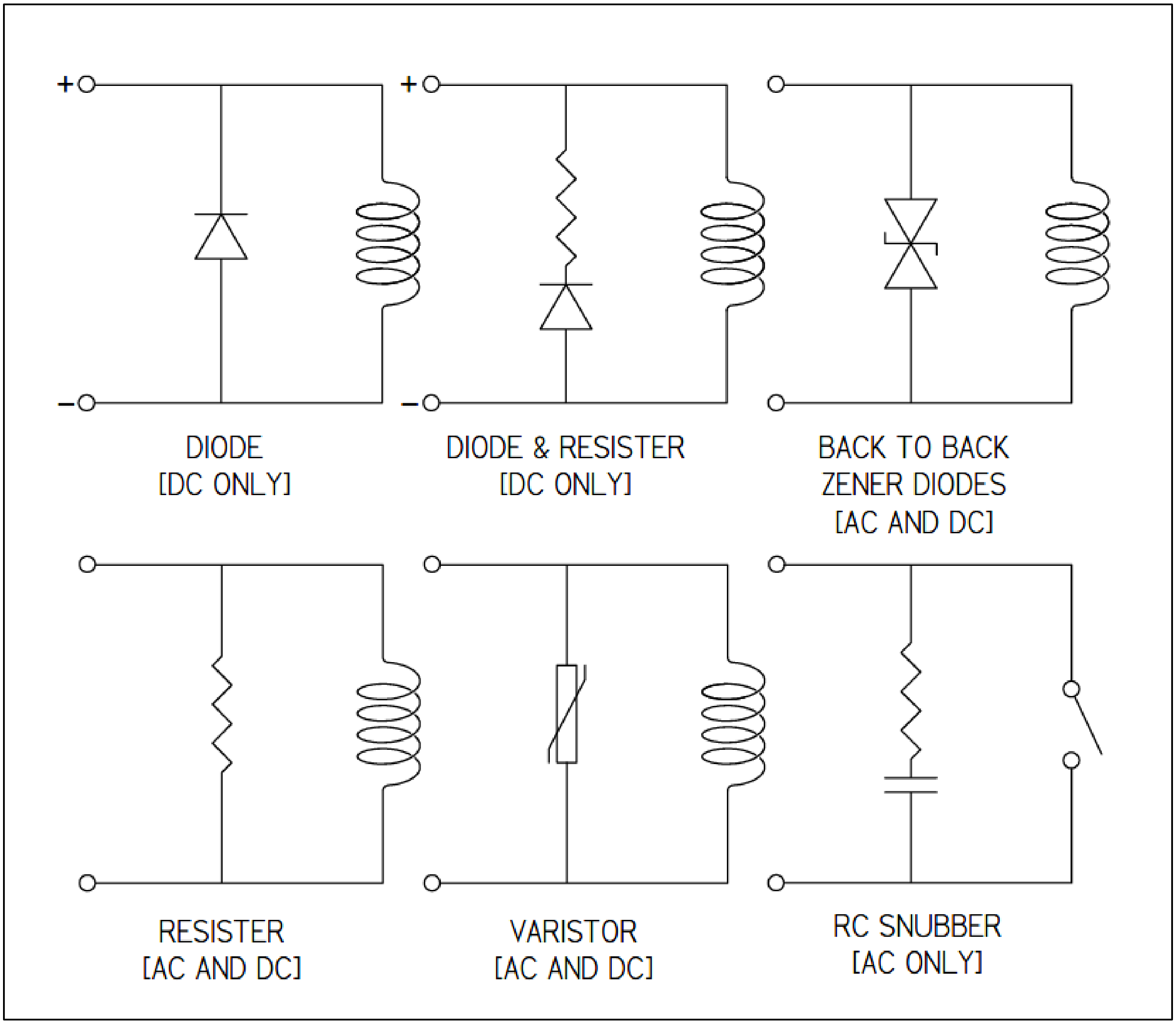
Placing a diode in parallel with the coil suppresses the spikes in a DC circuit. This is a low impedance path that prevents voltage buildup from collapsing coil field. The diode is back biased during normal operation and acts as a short-circuit to the inductive kick. The diode is selected so it has a high reverse current that matches the coil current.

For AC and DC circuits metal oxide varistors, back to back Zener diodes, varistors or Tranzorbs® clamp the inductive spike to a fixed voltage. They let the spikes through up to the clamping level of the device.

A resistor in series that is equal to the coil resistance reduces the switch-off delay and prevents a short circuit if the diode fails. It also lowers the Q factor in the LCR circuit which reduces the oscillations from the de-energized coil.

A variation is using a resistor, capacitor, or a resistor plus a capacitor; i.e. snubber, to suppress the inductive kick in both AC and DC circuits. They need to be correctly sized to minimize changes to the overall circuit.

Figure 27
Spike Limiters Across an Inductive Load



The best location for the protection is parallel to the coil. If the leads to the coil are long, it can be necessary to place added protection across the initiating contact since the cable inductance still can cause voltage spikes. RC snubbers are sometimes used across switches for this reason.

Noise suppression networks can change the operation speed. Diodes and resistor-diode networks should be used with caution where this affects safety. A diode used with a DC solenoid or relay can increase the dropout time by a factor of 10 or 20. It is best to consult supplier literature for selecting the proper components for snubber circuits.

8.7 Ethernet Installation

8.7.1 Installation Practices for Ethernet

There are several recognized installation practices for installing Ethernet and other industrial networks. See Table 39. They provided detailed requirements for planning and installing the infrastructure for high speed networks.

Table 39
Network Planning and Installing Specifications

Document Number	Title
ODVA 00035R0	Network Infrastructure for EtherNet/IP™
ODVA 00148R0	EtherNet/IP™ Media Planning and Installation Guide
PNO Order Number 8.072	PROFINET Installation Guideline for Cabling and Assembly
ANSI/TIA-568.0	Generic Telecommunications Cabling for Customer Premises
ANSI/TIA-568.1	Commercial Building Telecommunications Cabling Standard
ANSI/TIA-569	Telecommunications Pathways and Spaces
ANSI/TIA-607	Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises
ANSI/TIA-1005	Telecommunications Infrastructure Standard for Industrial Premises
IEC 61918	Industrial communication networks – Installation of communication networks in industrial premises
ISO/IEC 24702	Information technology – Generic cabling – Industrial premises
ISBN1-928886-32-9	BICSI Telecommunications Distribution Methods Manual

Further, the IEC 61784-5 Installation Profile set of standards provide guidelines for the installation of the IEC 61158 fieldbus types including FOUNDATION Fieldbus HSE (IEC 61784-5-1), EtherNet/IP™ (IEC 61784-5-2), PROFINET (IEC 61784-5-3) and Modbus TCP (IEC 61784-5-15).

8.7.2 Ethernet and Fieldbus Connectors

TIA/EIA-568 is the standard for data circuits installed with modular connectors. The 8P8C modular connector commonly referred to as the RJ-45 connector is used to connect four pair Ethernet Category 5 and 6 cables and their derivatives. The 8P8C connectors are built according to IEC 60603-7 standards. Due to a larger wire diameter Cat 6 wire does not fit into a Cat 5 connector.

The IEC 61076-3-106 Var. 1 connector and IEC 61076-3-117 connector for EtherNet/IP™ and PROFINET respectively are IP67 ruggedized 8P8C connectors equipped with hard metal shells and a locking features.

The IEC 61076-2-101 M12-4 Code D Ethernet are pin style connectors. It provides IP67 or better level of environmental protection. They are also used with MBP fieldbus systems. When an encapsulated connector is needed, the use of a single method is recommended throughout the facility.

The M12 is available in the following keying/coding options:

A: Primarily for sensors and actuators
B: PROFIBUS fieldbus connections
C: Dual keyway primarily for AC sensors and actuators
D: 100 MB EtherNet/IP™ 4-pin
X: Gigabit Ethernet 8-pin

The connectors should be terminated according to ISO/IEC 24702 with the ISO/IEC 24702 CFP designation. ISO/IEC 24702 also provides guidelines on other commonly used connects.

Standards based connectors are not rated for hazardous areas. However, there are military style threaded 8P8C connectors that are similar to the standard connectors available.

8.8 Close Circuit Television

This section covers the type of cabling required for CCTV and its installation. The specification of cameras, monitors and switches are covered elsewhere. For further details on camera applications see IEC 62676-5 plus UFC 4-021-02NF from the Department of Defense on security system design including peripheral CCTV devices such as monitors and switchers. For camera installation refer to NECA 303, “Standard for Installing Closed-Circuit Television Systems.”

Besides being used for general security and safety, CCTV is used in the following refining services:

a. Coke Cutting
b. Safety Showers
c. Liquid Decanting
d. Flares
e. Furnace Fireboxes
f. HF Alkylation
g. Pump Seals
h. Coke Conveyers and Crushers
i. Rail Car Loading and Spotting
j. Marine and Truck Terminals
k. Tank Farms

There are various methods for transmitting television signals:

1. Analog Transmission
    a. Coaxial Cable
    b. Twisted Pair
    c. Fiber
2. Digital Internet Protocol (IP)
    a. Hardwired
    b. Wireless

8.8.1 Analog Cable Transmission

Digital systems are displacing though analog CCTV a large infrastructure of these cameras and the related video equipment exists. NTSC or PAL, which have a resolution of 480i, are the most common standard analog TV signals. For 1080p analog video HD-TVI, AHD and HD-CVI are used with HD-TVI being the most common in North America.

Analog CCTV cables, regardless of the quality, have problems transmitting video signals. The issue is signal bandwidth. Cables signal losses are dependent on the frequency, the higher the frequency, the greater the loss. The result is degradation of image detail.

For instance, using a common 75 ohm coaxial RG59 cable 50% of the half the signal is lost in the first 200 meters. This limits an unamplified cable run to 250 m (820 ft.) Amplifiers are able to boost the higher frequency video signal components to overcome the cable losses.

Power for analog cameras is transmitted separately as either 24 VDC or more commonly 12 VDC. Power and video cables often run together in a Siamese cable.

Additional conductors are required to control the camera pan, tilt, and zoom. RS-485 signals typically are used for PTZ control. There is proprietary technology, some of which is used by multiple vendors, which allows control of PTZ cameras by combining video and control signals on the coaxial cable.

Also discrete alarm signals are frequently provided to control the camera position. Also space heaters are provided to manage the enclosure humidity. Except for space heating, IPTV camera using power over Ethernet (POE) technology combines these services into one twisted pair Ethernet cable

8.8.2 Analog Cable Types

Unbalanced; i.e. coaxial and balanced; i.e. twisted pair cable are used to transmit video signals. An unbalanced signal is a voltage referenced to ground. For instance, a video signal from a camera is between 0.3 and 1.0 volts above zero; i.e. with the shield being the ground level. BNC Connectors or less commonly F connectors are used with CCTV coaxial cables.

A balanced signal is a video signal that is converted for transmission along a twisted pair cable. The signal voltage is the difference between the voltage in each conductor.

Interference rejection is accomplished in different ways. Coaxial cable uses the center conductor being screened by the outer copper braid. The cable should have a 95% braided shield.

In the case of a twisted pair cable, interference is picked up by both conductors equally. The interference is then balanced out by the differential amplifier.

Table 40
Typical Analog Video Cables

Cable Type	Typical Effective Distance [1]
Coaxial Cables	
RG-59/U [2]	250 m
RG-6/U	350 m
RG-11/U	500 m
Twisted Pair Cables	
Cat 5 [3]	275 m
Cat 5e/6 [3]	335 m
Note 1: These distances are for planning purposes, actual distances vary depending on the camera signal and the resolution desired.	
Note 2: Based upon solid copper core with a 95% copper braid shield.	

Note 3: The distance is based upon a passive balun, the distance is reduced to as little a 50m when feeding power to the camera.

A video balun is used to go between 75 ohm coaxial and 100 ohm twisted pair system. Passive baluns contains an impedance matching transformer. Active baluns contain signal amplifiers that double or triple the effective distance. However, the distance power can be transmitted by the associated Cat 5 cable pair is limited by the camera current requirements.

Analog fiber boosts the distance that a signal can be transmitted. A transmitter converts the analog video into modulated light signals. A receiver on the far end converts it back to an analog voltage signal. The principle of transmitting video is similar to transmitting data over optical fiber. The signal loss in optical fiber is less than in coaxial cable, this allows longer distances.

8.8.3 Internet Protocol (IP) Transmission

IPTV systems use standard Ethernet systems to transmit the signal. Many cameras use IEEE802.3af power over Ethernet (PoE), which supplies power to the camera over the same wire pair.

Ethernet systems have advantages over analog systems such as ease of use, advanced search capabilities, simultaneous record and playback, improved image quality, and efficient compression and storage options.

IP-based systems benefits include:

a. Remote accessibility
b. High image quality
c. Flexibility [1]
d. Scalability
e. Power over the signal cable
f. Error correction

Note 1: IP-based systems can share a common Ethernet backbone with other systems.

To observe flames in furnace operations, infrared high definition images are used. High Definition (HD) requires 4 to 10 Mb/s, so Gb/s channels are recommended. MPEG-TS is the most common digital protocol for CCTV transmitting video. Live streams are compressed and sent as UDP packets rather than using the TCP protocol containing 7 x 188 byte MPEG-TS packets for a total of 1,316 data bytes. Including the standard UDP and IP headers. These packets are smaller than the standard maximum Ethernet MTU of 1,500 bytes which prevents image fragmentation.

The addition of encoded media equipment allows traffic shaping to eliminate traffic spikes, both overall and on individual streams. Smoothing are important, because the ability of individual client devices to manage traffic spikes can be much lower than that of the network infrastructure.

9 FIBER OPTIC CABLE

There are two fiber optic system types, point-to-point installations, and communication infrastructure systems. The plantwide fiber optic infrastructure is different from a single point-to-point installation and is more complex.

Fiber optic cables have supplied many advantages in petrochemical and refining applications over copper wires. The advantages are as follows:

a. The signals are not affected by electromagnetic interference and can be run near power and other electromagnetic energy sources.
b. Within a plant fiber optic transmission distance is limited by the sensitivity of the related systems, typically 10 kilometers for tight buffer, single mode cable and 200 kilometers for loose buffer.
c. Capacity is high and high-speed data transmission speeds are readily implemented.

9.1 Fiber Optic Planning

A fiber optic infrastructure needs planning that considers growth and technical evolution. There are issues on who controls the fiber infrastructure. Many older plants have ad hoc networks that started out as point to point links Installed by different organizations that evolved into a mesh with the addition of switches. Ad hoc routing is often used with cables being routed on existing supports without physical protection. Hardware incompatibility and duplication is common.

Conversely, new grass roots facilities have installed common fiber backbone networks that link voice networks, business systems, security surveillance, process communications and maintenance operations together. The overlap of security and access concerns has become issues.

A facility can be rendered ineffective and disabled if critical nodes were destroyed. Tightening access to these nodes to a few key personnel improves security but can make the facility brittle. Overhead is introduced that reduces the flexibility of the system. Over standardization can result in unique requirements not being met. As resources become tighter, a system of winners and loser emerges

Some facilities install fiber trunks and allocate the groups of fiber cores to the various departments with a significant percentage allocated at two levels for future use, at the department level and at the facility level.

The fibers are distrusted from a common trunk patch panel to patch panel cabinets that are secured and controlled by the end users. This approach requires additional floor space but gives the groups the ability to evolve their networks as needed.

The system should contemplate probable developments and the eventual migration due to the technological life cycle. An installation should include spare fibers; i.e. dark fibers, as well as unused duct banks and other raceways.

A facility site wide fiber optic system plan and naming scheme should be created considering future developments. In the same way as instrument circuits, raceways, cables, and fibers are shown on drawings and documents. TIA-606 supplies guidelines on now to label and document a system. plans and cable schedules should be kept and updated.

Fibers should be identified by the color, buffer bundle color, cable type and service. The plan should show the origination, normally a device with a patch panel or outlet box and the destination patch panel associated with switch or hub. See TIA-606 and TIA-for schematic symbols used to plan communication networks.

To achieve two-way communication fibers are used in pairs. Continuous process control networks and other critical applications need a second fiber optic pair for communication redundancy. The second pair needs a separate route and communication cabinets. Preferably path one should be underground or barring that made fire resistant. Also, critical applications require patch panel protection from tampering while otherwise making the system physically secure.

Care should be taken to ensure that there are no synchronization issues between redundant channels due to unequal path lengths. A fixed delay fiber coil should be added to the shorter path by spooling strands on a patch panel splice tray to equalize the two lengths. Several hundred feet of a clad, 250µm strand can be wound on the splice tray spools.

9.2 Multimode vs Single-Mode Fibers

There are two basic types of fibers, multimode and single-mode. See Table 41 below. Fibers of the same core diameter are compatible. Multimode is used at lower speeds and shorter distances. It is used for dedicated point-to-point services such as an analyzer system. The maximum length of a 100 Mbps Ethernet signal is 2000m. The faster signals have much shorter lengths.

Single-mode was developed for backbone systems or trunking, but single-mode fiber now is often preferred for standardization. It is capable of higher speeds and long distances. Since it has a low signal attention, problems have been found at short distances with the signal being too strong for some receivers. This is corrected by using a passive plug-in attenuator. The added attention ranges from 5 to 25 db.

9.3 Fiber Optic Cable Types

Fiber optic cables have a tight buffer or loose tube construction and have up to 288 fibers. Both have a strength member, such as aramid. Since they offer better temperature stability, steel or fiberglass epoxy rods can be chosen as strength member when extreme cold performance is needed. Often to avoid electrical grounding issues with Article 770 Part IV an all-dielectric cable that is it is free of electrical conductors is used. Regardless, they still need to conform to Article 770 Part V and VI as far as listing requirements are concerned.

Tight buffered cables can be used in either indoor or outdoor applications. Tight buffered cables are often preferred since they are easier to install since there is no gel to clean up. They come in two forms tight-buffered distribution cable and tight-buffered breakout cable.

The tight buffered cables for outdoor use have a two-layer coating. The first is plastic, and the other, waterproof acrylate. The acrylate jacket keeps moisture away from the cable. Being more robust than loose-tube cables, they are well suited for moderate distance connections, direct burial, and underwater use. Still, they have higher signal losses per kilometer than loose tube construction.

Breakout cable is rugged, but the cable is larger than distribution cable. It is chosen where direct termination to device desired. It does not need a fiber patch panel. For short, point-to-point installations, cable can be supplied pre-terminated or pre-connectorized with fiber optic connectors. To ensure that the connectors are protected these cables can be supplied with pulling eyes.

Loose tube cables are intended for outdoors conditions. They can be either gel filled or gel free. The tubes protect the fiber core by enclosing it within a rigid protective tube. The loose-tube design isolates the fibers from the outside environmental and mechanical stresses.

Loose tube cables can have a water-resistant gel that surround the fibers. Due to extra preparation needed gel filled cables are usually avoided when not needed for added transmission distances or protection.

When necessary, the gel helps make fiber suitable for high humidity environments. The gel filled tubes can also expand or contract with temperature changes. Excess strain such as being pulled through multiple bends can cause the fibers to emerge from the gel.

Blown optical fiber is an installation method that uses loose tube cables. The tubes or micro ducts are installed without the fiber stands. The strands are then blown through the tubes. Fiber tubes can be reused allowing improved fibers to be blown in. It is effective for long runs such as pipelines. Due to its flexibility the Navy uses it on their ships.

9.4 Typical Fiber Optic Cable Specification

Fiber optic cable should meet the requirements of TIA-568.3 Section 4 and related appendixes. The fiber should conform to the appropriate TIA-492 designation. See Table 42 below. To avoid using cable jacket knives, it should have a rip cord to split the jacket. The cable fibers should be bendable. The strength members should be Aramid yarn or other material suitable for the environment. The cable should be water blocked using water swellable materials. The jacket should be proven to be UV resistant by meeting UL 1581 testing requirements. For indoor cables, the jacket should be color coded according to its type and have an OFNR rating. See Table 41 below. The stands and the buffers should be color coded according to TIA-598 requirements. If not armor, it should have an all-dielectric construction. Lastly, the cable and fibers should be fabricated and evaluated according to ICEA standards. See Table 43 below.

Table 41
Fiber Optic Cable Types

Fiber Type	**TIA Designation**	**Jacket Color**	**Printed on Cable**
Multimode (100/140)	Obsolete	Orange	100/140
Multimode (62.5/125) (TIA-492AAAA)	(OM1) [2]	Orange	62.5/125
Multimode (50/125) (TIA-492AAAB)	(OM2) [2]	Orange	50/125
Multimode (50/125) (850 nm Laser-optimized)	(OM3) [3]	Aqua	850 LO 50/125
Multimode (50/125) (850 nm Laser-optimized)	(OM4) [3]	Aqua	850 LO 50/125
Single-mode (8/125) (TIA-492C000)	(OS1) [1]	Yellow	SM/NZDS, SM
Single-mode (8/125) (TIA 492CAAB)	(OS2) [1]	Yellow	SM/NZDS, SM

[1] OS2 fibers can work at longer distances than OS1 which is no longer recommended
[2] Not recommended for new installations
[3] OM4 has a 4700 MHz bandwidth at 850 nm, while OM3 has a 2500 MHz bandwidth

Table 42
Fiber Optic Cable Specifications

Fiber Type	**ISO/IEC 11801 TIA/EIA-568.3-D (cable)**	**IEC 60793-2-10 (fiber)**	**EIA (fiber)**	**ITU-T (fiber)**
62.5/125	OM1(1)	A1b	492AAAA	---
50/125	OM2(2)	A1a.1	492AAAB	G.651.1
50/125	OM3	A1a.2	492AAAC	---

Fiber Type	ISO/IEC 11801 TIA/EIA-568.3-D (cable)	IEC 60793-2-10 (fiber)	EIA (fiber)	ITU-T (fiber)
50/125	OM4	A1a.3	492AAAD	---
Std SM	OS1	B1.1	492CAAA	G.652.A or B
Low Wtr SM	OS2	B1.3	492CAAB	G.652.C or D
TIA/EIA-492AAAx	Detail Specification for Class 1a Graded-Index Multimode Optical Fibers			
TIA/EIA-568-C.3	Optical Fiber Cabling Components Standard			
IEC 60793-2-10	Product Specifications - Sectional Specification for Category A1 Multimode Fibers			
ISO/IEC 11801	Generic Cabling for Customer Premises			
ITU-T G.651.1	Characteristics of a 50/125 um Multimode Graded Index Optical Fiber Cable for the Optical Access Network			
ITU-T G.652	Characteristics of a single-mode optical fiber and cable			
ITU-T G.657	Characteristics of a bending-loss insensitive single-mode optical fiber and cable for the access network			
Note 1: OM1 is typically 62.5µm, but can also be 50µm				
Note 2: OM2 is typically 50µm, but can also be 62.5µm				

Table 43
IECA Standards for Cable Fabrication

ICEA Standard	Title
ICEA S-83-596	Indoor Optical Fiber Cable
ICEA S-87-640	Optical Fiber Outside Plant Communications Cable
ICEA S-104-696	Indoor-Outdoor Optical Fiber Cable
ICEA S-110-717	Optical Fiber Drop Cable
ICEA S-120-742	Standard for Hybrid Optical Fiber and Power Cable for Use in Limited Power Circuits
ICEA S-122-744	Standard for Optical Fiber Outside Plant Microduct Cables

9.5 Fiber Optic Cable Routing

The following is recommended for optical cable routing:

a. When multiple cables run between two locations, they should have diverse routing to supply added reliability and survivability.

b. Do not stack copper cables on top of fiber optic cables. Too many copper cables can crush and damage the fiber bundles.

c. It is recommended cables be bought in multiples of six with the minimum size being a six-strand cable.

d. Cable ties should be used cautiously to avoid crunching the cables. They should be loose enough they can be moved along the cable by hand. Stainless steel ties should be avoided. Instead, padded tapes designed for fiber optic cables are recommended.

e. It is recommended that fiber cable runs be installed as a continuous length from patch panel to patch panel. There should not be mid-span splices except for where a cable is repaired after damage or later rerouted. Cable damaged during construction should be replaced.

f. Multimode mode cable runs should be 1.2 miles or less depending on losses caused by connectors and the like. In the event the runs are longer single-mode fiber is needed.

g. To ensure fiber optic cable reliability, it is recommended to stay away from the following areas:

   i. High traffic areas unless heavily protected from damage.

   ii. Locations regularly subject to heavy construction equipment

   iii. The middle of process units

   iv. High or low temperature locations that are out of the cable supplier's operating specifications.

9.6 Fiber Terminations

The two splicing fiber basic methods are fusion and mechanical splicing. It is recommended that a specialist with quality equipment perform the splices. Both methods need a stripper, a precision cleaver and inspection tools.

Multimode and single-mode cables can be mechanically spliced. With the mechanical method the fibers are clamped and aligned by the splice fitting, and gel is often used to fill the gap which lowers the losses.

With the fusing method, an automated machine is used where the fiber ends are placed between electrodes which melt the fibers tips together under controlled conditions. An advantage of a suitable fusion machine is that supplies a magnified view of the splice, and it supplies a signal loss estimate.

Fusion splicing needs more time, but it gives a stronger splice and has lower losses. Typical losses in fusion and mechanical splices are 0.02 db and 0.2 db, respectively.

Both methods depend upon the cleaving quality. With proper fiber preparation, fusion splicing consistently produces better results, so it is the preferred technique.

Also, since the cable's jacket was removed to perform either fusion or mechanical splicing, supplemental mechanical protection is needed. The mechanical splice fitting serves this purpose while the fusion splice needs a heat shrink sleeve. A splice tray in a patch panel or splice box should be used to mechanically protect the 250µm clad fibers that have been fanned out from the cable and connectorized.

Fiber terminations should follow the recommendations listed below:

a. Cable fan-outs typically use field attached connectors. The fibers should be terminated during initial installation.

b. Patch panels should be used to terminate multi-fiber cables.

c. Multi-mode fiber optic terminations can be either be fusion or mechanical splice connections. These should not be a mix within a cable.

9.7 Fiber Connectors

ST, SC, and LC are the three fiber most used connectors. SC or LC, which are normally duplex connectors, is recommended for fiber runs. Ceramic LC connectors, the recommended connectors for new installations, are compact and are specified by TIA-1005.

ST is an earlier connector, and it is mostly used when expanding existing systems. The connector ST type should meet MIL-C-83522 (ST) specifications. Some devices still have SC or ST connectors but is mitigated by using jumpers that have the legacy connector on one end and a LC on the other. For interoperability it is recommended that UPC (Ultra-Physical Contact) connector cores be used.

Judgment should be used to identify connector specifics. The selection should consider the environmental conditions, durability, compatibility with existing equipment, installation effort, and signal criticality. The differences are construction materials; e.g. ceramic, stainless steel, plastic, and the affixing method to the fiber; e.g. hot melt adhesive epoxy, crimping.

For the best results fusion spliced pigtail connectors that are factory aligned and polished should be used. This process creates a clean environment and requires skills that involves cleaving the fiber, inserting, and mounting the fiber in the connector, and polishing the fiber end.

Adapters, often referred to as sleeve or coupling, are designed to mate connectors. They are found in interconnect units, cross-connect units, and patch panels. Adapters are available with ceramic, metal, and plastic sleeves. Ceramic and metallic couplers withstand more cycling with a low insertion loss while being stable over a wide temperature range.

9.8 Patch Panels and Outlet Boxes

Fiber optic cables are terminated on patch panels or local outlet boxes using fiber optic connector pigtails. Patch panels are used in control system rack rooms, data centers and communication rooms. The external home run cables terminate in a patch panel with splice trays. The front of the patch panel is used to fan out patch cords to the control systems, servers, and Ethernet switches. One of the disadvantages of using fiber optics is the footprint required for individual terminations is much larger than is needed for conventional wire termination panels.

Patch cords or jumpers are used to interconnect devices over distances up to thirty meters. Jumpers are flexible and capable of 35mm radius bends. Duplex jumpers use zip cords. Duplex connectors come with a straight through polarity but can be field swapped. The jackets are color coded according to type. See Table 41 for the jacket colors. They are supplied either with riser (OFNR), or low smoke zero halogen (LSZH) rated jackets. The latter is for North American installations and the former is for ATEX and IEC installations.

The patch panels hold the splices between the incoming field cable strands and the connector pigtails. A meter or so of the stand is wound on the splice tray spools prior to being routed to the front bulkhead or mounting frame that hold the snap-in adapters.

Patch panels, Ethernet switches, servers and other standard rack mounted equipment are vertically stacked in multiples of 1.75 inches which is a 1U. A 3U high device would be 5.25 inch high. The standard rack is 42U or 2000mm high. The nominal device width mounted in an EIA-310-D rack is 19 inches. External rack depths range from 800mm to 1200mm. For control systems the de-facto standard footprint for racks is 800mm by 800mm.

The individual field devices outside the rack room connect to fiber optic cable using either small outlet boxes or DIN Top Hat rail mounted port adapters. Outlet boxes come with between four and twelve small form factor LC duplex connections, and they have an integral spool for winding the pigtails. They are either wall or DIN rail mounted.

DIN rail mounted port adapters are devices that mount on a standard Top Hat rail and allow fiber to be terminated and managed like electrical wire. This allows the fiber to be integrated with other system components. Still, three-inch spooling fittings should be supplied to protect the stand splices.

9.9 Fiber Cable Installation

Fiber optic raceway or tray design should be compatible with the fiber optic cable selected e.g. bending radius, wind, moisture, and UV effects from the sun. Signals leak if the cable is bent too much and become lost to refraction. It is important to install the cable with the correct bending radius. This can be between 10 and 20 times the cable diameter. The installation radius is about five diameters greater than the service diameter. Conduit sweeps rather than elbows should be used.

Integral grounded armor or innerducts should be used to protect the fiber optic cables. The fiber optic cable and innerduct choice should suit the mounting method used e.g., messenger supported, ladder tray, underground. Depending on the location plenum or riser rated innerducts can be needed.

Underground installations can be placed in plastic or metal conduit. For non-metallic conduit, a metal locator tape should be installed when using all-dielectric cable. See TIA-758 for guidance for installing underground fiber cables.

In electrically hazardous locations to prevent gas migration down the jackets the fiber optic cable should be sealed. This is according to Article 770 and the applicable requirements of 501.15, 502.15, 505.16 or 506.16. See section 12.9 for further information on cable sealing.

Where the installation is serviced by qualified persons, the National Electrical Code allows nonconductive optical fiber cables to be installed with electrical power circuits. Cable entering buildings need to follow Part II of NEC Article 770.

Fiber optic cables in buildings need to be listed according to one of the eight cable types in Part VI of NEC Article 770. OFNR indoor cable is UL riser rated which allows it to be installed anywhere. Fiber optic cables and raceways in hollow spaces, vertical shafts, and air ducts are installed so that the fire or combustion products are not increased. Openings around penetrations through fire-resistant walls, partitions, floors, or ceilings need to be fire stopped using approved methods.

The NEC requires the cable installed in a neat and workmanlike manner. Plant standards for tray choice, corrosion protection, overall cable jackets, supports and the like should be followed. IEEE 1428, NECA/FOA 301, TIA-568 and TIA-758 supply further guidelines for installing and terminating fiber optical cable.

9.10 Fiber Optical Testing

The fiber strands should be identified, evaluated, and documented. The supplier should supply the ICEA cable test data including the cable power budget before shipment. Also, prior to acceptance at the site the cable should be retested to confirm its characteristics. After installation, the fiber should be evaluated according to TIA-568.0 Tier2 requirements.

The testing should be done with an Optical Time Domain Reflectometer (OTDR) and a stable light source and power meter. Testing after the cable installation is recommended. Fiber fusion splices should have a loss of less than 0.1 dB.

10 WIRELESS INSTALLATION

When considering a wireless installation, several factors should be reviewed:

a. The existing electromagnetic systems
b. Data to be transmitted and its criticality.
c. Needed update frequency or response time.
d. The number of devices and the bandwidth needed.
e. The area and layout to be covered
f. The existence of obstructions
g. The frequencies to be used
h. Security needed to prevent attacks and intrusion
i. The application's tolerance to lost signals
j. Device power; such as battery or hard-wired power

Planning for security methods should ensure correct authentication, authorization, and accounting. Protection such as firewalls should be part of the design. Wirewalls can be employed on backhaul networks to ensure security.

10.1 Frequencies

The facility should develop an overall frequency management plan. Spectrum usage in and around the facility should be documented. Overlapping systems that do not have frequency hopping and system join technologies should be analyzed for segregation.

Consideration should be given to interaction with other systems such as plant radios and business networks. While frequency hopping mitigates this issue, the plant radio system repeaters can pick up the signal and rebroadcast it resulting widespread interference. This problem can be avoided by understanding frequency usage and setting up the wireless instrument system not to use frequencies where interference can occur.

Wireless network management and planning includes online diagnostics and monitoring. IEC 62657-1 and ISA TR-100.20.02 serve as guides in this process.

10.2 Wireless Plant Networks

Wireless Plant networks are primarily IEEE 802.11a/b/g/n networks that supply TCP/IP network services. It should be rigorously planned, designed, and configured for robustness, throughput, and security.

The planning should start with modeling as well as a site survey. The survey determines the access points and frequency sources. This establishes link and fade margins as well as the bandwidth needed. Consideration should also be given to how these networks integrate into the existing plant network. IEC 62657-2 includes coexistence with other communication networks.

10.3 Wireless Sensor Networks

Wireless Sensor networks (WSN) are primarily IEEE 802.15.4 based. ISA 100.11a (IEC 62734), WirelessHART (IEC 62951) and proprietary systems are the choices for wireless measurement networks. They should be planned, designed, and configured to ensure high reliability and robustness by following the supplier's recommendations.

System integration for the process data and diagnostics should be planned to ensure that value is realized. The number of devices and overall data throughput should be considered.

The supplier should have network design tools and system design and integration guidelines to help with the planning and design process.

10.4 ISA 100.11a vs WirelessHART

ISA 100.11a and WirelessHART technologies are not directly interoperable, so thorough deliberation is recommended prior to the choice. When selecting wireless technology, the advantages and limitations associated with a technology should be understood.

Compatibility issues include:

a. Wireless applications are protocol dependent. Mixing systems at the device level with different protocols is not practical. [1]

b. A wireless network is typically stand-alone and connects to a host system. The network gateway and the host system need to be compatible.

c. Select devices that are certified by the organization that oversee the protocols.

Note 1: WirelessHART and ISA 100.11a devices are not directly interoperable. Supplier solutions exist that use a common network connection, but both meshes are used, one for ISA 100 devices and the other for WirelessHART. Also, ISA 100.11a has an object-oriented application layer that allows by tunneling for the potential inclusion of WirelessHART, FOUNDATION™ Fieldbus, HART, and PROFIBUS devices. This allows the possibility of commands from other networks to be transmitted over the wireless ISA-100.11a but would still keep the data packets separate.

Table 44
Function Comparison of
ISA 100.11a and WirelessHART

ISA 100.11a Roles	WirelessHART Device Types	Notes
I/O Device	Field Device	Note 1
Adapter	Adapter	Note 2
Router Device	Router Device	Note 3
Backbone Router	Access Point	Note 4
Gateway	Gateway	Note 5
System Manager	Network Manager	Note 5
Security Manager	Security Manager	Note 5
System Time Source		Note 5

ISA 100.11a Roles	WirelessHART Device Types	Notes
Provisioning		Note 5
Wireless Handheld	Wireless Handheld	

Note 1: WirelessHART devices are required to function as routers. For ISA 100.11a this role in not mandatory so an I/O only device is possible.

Note 2: An adapter is connected to a hardware device that transmits its HART data wirelessly. The hardware device provides the power. It can also be used as a router device when provided with a power source.

Note 3: A role that is incorporated into other devices. See Note 1.

Note 4: The devices that receives the wireless transmissions and passes them on to the Gateway. ISA 100.11a uses a backbone network to connect to the Gateway and other manager services. The backbone is optional with WirelessHART. An IEEE 802.11n network can serve as the backhaul network for the IEEE 802.15.4 networks. See section 3.4.1.3.5 further details.

Note 5: The Gateway connects to the plant control system network. Security, System/Network, Time Source, and Provisioning can be included as part of the Gateway or be separate functions in other devices.

10.4.1 Wireless Layout

Segment the networks by area so that the gateways are distributed in the field like marshalling panels and junction boxes. Wireless networks can also be broken down functional into subnetworks for instance process and mechanical maintenance networks can be created each with its own users.

To extend the network and improve the mesh robustness for complex networks, distributed field mounted gateways with an integral access point should be considered. The alternative is to use wireless repeaters or routers, but this can come at the expense of system capacity and hop latency but has the advantage of not requiring field wiring.

Universally access points are available that allow WirelessHART, ISA 100.11a and 802.11 signals to operate on the same backhaul network. See section 3.4.1.3.5 for further information.

The type and location antennas assist the network coverage. Antennas can be mounted on elevated structures, while for maintenance the transmitter or repeater is at grade. See section 10.4.5 concerning antenna wiring.

ISA TR84.00.08 “Guidance for Application of Wireless Sensor Technology to Non-SIS Independent Protection Layers” supplies guidance. Also, ISA TR 100.15, Wireless Backhaul Networks, describes network architectures, security practices and management practices for Wireless Backhaul applications in an industrial environment.

10.4.2 Wireless Device Installations

The following should be used for the installation of wireless devices:

a. Install at least five devices within range of the gateway. [1]

b. At least 25% of devices in a wireless mesh network should have a direct path or line of sight to the gateway. The number of gateways should be increased to meet this requirement.

c. At 2.4 GHz mount devices >1.5m off the ground and mount antennas >0.5m from vertical surfaces.

d. Use lightning protection on gateways.

e. A device should have at least three other devices inside its range.

f. To prevent aliasing update rates are to be three times faster than the process time constant. [2]

g. A device with a process time constant needing an update rate of less than four seconds should not be battery powered or placed within the range of a gateway. [3]

h. Devices driving actuators should be within effective rage of the gateway to ensure typical hop depth is one to two hops. Path redundancy and short transit times need to be achieved.

i. Supply repeaters as necessary to ensure access to the gateway. [4]

Note 1: See Table 45 for effective distances.

Note 2: Depending on the process time constant, updates rates should be from four seconds to sixty minutes. Update rates are based on the process variable and are not affected by neighboring devices. Routing from a neighboring device is not the basis for assigning an update rate to a device.

Note 3: Network hops introduce delays and battery life is reduced with higher measurement frequencies.

Note 4: The primary consumer of power for a field device is the sensor and its electronics. Using the wireless radio; such as a simple temperature transmitter, to function as a repeater for other devices requires minimal power. Also, ISA 100.11a and WirelessHART adapters can be used effectively as repeaters where 20 mA of 24 VDC power is available. The power can be scavenged from a two-wire device.

Table 45
Recommended spacing for IEEE 802.15.4 Wireless Devices

Distance	**Category**	**Description**
100 ft. (30 m)	Heavy Blockage [1]	A high density plant environment; such as process unit. Cannot drive a truck or equipment through.
250 ft (76 m)	Medium Blockage [1]	Light process areas, plenty of space between the equipment.
500 ft (152 m)	Light Blockage	This is typical in tank farms. Tanks are obstacles with lots of space between and above them so there is adequate propagation.

Distance	Category	Description
750 ft (230 m)	Line of Sight	No obstructions between wireless devices and devices mounted a minimum 1.5 meter above ground or obstructions.
Note 1: For 2.4 GHz the wavelength is 12 cm, so interfering diffraction is not expected due to the pipe or material smaller than one meter. Most signal interference is due to blockage by large equipment items.		

10.4.3 Wireless Gateway Installation

The following guideline are used for wireless gateway installation:

a. Each gateway should have its own network ID.

b. Gateways should be in the amongst the devices they serve.

c. Limit the number of hops to gateway to five or less

d. The number of gateways should be increased based on the distance between devices. [1]

e. A redundant gateway with redundant power supplies should be supplied for each network and powered by the UPS.

f. For protection, the gateways should connect to the control network through a switch and firewall. The connections should be redundant.

g. Provide 25% spare capacity or greater for each gateway.

Note 1: To facility network management they should be constrained to a plant unit or a unit subset if the unit is large compared to the hundred-foot range between instruments. The gateways should be above cable trays and placed to make connections with the maximum number of wireless devices.

If the gateway free time is constant, the reliability is increased as more wireless instruments are added to the network, since more network paths are created.

Although there are similarities in band usage worldwide, each country or region can be different; a frequency that is unlicensed in one country can require a licensed elsewhere. Since export-controlled technology is involved, the encryption and spectrum technology should be approved for the country.

10.4.4 Repeaters and Wireless Backhaul

10.4.5 Antennas

Up to 100 m for 2.4 GHz signal, the optimum antenna height for an unobstructed area is about one meter. Antennas mounted at three meters are affected by ground reflections.

However, obstacles in the Fresnel zone increase propagation loss and deteriorate the quality of wireless communication. Mounting antenna, above the interference improves reception. Inside process units mounting one or more repeaters on towers and other tall equipment can overcome transmission problems. This also applies to backhaul radios.

The process wireless devices should be within 50 m of a repeater. Signal reflection allows communication at distances as much as 50 m so direct path to the repeater is not necessary. Still, offshore platform equipment densities can defeat transmission since sight lines do not exist for repeaters on the lower decks.

Directional antennas; such as a parabolic grid, panel or Yagi antenna can send a focused signal a longer distance. Directional antennas have the added advantage that the signals are more secure in that they are harder to detect and jam.

Still a high antenna gain does not always provide a better connection. A high gain antenna has a small pickup angle, which requires precise alignment. Since they can take advantage of reflections omnidirectional antennas work better in congested areas. Antenna alignment can be affected by stability with wind, vibration, and similar influences.

Select the antenna position carefully, Install it away from obstacles such as buildings, trees, other antennas, or metal objects. Antennas should be minimum of one meter or more from vertical surfaces.

The antenna cable should be as short as possible to keep signal loss on the cable as low as possible. Do not route the antenna cable parallel to a lightning arrester and use surge protection.

Outdoor antenna cables should be connected to the antenna from below and the connectors protected from moisture. The assembly should be kept free of ice.

When a transmission line is used in between the antenna and the transmitter the maximum power transfer requires matching the impedance to minimize the standing wave ratio and transmission line losses.

10.5 Power Considerations

The power source is important in selecting wireless devices. Most wireless sensors are battery powered. Typical batteries are non-rechargeable lithium thionyl chloride batteries with a protentional life up to five years. Rechargeable batteries have a life expectancy of only several years during which they can maintain a full charge. This life expectancy is often shorter than that of non-rechargeable Lithium Thionyl Chloride batteries.

Some devices have options for using line or solar power. Energy harvesting is a possibility, but it has added considerations such as reliability, maintenance, and energy source availability.

When using a battery, a primary consideration is selecting an update rate for the application that delivers a suitable battery life. The faster the update rate the faster the device consumes its power.

It has been found that update rates are set high for operator reassurance. As a result, proprietary batteries life is much shorter than five years. For instance, a typical pressure transmitter with a one second update rate lasts 0.6 years while one with a sixteen second setting has a 5.8 year life.

As the number of wireless devices, multiples replacing batteries across a facility can become a daily occurrence, as a result it has been necessary to update work rules to allow operators to change them. A wireless devise that measures multiple values can have power requirements beyond what battery can reasonably supply. To support this extended functionality, wireless sensors can be equipped with external power supplies.

10.6 Host Interfaces

Most wireless systems have a host interface that manages the system and communicates with an HMI. Depending upon the system selected, the host interfaces included:

a. A personal computer connected to a gateway by interfaces such as RS-232, USB or TCP/IP. In smaller systems this device can be used as a dedicated interface. A personal computer can also be connected to a large control system with TCP/IP connections.

b. The Modbus protocol can transmit data to the control system. A personal computer with a temporary connection is then used to configure the wireless network.

c. A server that is loaded with TCP/IP connection software which supplies the connection to the control system while managing the wireless network.

10.7 Wireless System Management

Wireless systems should have documentation software that includes change management. The device locations should be documented. This includes any remote battery locations when they need to be replaced.

Network based configuration management is recommended for maintenance and security functions. There are complications by using just laptop computers for managing data security, software version control, configuration backups, and physical security.

The application should allow network set up and device configuration. It should check the network performance by measuring device status, wireless signal quality, battery status, and other parameters.

As higher update rates are used the more bandwidth is consumed. The system tools to determine the capacity such as user interface that shows the percentage of bandwidth being used are important. For planning a calculator to determine the expected load capacity by the type of device function as well as update rates are also useful.

Some devices such as vibration transmitters and guided wave radar need higher bandwidths to download files for graphical analysis. These downloads are typically done on demand so planning the network operation properly is needed ahead of time.

11 ELECTRICAL POWER SUPPLY

Wired, fiber optic and wireless installations need electrical power to operate. Though many wireless devices use batteries they rely on gateways that are externally powered.

11.1 AC Power Distribution

AC power circuits should come from a clean independent source, UPS, or an isolation transformer.

Depending on the ground system design, each AC power circuit should contain a ground conductor connected to the equipment frame that references it to the power source.

AC power should be distributed from the local power source to the cabinets using individual circuit breakers or fuses. Each circuit should be a dedicated service so it can function as a maintenance disconnect.

Circuit breakers and fuse curves should be coordinated so that the circuit is cleared at the lowest level.

IEEE 1100 "Recommended Practice for Powering and Grounding Electronic Equipment" provides extensive guidance on AC power distribution, UPS application, and related grounding practices.

11.2 DC Power Distribution

DC bulk power supplies provide power to the I/O cards, auxiliary devices and control system components not equipped with their own power supply. The bulk power supplies should be redundant or have an N+1 configuration. To simplify repair, it is recommended that a hot swappable configuration be used.

They should be equipped with diagnostics to indicate their loading and failure. The power supply failures should be alarmed remotely. O-ring diodes should be provided for short circuit protection. Depending on the current load and diode type, the diodes should have thermal sinks.

Load sharing should be used with regulated power supplies to prevent maldistribution of the load. Load sharing can be accomplished in a droop mode using balanced output circuits or if power supply has this feature, an active feedback circuit.

The AC inputs to each power supply should be provided with a circuit breaker or fuse. The DC outputs should be provided with a fuse or be current limited. Likewise, the DC load should be provided with a fuse. The fuses and circuit breakers can double as disconnects.

For distribution purposes the DC outputs can be bussed together. The bus can be terminal blocks jumpered together, a power distribution block or a copper bus bar. Their current rating should be suitable for the full output of all the power supplies including unused slots on the power supply shelf.

The feeder circuits from the bus to external cabinets should be equipped with fuses sized to protect the wire from a short circuit. The fuses and breaker sizing and thermal curves should be coordinated to ensure that a trip occurs at the lowest level.

The power supplies need to be kept cool. Ventilated enclosures are recommended. The supplies should be mounted according to the supplier's spacing and ventilation requirements. For effective convection cooling mounting power supplies vertically is not recommended. Power supplies outputs are de-rated as the ambient temperature rises about the specified temperature. Remote temperature monitoring of the power distribution enclosure should be considered.

Power supplies in outdoor enclosures require additional considerations. The interior temperature rise should be calculated using the highest historical temperature and maximum solar gain. The enclosure surface area can be increased for better heat dissipation and sun shields can be added as needed.

DC power supply offerings often come with auxiliary devices such as battery backup units. Also, diagnostic modules are available that provide comprehensive information about the bulk power system. They can monitor AC power feed status and spikes, output voltage and current, redundancy status, and internal temperatures.

12 ELECTRICAL CODE APPLICATION

Wired, fiber optic and wireless installations have to conform to the electrical hazard location requirements. The three most common hazard classifications in a petrochemical complex are; Class I, Division 1; Class I, Division 2; and Unclassified, which is non-hazardous.

Additionally, NEC article 502 Class II locations deal with combustible dusts; such as created by fine polyethylene powers. Depending on the quality; i.e. more than 8% entrapped volatile material, petroleum coke can be a Class II, Group F material.

NEC article 503, Class III locations covers combustible flyings which include ignitable fibers and larger particles. These locations are rarely encountered in petrochemical environments but have similar requirements to Class II locations.

Standard process instruments are widely available with the B, C, D, Group classifications, but some systems can need purging according to NFA 496 or other techniques such as placement within a NEMA 7 or XP explosionproof enclosure.

Explosionproof enclosures are not effective for Class II and Class III. A NEMA 4 dust tight enclosure or one of the other NEMA enclosures rated dust tight is acceptable for Class II, Division 2, or Class III locations. A Dust Ignition Proof (DIP) enclosure is required for Class II, Division 1 locations. If a location is classified both as a Class I and Class II location dual rated enclosures are needed.

See ANSI/ISA-12.01.01-2013 “Definitions and Information Pertaining to Electrical Equipment in Hazardous (Classified) Locations” for further information on the protection techniques available in electrical hazardous locations.

12.1 Codes and Standards

The equipment, enclosures, wire, and installation methods should conform to the regulations at the facility. In the United States the National Electrical Code (NEC) article 501 and OSHA 29 CFR 1910.307 gives the specific requirements for Class I hazardous locations. In Canada Section 18 of the Canadian Electrical Code covers hazardous locations.

API RP 500 and API RP 505 are guides for determining electrical location classifications in petroleum facilities. The Class I, Division 1 and Division 2 classifications are addressed in RP 500 while the classification method using Zones is addressed by RP 505.

Chemical facilities for Class I liquids are classified according to NFPA 497 requirements. NFPA 499 is used for the classification of Class II and Class III materials. IEC 60079-10-1 and IEC 60079-10-2 respectively are the international standards for determining explosive gas and dust atmospheres.

Table 46
Division and Zone Classifications

Hazard Level	Division Method	Zone Method	Definition
Continuous Hazard	Division 1	Zone 0 Zone 20	An explosive atmosphere is continuously present
Intermittent Hazard		Zone 1 Zone 21	An explosive atmosphere is likely to occur during normal operation

Hazard Level	Division Method	Zone Method	Definition
Abnormal Hazard	Division 2	Zone 2 Zone 22	An explosive atmosphere is not likely to occur during normal operation, but can occur for short periods

12.2 Zone Classifications

Besides the two level Division system for hazardous area classifications the NEC recognizes the international three level Zone system. NEC articles 505 and 506 encompasses the use of the Zone system in the United States. These articles align with IEC 60079-17 practices.

It is desirable to harmonize electrical standards so that a package for local domestic use has the same equipment and installation standards as one being sent offshore. This allows common designs and simpler material control.

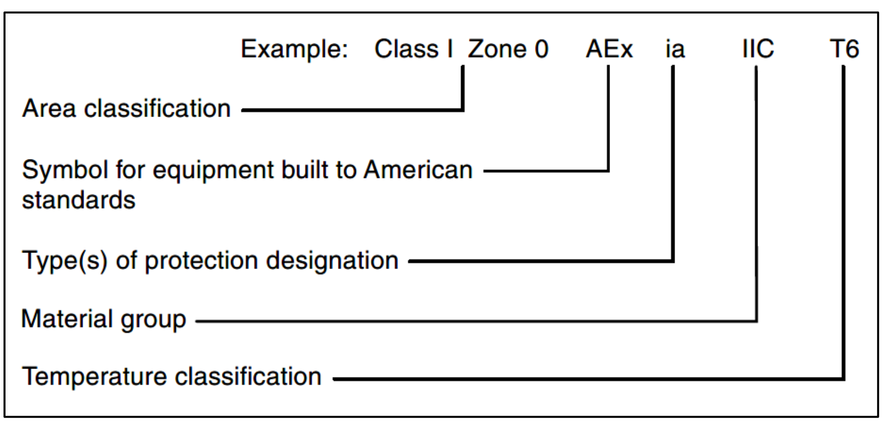
For example with the use of worldwide suppliers, a refrigeration package built to international standards can operate anywhere with minor modifications. This is possible by building the package to Zone 1 standards but with the option to rate the package for Zone 2 for the North American market.

This is possible since areas within the same facility that are classified under both systems, Class I, Zone 2 locations can border, but not overlap, Class I, Division 2 locations. Class I, Zone 0, or Zone 1 locations cannot abut Class I, Division 1, or Division 2 locations.

Also equipment listed for Class I, Zone 0, 1, or 2 locations are permitted in Class I, Division 2 locations for the same gas and with a suitable temperature class. Equipment listed for use in Zone 0 locations are permitted in Class I, Division 1 or Division 2 locations for the same gas and with a suitable temperature class.

Conversely OSHA requires that equipment be certified for Class I, Division 1 or Class 1, Division 2 to be marked with the appropriate Zone designation. See Figure 28.

Figure 28
Zone Marking



Besides the addition of Zone 0, additional protection methods; such as type AEx ma encapsulation or type AEx nR restricted breathing enclosures are allowed. All the Zone protection methods are allowed in Class I, Division 2 locations and type AEx ma encapsulation is allowed in Class I, Division 1 areas.

Table 47
Gas Classifications

Material	Hazard Class	Division Groups	Zone Groups
Acetylene	Class I Flammable Gases	Group A	IIC
Hydrogen		Group B	IIC
Ethylene		Group C	IIB
Propane		Group D	IIA
Methane		Group D	IIA
Combustible Metal Dusts	Class II Combustible Dusts	Group E [1]	IIIC
Combustible Carbonaceous Dusts		Group F	IIIB
Combustible Dusts not in Group E or F Flour, Grains, Wood, Plastics, Chemicals		Group G	IIIB
Combustible Fibers and Flyings	Class III Fibers and Flyings	Not Applicable	IIIA
Note 1: Group E is not applicable to Class II, Division 2			

12.3 National Recognized Testing Laboratories

OSHA requires electrical equipment to be certified by a National Recognized Testing Laboratory (NRTL). Section 1910.303 defines the general requirements and section 1910.307 applies to hazardous locations.

Electrical equipment used in the United States and its territories have to conform to the ANSI test standards that are listed by OSHA. With limited exceptions, NRTL's evaluate the equipment and hardware for electrical shock, fire, and arcing. The NRTL accepts, certifies, lists, labels, or otherwise determines an item to be acceptable.

There are two exceptions to NRTL certification requirements. The first is where no NRTL certifies the equipment type. It can be approved by an organization responsible for enforcing the National Electrical Code such as another Federal agency or other Authority Having Jurisdiction.

The second exception is for custom equipment that is intended for a particular customer. The supplier's test data determines if is safe. The employer keeps the test data with it available for inspection.

There are several NRTL organizations accredited and listed by OSHA for evaluating electrical equipment. Furthermore, they have to be approved by OSHA to conduct testing with a particular standard.

OSHA recognition is limited to a peculiar location. However, an NRTL can use test data generated by other sites or by other means provided specific conditions are met. Also, with approval OSHA allows acceptance of test data from independent organizations; e.g. the International Electrotechnical Commission Certification Body (IEC-CB) Scheme organizations.

12.3.1 OSHA 1910.303

According to section 1910.303, OSHA requires electrical hardware and equipment in the workplace has to be deemed as being safe for personnel. The material used in the installation of an electrical system; such as wire, tray, etc., is required to be listed by the NEC and so routinely meets OSHA requirements.

However, the NEC does not address the listing of most power consuming components; such as process controls with regards to hazards from a short circuit, overload or over voltages. Testing to UL 61010-1, UL 61010-2-030, or similar standards acceptable to OSHA is required for this type of equipment. Due to their low energy operation process instruments identified being intrinsically safe meet these requirements.

Additionally, electrical live parts; such as terminals, operating at 50 volts or more have to be guarded against accidental contact using cabinets or other enclosures certified according to UL 50, UL 50E or other OSHA acceptable standard.

12.3.2 OSHA 1910.307

Section 1910.307 applies to hazardous locations and requires specifically that intrinsically safe equipment be certified. Also explosionproof, dust ignition proof (DIP), and purging systems also needed to be certified by a NRTL.

Enclosures rated by a NRTL as being a type 3, 3S, 3SX, 4, 4X, 5, 6, 6P, 12, 12K, 13, or in other ways dust tight are acceptable for Class II, Division 2, and Class III locations. Class II, Division 1 enclosures are required to be DIP rated.

Other equipment have to be a type and design that the employer demonstrates provides protection from the hazards from the combustibility and flammability of vapors, liquids, gases, dusts, or fibers at the location. The National Electrical Code, NEC, contains the necessary guidelines to determine the type and design of this equipment as well as the installation practices that meet this requirement.

General-purpose equipment or equipment in general-purpose enclosures can be installed in Division 2 locations if the employer demonstrates that the equipment does not constitute a source of ignition under normal operating conditions.

12.4 Field Labeling

Field Evaluation is a certification process for unique or modified devices. A field evaluation is a process where devices that do not have a certification acceptable to the Authority Having Jurisdiction (AHJ) or owner can be evaluated to applicable safety standards.

The field labeling program is primarily intended for custom devices, and other systems that are not practical to list.

The field labeling program is not specifically mentioned in the Federal NRTL Listing program. Devices only having an ATEX Category 1 or IECEx third party listing as well as some CSA products do not meet OSHA requirements for NRTL listing. These listings can be the starting point for getting a Field Label by NRTL which can partly mitigate this requirement using one of the two allowed listing exceptions by a NRTL.

NFPA 790 contains the quality system documentation requirements, along with test and measuring equipment requirements for field evaluations. NFPA 791 contains more of the technical requirements related to performing evaluations such as pre-site preparation, construction inspection, and electrical testing.

A field evaluation uses the same standards as a listing evaluation. However, the certification agency is allowed to use some engineering consideration based on the unit, specific user, and other factors that apply. Field evaluations also can involve testing. Since the unit being inspected is going to be used this does not include destructive testing.

Most field labeling is done at the site. Cord connected systems can be labeled at the certification facility prior to delivery to the site.

The actual devices inspected bear the field labeling mark, and it is applied by the certification agency engineer. Other devices are not included. The supplier cannot claim that other units or future production is certified.

12.5 IEC Standards

12.5.1 IEC 60364

IEC 60364 is a guideline document that encompasses general electrical safety practices. A NEMA document “Electrical Installation Requirements” provides a comparison of the NEC and IEC 60364.

IEC 60364 and the NEC both establish performance requirements that address fire and electric shock protection for persons and property. Both documents are applicable to wiring systems for residential, commercial, and industrial use.

Hazardous locations (explosive atmospheres) are identified by the NEC; they are separately described in IEC 60079. Neither document includes installations for generation, transmission, or distribution of electrical energy, nor those under exclusive control of electric or communications utilities.

Countries adopting IEC 60364 need to develop national rules usable by electrical system designers, installers, and enforcement authorities.

12.5.2 IEC 60079

The IEC 60079 standards define the design and installation of electrical equipment in hazardous locations. These standards encompass the same general material as NEC Chapter Five plus several UL, NFPA and ISA standards. The IEC 60079 standards are the basis for international installations and are the source of the ISA standards for the design of electrically classified equipment. ISA has adopted those IEC 60079 standards related to testing and equipment design with minor modifications which is mostly for terminology.

12.5.3 IECEx

With the IECEx Scheme manufacturers of hazardous location equipment can obtain certificates of conformity that is accepted by participating countries. A certificate of conformity can be obtained from any certification body accepted into the Scheme.

The certificate attests that the equipment conforms to relevant IEC Standards and the product is manufactured under a quality plan assessed by an Approved IECEx Certification Body. Manufacturers holding certificates of conformity can affix the IECEx Mark of Conformity to their equipment that complies with the certified design.

12.6 Class I, Division 1 Areas

In a Class I, Division 1 location, a flammable gas can be present continuously or intermittently under normal operating conditions. Electrical equipment for a Class I, Division 1 location should be explosionproof, purged, intrinsically safe or protected by other approved methods. See the definition of Class I, Division 1 for a complete description of what constitutes a Class I, Division 1 location.

When the Zone classification method is used Class I Zone 0 the hazard is continuously present and Zone 1 the intermittently present. Only intrinsically safe devices and devices with Type “ma” Protection; i.e. encapsulation, are allowed in Class I Zone 0 locations. Intrinsically Safe Field Device connected to a Type “ib” Associated Apparatus cannot be used in a Class I, Zone 0 or Class I, Division 1 location, even if the Intrinsically Safe Field Device is rated “ia”.

12.7 Class I, Division 2 Areas

12.7.1 Division 2 Installation Requirements

In a Class I, Division 2 location, flammable vapor only exists during abnormal conditions, such as failure or rupture of a pressure boundary. Class I Zone 2 is the NEC article 505 designation that is equivalent to Class I, Division 2 is functionality similar in its requirements. See the definition of Class I, Division 2 for a complete description of what constitutes a Class I, Division 2 location. See ISA TR12.12.04 “Electrical Equipment in a Class I, Division 2/Zone 2 Hazardous Locations” for a detailed discussion of wiring methods allowed in these areas.

Equipment is acceptable for a Class I, Division 2 location if it does not have sparking contacts or parts hot enough to trigger an ignition. Class I, Division 2 wiring differs from ordinary wiring in that it requires mechanical protection. It can use general-purpose enclosures with approved seals without added protection techniques.

The most significant requirement for Class I, Division 2 location is that sparking; i.e. arcing, unprotected electrical contacts should be explosionproof or purged. Otherwise, they can be considered non-arcing by using nonincendive or intrinsically safe techniques as well as hermetically sealing or immersing them in oil. Oil immersion when used with potentiometers allows them to be used in Class I, Division 2 locations while protecting the windings from corrosion and moisture.

Unprotected arcing devices or contacts use listed equipment; such as explosionproof enclosures and seals. Listing by a NRTL is preferred for devices and fittings but according to the NEC that is not always mandatory.

Wiring can utilize methods that are not evaluated with respect to hazardous locations. Other than the normal listing as an electrical fitting, wiring products such as cable, raceways, boxes, and fittings, do not have to be marked as being suitable for Class I, Division 2 locations.

Seals are needed for threaded enclosure openings. The seals should be listed for their intended purpose, but they are only explosionproof when unprotected contacts are involved. See section 12.9 for further information on the use of seals.

12.7.2 General-Purpose Assemblies

NEC allows the following to be mounted in general-purpose enclosures in Class I, Division 2 locations:

a. Transformers

b. Impedance coils

c. Solenoid coils

d. Other contactless windings

e. Non-arcing surge arresters and surge-protective devices; e.g. sealed metal-oxide varister
f. Solid state switching without mechanical contacts [1]
g. Resistors, resistance devices, rectifiers, and similar equipment [2]
h. Fuses not subject to overloading in normal use if proceeded by a disconnect switch [3]
i. Oil immersed contacts, potentiometers, or rheostats
j. Hermetically sealed contacts [4]
k. A current interrupting device identified for the location i.e. contacts listed for Division 2 and marked as "Leads Factory Sealed", or equivalent [4]
l. Contacts in nonincendive or intrinsically safe circuits [5]

Note 1: Operates <80% of autoignition temperature, device derating can be needed for the higher T classes.

Note 2: Operates <80% of autoignition temperature and is marked with the maximum operating temperature

Note 3: The disconnect switch should meet the location requirements.

Note 4: These devices are equivalent to Type "n" protection in article 505 of the NEC or ISA 60079-15

Note 5: The combination of using an intrinsically safe NAMUR switch module with a solid state or hermetically sealed output contact suitable for Class I, Division 2 enables using ordinary non-rated contacts in a hazardous location.

The following device should be listed, approved, or identified for the location:

a. Unprotected mechanical make-and-break contacts
b. Thermionic or vacuum tubes
c. Solenoid driven bells or horns with oscillating action contacts
d. Motors that have brushes

It is not an NEC requirement that every electrical device or component be listed, approved, or identified as being acceptable for a Division 2 location. Occasionally, when allowed by the Authority Having Jurisdiction under section 500.8(A)(3) of the NEC, it can be necessary to use "engineering judgement" to evaluate the device suitability for a Division 2 location as a potential nonincendive equipment item. OSHA 1910.307 also allows employers to use this process.

An example is an embedded controller at a truck loading dock for a proprietary system where it is not desirable to purge the device and an explosionproof enclosure would prevent access to operational controls. Other examples are Fiber Optic converters, Ethernet interfaces or ASi valve controllers. A written report of the investigation and conclusion should be kept on file, and the markings on the equipment should identify the report.

Most network devices will meet the requirements of Class I, Division 2, if they are in an acceptable general purpose enclosure.

In Division 2 location, a hazard is an abnormal occurrence. It occurs infrequently and for short periods. As a result, NEC articles 501 through 503, allow devices in general-purpose enclosures to be installed in Division 2 locations if it is not an ignition source under normal operating conditions. Also, where an assembly is made up of components where general-purpose enclosures are acceptable a single general-purpose enclosure is also adequate.

ANSI/ISA-TR12.12.04-2011 states that “Equipment that does not contain make/break components or components that have surface temperatures more than the ignition temperature of the combustible material is generally considered acceptable.”

Non-heat producing equipment, such as junction boxes, conduit, and fittings, and heat-producing equipment, such as continuous process instruments, having a maximum temperature less than 100°C during normal operation do not have to be marked with their temperature. The surface temperature of equipment that runs at less than 30 watts and does not have vacuum tubes, power resistors and the like have temperatures that are indistinguishable from the surrounding ambient conditions.

Further, other than luminaires, fixed general-purpose equipment that is acceptable for Division 2 locations does not need to be marked with the Class, Division, and Group.

A Division 2 evaluation verifies that the equipment does not have unprotected current interrupting components such as load breaking relay contacts and switches. Other examples are motor brushes, circuit breakers, potentiometers, and adjustable resistors.

Membrane keypads and resistive touchscreens have make-and break-contacts. Conversely, capitative touchscreens do not use make and break contacts. Further, devices with Hall effect keypads and pushbuttons use solid state switching are acceptable to Division 2 locations.

Also, it can be necessary to determine if connectors can be separated by vibration. For evaluations that where a single system is being assessed the issue with vibration is not significant when the location is known to be stable. Also, with low mass components the allowance for this problem can be set aside.

Where a non-location specific general assessment is being made, connectors with a latch or other means to prevent separation are considered vibration resistant. Devices that are protected by tight-fitting, card retaining covers are also considered secure.

Otherwise, connector separation should be evaluated based upon their mass. A pulling force no greater than 3.35 lbs. (15 N) should be considered. DIN style plug headers which are designed to be vibration resistant have previously been found to be acceptable as are other standard electronic components that are used to assemble Division 2 certified instruments and controls.

Lastly, components, such as easily accessed fuses and lamps that can become an ignition source during replacement should be evaluated. The easiest method for managing removable components is by placing them in an enclosure and making them accessible by only using a tool; e.g. a screwdriver or key.

12.8 Wiring Methods for Class I Locations

Below is a table of the allowed methods allowed in Class I and Zone locations according to Article 501 of the NEC.

Table 48
Field Wiring in Class I Locations

Wiring System [a,b]	Zone 0	Zone 1 or Division 1		Zone 2 or Division 2	
	IS	**IS**	**NIS**	**IS/NI**	**NIS**
Threaded Rigid Metal Conduit	A	A	A	A	A
Threaded Steel Intermediate Metal Conduit	A	A	A	A	A
Flexible metal explosion proof fitting	A	A	A[c]	A	A
Type MI cable	A	A	A[d]	A	A
Type ITC, MC, MV, PLTC, and TC cable [g]	A	A	N	A	A
Type MC-HL, TC-HL, ITC-HL, TC-ER-HL and ITC-ER-HL	A	A	A	A	A
Flexible metal conduit	A	A	N	A	A[ce]
Liquid-tight, flexible metal conduit	A	A	N	A	A[ce]
Electrical metallic tubing (Steel)	A	A	N	A	N
Flexible cord	A	A	Note 1[f]	A	A[c,f] Notes 1,2
Other wiring methods suitable for unclassified areas	A	A	N	A	N

a. A:Acceptable, IS: Intrinsically Safe, N: Not Acceptable, NI: Nonincendive, NIS: Not Intrinsically Safe
b. See the NEC® for a description and use of wiring systems.
c. Acceptable only where flexibility is needed.
d. Acceptable only with termination fittings approved for Class I, Division 1, locations for the proper groups.
e. Special bonding/grounding methods for hazardous (classified) locations are required.
f. Types S, SO, ST, STO extra-hard usage flexible cords with grounded conductor.
g. The addition of the -ER suffix on Type ITC-ER, PLTC-ER and TC-ER cables have the same limitations as ITC, PLTC, and TC cables.

NOTE 1 Acceptable on approved portable equipment where provisions made for cord replacement, according to NEC® 501.140 requirements.

NOTE 2 Acceptable on process control instruments to facilitate replacements, according to NEC® 501.105(B)(6) requirements. The maximum length is 900mm (3 ft)

12.9 Conduit and Cable Seals

In a hazardous location electrical enclosure, threaded connections need a listed conduit or cable termination fitting. Unused openings need a listed plug. For cables cable grips and barrier glands are the two types of termination fittings. For conduit there are conduit hubs and seal fittings. Cable grips and conduit hubs are simple listed devices that only supply a weathertight connection to the enclosure and are used where general-purpose enclosures are allowed.

Sealing prevents flame propagation and explosive pressures from the enclosure into the conduit or cable system. Both seal fittings and barrier glands use a sealing compound. Seals should be selected so temperature extremes and highly corrosive liquids or vapors do not affect their functional abilities.

On the other hand, with a few exceptions, the National Electrical Code requires enclosure sealing in both Division 1 and Division 2 locations that have unprotected devices that produce arcs, sparks, or has apparatus that exceeds 80% of the autoignition temperature.

This is done either by conduit seal fittings or barrier cable glands. This applies to purged enclosures with conduit and explosionproof enclosures. The seals in the conduit or on cable need to be rated for the applicable Group. Also, conduit seal fittings are needed regardless of the enclosure contents if the entry is two inches or larger. This included enclosures with terminals, splices, or taps.

12.9.1 Conduit Seal Fittings for Enclosures

A conduit system is not vapor-tight, it is designed to breath and drain moisture. So, the gases inside the conduit come to the same concentration as the outside environment. Attaching conduit increases the volume of the vapor envelope, so the seal fittings needed to be within eighteen inches of the enclosure or as needed by the enclosure markings to avoid exceeding the enclosure's protective capabilities.

A liquid compound poured into the seal fitting that hardness surrounds each conductor. It is not necessary to remove shielding or separate twisted pairs. The compound prevents flame passage through the conduit from one electrical installation to another. Seals quench the flame and breakup the explosion's pressure wave as it travels past the seal.

12.9.2 Transition from Classified Locations

The National Electrical Code requires conduit leaving Division 1 or Division 2 locations be supplied with a seal. For conduit, the seal needs to be within ten feet of the boundary. Breather drains need to be installed to minimize the vapor within the hazardous location that can be communicated outside the seal. Also, the conduit between the seal fitting and division boundary needs to be solid and unbroken with the exception of explosionproof reducer at the conduit seal.

The following are exceptions to the requirement for conduit seals at the boundary of Division 1 or Division 2 locations:

a. Division 2 conduit that transitions to cable tray or MI cable does not need to be sealed if the boundary to the non-hazardous is outdoors. However, conduit cannot be connected to an enclosure with a continuous ignition source.
b. If the conduit is sealed at an enclosure that has terminals and the like, conduit systems in a Division 2 location do not need sealing as it passes into a non-hazardous location if the following three conditions are met:
    i. The conduit does not pass through a Division 1 location where it has boxes or fittings within twelve inches of the Division 1 location.
    ii. The conduit is found entirely outdoors.
    iii. The conduit has only threaded metal fittings in a non-hazardous location.

    The above guarantees that the seals are accessible and is the preferred method for dealing with a transition to a non-hazardous location.

An unbroken conduit or gas tight cable that passes completely through a classified location from an unclassified location does not need boundary seals.

12.9.3 Pressure Piling

Pressure piling is the buildup of pressure inside conduit systems ahead of an explosion's flame front as the explosion travels through the system. The compound effect of the exploding compressed gases can reach pressures that exceed the design pressure of the enclosures.

While not a NEC requirement, to minimize pressure piling particularly in Division I areas it is recommended that conduit runs be sectionalize by inserting seals about 15 m (50 ft) to 30 m (100') apart.

12.9.4 Exceptions to Sealing

Factory-sealed devices, such as switches, push buttons, and lighting panels can eliminate external sealing. The following exceptions exist:

a. A switch, circuit breaker, fuse, relay, or resistor is enclosed within a chamber hermetically sealed against the entrance of vapors.
b. A switch, circuit breaker, fuse, relay, resistor, or potentiometer that is immersed in oil
c. A switch, circuit breaker, fuse, relay, or resistor is enclosed within an enclosure, acceptable for the location, and marked "Factory Sealed," or the equivalent.
d. The switch, circuit breaker, fuse, relay, or resistor is part of a nonincendive circuit.

However, a factory seal for one enclosure cannot be used for another attached explosionproof enclosure unless it is specifically approved for that purpose.

12.9.5 Vapor Seals

The code requires in some instances using seals intended to prevent vapor flow. However, seal suppliers do not differentiate between seal fitting types and a common seal design is used for both purposes. Unless noted otherwise, the same cable or conduit seal fittings can be used for vapor sealing as those used for preventing flame propagation.

These barriers minimize vapor transmission at ambient conditions. They are especially effective if the conduit is equipped with breathers that vent the vapors. Nevertheless, pressures higher than ambient conditions need a seal fitting according to section 501.17 of the National Electrical Code.

12.9.6 Cable Glands

12.9.6.1 Gland Description

Barrier Glands have the same intent as conduit seal fittings which is to minimize vapor flows and prevent flame propagation down the cable core. Matching the cable diameter and jacket type is necessary.

The threaded gland bodies are made from aluminum, nickel plated brass or stainless steel. The barrier glands are sealed with either a putty or a liquid epoxy during installation. If gland is equipped with an integral disconnecting union fitting, then other fittings should not be necessary.

Further, cable glands and cord fittings use a split or tapered elastomer bushing to supply cable support and strain relief. This acts as a mechanical grip as well as forming a water and oil-resistant termination.

An optional deluge boot supplies enhanced protection from water penetration. Integral O-rings are also a useful choice for reducing water ingress to the enclosure.

12.9.6.2 Installation Requirements

Cables in Class I, Division 1 locations are protected with barrier glands at the termination enclosures. The conductors in MC-HL or ITC-HL cables should be sealed using a listed barrier gland after the jacket and the metal sheath have been removed.

The sealing compound surrounds the conductors and fiber tubes. Nevertheless, to protect against electrical noise shielding and twisted pairs can be left intact.

In Division 2 locations where explosionproof enclosures are used, listed barrier type glands are attached to the cable. They should be no further than eighteen inches from the enclosure or according to the enclosure markings. A fitting that is larger than the opening is not allowed between the barrier gland and the enclosure. Multi-conductor or optical multi-fiber cables; e.g. ITC-ER cables, which vapors can migrate through the core require gland sealing.

In Division 2 locations when a cable is attached to a continuous pressure greater than 1.5 kPa (0.2 psig) and goes to a non-hazardous location, a seal, a barrier, or other means needs to be installed. This is in addition to the section 12.9.7 process seals. These barriers are usually located at the junction box on the multi conductor cables going to the control center.

Otherwise, a listed threaded cable grip is adequate for cables with vapor tight jackets attached to non-explosionproof enclosures in Division 2 locations going to a non-hazardous location. Barrier seals are not necessary. So, network devices and non-continuous process devices need only a cable grip.

Cables that do not have a vapor tight continuous sheath should be sealed at the boundary of the Division 2 and non-hazardous location to minimize the passage of vapor into a non-hazardous location.

12.9.6.3 Vapor Blocked Cables

Division 2 cables with a continuous sheath that does not send vapors through the core more than allowed for seal fittings do not need barrier glands. The cable length cannot be less than the distance that keeps the vapor flow through the cable core to 0.007 ft^3 per hour of air 1.5 kPa (0.2 psig) pressure.

To measure the gas flow, the ends of conductors are sealed to prevent gas migration between the individual wire strands. This can be achieved by dipping the ends in hot wax. The flow rate through the filler between the insulated conductors can be determined, while excluding any leakage through the conductor strands. The wax should be removed before the system is placed in service.

12.9.7 Process Seals

Normal conduit seals are intended to reduce pressure piling during an ignition. They act like flame arrestors and are not intended to restrict vapor flows. When a device is connected to a process, NEC 501.17 requires that instruments which depend on a "single compression seal, diaphragm, or tube" have an added barrier. This is to prevent the flammable fluid from entering the conduit system if the primary seal fails. Typical examples are solenoid valves and level, pressure, temperature and flow switches or transmitters.

If the primary seal fails, the added barrier keeps the hazardous fluids from entering the conduit or cable and prevents the fluid transmission to non-hazardous locations or to arcing or high-temperature devices.

The four allowed methods for mitigating this issue are as follows:

a. Process connected instruments and equipment that are listed and marked as Dual Seal or Single Seal do not need added secondary process sealing when used according to the supplier's ratings. Standard process instruments commonly use this method.

b. A barrier can be installed that meets the process temperature and pressure conditions that occur upon the failure of the device's primary seal. There should be a vent or drain between the primary process seal and the barrier. A seal failure is indicated by visible leakage, an audible whistle, or other means.

c. A listed MI cable assembly rated for 125% of both the temperature and pressure can be installed between the cable or conduit and the device. MI cable has been evaluated to 2000 psig.

d. A drain or vent found between the single process seal and a conduit or cable seal. The drain or vent should be sized to prevent pressuring the electrical seal above 1.5 kPa (0.2 psig.) A seal failure should be indicated by visible leakage an audible whistle, or other means.

See ANSI/ISA-12.27.01-2011 "Requirements for Process Sealing Between Electrical Systems and Flammable or Combustible Process Fluids" for further information.

12.10 Maximum Surface Temperatures

To assist in preventing ignition of the surrounding material by equipment surfaces, heat producing apparatus in electrical hazardous location are marked with the surface temperature or temperature class regardless of the protect technique. The temperature class, is indicated with T Codes from the NEC.

The marking specifies the temperature class or operating temperature at a 40°C (104°F) ambient condition. It is also marked with the ambient temperature when it is greater than 40°C (104°F).

Class I equipment cannot have any exposed surface that operates at a temperature greater than the ignition temperature of the gases present. The ignition temperature of gas specific is determined from tables in NFPA 497. Internationally, IEC/TR3 60079-20 is used to determine ignition temperatures.

Class II equipment temperature markings cannot be greater than the related dust ignition temperature. For organic dusts that dehydrate or carbonize, the temperature marking cannot exceed the lower of either the ignition temperature or 165°C (329°F). The dust ignition temperature is determined from the tables in NFPA 499.

Class III equipment under operating conditions cannot exceed 165°C (329°F) for equipment that is not subject to overloading, and 120°C (248°F) for equipment, such as motor operated valves that can be overloaded.

For equipment installed in a Class II, Division 1 location, the temperature class or operating temperature is based on equipment operation when blanketed with the maximum amount of dust that can accumulate.

Similarly, in a Class III, Division 1 location, the operating temperature is the equipment temperature when covered with the maximum amount of material that can collect on the equipment.

Heat-producing apparatus, such as luminaires, switches, and circuit breakers, as well as plugs and receptacles are potential ignition sources. Instrument items such as solenoid valves, relays, gas chromatograph ovens, catalytic bead gas detectors, nuclear detector heaters, electrical heat tracing, and motor operated valves required investigation for suitability. This equipment can be listed for use in Class I, Division 2 locations if is not a continuous source of ignition.

Normally the operating temperature or the T Code is provided by the supplier. If a heat-producing apparatus; such as a proprietary metering pump or power supply, is not supplied with a marked enclosure, such as an explosionproof box, then the authority jurisdiction can accept an alternate means of evaluation.

One method to determine the maximum surface temperature is using a calibrated infrared temperature detector to scan the enclosure for hot spots with the apparatus operating at full load with 110% of equipment's rated voltage. After enough time to allow the system to come to equilibrium, the maximum temperature rise is then multiplied by a 1.2 factor and corrected to a 40°C ambient or the higher marked ambient. The process is documented, and the value or T Code is marked on the enclosure. See IEC 60079-1 for further information.

NFPA 496 has additional requirements that apply to determine surface temperature for purged enclosures and devices. The temperatures of the hottest internal component and the exit temperature of the protective gas is evaluated.

Non-heat producing equipment; such as junction boxes, conduit, and fittings and minimal heat producing equipment; such as industrial process transmitters and transducers having a maximum temperature not more than 100°C (212°F) are not required to be marked and are considered acceptable for Class I, Division 2 locations.

More than one temperature class or operating temperature, for gases, dusts, and different ambient temperatures, can appear. Equipment for both Class I and Class II is marked with the maximum safe operating temperature, as determined by simultaneous exposure to the combinations of Class I and Class II conditions.

Those NEC T Codes that do not have an alphabetical suffix, i.e., T1-T6, are recognized internationally by the International Electrotechnical Commission (IEC), by CENELEC, and by many national standards bodies.

12.11 Explosionproof Enclosures

An explosionproof, NEMA 7 enclosure is used in Class I, Division 1 locations where an ignition source, fuel, and oxygen coexist. The enclosure is designed so that it can contain the vapor explosion. The enclosure certification is gas/group dependent. An enclosure rated just for Group D is not suitable for a Group B area. However, it is common to have an enclosure coming from a supplier with multiple Group certifications.

Explosionproof enclosures need to withstand an internal explosion and their joint clearances sufficiently tight and wide enough to quench the flame to prevent its spread to the surroundings. These enclosures are listed by a recognized testing laboratory that engages in their evaluation.

The equivalent to explosionproof for Division 2 in Class II and Class III locations is a dust tight box; i.e. a NEMA 3 or NEMA 4 enclosure. For Class II, Division 1 area a dust ignition proof (DIP) rated enclosure, such as one with a NEMA 9 rating, is required. NEMA 7 explosionproof enclosures are not suitable for dust hazards.

Explosionproof enclosures are not acceptable in Zone 0 locations. The only intrinsically sage electronic devices are allowed in Zone 0 locations.

12.12 Pressurized and Purged Enclosures

NFPA 496 purging enclosures with approved components reduce the flammable gas concentration to a safe level. It protects the enclosure interior from the external atmosphere by keeping a slightly higher pressure; i.e. 25 Pa(0.1 inch WC), within the enclosure.

To be used NFPA 496 pressurization equipment needs one of the following:

a. Listed or labeled equipment
b. Testing by a qualified laboratory or agency
c. Otherwise evidence that is acceptable to the authority having jurisdiction [1]

Note 1: A supplier's evaluation, the owner's engineering judgement or similar can be acceptable.

Purging prevents the vapors from entering the enclosure. Except for interlock and disconnect switches being location rated, the purging technique is not Group dependent. For temperatures greater than 100°C (210°F) the enclosure should be marked with its NEC temperature class; i.e. the T code, or its actual temperature.

Purged enclosures can be used in Class I and Class II locations. They are not acceptable for Zone 0; Class III locations or where hazardous liquids can splash or spill on the enclosure.

Table 49 shows the NFPA 496 purging types to reduce the electrical hazard classification within an enclosure:

Table 49
NFPA 496 Purging Types

Type	Enclosure	
	Exterior	Interior
Type X [1]	Division 1	Unclassified
Type Y	Division 1	Division 2
Type Z	Division 2	Unclassified

Note 1: The Type X purge needs a de-energization of the enclosure contents upon purge failure, so it is used sparingly. Analyzer and similar buildings can used use double independent purges such as an overall fan purge and an air purge for devices that do not meet Division 2 requirements.

The protected equipment can only be energized after more than four volumes of the protective gas (ten volumes for motors, and other rotating electric machinery) have passed through the enclosure while maintaining an internal pressure above 25 Pa (0.1 in. of water). For manual startup this requirement is expressed in minutes tother with a minimum flow rate requirement. A minimum pressure can be used in place of the flow rate where the pressure is a positive indication of the correct flow.

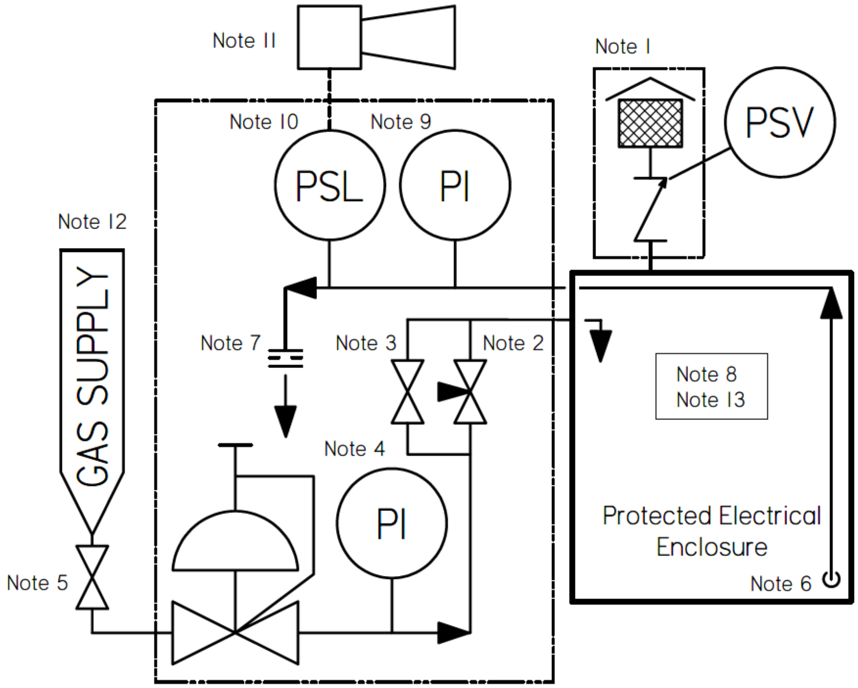
Doors or covers can open violently with high internal enclosure pressures. According to ISA 121.04.04 personnel should be protected from injury by one of the following methods:

a. Multiple fasteners shall be used so the enclosure safely vents before all the fasteners are released
b. A two-position fastener shall be used to allow safe release of the pressure when opening the enclosure
c. The maximum internal pressure shall be less than 2.5 kPa (10 in. WC)

When instructions require the user is required to limit the pressure, the Maximum Operating Pressure should be marked on the enclosure. Also, the instructions should contain one of the following requirements:

a. The user shall to install a Protective Gas Supply that will not exceed the Maximum Operating Pressure of the enclosure under single-fault conditions. The fault shall be self-revealing. Protection can be either with redundant regulators or an external pressure relief valve that is capable of handling the maximum flow rate
b. The user shall use a blower for the Protective Gas Supply. High pressure gas shall not be used for the gas supply.

Figure 29
Electrical Hazard Reduction through Purging or Pressurization



Note 1. Optional pressure safety protection with flame arrector. Recommended to prevent over pressure due to regulator failure, vent blockage or maladjustment of the needle valve restrictor. The flame arrestor can be omitted to avoid plugging.
Note 2. Adjustable restrictor to set enclosure pressure.
Note 3. Optional rapid purge valve used prior to enclosure energization.
Note 4. Pressure gauge for setting output pressure of the regulator.
Note 5. Optional maintenance valve adjacent to the enclosure.
Note 6. Vent tube inlet positioned opposite purge to enable full purging of the enclosure prior to energization. The supply inlet should be at the top of the enclosure for heavier than air hazardous gas. For hazardous gas that is lighter than air the supply inlet should be at the bottom of the enclosure and the vent outlet should be opposite it at the top.
Note 7. Optional vent orifice to control the back pressure in the enclosure.
Note 8. The NEC temperature class shall be shown when the highest temperature exceeds 100°C
Note 9. Pressure gauge for setting enclosure pressure. A variable area meter is acceptable.
Note 10. Electrical area rated switch or transducer to indicate low pressure or flow.
Note 11. Pressurization loss alarm that can be heard or seen at a constantly attended location.
Note 12. Clean dry gas supply, preferably air see Note 6.
Note 13. Nameplate according to NFPA 496 requirements, see Notes 14 and 15. For gases other than air see Note 16 for the warning about asphyxiation dangers.
Note 14.

WARNING PRESSURIZED ENCLOSURE This enclosure must not be opened unless the area atmosphere is known to be below the ignitable concentration of combustible materials or unless all devices within have been deenergized

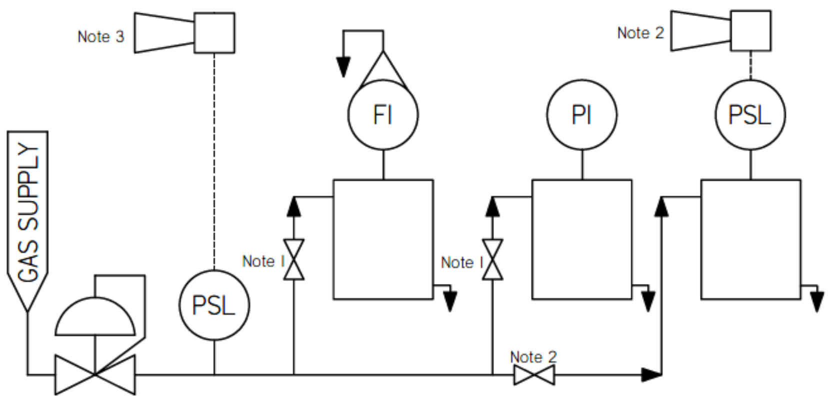
Note 15.

WARNING Protective Gas Release Poses Potential for Asphyxiation

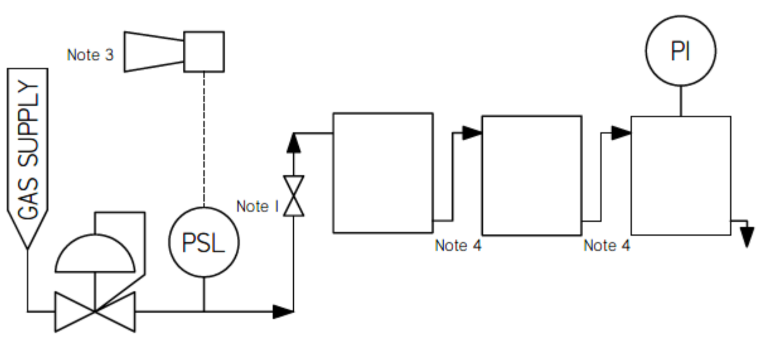
Note 16.

WARNING Power must not be restored after enclosure has been opened until enclosure has been purged for ____ minutes at an outlet pressure of 25Pa or 0.1 in WC

Purging or Pressuriztion with a Common Gas Supply



Purging in Parallel from a Common Gas Supply



Purging in Series from a Common Gas Supply

Note 1. Service valve adjacent to the enclosure shall be marked as follows:

WARNING: PROTECTIVE GAS SUPPLY VALVE This valve must be kept open unless the area atmosphere is known to be below the ignitible concentration of combustible materials or unless all equipment within the protected enclosure is de-energized.

Note 2. An enclosure with a shutoff valve not adjacent to requires an alarm that can be heard or seen in a constantly attended location.

Note 3. Required alarm to monitor the purge supply of the enclosures that are manifolded with the common supply.

Note 4. Conduit/wireways may be utilized as connections between protected enclosures. However, pressurized conduit and wireways should be sized to allow adequate gas flow through the enclosures.

See Example 1 for additional requirements such as enclosure markings, venting, etc. necessary for purge systems.

One disadvantage of purging is that NFPA 496 needs a directly connected alarm in a continuously monitored location to show the loss of purge or supply pressure. The usual method to meet this requirement is to send the alarm to the control room. An auditable alarm that can be heard by area personnel also meets this requirement. The auditable alarm should be distinct in nature or found at the purged device.

NFPA 496 allows the use of a maintenance valve that has a warning nameplate next to the enclosure with a local flow or pressure indicator. The indicators should be viewable, attached to the encloser not the gas supply, it should be directly connected without valves and lastly the common supply for the purged enclosures should have an alarm.

See ANSI/NFPA 496 "Purged and Pressurized Enclosures for Electrical Equipment" for further guidance on how to supply purged and pressurized enclosures. NFPA 496 covers the different requirements for purging small enclosures, power equipment enclosures, and large volume enclosures such as control centers. Analyzer shelters have requirements that are specified in detail in the document.

12.13 Combustible Gas Detection

A useful alternative to using purge or pressurized enclosures for electrical protection is a combustible gas detection system. They are allowed restricted access to industrial establishments with qualified personnel to service the installation.

The following locations can use combustible gas detection protection:

a. Inadequate Ventilation: A location that would be otherwise is classified Class I, Division 1 due to poor ventilation Division 2 electrical equipment can be used with the gas detection equipment listed for Class I, Division 1.

b. Building Interior: A building, such as an instrument shelter, which does not contain a flammable gas source but opens into or is in a Class I, Division 2 location, equipment for non-hazardous locations is allowed with the gas detection equipment listed for Class I, Division 1 or Class I, Division 2.

c. Control Panel Interior: In an enclosure interior containing instruments or analyzers using or measuring flammable liquids, gases, or vapors, equipment suitable for Class I, Division 2 locations is permitted with the gas detection equipment listed for Class I, Division 1.

Enough sensors should be installed to ensure the sensing of combustible gas in the space where the gas can accumulate. The detectors should meet the Group code and T code. Lastly, it needs to be selected for the specific gas. Redundant sensors can be installed to avoid disconnecting electrical power upon a device malfunction.

Sensing a combustible gas concentration of equal to 20% LFL or less when determined by risk assessment or 1 LFL.m should activate a low level alarm. An audible, visual or combination alarm that is appropriate for the location should be provided. Reference NFPA 72 for alarm specifics.

Detection of a combustible gas concentration of 40% LFL or less when determined by risk assessment or 3 LFL.m should activate a high alarm and initiate an automatic power disconnection. The device disconnects should be suitable for the location without the protection being gas detection active. When automatic shutdown can introduce additional or increased hazard, this method of protection is not used.

ISA TR12.13.03 should be used to design and implement the exact requirements; such as calibration features, when using a combustible gas detection system. The detection equipment, its listing, installation, alarm and shutdown criteria, and calibration frequency should be documented.

See the following standards for further application information:

d. ANSI/ ISA-60079-29-1 (12.13.01)-2013, Explosive Atmospheres Part 29-1: Gas detectors Performance requirements of detectors for flammable gases.

e. ANSI/API RP 500 2012, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division I or Division 2.

f. ANSI/ ISA-60079-29-2 (12.13.02)-2012, Explosive Atmospheres Part 29-2: Gas detectors Selection, installation, use and maintenance of detectors for flammable gases and oxygen.

g. ISA-TR12.13.03-2009, Guide for Combustible Gas Detection as a Method of Protection.

12.14 Optical Fiber in Classified Areas

Normally, there is not an ignition concern with flammable gas vapors. LED Diodes and Class 1 lasers are used for communications and neither type is capable of ignition. Class 1 and Class 2 laser emit less than one milli-watt which according to ISA TR12.21.01 is an inherently safe optical radiation level.

In Class I and Zone 0 locations fiber optic terminal devices incorporating the inherently safe concept should provide over-power fault protection to prevent excessive beam strengths. Optical sources such as laser diodes or light-emitting diodes can fail if over-heated under over-power fault conditions. If the optical source fails at a power out less than 35 mW this can provide the necessary over-power fault protection.

Also, electrical circuits such as intrinsically safe barriers placed between the optical source and the electrical power source can provide over-power fault protection.

Otherwise, fiber with OFNP, OFCP, OFNR, OFCR, OFNG, OFCG, OFN, and OFC jackets are acceptable in classified locations provided they are sealed at the ends with an approved seal for the location class. See ANSI/ISA TR12.21.01-2004 for further application of fiber in Division 1 hazardous locations.

12.15 Intrinsically Safe and Nonincendive

Non-Incendive Design (Division 2), and Intrinsically Safe Design (Division 1 or 2) allow general-purpose wiring. The equipment and instruments in a hazardous location are designed to run at low voltages and currents. They are still required to provide freedom from shock and fire according to the first four chapters of the NEC.

Intrinsically safe wiring and in some cases Nonincendive Field Wiring allows the use of strain free flexible cable or special connectors for weigh cells, strain gauges, speed probes, and vibration monitors, keyboards, and the like.

Except for intrinsically safe wiring or Nonincendive Field Wiring, listed tray cable is required for exposed runs in hazardous locations. Other cable types are installed in threaded conduit.

The low energy circuits eliminate shock hazards and hot work permits so field instruments can be replaced or calibrated while under power.

12.15.1 Intrinsically Safe Installations

12.15.1.1 Introduction

Intrinsically safe protection continuously limits the energy for ignition. An intrinsically safe device or apparatus is incapable of producing an arc or enough heat to ignite vapor. High-power circuits such as electric motors or lighting cannot use intrinsically safe protection. Another consequence is that 24 VDC power cannot effectively be fed to most four wire devices in the same multi-conductor cable as the intrinsically safe circuits. Except for simple apparatus such as a resistor or contact, intrinsically safe devices are listed.

A device or wiring is not intrinsically safe alone, it is a system. Safety is achieved by ensuring only low voltages and currents enter the hazardous location, and unnecessary energy accumulation is not possible in the field.

Intrinsically safe systems are designed to deal with device and wiring faults. There are many factors in designing intrinsically safe devices such as stopping sparks, controlling temperatures, and preventing gaps where dust can develop a short circuit. The amount of stored energy in a system depends on the device capacitance and inductance plus the cable energy so they are designed without large capacitors or inductors. It is highly tolerant to faults so unrelated failures can occur with the system staying safe.

12.15.1.2 Intrinsically Safe Apparatus

An Intrinsically Safe Apparatus is a device in which all the circuits are intrinsically safe. An Intrinsically Safe Apparatus or Intrinsically Safe Device is rated across a range of material group hazard classes. The requirements vary according to the circuitry's nature and the hazardous material. The allowed capacitance and inductance value change depending on the group rating. The lower the material auto-ignition point, less energy is allowed. Further, intrinsically safe devices are listed with a "T" code, or a maximum allowed surface temperature.

An Intrinsically Safe Apparatus are usually the devices located in the electrically hazardous location, but they could be devices that located elsewhere but has to be connected to an intrinsically safe circuit. For convince reasons, the device wiring could be running in a cable with intrinsically safe circuits located in an electrically hazardous location.

Isolating galvanic input barriers can be rated both as an Associated Apparatus and for wiring purposes as an Intrinsically Safe Apparatus. C_i and L_i values are provided which allow entity calculations for barrier to barrier interconnection with intrinsically safe wiring. However, according to the control drawing and certification barriers almost always require installation in an unclassified area or Division/Zone 2 area. So maximum allowed surface temperatures and the like are not needed since they do not coexist with hazardous vapors. On the other hand, simple Zener barrier certifications and control drawings do not list C_i and L_i values, so it is not possible to make an entity calculation with them in the role of Intrinsically Safe Apparatus.

Intrinsically safe protection allows devices with exposed wiring or conductors such as load cells or conductive level switches to be used in Division 1, Zone 1 and Zone 0 hazardous locations. Strain gauge load cells and conductive level switches meet the requirements of a simple apparatus, so they do not have to be listed. On the other hand, non-strain gauge load cells such capacitive or piezoelectric types, require component certification.

12.15.1.3 Associated Apparatus

There is an associated apparatus that is paired with the hazardous location device. This is a listed device in a safe location. Depending on the associated device, the safe location is a non-hazardous location, or it can be a Division 2 location when it is listed for that location.

The associated apparatus restricts the electrical energy going into the hazardous location. The most commonly associated apparatus is an independent barrier. The device connected to the barrier is defined as “control equipment.”

The associated apparatus can also be integral to the control equipment. This is common with 4-20 mA trip modules, NAMUR switch modules, and signal multiplexers.

Intrinsically safe design standards require that the associated apparatus not exceed the allowable voltage and current levels. One requirement that often applies to the control equipment is that its power source is less than 250 V_{rms} or VDC.

12.15.1.4 Intrinsically Safe Barriers

Intrinsically safe barriers, which are Associated Apparatus, are installed between the field device and the control equipment. The barriers protect the link between the instrument field circuit and control equipment. They limit the energy from the control equipment going to the hazardous location.

Galvanic and Zener barriers are the most common energy limiters. Zener barriers are the original intrinsic barrier. They are a passive device that use Zener shunt diodes to restrict the voltage and resistors to limit the current. They have a non-replaceable fuse that is as a second layer of protection. Special grounding requirements apply to the Zener barriers, see section 12.15.1.10 for information.

Galvanic barriers are signal isolations that prevent direct current flow. There is no electrical path between the input and output terminals. When they are used as intrinsically safe barriers, they are designed to limit the energy exchange. Transformer isolation is the most widely used method following by opto-isolators, but other methods also exist.

Table 50
Intrinsically Safe Barrier Types

Zener Barriers	**Galvanic Isolators**
Vulnerable to lightning and other surges	Less vulnerable to lightning and other surges
Irreparable once fuse is activated	When supplied the fuse is replaceable
Versatile, few types needed	Use specific, can perform signal conversion
Safety ground fundamental	Safety ground not important
Isolated from ground in hazardous location	Can be grounded once in a hazardous location
Nominal EMI immunity	Less EMI prone
Loop powered	Separate power supply

Zener Barriers	**Galvanic Isolators**
Tightly controlled power supply	Wider power supply range
Voltage restricted in hazardous location	More power allowed in hazardous location
Low heat dissipation	Higher heat dissipation, ≈2VA
Higher packing density	Lower packing density
Zero reference volt imposed across a system	Isolation between signals
Accuracy and linearity higher (0.1%)	Lower accuracy and linearity (0.25%)
Frequency response up to 100KHz	Frequency response to Ethernet frequencies

Zener diode barriers are a simple method for implementing intrinsic safety. One drawback is that they have special grounding requirements. If good ground is not available, operation can be a problem. Another disadvantage for Zener barriers is that non-replaceable fuses are required which can trip during a surge or a short circuit permanently disabling them.

Zener diode barriers come in two forms. The first uses resistors to limit the maximum current allowed into the field and is used to protect circuits with transmitters and other current regulated devices. The second type uses a current regulator rather than resistors. They are intended for discrete devices. In some cases, this allows the use of higher current devices such as solenoid valves. This type of barrier needs to be matched to the field device and the hazardous location.

Galvanic isolated barriers supply isolation, so a one ohm ground is not needed to shunt the excess energy. The isolated barriers use a power supply with a redundant supply typically powering them. These isolators can reduce electromagnetic interference from the field. Also, they do not fail due to fuse problems. Except for systems like load cells and strain gauges where signal accuracy is an issue, galvanic barriers tend to be the preferred protection method.

12.15.1.5 DART Protection

DART (Dynamic Arc Recognition and Termination) or “i” Power can supply more power to an intrinsically safe circuit. It relies on instant tripping. DART uses fault detection based upon current rate change. It instigates a trip in microseconds, so energy is not feed into the field wiring and a spark capable of ignition is prevented.

Depending on the application the DART power supply can feed 50 W of nominal power. This enables HMI’s, analytic equipment, lighting, valve automation systems, and MBP fieldbus segments to be supplied with power. For H1 FOUNDATION™ Fieldbus and PROFIBUS PA systems DART uses an intrinsically safe trunk concept for the segment which is certified according to IEC 60079-11.

12.15.1.6 Approval Types

System and entity are the two methods to certify intrinsically safe applications. With system approval the entire system is evaluated with the components; i.e. the barriers, wire type, measurement device, etc. are labeled by type and model. A variance vacates the entire installation.

Entity approval is where each device is evaluated separately and assigned parameters. With entity approval, a field device can be connected to generic barrier with compatible parameters. The entity approach needs an installation verification according to ISA TR12.2 “Intrinsically Safe System

Assessment using the Entity Concept" or ISA 60079-25 "Explosive Atmospheres Part 25: Intrinsically safe electrical systems."

Table 51
Entity Markings for Intrinsically Safe Devices

Entity markings	**Division**	**Zone**
FIELD DEVICE (Intrinsically Safe Apparatus)		
Maximum input voltage	V_{max}	U_i
Maximum input current	I_{max}	I_i
Maximum input power [1]	P_i	P_i
Maximum internal capacitance	C_i	C_i
Maximum internal inductance	L_i	L_i
Internal inductance-to-resistance ratio	L_i/R_i	L_i/R_i
ASSOCIATED APPARATUS		
Maximum output voltage	V_{oc}	U_o
Maximum output current	I_{sc}	I_o
Maximum output power [1]	P_{max}	P_o
Maximum allowed capacitance	C_a	C_o
Maximum allowed inductance	L_a	L_o
External inductance-to-resistance ratio	L_a/R_a	L_a/R_a
Maximum output voltage, multiple channel apparatus [2]	V_t	U_o
Maximum output current, multiple channel apparatus [2]	I_t	I_o
Note 1: Option parameter for examination of thermal effects. Note 2: This only applicable with intrinsically safe devices like temperature multiplexers.		

12.15.1.7 Control Drawing

NEC and CSA require, regardless of the approval, the system be installed according to the supplier's Control Drawing. If Control Drawings are furnished by the intrinsically safe device supplier and the associated barrier supplier, compliance with both drawings is needed.

ATEX or IEC do not have this requirement. In these situations, IEC 60079-14 defines the methods of evaluating circuits. However, an "X" at the end of certification number indicates that special installation requirements exists. These are usually stated at the end of the certificate.

The control drawing limits the components that can be present, so most NEC and CSA intrinsically safe installations use just a barrier and field device. For instance, the control drawing has to include local indicators for them to be allowed in the hazardous location wiring. On the other hand, ATEX or IEC allow multiple components to be used in intrinsically safe circuits. ISA RP12.06.01 "Recommended Practice for Wiring Methods For Hazardous (Classified) Locations Instrumentation Part 1: Intrinsic Safety' provides methods for evaluating complex circuits.

The control drawing details allowed interconnections between the intrinsically safe and the associated apparatus. Simple apparatus; e.g. as a selector switch, not shown on the supplier's control drawing, are allowed provided that the simple apparatus does not interconnect the wiring with another circuit.

RTD's, thermocouple and terminals are simple devices as are LED's and photocells. Simple devices cannot generate more than 1.5 V, 100 mA and 25 mW. Also, the maximum surface temperature of the simple device, based on its resistance, needs to be determined according to NEC Article 504.10 requirements.

12.15.1.8 Entity Calculations

Most installations are a barrier connected to an instrument, so simple calculations are used. See Table 52 or ANSI/ISA-60079-25 Appendix A. An entity calculation for a component pair mostly involve comparing parameters between the two devices. See ISA TR12.2 for more entity valuations involving more complex intrinsically safe circuits.

The most straight forward procedure is to create template installations for each device type and back calculated the maximum installed distance. Then determine the distance to each instrument to verify the installation.

Table 52
Truth Table for an Entity Pair Calculation

Field Device		Operator	Associated Apparatus	
ISA	IEC		ISA	IEC
V_{max}	U_i	≥	V_{oc}	U_o
I_{max}	I_i	≥	I_{sc}	I_o
P_i	P_i	≥	P_{max} [1]	P_o [1]
$C_i + C_{cable}$ [2]	$C_i + C_c$	≤	C_a	C_o
$L_i + L_{cable}$ [3]	$L_i + L_c$	≤	L_a	L_o
The cable length restrictions due to cable inductance (L_{cable}/L_c) can be ignored and L_a or L_0 can be less than L_i if the following two conditions are met.				
L_i/R_i	L_i/R_i	≤	L_a/R_a	L_o/R_o
L_{cable}/R_{cable}	L_c/R_c	≤	L_a/R_a	L_o/R_o
Note 1: Where an associated apparatus with a linear output is not marked with P_{max} or P_o, the parameter can be calculated as ¼ the product of V_{oc} times I_{sc} (or ¼ the product of U_o times I_o). Nonlinear outputs require other considerations. Note 2: If C_{cable} is not known, use a value of 197 pF/m (60 pF/ft) for a conventional cable that has two or three conductors. Note 3: If L_{cable} is not known, use a value of 0.66 µH/m (0.20 µH/ft) for a conventional cable that has two or three conductors.				

Care should be taken to evaluate the effects of cable capacitance and inductance on the suitability of the system, and to ensure that the proper operational voltage and current levels for the Intrinsically Safe Field Device occur with the Associated Apparatus selected.

The values of V_{max} (U_i) and I_{max} (I_i) are chosen by the Intrinsically Safe Field Device manufacturer to allow connection to a wide variety of Associated Apparatus.

V_{max} (U_i) and I_{max} (I_i) represent worst-case, associated-apparatus fault conditions and do not necessarily bear a relationship to the normal operating voltage and current parameters of the Intrinsically Safe Field Device. V_{max} (U_i) and I_{max} (I_i) are limited only by the maximum voltage and current that the Intrinsically Safe Field Device can receive and remain intrinsically safe, based on stored energy and thermal considerations.

The V_{max} (U_i) and I_{max} (I_i) values specified for an Intrinsically Safe Field Device, taken together, and compared to the spark gap ignition curves are in the ignition-capable location. This is not a problem; the field device can be paired with an Associated Apparatus that has a V_{oc} (U_o) and I_{sc} (I_o) combination that is not ignition-capable.

The connection of either Associated Apparatus to the Intrinsically Safe Field Device results in an intrinsically safe system, since in both cases, V_{max} (U_i) ≥ V_{oc} (U_o or V_t) and I_{max} (I_i) ≥ Isc (I_o or I_t).

Some older intrinsically safe field devices have been found to have negligible inductance and capacitance, so they are not listed on the certification so any C_a (C_o) and L_a (L_o) for a barrier is effective.

An additional parameter that is optionally assigned to either an intrinsically safe apparatus or an associated apparatus is P_i or P_{max}. When assigned to an intrinsically safe apparatus, P_i is the maximum power that can be applied safely to the intrinsically safe apparatus. When assigned to an associated apparatus, P_{max} is the maximum power that can be delivered under specified fault conditions by the associated apparatus.

The use of the P_{max} parameter provides flexibility with the entity concept. An assessment of thermal effects in the intrinsically safe field device is conducted using the value of P_i. So, in these situations V_{max} and I_{max} are limited by the allowed stored energy.

When P_{max} is not specified, the V_{max} and I_{max} parameters are used in the examination of thermal effects as well. When P_i is specified for an intrinsically safe field device, it is connected to an associated apparatus that has an equal or lower P_{max} (P_o).

12.15.1.9 Wire Installation

The control drawing does not define the physical installation requirements. The instrument is connected, using NEC article 504, CSA Appendix F or IEC 60079-25 wiring methods. Besides the field device wiring, the control equipment and the associated device in the non-hazardous location is addressed. ISA RP12.06.01 provides detailed guidelines for intrinsically safe wiring as well as an interpretation of NEC article 504.

Unless required by NEC Article 504, intrinsically safe circuits do not need to follow NEC Articles 501 through 503 and 510 through 516, so the circuits, in general, can be wired in the same manner as comparable circuits in non-hazardous locations for shock and fire safety. However, since the energy in an intrinsically safe circuit is inherently limited, overcurrent protection is not required.

One exception to using general purpose wiring methods is that vapor tight jackets and cable seals are still needed to prevent vapor transmission between classified boundaries. For instance, a seal is needed going from a Division 1 location to a non-hazardous location. The seals do not have to be explosionproof but should be intended for minimizing vapor passage and dust under normal conditions. They are required to be accessible as well.

Common cabling with non-intrinsically safe circuits is not allowed. The following restrictions apply to the routing of intrinsically safe cables:

a. In separate raceways [1]
b. In trays or a tray with a partition [2]
c. Secured and separated by 50 mm (2 in) from non-intrinsically safe conductors [3]
d. In Type MI or MC cables
e. Next to MI or MC non-intrinsically cables [4]

Note 1: One exception is that in Division 2 locations nonincendive and intrinsically safe conductors can share a raceway or tray when the intrinsically safe apparatus is in Class 1, Division 1, Zone 0, or Zone 1.

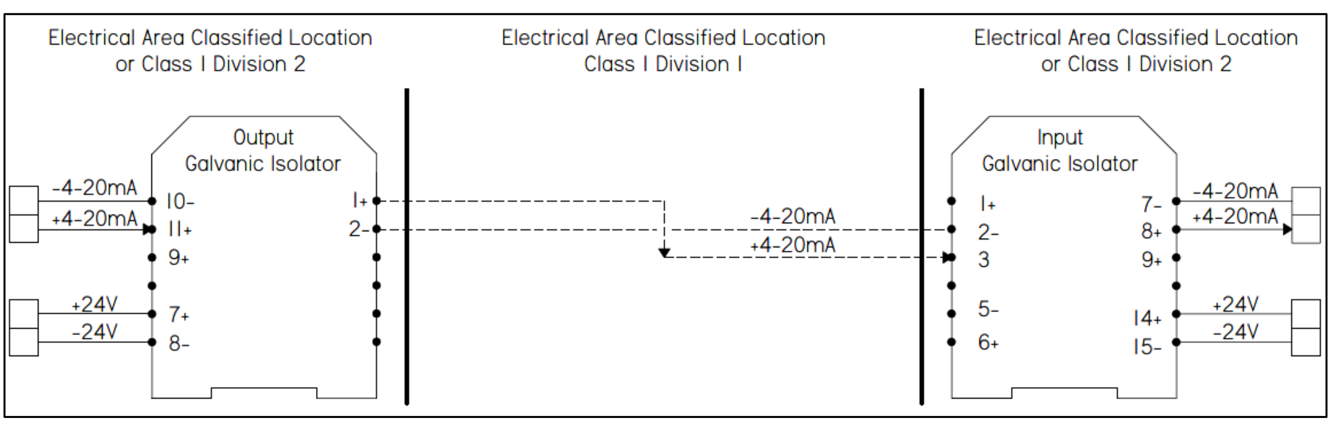
Note 2: An independent partition; such as a 0.90 mm metal divider, can be used. Insulating type partitions such as a wire duct need to be approved.

Note 3: In enclosures separation from other ducts by 19 mm (¾ in.) meets the spacing requirements.

Note 4: MI or MC cables can be used for the non-intrinsically safe circuits if the armor can carry the fault currents.

Interconnect barriers can be used to convert a non-intrinsically safe field signal into an intrinsically safe signal. These are isolator type barriers that are connected in a back to back arrangement. See Figure 30. This technique is useful to route four-wire instruments such as analyzers to an intrinsically safe junction box. Otherwise associated apparatus in two different safe locations normally cannot be interconnected using cables designated intrinsically safe.

Figure 30
Interconnected Intrinsically Safe Barriers



The clearance between the uninsulated parts of intrinsically safe conductors and grounded metal or other conducting items has to be at least 3 mm (⅛ in.)

Terminals of different intrinsically safe circuits should be separated from each other by a 6 mm (¼ in.) Standard IEC 60947-7-1 wire clamp terminals are 6 mm apart and meet this requirement. Also, the intrinsically safe circuits should be shielded or should have 0.25 mm insulation when sharing a common cable. The lightest gauge of 300V NEMA WC 57-2014 instrument wire has 0.38 mm of insulation, so this is not a problem in most cases. However, fluoropolymer insulations such as ECTFE, ETFE, FEP, MFA, PFA, PTFE, and TFE fabricated according to UL 2250 do not meet this minimum thickness. Plus, the fluoropolymer PVDF (Kynar®) and its copolymers lack the necessary thickness. Lastly SRPVC (semirigid PVC) insulation is unsatisfactory.

See ISA RP12.06.01 “Recommended Practice for Wiring Methods for Hazardous (Classified) Locations Instrumentation Part 1: Intrinsically safe” for further discussion how the NEC applies intrinsically safe systems.

12.15.1.10 Grounding and Bonding

NEC section 504.60 requires metallic intrinsically safe apparatus, enclosures, and raceways to be tied into the plant ground system. Also, grounding applies to the intervening raceways, fittings, boxes, enclosures, etc. through the hazardous locations to the final ground point. An approved grounding method for classified locations should be used. See ISA RP12.06.01 figures 4.4 to 4.12 typical grounding and bounding arrangements.

The associated apparatus and cable shields need to be grounded according to the control drawing. The ground conductors should be secure, permanent, visible, and accessible according to 504.10(A) requirements.

In addition to equipment grounding, a connection to the grounding electrode can be needed for the associated apparatus. For example, control drawings require that Zener barriers have a low resistance connection, one ohm or less, to the ground electrode. The barrier ground needs a specifically allocated conductor between them and the ground electrode that is separate for the other ground conductors. Redundant ground conductors are preferred.

Grounding electrodes for intrinsically safe systems are installed according to NEC Article 504.50 requirements. NEC does limit the ground types that are allowed for intrinsically safe systems. See Table 53. For instance, it constrains the use of isolated rods and plate electrodes. It is recommended that they be incorporated into the overall ground system.

Table 53
Acceptable Intrinsically Safe Ground Electrodes

GROUND ELECTRODES	CONTACT [1]	REQUIREMENTS
Preferred Electrode Types		
Metal Underground Water Pipe	3 m (10 ft)	Electrically continuous pipe
Metal In-Ground Support Structure	3 m (10 ft)	with or without concrete encasement
Concrete-Encased Electrode	6 m (20 ft)	13 mm (½ in) rebar or 4 AWG bare copper wire
Ground Ring	6 m (20 ft)	2 AWG bare copper wire
Alternate electrodes when the above types are not available		

GROUND ELECTRODES	CONTACT [1]	REQUIREMENTS
Rod-type grounding electrode	2.5 m (8 ft)	16 mm (⅝ in) stainless steel, copper or zinc coated steel rod
Plate Electrode	0.2 m^2 (2 ft^2)	6.4 mm (¼ in) thick conductively coated iron or steel plates or 1.5 mm (0.06 in) nonferrous, bare metal
Underground Metal Structures		Bare non-water pipe, bare underground tanks, etc.
Note 1: The electrodes should directly contact the earth using the values shown.		

ISA RP12.06.01 allows an equipotential ground rather than a single point ground can be used as the intrinsic safety ground if potential ground fault current from other equipment that is sharing the grounding conductor will not cause an unsafe voltage differential between the grounding electrode and a grounded conductor of an intrinsically safe circuit.

IEC 60079-14 requires that an intrinsically safe circuit should either be fully floating or bonded to the reference potential associated with a hazardous location at one point only. Where a shield is used, the shield is electrically connected to ground at one point only with certain exceptions. Otherwise this is normally at the non-hazardous location end of the circuit loop. This is to avoid the shield carrying an incendive level of current where there are local differences in ground potential.

If a grounded intrinsically safe circuit is run in a shielded cable, the shield for that circuit should be grounded at the same point as the intrinsically safe circuit.

IEC 60079-14 has three exceptions to single point grounding but the second one works best with MESH bonding and is applicable to process plants where technicians are capable of maintaining the system.

If the installation is maintained to a high standard so that potential equalization between each end of the circuit cable shields is assured ground at both ends of the cable and at any interposing points is allowed.

12.15.1.11 Identification

Intrinsically safe circuits should be identified at terminal locations such as junction boxes to prevent unintentional modifications. It is recommended that the cable jacket be a light blue color if there are no other existing circuits with this color.

Enclosures, raceways, cable trays, etc. should have permanent markers saying, "INTRINSICALLY SAFE WIRING" or its equivalent. The labels should be visible. This marking applies to non-hazardous locations as well.

Cable are located so they can be traced along their full length. The labels should appear in every section that is separated by enclosures, walls, partitions, or floors. Also, spacing between the labels is not greater than 7.5 m (25 ft.)

12.15.1.12 Maintenance

In North America, there is no standard for intrinsically safe equipment maintenance. The maintenance procedures are listed on the approved control drawing, manual or other installation documents.

Maintenance work on live intrinsically safe systems is conducted under controlled conditions. IEC 60079-17 provides guidelines for live-work on intrinsically safe field circuits. The work in hazardous locations is limited to:

a. Disconnecting, removing, or changing cables or equipment [1]
b. Adjustments required for calibration
c. Removing or changing plug-in components or circuit boards

Note 1: The ground connections of safety barriers should not be removed before the circuits in the hazardous location are disconnected.

With an operating loop, test instruments; such as a HART communicator, defined in the documentation or control drawing can be employed. Otherwise, evaluations can be performed on intrinsically safe field devices that are disconnected from the loop using intrinsically safe test instruments. The test instrument and the field device are operated according to their respective control drawings. The detached field wiring is evaluated in the same manner.

After maintenance, the following should be checked:

a. Easily identifiable marking of intrinsically safe circuits
b. The conformity of the installation with the documentation
c. Separation of components between intrinsically safe and non-intrinsically safe circuits
d. Cables and their shielding
e. Continuity of grounding of non-galvanically isolated circuits
f. Grounding or isolation of intrinsically safe circuits

12.15.2 Nonincendive Installations

Equipment that does not present an ignition hazard in normal operation is capable of being designated as nonincendive. Installations meeting the nonincendive criteria are suitable for Division 2 locations where the atmosphere is normally nonflammable. It is an alternative to the general wiring methods for Division 2/Zone 2. Nonincendive Equipment can use wiring methods that does not require the same degree of mechanical protection.

The term “Nonincendive Equipment” is often misunderstood due to its varied uses. It is more than a scaled back version of intrinsic safety. It is a family of protection methods. Nonincendive equipment can be quite varied and can be a simple switch, a thermocouple, a 4-20 mA two-wire transmitter, a sensor with a coaxial cable, or a 120 VAC powered controller.

The term “energy limited” refers to a circuit, it does not apply to a component; e.g. hermetically sealed switch. As a result, the terms “nonincendive component” and “nonincendive circuit” are used to differentiate these methods.

12.15.2.1 Nonincendive Methods

Nonincendive equipment can be installed in a hazardous location without further enclosure protection other than some limited sealing for the field wiring. NEMA 4 or general-purpose enclosures are used.

Equipment that does not have make-and-break contacts and does not have surfaces that exceed the ignition temperature of the combustible materials can be Nonincendive Equipment. Equipment with make-and-break contacts can also be nonincendive if these contacts are prevented from causing ignition by a Division 2 protection technique. See section 12.7.2 for specific cases.

Standards such as ANSI/ISA-12.12.01 are used to evaluate Nonincendive Equipment. The evaluate verifies that the equipment does not have unprotected make-and-break contacts such as found with relays, motor brushes and process switches. The evaluation also determines the maximum normal surface temperature during operation.

Other factors are also evaluated. This includes the connector's ability to resist vibration and an evaluation of components that can become an ignition source during replacement, such as fuses and lamps.

12.15.2.1.1 Nonincendive Component

A nonincendive component has contacts for making or breaking a circuit with the mechanism constructed so that it is incapable of igniting a specified flammable mixture. A nonincendive component housing is not intended to exclude the flammable atmosphere or have an explosion. Hermetically seal and solid state contacts are examples of this approach.

12.15.2.1.2 Nonincendive Circuit

Nonincendive circuit, other than field wiring, is an energy limited circuit where an arc or thermal effect is not possible of igniting a flammable mixture under the intended operating conditions. This is like a nonincendive component but incorporates elements such as a current regulator to limit the energy. However, it can be more than a simple discrete logic device, it can provide analog or serial data signals.

12.15.2.2 Nonincendive Equipment

Nonincendive equipment is a device with circuitry that is incapable, under normal operating conditions, of causing ignition of a specific flammable mixture due to arcing or thermal means.

The term Nonincendive Equipment has been used in a restricted sense to apply only to energy limited equipment used in a nonincendive circuit. The correct usage includes equipment that has circuits that are not necessarily energy limited, but have protected make/break components so that it is not an ignition source during normal operation.

ISA 12.12 permits equipment to be assembled using make/break components that are protected with techniques such as using nonincendive components or nonincendive circuits. These techniques also include restricting access to manually operated components; such as a power switch.

Circuits internal and external to Nonincendive Equipment can operate at ignition capable energy levels so disassembly; e.g. as removing circuit boards, is only allowed after an area safety assessment for combustible gases.

Nonincendive Equipment has the following advantages:

a. Limited maintenance on live devices [1]

b. Use of a general purpose enclosure

c. Wire sealing normally not required [2]

Note 1: unlimited disassembly is only possible with equipment rated as intrinsically safe. Still covers and doors can be removed to allow access and use of non-arcing controls and switches without a safety evaluation for flammable material. Removal of cards, fuses and the like that have not been found to be non-arcing is not allowed. Also, except for Nonincendive Field Wiring, de-termination of wiring is not allowed. Test instruments shown on the control drawing; e.g. an intrinsically safe multimeter, can be connected to the live instrument.

Note 2: Cable seals and vapor tight jackets are required to stop vapor transmission between classification boundaries such as going from a Division 2 location to a non-hazardous location. The seals should minimize vapor and dust passage under normal conditions but do not have to be explosionproof.

12.15.2.3 Nonincendive Field Wiring

In North America Nonincendive Field Wiring resembles intrinsic safety in principle but differs in detail. The main difference is nonincendive circuits are evaluated under normal conditions; i.e. fault conditions do not need to be considered.

Nonincendive Field Wiring that enters or leaves an equipment enclosure and, under normal equipment operating conditions, is not capable of igniting a flammable mixture. Normal operation includes opening, shorting, or grounding the field wiring.

Nonincendive Field Wiring installations removes the restrictions on termination and de-termination of the live field wiring. However, Nonincendive Field Wiring requires an entity evaluation.

The voltage and current delivered to the field wiring circuit is limited by the Associated Nonincendive Field Wiring Apparatus (ANIFW) and the energy storage is limited by the Nonincendive Field Wiring Apparatus (NIFW).

12.15.2.3.1 Associated Nonincendive Field Wiring Apparatus (ANIFW)

A Nonincendive Field Wiring installation is made according to a Control Drawing furnished by the supplier. To achieve this an ANIFW Apparatus is needed. This is the nonincendive version of either an intrinsically safe barrier or intrinsically safe device output.

An ANIFW Apparatus intended for Nonincendive Field Wiring has fewer components than an intrinsically safe barrier. Most ANIFW Apparatus channels consist of two components, a current limiting resistor and voltage limiting shunt diode. As a result, they are more dependable than Zener barriers.

For Group C and Group D, the ignition Group IIB spark gap curve from figures A.3 and A.4 Annex A of ISA 60079-11 are used to determine the maximum external capacitance (C_o) and maximum external inductance (L_o) respectively. For Group A and Group B ignition the Group IIC spark gap curve from figures A.3 and A.4 is used. For Nonincendive Field Wiring a safety factor of one applies to these values.

The Group IIA curves apply to a subset of Group D hydrocarbons, see NFPA 497. The Group I curves are concerned with mining using a mixture of methane and coal dust.

For evaluating the ANIFW Apparatus, the maximum output voltage (U_o) i.e. the open circuit voltage is used with Figure A.3. If a regulated power supply with a minimal droop the nominal voltage can be used. Unregulated supplies should use a 1.1 factor for the voltage value. The maximum output current (I_o) i.e. the short circuit current is applied.

12.15.2.3.2 Nonincendive Field Wiring Apparatus (NIFW)

To limit the energy input the NIFW device is connected to the ANIFW Apparatus in a safe location. The NIFW is a field device that is usually a continuous process instrument, but it can be a more complex device with just its I/O being the energy limited ANIFW Apparatus. Not every Nonincendive Equipment is a NIFW device, but a NIFW device is defined as being Nonincendive Equipment.

NIFW device connected to Nonincendive Field Wiring is identified by parameters specified in Table 54. The supplier provides this information with the Control Drawing. Also, the details of the permitted connections are shown on the control drawing.

Table 54
Entity Markings for Nonincendive Field Wiring

Entity Markings	**Label**
NIFW DEVICE	
Maximum open-circuit voltage	U_i
Maximum short-circuit current	I_i
Maximum-allowed capacitance	C_i
Maximum internal inductance	L_i
Internal inductance-to-resistance ratio	L_i/R_i
ANIFW Device	
Maximum output voltage	U_o
Maximum output current	I_o
Maximum allowed capacitance	C_a
Maximum allowed inductance	L_a
External inductance-to-resistance ratio	L_a/R_a

Though non NIFW devices can occupy the same field cable and terminate in the same junction box, having all the signals meet NIFW criteria simplifies the wire identification that ISA 12.12.01 requires. It also allows consistent maintenance practices.

This problem occurs with devices not having a North America origin as well analyzers and other four-wire devices that are not listed as NIFW devices. For those instances it is possible to make an “engineering judgement” that is acceptable to the Authority Having Jurisdiction under section 500.8(A)(3) of the NEC.

The easiest method is to use Class I, Division 1 as well as Zone 0, Zone 1, or Zone 2 intrinsically devices if they fall under the same Group and T codes. ATEX and IECex devices that are rate ia, ib, or ic are intrinsically safe.

Though it is not possible to use engineering judgement to certify a device as intrinsically safe, it is practical to verify four-wire device outputs as being a NIFW.

Four wire process instruments listed for Division 2 locations with NEMA 4, or IP 65 operator interfaces have a nonincendive construction. They use regulated 4-20 mA outputs that are nonincendive resistive circuits. Inputs to 24 VDC solenoids can be determined to be nonincendive by using figure A.4 and its inductance value.

By using at the output circuit schematics this can be confirmed by the ISA 12.12.01 section 7.3 “Evaluation by Analysis” method.

Depending on the circuit type if the intersection of C_i + C_{cable} and U_i or the intersection of L_i + L_{cable} and I_i are below the applicable group curves then the device is capable being used in a Nonincendive Field Wiring circuit as a NIFW device with the properly paired ANIFW apparatus. For devices with a C_i capacitance less than 0.01 µF and an L_i inductance is less than 0.1 mH then figure A.1 can be used to evaluate the device since it is essentially a resistive circuit.

12.15.2.3.3 NIFW Entity Evaluation

For NIFW Entity Evaluations, the user investigates the wiring characteristics as well as the connected equipment.

By means of a Table 52 type entity evaluation, the maximum input current (I_i) of the NIFW device should be equal to or greater than the maximum output current (I_o) of the ANIFW Apparatus. The maximum input voltage (U_i) of the NIFW device should be equal to or greater than the maximum output voltage (U_o) of the ANIFW Apparatus. The values of C_i + C_{cable} and L_i + L_{cable} should be less than C_a and $L_{a,}$ respectively.

As an exception to a Table 52 full entity evaluation, a NIFW device that controls its own operating current; e.g., 4-20 mA transmitter or control device, the maximum input current (I_i) of the NIFW device does not have to correspond to the maximum output current (I_o) of the ANIFW Apparatus.

Table 55
Truth Table for a Current Regulated NIFW Device

Field Device		**Operator**	**Associated Apparatus**	
ISA	**IEC**		**ISA**	**IEC**
V_{max}	U_i	≥	V_{oc}	U_o
$C_i + C_{cable}$ [1]	$C_i + C_c$	≤	C_a	C_o
$L_i + L_{cable}$ [2]	$L_i + L_c$	≤	L_a	L_o
The cable length restrictions due to cable inductance (L_{cable}/L_c) can be ignored and L_a or L_0 can be less than L_i if the following two conditions are met.				
L_i/R_i	L_i/R_i	≤	L_a/R_a	L_o/R_o
L_{cable}/R_{cable}	L_c/R_c	≤	L_a/R_a	L_o/R_o
Note 1: If C_{cable} is not known, use a value of 197 pF/m (60 pF/ft) for a conventional cable that has two or three conductors.				

Note 2: If L_{cable} is not known, use a value of 0.66 µH/m (0.20 µH/ft) for a conventional cable that has two or three conductors.

The evaluation of a circuit where the normal operating current is controlled by the nonincendive field wiring apparatus e.g. two wire 4-20 mA transmitter can be a simple exercise. If the signal is a regulated current, then I_i of the NIFW device does not have to be greater than the I_o of the ANIFW apparatus and Table 55 can be used.

Likewise, the maximum input voltage (U_i) of a NIFW device that controls its normal operating voltage; e.g. valve positioners that clamped the voltage at their terminals, need not be greater than the maximum output voltage (U_o) of the ANIFW Apparatus.

12.15.2.3.4 Nonincendive Field Wiring Installation

Nonincendive field wiring does not have the separation requirements that apply to intrinsically safe wiring. The cables can be mixed with ordinary Division 2 cables. They can also be run with intrinsically safe cables in a Class I, Division 2 location.

The following two requirements apply to Nonincendive Field Wiring:

a. Nonincendive Field Wiring systems are installed according to the supplier's control drawing.
b. The connections, including field devices, for Nonincendive Field Wiring are clearly identified [1]

Note 1: A ferrule or spade lug with uniquely colored, such as yellow, is recommended. Also, a unique acronym or symbol can be added to the wire tag. Further, the identification can be at the enclosure level if every circuit in it is Nonincendive Field Wiring. Similarly, terminal strips can be identified.

Nonincendive Field Wiring can be installed in the following ways:

a. The circuits are in individual cables
b. In multiconductor cables with each signal contained in a grounded metal shield
c. In multiconductor cables or raceways using a 0.25 mm minimum insulation thickness. [1]

Note 1: UL standard field wire types including ITC cables have an insulation thickness greater than 0.25 mm.

Nonincendive Field Wiring can use the following wiring methods:

a. Nonincendive Field Wiring can use non-hazardous locations wiring techniques. [1]
b. Simple apparatus; e.g. hand switches, terminals, and the like, not shown on the control drawing, can be used in a Nonincendive Field Wiring circuit. [2]

Note 1: The wiring methods have to conform to the NEC requirements for shock and fire protection. Since low power circuits are used, fusing is not required but some form of disconnect is recommended for maintenance purposes. Vapor tight jackets and cable seals are needed to prevent vapor transmission between the classification boundaries.

Note 2: The simple apparatus cannot interconnect a Nonincendive Field Wiring circuit to another circuit.

12.15.2.4 Class I Zone 2

Class I, Division 2 nonincendive equipment is closely related Zone 2 mb, mc, nA and nC non sparking equipment designations. Energy limitation protection “nL” has migrated to “ic” protection in ANSI/ISA 60079-11 where it is defined as electrical apparatus and systems containing intrinsically safe circuits that are incapable of causing ignition with the appropriate safety factor in normal operation.

The safety factors and equipment construction requirements are however more relaxed than for the “ia” and “ib” protection levels. However, “ic” following the same wiring segregation practices that apply to intrinsically safe circuits in general.

13 FIRE PROTECTION

When fires protection is necessary, thermal barriers and fire retardants can be supplied. Fire integrity ratings are specified by time. By using cable evaluated according to UL 2196 it is possible to maintain control for twenty minutes. Another approach is to bury the cables.

Fire and physical protection is necessary for safety Instrumented system (SIS) and critical network cables. Protection from mechanical and environmental damage is necessary. A minimum of forty feet of physical separation and independent support should be considered for critical cables.

13.1 Fire Resistant Cable and Tray

MI cable is effective at resisting fire for up to two hours. The electrical codes have specific requirements for Circuit Integrity cables with regards to jacket and insulation fire resistance. A two hour fire resistance cable with flexible jacket listed to UL 2196 is used for Circuit Integrity. These cables do not have moisture and vibration issues of MI cable. NEC article 728 and IEEE 1810 cover fire-resistant or Circuit Integrity cable installation.

Cable trays and their supports should be fire protected to meet the expected fire exposure as determined by an appropriate study. The fire protection should be specifically designed for cable trays. High temperature or fire resistant insulation can be used. Material such as a foil backed endothermic wrap is a possibility. Aluminum raceways and trays are not recommended for fire protected circuits. Refer to UL 1709 and API 2218 for additional information.

Fire rated cables should be installed in a dedicated tray or separated by a steel barrier. Cable tray materials, supports, accessories, wire ties, straps, couplings, covers; separators and the like should be made out of steel or other materials tested in a IEEE 1717 hydrocarbon fire pool test.

When fire rated cables are below non-fire rated cable, other combustible materials or falling debris a tray cover should be used. The fire rated cables should be installed in a single layer, unless evaluated in other configurations in the fire pool test.

13.2 Fire Resistant Junction Boxes

Junction box fire protection involves encasing the conduit or cables as well as the junction box with a fire resistant material; e.g. gypsum or similar commercial product. Fire rated junction boxes are available eliminating the need to provide special insulation.

Correctly installed fire protection lasts between one to two hours. The cables and conduit should be vertically protected to the elevation that is appropriate for the fire source. Parodic repairs are needed to ensure effective coverage. Additions and modifications to fire protection is difficult. Spray products are particularly inflexible.

13.3 Fires Stops

Electrical installations in hollow spaces, and vertical shafts as well as ventilation or air handling ducts need to be made so that the spread of fire or products of combustion is suppressed. Openings around electrical penetrations into or through fire resistant rated walls, partitions, floors, or ceilings need to be fire stopped using approved methods.

Fire stops are required to protect building penetrations and fire zones according to the NEC. These barriers are given a fire resistance rating in hours based on the results of a standard fire exposure test. Many conduit and cable seals can double as fire stops. See “Bisci Telecommunications Distribution Methods Manual” for further information on the selection and application of fire stops.

14 FUTURE GROWTH

It is recommended that 20% spare capacity be supplied at the component level for future use. This applies to junction boxes, panels, load centers, cabinets, cable pairs, and terminal blocks, as well as the air supply and UPS size.

The 20% percent spares for wires, terminals, circuit breakers or entries should be determined with respect to the total number. That is 1.20 times the active wire quantity, circuit breakers, terminals, or entries.

Instrument signal cables, with six or more pairs or triads, should have 20% minimum spares or two spare pairs or triads, whichever is greater. Underground conduit should have 25% spares.

A minimum of 20% unassigned terminals should be supplied in each building and local control panel, cabinet, or junction box. Also, 20% spare cable entries suitably plugged should be supplied.

Systems should have a minimum of 20% installed spare I/O points of each type in every system. A minimum of one spare module for each type should be supplied.

Other components to support the spare I/O, such as power supply capacity, terminal blocks, I/O cables, communication capacity, etc. should also be installed with the installed spare points.

Unused hot spares should also be supplied for the following components:

a. Logic Solver
b. Communications Module
c. I/O module of each type
d. I/O rack power supply
e. Termination assembly of each type

Compared to the installed base the systems should be capable of 10% future hardware expansion without changing or replacing existing equipment, communications cables, or operating software.

To accommodate this, the system should have 20% spare space without installed modules. This includes space in cabinets, marshalling for terminals, wiring, I/O modules, cables, etc. This would be in addition to the installed spare requirements specified above. The spare space should be distributed equally among the cabinets.

The systems should be designed so not more than 80% of the processing capability and memory is used. Further the following loading should be used:

a. Communication loading 40%
b. Tag loading 80%
c. Processor cycle time 60%
d. Operator console 80%

15 STANDARDS

15.1 American Petroleum Institute (API)

API 14F	Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1, and Division 2 Locations
API RP 500	Classifications of Areas for Electrical Installations at Petroleum Facilities
API RP 505	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2
API RP 540	Electrical Installations in Petroleum Processing Plants
API RP 551	Process Measurement
API RP 553	Refinery Valves and Accessories for Control and Safety Instrumented Systems
API RP 554	Control systems
API RP 555	Process Analyzers
API Std 670	Machinery Protection Systems
API Std 2218	Fireproofing Practices in Petroleum and Petrochemical Processing Plants

15.2 ASTM International (ASTM)

ASTM A123	Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A525	Specification for General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process
ASTM E230	Standard Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples
ASTM E608	Standard Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples
ASTM E1137	Standard Specification for Industrial Platinum Resistance Thermometers
ASTM E1350	Standard Guide for Testing Sheathed Thermocouples, Thermocouples Assemblies and Connecting Wires Prior to and After Installation or Service

ASTM E2181	Standard Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable
ASTM F1166	Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities

15.3 British Standard (BSI)

BS 6739	Code of practice for instrumentation in control systems: installation design and practice
BS PAS 5308-1	Control and Instrumentation Cables Part 1 Specification of polyethylene cables
BS PAS 5308-2	Control and Instrumentation Cables Part 2 Specification of PVC cables

15.4 European Standard (EN)

EN 45510-2-9	Guide for Design Procurement & Installation of Electrical Equipment Cabling
EN 50174-1	Information technology - Cabling installation - Part 1 Installation specification and quality assurance
EN 50174-2	Information technology Cabling installation Part 2: Installation planning and practices inside buildings
EN 50174-3	Information technology Cabling installation Part 3: Installation planning and practices outside buildings
EN 50288-1	Multi-element metallic cables used in analogue and digital communication and control - Part 1: Generic specification
EN 50288-7	Multi-element metallic cables used in analogue and digital communication and control - Part 7: Sectional specification for instrumentation and control cables
EN 50289-4-17	UV Cable Testing
EN 50290-1-1	Communication Cables General
EN 50290-1-2	Communication Cables Definitions
EN 50290-2-1	Communication Cables Common Design Rules and Construction
EN 50290-2-20	Communication Cables General
EN 50290-2-21	Communication Cables PVC Insulation Compounds
EN 50290-2-22	Communication Cables PVC Sheathing Compounds
EN 50290-2-23	Communication Cables PE Insulation
EN 50290-2-24	Communication Cables PE Sheathing
EN 50290-2-25	Communication Cables Polypropylene Insulation Compounds

EN 50290-2-26	Communication Cables Halogen Free Flame-Retardant Insulation Compounds
EN 50290-2-27	Communication Cables Halogen Free Flame-Retardant Thermoplastic Sheathing Compounds
EN 50290-2-28	Communication Cables Filling Compounds for Filled Cables
EN 50290-2-29	Communication Cables Cross-Linked PE Insulation Compounds
EN 50290-2-30	Communication Cables FEP Insulation and Sheathing
EN 50290-4-1	Communication Cables Environmental Conditions and Safety Aspects
EN 50290-4-2	Communication Cables Guide to Use
EN 62382	Electrical and Loop Check

15.5 FOUNDATION™ Fieldbus Standards

FF-569	Host Interoperability Support Test Profile and Procedures
FF-831	Fieldbus Power Supply Test Specification
FF-844	H1 Cable Test Specification
FF-846	Device Coupler Test Specification
FF-912	Field Diagnostic Profile

15.6 International Electrotechnical Commission (IEC)

IEC 60068-2-11	Basic Environmental Testing Procedures Part 2: Tests- Test Ka: Salt Mist
IEC 60381-2	Analogue Signals for Process Control Systems
IEC 60079-0	Explosive atmospheres Part 0: Equipment General requirements
IEC 60079-1	Explosive atmospheres Part 1: Equipment protection by flameproof enclosures
IEC 60079-11	Explosive atmospheres Part 11: Equipment protection by intrinsic safety “i”
IEC 60079-13	Explosive atmospheres Part 13: Equipment protection by pressurized room
IEC 60079-14	Explosive atmospheres Part 14: Electrical installations design, selection, and erection
IEC 60079-15	Explosive atmospheres Part 15: Equipment protection by type of protection “n”
IEC 60079-17	Explosive atmospheres Part 17: Electrical installations inspection and maintenance
IEC 60079-18	Explosive atmospheres Part 18: Equipment protection by encapsulation
IEC 60079-2	Explosive atmospheres Part 2: Equipment protection by pressurized enclosure

IEC/TR 60079-20	Electrical apparatus for explosive gas atmospheres, Part 20: Data for flammable gases and vapours, relating to the use of electrical apparatus
IEC 60079-25	Explosive atmospheres Part 25: Intrinsically safe electrical systems
IEC 60079-26	Explosive atmospheres Part 26: Equipment with equipment protection level (EPL) Ga
IEC 60079-28	Explosive atmospheres Part 28: Protection of equipment and transmission systems using optical radiation
IEC 60079-29-1	Explosive atmospheres Part 29-1: Gas detectors Performance requirements of detectors for flammable gases
IEC 60079-29-2	Explosive atmospheres Part 29-2: Gas detectors Selection, installation, use and maintenance of detectors for flammable gases and oxygen
IEC 60079-29-3	Explosive atmospheres Part 29-3: Gas detectors Guidance on functional safety of fixed gas detection systems
IEC 60079-29-4	Explosive atmospheres Part 29-4: Gas detectors Performance requirements of open path detectors for flammable gases
IEC 60079-31	Explosive atmospheres Part 31: Equipment dust ignition protection by enclosure
IEC 60079-33	Explosive atmospheres Part 33: Equipment protection by special protection
IEC 60079-7	Explosive atmospheres Part 7: Equipment protection by increased safety “e”
IEC 60112	Method for the determination of the proof and the comparative tracking indices of solid insulating materials
IEC 60204-1	Safety of machinery - Electrical equipment of machines Part 1: General requirements
IEC 60364-1	Electrical Installations for Buildings Part 1: Fundamental principles, assessment of general characteristics, definitions
IEC 60364-4-41	Part 4-41: Protection for Safety Protection against electric shock
IEC 60364-4-42	Part 4-42: Protection for Safety Protection against thermal effects
IEC 60364-4-43	Part 4-43: Protection for Safety Protection against overcurrent
IEC 60364-4-44	Part 4-44: Protection for Safety Protection against voltage disturbances and electromagnetic disturbances
IEC 60364-5-51	Part 5-51: Selection and Erection of Electrical Equipment Common rules
IEC 60364-5-52	Part 5-52: Selection and Erection of Electrical Equipment Wiring systems
IEC 60364-5-53	Part 5-53: Selection and Erection of Electrical Equipment - Isolation, Switching and Control

IEC 60364-5-54	Part 5-54: Selection and Erection of Electrical Equipment Earthing arrangements and protective conductors
IEC 60364-5-55	Part 5-55: Selection and Erection of Electrical Equipment Other equipment
IEC 60364-5-56	Part 5-56: Selection and Erection of Electrical Equipment Safety Services
IEC 60364-6	Electrical Installations for Buildings Part 6: Verification
IEC 60364-7-706	Part 7-706: Requirements for special installations or locations - Conducting locations with restricted movement
IEC 60529	Degrees of Protection Supplied by Enclosures for Electrical Equipment (IP Code)
IEC 60584-1	Thermocouples Part 1: EMF specifications and tolerances
IEC 60584-2	Thermocouples Part 2: Tolerances
IEC 60584-3	Thermocouples Part 3: Extension and compensating cables Tolerances and identification system
IEC 60654-2	Operating conditions for Industrial process measurement and control equipment Part 2: Power
IEC 60715	Dimensions of Low-Voltage Switchgear and Controlgear Standardized Mounting on Rails for Mechanical Support of Electrical Devices in Switchgear and Controlgear Installations
IEC 60751	Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors
IEC 60770-1	Transmitters for use in industrial-control systems Part 1: Methods for performance evaluation
IEC 60947-5-4	Low-voltage Switchgear and Controlgear Part 5-4: Control circuit devices and switching elements Method of assessing the performance of low-energy contacts Special tests
IEC 60947-5-6	Low-Voltage Switchgear and Controlgear - Part 5-6: Control Circuit Devices and Switching Elements - DC Interface for Proximity Sensors and Switching Amplifiers (NAMUR)
IEC 60947-7-1	Low-voltage switchgear and controlgear - Part 7-1: Ancillary equipment - Terminal blocks for copper conductors
IEC 60998-2-1	Connecting devices for low-voltage circuits for household and similar purposes Part 2-1: Particular requirements for connecting devices as separate entities with screw-type clamping units
IEC 61000-5-2	Part 5: Installation and Mitigation Guidelines - Section 2: Earthing and Cabling
IEC 61158	Industrial communication networks Fieldbus specifications

IEC 61298-2	Process measurement and control devices, General methods, and procedures for evaluating performance Part 2: Tests under reference conditions
IEC 61515	Mineral Insulated Thermocouple Cables and Thermocouples
IEC 61754-4	Fibre optic interconnecting devices and passive components Fibre optic connector interfaces Part 4: Type SC connector family
IEC 62194	Method of evaluating the thermal performance of enclosures
IEC 61326-1	EMC 1 General requirements
IEC 61326-2-1	EMC 2-1 Particular requirements - Test configurations, operational conditions and performance criteria for sensitive test and measurement equipment for EMC unprotected applications
IEC 61326-2-3	EMC 2-3 Particular requirements - Test configuration, operational conditions, and performance criteria for transducers with integrated or remote signal conditioning
IEC 61326-2-5	EMC 2-5 Particular requirements - Test configurations, operational conditions, and performance criteria for devices with field bus interfaces according to IEC 61784-1
IEC 61326-3-1	EMC 3-1 Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions functional safety - General industrial applications
IEC 61326-3-2	EMC 3-2 Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions functional safety - Industrial applications with specified el
IEC 62491	Industrial systems, installations and equipment and industrial products - Labelling of cables and cores
IEC 62591	Industrial communication networks - Wireless communication network and communication profiles WirelessHART
IEC 62734	Industrial networks - Wireless communication network and communication profiles - ISA 100.11a

15.7 Institute of Electrical and Electronics Engineers (IEEE)

IEEE 81	Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Grounding System
IEEE 142	Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE 315	Graphic Symbols for Electrical and Electronics Diagrams
IEEE 532	Guide for Selecting and Testing Jackets for Power, Instrument, and Control Cables

IEEE 1015	Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems
IEEE 1100	Recommended Practice for Powering and Grounding Electronic Equipment
IEEE 1143	Guide for Shielding Practice for Low Voltage Cables
IEEE 1185	Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities
IEEE 1202	Standard for Flame Testing of Cables for use in Industrial and Commercial Occupancies
IEEE 1242	Guide for Specifying and Selecting Power, Control and Special-Purpose Cable for Petroleum and Chemical Plants
IEEE 1428	Guide for Installation Methods for Fiber-Optic Cables in Electric Power Generating Stations and in Industrial Facilities
IEEE 1458	Recommended Practice for the Selection, Field Testing and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications

15.8 International Society of Automation (ISA)

ANSI/ISA-5.1	Instrumentation Symbols and Identification
ISA-5.4	Instrument Loop Diagrams
ANSI/ISA-12.00.02	Certificate Standard for AEx Equipment for Hazardous (Classified) Locations
ANSI/ISA-12.01.01	Definitions and Information Pertaining to Electrical Equipment in Hazardous (Classified) Locations
ISA-12.10	Area Classification in Hazardous (Classified) Dust Locations
ISA-RP12.2.02	Recommendations for the Preparation, Content, and Organization of Intrinsic Safety Control Drawings
ISA-TR12.2	Intrinsically Safe System Assessment Using the Entity Concept
ISA-RP12.06.01	Recommended Practice for Wiring Methods for Hazardous (Classified) Locations Instrumentation Part 1: Intrinsic Safety
ANSI/ISA-12.12.01	Nonincendive Electrical Equipment for Use in Class I and II, Division 2 and Class III, Divisions 1 and 2 Hazardous (Classified) Locations
ANSI/ISA-12.12.03	Standard for Portable Electronic Products Suitable for Use in Class I and II, Division 2, Class I Zone 2 and Class III, Division 1 and 2 Hazardous (Classified) Locations
ANSI/ISA-TR12.12.04	Electrical Equipment in a Class I, Division 2/Zone 2 Hazardous Location

ANSI/ISA-TR12.13.03	Guide for Combustible Gas Detection as a Method of Protection
ANSI/ISA-TR12.21.01	Use of Fiber Optic Systems in Class I Hazardous (Classified) Locations
ISA-TR12.24.01	Recommended Practice for Classification of Locations for Electrical Installations Classified as Class I, Zone 0, Zone 1, or Zone 2
ANSI/ISA-12.27.01	Requirements for Process Sealing Between Electrical Systems and Flammable or Combustible Process Fluids
ANSI/ISA 50.00.01	Compatibility of Analog Signals for Electronic Industrial Process Instruments
ANSI/ISA-50.00.01	Compatibility of Analog Signals for Electronic Industrial Process Instruments
ISA-TR50.02 Parts 3 & 4	Fieldbus Standard for Use in Industrial Control Systems, Parts 3 & 4: Technical Report for Fieldbus Data Link Layer : Tutorial
ISA-TR50.02 Part 9	Fieldbus Standard for Use in Industrial Control Systems: User Layer Technical Report
ANSI/ISA-51.1	Process Instrumentation Terminology
ISA-RP60.1	Control Center Facilities
ISA-RP60.2	Control Center Design Guide and Terminology
ISA-RP60.3	Human Engineering for Control Centers
ISA-RP60.4	Documentation for Control Centers
ISA-RP60.6	Nameplates, Labels, and Tags for Control Centers
ISA-RP60.8	Electrical Guide for Control Centers
ISA-RP60.9	Piping Guide for Control Centers
ISA-RP60.11	Crating, Shipping, and Handling for Control Centers
ISA-71.01	Environmental Conditions for Process Measurement and Control Systems: Temperature and Humidity
ISA-71.02	Environmental Conditions for Process Measurement and Control Systems: Power
ANSI/ISA-71.03	Environmental Conditions for Process Measurement and Control Systems: Mechanical Influences
ANSI/ISA-71.04	Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants
ISA-RP76.0.01	Analyzer System Inspection and Acceptance

ANSI/ISA-76.00.02	Modular Component Interfaces for Surface-Mount Fluid Distribution Components - Part 1: Elastomeric Seals
ISA-82.03	Safety Standard for Electrical and Electronic Test, Measuring, Controlling, and Related Equipment
ISA-TR84.00.06	Safety Fieldbus Design Considerations for Process Industry Sector Applications
ISA TR84.00.08	Guidance for Application of Wireless Sensor Technology to Non-SIS Independent Protection Layers
ANSI/ISA-84.91.01	Identification and Mechanical Integrity of Safety Controls, Alarms, and Interlocks in the Process Industry
ISA-TR91.00.02	Criticality Classification Guideline for Instrumentation
ANSI/ISA-95.00.01	Enterprise-Control System Integration - Part 1: Models and Terminology
ANSI/ISA-95.00.05	Integration, Part 5: Business-to-Manufacturing Transactions
ANSI/ISA-TR99.00.01	Security for Industrial Automation and Control Systems Part 1: Terminology, Concepts, and Models
ISA-TR100.00.01	The Automation Engineer's Guide to Wireless Technology Part 1: The Physics of Radio, a Tutorial
ISA-TR100.00.02	The Automation Engineer's Guide to Wireless Technology: Part 2 - A Review of Technologies for Industrial Asset Tracking
ISA-TR100.00.03	Wireless User Requirements for Factory Automation
ISA-100.11a	Wireless systems for industrial automation: Process control and related applications
ISA-TR100.14.01-Part I	Trustworthiness in Wireless Industrial Automation: Part 1, Information for End Users and Regulators
ANSI/ISA-TR100.15.01	Backhaul Architecture Model: Secured Connectivity over Untrusted or Trusted Networks
ANSI/ISA-TR104.00.03	Meeting the requirements for integrating fieldbus devices in engineering tools for field devices
ISA TR106.00.01	Procedure Automation for Continuous Process Operations Models and Terminology
ANSI/ISA-60079-0	Explosive atmospheres - Part 0: Equipment - General Requirements
ANSI/ISA-60079-1	Explosive Atmospheres - Part 1: Equipment Protection by Flameproof Enclosures "d"

ANSI/ISA-60079-6	Explosive atmospheres - Part 6: Equipment Protection by Oil Immersion "o"
ANSI/ISA-60079-7	Explosive Atmospheres - Part 7: Equipment protection by increased safety "e"
ANSI/ISA-60079-11	Explosive Atmospheres - Part 11: Equipment protection by intrinsic safety "i"
ANSI/ISA-60079-15	Electrical Apparatus for Use in Class I, Zone 2 Hazardous (Classified) Locations: Type of Protection "n"
ANSI/ISA-60079-18	Explosive atmospheres - Part 18: Equipment protection by encapsulation "m"
ANSI/ISA-60079-25	Explosive Atmospheres - Part 25: Intrinsically safe electrical systems
ANSI/ISA-60079-27	Fieldbus intrinsically safe concept (FISCO) and Fieldbus non-incendive concept (FNICO)
ANSI/ISA-60079-28	Explosive Atmospheres - Part 28: Protection of equipment and transmission systems using optical radiation
ANSI/ISA-60079-29-2	Explosive Atmospheres - Part 29-2: Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen
ANSI/ISA-60079-31	Explosive atmospheres - Part 31: Equipment dust ignition protection by enclosure "t"
ANSI/ISA-61010-1	Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use - Part 1: General Requirements
ANSI/ISA-61010-2-030	Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use - Part 2-030: Particular Requirements for Testing and Measuring Circuits
ANSI/ISA-61010-031	Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use - Part 031: Safety requirements for hand-held probe assemblies for electrical measurement and test
ANSI/ISA-61241-0	Electrical Apparatus for Use in Zone 20, Zone 21, and Zone 22 Hazardous (Classified) Locations - General Requirements
ANSI/ISA-61241-1	Electrical Apparatus for Use in Zone 21 and Zone 22 Hazardous (Classified) Locations - Protection by Enclosures "tD"
ANSI/ISA-61241-2	Electrical Apparatus for Use in Zone 21 and Zone 22 Hazardous (Classified) Locations - Protection by Pressurization "pD"
ANSI/ISA-61241-10-2	Explosive Atmospheres - Part 10-2 Combustion dust atmospheres
ANSI/ISA-61241-11	Electrical Apparatus for Use in Zone 20, Zone 21 and Zone 22 Hazardous (Classified) Locations - Protection by Intrinsic Safety "iD"

ANSI/ISA-61241-18	Electrical Apparatus for Use in Zone 20, Zone 21 and Zone 22 Hazardous (Classified) Locations - Protection by Intrinsic Safety "mD"
ANSI/ISA-61804-3	Function Blocks (FB) for Process Control - Part 3: Electronic Device Description Language (EDDL)
ANSI/ISA-TR61804-4	Function Blocks (FB) for Process Control - Part 4: EDD Interoperability Guideline
ANSI/ISA-62381	Automation Systems in the Process Industry - Factory Acceptance Test (FAT), Site Acceptance Test (SAT), and Site Integration Test (SIT)
ANSI/ISA-62382	Automation Systems in the Process Industry - Electrical and Instrumentation Loop Check
ANSI/ISA-62443-2-1	Security for Industrial Automation and Control Systems: Establishing an Industrial Automation and Control Systems Security Program

15.9 Joint ISO/IEC Standards (ISO/IEC)

ISO/IEC 11801	Information technology - Generic cabling for customer premises
ISO/IEC 11801-1	Information technology - Generic cabling for customer premises - Part 1: General requirements
ISO/IEC 11801-3	Information technology - Generic cabling for customer premises - Part 3: Industrial premises
ISO/IEC 11801-5	Information technology - Generic cabling for customer premises - Part 5: Data centres
ISO/IEC 14763-2	Information technology - Implementation and operation of customer premises cabling - Part 2: Planning and installation
ISO/IEC 14763-3	Information technology - Implementation and operation of customer premises cabling - Part 3: Testing of optical fibre cabling
ISO/IEC 18010	Information technology - Pathways and spaces for customer premises cabling
ISO/IEC 24702	Information technology - Generic cabling - Industrial premises
ISO/IEC 24764	Information technology - Generic cabling systems for data centres

15.10 National Electrical Contractors Association (NECA)

NECA 1	Standard for Good Workmanship in Electrical Contracting
NECA 101	Standard for Installing Steel Conduits (Rigid, IMC, EMT)
NECA 102	Standard for Installing Aluminum Rigid Metal Conduit
NECA/FOA 301	Standard for Installing and Testing Fiber Optic Cables
NECA 303	Standard for Installing Closed-Circuit Television Systems

15.11 National Electrical Manufacturer's Association (NEMA)

NEMA 250	Enclosures for Electrical Equipment (1000 Volts Maximum)
NEMA C80.5	American National Standard for Electrical Rigid Aluminum Conduit (ERAC)
NEMA HP 100	High Temperature Instrumentation and Control Cables
NEMA ICS 5	Industrial Control and Systems Control-Circuit and Pilot Devices
NEMA ICS 6	Industrial Control and Systems: Enclosures
NEMA ICS 19	Diagrams, Device Designations and Symbols for Industrial Controls and Systems
NEMA RV3	Guidelines for Liquidtight and Flexible Metal Conduit Installation
NEMA TCB 2	Guidelines for the Selection and Installation of Underground Nonmetallic Raceways
NEMA VE 1	Metal Cable Tray Systems
NEMA VE 2	Cable Tray Installation Guidelines
NEMA WC 57	Standard for Control, Thermocouple Extension, and Instrumentation Cables

15.12 User Association of Automation Technology in Process Industries (NAMUR)

NE 6	Standardized Electrical Signals and Questions relating to Engineering Technology
NE 21	Electromagnetic Compatibility (EMC) of Industrial Process and Laboratory Control Equipment
NE 24	Requirements governing Measuring Inserts for Temperature Sensors utilized in Intrinsically Safe Circuits
NE 43	Standardization of the Signal Level for the Failure Information of Digital Transmitters
NE 74	NAMUR-Fieldbus Requirements
NE 89	Temperature Transmitter with Digital Signal Processing
NE 97	Fieldbus for Safety-Related Uses
NE 98	Installation Requirements for Achieving EMC in Production Sites
NE 99	Explosion Protection Document
NE 103	Usage of Internet Technologies in Process Automation
NE 105	Specifications for Integrating Fieldbus Devices in Engineering Tools for Field Devices
NE 114	Best Practice Fieldbus Applications
NE 116	SensISCO: Sensor Intrinsically Safe Concept

NE 122	PROFIBUS Interface for Drives with Frequency Converters in Process Technology
NE 123	Service and Maintenance of the Physical Layer of Fieldbuses
NE 124	Wireless Automation Requirements
NE 131	NAMUR Standard Device - Field Device Requirements for Standard Applications
NE 133	Wireless Sensor Networks: Requirements for the Convergence of existing Standards
NA 135	Remote Maintenance for Automation Systems in the Process Industry
NE 136	Requirements and Specifications for Power Supply Solutions based on Batteries and Energy Harvesting
NA 137	Engineering and Operation of Wireless Sensor Networks
NE 139	Information Interfaces in Process Automation Operational Properties
NE 151	Frequency Management
NE 161	Remote Operation Basics

15.13 National Fire Protection Association (NFPA)

NFPA 70	National Electric Code (NEC®)
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 72	National Fire Alarm and Signaling Code
NFPA 78	Lightning Protection Code
NFPA 79	Electrical Standard for Industrial Machinery
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment

15.14 Process Industry Practices (PIP)

PIP ELSGL01	Electrical Construction Specification
PIP ELSPS01	Electrical Requirements for Packaged Equipment
PIP ELSWC03	600-Volt Power and Control Cable Specification
PIP ELSWC05	300-Volt Instrumentation Tray Cable Specification
PIP PCCEL001	Instrumentation Electrical Design Criteria
PIP PCCGN001	General Instrumentation Design Basis
PIP PCCGN002	General Instrument Installation Criteria
PIP PCEDO001	Guidelines for Control Systems Documentation
PIP PCFEL000	Instrumentation Junction Box Fabrication Details
PIP PCIEL000	Instrumentation Electrical Installation Details

PIP PCIGN200	General Instrument Purge Details
PIP PCSCP001	Control Panels Specification
PIP PCSEL001	Procurement of Instrumentation Junction Boxes
PIP PCSIP001	Instrument Tubing Material Specification
PIP PCSPS001	Packaged Equipment Instrumentation Specification
PIP PCSPS010	Small, General-purpose Packaged Equipment Instrumentation Specification

15.15 Telecommunications Industry Association (TIA)

ANSI/TIA-485-A	Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems
ANSI/TIA-568.0-D	Generic Telecommunications Cabling for Customer Premises
ANSI/TIA-568.1-D	Commercial Building Telecommunications Cabling Standard
ANSI/TIA-568-C.2	Balanced Twisted-Pair Telecommunication Cabling and Components Standard
ANSI/TIA-568.3-D	Optical Fiber Cabling and Components Standard
ANSI/TIA-569-C	Telecommunications Pathways and Spaces
ANSI/TIA-607-C	Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises
ANSI/TIA-1005-A	Telecommunications Infrastructure Standard for Industrial Premises

15.16 Underwriters Laboratories (UL)

UL 1709	Rapid Rise Fire Tests of Protection Materials for Structural Steel
UL 1277	Electrical Power and Control Tray Cables with Optional Optical-Fiber Members
UL 1581	Reference Standard for Electrical Wires, Cables, and Flexible Cords
UL 2196	Tests for Fire Resistive Cables
UL 2225	Standard for Cables and Cable-Fittings for Use in Hazardous (Classified) Locations
UL 2250	Instrumentation Tray Cable
UL-60079-2	Explosive atmospheres - Part 2: Equipment protection by pressurized enclosures "p"
UL-60079-5	Explosive atmospheres - Part 5: Equipment Protection by Powder Filling "q"
UL-60079-26	Explosive atmospheres - Part 26: Equipment for Use in Class I, Zone 0 Hazardous (Classified) Locations