EAT•N

TD 17513
Eaton Electrical Field Devices
Communication Wiring
Specification

Application Notes

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TD 17513 - Eaton Electrical Field Devices Communication Wiring Specification

Overview

The purpose of this document is to provide recommendations for the design, installation and maintenance of physical layer communications systems used by Eaton field bus products.

Information regarding INCOM, RS-485, and ETHERNET physical layers is provided. Adherence to recommendations contained within will ensure robust and reliable communications.

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Section 1 – INCOM

1.1 Overview

INCOM was developed specifically for power distribution and industrial applications. It centers on the Industrial Communications (INCOM) chip, which employs Frequency Shift Key (FSK) technology and has the following characteristics:

- Provides exceptional electrical noise immunity typically caused by nearby electrical sources.

- Devices supporting INCOM are easily "daisy chained" together with Twisted Shielded Pair – see Section 1.3.1 Cable Selection.

- Supports Daisy Chain, Star, and Multi-Level Network Segment Topologies – see Figures 1-1, 1-2 and 1-3 for details. Note: Star Segment Topology is not recommended for new designs.

- Wiring may be run as close to power wiring as NEC (or CSA) and local safety codes permit. Attention should be paid to NEC Articles 725 and 800 (NEC 1993); and CEC section 60 [in particular, rule 60-306 (CEC 1990)]. Note: To minimize data corruption it is not advisable to run INCOM wiring in a power tray common with high frequency loads such as adjustable frequency drives or soft starts.

- Supports distances up to 10,000 ft (3048 m) per segment when designed within the specifications of this guideline.

- Supports up to 1000 devices on a single network segment.

- Supports sub-network master devices and associated sub-networks – see Table 1-1.

- Supports baud rates of 1200 and 9600.

1.2 Definitions

Characteristic Impedance: The characteristic impedance (Z_0) of a transmission line (twisted pair) is a resistance, when connected to the output terminals of a uniform transmission line of arbitrary length, causes the line to appear infinitely long. This is sometimes called the surge impedance or natural impedance. The International System (SI) unit of characteristic impedance is the Ohm. Baring any dissipative effects such as dielectric leakage or conductor resistance, the characteristic impedance of a transmission line is the square root of the inductance per unit length divided by the capacitance per unit length (Eq 1-1). For real-world twisted pair transmission lines, the characteristic impedance will vary slightly with frequency.

$$Z_0 = \sqrt{\frac{L}{C}}$$

(Eq 1-1)

Daisy-Chain Segment Topology: (See Figure 1-1.) A cable layout containing a single main run of twisted pair. INCOM compatible devices are installed directly as parallel loads across the main run or are located on taps off the main run. Only two EOLTRs are used and must be located at the physical ends of the main run. This is the preferred network topology providing greatest signal integrity and network capacity.

EOLTR: An End of Line Termination Resistor is used to provide loading for transmitters located on the network segment and to eliminate signal reflections at the end of long network wire runs. It should be a 100 Ohm non-inductive resistor (¼ W or larger). Some INCOM devices have the EOLTR permanently installed and must be located at the end of a main run. Other INCOM devices have an EOLTR that can be switched to optionally terminate the network segment at the device. Care must be exercised when installing devices containing termination resistors that the switches are set appropriately. A minimum of 2, up to a maximum of 5 EOLTRs must be installed on each network segment as dictated by network topology.

Host Network Segment: (See Figure 1-3.) The INCOM protocol supports two levels of addressing in a hierarchical arrangement. The master device interface is connected to the upper-level, host network segment and initiates communication with slaves connected on that segment. All slave devices on the host network segment must have a unique address. Sub-network master devices can be used to create a second addressing level of slave devices connected to the sub-network masters via a "pass-thru" INCOM protocol.

INCOM compatible device: A product that is compatible with the electrical and protocol requirements of the INCOM field bus. The INCOM network connection may be built into the product or provided externally via the IPONI transceiver module. INCOM network attachments are made as parallel connections to either the main run twisted pair or to short taps off the main run.

INCOM Field Bus: INCOM is a transformer-isolated twisted-pair communication network utilizing FSK modulation of a carrier (approximately 100 KHz) to provide exceptional electrical isolation and noise immunity in industrial settings. It employs a master-slave protocol operating at base band bit rates of 300 bps to 9600 bps. All devices on an INCOM network segment must be set to the same base band bit rate (9600 bps is standard). Transceiver connections to the network twisted pair are non-polarized.

IPONI transceiver module: A standardized INCOM network that contains an INCOM twisted pair isolation transformer, INCOM MODEM chip, and transmitter and receiver circuitry. It is connected to the product by a standardized 9-pin interface connector. The product provides electrical power to the IPONI transceiver.

Master: A Master is an address-less device that is able to initiate communications at any time on the INCOM network segment. The Master is the only device on a Network segment that issues command signals. Only one active Master is permitted at any time. A Master must be utilized in conjunction with a higher-level system or host that determines which command messages and information requests that the Master should send over the segment.

Main Run: A length of twisted pair wiring greater than 200 feet (61 m) in length. A termination resistor (EOLTR) must be located at the open end(s) of a main run. If the total length of twisted pair in the network segment is less than 200 feet, the two required EOLTRs may be installed anywhere along the twisted pair segment.

Network Segment: An electrically continuous section of INCOM network cable (twisted pair). Each segment is constructed using one of two basic segment topologies: "Daisy-Chain" or "Star". Depending on topology, a network segment consists of up to 5 Main Runs, at least two end of line terminating resistors (EOLTR), network taps, and INCOM compatible devices. All slave devices attached to a network segment must have unique address settings.

Network Tap: A short run of twisted pair cable that physically "T"s off a main run. The twisted pair conductors are connected in parallel across the main run. INCOM compatible devices are connected along the network tap. The network tap can have additional taps placed along it as long as the total twisted pair cable in the complex of taps is less than 200 feet (61 m) in length. Taps located within 1000 feet (305 m) of another tap along the main run must be aggregated together to calculate the 200-foot limit. Taps exceeding the 200-foot limit must be considered main runs.

Repeater: The local display (LDISP) can be used as a repeater to extend the effective length of a network segment. The local display's "host" port must be connected to the network segment where the protocol master is connected. The local display's "slave" port creates a slave network segment from the host port. The repeater adds latency to the response times of devices attached to the slave network segment, but does not create a sub-network.

Slave: INCOM Slaves are addressable devices on a network segment that respond to commands from the Master.

Slave Network Segment: (See Figure 1-3.) The network segment attached to the local display's "slave" port. A slave network maintains the same level in the communication hierarchy as the "host" port and must maintain slave address uniqueness on both network segments.

Star Segment Topology: (See Figure 1-2.) A cable layout in which up to 5 main runs of twisted pair are paralleled at a single common connection point. An EOLTR must be installed at the open end of each main run. The common connection point does not have an EOLTR. INCOM compatible devices are installed directly as parallel loads across the main runs or are located on taps off the main run. The star segment topology does not permit multiple common connection points for main runs. *This network topology is not recommended for new designs and requires careful analysis of maximum system loading.*

Sub-network: (See Figure 1-3.) The lower-level network segment created by the sub-network master device. The sub-network master is a protocol master on the sub-network segment. Slave addresses must be unique on the sub-network segment. Multi-level addressing is limited to two-deep (i.e., the host port of another sub-network master cannot be attached to a sub-network). Multiple sub-network masters, however, can be installed on the host network.

Sub-Network Master: An INCOM compatible device that can be used to create a lower network of slave addresses on a host network segment. The sub-network master acts as a slave on its host network segment and as a master on its sub-network segment. Slave device addressing must be unique on the sub-network segment, but may repeat addresses used on the host network segment. Sub-network masters and the devices supported on their sub-network are listed in Table 1-1.

Table 1-1. Sub-Network Master and Supported Devices.

Sub-Network Master	Supported Sub-Network Devices
Assemblies Electronic Monitor (AEM II)	Digitrip RMS 700/800 PONI connected to: IQ Data, IQ Generator, IQ Data Plus II, or IQ Data Plus II HV.
Central Monitoring Unit (CMU)	Advantage Control Module (ACM) connected to: Advantage Starter/Contactor. WPONI connected to: Advantage Starter/Contactor/Overload. PONI connected to: IQ 500.
Central Energy Display (CED)	IQ Energy Sentinel Addressable Relay II (for sync. pulse only) PONI connected to: IQ Data Plus II, IQ Data Plus II HV.
Breaker Interface Module (BIM II)	Digitrip RMS 810/910, OPTIM, 1150, 520MC IQ Energy Sentinel, IQ Power Sentinel.
Local Display (LDISP)	IQ Multipoint Energy Submeter II, IQ Multipoint Energy Submeter Meter, IQ Energy Sentinel, IQ Power Sentinel, IQ220/230, Digitrip OPTIM.
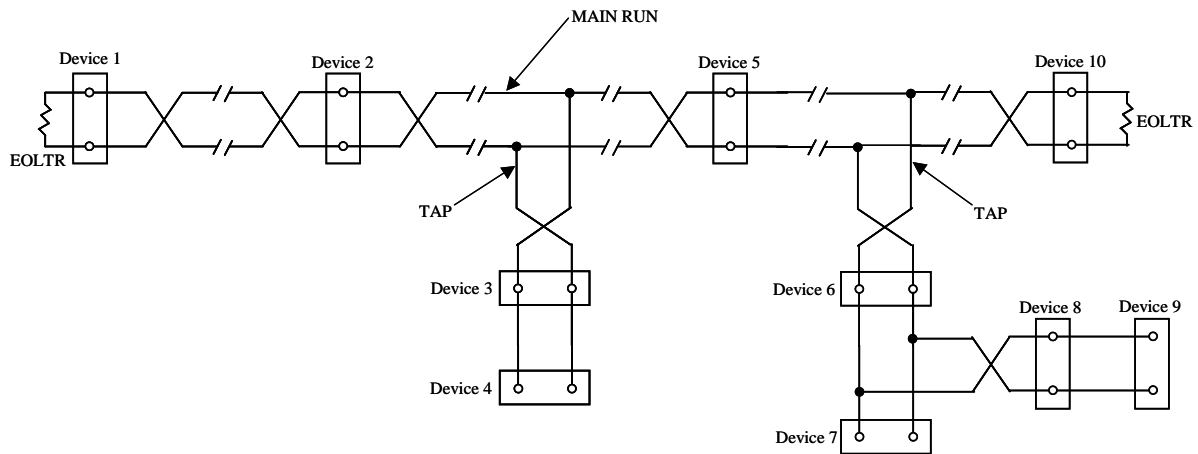
Figure 1-1. Daisy Chain Segment Topology
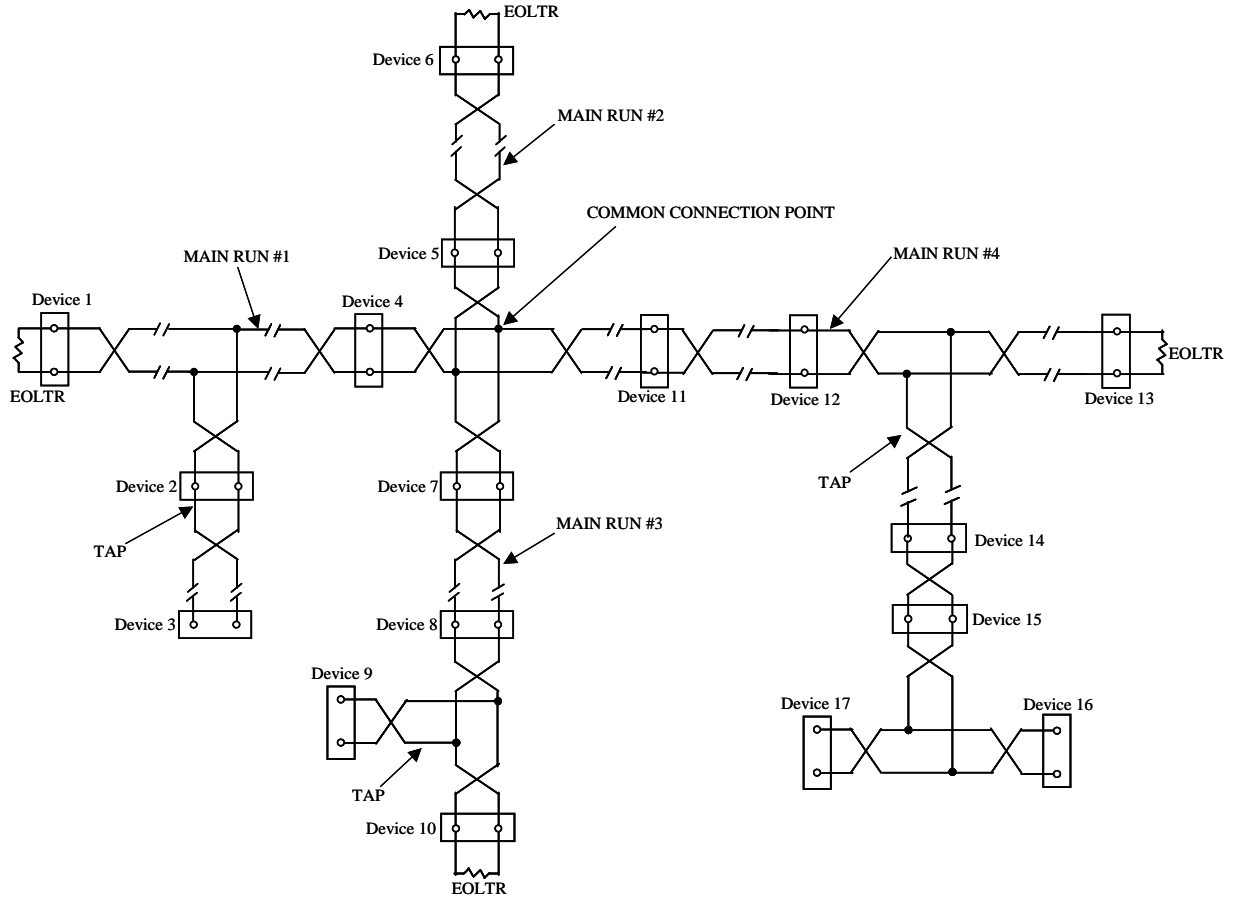
Figure 1-2. Star Segment Topology
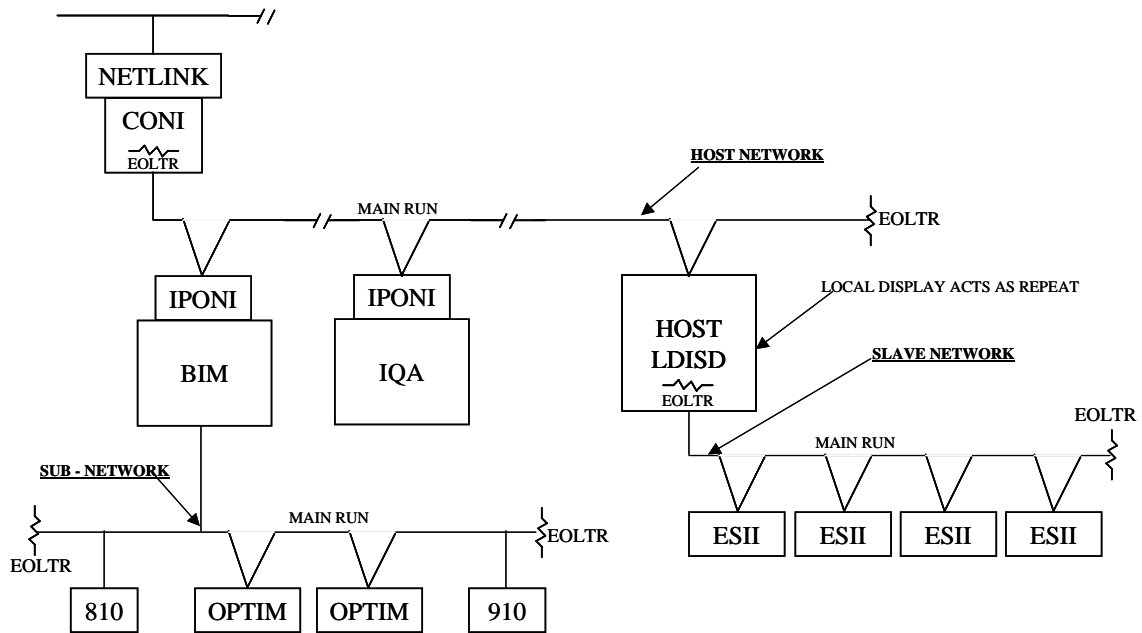
Figure 1-3. Multi-Level Network Topology Including Host, Slave, and Sub-Networks

1.3 Wiring Specifications

INCOM was designed with the intention of delivering a comprehensive and powerful energy management solution for use in electrical distribution environments while ensuring affordability, flexibility, simplicity, and noise immunity. An INCOM network segment installed according to the following rules allows the user to achieve all of these advantages. Failure to follow these rules may result in sub-optimal system performance.

1.3.1 Cable Selection

The characteristic impedance of the main run should remain the same across its length to minimize reflection signal loss. Do not mix cables of different characteristic impedances! Note that IMPCABLE is slightly higher than 100 Ohms; while 9463 is slightly lower, so do not swap back and forth between these two types of cables on the main run. All members of the 9463-cable family have the same characteristic impedance and so can be intermixed. The taps and the main run can vary between 9463 and IMPCABLE.

Cable manufacturers typically test the impedance of their communication grade cables at frequencies above 2 MHz while INCOM operates at about 100 KHz. The impedance of a cable is not constant with frequency and will be higher at the lower frequencies. As such you will see that the 9463 cables are typically rated at 78 Ohms but at 100 KHz the impedance is actually near 100 Ohms.

Since industrial or commercial installations often require a wide range of cable application choices, preference should be given to wiring with Belden 9463. The Belden 9463 family of cables contains choices for armored, high temperature, direct burial, or plenum applications, among others. IMPCABLE and the Belden 9463 family of cables were developed as communication grade cable having excellent shield performance and uniform and low attenuation. These are the cables that have been used for product testing and as the basis of the cabling rules. Any departure from these cables will give unpredictable results.

Table 1-2. Approved Cable Types

Cable Type	Voltage Rating	Z@ 100KHz	9463 Family	NEC Type	Notes
Belden 9463F	300V	100Ω	Y	CM	Sunlight Resistant
Belden 9463DB Belden YR28762	300V	100Ω	Y	CM	Outdoor, Aerial, Earth Burial, Sunlight Resistant
Belden 89463	300V	100Ω	Y	CM	Plenum Rated
IMPCABLE (Belden YR29090)	300V	100Ω	Close	CM	Meets CSA Type AWM (80 °C., 600V) Cable custom designed for INCOM.
Belden 3072F	600V	100Ω	Y	TC	Tray Cable, Conduit
Quabbin 6205	300V	100Ω	Y	CM	Non-plenum
Commscope 9022	300V	100Ω	Y	CM	Non-plenum
Manhattan Wire Products M4154	300V	100Ω	Y	CM	Non-plenum

1.3.2 Surge Protection Requirements

Cabling systems that leave a building require surge protection at the egress/ingress of the building. Surge protectors attenuate the signal strength and must be accounted for in system wiring. The Phoenix Contact devices FBK BE (base element) and UFBK-M2-PE-24DC-ST (plug) have an insertion loss of 0.5 dB and have been evaluated as compatible with INCOM communication systems.

1.3.3 Network Isolation Module

Primarily used with the MPCV Network Protector. INCOM devices typically provide 1500–3000 Volts of isolation (common mode) within the INCOM channel. For applications that require greater isolation, such as in Ground Potential Rise (GPR) situations, a Network Isolation Module can be used. This filter provides up to 5000 Volts of GPR isolation at power line frequencies and 3 dB of signal loss (per unit) to INCOM communication signals. See IL 70C1455H01 for complete details.

1.3.4 INCOM Network Asymmetrical Signal Conditioner

Modifications made to the INCOM demodulator found in the CONI, MINT II, EMINT, PMCOM5, BIM, AEM, CED, and CMU[1] created communication issues with older INCOM devices such as DT-3000, DigiTrip 810, 910 and Optim[2] when operated over very long communication runs (excess system capacity less than 12 dB). The INCOM Network Signal Conditioner corrects these communication issues and is used to interface an INCOM Network's Twisted Shielded Pair to the CONI, MINTII, EMINT, and sub-network masters (BIM,AEM,CED and CMU). The INCOM Network Signal Conditioner replaces a termination resistor and contributes a 6 dB signal loss (per conditioner) to the system capacity calculation. See IL 02603005 for complete details.

1.3.5 Cable Splicing

The mechanics of cable splicing and appropriate equipment are covered in Appendix 1. The goal is to create a secure electrical connection while minimizing exposure to electrical transients. Ferrules are used to dress cable ends in order to avoid problems associated with frayed and loose wires. Besides facilitating cable installation, subsequent data line troubleshooting and downtime are minimized. Most INCOM devices have built in three pole terminal blocks for data lines and shield. For older INCOM devices that have only two terminals, shield continuity must be ensured by other means. Additional terminal strips should be utilized when splicing elsewhere in the electrical enclosure or facility to ensure secure electrical connections. All devices, End of Line Termination Resistors, and Taps should be wired in parallel across the cable.

1.3.6 Cable Shield – Grounding and Bonding

The cable shielding and outer jacket should not be stripped back beyond 1.5 inches (38 mm). Terminal blocks are used at tap points to ensure a continuous metallic shield ground path. To ensure a secure electrical connection when daisy-chaining INCOM devices that have built-in two pole terminal blocks, use crimp sleeves to join the two shield drain wires. The cable shield ground path for a Main Network and Sub-Network must not be joined. Each should have a separate connection to earth ground reference.

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[1] Newer devices are: CONI III style numbers ending with G21 and above; MINT II style numbers ending with G02 and above; all EMINT and PMCOM5 styles; AEM, CED and CMU with style numbers ending with G04 and above; BIMII style numbers ending with G03 and above. PMCOM5 & PMCOM5U with assembly numbers 70C1331 located on the bottom (plug side) of the device.

[2] Older devices are: DT3000 with style numbers less than G20; DT1150 with firmware revision REV05 or less; Optim K/L/N with firmware less than Ver 63H Rev 4H; Optim R with firmware less than Ver 70H Rev 1AH; DT810/910 with firmware less than Ver 46H Rev 4 (catalog #E).

1.3.7 Cable Grounding

The shield should be continuous across a network segment and connected to the building's electrical system grounding electrode conductor. The 2005 NEC provides the following guidance on grounding communication cables:

1. When a communication cable enters a building, a primary protector is required and must be grounded as described in Section 800 IV. Specifically, paragraphs 800.93 & 800.100 define grounding requirements for the primary protector.

2. Grounding systems are generally covered by Section 250 III. The grounding electrode conductor is specifically covered by paragraphs 250.62, 250.64, 250.66, 250.68 and 250.70.

3. Bonding requirements between communication systems and the power distribution system is specified by paragraph 250.94.

A solid earth ground is accomplished by connecting the shield ground path's drain wire to a #14 AWG or larger multi-stranded wire that has an impedance path of 1 Ohm or less to the building's grounding electrode conductor.

1.3.8 Cable Termination

Each network segment requires a minimum of two End of Line Termination Resistors (EOLTRs) as shown in Figure 1-1 thru Figure 1-3. The EOLTRs maintain signal strength and minimize reflections. The EOLTRs should be ½ Watt non-inductive resistors, such as carbon composition or metal film. Wire-wound resistors are not acceptable. The EOLTR values must be chosen to match the characteristic impedance of the main run cable (typically 78 or 100 Ω). EOLTRs supplied in products may have a value different than the cable impedance. In this case the EOLTR in the product must be disabled and replaced with an external EOLTR of the appropriate value. Taps on network segments should not be terminated.

1.4 System Capacity Calculation

System capacity calculations are performed when new systems are being developed or devices are being added to existing systems. The purpose of the calculation is to determine if the system design has the capacity to support the number and type of devices intended for use. The equation for this calculation is shown in Eq 1-2 and is based on using cables near 100 Ω characteristic impedance at 100 KHz.

$$\sum L_{DEV} + \sum A_{CBL} + L_{STAR} \leq 26db - Tx_{MAX} - Rx_{MAX} \qquad \textbf{(Eq 1-2)}$$

Where: $\sum L_{DEV}$ = Accumulated total loss of all devices attached to the network segment.

$\sum A_{CBL}$ = Accumulated attenuation attributed to cable loss.

L_{STAR} = Loss associated with the type of network topology used.[3]

Tx_{MAX} = Penalty associated with the maximum Tx Output reduction[4] of any device attached to the network segment. Use the largest value from the table of any device in the system.

Rx_{MAX} = Penalty associated with the maximum Rx Sensitivity reduction[5] of any device attached to the network segment. Use the largest value from the table of any device in the system.

Values required for these calculations can be found in Table 1-3 thru Table 1-5. All units are in dB.

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[3] Star topologies are not recommended. Use 0 dB if only 2 terminators are used.

[4] The system capacity calculation is based on transmitters with a minimum output of 5Vp-p into 50Ω. Some designs have outputs lower than that reducing the overall system capacity.

[5] The system capacity calculation is based on receivers with a minimum sensitivity of 125mV. Some designs have increased thresholds that reduce the overall system capacity.

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1.4.1 Device Loading Tables

The values in the following tables are used in calculating total INCOM system capacities.

Table 1-3. Device Loading Table – Masters

Product	Loss per Device Units (dB)	Rx Sensitivity Units (dB)	Tx Output Units (dB)
Masters:			
PXG400	0.02	0.00	0.00
PXG600A	0.02	0.00	0.00
MINT II	0.21	5.34	0.92
CONI III	0.02	0.00	0.00
EMINT	0.01	1.58	0.00
MMINT	0.02	0.00	0.00
PMCOM5	0.01	0.00	0.00
Sub-Network Masters:			
AEMII	0.01	0.00	0.00
BIM	0.02	0.00	4.73
CED	0.01	0.00	0.00
CMU	0.04	0.00	0.00
Local Display	0.05	0.00	0.54

Table 1-4. Device Loading Table – Miscellaneous

Product	Units (dB)
INCOM Network Topology:	
0-leg Star connection	0.00
3-leg Star connection	3.50
4-leg Star connection	6.00
5-leg Star connection	8.00
INCOM Network Cable:	**Loss per 1000 ft**
Belden 9463 (per 1000ft)	2.00
IMPCABLE (per 1000ft)	1.60
Misc. INCOM Network Modules:	**Loss per 1000 ft**
INCOM Network Asymmetrical Signal Conditioner	6.00
INCOM Network Surge Protection FBK BE (base element) and UFBK-M2-PE-24DC-ST (plug)	0.50
Network Isolation Module	3.00

Table 1-5. Device Loading Table – Slave Devices

Product	Loss per Device Units (dB)	Rx Sensitivity Units (dB)	Tx Output Units (dB)
Current Products:			
WPONI M_D	0.24	0.00	0.00
ARII	0.23	8.63	2.85
IQ E Sentinel (note 5)	0.08	2.92	0.00
BPONI (note1)	0.20	1.58	0.00
IPONI (note1)	0.02	0.00	0.35
IQ P Sentinel (note 5)	0.02	0.00	2.85
MPCV	0.02	0.00	0.00
Digitrip Optim 1050KLN	0.02	0.00	0.00
Digitrip Optim 1050R	0.02	0.00	0.00
Digitrip 910	0.02	0.00	0.35
Digitrip 810	0.02	0.00	0.92
DT3000 (note3)	0.01	0.83	0.35
IQ Multipoint Energy Submeter-II	0.02	2.28	1.11
FP5000	0.01	2.28	0.35
IQ200	0.01	1.58	0.92
Digitrip 1150	0.02	0.59	0.35
Digitrip 520MC	0.02	0.00	0.00
DIM	0.01	3.52	0.54
Local Display	0.05	0.00	0.54
PowerXpert Meter	0.02	2.28	0.00
Obsolete Products:			
WPONI old	0.24	6.02	3.61
IQ E Sentinel (note 4)	0.21	0.00	2.85
DT3000 (note 2)	0.20	3.52	0.00

Notes:
1. Network interface for a number of slave devices and the "Main" network interface for most sub-network masters.
2. DT3K: revision 10 and below.
3. DT3K: revision 11 and greater.
4. IQEnergy or Power Sentinel: style numbers ending with G04 and below.
5. IQEnergy or Power Sentinel: style numbers ending with G11 and above.

1.4.2 INCOM Segment Load Calculations

The following are two examples of system capacity calculations for INCOM network segments.

Daisy-Chain Segment Topology Example

Suppose that there are a total of 25 devices consisting of 23 DT910 and 2 IQ Analyzers devices that are distributed along the INCOM Network shown in Figure 1-1. The INCOM Network is connected to a PC via a MINTII. Using the INCOM System Capacity Equation, a calculation is performed and it is found that this configuration will work since the expected total loss (2.09 dB) is less than the system capacity (19.74 dB).

$$\sum L_{DEV} + \sum A_{CBL} + L_{STAR} \leq 26db - Tx_{MAX} - Rx_{MAX}$$

(0.75dB + 0.14dB + 0.00dB) $\leq$ (26dB – 0.92dB – 5.34dB)

(0.89dB) $\leq$ (19.74dB)

$\sum L_{DEV}$ = 0.75dB

0.75dB = 0.46dB ($\sum$DT910) + 0.04dB ($\sum$IQAnalyzer) + 0.25dB (MINTII)
$\sum$DT910 = 0.46dB = 23 (DT910) * 0.02 (dB loss per DT910)
$\sum$IQAnalyzer = 0.04dB = 2 (IQAnalyzers) * 0.02 (dB Loss per IPONI)
MINTII = 0.25dB = 1 (MINTII) * 0.25dB (dB Loss per MINTII)

$\sum A_{CBL}$ = 0.14dB

0.14dB = (2.0dB * 700ft) / 1000ft
Total INCOM Network length = 700ft (540ft + 10ft + 150ft)
Main Run = 540ft (Belden 9463)
Tap 1   = 10ft (Belden 9463)
Tap 2   = 150ft (Belden 9463)
Line Attenuation of Belden 9463: 2.0dB/1000ft

L_{STAR} = 0dB

Since a Star configuration is not used, the penalty is 0.00dB.

Tx_{MAX} = 0.92dB (MINTII)

Use the largest of the following:
MINTII   = 0.92dB
IQAnalyzer   = 0.35dB (IPONI)
DT910   = 0.35dB

Rx_{MAX} = 5.34dB (MINTII)

Use the largest of the following:
MINTII   = 5.34dB
IQAnalyzer   = 0.00dB (IPONI)
DT910   = 0.00dB

Star Segment Topology Example

Suppose that there are a total of 50 devices consisting of 4 ARII, 10 IQDP4130, 10 IQ220/320, 10-1150, 10-IQESentinels (Chip), and 6 FP5000 distributed along the 4-leg Star INCOM network. The INCOM network is connected to a PC via a MINTII. Using the INCOM System Capacity Equation, a calculation is performed and it is found that this configuration will work since the total loss (14.31 dB) is greater than the system capacity (14.52 dB).

$$\sum L_{Dev} + \sum A_{CBL} + L_{STAR} \le 26db - Tx_{MAX} - Rx_{MAX}$$

$$(2.75dB + 5.56dB + 6.00dB) \le (26dB - 2.85dB - 8.63dB)$$

$$(14.31dB) \le (14.52dB)$$

$\sum L_{DEV}$ = 2.75dB

2.75dB = 1.04dB (ARII) + 0.20dB (IQDP4000) + 0.10dB (IQ200) + 0.20dB (1150) + 0.90dB (IQESentinel) + 0.06dB (FP5000) + 0.25dB (MINTII)

ARII loss = 1.04dB = 4 (ARII) * 0.26dB (loss per ARII)

IQDP4130 loss = 0.20dB = 10 (IQDP4000) * 0.02dB (loss per IPONI)

IQ220/320 loss = 0.10dB = 10 (IQ200) * 0.01dB (loss per IQ200)

DT1150 loss = 0.20dB = 10 (1150) * 0.02dB (loss per 1150)

IQESentinel loss=0.90dB=10 (IQESentinel) * 0.09dB (dB loss per IQESentinel (Chip))

FP5000 loss contribution = 0.06dB = 6 (FP5000) * 0.01dB (dB loss per FP5000)

MINTII dB loss contribution = 0.25dB = 1 (MINTII) * 0.25dB (dB loss per MINTII)

$\sum A_{CBL}$ = 5.56dB

5.6dB = (2,300ft * 2.0dB/1000ft) + (600ft * 1.6dB/1000ft)

Belden9463 = 2,300ft = 300ft + 500ft + 700ft + 800ft @ = 2.0dB/1000ft
Main Run #1 = 300ft (Belden 9463)
Main Run #2 = 500ft (Belden 9463)
Main Run #3 = 700ft (Belden 9463)
Main Run #4 = 800ft (Belden 9463)

IMPCABLE = 600ft = 200ft + 200ft + 200ft @ 1.6dB/1000ft
Tap 1 = 200ft (IMPCABLE YR29090)
Tap 2 = 200ft (IMPCABLE YR29090)
Tap 3 = 200ft (IMPCABLE YR29090)

L_{STAR} = 6dB

4-leg Star connection = 6.00dB

Tx_{MAX} = 2.85dB (ARII)

ARII	= 2.85dB
MINTII	= 0.92dB
IQ200	= 0.92dB
IQDP4000	= 0.35dB (IPONI)
FP5000	= 0.35dB
IQESentinel	= 0.00dB

Rx_{MAX} = 8.63dB (ARII)

ARII	= 8.63dB
MINTII	= 5.34dB
IQESentinel	= 2.92dB
FP5000	= 2.28dB
IQ200	= 1.58dB
1150	= 0.59dB
IQDP4000	= 0.00dB (IPONI)

Section 2 – RS-485

2.1 Overview

The purpose of this document is to provide guidelines for wiring RS-485 physical layer systems. These recommendations are based on requirements outlined in the ANSI/TIA/EIA-485-A standard and Application Guideline bulletin TSB-89-A. Adherence to these recommendations will provide robust RS-485 communications.

2.2 Definitions

Backbone Wiring Topology: (See Figure 2-4 and Figure 2-5.) A layout containing a single main run of cable, RS-485 compatible devices are installed directly as parallel loads across the main run (i.e., "daisy chain," and/or located on short stubs off the main run). Only two EOLTRs (End Of Line Termination Resistors) are used and must be located at the physical ends of the main run. This is the preferred network topology providing greatest signal integrity.

Baud Rate: Serial communications are exchanged with a specific bit rate per second. 1200, 9600,19.2K, 38.4K, 57.6K and 115.2K Baud rates are common selections but some devices may be restricted in what they support. All devices exchanging data on a common RS-485 network segment must be configured for the same baud rate.

Characteristic Impedance: The characteristic impedance (Z_0) of a transmission line (twisted pair) is a resistance, when connected to the output terminals of a uniform transmission line of arbitrary length, causes the line to appear infinitely long. This is sometimes called the surge impedance or natural impedance. The International System (SI) unit of characteristic impedance is the Ohm. Baring any dissipative effects such as dielectric leakage or conductor resistance, the characteristic impedance of a transmission line is the square root of the inductance per unit length divided by the capacitance per unit length (Eq 2-1). For real-world twisted pair transmission lines, the characteristic impedance will vary slightly with frequency.

$$Z_0 = \sqrt{\frac{L}{C}}$$ **(Eq 2-1)**

Data Frame: Serial communication used in industrial applications and on Personal Computer COM ports is typically transmitted and received asynchronously in byte sized data frames. Each byte is "framed" with a start bit and then followed by an optional parity bit and one or two stop bits. To interconnect nodes on a common RS-485 link, the devices must be configured to support a common data frame format.

EOLTR: An <u>E</u>nd <u>o</u>f <u>L</u>ine <u>T</u>ermination <u>R</u>esistor is used to provide loading for transmitters located on the network segment and to eliminate signal reflections at the end of long network wire runs. The value of each EOLTR should match the characteristic impedance of the interconnecting cable. Several EOLTR configurations are permitted (differential, AC and common mode) although they must not be inter-mixed and must be applied at either end of the main line. Differential mode termination is the most commonly used and easiest to implement.

Full-Duplex: A communications medium capable of operating in both directions simultaneously.

Half-Duplex: A communications medium capable of operating in both directions but not simultaneously.

Main Backbone Cable Run: A length of twisted pair wiring with termination resistors (EOLTR) located at the open end(s) of the run.

Master – A Master is a device that is able to initiate communications on the RS-485 network segment using a specific protocol (e.g. MODBUS). The Master is the only device on a Network segment that issues command signals. Only one active Master is permitted at any time.

Multipoint or Multidrop Bus: An architecture that supports multiple transceivers.

Network Segment: An electrically continuous section of RS-485 network cable (twisted pair). Each segment is constructed using one of two basic segment topologies: "Daisy-Chain" or "Star". Depending on topology, a network segment consists of up to 5 main runs, at least two "end of line terminating resistors" (EOLTR), network taps, and RS-485 compatible devices. All slave devices attached to a network segment must have unique address settings.

Network Stub: A short run of twisted pair cable that physically "T"s off a main run. The twisted pair conductors are connected in parallel across the main run. A single RS-485 compatible device is connected at the end of the stub.

Repeater: An RS-485 repeater can be used to extend the effective length of a network segment. A repeater adds latency to the response times of devices attached to the slave network segment and may provide isolation.

RS-485 Compatible Device: A product that is compatible with the requirements of the RS-485 field bus as defined in ANSI/TIA/EIA-485-A. The RS-485 network connection may be built into the product or provided externally. RS-485 network attachments are made as parallel connections to either the main run twisted pair or to short taps off the main run. The data lines of each device are polarized, each having a positive and negative data terminal.

RS-485 Field Bus: RS-485 is a method of transmitting digital information serially over a twisted pair wire network using balanced, differential transceivers at rates of up to 10 Mbps. RS-485 supports multiple devices on a network of up to 32 Unit Loads and total system loads (with termination and fail safe resistors) of no less than 54 Ohms. The data lines are identified as A or B and are polarized; A is positive and B negative. Although high levels of noise immunity are inherent with differential mode communications, greater levels can be achieved in extremely noisy environments with the use of shielded cable.

RS-485 Unit Load: A normalized value representing the loading effect that each RS-485 compatible device places on a network segment. RS-485 transceivers can represent fractional or whole multiples of the normalized value. One unit load represents 12,000 Ohms representing a single receiver transmitter pair. RS-485 networks can support 32 Unit Loads.

Slave – RS-485 Slaves are addressable devices on a network segment that respond to commands from the Master.

Star Segment Topology: A network topology in which multiple long runs are connected at a common point with more than two termination networks installed in the system. ***This network topology is not supported by RS-485.***

Transceiver: A device that includes a receiver and transmitter pair.

2.3 RS-485 Basics

- Supports two wire, half-duplex or four wire, full-duplex multi-drop applications.

- Signal rates of up to 10 Mbps (bits per second).

- Communications up to 4000 feet at bit rates up to 300 Kbps.

- Balanced, differential transceivers.

- Transmitter supports 32 Unit Loads (UL) and 60 Ohm cable termination (120 Ohm x 2) over a common mode voltage range of –7 V to +12 V.

- Receivers have ±200 mV differential input voltage threshold sensitivity over a common mode voltage range of –7 V to +12 V.

2.4 Wiring Specification

2.4.1 Cable

Agency Approval

Some installations require special approvals from agencies such as UL or CSA. Some items of interest include jacket material, sunlight, oil and abrasion resistance as well as flame and smoke performance. These issues are installation dependant and must be addressed accordingly.

Cable Impedance

The recommended cable impedance for RS-485 cables is 120 Ohms but due to cable and application limitations other cable impedances (100, 105, etc.) are sometimes used. **To minimize signal losses and distortion, the same cable impedance should be used along a network segment and the end of line termination must match the cable impedance.**

Polarity

RS-485 uses the difference voltage between the two data signal lines to indicate the state of the data being transmitted. The RS-485 standard labels the two data lines "A" and "B", although manufacturers have labeled their equipment with other designations such as "+" and "–", or even "A" and "B" with reversed polarity. The signaling sense of the voltages appearing across the two data lines on the interconnecting cable is defined in Figure 2-1 and as follows.

- The "A" terminal is negative with respect to the "B" terminal for a binary 1, OFF or MARKING state. This is the inter-symbol state when transmitting ASCII characters. ($V_A - V_B < -0.2$ V. Note that V_A & V_B are with respect to the transceiver common connection.)

- The "A" terminal is positive with respect to the "B" terminal for a binary 0, ON or SPACING state. This is the start-bit state when transmitting ASCII characters. ($V_A - V_B > +0.2$ V)
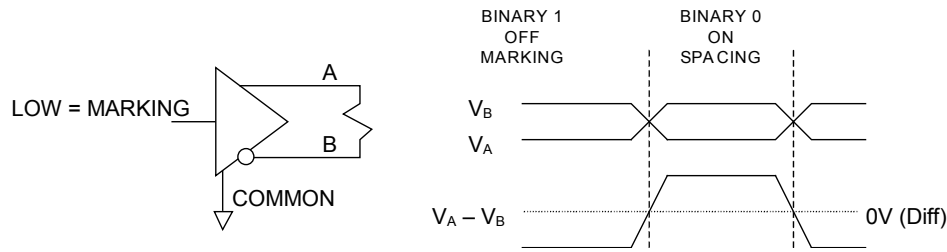
Figure 2-1. RS-485 Signaling Sense

The transmission of a typical asynchronous data byte and its corresponding signal levels in CMOS, RS-232, and RS-485 is shown in Figure 2-2. In this diagram, the ASCII character "U" (Binary 01010101) is being transmitted. Note that the inter-character state is binary one or "marking". This will cause the RS-485 data line "B" to be more positive than the RS-485 data line "A" between characters.
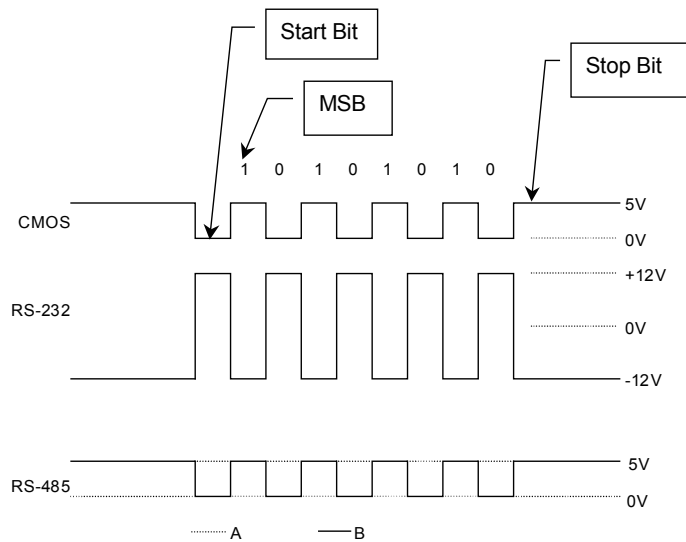
Figure 2-2. Comparison of CMOS, RS-232, and RS-485 Signal Levels

Regardless of the naming scheme used, in order for the RS-485 system to work properly all the drivers and receivers in the system must be connected so that the data terminals on all devices in the network are connected to produce the correct internal logic levels for the equipment. Several manufacturers label the "A" and "B" terminals with polarities opposite the RS-485 standard. In these cases, it will be necessary to reverse the "A" and "B" connections when interconnecting this equipment with a manufacturer that follows the standard. See Table 2-2 and Table 2-3 for guidance.

Shield

Power distribution and automation applications require shielded cable in RS-485 communication wiring. Cable is available with 2 types of shielding, foil and braid over foil. Either can be used, although braid over foil is preferred. The foil covers high frequency Radio Frequency and Electrical Fast Transient exposures, while the braid covers low frequency surge events. For typical terminal block connections, the cable must support a shield drain wire.

Temperature Rating

All communication cables have an insulation temperature range rating that determines the range of temperature that the cable can be continuously exposed to without changing its basic properties. The selection of a cable with respect to temperature rating should be matched with its application and any applicable local codes.

Type

Regulatory, environmental, and installation requirements determine the type of cable used within an RS-485 system. Many types are available, each having parameters suitable for individual environments. Below are several parameters that can be used to select the appropriate cable:

- Conductor Resistance – Determined by conductor size. The larger the conductor, the less resistance it has. This parameter is specified in Ohms per 1000 feet.
- Voltage Rating – The highest voltage that can be applied to a wire within or next to a cable.
- Shield – Electrically conductive material surrounding the inner conductors of a cable to prevent interference from entering or exiting the cable.
- Shield Coverage – The surface area of a cable covered by the shield specified in percent. The higher the percentage coverage, the greater the shield's ability to prevent interference.
- Number of Conductors – The signal carrying conductors within the cable. Several varieties are available including single, multi-pair, and twisted pairs. Twisted pair is preferred for RS-485 applications.
- Nominal Capacitance – The capacitance of a cable specified in pF per foot as supplied by the manufacturer. This parameter is construction dependant and can be significant with long cable runs causing distortion and data loss.
- Nominal Impedance – The impedance of the cable as specified in Ohms as supplied by the manufacturer. This parameter is construction dependant and is the value that determines the value of the termination resistors.
- Temperature Rating: The maximum continuous temperature the insulation of the cable can be exposed to.
- Installation Usage – special usages include plenum, cable tray, underground and outdoor.

Voltage Rating

The National Electric Code (NEC) defines voltage ratings under several use categories. The CM designation is for power limited communication applications but is limited to 300 V. For 600 V applications communication cables are pushed into categories used for control cable, such as TC for Tray Cable. This ignores the power-limited nature of the communication cable and puts some mechanical size burdens on these cables. Underwriters Laboratories (UL) tests cables to these NEC categories but also will give a voltage rating outside of these user designations for manufacturers. The Appliance Wire by Manufacture or AWM voltage rating is only valid if evaluated under the conditions of use by an UL inspector.

When routing cables in assembly gear the association with the highest cable voltage ratings in a wiring bundle will dictate the voltage requirement for the rest of the cables. By using physical separation with conduit or other raceway dividers, a cable with a lower voltage rating can be tolerated. Refer to NEC for details. This is often the approach taken with communication cabling that must coexist near high voltage control or power cabling.

Wire Gauge

The gauge of a data communication cable wire has both electrical performance and practical mechanical properties. The higher the gauge, the smaller the diameter of the wire. Smaller diameter wires have both a larger series resistance and a lower mechanical strength. For cables of equal impedance the cable with the higher gauge will have a greater attenuation of the signal. Cables designed for RS-485 applications tend to have data lines of 22–24 AWG but can be found with larger diameter 18–20 AWG wires to improve mechanical strength.

Recommended Cable

Cable selection is essential for robust communications. Cable developed for RS-485 communications is recommended and is available from various manufacturers. RS-485 cables with the following parameters are recommended: Shield with drain wire, twisted pair, 120 Ω impedance, 12 pF maximum capacitance per foot and a minimum of 24 AWG. **Control and instrumentation cables are not acceptable for RS-485 applications.**

Each manufacturer provides features that are installation dependant such as voltage, temperature and jacket material. Each must be considered by the designer based on individual system requirements. Table 2-1 is a list of several RS-485 compatible cables spanning the range of 30 to 600 V that can be used as a reference for cable selection.

Table 2-1. Recommended RS-485 Cables

120Ω RS-485 Compatible Cables								
Mfg	Part No.	Atten. dB/100' @1Mhz	Data AWG	Cable Diam.	Temp Rating °C	Voltage Rating	Data	Shld.
Belden	9842	0.60	24	0.34"	–30/+80	30v CM	2D,2C	F, B
Belden	82842	NA	24	0.27"	0/+70	300v CMP	2D,2C	F, B
Belden	3106A	0.50	22	0.30"	–20/+60	300v CM	2D,1C	F, B
Belden	7897A	0.40	18	0.46"	–20/+75	600v TC	2D,2C	F, B
Belden	7895A	0.70	20	0.38"	–20/+75	300V CM 600V AWM	2D,2C	F
Belden	3074F	0.34	18	0.46"	–40/+75	600V TC	2D	F, B
Belden	9841	0.60	24	0.23"	–30/+80	300v CM	2D	F, B
Belden	89841	0.60	24	0.20"	–70/+200	300v CMP	2D	F, B
100Ω RS-485 Compatible Cables								
Belden	3073F	0.41	18	0.38"	–40/+75	600v TC	2D	F, B

Note: This table does not cover all applications.
Cable Configuration Assumption – all cables have a shield drain
      D = Data
      C = common (isolated from shield)
      F = Foil Shield
      B = Braid Shield

2.4.2 Failsafe Biasing

In asynchronous RS-485 applications there are times between commands and responses where no transmitter is driving the data lines to a known state. During these idle states a mechanism is required to guarantee that the data lines are driven to a "Marked", logic =1 state where the "B" data line is electrically greater than "A" data line by at least 200 mV. This insures that the data packet start bit transition, logic 1 to 0, is properly recognized and that EMI does not create false transitions. The biasing must be strong enough to overcome the load of the EOLTR and work with the minimum to maximum number of RS-485 transceivers across the data lines. At the same time the biasing cannot be too strong or the signal level will be reduced to the point where the system capacity of cable length and number of transceivers supported will be reduced. This biasing is accomplished using pull up/down resistors relative to the transceiver power supply. With a 5V transceiver supply, 120-ohm termination resistors, and the standard 32 RS-485 transceiver loads this value should be 750 to 450 Ohms. There are two methods to apply this biasing: A lumped approach or distributed.

The preferred method is the lumped approach, which requires that the biasing resistors be applied at only one node on the RS-485 link. If it is always clear which nodes will be designated as slaves and which will be the master then the master link can default to supporting the resistors. If, however, the master/slave status is a programmable feature, then a mechanism is required to switch in or out the biasing resistors based on master selection. This engagement of the biasing resistors can be accomplished with jumpers or switches at the selected master node. See Figure 2-3.
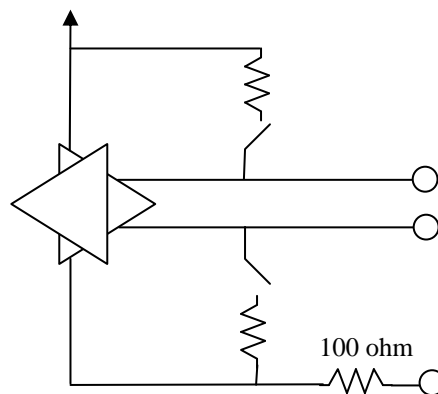

Figure 2-3. Biasing

The distributed approach adds much lighter resistor pairs at each RS-485 node regardless of the master/slave convention, where the sum bias load in parallel equals that of the lumped approach. If typical EOLTRs are used, then this requires that the total number of RS-485 nodes on the network be a known static value. This is typically not a practical approach except in limited applications. If no termination is used, however, or the termination is a capacitive / resistive series element, then the number of nodes per link can vary but must be evaluated to guarantee a Marked state in the presence of EMI. This approach is attractive to 3rd party communication equipment manufactures since it requires no unique treatment to each port and can coexist with a lumped biasing on other equipment.

2.4.3 Grounding, Shielding, and Signal Common

RS-485 communication employs the potential difference between the data-pair conductors (A & B) to determine the data value being transmitted. However, the common-mode voltage between the data-pair and each transceiver's supply common must remain within the common mode voltage limits specified by the RS-485 standard in order to properly receive or transmit data on the bus. Since this common-mode voltage is fairly limited (–7 V to +12 V), a connection must be provided between each of the transceiver's supply commons in all devices connected to the bus in order to avoid exceeding these limits. Operating RS-485 transceivers outside of their common mode voltage limits may corrupt data transmission or even damage the device. Unfortunately, not all RS-485 manufacturers provide an external connection to the transceiver's common. The transceiver common may be isolated in the device or internally connected to the device's ground. The device's transceiver configuration must be known to properly install the RS-485 communication wiring.

Electromagnetic compatibility requirements determine the need for shielding. Generally, industrial applications dictate the need for a shield. A shield serves two purposes: It limits the coupling of external noise to the communication bus, and also reduces emissions from the bus. Ideally, the shield should be continuous the entire length of the bus and should be connected to ground (earth) at only one point to limit the flow of ground-loop currents in the shield caused by ground potential differences.

The interaction between various manufacturers' transceiver connection decisions and the selection of 2- or 3-wire cabling is complex and ultimately determines the system's communication performance. The following recommendations cover the most common configurations.

Two-Terminal Devices

Devices with only two RS-485 connections are the most problematic, since the transceiver's common connection is unavailable. Typically, these devices do not isolate the transceiver and rely on the product's ground (earth) connection to provide common mode voltage limiting. It is recommended that these devices be used only in point-to-point configurations and only where the expected earth difference voltages are only a few volts. These devices are useable only in 2-wire cabling configurations. Connect the shield to ground at every device on the cable run. See Figure 2-11.

Three-Terminal Devices

RS-485 devices with three connections are quite common. Typically the third terminal is marked "common" or "shield" and is connected to the transceiver's common. These devices should be wired as follows based on the cabling configuration:

- 2-wire cable: Connect the two data wires to the device's data terminals and the shield drain to the "common" or "shield" terminal. Ground the shield only at one point in the system. See Figure 2-7 & Figure 2-9.

- 3-wire cable: Connect the two data wires to the device's data terminals and the third wire to the "common" or "shield" terminal. Connect the shield drain wires at every device and ground them at only one location. See Figure 2-6.

Four-Terminal Devices

RS-485 devices with four connections provide the system engineer with the most flexibility. The additional terminals are generally used for the transceiver common and the shield. These devices should be wired as follows based on the cabling configuration:

- 2-wire cable: Connect the two data wires to the device's data terminals and the shield drain to the "common". Jumper the "shield" terminal to the "common" terminal. Ground the shield only at one point in the system. See Figure 2-7 & Figure 2-9.

- 3-wire cable: Connect the two data wires to the device's data terminals and the third wire to the "common" terminal. Connect the shield drain wires to the "shield" terminal and ground them at only one location. See Figure 2-8 & Figure 2-10.

2.4.4 Transient Protection

Lightning surges and power distribution faults produce large amounts of transient energy that must be reduced or eliminated to prevent damage to the transceivers. Two generally accepted techniques for transient protection are galvanic isolation and shunting. Galvanic isolation can be achieved through the use of optical isolators or transformers. Shunting protection involves the use of MOVs or silicon avalanche diodes to shunt the high currents to ground. Most Eaton RS-485 devices employ transient protection within the circuitry and comply with IEC 61000-4-4 (Electrical Fast Transient) and 61000-4-5 (Surge Immunity). Consult the product's instruction manual for specific standards compliance. Systems that may be exposed to short circuits to power conductors will require a fuse type device in addition to isolation and shunting to protect the components. The type of transient suppression required is installation dependent and must be determined by the systems engineer.

RS-485 cables exiting a building must be equipped with transient suppression and grounded per National Electric Code Sections:

Article 250: Grounding
Article 280: Surge Arresters
Article 285: Transient Voltage Surge Suppressors (TVSS)
Article 800: Communications Circuits
Article 830: Network Powered Broadband Communications Systems

2.4.5 Line Length

The EIA/TIA RS-485 communications standard supports 32 devices (driver/receiver pairs) on a cable of up to 4,000 feet (1219 m). Cable lengths longer than 4000 feet are achievable by using repeaters, with each repeater capable of driving the signal another 4,000 cable-feet. In addition, 31 more RS-485 loads (driver/receiver pairs) can be attached to each repeater. Keep in mind that long networks are especially vulnerable to grounding and surge problems, and isolation may be required. Using optically isolated repeaters to connect the nodes of the network can create safe and reliable long-length networks.

2.4.6 Stub Length

Stub length should be made as short as possible, but less than 1.1 feet. The maximum stub length is determined by the shortest rise or fall time of any transmitter on the network. Stub lengths can be calculated using Eq 2-2.

$$StubLength = 1/3 \times \left[t(ns)(rise\ or\ fall)/1.5ns/ft \right]$$ **(Eq 2-2)**

Note that 5 ns rise and fall times are typical for RS-485 transmitters, resulting in maximum stub lengths of 1.1 feet.

2.4.7 Line Termination

All RS-485 systems require termination at the ends of the main run. Some RS-485 devices have an EOLTR that can be switched in or out of the circuit to optionally terminate the network segment at the device. Others require a separate resistor be attached to the input connector. Use ¼ W carbon-film resistors having values that match the characteristic impedance of the cable. Care must be exercised when installing devices to ensure that a termination resistor is attached or switched in, only at devices located at the ends of the main line (see Figure 2-4 and Figure 2-5).

2.4.8 2-wire vs. 3-wire vs. 4-wire Systems

In RS-485 systems, the data lines are a differential-pair that require a path for the return current. The return path is ideally a third wire in addition to the data lines (see Figure 2-5). In un-isolated systems this can be through direct earth connections, and in isolated systems through the cable shield or more desirably through a 3rd isolated wire separate from the shield. This creates applications where the cable connections can have only two field connections for data (ground connection is internal), 2 data plus shield (=3 total), or 2 data plus a 3rd separate common and a 4th shield drain connection. Those applications without the separate 3rd common wire are often referred to as 2 wire while the addition of this separate common is called 3-wire despite the presence of a 4th terminal used for the shield.

RS-485 is designed to handle half duplex communications with a single data pair of wires. Some manufactures have opted to use two RS-485 data pair in parallel to effectively create a RS-422 like connection. This is typically referred to as 4-wire, requiring cabling with two or three data pair, where the third pair serves as the common return.

These differences present a challenge in interconnecting RS-485 interfaces from different product families. For example, the unavailability of suitable 3-wire cables may force a system into a 2-wire mode. In hybrid applications the lowest common denominator approach must be accommodated forcing the 3-wire products to be terminated as 2-wire applications where the common and the shield are the same, sacrificing noise immunity in the process. For this reason system designers often segregate different product families on their own RS-485 links.

2.4.9 Topology

The physical layout of the cabling in an RS-485 network segment should be a single daisy chain cable run between nodes and terminated at the ends with EOLTRs. Communication nodes can be placed anywhere along the cable. Very short taps off the main run are workable, but best avoided. Star or radial topologies are not recommended.

2.4.10 System Capacity

The RS-485 standard was released as a specification by the EIA in 1983 to provide economical, high-speed, multipoint data transmission. (Refer to Section 2.7 References 1 and 2.) Systems employing components compliant with the standard can reliably support up to 32 unit loads distributed along a 4,000 foot twisted pair, at maximum communication speeds from 9,600 bps up to 100,000 bps depending on cable and transceiver characteristics. For devices with a unit load of 1, the maximum number of devices in a network cannot exceed 32.[6]

The RS-485 standard defines a "unit load" as a measure of each transceiver's input loading. Systems constructed with full unit load transceivers will be limited to 32 devices. However, modern integrated circuits are available with $^1/_2$, $^1/_4$, or even $^1/_8$ unit loading and may be used to extend the number of devices on the bus with a potential compromise of reduced bit rate. If a manufacturer does not specify a device's unit load, then it is recommended that systems be limited to a maximum of 32 devices.

Unit Loading Example:

```
        System baud rate ...................... 9600 bps
        Cable length ............................. 4000 ft.
        Unit Load of 30 devices............. 1 Unit Load each
        Unit Load of 4 devices............... ½ Unit Load each
        Total Unit Loads allowed  .......... 32 Unit Loads
```

Total Devices allowed =
(30 Devices x 1 Unit Load) + (4 Devices x ½ Unit Load) =
34 Devices in this example, which is equivalent to 32 Unit Loads

The RS-485 standard does not specify interconnecting media (cable) characteristics. Unfortunately, cable characteristics may severely limit system capacity (length, number of devices, and data rate) if selected unwisely. Generally, to support the maximum 4,000 foot distance:

- Wire diameter should not be smaller than 24 AWG,
- Cable capacitance should not be larger than 15 pF/ft,
- Attenuation should not be greater than 0.6 dB/100 ft @ 1 MHz.

---

[6] Note that the reference of 32 devices in most of the manufacturers' user manuals assumes a unit load of 1.

Most Common Problems that Reduce System Capacity

Cable Topology (See Section 2.4.9) – Star segment topology and stub lengths greater than 1.6 ft. are not recommended.

Cable Selection (See Section 0) – use RS-485 data cable, DO NOT use control or instrumentation cable.

Cable Length (See Section 2.4.5) – Do not exceed a maximum cable length of 4000 ft.

Cable Termination (See Section 2.4.7) – Termination components should be selected to match the cable impedance. A 120 Ohm resistor is recommended for use with RS-485 data cables.

Cable Biasing (See Section 2.4.2) – Single point biasing is recommended.

Baud Rate and Data Frame (See Section 2.2) – Set all devices to same baud rate and data frame style.

EMC Filtering (internal and external) – Capacitive loading of protection components must be managed/minimized.

Non-Ideal RS-485 Devices (See Section 2.4.10) – Isolate non-ideal RS-485 devices on their own network segment.

Number of Transceivers (powered off, etc.) (See Section 2.4.5) – The RS-485 communications standard supports 32 unit loads on a cable of up to 4000 feet in length. Transceivers that are powered off and attached to the line may represent additional loading.

Attenuation (See Sections 2.4.1, 2.4.2, 2.4.5, 2.4.6, 2.4.7) – Account for attenuation due to cable length, termination, biasing, cable selection, sub-standard or damaged transceivers, and slew rate.

Stub Length (See Section 2.4.6) – Stub lengths of less than 1.1 feet are recommended.

Potential Solutions

Consider the following when attempting to mitigate RS-485 communication problems:

Choice of Cable – If a less than ideal cable has been used, then upgrading to one with the recommended construction should be considered to improve signal strength (refer to Section 0). If electromagnetic interference (EMI) is suspect, then a cable with an improved shield construction, or routing of the cable away from the EMI source should also be considered.

Baud Rate – If data errors persist after ensuring that all devices on a common RS-485 network segment are configured for the same data frame and baud rate, then decreasing the baud rate of all devices may improve performance.

Shorter Cable Lengths – Cables attenuate and round off signals as the length of the cable increases. If shorter cable lengths can be managed without compromising the cable topology, this will provide a stronger signal along a segment to reduce errors.

Consider dividing the segment into multiple segments (e.g., using repeaters or parallel segments).

Reduce the Number of RS-485 Nodes – By reducing the number of nodes on a network segment, the signal strength will be increased to help reduce errors. Note that a powered-down node will attenuate the signal at approximately **twice** the powered-off state. If possible, isolate or disconnect nodes that are powered-down.

Repeaters – Repeaters can be used to essentially double the capacity of an RS-485 network link by splitting the network into two network segments. Repeaters with isolation between the links can also be used to isolate RS-485 common/grounding problems. Due to repeater retransmit delay and distortion issues, it is recommended to only extend a specific network segment once. Pick a repeater that is compatible with the segment's common baud rate and data frame. Note that if the power to the repeater is lost then the repeated segment will not be accessible.

Fiber Optic Repeaters – When interconnecting two distant network segments, an RS-485 fiber optic line driver can be used. This is particularly useful to interconnect segments in two buildings to avoid capacitive loading of surge protecting devices, to increase common mode isolation between the segments, and break possible common mode ground loops. The same baud rate, data frame, and power issues exist as with a repeater.

Parallel Links – Instead of pushing the limits of an RS-485 network segment, it may be possible to create separate parallel links to the master device using separate master communication ports. Often these links can operate in parallel thus increasing the overall system throughput.

Isolate Common Devices on their Own Network Segment – Because of the many variables in implementing an RS-485 interface, it is often useful to isolate common vendor devices on their own network segment. This helps minimize contentions between divergent implementations and allows one to follow the manufacturer's recommendations.

2.5 RS-485 Implementation

Table 2-2 and Table 2-3 provide connection guidance for common RS-485 products. Entries in these tables represent the terminal number and label found on the equipment. Note that the table data A/B header definition is referenced to the RS-485 standard (marked state B>A).

Table 2-2. RS-485 Wiring Guide – 3 Terminal Devices

Device Name	A (– Wire)	B (+ Wire)	Common Wire	XCVR Common*	Data Bias
IQ230M	12 (MOD2)	11 (MOD1)	10 (INCOM 3)	I 26V	None
IQ250	(–) Older models are marked B (-)	(+) Older models are marked A (-) or A(+)	SH	I	None
IQ260	(–) Older models are marked B (-)	(+) Older models are marked A (-) or A (+)	SH	I	None
IQ330M	12 (MOD2)	11 (MOD1)	10 (INCOM 3)	I 26V	None
IQ7000	B (–)	A (+)	Shield	I 1KV	None
NETLINK	1 (DATA–)	2 (DATA+)	5 (GND)	E	None
INSULGARD**	B	A	None	Floating	None
BUSHING GARD** (INSULGARD G3**)	B	A	None	Floating	None
Power Xpert Meter 4000/6000/8000	Data A 750B -S	Data B 750B - S	Shield (COM)	I 300V	750 Ohm switch sel
PXG400 / PXG600A	A(–)	B(+)	COM	I	
Powerware Modbus Card (Terminal Block)	RxD–	RxD+	GND	I	620 Ohm switch sel
Powerware Modbus Card (DB-9 Connector)	Pin 6	Pin 1	Pin 3	I	620 Ohm switch sel

* Transceiver (XCVR) Common Connected to:
   I = Isolated
   NI = Non Isolated
   E = Earth Ground
** Center terminal on Insulgard (marked with Ground symbol) is for shield splicing only and is electrically floating. See Figure 2-11.

Table 2-3. RS-485 Wiring Guide – 4 Terminal Devices

Device Name	A (– Wire)	B (+ Wire)	Common Wire	Shield Wire	XCVR Common*	Data Bias
MMINT	2 (B)	1 (A)	3 (COM)	SHD	I 220V	None
DNP MINT	2 (A)	1 (B)	3 (COM)	SHD	I 220V	None
RS-485 PONI	1 (A)	2 (B)	3 (COM)	4 (Shield)	220V	None
Sophia TVSS	3 (B)	2 (A)	1 (Sys Common)	4 (Shield)	250V	None
FP4000/5000	J5-1 RS-485(+)	J5-2 RS-485(–)	J5-3 RS-485 Com.	J5-4 RS-485 Shield	I 250V	1.5K ohm
Power Xpert Gateway 4000/5000/6000 (eLutions)	A(–)	B(+)	CMN		I	
Powerware Modbus Card (Terminal Block)	RxD–	RxD+	GND		I	620 ohm switch sel
Powerware Modbus Card (DB-9 Connector)	Pin 6	Pin 1	Pin 3		I	620 ohm switch sel

 * Transceiver (XCVR) Common Connected to:
     I = Isolated
     NI = Non Isolated
     E = Earth Ground

2.6 Wiring Diagrams

Legend:

D/R = RS-485 Driver/Receiver.
EOLTR = End of Line Termination Resistor.
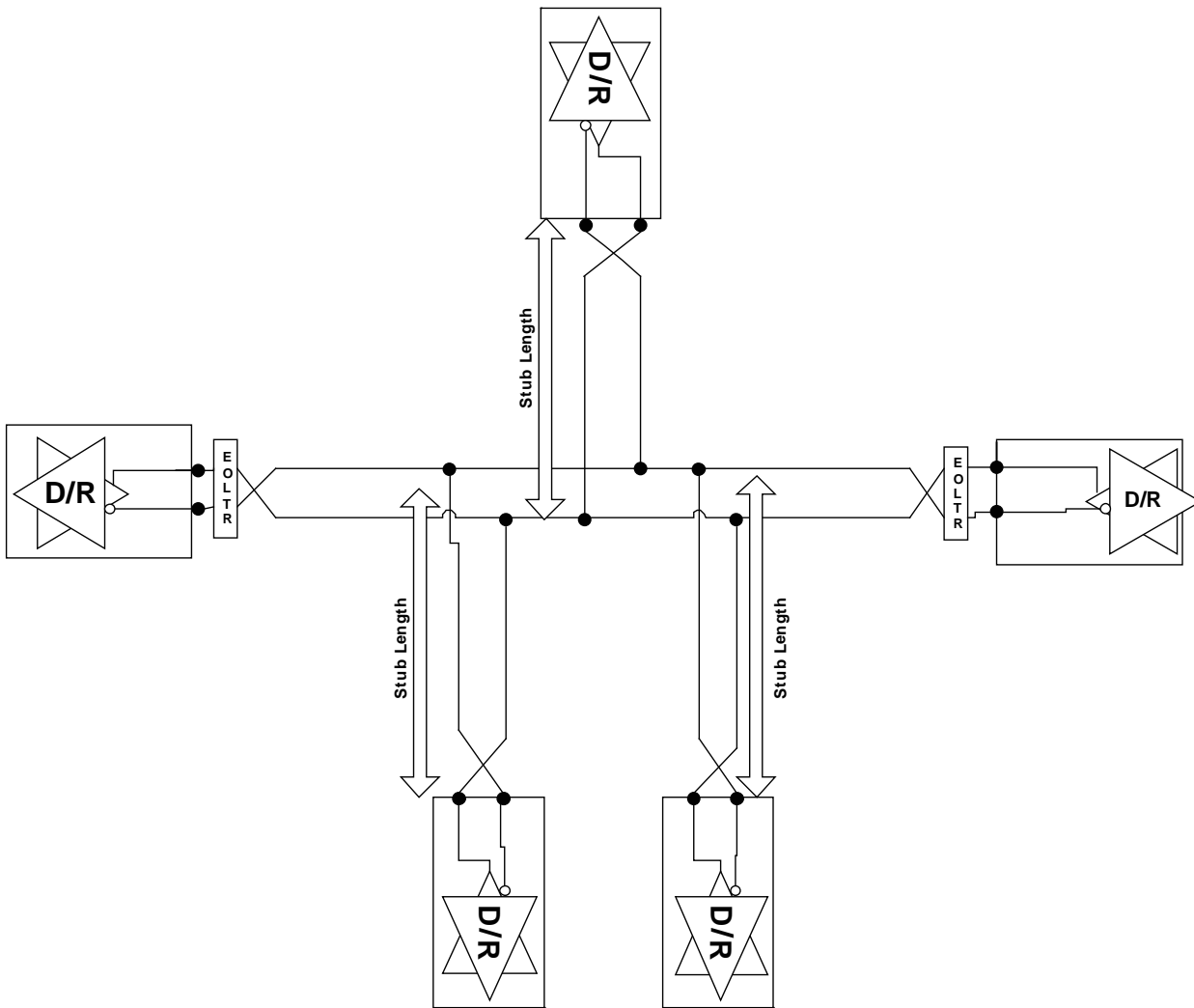
= Twisted Pair

Figure 2-4. Main Run w/ Stubs

Legend:

D/R = RS-485 Driver/Receiver.
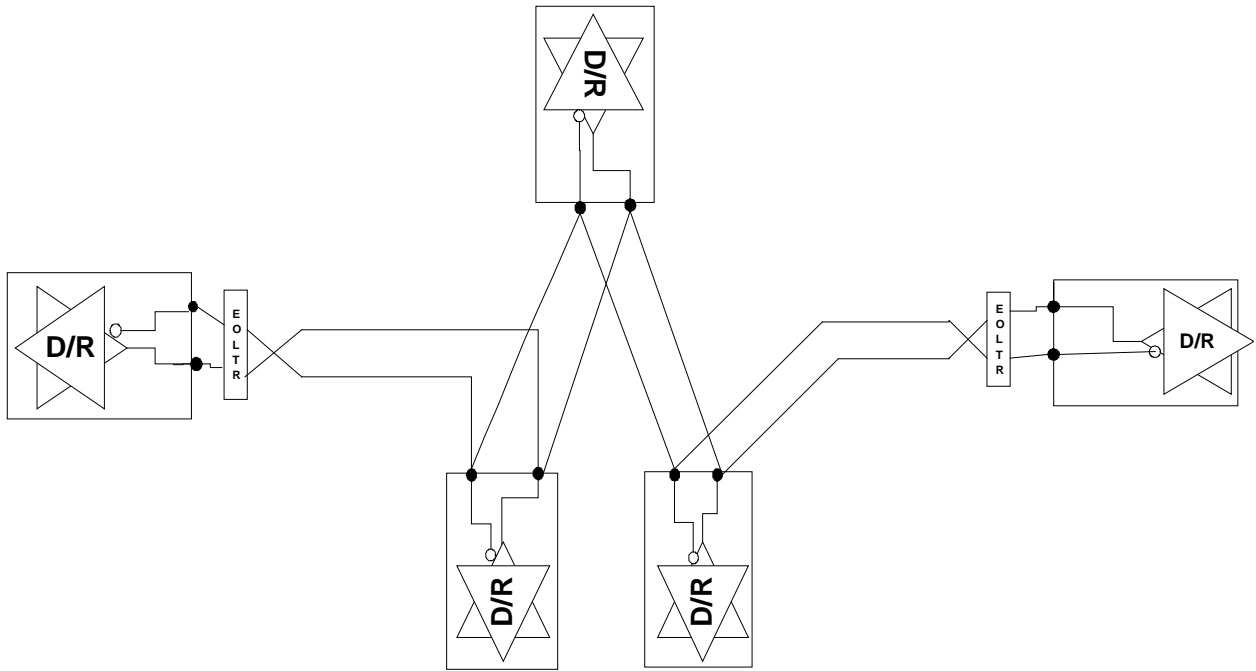**EOLTR = End of Line Termination Resistor.**
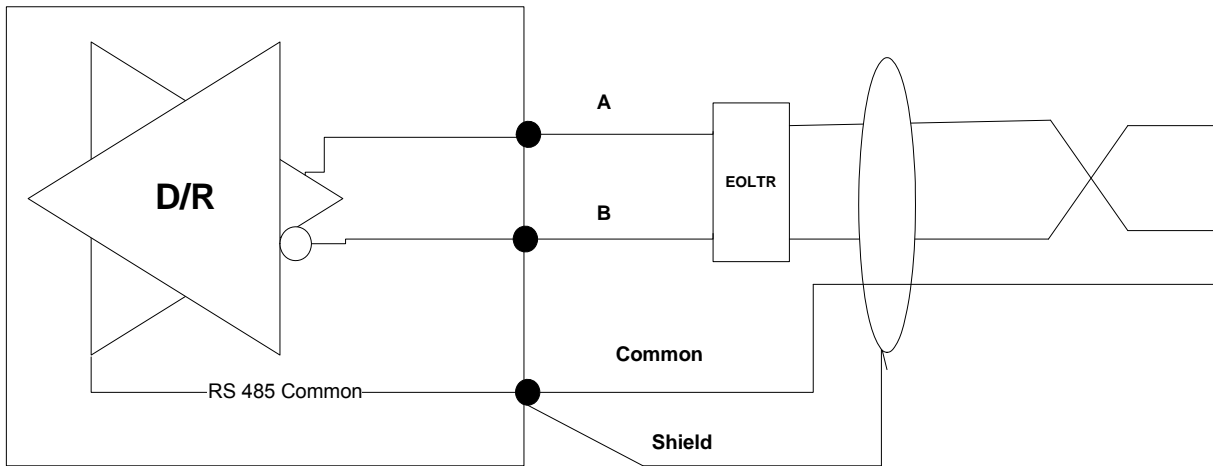
= Twisted Pair

Figure 2-5. Example of Daisy Chain w/o Stubs

Legend:

D/R = RS-485 Driver/Receiver.
EOLTR = End of Line Termination Resistor.

= Twisted Pair

= Shielded Cable

Note 1.

Note:
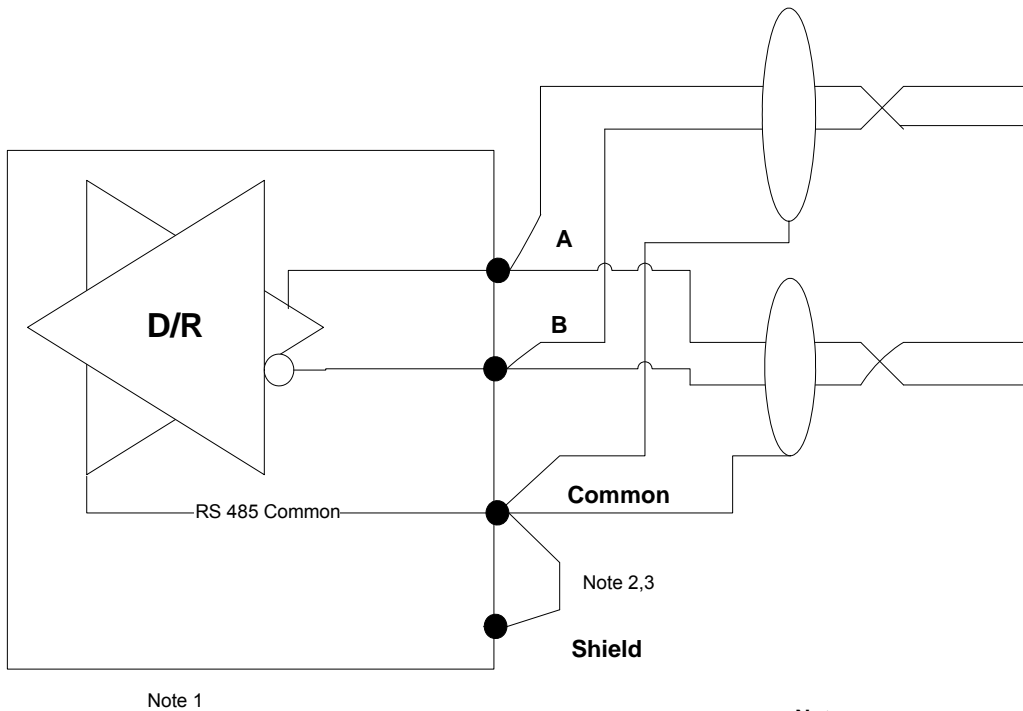1. Example showing 3-wire with shield cable attached to 3-pin connector.

**Figure 2-6. End of Line Node Connection
(3-Pin Terminal Connector)**

Legend:

D/R = RS-485 Driver/Receiver.
EOLTR = End of Line Termination Resistor.

= Twisted Pair

= Shielded Cable

D/R

A

B

RS 485 Common

Common

Note 2,3

Shield

Note 1

Notes:
1. Example showing 2-wire plus shield cable terminated to 3- or 4-pin connector.
2. This pin does not exist on devices utilizing 3-pin connector.
3. Add jumper for 4-terminal connector applications.

Figure 2-7. Daisy Chain Connection
(3- or 4-Terminal Connector Style)

Legend:

D/R = RS-485 Driver/Receiver.
EOLTR = End of Line Termination Resistor.

= **Twisted Pair**

= **Shielded Cable**

D/R

A

B

EOLTR

RS 485 Common

Common

Shield

Note 1

Note:
1. Example showing 3-wire plus shield cable attached 4-pin connector.

Figure 2-8. End of Line Node Connection
(4-Terminal Connector Style)

E:T•N

D/R

A

B

EOLTR

RS 485 Common

Common

Note 2,3
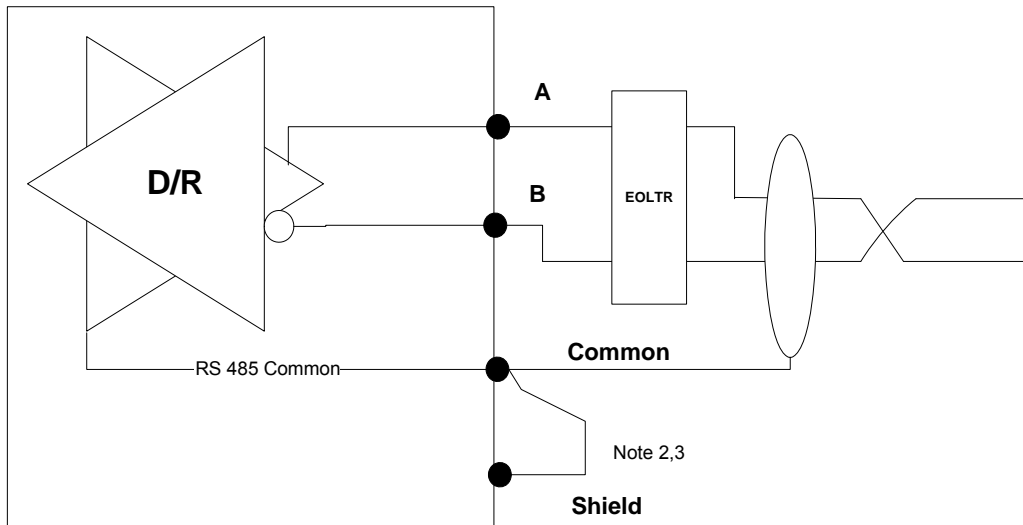
Shield

Note 1

Notes:
1. Example showing 2-wire plus shield cable attached to 3- or 4-pin connector.
2. This terminal does not exist on 3-pin connectors.
3. Add jumper for 4-terminal connector applications.

Figure 2-9. End of Line Node Connection
(3- or 4-Terminal Connector with 2-Wire Plus Shield Cable)

Legend:

D/R = RS-485 Driver/Receiver.
EOLTR = End of Line Termination Resistor.

= Twisted Pair
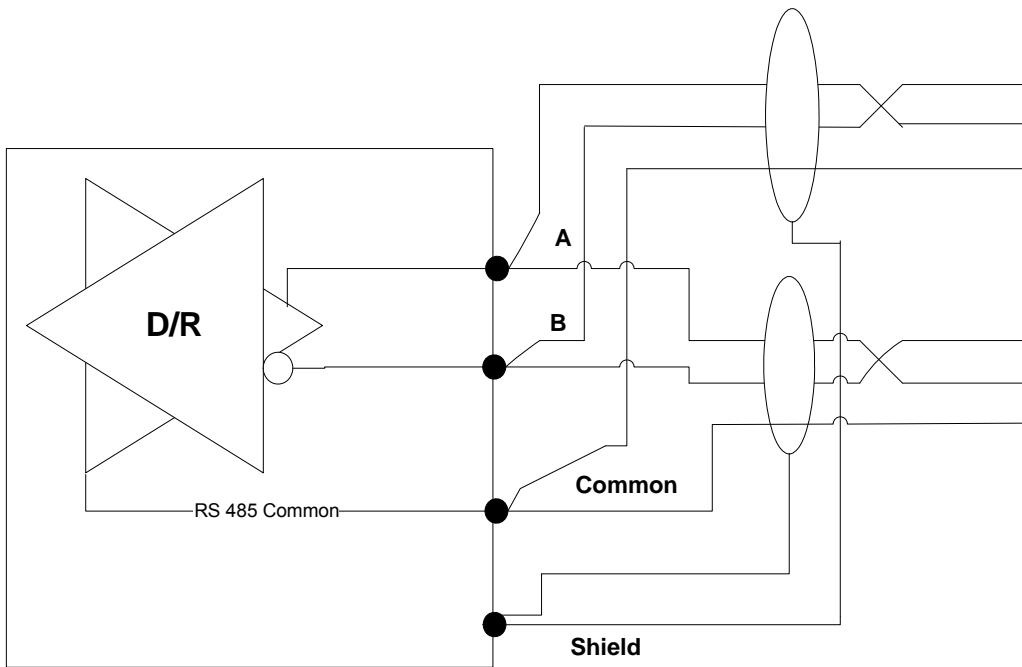
= Shielded Cable

Note 1

Note:
1. Example showing 2-wire plus
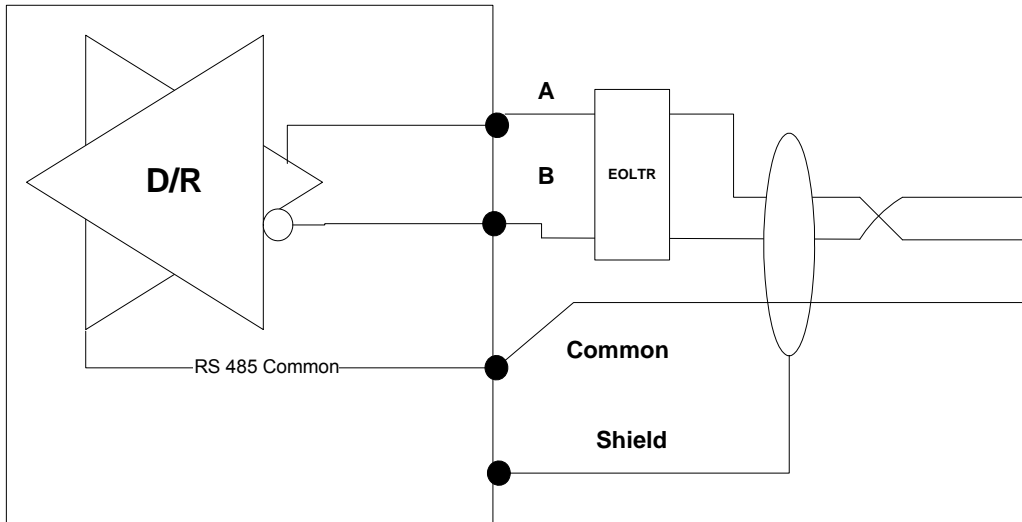   shield cable attached to 3- or
   4-pin connector.

**Figure 2-10. Daisy Chain Connection
(4-Terminal Connector Style)**

Legend:

D/R = RS-485 Driver/Receiver.
EOLTR = End of Line Termination Resistor.

= Twisted Pair

= Shielded Cable

Note 2, 3

Note 2, 3
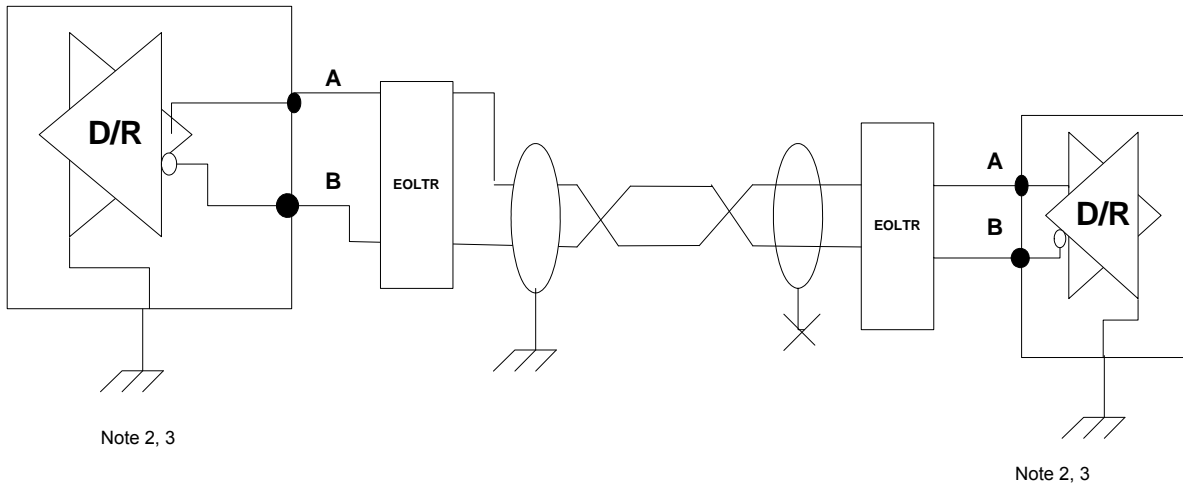
Notes:
1. Tie shield to earth ground at one point only!
2. RS-485 common is internally connected to chassis. Chassis must be terminated to earth ground at BOTH locations for return path.
3. Caution! Do not exceed common mode voltage range of transceiver pairs.

Figure 2-11. 2-Terminal RS-485 – Point to Point Installation

2.7 References

1. ANSI/TIA/EIA-485-A-1998, *Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems*.

2. TSB-89-A, *Applications Guidelines for TIA/EIA-485-A*.

3. ANSI/TIA/EIA-422-B, *Electrical Characteristics of Balanced Voltage Digital Interface Circuits*.

4. AN-1057, *Ten Ways to Bulletproof RS-485 Interfaces* (National Semiconductor).

5. AN-979, *The Practical Limits of RS-485* (National Semiconductor).

6. RS-422 and RS-485 Application Note (B&B Electronics).

Section 3 – ETHERNET

3.1 OVERVIEW:

The Purpose of this document is to provide information regarding the proper installation of Ethernet cable. Information regarding the type and construction of connectors as well as copper and fiber optic cables are provided. Recommendations regarding the installation of cable types are presented as a starting point for those designing an Ethernet system. This document is not intended as a comprehensive evaluation of environmental conditions nor certifying agency requirements needed to design Ethernet communications systems.

3.1.1 Ethernet Cable Definitions:

Bandwidth: The total amount of data that can be transmitted per second.

Category 3 Cable: Ethernet cable used in legacy 10 Mbps systems. It cannot be mixed with other cable types. *This cable type is not recommended for new designs.*

Category 5 Cable: Twisted pair cable type designed for high signal integrity which can be used in systems with data rates up to 100Mbps.

Category 5e Cable : Enhanced version of Cat 5 that adds specifications for far end cross talk which can be used in systems with data rates up to 1000Mbps.

Category 6 Cable: Cat-6 features more stringent specifications for crosstalk and system noise vs. cat 3 and 5 variants. Suitable for 10BASE-T/ 100BASE-TX and 1000BASE-T Gigabit Ethernet.

Collision Domain: a network scenario wherein one particular device sends a packet on a network segment, forcing every other device on that same segment to pay attention to it.

Cross Talk: any signal or circuit unintentionally affecting another signal or circuit. A disturbance, caused by electromagnetic interference, along a circuit or cable pair. A telecommunication signal that disrupts a signal in an adjacent circuit.

Enterprise Networks: Enterprise networks are defined as networks that support large volumes of IP-based data communications across an Enterprise.

Ethernet Cable Connector: Also known as 8P8C Ethernet Cable Connector. Plug and jack used for Ethernet communications. Shielded and unshielded versions are available. 8P8C modular connector (plug or jack) is a modular connector with eight positions, all containing conductors. 8P8C modular plugs and jacks look very similar to RJ45 plugs and jacks but the 2 may not be compatible as the RJ45 variant is keyed.

Ethernet Hub: a device for connecting multiple twisted pair or fiber optic Ethernet devices together making them act as a single segment. The device is a form of multi-port repeater. Ethernet hubs do not isolate traffic between devices within the segment. Packets entering a port are broadcast on every other port (other than port of entry).

Ethernet Router: a computer networking device that interconnects separate logical subnets. It determines the proper path for data to travel between different networks, and forwards data packets to the next device along this path. Routers, isolate traffic between devices reducing the

number of Ethernet frame collisions. They also act as a junction between 2 or more networks to buffer and transfer data packets among them.

Ethernet Switch: Ethernet switches are similar to hubs but are capable of inspecting data packets as they are received, determining the source and destination device of that packet, and forwarding it appropriately. A network switch conserves network bandwidth and offers better performance than a hub by delivering messages directly to devices they are intended for and no others.

Four Hub Rule: IEEE 802.3 standards dictate a maximum of four repeaters in cascade within a network segment.

Ground Loop: the difference in voltage potential present between the grounds at both ends of a cable. This potential can induce noise in the cable.

Horizontal Cabling: cabling system that extends from the work area telecommunications outlet to the horizontal cross-connect in the telecommunication room including the horizontal cables, telecommunication outlet in the work area, and the horizontal cross-connect. Total distance between the end points of the network should never exceed 90 meters (295 feet) as defined by TIA/EIA-568-B.

Insertion Loss: The attenuation caused by the insertion of a device (such as a splice or connection point) to a cable.

Network Segment: a portion of a computer network where every device communicates using the same physical layer.

Outlet Extension Cable: (patch cable) Extends from the work area telecommunications outlet to the destination device. Total distance between the end points of the network should **never** exceed 5 meters (16 feet) as defined by TIA/EIA-568-B.

Physical Layer: The physical layer is the most basic network layer, providing the means of transmitting raw bits over a physical data link connecting network nodes. It is the Ethernet cable or fiber connection

Return Loss: The ratio of the amplitude of the reflected wave to the amplitude of the incident wave. If the device or cable is not purely resistive, the return loss will vary with frequency.

Stand Alone LAN: A repeated or shared network where all Ethernet devices would be

isolated to a common collision domain using Ethernet repeaters. **See Figure5**.

STP Cable: Shielded twisted pair wiring is available in 3, 5, 5e and 6 cable categories. This cable type is used in high noise (Industrial) environments

Subnet: a range of logical addresses within the address space that is assigned to an organization or a physical network served by one router.

UTP Cable: Unshielded twisted pair wiring available in all Ethernet cable categories. This cable type is used in Non-Industrial (low noise) environments.

Vertical Cabling: typically referred to as backbone wiring. Network segments providing interconnections between telecommunication rooms, equipment rooms and entrance facilities. Total distance between the end points of the network should never exceed 100 meters (328 feet) as defined by TIA/EIA-568-B.

Virtual LAN: Many Ethernet networks today have the ability to support Virtual LANs or VLANs. VLANs provide the ability to segment a network at the Data Link layer (OSI Layer 2). Though all VLANs compete equally for backbone network bandwidth, VLANs confine common traffic such as network broadcasts to their own VLANs, and provide an additional layer of security between Ethernet devices and the rest of the network. **See Appendix Fig.6**

3.1.2 Fiber Optic Definitions:

Absorption: One cause of attenuation where light signal is absorbed into the glass during transmission.

Adapter: A device used to interconnect two different connector types.

Attenuation: Optical loss of power. Attenuation is measured in dB loss per length of cable. Attenuation is usually caused by absorption and scattering.

Attenuator: A device used to attenuate a signal.

Back Reflection: A measure of the light reflected off the polished end of a fiber connector. Measured in negative dB relative to incident power.

Bandwidth: The range of signal frequencies that a fiber optic cable will transmit.

Buffer: The protective coating over the fiber. **See Appendix Fig. 3 and Fig.4**

Coupler: A device used to connect two similar connector types.

Fusion Splice: A permanent splice where the two fiber ends are welded together.

Connector Repeatability: Tolerance value (delta) of the insertion loss associated with misalignment within the connector between mating cycles. The ability of a connector to align itself consistently to its mating end between connection cycles. Misalignment will cause greater loss (attenuation in db) across the mating ends**.   See Appendix Fig.1**

Graded-Index Multimode Fiber: This type of optical fiber is mostly used for communication over shorter distances, such as within a building. It can carry 1 Gbit/s for typical building distances; the actual maximum data rate (given the right electronics) depends upon the distance. Multi-mode fiber has a higher light-gathering capacity than single-mode optical fiber, making splicing less difficult, but its limit on speed × distance is lower. Because multi-mode fiber has a larger numerical aperture than single-mode fiber, it supports more than one propagation mode, resulting in larger modal dispersion and consequently higher pulse spreading rates, limiting information transmission capacity. Typically, multi-mode fibers carry wavelengths of 850 nm or 1300 nm.

Insertion Loss: Loss due to optical misalignment associated with variation in manufacturing tolerances within the connector. **See Appendix Fig.1**

Link: The entire span between two optical devices. Includes all cable, connections, and splices.

Loose-Tube Fiber Optic Cable Design: Color-coded plastic buffer tubes that house and protect optical fibers. A gel filling compound impedes water penetration. Excess fiber length (relative to buffer tube length) insulates fibers from stresses of installation and environmental loading. Buffer tubes are stranded around a dielectric or steel central member, which serves as an anti-buckling element. This fiber cable type is typically used in harsh outdoor environments. **See Appendix Fig. 3 and Fig.4**

Loss Budget: The maximum amount of power that is allowed to be lost per optical link.

Jack: The female receptacle - usually found on equipment.

Mandrel: A fiber wrapping device used to cause attenuation within a fiber cable.

Mechanical Splice: A mechanical means of connecting two fibers.

Modal Dispersion: distortion mechanism occurring in multimode fibers and other waveguides in which the signal is spread in time because the propagation velocity of the optical signal is not the same for all modes. Other names for this phenomenon include modal dispersion, multimode dispersion, modal distortion, intermodal distortion, intermodal dispersion, and intermodal delay distortion.

Multimode: A type of fiber optic cable where the core diameter is much larger than the wavelength of light transmitted. Two common multimode fiber types are 50/125 and 62.5/125.

Network Certification: the process of testing certain fiber network parameters and then comparing the actual results against an industry or user-defined standard. Two tiers of network certification are available - Tier one and Tier two. Refer to Tier One Network Certification and Tier Two Network Certification definitions.

Numerical Aperture: the range of angles over which the system can accept or emit light.

Optical Time Domain Reflectometer (OTDR): A device for finding breaks in fiber optic cables or measuring the length. OTDRs should not be used to measure overall cable system loss nor used with multi mode fiber. An OTDR is useful to check if the fiber and splices are good. It can also find stress problems in the cables caused by improper handling during installation. An OTDR can help locate a break in the cable and can identify bad connectors in single mode fiber cable but can have difficulty resolving features in short cables of a LAN. It can detect and measure the amount of light scattered within the cable including connection points and splices. **See Appendix Fig. 7**

Optical Loss Test Set (OLTS): A measurement instrument that includes a meter and source that determines the total amount of loss or attenuation in a fiber span under test. At one end of the fiber, a stable light source emits a signal that consists of a continuous wave at a specific wavelength. At the other end, an optical power meter detects and measures the power level of that signal. The difference in power level of the signal measured at the transmitting and receiving ends corresponds to the loss of the fiber under test.

Plug: The male connector. **See Appendix Fig.2**

Return Loss: The ratio of the power launched into a cable and the power of the light returned down the fiber. This measurement is expressed in positive decibel units (dB). A higher number is better. Return Loss = 10 log (incident power / returned power).

Scattering: A type of attenuation when light collides with individual atoms in the glass.

Single Mode Fiber: This type of fiber cable is used for long distance transmission offering lower attenuation than multi-mode fibers. It has a small core that allows only one mode of light to propagate providing it the highest performance of all fiber types. Reflections are kept to a minimum by the small dimensions of the core. Light pulses introduced at one end are reproduced at the other end with very little dispersion. Single mode fiber typically supports signals with wavelengths of 1320 nm or 1550 nm. It is relatively expensive and must be aligned very accurately when terminating and splicing.

Stand-alone Network: A repeated or shared network where all Ethernet devices would be isolated to a common collision domain using Ethernet repeaters. **See Figure5**.

Step-Index Multimode Fiber: This cable type is obsolete and not recommended for new installations.

Termination: The process of mechanically installing a connector onto a fiber cable.

Tier One Testing: testing that identifies insertion loss (attenuation), length and polarity of a fiber optic system. Each fiber link is measured for attenuation with an optical loss test set (OLTS); length is measured optically or calculated via the cable sheath markings; polarity is verified either with the OLTS or a visible light source, such as a visual fault locator (VFL).

Tier Two Testing: Used to supplement Tier 1 testing and includes an OTDR trace of each fiber link. Tier Two testing is a means to certify the performance of the link components (cable, connectors and splices) and the quality of the installation by examining non-uniformities in a link and provides a "graphical signature" of a fiber's attenuation along its length. The OTDR provides the end user "proof of quality" along the cables length but cannot provide attenuation information as easily as an OLTS.

Tight-Buffered Fiber Optic Cable Design: The buffering material is in direct contact with the fiber providing a rugged cable structure to protect individual fibers during handling and routing. Yarn strength members keep the tensile load away from the fiber. This fiber cable type is typically used in less harsh indoor environments. **See Appendix Fig.3 and Fig.4**

Wavelength: A means of measuring light color expressed in nanometers (nm).

Virtual LANs – Many Ethernet networks today have the ability to support Virtual LANs or VLANs. VLANs provide the ability to segment a network at the Data Link layer (OSI Layer 2). Though all VLANs compete equally for backbone network bandwidth, VLANs confine common traffic such as network broadcasts to their own VLANs, and provide an additional layer of security between Ethernet devices and the rest of the network. **See Appendix Fig.6**

Visual Fault Locator (VFL): The (VFL) is a visible light source that helps trace optical fibers, check fiber continuity, and find faults such as breaks, bad splices, and tight bends in fiber optic cable.

3.1.3 Copper Ethernet Cable Application Information:

The following information can be used as a guide when designing an Ethernet system using Copper Ethernet Cable.

- Cables should not be routed near equipment that generates strong electric or magnetic fields such as motors, drive controllers, arc welders and conduit.

- Ethernet cable insulation has a voltage rating of 300Vac. Use of barriers, cable trays or high voltage sheathing with STP Ethernet cable may be required in installations with cables carrying voltages greater than 300Vac. This may also be necessary in order to comply with UL requirements. In installations where the cable cannot be physically separated from the power cables (where a physical barrier is not practical) fiber optic cable should be used.
- When crossing power conductors with Ethernet cable, cross at right angles.
- Shielded Twisted Pair (STP) Ethernet cable should be specified for use in high noise environments. Shielded shrouded connectors must be used and the shield must be connected at both ends of the wire. The mating plug must have a shielded shroud that is terminated to ground at both ends. Where there is a possibility of a difference in ground potential (common mode) voltages between the two terminated ends, fiber optic cable is recommended.
- When using conduit or a metal cable tray, each section of the conduit or tray must be bonded to each adjacent section and the conduit or tray needs to be bonded to earth ground. Do not allow the shields to touch the conduit or metal tray at any point.

- Only shielded (STP) Ethernet cables should be placed into metal conduit. Some UTP cables may not function properly when installed in conduit, as the metal conduit can affect the electrical properties of an unshielded cable. Consult the cable manufacturer when installing UTP cables in conduit.

- As a general rule for noise protection, Ethernet Cable should maintain a minimum distance of 8 cm (3") from electric power conductors for up to 100 volts and 3 cm (1") for each additional 100 volts up to 400 volts. STP cable is recommended.

- For Ethernet cable run within conduit but near conductors with potentially noisy power conductors carrying currents of greater than 20 A or voltages greater than 400V, maintain the following distances. STP cable is required.

  - Conductors of less than 20 A = 3 inches.
  - Conductors of 20 A or more and up to 100 KVA = 6 inches.
  - Conductors greater than 100 KVA = 12 inches.

- For Ethernet cable run near conductors with potentially noisy power conductors carrying currents of greater than 20 A or voltages greater than 400V, maintain the following distances. STP cable is recommended.

  - Conductors of less than 20 A = 6 inches.
  - Conductors of 20 A or more and up to 100 KVA = 12 inches.
  - Conductors greater than 100 KVA = 24 inches.

- Route Ethernet cable at least 1.5 m (5 ft) from sources of rf/microwave radiation. STP cable is required.

- Do not cascade more than 4 Ethernet repeaters (router, switch or hub) within a network segment.

- Environmentally sealed connectors should be specified for cables used in outdoor installations.

- Avoid pinching the cable when using cable ties.

- Total distance between an Ethernet Transmitter and Receiver at the end points of the network should not exceed 100 Meters (328 feet).

- Total distance from a patch panel to a wall jack (using solid cable) shall not exceed 90 meters (295 feet). Splices are not permitted.

- Patch cords used as cross connect jumpers in a patch panel should not exceed 6 meters (20 ft.).

- Patch cords from a wall jack to the work area PC (or device) shall not exceed 5 meters (16 feet).

- Ethernet cable used in harsh environments must be selected to withstand the following conditions: vibration, air born contaminants, chemicals, temperature, Electromagnetic Interference, combustible atmospheres and local regulatory standards such as UL and NEMA.

- Ethernet connectors used in harsh environments must be robust enough to withstand vibration, multiple connection cycles, temperature changes, and provide a proper seal to protect against moisture, dust/dirt and chemical attack.

- Different cable media support different bandwidth capabilities. When installing cable in a network, care should be taken to install the cable that will fill current network loading requirements and future expansion needs. In general, fiber optic cable can support the greatest bandwidth (upwards of 25,000 gigabits) and UTP has the lowest. CAT 5e cabling is designed to operate a bit rates up to 1000Mb and CAT 6 cable up to 2000Mb.

- Operating your cable at maximum speed reduces the distance between network segments. Check with your cable supplier for specifications regarding segment distance vs. speed.

- Cable with 5% impedance mismatch or return loss of 27 to 32 dB is recommended. Ethernet cable impedance can vary by as much as 15% (85 to 115 Ohms). Average Ethernet cable with 15% impedance variation can have up to 10 dB additional return loss. This discontinuity is referred to as return loss, since it causes some of the signal to be reflected back down the cable instead of propagating forward. It is measured in decibels or ratio of transmitted versus reflected signal.

Fiber Optic Technology:

The use of fiber optics in telecommunications and wide area networking has been common for many years, but more recently fiber optics have become increasingly prevalent in industrial data communications systems as well. High data rate capabilities, noise rejection and electrical isolation are just a few of the important characteristics that make fiber optic technology ideal for use in industrial and commercial systems.

Although often used for point-to-point connections, fiber optic links are being used to extend the distance limitations of RS-232, RS-422/485 and Ethernet systems while ensuring high data rates and minimizing electrical interference.

Conventional electrical data signals are converted into a modulated light beam, introduced into the fiber and transported via a very small diameter glass or plastic fiber to a receiver that converts the light back into electrical signals.

Optical fibers allow data signals to propagate through them by ensuring that the light signal enters the fiber at an angle greater than the critical angle of the interface between two types of glass. Optical fiber is actually made up of three parts. The center *core* is composed of very pure glass. Core dimensions are usually in the range of 50 to 125 um for multi-mode cables and 8-9 um for single-mode cables. The surrounding glass, called *cladding*, is a slightly less pure glass. The diameter of the core and cladding together is in the range of 125 to 440 um.

Surrounding the cladding is a protective layer of flexible silicone called the *sheath*.

3.1.4 Fiber Optic Cable Application Information:

The following information can be used as a guide when designing an Ethernet system using Fiber Optic Ethernet Cable:

- Select a fiber cable that is suited for the application e.g. outdoor, aerial, duct, intra-building, risers, general building and plenum applications.
- Fiber optic cable is useful in applications where the environment is combustible, electrically noisy, the cable must be bundles with high voltages wires or where common mode voltages may exist between the earth ground points of the terminating connectors.
- Fiber optic cable is available in various operating temperature ranges. Care should be taken to match the temperature rating of the fiber to the environment it will be exposed to. The temperature specification for fiber may be narrower than copper cable. Consult the cable manufacturer for temperature specifications of your cable type.
- Sealed fiber connectors are available for use in harsh environments to prevent contamination from entering the connector and fiber. The type of seal required will be application dependant and can vary from dust and moisture proof to water tight.
- Mixing fiber cable types is not permitted. The same core dimensions and mode must be used within cable segments.
- Care should be taken when purchasing connectors to include strain relief which reduces mechanical strain (vibration) within the cable as well as the connector. Strain relief also provides support to the cable to insure proper bend radius at the connector. **See Appendix Fig. 2**
- Single-Mode Fiber is used for long distance transmission of up to 120 km. Distance may vary depending on speed and type of converter used.
- Multi-Mode Graded-Index Fiber Cable is used for communication over shorter distances of up to 2 km.
- Fiber cable is composed of glass and is not well suited for applications requiring tight bend radiuses. Cable radius dimensions vary per manufacturer. If the manufacturer does not provide a bend radius, a typical rule of thumb is a radius not less than 15x the cable diameter.
- Fiber cable to connector terminations can be performed in the field using special equipment. This method is not recommended.

- Tier One testing is recommended when diagnosing system irregularities and should be performed in all new installations.

- Tier Two testing is recommended to certify that a system complies with standards set forth by the owner/installer.
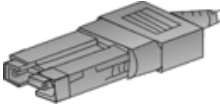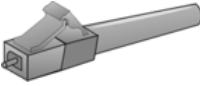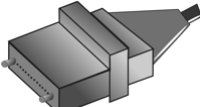
Appendix:

Fiber Optic Connector Types:
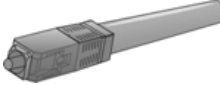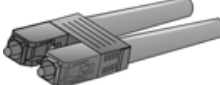
Connector	Insertion Loss	Repeatability	Fiber Type	Applications
FC	0.50-1.00 dB	0.20 dB	SM, MM	Datacom, Telecommunications
FDDI	0.20-0.70 dB	0.20 dB	SM, MM	Fiber Optic Network
LC	0.15 db (SM) 0.10 dB (MM)	0.2 dB	SM, MM	High Density Interconnection
MT Array	0.30-1.00 dB	0.25 dB	SM, MM	High Density Interconnection
SC	0.20-0.45 dB	0.10 dB	SM, MM	Datacom
SC Duplex	0.20-0.45 dB	0.10 dB	SM, MM	Datacom
ST	Typ. 0.40 dB (SM) Typ. 0.50 dB (MM)	Typ. 0.40 dB (SM) Typ. 0.20 dB (MM)	SM, MM	Inter-/Intra- Building, Security, Navy

Fig.1

Type ST and SC Fiber Optic Connector – Exploded View.
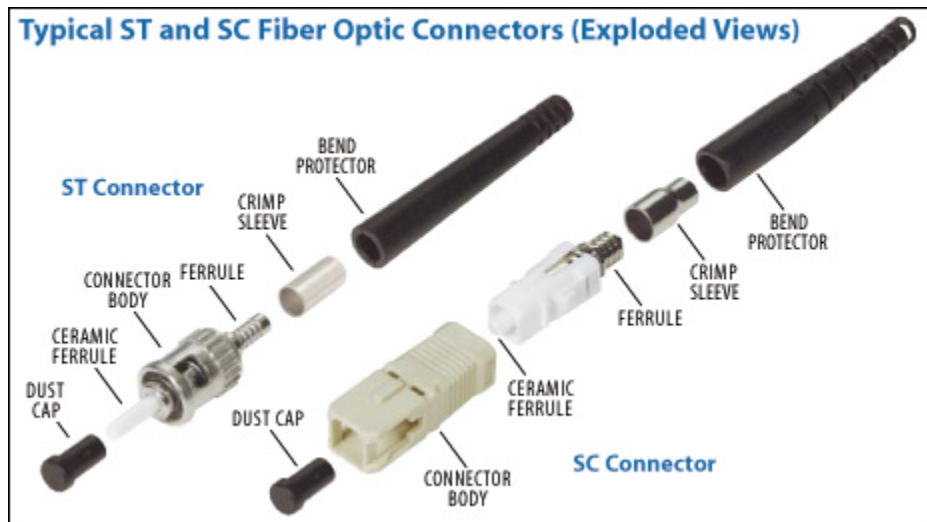
Fig. 2

Typical Fiber Optic Cable – Exploded View:

Typical Fiber Optic Cabling (Exploded View)

JACKET:
PROTECTS AND ALLOWS EASY HANDLING
OF THE FIBER. EXTRUDED PVC IS TYPICAL.

ARAMID YARN (KEVLAR™)
STRENGTH MEMBER

FIBER

900 µM BUFFER:
COATS AND PROTECTS THE FIBER
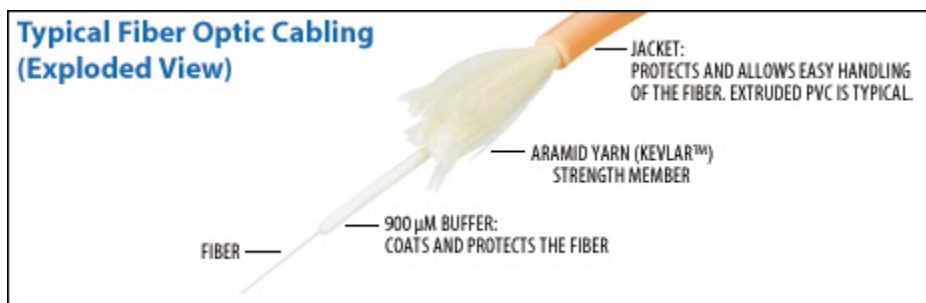
Fig. 3

Tight Buffered Cable – Exploded View:

PVC Jacket
(Non-Plenum) or
Fluoride Co-Polymer
Jacket (Plenum)

Glass Fiber

Thermoplastic
Overcoating or Buffer

Fiber Coating

Aramid
Strength Member
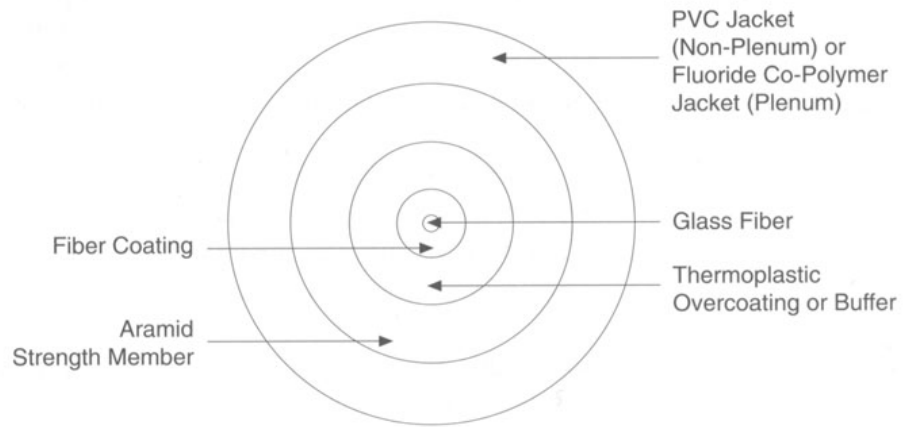
Tight-Buffered Cable

Fig.4

Stand-alone LAN Network Diagram
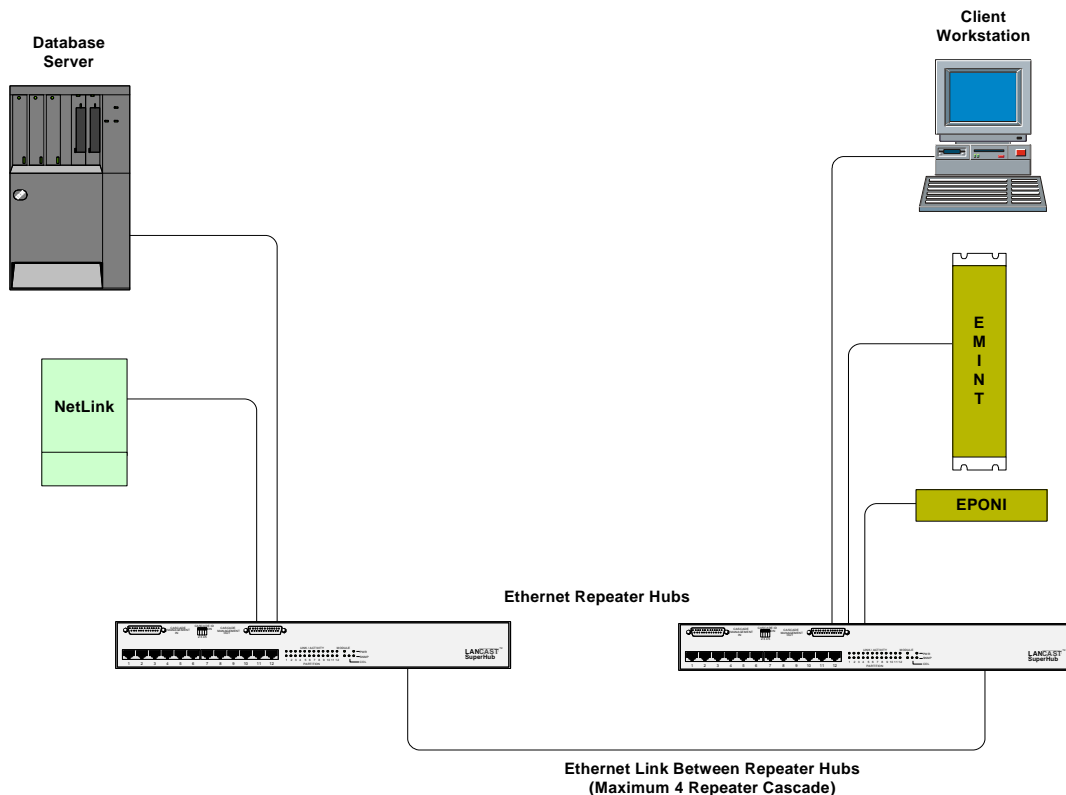
Fig. 5

Virtual LAN Network Diagram :

Fig. 6

Power (dB)

Fiber
connection
attenuation

Fiber splice
attenuation

Fiber
connection
attenuation

Fiber end

Fiber Length

Optical Time Domain Reflectometer Display

Fig. 7

3.2 References:

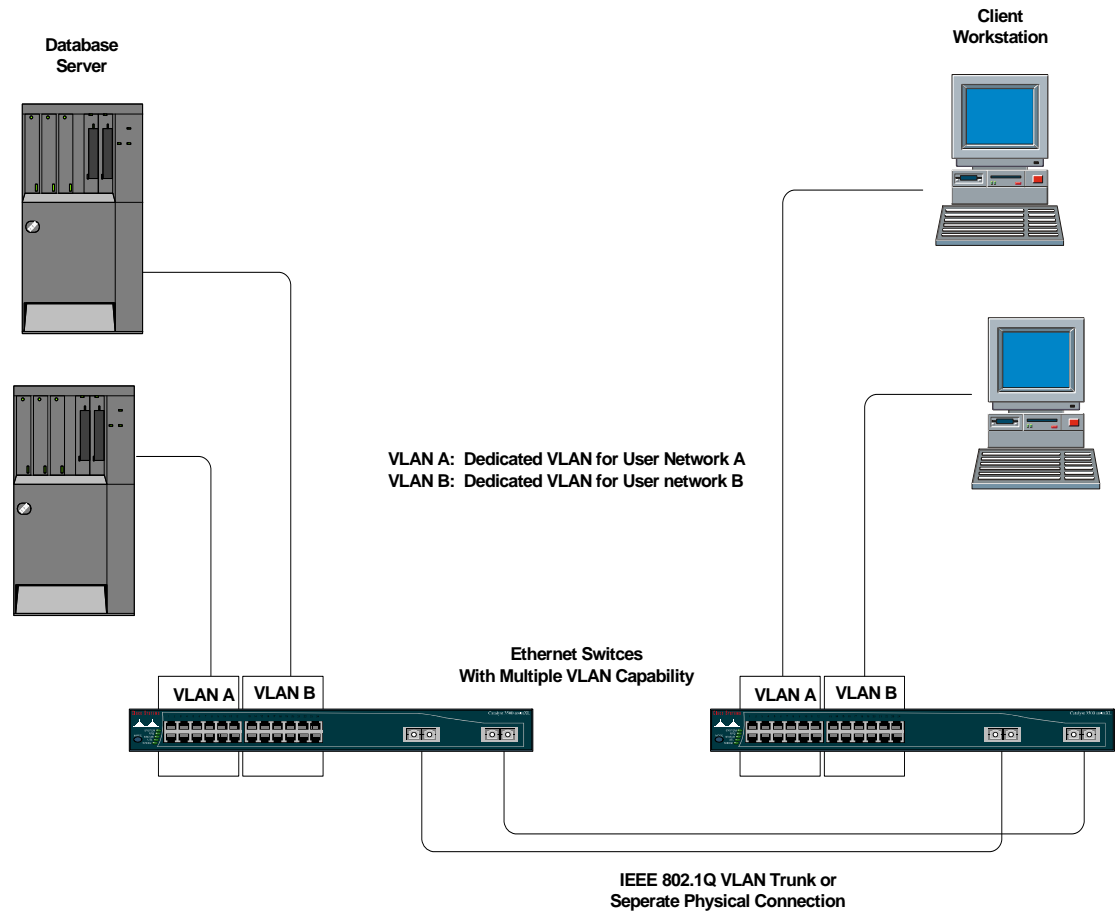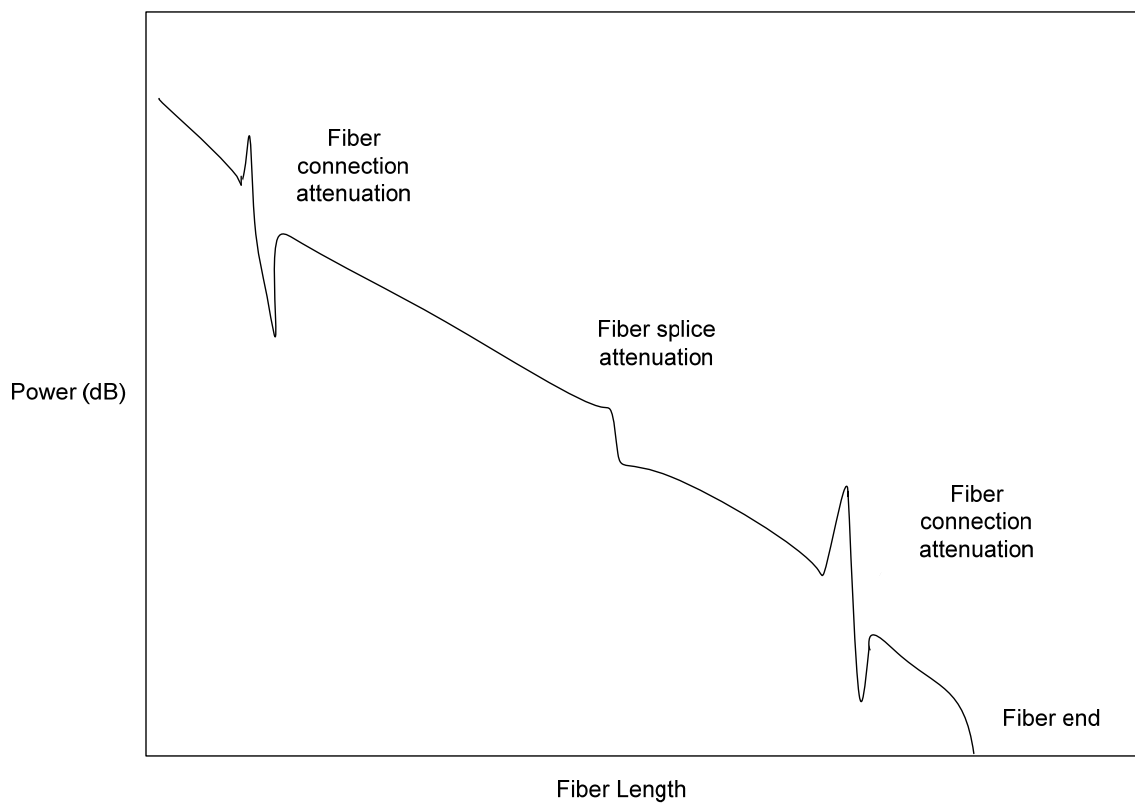**Information contained within this document may have been obtained from one or more of the following references;**

IEC 60529 Degrees of Protection Provided by Enclosures (IP Code)

ISO/IEC 11801: 2002

IEC 61850 Communication Networks and Systems in Substations

IEEE 802.3 Ethernet Standard

ANSI/TIA/EIA-568-B.1 -2001 General Requirements - Commercial Building Telecommunications Cabling Standard

ANSI/TIA/EIA-568-B.2-2001 Balanced Twisted Pair Cabling Components

ANSI/TIA/EIA-568-B.3-2001 Optical Fiber Cabling Components

TIA's TSB140 bulletin "Guidelines for Field-Testing Length, Loss and Polarity of Optical Fiber Cabling Systems"

Lennie Lightwave's Guide To Fiber Optics Understanding OTDRs.
www.Lennielightwave.com

FLUKE Networks White Paper: "Choosing between Optical Loss and Optical Time Domain Reflectometry? Choose both."
www.flukenetworks.com

WWW Fiber Optics Info - www.fiber-optics.info/articles/connector-care.htm

ARCELECT – The Basics of Fiber Optic Cable- a tutorial.
http://www.arcelect.com/fibercable.htm

B&B Electronics White Paper – "Ethernet Basics**".**
B&B Electronics White Paper – "The Ethernet Buzzword Guide".
http://www.bb-elec.com/ethernetbasics/ethernetbasics_info.asp

B&B Electronics Tech Notes - An Overview of Fiber Optic Technology
http://www.bb-elec.com/tech_articles/fiber_optic_technology.asp

Wikipedia, the free encyclopedia.
http://www.wikipedia.org/

L Com Connectivity Products – "Fiber Optic Tutorial".
http://www.l-com.com/multimedia/catalog_page/LC100_Fiber_Optic_Tutorial.PDF

Appendix 1 – Cable Splicing

Although cable terminating tools, techniques, and accessory devices may seem to be of lesser importance to the bigger picture of network architecture, this topic of cable splicing is critical for successful network implementation. Network performance may be compromised by a loose or frayed wire; requiring considerable effort to locate. In addition to reducing potential system downtime for the customer, proper cable end preparation results in faster and higher quality system startup and troubleshooting.

Termination Tools

The tools for network termination fall into several categories of cable sheath and shield removal, wire insulation removal and wire end dressing. Belden 9463 cable consists of one twisted-pair of insulated wire covered by two layers of shielding and an outer PVC jacket (see Figure A-1). The first shield is an aluminized Mylar shield followed by a 57% tinned copper (TC) braid. In between the two shields lies a #20 AWG drain wire for shield splicing and termination. When terminating, no more than 1.5 inches (38 mm) of the cable, the outer jacket, and shield layers must be removed in the process of baring the drain wire and the twisted-pair. Do not nick the drain wire since any break will affect the shield coverage.
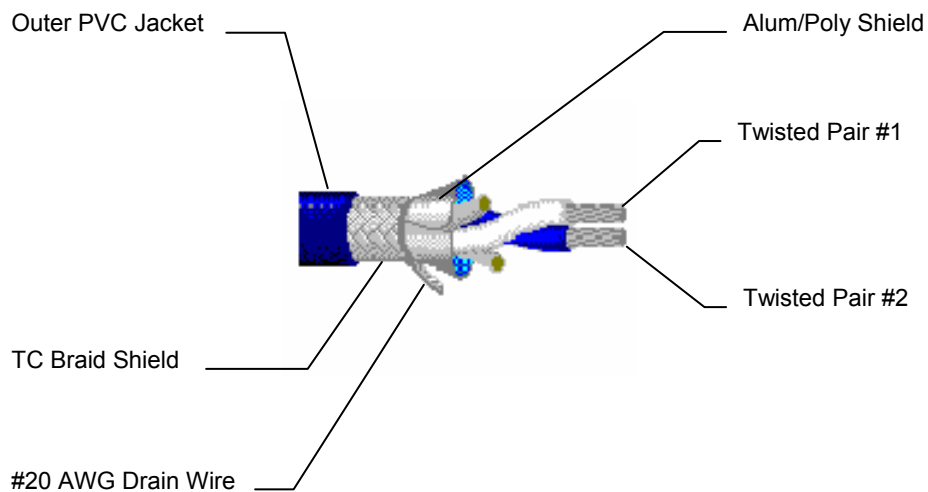
Outer PVC Jacket

Alum/Poly Shield

Twisted Pair #1

Twisted Pair #2

TC Braid Shield

#20 AWG Drain Wire

Figure A-1. Belden 9463 Cable Components

Outer Jacket

Ideal Industries (refer to Cable Tool and Accessory Vendors on Page A-3) is a supplier for many wire terminating tools. For hand-removal of the outer jacket, the Ideal "Coaxial Cable Stripper" Cat # 45-165 works best. It has several sets of replaceable blades, which can make the circular cut around the cable and then split the cable length wise for removal. The blade can be set to cut the TC braid; however, it is not recommended since the drain wire is often nicked as well. An alternative hand tool for the circular cut is the Ideal "Cyclops Stripper" Cat # 45-514. An automated approach for jacket removal can be achieved with Schleuniger wire processing equipment. The Schleuniger HC207 is a programmable semi-portable device that is adept at removing the outer jacket, braid and twisted-pair ends. The tool quickly creates a precise cut depth and length.

Shield Removal

The TC braid can be removed by combing out the braid and cutting it off at the base of the PVC jacket. The combing process can be handled with a thin screwdriver inserted between the braid and the inner shield. The tip of the screwdriver is driven through the braid and then pulled up through the braid in effect combing it out. It may require several passes to accomplish. The inner Aluminum Polyester Foil shield has a seam that can be unfolded and with the help of a sharp nick at the PVC base, can be easily peeled off.

Twisted-Pair

The twisted-pair can be stripped with a wide variety of hand or automated devices manufactured by Schleuniger and Ideal. The goal is to form a clean and uniform length of insulation strip. Uneven lengths or nicked wires lead to bad connections and mismatch with ferrule devices (discussed below).

Ferrules

The use of ferrules to dress wire ends eliminates frayed wires, strengthens connection points, and joins daisy-chained wires easily. Phoenix Contact has a series of ferrules for single- and double-wires per terminal block jaw. As an additional benefit, ferrules for daisy-chained applications maintain network continuity even when the terminal block jaw is loose. For all applications, initial and rework wiring is made quicker and cleaner. A longer version of the ferrule works well with the Addressable Relay II.

Cable Tool And Accessory Vendors*

Ideal Industries
Sycamore, Illinois 60178
(800)435-0705
www.idealindustries.com

Schleuniger
150 Dow St.
Manchester, New Hampshire 03101
(603)668-8117
www.schleuniger.com

Phoenix Contact
Harrisburg, Pennsylvania 17111-0100
(717)944-1300
www.phoenixcontact.com

Technical Support

For technical support on this topic or PowerNet in general, contact Power Quality
Technical Support at 800-809-2772, or outside the U.S. at 412-494-7100. Technical
support can also be reached via e-mail at: pqsupport@eaton.com .

Notes:

* Eaton Corporation does not exclusively endorse these vendors, nor
  does Eaton receive compensation for the purchase of their products.

REVISION HISTORY

Each time this manual is updated, the Title Page lists the new revision number and date, and this page describes the changes.

Rev.	Date	Revised Pages	Description	Changed By
1 Initial release	1/30/07	Title Page	Added revision number and date	JB
		Inside Back Cover	Added Revision History page	
2	1-30-08	Ethernet Section	Added Ethernet Section	VF
3	7-15-08	Table	Modified tables 1-3 and 2-2	BL
4	8-20-08	Table	Changed label for PXG in table 2-2	

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