Version 3.0

LONMARK®
Layers 1-6 Interoperability Guidelines

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LONMARK Interoperability Association

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LONMARK Interoperability Association

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Contents

1

Introduction

LONWORKS® nodes communicate with each other via the LonTalk™ protocol that is implemented in firmware on the Neuron® Chip. To meet the objective of supporting applications in a wide range of industries, the LonTalk protocol is presented as a collection of services from which the designer can pick and choose as desired. The LONWORKS interoperability guidelines provide direction to designers on which selections to make and what values to use to enable their product to interoperate with other LONWORKS products.

The goal of these guidelines is to provide a set of standards that allow LONWORKS products to be designed independently and integrated with other LONWORKS nodes and systems from other vendors *without* the need to develop custom application code, hardware or tools. The guidelines are presented in separate volumes for layers 1-6 and layer 7 of the LonTalk Protocol. This document provides Layer 1-6 design guidelines.

LONMARK Program

A product that is designed according to these interoperability guidelines may qualify to carry the LONMARK logo to indicate that it is LONWORKS interoperable. Products submitted for the LONMARK logo will be tested to verify conformance with these guidelines. For more information on the LONMARK program, please complete the form at the end of this document.

Definition of Terms

Interoperability between products can be achieved at many different levels. The interoperability guidelines use the following terms to discuss interoperability:

Node — A single Neuron 3120 or 3150 Chip.

Interoperability — A process that ensures that multiple nodes (from the same or different manufacturers) can be integrated into a single network without requiring custom node or tool development.

Sub-system — One or more nodes working together to perform a function. The configuration of all the nodes in a sub-system are managed by a single network management tool. A sub-system may use one or more LonTalk domains.

System	One or more independently managed sub-systems working together to perform a function. A system may use one or more LonTalk domains.

Audience

The information contained in the *Layer 1-6 Interoperability Guidelines* is pertinent to OEMs who plan to design interoperable LONWORKS-based products.

Contents

The *Layer 1-6 Interoperability Guidelines* provide design guidelines that must be followed to qualify for the LONMARK logo.

- *Chapter 1* introduces the scope of the Layer 1-6 design guidelines.
- *Chapter 2* describes the requirements for compatibility at Layer 1, the physical layer.
- *Chapter 3* describes the Layer 2-6 guidelines.

Related Documentation

- The *LonTalk Protocol* engineering bulletin summarizes the services available at each of the seven layers of the LonTalk protocol embedded within every Neuron Chip.
- The *LONMARK Application LayerInteroperability Guidelines* (078-0120-01) provide the interoperability design guidelines for the Application Layer of the LonTalk Protocol. These guidelines form the basis for obtaining the use of the LONMARK logo, which indicates that a product is LONWORKS interoperable.

2

Physical Layer

The LonTalk protocol supports networks with channels using different media, including twisted pair, link power, power line, radio frequency, infrared, coaxial cable, and fiber optic media. Every LONWORKS node is physically connected to a channel that is a physical transport medium for packets. The physical form of a channel depends on the medium. For example, a twisted pair channel is a twisted pair of wires, an RF channel is a specific radio frequency, and a power line channel is a section of AC or DC power wiring. The data rate of a channel is dependent upon the transceiver design.

A standard electrical network interconnection between products is necessary in order for LONWORKS products made by different manufacturers to interoperate. The transceiver design plays an important role in allowing nodes on a channel to interoperate reliably and predictably.

To facilitate and promote interoperability, the LONWORKS interoperability guidelines include transceiver designs for a variety of media. These transceiver designs must be used as the physical layer for interoperable LONWORKS nodes. Using these designs is a requirement for passing the LONMARK conformance review. The physical channels supported by documented designs are listed in table 2-1.

Table 2.1 Interoperable Physical Channels

Physical Channel	*Medium*	*Data Rate*	*Characteristics*	*Notes*
TP/XF-1250	Twisted Pair	1.25Mbps	Transformer Coupled	Bus topology
TP/XF-78	Twisted Pair	78kbps	Transformer Coupled	Bus topology
TP-RS485-39	Twisted Pair	39kbps	EIA RS-485 specifications	Bus topology
PL-10(L-N)	Power Line	10kbps	100kHz-450kHz, spread spectrum, Line-to Neutral coupling.	FCC, Industry Canada compliant
PL-10(L-E)	Power Line	10kbps	100kHz-450kHz, spread spectrum, Line-to Earth coupling	FCC, Industry Canada compliant
PL-20(L-N)	Power Line	5kbps	125kHz-140kHz, BPSK, Line-to-Neutral coupling, 50/60Hz mains frequency	FCC, Industry Canada , CENELEC, compliant
PL-20(L-E)	Power Line	5kbps	125kHz-140kHz, BPSK, Line-to-Earth coupling, 50/60Hz mains frequency	FCC, Industry Canada , CENELEC, compliant
PL-30(L-N)	Power Line	2kbps	9kHz-95kHz, spread spectrum, Line-to Neutral coupling.	FCC, Industry Canada , CENELEC, compliant
TP/FT-10	Twisted Pair	78 kbps	Flexible Topology and Link Power	Free topology and Link Power
RF-100	Radio Frequency	4.883 kbps	UK MPT1329, FCC Part 90, European ETS 300220 or Australian radio bands	Radio Frequency

For each physical channel, the performance specifications and the LONMARK-approved transceiver schematics are provided. The LonTalk communication channel parameters for each transceiver are specified in the Layer 2 guidelines. These parameters must be set correctly to ensure that all nodes on a channel will interoperate without requiring parameter adjustment prior to installation.

Guideline: Specified transceiver schematics must be followed exactly.

LONMARK-Approved Transceivers

For a product to carry the LONMARK logo, it must use a LONMARK-approved transceiver design. Products that use LONMARK-approved transceiver designs automatically satisfy the stated performance specifications and no additional

performance testing of the physical layer is required for the LONMARK conformance review.

Additional LONMARK-approved transceivers will be added as market requirements demand. The criteria used in adopting a transceiver as a standard include:

- Is this transceiver design thoroughly tested?
- Is this design open and publicly available?
- Does this transceiver have long-term, widespread applicability?

LONMARK approval of additional transceivers is handled separately from the LONMARK product certification. For more information on additional transceivers under consideration, or for information on how to submit a transceiver for LONMARK approval, contact the LONMARK Secretary.

Products designed using a non-interoperable transceiver can be connected to an interoperable network via a router that uses an interoperable transceiver; all other interoperability guidelines still apply. This option is described in the Layer 7 Application Layer Guidelines.

Performance Testing

Products submitted for the LONMARK logo are expected to comply with all applicable EMI and agency regulations of the markets they intend to serve such as UL, FCC, CSA, VDE, TUV, CENELEC as appropriate.

Transformer-Coupled Twisted Pair Transceiver Communication on TP/XF-78 and TP/XF-1250 Channels

Performance Specification

Table 2.2 provides a summary of the performance specifications for the 78kbps and 1.25Mbps transformer-coupled twisted pair channels.

Table 2.2 Performance Specification for Transformer-coupled 78kbps and 1.25Mbps Twisted Pair Channels

Performance Specification	***TP/XF-78***	***TP/XF-1250***
Transmission Speed	78kbps	1.25Mbps
Nodes per Channel	64 (0 to +70°C) 44 (-40 to +85°C)	64 (0 to +70°C) 32 (-20 to +85°C) 20 (-40 to +85°C)
Node Distribution	NA	≤ 8 nodes per 16m section
Network Bus Wiring	UL Level IV, 22 AWG (0.65 mm) twisted pair	
Network Stub Wiring	UL Level IV, 22 or 24 AWG (0.5 mm) twisted pair	
Network Bus Length - Typical [1] - Worst case[2]	 2000m 1330m	 500m 125m
Maximum Stub Length[3]	3m	0.3m
Network Terminators	Required at both ends of the network	
Temperature Operating Non-operating	 0 to +70° C (64 node load) -40 to +85° C (44 node load)	 0 to +70° C (64 node load) -20 to +85°C (32 node load) -40 to +70° C (20 node load)
Electrostatic Discharge to Network Connectors No Errors No Hard Failures	 to 15,000V to 20,000V	 to 15,000V to 20,000V
Isolation between Network and I/O Connectors 0 - 60Hz (60 seconds) 0 - 60 Hz (continuous)	 1,000 VRMS 277 VRMS	 1,000 VRMS 277 VRMS

[1] Typical conditions are 20. C, 5.0 V supply voltage, normal wire temperature and 64 evenly distributed nodes

[2] Worst case conditions are the combined effect of worst case conditions of all the above parameters

[3] The stub length in table 2-2 assumes a mutual capacitance of 17 pF/ft (56 pF/m) for the twisted pair stub cable.

Echelon's TPT/XF-78 and TPT/XF-1250 modules are LONMARK-approved for use.

Manufacturers of LONMARK-certified products are free to use any connection scheme customary in their industry.

Transceiver Schematic

Figure 2-1 shows the circuit that is required with Echelon's TPT/XF-78 and TPT/XF-1250 twisted pair modules. Each module contains the complete twisted pair transceiver and can be mounted on a PCB assembly either as a plug-in or soldered component.

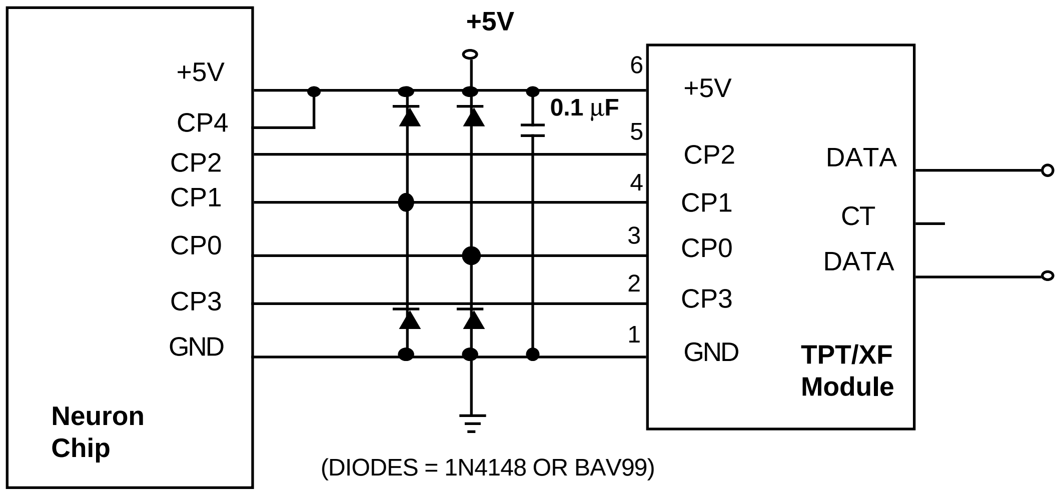


Figure 2-1 Transformer-coupled Twisted Pair Transceiver using either Echelon's TPT/XF-78 or TPT/XF-1250 Twisted Pair Transceiver Module

Using the TPT/XF-78 and TPT/XF-1250 Twisted Pair Transceiver Modules (see figure 2-1) minimizes circuit layout considerations, since most layout sensitive components are encased in the module. However, the following guidelines must be observed.

Guideline: *PCB trace lengths between the TPT/XF module P2 header and the twisted pair stub connector should be kept less than 5 cm for the TPT/XF-78 module and less than 2 cm for the TPT/XF-1250 module.*

Guideline: *The total differential trace capacitance between CP0 and CP1 lines connecting the TPT/XF module and the Neuron Chip must be ≤ 3 pF.*

This is achieved by keeping the total trace distance between the Neuron Chip CP lines and the TPT/XF module less than 2 cm. To achieve shielding and minimize

capacitance, symmetrical layout guidelines must be followed for the communications port traces connecting the TPT/XF module with the Neuron Chip. CP0 and CP1 may be exchanged with one another. CP2 and CP3 also may be exchanged with one another independently of CP0 and CP1. Pins should be exchanged to optimize the PCB layout to eliminate crossovers. When routing CP traces from the Neuron Chip it is recommended that CP3 be routed directly underneath the Neuron Chip via the NC pin to achieve symmetry and shielding of the trace from the Neuron Chip to the module. On multi-layer boards the use of a 25% cross hatch ground plane underneath the CP lines will enhance the shielding while minimizing capacitance.

Network Cabling and Connection

Network Cable

Guideline: Use UL Level IV, 22 AWG (0.65 mm) twisted pair cable.

The characteristics of the wire used to implement a network will affect the overall system performance with respect to total distance, stub length, and total number of nodes supported on a single channel. The network performance is characterized for UL level IV, 22 AWG twisted pair cable for the network bus wiring as defined in: *UL's LAN Cable Certification Program, Document number 200-120 20M/11/91.* Level IV 22 or 24 AWG (0.5 mm) twisted pair cable may be used for the stub wiring.

Bus Termination

Guideline: Use specified termination circuit to terminate TP 1.25Mbps and TP 78kbps physical channels.

It is necessary to terminate the ends of a twisted pair bus to minimize reflections. Failure to terminate the bus will degrade network performance. Figure 2-2 details the circuit required to terminate the TP 1.25Mbps and TP 78kbps physical channels.

Note: Products do not need to include any network cable or bus termination. However, if they are provided, they must conform to these guidelines.

The following rated devices should be used.

Component	***Type***	***Rating***
Resistors	Metal Film	1%
Capacitors	Polyester	10%

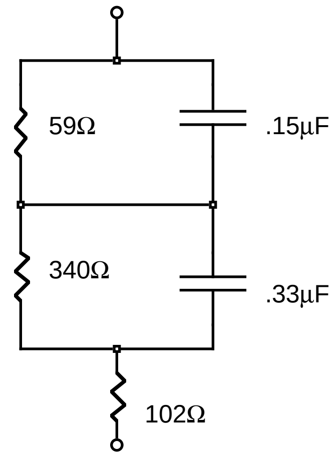


Figure 2-2 Bus Termination Circuit for TP 1.25Mbps and TP 78kbps Channels

Twisted Pair Communication on TP-RS485-39 Channels

Overview

The LONMARK TP-RS485-39 channel uses transceivers that support the EIA RS-485 specification. The RS-485 transceiver operates at V_{DD} = +5V, provides -7V to +12V common-mode range, and offers both short circuit protection and a high impedance output in the event of a local power failure. The RS-485 standard allows for a continuum of bit rates. However, the TP-RS485-39 channel operates at a bit rate of 39kbps.

Performance Specifications

The performance specification for the TP-RS485-39 channel is summarized in table 2-3.

Table 2-3 Performance Specification for the TP-RS485-39 Channel

Performance Specification	***TP-RS485-39***
Transmission Speed	39kbps at listed bus length
Nodes per Channel [1]	32
Network Stub Wiring	UL Level IV, 22 or 24 AWG twisted pair
Network Bus Wiring	UL Level IV, 22 AWG twisted pair
Maximum Channel Lengths	1200m per EIA RS-485 standard

Table 2-3 Performance Specification for TP-RS485-39 *(continued)*

Performance Specification	***TP-RS485-39***
Maximum Stub Length [1]	0 m
Network Terminators	Required at both ends of network
Temperature Operating Non-operating	 0 to +70° C -40 to +85° C
Electrostatic Discharge to Network Connectors No Errors No Hard Failures	 to 15,000V to 20,000V

1 These are standard specifications detailed in the EIA RS-485 Specification Section 3, entitled "Electrical Characteristics."

Echelon's TP-RS485 transceiver is LONMARK approved for use.

Transceiver Schematic

The schematic for the TP-RS485-39 transceiver design is shown in figure 2-3. Components for EMI, ESD, and transient protection should be added as needed. Unless otherwise noted, the following ratings apply to all devices on the schematic.

Component	***Type***	***Rating***		
Resistors	Metal film	5%	100PPM per °C	1/8 watt

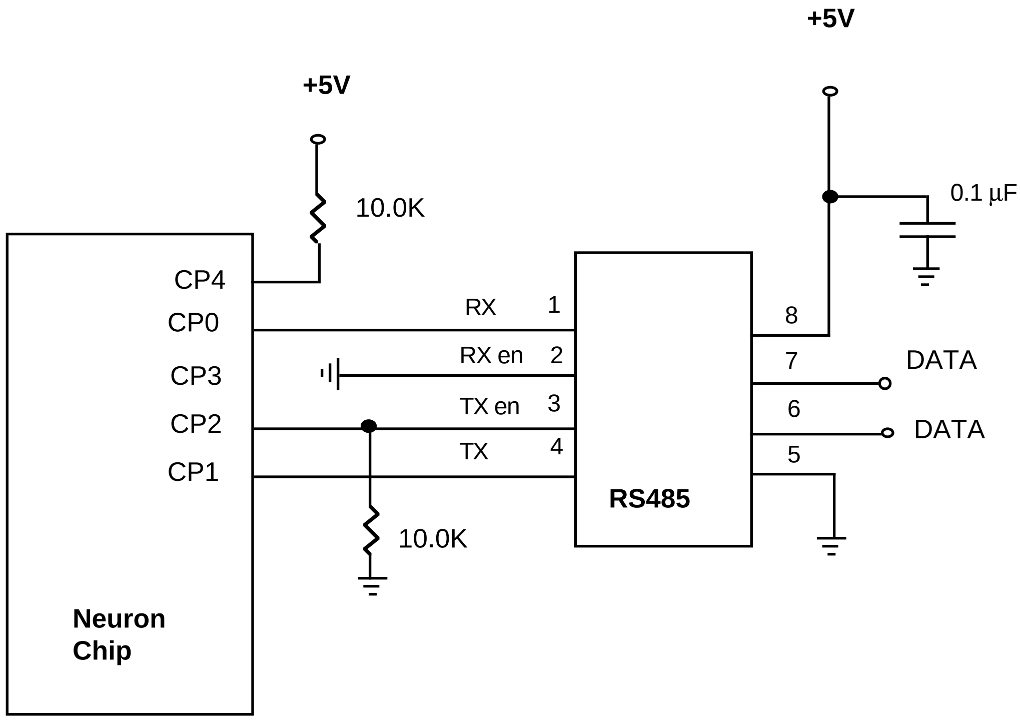


Figure 2-3 TP-RS485-39 Transceiver

Bus Termination

Guideline: Use specified termination circuit or TP 78kbps and TP 1.25Mbps terminator to terminate the TP-RS485-39 channel.

It is necessary to terminate the ends of a twisted pair bus to minimize reflections. Failure to terminate the bus will degrade network performance. Figure 2-4 details the circuit required to terminate the TP-RS485-39 physical channel. The TP 78kbps and TP 1.25Mbps termination circuit may be substituted, see figure 2-2.

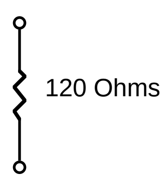


Figure 2-4 Bus Termination Circuit for TP-RS485-39 Channels

EIA Standard RS-485

Guideline: *The TP-RS485-39 nodes must comply with the grounding requirements of the EIA RS-485 Standard detailed in the EIA RS-485 Specification Section A.3 entitled* Optional Grounding Arrangements.

A signal return path between the circuit grounds of nodes on a TP-RS485-39 network must be provided. The ground reference may be established by a third conductor or by providing a connection to an earth reference at each node.

Power Line Communication Using the PL-10(L-N) and PL-10(L-E) Channels

Table 2.4 provides a summary of the specifications for the 10kbps power line channels.

Table 2.4 Specifications for PL-10 Line-to-Neutral and Line-to-Earth Coupled 10kbps Power Line Channels (100kHz - 450kHz)

Parameter	***PL-10(L-N)***	***PL-10(L-E)***
Coupling Technique	Line-to-Neutral	Line-to-Earth
Transmission Speed	10kbps	
Transceiver Crystal	10MHz, 200ppm, 13pF, parallel resonant	
Transmission Technique	Direct sequence spread spectrum, 31 chips-per-bit	
Frequency Band	100kHz - 450kHz	
Output Level	≥5.0V peak-to-peak into 50Ω	
Output Impedance	≤2Ω in series with 0.43µF±10%	≤1.5Ω in series with 0.064µF±10% (120VAC) ≤1.5Ω in series with 0.032µF±10% (240VAC)
Input Impedance*	≥100Ω average over 100kHz - 450kHz	

* Note: Input impedance applies to PLT-10A and associated coupling circuit only and does not include effect, if any, of system power supply. See the *LONWORKS PLT-10 A Transceiver User's Guide*.for further guidelines.

Echelon's PLT-10 transceiver is LONMARK-approved for use on the PL-10(L-N) and PL-10(L-E) channels.

Transceiver Interface Specification

Figure 2.5 shows a typical PLT-10A transceiver application block diagram. The coupling circuit and power supply must be selected based on the intended application.

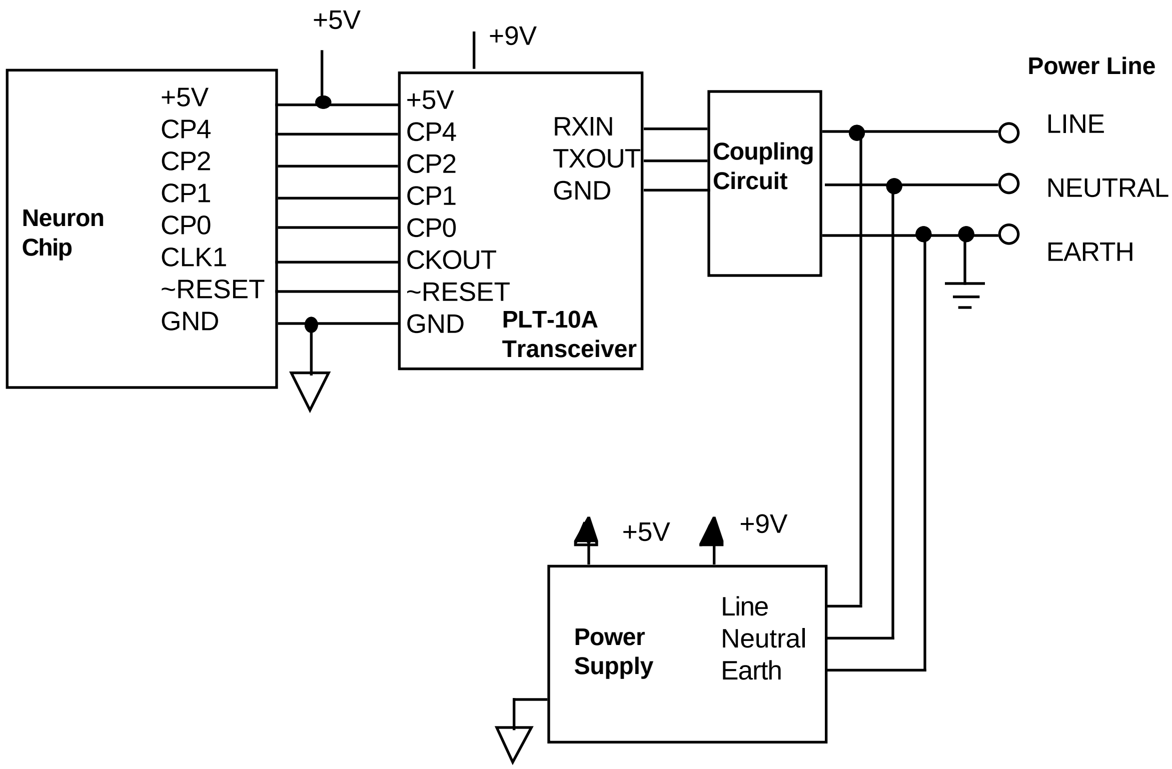


Figure 2.5 PLT-10A Transceiver Circuit

Coupling Circuits

The two methods of coupling to the power line, Line-to-Neutral coupling and Line-to-Earth coupling, define two different power line channels referred to as PL-10(L-N) and PL-10(L-E), respectively. Most installations will consist of only one channel type in order to achieve maximum communication reliability. However, L-N and L-E devices may be mixed within an installation with the possibility of significant loss (2-20dB) of communication margin between L-N and L-E devices depending on physical location and power line environment.

Line-to -Neutral Coupling, PL-10(L-N))

The PL-10(L-N) power line channel specifies coupling circuits that transmit and receive power line communications signals between the Line and Neutral mains conductors. Line-to-Neutral coupling is used in power mains circuits where a ground is not available, or where low ground leakage is required.

Line-to -Earth Coupling, PL-10(L-E))

The PL-10(L-E) power line channel specifies coupling circuits that transmit and receive the power line communications signals between the Line and Earth mains conductors. Line-to-Earth coupling is used in power mains circuits where an Earth conductor is available.

Specific coupling circuits for use with the PLT-10 transceiver are described in the *LONWORKS PLT-10 A Transceiver User's Guide.*

Power Supply Requirements

Most linear power supplies do not load the transmitted signal, nor do they generate significant electrical noise. Switching power supplies may load the transmitted signal or generate significant electrical noise, either of which will limit system performance. The following guidelines must be met to avoid attenuation of the transmit signal and coupling of noise directly into the input of a receiver.

Attenuation

Guideline: *When connecting the input (line side) of a switching power supply directly to the coupling circuit of a PLT-10 A-based device , the guidelines for preventing the switching supply from attenuating the communications signal as outlined in the PLT-10A User's Guide must be followed.*

Noise

Guideline: *When connecting the input (line side) of a switching power supply directly to the coupling circuit of a PLT-10 A-based device , the guidelines for preventing the switching supply from conducting excessive noise onto the communications channel as outlined in the PLT-10A User's Guide must be followed.*

Power Line Communication Using the PL-20(L-N) ,and PL-20(L-E) Channels

Table 2.5 provides a summary of the specifications for the PL-20 power line channels.

Table 2.5 Specifications for PL-20Line-to-Neutral and Line-to-Earth Coupled Power Line Channels

Parameter	***PL-20(L-N)***	***PL-20(L-E)***
Coupling Technique	Line-to-Neutral	Line-to-Earth
Transmission Speed	5kbps	
Transceiver Crystal	10MHz, 200ppm, 13pF, parallel resonant	
Modulation	BPSK	
Frequency Band	125kHz-140kHz	
Output Level	≤ 116dBμV per EN50065-1 for Class 116 EN50065-1 compliance ≥115dBμV per EN50065-1 otherwise	
Output Impedance	|Z|≤6Ω 129kHz-134kHz	|Z|≤8Ω,120VAC |Z|≤15Ω, 240VAC 129kHz-134kHz
Input Impedance*	≥100Ω 125kHz-140kHz	

* Note: Input impedance of PLT-20 and associated coupling circuit only. Does not include effect, if any, of system power supply. See *LONWORKS PLT-20 Transceiver User's Guide.* for guidelines.

Echelon's PLT-20 transceiver is LONMARK-approved for use on the PL-20(L-N) and PL-20(L-E) channels.

Transceiver Interface Specification

Figure 2.6 shows a typical PLT-20 transceiver application block diagram . The coupling circuit and power supply must be selected based on the intended application.

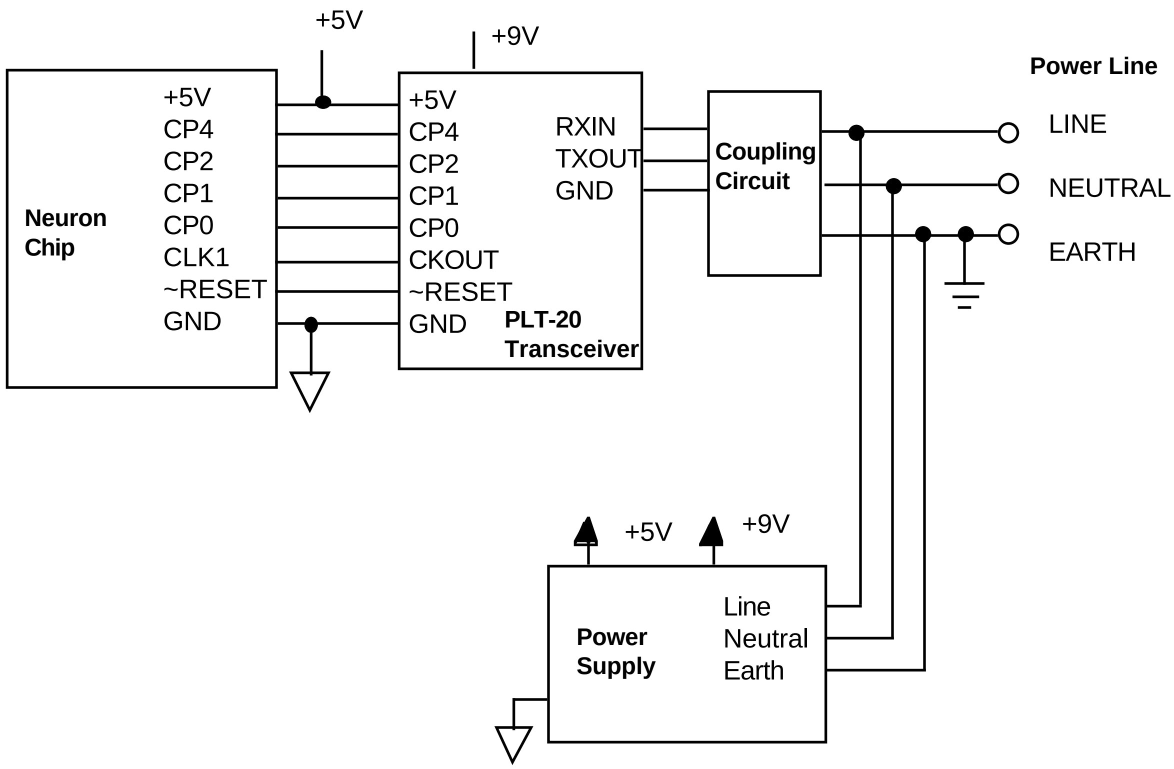


Figure 2.6 PLT- 20 Transceiver Circuit

Coupling Circuits

The two methods of coupling to the power line, Line-to-Neutral coupling and Line-to-Earth coupling, define two different power line channels referred to as PL-20(L-N) and PL-20(L-E), respectively. Most installations will consist of only one channel type in order to achieve maximum communication reliability. However, L-N and L-E devices may be mixed within an installation with the possibility of significant loss (2-20dB) of communication margin between L-N and L-E devices depending on physical location and power line environment.

Line-to -Neutral Coupling, PL-20(L-N))

The PL-20(L-N) power line channel specifies coupling circuits that transmit and receive the power line communications signals between the Line and Neutral mains conductors. Line-to-Neutral coupling is used in power mains circuits where a ground is not available, or where low ground leakage is required.

Line-to -Earth Coupling, PL-20(L-E))

The PL-20(L-E) power line channel specifies coupling circuits that transmit and receive the power line communications signals between the Line and Earth mains conductors. Line-to-Earth coupling is used in power mains circuits where an Earth conductor is available.

Specific coupling circuits for use with the PLT-20 transceiver are described in the *LONWORKS PLT-20Transceiver User's Guide.*

Power Supply Requirements

Most linear power supplies do not load the transmitted signal, nor do they generate significant electrical noise. Switching power supplies may load the transmitted signal or generate significant electrical noise, either of which will limit system performance. The following guidelines must be met to avoid attenuation of the transmit signal and coupling of noise directly into the input of a receiver.

Attenuation

Guideline: *When connecting the input (line side) of a switching power supply directly to the coupling circuit of a PLT-20 based device, the guidelines for preventing the switching supply from attenuating the communications signal as outlined in the PLT-20User's Guide must be followed.*

Noise

Guideline: *When connecting the input (line side) of a switching power supply directly to the coupling circuit of a PLT-20-based device, the guidelines for preventing the switching supply from conducting excessive noise onto the communications channel as outlined in the PLT-20User's Guide must be followed.*

Power Line Communication Using the PL-30(L-N) Channel

Table 2.6 provides a summary of the specifications for the PL-30 power line channel.

Table 2.6 Specifications for PL-30Line-to-Neutral Coupled Power Line Channel

Parameter	***PL-30(L-N)***
Coupling Technique	Line-to-Neutral
Transmission Speed	2kbps
Transceiver Crystal	10MHz, 200ppm, 13pF, parallel resonant
Modulation	Direct sequence spread spectrum, 31 chips-per-bit
Frequency Band	9kHz - 95kHz
Output Level	≥9V peak-to-peak into 50Ω
Input Impedance*	≥75Ω 9kHz-95kHz
Output Impedance	≤6Ω 30kHz-80kHz

* Note: Input impedance of PLT-30 and associated coupling circuit only. Does not include effect, if any, of system power supply. See *LONWORKS PLT-30 Transceiver User's Guide.* for guidelines.

Echelon's PLT-30 transceiver is LONMARK-approved for use on the PL-30(L-N) channel.

Transceiver Interface Specification

Figure 2.7 shows a typical PLT-30 transceiver application block diagram . The coupling circuit and power supply must be selected based on the intended application.

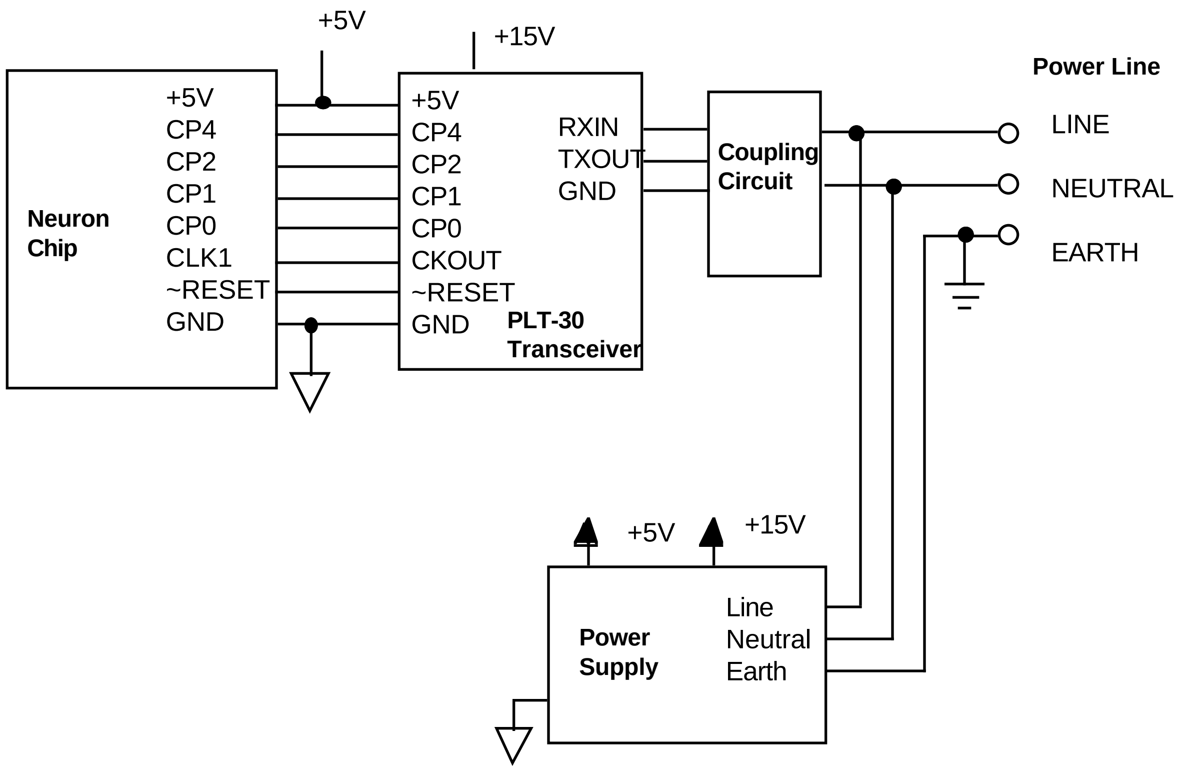


Figure 2.7 PLT-30 Transceiver Interface

Coupling Circuits

Line-to-Neutral coupling has been defined as the power line channel for the PLT-30 transceiver. Line-to-Earth coupling is not defined for the PLT-30 transceiver.

Line-to -Neutral Coupling, PL-30(L-N))

The PL-30(L-N) power line channel specifies coupling circuits that transmit and receive the power line communications signals between the Line and Neutral mains conductors. Specific coupling circuits for use with the PLT-30 transceiver are described in the *LONWORKS PLT-30Transceiver User's Guide.*

Most linear power supplies do not load the transmitted signal, nor do they generate significant electrical noise. Switching power supplies may load the transmitted signal or generate significant electrical noise, either of which will limit system performance. The following guidelines must be met to avoid attenuation of the transmit signal and coupling of noise directly into the input of a receiver.

Attenuation

Guideline: *When connecting the input (line side) of a switching power supply directly to the coupling circuit of a PLT-30-based device , the guidelines for preventing the switching supply from attenuating the communications signal as outlined in the PLT-30User's Guide must be followed.*

Noise

Guideline: *When connecting the input (line side) of a switching power supply directly to the coupling circuit of a PLT-30 based device , the guidelines for preventing the switching supply from conducting excessive noise onto the communications channel as outlined in the PLT-30User's Guide must be followed.*

Free Topology Twisted Pair Transceiver Communication on TP/FT-10 Channels

Overview

The TP/FT-10 channel consists of up to 128 nodes on a single network segment along with a link power source which supplies DC power to the nodes on the network. The channel is specified to support free topology wiring, and will accommodate bus, star, loop, or any combination of these topologies. The total network length and number of nodes may be extended by use of TP/FT-10 channel physical layer repeaters, or LONWORKS routers. The channel data rate is 78,125kbps. The data is transmitted using Differential Manchester encoding, which is polarity insensitive. Nodes can be either locally powered or link powered. A link powered node derives its power from the network.

Performance Specifications

The TP/FT-10 channel supports up to 128 link powered or 64 locally powered nodes at a maximum bit error rate of 1 in 100 000. Both types of nodes can be supported on a given segment, provided that the following constraint is met:

(1 x number of link powered nodes) + (2 x number of locally powered nodes) ≤ 128

Transmission performance varies with the type of network cable used. Network performance has been characterized for several cable types as detailed below. Table 2.7 shows the maximum bus length for a doubly-terminated topology network using various cables.

Table 2.8 shows the maximum node-to-node distance and maximum wire length for a singly-terminated free topology network using various types of cables. The distance from each node to each of the other nodes and to the link power source shall not exceed the maximum node-to-node distance. If multiple paths exist, e.g., a loop topology, then the longest path shall be used for the calculations. The maximum wire length is the total amount of wire connected to a network segment.

Table 2.7: Doubly-Terminated Bus Topology Specifications

Cable*	***Maximum bus length***	***Maximum stub length***	***Units***
Control/Signaling-grade/16AWG (1,3mm)	2200	3	meters
General Purpose-grade/16AWG (1,3mm)	2200	3	
Level 4/22AWG	1150	3	
JY (St) Y 2x2x0.8	750	3	

* Note: Detailed cable specifications provided in Appendix A

Table 2.8: Free Topology Specifications

Cable*	***Maximum node-to-node distance***	***Maximum total wire length***	***Units***
Control/Signaling-grade/16AWG (1,3mm)	500	500	meters
General Purpose-grade/16AWG (1,3mm)	400	500	
Level 4/22AWG	400	500	
JY (St) Y 2x2x0.8	320	500	

* Note: Detailed cable specifications provided in Appendix A

The Echelon FTT-10 transceiver is LONMARK approved for use on the LONMARK TP/FT-10 channel.

Power Specifications

Guideline: The sum of the steady-state power drawn by all nodes on a segment shall not exceed 36.5 watts.

The node power, P, is the maximum steady-state power drawn from the network, in watts. The node distance, d, is the distance of a node from the link power source, in meters. For each branch, the sum of the products of each node's distance multiplied by that node's power shall not exceed a constant:

$$P_1 * d_1 + P_2 * d_2 + P_3 * d_3 + \ldots \leq C * \alpha$$

where

C is a constant, dependent on wire type, taking into account manufacturing tolerance and all other variations except wire temperature:

$C=12.9*10^3$ watts*meters for 16 AWG [1.3mm] cable types

$C=4.9*10^3$ watts*meters for JY (St) Y 2x2x0.8

$C=3.4*10^3$ watts*meters for Level 4/22AWG

$\alpha = 1/(1 + 0.00393*(temp - 25°C))$, accounting for average wire temperature

Environmental Specifications

Guideline: All nodes on an TP/FT-10 channel shall operate normally while meeting the EMC standards detailed in Table 2.9

Table 2.9 EMC Standards

EMI	FCC Part 15 Level B and VDE 0871 Level B
ESD	IEC801-2, Level 4
Radiated Electromagnetic Susceptibility	IEC801-3, Level 2
Fast Transient/ Burst Immunity	IEC801-4, Level 4
Surge Immunity	IEC801-5, Level 1
Transceiver Operating Temperature	-40 to +85˚C
Average Wire Temperature	-40 to +55˚C

Cable

Guideline: *The TP/FT-10 channel performance is characterized for the cables listed in Table 2.10- one of these cables must be used for the network wiring. Cables shall meet specifications outlined in Appendix A. If the cable has a shield, the shield shall be connected to link power source ground via a 470kΩ, 1/4 Watt, ≤ 10%, metal film resistor to prevent static charge build up.*

Table 2.10: Cable Parameters

Cable Type	**Wire dia./AWG**
Control/Signaling-grade/16AWG, single twisted pair, stranded 19/29, unshielded, Tefzel Insulation & Jacket High Temperature - 150°C max.	1.3mm/16
General Purpose-grade/16AWG, single twisted pair, stranded 19/29, unshielded, PVC Insulation & Jacket Medium Temperature - 80°C max.	1.3mm/16
Data -grade, Level 4/22AWG, twisted pair, single or multiple, typically solid & unshielded	0.65mm/22
JY (St) Y 2x2x0.8, 4-wire helical twist, solid, shielded	0.8mm/20.4

Topology

The network may be configured as either a singly-terminated free topology or a doubly-terminated bus topology.

Two network segments may be interconnected with a TP/FT-10 channel physical layer repeater.

Guideline: *No more than one physical layer repeater shall be in a path between two nodes on a network. Physical layer repeaters shall not be interconnected in such a way as to create a loop.*

Cable Termination

Guideline: *A singly-terminated free topology network shall have a single termination provided by the link power source. This termination shall be approximately 53Ω. The link power source and termination may be located at any point in the network.*

Guideline: A doubly-terminated bus topology network shall have two terminators. One terminator shall be provided by the link power source. This termination shall be approximately105Ω. The second termination shall be as shown in Figure 1. One terminator shall be placed at each end of the bus.

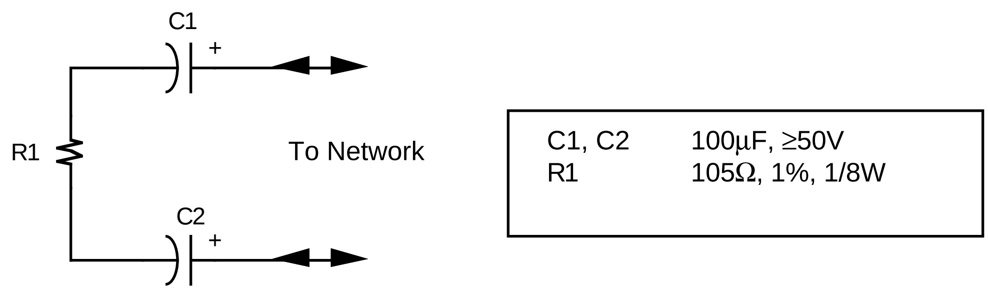


Figure 2.8: Termination

Node Specifications- Link Power

Guideline: A Link Power Unit Load (LPUL) is defined to be 285mW DC drawn from the network. A node may consume multiple Link Power Unit Loads. A maximum of 128 LPUL's is allowed on the network. A link powered node shall meet the requirements of Table 2.11.

Table 2.11: Link Power Requirements

Maximum charge storage per LPUL	4.7	mA-seconds
Application power holdoff minimum delay on network powerup after network voltage exceeds 26V	220	msec
Network voltage over which node shall be operational	26 to 42.4	volts
Maximum network voltage below which node application power is shut off	24	volts

Link Power Source Requirements

The Link Power Source for an TP/FT-10 channel consists of a Coupler together with a Power Supply having special attributes. The requirements for the power supply for proper system operation include its startup behavior, tolerance to direct shorts across its output, and output voltage regulation. These requirements in addition to a schematic for the Coupler is included in Appendix B. The combination coupler/power supply block diagram is shown in the figure below. Any deviations from the Power Supply

requirements and Coupler schematic described herein are allowed provided that the Link Power Source design be electrically equivalent.

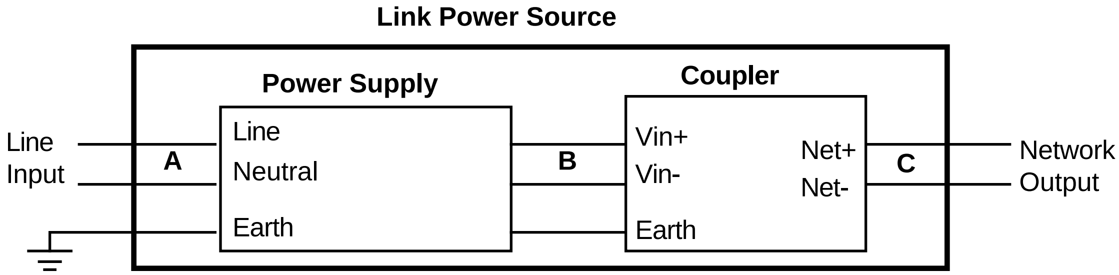


Figure 2.9: Link Power Source

The differential DC output voltage of the Link Power Source must be 41,0 to 42,4VDC over full operating conditions. Under normal (non-fault) conditions, the Link Power Source shall "center" the output voltage with respect to earth ground resulting in +21V and -21V outputs at "Net+" and "Net-" respectively. The Link Power Source shall recover after a continuous direct short across the output and shall properly restart the TP / FT-10 network.

A means for selecting either of two differential AC termination impedances shall be provided - approximately 105Ω for a bus topology termination and approximately 53Ω for a free topology network.

Power Supply Requirements

Power supply requirements are listed in Appendix B.

Transceiver Interface Specifications

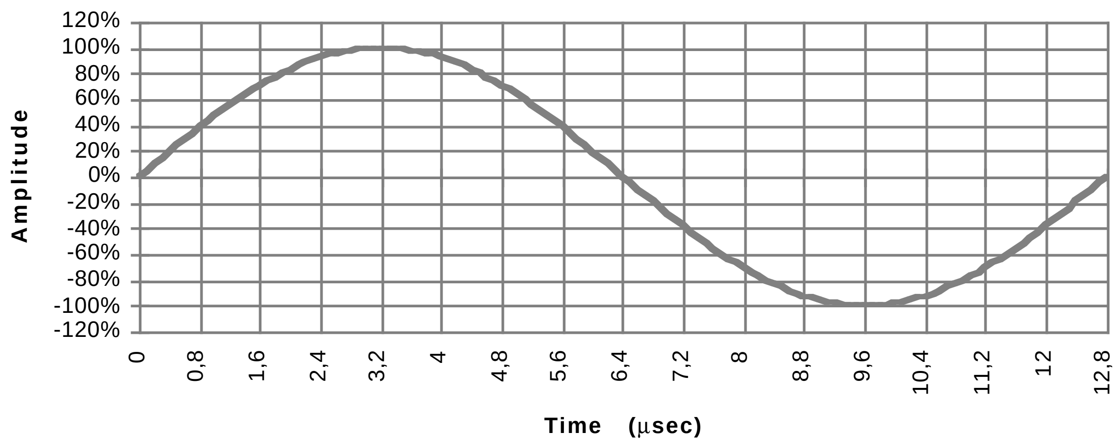
Hot Plugging

Guideline: *A TP/FT-10 node shall sustain no hard failure and start up successfully when plugged into a powered network.*

Transmitter

Guideline: *The transmitter shall employ differential Manchester encoding of data and clock information with a raised cosine waveform as illustrated in figures 6 and 7. The polarity of the transmitted waveforms may be inverted depending on the state of the preceding bit; at the start of transmission, polarity is arbitrary.*

The transmitter peak amplitude (Vp) into a network termination of approximately 53Ω (as defined earlier in the cable termination section) connected directly at the transceiver output shall be between 0.425 and 0.900V over all manufacturing variations and operating conditions. At the end of packet transmission, the waveform shall remain transitionless for at least 3 bit periods after the final clock transition (excepting the final data transition, if present). The net voltage remaining on the transmission line after 8 bit times from the last clock transition shall be no more than that created by transmitting a pulse of either polarity at peak amplitude for one half of a bit time. The delay from the Neuron Chip transmit enable output to the start of transmission on the network shall not exceed 1.125 bit times.



F

Figure 2.10: Idealized Transmit Waveform - Zero Bit

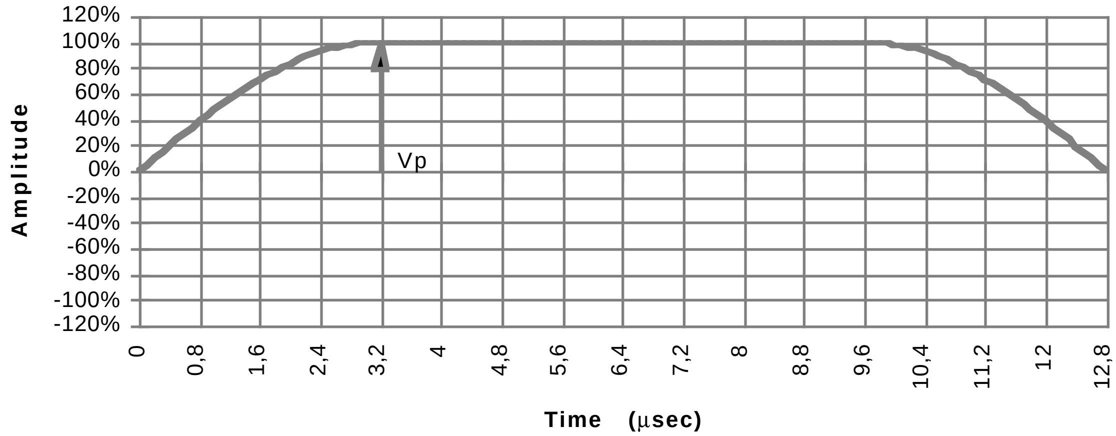
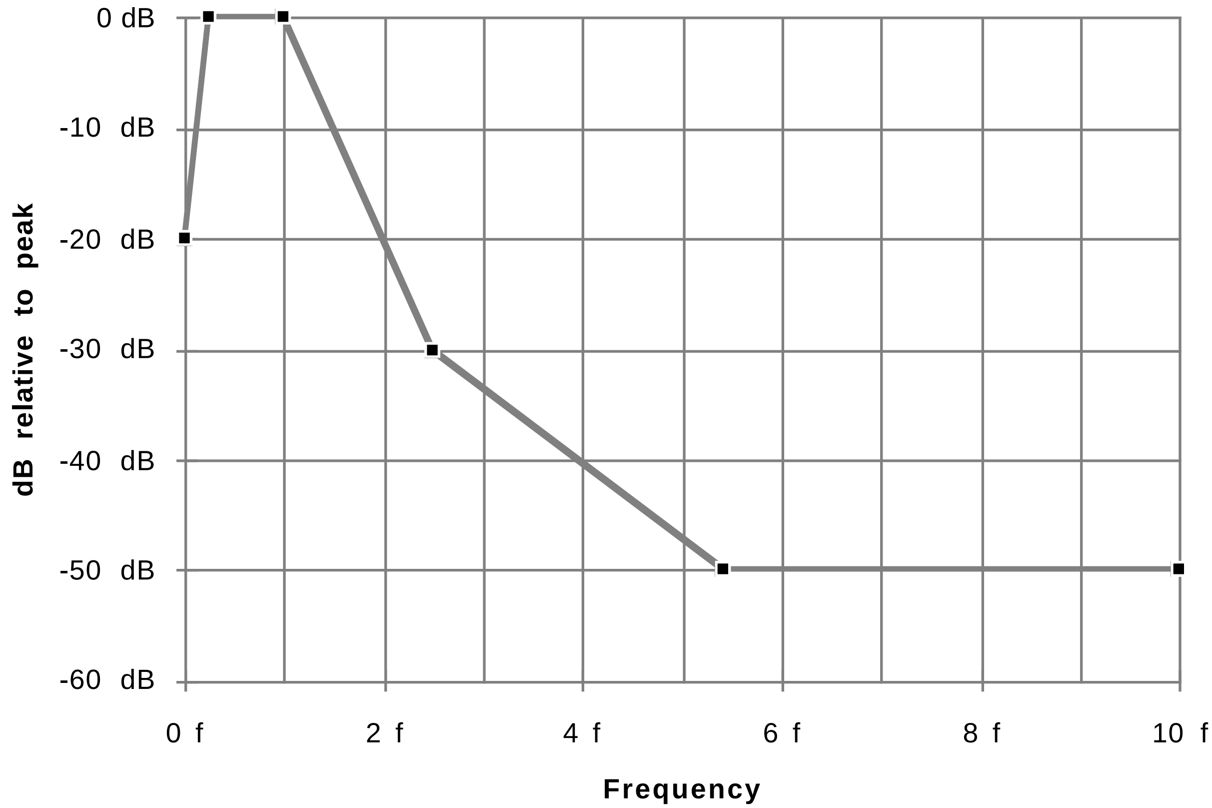


Figure 2.11: Idealized Transmit Waveform - One Bit

Guideline: *The voltage spectrum into a network termination of approximately 53Ω (as defined earlier in the cable termination section) connected directly at the transceiver output shall meet the maximum specification of figure 8 over all manufacturing variations and operating conditions. The data pattern to be used for evaluating the voltage spectrum shall be generated by the CRC polynomial* $X^8 + X^6 + X^5 + X^4 + 1$.



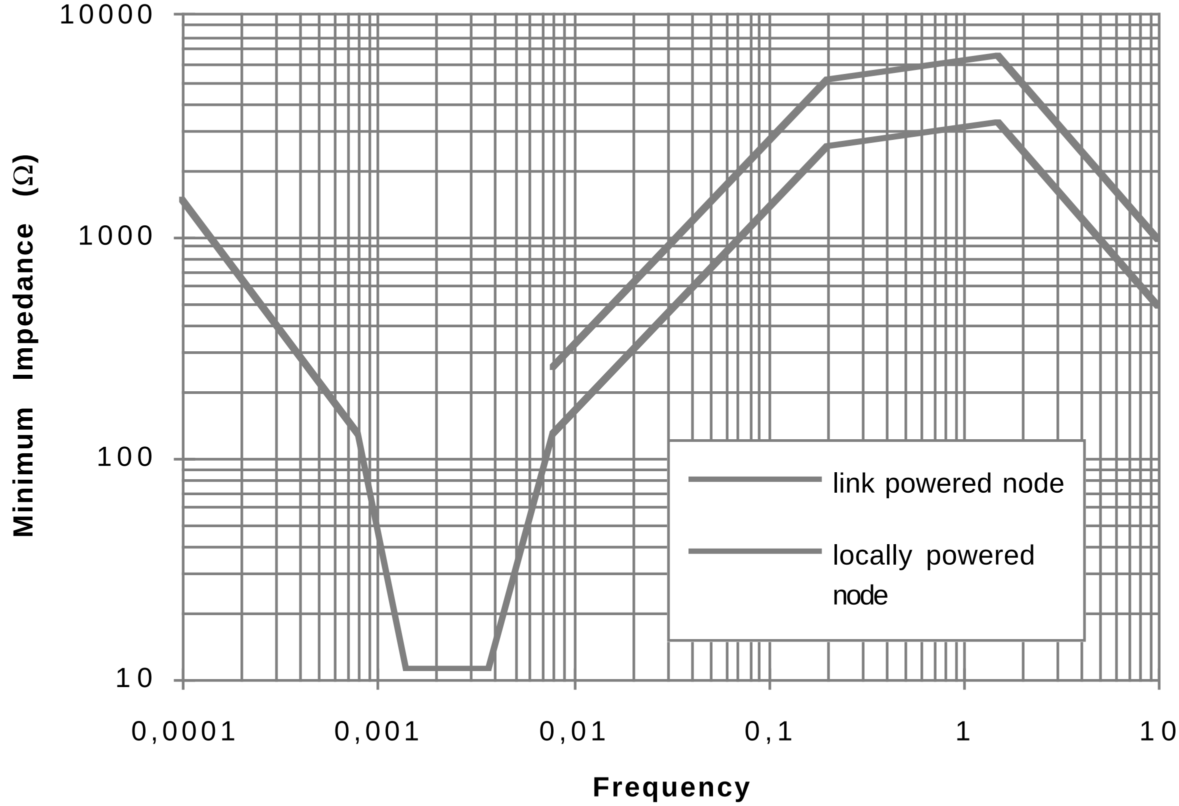
Frequency	Maximum
0 f	-20 dB
0.25 f	0 dB
1.0 f	0 dB
2.5 f	-30 dB
5.4 f	-50 dB
10 f	-50 dB

Figure 2.12: Maximum voltage spectrum over frequency relative to peak

Impedance

Guideline: *A node shall meet the minimum impedance specified in figure 2.13. In link powered nodes, a notch in the impedance specified by figure 2.13 is permitted to allow use of fixed frequency switching regulators. This notch shall be less than 3kΩ in depth, less than 0.25f in width and above 1,6f, where f =*

78.125kHz. During packet transmission, the transmitter impedance shall be a minimum of 2000Ω from 0.1f to 2f.



Frequency	link powered node	locally powered node
0.0001f	na	1460
0.0008f	na	129
0.0014f	na	11
0.0037f	na	11
0.0080f	258	129
0.2f	5080	2540
1.5f	6500	3250
10.0f	975	488

Figure 2.13: Minimum Impedance -- Receive or Power-down modes

Receiver

Guideline: *The receiver shall ensure reception of data by the Neuron Chip under all conditions allowed by the TP/FT-10 system and node specifications .*

The transceiver communicates with the Neuron Chip in single-ended mode. In single-ended mode, the communications port encodes transmitted data and decodes received data using Differential Manchester coding (also known as bi-phase space coding). This scheme provides a transition at the beginning of every bit period for the purpose of synchronizing the receiver clock, referred to as the *clock transition*. Zero / one data are indicated by the presence or absence of a second transition (the *data transition*) halfway between clock transitions. A mid-cell transition indicates a 0. Lack of a mid-cell transition indicates a 1. Figure 2.14 below shows a typical packet where T is the bit period, equal to 1 / (bit rate). Note that clock transitions occur at the beginning of a bit period, and, therefore, the last valid bit in the packet does not have a trailing clock edge.

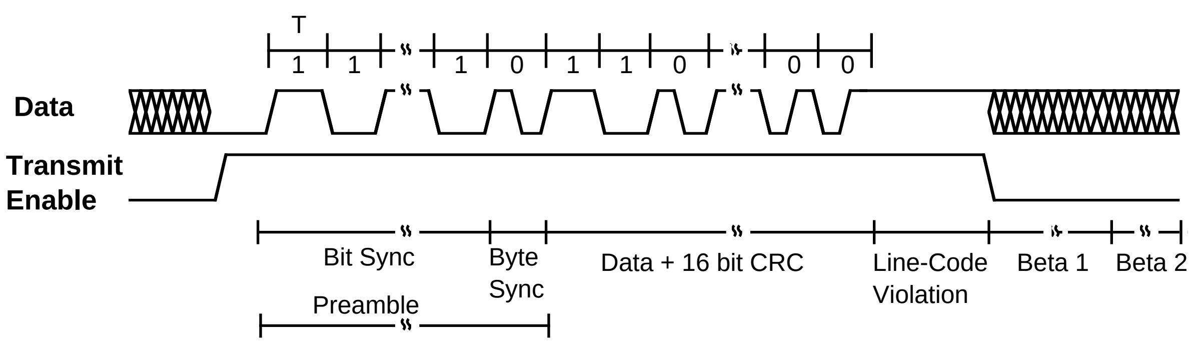


Figure 2.14: Single-ended mode data format

Before beginning to transmit the packet, the transmitting Neuron Chip initializes the output data pin to start low. It then asserts the Transmit Enable pin (CP2); this ensures that the first transition in the packet is from low to high. This first transition occurs within 1 bit time of asserting Transmit Enable, and marks the beginning of the packet. Note that Transmit Enable and Data Output are actively driven at all times in single-ended mode.

The transmitter transmits a *preamble* at the beginning of a packet to allow the other nodes to synchronize their receiver clocks. The preamble consists of a bit-sync field and a byte-sync field. The bit-sync field is a series of Differential Manchester 1's; its duration is user selectable and is at least six bits long. The byte-sync field is a single bit Differential Manchester 0 that marks the end of the preamble, and the beginning of the first byte of the packet.

The Neuron Chip terminates the packet by forcing a Differential Manchester line-code violation; i.e., it holds the data output transitionless long enough for the receiver to recognize an invalid code that signals the end of transmission. The data output can be

either high or low for the duration of the line-code violation, depending on the state of the data output after transmitting the last bit. The line-code violation begins after the end of the last CRC bit and lasts for at least 2 bit times. Note that the last bit does not have a trailing clock edge, so the data output actually remains transitionless for at least 2-1/2 bit times. The Transmit Enable pin is held active until the end of the line-code violation, and is then released.

In order for the receiver to detect the edge transitions, two windows are set up for each bit period, T. The first window is set at T/2 and determines if a 0 is being received. The second window is at T and defines a 1. This transition then sets up the next two windows (T/2 and T). If no transition occurs, a Manchester code violation is detected and the packet is assumed to have ended. Table 2.13 shows the width of this window as a function of the ratio of the Neuron Chip input clock (MHz) and the network bit rate (Mbps) selected. If a transition falls outside of either window, it is not detected and the packet will contain errors. The receiving Neuron Chip detects these errors and reports a bad packet. Timing instability of the transitions, known as jitter, may be caused by changes in the communications medium, or instability in the transmitting or receiving nodes' input clocks. The jitter tolerance windows are expressed as fractions of the bit period, T, in Table 2.13.

Table 2.13: Receiver jitter tolerance and line-code violation windows

Neuron Chip Input Clock	***Next Data Edge***			***Next Clock Edge***			***Line-Code Violation to Receive***
	Min	*Nominal*	*Max*	*Min*	*Nominal*	*Max*	*Min*
5MHz	0.330T	0.500T	0.702T	0.830T	1.000T	1.170T	1.46T
10MHz	0.323T	0.500T	0.695T	0.823T	1.000T	1.177T	1.46T

For the receiver to reliably terminate reception of a packet, the received line-code violation period must have no transitions until the Neuron Chip detects the end of the packet. The receiving Neuron Chip terminates a packet if no clock transitions are detected after the last bit. Table 2.13 shows the minimum duration from the last clock edge to where the Neuron Chip is guaranteed to recognize the line-code violation. Note that data transitions are allowed in this period (and must fall within the data window).

Radio Frequency Communication on RF-100 channels

Overview

The LONMARK RF-100 channel uses the UK MPT1329, FCC Part 90, European ETS 300220 or Australian radio bands, with a raw data rate of 4.883 kbps.

Performance Specification

Table 2.14 provides a summary of the performance specifications for the RF-100 radio-frequency channel.

Table 2.14 Performance Specification for the RF-100 Channel

Performance Specification	**RF-100 Channel**
Transmission Speed	4.883 kbps
Neuron Interface	Single ended - full implementation including sleep mode. No collision detection.
Power Supply Voltage	Nominal 5 V DC ± 10%
Power Supply Current	Transmit - 95mA Sleep Mode - <100 µA
Topology	Free topology within usable range
Effective Radiated Power	Nominally 10mW with approved off-board antenna. 300 µW with on-board antenna.
Antenna Impedance	50 ohms
Temperature - operating and non-operating	-20 deg C to +55 deg C
Modulation	Frequency shift keying: ± 4.5 kHz ± 10%
Carrier Stability	< ± 2.5 kHz

Table 2.14 Performance Specification for the RF-100 Channel

Performance Specification	RF-100 Channel
Sensitivity	12dB SINAD sensitivity = -118dBm (typical) Sensitivity for 1/250 BER typically -114dBm
Frequencies of Operation and Radio Regulations	CEPT - Conforms to ETS 300 220 433.075 MHz - 433.850 MHz, 434.000 MHz - 434.775 MHz. (64 channels @ 25KHz spacing) UK - Conforms to MPT 1329 458.525 MHz - 458.775 MHz (11 channels @ 25KHz spacing) USA - Conforms to FCC Part 90 464.075 - 464.850 MHz, 465.100 to 465.875 MHz (64 channels @ 25 KHz spacing) Australia - Conforms to RCL 1993/1 472.025 - 472.100 MHz (4 channels at 25 KHz spacing)
Electrostatic Discharge Performance	A product incorporating the DTR 100 must be capable of passing the test required to obtain CE mark.
Switching Time	Rx-Tx turnaround time is approximately 2 msec. This is the time taken for the transmitter to switch from 'receive' to 'transmit', to start transmitting data, and for another node to start receiving data. 'Receive end delay' is approximately 1 bit (0.2 msec). This is the propagation delay between the data being sent to the transmitter and being obtained from the receiver. Tx-Rx turnaround time is approximately 2 msec. This is the time taken for the transmitter to stop transmitting, and the receiver to be in a position to start receiving a packet.

Note: The above range of frequencies of operation and channel spacing relate to regulatory requirements in those countries. Additional frequencies will be added in due course.

The Multitone DTR100 is LONMARK approved for use on the RF-100 channel.

Using the Multitone DTR-100, data is communicated via a 6-way HE14 PCB header and the RF connection is a SMB jack.

Table 2.15 Pin Connections for the Multitone HE14 PCB header

Pin 1	TX Enable
Pin 2	RX Enable
Pin 3	RX Data
Pin 4	Sleep
Pin 5	5V
Pin 6	0V

The communication parameters for the RF-100 channel are listed in Table 2.16

Table 2.16 Communications parameters for the RF-100 channel

Comm mode	Single-ended
Comm rate	4.883 Kbps
Num priorities	0
Min clock rate	5 MHz
Average packet size	15
Osc accuracy	200 ppm
Osc wakeup	0 μsec
Collision detect	No
Bit sync threshold	4 bits
Receive start delay	0 bits
Receive end delay	0 bits
Indeterminate delay	0 bits
Minimum interpacket	0 bits
Turnaround time	0 μsec
Missed preamble	15 bits
Use raw data	No
Raw data clock rate	5 MHz

For a 5 MHz Neuron chip these communication parameters result in the hexadecimal parameter string of '5F 10 07 00 06'.

3

Layers 2-6

In addition to having the appropriate transceiver connected to the communication port of the Neuron Chip, there must be appropriate channel settings present in the memory of the Neuron Chip to enable the LonTalk protocol to send out messages in the correct format to allow interoperability. Compliance with the guidelines for Layers 2-6 of the LonTalk protocol is easily accomplished by making selections within the LonBuilder software and via *pragma* statements in the Neuron C application code.

Layer 2

Channel Parameters

The Neuron Chip communications port supports a number of configurable parameters. These parameters govern the low-level communication characteristics. On each communications channel, a unique combination of settings provides optimum communications. The collections of settings used for a particular physical communication medium is called the medium's channel parameter.

The Neuron Chip communications port used in direct mode encodes and decodes data using Differential Manchester or bi-phase space coding. A *preamble* is transmitted at the beginning of a packet to allow the other nodes to synchronize their receiver clocks. An idle period called the *beta 1* time is provided after each packet to allow nodes on a channel to synchronize to the end of a packet. Another important characteristic of a message is the *beta 2* time, which defines the width of the randomizing slots. The lengths of the *preamble*, *beta 1* and *beta 2* times are configurable by the LONWORKS designer independently of the transceiver design. In order for a set of nodes to interoperate, the "channel parameters" that control the *preamble*, *beta 1*, and *beta 2* times must match. For more information about channel parameters see the *LonTalk Protocol* engineering bulletin.

Guideline: To be interoperable, all of the nodes on a channel must be configured with the same channel parameters and the parameters must be for one of the standard transceiver types.

The channel parameters corresponding to each of the standard transceiver choices are shown in table 3-1. The correct channel parameters are automatically loaded by selecting the appropriate standard transceiver type on the `Channel Create` screen of the LonBuilder system.

Table 3.1 Channel Parameters

Channel	*Communi-cations Port Mode*	*Comm Rate*	*Default Number of Priority Slots*	*Minimum Clock Rate (MHz)*	*Oscillator Accuracy*	*Average Packet Size*
TP-RS485-39	Single-ended	39 Kbps	4	5	200 ppm	15 bytes
TP/XF-78	Differential	78 kbps	4	5	200 ppm	15 bytes
TP/XF-1250	Differential	1.25 Mbps	16	10	200 ppm	15 bytes
TP/FT-10	Single-ended	78 Kbps	4	5	200 ppm	15 bytes
PL-10 (L-E)	Special purpose	10 Kbps	8	5	200 ppm	15 bytes
PL-20 (L-N)	Special purpose	5 Kbps	8	1.25	200 ppm	15 bytes
PL-20 (L-E)	Special purpose	5 Kbps	8	1.25	200 ppm	15 bytes
PL-30 (L-N)	Special purpose	2 Kbps	8	5	200 ppm	15 bytes
RF-100*	Single-ended	4.883 Kbps	0	5	200 ppm	15 bytes

* Refer to the RF-100 section of chapter 2 for the detailed communication parameter settings for the RF-100 channel

Guideline: Minimum acceptable clock rate is indicated in table 3-1.

The LONTALK protocol supports interworking of nodes running at different clock speeds by lengthening the preamble to accommodate the slowest node. However, there is a penalty on network throughput associated with nodes running at slower speeds. This network performance penalty is shared by all nodes on the channel even by the nodes whose clocks run at the maximum clock speed of 10MHz. In order to provide some flexibility but also sustain good network performance, all interoperable nodes must adhere to the minimum clock speed values indicated in table 3-1.

Guideline: An oscillator with an accuracy of 0.02% or better must be used.

The oscillator accuracy directly affects the throughput of a physical channel by affecting the width of the priority and randomizing slots that may be supported. The accuracy of the oscillator has the largest effect on network throughput of all of the parameters discussed. In order to not degrade network throughput and also to support a reasonable number of priority slots per channel, all interoperable nodes must include an oscillator with an accuracy of at least 0.02% over the complete temperature range within which the node is operated. This means that crystals must be used rather than ceramic resonators.

Guideline: The default number of priority slots must be configured as shown in table 3.1.

All nodes sharing the same physical channel must be configured with the same number of supported priority slots so that they can reliably exchange messages. Each priority time slot on a channel adds a minimum of two bit times to the transmission of every message. The amount of overhead associated with priority messaging varies based upon the data rate and oscillator accuracy and transceiver characteristics of nodes on the channel.

The LonTalk protocol permits a developer or user to optionally allocate priority time slots on a channel to nodes. The network management tool that assigns priority slots to individual nodes can ensure that one and only one node is assigned to a particular priority slot on the channel. Because there is no contention for the medium during the priority portion of a packet cycle, nodes configured with priority have better response time than non-priority nodes when the channel is heavily utilized.

The number of default priority slots is kept small to minimize effects on throughput, but may be increased at installation time by a network management tool. By requiring a higher accuracy oscillator, the effect of each priority slot on throughput is also minimized.

Guideline: Application nodes must not use priority slot 1, it is reserved for use by network management tools.

Network Buffers

The network I/O buffer sizes are configurable within the application program on a node via the use of Neuron C pragmas. There are three buffer sizes and counts to configure: network output buffers, network output priority buffers, and network input buffers.

Guideline: Network input buffers must be at least 66 bytes.

The network input buffers must be at least 66 bytes to allow the node to receive all network management messages.

Guideline: Network output buffers must be sized to accommodate the longest packet that the node can send.

Network output buffers must be large enough to send the longest packet that the node application can generate. However, a minimum size is required to support all network management responses. This length includes not only the application information, but also the worst case addressing overhead for the packet. The formula calculation is in table 6-1 of the *Neuron C Programmer's Guide.*

Guideline: Priority network output buffers are necessary if the product can send priority messages or network variables.

Network output priority buffers are needed if the node can be installed to use priority messaging. The same sizing and count rules apply for priority buffers as for ordinary network output buffers. By using the `nonpriority nonconfig` declaration for network variables, and by not setting the priority field for explicit messages, you can ensure that no priority can be assigned on a node. In that case, priority network output buffers are not needed.

Layer 4

Guideline: The receive transaction buffer pool must be sized to the LonBuilder minimum default or greater. The formula for the default is given in table 6-1 of the Neuron C Programmer's Guide.

Guideline: Acknowledged or Request/Response service is not permitted for packets requiring a network output buffer greater than 66 bytes.

Acknowledged or Request / Response service is not permitted when the packet to be sent requires a network output buffer greater than 66 bytes. The reason for this is that all nodes on a channel must receive every message in order to maintain the correct estimate of the channel backlog. If an incoming message is longer than the network input buffer allocated to hold it, the message will fail CRC and will be discarded prior to extracting the backlog information from it. Since unacknowledged packets always have a backlog increment of zero, there is no problem sending longer packets using one of the unacknowledged services provided by the LonTalk protocol.

All nodes must use unacknowledged protocol services when transmitting packets that require output buffers longer than 66 bytes.

Appendix A

Cable Requirements for the TP/FT-10 channel

This appendix provides details of the cable requirements for use on the LONMARK TP/FT-10 channel.

Cable Requirements

Table A.1: Control / Signaling-grade / 16AWG (1,3mm) cable specification

D-C Resistance (Ohms/km at 20°C) loop maximum	28,2
Mutual Capacitance of a Pair (nF/km) maximum	58
Impedance (Ohms at 1,0MHz) nominal	95
Pair twists per meter nominal	20

Table A.2: General Purpose-grade / 16AWG (1,3mm) cable specification

D-C Resistance (Ohms/km at 20°C) loop maximum	28,2
Mutual Capacitance of a Pair (nF/km) maximum	74
Impedance (Ohms at 1,0MHz) nominal	100
Pair twists per meter minimum	20

Table A.3: Level 4 / 22 AWG (0,65mm) cable specification

D-C Resistance (Ohms/km at 20°C) loop maximum	118
D-C Resistance Unbalance (percent) maximum	5
Mutual Capacitance of a Pair (nF/km) maximum	56
Pair-to-Ground Capacitance Unbalance (nF/km) maximum	3,28
Impedance (Ohms)	
772kHz	102±15% (87-117)
1,0MHz	100±15% (85-115)
4,0MHz	100±15% (85-115)
8,0MHz	100±15% (85-115)
10,0MHz	100±15% (85-115)
16,0MHz	100±15% (85-115)
20,0MHz	100±15% (85-115)
Attenuation (dB/km at 20°C) maximum	
772kHz	15
1,0MHz	18
4,0MHz	36
8,0MHz	49
10,0MHz	56
16,0MHz	72
20,0MHz	79

Worst-Pair Near-End Crosstalk (dB) minimum. Values are shown for information only. The minimum NEXT coupling loss for any pair combination at room temperature is to be greater than the value determined using the formula NEXT (F_{MHz})>NEXT(0,772)-15$_{log10}$(F_{MHz}/0,772) for all frequencies in the range of 0,772MHz-20MHz for a length of 305 meters.	
772kHz	58
1,0MHz	56
4,0MHz	47
8,0MHz	42
10,0MHz	41
16,0MHz	38
20,0MHz	36

Table A.4: JY (St) Y 2x2x0.8 cable specification

Wire Pair	Red/ Black
D-C Resistance (Ohms/km at 20°C) loop maximum	74,0
Mutual Capacitance of a Pair (nF/km) maximum	100
Pair twists per meter minimum	5
Other specifications	per DIN VDE 0815

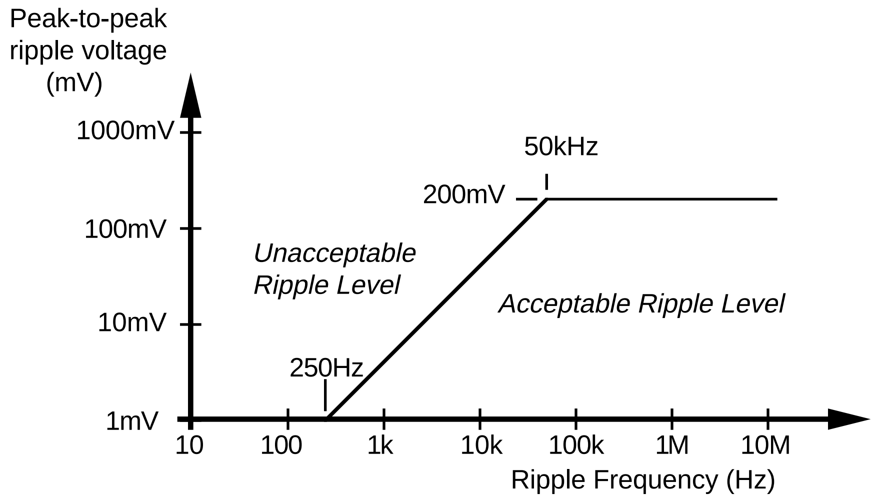


Figure B-1 Power Supply Output Ripple Voltage Requirement

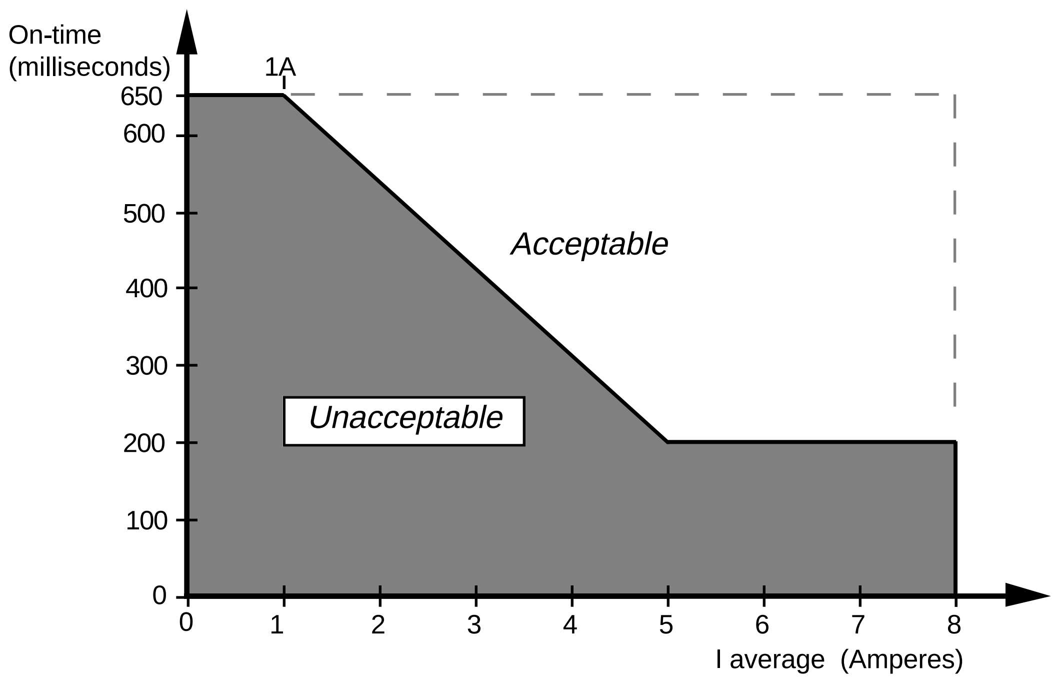


Figure B-2: Power Supply Startup Interval Behavior

Notes and definitions for figure B-2:

•On-time is defined as the time for the source power supply to charge the network from 0V to 42VDC for a given average output current.

•$I_{average}$ is the average output current available from the source power supply when charging the network from 0V to 42VDC. Once the output voltage has reached 42V, the output current capability must be at least 1,5 amperes.

Passive Coupler Circuit Schematic

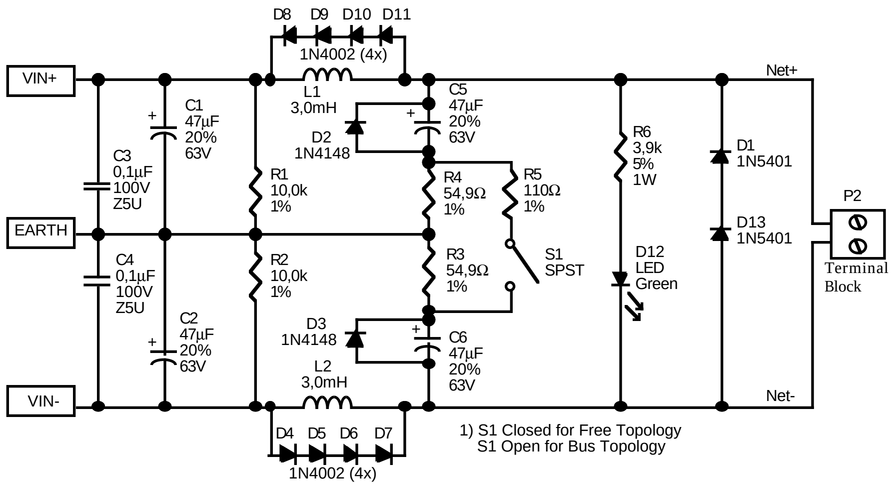


Figure B-3: Passive Coupler Circuit

Table B-3- Coupler Circuit Bill of Materials

Item	Quantity	Reference	Description
1	4	C1, C2, C5, C6	Capacitor, Aluminum Electrolytic, 47µF, 20%, 63V
2	2	C3, C4	Capacitor, Ceramic, 0,1µF, 100V, Z5U
3	2	D1, D13	Diode, 1N5401, 3 ampere, 100V
4	2	D2, D3	Diode, 1N4148 or equivalent
5	8	D4, D5, D6, D7, D8, D9, D10, D11	Diode, 1N4002, 1 ampere, 100V
6	1	D12	LED, Green, Hewlett Packard HLMP-3502 or equivalent
7	2	L1, L2	Inductor, 3,0mH, Ferrite Core, 1,5 ampere, RDC≤0,36Ω,
8	1	P2	Terminal block, 2 conductor, accepts conductor size AWG 24 - 14 (0,5mm - 2,05mm)
9	2	R1, R2	10,0kΩ, 1%, 1/4W
10	2	R3, R4	54,9Ω, 1%, 1/4W
11	1	R5	110Ω, 1%, 1/4W
12	1	R6	3,9kΩ, 5%, 1W
13	1	S1	Switch, SPST or equivalent jumper