Centralized Commercial Building Applications with the LONWORKS® PLT-21 Power Line Transceiver

April 1997 LONWORKS Engineering Bulletin

Introduction

This engineering bulletin describes the use of the PLT-21 Power Line Transceiver in commercial monitoring and control systems, and discusses how to implement a field-proven, robust network architecture that can be applied worldwide. This architecture uses a twisted pair back-bone to broadcast signals from a central monitoring location. The twisted pair extends the effective communication distance of the power line communications signal and bypasses any distribution transformers that would otherwise block power line communication signals. Twisted pair-to-power line routers located at selected mains distribution panels then pass communication signals to the nodes via the power mains. Each router is equipped with a PLA-21 Power Line Amplifier, which boosts the level of the PLT-21 transceiver signal to overcome signal injection losses associated with multiple phase signaling at the mains circuit breaker panels. Examples that include both North American and European buildings are discussed.

Centralized Monitoring and Control Applications

In a centralized monitoring and control application all of the supervisory functions are performed by a "central" node such as a computer. Two-way communications are implemented between the central device and the remote nodes that need to be monitored and controlled: communications are not required between the remote nodes.

Figure 1 illustrates the electrical wiring of a typical commercial building in North America. It is common to find multiple distribution transformers in commercial and industrial buildings in North America. These distribution transformers step down the 3-phase 277VAC (used primarily for overhead lighting and high power equipment) to 120VAC required by electrical appliances. The distribution of a relatively low voltage (120VAC) requires heavier gauge wiring for a given load. The trade-off between the cost of additional distribution transformers and the cost of heavier gauge wiring generally favors multiple distribution transformers in larger buildings. These distribution transformers typically block power line communication signals from passing between their primary and secondary windings.

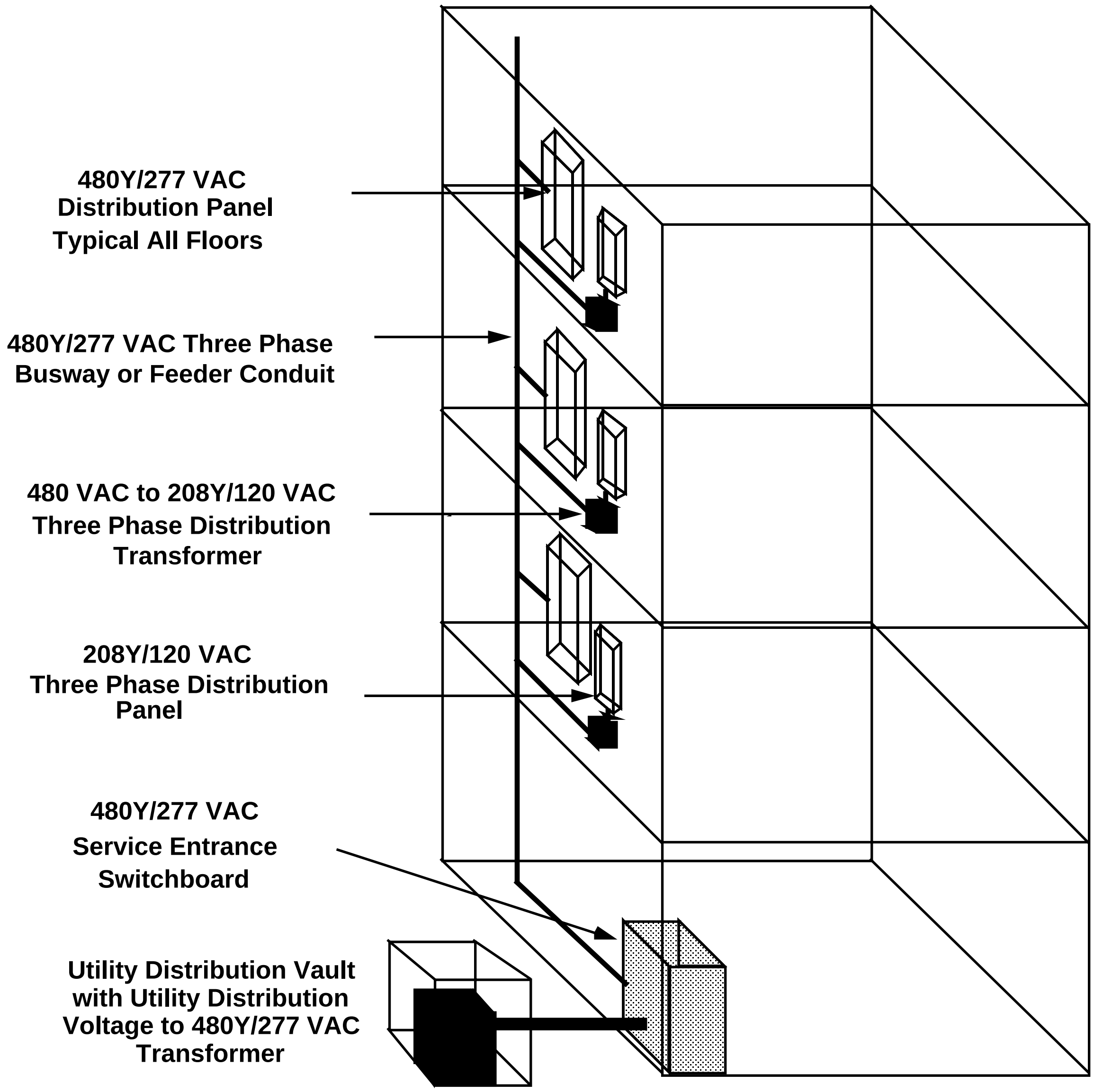


Figure 1 Electrical Wiring in a Typical North American Commercial Building

An exception to this power distribution model occurs in some larger, densely populated cities in North America. In some cases the 120VAC outputs of multiple distribution transformers are connected together in a below-ground grid which services multiple buildings. As will be described below, this situation resembles common European power distribution practices.

With the exception of large, multi-floor facilities, most commercial and industrial buildings in Europe do not utilize multiple distribution transformers. This is largely due to the higher distribution voltage (typically 230VAC) used within buildings. It is not uncommon for two or more smaller European buildings to share the same distribution transformer. Figure 2 illustrates a common European wiring example. If the application is a large, multi-floor European building, refer to figure 1.

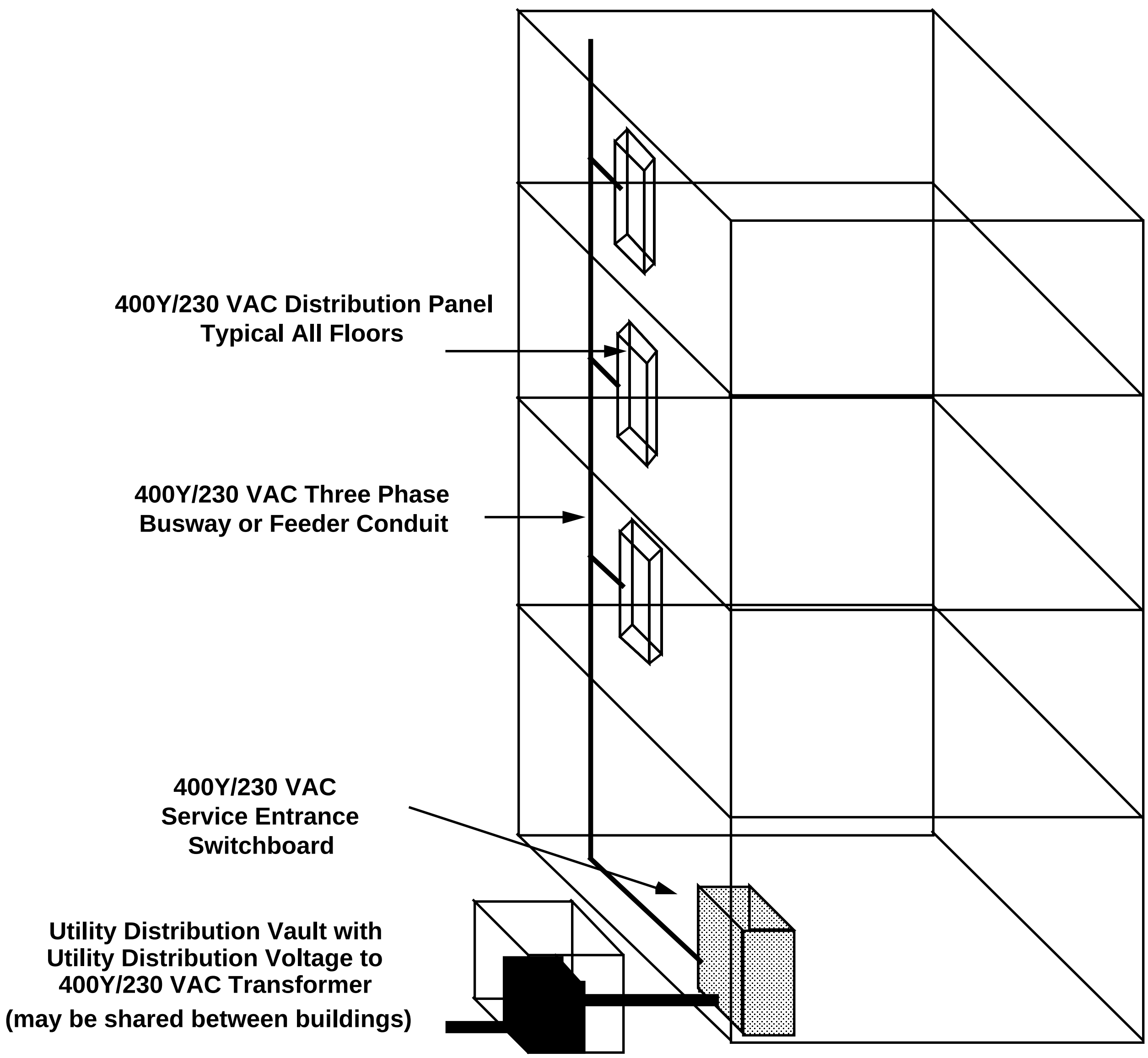


Figure 2 Electrical Wiring in a Typical European Commercial Building

Safety agency regulations differ between North America and Europe with regard to ground or earth fault detectors, and this affects the method of power line signal coupling employed in a building. When considering communications between any two points, the signal-to-noise ratio at the receiver is typically 10-20dB better with Line-to-Earth coupling than with Line-to-Neutral coupling (see the *LONWORKS PLT-21 Power Line Transceiver User's Guide* for details). North American buildings generally incorporate a single high-current Ground Fault Protector (GFP), also referred to as a Ground Fault Interrupter (GFI), which is shared between multiple branch circuits. These high current GFPs have trip points of many amperes and are not affected by a few milli-amperes of ground leakage current produced by a Line-to-Earth coupling circuit. In North America, low current (4-6mA) Ground Fault Circuit Interrupters (GFCIs) are typically only required in wet areas such as kitchens and rest rooms.

In many European countries individual low-current fault detectors (referred to as Residual Current Devices or RCDs) are installed on each separate branch circuit. The use of low-current RCDs on individual branch circuits makes the use of Line-to-Earth coupling problematic in Europe, in spite of the performance benefits of Line-to-Earth coupling. Some European countries prohibit the use of Line-to-Earth coupling and require all power line communication systems to use Line-to-Neutral coupling circuits. The net result is a shorter effective power line communication signal propagation distance for European applications in which Line-to-Earth coupling is prohibited or impractical.

Figures 3 and 4 illustrate the details of wiring in North American and European buildings.

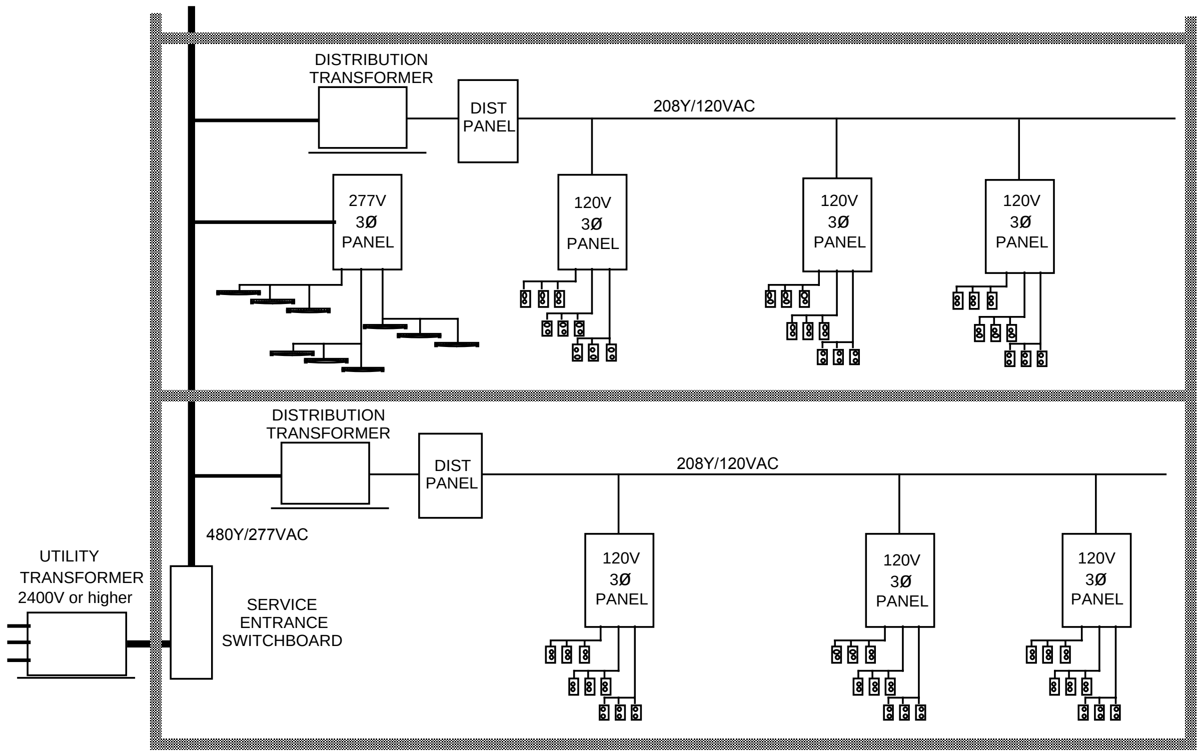


Figure 3 Electrical Wiring Detail in a Typical North American Commercial Building

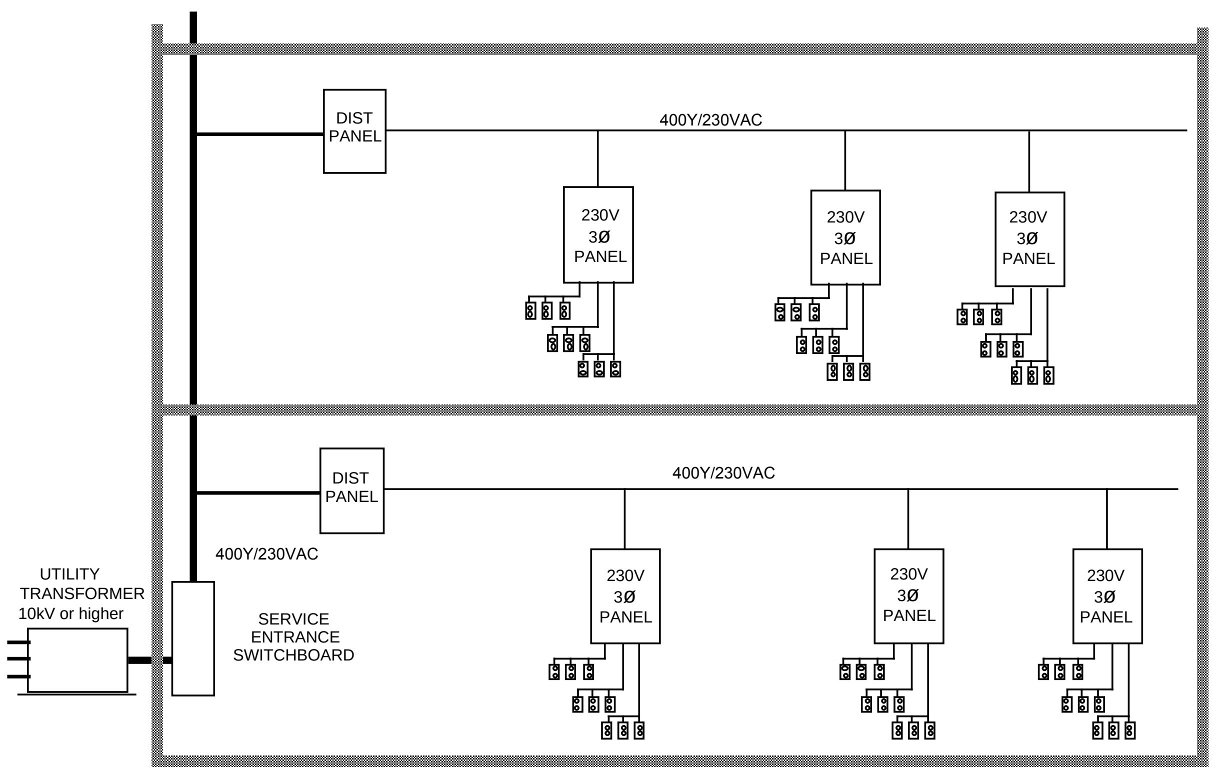


Figure 4 Electrical Wiring Detail in a Typical European Commercial Building

LONWORKS Centralized Monitoring and Control Architecture

A LONWORKS centralized monitoring and control architecture in North American installations consists of a twisted pair backbone originating at the central node, and twisted pair-to-power line routers located as near as possible to each distribution transformer. The twisted pair backbone serves to extend the effective communication distance of the power line transceivers and to bypass any distribution transformers that would block power line communications signals.

The routers convert network traffic between the twisted pair backbone and the power line channel that services the PLT-21 transceiver-based nodes that are to be monitored and controlled. In order to circumvent attenuation of the PLT-21 transceiver's power line signal by distribution transformers, at least one router must be used per distribution transformer. It is recommended that these routers be connected at the main distribution panel associated with each transformer. By installing a router near the distribution transformer, the router is placed at the hub of the branch circuits supplied by the distribution transformer. This configuration maximizes the probability that the router can communicate with any node connected to the mains supplied by the distribution transformer.

In North American installations with Line-to-Earth coupling and multiple distribution transformers, the use of one router per distribution transformer usually allows all nodes to be controlled and monitored from the central location. However, there can be exceptions where a node cannot be “heard” by the single router associated with a distribution transformer. Usually these nodes cannot be “heard” because of signal attenuation caused by physical distance from the router or high background noise. In both cases an additional router connected to a distribution panel located closer to the remote nodes may be required. It is recommended that site testing be performed using the PLCA-21 Power Line Communications Analyzers prior to system installation to confirm adequate communication margin for a given router installation plan.

In European installations the number and placement of routers is chosen based on building topology and characterization of the building using PLCA-21 Power Line Communications Analyzers. One router per building floor is a reasonable starting point when planning an installation, but this must be confirmed with on-site testing. The number of routers required will be greater for a European installation employing Line-to-Neutral coupling than for a similarly sized North American installation employing Line-to-Earth coupling.

Figures 5 and 6 present the recommended electrical wiring topology for North American and European buildings, respectively.

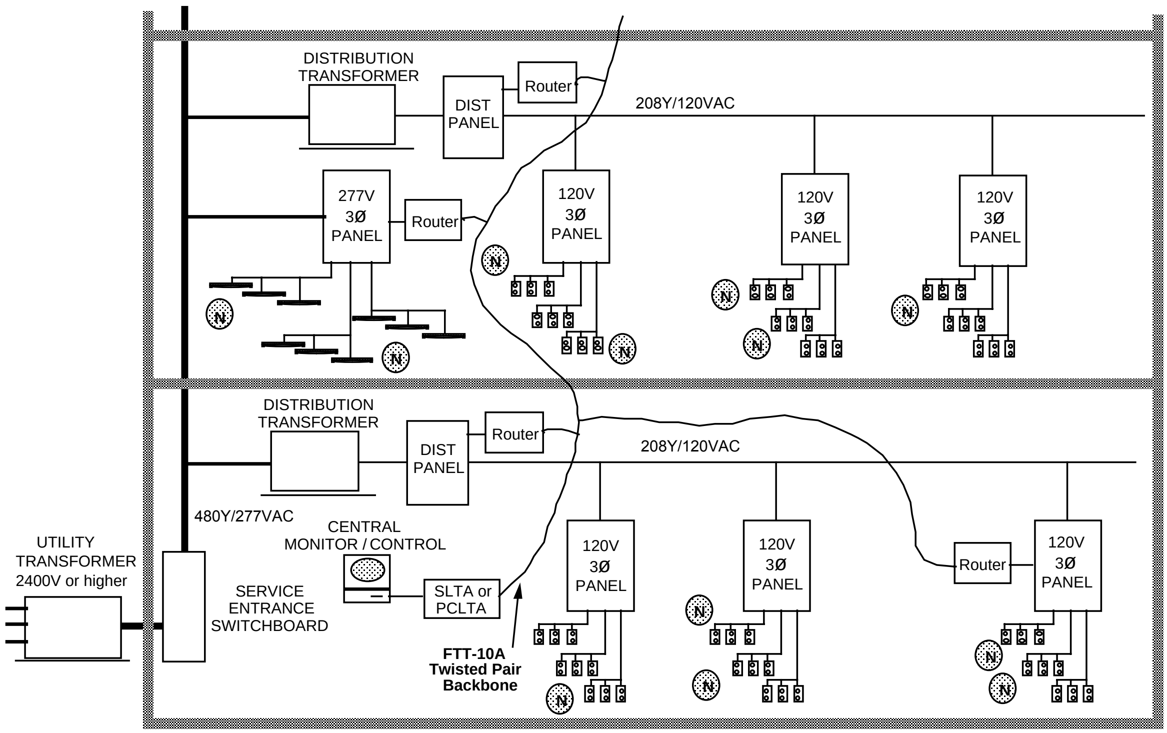


Figure 5 A North American Commercial Building Retrofitted with a LONWORKS Monitoring and Control System

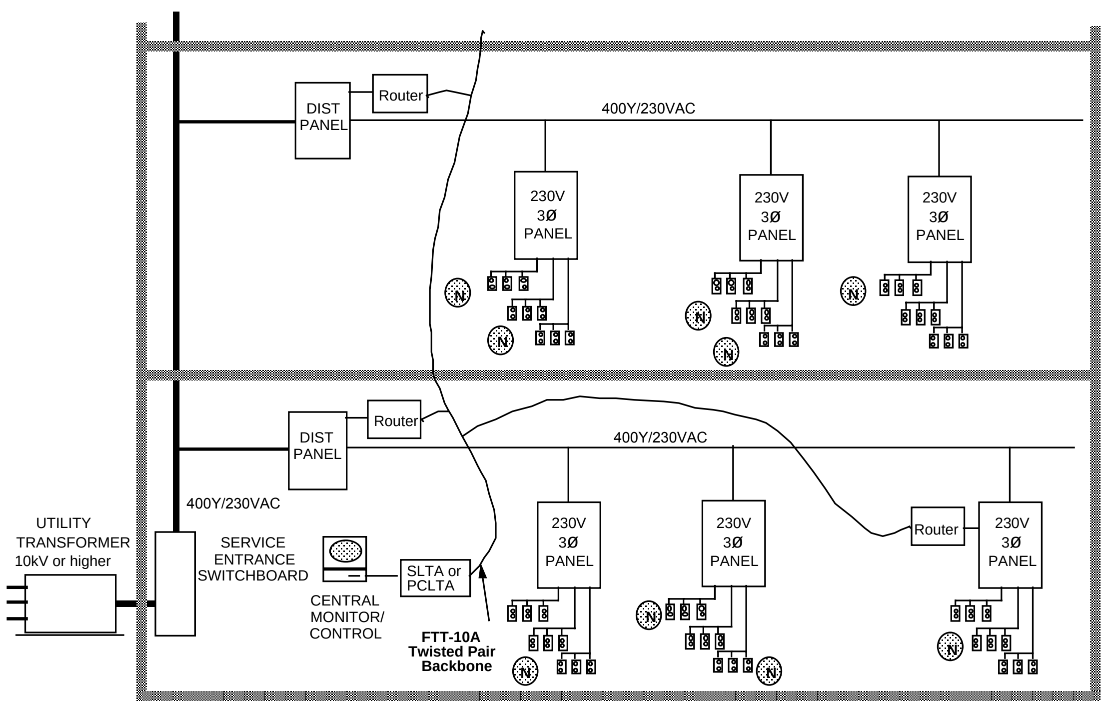


Figure 6 A European Commercial Building Retrofitted with a LONWORKS Monitoring and Control System

Implementing the Twisted Pair-to-Power Line Router

In addition to extending the physical size of a network, routers are frequently used to manage network traffic by forwarding only those packets that, by virtue of their address, must be sent across the router. Power line signaling presents a particular challenge in the area of traffic routing. Signals from PLT-21 transceivers can travel along unanticipated pathways, such as adjacent AC mains that are inductively coupled, and reach channels that were thought to be logically isolated by a router. Such a pathway could create a communications loop in which a signal would be passed continuously between routers on two different channels. A signal loop would dramatically reduce channel throughput since the offending packet would cycle continuously between routers until a collision finally destroys it.

This situation can be avoided by ensuring that all twisted pair-to-power line routers installed on potentially common (inductively coupled) power segments are configured identically. Routers configured to connect the same two channels with identical routing tables are referred to as “redundant configured routers”. A network management tool may define redundant routers by simply connecting two channels with multiple routers (in the same domain) or it could require explicit identification of routers as redundant. Multiple subnets may then be used to support installations of up to 32,258 nodes on the single power line channel (254 subnets x 127 nodes per subnet).

In general, all of the power line-to-twisted pair routers installed in any one North American building must be configured identically. In Europe this requirement extends to all of the twisted pair-to-power line routers serviced by a common distribution transformer—whether or not they are all within one building. While redundant configured routers forward all power line traffic to the central monitoring station via the twisted pair channel, they do not pass these messages back to the other redundantly serviced power line segments. The use of redundant configured routers forces the power line wiring serviced by each redundantly configured group to become a single power line channel to prevent looping of broadcast (e.g., Service Pin) messages. Thus while redundant configured routers do address the requirements of control monitoring applications, they do not support peer-to-peer traffic between weakly coupled power line segments.

In order to maximize the effectiveness of each router, two sources of communication signal loss should be addressed: cross phase signal loss and signal injection loss at low impedance locations. Signal losses occur when a power line signal must cross from one electrical phase to another, i.e., when the signal must pass between phases in a three phase electrical distribution system. These losses occur due to the isolating effects of the distribution transformer’s secondary windings at the communication frequency of the PLT-21 transceiver. Signal losses of 10-30dB while crossing phases are not uncommon. To offset the cross-phase signal loss phenomenon, the power line side of the routers should be coupled simultaneously to all three power phases at the electrical distribution panels.

Signal injection loss occurs when coupling the power line communication signal into points which are low impedance at the communication frequency of the PLT-21 transceiver. The placement of routers at distribution panels is ideal in that it couples the power line signal at a central point in the power wiring, however, the central point is often a very low impedance point due to the parallel combination of impedances of the multiple branch circuits. When compared with signal injection at locations somewhat distant from distribution panels, additional unwanted signal injection loss on the order of 6-12dB can occur at distribution panels. In addition, asymmetries in both noise and attenuation can make it difficult for a node distant from a router to "hear" the router even while the router can easily hear the distant node. To overcome these asymmetries, all power line routers should incorporate a PLA-21 Power Line Amplifier in order to boost the transceiver's transmit signal from 7Vp-p and 1Ap-p to 10Vp-p and 2Ap-p.

European power line applications are governed by CENELEC EN50065-1 which defines the maximum allowable signal level. Resistor R_{gain} in figure A1 (in Appendix A) allows the user to set the PLA-21 amplifier signal level. See the *PLA-21 Power Line Amplifier Specification and User's Guide* (078-0161-01A) for amplifier signal level details. Where permitted by local regulation, R_{gain} should be chosen for 10Vp-p operation. Otherwise, choose R_{gain} to comply with applicable signal level regulations.

The most straightforward implementation of a twisted pair-to-power line router combines an Echelon RTR-10 Router Core Module together with an FTT-10A transceiver, a PLT-21 transceiver, and a PLA-21 amplifier. RTR-10-based routers with different transceiver options are available from many third party sources: see the *Off-the-shelf LONWORKS Transceivers, Gateway, I/O Modules and 3rd Party OEM Products* document and the LONWORKS *Resource Directory* for more information.

Figure 7 shows the functional blocks that comprise a twisted pair-to-power line router suitable for central control and monitoring applications.

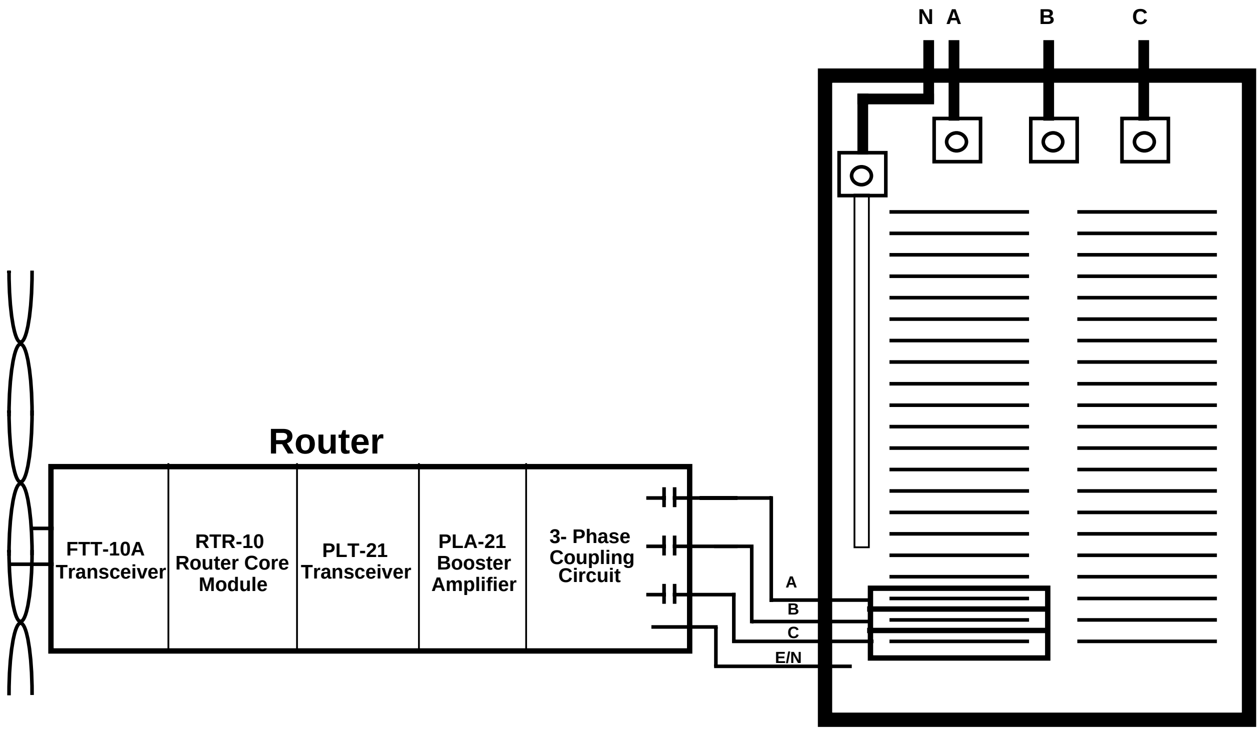


Figure 7 Twisted Pair-to-Power Line Router

Details of the components shown can be found in the respective User's Guides. Details of the three phase coupling circuit - including schematics, a parts list, and parts vendors - are presented in Appendix A.

Central Control and Monitoring Node

All of the supervisory functions in a centralized monitoring and control system are performed by a central node. Figure 8 presents an overview of a system that uses a computer and network interface as the central node. In a typical LONWORKS system, the monitoring software is typically either an Echelon LCA or DDE server-based client, or a custom host application. The network interface is typically an Echelon Serial LonTalk Adapter (SLTA/2, SLTA-10), PC LonTalk Adapter (PCLTA, PCLTA-10, PCNSI), PCMCIA adapter (PCC-10), or PC Network Services Server (PCNSS), equipped with a network services interface for LNS applications. A 78kbps TP/FT-10 free topology channel is best suited for the backbone because its free topology feature can easily accommodate most installation scenarios; a 1.25Mbps TP/XF-1250 channel also may be used if additional bandwidth is required.

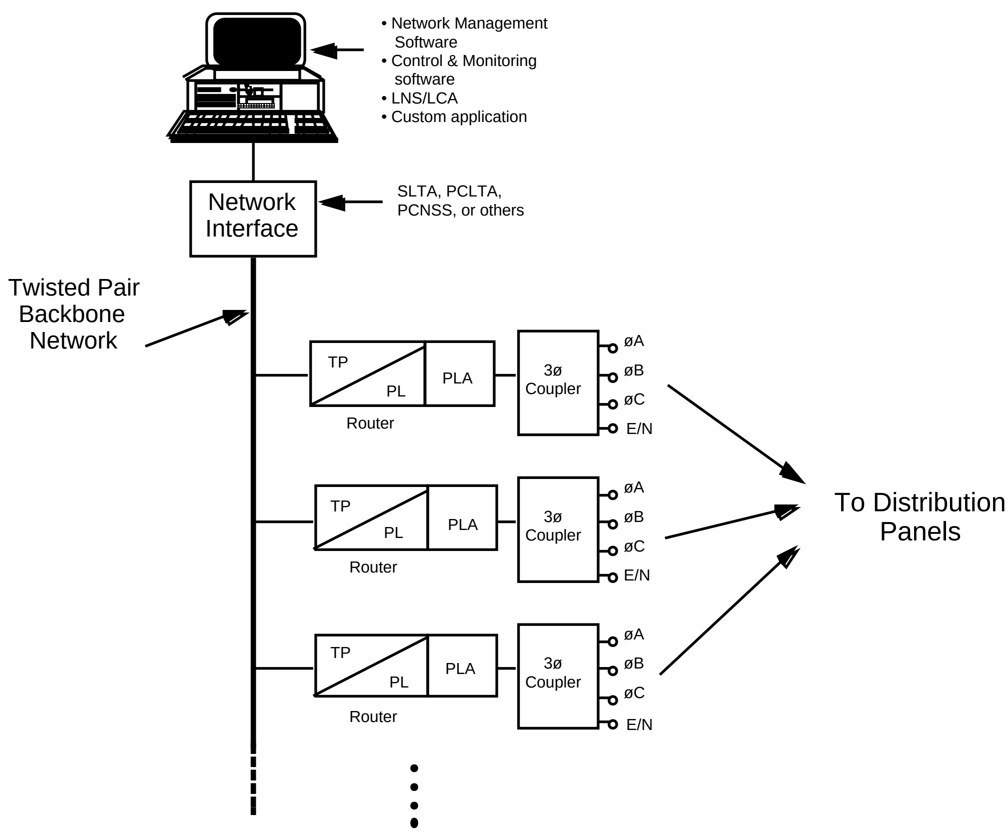


Figure 8 LONWORKS Central Node

Expansion to Multiple Building Networks

In many instances a centralized monitoring scenario must be extended to include multiple buildings, all of which are controlled by a central node. Figure 9 illustrates the layout of a five-building commercial complex.

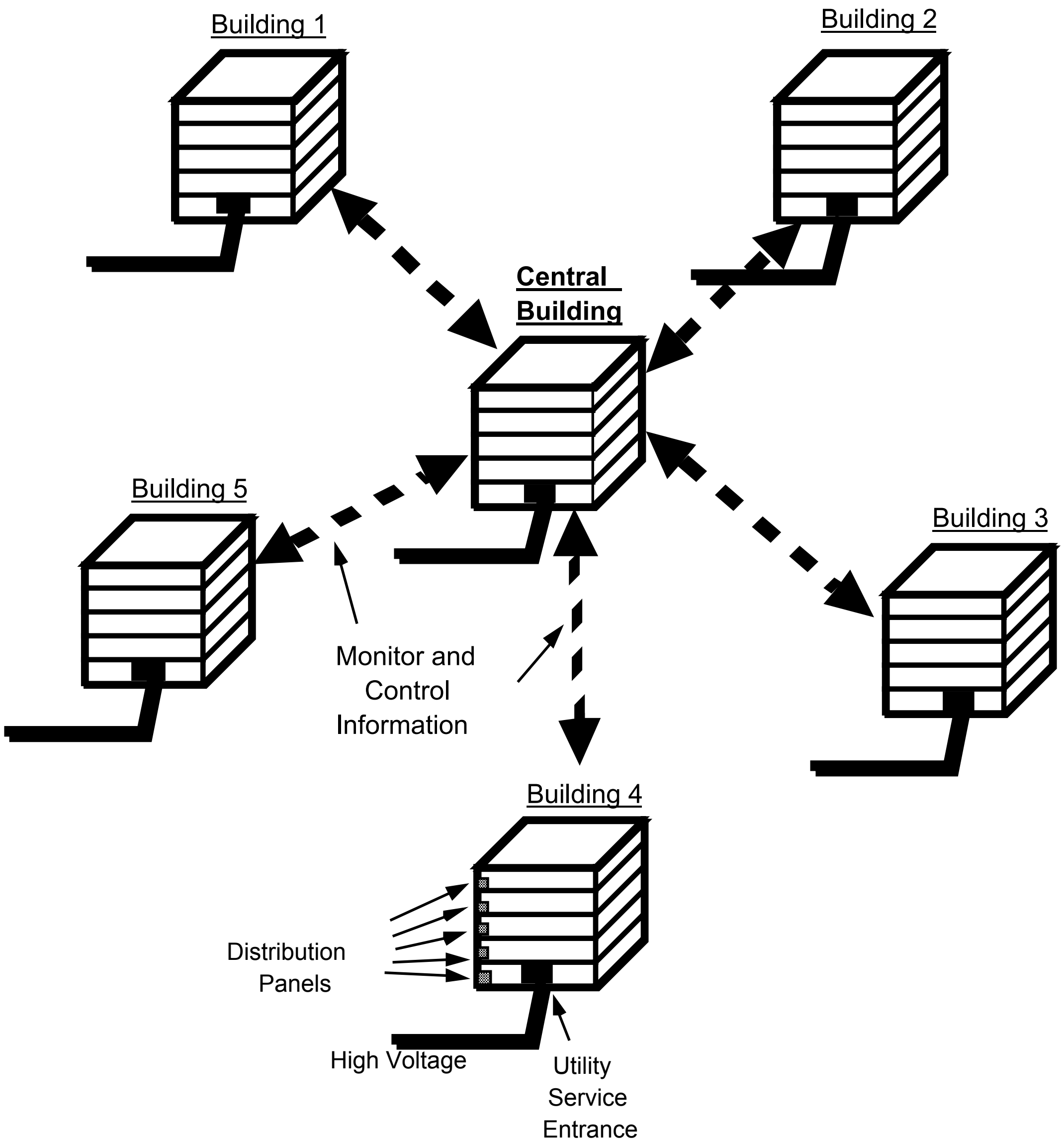


Figure 9 A Typical Commercial North American Building Complex

Commercial complexes with multiple buildings require a slightly more complex monitoring and control architecture due to the distances between buildings. By using a *separate* twisted pair and router in the central building to connect to each remote building, the main backbone from the central node is partitioned into secondary backbones. Each remote building then follows the same architecture discussed earlier for a single building. Figure 10 presents an overview of the secondary backbones. Figure 11 presents a detailed view of the central and remote nodes, including both main and secondary backbone routers and cabling.

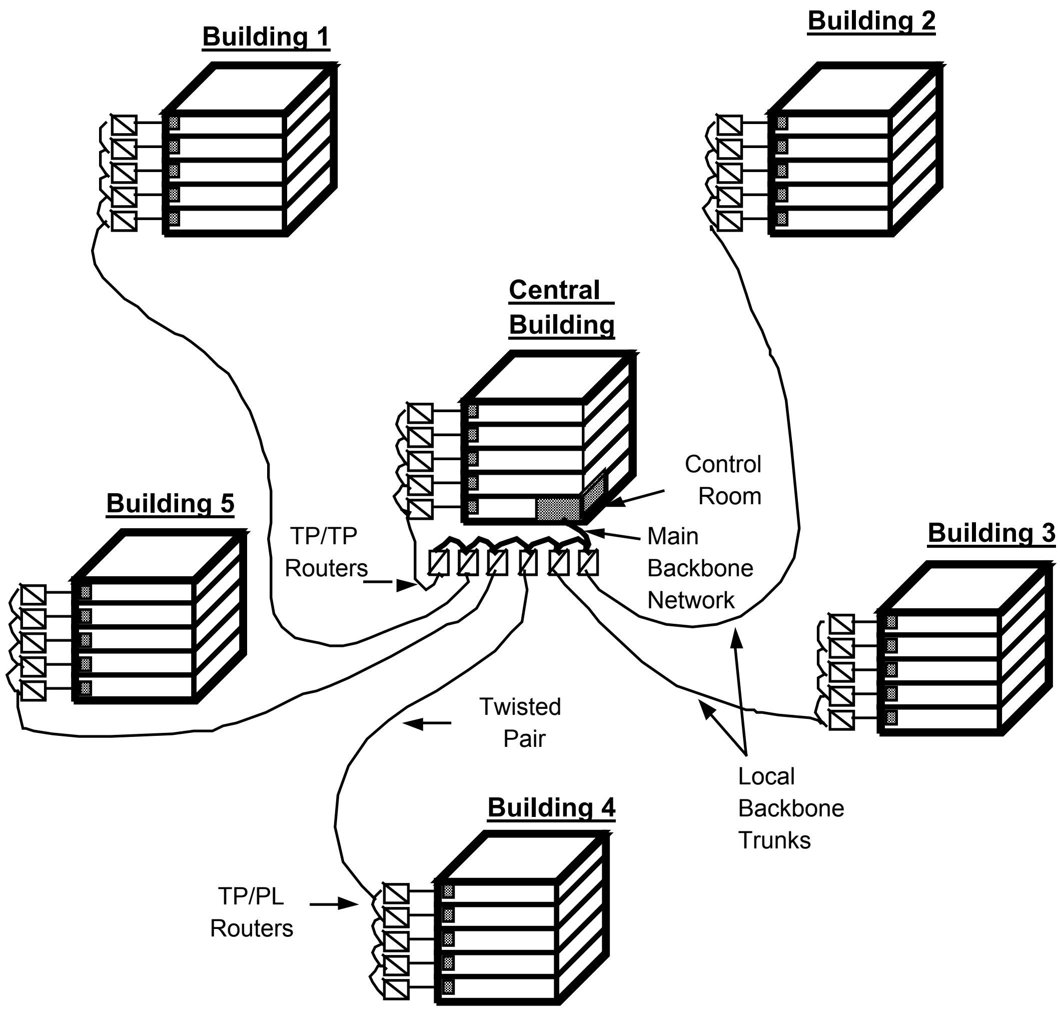


Figure 10 Overview of Secondary Backbones

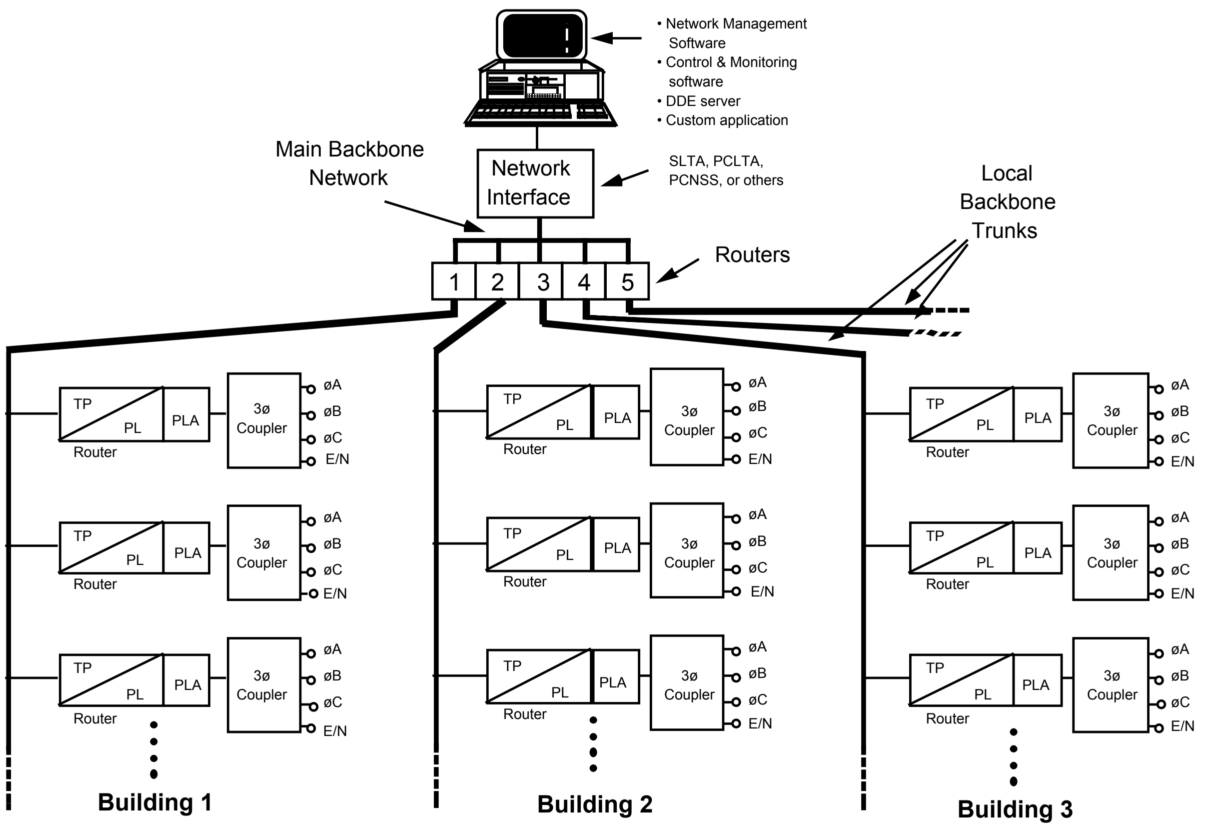


Figure 10 Detailed View of the Central and Remote Nodes with Both Main and Secondary Backbone Routers (for clarity only three buildings are shown)

The medium chosen for the main backbone network and the local backbone trunks should be able to satisfy the throughput requirements of the overall system. Generally, the main backbone channel should have high throughput capability, such as is provided by a TP/FT-10 or TP/XF-1250 channel. As mentioned earlier, the local backbone trunks are typically best served by a 78kbps TP/FT-10 free topology channel.

Both the main and secondary backbones can be easily extended to accommodate building additions or changes through the use of additional routers. Routers are available both from Echelon and from third-party manufacturers (see the Echelon bulletin *Off-the-shelf LONWORKS Transceivers, Gateway, I/O Modules and 3rd Party OEM Products*). Note that in North America the twisted pair-to-twisted pair routers numbered 1-5 in figure 10 are installed as configured routers, *not* as redundant configured routers. In this case, each twisted pair segment on the lower (building) side of the routers is defined as a separate channel. Only the twisted pair-to-power line routers are installed as groups of configured redundant routers with each potentially common (i.e., inductively coupled) group being identically configured.

In Europe, all of the twisted pair-to-twisted pair routers which are serviced by common distribution transformers must also be configured identically.

Guidelines for Optimizing Performance

Obtaining optimum performance in a centralized monitoring and control system requires careful design and planning. While every application is unique, here are some general guidelines which provide a starting point for planning a field installation:

1. Obtain an electrical wiring layout of the building(s). This should help identify the physical wiring of the building(s), the location of any transformers, and the size and location of electrical distribution panels.
2. Determine the location of the central monitoring and control node. Plot the location of the main and secondary backbone(s) to establish the optimum location of the routers and identify any unusual noise sources or wiring conditions that may impair communications. This is accomplished by testing representative locations at the site with PLCA-21 Power Line Communications Analyzers, ensuring that reliable power line communications are possible between the location of the routers and the nodes (see the *LONWORKS PLCA-21 Power Line Communications Analyzer User's Guide* for details). Testing will also provide an opportunity to verify the physical locations of transformers and electrical distribution panels vis-à-vis the site electrical wiring plan.
3. Select the proper channel type(s) for the main and secondary twisted pair network(s).

Once the survey has been completed the following guidelines will simplify the task of installing the monitoring and control network:

1. Use a network management tool to define a database for the site. The database contains a list of all of the nodes and routers throughout the site. It is important to follow a consistent naming convention for the nodes to simplify installation and reduce the possibility of programming errors. If bindings are required, define them with the network management tool.
2. Load the application image of each device at the factory. The nodes should all be in an *unconfigured* state prior to installation. This simplifies the installation process by allowing a network management tool to query the network for unconfigured (uninstalled) devices. In addition, starting the system installation with all of the devices in an unconfigured state allows the installer(s) to easily identify as yet uninstalled devices by looking for flashing service LED indicators.
3. Configure each group of twisted pair-to-power line routers which potentially share a common path as redundant configured routers to eliminate the possibility of packet looping.

4. Physically install the nodes throughout the building. Prior to configuring all of the nodes in the system, perform a quick communication test on each device by pressing its service pin and either observing a packet detect LED on a known good installed node or by observing the packet LED on a PLCA-21 analyzer. (This functionality test will not verify the full communication performance between the installed node and the central monitoring station as this requires more extensive testing.)
5. Use a LonManager® Protocol Analyzer to ensure that network traffic does not exceed 70% of channel capacity if connections are bound such that network traffic is initiated by individual nodes (as opposed to a polled system where network traffic is initiated by a central node which polls remote nodes). For master/slave polled communication, traffic may safely approach 100% of channel capacity.

Troubleshooting

The architecture described in this document is designed to optimize power line signaling in commercial building applications. Occasionally, however, impairments may be present which can disrupt communications and for which some additional action is required. These impairments, together with the recommended corrective action, are listed below. Most of the impairments described can be identified with Echelon's PLCA-21 Power Line Communications Analyzer (model 57010-02). Details of how to use the PLCA-21 analyzer are described in the *PLCA-21 Power Line Communications Analyzer User's Guide.*

In addition, the service switch/LED and the Packet Detect LED on the devices being installed can be useful diagnostic tools. Since a valid incoming LonTalk packet causes the PKD LED of a power line-based node to blink, observing this LED while the service switch on a remote device is pressed can provide a quick pass-or-fail test of both the node electronics and the communication path between the two nodes.

Impairments and their Remedy

1. Problem: Faulty node hardware.

   Diagnosis: If the initial site survey with the PLCA-21 analyzers indicates good communication margin in locations where an installed node fails to communicate, the most likely cause is faulty node hardware. The node hardware may either be loading the power line, injecting excessive noise onto the power line, or degrading receive performance. Note that the presence of excessively noisy or low impedance nodes will cause degraded PLCA-21 analyzer results if retested with all nodes in place.

   Solution*:* Verify the performance of ***all*** power line communication hardware ***prior*** to installation as recommended in the Chapter 7 of the *LONWORKS PLT-21 Power Line Transceiver User's Guide.*

2. Problem: Excessive signal attenuation prevents communication from the central node to a device or a group of devices.

   Diagnosis: PLCA-21 analyzer testing shows insufficient signal-to-noise ratio along with a low background noise component.

   Solution: For locations which do not exhibit strong signal-to-noise ratios, additional twisted pair-to-power line routers may be necessary. This is accomplished by extending the primary twisted pair backbone to an additional twisted pair-to-power line router situated at the electrical distribution panel closest to the problem node(s).

3. Problem: Excessive background noise prevents communication from the central node to a device or a group of devices.

   Diagnosis: PLCA-21 analyzer testing shows an insufficient signal-to-noise ratio along with a high background noise component and a low receive signal strength.

   Solution: A commercially available filter may be required to isolate equipment which is generating excessive noise on the power line. Examples of such filters are the Leviton models 6282, 6287, and 6288, plus the Busch-Jaeger models 2292 and 2289. If it is not practical to locate or isolate an excessively noisy device then additional twisted pair-to-power line routers may be required.

4. Problem: An unusual impedance modulation on the power line is distorting packets.

   Diagnosis: PLCA-21 analyzer shows good signal-to-noise ratio along with a high error rate. This is a rare condition which is most commonly associated with equipment connected to the power line.

   Solution: A commercially available filter may be required to isolate the equipment causing the problem from the power line. Examples of such filters are the Leviton models 6282, 6287, and 6288, plus the Busch-Jaeger models 2292 and 2289. If it is not pratical to locate or isolate the offending device then it may be possible to communicate by increasing the number of retries (while many devices are programmed for 3 or 4 attempts allowing 7 or 8 tries will frequently overcome this impairment).

5. Problem: Poor ground (earth) connection.

   Diagnosis: Ground / earth tester indicates faulty ground / earth connection, typically in violation of local electrical codes.

   Solution: The building wiring must be corrected to meet electrical codes.

Related Documents

Echelon LONWORKS Product Data Book; Echelon

Resource Directory, LONWORKS Control Network Products and Services; Echelon

Neuron® Chip Data Book; Motorola and Toshiba

Off-the-shelf LONWORKS Transceivers, Gateway, I/O Modules and 3rd Party OEM Products; Echelon

LONWORKS PLT-21 Power Line Transceiver User's Guide; Echelon

LONWORKS PLA-21 Power Line Amplifier Specification and User's Guide, Echelon

LONWORKS PLCA-21 Power Line Communication Analyzer User's Guide; Echelon

LONWORKS FTT-10A Free Topology Transceiver User's Guide; Echelon

LONWORKS TPT Twisted Pair Transceiver User's Guide; Echelon

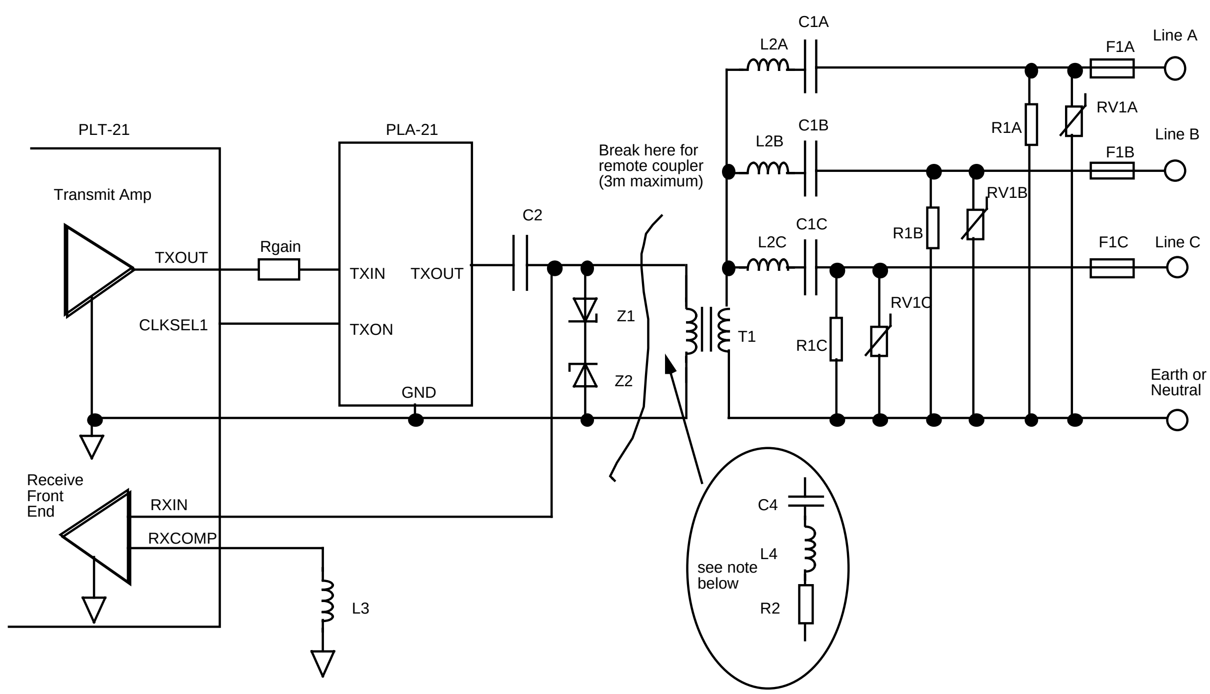
LONWORKS Router User's Guide; Echelon

LonManager Protocol Analyzer User's Guide

Appendix A

Three-Phase Transformer-Isolated Coupling Circuit

Figure A1 shows a schematic for a transformer-isolated, three phase coupling circuit. This circuit may be used for either Line-to-Earth (L-to-E) or Line-to-Neutral (L-to-N) coupling by the selection of the appropriate Earth or Neutral return connection. Table A1 lists component values and recommended suppliers / part numbers for coupling to AC mains with a nominal line voltage in the range of 100-277VAC per phase.



Note: This optional circuit should be added to nodes located adjacent to a triac or SCR load switching device.

Figure A1 Line-to-Neutral or Line-to-Earth, Transformer-Isolated 3-Phase Coupling Circuit Schematic

Table A1 100-277VAC, L-to-N or L-to-E, Transformer-Isolated Three Phase Coupling Circuit Component Values

Comp	***Value***	***Specifications***	***Vendor / Part Number***
C1A-C	0.10µF	±10%, 250VAC(4), X2 type(1)	Nissei Denki/Arcotronics R40104K275xxxx
C2	1.0µF	±5%, 50VDC, metalized polyester	Matsushita Electric / ECQ-V1H105JL
C4	0.22µF//0.22µF	±5%, 50VDC	AUX/SR205224JAA
F1A-C	6A	250VAC(4), slow blow(2)	
L2A-C	12µH	±10%, Imax2A , R_{DC}0.1	TAIYO YUDEN / LHL08NA120K
L3, L4	1.0mH	±10%, Imax30mA , R_{DC}50	TAIYO YUDEN / LAL03NA102K
R1A-C	1M	±5%, 1/4W, max working volt 400V (3)(4)	
RV1A-C	300VAC(4) (470VDC)	14mm varistor(5)	Matsushita Electric / ERZ-V14D471
R2	82-$L4_{RDC}$(6)	±5%, 1/16W	
T1		See Appendix B	Precision Components, Inc / 0505-0569
Z1, Z2	7.5V	±5% Zener, 180W surge for 8.3ms	1N5343B

Notes:

(1) In some applications smaller, lower-cost self-healing metalized polyester capacitors with a DC rating 1.5 X V_{ac_line} may be used. Consult applicable safety standards.

(2) In some applications fuses may not be required. Consult applicable safety standards.

(3) The working voltage rating of R1A-C may be achieved by using two 470k resistors in series, each with a working voltage rating of at least half of the value listed above. For L-to-E coupling, the peak power and peak voltage ratings of RIA-C must be chosen to meet the high-pot testing requirements of the application.

(4) For 277V applications the following components will require higher voltage ratings:

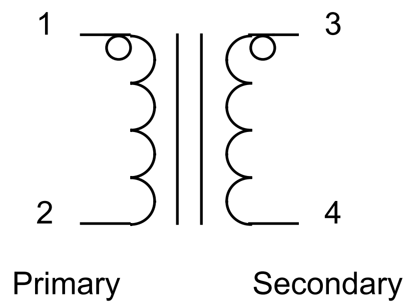
C1A-C : 300VAC rating
R1A-C : 450VDC working voltage rating
F1A-C : 300VAC rating
RV1A-C: 320VAC (510VDC) rating

(5) For L-to-E coupling these varistors must be post loaded after HI-POT testing. Also for L-to-E coupling the HI-POT tester must use a DC source to avoid excessive current flow through C1A-C.

(6) The value of R2 should be selected so that the series combination of the DC resistance of L4 and R1 is equal to 82.

Appendix B

PLT-21 Transceiver Isolation Transformer Schematic



PLT-21 Transceiver Isolation Transformer Electrical Specifications

Below are specifications for the PLT-21 Transceiver Isolation Transformer Schematic shown above.

Parameter	***Min***	***Typ***	***Max***	***Units***
Turns Ratio (1-2) : (3-4)		1.0		
DC Resistance 1-2 3-4			 0.50 0.50	 Ohm Ohm
Magnetizing Inductance 1-2 Dry, @100kHz, 1Vrms	1.1		1.8	mH
Magnetizing Inductance 1-2, 3-4 Wet, @100kHz, 1Vrms, plus 45mADC	1.0			mH
Leakage Inductance 1-2 (3-4 shorted) @100kHz, 1Vrms			1.0	µH
Winding Capacitance 1-2			25	pF
Winding to Winding Capacitance 1-2 shorted to 3-4 shorted			50	pF

PLT-21 Transceiver Isolation Transformer Vendors

Contact vendor for details on operating temperature ranges, storage temperature ranges, safety agency compliance, mechanical design information, and pricing.

Vendor	*Part Number*	*Contact Instructions*
Precision Components, Inc. 400 W. Davy Lane Wilmington, Illinois 60481	0505-0569	Telephone: +1-630-980-6448 Fax: +1-630-980-6485

Part Number 005-0056-01 Rev. B

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