CHAPTER
NINETEEN

I/O BUS NETWORKS

Necessity is the mother of invention.

—Latin Proverb

CHAPTER HIGHLIGHTS

Advances in large-scale electronic integration and surface-mount technology, coupled with trends towards decentralized control and distributed intelligence to field devices, have created the need for a more powerful type of network—the I/O bus network. This new network lets controllers better communicate with I/O field devices, to take advantage of their growing intelligence. In this chapter, we will introduce the I/O bus concept and describe the two types of I/O bus networks—device-level bus and process bus. In our discussion, we will explain these network's standards and features. We will also list the specifications for I/O bus networks and summarize their uses in control applications. When you finish this chapter, you will have learned about all the aspects of a PLC control system—hardware, software, and communication schemes—and you will be ready to apply this knowledge to the installation and maintenance of a PLC system.

19-1 INTRODUCTION TO I/O BUS NETWORKS

I/O bus networks allow PLCs to communicate with I/O devices in a manner similar to how local area networks let supervisory PLCs communicate with individual PLCs (see Figure 19-1). This configuration decentralizes control in the PLC system, yielding larger and faster control systems. The topology, or physical architecture, of an I/O bus network follows the bus or extended bus (tree) configuration, which lets field devices (e.g., limit, photoelectric, and proximity switches) connect directly to either a PLC or to a local area network bus. Remember that a bus is simply a collection of lines that transmit data and/or power. Figure 19-2 illustrates a typical connection between a PLC, a local area network, and an I/O bus network.

The basic function of an I/O bus network is to communicate information with, as well as supply power to, the field devices that are connected to the bus (see Figure 19-3). In an I/O bus network, the PLC drives the field devices directly, without the use of I/O modules; therefore, the PLC connects to and communicates with each field I/O device according to the bus's protocol. In essence, PLCs connect with I/O bus networks in a manner similar to the way they connect with remote I/O, except that PLCs in an I/O bus use an **I/O bus network scanner**. An I/O bus network scanner reads and writes to each field device address, as well as decodes the information contained in the network information packet. A large, **tree topology** bus network (i.e., a network with many branches) may have up to 2048 or more connected discrete field devices.

The field devices that connect to I/O bus networks contain intelligence in the form of microprocessors or other circuits (see Figure 19-4). These devices communicate not only the ON/OFF state of input and output controls, but also diagnostic information about their operating states. For example, a photoelectric sensor (switch) can report when its internal gain starts to

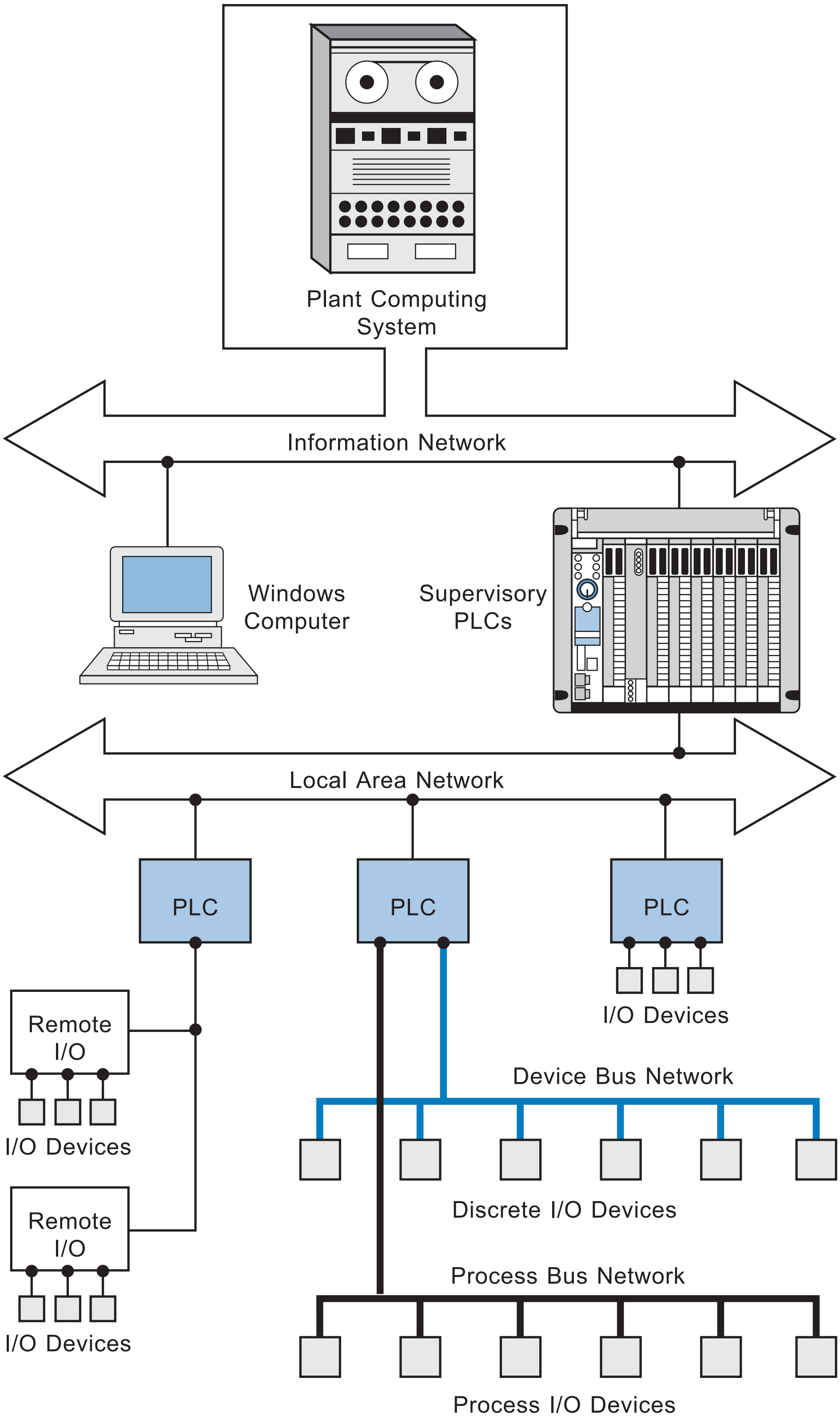


Figure 19-1. I/O bus network block diagram.

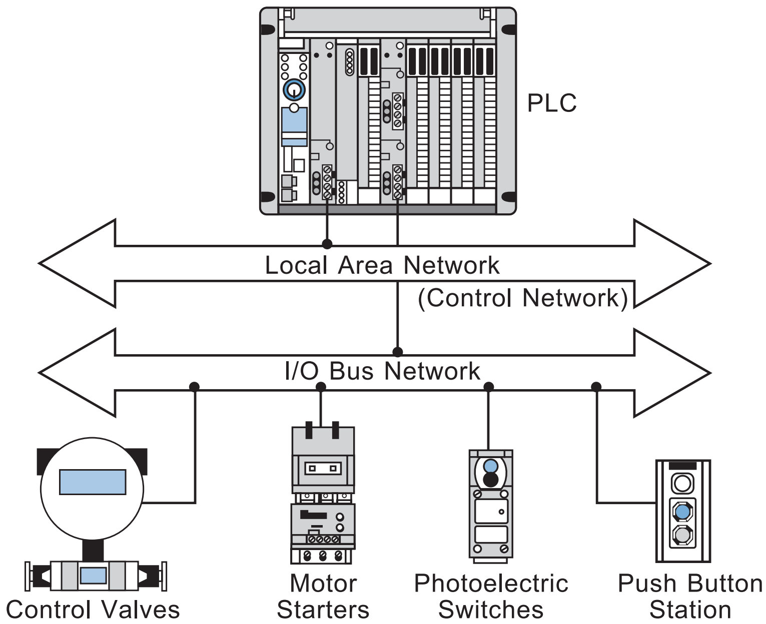


Figure 19-2. Connection between a PLC, a local area network, and an I/O bus network.

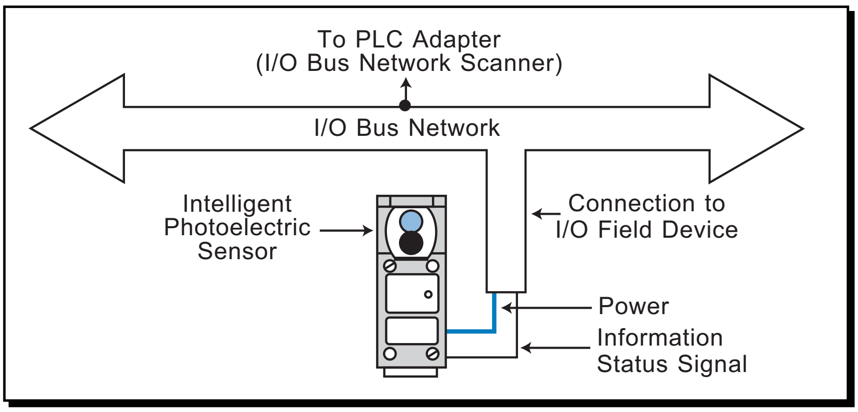


Figure 19-3. Connections for an I/O bus network.

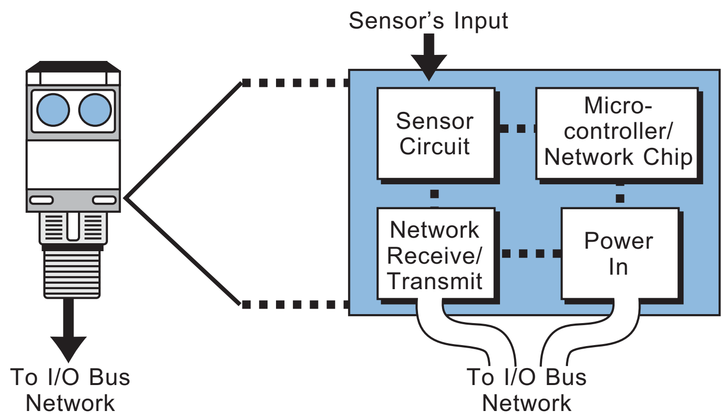


Figure 19-4. Intelligent field device.

decrease because of a dirty lens, or a limit switch can report the number of motions it has performed. This type of information can prevent I/O device malfunction and can indicate when a sensor has reached the end of its operating life, thus requiring replacement.

19-2 TYPES OF I/O BUS NETWORKS

I/O bus networks can be separated into two different categories—one that deals with low-level devices that are typical of discrete manufacturing operations and another that handles high-level devices found in process industries. These bus network categories are:

- device bus networks
- process bus networks

Device bus networks interface with low-level information devices (e.g., push buttons, limit switches, etc.), which primarily transmit data relating to the state of the device (ON/OFF) and its operational status (e.g., operating OK). These networks generally process only a few bits to several bytes of data at a time. **Process bus networks**, on the other hand, connect with high-level information devices (e.g., smart process valves, flow meters, etc.), which are typically used in process control applications. Process bus networks handle large amounts of data (several hundred bytes), consisting of information about the process, as well as the field devices themselves. Figure 19-5 illustrates a classification diagram of the two types of I/O bus networks.

The majority of devices used in process bus networks are analog, while most devices used in device bus networks are discrete. However, device bus networks sometimes include analog devices, such as thermocouples and variable speed drives, that transmit only a few bytes of information. Device

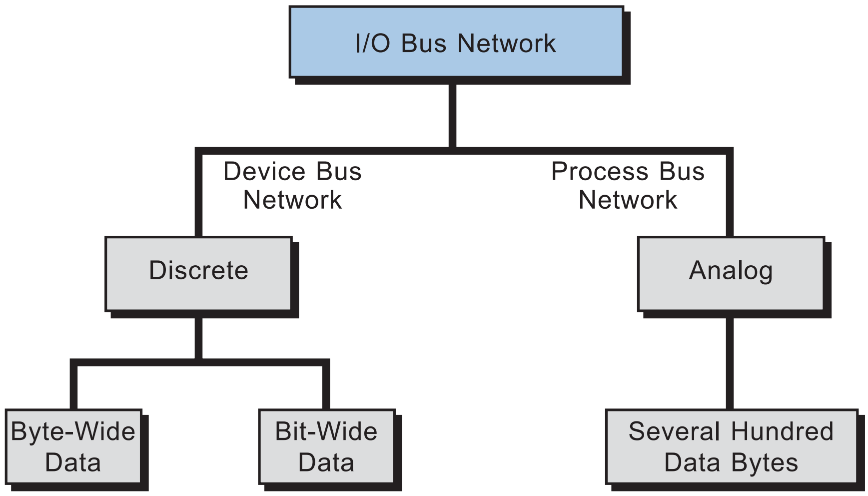


Figure 19-5. I/O bus network classification diagram.

bus networks that include discrete devices, as well as small analog devices, are called **byte-wide bus networks**. These networks can transfer between 1 and 50 or more bytes of data at a time. Device bus networks that only interface with discrete devices are called **bit-wide bus networks**. Bit-wide networks transfer less than 8 bits of data from simple discrete devices over relatively short distances.

The primary reason why device bus networks interface mainly with discrete devices and process bus networks interface mainly with analog devices is the different data transmission requirements for these devices. The size of the information packet has an inverse effect on the speed at which data travels through the network. Therefore, since device bus networks transmit only small amounts of data at a time, they can meet the high speed requirements for discrete implementations. Conversely, process bus networks work slower because of their large data packet size, so they are more applicable for the control of analog I/O devices, which do not require fast response times. The transmission speeds for both types of I/O bus networks can be as high as 1 to 2.5 megabits per second. However, a device bus network can deliver many information packets from many field devices in the time that it takes a process bus network to deliver one large packet of information from one device.

Since process bus networks can transmit several hundred bytes of data at a time, they are suitable for applications requiring complex data transmission. For example, an intelligent, process bus network–compatible pressure transmitter can provide the controller with much more information than just pressure; it can also transmit information about temperature flow rate and internal operation. Thus, this type of pressure transmitter requires a large data packet to transmit all of its process information, which is why a process bus network would be appropriate for this application. This amount of information just would not fit on a device bus network.

PROTOCOL STANDARDS

Neither of the two I/O bus networks have established protocol standards; however, many organizations are working towards developing both discrete and process bus network specifications. In the process bus area, two main organizations, the Fieldbus Foundation (which is the result of a merger between the Interoperable Systems Project, ISP, Foundation and the World FIP North American group) and the Profibus (Process Field Bus) Trade Organization, are working to establish network and protocol standards. Other organizations, such as the Instrument Society of America (ISA) and the European International Electronics Committee (IEC), are also involved in developing these standards. This is the reason why some manufacturers specify that their analog products are compatible with Profibus, Fieldbus, or another type of protocol communication scheme. Figure 19-6 illustrates a block diagram of available network and protocol standards.

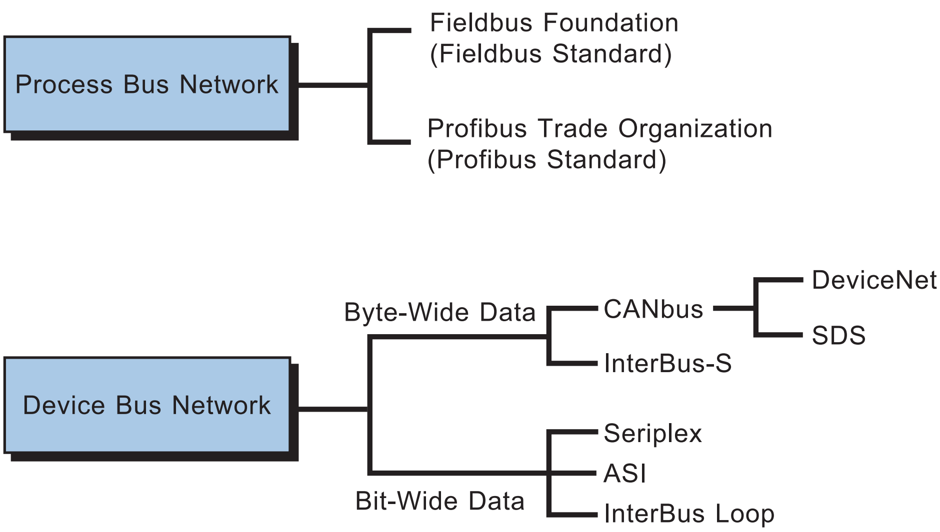


Figure 19-6. Network and protocol standards.

Although no proclaimed standards exist for device bus network applications, several de facto standards are emerging due to the availability of company-specific protocol specifications from device bus network manufacturers. These network manufacturers or associations provide I/O field device manufacturers with specifications in order to develop an open network architecture, (i.e., a network that can interface with many types of field devices). In this way, each manufacturer hopes to make its protocol the industry standard. One of these de facto standards for the byte-wide device bus network is DeviceNet, originally from PLC manufacturer Allen-Bradley and now provided by an independent spin-off association called the Open DeviceNet Vendor Association. Another is SDS (Smart Distributed System) from Honeywell. Both of these device bus protocol standards are based on the control area network bus (CANbus), developed for the automobile industry, which uses the commercially available CAN chip in its protocol. InterBus-S from Phoenix Contact is another emerging de facto standard for byte-wide device bus network.

The de facto standards for low-end, bit-wide device bus networks include Seriplex, developed by Square D, and ASI (Actuator Sensor Interface), a standard developed by a consortium of European companies. Again, this is why I/O bus network and field device manufacturers will specify compatibility with a particular protocol (e.g., ASI, Seriplex, InterBus-S, SDS, or DeviceNet) even though no official protocol standard exists.

19-3 Advantages of I/O Bus Networks

Although device bus networks interface mostly with discrete devices and process bus networks interface mostly with complex analog devices, they both transmit information the same way—digitally. In fact, the need for digital communication was one of the major reasons for the establishment of I/O bus networks. Digital communication allows more than one field device to be connected to a wire due to addressing capabilities and the device's ability to recognize data. In digital communication, a series of 1s and 0s is serially transmitted through a bus, providing important process, machine, and field device information in a digital format. These digital signals are less susceptible than other types of signals to signal degradation caused by electromagnetic interference (EMI) and radio frequencies generated by analog electronic equipment in the process environment. Additionally, PLCs in an I/O bus perform a minimal amount of analog-to-digital and digital-to-analog conversions, since the devices pass their data digitally through the bus to the controller. This, in turn, eliminates the small, but cumulative, errors caused by A/D and D/A conversions.

Another advantage of digital I/O bus communication is that, because of their intelligence, process bus–compatible field devices can pass a digital value proportional to a real-world value to the PLC, thus eliminating the need to linearize or scale the process data. For example, a flow meter can pass data about a 535.5 gallons per minute flow directly to the PLC instead of sending an analog value to an analog module that will then scale the value to engineering units. Thus, the process bus is an attempt to eliminate the need for the interpretation of analog voltages and 4–20 mA current readings from process field devices.

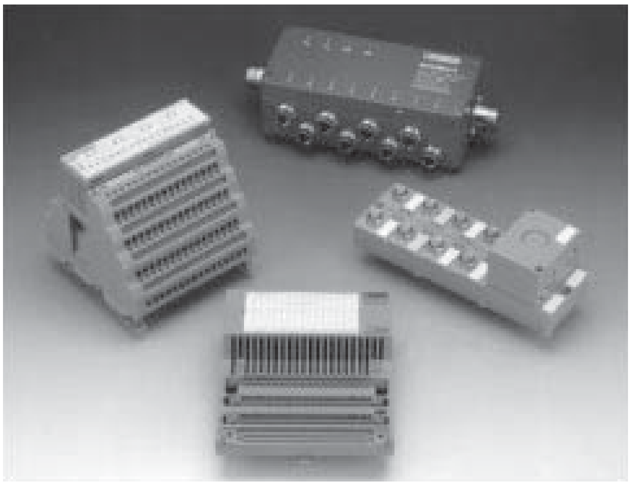
The advantages of digital communication in I/O bus networks are enormous. However, I/O bus networks have physical advantages as well. The reduction in the amount of wiring in a plant alone can provide incredible cost savings for manufacturing and process applications.

19-4 DEVICE BUS NETWORKS

BYTE-WIDE DEVICE BUS NETWORKS

The most common byte-wide device bus networks are based on the InterBus-S network and the CANbus network. As mentioned previously, the CANbus network includes the DeviceNet and SDS bus networks.

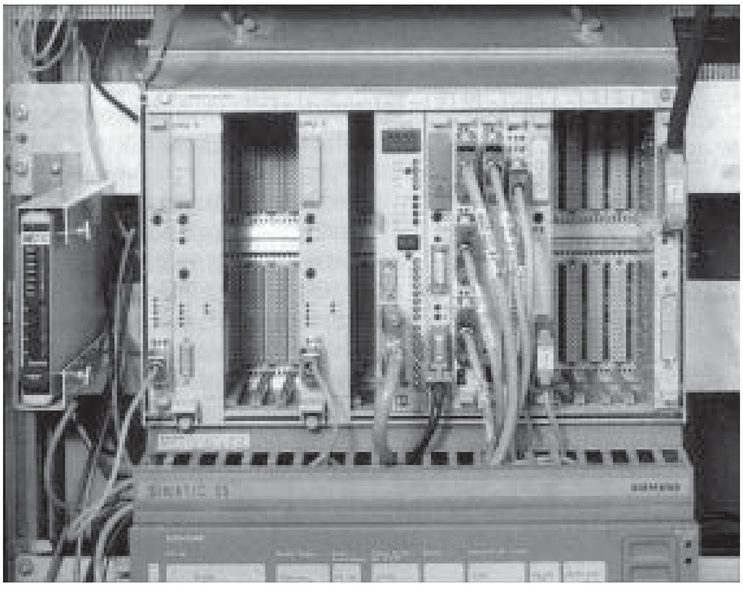
InterBus-S Byte-Wide Device Bus Network. InterBus-S is a sensor/actuator device bus network that connects discrete and analog field devices to a PLC or computer (soft PLC) via a ring network configuration. The InterBus-S has built-in I/O interfaces in its 256 possible node components, which also include terminal block connections for easy I/O interfacing (see Figure 19-7). This network can handle up to 4096 field I/O devices (depending on the configuration) at a speed of 500 kbaud with cyclic redundancy check (CRC) error detection.



Courtesy of Phoenix Contact, Harrisburg, PA

Figure 19-7. InterBus-S I/O block interfaces.

A PLC or computer in an InterBus-S network communicates with the bus in a master/slave method via a host controller or module (see Figure 19-8). This host controller has an additional RS-232C connector, which allows a laptop computer to be interfaced to the network to perform diagnostics. The laptop computer can run CMD (configuration, monitoring, and diagnostics) software while the network is operating to detect any transmission problems. The software detects any communication errors and stores them in a time-stamped file, thus indicating when possible interference might have taken place. Figure 19-9 illustrates a typical InterBus-S network with a host controller interface to a PLC.



Courtesy of Phoenix Contact, Harrisburg, PA

Figure 19-8. InterBus-S I/O network interface connected to a Siemens PLC.

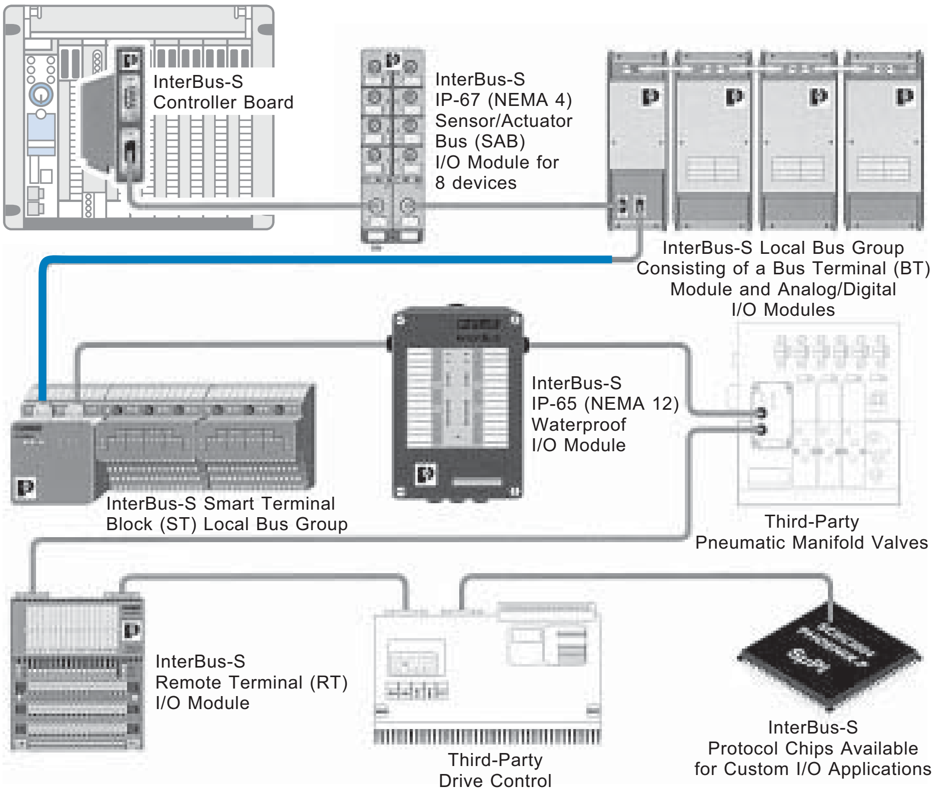


Figure 19-9. An InterBus-S network with a host controller interface to a PLC.

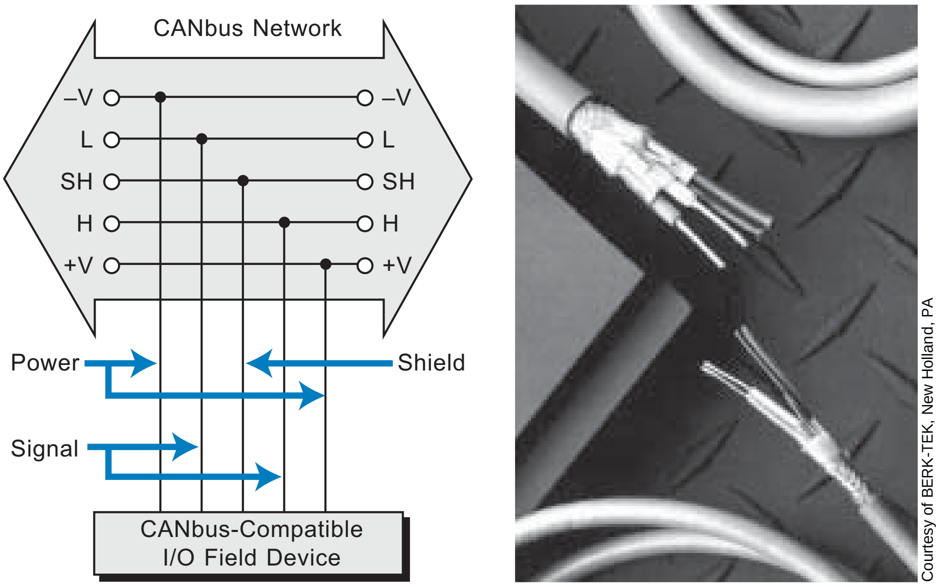
I/O device addresses in an InterBus-S network are automatically determined by their physical location, thus eliminating the need to manually set addresses. The host controller interface continuously scans data from the I/O devices, reading all the inputs in one scan and subsequently writing output data. The network transmits this data in *frames*, which provide simultaneous updates to all devices in the network. The InterBus-S network ensures the validity of the data transmission through the CRC error-checking technique. Table 19-1 lists some of the features and benefits of the InterBus-S device bus network. Note that this network uses the first, second, and seventh layers—the physical, data link, and application layers, respectively—of the ISO OSI reference model.

CANbus Byte-Wide Device Bus Networks. CANbus networks are byte-wide device bus networks based on the widely used CAN electronic chip technology, which is used inside automobiles to control internal components, such as brakes and other systems. A CANbus network is an open protocol system featuring variable length messages (up to 8 bytes), nondestructive arbitration, and advanced error management. A four-wire cable plus shield—two wires for power, two for signal transmission, and a "fifth" shield wire—

Network Characteristics	InterBus-S Features	User Benefits
Physical Layer (Layer 1):		
Protocol structure	Hardware ring network	Self-configuring, no network addresses to set
Distance	Inherently distributed up to 42,000 feet	Significantly lowers system installation cost
Physical media	Cabeling options allow for twisted-pair, fiber-optic, slipring, infrared, or SMG connections	Network connections can be made in all types of industrial environments
Data Link Layer (Layer 2):		
Protocol transmission	Full-duplex, total frame transmission	All network I/O updated simultaneously
Protocol arbitration	No arbitration	All data is transmitted continuously without any interruptions
Throughput	Read and write up to 4096 digital inputs and outputs in under 14 msec	Updates I/O many times faster than the application logic can be solved
Error checking	CRC error checking between every network connection	Accurate, reliable data transmissions
Application Layer (Layer 3):		
Diagnostics	Pinpoints the cause and location of network problems	More uptime, less downtime, reduced maintenance cost, improved reliability
Protocol flexibility	Supports high-speed digital data, analog data, and client-server messaging	Achieves maximum control
I/O expandability	Connects up to 256 I/O drops for a total of 4096 digital input and 4096 digital output points or a combination of digital and analog signal types	Provides greater system flexibility
Connectivity:		
Openness	Over 300 third-party manufacturers provide compatible products	Standard analog and digital I/O signal types and the widest variety of form factors available to provide optimum system flexibility for tomorrow's manufacturing requirements
Standards	DIN standard 19258 with profiles for robotics, drives, process controllers, encoders, and operator interfaces	Greater system integrity

Table 19-1. Features and benefits of the InterBus-S network.

provides the communication link with field devices (see Figure 19-10). This communication can either be master/slave or peer to peer. The speed of the network (data transmission rate) depends on the length of the trunk cable. Table 19-2 illustrates speed-versus-length tables for the DeviceNet and SDS CANbus networks.



(a) (b)

Figure 19-10. (a) A CANbus communication link and **(b)** a CANbus four-wire cable.

(a)

Distance		
Meters	**Feet**	**Transmission Rate**
500	1640	125K bits/sec
200	656	250K bits/sec
100	328	500K bits/sec

(b)

Maximum Total Cable Trunk Length (ft.)	Data Rate (bits/second)
1600	125 kbaud
800	250 kbaud
400	500 kbaud
100	1000 kbaud (1Mb)

Table 19-2. Speed-versus-length tables for **(a)** DeviceNet and **(b)** SDS CANbus networks.

The DeviceNet byte-wide network can support 64 nodes and a maximum of 2048 field I/O devices. The SDS network can also support 64 nodes; however, this number increases to 126 addressable locations when multiport I/O interfaces are used to multiplex the nodes. Using a 4-to-1 multiport I/O interface module, an SDS network can connect to up to 126 nonintelligent I/O devices in any combination of inputs and outputs. Figure 19-11 shows this multiplexed configuration. This multiport interface to nonintelligent field devices contains a slave CAN chip inside the interface, which provides status information about the nodes connected to the interface. In a DeviceNet network, the PLC connects to the field devices in a trunkline configuration, with either single drops off the trunk or branched drops through multiport interfaces at the device locations.

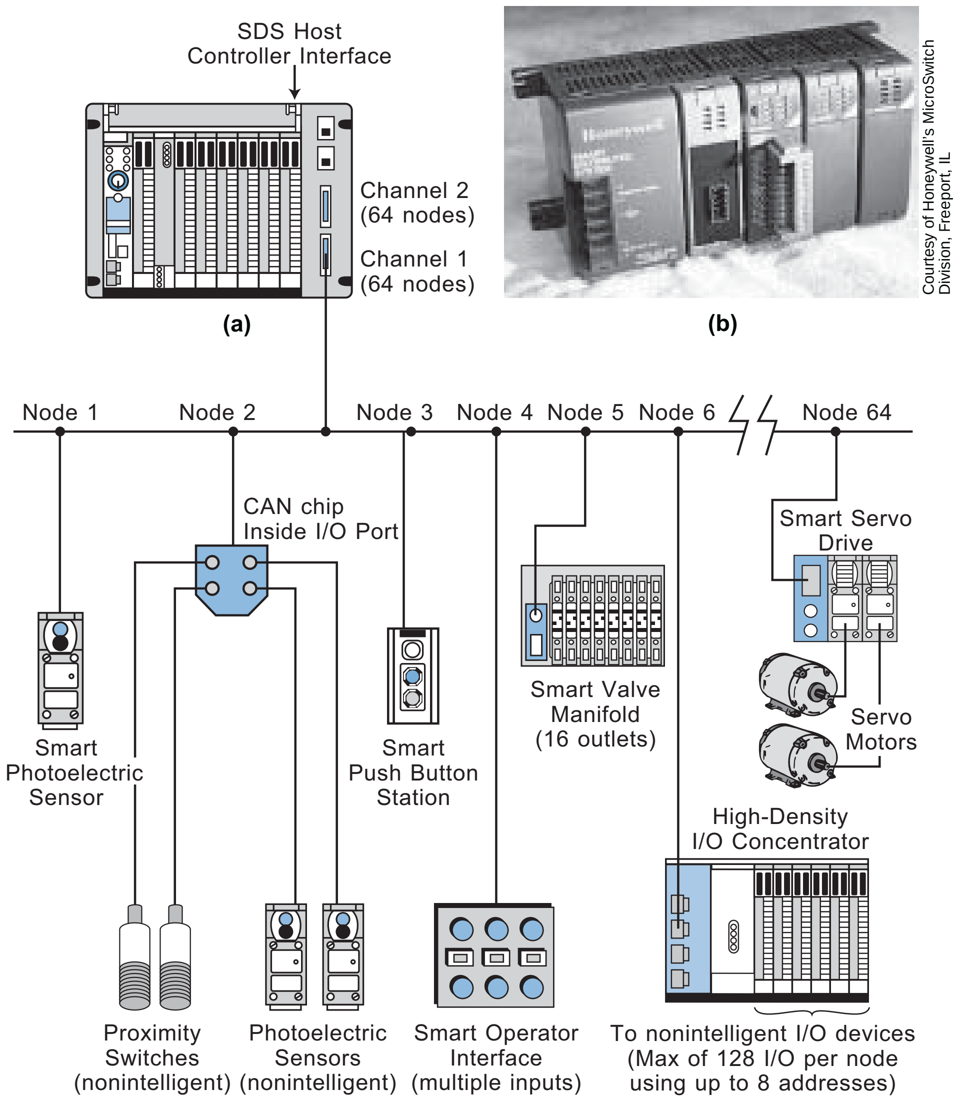
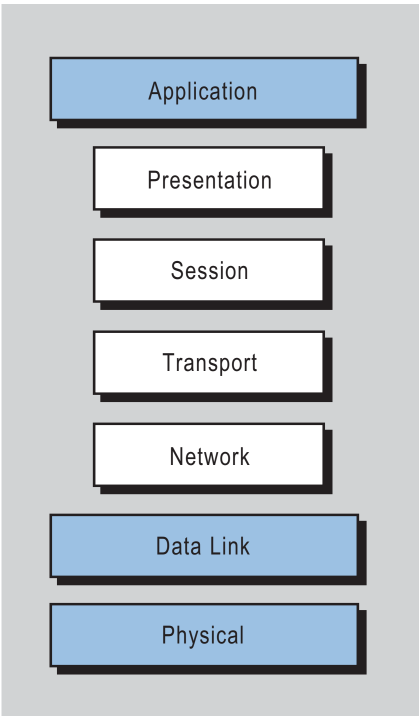


Figure 19-11. (a) A multiplexed SDS network and **(b)** a high-density I/O concentrator.

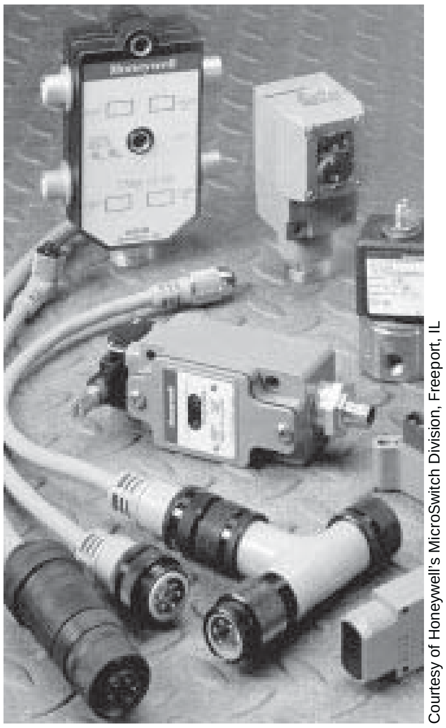
Because an SDS network can transmit many bytes of information in the form of variable length messages, it can also support many intelligent devices that can translate one, two, or more bytes of information from the network into 16 or 32 bits of ON/OFF information. An example of this type of intelligent device is a solenoid valve manifold. This kind of manifold can have up to 16 connections, thereby receiving 16 bits (two bytes) of data from the network and controlling the status of 16 valve outputs. However, this device uses only one address of the 126 possible addresses. Thus, in this configuration, the SDS network can actually connect to more than just 126 addressable devices.

The CANbus device bus network uses three of the ISO layers (see Figure 19-12) and defines both the media access control method and the physical signaling of the network, while providing cyclic redundancy check (CRC) error detection. The media access control function determines when each device on the bus will be enabled.

A CANbus scanner or an I/O processor provides the interface between a PLC and a CANbus network. Figure 19-13 illustrates a CANbus scanner designed for Allen-Bradley's DeviceNet network, which has two channels with up to 64 connected devices per channel. Block transfer instructions in the control program pass information to and from the scanner's processor (see Figure 19-14). The scanner converts the serial data from the CANbus network to a form usable by the PLC processor.



(a)



(b)

Figure 19-12. (a) CANbus ISO layers and **(b)** typical components and devices that connect and support the CANbus (SDS) layers.

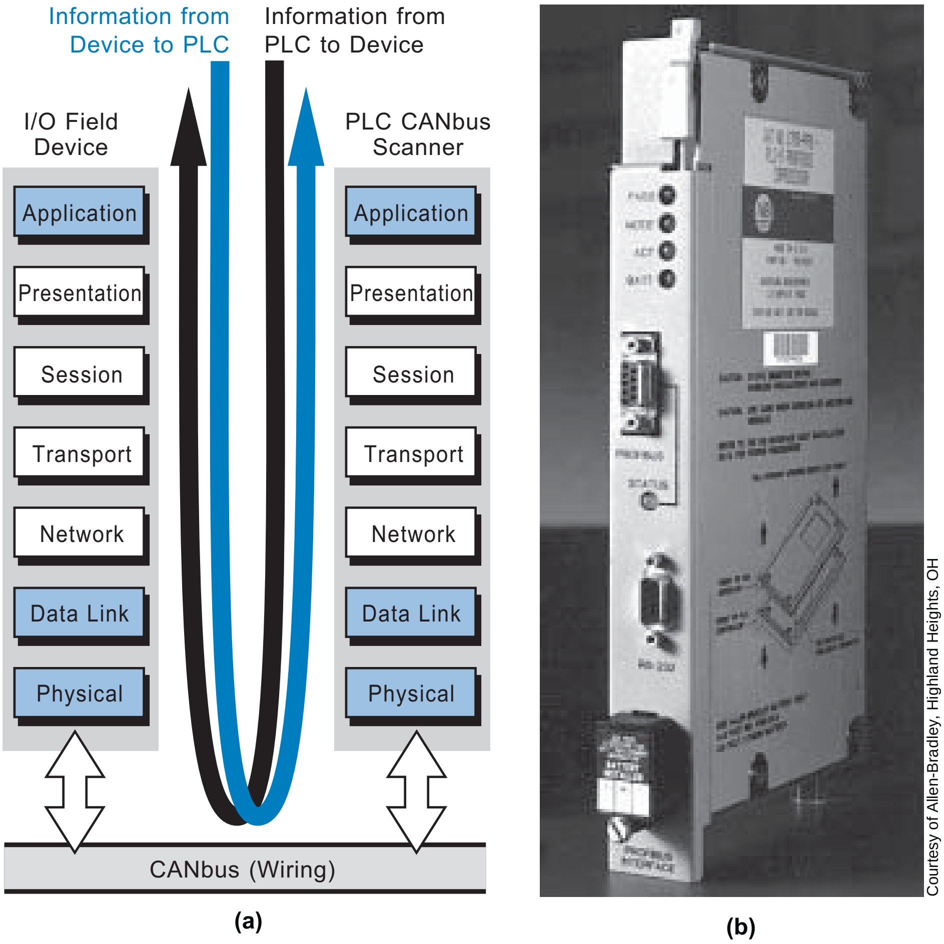


Figure 19-13. **(a)** Information transfer through a CANbus network and **(b)** Allen-Bradley's CANbus DeviceNet scanner.

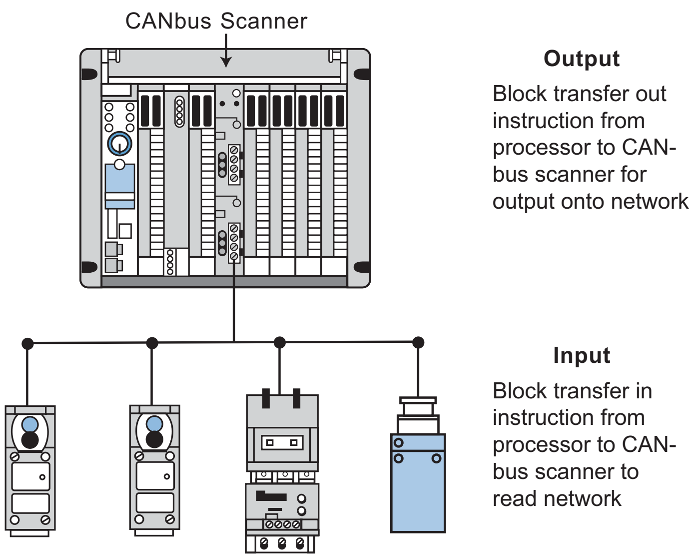


Figure 19-14. Block transfer instructions used to pass information to a CANbus scanner.

As mentioned earlier, the SDS CANbus network can handle 126 addressable I/O devices per network per channel. To increase the number of connectable devices, a PLC or computer bus interface module with two channels can be used to link two independent networks for a total of 252 I/O addresses. Moreover, each address can be multiplexed, making the network capable of more I/O connections. If the application requires even more I/O devices, another I/O bus scanner can be connected to the same PLC or computer to implement another set of networks. The SDS CANbus network connects the PLC and field devices in the same way as a DeviceNet network—in a trunkline configuration.

Some manufacturers provide access to remote I/O systems via a CANbus with an I/O rack/CANbus remote processor. Figure 19-15 illustrates an example of this type of configuration using Allen-Bradley's Flex I/O system with a DeviceNet processor, thus creating a DeviceNet I/O subsystem.

BIT-WIDE DEVICE BUS NETWORKS

Bit-wide device bus networks are used for discrete applications with simple ON/OFF devices (e.g., sensors and actuators). These I/O bus networks can only transmit 4 bits (one nibble) of information at a time, which is sufficient to transmit data from these devices. The smallest discrete sensors and

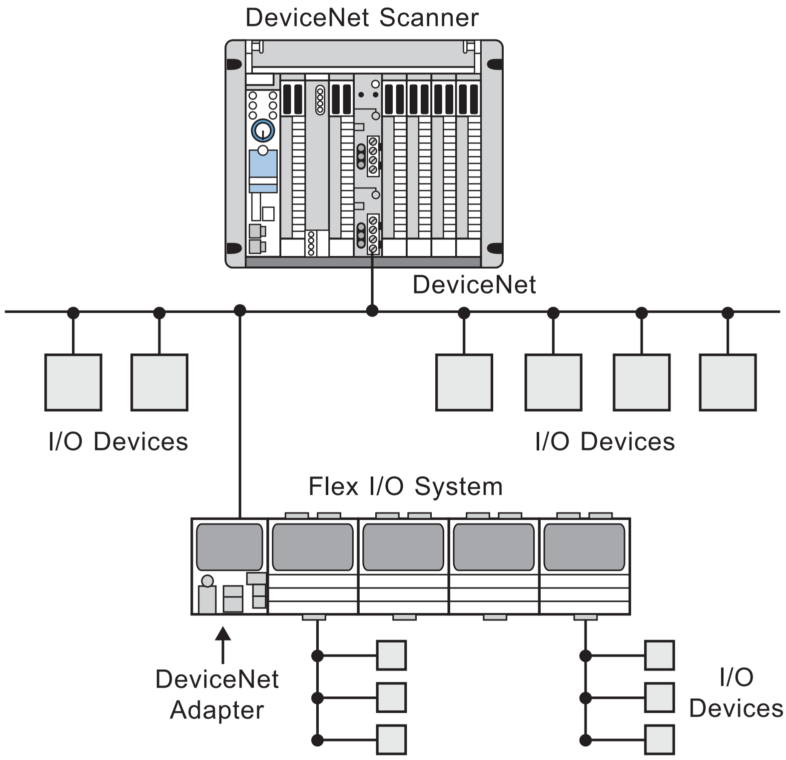


Figure 19-15. Flex I/O system connecting remote I/O to the DeviceNet processor.

actuators require only one bit of data to operate. By minimizing their data transmission capabilities, bit-wide device bus networks provide optimum performance at economical costs. The most common bit-wide device bus networks are ASI, InterBus Loop, and Seriplex.

ASI Bit-Wide Device Bus Network. The ASI network protocol is used in simple, discrete network applications requiring no more than 124 I/O field devices. These 124 input and output devices can be connected to up to 31 nodes in either a tree, star, or ring topology. The I/O devices connect to the PLC or personal computer via the bus through a host controller interface. Figure 19-16 illustrates an ASI bit-wide device bus network.

The ASI network protocol is based on the ASI protocol chip, thus the I/O devices connected to this type of network must contain this chip. Typical ASI-compatible devices include proximity switches, limit switches, photoelectric sensors, and standard off-the-shelf field devices. However, in an application using an off-the-shelf device, the ASI chip is located in the node (i.e., an intelligent node with a slave ASI chip), instead of in the device.

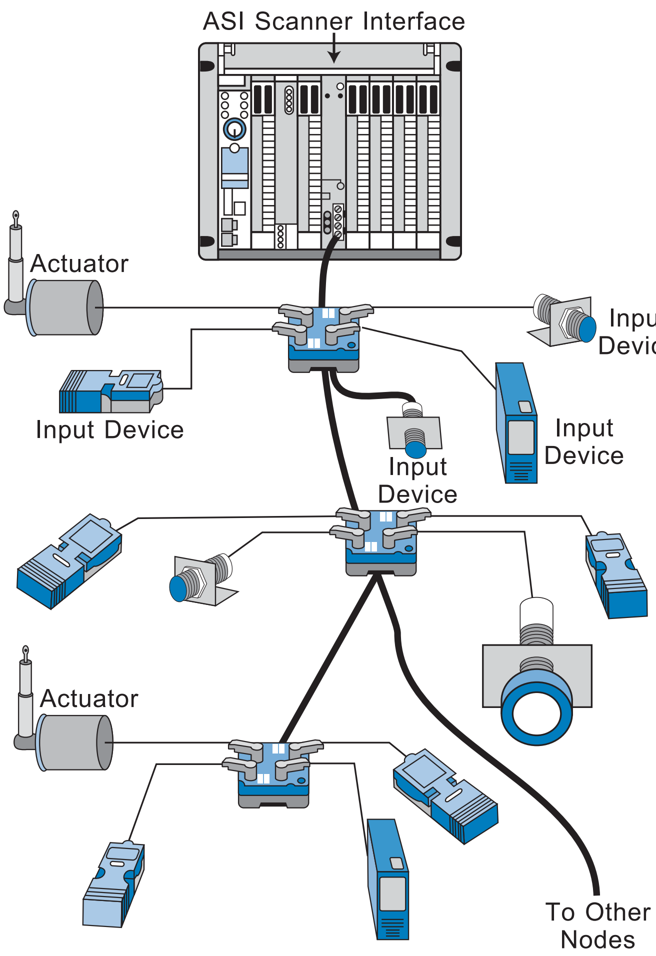


Figure 19-16. ASI bit-wide device bus network.

ASI networks require a 24-VDC power supply connected through a two-wire, unshielded, untwisted cable. Both data and power flow through the same two wires. The cycle time is less than 5 msec with a transfer rate of 167K bits/second. The maximum cable length is 100 meters (330 ft) from the master controller. Figure 19-17 illustrates an I/O bus network that uses both the ASI bit-wide network and the byte-wide CANbus network. Note that the ASI network connects to the byte-wide CANbus network through a gateway.

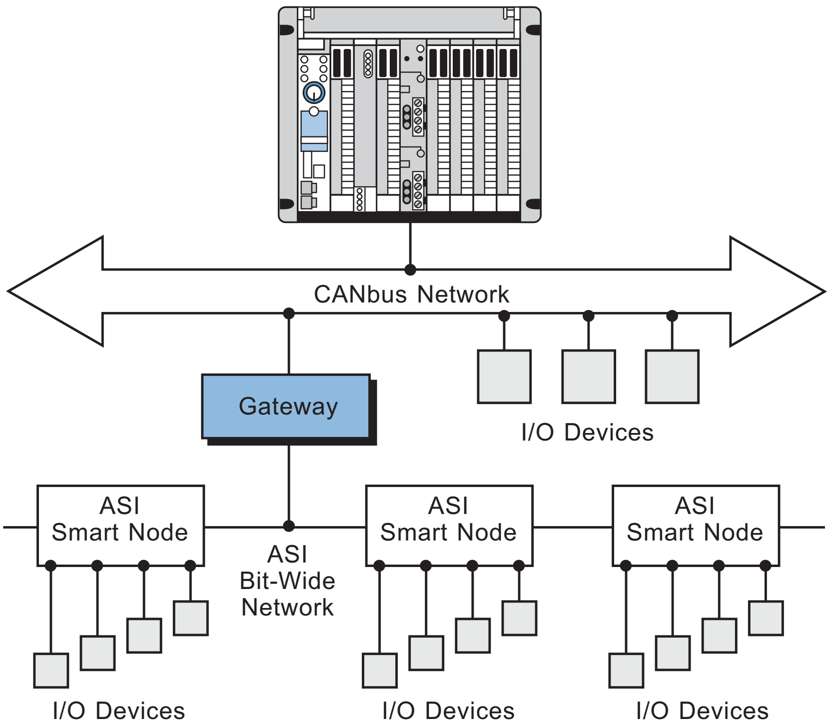


Figure 19-17. I/O bus network using the CANbus and ASI networks.

InterBus Loop Bit-Wide Device Bus Network. The InterBus Loop from Phoenix Contact Inc. is another bit-wide device bus network used to interface a PLC with simple sensor and actuator devices. The InterBus Loop uses a power and communications technology called PowerCom to send the InterBus-S protocol signal through the power supply wires (i.e., the protocol is modulated onto the power supply lines). This reduces the number of cables required by the network to only two conductors, which carry both the power and communication signals to the field devices.

Since the InterBus-S and InterBus Loop networks use the same protocol, they can communicate with each other via an InterBus Loop terminal module (see Figure 19-18). The InterBus Loop connects to the bus terminal module, located in the InterBus-S network, which attaches to the field devices via two wires. An InterBus Loop network can also interface with nonintelligent, off-the-shelf devices by means of module interfaces containing an intelligent slave network chip.

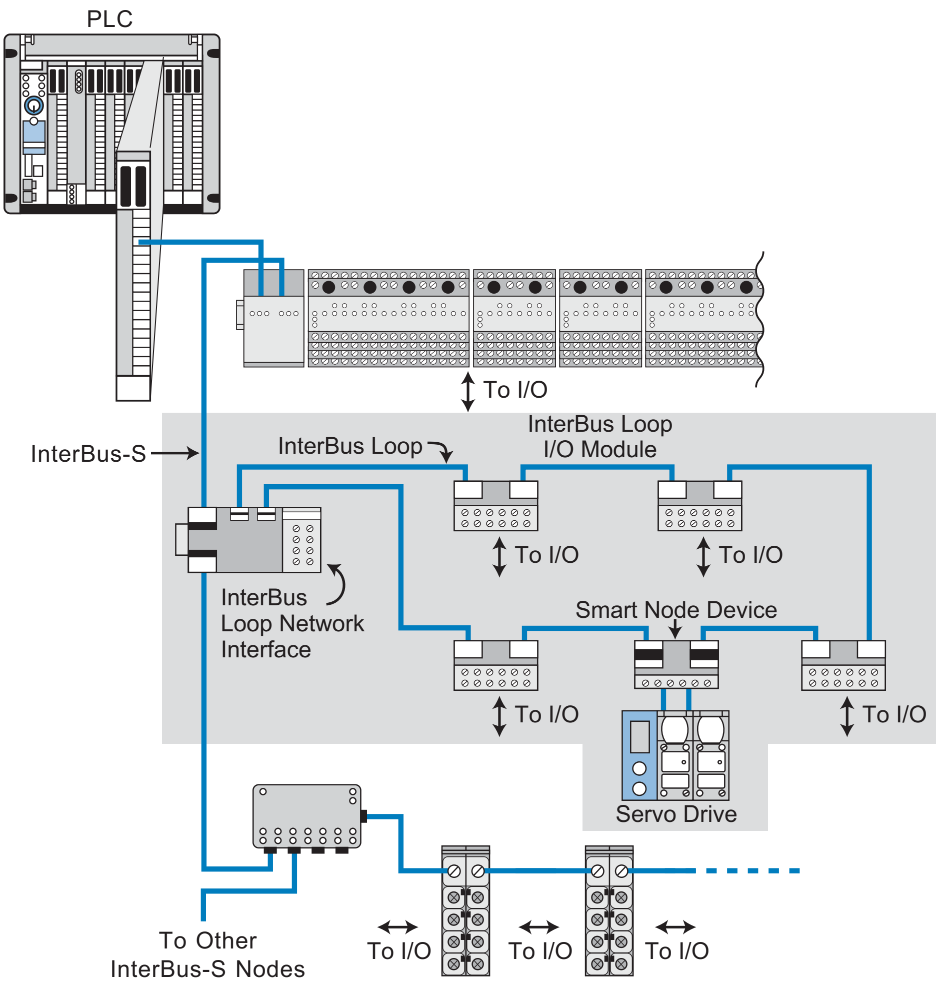


Figure 19-18. InterBus Loop and InterBus-S networks linked by an InterBus Loop terminal module.

Seriplex Bit-Wide Device Bus Network. The Seriplex device bus network can connect up to 510 field devices to a PLC in either a master/slave or peer-to-peer configuration. The Seriplex network is based on the application-specific integrated circuit, or ASIC chip, which must be present in all I/O field devices that connect to the network. I/O devices that do not have the ASIC chip embedded in their circuitry (i.e., off-the-shelf devices) can connect to the network via a Seriplex I/O module interface that contains a slave ASIC chip. The ASIC I/O interface contains 32 built-in Boolean logic function used to create logic that will provide the communication, addressability, and intelligence necessary to control the field devices connected to the network bus (see Figure 19-19).

A Seriplex network can span distances of up to 5,000 feet in a star, loop, tree, or multidrop configuration. This bit-wide bus network can also operate without a host controller. Unlike the ASI network, the Seriplex device bus

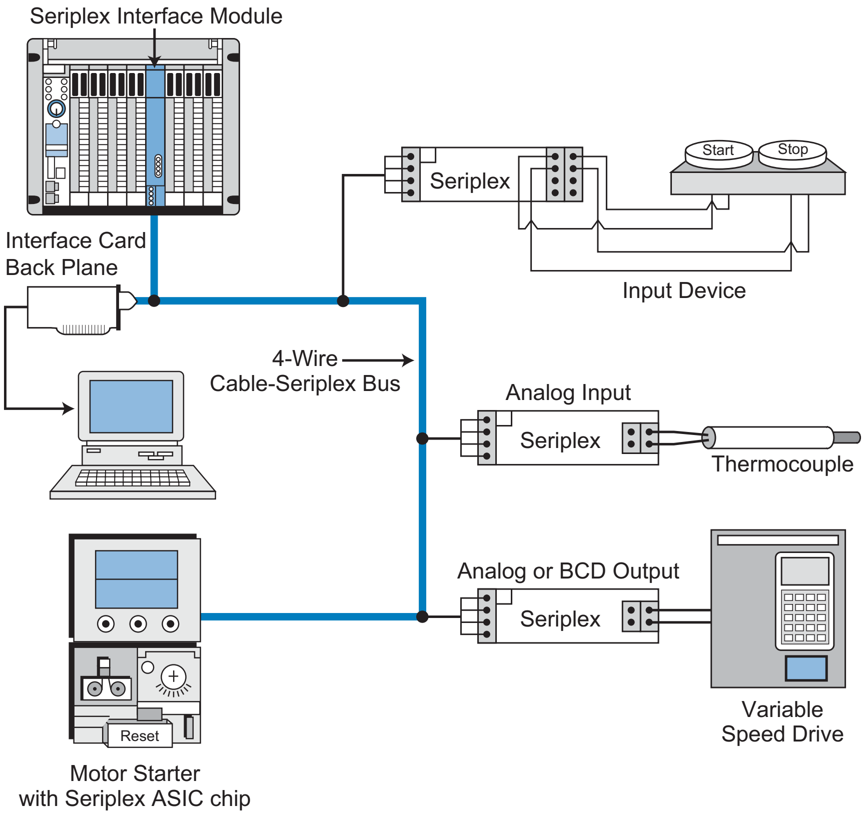


Figure 19-19. Seriplex bus network with a controller.

network can interface with analog I/O devices; however, the digitized analog signal is read or written one bit at a time in each scan cycle. Figure 19-20 illustrates a typical Seriplex bus network without a controller.

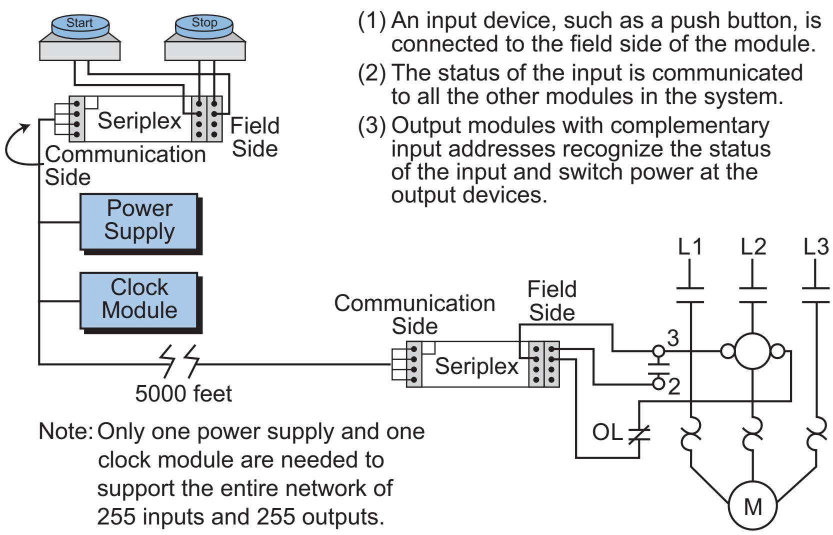


Figure 19-20. Seriplex I/O module interface without a controller.

19-5 Process Bus Networks

A process bus network is a high-level, open, digital communication network used to connect analog field devices to a control system. As mentioned earlier, a process bus network is used in process applications, where the analog input/output sensors and actuators respond slower than those in discrete bus applications (device bus networks). The size of the information packets delivered to and from these analog field devices is large, due to the nature of the information being collected at the process level.

The two most commonly used process bus network protocols are Fieldbus and Profibus (see Section 19-2). Although these network protocols can transmit data at a speed of 1 to 2 megabits/sec, their response time is considered slow to medium because of the large amount of information that is transferred. Nevertheless, this speed is adequate for process applications, because analog processes do not respond instantaneously, as discrete controls do. Figure 19-21 illustrates a typical process bus configuration.

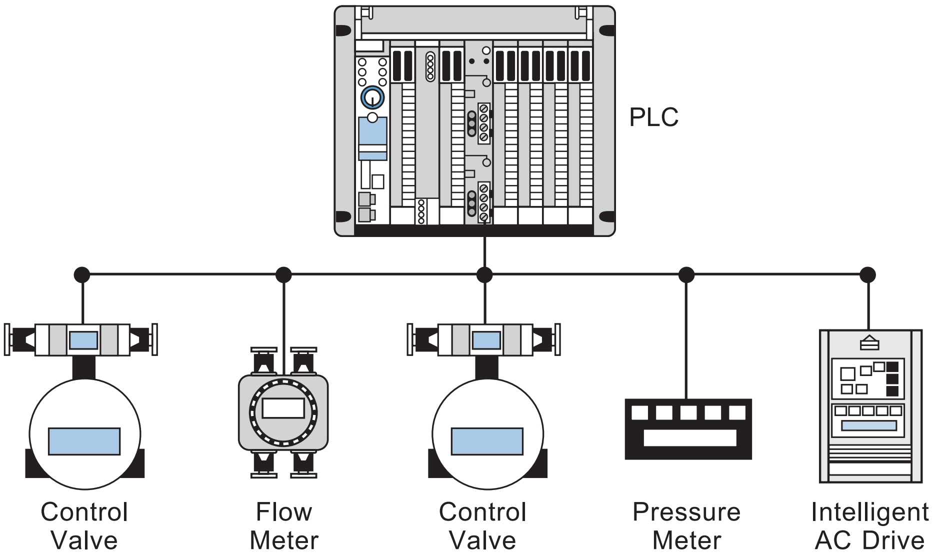
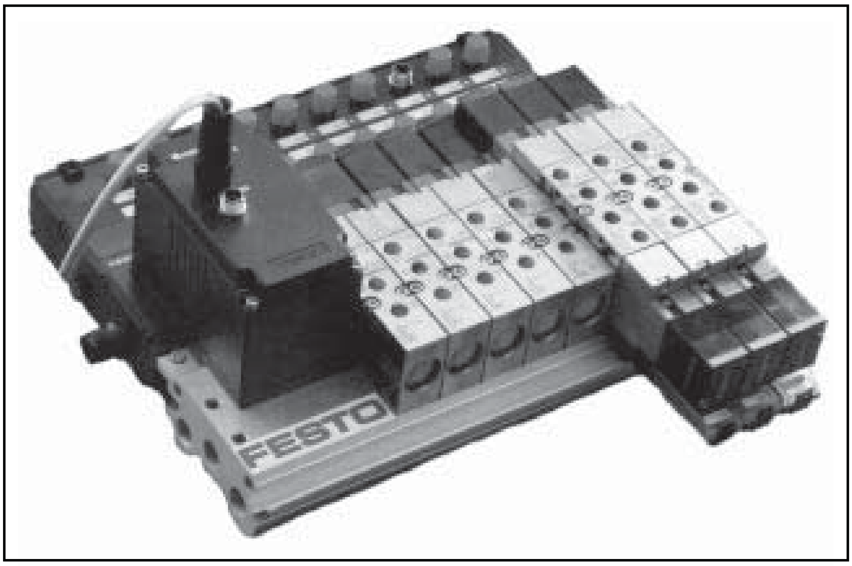


Figure 19-21. Process bus configuration.

Process bus networks can transmit enormous amounts of information to a PLC system, thus greatly enhancing the operation of a plant or process. For example, a smart, process bus–compatible motor starter can provide information about the amount of current being pulled by the motor, so that, if current requirements increase or a locked-rotor current situation occurs, the system can alert the operator and avoid a potential motor failure in a critical production line. Implementation of this type of system without a process bus network would be too costly and cumbersome because of the amount of wire runs necessary to transmit this type of process data.

Process bus networks will eventually replace the commonly used analog networks, which are based on the 4–20 mA standard for analog devices. This will provide greater accuracy and repeatability in process applications, as well as add bidirectional communication between the field devices and the controller (e.g., PLC). Figure 19-22 illustrates an intelligent valve/manifold system that can be used in a process bus network.



Courtesy of FESTO Corp., Hauppauge, NY

Figure 19-22. Intelligent valve/manifold system compatible with the Fieldbus protocol.

A PLC or computer communicates with a process bus network through a host controller interface module using either Fieldbus or Profibus protocol format. Block transfer instructions relay information between the PLC and the process bus processor. The process bus processor is generally inserted inside the rack enclosure of the PLC. Figure 19-23 shows a PLC with a Profibus processor communication interface.

Courtesy of Siemens, Alpharetta, GA

Figure 19-23. Siemens' Simatic 505 PLC with an integrated Profibus-DP interface.

FIELDBUS PROCESS BUS NETWORK

The Fieldbus process bus network from the Fieldbus Foundation (FF) is a digital, serial, multiport, two-way communication system that connects field equipment, such as intelligent sensors and actuators, with controllers, such as PLCs. This process bus network offers the desirable features inherent in 4–20 mA analog systems, such as:

- a standard physical wiring interface
- bus-powered devices on a single pair of wires
- intrinsic safety options

However, the Fieldbus network technology offers the following additional advantages:

- reduced wiring due to multidrop devices
- compatibility among Fieldbus equipment
- reduced control room space requirements
- digital communication reliability

Fieldbus Protocol. The Fieldbus network protocol is based on three layers of the ISO's seven-layer model (see Figure 19-24). These three layers are layer 1 (physical interface), layer 2 (data link), and layer 7 (application). The section comprising layers 2 and 7 of the model are referred to as the Fieldbus *communication stack*. In addition to the ISO's model, Fieldbus adds an extra

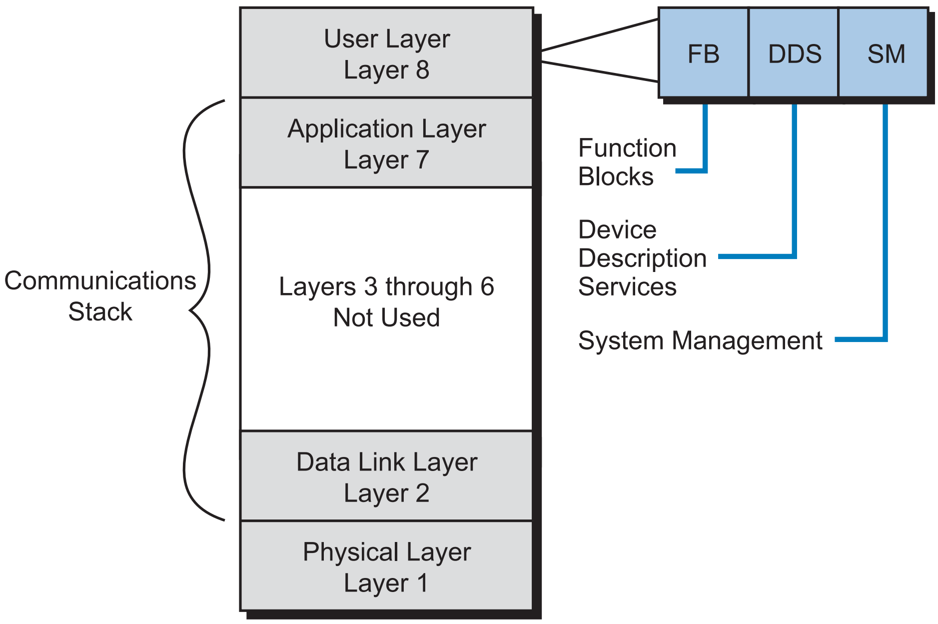


Figure 19-24. Fieldbus protocol.

layer on top of the application layer called the *user layer*. This user layer provides several key functions, which are function blocks, device description services, and system management.

Physical Layer (Layer 1). The physical layer of the Fieldbus process bus network conforms with the ISA SP50 and IEC 1152-2 standards. These standards specify the type of wire that can be used in this type of network, as well as how fast data can move through the network. Moreover, these standards define the number of field devices that can be on the bus at different network speeds, with or without being powered from the bus with *intrinsic safety* (IS). Intrinsically safe equipment and wiring does not emit enough thermal or electrical energy to ignite materials in the surrounding atmosphere. Thus, intrinsically safe devices are suitable for use in hazardous environments (e.g., those containing hydrogen or acetylene).

Table 19-3 lists the specifications for the Fieldbus network's physical layer, including the type of wire (bus), speed, number of devices, and wiring characteristics. The Fieldbus has two speeds—a low speed of 31.25 kbaud, referred to as H1, and a high speed of 1 Mbaud or 2.5 Mbaud (depending on the mode—AC current or DC voltage mode), called H2. Figure 19-25 illustrates how a bridge can connect an H1 Fieldbus network to an H2 Fieldbus network.

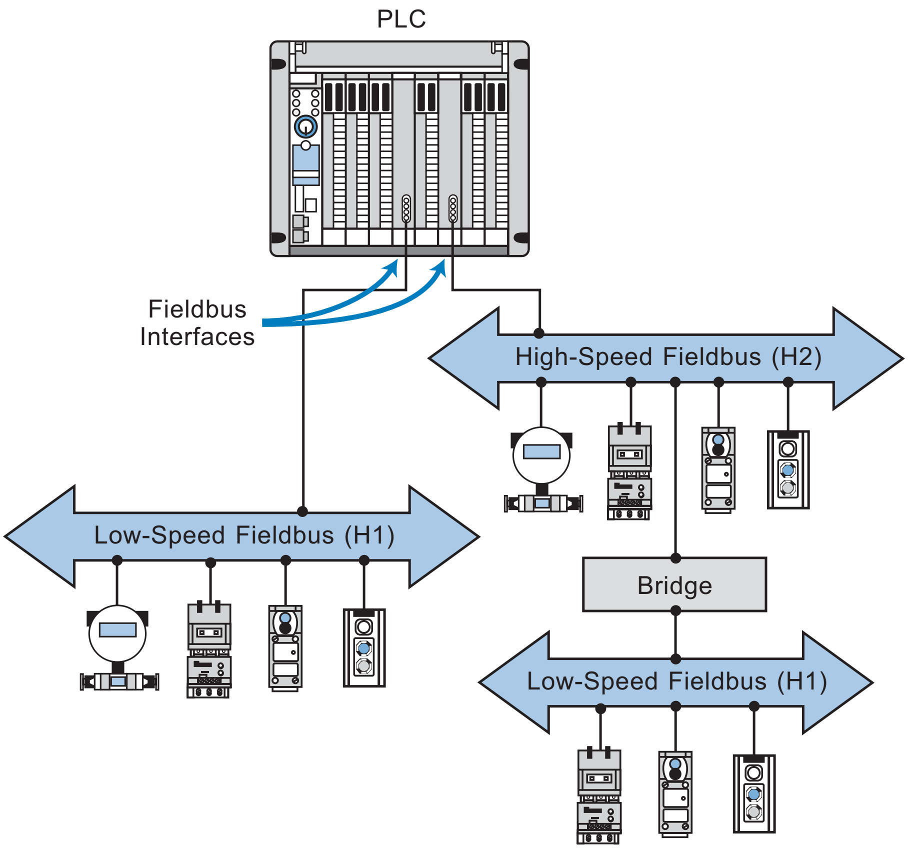


Figure 19-25. Bridge connecting low-speed and high-speed Fieldbus networks.

			Type of Wire	
Bus Type	**Speed**	**Number of Devices/ Fieldbus Segment**	**New Bus Segment (Shielded/Twisted-Pair)**	**Existing Bus Segment (Shielded/Multitwisted Pair)**
Low-speed bus (H1)	31.25 kbaud	2–32 devices that are not bus powered 2–12 devices that are bus powered 2–6 devices that are bus powered in an intrinsically safe (IS) area	#18 AWG, up to 1900 m*	#22 AWG, up to 1200 m
High-speed bus (H2)	1 Mbaud	127 devices, AC current mode (16 KHz frequency), powered from bus in IS area	#22 AWG, up to 750 m	
	1 Mbaud	127 devices, DC voltage mode, not powered from bus, and no IS devices	#22 AWG, up to 750 m	
	2.5 Mbaud	127 devices, DC voltage mode, not powered from bus, and no IS devices	#22 AWG, up to 500 m	

*A Fieldbus low-speed bus (H1) can also be implemented using unshielded, multitwisted wired with #26 AWG at up to 400 m. The low-speed bus can also use unshielded, multicore wire with #16 AWG at up to 200 m.

Table 19-3. Fieldbus physical layer specifications.

At a speed of 31.25 kbaud, the physical layer of the Fieldbus process network can support existing 4–20 mA wiring. This increases cost-effectiveness when upgrading a plant or process's network communication scheme. At this H1 speed, the Fieldbus network can also support intrinsically safe network segments with bus-powered devices.

Communication Stack (Layers 2 and 7). The communication stack portion of the Fieldbus process bus network consists of layer 2 (the data link layer) and layer 7 (the application layer). The data link layer controls the transmission of messages onto the Fieldbus through the physical layer. It manages access to the bus through a *link active scheduler*, which is a deterministic, centralized bus transmission regulator based on IEC and ISA standards. The application layer contains the *Fieldbus messaging specification* (FMS) standard, which encodes and decodes commands from the user layer, Fieldbus's additional 8th layer. The FMS is based on the Profibus process bus standard. Layer 7 also contains an *object dictionary*, which allows Fieldbus network data to be retrieved by either tag name or index record.

The Fieldbus process network uses two types of message transmissions: **cyclic** (scheduled) and **acyclic** (unscheduled). Cyclic message transmissions occur at regular, scheduled times. The master network device monitors how busy the network is and then grants the slave devices permission to send network transmissions at specified times. Other network devices can listen to and receive these messages if they are subscribers.

Acyclic, or unscheduled, messages occur between cyclic, scheduled messages, when the master device sends an unscheduled informational message to a slave device. Typically, acyclic messages involve alarm acknowledgment signals or special retrieving commands designed to obtain diagnostic information from the field devices.

User Layer (Layer 8). The user layer implements the Fieldbus network's distributed control strategy. It contains three key elements, which are function blocks, device description services, and system management. The user layer, a vital segment of the Fieldbus network, also defines the software model for user interaction with the network system.

Function Blocks. Function blocks are encapsulated control functions that allow the performance of input/output operations, such as analog inputs, analog outputs, PID control, discrete inputs/outputs, signal selectors, manual loaders, bias/gain stations, and ratio stations. The function block capabilities of Fieldbus networks allow Fieldbus-compatible devices to be programmed with blocks containing any of the instructions available in the system. Through these function blocks, users can configure control algorithms and implement them directly through field devices. This gives these intelligent field devices the capability to store and execute software routines right at their connection to the bus. The process information gathered through these function block programs can then be passed to the host through the network, either cyclically or acyclically.

Figure 19-26 illustrates an example of a process control loop that is executed directly on the Fieldbus network. In this loop, the analog input function block reads analog process information from the meter/transmitter, executes a PID function block, and then outputs analog control data to an intelligent process valve. This configuration creates an independent, self-regulating loop, which obtains its own analog input data from the flow meter. Information about the required flow parameters is passed from the host controller to the intelligent valve system, so that it can properly execute its function blocks. The function blocks allow the field device to be represented in the network as a collection of software block instructions, rather than just as an instrument.

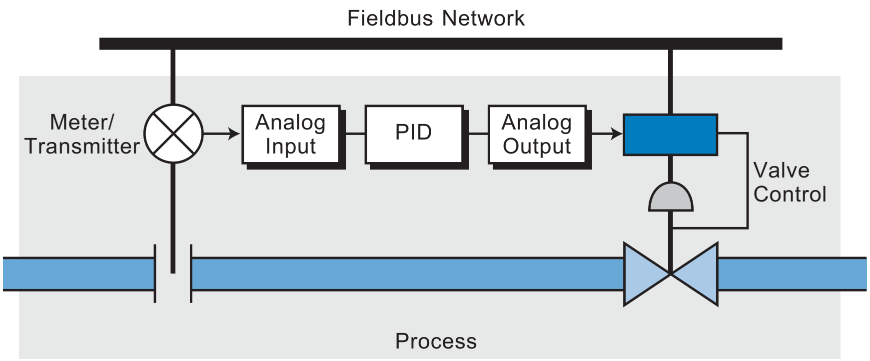


Figure 19-26. Process control loop executed on the Fieldbus network.

<u>Device Description Services.</u> *Device descriptions* (DD) are Fieldbus software mechanisms that let a host obtain message information, such as vendor name, available function blocks, and diagnostic capabilities, from field devices. Device descriptions can be thought of as “drivers” for field devices connected to the network, meaning that they allow the device to communicate with the host and the network. The network’s host computer uses a device description services, or DDS, interpreter to read the desired information from each device. All devices connected to a Fieldbus process network must have a device description. When a new field device is added to the network, the host must be supplied with its device description. Device descriptions eliminate the need to revise the whole control system software when revisions are made to existing field device software or when new devices are added to the process control system.

<u>System Manager.</u> The system management portion of the user layer schedules the execution of function blocks at precisely defined intervals. It also controls the communication of all the Fieldbus network parameters used by the function blocks. Moreover, the system manager automatically assigns field device addresses.

Profibus Process Bus Network

Profibus is a digital process bus network capable of communicating information between a master controller (or host) and an intelligent, slave process field device, as well as from one host to another. Profibus actually consists of three intercompatible networks with different protocols designed to serve distinctive application requirements. The three types of Profibus networks are:

- Profibus-FMS
- Profibus-DP
- Profibus-PA

The Profibus-FMS network is the universal solution for communicating between the upper level, the cell level, and the field device level of the Profibus hierarchy (see Figure 19-27). Cell level control occurs at individual

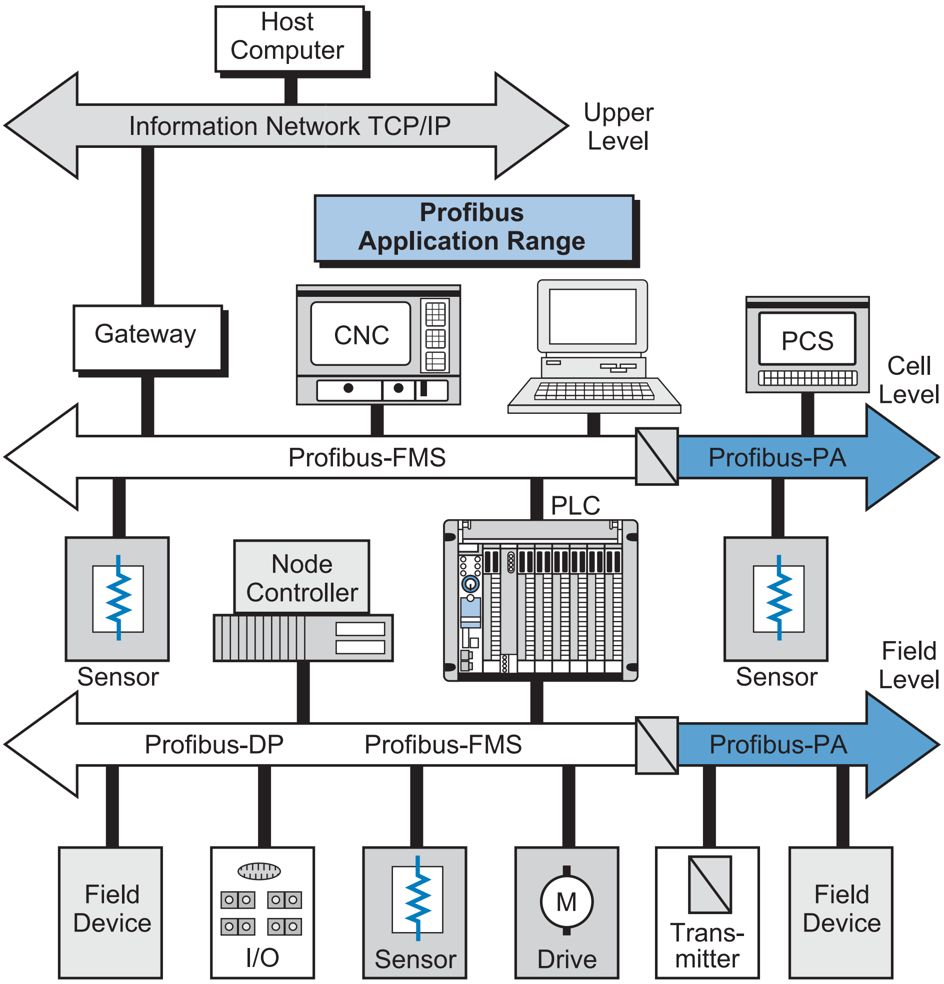


Figure 19-27. Profibus hierarchy.

(or cell) areas, which exercise the actual control during production. The controllers at the cell level must communicate with other supervisory systems. The Profibus-FMS utilizes the Fieldbus message specification (FMS) to execute its extensive communication tasks between hierarchical levels. This communication is performed through cyclic or acyclic messages at medium transmission speeds.

The Profibus-DP network is a performance-optimized version of the Profibus network. It is designed to handle time-critical communications between devices in factory automation systems. The Profibus-DP is a suitable replacement for 24-V parallel and 4–20 mA wiring interfaces.

The Profibus-PA network is the process automation version of the Profibus network. It provides bus-powered stations and intrinsic safety according to the transmission specifications of the IEC 1158-2 standard. The Profibus-PA network has device description and function block capabilities, along with field device interoperability.

Profibus Network Protocol. The Profibus network follows the ISO model; however, each type of Profibus network contains slight variations in the model's layers. The Profibus-FMS does not define layers 3 through 6; rather, it implements their functions in a lower layer interface (LLI) that forms part of layer 7 (see Figure 19-28). The Profibus-FMS implements the Fieldbus message specification (FMS), which provides powerful network communication services and user interfaces, in layer 7 as well.

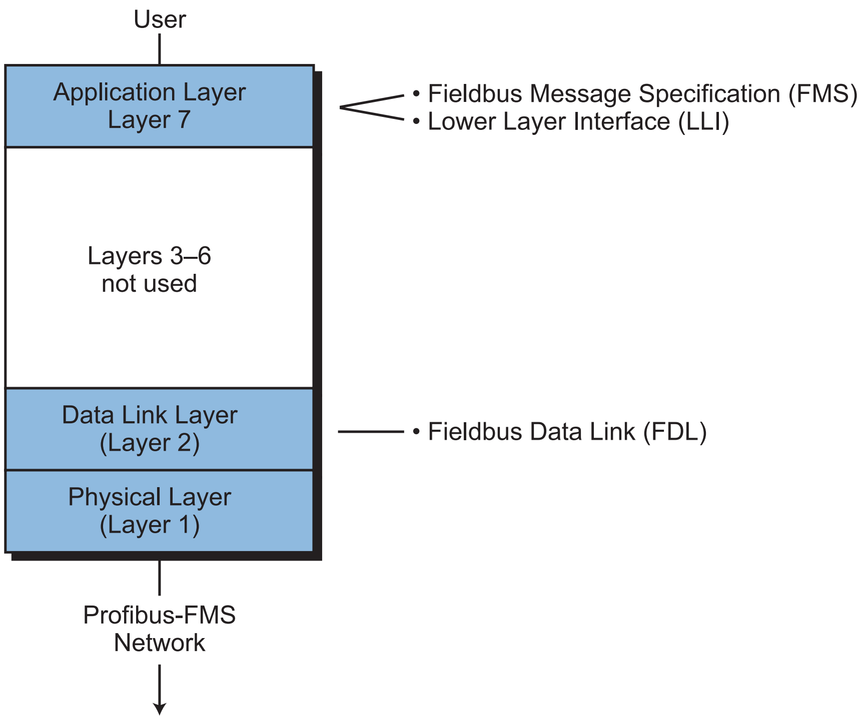


Figure 19-28. Profibus-FMS protocol.

The Profibus-DP network, on the other hand, does not define layers 3 through 7 (see Figure 19-29). It omits layer 7 primarily to achieve the high operational speed required for its applications. A *direct data link mapper* (DDLM), located in layer 2, provides the mapping between the user interface and layer 2 of the Profibus-DP network.

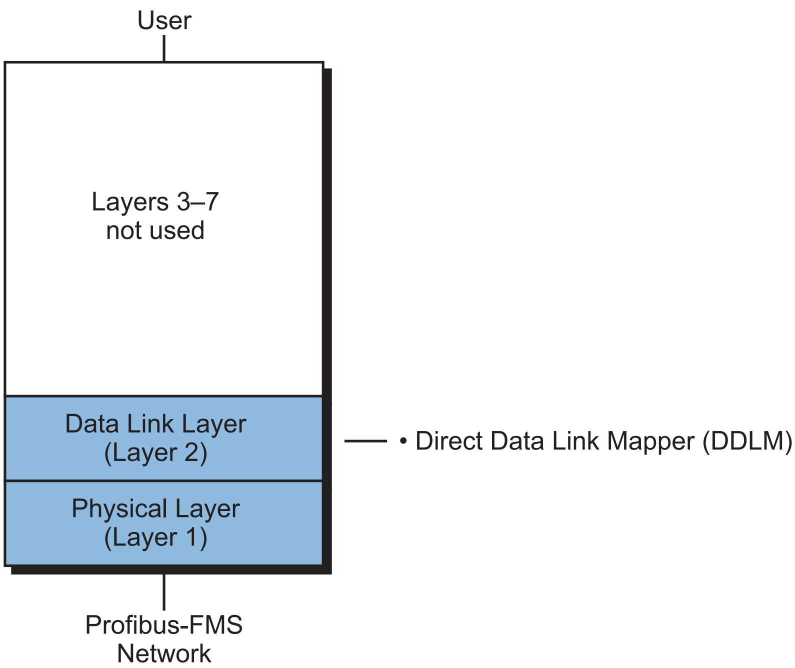


Figure 19-29. Profibus-DP protocol.

The Profibus-PA network uses the same type of model as the Profibus-FMS (see Figure 19-30), except its seventh layer differs slightly. Layer 7 implements the function block control software and also contains a device description language used for field device identification and addressing.

The data link layer, designated in the Profibus network as the *fieldbus data link layer* (FDL), executes all message and protocol transmissions. This data layer is equivalent to layer 2 of the ISO model. The fieldbus data link layer also provides **medium access control (MAC)** and data integrity. Medium access control ensures that only one station has the right to transmit data at any time. Because Profibus can communicate between masters with equal access rights (e.g., two PLCs), medium access control is used to provide each of the master stations with the opportunity to execute their communication tasks within precisely defined time intervals. For communication between a master and slave field devices, cyclic, real-time data exchange is achieved as quickly as possible through the network.

The Profibus's medium access protocol is a hybrid communication method that includes a token-passing protocol for use between masters and a master-slave protocol for communication between a master and a field device.

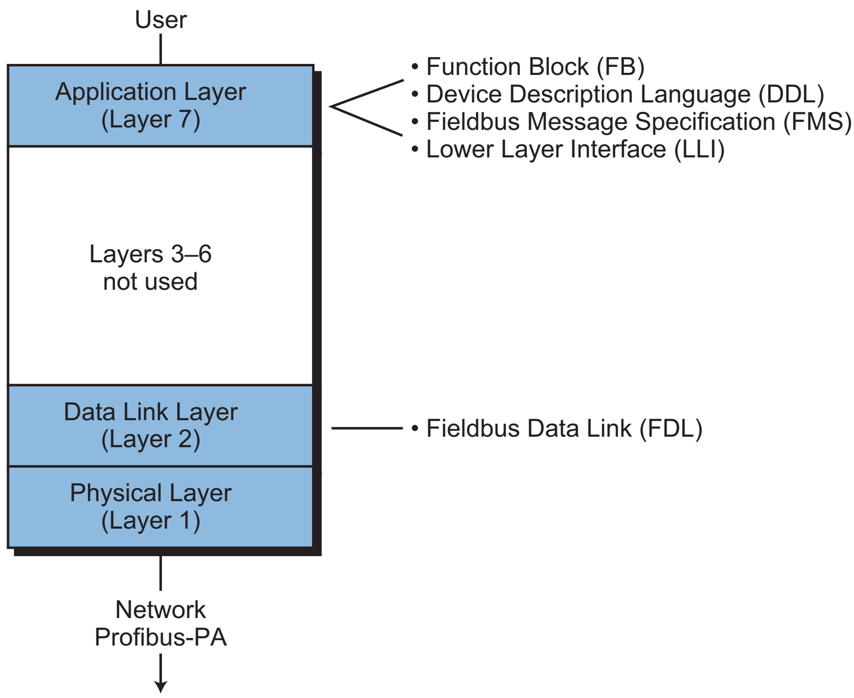


Figure 19-30. Profibus-PA protocol.

Through this hybrid medium access protocol, a Profibus network can function as a master-slave system, a master-master system (token passing), or a combination of both systems (see Figure 19-31).

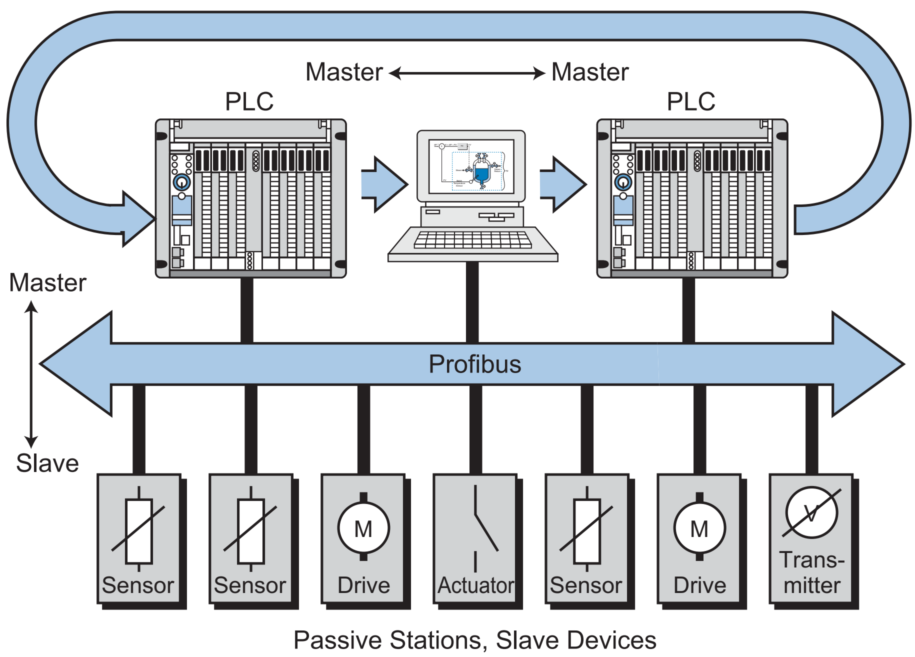


Figure 19-31. Master-slave and master-master Profibus communications.

As mentioned earlier, layer 2 of the Profibus network is responsible for data integrity, which is ensured through the Hamming Distance HD = 4 error detection method. The Hamming distance method can detect errors in the transmission medium, as well as in the transceivers. As defined by the IEC 870-5-1 standard, this error detection method uses special start and end delimiters, along with slip-free synchronization and a parity bit for 8 bits.

Profibus networks support both peer-to-peer and multipeer communication in either broadcast or multicast configurations. In broadcast communication, an active station sends an unconfirmed message to all other stations. Any of these stations (including both masters and slaves) can take this information. In multicast communication, an active station sends an unconfirmed message to a particular group of master or slave stations.

The physical layer, or layer 1, of the ISO model defines the network's transmission medium and the physical bus interface. The Profibus network adheres to the EIA RS-485 standard, which uses a two-conductor, twisted-pair wire bus with optional shielding. The bus must have proper terminations at both ends. Figure 19-32 illustrates the pin assignment used in the Profibus. The maximum number of stations or device nodes per segment is 32 without repeaters and 127 with repeaters. The network transmission speed is selectable from 9.6 kbaud to 12 Mbaud, depending on the distance and cable type. Without repeaters, the maximum bus length is 100 m at 12 Mbaud. With conventional type-A copper bus cable, the maximum distance is 200 m at 1.5 Mbaud. This distance can be increased to up to 1.2 km if the speed of the network is reduced to 93.75 kbaud. With type-B cable, the maximum distance is 200 m at 500 kbaud and up to 1.2 km at 93.75 kbaud. The type of connector used is a 9-pin, D-sub connector.

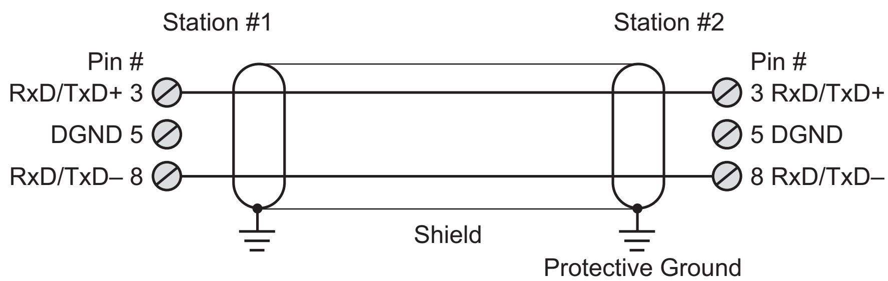
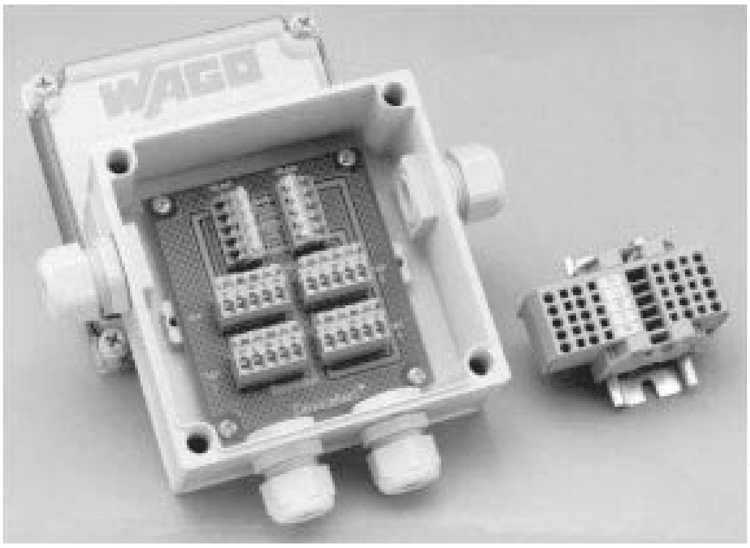


Figure 19-32. Profibus pin assignment.

19-6 I/O Bus Installation and Wiring Connections

Installation Guidelines

One of the most important aspects of an I/O bus network installation is the use of the correct type of cable, number of conductors, and type of connectors for the network being used. In device bus networks, the number of conductors and type of communication standard (i.e., RS-485, RS-422, etc.) varies depending on the specific network (e.g., DeviceNet, Seriplex, ASI, Profibus, Fieldbus, etc.). The connector ports (see Figure 19-33), which connect the I/O field devices to the I/O bus network, can be implemented in either an open or an enclosed configuration. Figure 19-34 illustrates the port connections for a DeviceNet I/O bus network.



Courtesy of WAGO, Brown Deer, WI

Figure 19-33. Connector ports from a DeviceNet bus network (left: enclosed, right: open).

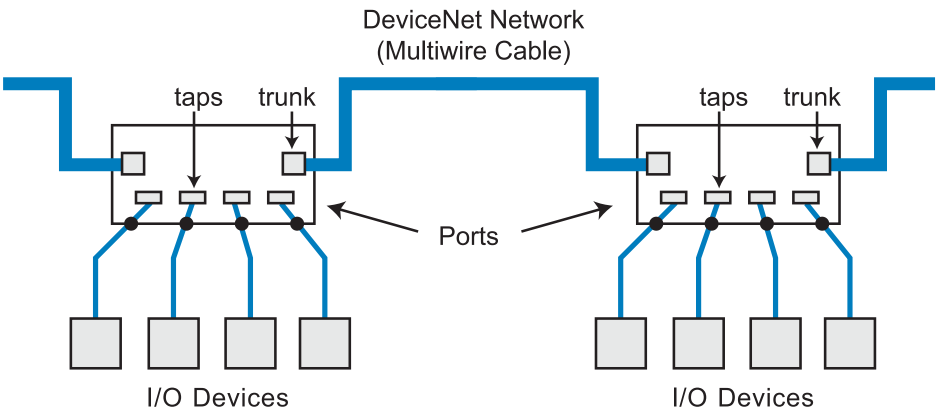


Figure 19-34. DeviceNet I/O bus port connections.

In general, an enclosed configuration can connect from 4 to 8 I/O field devices in one drop, while an open configuration can accommodate two to four I/O devices. Enclosed connector ports are used when the network must be protected from the environment, as in a NEMA 4–type enclosure. Open ports are used when replacing I/O connections in a system that already has a DIN rail installation, where the open ports can be easily mounted onto the rail.

Device Bus Network Wiring Guidelines

Figure 19-35 illustrates a typical wiring diagram connection for a DeviceNet CANbus network. Note that the two trunk connections constitute the main cable of the network, with the five wires providing signal, power, and shielding. A printed circuit board assembly internally connects the two trunk connectors, or ports, and the I/O device taps. Most manufacturers of device bus networks provide "plug-and-play" connectors and wiring systems, which facilitate installation and system modifications (see Figure 19-36).

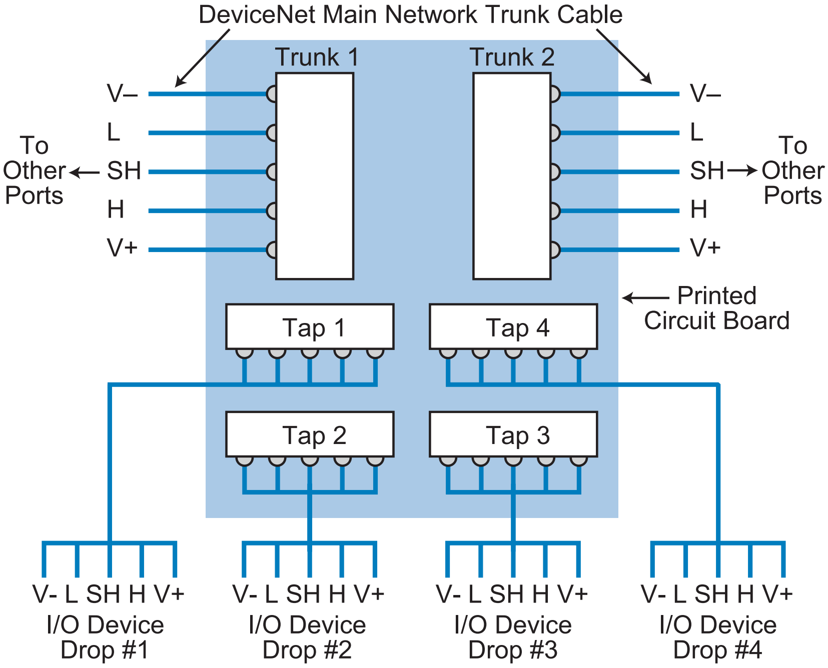
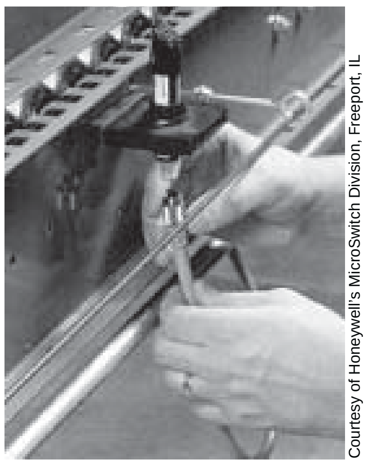


Figure 19-35. CANbus DeviceNet wiring diagram for the multiport tap in Figure 19-34.

(a)



(b)

Figure 19-36. (a) Plug-and-play connectors and **(b)** their installation.

The majority of device bus networks require that a terminator resistor be present at the end of the main trunk line for proper operation and transmission of network data. Each network may also specify the number of nodes that can be connected to the network, the speed of transmission depending on the trunk length, and the maximum drop length at which field devices can be installed. The network may also limit the cumulative drop length, meaning that the combined lengths of all the drops cannot exceed a particular specification. Table 19-4 shows the specifications for Allen-Bradley's DeviceNet communication link network.

Data Transmission Rate	Trunk Length	Max. Drop Length	Max. # of Nodes	Cumulative Drop Length
125K bits/sec	500 m (1640 ft)			156 m (512 ft)
250K bits/sec	200 m (656 ft)	3 m (10 ft)	64	78 m (256 ft)
500K bits/sec	100 m (328 ft)			39 m (128 ft)

Table 19-4. DeviceNet specifications.

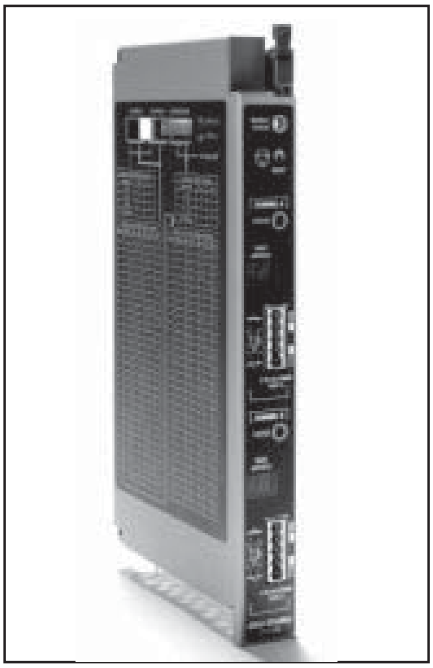
PROCESS BUS NETWORK WIRING GUIDELINES

Cable criteria similar to device bus networks apply to process bus networks. Depending on the network protocol specifications, specifically those of layer 1 (physical) of the OSI model, the conductor may be twisted pair or coaxial, operating at different network transmission speeds. Table 19-5 shows the wiring and network speed characteristics of the Fieldbus Foundation network (Fieldbus protocol). Figure 19-37 shows the process bus interface for Allen-Bradley's family of PLCs, which is compatible with the Profibus protocol. This Profibus interface can work at network speeds of 9.6, 19.2, 93.75, 187.5,

	Data Rate		
	Slow	Standard	High
Speed	31.25K bps	1M bps	2. Mbps
Cable	twisted-pair	twisted-pair	twisted-pair
Distance	1900 m	750 m	500 m

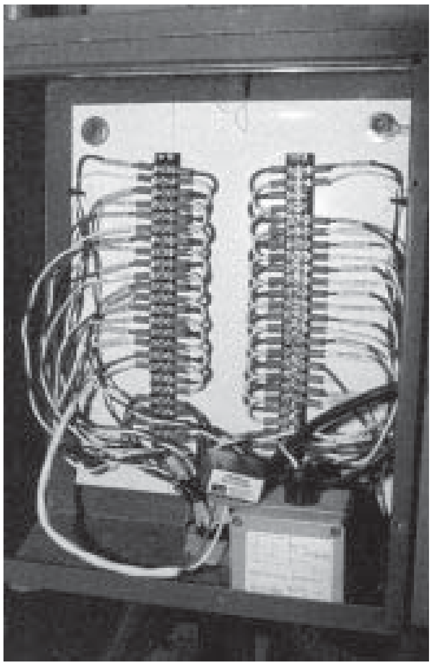
Table 19-5. Fieldbus network characteristics.

and 500 kbits/sec. Process bus wiring installations may also require a termination block at the end of the wiring. T-junction connectors provide the connections to different I/O field devices (see Figure 19-38).



Courtesy of Allen-Bradley, Highland Heights, OH

(a)



Courtesy of Fieldbud Foundation, Austin, TX

(b)

Figure 19-37. (a) Allen-Bradley's Profibus process bus interface and **(b)** the wiring installation of a Fieldbus network using two sets of shielded twisted-pair wire.

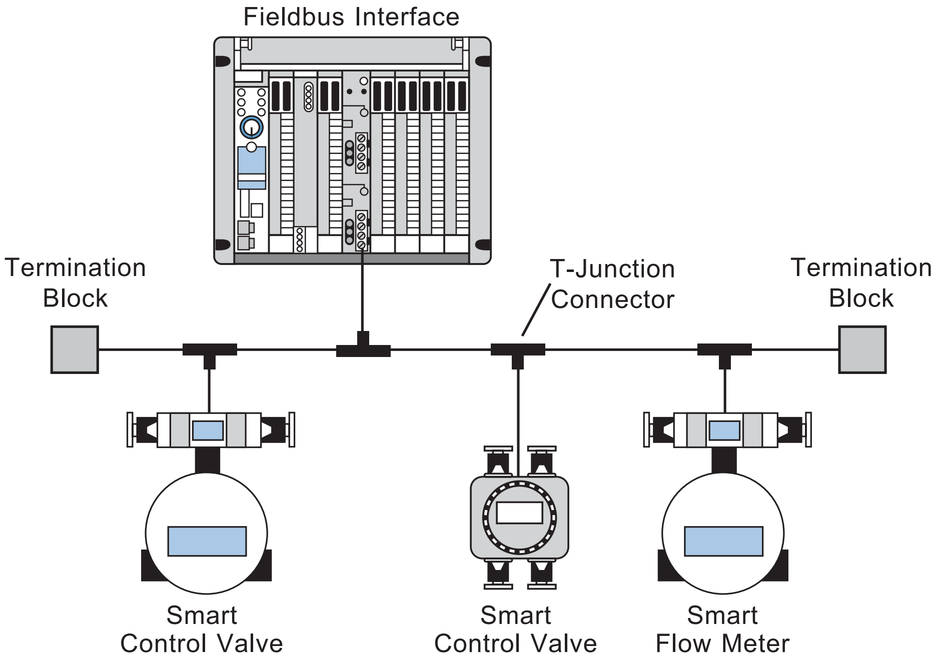


Figure 19-38. Fieldbus network using T-junction connectors.

I/O BUS NETWORK ADDRESSING

Addressing of the I/O devices in an I/O bus network occurs during the configuration, or programming, of the devices in the system. Depending on the PLC, this addressing can be done either directly on the bus network via a PC and a gateway (see Figure 19-39a) or through a PC connected directly to the bus network interface (see Figure 19-39b). It can also be done through the PLC's RS-232 port (see Figure 19-40). Some I/O bus networks have switches that can be used to define device addresses, while others have a predefined address associated with each node drop.

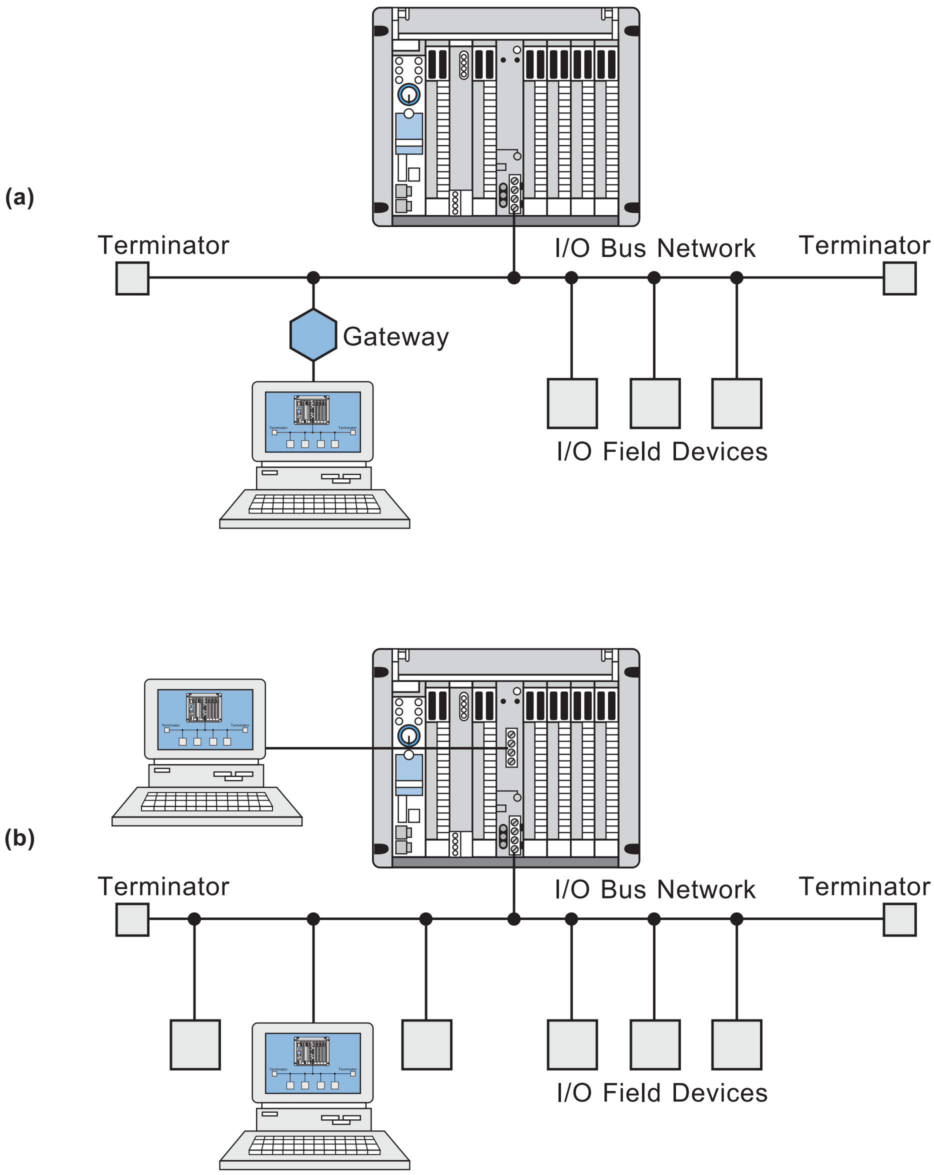


Figure 19-39. I/O addresses assigned using **(a)** a PC connected to the network through a gateway and **(b)** a PC connected directly to the network.

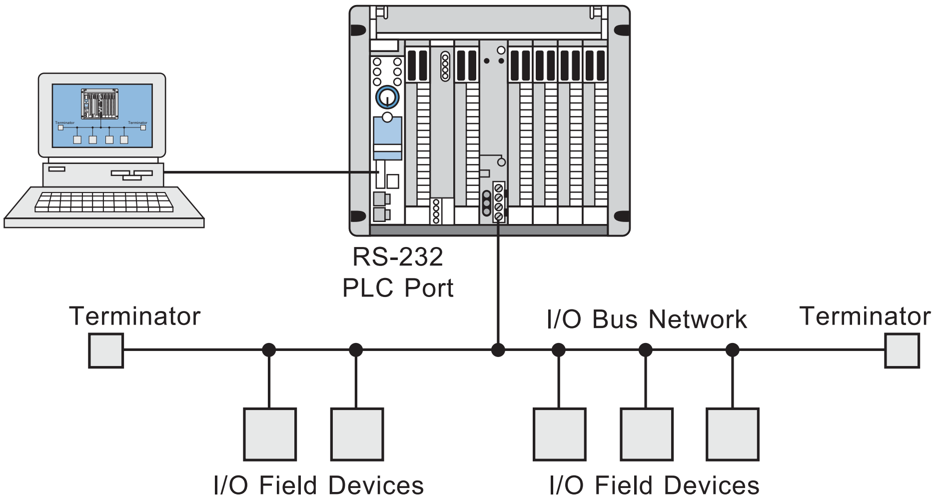


Figure 19-40. I/O addresses assigned using a PC connected to the PLC's RS-232 port.

19-7 SUMMARY OF I/O BUS NETWORKS

The device and process types of I/O bus networks provide incredible potential system cost savings, which are realized during installation of a control system. These two types of I/O networks can also form part of a larger, networked operation, as shown in Figure 19-41. In this operation, the information network communicates via Ethernet between the main computer system (or a personal computer) and a supervisory PLC. In turn, these PLCs communicate with other processors through a local area control network. The PLCs may also have remote I/O, device bus, and process bus subnetworks. The addition of field devices to this type of I/O network is relatively easy, as long as each field device is compatible with its respective I/O bus network protocol.

The main difference between the device bus and the process bus networks is the amount of data transmitted. This is due to the type of application in which each is used. Device bus networks are used in discrete applications, which transmit small amounts of information, while process bus networks are used in process/analog applications, which transmit large amounts of data. Figure 19-42 shows a graphic representation of these networks based on the potential amount of information that can be transmitted through them.

In terms of cost, a process bus network tends to be more expensive to implement than a device bus network, simply because analog I/O field devices are more expensive. Also, the intelligence built into a process bus network is more costly than the technology incorporated into a device bus network. For example, the CAN, SDS, ASI, ASIC, and InterBus-S chips used in device networks are readily available, standard, off-the-shelf chips, which

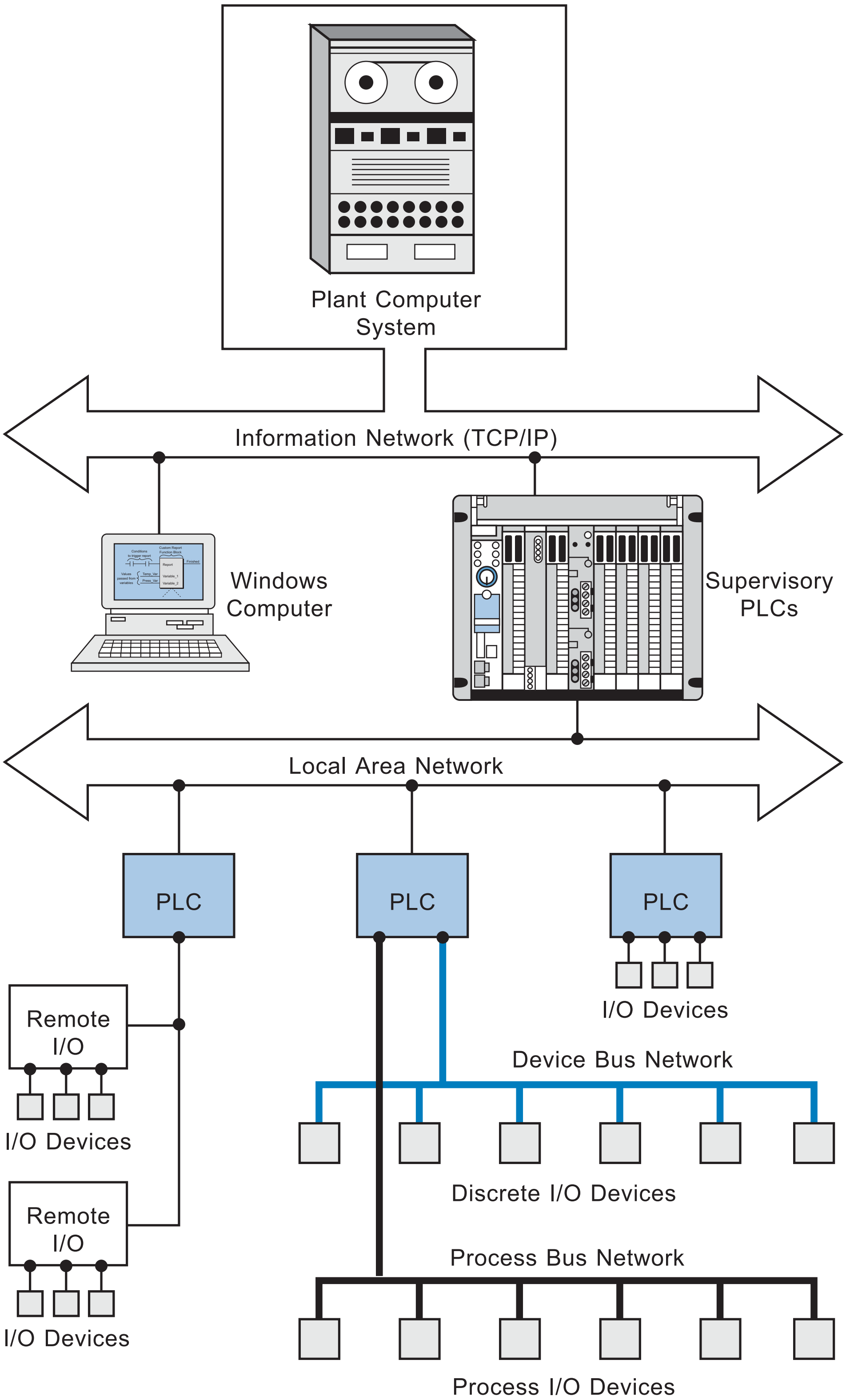


Figure 19-41. Large plantwide network.

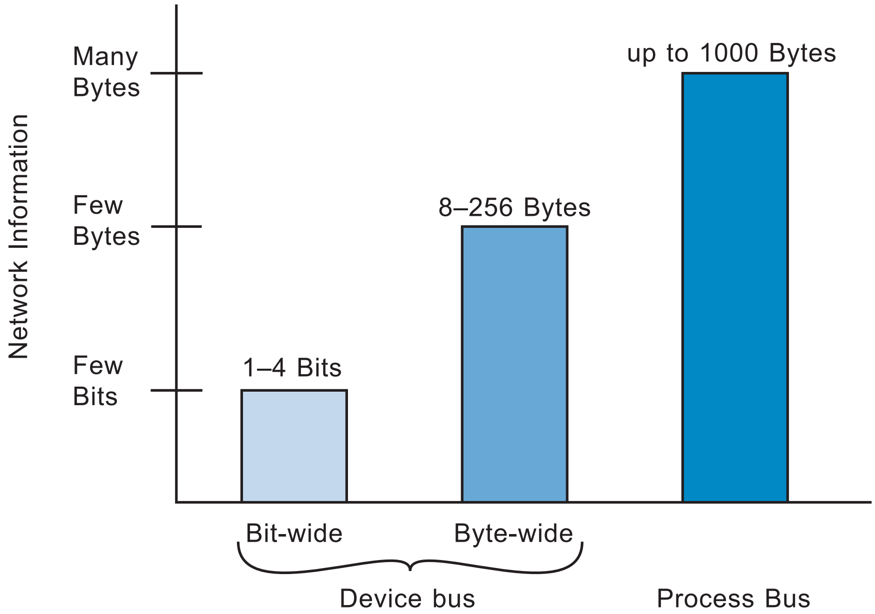


Figure 19-42. Network data transmission comparison.

can be purchased at a relatively low cost. Process bus networks, on the other hand, require devices with more sophisticated electronics, such as microprocessors, memory chips, and other supporting electronic circuitry, which makes process network I/O devices more expensive. This expense, however, is more than offset by the total savings for system wiring and installation, especially in the modernization of existing operations where wire runs may already be in place.

KEY TERMS

acyclic message
bit-wide bus network
byte-wide bus network
cyclic message
device bus network
I/O bus network
I/O bus network scanner
medium access control (MAC)
process bus network
tree topology