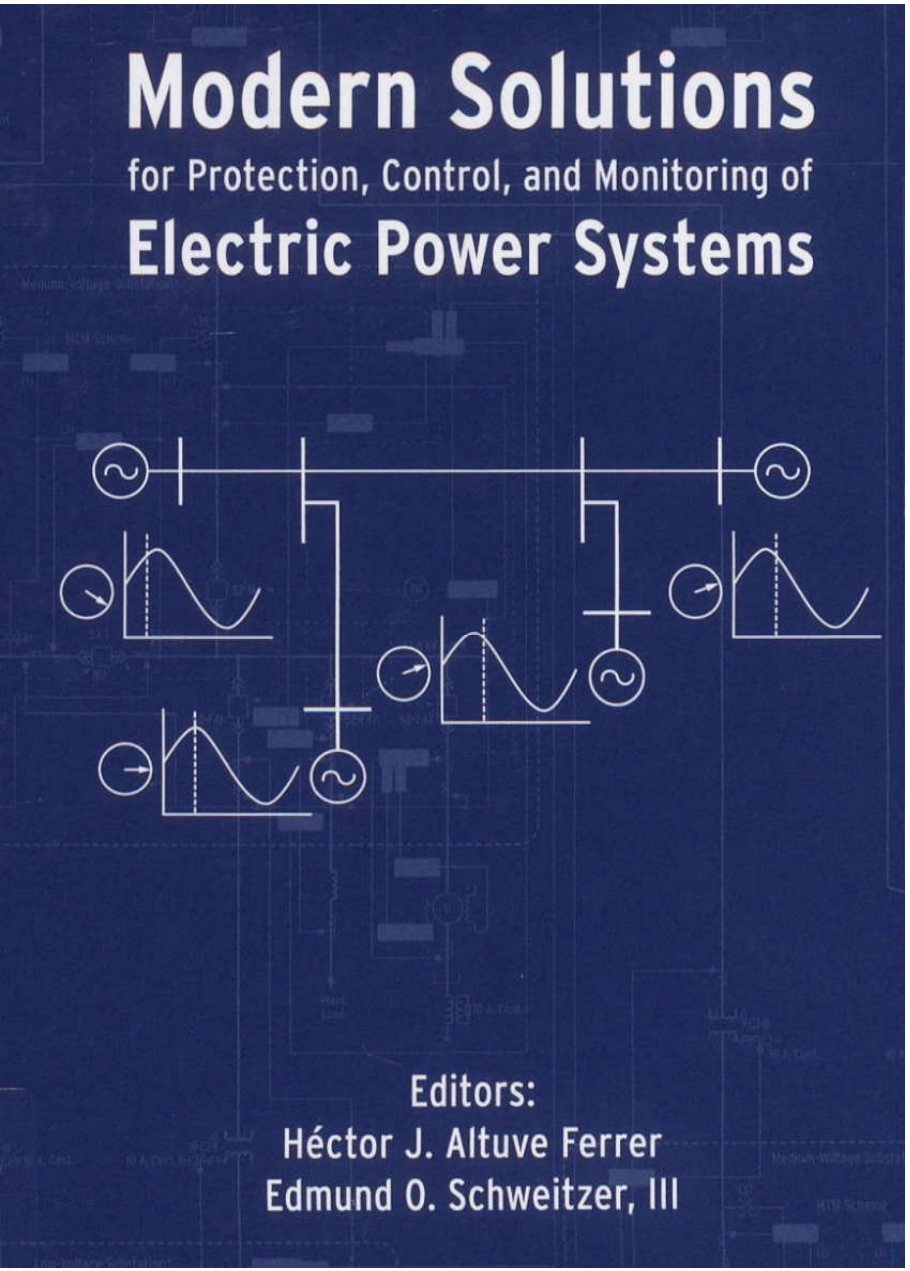


Chapter 9

Power system communication

Power system communication
Introduction

- Communications technology plays an important role in power system operation and management.
  - ✓ This role is expanding because of lower transmission margins, fluctuating market demands, and the need for more efficient power system operation, improved reliability, and faster response to power system events.

- System-wide, network-based communications technologies, such as Synchronous Optical Network (SONET) and Ethernet, allow contact with virtually all protection, control, and monitoring (**PCM**) devices on the power system.
  - ✓ This ability boosts a variety of applications, such as remote equipment monitoring, centralized control, distributed peer-to-peer control, and wide area protection.

- Modern communication, local processing, and time-synchronized measurements open many doors to improving power system operation, protection, and control.

- **SEL** uses the latest advances in network-based communications technologies, including **Ethernet**, **IEC 61850**, and **traditional supervisory control** and **data acquisition (SCADA) protocols**.
  - ✓ Ethernet technology is available in many SEL products, spanning all application areas from industrial to utility.

Power system communication

Communications System Overview

- Modern communications systems are very large, with their connectivity virtually mirroring that of the underlying power system.
- **Protecting**, **controlling**, and **monitoring** the power system requires the exchange of locally generated information.

Communication-based power system applications include:

- ✓ Pilot protection
- ✓ Substation and distribution system automation
- ✓ Wide-area protection, control, and monitoring
- ✓ SCADA
- ✓ Energy management systems (**EMS**)
- ✓ Security (video monitoring, for example)
- ✓ Engineering access and maintenance

- **These applications have different requirements.**
- In next slide ,Table lists the typical response times and event durations for each application.

Power system communication

Communications System Overview

Table. Response time and event durations for different power system communication applications.

application	participants	Application Response Time	Typical Event Duration
Pilot protection	IED to IED	1ms to 30ms	Less than 100ms
Substation and distribution system automation	IED to IED and IED to automation controller	30ms to 1 second	30ms to several minutes
Wide-area protection, control, and monitoring	IED to IED and IED to Wide-area controller	100ms to 1 second	100ms to several minutes
SCADA	IED/RTU to master and system operator	Less than 5 second	Seconds to hours
Energy management systems (EMS)	Operator/dispatcher communication	Less than 5 second	Minutes to hours
Security	Various	Less than 5 second	Minutes to days
Engineering access and maintenance	Engineer to IED/RTU	Less than 5 second	Hours to months

Power system communication

Communications System Overview

1) Pilot protection

- Pilot protection requires relay-to-relay communication and typically operates within a few cycles.
- Relay-to-relay communications protocols include:
  - ✓ SEL MIRRORED BITS,
  - ✓ IEC 61850 Sampled Values (SV),
  - ✓ IEC 61850 Generic Object-Oriented Substation Events (**GOOSE**).

2) Substation and distribution automation

- These systems are fast growing areas in power system communications.
- They use autonomous devices capable of monitoring, reconfiguring, and optimizing power system operation, such as faulted circuit indicators, recloser controls, regulator controls, programmable logic controllers, and hardened substation computing platforms.

Power system communication

Communications System Overview

3) Wide-area protection and control

- Wide-area protection and control systems are critical communication-based systems acting on a large geographic area.
- While pilot protection systems normally protect a transmission line, wide-area protection and control systems are focused on overall power system stability and survival.

4) SCADA and EMS

- SCADA and EMS systems traditionally cover large geographic areas and use a combination of direct serial links, modems, radio/microwave, and SONET/Ethernet networks to meet stringent availability requirements.
- **SCADA networks are often independent** and managed separately from other communications resources.

SCADA protocols include:

- ✓ **Legacy protocols** (optimized for low-speed serial communications channels), such as PG&E 2179, Modbus, and Harris.
- ✓ **Standardized, low-speed serial protocols**, such as DNP3, IEC 60870-5-101, and IEC 60870-5-103.
- ✓ **Ethernet protocols** such as Modbus-IP, DNP3-IP, and IEC 60870-104.

Power system communication

Communications System Overview

3) Security

- Power system infrastructure is a critical asset that must operate reliably in spite of a variety of threats, such as equipment failures, weather-related damage, operator errors, and malicious attacks.
- Modern communications systems provide fast response to such problems, enabling reliable delivery of power to the affected areas.
- New applications in this category include wide area protection schemes, synchrophasor measurements, real-time fault location, geographic-information-system (**GIS**) outage management, and video monitoring.
  - ✓ All of these applications require additional bandwidth and must be coordinated with existing communications services.

1) Engineering access and maintenance

- Engineering access communication allows remote monitoring and configuration of substation IEDs.
- Protection engineers remotely access Oscillography falut records, sequential events records, and device settings.
- They also execute firmware upgrades and per for other management functions.
- Engineering access often limited to a small group of well-trained engineers directly responsible for protection system operation.

Power system communication

Communications System Overview

This figure shows the use of

- ✓telephone networks (PSTN) for engineering access
- ✓dedicated optical fibers
- ✓ radio communication
- ✓ leased analog lines
- ✓relay-to-relay
- ✓Transmission Control Protocol/Internet Protocol (TCP/IP) networks for SCADA access

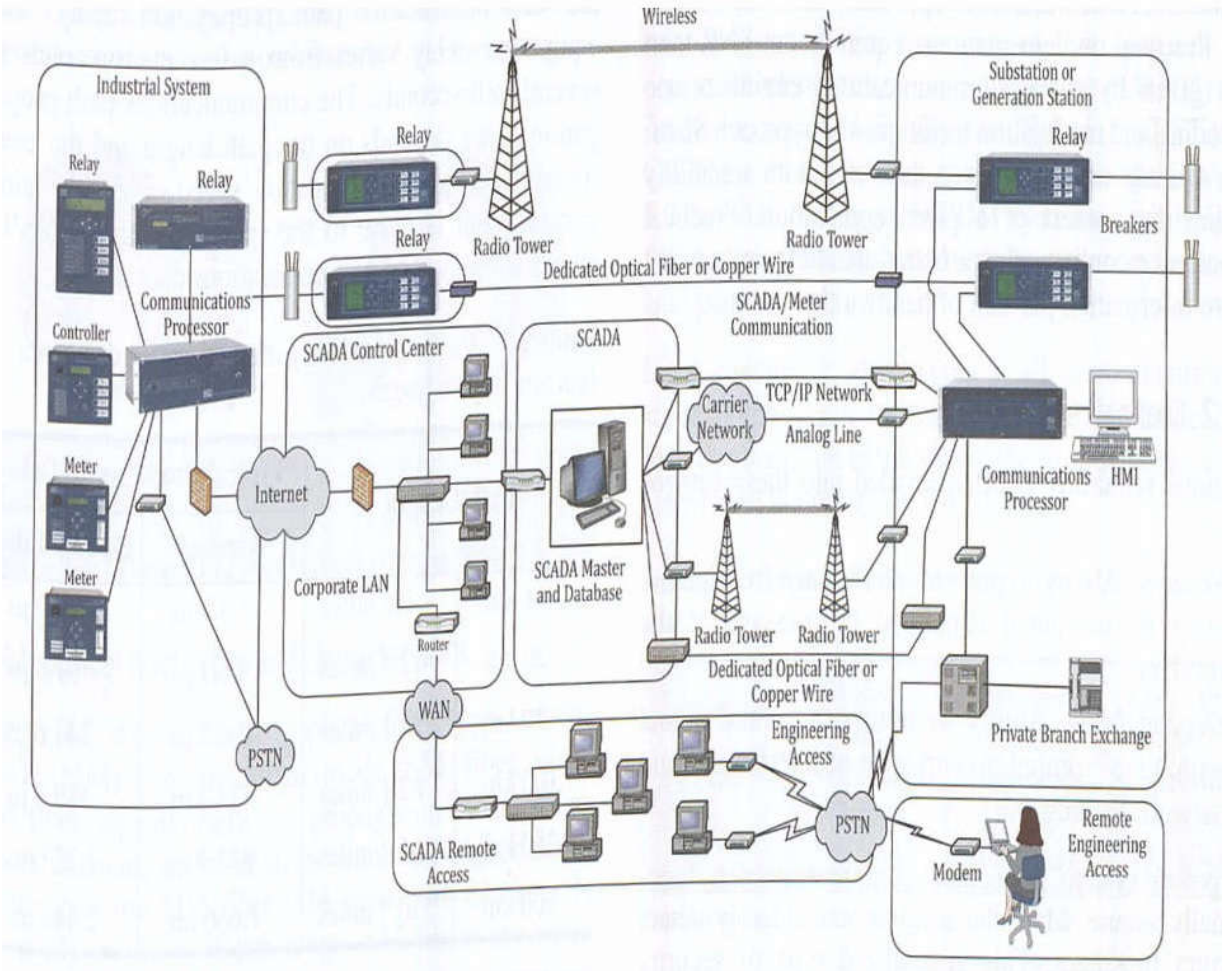


Fig. Power system communications example.

Power system communication

Communications Channels

- **Early communications systems** used copper conductors and included privately owned pilot wire channels, dedicated telephone circuits, and power line carrier channels.
- Today, modern communication uses optical fibers combined with digital data transmission.
- **Fiber-optic channels feature** high capacity and reliability, low noise, interference immunity, and safety.
- Spread-spectrum radio communication offers cost-effective ways to reach the most remote parts of the power system.

Communications Channels

1) Channel capacity
2) Channel reliability
3) Channel availability
4) Propagation delay

Power system communication

Communications Channels

1) Channel capacity

Channel capacity is the amount of information that can be communicated through the channel.

- Shannon established that information can be reliably transmitted over a noisy channel if the data transmission rate is sufficiently low.

$$C = W \log_2 \left(\frac{P}{N} + 1\right)$$

  - ✓ W is the channel bandwidth in hertz , P is the signal power in watts; N is the noise power in watts, and channel capacity **C** is measured in bits per second (**bps**).

- Channels with better signal-to-noise ratio **(SNR)** provide faster data transmission.

  - ✓ Conversely, faster data transmission requires a quieter channel or more bandwidth.

- **In practice**, it is difficult to approach Shannon's limits.

- Practical experience confirms that a better channel can transmit more information per unit of bandwidth.

Power system communication

Communications Channels

2) Channel reliability

Channel reliability is often divided into these categories:

- ✓ Security: Ability to prevent interference from generating an unwanted command or message at the receiver.
- ✓ Dependability: Ability to transport a valid signal within the required time in spite of interference and network loading.

- ❖ In power system protection, communication is functionally secure when the receiver can reliably detect corrupt messages.
- ❖ This generalized type of security should not be confused with cybersecurity, which refers to operational security.
  - ✓ Cybersecurity methods enhance functional message security by hiding message content, by generating message digests aimed at preventing message tampering, or by clearly identifying the sender.

- ❖ **IEC Standard 60834-1** contains explicit recommendations for blocking, permissive tripping, and direct tripping pilot protection schemes in terms of their susceptibility to noise bursts.(Table)

Table. Susceptibility to noise bursts per IEC Standard 60834-1

Pilot Scheme Type	Security (Bursts/Undetected Error)
Blocking	10^4
Permissive tripping	10^7
Direct tripping	10^8

Power system communication

Communications Channels

3) Channel availability

- Channel availability is the proportion of time during which the channel remains operational.
  - ✓ Adding redundancy improves availability.

4) Propagation delay

- Propagation delay is the time that a signal spends traveling through the communications channel.
- It equals the sum of the communications equipment delay and the communications path propagation delay.
  - ✓ The equipment delay varies from a few microseconds to several milliseconds.

- The communications path propagation delay depends on the path length and the electromagnetic wave propagation speed, which is fairly constant and is close to the speed of light

Table. Communications path propagation delay as a function of path length.

Path Length		Typical Propagation Delay	
		Wireless	Optical Fiber
1 km	0.6 miles	3.3 μs	4.9 μs
20 km	12.4 miles	66.7 μs	97.8 μs
50 km	31.1 miles	166.7 μs	244.6 μs
100 km	62.1 miles	333.3 μs	489.2 μs
250 km	155.4 miles	833.3 μs	1.223 ms
500 km	310.7 miles	1.666 ms	2.446 ms

Power system communication

Fiber-Optic-Based Communication

❖ Optical fiber offers high bandwidth, very high reliability, exceptional SNR, inherent immunity to electromagnetic interference (**EMI**), and electrical safety.

✓ Because of these properties, optical fiber is a preferred medium for modern power system communications.

1) Optical fiber types and characteristics

❖ An optical fiber is a dielectric waveguide that uses a total internal reflection process to transmit light along its longitudinal axis.

❖ The fiber has a core with a high refractive index (such as silica glass), surrounded by cladding, a material with a lower refractive index.

❖ Additional buffer and jacket layers provide shielding from external light, enhance mechanical properties, prevent water penetration, and ease termination.

❖ Using a high purity glass for the core reduces the optical signal transmission losses.

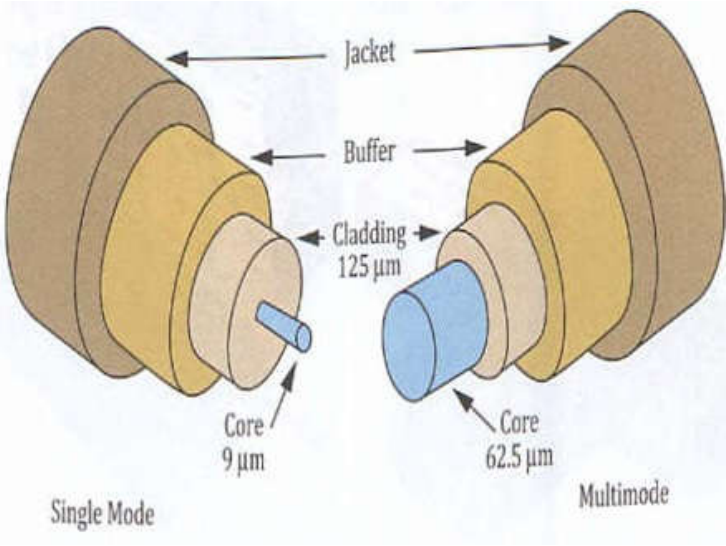


Fig. Typical fiber-optic cable construction.

Power system communication

Fiber-Optic-Based Communication

The two optical fiber types:

1) multimode (MM) fiber
   - ✓ MM fiber supports several propagation modes.
   - ✓ Typical MM fiber core diameters are 50 μ_m , 62.5 μ_m, and 200 μ_m.
2) single-mode (SM) fiber.
   - ✓ SM fiber core diameter is generally in the 8–10 um range.
   - ✓ SM fibers are more expensive to terminate and require more expensive electro-optical components.

❖ Since SM fiber supports only one propagation mode, it has lower attenuation, lower dispersion, and higher bandwidth than the MM fiber.

Fiber-optic cable size is often expressed as two numbers.

1) The first number specifies the core diameter;
2) the second specifies the cladding outer diameter.

For example, 50/125 indicates an MM fiber with 50 μ_m core and 125 μ_m cladding.

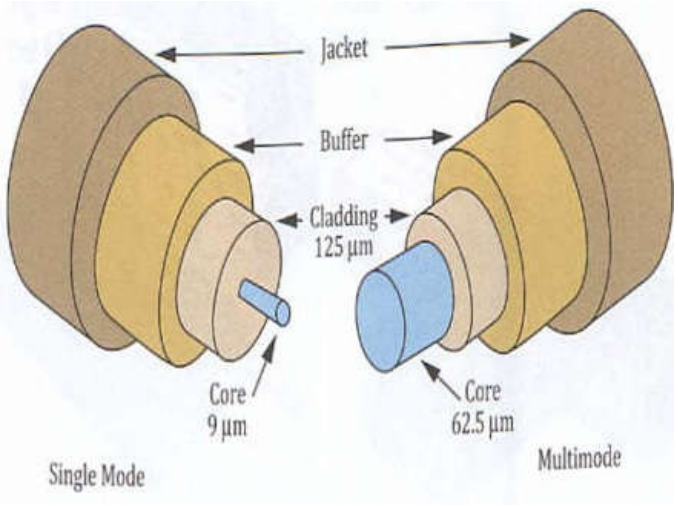
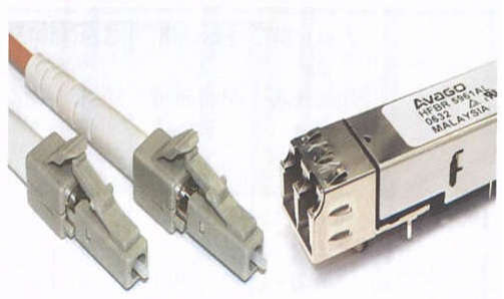


Fig. Typical fiber-optic cable construction.

Fiber-Optic-Based Communication

Fiber-optic connectors and transceivers

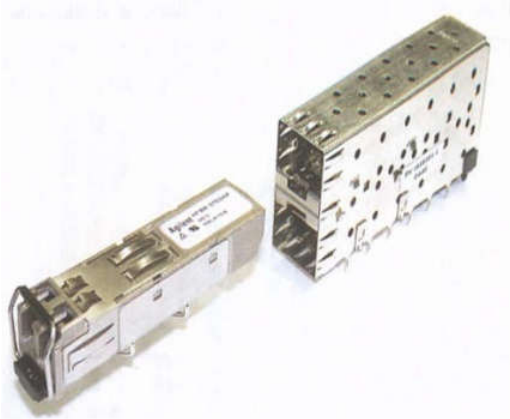
- ✓ The V-pin connector shown in Figure(1) is a low-cost solution optimized for 200 μ_mHCS fiber, widely used for short connections between relays and a communications processor or a substation computer.
- ✓ Figure(2) shows one of the more recent small form factor pluggable (**SFP**) transceivers;
- ✓ these transceivers normally also have a diagnostic interface port so the associated device can detect abnormal situations, such as a slowly deteriorating fiber-optic link (by monitoring the received power level).
- ✓ The module inserts into a mating cage via a special connector on the bottom.
- ✓ An optional locking mechanism further enhances module fastening.



Figure(1). V-pin connector with the optional latching mechanism.

Table. different SFP options for Ethernet interfaces

Speed	Wavelength	Media Type	Standard	Range
100 Mbps	850 nm	MM fiber	100BASE-SX	300 m
100 Mbps	1,310 nm	MM fiber	100BASE-FX	2 km
100 Mbps	1,310 nm	SM fiber	100BASE-FX	10–90 km
100 Mbps	1,550 nm	SM fiber	100BASE-LH	80–160 km
1 Gbps	N/A	Copper	10/100/1000BASE-T	100 m
1 Gbps	850 nm	MM fiber	1000BASE-SX	300 m
1 Gbps	1,310 nm	MM fiber	1000BASE-LX	500 m
1 Gbps	1,310 nm	SM fiber	1000BASE-LX	10–70 km
1 Gbps	1,550 nm	SM fiber	1000BASE-LH	50–80 km



Figure(2). SFP fiber optic transceiver.

Fiber-Optic-Based Communication

Dedicated fiber-optic channels

❖ Dedicated fiber-optic channels are the best choice in terms of dependability, security, speed, and simplicity.

❖ SEL low-cost fiber-optic transceivers, shown in Figure , make dedicated fiber optic channels even more attractive:

- ✓ The relay often powers the transceiver, eliminating the cost and reliability concerns associated with a separate power source.
- ✓ Some transceivers also plug directly onto the relay, eliminating a metallic cable.
- ✓ Elimination of cable and external power source reduces EMI susceptibility.
- ✓ As with all communications systems, there is always a risk that the physical event causing a power system fault will also break the optical fiber.
  - For example, a tower collapse or an overhead ground wire failure may affect the optical fibers embedded in the ground wire. Other failure causes include tornadoes, ice loading, and airplane collisions.

❖ **Dedicated fiber optic link simplicity further increases the overall system reliability.**

Fig. SEL low-cost fiber-optic transceivers.

Fiber-Optic-Based Communication

Dedicated fiber-optic channels

Table. the characteristics of the SEL-2800 series fiber-optic transceivers.

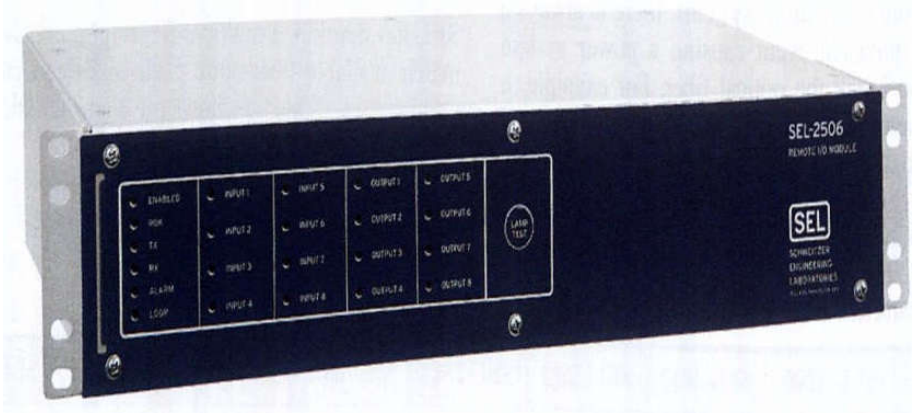
	SEL-2800	SEL-2810	SEL-2812	SEL-2814	SEL-2815	SEL-2829	SEL-2830	SEL-2831
Wavelength	650 nm	650 nm	850 nm	850 nm	850 nm	1300 nm	1300 nm	1550 nm
Optical connector	V-Pin	V-Pin	ST®	ST	ST	ST	ST	ST
Fiber type	Multimode	Multimode	Multimode	Multimode	Multimode	Single mode	Single mode	Single mode
Link budget	9 dB	9 dB	16 dB	16 dB	41 dB	23 dB	40 dB	40 dB
Typical TX power	–30 dBm	–30 dBm	–13 dBm	–13 dBm	–10 dBm	–27 dBm	–10 dBm	–10 dBm
RX minimum sensitivity	–39 dBm	–39 dBm	–29 dBm	–29 dBm	–51 dBm	–50 dBm	–50 dBm	–50 dBm
Fiber size	200 µm	200 µm	50–200 µm	50–200 µm	50–200 µm	9–10 µm	9–10 µm	9–10 µm
Approximate range	500 m	500 m	1.2–4 km	1.2–4 km	6–15 km	23 km	80 km	110 km
Data rate	0–40 kbps	0–20 kbps	0–115 kbps	0–115 kbps	0–40 kbps	0–40 kbps	0–40 kbps	0–40 kbps
Time code	None	IRIG-B	IRIG-B	None	None	None	None	None

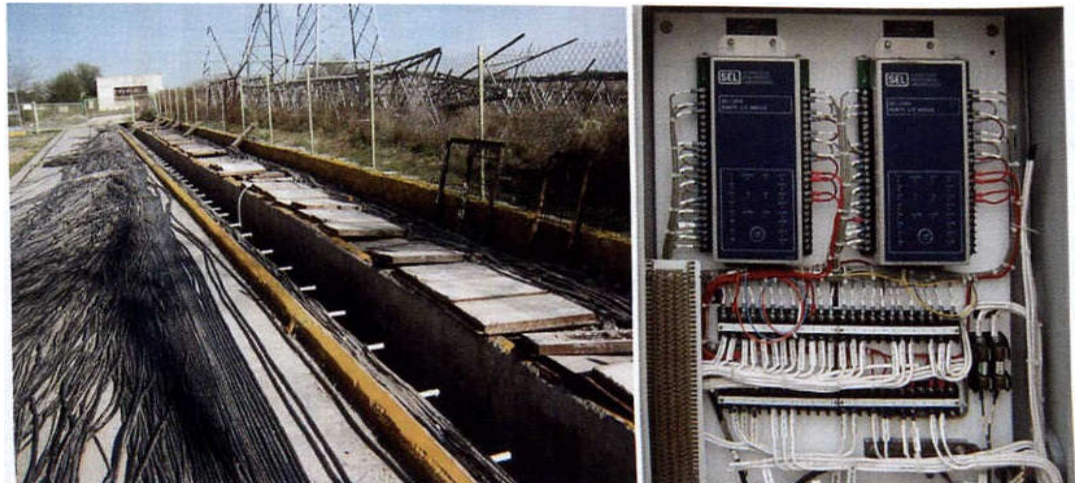
Fiber-Optic-Based Communication

Dedicated fiber-optic channels

Fiber-optic-based remote 1/0 modules

- Remote input/output (1/0) modules, such as the SEL-2505 and SEL-2506.
  - typically installed in outdoor cabinets on the substation switchyard, communicate via dedicated fiber-optic cable with IEDs located in the substation control enclosure.
  - These modules lower installation costs and the amount of copper substation wiring.
  - By multiplexing digital signals over a single pair of optical fibers, each module controls eight discrete contact outputs and transmits the state of eight contact inputs.
  - SEL remote I/O modules interface with a number of SEL IEDs and use the field-proven MIRRORED BITS communications protocol, offering low latency combined with exceptionally reliable data transmission and built-in error detection features.





Fiber-Optic-Based Communication

Shared fiber-optic channels

- A single optical fiber easily carries multiple contact states and/or measurement channels, such as those needed when using remote I/O or RTD modules.
- In Fact, A single fiber can transport millions of channels with millisecond latency.
- Multiplexed data Streams usually contain different types of traffic, including power system protection, SCADA, engineering access, telephone service, video surveillance, and data network traffic.

1. Fiber-optic multiplexer

- Fiber-optic multiplexers combine many relatively slow digital and analog channels into a single wideband light signal.
  - ✓ Multiplexers, therefore, make more efficient use of fiber and of fiber bandwidth.

Multiplexer types are:

- ✓ **Analog FDM**. Each channel has its own frequency band (4 kHz wide for a voice channel).
- ✓ **Digital TDM (SONET, etc.).** Each channel has its own time slot in a 125 us frame (8 bits for a voice channel).
- ✓ **Ethernet**. Each end unit maps its information into Ethernet packets (64 to 1,500 bytes long).

Fiber-Optic-Based Communication

Shared fiber-optic channels

2. SEL support for direct fiber optic interface to multiplexers

❖ To avoid the problems of using copper pairs for data transmission, IEEE Standard C37.94 defines a direct fiber-optic interface between relays and the multiplexer.

- ✓ This standard defines transport of as many as twelve 64-kbps DSO channels over a single, synchronous, serial fiber-optic connection.
- ✓ This interface has built-in error detection and is optimized for power system protection.
- ✓ Error detection mechanisms include strict framing structure and bit repetition (actual value and its complement).

The complete list includes:

- ✓ SEL-311L Line Current Differential Relay.
- ✓ SEL-3094 and SEL-2894 Interface Converters (fiber-optic modems).
- ✓ SEL-2126 Fiber-Optic Transfer Switch.
- ✓ SEL-2594 Contact Transfer Module and
- ✓ SEL-2595 Teleprotection Terminal.

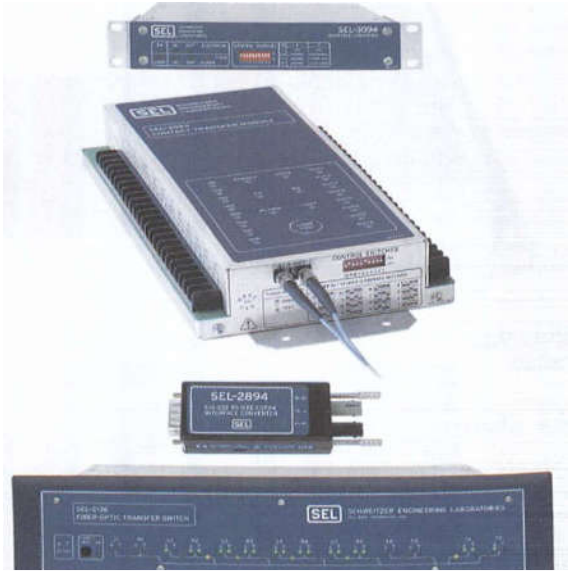


Fig. some SEL products that include the **C37.94** fiber-optic interface.

Fiber-Optic-Based Communication

Shared fiber-optic channels

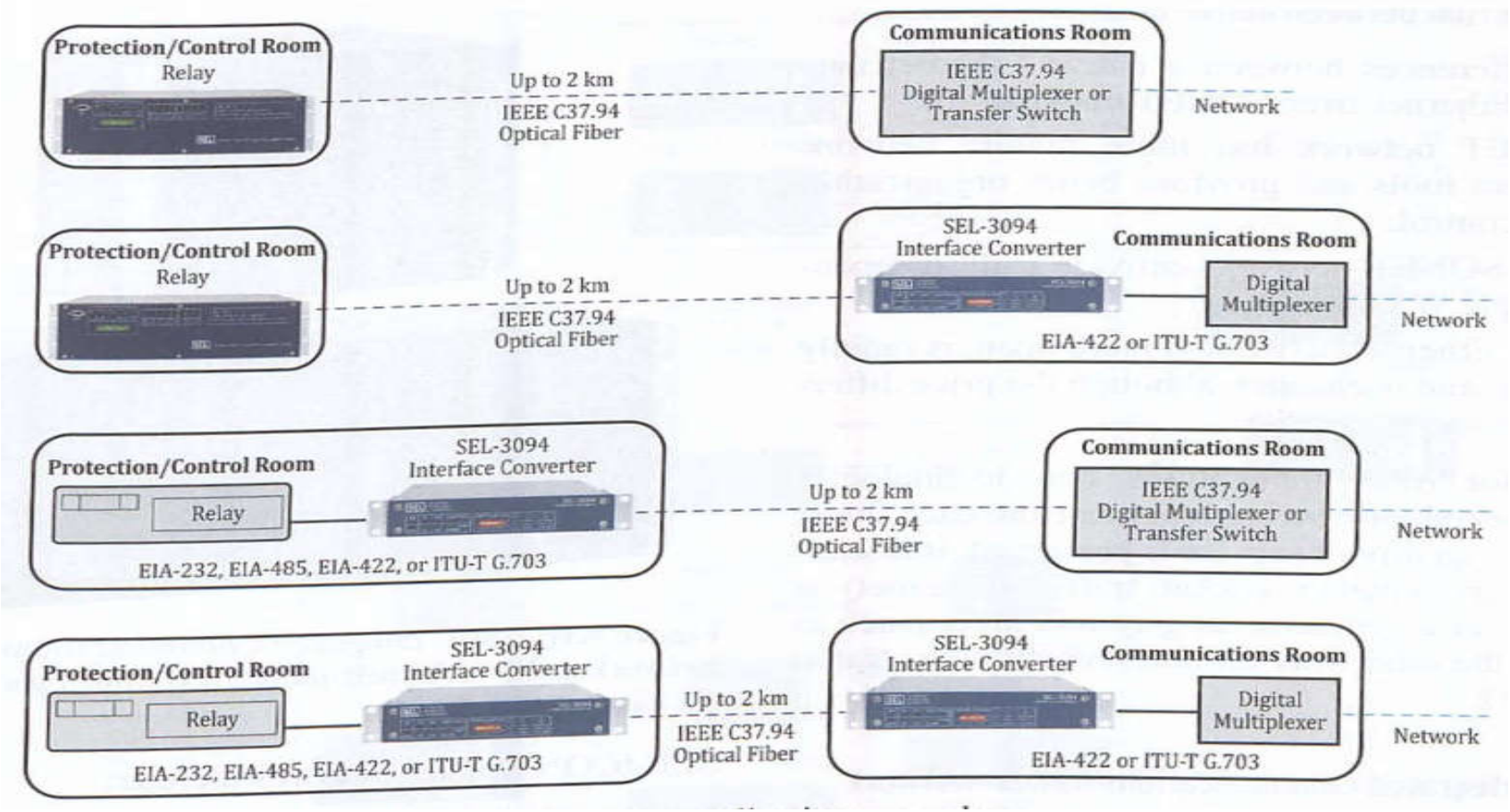


Fig. illustrates typical **IEEE C37.94** interface applications.

Fiber-Optic-Based Communication

Shared fiber-optic channels

3. SONET

- **SONET multiplexers** are traditionally used to establish long-distance communication between substations.
- **versatility of SONET:** equipment manufacturers now offer SONET multiplexers that can be user-configured to handle multiple Ethernet wide area networks (**WAN**).
  - Each WAN has its own dedicated pipe of whatever bandwidth (bit rate) the user desires.
  - This topology mitigates security and dependability concerns in a SONET network by guaranteeing that the Ethernet traffic on one WAN cannot affect traffic on another WAN.

4. Native Ethernet transport

- Similar to SONET, native Ethernet can also transport data over long distances, such as inter substation networks.
- The main concern with using Ethernet for transporting multiple signals is the quality of service delivered to the end device.

Fiber-Optic-Based Communication

Shared fiber-optic channels

4. Native Ethernet transport

- The main concern with using Ethernet for transporting multiple signals is the quality of service delivered to the end device.
  - At every port of every Ethernet device in the end-to-end path, the Ethernet packet has to wait in queue to enter a physical layer, which causes packet delay variation (**PDV**) in the signal delivered to the end device.
  - The usual way to reduce PDV is to use a physical layer (connection) that is at least an order of magnitude larger than needed for the traffic total bit-rate.
  - Another approach is to use virtual LANs (VLANs) to segregate the critical traffic from the noncritical traffic.

- Common VLAN types include IEEE 802.1Q-based VLANs, which are formed using IEEE 802.1Q tags and port-based VLANs.
  - These VLANs are often referred to as QVLANs.

Ethernet supports two standards for path protection switching:

- Spanning tree, with a switching time of one minute.
- Rapid spanning tree, with switching times ranging from tenths of a millisecond to one second.

Fiber-Optic-Based Communication

Shared fiber-optic channels

5. The main differences between a native Ethernet network and an Ethernet-over-SONET network are:

- The SONET network has more mature network management tools and provides better organization and more control.
- Multipipe SONET networks provide truly independent multiple WANS.
- The native Ethernet network is more open, is rapidly developing, and is cheaper, although the price difference is narrowing.
- When used for WAN applications, both technologies must be enhanced, borrowing features from each other.

Fiber-Optic-Based Communication

Shared fiber-optic channels

6. SEL Integrated Communications Optical Network

- The SEL Integrated Communications Optical Network (ICON) is a versatile communications multiplexer optimized for both intera-substation and intra-substation communications networks.

- It offers seamless network management across these networks.

- The SEL ICON efficiently supports TDM and Ethernet traffic on a single platform and is capable of transporting this traffic over SONET and/or Ethernet links.

- In addition, the SEL ICON performs terrestrial distribution of precise time over the WAN to virtually all substation IEDs, with accuracy better than $1\mu_s$.

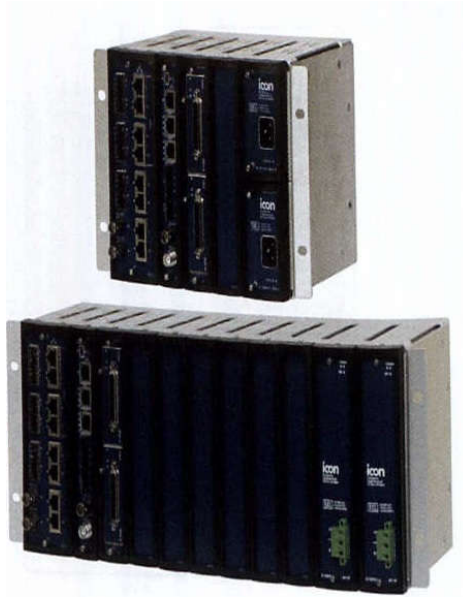


Fig. SEL Integrated Communications Optical Network in 19-inch shelf-mount and 8-inch panel-mount packages.

Fiber-Optic-Based Communication

Shared fiber-optic channels

SEL ICON product features include:

1. **SONET features:**
   - ✓ Up to four long-distance SFP OC-48 optical transceivers (2.488 Gbps per SFP).
   - ✓ Protected path switching ring with less than 5-ms switching time.
   - ✓ Path direction selection and switch upon far end failure indication (FEFI, also called switch on yellow) to eliminate asymmetrical delays.
   - ✓ STS-1 and virtual tributaries cross connect for interring traffic between ports.
   - ✓ Optical receive level and laser current monitor; error monitoring.

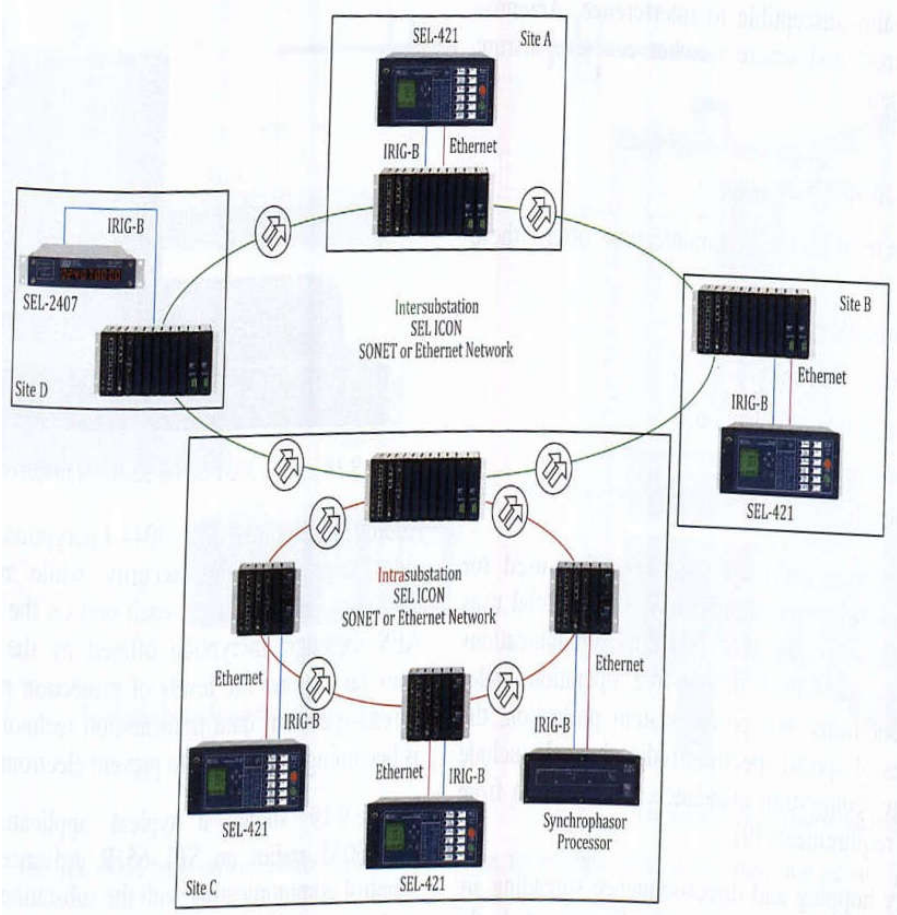


Fig. Example of network configuration using the SEL ICON.

Fiber-Optic-Based Communication

Shared fiber-optic channels

SEL ICON product features include:

2. Ethernet features:

- 1 Gbps and 100 Mbps Ethernet support.
- Ring topologies with less than 5-ms link failure recovery time.
- Advanced Media Access Control (MAC) table management:
  - ✓ Learn and age with user-configurable aging time out.
  - ✓ Learn and lock with user-configurable learning timeout.
  - ✓ Static with user-configured MAC addresses.
- Port-based VLANs, IEEE 802.10 VLANS, nested VLANs, and four levels of Q-in-Q tagging.
- QVLAN filtering per port with list of allowed and forbidden QVLANs.
- Port rate limiting with broadcast storm limiting and port statistics.
- Guaranteed traffic isolation and traffic latency management
- Port mirroring.

Fiber-Optic-Based Communication

Shared fiber-optic channels

SEL ICON product features include:

2. **Time synchronization features:**
   - ✓ IEEE 1588 V2-based wide-area time master.
   - ✓ Land-based time synchronization across the network.
   - ✓ GPS timing with immunity to GPS system outage.
   - ✓ IRIG-B input and output.

4. **Network management features:**
   - ✓ Graphical representation of the entire network.
   - ✓ Alarm and event management.
   - ✓ Inventory and configuration management.
   - ✓ Performance management.
   - ✓ Security management.
   - ✓ Remote firmware management.

3. **TDM features:**
   - ✓ Seamless TDM traffic support, including EIA-232, EIA-485, EIA-422. V.35, and IEEE C37.94 inter faces.
   - ✓ Real-time channel latency monitoring.
   - ✓ Circuit addressing.
   - ✓ Built-in pseudorandom binary sequence (PRBS) test generator

Power system communication

Wireless Systems

Wireless systems are attractive because of their low cost and relatively good availability**. Basic wireless systems are:**

1) Microwave.
2) Narrow-band VHF/UHF radio.
3) Spread-spectrum radio.
4) Cell phone/paging.
5) Satellite communication

1) Microwave

- Digital microwave systems provide direct relay-to relay communication and are not affected by power system faults.
- Typically, electric utilities own the microwave system, providing an additional level of control over system performance and reliability.
- microwave systems can fail because of failures in multiplexers, radio gear, or cabling, and because of antenna-pointing errors.

Power system communication

Wireless Systems

2) Narrow-band VHF/UHF radio

- Legacy systems used narrow-band VHF/UHF radios for SCADA and dedicated pilot channels.
- These systems used analog (voice-grade) channels with a single on-/off-keyed tone interface between the radio and the relay contact I/O.
- Modern systems use digital radios with direct digital communication.
  - ✓ Radio channels are not affected by power system faults, although the radio wiring remains susceptible to interference.
  - ✓ Antenna pointing errors and severe weather can also disrupt radio channels.

3) Spread-spectrum radio

Spread-spectrum radio communication offers these advantages:

- ✓ Communications security
- ✓ Interference immunity
- ✓ Low probability of detection.
- ✓ Low jamming
- ✓ Low cost

Power system communication

Wireless Systems

3) Spread-spectrum radio

- Spread-spectrum radio systems were first used for secure government communication.
  - ✓ For power system protection, **the advantages of spread-spectrum radio channels include** long range, congestion avoidance, and freedom from licensing requirements.

- Power system applications frequently require multiple serial connections to the same location, for example:
  - ✓ one serial channel for protection communication (MIRRORED BITS)
  - ✓ one channel for SCADA communication to the control center.
  - ✓ one channel for engineering access (event retrieval, remote maintenance, and Oscillography).
  - ✓ With legacy systems, these applications would require as many as three separate radios.
    - The SEL-3031 Serial Radio Transceiver simultaneously supports three independent serial channels

Fig. SEL-3031 Serial Radio Transceiver.

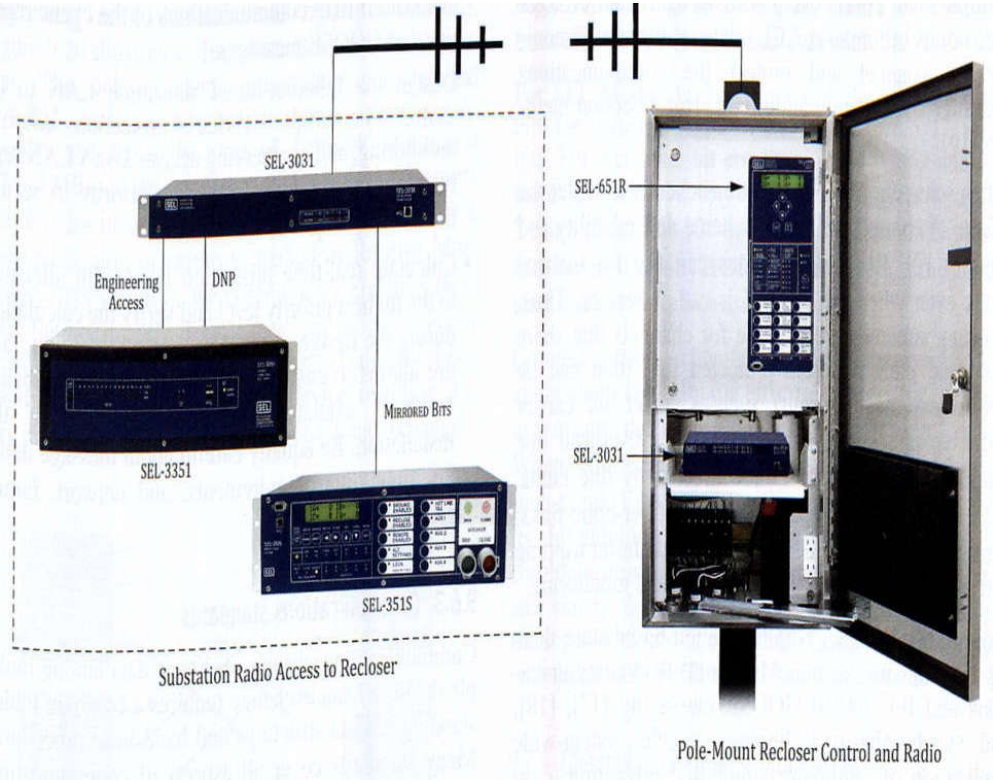
Power system communication

Wireless Systems

3) Spread-spectrum radio

Figure shows a typical application of the SEL-3031 radio:

- ✓ An SEL-651R Advanced Recloser Control communicating with the substation-based control system.
- ✓ This spread-spectrum radio link enables high-speed protection using MIRRORED Bits communications, SCADA communication supporting DNP protocol, and engineering access supporting event an Oscillography retrieval.



Power system communication

Modern Communication-Based Protection

❖ Communication-based protection is now possible at an power system voltage levels using:

- ✓ Modern microprocessor-based relays with built-in communications abilities.
- ✓ Increasingly available utility-owned fiber-optic channels and spread-spectrum radio channels.

Modern Communication-Based Protection

1) Communication-based protection schemes
2) Improving the reliability of communication based protection
3) Communications standards
4) Environmental and performance standards

Power system communication
Modern Communication-Based Protection

1) Communication-based protection schemes

- Communication-based protection schemes are either communication dependent or communication assisted.
- Communication-dependent protection schemes become inoperative if the communications system fails.

❖ Typical communication-dependent protection schemes include:

- ✓ Line differential protection.
- ✓ Line phase comparison protection.
- ✓ Direct transfer trip (**DTT**) schemes.
- ✓ Distributed bus differential protection.

Power system communication
Modern Communication-Based Protection

2) Improving the reliability of communication based protection

- Communications channel failures may impair operation of communication-based protection schemes.
  - This possibility is very important for the latest Ethernet based systems, which could increase our reliance on communicated data.
  - Redundant protection schemes are one solution to this problem. For example, the SEL-311L relay

The basic rules for applying communication-based protection are:

- Use proven protection methods in communication based protection schemes
  - ✓ Analyze protection scheme failure modes carefully and use additional programmable logic elements to address such failures.
- Monitor communications channels continuously.
  - ✓ Enhance system security by continuously exchanging messages multiple times per cycle, such as via MIRRORED BITS communications or the cyclic repetition of GOOSE messages.
- Design the Ethernet-based substation LAN to be shared by multiple services: protection, control, monitoring, and engineering access.
  - ✓ Use VLAN segregation and individual message priority to secure the delivery of protection traffic.
- Calculate real-time protection bandwidth allocated to the highest priority level and verify the calculation during the design phase.

Power system communication
Modern Communication-Based Protection

3) Communications standards

- Communications systems exchange data among multiple devices.
- Data exchange requires a common understanding of data structures and handshake procedures.
- Many standards cover all aspects of communications systems data exchange.

4) Environmental and performance standards

- In power system applications, communications devices often operate as part of the protection scheme.
- Communications systems used for power system protection an control must meet the environmental and performance requirements of other protection system components.

Power system communication
MIRRORED Bits Communications

- MIRRORED BITS protocol applications include line pilot protection schemes, remote device monitoring/control relay cross tripping, contact multiplexing, etc.
- MIRRORED BITS protocol performs continuous (**every to 10 ms**) sharing (mirroring) of eight data points between two devices.
- The devices continuously monitor the communications exchange and protect information using error detection and reporting methods.

- ✓ The devices share information via standard EIA-232 serial ports.
- ✓ Each device continuously encodes and sends the state of Transmit MIRRORED BITS (TMBs) to the other device.
- ✓ Each device inspects and decodes incoming bits before copying them into a reserved section of memory marked as Receive Mir-RORED BITS (RMBs).
- ✓ By continuously updating their data (approximately four times per power system cycle), communicating devices keep valuable information on the logic state of the other device, resulting in a Very powerful method for bidirectional data exchange.

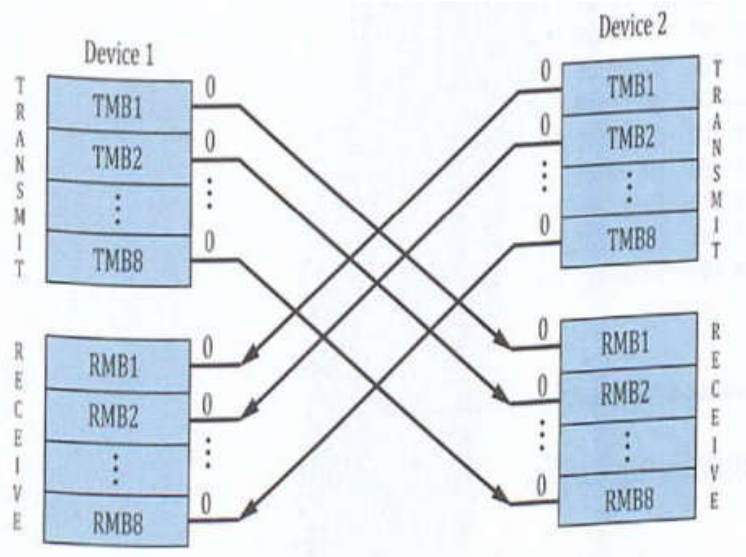


Fig. MIRRORED Bits protocol operation.

Power system communication

Ethernet Communication

- Ethernet allows multiple computers to communicate with each other, it was originally deployed over a tapped coaxial cable.
- The Carrier-Sense Multiple Access with Collision Detection (**CSMA/CD**) technology mitigated simultaneous access events, with half duplex traffic being broadcast to all devices.
- Today, dedicated twisted-pair cables or dual optical fibers connect full-duplex Ethernet devices to switches, which learn the locations of all devices and direct traffic only to the desired destinations.
- The speed of Ethernet links has steadily increased from **10 Mbps** to **100 Mbps**, then to **1 Gbps**, and recently to 10 **Gbps.**

Ethernet port speed and fiber-optic interface

- The 100-Mbps line interface has almost completely replaced the original 10-Mbps Ethernet.
- modern fiber-optic transceivers favor the 1,300nm 100-Mbps or 1-Gbps option and cannot switch wavelengths.
  - ✓ The result is virtual obsolescence of the 850-nm 10-Mbps interface.
- The connection between 10 and 100 Mbps network segments requires bridging, which causes delays.

Power system communication
Ethernet Communication

Full-duplex operation and collision-free environment

- Modern switches use a full-duplex interface able to simultaneously transmit and receive remote device traffic.
- The primary function of an Ethernet switch is to establish a connection between the sender and the receiver, **based** on the physical device MAC address.
  - ✓ Therefore, individual unicast packets (packets for a single, specific receiver) travel only between the two communicating ports, without affecting the bandwidth available to other ports.

Priority queuing and VLAN support

- VLAN support and class of service are essential technologies for segregating and prioritizing Ethernet traffic as networks grow in size, complexity, and traffic diversity.
- A VLAN is a logically separate Ethernet network that shares cabling and physical equipment infrastructure with other VLANs.
- Each VLAN on a network has its own broadcast domain, meaning that Ethernet frames from one VLAN will not be transmitted onto another VLAN.
- Implementing a VLAN-enabled network requires managed Ethernet switches to ensure that traffic from one VLAN does not cross the boundary to another VLAN.

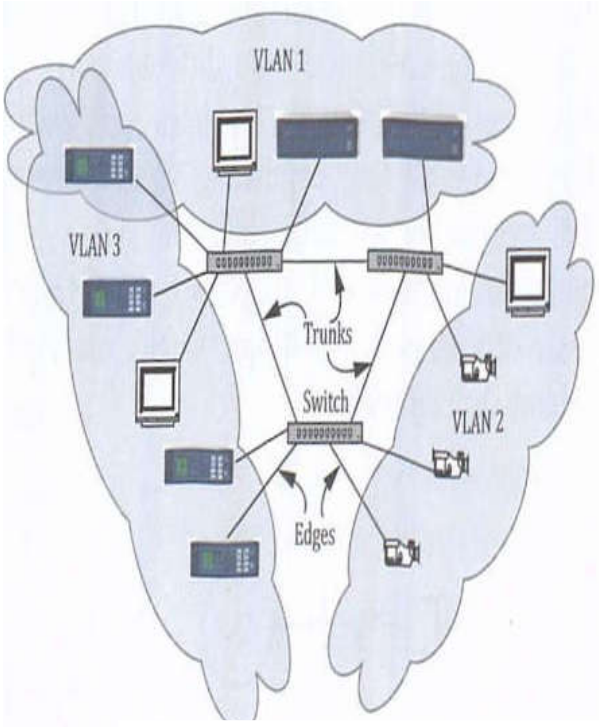


Fig. VLAN segregated network.

Power system communication
Ethernet Communication

- **IEEE Standard 802.1Q** defines a four-byte extension (tag) to the Ethernet frame header that allows traffic from one VLAN to be distinguished from that of another VLAN.

- **The VLAN Identifier (VID)** is a 12-bit field that allows 4,094 different VLANs to exist on a single network.

- A substation application may have mission-critical protection traffic (such as a command to trip a breaker) coexisting with SCADA or device maintenance traffic (such as event Oscillography retrieval).
  - ✓ The differing delivery time needs of these messages require separation of incoming traffic into priority queues.
  - ✓ The priority queuing mechanism uses a three-bit quality-of-service field.

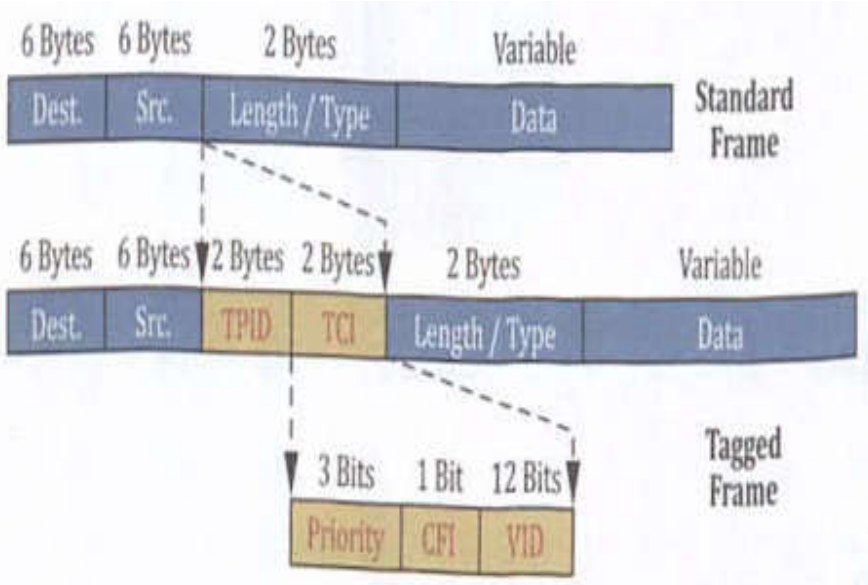


Fig. Layer 2 tagged Ethernet MAC header showing four-byte VLAN tag structure.

Power system communication
Ethernet Communication

Remote monitoring, port mirroring, and diagnostics

- Given the scalable nature, speed, and complexity of modern Ethernet networks, network management, troubleshooting, and diagnostics can become a major issue.
- A variety of standard tools are available for managing networks, typically using Simple Network Management Protocol (SNMP) , most vendors offer their own network management tools.
- One way to diagnose problems is by monitoring them remotely using port mirroring.
- Port mirroring allows users to mirror traffic going into or out of (or both) a particular port to a spare port (or ports) connected to a traffic analyzer.

LAN-based network protocols

- ✓ The most popular SCADA protocols, such as **Modbus-IP**, **DNP3-IP**, and **IEC 60870-104**, work in an Ethernet network environment.
- ✓ In addition to the SCADA protocols, Ethernet networks typically offer multiple tools and services, such as Dynamic Host Configuration Protocol (**DHCP**), Network Time Protocol (**NTP**), File Transport Protocol (**FTP**), and Virtual Terminal Emulation Protocol (**Telnet**).
- ✓ **FTP** is especially useful for transferring large Oscillography records.
- ✓ **Telnet** can provide remote engineering access to substation IEDs.

Power system communication
Ethernet Communication

Ethernet-based protection message standards

- There are many standard SCADA protocols, but very few are optimized for power system protection.
- Today, only two types of messaging, part of the **IEC 61850 standards** family, apply to protection applications:
  1) IEC 61850 Generic Substation Event (GSE, GOOSE, GSSE) messages
  2) IEC 61850-9-2 SV messages.

Ethernet-based SEL product portfolio

- SEL uses the latest advances in network-based communications technologies, including Ethernet, IEC 61850, and the traditional SCADA protocols.
- The list of relays with Ethernet includes SEL-710, SEL-751A, SEL-787, SEL-311L, SEL-387E, SEL-421, SEL-451, SEL-487B, SEL-487E, and SEL-487V relays.

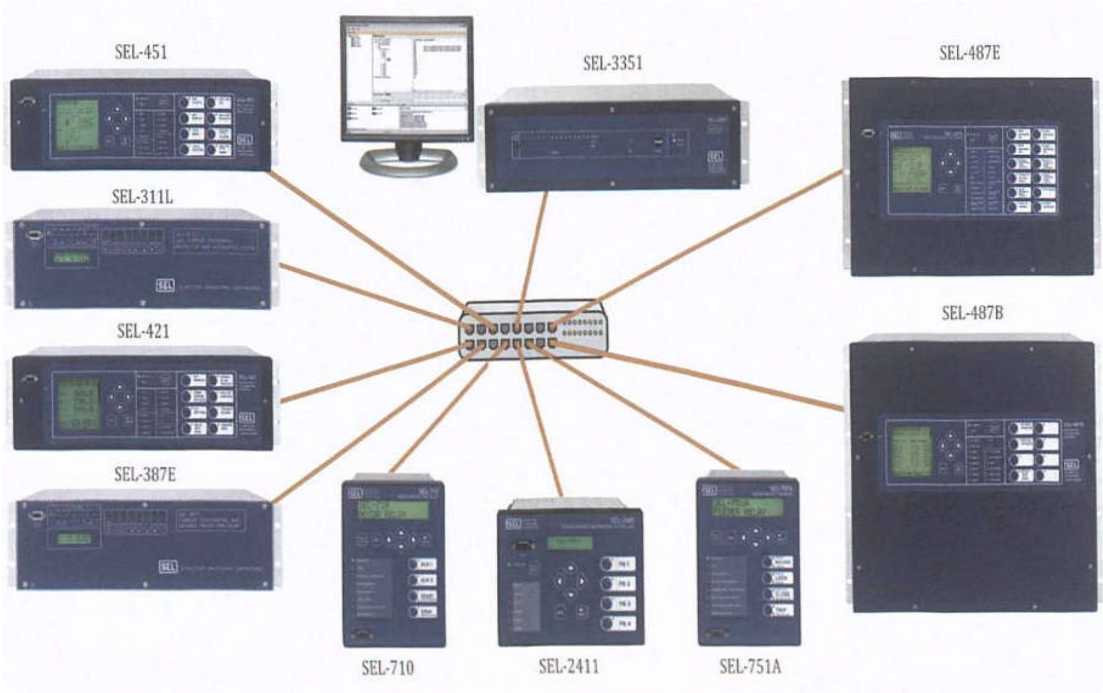


Fig. SEL supports a wide range of Ethernet products

Power system communication
Ethernet Communication

Ethernet radio

- An Ethernet radio is a combination of:
  - ✓ Ethernet-based communications interface.
  - ✓ Digital modulation/demodulation/coding module.
  - ✓ Ethernet bridge (switch)
  - ✓ Radio subsystem.

- This technology is also known as **digital radio or IP radio**, not to be confused with IEEE Standard 802.11 wireless LAN and IEEE Standard 802.16 wireless metropolitan area network technologies.

- Ethernet radios for electric utility applications typically operate in the unlicensed 960-MHz or 2.4-GHz industrial, scientific, and medical (ISM) bands, with maximum output power limited to 1 W.

- Maximum data rates for half-duplex schemes vary from 154 kbps to 8 Mbps, with maximum range between 5 and 40 miles.

Power system communication
Future Trends

- Improved power system communications and improved secondary equipment abilities allow better use of the existing power system infrastructure. Key technologies shaping future power system developments include the following:
  - ✓ Network-based communication.
  - ✓ Absolute time distribution and synchrophasor-based technologies.
  - ✓ Protection, control, and monitoring using information from multiple relays.
  - ✓ Wide-area protection, control, and monitoring.
  - ✓ International standardization.
  - ✓ Automated, web-based information technologies.
  - ✓ Geographic information systems.