SEL-T400L
Time-Domain Line Protection

Ultra-High-Speed Transmission Line Relay
Traveling-Wave Fault Locator
High-Resolution Event Recorder

Major Features and Benefits

The SEL-T400L is a state-of-the-art time-domain line protective relay operating within a few milliseconds for a wide range of fault and system conditions. Available in both 5 A and 1 A models, the SEL-T400L incorporates fault locating with accuracy typically within one tower span. With only a handful of settings and preconfigured protection logic, the SEL-T400L is simple to apply, yet it supports a variety of applications and protection philosophies.

- **Ultra-High-Speed Line Protection.** Apply a traveling-wave line current differential scheme with a point-to-point fiber-optic channel to trip faults in 1–5 ms depending on the line length. Apply an incremental-quantity Zone 1 element with a 2–5 ms operating time without communication. Apply a permissive overreaching transfer trip scheme with any standard teleprotection channel using traveling-wave and incremental-quantity directional elements operating in 0.1–3 ms.
- **Versatile Applications.** Apply the SEL-T400L to two-terminal overhead transmission lines, including series compensation, single- and dual-breaker terminations, and three-pole and single-pole tripping.
- **Simple Configuration.** Use preconfigured relay logic and set only a few protection settings without the need for extensive short-circuit studies.
- **Accurate Fault Locating.** Locate faults to the nearest tower.
- **Line Monitoring.** Monitor the line for incipient faults, recurring faults, or incipient cable faults.
- **High-Resolution Oscillography.** Record line currents and voltages with a 1 MHz sampling rate, storage for as many as 50 events, and a duration of 1.2 seconds per event.

Features and Benefits

Traveling-Wave Differential Protection Scheme

The traveling-wave differential (TW87) protection scheme uses current traveling waves (TWs) and a point-to-point fiber-optic channel to detect in-zone faults with operating times in the range of 1–5 ms depending on the line length. The TW87 scheme is independent from external time sources and provides internal synchronization of data over the communications channel. The TW87 scheme is suitable for series-compensated lines and can be used for single-pole tripping applications. The TW87 scheme uses traditional CTs and wiring. It uses voltage signals and works well with capacitively coupled voltage transformers (CCVTs). The TW87 scheme can be applied on two-terminal tapped lines owing to its first-ever location-dependent supervision.

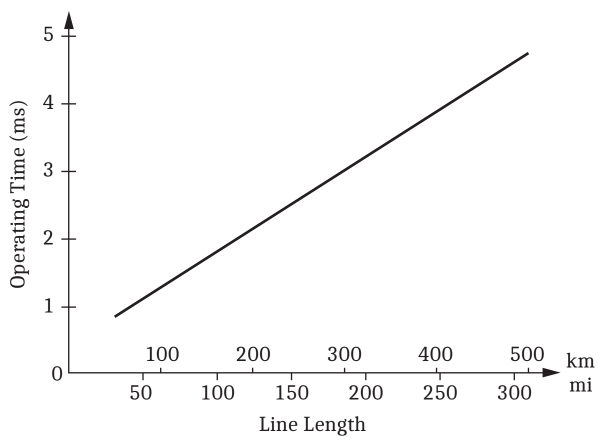


Figure 1 TW87 Operating Time as a Function of Line Length

Incremental-Quantity Distance Protection Element

The incremental-quantity distance (TD21) protection element uses incremental voltages and currents to provide underreaching distance protection. The element can be set as high as 80 percent of the line length, has a transient overreach below 10 percent, and operates between 2–5 ms depending on the fault location, system short-circuit level, fault resistance, and point on wave. The TD21 element is suitable for series-compensated lines and can be set using the line impedance, neglecting the in-line capacitors. The element is suitable for single-pole tripping applications.

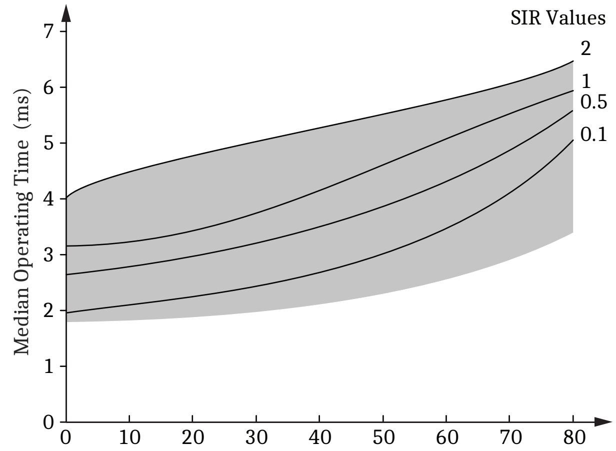


Figure 2 TD21 Element Median Operating Time for Varying Fault Location and Different Source-to-Line Impedance Ratios

Permissive Overreaching Transfer Trip Protection Scheme

The permissive overreaching transfer trip (POTT) scheme uses a dedicated fiber-optic SEL MIRRORED BITS® communications port for communicating over TDM multiplexers and ultra-high-speed and sensitive directional elements for fault direction discrimination. The traveling-wave directional element (TW32) operates in 0.1 ms and the incremental-quantity directional element (TD32) operates in 1–3 ms depending on system conditions. Both directional elements are suitable for series-compensated lines. The POTT scheme can be applied in single-pole tripping applications. Being phase-segregated, the POTT scheme performs very well on evolving and intercircuit faults.

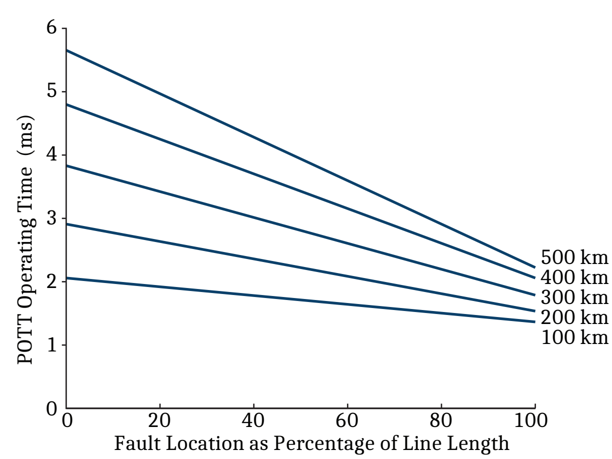


Figure 3 POTT Operating Time as a Function of Fault Location for Different Line Lengths Assuming TW32 Keying and a 115,200 bps MIRRORED BITS Channel With SEL MB8 Encoding Over Fiber-Based SONET/SDH

Direct Transfer Trip Protection Scheme

The direct transfer trip (DTT) scheme works with a fiber-optic MIRRORED BITS communications port and uses phase-segregated signaling for single-pole tripping. DTT logic uses extra security to guard against undetected bit errors in the communications channel.

Protection Communications Channels

The SEL-T400L uses digital protection signaling, rather than contact I/O, for line protection schemes and initiating local breaker failure and autoreclosing relays. Digital protection signaling is provided on Port 6 over a direct point-to-point fiber-optic channel using a proprietary protocol and on fiber-optic Ports 1, 2, and 3 with user-configurable SEL MB8, or IEEE C37.94 encoding. On a per port basis, select either SEL MB8 encoding for signaling local SEL relays and SEL I/O devices or IEEE C37.94 encoding for signaling the remote SEL-T400L over C37.94-compliant multiplexers. Use SEL MB8 encoding to interface with multiplexers not compliant with IEEE C37.94. When using SEL MB8 encoding, select the baud rate on a per port basis. When using IEEE C37.94 encoding, the data rate is 1x64 kbps.

Trip Logic

A preconfigured trip logic processed ten times per millisecond allows for easy configuration of the relay for single-pole and three-pole tripping applications with a flexibility to accommodate different protection philosophies. Program the relay by using simple bit masks (lists) to accommodate various preferences and requirements for a wide variety of applications.

Arming Logic

The SEL-T400L includes arming logic to check for normal line operating conditions before allowing the ultra-high-speed and sensitive protection elements to operate for a fault. The arming logic is fully preconfigured and does not require user customization. If line operating conditions prior to the fault prevent secure application of the ultra-high-speed protection elements, the arming logic deasserts and blocks protection elements while alerting the user to the problem.

Loss-of-Potential Logic

Based on incremental quantities and TWs, the SEL-T400L is inherently secure when loss-of-potential (LOP) conditions develop. A zero-setting LOP logic blocks the voltage-dependent elements to prevent misoperation on switching events or faults following a loss of potential.

Load-Encroachment Conditions

Based on incremental quantities and TWs, the SEL-T400L is secure under high-load conditions. The relay does not include, nor require, a load-encroachment blocking element. Heavy line loading does not impair dependability of the SEL-T400L.

Power-Swing Conditions

Based on incremental quantities and TWs, the SEL-T400L is secure during power-swing conditions. The relay does not include, nor require, a power-swing blocking element. Under stable or relatively slow, unstable power swings, the SEL-T400L remains armed and continues to provide protection for the line.

Dual-Breaker Applications

The SEL-T400L includes two sets of CT inputs and two sets of tripping outputs to protect lines connected in breaker-and-a-half, double-bus double-breaker, and ring-bus configurations.

High-Speed Trip-Rated Outputs

The SEL-T400L includes six high-speed trip-rated outputs for single-pole tripping of two breakers. For fast operation, connect the outputs directly to the breaker trip coils. The trip logic provides a seal-in mechanism for the trip outputs without the need to wire the breaker status contacts to the relay.

Protection, Security, and Dependability

The SEL-T400L is designed for speed and security. The TW87, TD21, TD32, and TW32 elements are highly dependable, but—by nature of their operating principles—they cannot be 100 percent dependable. Apply a companion relay—such as the SEL-411L or SEL-421—with phasor-based protection to cover the cases for which the SEL-T400L elements may fail to operate, such as faults at voltage zero-crossing.

Breaker Failure and Autoreclosing

The SEL-T400L provides MIRRORED BITS communications ports to communicate with a companion relay for breaker failure and autoreclose initiation. Use the companion relay for these protection functions.

Metering

The SEL-T400L provides basic voltage, current, and frequency metering for the line and current metering for each of the two breakers.

Traveling-Wave-Based Fault Locating

The SEL-T400L incorporates a single-ended traveling-wave-based fault-locating (TWFL) method, which works on local current TWs and analyzes the first TW as well as a number of successive TW reflections. The relay also incorporates a double-ended method, which uses only the first TWs at both line terminals, but requires communications. Deploy the double-ended TWFL method by using a 64 kbps IEEE C37.94-encoded channel and an IRIG-B-connected high-accuracy clock at both line terminals, and benefit from the reliability and accuracy of the double-ended method. Alternatively, use the direct fiber-optic channel between the two relays to perform fault locating and eliminate the need for external clocks. The TW-based fault-locating technology used in the SEL-T400L has a field-proven accuracy in the order of about one tower span regardless of the line length.

Line Monitoring

The SEL-T400L uses a line monitoring function to monitor the line for incipient faults, recurring faults, or incipient cable faults and provides a location-tabulated event count to detect low-energy activity and faults along the line. Prevent faults by selectively cleaning or replacing insulators, trimming vegetation, improving antigalloping solutions, applying line spacers, or improving lightning protection. Line monitoring works over a direct fiber-optic channel or a 64 kbps IEEE C37.94-encoded multiplexed channel.

High-Resolution Oscillography

The SEL-T400L provides time-stamped fault recording at a 1 MHz sampling rate with back-to-back recording capability, storage for as many as 50 events with a duration of 1.2 seconds per event, IEEE C37.111-2013 COMTRADE file format, and a user-configurable trigger. This 1 MHz, 18-bit recording capability allows analysis of high-frequency power system events including lightning strikes, breaker restrikes, and breaker transient recovery voltages.

Sequential Events Recorder

The relay records as many as 10,000 time-stamped Sequential Events Recorder (SER) events, including element states, alarms, digital inputs, and MIRRORED BITS communications inputs and outputs. The events are logged every 100 µs.

File Access

The relay supports File Transfer Protocol (FTP) for access to stored records over the Ethernet communications port.

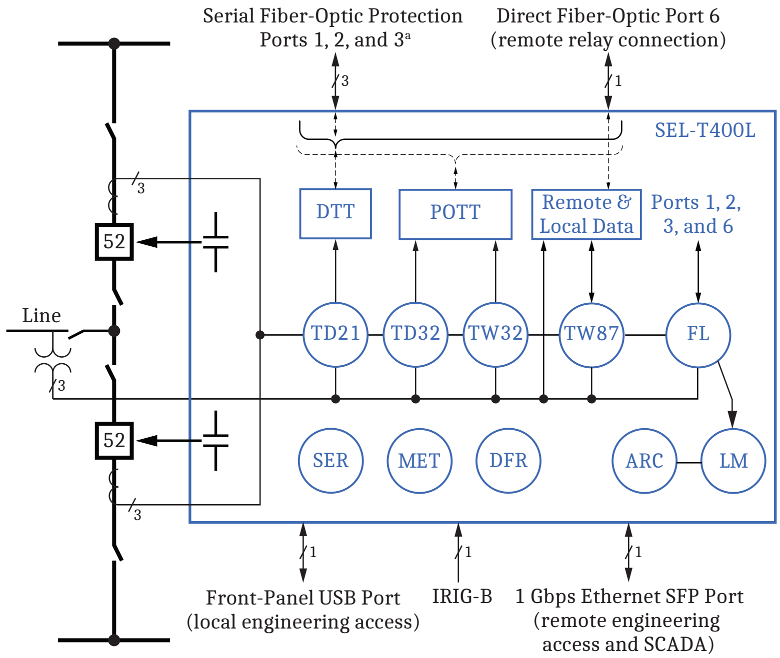
Electromagnetic Interference Monitoring

Sampling at 1 MHz and using TWs for protection and fault locating, the SEL-T400L monitors electromagnetic interference (EMI) noise in its input currents and voltages for security. Excessive noise that cannot be correlated with normal power system events is flagged, logged, alarmed on, and optionally recorded. If the standing EMI can compromise relay security, the TW protection elements are automatically disarmed and remain out of service until the noise subsides. This first-ever function provides users with invaluable insight into the overall condition of the substation installation.

Built-In Test Functions

Simplify SEL-T400L commissioning, troubleshooting, and approval testing with built-in testing and commissioning functions. Test and troubleshoot digital teleprotection channels with the SEL standard loopback mode. Apply the TW test mode to test and commission the TW87 protection scheme with high-frequency signal components alone, without the need to simultaneously inject the fundamental frequency currents and voltages. Test protection and fault-locating functions without the need for a physical relay test set by using the built-in event playback function and events recorded in the field or simulated with electromagnetic transient programs.

Functional Overview



[a]Encoding is user-configurable per port; select either SEL MB8 or IEEE C37.94.

ANSI NUMBERS/ACRONYMS AND FUNCTIONS	
1	Arming and Starting Logic
TD21	Incremental-Quantity Distance
TD32	Incremental-Quantity Directional
TW32	Traveling-Wave Directional
TW87	Traveling-Wave Differential
TD50	Incremental-Quantity Nondirectional Overcurrent Supervision
TD67	Incremental-Quantity Directional Overcurrent Supervision
DTT	Direct Transfer Trip Logic
POTT	Permissive Overreaching Transfer Trip Logic
94	High-Speed Trip-Rated Outputs
85 RIO	SEL Mirrored Bits® Communications
LOP	Loss-of-Potential Logic
TWDD	Traveling-Wave Disturbance Detection
DFR	1 MHz Event Recorder
SER	Sequential Events Recorder
FL	Fault Locator (with traveling-wave and impedance methods, single-ended and double-ended)
LM	Line Monitor
ARC	Adaptive Autoreclose Cancel Logic
MET	Metering
HMI	Operator Interface

ADDITIONAL FUNCTIONS
Preconfigured Trip Logic
Single-Pole Tripping Logic
Open-Pole Detection Logic
Traveling-Wave Test Mode
Event Playback
Front-Panel USB 2.0 Port for Engineering Access
Ethernet Port for Engineering and SCADA Access
Multilevel Passwords for Secure Access
Electromagnetic Interference Monitoring
Enhanced Self-Monitoring
Fast Time-Domain Values (FTDV)

Figure 4 Functional Diagram

Protection Features

The SEL-T400L provides two communications-based protection schemes (TW87 and POTT) and one incremental-quantity distance protection element (TD21). These time-domain elements work by using traveling waves and incremental quantities and use patented SEL technology.

Incremental-Quantity Elements

These elements use incremental quantities—the differences between the instantaneous voltages and currents and their one-cycle-old values. As such, the incremental quantities contain only the fault-induced components of voltages and currents. The SEL-T400L low-pass filters the incremental quantities so that when deriving the TD32 and TD21 operating equations, the protected line and the system can be represented by an equivalent resistive-inductive (RL) circuit. The incremental-quantity calculations and logic are run at 10 kHz.

TD32 Directional Element

To realize the TD32 element, the SEL-T400L calculates a replica current as a voltage drop from the incremental current (Δi) at the relay location across a unity impedance (1 Ω) RL circuit representing the line and the system. As shown in *Figure 5*, the incremental replica current is directly proportional to the incremental voltage (Δv) at the relay location. For forward faults, the incremental replica current and the incremental voltage are of opposite polarities (*Figure 5(a)*). They are of matching polarities for reverse faults (*Figure 5(b)*).

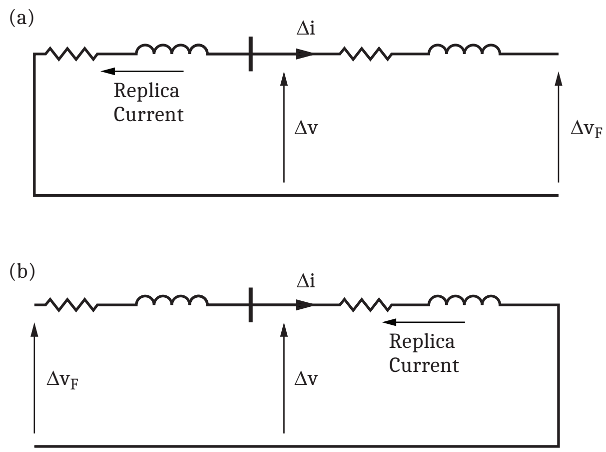


Figure 5 TD32 Directional Element Operating Principle: (a) Forward and (b) Reverse Faults

The SEL-T400L implementation of the TD32 element uses six measurement loops to cover all fault types, calculates and integrates an operating torque, and applies adaptive thresholds for optimum sensitivity and speed. These adaptive forward and reverse thresholds are fractions of the expected operating torques for a forward and reverse fault, respectively, and are calculated using impedance threshold settings.

The TD32 element operates dependably and quickly for faults at any point on wave and for resistive faults. The element sensitivity is effectively set by the overcurrent supervision embedded in the POTT logic.

TD21 Distance Element

To realize the TD21 element, the SEL-T400L calculates an instantaneous voltage change at the intended reach point using the incremental replica current, the incremental voltage, and the line RL parameters. Prefault voltage is the highest value possible for the change in voltage at the fault point. With reference to *Figure 6*, if the calculated voltage is higher than the prefault voltage at the reach point, the fault must be closer than the set reach, m_1. If so, the element is allowed to operate assuming the TD32 directional element asserts forward and other proprietary security conditions are met.

The SEL-T400L implementation of the TD21 element uses six measurement loops to cover all fault types and applies instantaneous prefault voltage at the reach point as a restraint for sensitivity and speed.

The TD21 element operates as fast as 2 ms for close-in faults in strong systems, and in a few milliseconds for faults closer to the reach point and in weaker systems. The element provides independent reach settings for the ground and phase measurement loops.

The TD21 element is dependable for metallic faults in relatively strong systems. The element responds to resistive faults and in weaker systems, but with a slightly slower speed and reduced dependability. When applied in weak systems, the effective resistive coverage of the element increases as the source-to-line-impedance ratio (SIR) increases up to a point beyond which the element reach becomes gradually reduced. For high SIRs, the element automatically shuts down, favoring security over dependability.

Owing to its operating principle, the TD21 element is not affected by CCVT transients.

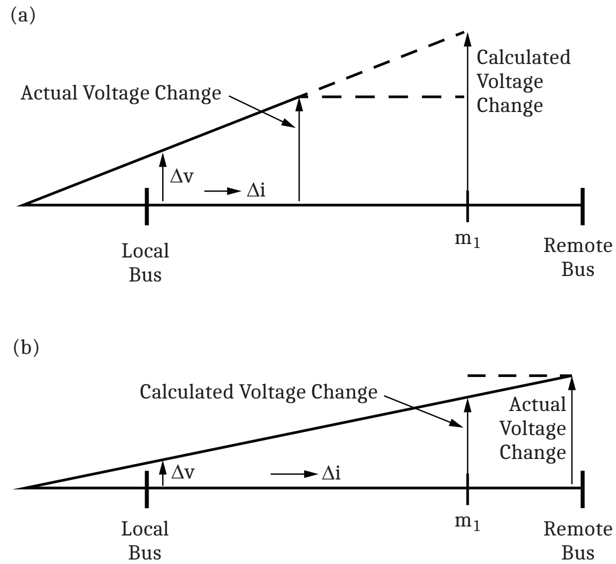


Figure 6 TD21 Underreaching Element Operating Principle: (a) In-Zone and (b) Out-of-Zone Faults

Traveling-Wave Elements

These elements respond to high-frequency content in the relay input currents and—to a lesser degree—voltages. Traveling waves can be understood as sharp changes in the input signals with the rise time in the order of a few microseconds. The SEL-T400L extracts TWs from the 1 MHz signals using a dedicated filter. The relay runs the TW calculations every microsecond and the associated logic every 100 µs.

TW87 Differential Scheme

The TW87 scheme compares time-aligned current TWs at both ends of the protected line. For an external fault, a TW that entered one terminal with a given polarity leaves the other terminal with the opposite polarity exactly after the known line TW propagation time (see *Figure 7*). To realize the TW87 scheme, the SEL-T400L extracts current TWs from the local and remote currents, identifies the first TWs in the local and remote currents, searches for exiting TWs that arrive at the opposite line terminal after the line propagation time, and calculates the operating and restraining signals from the first and exiting TWs.

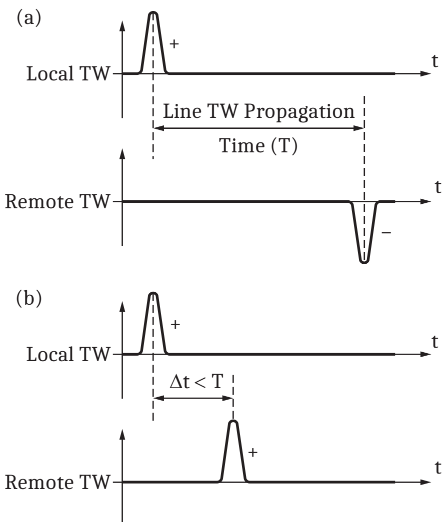


Figure 7 Current TW Timing and Polarities for (a) External and (b) Internal Faults

The SEL-T400L implementation of the TW87 scheme uses real-time fault-location information obtained with a double-ended method similar to the one used in the fault-locating algorithm. It also uses other proprietary security conditions in addition to the pickup and slope settings customary in any differential protection logic.

The TW87 logic applies a factory-selected security slope and provides for user-selected ground and phase minimum pickup settings. The minimum pickup thresholds apply to the low-frequency incremental replica current. The supervision confirms that the in-zone event is actually a fault and not a switching event or a nearby lightning strike.

The TW87 scheme uses prefault voltage for additional security to verify if the polarity of the current TWs agrees with the polarity of the voltage at the place and time of the fault.

The TW87 scheme is suitable for series-compensated lines. In applications to series-compensated lines, the TW87 element is internally supervised with the TD32 elements.

The TW87 scheme incorporates a built-in fault-type identification logic based on TWs to support single-pole tripping applications. This logic analyzes magnitudes and polarity patterns of three-phase current TWs (see *Figure 8*). These current TWs are time-aligned sums of the first local and the first remote TWs recorded by the scheme. As such, these TWs approximate the total current TWs launched from the fault location.

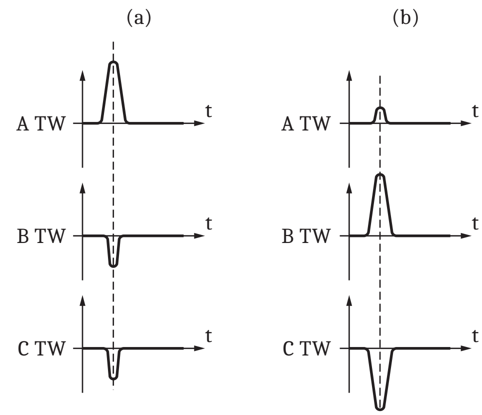


Figure 8 TW Pattern for (a) a Single-Line-to-Ground Fault in Phase A and (b) a Line-to-Line Fault Between Phases B and C

TW32 Directional Element

The TW32 directional element compares the relative polarity of the current TWs versus the voltage TWs. For a forward event, the two TWs are of opposite polarities, and for a reverse event, they are of matching polarities. To realize the TW32 element, the SEL-T400L integrates a torque calculated from the current and voltage TWs, and checks the value of the integral a few tens of microseconds into the fault (see *Figure 9*). As a result, the relay responds to the TW activity during the few tens of microseconds following the first TW. Once asserted, the TW32 element is kept asserted for a short period of time to act as an accelerator for the dependable TD32 directional element in the POTT scheme.

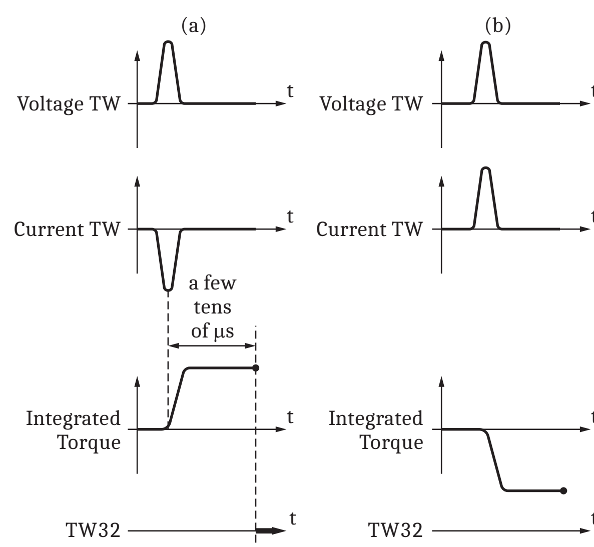


Figure 9 Voltage and Current TWs for (a) a Forward Fault and (b) a Reverse Fault

When applied with CCVTs, the TW32 element benefits from the stray capacitances across the CCVT tuning reactor and step-down transformer. These capacitances create a path for high-frequency signal components, allowing some voltage TW signals to appear at the secondary CCVT terminals. The element uses only the polarity and timing of the first voltage TW, and therefore the element is suitable for CCVTs despite their poor reproduction of voltage TW magnitudes in general.

The TW32 element accelerates the POTT signal and is not critical for SEL-T400L dependability. The element may not assert for faults at the voltage zero-crossing or with some CCVTs. The TD32 element ensures dependability under these operating conditions.

Starting Element and Fault Identification Logic

The SEL-T400L combines a fault-type identification logic with a nondirectional starting logic. The combined starting and fault identification logic is based on incremental voltages in six measurement loops. The logic calculates incremental voltages at a certain electrical distance away from the relay using the voltages and currents at the relay location and the line RL data (see *Figure 10*). For the incremental-quantity protection elements to start, the change in these calculated incremental voltages must be higher than a factory-selected minimum value. By comparing the voltage changes in all six measurement loops, the relay identifies the fault type.

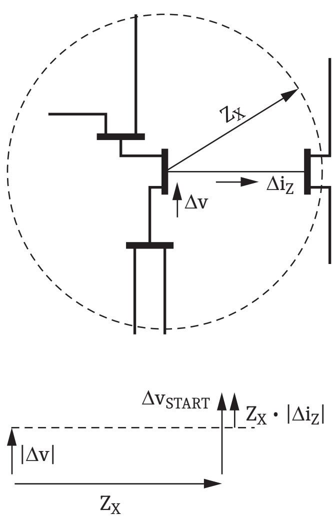


Figure 10 Starting and Fault-Type Identification Logic

Overcurrent Supervision

The SEL-T400L supervises the TW87, TD21, and POTT schemes with ultra-high-speed overcurrent elements. These elements respond to the incremental replica currents and measure the current level in the low-frequency spectrum (below 1 kHz). Their primary purpose is to verify that the event is a fault and not a switching or other low-energy event. The overcurrent supervision allows the SEL-T400L to remain secure during switching events that may launch TWs or cause high-frequency incremental quantities.

The SEL-T400L overcurrent elements are implemented in time domain, observing that the incremental replica currents are not affected by the decaying dc component and are at zero before the fault happens. The relay uses this characteristic of the currents to implement the novel overcurrent principle illustrated in *Figure 11*.

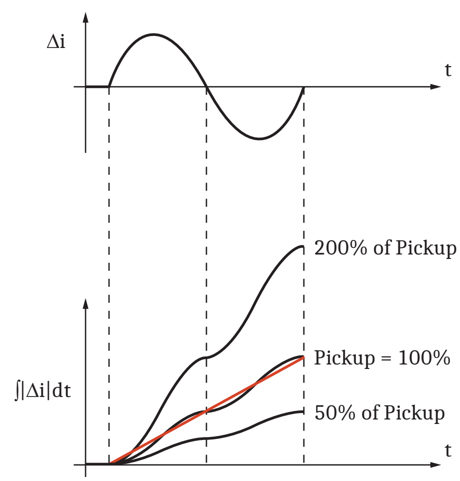


Figure 11 Instantaneous Overcurrent Element Principle of Operation

Tripping Schemes

The SEL-T400L provides trip logic to conveniently route protection elements intended for tripping to the output contacts (see *Figure 12*). The logic allows for three-pole and single-pole tripping, responds to faults during the open-pole condition following a single-pole trip, and maximizes selectivity of single-pole tripping during evolving and intercircuit faults. The trip logic incorporates a current-reversal security logic and provides seal-in for the trip outputs using a timer and the ac current level.

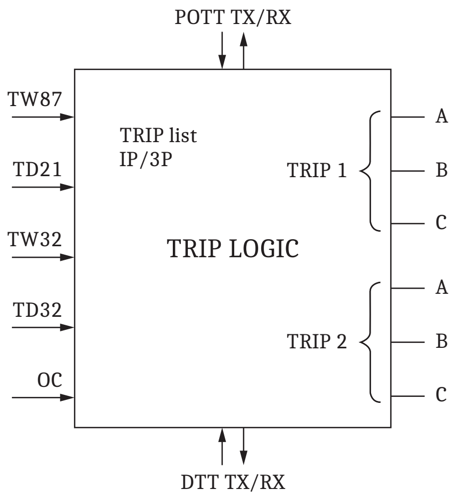


Figure 12 Preconfigured SEL-T400L Trip Logic Allows Implementing Various Protection Philosophies Without the Need for Programmable Logic

The logic incorporates communications-assisted tripping from the POTT and DTT schemes through use of digital communication over a serial fiber-optic MIRRORED BITS communications port and/or the TW87 point-to-point fiber-optic channel. The DTT scheme applies extra security against undetected bit errors in the communications channel before accepting the received DTT bits.

Both the POTT and DTT use phase-segregated communication to improve selectivity of single-pole tripping.

Protection Settings

The protection elements of the SEL-T400L are easy to set. The relay requires only a handful of protection settings, and most of them are nameplate data such as CT and PT ratios, line length and impedance, nominal voltage and frequency, and series capacitor reactance and location. The few settings that require protection judgment and knowledge are either multiple-choice preferences or simple overcurrent or impedance thresholds. The multiple-choice settings include values such as a trip mask, single-pole or three-pole tripping preference, and presence of external series compensation in the vicinity of the protected line. *Table 1* lists the numerical protection settings and briefly explains their purpose and recommendations.

Table 1 Key Protection Settings

Name	Purpose	Recommendation for Typical Applications
TD21MP	Phase TD21 reach	Set to 0.7 to 0.8 pu
TD21MG	Ground TD21 reach	Set to 0.6 to 0.75 pu
TD32ZF	Forward TD32 impedance threshold	Set to a quarter of the net positive-sequence impedance of the strongest local system
TD32ZR	Reverse TD32 impedance threshold	Set to a third of the net positive-sequence impedance of the line
TP67G	POTT overcurrent supervision for ground loops	Set to ride through switching of in-line reactors and in-line series capacitors
TP67P	POTT overcurrent supervision for phase loops	Set to ride through switching of in-line reactors and in-line series capacitors
TWLPT	TW line propagation time	Measure using the SEL-T400L during commissioning
TP50G	TW87 overcurrent supervision for ground loops	Set below the minimum ground fault current level
TP50P	TW87 overcurrent supervision for phase loops	Set below the minimum phase fault current level

Fault Locating

The SEL-T400L incorporates advanced traveling-wave-based fault-locating algorithms with accuracy in the order of one tower span, allowing for reduced operating expenses and faster line restoration after a fault.

Upon the assertion of a user-programmable trigger, including a preconfigured trip command, the relay executes a single-ended TW-based fault-locating algorithm and—if the communications channel is available and operational—a double-ended algorithm. The single-ended fault-locating results are available to internal relay logic within 50 ms following the fault locator trigger assertion. When using the direct fiber-optic channel, the traveling-wave double-ended algorithm result is available within 10 ms, i.e., before the circuit breakers finish clearing the fault.

The TW-based fault-locating algorithms use time stamps of current TWs to calculate the distance to the fault. The algorithms interpolate the time-stamp data to obtain high-precision time stamps, with resolution and accuracy in the order of a small fraction of a microsecond.

The SEL-T400L fault-locating accuracy, including tolerances in the current and time input circuitries, is in the order of ±10 m (±33 ft). Application errors such as line data inaccuracy or line sag may increase the total fault-locating error in any given application. SEL field experience with the TW-based fault-locating technology proves the total accuracy is in the range of ±300 m (±1,000 ft). The relay compensates the fault location for the length of the CT secondary wires as provided by the user setting. The SEL-T400L fault-locating function does not depend on external time sources.

SEL-T400L event summaries include fault location, fault type, prefault and fault voltage and current levels, and other customary data. The fault-locating information is available in the event summary and available via the SEL ASCII and DNP3 LAN/WAN protocols. The event summary is also provided in the IEEE COMTRADE header file.

The SEL-T400L selects the best result from the double-ended TW-based fault-locating algorithm and the single-ended TW-based algorithm, and—if required—it falls back on the impedance-based algorithm if no reliable TWs are present in the input currents.

Double-Ended TWFL Algorithm

The double-ended TW-based fault-locating algorithm calculates the fault location using the time difference between the first current TWs recorded at both the line terminals, as shown in *Figure 13* and defined by the following equation:

$$M = \frac{L}{2}\left(1 + \frac{t_S - t_R}{T}\right)$$

where M is the distance to the fault from Terminal S in line length units, t_S and t_R are time stamps of the first TWs, and L and T are user settings specifying the line length and the TW propagation time for the entire line length.

The double-ended algorithm requires a communications channel to exchange the fault-locating data, and it requires the time stamps from both ends of the line to be aligned to the same time reference. Use a 64 kbps IEEE C37.94-encoded channel with IRIG-B-connected high-accuracy clock at both line terminals, or use the direct fiber-optic channel for both data communication and time alignment.

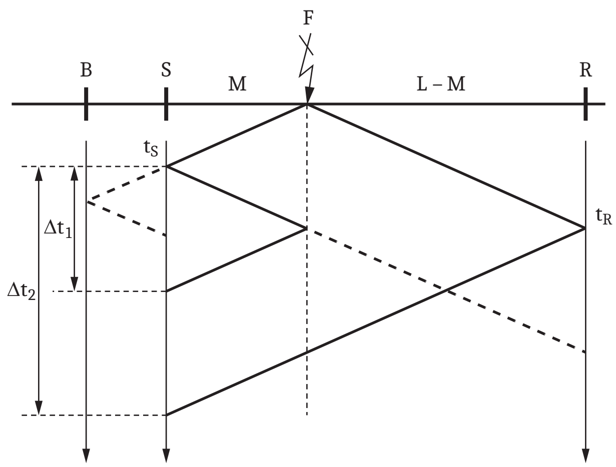


Figure 13 Bewley Diagram Illustrating TW Fault-Locating Principles

Single-Ended TWFL Algorithm

The single-ended algorithm calculates the fault location using the time difference between the first TW and the first reflection from the fault as shown in *Figure 13* and defined by the following equation:

$$M = L\frac{\Delta t_1}{2T}$$

The single-ended algorithm does not need remote data, and therefore it works without communications and is not affected by the timing errors between the two line terminals. However, it relies on reliable identification of the first reflection from the fault among many other TWs that may arrive at the local relay terminal, especially from discontinuities behind the relay (Bus B in *Figure 13*).

Line Monitoring

The SEL-T400L uses a line monitoring function to enable identification of trouble spots along the line and fault prevention through a condition-based line maintenance program. The line monitor logic triggers on current TWs launched by fault precursors, locates these events with high accuracy by using the double-ended TWFL method (an IEEE C37.94 channel or direct fiber-optic channel is required), tabulates these events for locations along the line, and alarms if the event count exceeds a user-settable threshold. Use the line monitor function to monitor the line for dirty or cracked insulators, encroaching vegetation, marginal clearances, marginal lightning protection, incipient cable faults, conductor galloping resulting from insufficient damping or faulty spacers, ice unloading, and similar conditions. Reset the event counters for the problem locations after performing adequate maintenance and addressing the underlying problem.

The user can configure as many as two blocking regions to prevent false alarms for routine switching operations of tapped loads or in-line series capacitors. The logic tabulates the daily event counts at the tap or series capacitor locations, and alarms on unexpected switching patterns.

Applications

Ultra-High-Speed Protection With Auxiliary Protection and Control Functions

The SEL-T400L is designed for speed, security, and ease of use. Its purpose is to provide ultra-high-speed and secure line protection. Use a multifunction line protective relay in parallel with the SEL-T400L to provide a full suite of protection, control, and monitoring functions, including but not limited to time-coordinated backup protection, breaker failure protection, reclosing with synchronism check, switch-onto-fault protection, and bay control.

Figure 14 illustrates a typical SEL-T400L application with a MIRRORED BITS communications-compatible companion relay, such as the SEL-411L or SEL-421, and a digital protection channel, such as the SEL ICON® multiplexer.

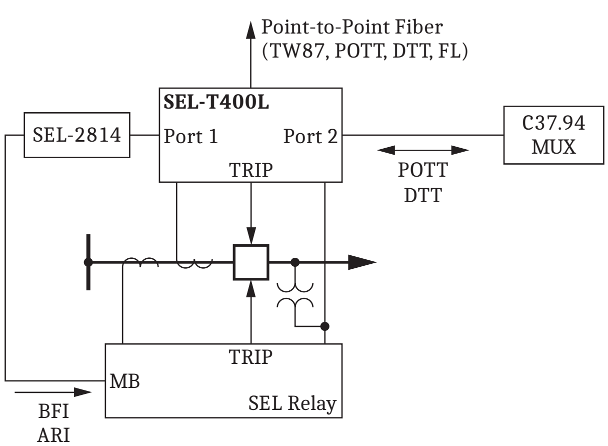


Figure 14 Recommended All-SEL Application of the SEL-T400L

In this application, the SEL-T400L trips the circuit breaker directly and uses a fiber-optic MIRRORED BITS communications port to communicate with the remote SEL-T400L over an IEEE C37.94-compliant multiplexer for the POTT and DTT applications. The SEL-T400L uses another MIRRORED BITS communications port to signal the companion SEL relay for breaker failure and autoreclose initiate functions and uses a point-to-point fiber-optic connection with the remote SEL-T400L to provide the TW87 protection.

Use SEL-2814 Fiber-Optic Transceivers to connect the fiber-optic MIRRORED BITS communications Port 1 (data encoding configured for SEL MB8) of the SEL-T400L with the companion SEL relay. Program the companion SEL relay to receive the SEL-T400L trip commands and to interpret them as breaker failure initiate (BFI) and autoreclose initiate (ARI) signals. The SEL companion relay either directly trips the circuit breaker or passes the trip command back to the SEL-T400L via the MIRRORED BITS communications connection. Configure Port 2 connected to the multiplexer to use IEEE C37.94 encoding to exchange POTT and DTT signals with the remote SEL-T400L.

Figure 15 illustrates a typical SEL-T400L application with a generic relay, not capable of MIRRORED BITS communications, and a generic protection channel, such as a power line carrier. In this application, the companion relay and the protection channel equipment use contact inputs and outputs to signal the SEL-T400L.

In this application, use the SEL-2507 (or SEL-2505) Remote I/O Module to convert the fiber-optic MIRRORED BITS communications inputs and outputs (Port 1 and Port 2 are configured to SEL MB8 encoding) to contact I/O, and wire the companion relay and the communications equipment accordingly.

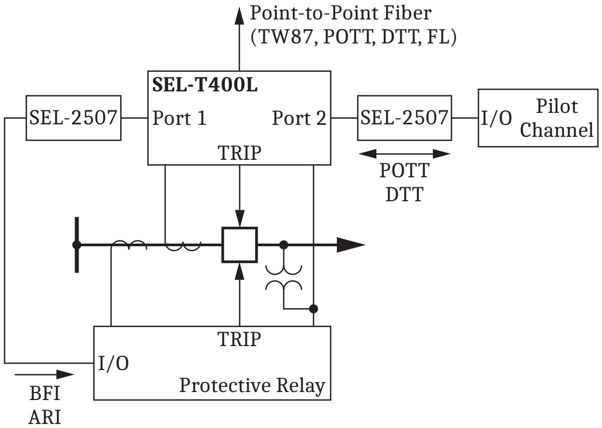


Figure 15 Recommended Application of the SEL-T400L Using Contact I/O Signaling

Series-Compensated Lines

Apply the SEL-T400L to series-compensated lines. Series capacitors represent a very small reactance at higher frequencies, allowing the SEL-T400L protection principles to work well. Use the relay with series capacitors located anywhere along the line and with either line-side or bus-side voltage transformers.

Configure only a few settings in applications on series-compensated lines as follows:

- ➤ Enter the reactance value of the in-line capacitors as a setting to let the TD21 element restrain properly for series-compensated lines. Use the TD21 reach at 70 or 80 percent of the physical line length, neglecting the in-line series capacitance.
- ➤ Set the impedance thresholds in the TD32 elements to factor in the values of the in-line and external capacitors.
- ➤ Set the POTT overcurrent supervision thresholds above incremental currents caused by capacitor switching.
- ➤ Optionally, enter the location of the series capacitors to allow the TW87 scheme to coordinate with the series capacitor platform protection.

When applying the relay to lines with adjacent series compensation, set the external series compensation setting to "Y" to allow the SEL-T400L to apply proper security measures.

Hybrid Overhead/Underground Lines

The SEL-T400L is designed to protect overhead transmission lines. However, with careful engineering and analysis, you may consider the SEL-T400L for applications on underground cables and feeders with a combination of overhead sections and underground cable sections.

Protection of Hybrid Lines

Consider the following protection applications:

- ➤ Apply both the TD21 element (for unconditional tripping) and the TD32 element in the POTT scheme to lines where the positive- and zero-sequence impedance of the underground cable sections is less than about 20 percent of the total line impedance, and the line steady-state, positive-sequence charging current is less than 300 A.
- ➤ Apply the TW87 scheme to lines where positive- and zero-sequence impedance of the cable section is less than about 5 percent of the total line impedance or 2 km, whichever is shorter.

Contact SEL Engineering Services to learn more about relay setting consulting and transient simulation services for special relay applications.

Fault Locating on Hybrid Lines

Use the double-ended traveling-wave-based fault locator to locate faults on hybrid lines. In reference to *Figure 16*, the SEL-T400L fault-locating algorithm corrects for the nonhomogeneity of the propagation velocity in the overhead sections and underground cable sections of the line.

Enter the total line length (LL) and the total traveling-wave line propagation time (TWLPT) as settings, and provide the breakdown of these values for each section of the line.

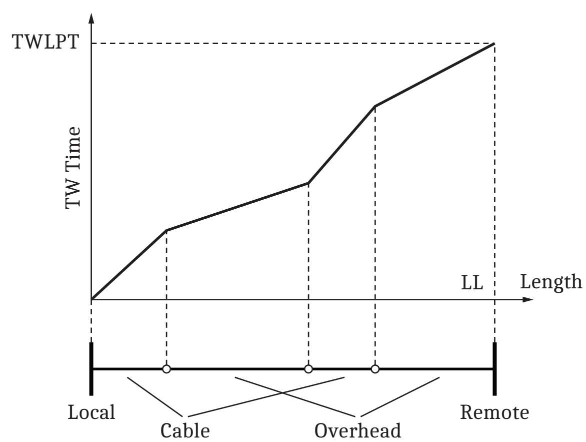


Figure 16 SEL-T400L Double-Ended Fault Locator Corrects for Differences in Traveling-Wave Propagation Velocities Between Overhead and Cable Sections

Adaptive Autoreclosing on Hybrid Lines

Use the double-ended traveling-wave-based fault locator to adaptively control autoreclosing by allowing reclosing for faults on overhead sections and inhibiting reclosing for faults on underground cable sections, as illustrated in *Figure 17*. Set the blocking intervals for the autoreclosing based on the location of the underground cable sections. The SEL-T400L provides a preconfigured adaptive autoreclose cancel bit in the MIRRORED BITS communications output to an external autorecloser. This feature requires double-ended traveling-wave-based fault locating, and therefore it works with either a 64 kbps IEEE C37.94-encoded channel and a high-accuracy clock at both terminals of the line or with the direct fiber-optic channel on Port 6. When using the direct fiber-optic channel, the fault-locating result is available to internal relay logic in less than 10 ms following the fault locator trigger assertion.

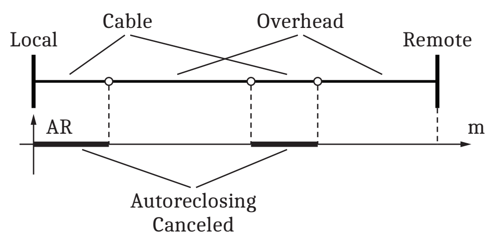


Figure 17 SEL-T400L With Double-Ended Fault Locator Allows Adaptive Autoreclosing for Hybrid Lines

Multiterminal Lines

The SEL-T400L is designed to protect two-terminal lines. However, with careful engineering and analysis, you may also consider the SEL-T400L for applications on multiterminal and tapped lines. *Figure 18* shows the principle of applying the SEL-T400L POTT scheme to three-terminal lines.

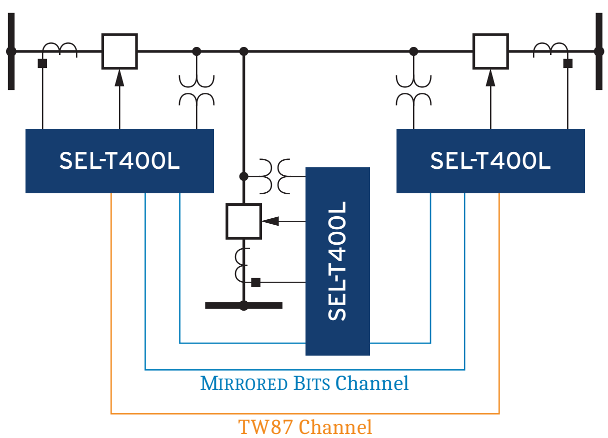


Figure 18 Principle of Applying the SEL-T400L POTT to Three-Terminal Lines

Consider the following protection applications:

- ➤ Apply the TW87 scheme to protect the line between the two main terminals. Make the scheme insensitive to faults downstream from the taps by setting blocking intervals around the taps using the scheme's location-dependent supervision.
- ➤ Use the TD21 elements on multiterminal lines, assuming proper reach setting analysis is performed.
- ➤ Deploy the POTT scheme on multiterminal lines as per the standard practice. With three MIRRORED BITS ports, apply the SEL-T400L to lines with as many as four terminals.

Contact SEL Engineering Services to learn more about relay setting consulting and transient simulation services for special relay applications.

Standalone DFR and Fault Locator

Use the SEL-T400L as a standalone high-resolution digital fault recorder (DFR) or fault locator.

Trigger the DFR with a contact input or MIRRORED BITS communications to capture six currents and three voltages at a 1 MHz sampling rate and 18 bits of true analog-to-digital resolution. Connect the current inputs of the SEL-T400L to breaker CTs to study breaker restrike, especially for reactor and capacitor banks, generators, or otherwise stressed or marginally rated breakers. *Figure 20* shows the current through one phase of a breaker while de-energizing a shunt reactor. Observe the restrike occurring at 50.2 ms, indicating the inability of the breaker to interrupt this current at the first zero-crossing.

Trigger the fault locator with a contact input or MIRRORED BITS communications to perform single-ended or double-ended fault locating with high accuracy.

Complement your existing line protection systems for overhead lines with the SEL-T400L installed as a single-ended fault locator (see *Figure 19*). The SEL-T400L is an economical and easy-to-apply solution for ultra-accurate fault locating. The SEL-T400L uses standard CTs and wiring and performs the fault-locating calculations automatically without human intervention and without the need for communication with the remote line end.

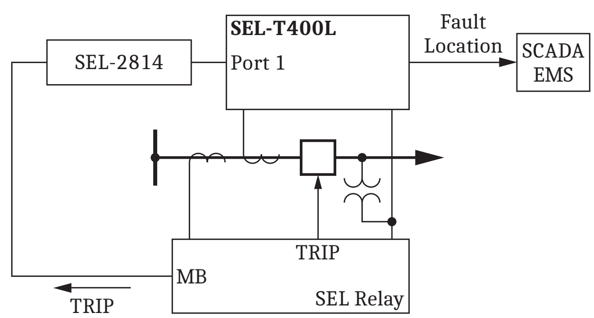


Figure 19 Standalone Single-Ended Fault-Locating Retrofit Application

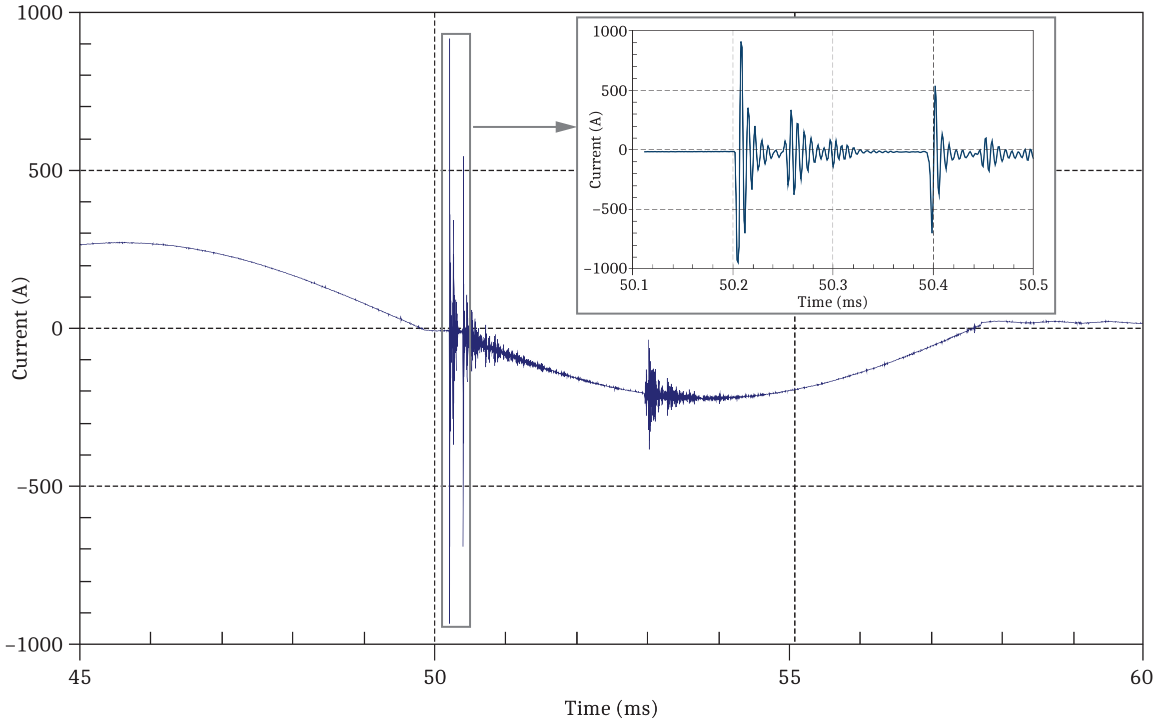


Figure 20 Breaker Restrike While De-Energizing a Shunt Reactor

Metering and Monitoring

Metering

The SEL-T400L provides fundamental frequency phasor metering values (magnitude and angle) for the relay input voltages and currents. Phase quantities as well as symmetrical components are available. Current metering is available for each of the two CT inputs separately, as well as for the combined terminal line current. When the point-to-point fiber-optic connection is available to the remote SEL-T400L, the local relay also provides metering data for the remote voltages and line currents.

The metering data are useful during commissioning and troubleshooting and are available on the front-panel HMI, in response to a command, and via the SEL Fast Meter protocol.

Recording

Time-synchronized fault and SER records simplify post-fault analysis and help improve understanding of protection scheme operations and power system disturbance analysis. These features also aid in testing and troubleshooting relay settings and protection schemes. Record oscillograms at 1 MHz and 10 kHz resolutions. Use SEL-5601-2 SYNCHROWAVE® Event Software or any IEEE COMTRADE-compatible program for post-event analysis.

Oscillography

Capture voltages and currents with 1 MHz oscillography using a trigger selected from internal Relay Word bits or using an input to the relay, including MIRRORED BITS communications. The captured data are available in the IEEE COMTRADE format and are stored in nonvolatile memory.

The 1 MHz COMTRADE file contains voltage, current, active settings, fault location, and event summary data. The SEL-T400L stores as many as 50 events with a back-to-back recording capability and a duration of 1.2 seconds per event.

The SEL-T400L also offers a 10 kHz COMTRADE file that contains currents and voltages sampled at 10 kHz, selected operating quantities for the incremental-quantity elements, Relay Word bits, active settings, fault location, and event summary data. When the point-to-point fiber-optic channel is available, the local 1 MHz and 10 kHz records contain remote voltages and line currents as well.

The samples in the oscillography files are time-stamped with a microsecond resolution and 100 ns accuracy. Use the SEL-T400L Ethernet Port 5 for fast download of the oscillography files.

Event Summary

Each time the SEL-T400L creates an event report, it also generates a corresponding event summary. The event summary contains key information including relay identification, time and date, event type, fault location, and prefault and fault voltage and current phasors. The event summary is available as a file and is also included in the header file of the IEEE COMTRADE record.

Sequential Events Recorder

Monitor the relay element operation with the SER. Select Relay Word bits that trigger an SER entry including input/output change of state and element operation. The SER automatically records device events such as power-up and settings changes. The relay SER stores the latest 10,000 entries in nonvolatile memory. The events are time-stamped with a 100 μs resolution and 100 ns accuracy.

Fast Time-Domain Values Streaming

Fast Time-Domain Values (FTDV) are precisely time-stamped instantaneous voltages and currents obtained with a 1 μs resolution and streamed over Ethernet for remote monitoring and research applications. These applications run continuously in real time on high-performance computing platforms and provide capabilities such as continuous monitoring, recording, signal feature extraction, and visualization. Contact SEL to obtain detailed format descriptions and tools to experiment with this advanced SEL-T400L functionality.

High-Accuracy Timekeeping

To keep track of absolute time, the SEL-T400L accepts a high-accuracy, demodulated, IEEE C37.118-compliant IRIG-B external timing signal from a global positioning satellite clock, such as an SEL-2488 Satellite-Synchronized Network Clock or an SEL ICON system. The relay keeps internal time with an accuracy of 100 ns with respect to the time input. All event reports and summary times are reported in UTC.

The external time source is used only for precise time-stamping of relay records. The SEL-T400L protection and fault-locating functions do not depend on the external time input. When connected using the point-to-point fiber-optic channel, the two SEL-T400L relays synchronize to one another over the fiber-optic channel, enabling the relays to provide the TW87 protection and double-ended fault locating independently from the external time sources.

Built-In Testing and Commissioning Tools

Loopback Mode for Digital Teleprotection Channels

Simplify testing and troubleshooting of digital teleprotection channels with a port loopback mode. The loopback mode allows the relay to receive its own packets while either permitting the teleprotection bits to be received as sent or forcing the received bits to fail-safe values. Put the SEL-T400L port under test into loopback mode and loop the transmit path back to the receive path at various points in the communications chain to pinpoint problems related to data clocking, data corruption, noise, or misconnections between relays. Use the port communications report to obtain the present channel status and the statistical data collected over time during normal operation and while in loopback mode.

Traveling-Wave Test Mode

Commission the TW87 protection with only high-frequency signals, using a test source such as the SEL-T4287 Traveling-Wave Test System, without the need to simultaneously inject fundamental frequency voltages and currents into the relay. While operating in the TW test mode, the TW87 logic suspends security conditions that require fundamental frequency voltages and currents, thus allowing the TW87 protection scheme to operate on the high-frequency signals alone. The TW test mode maintains security of in-service relays by requiring your testing and commissioning personnel to acknowledge the TW test mode initiation sent over the engineering port on the relay front panel, thus preventing an unintentional or malicious initiation of the TW test mode. Monitor the ALARM output to detect the TW test mode in progress. The TW test mode expires after 30 minutes, should your testing and commissioning personnel leave the relay in the TW test mode unintentionally.

Event Playback

Test protection and fault-locating functions in the relay using event playback (firmware revision R102 and newer). In playback mode, the relay substitutes the voltage and current samples from the analog-to-digital converter with values uploaded to the relay memory prior to the playback test. Use historical field records or cases simulated using any standard electromagnetic transient program as your test cases.

Use the Playback File Conversion Utility in ACSELERATOR QuickSet® SEL-5030 Software to convert a compliant C37.111 COMTRADE file to the SEL playback file format. Use the Event Playback Test Dashboard in QuickSet to upload and manage playback test files in the relay memory and to execute event playback tests. Provide at least 50 ms of pre-event steady-state data in your test file, and allow the relay to loop the periodic pre-event data for 1 second to simulate the pre-event steady state. This stabilizes the relay measurements and logic prior to the test event.

Allow relay outputs during the event playback test, or suppress them to ensure security of in-service relays. Test a single relay using manual trigger mode (on demand), or test an SEL-T400L scheme by uploading test files to multiple relays and scheduling simultaneous test triggers based on relay time (end-to-end testing).

Event playback maintains security of in-service relays by requiring your testing and commissioning personnel to acknowledge the initiation of the event playback session sent over the engineering port on the relay front panel, thus preventing an unintentional or malicious initiation of event playback. Monitor the ALARM output to detect event playback in progress. The event playback mode expires after one hour, preventing unintentional or malicious playback after the intentional testing session.

User Interfaces

Software Configuration and Engineering Tool

Use QuickSet to perform the following:

- ➤ Develop SEL-T400L settings offline, and then connect to your devices to transfer settings and monitor device performance.
- ➤ Design and organize SEL-T400L settings using Device Manager features, helping your protection and control department to organize all of their relevant device information in a central database with historical information of changes.
- ➤ Use integrated tools in QuickSet to compare, convert, merge, and amend multiple SEL-T400L settings files to help reduce the overall life-cycle costs of the device.
- ➤ Access SEL-T400L data locally or remotely from the convenience of your PC using the integrated HMI feature.
- ➤ Convert compliant C37.111 COMTRADE files into SEL playback files for event playback, upload and manage the event playback test files in the SEL-T400L memory, and execute the event playback tests in the relay.
- ➤ Seamlessly integrate QuickSet data into your company's workflow with customizable reporting tools.

Use SEL Compass® support to keep your software, drivers, and SEL documentation up to date.

Front-Panel Display and Targets

The SEL-T400L front-panel LCD shows metering, fault location, events, communications statistics, and relay self-test messages. The LEDs display relay target information as shown in *Figure 21*.

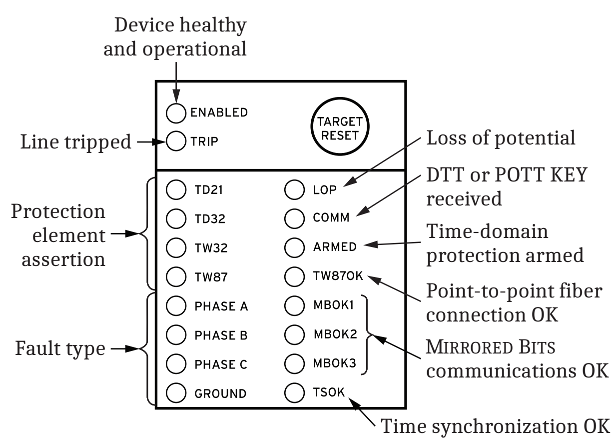


Figure 21 Status and Trip Target LEDs

Network Connection and Integration

Figure 22 presents an overview of the SEL-T400L communications ports, communications media, and associated functionality.

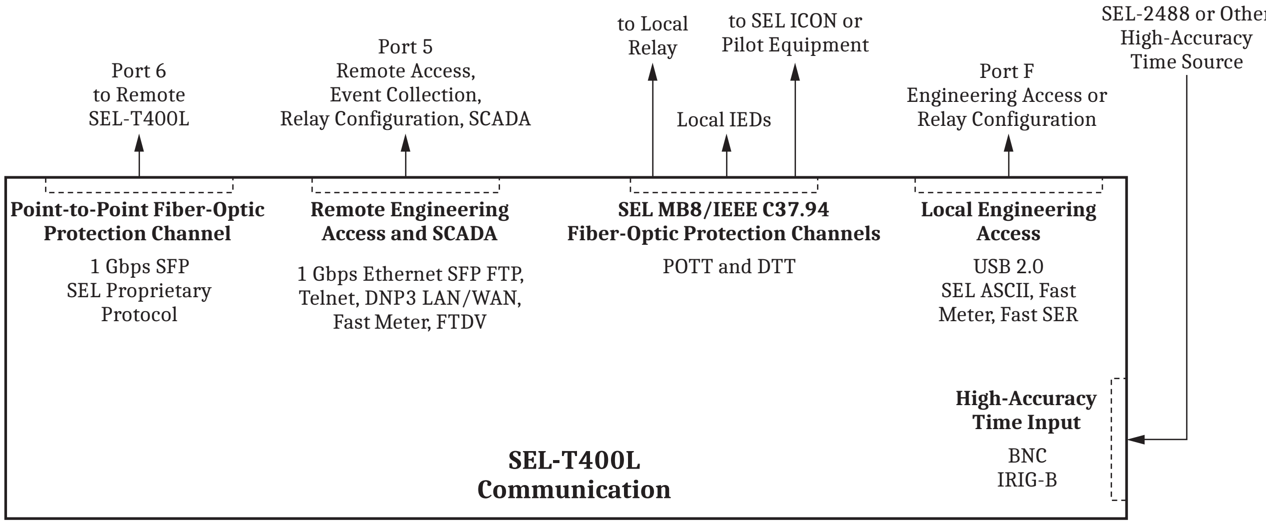


Figure 22 SEL-T400L Communications Overview

MIRRORED BITS Communications Ports. Multimode fiber-optic Ports 1, 2, and 3 allow for exchanging protection bits with the remote SEL-T400L for POTT and DTT applications and with local relays for breaker failure initiation and other applications. Select either SEL MB8 encoding for signaling local SEL relays and SEL I/O devices or IEEE C37.94 encoding for signaling the remote-end SEL-T400L over compliant multiplexers. When using IEEE C37.94 encoding, the ports allow data transfers required for double-ended traveling-wave-based fault locating, adaptive autoreclose cancel logic, and line monitoring.

Point-to-Point Protection Channel. The traveling-wave line current differential scheme, POTT and DTT schemes, double-ended traveling-wave-based fault locating, adaptive autoreclose cancel logic, and line monitoring use the direct fiber-optic, 1 Gbps Port 6. This port accepts small form-factor pluggable (SFP) fiber-optic transceivers (ordered separately) and uses a proprietary SEL protocol. Port 6 is meant exclusively for connecting local and remote SEL-T400L relays.

This protection channel supports seamless exchange of 1 MHz data, allowing each of the relays to continuously monitor both ends of the line. Link delay is minimal, determined by the light propagation speed in the single-mode fiber. Order and install the correct SFP transceiver to apply the relay with point-to-point fiber-optic channels of different lengths. The maximum reach exceeds 100 km without optical signal amplification. Contact SEL for a full list of supported SFP modules. The communications link between the two relays is private, secure, and requires a dedicated pair of single-mode fibers. The link also provides time synchronization services, allowing the two relays to stay synchronized with each other and share common UTC time.

Remote Access Over Ethernet. Use Ethernet Port 5 for relay configuration, event collection, SCADA applications, and streaming of fast time-domain values (FTDV) over the network. Connect QuickSet and run FTP, Fast Meter, and Telnet applications using Port 5. Use DNP3 LAN/WAN protocol over Ethernet for interconnecting with DNP-based SCADA systems.

Local Access. Use front-panel USB 2.0 Type B Port F for local relay configuration and event collection. In addition, Port F can be used for connecting to QuickSet and for running SEL ASCII and Fast Meter applications.

External Time Input. Connect an IEEE C37.118-compliant IRIG-B time signal from an external clock to the rear-panel BNC port for precise timekeeping.

Cybersecurity. The SEL-T400L supports four levels of access for various functions, including viewing status, diagnostics, and changing settings. The relay supports strong passwords with as many as 12 characters, using any printable character, allowing users to select complex passwords if they so choose. The SEL-T400L is compatible with SEL cybersecurity products, such as the SEL-3620 Ethernet Security Gateway.

Front- and Rear-Panel Diagrams

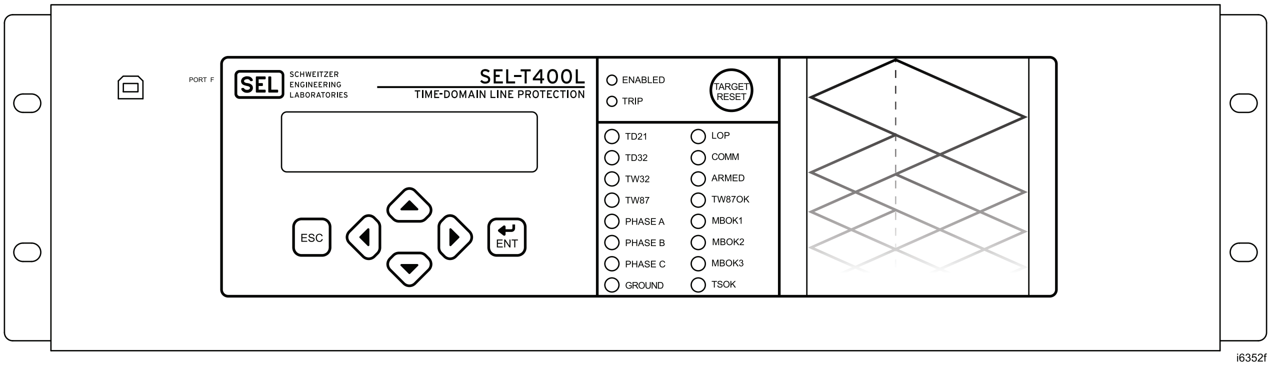


Figure 23 SEL-T400L Front Panels

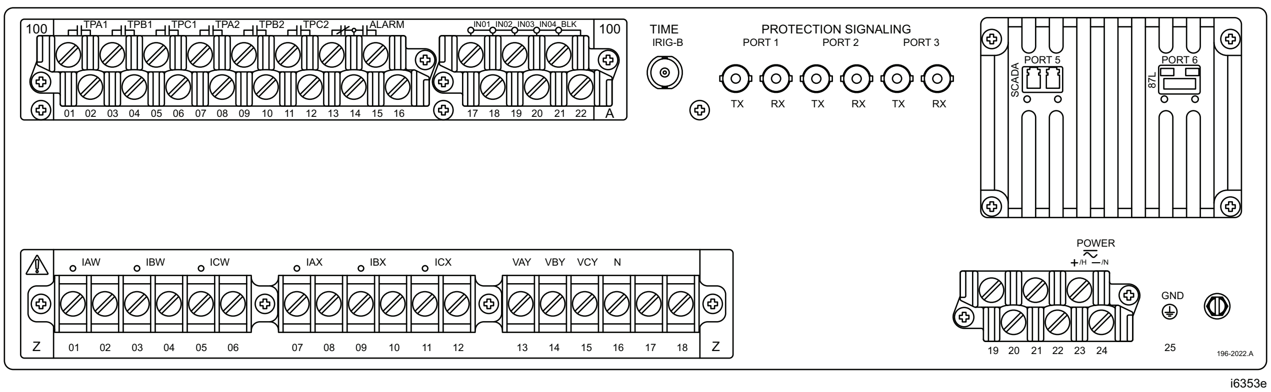


Figure 24 SEL-T400L Rear Panel Diagrams

Dimensions

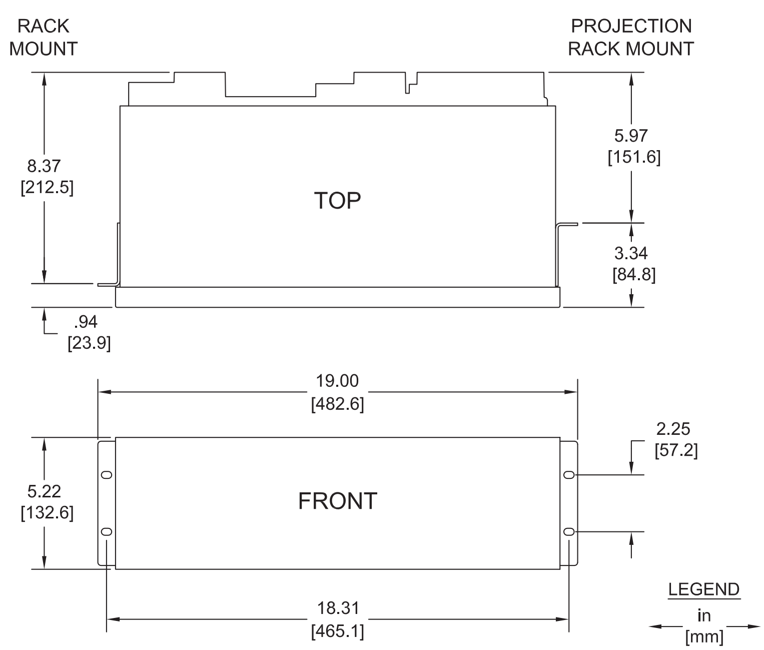


Figure 25 SEL-T400L Rack-Mount Chassis Dimensions

Specifications

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

FCC Compliance Statement

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference in which case the user will be required to correct the interference at his own expense.

UL Listed to U.S. and Canadian safety standards (File E212775; NRGU, NRGU7)

CE Mark

General

AC Analog Inputs

Sampling Rate: 1 MHz

A/D Resolution: 18 bits

AC Current Inputs

Rated Input Current:

1 A Model: 1 A

5 A Model: 5 A

Continuous Thermal Rating:

1 A Model: 3 A

5 A Model: 15 A

A/D Measurement Limit:

1 A Model: 50 A peak (17.67 A rms fully offset ac current)

5 A Model: 250 A peak (88.4 A rms fully offset ac current)

One-Second Thermal Withstand:

1 A Model: 100 A rms

5 A Model: 500 A rms

Burden:

1 A Model: <0.1 VA at 1 A, 60 Hz

5 A Model: <0.5 VA at 5 A, 60 Hz

AC Voltage Inputs

Connection: Four-wire wye with a common neutral, dc coupled

Rated Voltage Range: 57.7–144.3 V LN (VNOM = 100–250 V LL)

Continuous Thermal Rating: 175 V rms LN

A/D Measurement Limit: 280 V peak LN

Ten-Second Thermal Withstand: 350 V rms LN

Burden: <0.1 VA at 120 V LN

Power Supply

Rated Voltage: 125–250 Vdc
110–240 Vac

Operational Voltage Range: 85–300 Vdc
85–264 Vac

Rated Frequency: 50/60 Hz

Operational Frequency Range: 30–120 Hz

Vdc Input Ripple: 15% per IEC 60255-26:2013

Interruption: 46 ms @ 125 Vdc, 250 ms @ 250 Vdc per IEC 60255-26:2013

Burden: <35 W, <90 VA

Control Outputs

Note: IEEE C37.90-2005 and IEC 60255-27:2013

Update Rate: 10 kHz

Make (Short Duration Contact Current): 30 Adc

Limiting Making Capacity: 1000 W at 250 Vdc (L/R = 40 ms)

Mechanical Endurance: 10,000 operations

Fast Hybrid (High-Speed, High-Current Interrupting) Form A

Rated Voltage: 125–250 Vdc

Operational Voltage Range: 0–300 Vdc

Operating Time: Pickup time ≤10 µs (resistive load)
Dropout ≤8 ms (resistive load)

Short Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance: 10,000 operations
4 operations in 1 second, followed by 2 minutes idle

Rated Voltage	Resistive Break	Inductive Break
125 Vdc	10 Adc	10 Adc (L/R = 40 ms)
250 Vdc	10 Adc	10 Adc (L/R = 20 ms)

Alarm Output (Form C)

Rated Voltage: 125–250 Vdc

Operational Voltage Range: 0–300 Vdc

Operating Time: Pickup time ≤6 ms (resistive load)
Dropout ≤6 ms (resistive load)

Short Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance: 10,000 operations
4 operations in 1 second, followed by 2 minutes idle

Rated Voltage	Resistive Break	Inductive Break
125 Vdc	0.30 Adc	0.30 Adc (L/R = 40 ms)
250 Vdc	0.20 Adc	0.20 Adc (L/R = 20 ms)

Control Inputs

Optoisolated (Bipolar Operation)

Connection: 5 inputs with a shared common terminal

Voltage Option: 125 Vdc

Current Draw: ≤5 mA at nominal voltage

Sampling Rate: 10 kHz

DC Threshold

125 Vdc: Pickup 105–150.0 Vdc; Dropout <75 Vdc

Communications Ports

Fiber-Optic Protection Signaling Ports 1, 2, and 3

Applications: Relay-to-relay signaling, POTT[1], DTT, double-ended traveling-wave fault locating (IEEE C37.94[2]), adaptive autoreclose cancel logic (IEEE C37.94[2]), and line monitoring (IEEE C37.94[2])

[1] 15 ms maximum channel latency
[2] 30 ms maximum channel latency

Data Rate: 19200 to 115200 bps (SEL MIRRORED BITS encoding)
64 kbps (IEEE C37.94 encoding)

Fiber Connector Type: ST

Fiber Type: Multimode

Fiber Wavelength: 820 nm

Fiber Size: 62.5/125 µm

Minimum Receiver Sensitivity: –24 dBm

Transmitter Power: –18.5 dBm (minimum)
–10.5 dBm (maximum)

Data Integrity Protection: Meets IEC 60834-1 transmission time, bit error rate security, and bit error rate dependability recommendations for direct tripping and teleprotection applications over digital channels

USB Port (Port F)

Connector Type: Type B

USB Type: 2.0

Fiber Ethernet Port 5

Maximum Data Rate: 1 Gbps

Connector Type: SFP

Wavelength: 850 nm

Distance: 0.3 km multimode

Fiber-Optic Protection Signaling Port 6 (Transceivers Ordered Separately)

Applications: POTT and DTT for two-terminal applications, traveling-wave differential protection scheme[1], double-ended fault locating, adaptive autoreclose cancel logic, line monitoring, and remote line-end recording and metering

[1] One-way channel delay less than 4 ms and less than the TW line propagation time plus 2 ms

Data Rate: 1 Gbps

Connector Type: SFP

Wavelength: 850–1550 nm depending on transceiver

Distance: 0.3–200 km depending on transceiver

Port 5 and Port 6 SFP Transceivers

0.3 km, 850 nm, multimode
0.5 km, 850 nm, multimode
10 km, 1310 nm, single-mode
20 km, 1310 nm, single-mode
30 km, 1310 nm, single-mode
40 km, 1310 nm, single-mode
50 km, 1550 nm, single-mode
80 km, 1550 nm, single-mode
160 km, 1550 nm, single-mode
200 km, 1550 nm, single-mode

Time Input

IRIG-B Input

Applications: Precise time synchronization for digital fault recording and sequential events recording
When using an IEEE C37.94 channel, precise time synchronization for double-ended traveling-wave fault locating, adaptive autoreclose cancel logic, and line monitoring

Input: Demodulated IRIG-B

Rated I/O Voltage: 5 Vdc

Operating Voltage Range: 0–8 Vdc

Input Impedance: ≥1 kΩ

Operating Temperature

Relay: –40° to +85°C (–40° to +185°F)

Note: LCD contrast impaired for temperatures below –20°C (–4°F) and above +70°C (+158°F).

SFP Transceivers: –40° to +70°C (–40° to +158°F)

Humidity

5% to 95% without condensation

Overvoltage Category

Category III

Insulation Class

I

Pollution Degree

2

Weight (Maximum)

3U Rack Unit: 6.01 kg (13.25 lb)

Terminal Connections

Rear Screw-Terminal Tightening Torque, #8 Ring Lug

Minimum: 1.0 Nm (9 in-lb)

Maximum: 2.0 Nm (18 in-lb)

User terminals and stranded copper wire should have a minimum temperature rating of 105°C (221°F). Ring terminals are recommended.

Wire Sizes and Insulation

Wire sizes for grounding (earthing), current, voltage, and contact connections are dictated by the terminal blocks and expected load currents. Use the following table as a guide in selecting wire sizes. The grounding conductor should be as short as possible and sized equal to or greater than any other conductor connected to the device, unless otherwise required by local or national wiring regulations.

Connection Type	Minimum Wire Size	Maximum Wire Size
Grounding (Earthing) Connection	14 AWG ($2.5\ mm^2$)	N/A
Current Connection	16 AWG ($1.5\ mm^2$)	10 AWG ($5.3\ mm^2$)
Potential (Voltage) Connection	18 AWG ($0.8\ mm^2$)	14 AWG ($2.5\ mm^2$)
Power, Contact I/O	18 AWG ($0.8\ mm^2$)	10 AWG ($5.3\ mm^2$)

Type Tests

Electromagnetic Compatibility (EMC)

Emissions:	IEC 60255-26:2013, Section 7.1 Class A 47 CFR Part 15B Class A Canada ICES-001 (A) / NMB-001 (A)

Electromagnetic Compatibility Immunity

Conducted RFI Immunity:	IEC 60255-26:2013, Section 7.2.8 10 Vrms
Radiated RFI Immunity:	IEC 60255-26:2013, Section 7.2.4 10 V/m (modulated) IEEE C37.90.2-2004 20 V/m (modulated, >35 V/m peak)
Electrostatic Discharge Immunity:	IEC 60255-26:2013, Section 7.2.3 IEEE C37.90.3-2001 2, 4, 6, and 8 kV contact discharge 2, 4, 8, and 15 kV air discharge
Electrical Fast Transient Burst Immunity:	IEC 60255-26:2013, Section 7.2.5 Zone A 4 kV, 5 kHz repetition rate on power supply I/O, signal data, and control lines 2 kV, 5 kHz repetition rate on communications ports (IRIG)
Power Frequency Immunity:	IEC 60255-26:2013, Section 7.2.9 Zone A
Power Frequency Magnetic Field Immunity:	IEC 60255-26:2013, Section 7.2.10 Level 5 1000 A/m for 3 s 100 A/m for 60 s
Pulse Magnetic Field Immunity:	IEC 61000-4-9:2001 Level 5 1000 A/m
Damped Oscillatory Magnetic Field:	IEC 61000-4-10:2001 Level 5 100 A/m at 100 kHz and 1 MHz
Power Supply Immunity:	IEC 60255-26:2013, Section 7.2.11, 7.2.12, and 7.2.13 IEC 60255-27:2013, Section 5.1.3, 10.6.6
Surge Immunity:	IEC 60255-26:2013, Section 7.2.7 Zone A Line-to-line: 0.5, 1.0, 2.0 kV Line-to-earth: 0.5, 1.0, 2.0, 4.0 kV
Surge Withstand Capability Immunity and Damped Oscillatory Wave Immunity:	IEC 60255-26:2013, Section 7.2.6 2.5 kV peak common mode 1.0 kV peak differential mode 1 MHz damped oscillatory IEEE C37.90.1-2012 2.5 kV oscillatory 4.0 kV fast transient 2.5 kV, 1 MHz damped oscillatory

Environmental

Cold, Operational:	IEC 60255-27:2013, Section 10.6.1.2 Test Ad: 16 hours at –40°C
Dry Heat, Operational:	IEC 60255-27:2013, Section 10.6.1.1 Test Bd: 16 hours at +85°C
Damp Heat, Cyclic:	IEC 60255-27:2013, Section 10.6.1.6 Test Db: +25°C to +55°C, 6 cycles (12 + 12-hour cycle), 95% RH
Damp Heat, Steady State:	IEC 60255-27:2013, Section 10.6.1.5 Test Cab: 93% RH, +40°C, 10 days
Object Penetration:	IEC 60255-27:2013, Section 10.6.2.6 Protection Class: IP30
Vibration Resistance:	IEC 60255-27:2013, Section 10.6.2.1 Class 2 Endurance, Class 2 Response
Shock Resistance:	IEC 60255-27:2013, Section 10.6.2.2, 10.6.2.3 Class 1 Shock Withstand, Class 1 Bump Withstand, Class 2 Shock Response
Seismic:	IEC 60255-27:2013, Section 10.6.2.4 Class 2 Quake Response

Safety

Dielectric Strength:	IEC 60255-27:2013, Section 10.6.4.3 IEEE C37.90-2005, Section 8 2.2 kVdc: IRIG-B 2.5 kVrms: Analog Inputs, Digital Inputs, and Digital Outputs 3.6 kVdc: Power Supply
Impulse:	IEC 60255-27:2013, Section 10.6.4.2 IEEE C37.90-2005, Impulse Section 2.5 kV: IRIG-B 5.0 kV: Analog Inputs, Digital Inputs, Digital Outputs, and Power Supply
Product Safety Requirements:	IEC 60255-27:2013
Laser Safety:	21 CFR 1040.10 IEC 60825-1:2014 Class 1

Reporting Functions

Fault Locator

Methods:	Double-ended and single-ended traveling-wave; double-ended and single-ended impedance
Communications Port for Double-Ended Methods:	User-selectable, Port 1, 2, 3, or 6
Time Synchronization Requirements:	None for single-ended methods or when using Port 6 High-accuracy IRIG-B when using Port 1, 2, or 3
Data Presentation:	Summary report, event report (IEEE COMTRADE[1] header file), local relay HMI, supported SCADA protocols

[1] IEEE Std C37.111-2013 (IEC 60255-24:2013), *Measuring Relays and Protection Equipment – Part 24: Common Format for Transient Data Exchange (COMTRADE) for Power Systems*.

Double-Ended Traveling-Wave-Based Method

Channel Requirements:	Direct point-to-point fiber on Port 6 or IEEE C37.94 multiplexed channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at both line terminals and channel latency less than 30 ms
Device Accuracy[1]:	20 m (90th percentile error), 10 m (median error)

[1] Tested with a current step

Application Accuracy:	300 m typical, see *Accuracy Analysis on page 4.8 of the SEL-T400L Instruction Manual*
Number of Nonhomogeneous Line Sections:	Up to 5
CT Cable Length Compensation:	0.000 to 10.000 µs

Single-Ended Traveling-Wave-Based Method

Device Accuracy[1]:	20 m (90th percentile error), 10 m (median error)

[1] Tested with a current step

Application Accuracy:	300 m typical, see *Accuracy Analysis on page 4.10 of the SEL-T400L Instruction Manual*

Number of Ranked Fault Location Candidates Reported:	Up to 4
CT Cable Length Compensation:	Not required

Double-Ended Impedance-Based Method

Channel Requirements:	Direct point-to-point fiber on Port 6
Method:	Negative-sequence line voltage profile (unbalanced faults) or positive-sequence line voltage profile (three-phase faults)
Application Accuracy:	See *Accuracy Analysis on page 4.13 of the SEL-T400L Instruction Manual*

Single-Ended Impedance-Based Method

Method:	Apparent impedance polarized with negative-sequence (unbalanced faults) or positive-sequence (three-phase faults) current
Application Accuracy:	See *Accuracy Analysis on page 4.11 of the SEL-T400L Instruction Manual*

High-Resolution Event Reports

Sampling Rate:	1 MHz 10 kHz
Maximum Duration:	Three back-to-back 1.2-second events sampled at 1 MHz
Output Format:	Binary 32-bit COMTRADE

Note: IEEE Std. C37.111-2013, Common Format for Transient Data Exchange (COMTRADE) for Power Systems

Event Storage (Summary, History, Events)

Total Storage:	50 records at LER = 1.2 s 300 records at LER = 0.2 s

Sequential Events Recorder

Storage:	10,000 entries
Resolution:	100 µs

Protection Specifications

Sampling and Processing

Currents and Voltages:	Sampled at 1 MHz with 18-bit resolution
TW Calculations:	Every 1 µs
Incremental-Quantity Calculations:	Every 100 µs
Protection Logic Processing:	Every 100 µs

System Configuration

Nominal System Frequency:	50 Hz or 60 Hz
Frequency Tracking Range:	±10 Hz from nominal
Maximum Frequency Slew Rate:	±10 Hz/s
System Phase Rotation:	ABC or ACB
Current Transformer Ratio:	1 to 50000 in steps of 1
Line Current Source:	IW, IX, or COMB
Secondary CT Cable-Delay Compensation:	0.000 to 10.000 µs in steps of 0.001 µs
Potential Transformer Ratio:	1.00 to 10000.0 in steps of 0.01
Nominal Voltage (L-L):	100 to 250 V secondary in steps of 1 V

Line Configuration

Positive-Sequence Line Impedance Magnitude:	
1 A Model:	0.25 to 1275 Ω secondary in steps of 0.01 Ω
5 A Model:	0.05 to 255.00 Ω secondary in steps of 0.01 Ω
Positive-Sequence Line Impedance Angle:	5.00° to 90.00° in steps of 0.01°
Zero-Sequence Line Impedance Magnitude:	
1 A Model:	0.25 to 1275 Ω secondary in steps of 0.01 Ω
5 A Model:	0.05 to 255.00 Ω secondary in steps of 0.01 Ω
Zero-Sequence Line Impedance Angle:	5.00° to 90.00° in steps of 0.01°
Line Length:	0.01 to 500.00 in steps of 0.01
Line Length Unit:	km or mi
TW Line Propagation Time:	10.0 to 1700.0 µs in steps of 0.01 µs
In-Line Series Capacitance:	
1 A Model:	0.00 to 1275 Ω secondary in steps of 0.01 Ω
5 A Model:	0.00 to 255.00 Ω secondary in steps of 0.01 Ω
External Series Compensation:	Y or N

Traveling-Wave Differential Scheme (TW87)

Channel Requirements:	Direct fiber-optic channel One-way channel delay less than 4 ms and less than the TW line propagation time plus 2 ms
External Time Source Requirements:	None
Voltage Requirements:	TW87 requires voltage to operate
TW87 Overcurrent Supervision:	
1 A Model:	0.02 to 2 A secondary in steps of 0.01 A
5 A Model:	0.1 to 10 A secondary in steps of 0.01 A
Blocking Fault Location:	OFF, 0.00 to 1.00 line pu in steps of 0.01
Blocking Fault Location Radius:	0.01 to 0.25 line pu in steps of 0.01
Number of Blocking Fault Location Zones:	2
Operating Time (in ms):	0.5 + 0.0087 • line length (km); or 0.5 + 0.014 • line length (mi)

Note: Operating time is defined from the time the first TW reached the local terminal.

Incremental-Quantity Distance Element (TD21)

Phase Reach:	OFF, 0.10 to 0.90 pu of line length in steps of 0.01
Ground Reach:	OFF, 0.10 to 0.90 pu of line length in steps of 0.01
Operating Time:	<5 ms typical for bolted faults; <50% of the reach and SIR <1
Transient Overreach:	<10%

Note: Operating time is defined from the time the first TW reached the local terminal.

Traveling-Wave Directional Element (TW32)

Application:	Accelerating POTT keying (optional)
Operating Time:	0.1 ms typical

Note: Operating time is defined from the time the first TW reached the local terminal.

Incremental-Quantity Directional Element (TD32)

TD32 Forward Impedance Threshold:

1 A Model:	0.05 to 1275.0 Ω secondary in steps of 0.01 Ω
5 A Model:	0.01 to 255.0 Ω secondary in steps of 0.01 Ω

TD32 Reverse Impedance Threshold:

1 A Model:	0.05 to 1275.0 Ω secondary in steps of 0.01 Ω
5 A Model:	0.01 to 255.0 Ω secondary in steps of 0.01 Ω
Operating Time:	<2 ms typical

Note: Operating time is defined from the time the first TW reached the local terminal.

Permissive Overreaching Transfer Trip (POTT)

Operation:	Phase-segregated POTT scheme with TD32 and optionally TW32 via fiber-optic serial ports (SEL MB8 or IEEE C37.94 encoding) or point-to-point fiber-optic channel

POTT Overcurrent Supervision:

1 A Model:	0.02 to 2 A secondary in steps of 0.01 A
5 A Model:	0.1 to 10 A secondary in steps of 0.01 A

Direct Transfer Trip (DTT)

Operation:	Phase-segregated DTT scheme via fiber-optic serial ports (SEL MB8 or IEEE C37.94 encoding) or point-to-point fiber-optic channel

Monitoring Functions

Adaptive Autoreclose Control

Operation:	Asserts an autoreclose cancel signal based on the fault location obtained with the double-ended traveling-wave fault-locating method for user-settable line sections
Channel Requirements:	Direct fiber-optic on Port 6 or IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at both line terminals and channel latency less than 30 ms
Number of Autoreclose Blocking Regions:	2
Default Output if Fault Locating Fails:	Cancel or allow reclosing (user-selectable)

Line Monitor

Operation:	Detects, locates, tabulates, and alarms on fault precursors. Provides blocking regions for line taps with load or generation, or in-line series capacitors. Tabulates and alarms for total line events outside of the blocking regions and for daily event counts within the blocking regions.
Channel Requirements:	Direct fiber-optic on Port 6 or IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at both line terminals and channel latency less than 30 ms
Triggering Mechanism:	Low-energy events only, faults only, low-energy events and faults (user-selectable)
Sensitivity:	Current traveling waves at both line terminals greater than 2.5% of peak nominal current
Location Resolution:	0.25 mi or km
Counter Range per Location:	0–255 (counting stops at 255)
Number of Line Monitoring Blocking Regions:	2
Alarm Threshold:	1–200
Data Presentation:	A text file with tabulated event location and count, alarm bits, and alarm locations available over supported SCADA protocols

Metering Accuracy

All metering specifications apply at 20°C and nominal frequency unless otherwise noted.

Current (Local)

Phase Current Magnitude:	±0.2% plus ± 0.001 • Inom (0.05 • Inom – 3 • Inom)
Phase Current Angle:	±1° (0.05 • Inom – 0.2 • Inom) ±0.2° (0.2 • Inom – 3 • Inom)
Sequence Current Magnitude:	±0.3% plus ± 0.001• Inom (0.05 • Inom – 3 • Inom)
Sequence Current Angle:	±1.5° (0.05 • Inom – 0.2 • Inom) ±0.3° (0.2 • Inom – 3 • Inom)

Voltage

Phase Voltage Magnitude:	±0.2% (5–175 V_{L-N})
Phase Voltage Angle:	±0.2° (5–175 V_{L-N})
Sequence Voltage Magnitude:	±0.3% (5–175 V_{L-N})
Sequence Voltage Angle:	±0.3° (5–175 V_{L-N})

Frequency (Input 5–175 V_{L-N}, 40–70 Hz)

Accuracy:	±0.001 Hz

Built-In Testing Functions

Loopback Mode for MIRRORED BITS Channels

Purpose:	Troubleshoot a teleprotection channel by allowing the relay to receive its own packets while passing the received teleprotection bits to the downstream logic or substituting them with fail-safe values
Initiation:	SEL ASCII command
Annunciation:	Relay Word bit
Security:	Access Level 2 and time-out

Traveling-Wave Test Mode

Purpose:	Test the TW87 scheme by using only high-frequency signals, without the presence of fundamental frequency components in currents or voltages
Initiation:	SEL ASCII command
Annunciation:	Front-panel LED, Relay Word bit, ALARM output
Security:	Access Level 2 and confirmation of the initiating command from the front panel; time-out

Event Playback

Purpose:	Test protection and fault-locating functions by substituting samples from the local analog-to-digital converter in real time, with values from relay memory (e.g., playing back event records)
Test File Format:	SEL playback file (.ply)

File Conversion:	Playback File Conversion Utility in QuickSet converts compliant C37.111 COMTRADE files into the SEL-T400L-compatible SEL playback file
Sampling Rate:	1 MHz, with the conversion software utility accepting and resampling files recorded or simulated at a fixed sampling rate of 1, 2, 4, 8, or 10 kHz or 1, 2, 3, 4, or 5 MHz
Test File Storage:	As many as five files in addition to storage for relay records
Test File Duration:	0.1–1.2 s
Pre-Event:	Pre-event steady-state emulation by looping the first cycle in the test file for 1 second; requires at least 50 ms of pre-event steady-state data in the input COMTRADE file
Test Trigger:	Manual (on demand) or time-based (scheduled and synchronized to absolute time for end-to-end testing)
Front-End Circuitry:	Playback File Conversion Utility optionally models the SEL-T400L analog anti-aliasing filters
Initiation:	SEL ASCII command or Event Playback Test Dashboard in QuickSet
Annunciation:	Front-panel HMI message, Relay Word bit, ALARM output
Security:	Access Level 2 and confirmation of the initiating command from the front panel; time-out

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