SEL Products and Features Make Integration Easy

E. O. Schweitzer, III and Gary W. Scheer
Schweitzer Engineering Laboratories, Inc.

Revised edition released November 1999

Original edition released 1996

SEL Products and Features Make Integration Easy

E.O. Schweitzer, III and Gary W. Scheer

ABSTRACT

Microprocessor relays have data that people and organizations want: relay operations, metering, event reports, self-test status, and fault location. From the beginning, SEL has offered easy ways to get these data from the relays to the users. Today, we offer a broad range of technologies that addresses the entire spectrum of application, from communicating with a single relay at one substation through integrating the metering, control, and protection of a large system. We will see even further advances in systems, protocols, and protection in the future.

THE BEGINNING

SEL introduced the first commercial digital distance relay in 1984. The SEL-21 offered protection, metering, event recording, fault locating, and automatic self-testing.

SEL included modem control firmware in these and later relays, to ease remote access. Slow 300-baud modems, accessed by printing terminals or Tandy 100 computers, were the beginning. We quickly moved to higher baud rates, more sophisticated computers, and powerful communications software, as the personal computer industry advanced.

In 1984, we also introduced the SEL-PRTU Protective Relay Terminal Unit. It is still a very popular and economical way to communicate with up to eight relays, buffer data for remote access, and display events as they happen on a local printer or computer. Thousands of Protective Relay Terminal Units are in service, communicating with SEL relays and other relays and equipment.

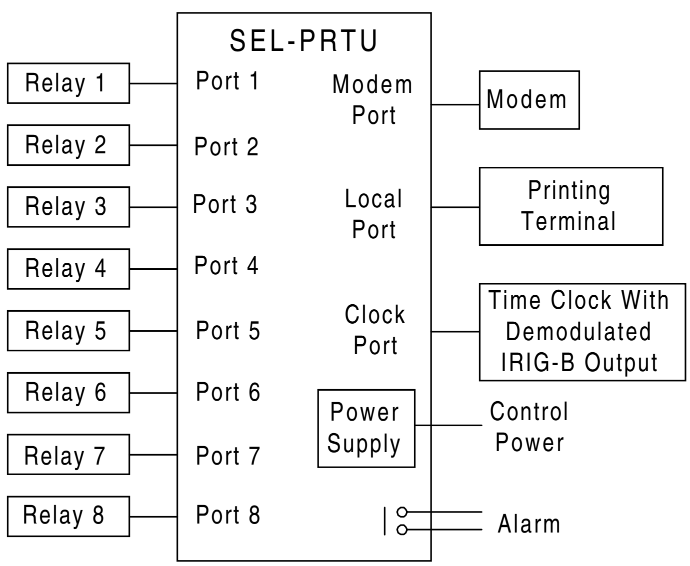

Figure 1: The First Integrated Protection Systems Used the SEL-PRTU

Schweitzer Engineering Laboratories, Inc.
2350 NE Hopkins Court • Pullman, WA • 99163-5603 • USA
Phone: (509) 332-1890 • Fax: (509) 332-7990
E-mail: info@selinc.com • Internet: www.selinc.com

DIGITAL RELAYS IN AN ANALOG WORLD

Users quickly realized that SEL relays have valuable information that they wanted to get into their SCADA systems. The problem was how to get the digital representations of metering, event, fault location, and other information into the Remote Terminal Units (RTUs), which were designed to accept the analog outputs of transducers. The "protocol" inside the station for analog information was “analog” (e.g., 0 - 1 mA, ±5 volts, ±10 volts). Although some RTUs were computer-based, none were designed to accept digital data from meters or relays.

SEL developed the SEL-DTA Display/Transducer Adapter to take the digital information from SEL relays, and then to convert it back to analog for the RTU or to drive panel-meters to display the information for a local station operator.

Utilities began displaying fault location on their SCADA master station screens, so operators could immediately use the valuable information. Some users integrated the readings onto their map displays. These displays resulted in much shorter outages, so electric power users benefit from more reliable service.

Many designers began eliminating separate transducers and meters. Others retained the traditional devices along with the SEL relays.

At first, the idea sounds strange – start with analog CT and VT information, convert it to digital in the SEL relay, then back to analog in the SEL-DTA, then back to digital in the RTU, then display it for the operator. However, it remains a practical solution for many reasons:

1. There are many older RTUs in stations with SEL relays, and users want the data.
2. The SEL-DTA can be located close to the RTU, eliminating long analog cable runs in favor of a digital interconnection between the relay and the SEL-DTA.
3. The SEL-DTA provides one-button selection of faults, metering, or status displays – the easiest-to-use human-machine interface in the industry!

SEL has improved the Display/Transducer Adapter over the years. Several improvements are: from 8 to 12 bits of resolution for greater accuracy, an internal power supply for easier remote location, faster metering response, and a shallower package.

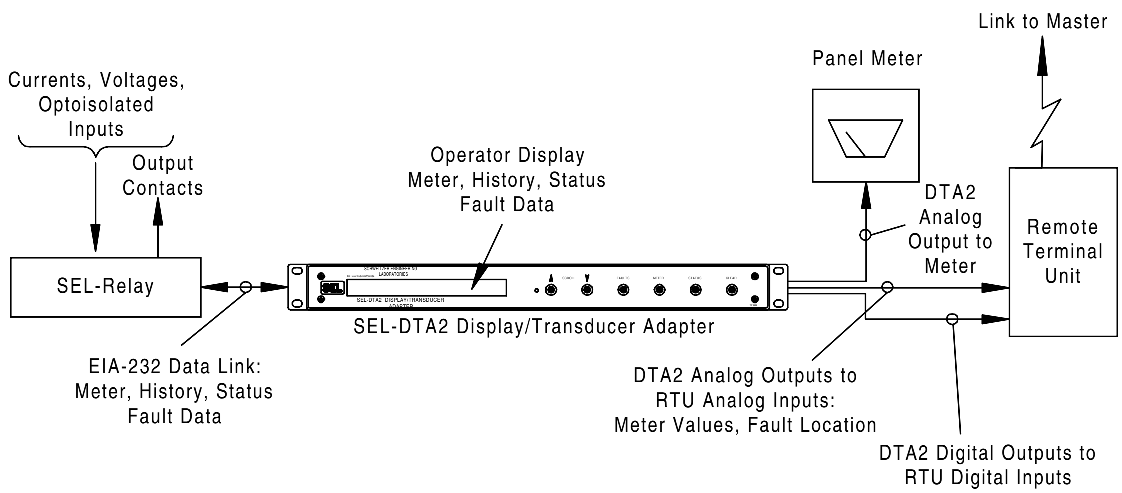

Figure 2: The SEL-DTA2 Display Transducer Adapter Provides Easy Operator Access and Interfaces to Traditional remote Terminal Units

DIGITAL COMMUNICATIONS FEATURES IN SEL RELAYS: OPEN PROTOCOLS

SEL has used ASCII plain-language commands for metering (METER command), setting (SET command), self-test status (STATUS command), event reporting (EVENT command), and other functions. Because we use plain-language commands, and the responses are formatted neatly for immediate interpretation, the user can always communicate with an SEL relay, even if all the user has at hand is a dumb terminal or a computer with terminal-emulation or communications software. No proprietary software is required, and users can easily take advantage of spreadsheets and other programs to handle relay settings, event reports, and other information. Ours is truly an open and versatile system. Reference the SEL-321 Relay commands summarized in Table 1, below:

Table 1: SEL-321 Relay Command Summary

Access Level 0	
ACCESS	Answer password prompt (if password protection is enabled) to enter Access Level 1. Three unsuccessful attempts pulse ALARM contacts closed for one second.
Access Level 1	
2ACCESS	Answer password prompt (if password protection is enabled) to enter Access Level 2. This command always pulses the ALARM contacts closed for one second.
BREAKER	Answer password prompt (if password protection is enabled) to enter breaker control Access Level B. Allows execution of OPEN, CLOSE, GROUP N, and Access Level 1 commands.
DATE	Shows or sets date. DAT 2/3/92 sets date to Feb. 3, 1992. IRIG-B time-code input overrides existing month and day settings. DATE pulses ALARM contacts when year entered differs from year stored.
EVENT	Shows event record. EVE 1 shows newest event; EVE 12 shows oldest. Default report is 1/4-cycle standard, EVE n L=1/16-cycle standard, EVE n R=1/16-cycle unfiltered, EVE n C=1/16-cycle SEL-5601 Event Report, EVE n U=1/16-cycle unfiltered.
GROUP	Shows setting group to use in lieu of active group.
HISTORY	Shows DATE, TIME, ZONE/TYPE, LOCATION (distance), GROUP, and front-panel targets for the last 40 events.
IRIG	Forces immediate attempt to synchronize internal relay clock to time-code input. Reports ID, Date, Time, or Error Message.
METER	Displays meter data.
QUIT	Returns control to Access Level 0; returns target display to Relay Targets TAR O. Displays ID, Date, and Time.
SHOWSET n	Shows active group settings for Group n. Shows active relay group settings if n omitted.
SHOWSET C	Shows calibration settings.
SHOWSET G	Shows global settings.
SHOWSET L	Displays active logic settings. Append group number (1-6) to display that group's logic settings.
SHOWSET P	Shows active port's settings. Append port number (1-3) to display that port's settings.
STATUS	Shows self-test status.
TIME	Shows or sets time. TIM 13/32/00 sets clock to 1:32:00 PM. IRIG-B synchronization overrides this setting.
TRIGGER	Triggers an event report.

Access Level B	
CLOSE	Asserts the CLOSE condition.
GROUP	Specifies currently selected group. Use GROUP n to change selected group to n.
OPEN	Asserts trip condition.
Access Level 2	
COPY m n	Copies settings and logic from setting Group m to Group n.
PASSWORD	Shows or sets passwords. Command pulses ALARM contacts closed momentarily after password entry. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.
SET n	Enter or edit group settings. If n argument omitted, edits active group.
SET G	Enter or edit new global settings.
SET L n	Enter or edit logic settings for group n. If n argument omitted, edits active group.
SET P n	Edit Port n's settings. If n is omitted, changes active port's settings.
TARGET	Shows target values, and defines target group for display. TAR n displays target row n. TAR R command resets front panel targets to TAR 1.

The ASCII plain-language command and human-oriented responses have been used in automatic systems, but SEL engineers devised a unique and better way to handle machine-to-machine communications.

What was needed was a way for people to communicate with SEL relays (to get reports, to set relays, etc.) and for machines to simultaneously get the metering information for SCADA. A system is not satisfactory if the control operator loses metering information while the relay technician is transferring an event report.

To meet this need, we developed the checksum-protected *Fast Meter* open binary protocol for fast machine-to-machine communications over the same communications lines that are being used for ASCII communications with the relay. SEL first introduced the *Fast Meter* capability in relays to speed up the metering response in the SEL-DTA Display/Transducer Adapters.

Because the *Fast Meter* open binary protocol transfers phasor representations of voltages and currents, a computer can perform any sort of metering calculations (e.g., demand, peak demand, moving window demand, watts/phase, energy, symmetrical components, and unbalance).

SEL extended the protocol to include the following:

- Phasor representation of voltages and currents
- States of all inputs, outputs, and relay elements
- Time-tagging, accurate to 2 ms in the SEL-321-1 and SEL-587
- Open and Close commands, with checksum and redundancy for security
- Short-event report binary messages

The SEL-2020 and SEL-2030 Communications Processors (SEL-2020/2030) (and some RTUs from other vendors), take great advantage of the binary protocols, to quickly keep the metering and relay elements up-to-date in local data storage.

The binary protocols are open and easy to use. SEL Application Guides are available, which define the protocols, so systems integrators or users wishing to take advantage of this powerful tool can design their own systems.

The SEL solution of simultaneous binary and ASCII communications is unique, open, and very friendly.

1. If you just use ASCII (e.g., communicate to an SEL relay using a computer and a terminal-emulation program), you need not know about the binary protocol.

2. If you use the SEL-DTA, the SEL-RD, or an SEL communications processor, the system automatically takes advantage of the binary protocol, and you still do not need to know its details. You just plug the equipment together, and it works.

3. If you want to develop your own communications system to use the binary protocol, just ask us for the application guides, and we will help you. Because the SEL-2020/2030 already communicates with all SEL relays (and many other IEDs), your development effort will be far less if SEL-2020/2030s are included in your system.

SEL is also making communications easier by including binary and ASCII communications-definition messages and commands in the relays. The relay provides information to the SEL-2020/SEL-2030 or other substation integration equipment, and this information defines the data formats and labels in the other messages honored by the relay. Because the next level can retrieve all labels, scale factors, and formats from the connected device, we eliminate the need to program such information into that next level.

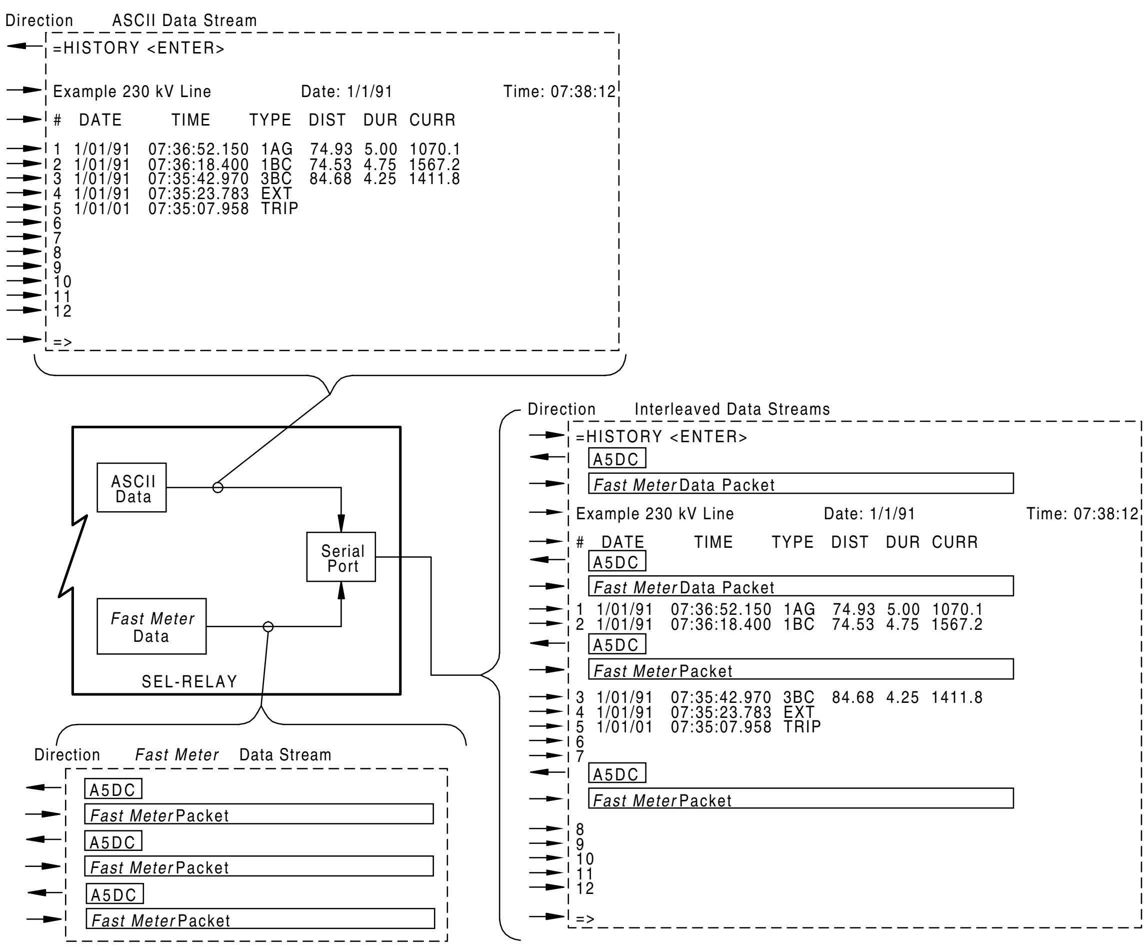

Figure 3: Interleaved Data Streams Allow Uninterrupted Data to SCADA System During ASCII Reports and Commands

For example, the extended *Fast Meter* message includes digital I/O and relay word elements, and the configuration message identifies the ASCII label for each element. A computer (or the SEL-2020/2030) can interrogate the relay once to get the labels and then interpret the *Fast Meter* data routinely.

Larger numbers of devices are integrated into the system using multiple SEL-2020/2030s. These “multi-tiered” systems use a top-tier communications processor to communicate with lower tier-level communications processors. These lower tier-level communications processors communicate with relays and other devices. The communications links between the communications processors are also interleaved binary and ASCII data channels.

Still another way we are making communications easier is through standard comma-delimited ASCII data reports. Its purpose is to efficiently import metering and event report data to databases and spreadsheets, where comma-delimited files are commonly used.

```
=>>EVE <ENTER>

SYSTEM SIDE 950617                    Date: 07/26/95    Time: 15:38:39.947

FID=SEL-321-5-X013-V516112pb-D950623

    CURRENTS (pri)            VOLTAGES (kV pri)     RELAY ELEMENTS  OUT   IN

                                                   ZZZZZZO  555566L 1357 1357
                                                   ABCABCO 3111077O &&&& &&&&
   IR     IA     IB     IC     VA      VB      VC   BCAGGGS 2NQPPNQP 2468 2468
                                :
    -8   -106      1     98  -152.1   302.5  -150.7 ....... ........ .... ....
  -303   -245   -118     60  -225.7     1.8   263.0 ....... ....M... .... ....
 -3125  -3013     -8   -105   144.2  -305.3   148.1 ....... ....H... .... ....
  4239   4183    118    -61    96.4     0.5  -259.1 ...2... Fp..H... 1... ....

  8284   8198     -6     93   -65.5   307.1  -147.3 ...1... Fp..H... 136. ....
 -8184  -8131   -115     63    -5.7    -3.2   254.8 ...1... Fp..H... 136. ....
-10585 -10526     19    -78    -5.8  -305.1   149.8 ...1... Fp..H... 136. ....
  8279   8241    108    -70     6.8     1.6  -256.7 ...1... Fp..H... 136. ....
                                :
```

```
=>>CEVE <ENTER>
"MONTH","DAY","YEAR","HOUR","MIN","SEC","MSEC","0ACA"
7,26,1995,15,38,39,947,"048C"
"IR","IA","IB","IC","VA","VB","VC","MID","RLY_BITS","OUT","IN","0DC5"
                                :
-8,-106,1,98,-152.1,302.5,-150.7,,"....... ........"," ...."," ....","0C41"
-303,-245,-118,60,-225.7,1.8,263.0,,"....... ....M..."," ...."," ....","0CC4"
-3125,-3013,-8,-105,144.2,-305.3,148.1,,"....... ....H..."," ...."," ....","0D7B"
4239,4183,118,-61,96.4,0.5,-259.1,,"...2... Fp..H..."," 1..."," ....","0D0D"
8284,8198,-6,93,-65.5,307.1,-147.3,,"...1... Fp..H..."," 136."," ....","0D56"
-8184,-8131,-115,63,-5.7,-3.2,254.8,,"...1... Fp..H..."," 136."," ....","0D6A"
-10585,-10526,19,-78,-5.8,-305.1,149.8,,"...1... Fp..H..."," 136."," ....","0E0A"
8279,8241,108,-70,6.8,1.6,-256.7,,"...1... Fp..H..."," 136."," ....","0CEF"
                                :
```

ASCII Hex Checksum of Characters

Figure 4: Standard EVE and CEVE Report Examples

TIME IS OF THE ESSENCE

Accurately time-tagged event reporting eases analysis. Accurately time-tagged metering information is more useful for state estimation than transducer data received after indefinite SCADA delays.

SEL introduced time synchronization of relays to the industry in 1985, in the 100-series hardware. Based on the advice of a customer, SEL chose the demodulated version of the IRIG-B time code. This time code was developed in the early days of the space program as a way to synchronize rocket range instrumentation.

Probably all time-code receivers and clocks generate IRIG-B time code in either the modulated (on a 1 kHz carrier) or demodulated (TTL-level) format.

The pulse-width modulated code consists of 100 pulses per second in a one-second frame. The pulse widths are 2, 5, or 8 ms. The 2 and 5 ms pulses are '0' and '1', respectively. The 8 ms pulses are for framing. Leading edges of the pulses occur every 10 ms.

SEL introduced the SEL-IDM IRIG-B Demodulator to accept modulated or demodulated time code from a clock, demodulate it if necessary, and buffer it to drive up to 12 relays.

When SEL developed the communications processor, one goal was to eliminate the need for a separate time-code distribution means. We accomplished this goal by including an IRIG-B time-code demodulator in the SEL-2020/2030. Each of the 16 rear ports includes a buffered demodulated IRIG-B time-code output, which directly drives SEL relay time-code inputs. Now, a single cable from the SEL-2020/2030 to the SEL relay transfers not only the EIA-232 signals but also the time code. The SEL-2810 Fiber-Optic Transceivers, with a two-fiber cable between the SEL-2020/2030 and IEDs, transfer bi-directional EIA-232 signals and IRIG-B time code.

The SEL-2020/2030 also includes a clock/calendar with battery back-up. Normally, the demodulated IRIG-B outputs are synchronized to the SEL-2020/2030 time-code input. But, if no input is present, the SEL-2020/2030 continues to generate demodulated IRIG-B outputs based on the internal clock/calendar, to keep all of the relays connected to that SEL-2020/2030 synchronized. This convenience eliminates or postpones the need for a time-code receiver in many applications.

TIMING ACCURACY

1. The time-code outputs of the SEL-2020/2030 track a demodulated IRIG-B input to within a few microseconds. Each time-code output tracks a modulated input to within a few hundred microseconds.
2. The early SEL relays tracked the time code to within approximately 0.1 second.
3. Most 100/200 series relays have been upgraded to track time to within approximately one cycle.
4. The SEL-321 relay clock synchronizes to ± 1 ms.

A system of SEL relays, synchronized by IRIG-B time code, provides accurately timed metering and event measurements across the entire power system. As an industry, we have just begun to scratch the surface of what can be done with information timed to one cycle or better accuracy from SEL relays:

1. Using phasors taken at precise instants for state estimation.
2. Reconstructing sequence of events.
3. Evaluating control and protection performance.
4. Tracking unbalance and oscillations.

SEL-2020 AND SEL-2030 COMMUNICATIONS PROCESSORS (PATENTED)

The SEL-2020/2030 is a low cost, highly-integrated solution for integration and automation as outlined below:

1. Automate a substation without the usual programming time and expense.
2. Set the SEL-2020/2030 with simple commands.
3. Focus on the application and perform perhaps 1/10 or less of the work that starting with a computer or PLC would involve.
4. Use the hardware and firmware, tailor-made to the substation application.
5. Centralize multiple host and slave communication ports in one device capable of building integrated databases.

The SEL-5020 Settings Assistant is a graphical user interface tool that makes an easy job still easier by guiding you through the process step-by-step, saving your configuration, and storing it in easily-read ASCII files.

The SEL-2020/2030 combines the following:

1. Local or remote port switch.
2. Multitasking/multi-user communications processor.
3. Time-code generation, regeneration, and time keeping.
4. Database, including FLASH memory for nonvolatile storage.
5. Contact inputs and outputs for local monitoring and control.
6. Programmable logic, which links the features listed in 4 and 5 above, and enables automatic control based on sensed data.
7. Arithmetic functions to concentrate data and perform comparisons.
8. Optional internal modem for remote access (SEL-2020 only).
9. Support for external modems for remote access.

The unique concept that is at the heart of easy integration is combining port switching with communications processing and a database. Using this concept, the SEL-2020/2030 can be used with virtually anything having an EIA-232 port.

The multitasking/multi-user operating system in the SEL-2020/2030 permits multiple and simultaneous communications tasks. For instance, several host systems can utilize different protocols to obtain data from the database, while a field engineer retrieves an event report, while the communications processor automatically continues collecting metering and element data from the relays.

The SEL-2030 Communications Processor encompasses all of the SEL-2020 features and also includes two slots to accommodate plug-in communications adapters.

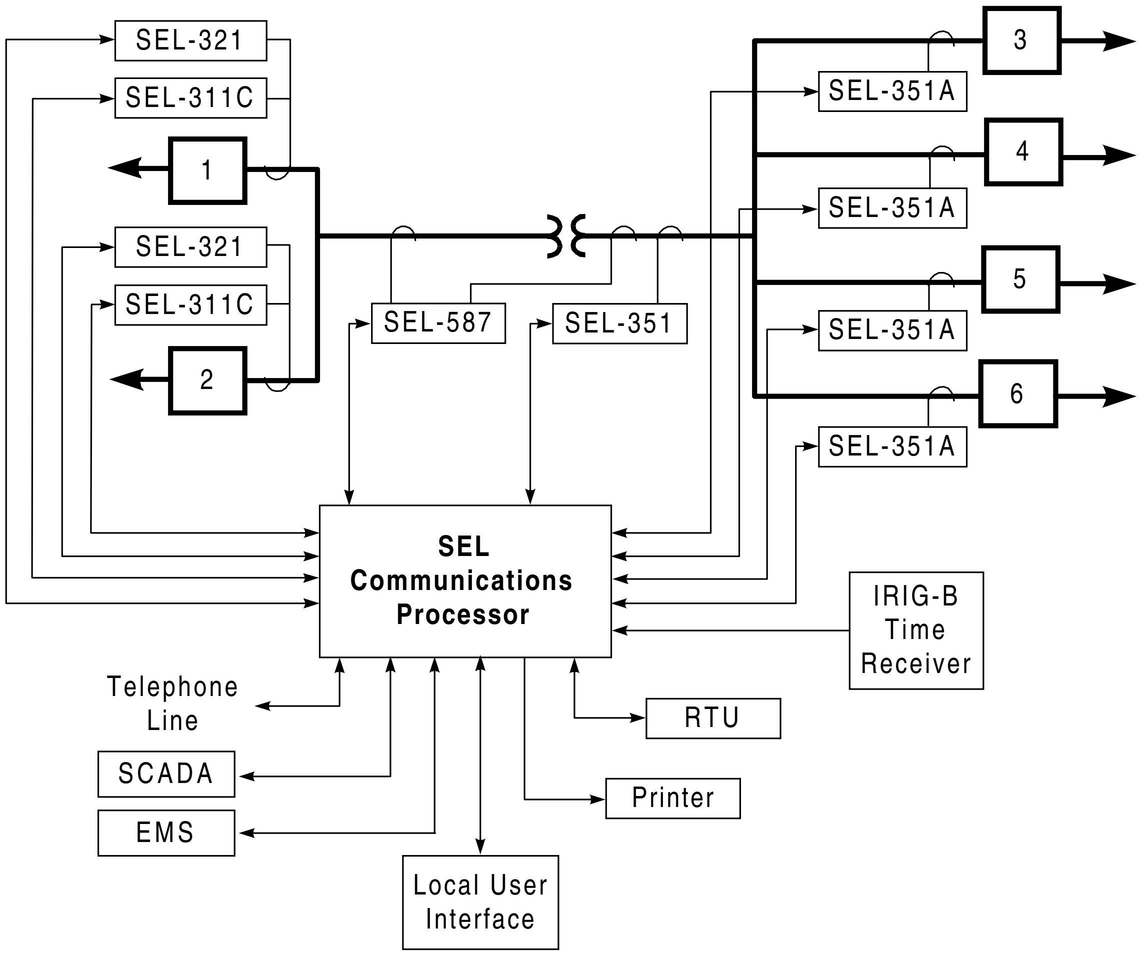

Figure 5: Example Configuration Diagram

System Performance

The database, time synchronization, communications, and control are tightly integrated in the SEL-2020/2030 which uses a powerful 32-bit microcomputer to achieve impressive system performance:

1. Simultaneous communications on all ports at up to 38.4 kbps.

2. Metering and relay element data can be updated once per second, or faster, simultaneously on all relays attached to the SEL-2020/2030.

3. Using the *Fast Operate* message, an operator can control circuit breakers from a computer in less than 100 ms. The average is 61 ms. These times include passing the control command from the computer to the SEL-2020/2030, from the SEL-2020/2030 to the relay and the relay actuating output contacts.

4. The SEL-2020/2030 time-code outputs are accurate to within a few microseconds of a demodulated IRIG-B input.

SEL-2800, -2810, AND -2815 FIBER-OPTIC TRANSCEIVERS

The SEL-2800, -2810, and -2815 Fiber-Optic Transceivers are built in compact packages that directly mount to the subminiature 9-pin "D" connectors on an SEL-2020/2030 and some SEL relays. For other relays and IEDs, use an intermediate adapter cable. The transceivers are powered by EIA-232 signals and are connected by a two-fiber cable to the other end of the link. The SEL-2800 provides bi-directional communication at up to 38.4 kbps and up to and greater than 500 meters. The SEL-2815 provides bi-directional communication for distances up to 15 kilometers. The SEL-2810 provides bi-directional communication up to 19.2 kbps and transmits IRIG-B time code from the SEL-2020/2030 to the IED using the same fibers.

COMMUNICATIONS PROTOCOLS

SEL has received hundreds of inquiries involving over 90 protocols. There are many committees, research activities, demonstration projects, and proposals under consideration in the electric power and related industries. Protocol discussions will probably last for a decade. Even if the industry could come to a short-term agreement on a standard protocol, additional requirements and technological advancements will move the industry to more powerful data networks requiring improved protocols. In the meantime, there is work to be done automating systems.

To understand protocols in substations, it is essential to identify the level in the communications block diagram where you apply a protocol. The lowest tier of the communications hierarchy utilizes protocols to directly communicate with each Intelligent Electronic Device (IED). IED examples include microprocessor-based protective relays, meters, and transducers. These devices may communicate in a point-to-point protocol to the hub of a star network, or they may have a multidrop (i.e., party-line or daisy-chain) protocol to connect multiple devices to the same network.

The next level of protocol connects devices and communications hubs to a local network, with data from all IEDs in the substation, and from hubs in different parts of the station. This station level protocol is often a Programmable Logic Controller (PLC) protocol, such as Modbus®, Modbus Plus®, A-B DH-485, or A-B Data Highway Plus™.

Finally, for station-to-station or station-to-control-center communications, the SCADA industry has defined many specialized or proprietary wide-area protocols. Often, an RTU provides the translation from station data to the control center protocol, but in some applications, a bridge, gateway, or other network interface device provides the connection or translation.

Most protection equipment protocol discussions involve connection to the station level network. The SEL–2020/2030can serve as the hub of a star network connecting to individual IEDs and providing connection to the station-level system or network.

A list of SEL's plans and activities for station-level protocols follows:

1. Modbus. This PLC communications protocol is in the public domain and is typically used with EIA-485 networks. Modbus is available for virtually every PLC system and for PCs. Many RTUs produced in recent years support a Modbus link or option.

Offsetting the advantages of ubiquity, openness, and standard physical interfaces are the disadvantages of supporting only 32 addresses per net and a typical data rate of 9600 bps. Fortunately, these disadvantages usually do not limit typical SCADA system performance.

SEL introduced Modbus in the SEL-2020 in July 1995. This interface provides immediate network connectivity for SEL relays and for virtually any IED that can communicate with an EIA-232 terminal.

2. DNP3.0 Level 2. The IEEE Substations Committee Working Group on IED Communications, Task Force 10 ranked DNP3.0 as their first choice recommended practice for IED Communications. The SEL-2020/2030 include DNP3.0 software as a “slave” in a single-master network. DNP3.0 is available on Port 16. Any data which are already accessible in the SEL-2020/2030 database can be accessed through DNP3.0. Large data files are not supported in the first released versions of the product. The SEL-2020/2030 supports binary writes, generally for the purpose of triggering relay operates or as general SELOGIC® control equation inputs.

3. Ethernet. Because of its popularity around the world in PC, workstation, and other systems, we believe Ethernet is an especially logical choice for integrating station computers, PLCs, and devices like the SEL-2020/2030. SEL will introduce the SEL-2701 Ethernet Network Protocol Card (SEL-2701) for the SEL-2030 in the first quarter of 2000 with fiber and copper interfaces.

4. UCA. The Utility Communications Architecture is sponsored by EPRI and embraced by a number of North American utilities. In the first quarter of 2000 we will offer a subset of the UCA as an application layer on our products which support the SEL-2701.

5. Modbus Plus. Modbus Plus is popular with North American electric utilities. To accommodate their needs, we developed the SEL-2711 Modbus Plus Protocol Card (SEL-2711) for the SEL-2030. In addition to compliance with Schneider Automation requirements, our implementation is compatible with PC software from Universal Dynamics, Ltd.

INDUSTRY COOPERATION AND DATA CONNECTIONS

SEL is committed to providing information to system integrators, SCADA vendors, and RTU manufacturers. We openly distribute our protocol information. We provide technical assistance to help system integrators interconnect with SEL relays and use our communications products as building blocks in their integrated designs.

We work with customers and intermediate suppliers to analyze specifications to serve as part of the proposal preparation team and to provide equipment, system design, simulation, testing, commissioning, and documentation as a part of the project implementation team.

CONCLUSIONS

Protective relays acquire and calculate information that is valuable to automated systems and people that may be located in the same substation or far away in a control center or office. Protective relays have output contacts to operate breakers and perform other functions in control and protection schemes; these contacts can be used by other systems connected to intelligent relays. Historically, SEL has provided open solutions to allow analog, contact, and data-stream connections between our relays and remote terminal units and other communications or display devices. The SEL-2020 and SEL-2030 can serve as a key building blocks to provide data from IEDs to data users via telephone modems, RTUs, PLC systems, and other communications media.

SEL is a collaborative member of the multi-company teams working together to meet the needs of the electric power industry. We will continue to work with the industry to evolve system integration, control, and protection into tomorrow's electric power systems.

FACTORY ASSISTANCE

The employee-owners of Schweitzer Engineering Laboratories, Inc. are dedicated to making electric power safer, more reliable, and more economical.

We appreciate your interest in SEL products, and we are committed to making sure you are satisfied. If you have any questions, please contact us at:

Schweitzer Engineering Laboratories
2350 NE Hopkins Court
Pullman, WA USA 99163-5603
Tel: (509) 332-1890
Fax: (509) 332-7990

We guarantee prompt, courteous, and professional service.

We appreciate receiving any comments and suggestions about new products or product improvements that would help us make your job easier.