Pulsar Technologies, Inc.

APPLICATION NOTES
FOR THE
PULSAR MBT9600 MODEM AND SEL-321/SEL-351 RELAYS

GENERAL

The Pulsar Technologies, Inc. MBT9600 Modem is designed for application with the Schweitzer Engineering Laboratories, Inc. SEL-321-1 and SEL-351-1 Relays to optimize Mirrored Bit communication on analog communication channels. The Mirrored Bit communication scheme provides an RS232 channel to communicate status information between relays providing pilot relay protection, control, and monitoring functions. When used with the MBT9600 on an analog communication channel, The relay's RS232 communications port operates at a rate of 9600 bps. The MBT9600 is a special modem that takes the Mirrored Bit Logic data stream at 9600 bps and converts it for use on a full duplex (four wire) analog voice channel. Analog voice channels are most commonly available on analog microwave and leased phone circuit installations.

The purpose of this application note is to provide the user with a description of the operation of this combination (MBT9600 & Mirrored Bit Logic) of hardware and then to discuss the application of this combination to analog communication channels.

MIRRORED BITS APPLICATIONS

The SEL-321-1 and SEL-351-1 Relays includes an innovative, low-cost, relay-to-relay communication technique that sends internal logic status, encoded in a digital message, from one relay to the other. This new Relay-to-Relay Logic Communication capability, referred to as *Mirrored Bits,* opens the door to numerous protection, control, and monitoring applications that would otherwise require more expensive external communication equipment wired through contacts and control inputs. Applications for Mirrored Bit include line protection pilot schemes, remote device control and monitoring, relay cross tripping, and more. It is faster, simpler, less expensive, and more powerful than conventional communication schemes.

To implement Relay-to-Relay Logic Communication, you simply select the new Mirrored Bits protocol option on either of the two SEL-321-1 rear-panel EIA-232 serial communication ports or on one or two SEL-351-1 rear-panel serial ports, and connect the selected port(s) to a communication medium that supports full duplex digital data transfer. The Pulsar Technologies, Inc. MBT9600 converts the relay's transmitted digital message to analog signals for transmission on the analog communication channel and back to a digital message format at the receiving relay.

Once the communication link is established, each of the relays in the scheme repeatedly send and receive the digital logic message. Each relay continuously monitors received messages and channel condition, and checks for loop-back. Several internal relay elements are available to alarm, supervise, or control based on any adverse conditions.

The *Mirrored Bits* communication scheme repeatedly sends the status of eight internal relay elements, TMB1 to TMB8, from one relay to the other, encoded in the digital message. Bi-directional communication, transmit and receive, in each SEL Relay, creates eight additional "virtual" outputs on each relay "wired" through the communication channel to eight "virtual" control inputs on the other relay. The eight "virtual" inputs, RMB1 to RMB8, are internal relay elements in the receiving relay that follow, or "mirror", the respective status of the TMB1 to TMB8 elements in the sending relay.

Each TMB is programmed like an output contact, using SELogic® Control Equations, to provide the logical status of one or more elements in the relay, . Each SEL-321-1 Relay RMB is programmed with an input assignment, like the physical control inputs. In the SEL-351-1 Relay, each RMB is simply programmed in a SELogic® Control Equation to perform a logic function.

DESCRIPTION ON MBT9600

The MBT9600 modem is a four wire device that has a separate transmit and receive pair (full Duplex). Most modems available are capable of both transmitting and receiving on two wires (half-duplex). However, the turn around time for the modem between transmit and receive is much too long for application in a protective relay pilot system. In order to prevent this type of delay, each MBT9600 uses two modems operating independently. One for transmit data and one for receive data.

The MBT9600 also has a processor for the purposes of initializing the modem at power-up or reset, monitoring channel quality, buffering transmit data and controlling retrain time of the modem chips. The first task of the processor is to initialize and set the modem to its desired state at power-up or after a reset condition. During normal operation and between blocks of receive data the processor checks on the status of the modem chips. It confirms the signal-to-noise ratio or received data quality is adequate. Second, it looks at the state of the modems to determine whether or not either modem needs to retrain. The last major function of the processor is to

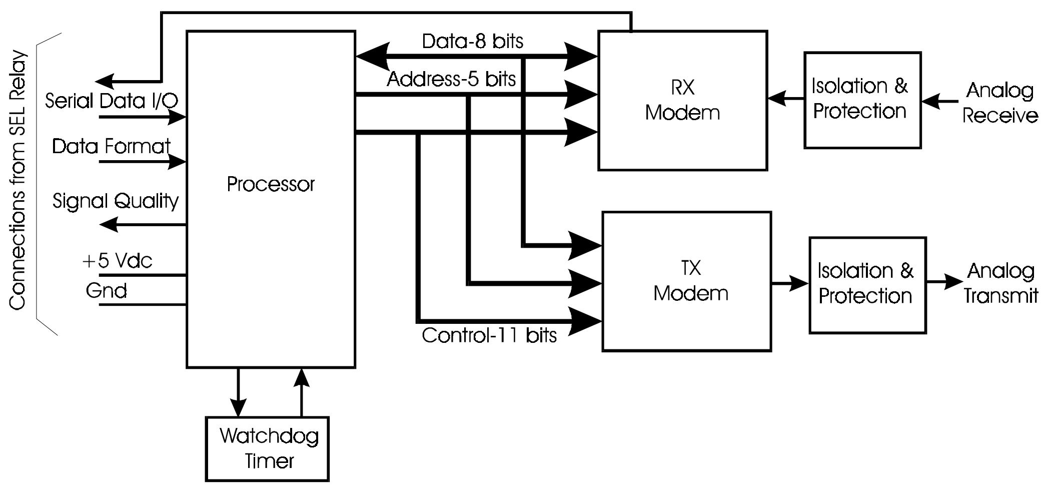

Figure 1 - MBT9600 Basic Block Diagram

buffer the in-coming transmit data from the relay since there may be slight clock differences between the relay clock and the modem clock. Buffering is also required because the relay data is arriving to the MBT9600 asynchronously and the modem chip needs to operate synchronously. A simple block diagram of the MBT9600 is shown in Figure 1.

In general modems that operate at data rates above 2400 bps require more elaborate modulation schemes than simple binary Frequency Shift Keying (FSK). This is due to the bandwidth limitations of available analog circuits, typically 300 to 3400 Hz. The MBT9600 uses Quadrature Amplitude Modulation (QAM). QAM is a combination of phase and amplitude modulation used to pack four bits into one *symbol*. Since there are four bits per symbol, there are 16 different symbols that can be transmitted. The modem uses a 1700 Hertz carrier modulated at a rate of 2400 baud. Thus symbols can be sent at a rate of 2400 times/s, and since there are 4 bits/symbol the modem's effective data rate 9600 bps. The modem adheres to the V.29

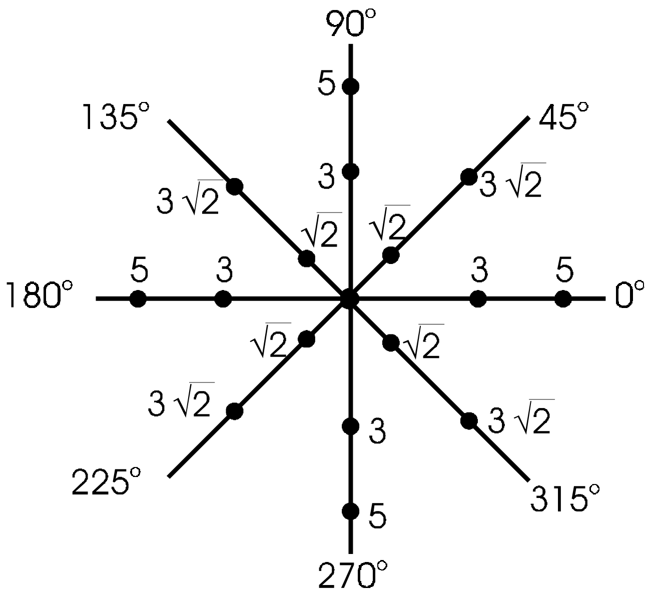

Figure 2 - MBT9600 Constellation Pattern

transmission standard. Figure 2 shows the phase and amplitude characteristics of the MBT9600. This is referred to as a constellation pattern.

MBT9600 CHANNEL REQUIREMENTS

Because the MBT9600 modem requires 16 transmission states in order to transmit 9600 bps on a normal bandwidth voice channel, some stringent channel requirements must be met The MBT9600 will require the full bandwidth of a four wire circuit. The channel must meet the minimum requirements of the 3002 C4 conditioned data channel specification. The characteristics of this channel are shown in the table I, II and III below.

Table I
Typical Interface Requirements and Transmission Characteristics
for Leased Voice Band 3002 Data Channels

	Parameter	Basic Channel
Requirements at Customer-Telephone Company Interface		
(1)	Maximum transmitted signal power	0 dBm
(2)	Impedance of terminal equipment	600 Ω ±10% resistive balanced
(3)	Received signal power of 1004 Hz test tone (at installation)	-16 dBm ±1 dB
Transmission Characteristics		
(1)	Attenuation distortion variation with reference to 1004 Hz	500-2500 Hz, -2 to +8 dB 300-3000 Hz, -3 to +12 dB Altered by conditioning in Table III
(2)	1004 Hz loss at installation	16 dB ±1 dB
(3)	1004 Hz short term loss variation	< ±3 dB
(4)	1004 Hz long term loss variation	< ±4 dB
(5)	Envelope delay distortion	<1750 µs, 800-2600 Hz Altered by conditioning in Table III
(6)	C-Notched noise-signal-to-noise ratio with 1004 Hz test tone	24 dB minimum
(7)	C-message noise	See Table II
(8)	Impulse noise-threshold with respect to received 1004 Hz test tone -6 dB -2 dB +2 dB	Maximum count above threshold allowed in 15 min. 15 9 5
(9)	Local Channel resistance unbalance	Not specified

Table II
C-Message Noise

Circuit Length (Miles)	Noise at Receiver (dBrnC)
0-50	28
51-100	31
101-400	34
401-1000	38

Table III
C4 Conditioning Requirements

Attenuation distortion variation with reference to 1004 Hz	**Frequency Range (Hz)**	**Variation (dB)**
	300-3200	-2 to +6
	500-3000	-2 to +3
Envelope Delay Distortion		**Distortion (µs)**
	1000-2600	<300
	800-2800	<500
	600-3000	<1500
	500-3000	<3000

CHANNEL REQUIREMENTS DISCUSSIONS

MBT9600 RETRAIN CHARACTERISTICS

Like all modems, the MBT9600 requires a training interval when initiating communications with a remote modem. This training interval enables the two modems to synchronize and establish a data path with each other. This section discusses aspects of this training function and MBT9600 communications.

Each four bit symbol, as discussed above, carries phase and amplitude information to the remote modem. The receiving modem plots the incoming symbol according to this phase and amplitude. This (Figure 2) plot is referred to as a *constellation* or *eye pattern*. In order to transfer data, the constellations of the two modems must match.

During initialization the modems start communicating with a predetermined (optimal) constellation pattern. Due to variations in the communications line characteristics equalization may be required. During training, equalization is adjusted in the receive modem until its constellation matches the transmit modem's constellation. After the two modems are communicating successfully, if a noise disturbance or loss of analog signal occurs, *retraining* may be required.

Standard off-the-shelf modems have to deal with many data formats and data rates. These modems also have the ability to automatically adjust their transmission rate for best performance with the current communication line conditions. While normally desirable, these features are obtained at the cost of vastly increased training time and data throughput delay.

The retrain specification for the MBT9600 is stated as being <1.0 second 70% of the times that retraining is required. Often this time is as low as 45 ms.

The time required for MBT9600 to retrain is influenced by the duration and severity of the interference condition. The MBT9600 has two levels of retrain initiation. The first and fastest is initiated by the modem chips, the second and longest is initiated by the microprocessor. For example, for high noise disturbances with a duration of 20 to 200 ms the retrain is initiated by the modem chips. When the disturbances are greater than 300 ms, a processor forced retrain can occur and in this case the retrain period can be as high as 1.5 to 2.0 seconds.

Because availability of the modem and its data are critical for power system protection applications, retrain times of less than 1.0 second are desirable. The MBT9600 has been designed for optimal retrain performance based on the timing requirements for power system protection.

The worst case scenario in relaying applications is fault inception coincidental with a disturbance on the communications channel. This condition is common on systems where the media is a direct wire connection. Private or leased four wire circuits pass through the substation premise and can be affected by the high levels of EMI, RFI and induced voltages that occur during faults inside or close to the substation

When a microwave channel (analog or digital) is used these concerns are not as great. Tests have shown that noise conditions are rarely coincidental with power system disturbances and most likely caused by atmospheric conditions.

Table IV is offered to clarify the range of retrain time verses the duration and severity of the channel disturbance. The time in which a pilot protection system is required to operate is based on the voltage level of the transmission line, the effects on power system stability and risk of equipment damage. This information is provided to aid the protection engineer in determining if the SEL-321 / MBT9600 is a viable alternative for specific applications.

Table IV
Typical Retrain Time

Disturbance Duration	Noise Burst 6 dB>Signal	Noise Burst 20 dB>Signal
25 ms	45 - 55 ms	100 -150 ms
50 ms	45 - 55 ms	100 - 200 ms
100 ms	45 - 55 ms	150 - 200 ms
200 ms	45 - 55 ms	200 ms

BASIC CHANNEL REQUIREMENTS

The minimum channel requirements are listed in table 1.

SPECIFIC CONCERNS WHEN APPLYING ON MICROWAVE CHANNELS

Analog or digital microwave circuits are ideal for application of the MBT9600. It has been proven through field tests that microwave systems are not subject to noise during faults on the power system. When applying the MBT9600 over these circuit it is desirable to set the system gain for unity or as close to unity as possible. This means with a transmitter output signal of -9dB, the receiver input level at the other end of the circuit will be -9dB without any additional attenuation or gain. This increases the dynamic operating range of the modem and brings the overall signal level farther away from the noise floor of the microwave system.

SPECIFIC CONCERNS WHEN APPLYING ON LEASED OR METALLIC CIRCUITS

The MBT9600 is not recommended for application over leased telephone circuits or private metallic circuits. In these applications it is highly probable that high levels of noise will be coincidental with a fault on the protected line. While the MBT9600 is protected against damage due to induced voltages and the RFI noise generated during faults, the current version is not capable of operating reliably during these conditions. The reason for this is the current MBT9600 has an operating range of -9 to -30 dB with a -9 dB transmit level. This yields a 21 dB operating range assuming unity gain on the communications system. Most leased circuits will induce an attenuation of around 16 dB. This leaves about 5 dB of dynamic operating range in the circuit. The modem also has a minimum signal to noise ratio of 27dB. This value is based on the noise level required to degrade the data output to a bit error rate of 10^{-6} . Under fault conditions noise levels on the circuit are likely to exceed a SNR of 27dB for a duration great enough to force the MBT9600 into a retrain condition.