SELECTION OF
DIRECTIONAL COMPARISON/PLC SYSTEMS

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INTRODUCTION

Powerline carrier equipment designed exclusively for protective relaying communications is known as "single-function powerline carrier". The carrier frequency is typically between 30 kHz and 300 KHz, but can be as high as 500 kHz. The carrier is keyed on and off or frequency-shifted, and an amplitude-modulated or single-sideband modulated voice channel can be added as an option. The rf output frequency from the carrier set is coupled onto a transmission line through the use of coaxial cable, line tuning units, coupling capacitors, and line traps.

Fifty years of powerline carrier equipment evolution has resulted in electron tube units that occupied entire 90-inch open relay racks being replaced first by smaller transistorized units, and now by units using integrated circuits. A typical unit today would occupy one or two 5 1/4-inch high rack-mounting chassis.

Single-function powerline carrier includes seven basic protective relaying communications-type applications:

1. Directional Comparison Blocking (DCB)
2. Directional Comparison Unblocking (DCU)
3. Permissive Overreaching Transfer Trip (POTT)
4. Permissive Underreaching Transfer Trip (PUTT)
5. Direct Underreaching Transfer Trip (DUTT)
6. Direct Transfer Trip for Apparatus Protection (DTT)
7. Phase Comparison Relaying (PCR)

The first five systems are generically classified as "directional comparison" systems. Focusing on these, the traditional method has been to use single-frequency on/off keyed powerline carrier equipment for DCB. In recent years, a new method has been developed using frequency-shift keyed (FSK) powerline carrier equipment for DCB. Each method has its advantages and disadvantages, which should be considered when specifying a system.

This paper discusses four overreaching directional comparison systems: on/off blocking, FSK blocking, FSK unblocking, and on/off unblocking. In order to limit the scope of this paper, the audio tone schemes and underreaching schemes are not considered. The overreaching schemes are more commonly used than underreaching schemes; this is probably due to the problems often experienced when setting the Zone 1 relays to overlap without overreaching. The POTT scheme using PLC is also not considered, because current practice within the United States favors unblocking over POTT when using PLC, since the carrier tripping signal may not get through an internal fault.

SYSTEM TYPES

ON/OFF BLOCKING

Figure 1 illustrates the typical phase-to-ground coupling technique used for on/off blocking single-frequency powerline carrier. In the example shown, a 200-kHz transmitter and receiver are used at each station for the carrier blocking functions.

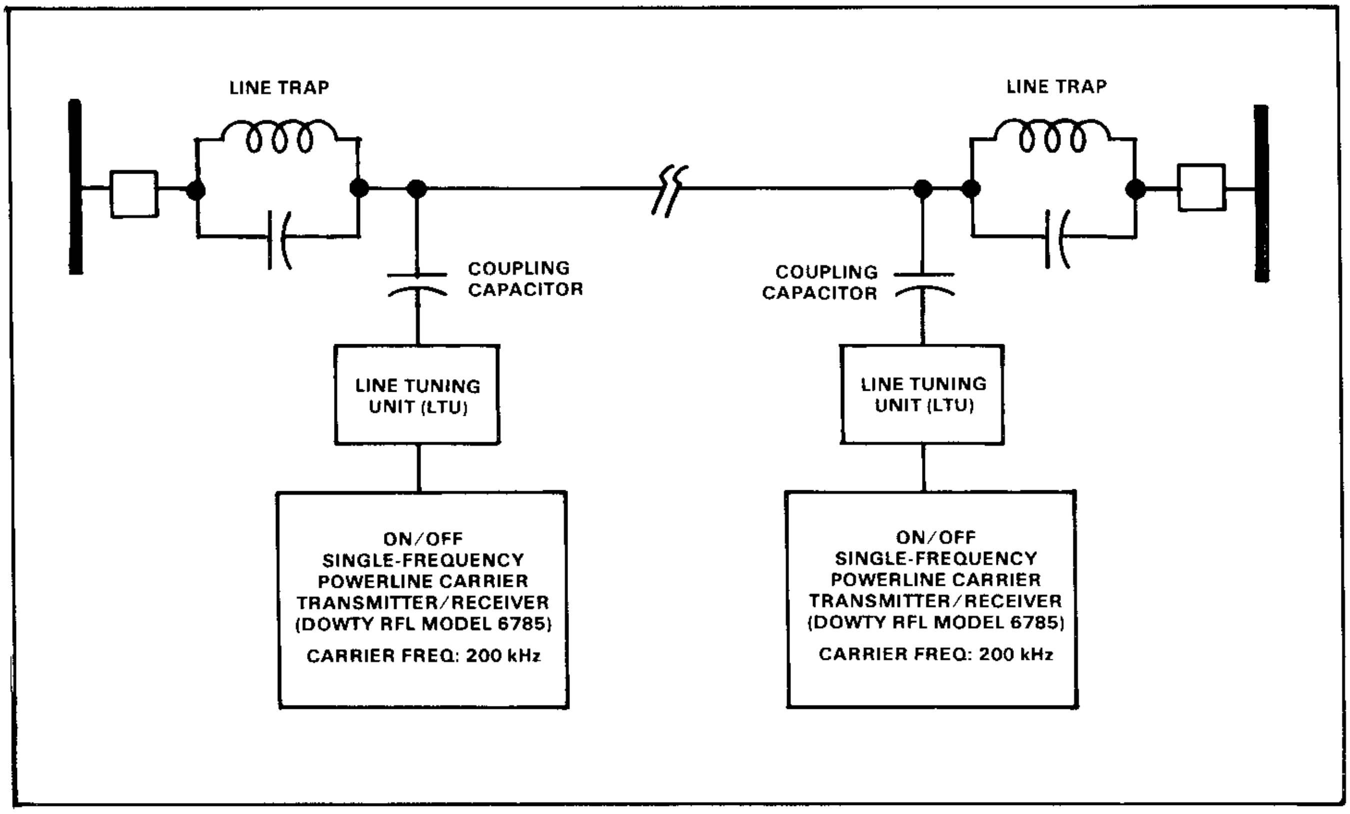


Figure 1. Transmission line coupling for on/off blocking

Figure 2 is a one-line diagram for a two-terminal line configuration. The PLC transmitter at each station is normally off, allowing the relays to trip the line for an internal fault. The carrier stop directional relays (device 21P) control breaker tripping and instruct the transmitter to remain off during internal fault conditions. If an external fault occurs, the carrier start relay (device 21S) commands the local transmitter to turn on, causing a 200-kHz signal (F1) to be sent to the remote station. The receiver at the remote station must detect F1 within a set time period (normally 1.5 to 3 ms) in order to block the overreaching relay (21P). The overreaching relay will overtrip if the blocking command is not successfully received.

The logic diagram in figure 3 shows the relationships between the carrier start (21S) and carrier stop (21P) relay contacts, the carrier receiver contacts (Rx), the transmitter input and the tripping of the breaker. The local carrier receiver contact (Rx) is normally open (no current to the relay); this enables the 21P relay contact to trip the breaker. An external fault sensed by the 21S relay will close a

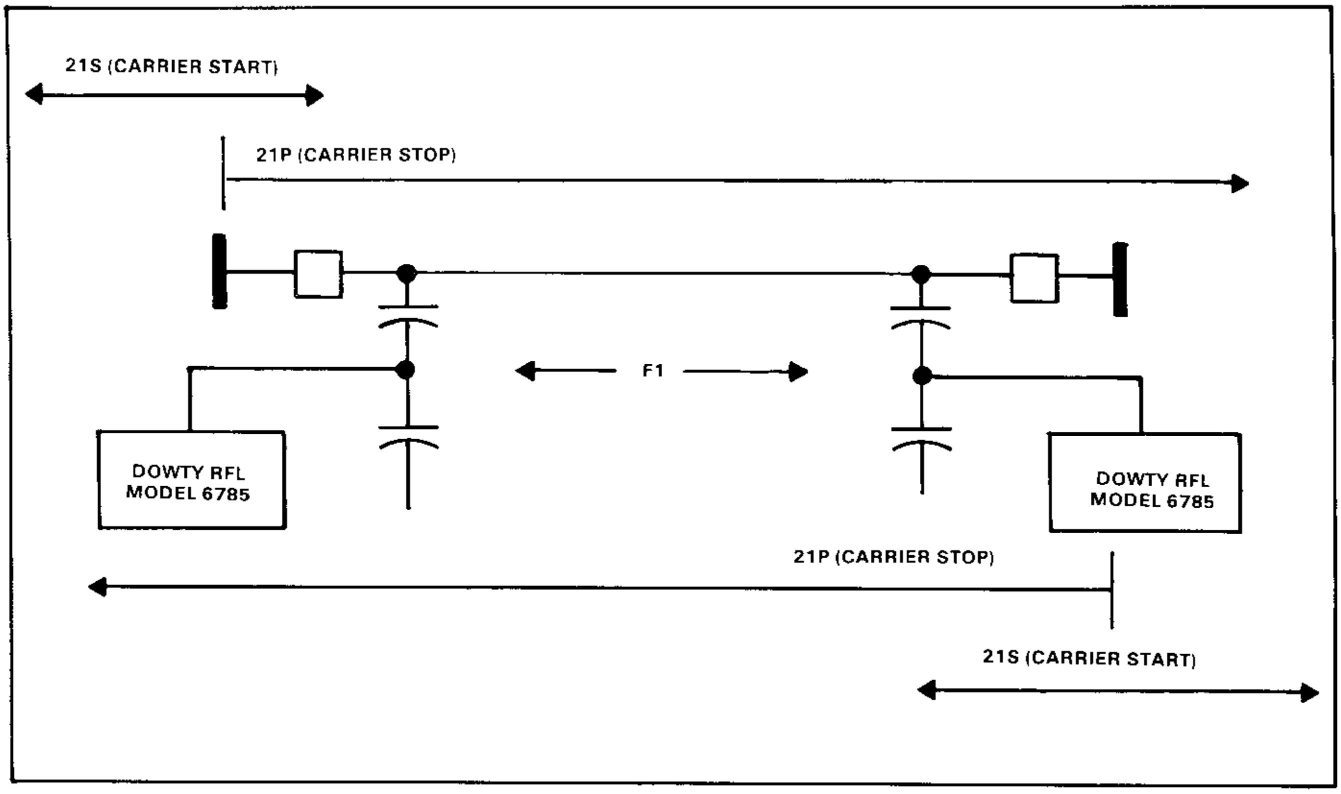


Figure 2. One-line diagram, on/off blocking

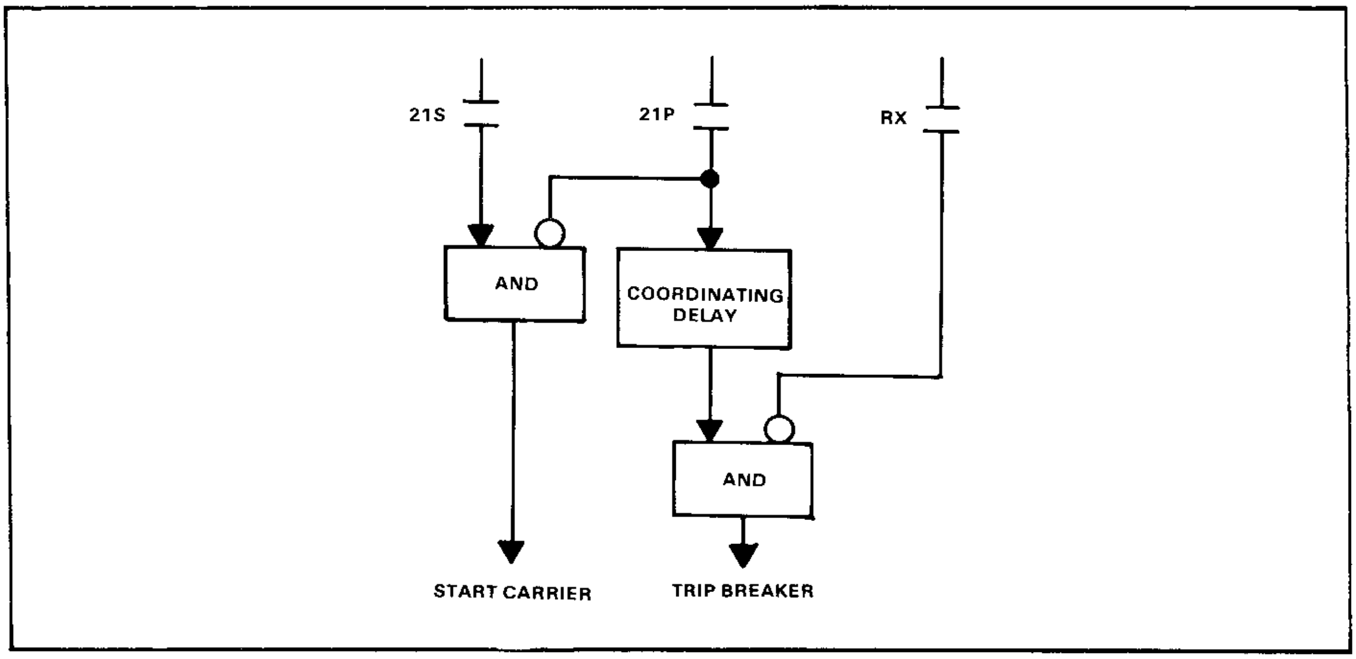


Figure 3. Logic diagram, on/off blocking

contact and turn on the local transmitter (providing the 21P relay does not see the fault), to block tripping. The 21P supervision of the carrier transmitter is called "stop-preference"; this is required whenever the carrier start relays are non-directional and can respond to close-in internal faults. At the remote station, the carrier receiver (Rx) detector will energize a relay; this will block the 21P over-reaching relay from tripping the breaker. In actual practice, the Rx contact is normally closed using a "b" contact from the carrier relay and opens to block tripping.

The "coordinating delay" shown in figure 3 is required to give the blocking carrier a chance to operate for external faults. Figure 4 shows the time charts for two typical blocking schemes: one without the coordinating delay, and one with the delay.

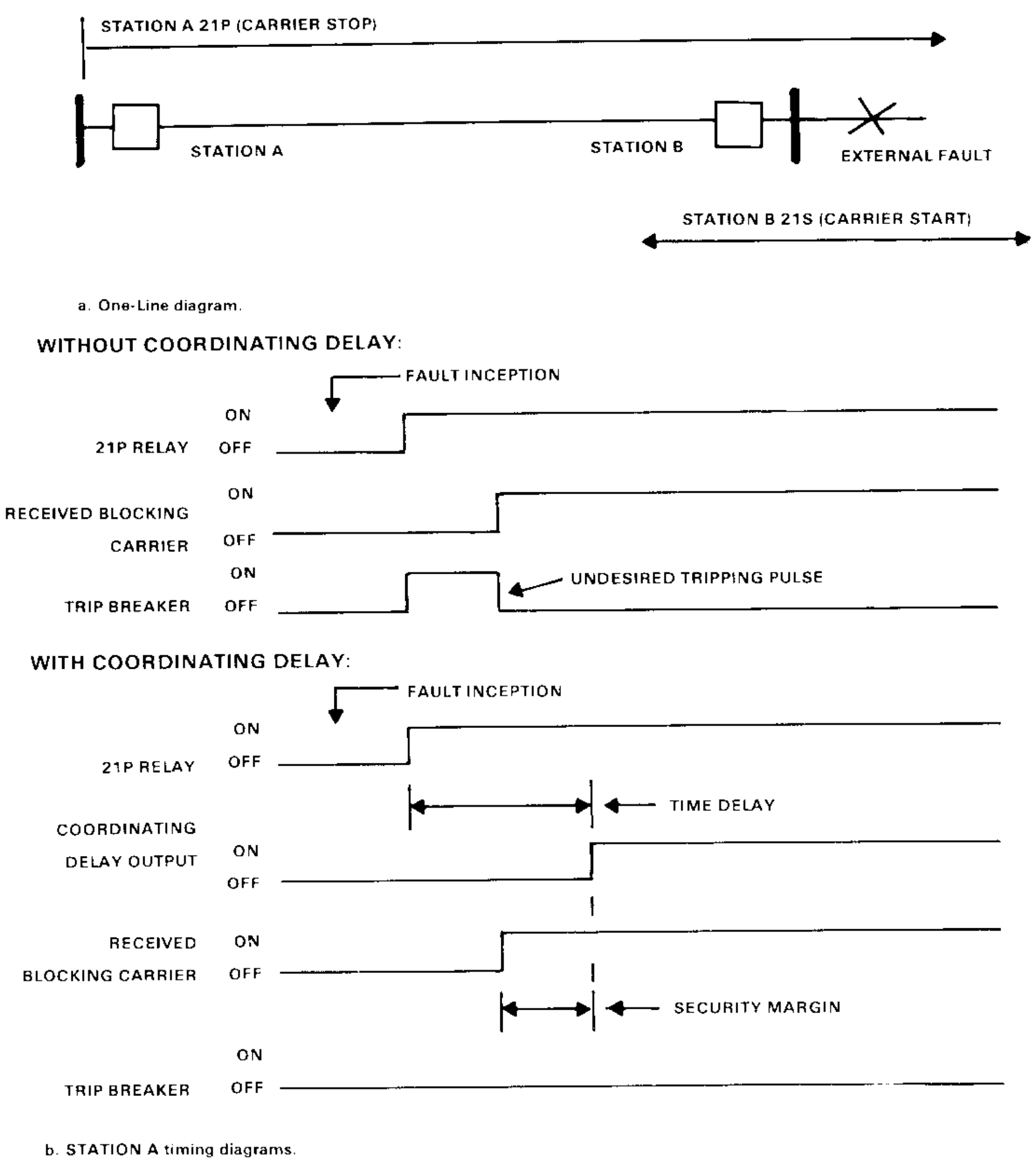


Figure 4. Coordinating delay

Figure 5 is a block diagram of a typical carrier communications channel used for on/off blocking, the Dowty RFL Series 6785. Each terminal end is housed in a 5 1/4-inch high chassis (3 EIA rack units) suitable for rack mounting, and contains a transmitter, a receiver, and a dc-dc converter power supply. An interface card provides optically isolated carrier start, carrier stop, and block output circuits. For diagnostic purposes, a carrier failure alarm monitors the timing sequence between carrier start and full-power transmission; this alarm data allows an engineer to evaluate inadvertent trip and failure-to-block occurrences, and determine if the transmitter was keyed and if a full 10-watt signal was transmitted. The reserve signal function allows testing at a 1-watt level to verify the receiver's dynamic range and to verify margin.

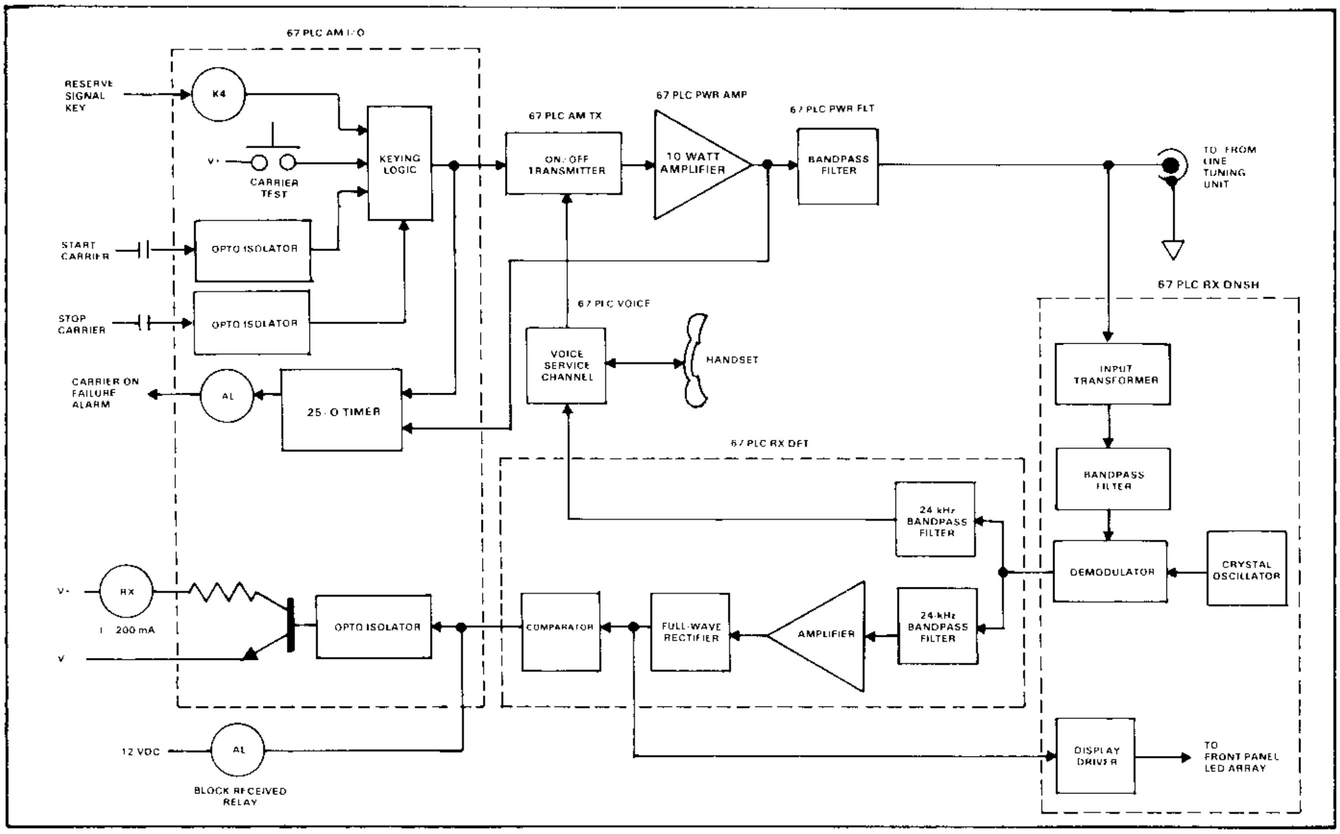


Figure 5. Block diagram, on/off blocking transmitter/receiver

The transmitter's output signal is amplified and fed to a symmetrical high-power bandpass filter; from there it is passed through a rear-panel UHF connector to the line tuning unit. Signals received by the line tuning unit are coupled through an isolation transformer to a bandpass filter. The filter output is demodulated to 24 kHz, and a detector converts the analog information into a filtered dc component which operates the floating optically-isolated output transistor switch. An array of light-emitting diodes visually indicates the received signal level, and further diagnostics are provided by a BLOCK RECEIVED status relay.

High speed and security are critical in on/off blocking schemes. Overtripping can be caused by noise associated with an external fault; to prevent this, security can be added to the blocking channel. For a blocking scheme, the "security" of the system is directly related to the expected carrier signal being received at the proper time. The comparator threshold can be lowered, which will make the receiver more sensitive. (See figure 6.) However, this will lead to a dependability problem, possibly causing a false block on an internal fault. The need for a compromise between security and dependability has led some utilities to experiment with FSK blocking schemes.

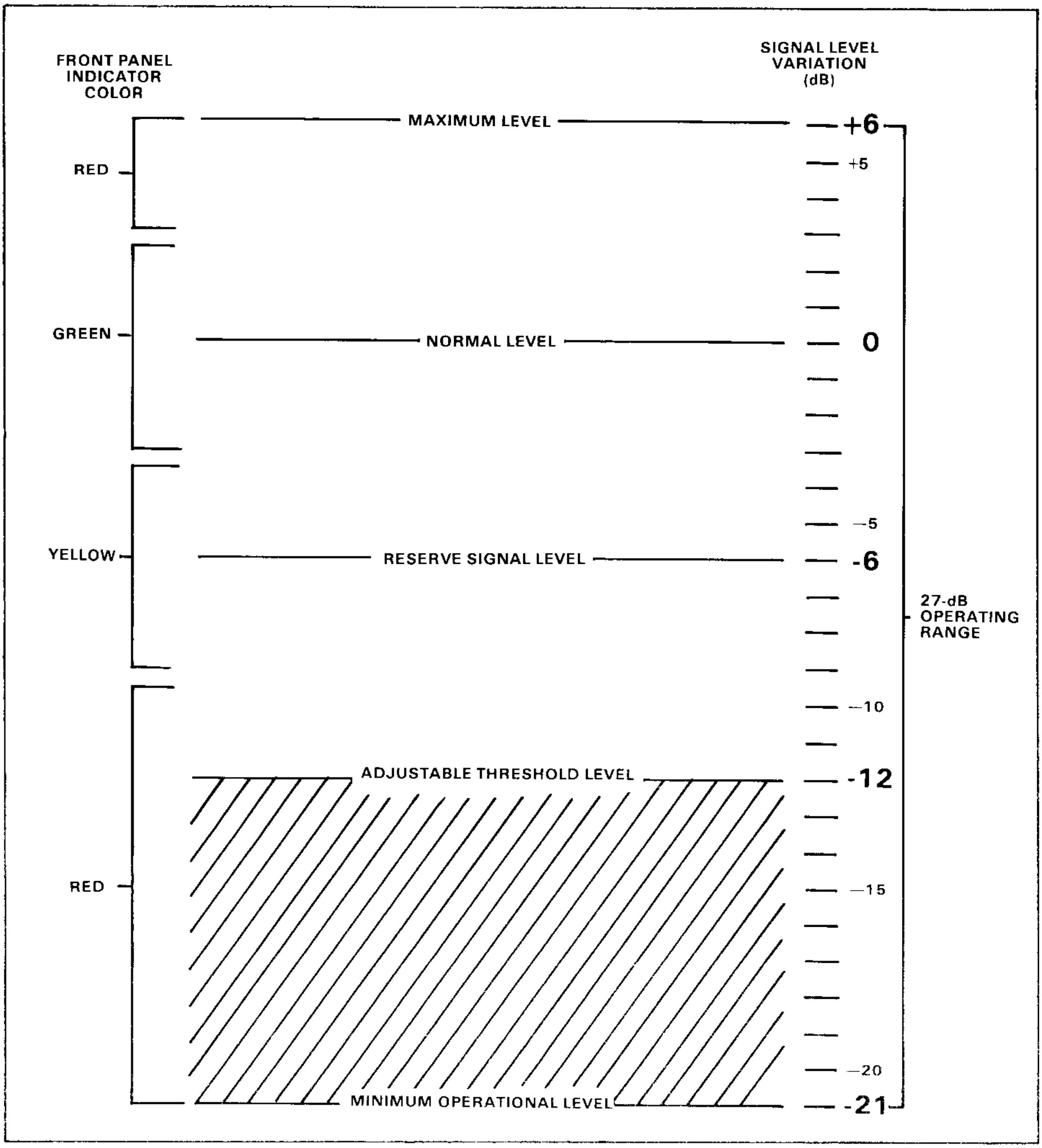


Figure 6. Dowty RFL Series 6785 on/off blocking level characteristics

FSK BLOCKING

Figure 7 illustrates the typical phase-to-ground coupling technique used for FSK blocking applications using two-frequency PLC equipment. For a two-terminal line, each station end contains a transmitter and a receiver.

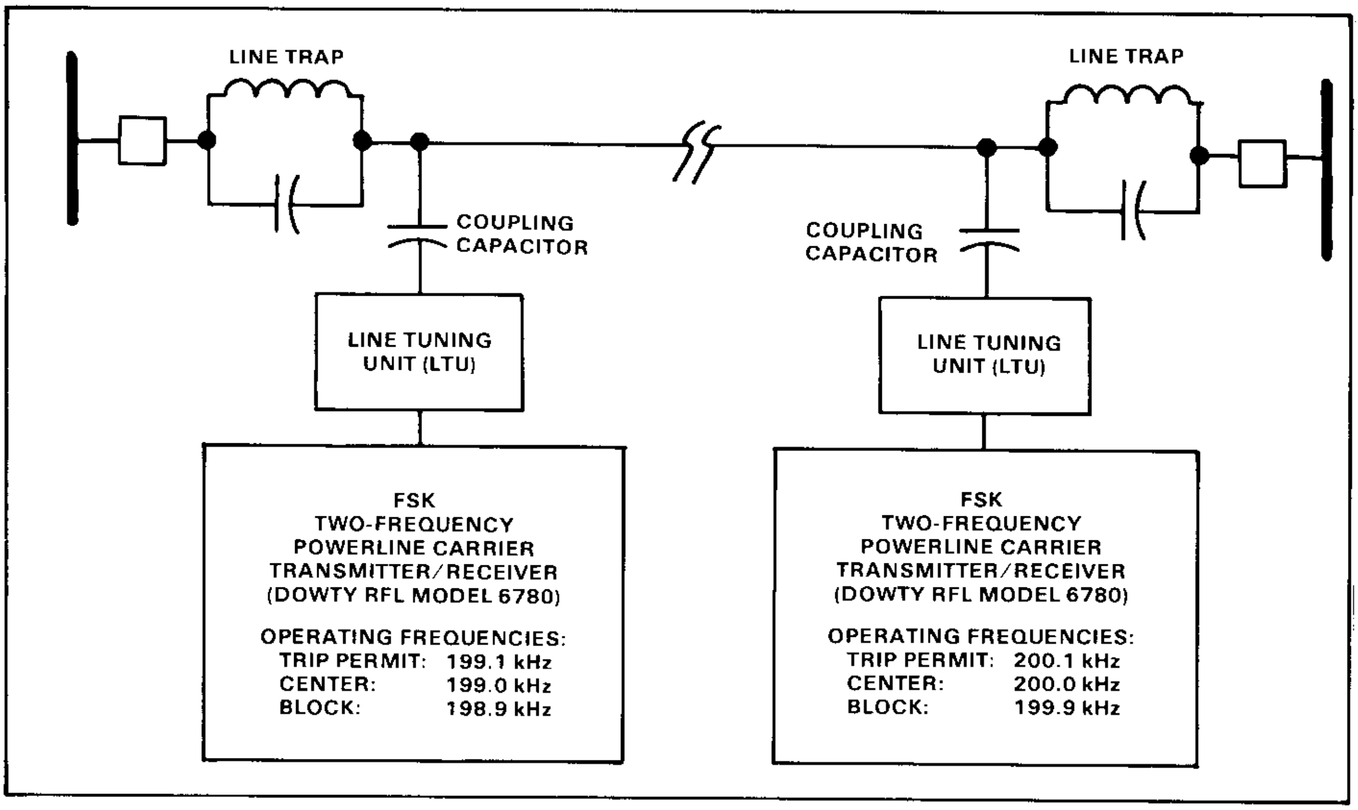


Figure 7. Transmission line coupling for FSK blocking

The transmitter center frequencies shown in figure 7 are spaced 1 kHz apart (199 KHz and 200 KHz). In normal FSK applications (such as DTT or unblocking), the unkeyed or quiescent FSK state is called "guard", and the keyed FSK state is called "trip". In DCB applications, the unkeyed state is called "trip permit" and the keyed state is called "block". Slight variations in circuitry and adjustments allow similar equipment to be used for all the above applications.

Figure 8 is a one-line diagram for a two-terminal line configuration. The same relaying scheme used for on/off blocking is employed, with the exception of two frequencies (F1 and F2) being used.

The logic diagram in figure 9 shows how the low-frequency block and high-frequency trip permit signals interact with the overreaching and directional relays to accomplish the same DCB task. A channel monitor is used that is held high when either block or trip permit are received; this continuous carrier supervision is an added benefit of FSK blocking. (The channel monitor is described later as the drive for the loss-of-carrier alarm.)

A simplified block diagram for the communication channel used in FSK blocking applications is shown in figure 10. Each terminal contains a transmitter, a receiver, and a dc-dc converter power supply, all housed in a rack-mount chassis 10 1/2 inches high (6 EIA rack units). A Dowty RFL Model 67 PLC AM I/O interface card is used for

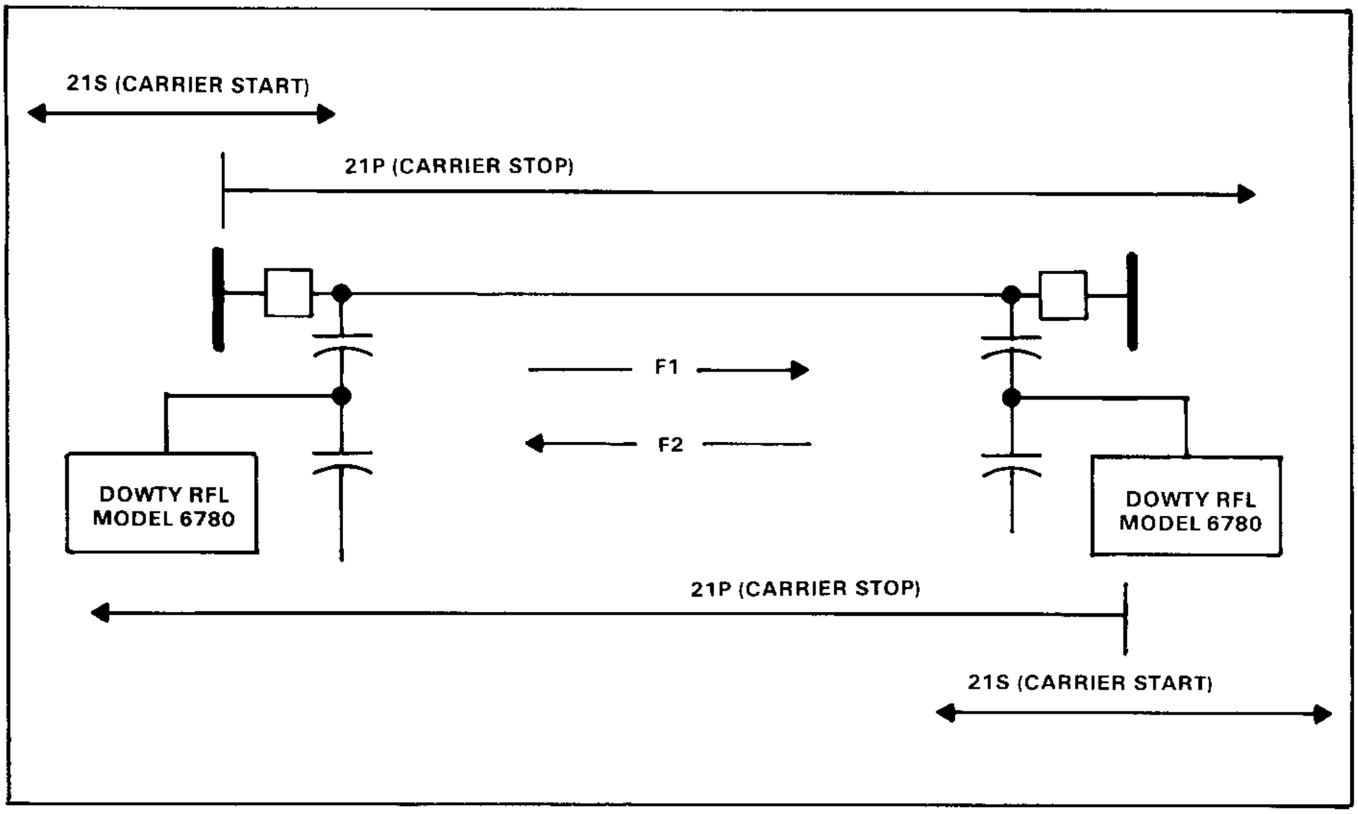


Figure 8. One-line diagram, FSK blocking

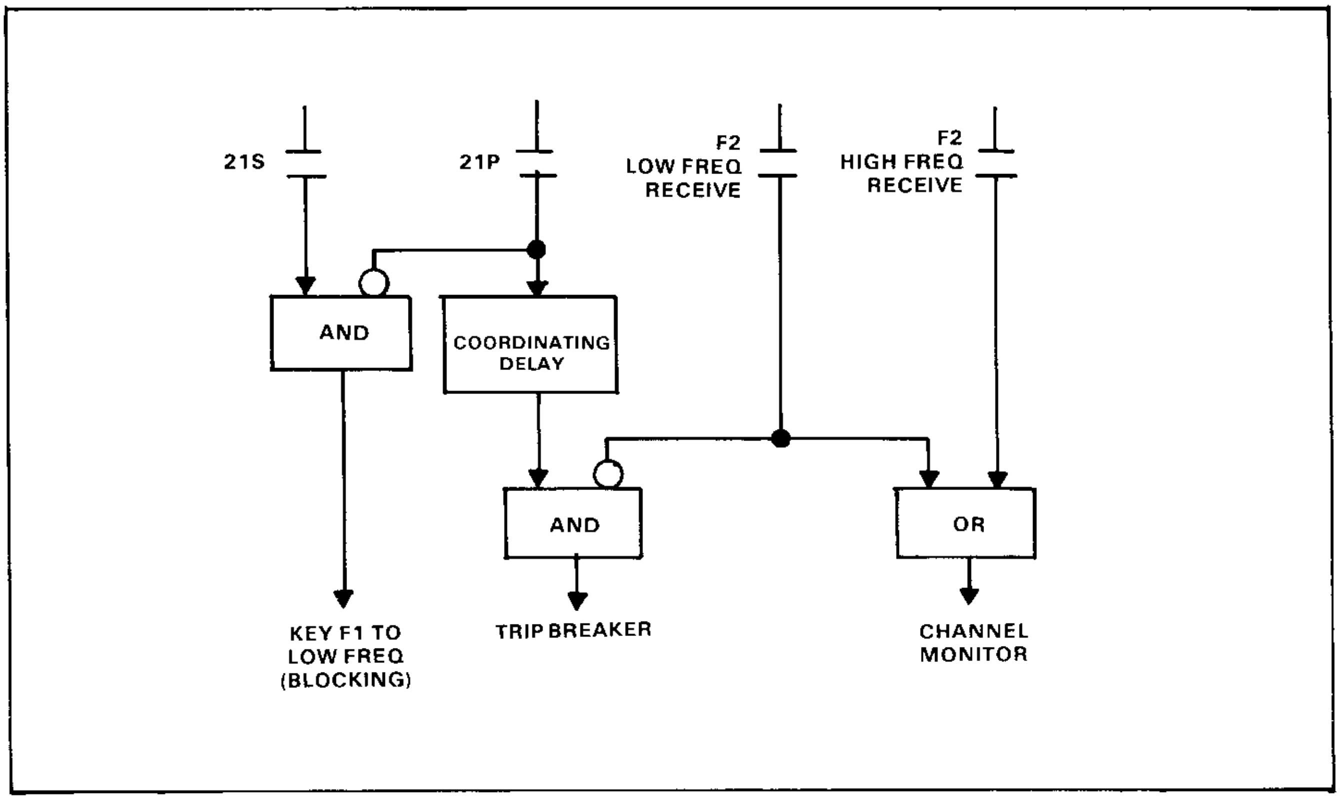


Figure 9. Logic diagram, FSK blocking

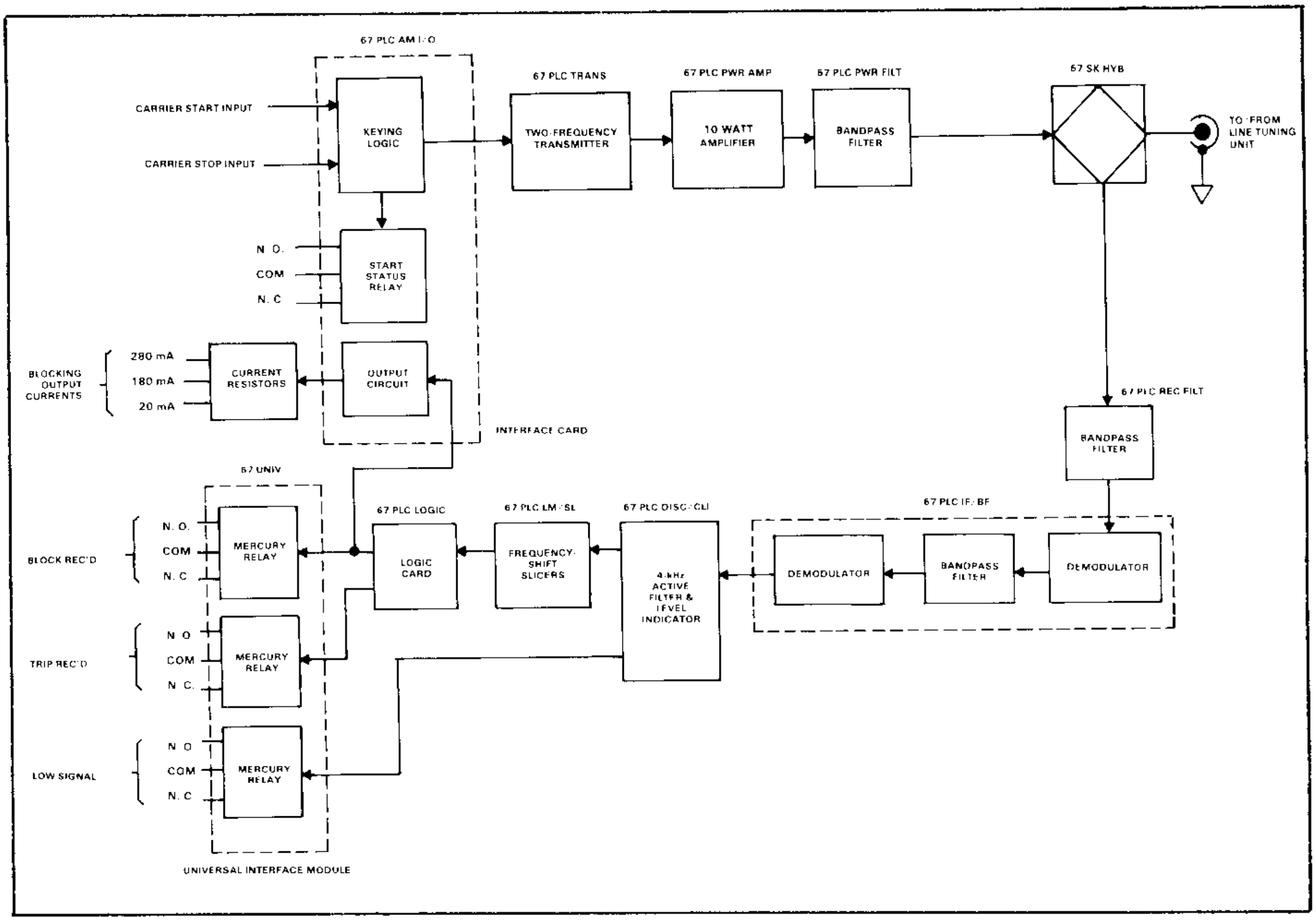


Figure 10. Block diagram, FSK blocking transmitter/receiver

the CARRIER START and CARRIER STOP keying inputs and the BLOCKING CURRENT output; this is the same card used in on/off blocking applications. The CARRIER START input shifts the carrier frequency, and the CARRIER STOP input inhibits the frequency shift. The start status relay will respond to the CARRIER START keying input and the occurrence of a frequency shift from trip permit to block. The two-frequency transmitter output is amplified and fed to a symmetrical high-power bandpass filter; the filtered signal is fed to a UHF connector for interfacing to the line tuning unit. Operating the system at two different power levels (such as trip permit at 1 watt and block at 10 watts) can provide a 10-dB improvement in security as well as greater signal reception capability.

Incoming signals received from the line tuning unit are applied to a skewed hybrid. The hybrid output signal is filtered and demodulated in two stages, yielding a 4-kHz signal. The demodulated signal is passed through a selective active 4-KHz filter and then to a phase shift discriminator, which converts the high-frequency and low-frequency analog signals into digital information. The logic card monitors signal levels and noise content to build security and dependability into the channel. The level indicator drives a Form C low-level alarm relay for low-signal monitoring. Two mercury relays are also provided to interface the blocking signal to the breaker tripping path and an indicator lamp shows trip permit status.

FSK blocking has its advantages and disadvantages:

Advantages:

1. 1-watt/10-watt boost for blocking S/N improvement
2. FSK narrowband filters and phase shift discriminator improve S/N ratio
3. Built-in trip permit monitor provides continuous self-monitoring
4. Low signal alarm monitor indicates greater path attenuation on line than original setting
5. Improved channel performance, achieved through dynamic threshold detector in receiver

Disadvantages:

1. Longer channel operate time (typically 3 to 9 ms)
2. Higher cost per terminal end
3. Increased equipment space requirements (6 rack units vs. 3 for on/off)
4. Continuously-on carrier may be vulnerable to interference
5. Two receivers are required at each terminal on a three-terminal line

FSK UNBLOCKING

The blocking schemes have a security hazard, since external faults must be detected by the carrier start relays and the blocking signal must be received at the remote station to prevent an overtrip. To eliminate this security problem and the need for carrier-start relays, the "unblocking" schemes were developed. These schemes involve the transmission of a continuous guard signal, which blocks tripping.

Figure 11 is a one-line diagram for a typical FSK unblocking scheme. A logic diagram appears in figure 12, and figure 13 is a block diagram for a typical FSK unblocking channel using the Dowty RFL Model 6780. In this scheme, a "guard" signal is normally transmitted, eliminating the need for reverse-looking relays. When an internal fault occurs, the forward-looking relays operate to key the carrier transmitters to a "trip" frequency. When the receiver terminal detects a trip signal and the local forward-looking relays also operate, the local breaker is tripped. Since an internal fault may severely attenuate the carrier signal, tripping is also allowed for a brief period after loss of carrier (typically 150 ms). This is the so-called "unblock timer" function.

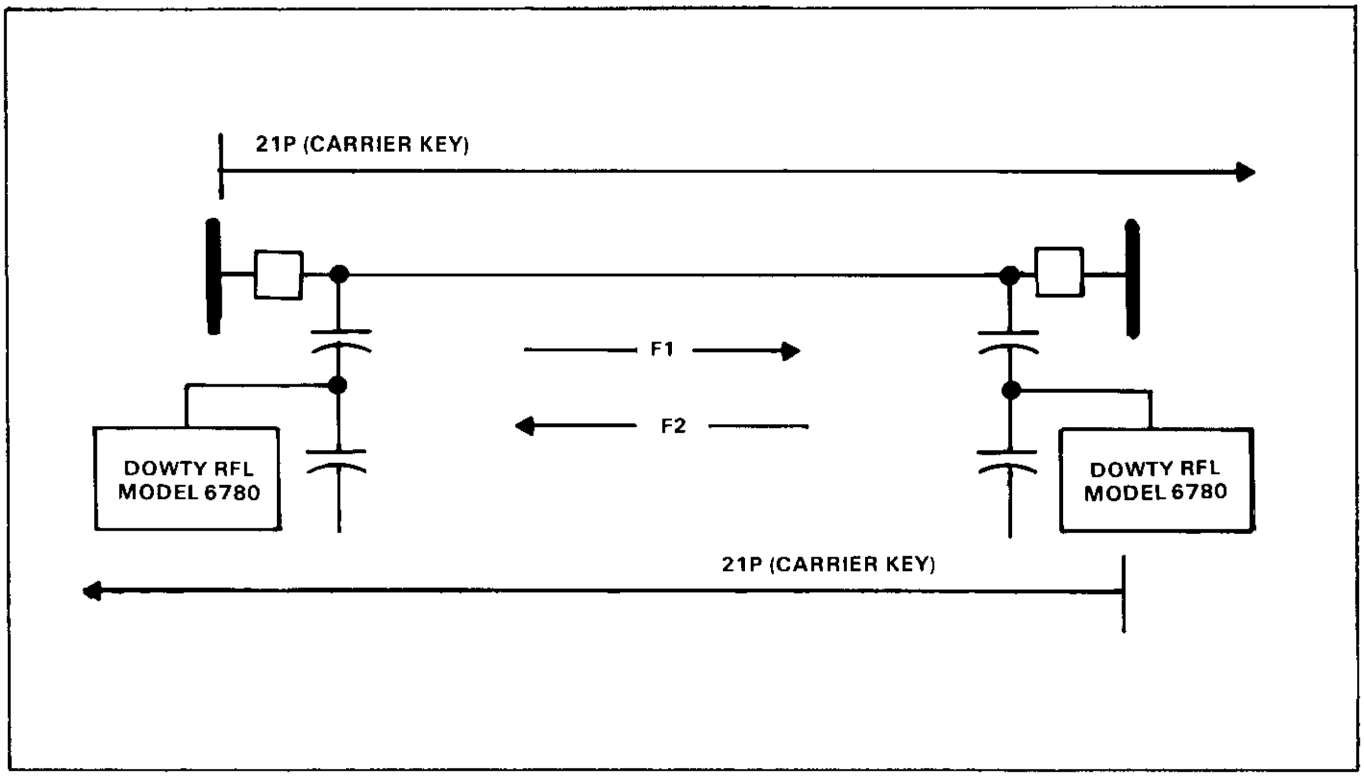


Figure 11. One-line diagram, FSK unblocking

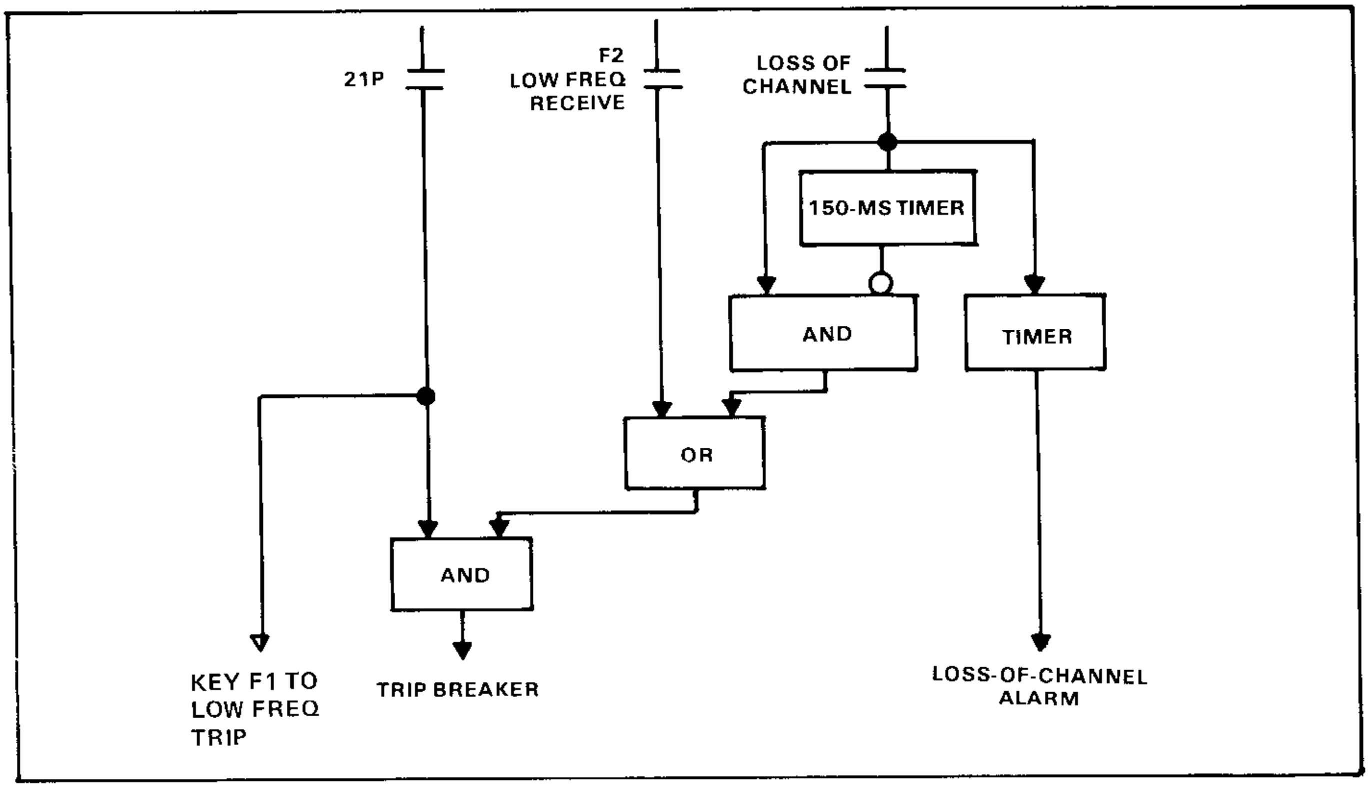


Figure 12. Logic diagram, FSK unblocking

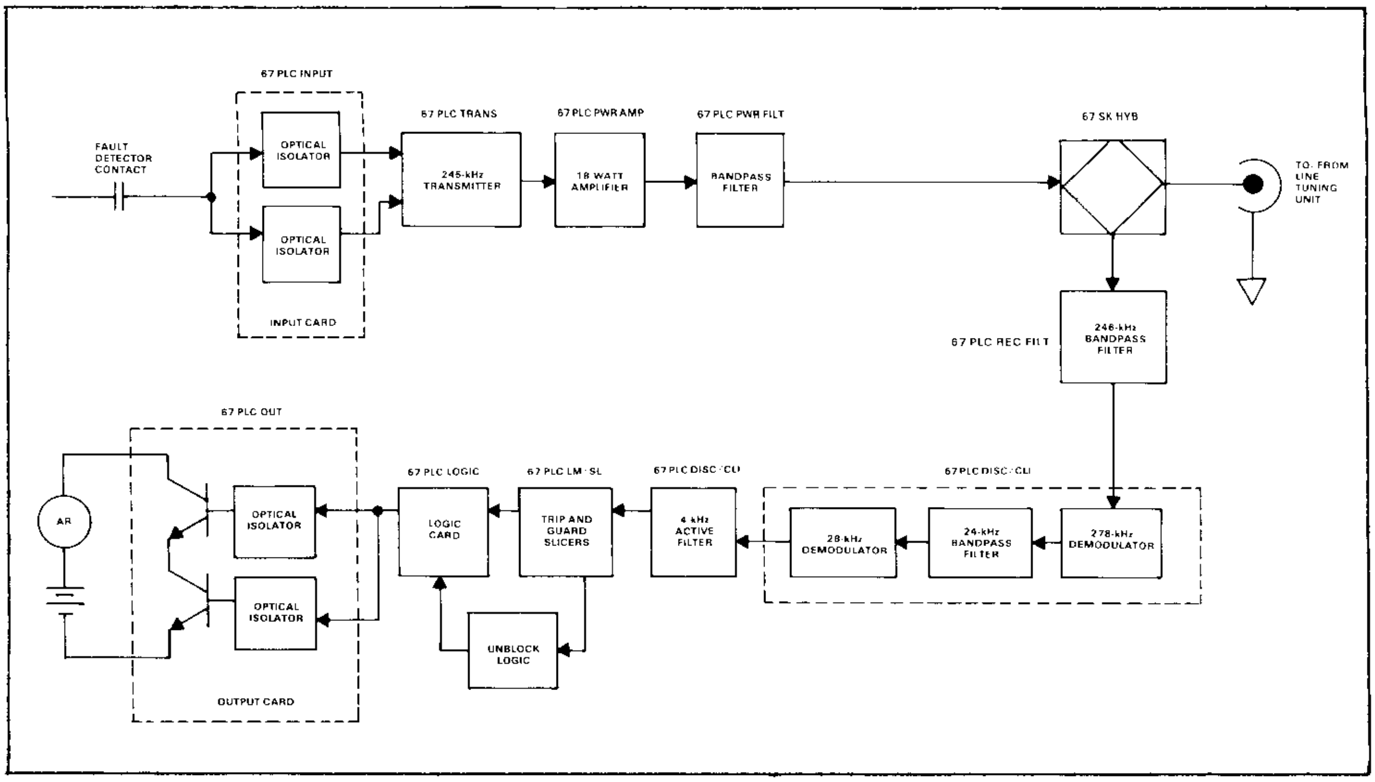


Figure 13. Block diagram, FSK unblocking transmitter/receiver

ON/OFF UNBLOCKING

The on/off unblocking scheme is similar to the FSK unblocking scheme in that a continuous blocking carrier signal is transmitted. It utilizes less-expensive on/off carrier equipment, which can be an advantage on three-terminal lines. During internal faults, the carrier transmitter is turned off, so the unblocking timer is not required. On the other hand, on/off unblocking schemes do not enjoy the improved S/N ratio capability and dynamic threshold features of FSK unblocking schemes.

Figure 14 is a one-line diagram for a typical on/off unblocking scheme, with its logic diagram appearing in figure 15.

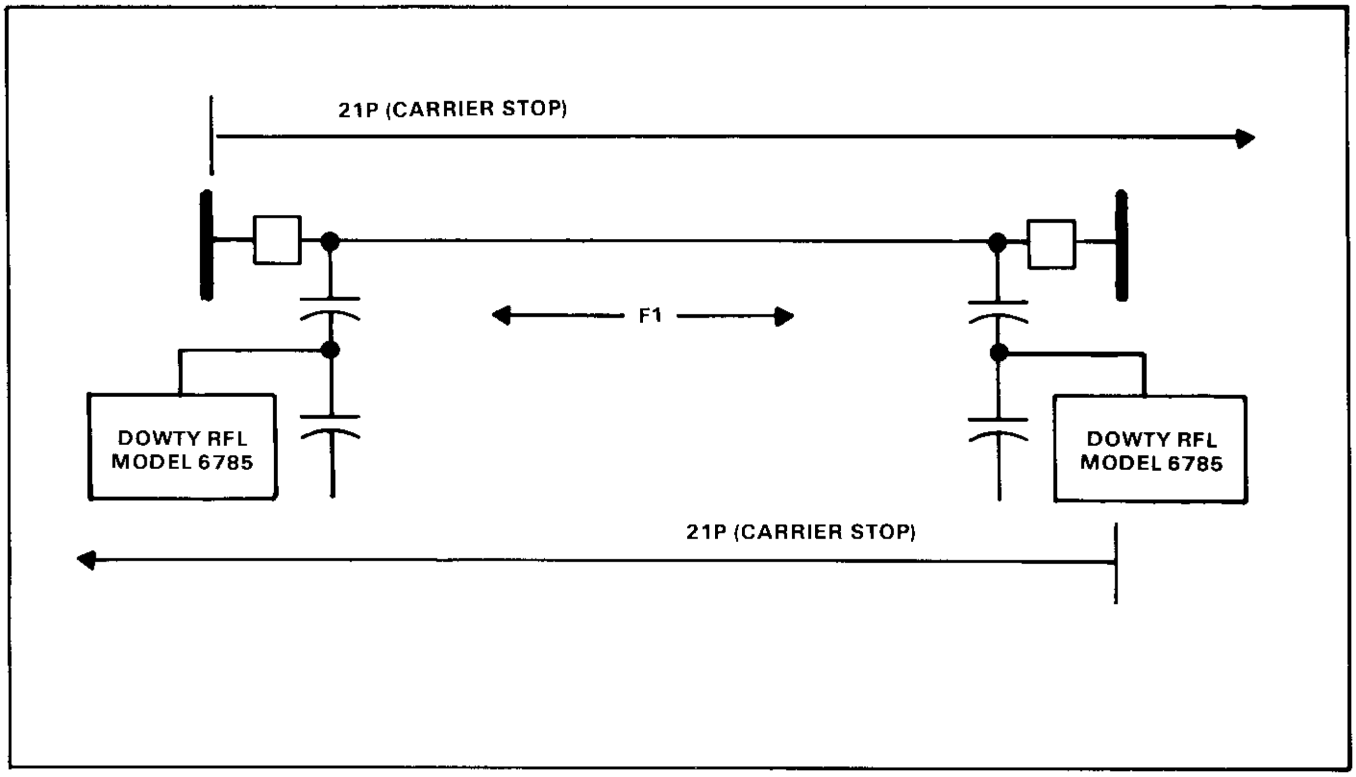


Figure 14. One-line diagram, on/off unblocking

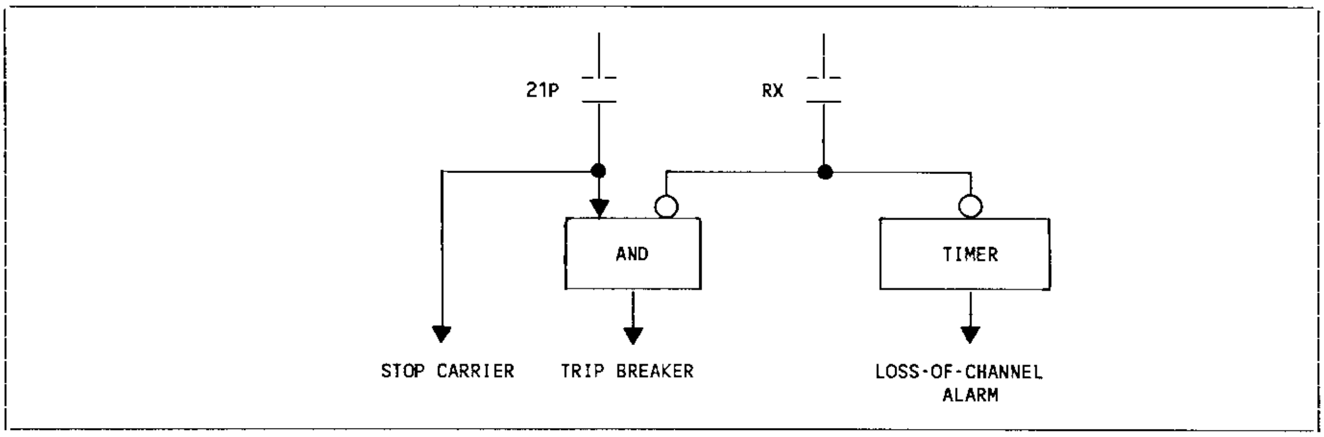


Figure 15. Logic diagram, on/off unblocking

CONSIDERATIONS

OVERALL CONSIDERATIONS

The relay engineer must consider system cost, available panel space, and operating speed when selecting one of the four discussed systems. Table 1 lists typical values for each system type. The cost figures shown are strictly budgetary. Each category shown is for one terminal; two terminals are required for a complete channel or typical two-terminal line. Each terminal consists of a chassis containing a transmitter, a receiver, and a power supply. The panel space indicated refers to the vertical height in EIA rack units; each rack unit equals 1.75 inches. The speed figures relate to the channel operate time from the point of contact closure at the transmit end to the generation of a trip or block output at the receive end; this is exclusive of propagation delay and includes any required coordinating time delays.

In FSK blocking systems, the pre-trip timer is eliminated. This improves the security of the system, by ensuring the fastest possible reception of the blocking signal.

Table 1. Comparison of typical PLC systems

System Type	Budgetary Price Range (dollars)	Panel Space (rack units)	Speed (milliseconds)	
			Narrowband	Wideband
On/Off Blocking	4,500 - 5,500	3	3	1.5
FSK Blocking	6,000 - 7,000	6	. . .	3
FSK Unblocking	6,000 - 7,000	6	12	7
On/Off Unblocking	4,500 - 5,500	3	3	1.5

CHANNEL CONSIDERATIONS

"Channel considerations" is the generalized term used to describe all the PLC system requirements that relate directly to the communications channel. These include verification, frequency spectrum, S/N ratio, receiver level threshold, and interference with adjacent channels or other equipment.

Channel Verification

Regardless of the DCB method used, the communications channel should be verified or checked from time to time to be sure that all equipment is functioning properly and that all stations are able to respond to faults. Channel verification can be done periodically (under either manual or automatic control), or a continuous carrier monitor can be used.

FSK channels and on/off unblocking schemes feature a continuous guard or monitor frequency. The engineer can depend on the carrier detector alarm relay to provide loss-of-carrier information, or choose to go with manual or automatic testing. Manual testing will require an operator at each station, while checkback testing will require an operator at only one station; either test method will increase system maintenance costs. Automatic testing can be initiated by a SCADA system or by a self-contained clock, programmed to test the channel at specified times during the day, without operator intervention.

Because on/off blocking schemes are quiescent, they generally employ automatic testing. There are several testing designs currently available, though most are limited to single-line testing (verifying the line between two stations); some testing systems allow more than one line to be tested at the same time. In general, channel verification tests are conducted at the 10-watt power level, though some testing systems allow both low-power (1 watt) and high-power (10 watt) tests to be run. Low-power testing assures that the channel will operate with as much as 10 dB of additional attenuation on the line. The Dowty RFL Series 6720 Multiline Automatic Checkback System (MACS) can test up to eight line sections, using a master station automatic clock or remote-initiated control.

Three-terminal line testing becomes an issue when selecting on/off blocking automatic checkback. (See figure 16 on page 18.) To verify all valid conditions, a test must be conducted as follows:

1. Send BLOCK from Terminal A to Terminal B; return verification to Terminal A.

2. Send BLOCK from Terminal A to Terminal C; return verification to Terminal A.

3. Send BLOCK from Terminal B to Terminal C; return verification to Terminal A.

4. Send BLOCK from Terminal C to Terminal B; return verification to Terminal A.

Do not assume that performing the first two steps alone will verify the entire three-terminal line; the distance between Terminal B and Terminal C could be longer than the distance from Terminal A to Terminal B or from Terminal A to Terminal C. The Dowty RFL Model 6720 MACS meets all the requirements for successful three-terminal line testing.

Frequency Spectrum Requirements

Today's electric utility engineer must be familiar with the North American Electric Reliability Council, and their role as administrator in documentation and notification of all activity regarding PLC frequency use. The NERC guideline "Transmission Power Line Carrier Notification Activity Instructions" provides a good overview of the information required for documentation and selection.

There are several other publications which may be useful:

1. <u>IEEE Guide for Power Line Carrier Applications</u>; ANSI/IEEE Standard 643-1980.

2. <u>Single Sideband Vs. Single Function Power Line Carrier: A frequency Spectrum Use Comparison</u>; Pennsylvania Electric Association Telecommunications Committee, April 30, 1982.

3. <u>The PLC Handbook</u>; Dowty RFL Industries Inc., October 1984 (including complimentary modal analysis).

The first consideration will be to list all PLC frequencies currently in use within two line sections of each planned coupling point. Next, review the equipment manufacturer's recommended frequency spacing allocation specification. Tables 2 and 3 list the typical spacing requirements for Dowty RFL on/off and FSK systems. For example, Table 2 lists the required spacing for a typical 1.5-ms on/off blocking channel as 3 kHz. If 200 kHz is already in use within two line sections of either terminal, the proposed channel can operate at either 197 kHz or 203 kHz. As shown in Table 3, a typical 7-ms FSK blocking channel (without voice) requires 1.5-kHz spacing; the proposed channel could operate on either 198.5 kHz or 201.5 kHz.

Table 2. Typical on/off blocking and unblocking speeds

Nominal Bandwidth (Hz)	Minimum Permissible Channel Spacing (kHz)		Delay Time (ms)
	w/o Voice	w/ Voice	
500	1	4	5
1000	2	4	3
1500	3	4	1.5

Table 3. Typical FSK blocking and unblocking speeds

Frequency Shift (±Hz)	Nominal Bandwidth (Hz)	Minimum Permissible Channel Spacing (kHz)				Delay Time (2) (ms)	
		Unidirectional		Bidirectional (1)			
		w/o Voice	w/ Voice	w/o Voice	w/ Voice	Blocking	Unblocking
100	200	0.5	4	1	4	9	12
250	500	1	4	1.5	4	4	7
500	1000	2	4	3	4	3	5

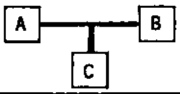
NOTES:

1 - Minimum spacings for bidirectional channels may not apply where losses between terminals are unusually high.

2 - Unblocking delay times shown include the period of the pre-trip timer. In blocking systems, the pre-trip timer is bypassed.

Table 4 depicts the frequency consumption on typical two-terminal and three-terminal lines for both on/off and FSK powerline carrier. As shown in the table, using on/off PLC will result in a considerable amount of frequency conservation. For a three-terminal on/off channel, a common 200-kHz receiver with a wide bandwidth (1.5 kHz) can very easily detect three transmitters that are offset by 100 Hz (199.9 kHz, 200 kHz, and 200.1 kHz). The 100-kHz offset eliminates beating in the event that two transmitters are keyed simultaneously for an external fault.

Table 4. Typical frequency consumption (in Kilohertz)

Line Configuration	PLC Method	Terminal A		Terminal B		Terminal C	
		Transmit	Receive	Transmit	Receive	Transmit	Receive
Two-Terminal	On/Off	200.0	200.0	200.0	200.0	...	...
	FSK	200.0	201.5	201.5	200.0	...	...
Three-Terminal	On/Off	200.0	200.0	200.1	200.0	199.9	200.0
	FSK	200.0	R-2 - 201.5	201.5	R-1 - 200.0	198.5	R-2 - 201.5
			R-3 - 198.5		R-3 - 198.5		R-1 - 200.0

A trade-off of the FSK approach for three-terminal line applications is that more frequency spectrum is required, because one transmitter and two receivers are required at each station. This is less of a problem on new transmission lines, or on low-density existing lines. Figure 16 is a one-line diagram for a typical single-frequency three-terminal line; a typical multiple-frequency three-terminal line is shown in figure 17.

Signal-To-Noise Ratio Capability (Narrowband vs. Wideband)

The relationship between the powerline carrier signal level at the carrier set receiver input and the amount of noise in the line is very important. "Noise" refers to inherent noise, atmospheric noise, and weather-related noise.

When making a selection between on/off and FSK, the relationship between timing, bandwidth, and frequency detection methods must be considered. Wider bandwidths allow greater speed. A narrowband receiver filter will present less noise energy to the receiver detector than a wideband filter; this can be seen by comparing a 1500-Hz on/off blocking channel filter to a 500-Hz FSK blocking channel filter. Calculating the relationship between the two filters, a 4.77-dB improvement in S/N ratio can be obtained by using the narrowband filter.

$$S/N = 10 \log \frac{BW\ I}{BW\ II}$$

$$S/N = 4.77\ \text{dB}$$

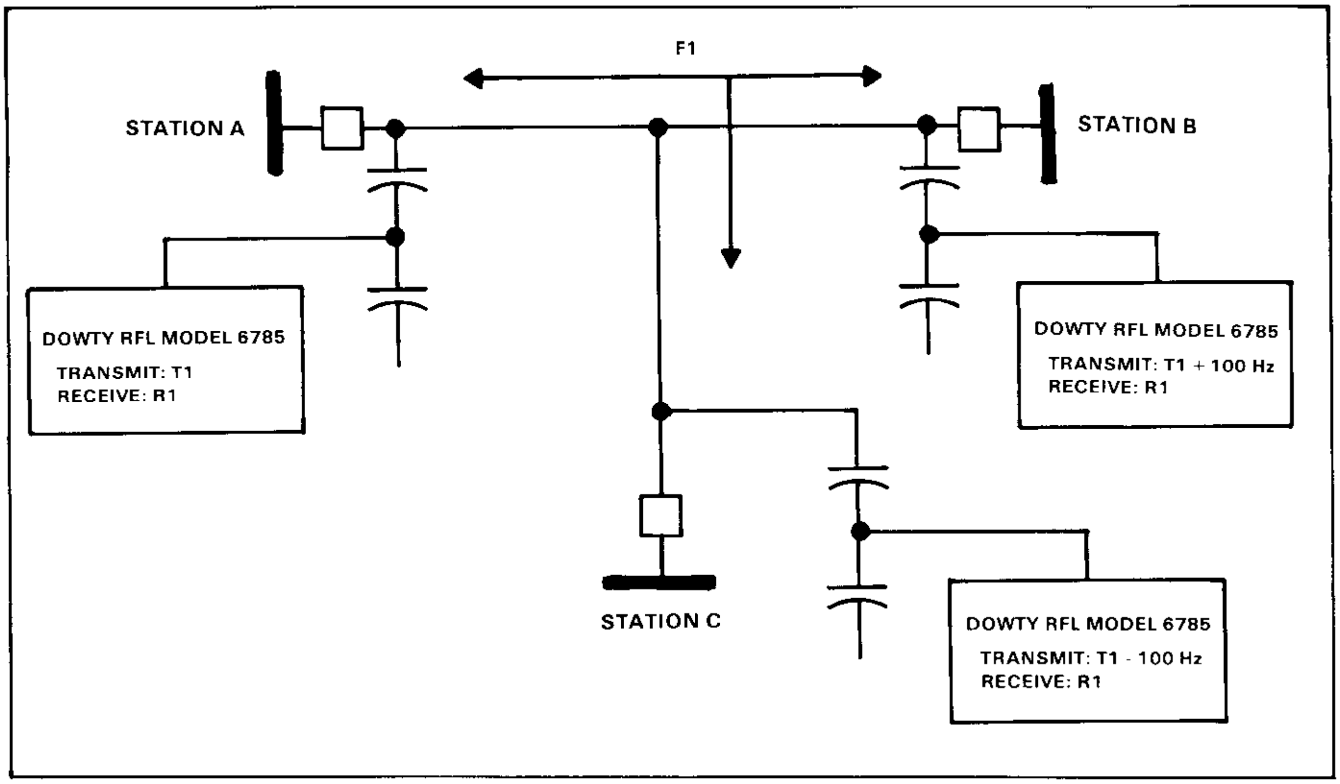


Figure 16. One-line diagram, single-frequency three-terminal line

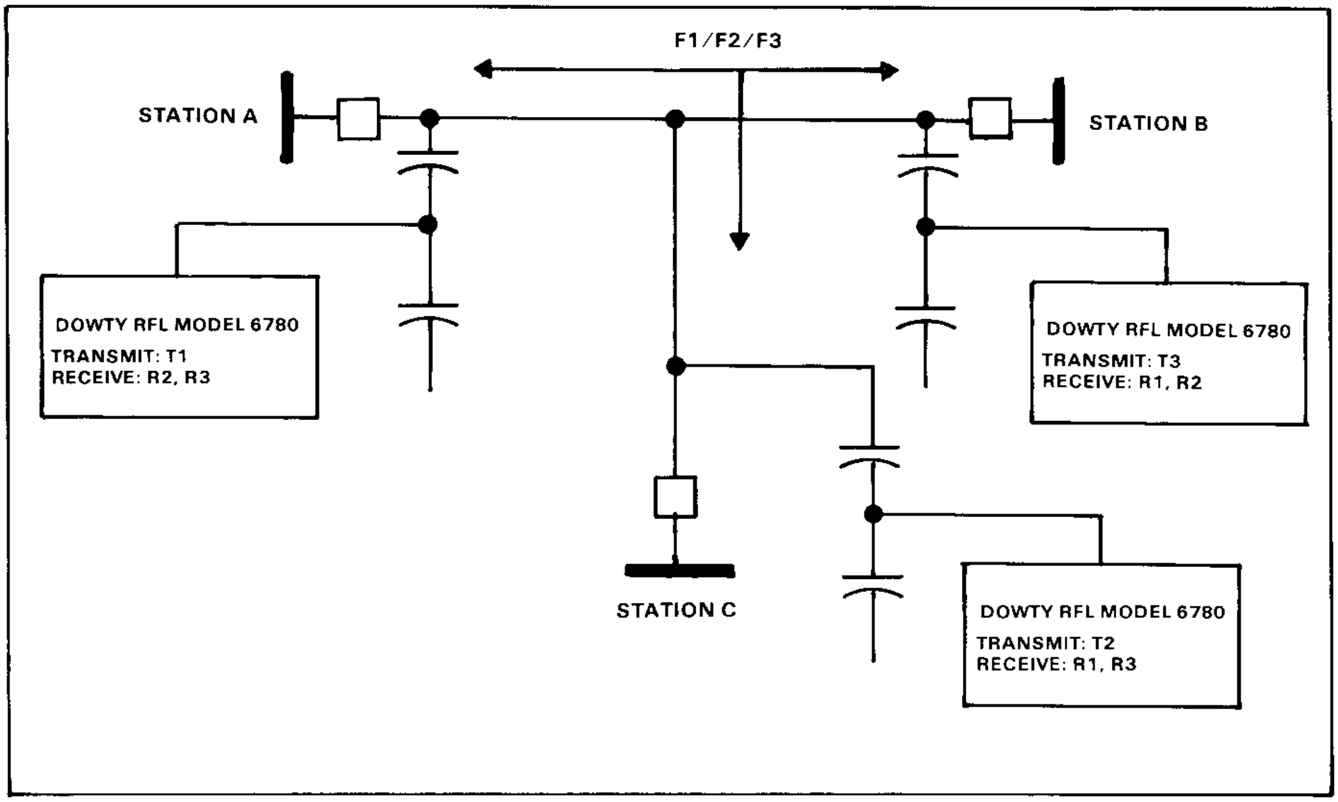


Figure 17. One-line diagram, multiple-frequency three-terminal line

The wide bandwidth associated with on/off blocking carrier systems is dependable as long as a good S/N ratio is maintained. Under adverse weather conditions, high noise energy levels are present at the receiver input; this may cause a block at a time when an internal fault may need to be cleared.

By switching to FSK and narrowband filters, the channel's dependability is greatly enhanced. The FSK blocking channel is always transmitting a guard (trip permit) or trip (block).

Fixed Vs. Dynamic Receiver Level Threshold

On/off blocking systems are dependent upon a fixed threshold (typically -12 dB) that will not automatically compensate for changing line level conditions. All received blocking signals higher than this fixed threshold will be successfully detected. However, the channel will not respond if a sudden low-level condition occurs and the received signal is below the fixed threshold. FSK blocking systems have a dynamic threshold, which can self-adjust to high-level and low-level changes within the channel's operating range. In addition, FSK blocking has the advantage of self-monitoring. Comparisons are made between trip present and block pertaining to a S/N ratio that will allow the channel to be squelched when the S/N ratio is too low.

Continuous Carrier Interference (adjacent channels, RI, TVI)

In some applications, continuous carrier can cause interference with adjacent channels, or can interfere with radio and television reception. Other transmitters can also interfere with the relaying channel, causing nuisance alarms.

RELAYING CONSIDERATIONS

The four directional comparison systems described in this paper differ from each other with regard to numerous relaying considerations. The following paragraphs describe each of these considerations; the first three considerations favor the unblocking schemes, while the last four favor the blocking schemes.

Requirement For Reverse-Looking Relays

The blocking schemes are normally in a "trip permit" state. The channel must change state (turn on or change frequency) if an external fault occurs. This function is provided by reverse-looking relays used to detect the external fault. Unblocking schemes do not require reverse-looking relays, since they are normally in a blocking state prior to the fault.

Trip Coordinating Timer

This requirement was discussed earlier in this paper, under "Coordinating Delay".

Security During Loss Of Potential

If a loss of potential causes the carrier trip relays to operate inadvertently, the blocking schemes immediately result in a false trip. This happens because these schemes are normally in a "trip permit" state. Fault detectors set above load are required to overcome this problem. Because unblocking schemes maintain the channel in a continuous "blocking" state, they are not vulnerable to a false trip during loss-of-potential.

Weak Feed Capability

Before local tripping can occur in an unblocking scheme, the received carrier signal must change state and the local tripping relay must pick up. This means that internal faults must be recognized by the tripping relays at all terminals before tripping can occur. Special echo-keying logic is required to handle weak-feed situations. The blocking schemes do not share this problem, since tripping occurs at the strong terminal even if the relays at the weak terminal do not operate.

Switch-Into-Fault (SIF) Capability

During SIF conditions, the open breaker terminal behaves like a weak-feed terminal, since it does not contribute any current to the fault. Because of this, the previous discussion on weak-feed also applies to SIF. The difference is that it is easier to implement corrective logic to handle the SIF condition; the 52b contact at the open breaker can be used to key continuously, turn off the carrier in on/off unblocking schemes, or set up echo keying at the open breaker terminal.

Security During Current Reversals

Figure 18 is a one-line diagram showing a current-reversal condition. Assume that the upper line in figure 18a (Station A to Station B) is protected, and that a fault on the lower line (Station C to Station D) causes the breaker at Station D to clear first. This will result in a "current reversal" on the upper line, as shown in figure 18b. In unblocking schemes, this will cause a "race" on the upper line, in which the relay pick-up at Station B is racing with the relay drop-out at Station A. (In FSK unblocking schemes, channel shift time must be added in.) If this race is "lost", a false trip will result. To provide security during this condition, a current-reversal timer and associated logic are required. The Dowty RFL Model 67 PER COOR Permissive Coordinating Module can be used to add these circuits to any PLC system. Blocking schemes do not experience this problem, because the sensitive reach settings of the reverse-looking relays provide the necessary coordination.

Additional information on the Model 67 PER COOR can be found in Dowty RFL Application Note TPR 8609, "Model 67 PER COOR Permissive Coordinating Module". Single copies are available upon request.

Unblock Window Timer And Associated Logic

The unblock window timer and its associated logic are only required in FSK unblocking schemes. On/off unblocking schemes do not require this timer, since the carrier is turned off during an internal fault. Also, blocking schemes do not experience this problem, since the only carrier that must be received is the BLOCK signal, transmitted during external faults.

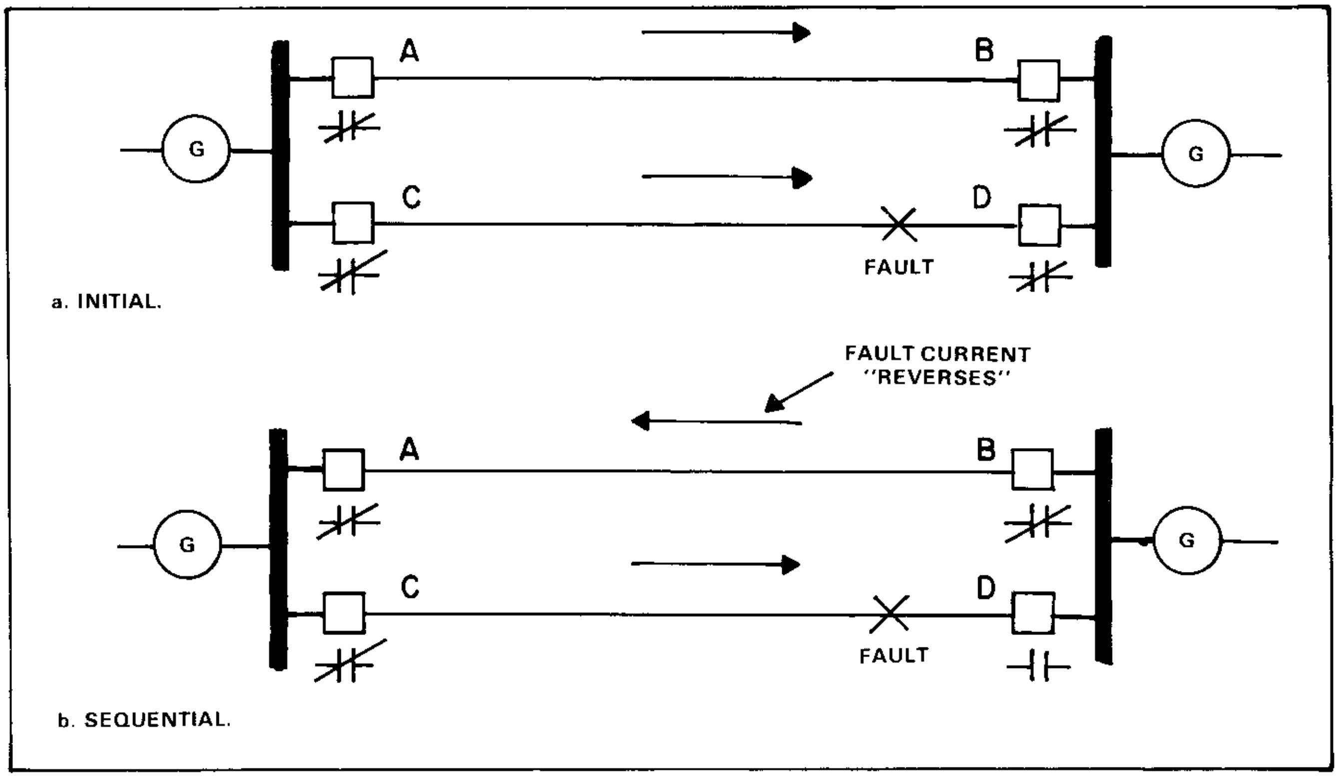


Figure 18. One-line diagram, current reversal

ADVANTAGES AND DISADVANTAGES OF EACH METHOD

Table 5 summarizes the advantages and disadvantages of each directional comparison method. This comparison is based on ones and zeroes, where ones signify relative advantages, and zeroes relative disadvantages. Table 6 is a worksheet that can be used to determine the best method for an application, based on the relative importance of each characteristic. This is an entirely subjective determination, since the relative importance of each item differs from user to user and depends upon the parameters of a particular application. To determine relative importance, the user would assign a weighting factor to each characteristic in the table and then add up the score for each method. Tables 7 and 8 show the worksheet completed for the two typical applications described below; the weighing factors shown are for illustrative purposes only, and should not be taken as recommendations.

Table 5. DCB method advantages and disadvantages

Characteristic	Directional Comparison Method			
	On/Off Blocking	FSK Blocking	FSK Unblocking	On/Off Unblocking
Adaptability to 3-Terminal Lines	1	0	0	1
Continuous Channel Monitoring	0	1	1	1
Cost	1	0	0	1
Improved Dynamic Threshold	0	1	1	0
Inherent Dependability	1	1	0	0
Inherent Security	0	0	1	1
Panel Space	1	0	0	1
Reverse-Looking Relays Requirements	0	0	1	1
RI/TVI Interference	1	0	0	0
S/N Ratio	0	1	1	0
Security During Current Reversal	1	1	0	0
Switch-Into-Fault Capability	1	1	0	0
Trip Coordinating Timer Required	0	0	1	1
Unblock Window Timer/Logic Required	1	1	0	1
Weak Feed Capability	1	1	0	0

Table 6. Directional comparison worksheet

Description Of Proposed Application ______________________________

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Characteristic	Weighting Factor	Directional Comparison Method			
		On/Off Blocking	FSK Blocking	FSK Unblocking	On/Off Unblocking
Adaptability to 3-Terminal Lines			. . .	. . .	
Continuous Channel Monitoring		. . .			
Cost			. . .	. . .	
Improved Dynamic Threshold		. . .			. . .
Inherent Dependability				. . .	. . .
Inherent Security		. . .	. . .		
Panel Space			. . .	. . .	
Reverse-Looking Relays Required		. . .	. . .		
RI/TVI Interference			. . .	. . .	. . .
S/N Ratio		. . .			. . .
Security During Current Reversal				. . .	. . .
Switch-Into-Fault (SIF) Capability				. . .	. . .
Trip Coordinating Timer Required		. . .	. . .		
Unblock Window Timer And Logic Required				. . .	
Weak Feed Capability				. . .	. . .
Total Score	. . .				

TYPICAL APPLICATION 1

Typical Application 1 is a long two-terminal EHV line that will probably never become a three-terminal line. Both terminals will probably always be strong feed (and seldom, if ever, weak feed). A parallel line is not planned and distance relays are used for both ground and phase protection, so current reversals are not a problem. A determination has been made that speed and security are very important, while cost, panel space, carrier spectrum, and carrier interference are less important. Security is more important that dependability, since alternate pilot protection over microwave will exist. Due to line length, a high margin of carrier performance is desired.

Based on the above application requirements, weighing factors are assigned to each characteristic in the worksheet, as shown in Table 7. By adding up the score in each vertical column, it is seen that the FSK unblocking scheme is favored for this application.

TYPICAL APPLICATION 2

Typical Application 2 is a short 69-kV subtransmission line, in which speed is not critical, carrier interference and spectrum utilization are fairly important, and cost and panel space are very important. This is a two-terminal line that may become a three-terminal line in the future. A parallel line exists, creating the possibility of a current-reversal condition. During some operating conditions, one of the terminals may be weak-feed. There is no alternate pilot system, and the non-pilot ground back-up is time-delayed directional overcurrent. This, plus the use of high-speed relaying, means that dependability is more important than security.

Using the above information to complete the worksheet shown in Table 8, it can be seen that a traditional on/off blocking scheme is best suited for this application.

Table 7. Worksheet completed for Typical Application 1

Description Of Proposed Application EHV line, parallel line not planned, distance relays used for ground and phase protection, alternate pilot protection over microwave.

Characteristic	Weighting Factor	Directional Comparison Method			
		On/Off Blocking	FSK Blocking	FSK Unblocking	On/Off Unblocking
Adaptability to 3-Terminal Lines	1	1	. . .	. . .	1
Continuous Channel Monitoring	8	. . .	8	8	8
Cost	3	3	. . .	. . .	3
Improved Dynamic Threshold	10	. . .	10	10	. . .
Inherent Dependability	5	5	5	. . .	. . .
Inherent Security	10	. . .	. . .	10	10
Panel Space	1	1	. . .	. . .	1
Reverse-Looking Relays Required	5	. . .	. . .	5	5
RI/TVI Interference	2	2	. . .	. . .	. . .
S/N Ratio	10	. . .	10	10	. . .
Security During Current Reversal	0	0	0	. . .	. . .
Switch-Into-Fault (SIF) Capability	2	2	2	. . .	. . .
Trip Coordinating Timer Required	8	. . .	. . .	8	8
Unblock Window Timer And Logic Required	2	2	2	. . .	2
Weak Feed Capability	2	2	2	. . .	. . .
Total Score	. . .	18	39	51	38

Table 8. Worksheet completed for Typical Application 2

Description Of Proposed Application 69-kV subtransmission line, two-terminal, may become three-terminal, parallel line exists, no alternate pilot system, time-delayed dir. overcurrent gnd. backup.

Characteristic	Weighting Factor	Directional Comparison Method			
		On/Off Blocking	FSK Blocking	FSK Unblocking	On/Off Unblocking
Adaptability to 3-Terminal Lines	5	5	. . .	. . .	5
Continuous Channel Monitoring	8	. . .	8	8	8
Cost	10	10	. . .	. . .	10
Improved Dynamic Threshold	2	. . .	2	2	. . .
Inherent Dependability	10	10	10	. . .	. . .
Inherent Security	5	. . .	. . .	5	5
Panel Space	10	10	. . .	. . .	10
Reverse-Looking Relays Required	10	. . .	. . .	10	10
RI/TVI Interference	10	10	. . .	. . .	. . .
S/N Ratio	2	. . .	2	2	. . .
Security During Current Reversal	10	10	10	. . .	. . .
Switch-Into-Fault (SIF) Capability	5	5	5	. . .	. . .
Trip Coordinating Timer Required	2	. . .	. . .	2	2
Unblock Window Timer And Logic Required	5	5	5	. . .	5
Weak Feed Capability	10	10	10	. . .	. . .
Total Score	. . .	75	52	29	55

CONCLUSION

The tables and guidelines presented in this paper are offered only as "tools" to assist the user in his evaluation of the relative merits of the various directional comparison systems that use overreaching relays and powerline carrier. This paper does not make any effort to influence the user in the selection of the best scheme for a given application, since only the user can know and evaluate the significant parameters that go into making the selection. It is our hope and intent that this paper will help the user in making this selection.

Dowty RFL has furnished carrier sets for all four systems described in this paper, and we recognize the merits of each system, depending upon the particular application requirements.