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IEEE Guide for Power System Protective Relay Applications of Audio Tones over Telephone Channels

Sponsor

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of the
Power System Relaying Committee
of the
IEEE Power Engineering Society

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Foreword

(This foreword is not a part of ANSI/IEEE C37.93-1987, IEEE Guide for Power System Protective Relay Applications of Audio Tones over Telephone Channels.)

This guide, last revised in 1976, recognized the reliability demands placed on audio tone relaying equipment and the associated telephone facilities. The challenges for providing reliable (secure and dependable), high-speed pilot protection have increased enormously over the years. These challenges have occurred as power systems are operated closer to design limits due to economic, environmental, and regulatory considerations.

This revision retains the original intent of providing a reference for manufacturers, designers, and users of audio tone equipment and for providers of the telecommunication channels employed with the audio tone protective relay schemes. It was prepared not only for those using an audio tone relay system for the first time but also as a reference for the experienced user.

This revision provides a basic introduction and description of leased telephone channels. Also included are typical interface requirements and the transmission line characteristics of three channel offerings along with examples. Since other IEEE standards cover the subject of protection more comprehensively, a brief description of special protection devices is provided for informational purposes. Sections have been revised to be consistent with current telephone company practices and the section concerning periodic maintenance has been expanded.

Acknowledgment

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An American National Standard

IEEE Guide for Power System Protective Relay Applications of Audio Tones over Telephone Channels

1. Scope and References

1.1 Scope

1.1.1

This guide contains information and recommendations for applying audio tones over telephone channels for power system relaying. Included are sections on transmitting and receiving equipment, leased telephone channels, application principles, installation, and testing. Reflected in this work is the knowledge and experience of equipment manufacturers and telephone companies as well as that of power utility users.

1.1.2

This guide is not intended to supplant specific or general instructions contained in the manufacturers' instruction books or in any contractual agreement between a manufacturer or telephone company(s) or both and a purchaser of a given relaying system. The illustrations in 5.7 are used for illustrative purposes only and do not represent the preferred protection under all conditions.

1.2 References

The following publications shall be used in conjunction with this standard:

[1] ANSI/IEEE C37.90-1978, IEEE Standard Relays and Relay Systems Associated with Electric Power Apparatus.

[2] ANSI/IEEE C37.90.1-1974 (Redesignation of ANSI C37.90a-1974/IEEE Std 472-1974), IEEE Guide for Surge Withstand Capability (SWC) Tests.

[3] ANSI/IEEE Std 281-1984, IEEE Standard Service Conditions for Power System Communication Equipment.[1]

[4] ANSI/IEEE Std 367-1979, IEEE Guide for Determining the Maximum Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

[5] ANSI/IEEE Std 487-1980, IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations.

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[1]ANSI/IEEE publications can be obtained from the Institute of Electrical and Electronics Engineers Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, or from the American National Standards Institute, Sales Department, 1430 Broadway, New York, NY 10018.

2. Purpose

2.1

The primary purpose of this document is to guide the power system user in applying, installing, and operating audio-tone protective relaying systems over telephone channels. Secondly, it is to provide a reference for equipment manufacturers engaged in the design and application of relaying equipment and for telephone personnel engaged in providing telecommunications channels for audio-tone protective relay schemes. The guide has been prepared not only for those considering audio-tone relaying for the first time, but as a reference for the experienced.

3. Transmitting and Receiving Equipment

3.1 Relaying Requirements

3.1.1

Receiver response is very essential in ensuring correct operation of an audio-tone relay scheme. It is most important that receivers be capable of discriminating between valid signals and spurious signals which may be introduced into the telephone lines particularly during power system disturbances.

3.1.2

Extremely high on the list of desirable system objectives is security — the assurance that false tripping will not occur. Here the goal is no false operations under any and all operating conditions. A trip signal should provide satisfactory operation down to a signal-to-noise ratio of zero decibel (0 dB) using a C-message weighted noise measurement. However, a proper balance between security and dependability — the assurance that valid tripping will occur — should be accepted.

3.1.3

Equipment designed for relaying functions and for use with available types of telephone communication circuits should meet the following requirements:

1) The operate time should be consistent with the relay application requirements but in the interest of security the tone operate time should not be any faster than necessary, typically 10–16 ms. This includes tone transmitter operation time (after being keyed), tone receiver response time, and operate time of an output device. This does not include telephone channel delay time, which may vary from a few milliseconds to over 10 ms. Accordingly, in writing audio-tone terminal equipment specifications, the user should exclude telephone channel delay time when specifying required speed, since this time is not under the control of the tone equipment manufacturer.
2) Highest dependability possible.
3) Highest possible security for conditions such as:
    a) steady state noise equal in magnitude to the signal over the voice frequency bandwidth
    b) failure of the monitoring signal
    c) intermittent shorting, opening, or grounding of the communication circuit
    d) complete interruption of the communication circuit
    e) cross talk from an adjacent circuit
    f) inadvertent application of test signals normally encountered in channel testing
    g) power system disturbances
    h) removal and application of power supply

i) multiplex or carrier frequency translations
j) single component failure
k) voltage transients in power supply and output circuits
l) electromagnetic interference (EMI) and radio frequency interference (RFI) effects
m) physical substation environment

3.2 Basic Types of Audio-Tone Systems

3.2.1 General

Equipment to meet the relaying requirements may take any of several forms. The importance of the function requires that the user be assured of a workable system on a continuous basis with an alarm to indicate an inoperative condition. Each type of equipment has both advantages and disadvantages.

3.2.2 Frequency Shift Modulated Equipment

This equipment is the type most frequently used. A signal is always present under normal conditions on one of two possible frequencies, guard or trip. Frequency shift equipment is inherently self monitoring when the design is such that the same components generate, amplify, and receive both frequencies. Some frequency shift equipment also employs an enhanced trip signal so that the signal to noise ratio is improved at the time of trip signal transmission. (See 4.3.2.1.) This increase in signal power during enhanced signaling trip typically lasts for 50 to 100 ms.

3.2.3 ON-OFF Modulated Equipment

ON-OFF equipment is not inherently self-monitoring because many components are inactive in their quiescent state. If the scheme utilizes more than one tone signal, the circuit can be designed for periodic in-service testing. This type of equipment is presently applicable only to blocking type relaying systems.

3.2.4 Coded Pulse Signaling

Coded pulse signaling is another mode of signal applicable to relay functions employing one of the above types of signal transmission. The signal is keyed in a time sequence to form a code composed of marks and spaces.

Coded pulse equipment appears to offer great security against false operation due to interference. Coded pulse systems require greater channel bandwidths for the same operating speed than do the basic frequency shift or ON-OFF systems. This factor should be considered in view of the frequency range of the telephone channel and the overall function of the equipment.

3.2.5 Phase Shift Keying Modulated Equipment

The form of phase modulation in which the modulating function shifts the instantaneous phase of the modulated wave between predetermined discrete values is called phase shift keying. One predetermined phase of the signal may be guard and another may be trip; or, a combination of keying between two or more phases can be guard and another combination trip. The band-width of the channel is dependent on the channel time required and the keying rate (frequency of keying between phases).

3.3 Power Supplies

3.3.1 General

Solid state audio-tone equipment operates at voltages typically below 24 V direct current. This is not usually the concern of the power application engineer because of the integral power supplies that go with these equipments. Practically all such power supply units are designed with regulators to maintain output voltage to assure performance of the tone equipment within its specified limits. These supplies operate from standard power station sources: 120 V alternating current, 24, 48, 125, and 250 V direct current (ANSI/IEEE Std 281-1984) [3].[2] In applying solid state equipment, care should be taken to insure that the power supply ratings are adequate for battery equalizing overvoltages.

Power supplies in newer type audio-tone equipment are of the DC-DC converter type. The isolation afforded by this type of supply reduces the effects of surges appearing at the power supply input, and is of particular benefit when the station battery is used as the source. Converter type power supplies are preferred over the less effective dropping resistor and tapped station battery techniques.

3.3.2 Station Battery Source

From an operating point of view, the use of the station battery may be preferable to a separate battery since it reduces maintenance.

3.3.3 Separate Battery Source

For solid state equipment, there are advantages to separate battery sources since this equipment usually operates below 48 V. This method of supply has the advantage of being independent of the station battery source, thus minimizing exposure to surge phenomena originating in the station battery circuits.

3.3.4 Alternating Current Source

Alternating current as a source of power is suitable only when supplied from an uninterruptible power source (UPS).

3.3.5 Telephone Company Power Requirements

Particular attention should be given to the power requirements for any on-site active network channel terminating equipment owned by the telephone company. If this equipment is essential to the proper operation of relay schemes, the same considerations listed in this section must apply.

3.4 Equipment Protection from Surge Phenomena

3.4.1

The manufacturer of the terminal equipment normally includes all necessary components for suppression of surges in the power supply and output circuits. Such components are provided to reduce the effect of surges in the signal channels and include those necessary to prevent damage to components. Suitable surge reducing components should be applied to the communications channel and to the power supply connections. Such surge isolation and protective equipment should be coordinated with that of the communications facilities and tested in accordance with capability (SWC) Test, ANSI/IEEE C37.90.1-1978 [1].

3.5 Noise Suppression Circuits or Devices

3.5.1 General

Most commercial equipment contains circuits to sort the incoming signals and yield the desired output. These circuits provide a measure of protection against false operation from spurious frequencies or noise.

[2]The numbers in square brackets correspond to those of the references listed in 1.2 of this guide; when preceded by the letter B, they refer to bibliographic selections listed in Section 7

3.5.2 Circuit Arrangement

In frequency shift keyed systems, the tripping circuits are usually arranged to operate upon loss of guard tone and reception of a trip tone. The condition of loss of guard tone output may result from or be coincident with the presence of noise. If a trip frequency or trip frequencies appear under these conditions, an undesired trip may occur. Protection against this is difficult.

3.5.3 Noise Presence

The presence of noise offers a degree of information that can be used to block the receiver if desired:

1) A filter can be used to detect broad band noise which, through suitable amplification, can be used to prevent receiver operation. The noise filter should have a sufficiently wide passband (wider than the receiver filter) so that the response time of this “squelch” circuit is rapid enough to block the receiver output circuits before an impulse can travel through the tone receiver. The frequency of the noise filter shall fit into the spectrum of the system at a point not utilized for information transfer.
2) If the noise to be protected against is not broad band or the frequency spectrum for a noise filter is not available, some means shall be found to operate successfully with the information available through the receive filter. This may be accomplished through the use of a discriminator or logic.

3.5.4 Signal-to-Noise Ratio Comparison Circuits

Such circuits have performed with a satisfactory history of security. It is necessary that a true comparison be made between noise and signal and that trip blocking be performed rapidly. A second area of importance is the time delay in restoration of tripping to permit all residual noise components to clear the equipment.

3.5.5 Loss-of-Tone Monitoring

A loss-of-tone squelch feature improves the security of the toner eceiver in the presence of noise. This feature is provided to prevent false operation of the receiver output relays whenever low-level noise is received in the absence of tone.

3.5.6 Tone Level Meter

Tone level meters may be used to provide a visual indication of the relative operating condition of tone receivers and channel attenuation.

3.6 Frequency Translation Protection

1) Tripping can be blocked during a frequency translation caused by multiplex or carrier equipment switching with the use of a pilot tone in conjunction with a “notched” noise squelch bandpass filter. The pilot tone is selected to fall within the “notch” or rejection band of the noise squelch receiver. Should the telephone channel translate the relaying frequencies, it will also translate the pilot tone out of the rejection band to allow the pilot tone to activate the noise squelch receiver.
2) By using two frequency shift tones, one can be made to shift up for trip and the other down to trip. This will permit in-band noise monitoring and with proper logic protects against the effects of frequency translation.

4. Leased Telephone Channels

4.1 Introduction

4.1.1

Leased telephone channels as referred to in this guide are dedicated (that is, private line, nonswitched) voiceband communication paths that interconnect two or more locations for the purpose of transmitting electrical signals from one location to another. These channels, which have usable bandwidths from approximately 300 to 3000 Hz, are provided over a variety of transmission media including paired wire, multipaired cable, coaxial cable, microwave radio, and optical fibers. Voiceband signals may be transmitted from one location to another entirely as voice frequency signals, or they may be converted to equivalent electrical signals for transmission on analog or digital carrier systems. Combinations of various transmission media and transmission systems are frequently employed by telephone companies so that customer demand for telecommunication services might be met in the most cost effective manner.

Channel characteristics described in this section are for two types of voiceband telephone channels:

1) Typical widely available voiceband channels, either basic (nonconditioned) or conditioned, which can be used for a variety of voiceband applications, including audio-tone protective relaying.
2) A voiceband channel specifically designed for audio-tone protective relaying applications. This channel is intended to provide increased reliability for protective relaying systems through improved signal to noise performance in that portion of the circuit in the immediate vicinity of the power station (between the power station and the serving telephone company central office).

4.2 Need for Joint Discussions

4.2.1

When leased telephone channels are contemplated for highly critical audio-tone protective relaying applications, consideration should be given to joint discussions so that those involved may have a mutual understanding of the system requirements and have ample opportunity to work out any problems prior to initiation of service. Such discussions should include responsible engineering representatives from the telephone company and the power utility, and where appropriate, the audio-tone equipment manufacturer or supplier. The discussion should include the following items:

1) audio-tone terminal equipment operation and performance
2) special high voltage protection requirements at the power station(s) and any other protection requirements throughout the length of the channel
3) reliability requirements (including the possibility of dual alternate routed channels)
4) telephone channel characteristics (such as covered in 4.3)
5) channel testing and maintenance arrangements (including special services maintenance concepts)
6) equipment compatibility
7) tariff offerings and requirements
8) central office termination markings (including joint inspections)
9) power requirements for the telephone company's network channel terminating equipment
10) use of sealing current (a circulation of approximately 1 mA of dc current) by the telephone company to prevent circuit noise caused by small accumulations of oxides at splices and other connection points.

This is not an all inclusive list but represents items that should be mutually understood to increase the likelihood of successful operation.

4.3 Characteristics of Telephone Channels

4.3.1 Voiceband Channel Offerings

Table 1 gives typical interface requirements and transmission characteristics for two leased voiceband telephone channels that can be employed for audio-tone protective relaying. These typical specifications are representative of specifications for telecommunication channels that are provided under both interstate and intrastate tariffs in the United States. Since the channel specifications in Table 1 are only representative, it is recommended that actual specifications be obtained from the local telephone company serving a particular area or jurisdiction.

It is anticipated that the requirements for most audio-tone protective relaying systems will be met by one of the channels described in Table 1. If there are unusual transmission requirements, or if special engineering considerations are involved, those should be fully discussed with the telephone company so that they can be provided on a custom engineering basis.

4.3.2 Interface Requirements

Requirements at the customer-telephone company interface are established for the electrical protection of the telephone network, for the proper functioning of the protective relaying channel and the terminal equipment, and for purposes of standardization in private line channel design.

4.3.2.1 Transmitted Signal Power

For the leased voiceband telephone channels listed in Table 1, the maximum allowable composite transmitted signal power at the customer-telephone company interface, averaged over any three second interval, is 0 dBm (0 dB referred to 1 mW). The Special Audio-Tone Protective Relay Channel, described in the Bell publication PUB 41011 [B1] and shown in Table 1, permits a short term enhanced trip signal up to +16 dBm at the transmitting interface. This is so that the transmitted trip signal might override the fault coincident noise often introduced onto telephone facilities at times of power system faults. The duration of the enhanced trip signal is typically 50 to 100 ms, depending upon the terminal equipment design. If enhanced trip is used, the steady state transmitted power must be less than 0 dBm by the amount necessary to permit the three second intervals, including the enhanced trip signal and the three seconds before and afterwards, to meet the three second average power limitation. For example, if an enhanced signal of +16 dBm is sent for a duration of 50 ms, the maximum permissible steady state power before and after the enhanced signal would be –4.7 dBm. This is determined as follows:

1) 0 dBm for three seconds is equal to 3 mW-s per three second interval
2) +16 dBm for 50 ms is equal to 40 mW · 0.05 seconds or 2 mW-s
3) 3 mW-seconds total for any three second interval minus 2 mW-s of enhanced trip signal is equal to 1 mW-s available for the remaining 2.95 s
4) 1 mW-s ÷ 2.95 s = 0.34 mW or –4.7 dBm

When more than one protective relaying tone transmitter is connected to the same telephone channel, the power limitations apply to the total signal at the customer-telephone company interface. (See example in the Annex.)

4.3.2.2 Terminal Impedance and Balance

For the channels listed in Table 1, the nominal impedance of the protective relaying terminal equipment should be 600 Ω resistive ±10% and balanced to ground over the 300 to 3000 Hz band. The impedance of telephone company test equipment used for installation and maintenance tests is ordinarily 600 Ω resistive. Therefore, channels whose transmission characteristics were adjusted using 600 Ω test equipment should also employ protective relaying terminal equipment that has the same impedance to ensure that channel transmission performance is as specified.

4.3.2.3 Received Signal Power

For the channels in Table 1, the 1004 Hz channel loss at the time of installation is 16 dB ±1 dB. This assumes a 1004 Hz test signal transmitted at 0 dBm from the transmit interface. Therefore, the received signal power at the receive interface is nominally –16 dBm at 1004 Hz.

4.3.3 Transmission Characteristics

4.3.3.1 Attenuation Distortion

Attenuation distortion is the difference in the attenuation of a channel at any two frequencies. It is specified by placing a limit on the maximum loss at any frequency in a specified band of frequencies with respect to the loss at a 1004 Hz reference frequency.

For the basic channel listed in Table 1, in the overall frequency band between 300 and 3000 Hz, the loss may vary from –3 to +12 dB with respect to the loss at the reference frequency ("–" means less loss, "+" means more loss). In the 500 to 2500 Hz portion of the overall band, less variation is permitted and the loss may vary only from –2 to +8 dB with respect to the loss at 1004 Hz.

For the Special Audio-Tone Protective Relaying Channel listed in Table 1, the attenuation distortion is significantly less (the frequency response is much flatter) than for the basic channel. For the overall frequency band between 300 and 3000 Hz, the loss may vary from –2 to +6 dB compared with the loss at 1004 Hz. For that portion of the band between 500 and 2800 Hz, the loss may vary only from –1 to +3 dB compared with the loss at 1004 Hz. In this channel, the significance of improved attenuation distortion is that, for protective relaying systems employing multiple voice frequency tones at different frequencies, the tones will be received with much less variation in their signal amplitudes than with the basic channel.

Table 1—Typical Interface Requirements and Transmission Characteristics for Leased Voice Band Telephone Channels Used for Audio-Tone Protective Relaying

Parameter	Basic Channel	Special Audio-Tone Protective Relay Channel
	Requirements at Customer-Telephone Company Interface	
(1) Maximum transmitted–signal power	0 dBm	+16 dBm (Note 1) 0 dBm
(2) Impedance of terminal equipment	600 Ω ±10 % resistive, balanced	600 Ω ± 10% resistive, balanced
(3) Received signal power of 1004 Hz test tone (at installation)	–16 dBm ± 1 dB	–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 (Note 3)	500–2800 Hz, –1 to +3 dB; 300–3000 Hz, –2 to +6 dB
(2) 1004 Hz loss at installation	16 dB ± 1 dB	16 dB ± 1 dB
(3) 1004 Hz short term loss variation	<±3 dB	<±3 dB
(4) 1004 Hz long term loss variation	<±4 dB	<±4 dB
(5) Envelope delay distortion	<1750 µs, 800–2600 Hz (Note 3)	<2000 µs, 800–2600 Hz
(6) C–Notched noise — signal-to-noise ratio with 1004 Hz test tone	24 dB minimum	24 dB minimum
(7) C–message noise	Note 2	Note 2

Table 1—Typical Interface Requirements and Transmission Characteristics for Leased Voice Band Telephone Channels Used for Audio-Tone Protective Relaying *(Continued)*

Parameter	Basic Channel	Special Audio-Tone Protective Relay Channel
(8) Impulse noise — threshold with respect to received 1004 Hz test tone	Maximum count above threshold allowed in 15 min	Maximum count above threshold allowed in 15 min
–6 dB	15	15
–2 dB	9	9
+2 dB	5	5
(9) Local channel resistance unbalance	Not specified	Maximum 1% unbalance
(10) Special channel design	None	Gain and loss devices placed to maximize signal-to-noise ratio during fault conditions; receiving amplifiers not used at power station; enhanced trip signal power levels permitted.

NOTES:

1) +16 dBm is classified as a short-term enhanced signal.
2) C-Message Noise:

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

3) C-conditionings may be applied to the Basic Channel above to improve the Attenuation Distortion and Envelope Delay Distortion characteristics. Several conditionings are defined as follows:

	C_1 Conditioning		C_2 Conditioning		C_4 Conditioning	
Attenuation Distortion — Variation with reference to 1004 Hz	Frequency Range (Hz)	Variation (dB)	Frequency Range (Hz)	Variation (dB)	Frequency Range (Hz)	Variation (dB)
	300–2700	–2 to +6	300–3000	–2 to +6	300–3200	–2 to +6
	1000–2400	–1 to +3	500–2800	–1 to +3	500–3000	–2 to +3
	300–3000	–3 to +12				
Envelope delay distortion	Frequency Range (Hz)	Distortion (µs)	Frequency Range (Hz)	Distortion (µs)	Frequency Range (Hz)	Distortion (µs)
	1000–2400	<1000	1000–2600	< 500	1000–2600	< 300
	800–2600	<1750	600–2600	<1500	800–2800	< 500
			500–2800	<3000	600–3000	<1500
					500–3000	<3000

4.3.3.2 Channel Loss and Variations

For the channels listed in Table 1, the standard 1004 Hz loss at channel installation is 16 dB ±1 dB. However, variations after installation can be expected. Short-term loss variations may be caused by dynamic regulation of carrier system amplifiers, switching to standby facilities, and some maintenance activities. “Short-term” is meant to be a few seconds or less. The limit on short-term variations is ±3 dB.

Long-term variations are primarily caused by temperature changes affecting local plant, component aging, amplifier drift, and other phenomena. “Long-term” is meant to be periods of days, weeks, or even longer. Long-term variations are corrected during periodic routine measurements. They should not exceed ±4 dB with respect to the nominal 16 dB channel loss.

4.3.3.3 Channel Delay Characteristics

The subject of telephone channel time delay should be thoroughly discussed on a system basis by all concerned parties. Of particular importance to the protective relaying engineer is the contribution of channel time delay to the overall fault clearing time and the resulting effect on power system relaying performance. The telephone engineer should have an appreciation of this effect and should be aware that there are delay constraints of some types of relaying applications such as phase comparison.

It is important that any limit established for channel delay not be overly restrictive. The reason for this is that unless special telephone facilities are constructed for minimum achievable delay, the channel delay will be dependent upon the type and length of available telephone facilities and upon the type of carrier terminal equipment being used by the telephone company. In most instances, the delay of existing facilities and terminal equipment will be perfectly satisfactory for protective relaying applications. For example, if a preliminary delay limit has been given as 8 ms, and the shortest available telephone channel has a total delay of 10 ms, it would appear that the limit is exceeded by 25%. However, the additional 2 ms may be acceptable when one considers the overall fault clearing time, which also includes the fault sensing relay, audio-tone terminal equipment, and circuit breaker operating times.

The total time delay of the telephone channel consists of the propagation delay of the line facilities over which the channel is provided, plus the delay introduced by any carrier terminal equipment. These delay times can generally be obtained from a telephone company transmission engineer. The end-to-end telephone facilities used for the transmission of audio tones will ordinarily consist of both local and interoffice facilities. Local facilities, known as loops, are the portion of the total facility that exists between the power station and the serving telephone central office. Local facilities typically consist of metallic cable pairs over which the audio tones are transmitted.

In some instances, pair gain systems such as digital loop carrier systems may be part of the local facility. Interoffice facilities, which provide the transmission path between serving telephone central offices, may occasionally consist of cable pairs (voice frequency trunks) over which the audio tones are transmitted, but will typically consist of analog or digital carrier systems operating on a variety of transmission media such as nonloaded cable pairs, coaxial cables, optical fibers, and microwave radio.

Some typical line facility propagation delays are as follows:

1) Approximately 1 ms per 12 miles of H88 loaded cable pairs commonly used in local facilities to serve user locations.
2) Approximately 1 ms per 100 miles of repeated analog carrier line operating on nonloaded cable pairs.
3) Approximately 1 ms per 150 miles of repeated analog carrier line operating on coaxial cables
4) Approximately 1 ms per 125 miles of repeated digital carrier (T1) line operating on nonloaded cable pairs
5) Approximately 1 ms per 120 miles of optical fiber systems
6) Approximately 1 ms per 180 miles of microwave radio carrier links.

The delay introduced by the carrier terminal equipment is primarily due to the delay associated with the channelizing filters and equalizers. This delay is typically in the range of 0.3 to 1.3 ms per carrier terminal pair (modulation and demodulation). In determining the delay of a terminal to a frequency shift keying signal such as used in protective relaying, the Absolute Envelope Delay of the terminal at the trip frequency is the quantity of greatest importance. The Absolute Envelope Delay of the terminal is the incremental phase shift between the input and the output of the terminal with respect to the frequency of a single sinusoidal amplitude modulated signal. It is often used in the specification of telephone equipment and is relatively easy to measure.

The variation of Envelope Delay over a specified frequency range is referred to as Envelope Delay Distortion. Envelope Delay Distortion has little effect on the single frequency tone signals of a Frequency Shift, ON-OFF, or Phase Shift Keying audio-tone system, but may be very important in the performance of a Coded Pulse Signaling system because Envelope Delay Distortion contributes to pulse distortion and interference between successive pulses of a pulse code data signal. Typical values of Envelope Delay Distortion for two types of leased telephone channels are shown in Table 1.

From the brief discussion given here, two generalized guidelines can be derived that will be useful for understanding the importance of channel delay and evaluating its effect in protective relaying applications. First, the total delay of the telephone channel consists of the propagation delay of the line facilities plus the delay of the carrier terminal equipment. In most instances, the total delay of typically available telephone channels will be completely satisfactory for protective relaying applications. However, in phase comparison systems, delay times are critical (usually only 3–4 ms can be tolerated) and the delay of available telephone channels may sometimes be excessive for this application. Second, since Envelope Delay Distortion is relatively unimportant for the most common types of audio tone protective relaying signals (Frequency Shift, ON-OFF, or Phase Shift Keying), the Envelope Delay Distortion requirements can be greatly relaxed (for reasons of economy of channel design) for these systems. Table 1 shows such a relaxation for the Special Audio-Tone Protective Relaying Channel. It should be noted, however, that systems using Coded Pulse Signaling and some phase comparison systems will likely have more stringent Envelope Delay Distortion limits which must be included in the telephone channel design specifications.

4.3.3.4 C-Message Noise

Message circuit noise is normally referred to in units of decibels above reference noise (abbreviated dBrn). The level of 1 pW (10^{-12} W) at 1000 Hz is used as the reference power. Noise powers of a magnitude to cause interfering effects will then be expressed as positive values of dBrn.

C-message noise is the telephone circuit noise measured using a frequency weighted filter which simulates the interfering effect of the various frequency components of the noise. It is expressed in decibels above reference noise with C-message weighting (dBrnC). The C-message weighting filter has zero relative loss at 1000 Hz and gives a reading of 88.5 dBrnC with an input of 0 dBm of flat noise in the bandwidth between 0 and 3000 Hz. Note in Table 1 that C-message noise limits on telephone channels are a function of channel length since noise is generally cumulative depending on the number of repeaters and terminals in the circuit.

C-message noise is a measure of the noise output from a channel n the idle condition. It is a valid measure of the noise on channels which do not include compandors or other level sensitive devices.

Compandors improve the signal to noise performance of voice circuits by compressing the range of speech signal amplitudes at the input of the circuit and expanding it at the output, for example, when low signal level is present, gain is added at the input to the channel and attenuation is added at the output. Thus channels equipped with compandors will have noise outputs that vary depending on the level of the signal present and will show an artificially low C-message noise when no signal is present. These channels must be measured using C-notched noise. Although compandors are frequently used on voice circuits, they should not be used on audio tone circuits used for protective relaying because they can change the signal and noise levels.

4.3.3.5 C-Notched Noise

C-notched noise is a measure of the amount of noise on a channel with a signal of standard level present. The measurement is made by applying a 1004 Hz “holding tone” at the transmitting end of the channel to operate the compandors and other signal dependent devices; removing the tone at the receiving end with a very narrow band elimination filter (notch filter); and measuring the resultant noise through a C-message weighting filter.

4.3.3.6 Impulse Noise

Impulse noise is characterized by large peaks or impulses in the total noise waveform. It is measured with an instrument that responds to noise waveform excursions above a selectable power threshold using a counter having a maximum counting rate of 7 counts per second. Measurements are made through a C-message filter. A holding tone which is transmitted to activate any compandored facilities in the channel is notched out at the receiver. The impulse noise measurement for the protective relaying channel involves counting the number of noise peaks exceeding a threshold numerically 6 dB below the received test tone power. In addition, counts are made of the number of noise peaks exceeding thresholds which are 2 dB below and 2 dB above the received test tone power. Limits for impulse noise at the receiver are given in Table 1.

4.3.3.7 Special Local Channel Design

As shown in Table 1, only the Special Audio-Tone Protective Relaying Channel incorporates special local channel design measures. The objective of these measures is to increase substantially the signal-to-noise ratio of both guard-type and trip-type signals in the local channel during power system fault intervals.

One of the unique problems inherent in providing communication service to power stations is the severe noise signals that are frequently introduced into cable facilities during power faults. This noise is often responsible for inhibiting the reception of valid trip signals during the most critical interval. Thus protective relaying system dependability can be compromised by noise generated during fault intervals.

The improved dependability of this channel comes about from a basic improvement in the signal-to-noise ratio of the received trip signal. This improvement is accomplished by the following means:

1) Selection of cable pairs in the local loop portion of the channel to ensure better than average resistance balance, as discussed in 4.3.3.8.
2) Authorizing the employment of short-term enhanced trip signals while retaining the normal three-second average power limitation.
3) Installing any necessary gain or loss devices at locations which ensure a true improvement in the signal-to-noise ratio. For example, receiving amplifiers are not provided at power stations since these would amplify locally generated noise as well as the incoming signal and thus would not contribute to an improvement in the signal-to-noise ratio.

Finally, higher than ordinary signal powers are permitted on the local channel at all times for both the continuous guard signals and also the infrequent trip signals. This is accomplished by not installing the usual 8 dB pad (attenuator) on the telephone company side of the transmit interface with the customer, and also by applying higher than ordinary signal power (by 8 dB) to the local channel from the telephone central office on the receive end of the channel.

4.3.3.8 Local Channel Resistance Unbalance

During the power fault condition, longitudinal voltages of large magnitude may be induced in the local channels (the portion of the circuit between the power station and the serving telephone central office). Because the channel is terminated by a well-balanced transformer, the conversion from common (longitudinal) to differential (metallic) mode for 60 Hz voltage depends primarily on the resistance balance of the cable pair serving the power station. For the Special Audio-Tone Protective Relaying Channel only, the resistance unbalance of the local channel cable pairs will be 1% or less.

5. Application Principles

5.1 Audio-Tone Relaying Systems

5.1.1 General

Application of audio-tone systems for protective relaying can be divided into two categories:

5.1.1.1 Transformer and Circuit Breaker Failure Protection or Other Direct Trip Applications

These applications are termed “direct transfer tripping.” The audio-tone system functions as the communication link to extend relay tripping circuits to remote circuit breaker locations. These type of direct transfer tripping applications have the greatest difficulty in meeting the relay demands listed in 3.1.3. These systems, with few exceptions, cannot have fault detector supervision of the receivers and the security against undesired tripping rests solely with the audio-tone equipment.

5.1.1.2 Transmission Line Protection

Audio-tone systems function as the communication link for pilot relaying schemes employed for transmission line protection. Transfer trip schemes, including direct underreaching, permissive underreaching, and permissive overreaching protection are used extensively with telephone channels. Directional comparison blocking and phase comparison schemes are used primarily with power line carrier but they are also employed with audio-tone systems over telephone channels and microwave channels. Tripping with line protective schemes can be made dependent on line relay and fault detector relay operation.

5.1.2 Transformer and Circuit Breaker Failure Protection

Transfer tripping schemes using audio-tone systems over telephone channels have been used extensively for transformer protection where high voltage breakers have been omitted or for breaker backup protection where system arrangement places a backup breaker(s) at a remote location. The operation of a frequency shift audio-tone system for remote clearing is described in the following paragraph.

During normal conditions, a guard signal(s) is transmitted continuously. Receipt of the guard signal by the tone receiver produces blocking of the breaker trip circuit. At the same time, the guard signal provides continuous monitoring of the tone system. When the protective relays detect abnormal operation, they initiate removal of the guard signal(s) and transmission of the trip signal(s). The absence of guard and the reception of the trip constitutes a valid trip condition to effect remote clearing.

5.1.3 Transmission Line Protection

Pilot relaying systems applicable for the protection of power-transmission lines and for which audio-tone channels may be used are briefly described below. The transmission lines may have two or more terminals each with circuit breakers for disconnecting the line from the rest of the power system. All of the relaying systems described can be used on two-terminal or multiterminal lines. These relaying systems program the automatic operation of the circuit breakers during power system faults.

Where possible, fault detector relays should supervise the receiver relay trip circuits to improve security.

However, their use should not be a substitute for an audio-tone system of highest reliability, since the greatest noise levels are likely to occur at the very instant when the fault detectors have operated, that is during a power system fault.

5.1.3.1 Direct Underreaching (Fig 1)

Fault relays at each terminal of the protected line sense fault current flow into the line. Their zones of operation must overlap but not overreach any remote terminals. The operation of the relays at any terminal initiates both opening of the local breaker and the transmission of a continuous remote tripping signal to effect instantaneous operation of all remote breakers. For example, in Fig 1, for a line fault near A, the fault relays at A open (trip) breaker A directly, and send a transfer trip signal to B. The reception of this trip signal at B trips breaker B.

5.1.3.2 Permissive Underreaching (Fig 2)

The operation and equipment for this system is the same as the direct underreaching system with the addition of overreaching fault detector units at each terminal. They provide added security by supervising remote tripping of the local breakers. As an example, for a fault near A in Fig 2, the fault relays at A trip breaker A directly, and send a transfer trip signal to B. The reception of the trip signal plus the operation of the fault detector relays at B trip breaker B.

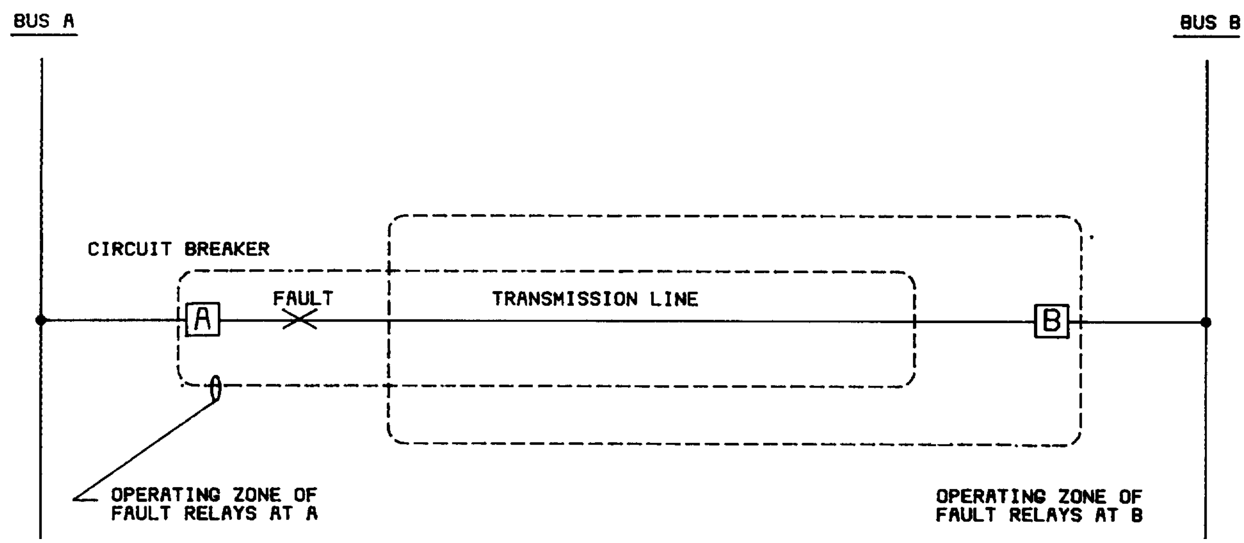

Figure 1—Fault Relay Operation Zones for the Underreaching Transfer Trip Transmission — Line Pilot Relaying Systems

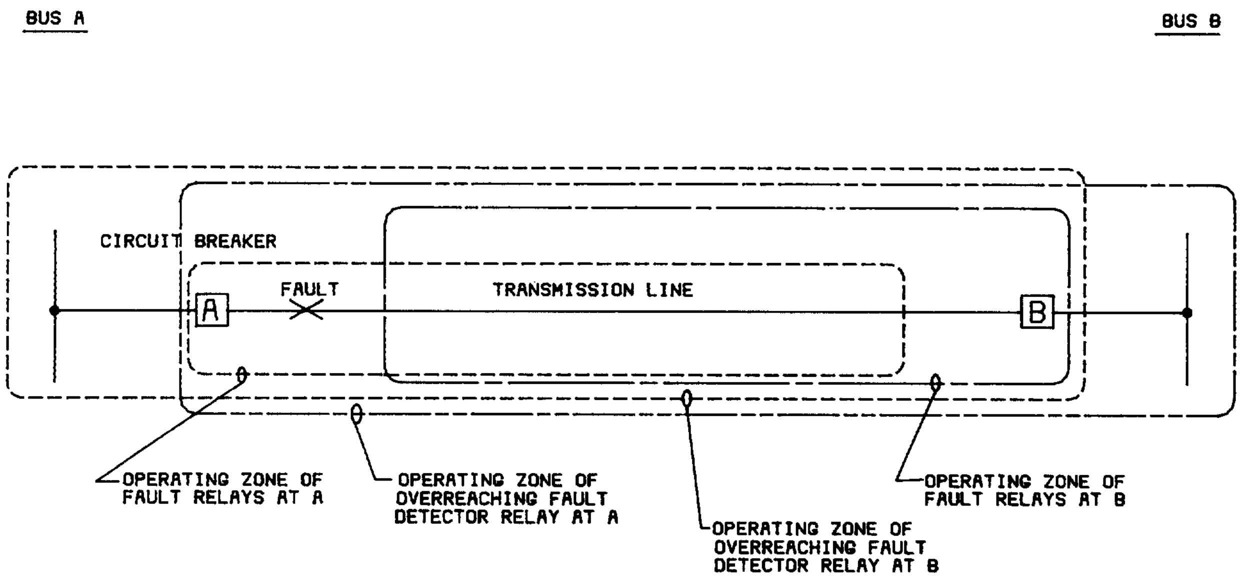

Figure 2—Fault and Supervising Relay Operating Zones for the Permissive Underreaching Transfer Trip Transmission — Line Pilot Relaying Systems

5.1.3.3 Permissive Overreaching (Fig 3)

Fault relays at each terminal of the protected line sense fault power flow into the line with their zones of operation overreaching all remote terminals. Both the operation of the local fault relays and a transfer trip signal from all of the remote terminals are required to trip any breaker. Thus, in the example of Fig 3 for the line fault near A, fault relays at A operate and transmit a trip signal to B. Similarly, the relays at B operate and transmit a trip signal to A. Breaker A is tripped by the operation of the fault relays at A plus the remote trip signal from B. Likewise, breaker B is tripped by the operation of the fault relay at B plus the remote trip signal from A.

5.1.3.4 Directional Comparison Blocking (Fig 4)

The channel signal in these systems is used to block tripping in contrast to its use to initiate tripping in the previous three systems. Fault relays at each terminal of the protected line section sense fault power flow into the line. Their zones of operation must overreach all remote terminals. Additional fault detecting units are required at each terminal to initiate the channel blocking signal. Their operating zones must extend further or be set to be more sensitive than the fault relays at the far terminals. For example, in Fig 4, the blocking zone at B must extend further behind breaker B (to the right) than the operating zone of the fault relays at A. Correspondingly, the blocking zone at A must extend further into the systems (to the left) than the operating zone of the fault relays at B.

For an internal fault on line AB, no channel signal is transmitted (or if transmitted, it is cut off by the fault relays) from any terminal. In this absence of any channel signal, fault relays at A instantly trip breaker A, and fault relays at B instantly trip breaker B. For the external fault to the right of B as shown in Fig 4, the blocking zone relays at B transmit a blocking channel signal to prevent the fault relays at A from tripping breaker A. Breaker B is not tripped because the B protective relays do not see this fault.

5.1.3.5 Phase Comparison

At each end of the protected line, the three line currents are either converted into three proportional signal phase voltages or, through appropriate sequence networks, into a proportional single phase voltage. The phase angles of these voltages are then compared via the pilot channel in the following manner. A squaring amplifier converts the voltages into a square wave which is used to key the channel to the remote terminal.

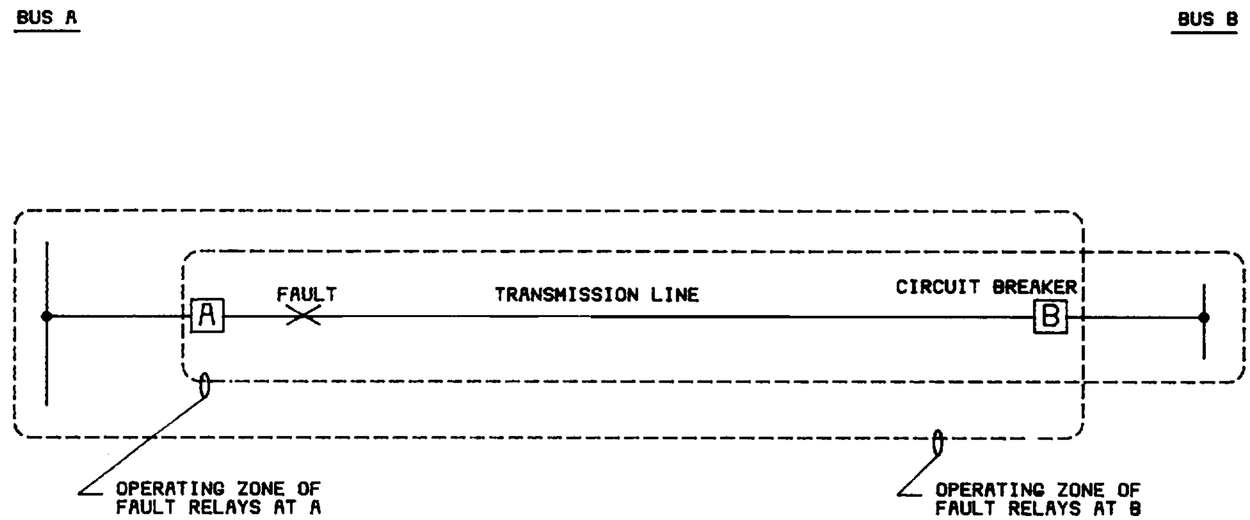

Figure 3—Fault Relay Operating Zones for the Overreaching Transmission — Line Pilot Relaying Systems

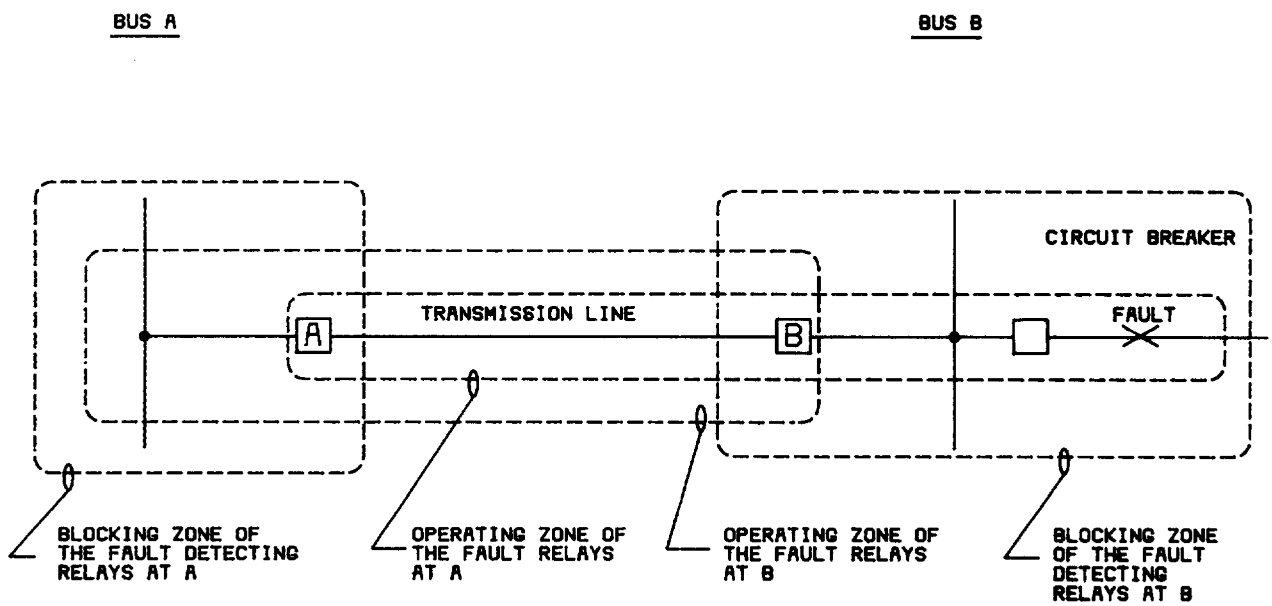

Figure 4—Fault and Blocking Relay Operating Zones for the Directional Comparison Transmission — Line Pilot Relaying Systems

With ON-OFF equipment, one of the half cycles of the square wave keys the transmitter ON and the other half cycle keys it OFF. For external faults, the received carrier half cycles are out-of-phase so that, alternately, the local and then the remote signal provide essentially a continuous signal to block tripping. On internal faults, the local and remote signals are essentially in phase so that approximately a half cycle of no channel signal exists. This is used to permit the protective relays at each terminal to trip their respective breakers. With frequency shift equipment, the current derived voltage controls transmitter shift on alternate half-cycles. For an internal fault, the receiver output coincides with the local voltage to effect tripping.

In phase comparison systems, telephone channel delay times are critical. Any change in channel routing must be carefully coordinated between the power and telephone companies. Arbitrary changes in channel routing could cause false trips or failure to trip during a fault.

The tone equipment design can be identical for all of the transfer trip type of systems 5.1.3.1, 5.1.3.2, and 5.1.3.3 above where the audio-tone signal is utilized to order or request tripping of the remote breaker. The directional comparison blocking systems can use the same tone equipment designs with different transmitter keying and receiver output circuits. Phase comparison systems may require wider bandwidth and other design changes because of waveform requirements. It is easier to integrate tones and relays of different manufacturers in the transfer trip systems than it is to mix equipment of different suppliers in the blocking systems.

5.2 Mode of Operation

5.2.1 General

In the application of audio-tones to protective relaying, three basic types of equipment have been used: frequency shift, ON-OFF, and coded pulse signaling.

5.2.2 Frequency Shift

The center frequency for frequency shift signaling is the midpoint between the guard and trip frequencies. If more than one frequency shift signal is being used on a single telephone channel, the spacing of center frequencies varies between 150 and 1200 Hz depending on the equipment design. The frequency shift signal is normally operated in the guard mode, which is 40–300 Hz above or below the center frequencies. When in the trip mode the frequency is shifted to the opposite side of the center frequency by an equal amount. With modern, solid-state tone equipment the speed of the channel is independent of the keying method and of whether the high-shift or low-shift frequency is used for “trip.” Applications involving two transmitter and receiver systems (for example, for added security in a direct transfer trip application) may utilize one system with a high-shift to trip and the other with a low-shift to trip. This technique is useful in negating the effects of large abnormal frequency shifts associated with major malfunctions of the telephone channel.

The frequency bandwidth required by a given signaling system is related to the (desired) speed of operation. The greater the speed, the greater the bandwidth that must be designed into the equipment. The bandwidth required by each signal limits the number of signals that can be transmitted over a single leased telephone channel.

5.2.3 ON-OFF

The ON-OFF method has been utilized for both blocking and transfer trip relaying systems and uses amplitude modulation signals with the discrete frequencies spaced a minimum of 120 Hz apart. However, this type of equipment is seldom applied when using audio tones for relaying.

5.2.4 Coded Pulse Signaling

This is another form of signal employing one of the above types of signal transmission. The signal is keyed in a time sequence to form a code. Several systems using this principle have been developed and are in service on operating power systems.

For power-system relaying functions, coded-pulse systems appear to offer security against false operation due to interference. Tripping is blocked if noise or other interference disturbs the coded-pulse pattern.

Coded pulse systems require greater channel bandwidths than the basic frequency shift or ON-OFF systems. For the security and speeds that relaying functions demand, channel bandwidth requirements could exceed that of a voice-grade channel. This factor should be considered in view of the frequency range of the telephone channel and the overall function of the equipment.

5.3 Signal and Channel Arrangements

5.3.1 General

Reliability can be improved by installing additional telephone channels and terminal equipment to provide redundant operation. These channels and terminal equipment may be arranged to increase the dependability or the security of the relaying function. Paralleled receiver outputs increase dependability, but lower the security. Conversely, a series receiver output arrangement gives improvement in security at the expense of dependability.

Paralleled receiver outputs may be used to advantage in permissive schemes since the permissive fault detector units tend to compensate for the decrease in security, but they are not recommended for nonpermissive schemes. The decrease in dependability of the series connection can be largely offset by output bypass arrangements coupled with the use of separate communications channels. The audio-tone system can be designed for either automatic or manual bypassing. Bypassing the receiver output of the inoperative channel allows the tone system to remain operative even though one of the tone signals is lost. Accidentally bypassing both channels may cause tripping; therefore, an interlock should be provided.

Separation of the communication channels can be accomplished by employing two telephone channels, preferably with separate routing, or using one telephone channel in combination with another medium of communication such as microwave, power line carrier, or fiber optics. Telephone channel and signal arrangements are described in more detail below.

5.3.1.1 Single Audio-Tone Signal (One Guard and One Trip) over Single Telephone Channel

This arrangement provides the most economical system. However, it does not allow in-service testing with direct transfer tripping without removal of the desired protection.

The single signal may be adequate when employed with permissive line relaying schemes, but its use in other schemes may allow incorrect operation due to momentary noise bursts and foreign signals.

5.3.1.2 Two Audio-Tone Signals (Two Guards and Two Trips) over Single Telephone Channel

This system can provide additional flexibility of operation and more reliable protection with the receiver outputs connected in series or parallel arrangements to enhance security or dependability, respectively. The tripping circuits can be designed to permit maintenance or testing of each signal in turn without removing the protection. Signal to noise ratios of the individual tones are degraded in this arrangement because of the required reduction in power of the individual transmitted signals so that the maximum composite transmitted signal power limit is not exceeded.

5.3.1.3 Two Audio-Tone Signals (Two Guards and Two Trips) over Separate Telephone Channels

The receiver output from the second telephone channel can be arranged to enhance either security or dependability as well as flexibility of application and operation in a system of employing two audio tones. In-service testing and maintenance can be extended to include the associated telephone channel. Also, separate telephone channels simplify terminations of the telephone channels with the transmitting and receiving equipment and permit better signal to noise performance than in 5.3.1.2 due to the higher tone levels allowed when the two audio-tone signals are on separate telephone channels. This arrangement protects for both facility and equipment failure.

Where relay protection requires transmission of audio-tone signals in two directions simultaneously (full duplex), a four-wire facility is preferred over a two-wire facility. By using a separate channel in each direction, the full voiceband is available for use in both directions simultaneously, simplified channel designs can be used, and signal to noise ratios are optimized. Simultaneous two-way transmission over a two-wire facility requires dividing the channel bandwidth into bands used for transmitting in different directions, reduces signal to noise performance, and requires more complicated channel design.

Also in 5.3.1.2 and 5.3.1.3, since both audio tone channels are located within a common facility, and station noise and disturbances could affect both channels, it is prudent to apply each tone channel with opposite shifts (that is, shift one channel down to trip, and the other up to trip).

5.3.2 Multistation Applications

Normally, the telephone company will be able to custom engineer and provide channels, correctly terminated and balanced, to interface with the specified audio-tone terminals on a multistation circuit. Under such an arrangement, the telephone company is usually responsible for providing and maintaining all facilities, amplifiers, hybrids, pads, filters, bridges, etc, which make up the leased multipoint channel.

The ultimate objective is a communication system that reliably delivers the desired signals at a reasonable signal power level with a minimum of distortion and delay and with an adequate signal to noise ratio. It is particularly important with multi-point leased circuits for the user to consult with the telephone company at an early date, especially for phase comparison applications. Since tone equipment applications and telephone circuit designs are interdependent, the circuit designs should be fixed with regard to configuration and signal levels before firm bids are requested from the tone equipment manufacturers.

In general, the telephone companies will custom engineer multistation systems, but where such engineering is not available, power utilities may create small multistation arrangements of their own. The following examples assume telephone company-provided facilities between power stations, and power utility-provided communications apparatus at the power stations.

5.3.2.1 Path Agreements

Figure 5 shows three possible circuit configurations for interconnecting three stations. Such would be needed for a three terminal line or for a tapped two-terminal transmission line. In Fig 5(a), the interconnection occurs at some point N other than one of the three stations. In Fig 5(b), point N vanishes into Station III. Figure 5(c), while perhaps requiring additional channel facilities, can simplify the overall problems in some cases.

Any of the circuit legs in Fig 5 may be two wire or four wire, depending upon tone transmission requirements and economic factors. Some specific examples will be given later.

5.3.2.2 Design Requirements

When interconnecting facilities or connecting tone equipment to facilities, the impedances should be matched to minimize losses and prevent reflections. Matching transformers or resistance pads accomplish this.

Where a received signal must be retransmitted to another circuit leg, as could be true at Station III in Fig 5(b), amplification will usually be needed to raise the signal power to about the same level as a locally transmitted tone. On full duplex (simultaneous two-way transmission) two-wire facilities, hybrids or filters are required with the amplifiers to avoid feedback or “singing.” These devices act to segregate the signals going in one direction from those going in the opposite direction.

5.3.2.3 Application Examples

Figure 6(a) is the simplest case, transmitting from Station III to I and II. Transmitter T_1 sees half the normal impedance so that a matching transformer M_T or resistance pads may be required at Station III. Stations I and II may also need matching, but the application here is no different than for a two-terminal line. Putting the tap at N does not change the picture much, although the pads or matching transformer must be at N instead of at Station III. For this reason, the open delta is preferred over the T path.

Figure 6(b) is another open delta configuration. Here each station transmits to the other two, utilizing two-wire facilities. Frequencies 1 and 2 are amplified at Station III before being retransmitted. Segregating filters prevent amplification of the wrong frequencies to prevent singing. The attenuation of the unwanted signals by the segregating filters must exceed the amount of amplification of the desired signal. Therefore, the lower the level of received signals and hence the greater the required amplification, the greater must be the filter attenuation of the unwanted signals; the more filtering required, the more signal delay.

Hybrids may replace the filters in Fig 6(b); however, these are of limited value in a circuit employed for power system protection since a fault on the wire facility may unbalance the hybrid with the likelihood of amplifier singing or ringing.

Two transmitters T_3 are used at Station III in Fig 6(b) to maintain isolation of the “east-west” and “west-east” amplifier paths. These are keyed simultaneously to transmit F_3 in both directions.

Figure 6(c) accomplishes the same functions as in Fig 6(b), but by utilizing four-wire facilities the isolation problem is solved without requiring filtering (other than the normal receiver bandpass filters) or hybrids. This arrangement would introduce less delay and would be free from the possibility of singing. The amplifiers should be broad enough so that they introduce negligible delay.

Figure 6(d) shows another alternative that achieves the ultimate in simplicity. On relatively short hops, this arrangement may be cost competitive with the Fig 6(b) setup. It is attractive where there are more tone signals to be transmitted than can be handled by the Fig 6(b) and 6(c) arrangements. In particular, note that the three paths in Fig 6(d) are independent and the frequencies could be duplicated on each path. This is not true in Fig 6(b) and is only partly the case in Fig 6(c) since all three stations are in common on the “east-west” and “west-east” paths. Note also that Fig 6(d) could readily be less costly than Fig 6(c) since the latter has four two-wire paths versus three in Fig 6(d). Of course, Fig 6(d) does not obviate the need for two-way amplifiers at intermediate points for long hops. In contrast, Fig 6(c) requires only one-way amplifiers. This is an advantage of four-wire versus two-wire circuits. However, Fig 6(d) has only a single set of protective relaying tones in each direction on all of the paths. This provides a 3 dB signal-to-noise advantage over two sets of tones on a path.

Figure 6(e) shows another alternative offering simplicity for three terminal applications. Full duplex two-wire circuits from each terminal are connected together with impedance matching networks at the telephone company office. Thus, all stations are common to one full duplex two-wire path. Transmitted signals from any one station appear at the other two stations.

Of course, the complexities mount with the number of tones to be carried and with the number of power stations to be interconnected. Careful planning and design is essential to achieve a reliable installation.

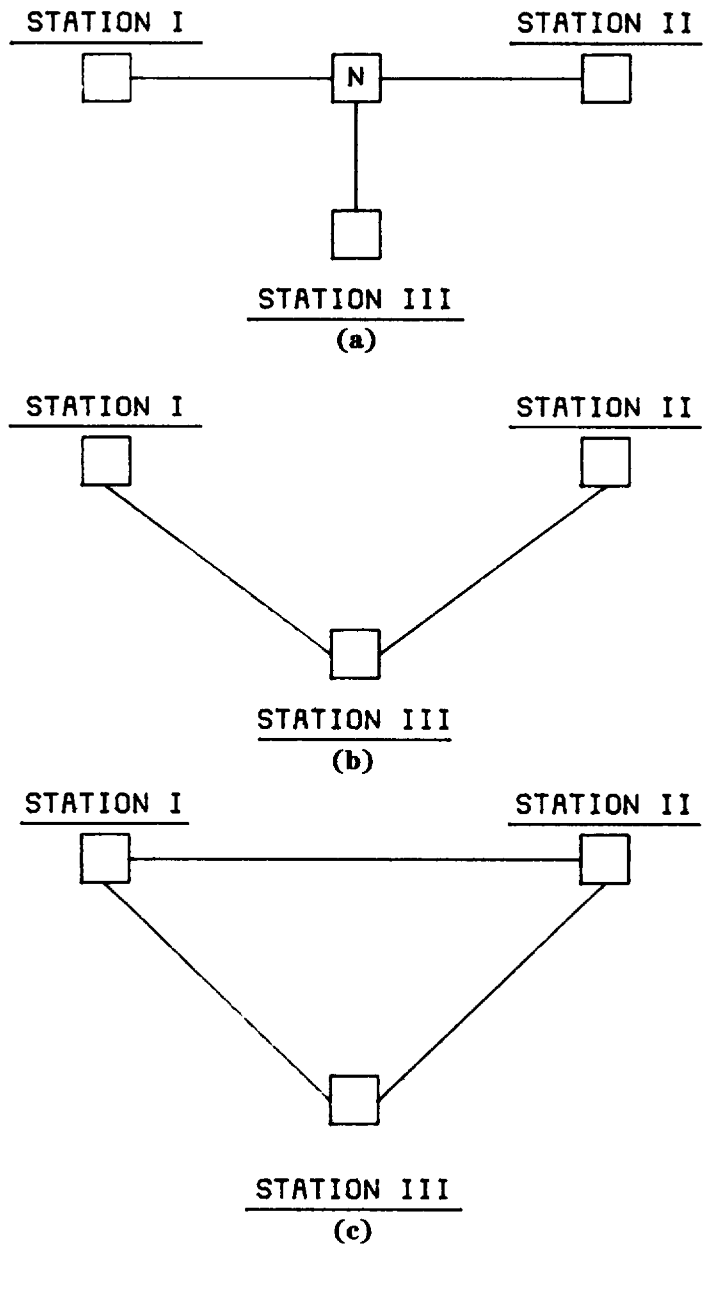

Figure 5 —Possible Circuit Paths for Three-Terminal Protection
(a) T Path; (b) Open-Delta Path; (c) Closed-Delta Path

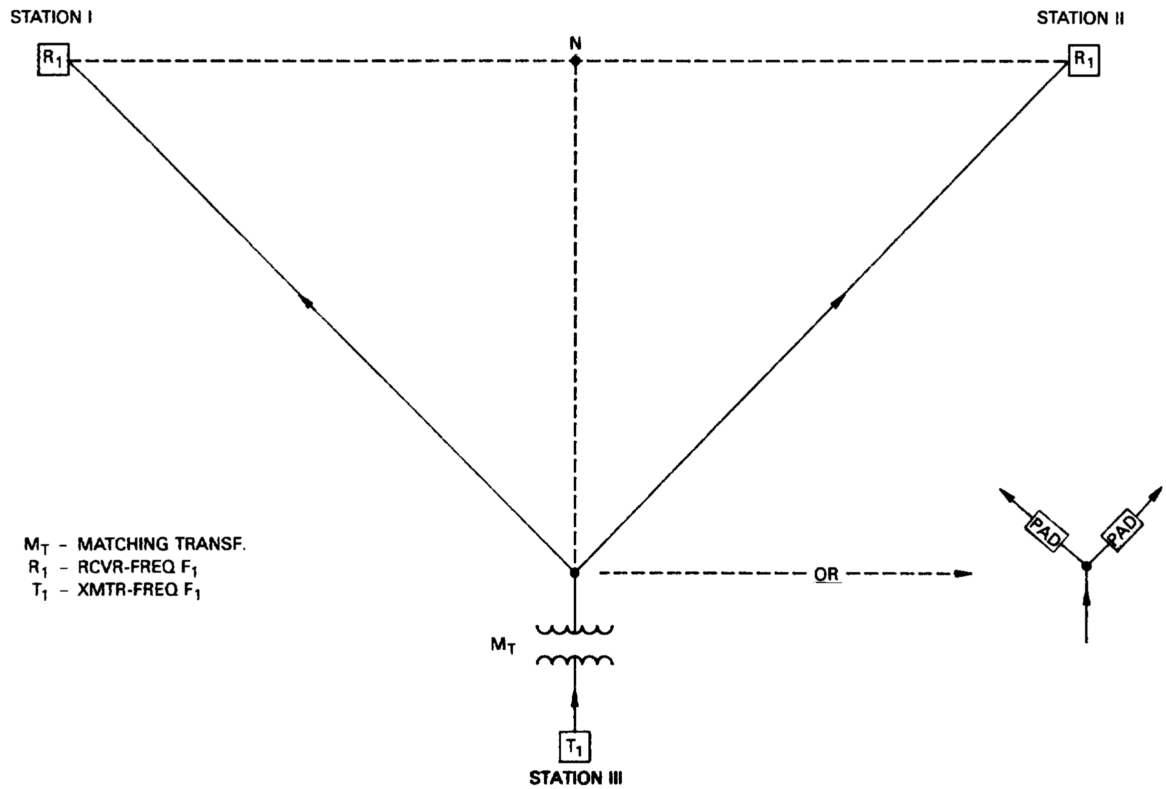

Figure 6(a) —Multistation Application One-Way Open-Delta

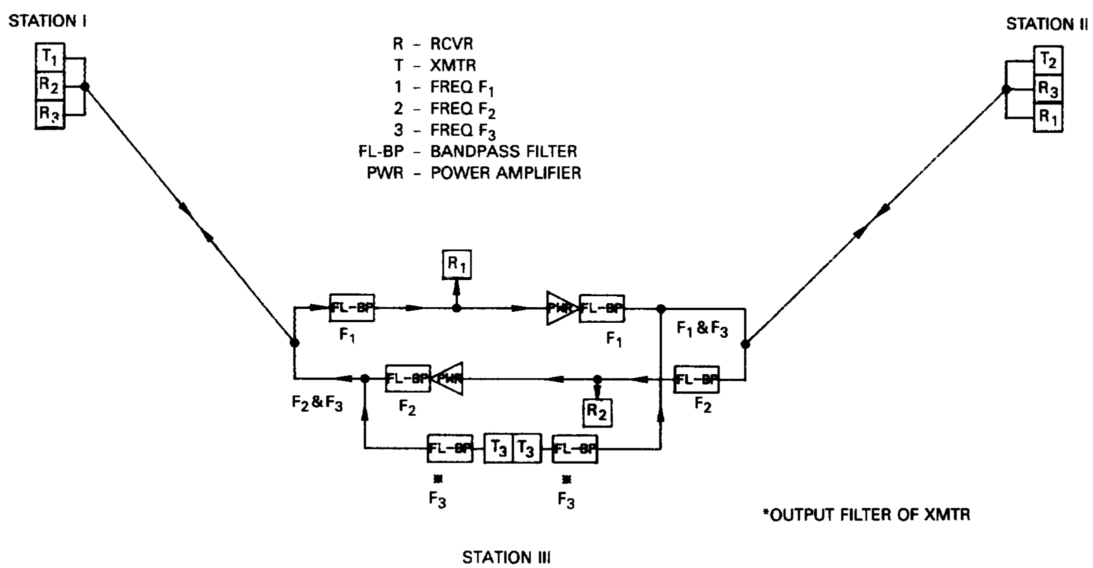

Figure 6(b) —Two-Way Two-Wire Open-Delta Path

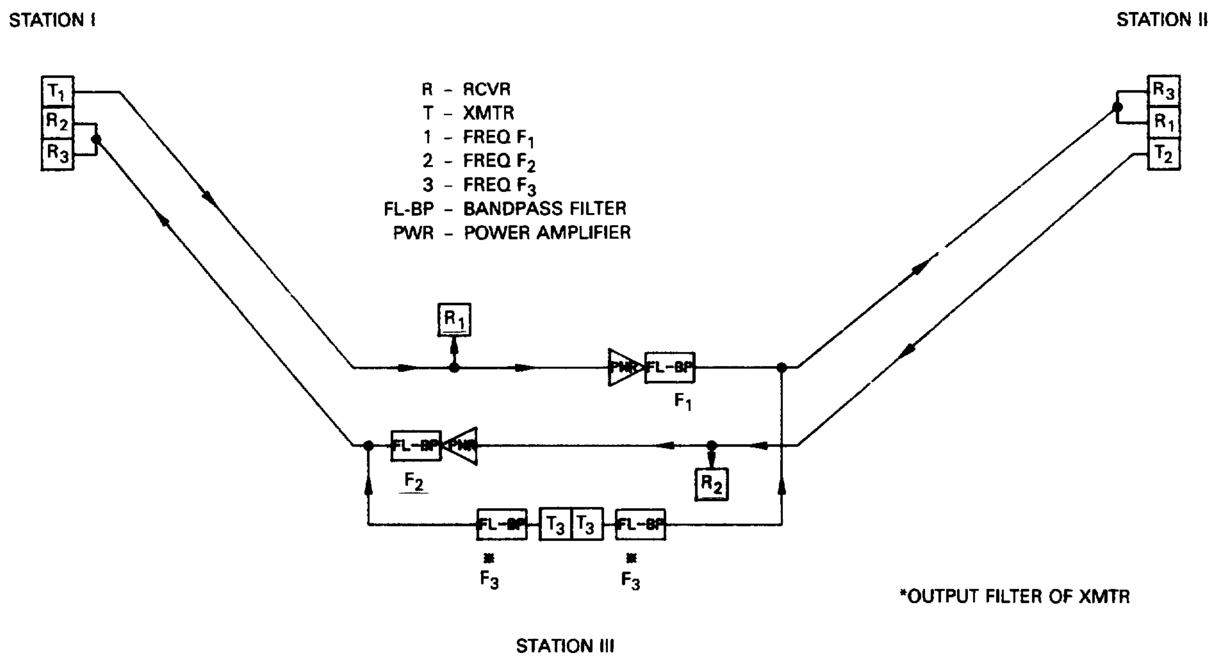

Figure 6(c) —One-Way Four-Wire Open-Delta Path

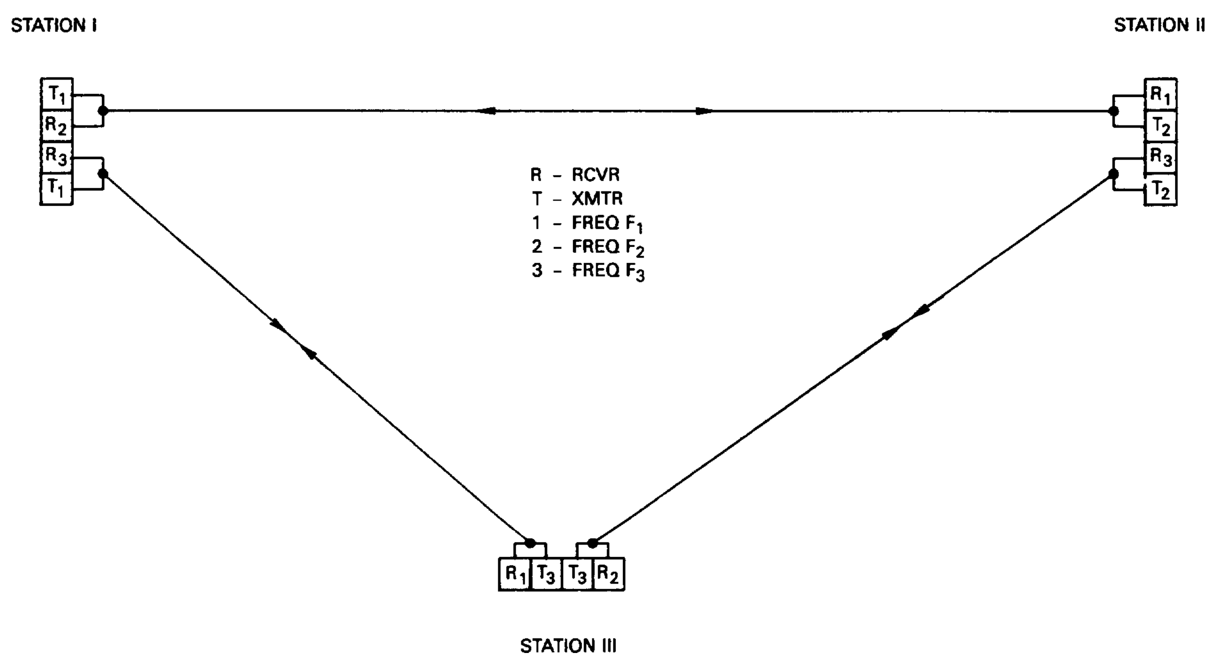

Figure 6(d) —Two-Way Two-Wire Closed-Delta Path

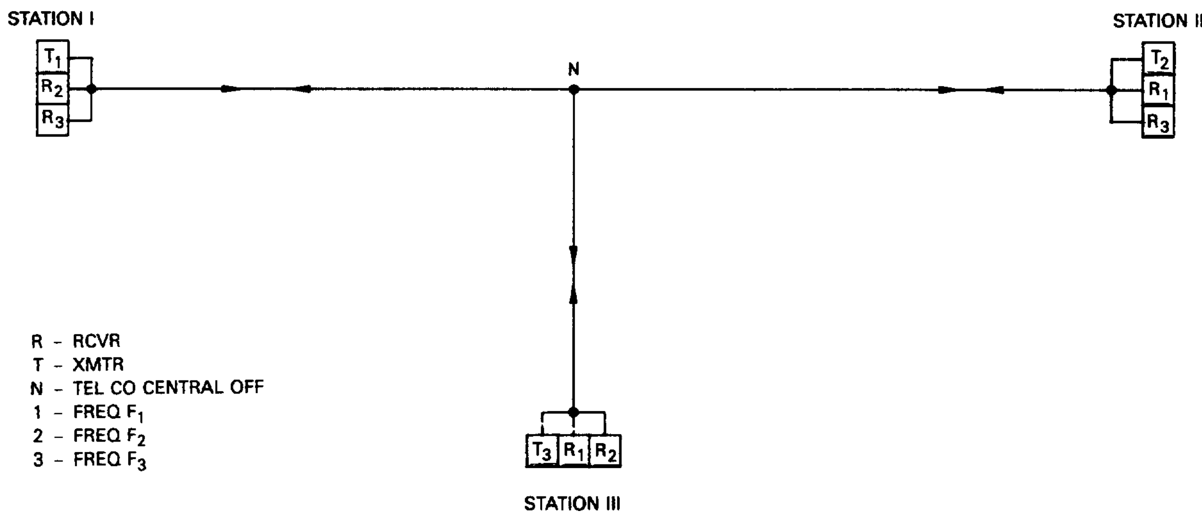

Figure 6(e) —Two-Way Two-Wire T-Path with Telephone Company Central Office

5.3.3 Physical Separation of Telephone Channels for Reliability

5.3.3.1 Separate Cables

Separate cables provide a measure of increased reliability over circuits in a single cable, since defects or repair work should not affect more than one cable at a time. However, construction equipment can damage both cables.

5.3.3.2 Separate Cables in Separate Ducts

This arrangement decreases the possibility of coincident trouble in both cables, but experience has shown that major disturbances can affect both.

5.3.3.3 Separate Routing

This routing minimizes the possibility of simultaneous physical damage to the two channels. However, in many cases, this may require special construction and additional charges at the terminal location since these are very often fed by only one cable route. Separate routing is preferred and should be obtained whenever feasible. However, the use of separate cables and separate routing does not in itself reduce the exposure to induction or the effects of ground potential rise.

5.4 Signal Transmission

5.4.1 Audio Frequency Considerations

It is essential that the range of frequencies employed for audio-tone relaying fall within the frequency capabilities of the channel to be used. The tone frequency, bandwidth, and selectivity are the variables to be specified in the application of tone equipment. In some applications, the system requirements dictate a specific choice of tone equipment while in other situations the application engineer has several alternatives.

There is a relationship among the following:

1) response time of a voice band telephone channel
2) the number of audio-tone signals possible on a voice band telephone channel
3) the selectivity of the receiver band-pass filters in terms of adjacent signal rejection
4) usable frequency spectrum of a voice band telephone channel.

The local telephone company should be consulted on the use of all frequencies so that restricted frequencies, such as those used when remote loop back testing is employed, are not selected.

5.4.2 Audio-Tone Signal Spacing

The spacing of individual tone signals in the permissible frequency band of a telephone channel will be governed by several factors. Included in these are the bandwidth of the signal and desired attenuation of adjacent band signals. When high speed operation is required, the channel bandwidth must be greater than that required for slower speed operation. This bandwidth and signal spacing will limit the number of similar tone signals that may be assigned to a given telephone channel.

The separation between any two signals utilizing a common telephone channel should consider the steepness of the skirts of the filter characteristic because the operating frequencies of one signal must be attenuated sufficiently to prevent interference with the operating frequencies of the adjacent signal. The wide bandwidth necessary for high-speed operation limits the lowest usable frequency to about 1000 Hz. This in turn limits the number of high-speed channels. The manufacturer of such equipment will recommend the channel spacing for a particular application.

5.4.3 Telephone Channel Maintenance

In the interest of good operating practice, it is imperative that the power and telephone companies agree at the time the circuit is installed as to the procedure to be followed in obtaining clearance for any subsequent channel testing by the telephone company. In general, maintenance tests on private line telephone channels are performed by telephone companies only after receiving a customer trouble report. When telephone channel maintenance testing is being performed, test signals will be placed on the lines.

5.4.4 Maximum Usable Circuit Attenuation (Operating Range)

The operating range of tone equipment is a statement of the communication circuit attenuation in decibels, through which the equipment can function satisfactorily. The maximum usable circuit attenuation is the difference between the level of the applied power permitted on the telephone line and the maximum sensitivity of the receiver, taking noise conditions into consideration.

Operation with maximum permissible signal attenuation does not provide any insurance against the possibility of increases in circuit attenuation that can occur in most systems. For example, a tone receiver designed for a maximum sensitivity of -35 dBm can operate through a 27 dB loss communication circuit where the tone transmitter can deliver a -8 dBm signal to the customer-telephone company interface. Maximum range of the tone equipment is thus 27 dB.

Conservative system design does not allow for normal operation through maximum attenuation but through a value several decibels lower in order to have some signal in reserve when circuit attenuation becomes abnormal for any reason. Generally, it is advisable to place a limit on the normal attenuation of the transmission channel at approximately 6–10 dB less than the permissible maximum value. The recommended way of deciding how much signal margin is needed is to determine the maximum increase in attenuation likely to be experienced and to adopt this figure as the amount of signal margin.

An example is included in the Annex to clarify this matter of signal level, signal margin, and receiver sensitivity.

5.4.5 Receiver Sensitivity

Maximum receiver sensitivity is the minimum tone level at which any increase in that level causes no appreciable increase in or change of state of the receiver output. Its value is in dBm and typically is measured at the input to the receiver system. Most audio-tone receivers can be adjusted to receive signal levels down to –40 dBm. If the receiver is adjusted for maximum sensitivity, local transmitter inter-modulation products may cause interference by falling within the receiver bandpass. This condition would normally occur when two or more transmitters are paralleled. Another factor that governs the receiver sensitivity setting is the security of the channel against undesired blocking or tripping from noise.

Typical nominal receiver signal levels are –20 dBm. However, specific levels are dependent upon the frequencies used and should take into account the channel loss and attenuation distortion specifications given in Table 1. Channel losses less than those given in Table 1 may be negotiated with the telephone company, but may require special engineering and additional charges.

5.5 Operating Time of Relay Systems

5.5.1 General

One of the main objectives of protective relaying is to provide simultaneous high-speed tripping at all terminals for equipment and line faults. In order to achieve this objective, the speed of operation must be made as fast as possible, consistent with well-designed equipment and channels.

Relay system time is generally separated into two parts:

1) protective relay operating time
2) tone communication time Tone communication time includes the interval between transmitter keying by the protective relays and receiver output. The primary sources of delay in the audio-tone system are:
   a) transmitter bandpass filters
   b) propagation delay of telephone line facilities (refer to 4.3.3.3)
   c) delay of telephone terminal equipment (refer to 4.3.3.3)
   d) receiver bandpass filter
   e) discriminator (frequency-shift) or detector integrator (amplitude modulation)
   f) output relay or circuit

5.5.2 High-Speed Systems

High-speed relay communication systems are considered to have operating times of less than 20 ms. Frequency shift designs are generally used for high-speed systems. Frequency shift equipment may have a response time as fast as 4 ms, exclusive of protective relay and channel delay time.

5.5.3 Medium-Speed Systems

Other audio-tone communication systems having response time in excess of 20 ms are in service, but in view of present high-speed equipment available, it is not anticipated that they will have wide use in the future.

5.6 Noise and Noise Suppression

5.6.1 General

Noise is considered to be extraneous potentials tending to interfere with the correct and easy perception of those signals which it is desired to receive.

On telephone facilities, noise is categorized as being either of the message circuit or the impulse type, both of which are measurable and have been previously described in paragraphs 4.3.3.4, 4.3.3.5, and 4.3.3.6. The operational performance of various systems in the presence of noise is evaluated in terms of these quantities.

Due to the randomness often characteristic of noise waveforms, measurements depend, in part, upon the properties of the measuring device. Unless otherwise stated, reference to noise on telephone facilities assumes standard measuring equipment, such as AT&T Technologies 3 or 6 type sets or their equivalents.

5.6.2 Noise Terms

For applications that involve the performance of audio-tone systems or other equipment on telephone Channels, noise should be evaluated in terms of the measurable quantities specified above. Other noise terms are sometimes used in relation to communication channels and often tend to be misleading. These include the terms “circuit,” “background,” “thermal,” “random,” “white,” “static,” (“atmospherics”), and “ambient noise,” which are defined as follows:

circuit noise. In telephone practice, this is noise that is brought to the receiver electrically from a telephone system excluding noise picked up acoustically by the telephone transmitters.

background noise. The total system noise independent of the presence or absence of a signal.

thermal noise. Noise occurring in electric conductors and resistors and resulting from the random movement of free electrons contained in the conducting material. The name derives from the fact that such random motion depends on the temperature of the material. Thermal noise has a fiat power spectrum out to extremely high frequencies.

random noise. Noise that comprises transient disturbances occurring at random. The term is most frequently applied to the limiting case where the number of transient disturbances per unit time is large, so that the spectral characteristics are the same as those of thermal noise.

white noise. Either random or impulse type, that has a fiat frequency spectrum at the frequency range of interest. This type of noise is used in the evaluation of systems on a theoretical basis and is produced for testing purposes by a white noise generator. The use of the term should be limited and is not good usage in describing message circuit noise.

static noise or **atmospherics.** Interference caused by natural electric disturbances in the atmosphere, or the electromagnetic phenomena capable of causing such interference.

ambient noise. Acoustic noise existing in a room or other location.

5.6.3 Effect of Noise on Receiver Operation

Noise voltage sensitivity is the level of noise voltage, in dBm, measured at the output of the squelch receiver filter, required to disable the relaying receiver. This is the condition referred to as receiver squelched.

The receiver signal level should be well above the background or quiescent noise level, so that the receiver will be secure against operation due to strong impulse noise such as can be generated within the power station or by lightning. Noise suppression circuits or devices can be used to improve security. When these circuits or devices are used to block tripping, there is a possibility of failure to trip during power-system faults.

The received signal level should be as high as practical not only to permit reduced receiver sensitivity but also to insure that the trip signal can override the unusually high noise level generally encountered during power system faults. Sources of this noise include protective gap firing and increased metallic (transverse) 60 Hz voltage and its harmonics due to induction.

Note that power system protective relay channels have an extremely stringent problem as compared with other services, since they are needed only during the worst period of noise; further, an occasional false operation is intolerable. Although other services have operated successfully at lower received signal levels, experience indicates that –20 dBm is a good received signal level for protective relaying services. This is particularly true for direct transfer tripping systems.

5.6.4 Sources of Noise

5.6.4.1 Power System Induction

Induction from power system operation unavoidably appears on the telephone cable pair. Well balanced telephone circuits (with respect to ground), along with the proper protective devices will minimize the amount of longitudinal (common mode) voltage that is converted into metallic or wire to wire potential.

During faults, the metallic voltage could readily reach 10 V; if one wire becomes grounded, several hundred volts or more could be encountered. Some of the harmonics present in the power system inducing current are bound to fall within the passband of the tone receiver. Distortion of the induced 60 Hz voltage will increase the relative level of these harmonics. This 60 Hz distortion, which is due to the nonlinearity of the telephone channel components, may be greatly increased during the very high metallic voltage levels caused by an accidental ground. If these harmonics concentrate in the trip band, they can cause undesired tripping, while, if they concentrate in the guard band or in the squelch band, they can block a desired trip if they are of higher level than the trip signal.

If the 60 Hz metallic voltage level causes breakdown of the surge protection within the tone equipment, tripping may not be effected because the surge protection short-circuits the trip signal. This breakdown can also cause loss of guard tone, which unblocks the tone receiver; and, if filter ringing occurs, a false trip could also occur. However, if surge protectors are connected to the tone line through drainage reactors as discussed in 5.7.2.3 and shown in Fig 9(b), (c), and (d), the tone signals (either guard or trip) will not be shorted out but some arcing noise will be introduced into the line. The type and arrangement of surge protection utilized should be discussed with the telephone company.

5.6.4.2 Surge Phenomena

Surges, in addition to their destructive effects, can cause undesired tripping if they cause filter ringing at the trip frequency. This effect can be minimized by surge protectors in the tone equipment. This protector breakdown voltage should be as high as possible to minimize breakdown due to metallic voltages. The permissible level of metallic voltages will ordinarily be lower than the limiting value that the telephone system permits; accordingly, surge protection should be provided with the tone equipment in addition to whatever protection is installed by the telephone company.

5.6.4.3 Shorting, Opening, and Grounding of the Telephone Channel

Disturbances to the telephone circuit can be detrimental to relay systems. Equipment bandpass filters may be shock-excited by momentary disturbances causing generation of many frequency components. This shock excitation can be caused by the sudden change in the terminating impedance, particularly where a transmitter and receiver are paralleled, or it can be caused by the sudden introduction of an abnormally high 60 Hz voltage due to a ground on the telephone channel.

Filter ringing is not the only cause of possible undesired tripping. The high 60 Hz voltage can be distorted by the nonlinearity of telephone-pair protective components resulting in the generation of sizable harmonic voltages, which could fall predominantly in the receiver trip band.

Nonpermissive relay systems are especially prone to troubles caused by inadvertent grounding of the facility. The disturbances produced by solid and intermittent grounds can cause both the trip- and guard-frequency output relays to flutter and result n the tripping of a circuit breaker when coincident closing of the trip and guard contacts occur. Therefore, to avoid inadvertent grounds, considerable care should be exercised in the design, maintenance, and testing techniques on facilities for this type of system.

5.6.5 Signal-to-Noise Ratio Comparison Circuits

These circuits are used to compare the incoming signal level to the noise level and operate rapidly to block the receiver to prevent a false operation. The signal-to-noise ratio (SNR) circuit uses a sampling of noise from an area of the band which contains no signal, and compares that level to the signal level of the monitored channel to determine if the receiver is to be blocked. The noise monitoring area may be out-of-band such as 300 to 1000 Hz area or it may be in-band. The in-band type of SNR detectors tend to make the channel more dependable since the noise being monitored is the noise seen by the receiver and is that which may cause a false operation. On the other hand, an SNR detector which monitors out-of-band noise in the 300 to 1000 Hz area will make the channel more secure since the noise level in this area is usually higher than in the rest of the band. The out-of-band circuits are more secure since the receiver will be blocked before the in-band noise to the receiver reaches the critical level.

Either circuit will generally provide a better overall performance than the older type “squelch” circuit, which monitored the absolute level of noise in the 300 to 1000 Hz band and blocked the receiver operation based on this information alone. The in-band SNR detector will provide the best dependability with a very small sacrifice in security when compared to that of systems using out-of-band detection. However, the channel using in-band SNR detection will have to pay a small price in terms of channel time because the monitoring takes place through the same channel bandwidth as the information. Thus the trip output must be delayed to allow the SNR detector a chance to operate.

5.6.6 Balanced Circuits

In the telephone communications industry, extensive use is made of balanced transmission techniques. One of the principal purposes for the use of balanced communications circuits is to eliminate or significantly reduce the longitudinal to metallic conversion of noise. These techniques involve the use of balanced transformers, mutual drainage reactors, balanced filters, balanced equalizers, and many similar devices as well as balanced cable pairs. This latter factor is most important and involves basically the questions of capacitance and resistance unbalances that must be minimal. Just how well a communication circuit is balanced will determine its effectiveness in reducing the effects of the noise. With respect to audio-tone channels, the reduction of noise is of critical importance.

5.7 Telephone Channel and Terminal Equipment Protection

5.7.1 General

Special high-voltage protection on the serving telephone facilities is a fundamental consideration for audio-tone protective relaying channels and systems. In the presence of a hostile electrical environment, special protection is essential, not only to protect personnel and to safeguard telephone facilities and terminal equipment against damage, but also to prevent foreign voltages and currents from affecting the dependability and security of the relaying system. ANSI/IEEE Std 487-1980 [5] provides guidance for the protection of wire line communications facilities serving electric power stations.

Foreign potentials and currents can adversely affect telephone channels through inductive and capacitive coupling or as a result of ground potential rise (GPR). The major sources of extraneous potentials and currents that should be considered when designing special protection for protective relaying channels and systems are lightning, switching transients, and power system faults that produce GPR at power stations and longitudinal induction on the serving telephone facilities. ANSI/IEEE Std 367-1979 [4] provides data on the determination of foreign potentials.

5.7.2 Protection Devices

The reliability of the protective relaying channel is dependent in part on the special protection devices employed on the serving telephone facilities. If necessary protection devices are omitted, or if the devices used are inappropriate for the electrical environment, then interruptions of telecommunications signal transmission or damage to telephone facilities or terminal equipment may result. Reliability is determined largely by the proper selection and application of protective devices in a coordinated system of special protection. (See 5.7.3.) Special protection devices commonly used are briefly described in this subsection. More complete descriptions and recommendations on the engineering and design of special protection systems are contained in ANSI/IEEE Std 487-1980 [5].

5.7.2.1 Isolating Transformer

An isolating transformer is a two-winding transformer that is inserted in the telephone line between the external telephone cable and the wiring within the power station as shown in Fig 7. It is provided with high-voltage insulation between the windings and between the windings and ground so the entire GPR and induced voltage on the pair appears harmlessly across the transformer dielectric barrier. The winding(s) of an isolating transformer may be center-tapped to serve as a combined isolating and drainage transformer; see 5.7.2.3, which describes drainage reactors. However, when used in this manner, the winding so used must have suitable drainage current handling capabilities.

5.7.2.2 Neutralizing Transformer

A neutralizing transformer has a primary winding or exciting winding plus one or more pairs of secondary windings that are inserted longitudinally in the telephone channel(s) as shown in Fig 8. The primary winding is connected between the power station ground and low impedance remote ground. The GPR and induced voltage on the cable are both impressed across the primary winding and, by transformer action a nearly equal voltage is induced into the secondary windings. By virtue of the transformer connection, this voltage opposes (neutralizes) the GPR and induced voltages to prevent unsafe and damaging voltages from appearing on the telephone pair(s).

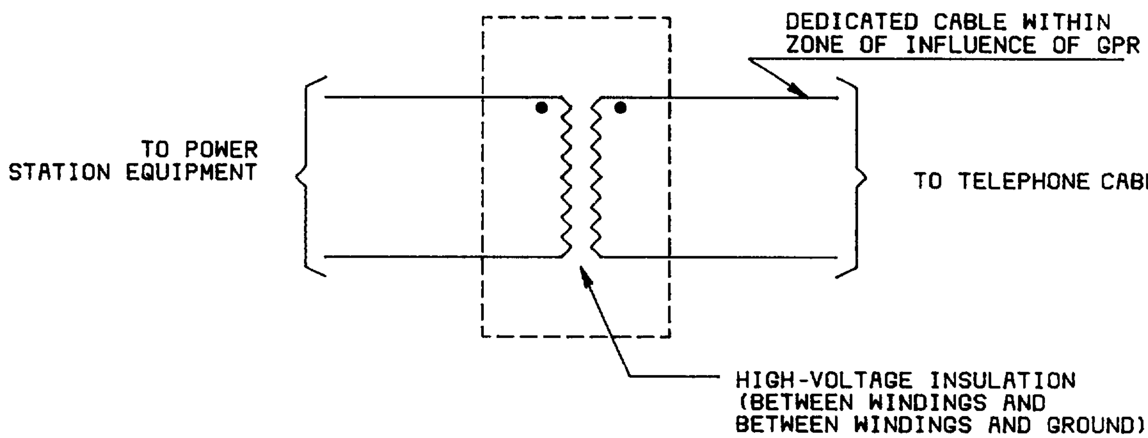

Figure 7 —Isolating Transformer

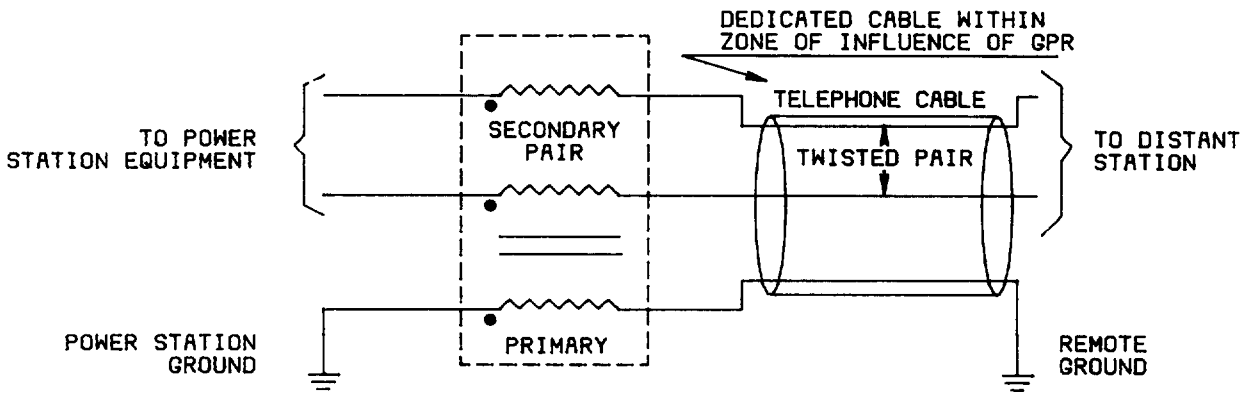

Figure 8 —Neutralizing Transformer

5.7.2.3 Drainage Reactor or Mutual Drainage Reactor

A drainage reactor is a center-tapped or two-winding coil connected across the telephone pairs shown in Fig 9. It presents a high shunt impedance to metallic signals while providing a low impedance path for draining longitudinal currents to ground. It may be connected to ground as in Fig 9(a), through a single protector to ground as in Fig 9(b), or through two protectors as shown in Fig 9(c) and 9(d), depending on which arrangement is required to control the flow of any dc sealing current that may be present. The arrangement shown in Fig 9(c) is used when carrier frequency signals are present to minimize the attenuation resulting from the stray capacitance to ground in the drainage reactor. Since any protector produces noise when it operates, direct drainage, when it can be used, is the quietest configuration. In the circuits shown, a drainage reactor couples nearly equal levels of noise from an operating protector(s) to both tip and ring conductors of the telephone pair, thereby greatly reducing the metallic circuit noise resulting from the protector operation. When used with two protectors, the drainage reactor helps to force nearly simultaneous firing of the two protectors. ANSI/IEEE Std 487-1980 [5] presents a more detailed discussion on this topic.

5.7.2.4 Protectors

Carbon block and gas tube protectors are spark gap devices that fire (arc across the gap) when the voltage on the conductor to which they are connected exceeds a design voltage. When used with drainage reactors noted in 5.7.2.3, metallic noise into the circuit from the arc discharge is minimized.

5.7.2.5 Dedicated Cable

A section of telephone cable extending from the power station to a point near the edge of the GPR zone of influence and carrying only circuits for the power station is referred to as a dedicated cable. The dedicated cable may need special dielectric strength requirements. ANSI/IEEE Std 487-1980 [5] describes such a cable.

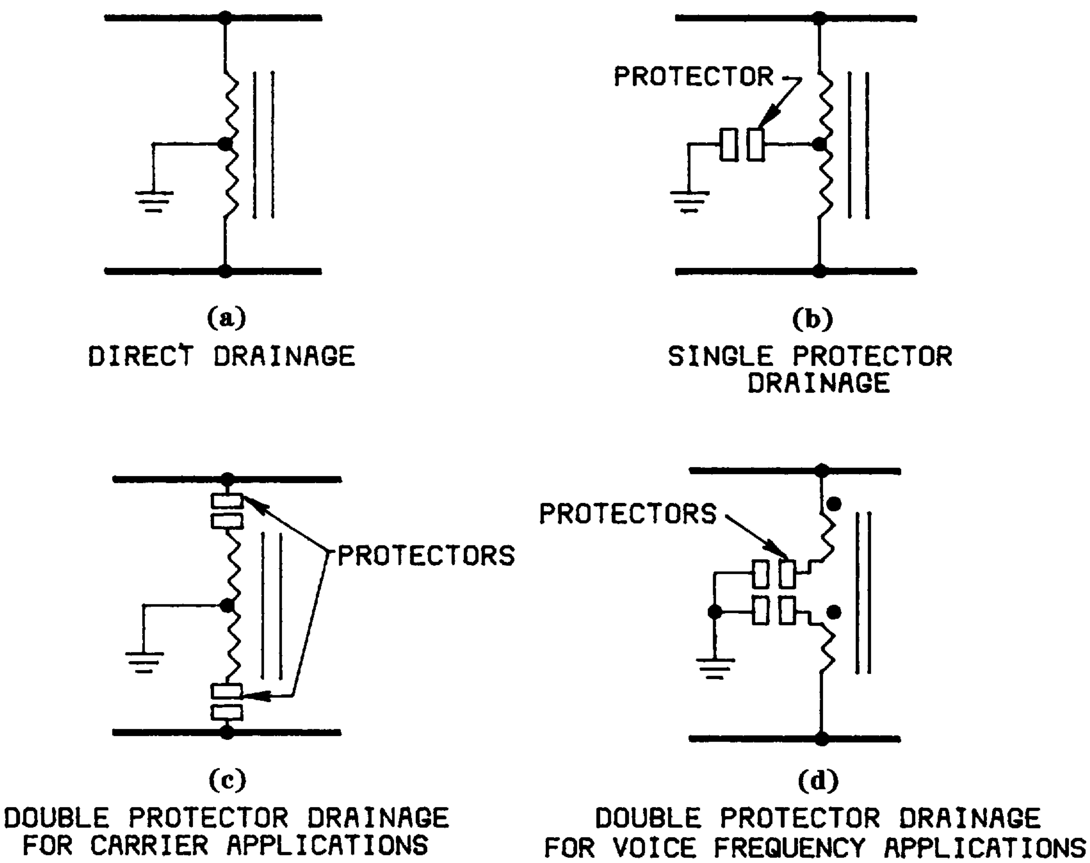

Figure 9 —Drainage Reactor

5.7.2.6 Optical Couplers

An arrangement of high dielectric optical couplers may be used to replace an isolating transformer or a neutralizing transformer. When optical couplers are used, battery supplies or noninterruptible power supplies are required on both sides of the high voltage isolation point.

5.7.3 Coordinated Protection

A fundamental concept of special protection is that of a "coordinated" system of protection. A "coordinated" system of protection is one in which special protection measures are applied to less important, interruptible telephone services as well as to critically important, noninterruptible services (for example, audio-tone protective relaying), which are provided in the same cable. This is to ensure that circuit failure or operation of noncoordinated protection on a less critical pair will not cause excessive pair-to-pair stress, which might result in failure or interruption of a critical, noninterruptible service. The protection devices used on the various services should, therefore, be coordinated with each other with respect to the electrical environment and the service performance objectives of the telecommunication services on which they are employed. The object of the coordination is to minimize the likelihood of cable failure, protector operation, failure of special protection devices, failure of terminal equipment, or other similar occurrences, which could create hazards to personnel and plant and result in interruptions or outages of critical and noncritical services alike.

6. Installation and Testing

6.1 Installation Considerations

6.1.1 Accessibility

The tone equipment should be mounted on relay racks or in cabinets readily accessible from front and back for ease of testing, inspection, and maintenance. The location of the audio-tone equipment relative to the associated protective relays should be considered to facilitate testing and maintenance and to reduce the exposure of the keying leads.

6.1.2 Environment

6.1.2.1 Ambient Temperature

Indoor installations are preferable because temperature variation can be more conveniently controlled, and maintenance in inclement weather is more readily accomplished.

Audio-tone equipment should be capable of functioning within the same temperature ranges as the equipment with which it operates as specified in ANSI/IEEE C37.90-1978 [1]. Particular attention should be given to the location of any heat generating components or nearby heat generating equipment.

6.1.2.2 Vibration

Shock and vibration have little effect on equipment employing solid-state output devices. However, sensitive electro-mechanical output relays may operate incorrectly when subjected to shock or vibration.

6.1.3 Equipment Identification

Identification of audio-tone receivers and transmitters is desirable. In order to minimize any errors in testing or blocking, the companion transmitters and receivers at all terminals should be similarly identified. For example, if trouble developed on Receiver No. 4 at station X or on the associated leased channel, instructions to block or place in the “test” position the tone equipment numbered 4 at all terminals would minimize errors.

For the same reasons, the channel facility should also be designated and identified with the tone equipment in the same relaying system. Relay communication channels should be separated from other communication channels in the station or substation to minimize electric interference and inadvertent contact. They should be adequately identified at all appearances.

Draw out modules should be keyed to prevent erroneous interchange of modules. Provision should be available for placing identification labels on both draw out module and corresponding rack position.

6.2 Testing

6.2.1 Tone Equipment Test and Monitoring Facilities

Audio-tone systems designed for relaying functions should be provided with trip cutoff switches, guard and trip lights and alarms, as well as the necessary test switches for maintenance.

Test facilities may include front panel jacks that permit measurement of the decibel output level of the transmitter, input level to the receiver and, input level to a squelch receiver, if used. Some users install voltmeters at the output of each transmitter and milliammeters in the output of each receiver and others employ a built-in test pad to simulate a given decibel signal attenuation.

For solid state equipment, card extenders or “cheater” cords should be provided for troubleshooting a card in service.

6.2.2 Facilities for Isolating and Testing Telephone Channel(s)

Double pole test switches or an equivalent disconnecting means should be installed in terminal equipment cabinets for disconnecting the telephone channel for tests by both the power company and the telephone company. Where three terminal lines are involved, a test switch should be provided in each of the two telephone channels that are bridge-tapped at one terminal.

6.2.3 In Service and Out of Service Operational Tests

In all audio-tone relay systems, the channel and to some extent the tone equipment is continuously monitored by a guard tone. However, periodic tests should be made to determine if the tone equipment remains capable of performing its relaying function.

Test switches for dual channel direct transfer trip schemes can be so arranged that in-service tests can be conducted on each channel without removing the protected equipment from service or causing a trip of those facilities.

Permissive schemes using only one channel can also be tested while the protected facilities remain in-service. However, undesired tripping of a terminal may occur if a fault to the power system occurs on any external facility during the in-service test.

In-service checkback test facilities can be provided so that a signal from the local transmitter will cause the remote receiver to key the remote transmitter when the local test switch is held in “test-position” for a few seconds. The operation of both trip and guard contacts can be checked by this method.

Local loop testing (manual or automatic) can be provided when transmitters and receivers are applied as bidirectional, use the same audio frequencies, and operate on a four-wire circuit.

6.3 Periodic Maintenance

6.3.1 Test Equipment

An oscilloscope, audio-signal generator, electronic voltmeter, and frequency counter are recommended for testing and maintenance. A digital timer is recommended for checking time of operation, particularly for higher speed equipment. A wave analyzer or frequency selective electronic voltmeter has also been found to be useful for testing and maintaining equipment.

6.3.2 Maintenance Schedule

Nearly all users make periodic maintenance checks, but some rely on signal alarms or operational tests to indicate the need for maintenance. The maintenance schedules vary from one month to two years.

Periodic maintenance should include tests on the communication channel and protection on both sides of the interface as well as the tone equipment. The periodic maintenance should include measurements of the transmit and receive levels. A comparison should be made between these levels and those recorded at the time of installation or at the time of the last alignment. If the levels measured indicate that the telephone circuit has deteriorated outside of limits in Table 1 (that is, transmit level unchanged but a different receive level), the telephone circuit should be suspected. The tone equipment should not be adjusted until corrections are made to the telephone circuit.

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Annex Example of Audio-Tone Circuit Considerations

(Informative)

Given: two frequency shift protective relay systems are to be operated on a single leased telephone channel. The two systems operate at center frequencies of 1105 and 2125 Hz with a frequency shift of ± 125 Hz and a receiver bandwidth of 500 Hz for each signal frequency. Assume that an unconditioned channel is being considered for this service.

Section 4.3.3.2 states that the 1004 Hz attenuation will be 16 dB and 4.3.3.1 states that attenuation distortion of –2 to +8 dB over the band 500–2500 Hz can be expected for unconditioned channels. It is, therefore, reasonable to assume that the channel attenuation will be approximately 16 dB at 1105 Hz and as much as 24 dB at 2125 Hz.

Since the maximum allowable composite root-mean-square input to the leased channel was given in 4.3.2.1 as 0 dBm (0 dB relative to 1 mW), we can adjust each of the two tones for half this transmitted power, or –3 dBm. The expected signal powers at the receiver are approximately –19 dBm at 1105 Hz and –27 dBm at 2125 Hz.

If the receiver has a sensitivity setting to monitor for loss of tone, a reasonable threshold adjustment for this example would be –35 dBm, providing an 8 dB margin for the 2125 Hz signal. This will provide sufficient margin for short-term and long-term variations as specified in Table 1.

Receiver designs seldom allow for sensitivities lower than –40 dBm, and it is preferable not to operate at the minimum signal input. This constraint, together with the greater high frequency attenuation variation, may limit the usage of the higher frequency protective relaying systems or the use of more than one protective relaying system on a single unconditioned telephone channel. A more reliable design may call for the use of a separate telephone channel for each relaying system or for use of a conditioned telephone channel with less attenuation variation at the higher frequencies.

The noise conditions at the receiver can be checked as follows. Assuming a maximum channel length of less than 100 mi, the expected message circuit noise is given in Table 1 as 31 dBrnC (dB relative to reference noise with C message weighting) at the receiver input. To find the amount of noise seen by a receiver detector with a 500 Hz bandwidth, we assume the noise is uniformly distributed across the voice band (approximately 3000 Hz wide) and convert as follows:

1) Expected noise input in 3000 Hz bandwidth = 31 dBrnC — from text
2) 0 dBrnC of white noise in 3000 Hz bandwidth = –88.5 dBm — defined in in 4.3.3.4
3) Noise input power in 3000 Hz bandwidth = –88.5 + 31 = –57.5 dBm
4) Bandwidth correction for flat noise = 10 log (bw2/bw1) — in dB
5) Correction from 3000 Hz to 500 Hz = 10 log (500/3000) = –7.78 dB
6) Noise input power in 500 Hz bandwidth = –57.5 dBm + (–7.78 dB) = –65.28 dBm

The –65 dBm noise n the 500 Hz detector bandwidth is negligibly low compared to the received signal powers of -19 dBm (1105 Hz signal) and –27 dBm (2125 Hz signal). However, it should be noted that the noise values given in Table 1 are expected (mean) values and not worst case and that the received signal power can be further reduced by short-term and long-term variations. In addition, it is important to realize that the noise values in Table 1 are the expected values for normal telephone circuits. It is quite possible that a particular circuit to a power station may be subjected to severe induction which may cause the total noise to be considerably greater than the values of Table 1. All of these aspects should be carefully evaluated in the over-all design.

Perhaps more critical than simple signal to noise specifications are considerations related to operation of the noise squelch. The very special security requirement of protective relaying dictates that the receiver have the capability of monitoring circuit noise so as to squelch the circuit in the presence of high noise and thus prevent false operation. Specific squelch criteria depend on the receiver design and the relative emphasis placed on dependability and security. However, an approach once fairly common in frequency-shift terminals was to monitor the noise in the 300–1000 Hz band and to set the squelch threshold to be about 15–20 dB below the received signal power. For our example, such a squelch threshold would be set at about –45 dBm (18 dB below the –27 dBm input power of the 2125 Hz signal) into the receiver's 700 Hz bandwidth detector.