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IEEE Guide for

**PROTECTIVE RELAY APPLICATIONS OF
AUDIO TONES OVER TELEPHONE CHANNELS**

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FOREWORD

Electric power systems, having outgrown simplicity a long time ago, continue to require more and better protection as the demand for power increases and the need for reliability becomes greater. Protective relaying has met this challenge by providing more sensitive, higher speed relay systems that are inherently reliable. Among the more significant protective developments that furthered the economic design of power systems are pilot relaying schemes and direct transfer tripping over telephone channels.

In recent years a growing need developed for more versatile wire-pilot relay systems and more secure means for direct transfer tripping. These factors, in addition to technological changes in telephone communication plants affecting availability of metallic telephone circuits, led to the consideration of audio-tone signals over telephone channels for these functions. Since audio tones had already been employed extensively for less demanding applications—telemetry, telegraphy, dial signaling, etc.—it appeared logical that audio tones could also be employed successfully for remote tripping of circuit breakers and wire-pilot relaying.

The logic of the thinking was sound but all the important application problems were not recognized at the outset. During the past few years, those active in supplying and applying relaying tone equipment have recognized the special problems involved and have largely resolved them. In general, application of tones for telemetry, telegraphy, and dial-pulse signaling is simpler than for relaying. The big differences are the need for higher reliability and for greater immunity to noise voltages, both random and impulse types. An occasional extraneous pulse in a telemetry or teletype circuit generally is not unexpected and not considered to be a serious occurrence. In a relaying tone circuit, receiver response to a noise-generated signal can cause the undesired tripping of a circuit breaker.

The most satisfactory relaying tone equipment is equipment especially designed for relaying applications. It is not impossible to design tone equipment for reasonably satisfactory service in all application areas but this generally is not done because design objectives for relaying and for general applications are not the same. An all-purpose design, if it truly satisfies the needs, is almost always more costly.

Satisfactory tone equipment does not alone insure satisfactory service. Proper application and correct installation and adjustment are also obviously necessary. Reliable suppliers of relaying tone equipment and those responsible for the telephone channels should be consulted to assure that all phases of an installation are satisfactory.

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PROTECTIVE RELAY APPLICATIONS OF AUDIO TONES OVER TELEPHONE CHANNELS

1. SCOPE

1.1. This Guide contains information and recommendations for applying audio-tone communication over telephone channels for power-system relaying. It is intended to cover applications to both leased and private telephone systems but not applications to private microwave or carrier channels. 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 the users. Pertinent information previously published is also included.

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 and/or telephone company(s) and a purchaser of a given relaying system.

2. PURPOSE

2.1. The primary purpose of correlating this information and experience is to guide the power-system user in applying, installing, and operating audio-tone protection systems, including considerations for the telephone-channel facility. In doing so, it will also provide a reference for the manufacturers and telephone personnel engaged in design and application of equipment and facilities. 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. As in the majority of communication systems, the receiving device deserves and gets the most attention. It must essentially make decisions regarding the nature of the input signal and cause a corresponding output response. The ability of a receiver to respond to the basic signals for which it was designed under ideal conditions will be accepted as an established fact since the purpose here is not to discuss how to design. The "what to design" is the more difficult consideration.

3.1.2. Extremely high on the list of desirable system properties is never to have a false trip. This requirement is in contrast to other tone systems wherein a probability

of error is a design criterion. Here we want absolutely no false operation under any and all operating conditions. A trip signal should provide satisfactory operation down to a short-term signal-to-message circuit noise (steady-state) ratio of zero decibel over the voice-frequency bandwidth.

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

- (a) operation time of generally not over 15 milliseconds. This includes tone-transmitter operation time (after being keyed), tone-receiver response time, and operate time of an output device capable of closing a 30-ampere 250-volt direct-current circuit. This does not include channel propagation time, which may vary from a few milliseconds to over 10 milliseconds. Accordingly, in writing audio-tone terminal equipment specifications, the user should exclude telephone circuit time when specifying required speed, since this time is not under the control of the tone-equipment manufacturer,
- (b) high dependability,
- (c) no false operations for conditions such as
 - (1) steady-state noise equal in magnitude to the signal over the voice-frequency bandwidth,
 - (2) failure of the monitoring signal,
 - (3) intermittent shorting, opening, or grounding of the communication circuit,
 - (4) complete interruption of the communication circuit,
 - (5) crosstalk from an adjacent circuit,
 - (6) inadvertent application of test signals normally encountered in telephone-channel testing,
 - (7) power-system disturbances,
 - (8) removal and application of power supply,
 - (9) multiplex or carrier frequency translations.

This short list of severe operating requirements spells out conditions peculiar to relaying. Unless these situations are known before the receiver design is initiated, it is safe to state that the result will not satisfy the need.

3.2. Basic Types of Equipment

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, insofar as is possible, on a continuous basis with an alarm to indicate below-minimum performance.

Each type of equipment has both advantages and disadvantages.

3.2.2. Frequency Shift. A signal is always present under normal conditions on one of two possible frequencies, guard or trip. Frequency-shift equipment is nearly completely self-monitoring since the same components generate, amplify, and receive both frequencies.

3.2.3. ON-OFF. As applied to relaying which is a two-state situation, trip or no-trip, the application would be no-tone for nontrip and tone-on for trip. A separate, normally ON signal (guard tone) must be employed for monitoring and the system can be arranged to trip on loss of guard and presence of the trip signal.

ON-OFF equipment is not inherently self-monitoring because many components are inactive in their OFF state. If the scheme utilizes more than one tone signal, the circuit can be designed for periodic in-service testing.

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.

While not yet proved under power-system conditions, coded-pulse equipment appears to offer great security against false operation due to interference. Coded-pulse systems require greater channel bandwidths than the basic frequency-shift or ON-OFF systems. This factor must be considered in view of the frequency range of the telephone channel and the overall function of the equipment.

3.3. Solid-State Versus Tube Equipment

3.3.1. Solid-state circuitry is best suited for tone equipment, primarily because the levels of energy to be generated, amplified, transmitted, detected, and switched are low. They are in the range that can be handled easily with currently available low-cost solid-state devices. The most important differences between solid-state and tube equipment is in power requirements and heat generated; both favor the solid-state equipment. However, some of the advantages may be lost if solid-state equipment must be operated on 125- or 250-volt station batteries. Some other advantages of solid-state circuitry are

- (a) less space required,
- (b) lower operating voltage,
- (c) availability of modular construction,
- (d) long life,
- (e) minimum need for preventive maintenance.

3.3.2. In the design and application of equipment having solid-state components, consideration must be given to the effect of surge phenomena originating in the external communication, power, and control circuits.

3.4. Power Supplies

3.4.1. General. Solid-state audio-tone equipment operates at voltages below 48 volts 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 within 10 percent of the nominal voltage to assure performance of the tone equipment within its specified limits. These supplies operate from standard power-station sources: 120 volts alternating current, 24, 48, 125, and 250 volts direct current. In applying solid-state equipment care should be taken to insure that the battery-equalizing voltage does not exceed the ratings of the equipment.

3.4.2. 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. Vacuum-tube equipment will normally require some dropping resistors for filament circuits while plate circuits employ tubes designed for the station battery voltage.

The use of a tapped station battery with separate chargers and proportionally rated cells eliminates the power-wasting and heat-generating dropping resistors.

A direct-current to direct-current inverter is another method used to supply low-voltage equipments from station batteries.

3.4.3. Separate Battery Source. For solid-state equipment there are substantial advantages to separate battery sources. Since this equipment operates below 48 volts, a suitable voltage supply eliminates the need for power-wasting resistors. This method of supply has the additional advantage of being independent of the station battery source, thus minimizing exposure to surge phenomena originating in the station battery circuits.

3.4.4. Alternating-Current Source. Sources of alternating-current power affected by faults on the power-system equipment being protected are unsatisfactory except under special circumstances. *B* supply storage facilities may be incorporated in the equipment to provide operating energy during the fault-clearing period. In vacuum-tube equipment, the heaters and cathodes of the tubes must have sufficient thermal capacity to provide adequate electronic emission for the time required to clear faults.

3.5. Equipment Protection From Surge Phenomena

3.5.1. The manufacturer of the terminal equipment should include all necessary components for suppression of surges in the power-supply and output circuits. Such components should be provided to reduce the effect of surges in the signal channels and should include those necessary to prevent damage to components, especially to solid-state components. Suitable surge-reducing components should be

applied for the communications channel and to the power-supply connections. Such surge-isolation and protective equipment should be coordinated with that of the communications facilities.

Unusual surge conditions should be eliminated at the source as it is not feasible to provide standard surge protection for extreme conditions.

3.6. Noise-Suppression Circuits or Devices

3.6.1. General. Most commercial equipment contains circuits to sort the incoming signals and yield the desired output. Thus, protection is provided against false operation from spurious frequencies or noise.

3.6.2. Circuit Arrangement. 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 sine wave only were to appear on the trip frequency or frequencies under these conditions, protection is not possible for this constitutes a valid trip signal. The only option here would be to employ a coded tone signal, excepting that the time-bandwidth considerations may not permit this amount of information to be transmitted.

3.6.3. Noise Presence. The presence of noise offers a degree of information that can be used to block the receiver if desired. Two approaches are evident.

- (a) A filter can be used to detect broad-band noise and, through suitable amplification, can be used to prevent receiver operation. The noise filter must have a sufficiently wide passband (wider than the receive 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 must fit into the spectrum of the system at a point not utilized for information transfer.
- (b) If the noise to be protected against is not broad band or the frequency spectrum for a noise filter is not available, some means must be found to operate successfully with the information available through the receive filter. This may be accomplished through the use of an unsymmetrical discriminator. The guard signal passband is made wider than that of the trip. Thus noise across the spectrum of the receive filter will provide more energy to the guard side. Noise levels that exceed the receiver threshold will tend to cause the guard side of the receiver to pick up first, since the guard side receives more energy and has a faster response time due to the wider passband.

3.6.4. Loss-of-Tone Monitoring. A loss-of-tone squelch feature improves the security of the tone receiver 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. The circuits are normally arranged to restore the tripping circuit only after the reception of a valid guard signal.

3.6.5. 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.

3.6.6. 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.

3.7. Frequency Translation Protection

3.7.1. 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.

4. LEASED TELEPHONE CHANNELS

4.1. Introduction

4.1.1. Telephone channels as referred to in this Guide are electric paths that interconnect two or more locations for the purpose of transmitting electric signals from one place to another. The term "circuit" as used in this Guide denotes the telephone channel as well as the terminal audio-tone and relay equipment.

It is quite important to note that the characteristics described in this section are for widely available, typical telephone channels. Such channels could include multipaired cable from the end telephone central office to the customer's location, and various types of wire line, cable, coaxial cable, and microwave radio carrier facilities for interoffice transmission. Combinations of the various methods will frequently be encountered, the method in a particular instance being determined by available facilities, transmission requirements, and economies involved.

A point of confusion that sometimes arises is the difference in channel characteristics between point-to-point microwave systems and the typical, widely available telephone channels described in the previous paragraph. There are definite differences, of course, in channel bandwidth, flatness, delay distortion, and signal levels. This Guide discusses only typical telephone channels and does not concern itself with point-to-point microwave characteristics. If properly engineered and maintained, most critical

services will function entirely satisfactorily on typical telephone channels. However, if the number of services and resulting system economies and/or unusual technical considerations dictate point-to-point microwave, such services can also be provided by the telephone companies or, in some instances, the preference may be to provide them on a private basis.

4.2. Need for Joint Discussions

4.2.1. When leased telephone channels are contemplated for highly critical audio-tone services, such as protective-relaying applications, it is important that a joint conference be arranged 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 a conference should include responsible engineering representatives from the equipment manufacturer, the telephone company, and the user. The discussion should include the following items:

- (a) terminal-equipment operation (including a description),
- (b) protection requirements (including possible hazardous voltages),
- (c) reliability requirements (including the possibility of dual channels),
- (d) telephone-channel characteristics (such as covered in Section 4.3),
- (e) testing and maintenance arrangements (including special service maintenance bureaus concept),
- (f) equipment compatibility,
- (g) tariff offerings.

This may not be an all-inclusive list but represents items that must be mutually understood to assure successful operation.

4.3. Transmission Characteristics of Telephone Channels

4.3.1. Voice-Frequency Channel Offerings. Channels will normally be easier to provide and maintain as well as be less expensive if the user selects audio-tone systems compatible with available standard offerings so that additional specialized treatment of channels is not required. The transmission objectives of several grades of interstate voice-frequency private line data channel offerings are given in Table 1.*

* Interstate channels are those which cross State boundaries and have tariffs regulated by the United States Federal Communications Commission. They have been chosen for descriptive purposes since the specifications pertain to any sector of the United States whenever interstate operation is involved. In addition, these specifications are representative of *intrastate* channels where similar offerings are generally available, although the precise specification for a particular State may vary slightly from those given in Table 1.

It should also be noted that Table 1 is specifically concerned with the description of data-communication channel tariff offerings. These are precisely the types of channels used for protective-relaying applications; however, certain of the parameters given in Table 1 pertaining to data communications may not be of concern in a particular type of relaying system.

It is anticipated that the requirements of most of the common audio-tone systems will be met by one or more of these offerings. If wider bandwidths or special engineering considerations are required, these should be fully discussed with the telephone company and can be provided on a custom-engineered basis.

Where a number of channels are required between points, consideration should be given to one of the broadband channel offerings that may be leased from many of the telephone companies. The terminal channelizing equipment in such instances is provided by the company.

4.3.2. Basic Interface Requirements. The basic interface requirements for a telephone channel are quite simple. The terminal equipment should have a balanced 600-ohm termination and a maximum composite root-mean-square signal level of 0 decibel referred to one milliwatt. In addition, the typical telephone channel will have a nominal 1000-hertz loss of 16 decibels from the transmitter interface to the receiver interface. These basic interface requirements are straightforward; however, oversimplification sometimes results in their misuse. In order to insure proper system operation it is necessary to understand the detailed description given in paragraphs 4.3.3–4.3.6.

4.3.3. Signal Input Requirements. The maximum allowable composite signal input is 0 decibel referred to one milliwatt for a leased private-line voice-bandwidth telephone channel. This value offers certain obvious administrative and maintenance advantages. Whenever inter-office common carrier facilities are involved the signal will be padded down by the telephone company to be compatible with complex interference requirements where these facilities may be simultaneously handling many diverse types of voice, data, and special services.

If the audio-tone terminal equipment has less than 0-decibel-referred-to-one-milliwatt output capability or if a lower level is decided on for some other reason, the telephone company will provide any required padding to coordinate with the carrier facility limits. However, once a particular level has been agreed on for a given application, it is imperative that the signal not be adjusted to exceed this level at some future time.

4.3.4. Channel Attenuation Characteristics. The typical channel 1000-hertz loss is nominally 16 decibels as previously stated. However, it is important to realize that the channel will have a considerable amount of variation from this 1000-hertz loss as a function of frequency, primarily due to the channel filter characteristics, mismatch reflections, and the loss versus frequency characteristics of the cable used to provide service to the customer's location.

For a standard unconditioned 3002 channel this loss will typically vary -3 to $+12$ decibels from the 1000-hertz loss over the band 300–3000 hertz. Many types of services will only be concerned with the 500–2500-hertz band