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IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee



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Sponsor

**Power Systems Relaying Committee
of the
IEEE Power Engineering Society**

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Abstract: Guidelines for applying audio tones over voice grade channels for power system relaying are provided in this document, including transmitting and receiving equipment, leased voice grade channels, application principles, installation, and testing. The primary purpose of this document is to guide the power system user in applying, installing, and operating audio-tone protective relaying systems over voice grade 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.

Keywords: audio tone, dependability, frequency shift keying, power system, protective relaying, security, telephone circuits, teleprotection, voice grade channels

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Introduction

(This introduction is not part of IEEE Std C37.93-2004, IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels.)

This guide, which was last revised in 1987, 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, IEEE Std C37.93-2004, 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.

IEEE Std C37.93-2004 includes more information on utility-owned telecommunications equipment than the previous revision. More multiplexing equipment is being used by the utilities for digital transmission over fiber and microwave. This revision has more detailed information regarding these types of systems. Noise characteristics of digital systems are different from analog, and their effect is covered in this revision.

This guide 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. Clauses have been revised to be consistent with current telephone company practices, and the subclause concerning periodic maintenance has been expanded.

Acknowledgments

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Participants

At the time this guide was completed, the Audio Tone Guide Working Group had the following membership:

William Higinbotham, *Chair*
Jerry Hohn, *Vice Chair*

Doug Dawson
Kenneth Fodero
Jeff Gilbert

John Horwath
Chris Huntley
Tim Phillippe
Roger Ray

Mark Simon
Veseun Skendzic
D. Wardlow

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman
Steve Alexanderson
George Bartok
Kenneth Behrendt
Stuart Bouchey
Gustavo Brunello
Terry Burns
Ronald Daubert
Paul Drum
Gary Engmann
Kenneth Fodero
William Higinbotham

Jerry Hohn
Edward Horgan, Jr.
James D. Huddleston, III
Chris Huntley
James Ingleson
David Jackson
Joseph L. Koepfinger
William Lowe
Gregory Luri
Jesus Martinez
Jeff McElray
Gary Michel
Brian Mugalian

Anthony Napikoski
Roger Ray
Charles Rogers
James Ruggieri
Mohindar S. Sachdev
Tony Seegers
Mark Simon
James Teague
John T. Tengdin
Demetrios Tziouvaras
Philip Winston
Zhenxue Xu

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IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels

1. Overview

1.1 Scope

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

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 figures in 4.3 are used for illustrative purposes only and do not represent the preferred protection under all conditions.

1.2 Purpose

The primary purpose of this document is to guide the power system user in applying, installing, and operating audio-tone protective relaying systems over voice grade 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.

2. References

This guide shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

IEEE Std 367TM-1996 (Reaff 2002), IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.^{1,2}

IEEE Std 487TM-2000, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations.

IEEE Std C37.90TM-1989 (Reaff 1994), IEEE Standard Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.1TM-2002, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.2TM-1995 (Reaff 2001), IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

3. Transmitting and receiving equipment

3.1 Relaying requirements

3.1.1 Receiver response

Receiver response is 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 voice-grade audio channels particularly during power system disturbances

3.1.2 Security/dependability/speed

The three characteristics—security, dependability, and speed—comprise the core requirements of any teleprotection system. Security, the assurance that false tripping will not occur, can be highly desired in some applications. In applications like direct transfer tripping, false trips can have disastrous effects. Other applications, like unblocking, favor dependability, the assurance that valid tripping will occur, because the effect of missing a trip is more serious. Speed, or trip time, can be the ultimate requirement in other applications. Each application must be examined because it is difficult, or often impossible, to improve security, dependability, or speed without adversely affecting the other characteristics.

3.1.3 General requirements

Equipment designed for relaying functions and for use with available types of voice-grade audio communication circuits should meet the following requirements:

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 voice-grade audio channel delay time, which may vary from a few milliseconds to more than 10 ms. Accordingly, in writing audio-tone terminal equipment specifications, the user should exclude voice grade-audio channel delay time when specifying required speed, since this time is not under the control of the tone equipment manufacturer.

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The highest possible security for the following conditions should be considered:

- 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) Crosstalk 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

The 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 (SNR) 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 50–100 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 frequency shift or ON-OFF modulation for 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 voice-grade audio 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 bandwidth of the channel is dependent on the channel time required and the keying rate (frequency of keying between phases).

3.2.6 Advanced modulation techniques

The advancement in audio data communications techniques has resulted a wide range of new modulation techniques. The modulation includes phase and amplitude variations to produce a constellation of points that are interpreted as data by the receiver. These techniques are based on sending a serial digital data stream over an audio link. Data rates vary from 2400–56 000 bits/s. The teleprotection equipment uses this data stream to send coded messages with the required trip information. The teleprotection equipment adds security to this stream by using some form of error detection. These modulation techniques provide the ability to get a reasonable amount of data over a relatively good channel. They typically require a higher SNR than any of the other techniques. A simple relationship exists that as data rate increases, a higher quality channel is required. Typically, security is not much of a concern with these types of systems since the data is encoded. Dependability at higher data rates can be a major challenge as fault induced noise can easily impair the channel.

3.3 Power supplies

3.3.1 General

Power supply requirements are covered by the IEEE environmental standards IEEE Std C37.90-1989,³ IEEE Std C37.90.1-2002, and IEEE Std C37.90.2-1995. High-power supply efficiency minimizes station battery loading and heating of the surrounding environment. At least one alarm output contact to signal out-of-tolerance voltage should be provided and monitored. Other power supply problems may activate the voltage alarm output or separate alarm outputs. Alarm contacts that are Form C may simplify connecting alarms to SCADA and other devices, but common practice is to monitor a normally closed contact of an alarm relay that is energized for normal conditions and de-energized for alarm conditions.

3.3.2 Alternating current source

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

3.3.3 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 subclause must apply.

3.4 Equipment protection from surge phenomena

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

³Information on references can be found in Clause 2.

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 SWC tests, IEEE Std C37.90.1-2002.

3.4.1 Noise suppression circuits or devices

3.4.1.1 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.

3.4.1.2 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.

3.4.1.3 Noise presence

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

A filter can be used to detect broadband noise that, through suitable amplification, can be used to prevent receiver operation. The noise filter should have a sufficiently wide pass band (wider than the receiver filter) so that the response time of this 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 will fit into the spectrum of the system at a point not utilized for information transfer. If the noise to be protected against is not broadband 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.

3.4.1.4 SNR comparison circuits

SNR comparison 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.

3.4.1.5 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.

3.5 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

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 band-pass filter. The pilot tone is

selected to fall within the *notch* or rejection band of the noise squelch receiver. Should the voice-grade audio 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. 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. Voice grade channels

4.1 Introduction

Voice grade channels as referred to in this guide are dedicated 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 of approximately 300–3000 Hz, are transported over a variety of media including paired wire, multipaired cable, coaxial cable, microwave radio, and optical fibers. These signals may be transmitted from one location to another entirely as voice frequency signals or be converted to allow transmission on analog or digital carrier systems. Combinations of various transmission media and transmission systems are frequently employed by telecommunications providers so that demand for telecommunication services is met in the most cost-effective manner.

The reliability of voice grade channels during power system faults is classified according to service performance objectives (SPO). These objectives, with respect to the effects of power system faults, fall into the following three classifications:

- 1) Class A—Noninterruptible service performance (must function before, during, and after the power fault condition)
- 2) Class B—Self-restoring interruptible service performance (must function before and after the power fault condition)
- 3) Class C—Interruptible service performance (can tolerate a station visit to restore service)

IEEE Std 487-2000 presents a more detailed discussion of this topic.

Channel characteristics described in this subclause are for two types of voice grade channels:

- a) Typical available voice grade channels, either nonconditioned or conditioned, which can be used for a variety of utility applications, including protective relaying.
- b) A voice grade channel specifically designed for protective relaying applications may be available. This channel designation provides increased reliability for protective relaying schemes through improved signal-to-noise performance in that portion of the telecommunications circuit between the power station and the telecommunications service provider's central office.

4.2 Need for joint discussions

When the use of voice grade channels are contemplated for protective relaying applications, discussions among engineering representatives from the telecommunications service provider and the power utility, and where appropriate, the audio-tone equipment manufacturer or supplier should be held. This will insure that those involved in the project have a clear understanding of the system requirements and have ample opportunity to work out any problems prior to initiation of service. The discussion should include the following items:

- a) Audio-tone terminal equipment operation and performance
- b) Special high-voltage protection requirements at the power station(s) and any other protection requirements throughout the length of the channel

- c) Reliability requirements, including the possibility of dual alternate routed channels
- d) Voice-grade channel characteristics
- e) Channel testing procedure used by the telecommunications service provider and the power utility
- f) Audio-tone equipment and channel compatibility
- g) Tariff offerings and requirements
- h) Central office termination markings, including joint inspections
- i) Power requirements for the telecommunications service provider's network channel terminating equipment
- j) Use of sealing current (a circulation of approximately 1 mA of dc current) by the telecommunications service provider 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 voice grade channels

4.3.1 Voice-band offerings

Table 1⁴ gives typical interface requirements and transmission characteristics for two leased voice-band voice grade 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.

⁴Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the guide.

Table 1—Typical interface requirements and transmission characteristics for leased voice-band voice grade 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 (See Note 1) 0dBm
(2)	Impedance of terminal equipment	600 Ω $\pm$ 10% resistive, balanced	600 Ω $\pm$ 10% resistive, balanced
(3)	Received signal power of 1004 Hz test tone (at installation)	−16 dBm $\pm$ 1 dB	−16 dBm $\pm$ 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 (See Note 3)	500–2800 Hz, −1 to +3 dB 300–3000 Hz, −2 to +6 dB
(2)	1004 Hz loss at installation	16 dBm $\pm$ 1 dB	16 dBm $\pm$ 1 dB
(3)	1004 Hz short-term loss variation	< $\pm$ 3 dB	< $\pm$ 3 dB
(4)	1004 Hz long-term loss variation	< $\pm$ 4 dB	< $\pm$ 4 dB
(5)	Envelope delay distortion	< 1750 ms, 800–2600 Hz (See Note 3)	< 2000 ms, 800–2600 Hz
(6)	C-notched noise-SNR with 1004 Hz test tone	24 dB minimum	24 dB minimum
(7)	C-message noise	(See Note 2)	(See Note 2)
(8)	Impulse noise-threshold with respect to received 1004 Hz test tone −6 dB −2 dB +2 dB	Maximum count above threshold allowed in 15 min 15 9 5	Maximum count above threshold allowed in 15 min 15 9 5
(9)	Local channel resistance unbalance	Not specified	Maximum 1% unbalance
(10)	Special channel design	None	Gain and loss devices placed to maximize SNR during fault conditions; receiving amplifiers not used at power station; enhanced trip signal power levels permitted.

NOTES to Table 1

1—The +16 dBm is classified as a *short-term enhanced signal*.