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TRANSMISSION SPECIFICATIONS for VOICE GRADE PRIVATE LINE PROTECTIVE RELAYING CHANNELS

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Transmission Specifications for Voice Grade Private Line Protective Relaying Channels

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ENGINEERING DIRECTOR - TRANSMISSION SERVICES

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If further information is required, please contact:

Engineering Director — Transmission Services
American Telephone and Telegraph Company
195 Broadway
New York, New York 10007

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1. INTRODUCTION

The purpose of this technical reference is to provide information on a new voice grade private line channel specifically designed for power industry protective relaying applications. This channel is intended to provide improved reliability, for protective relaying systems during the power fault interval, over that which can be obtained from other voice grade channels offered under Tariff F.C.C. No. 260 and similar intrastate tariffs. Reliability implies both dependability and security; dependability being the degree of assurance of delivering valid trip signals and security the assurance of avoiding delivery of false trip signals.

One of the unique problems inherent in providing communication service to power stations is the severe noise signals which 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 dependability can be compromised by noise generated during fault intervals.

The improved dependability of this channel offering 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 facilities with better than average resistance balance.
2. Authorizing the employment of enhanced trip signals.

The channel net loss is 16 dB with any necessary gain or loss devices installed at locations which insure 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.

The conversion of common mode (longitudinal) noise voltage to differential mode (metallic) noise voltage is directly dependent on the resistance balance of the cable pairs serving the power stations. Therefore, in order to minimize differential mode noise voltage, cable facilities with better than average resistance balance will be employed. The local channel portion of a protective relaying channel will have resistance unbalance of 1% or less.

The employment of enhanced trip signals to indicate a fault condition may result in adjacent channel interference. To minimize this interference, restrictions on signal levels, format and frequency of occurrence are given in the section on interface criteria. Because the use of enhanced trip signals results in the prompt de-energization of power line faults, the period during which interfering noise from power line faults are introduced into telephone cable plant is reduced to a minimum. Thus the net effect on adjacent channels users from the employment of enhanced signals is beneficial.

2. TYPES OF ARRANGEMENTS PROVIDED

F.C.C. Tariff No. 260 and similar intrastate tariffs will provide* for a basic voice grade private line protective relaying channel. This channel may be one-way, two-wire or two-way, four-wire and may be ordered in two-point or multipoint configurations.

3. INTERFACE

The interface between the customer-provided terminal and the Telephone Company channel facilities will, in general, be a terminal block arranged for convenient connection of the cable conductors to the customer-provided equipment. The terminal block will be provided by the Telephone Company and space must be provided by the customer for the Telephone Company to install the terminal block in a suitable location to permit maintenance testing of the circuit when the customer's equipment is disconnected. The customer is responsible for the connection of his equipment to the terminal block and is also responsible for disconnecting

* Tariffs will be filed, as appropriate, when the initial order for this service is placed.

his equipment at the interface to allow Telephone Company repair personnel to make maintenance tests.

As part of the channel, a transformer is provided for the purpose of cable equalization and voltage limitation. This equipment does not eliminate the need for special protective devices at power stations which are subject to hazardous voltages from ground potential rise or induction during fault conditions.

Where telephone lines are exposed to lightning, power circuit contact, or induction, direct drainage devices are installed at the central office and on subscriber premises. The maximum surge between conductors (tip and ring) that the protective relaying terminal should encounter due to foreign potential is limited to approximately 30 volts.

4. INTERFACE CRITERIA

4.1 General

The interface criteria listed below are required for the protection of the telephone network and the proper functioning of both the protective relaying channel and terminal equipment.

4.2 Terminal Impedance

The nominal impedance of customer-provided protective relaying terminal equipment should be 600 ohms resistive ±10% over the 300 to 3000 Hz band in order to minimize installation and maintenance problems. The impedance of Bell System test equipment used for installation and maintenance tests is 600 ohms resistive. Therefore, channels lined up using 600 ohm test equipment should use protective relaying terminal equipment which has the same impedance to assure transmitted and received signal power is as specified.

4.3 Power Criteria for Inband Signals (300-3995 Hz)

In order to protect other services, it is necessary that the signal which is applied by the customer-provided equipment to the Telephone Company interface, located on the customer's premises, meet the following limits:

4.3.1 Non-enhanced Signals

Signals which are employed continuously for circuit assurance or other purposes must meet all the following requirements:

a. Three second average limitation — see Section 4.3.3.

b. Instantaneous signal power limitation — see Section 4.3.4.

c. Weighted rms voltage limitation — see Section 4.3.5 and Subsections 4.3.5.1 and 4.3.5.2.

Signals which meet all of the above criteria are defined as non-enhanced signals. Appendix I contains an example of computation for non-enhanced signals.

4.3.2 Enhanced Signals

Trip signals sent from a protective relaying terminal must meet all the following requirements:

a. Three second average limitation — see Section 4.3.3.

b. Short term power limitation — see Section 4.3.6.

c. Frequency of occurrence limitation — see Section 4.3.7.

Trip signals may exceed the criteria for rms voltages specified in Section 4.3.5 as well as the instantaneous signal power limitation specified in Section 4.3.4. Signals which exceed these criteria are defined as enhanced signals. Appendix 2 contains an example of computation for enhanced signals.

4.3.3 Three-Second Average Limitation

The transmitted inband signal power, averaged over any 3-second interval, must not exceed 0 dBm. This criterion must be met at all times.

4.3.4 Instantaneous Signal Power Limitation

The instantaneous signal power must not exceed +13 dBm (3.46 volts peak across 600 ohms).

4.3.5 Weighted RMS Voltage Limitation

To prevent interference into adjacent cable pairs, it is necessary that the voltage applied to a cable pair should not exceed the limits given in the following two subsections.

4.3.5.1 Signal Frequency Signal Limitation

Signals consisting solely of a single frequency must not exceed the limits given in Figure 1. Mathematically, this restriction is expressed as follows:

$$E\ (f) \leq \frac{10^{5.3}}{f^{1.65}} \text{ or}$$

$$20 \log_{10} E\ (f) \leq 106 - 33 \log_{10} f$$

$$300 \text{ Hz} \leq f \leq 3995 \text{ Hz}$$

Where f = frequency in Hertz
E(f) = rms voltage at frequency f

Power (dBm 600 ohms)

$$\leq 10 \log_{10} \frac{E(f)^2}{600} \times \frac{1000}{1}$$

$$\leq 10 \log_{10} \frac{1000}{600} + 10 \log_{10} E(f)^2$$

$$\leq 10 \log_{10} 1.667 + 20 \log_{10} E(f)$$

$$\leq 2.2 + 20 \log_{10} E_f$$

$$\leq 2.2 + 106 - 33 \log_{10} f$$

$$\leq 108.2 - 33 \log_{10} f$$

$$300 \text{ Hz} \leq f \leq 3995 \text{ Hz}$$

4.3.5.2 Multiple Frequency Signal Limitation

The signal level restriction of Subsection 4.3.5.1 applies to a signal consisting solely of a single frequency tone. The restriction does not permit two or more tones to be applied simultaneously to the protective relaying channel at the maximum value permitted for each individual tone. If the signal contains more than one frequency (e.g., multiple tones), it is necessary to weight the individual frequency components and then take the square root of the sum of the squares of these weighted rms voltages to determine if the signal is acceptable. Weighting is performed referencing all signal components to a chosen reference frequency. Each component rms voltage is multiplied by a weighting factor which is calculated by dividing the maximum permitted rms voltage at the reference frequency by the maximum permitted rms voltage at the signal component frequency. The square root of the sum of the square of all the weighted signal components must be less than the maximum permitted rms voltage at the reference frequency. This procedure can be expressed mathematically as follows:

$$\sqrt{\sum_i \left[W(f_i)\ E(f_i)\right]^2} \leq E_r(f_r)$$

$$300 \text{ Hz} \leq f_i \leq 3995 \text{ Hz}$$

Where $E(f_i)$ = rms voltage of the signal component at frequency f_i

$W(f_i)$ = weighting factor for frequency f_i

$$= \frac{E_r(f_r)}{E_r(f_i)} = \left[\frac{f_i}{f_r}\right]^{1.65}$$

$E_r(f_r)$ = rms voltage restriction for the chosen reference frequency f_r

$$= \frac{10^{5.3}}{f_r^{1.65}}$$

$E_r(f_i)$ = rms voltage restriction for frequency f_i

$$= \frac{10^{5.3}}{f_i^{1.65}}$$

If 1000 Hz is chosen as the reference frequency, then the limitations for inband signals can be expressed as:

$$\sqrt{\sum_i \left[W(f_i)\ E(f_i)\right]^2} \leq 10^{0.35} \text{ volts} \cong 2.24 \text{ volts}$$

$$\text{Where } W(f_i) = \left[\frac{f_i}{1000}\right]^{1.65}$$

$$300 \text{ Hz} \leq f_i \leq 3995 \text{ Hz}$$

and f_i is the numerical value of the frequency in Hertz.

4.3.6 Short Term Power Limitation

The transmitted inband signal power must not exceed +16 dBm (rms). This criterion must be met at all times. It should be noted that signal peaks which exceed a +12 dBm sine wave may experience clipping.

4.3.7 Frequency of Occurrence of Enhanced Signal Transmission

Transmission of enhanced trip signals may result in observable crosstalk on adjacent channels. Because of this possible interference, the number of enhanced signals for <u>test</u> purposes is limited to 7 occurrences per week. An occurrence is defined as an enhanced signal transmission within a 3-second interval. The number of actual trip signal transmissions on the protective relaying channel will, of course, depend on the number of power fault occurrences and hence is undefined.

4.4 Power criteria for Out-of-Band Signals

In order to protect other services, it is necessary that the signal which is applied by the customer-provided equipment to the Telephone Company interface, located on the customer's premises, meet the following limits:

a. The power in the band from 3995 to 4005 Hz shall not exceed −18 dBm.
b. The power in the band from 4 to 10 kHz shall not exceed −16 dBm.
c. The power in the band from 10 to 25 kHz shall not exceed −24 dBm.
d. The power in the band from 25 to 40 kHz shall not exceed −36 dBm.
e. The power in the band above 40 kHz shall not exceed −50 dBm.

4.5 Longitudinal Balance Recommendations for Protective Relaying Terminal

As indicated in Section 3, a transformer will be provided by the Telephone Company at a location close to the interface. An unbalanced protective relaying terminal located some distance from this transformer and exposed to a severe noise environment will convert longitudinal (common mode) induced noise voltage to metallic (differential mode) voltage. In the interest of reducing noise signals, it is advantageous to employ longitudinally balanced terminal equipment.

5. TRANSMISSION FACILITY PARAMETER LIMITS

5.1 General

The facility parameters covered in this section represent minimum limits to which the Telephone Company will maintain the protective relaying channel. The limits specified are different in a number of areas from the usual voice grade private line transmission specifications. These differences are due to the particular requirements for protective relaying systems. A summary of transmission facility parameter limits is given in Table A.

5.2 Channel Net Loss and Variations

5.2.1 The engineered net loss of a protective relaying channel is 16.0 dB at 1000 Hertz.

5.2.2 The initial loss (at time of installations) of a protective relaying channel is 16.0 dB ±1 dB at 1000 Hertz.

5.2.3 Short term loss variations may be caused by dynamic regulation of carrier system amplifiers, switching to standby facilities and some maintenance activities. The variation in channel loss due to short term variations should not exceed ±3 dB.

5.2.4 Long term loss variations are primarily caused by temperature changes affecting local plant, component aging and amplifier drift. Long term variations are corrected during periodic routine measurements. These variations should not exceed ±4 dB. Long term, short term and line-up variations are not cumulative; (i.e.), channel loss is 16 dB ±4 dB not 16 dB ± (4 + 3 + 1) dB.

5.3 Attenuation Distortion

Attenuation distortion is the difference in the response 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 of a 1000 Hertz reference frequency.

For the frequency band between 300 and 3000 Hertz, the loss may vary from −2 to +6 dB compared with the loss at 1000 Hertz. ("−" means less loss, "+" means more loss.)

For the frequency band between 500 and 2800 Hertz, the loss may vary from −1 to +3 dB compared with the loss at 1000 Hertz.

5.4 Envelope Delay Distortion

Envelope delay is defined as the derivative of the phase shift with respect to frequency. The maximum difference in the derivative over any frequency interval is called envelope delay distortion. Envelope delay distortion for this channel will be less than 2000 microseconds over the band from 800 to 2600 Hertz.

5.5 C-Notched Noise

C-notched noise is a measure of the amount of noise on a channel when a signal is present. In making this measurement, a single frequency "holding tone" at 2804 Hz is applied at 0 dBm to the transmitting end of the protective relaying channel to act as a signal. This tone operates compandors and other signal dependent devices. At the receiving end, the tone is removed by a very narrow band elimination filter (notch filter) and the noise is then measured through a C-message filter.

The limit for the ratio of received power of a 1000 Hz test signal to C-notched noise power is 24 dB. Assuming the transmitted signal power of a 1000 Hz test signal is 0 dBm and the received signal power is −16 dBm (74 dBrnC), the C-notched noise will be at least 24 dB less (50 dBrnC or less) at the receiver.

5.6 C-Message Noise

C-message noise is a measure of the amount of noise on a channel in the idle condition. These readings are not valid for determining the signal-to-noise ratio of the received trip signal when compandors are employed on the channel. When compandors are <u>not</u> employed on the channel, then a measurement of C-message noise does provide a good indication of the received noise when a signal is being transmitted. Limits for C-message noise at the receiver are given below:

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

5.7 Single Frequency Interference

Single frequency interference tone appearing at the protective relaying receiver should be less than the following:

Circuit Length (Miles)	Single Frequency Limit (dBrnC)
0-50	25
51-100	28
101-400	31
401-1000	35

5.8 Frequency Shift

Most long haul carrier systems operate in a single sideband suppressed carrier mode. Because the carrier is not transmitted and must be reinserted at the received end, there may be a slight difference in frequency between the modulating and demodulating carriers. The resulting frequency shift contributes a constant change at all frequencies in the voiceband.

Maximum frequency shift limit for the overall channel is ±5 Hz, although it is very unusual for this limit to be approached.

5.9 Local Channel Balance

During power fault condition, longitudinal voltages of large magnitude may be induced in the local channels serving power stations. Because the channel is terminated by the 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 facility serving the power station. The resistance unbalance of the local channel cable pairs provided for protective relaying channels will be 1% or less.

5.10 Phase Hits

Phase hits are sudden uncontrolled changes in phase of the transmitted signal. Limits are currently unspecified.

5.11 Gain Hits

Gain hits are sudden uncontrolled changes in the gain (or loss) of the channel. Limits are currently unspecified.

5.12 Dropouts

Dropouts are large negative gain changes. Limits are currently unspecified.

5.13 Propagation Time

Propagation time is not specified. Applications where propagation time is crucial should be reviewed with a Bell System Engineering Representative.

6. SYSTEM DESIGN CONSIDERATIONS

6.1 Reliability

Services outages in the Telephone Company facilities are generally due to vehicle accidents involving utility poles, storms, malicious destruction, maintenance and construction activities. Plans exist for the restoral of service, after interruptions, as rapidly as feasible. However, extended delays are sometimes encountered. Efforts are continuing to shorten the duration and frequency of these outages. Some of the alternatives available when a very high degree of reliability is required are indicated in Section 6.2.

6.2 Backup

A 100% backup over diversified routes (when feasible) is recommended for critical protective relaying application. It is recognized that even this would not guarantee 100% reliability, but past experiences indicates this arrangement provides a very high degree of reliability. It is also possible to request avoidance routing in order to avoid specified geographical locations.

7. MAINTENANCE CONSIDERATIONS

7.1 General

In order to reduce the possibility of transmission impairments and out-of-service conditions, it is necessary to perform preventive maintenance on the equipment and on the associated transmission facilities of a communications service. For this reason, the Telephone Company will perform preventive maintenance on the private line facilities and terminal equipment which they provide. To allow for this, the Tariffs generally specify that these facilities must be released by the customer at a mutually agreed-upon time for maintenance purposes. The release of the facilities will be required during normal business hours. However, the Telephone Company will cooperate with the customer in order to limit disruption of his service.

7.2 Reporting Trouble

When trouble is experienced on a Protective Relaying Channel employing customer-provided terminal equipment, the customer should first isolate and check (sectionalize) his portion of the circuit before reporting the trouble to the Telephone Company. This will preclude the customer from incurring a Telephone Company maintenance of service charge for visits by the

Telephone Company to the customer's premises where the service difficulty or trouble report results from the use of equipment or facilities provided by the customer.

After the customer has sectionalized the trouble and determined that it is in a Telephone Company provided facility, it should be promptly reported to the Telephone Company listed "Repair Service" telephone number unless directed otherwise. In order to provide speedy handling of the trouble report, the following information should be given to the attendant processing the call:

a. Customer's name
b. Customer's address (and equipment location if different)
c. Circuit identification number
d. Description of type of trouble
e. Pertinent test information
f. Customer contact for additional information

The Telephone Company will test the transmission capabilities of its private line facility and equipment and, when necessary, dispatch repair forces to clear the trouble, but will not assume responsibility for locating trouble in the customer's equipment.

8. REFERENCES

Some of the references used in the preparation of this technical reference are listed below:

(a) Hinderliter, R.G., "Transmission Characteristics of Bell System Subscriber Loop Plant", IEEE Transaction, Communications and Electronics, (September 1963).

(b) Bodle, D.W. and Gresh, P.A., "Lightning Surges in Paired Telephone Cable Facilities", BSTJ, 40, No. 2 (March 1963).

(c) Transmission System for Communications, Bell Telephone Laboratories, 1970.

(d) PUB43401 — Transmission Specifications for Private Line Metallic Circuits — Preliminary — December 1971.

(e) PUB41004 — Transmission Specifications for Voice Grade Private Line Data Channels — March 1969.

(f) PUB41007 — 1969-70 Switched Telecommunications Network Connection Survey (Reprint of Bell System Technical Journal Articles) — April 1971.

(g) PUB41008 — Analog Parameters Affecting Voiceband Data Transmission — Description of Parameters — October 1971.

(h) PUB41009 — Transmission Parameters Affecting Data Transmission — Measuring Techniques — January 1972.

TABLE A

Transmission Facility Parameter Limits

1. Engineered loss: 16 dB @ 1000 Hz :
2. Initial loss at installation: 16 dB ±1.0 dB @ 1000 Hz
3. Short term loss variations: less than ±3 dB
4. Long term loss variations: less than ±4 dB
5. Attenuation distortion (Reference 1000 Hz)

Frequency Range	Variation (dB)
300-3000 Hertz	−2 to +6
500-2800 Hertz	−1 to +3

6. Envelope delay distortion: less than 2000 microseconds over band from 800 to 2600 Hz
7. C-Notched Noise: less than 50 dBrnC at receiver
8. C-Message Noise:

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

9. Single frequency interference:

Circuit Length (Miles)	Receiver Single Frequency Limit (dBrnC) Less Than
0-50	25
51-100	28
101-400	31
401-1000	35

10. Frequency shift: less than ±5 Hz
11. Local channel resistive balance: 1% or less unbalance between conductors
12. Phase hits: unspecified
13. Gain hits: unspecified
14. Dropouts: unspecified
15. Propagation time: unspecified

APPENDIX I

Computation Example — Multiple Frequency Signal

A transmitter used for protective relay purposes employs the following signals on a continuous basis:

Frequency	Voltage (RMS)
2700 Hz	0.5 volt
3000 Hz	0.4 volt

$$\text{Power (2700 Hz)} = \frac{(0.5)^2}{600} \times 10^3 = 0.417 \text{ mw}$$

$$\text{Power (3000 Hz)} = \frac{(0.4)^2}{600} \times 10^3 = 0.267 \text{ mw}$$

Power (Total = 0.417 mw + 0.267 mw = 0.684 mw

The total power transmitted meets the requirement that inband power must not exceed 0 dBm (1 mw) averaged over any 3-second interval and also meets the instantaneous signal power limitation limiting the signal power to +13 dBm (3.46 volts peak across 600 ohms).

Using 1000 Hz as the reference frequency, the weighted signal voltage is calculated as follows:

Frequency	Weighting Factor* X	rms Voltage	= Weighted Voltage
2700	$\left[\frac{2700}{1000}\right]^{1.65} = 5.15$ X	0.5	= 2.57
3000	$\left[\frac{3000}{1000}\right]^{1.65} = 6.13$ X	0.4	= 2.45

$$\text{Equivalent Voltage} = \sqrt{(2.57)^2 + (2.45)^2}$$

= 3.55 volts (equivalent 1000 Hz voltage)

Since 3.55 volts (equivalent 1000 Hz voltage) exceeds the 2.24 volts limit for a 1000 Hz signal, the signaling frequency and/or level needs to be modified before this equipment can be connected to Telephone Company facilities.

* See Section 4.3.5.2

APPENDIX II

Computation Example — Enhanced Trip Signals

A protective relaying terminal transmitter normally transmits a supervisory tone of 2200 Hz at a power level of -10 dBm. During a power fault, the supervisory tone is removed and enhanced 2000 and 2400 Hz signal are transmitted at +10 dBm each. After a 50 millisecond interval, the level of each tone is reduced to a -10 dBm level until the fault is cleared. After the fault is cleared, the normal supervisory tone of 2200 Hz is transmitted at a power level of -10 dBm.

A single frequency signal of 2200 Hz at a power level of -10 dBm must meet both the three second average limitation of 0 dBm and the single frequency voltage limitation. The supervisory signal does meet the three second average limitation (i.e., -10 dBm is less than 0 dBm). The single frequency limitation for 2200 Hz is:

$$\text{Power (dBm 600 ohms)} \leq 108.2 - 33 \log_{10} f$$

$$\leq 108.2 - 33 \log_{10} (2200)$$

$$\leq -2.1 \text{ dBm}$$

Thus, since -10 dBm is less than -2.1 dBm, the supervisory signal meets the single frequency voltage limitation.

The composite power of the enhanced 2000 and 2400 Hz signal is the sum of two + 10 dBm signals and is equal to + 13 dBm. This meets the short term power criterion of +16 dBm listed in section 4.3.6.

The maximum energy permitted in any 3 second interval is equal to 1 milliwatt (0 dBm) x 3 seconds = 3 mw seconds.

The energy in the enhanced signal is equal to (10 mw +10 mw) x 0.05 seconds = 1 mw second.

The energy in the 2.95 second interval prior to the advent of the enhanced trip signals is equal to 0.1 mw (-10 dBm) x 2.95 sec. = 0.295 mw sec.

Total energy = 1.0 mw second + 0.295 mw second = 1.29 mw second.

The energy in the 2.95 second interval after the advent of the enhanced trip signal is equal to [0.1 mw (-10 dBm) + 0.1 mw (-10 dBm)] x 2.95 seconds = 0.2 mw x 2.95 second = .59 mw second.

Total energy = 1.0 mw second + 0.59 mw second = 1.59 mw second.

The total energy in any three-second interval is less than 3 mw second and hence meets requirements.

Because each of the two trip tones of 2000 and 2400 Hz could be transmitted at a power level of -10 dBm (0.245 volts across 600 ohms) for a considerable amount of time, this arrangement must be checked for long-term suitability.

Using a 1000 Hz as the reference frequency, the weighted signal voltage is calculated as follows:

Frequency	Weighting Factor	x rms Voltage	= Weighted Voltage
2000 Hz	$\left[\frac{2000}{1000}\right]^{1.65} = 3.14$	x 0.245	= 0.769
2400 Hz	$\left[\frac{2400}{1000}\right]^{1.65} = 4.24$	x 0.245	= 1.04

APPENDIX II (CONT'D)

$$\text{Equivalent Voltage} = \sqrt{(0.769)^2 + (1.04)^2}$$

$$= 1.29 \text{ volts (equivalent 1000 Hz voltage)}$$

Since 1.29 volts does not exceed the allowable 2.24 volt limit for a 1000 Hz signal, the use of 2000 and 2400 Hz tones at -10 dBm power level is permissible.

Figure 1

Single Frequency Signal Limitation