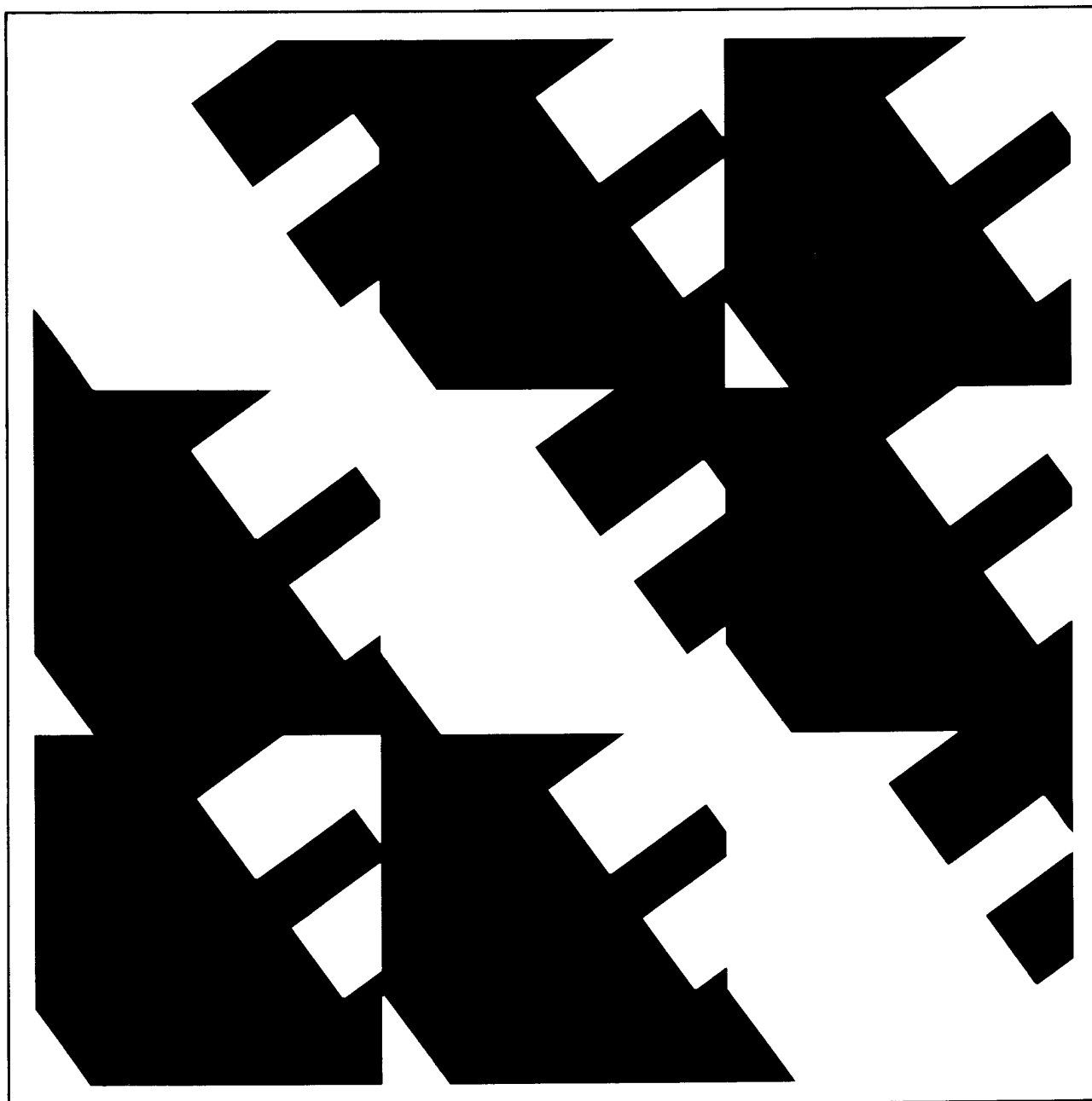


IEEE Guide for Inductive Coordination of Electric Supply and Communication Lines



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IEEE Guide for Inductive Coordination of Electric Supply and Communication Lines

1. Scope

This guide addresses the inductive environment that exists in the vicinity of electric power and wire line telecommunications systems and the interfering effects that may be produced thereby; guidance is offered for the control or modification of the environment and the susceptibility of the affected systems in order to maintain an acceptable level of interference.

To aid the user of this guide in calculating induction between power and telecommunication lines, the concept of an interface is developed. This guide permits either party, without need to involve the other, to verify the induction at the interface by use of a probe wire. This guide does not apply to railway signal circuits.

2. References

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

- [1] ANSI/IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.¹
- [2] ANSI/IEEE Std 487-1980, IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations.
- [3] ANSI/IEEE Std 820-1984, IEEE Standard Telephone Loop Performance Characteristics.
- [4] IEEE Std 367-1987, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.²

¹ ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

² IEEE publications can be obtained from the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

3. General

3.1 Inductive Interference. An effect, arising from the characteristics and inductive relations of electric supply and telecommunication systems, of such character and magnitude as would prevent the telecommunication circuits from rendering service satisfactorily and economically if methods of inductive coordination were not applied. Inductive interference is produced by the simultaneous coexistence of three factors:

- (1) An inductive influence,
- (2) A coupling mechanism between two electrical systems or circuits, one of which produces the influence, and
- (3) A susceptibility of the second system or circuit to interference.

While inductive interference may occur at any time the above conditions are satisfied, the majority of cases and the principal concern of this guide involve interference in telecommunication systems as a result of their proximity to electric power systems. Therefore, subsequent discussion is limited to that general case, although the principles and practices may apply to other cases as well.

3.1.1 Inductive Influence (Electric Supply Circuit with its Associated Apparatus). Those characteristics that determine the character and intensity of the inductive field that it produces.

The voltages and currents present on an operating power system produce electric and magnetic fields in the vicinity of the system. The character and intensity of those fields determine the inductive influence. Character is related primarily to the frequencies present, while intensity is related to the magnitudes of voltages and currents modified by line configuration, current distribution, and any shielding structures in the immediate vicinity, excluding the shield of a telecommunications cable.

3.1.2 Coupling. The effect of an interfering source on a signal transmission.

For the inductive influence of a power system to affect another system or circuit, there must be coupling between the two. The coupling mechanism consists of the mutual impedance between circuits in proximity to each other. This has resistive, capacitive, and inductive components. Electric induction, via capacitive coupling, may be consequential when the exposed circuit is composed of unshielded conductors above ground. However, when the exposed circuit conductors are enclosed in a grounded metallic sheath or shield, capacitive coupling generally may be considered negligible compared to the magnetic induction via inductive coupling. Therefore, the coupling mechanism of primary concern will generally be the mutual inductance between an electric supply circuit or circuits and telecommunications. The primary factors affecting coupling are separation of the systems, frequency of the magnetic field, and earth resistivity.

3.1.3 Inductive Susceptiveness (Telecommunication Circuit with its Associated Apparatus). Those characteristics that determine, so far as such characteristics are able to determine, the extent to which the service rendered by the circuit can be adversely affected by a given inductive field.

The existence of an inductive field and coupling with a metallic telecommunication circuit will cause longitudinal voltages to be induced in the telecommunication circuit. However, interference does not occur unless the circuit is susceptible to being adversely affected by the induced voltages and resulting currents. One kind of interference is the introduction of an unwanted signal (noise) into the circuit. The susceptibility of the circuit to noise depends upon the cable shield, the amplitude and the frequency of the signal normally transmitted, circuit impedances, and the longitudinal balance of the circuit and its associated equipment. Longitudinal balance determines the extent to which longitudinal (common-mode) voltages are converted to metallic (differential-mode) voltages. Interference may also be manifested as a malfunction in the operation of the circuit. The malfunction may be caused by electrical or thermal overstress of a circuit component by the induced voltage or resulting current.

3.2 Need for Coordination. The continued successful coexistence of systems for the transmission, distribution, and utilization of electric

power and wire line telecommunications depends upon the ability of their operators to resolve problems of interference between the systems. The need for coordination between operators of electric supply and telecommunications lines has existed since the early days of the industries. At various times, cooperative studies have been undertaken, resulting in the production and dissemination of a large body of technical information on the subject. This information continues to grow with the expansion of these industries and the introduction of new technology. However, this growth and change introduces new concerns that should be addressed if continued compatibility of the systems is to be accomplished. Some of those concerns are as follows:

- (1) Extension of services to more customers, leading to longer lengths of serving facilities.
- (2) Ecological considerations, which encourage the concentration of facilities on joint or adjacent rights-of-way.
- (3) Higher capacity power systems serving larger loads and more nonlinear loads.
- (4) The deployment of more susceptible electronic devices and equipment for telecommunication and signaling systems along telecommunication lines, thus exposing them to the effects of the inductive environment.

These concerns emphasize the need for continued cooperative inductive coordination to avoid interference where possible and to reduce it to an acceptable level whenever it occurs.

3.3 Mutual Responsibility of Parties Involved. Inductive coordination is defined as the location, design, construction, operation, and maintenance in conformity with harmoniously adjusted methods that will prevent inductive interference.

Historically, inductive coordination has been accomplished through the cooperative efforts of the industries involved, without regulatory intercession. This cooperative effort best meets the service needs of the public and resolves interference problems in the most equitable and economical manner. However, for such a cooperative effort to succeed, all parties involved should recognize and be willing to discharge a mutual responsibility for the handling of all inductive coordination problems that may arise. Failure to do so may result in regulatory authority action to protect the public interest.

4. The Inductive Environment

4.1 Guidelines for an Acceptable Environment. This portion of the guide will address the following:

- (1) Areas of concern
- (2) Threshold considerations
- (3) Suggestion of a classification system
- (4) Definition of the interface
- (5) Establishment of an acceptable environmental threshold for positive action
- (6) Susceptiveness criteria for telecommunications plant.

4.1.1 Areas of Concern. Three areas of consideration are as follows:

- (1) Safety from electrical shock due to personal contact with telecommunications conductors.
- (2) The destruction of plant facilities as a result of dielectric breakdown or energy dissipation.
- (3) The degradation or interruption of telecommunications.

Each of these considerations is the result of the influencing current of the power system, the coupling between the two systems, and the susceptibility of the telecommunication system.

4.1.2 Threshold Considerations. The following is a list of threshold considerations from various standards on the telecommunications system:

(1) *Safety.* 50 V rms continuously induced with respect to ground at 60 Hz on telecommunication facilities has historically been considered an upper threshold in North America by telecommunications companies. Electric power companies and railway telecommunications systems have historically used 60 V rms to ground at 60 Hz as their safety threshold. CCITT (telephone) also uses the 60 V rms level except for special cases when 150 V rms is accepted. Other higher thresholds have been established in other administrations.

(2) *Destruction of Cable.* ANSI/IEEE Std 487-1980 [2]³ provides a method to obtain the 60 Hz conductor-to-conductor dielectric strength for plastic insulated cable (PIC) typically used in telephone systems:

- 1.8 kV rms for 19 gauge
- 1.4 kV rms for 22 gauge
- 1.2 kV rms for 24 gauge
- 0.96 kV rms for 26 gauge

³ The numbers in brackets correspond to those of the references listed in Section 4; when preceded by B, they correspond to the bibliography in Section 14.

Conductor-to-shield failure may also occur and should be considered. Paper insulated cables require special protection for peak voltages in excess of 1000 V.

(3) *Destruction of Equipment.* An indication of energy dissipation or the product of the current squared and time in line-repeater electronics is typically between 16 and 80 A² · s ($I^2 \cdot t$).

(4) *Circuit Degradation.* ANSI/IEEE Std 820-1984 [4] states that the recommended level of noise to ground is less than or equal to 80 dBmC. The reference also states that 81-90 dBmC levels are considered acceptable and those in excess of 90 dBmC are not recommended on telephone voice frequency circuits.

(5) *Circuit Failure*

(a) the supervision on some voice frequency circuits may be adversely affected when longitudinal current exceeds 5 mA.

(b) communications carrier systems that are powered over the simplex may be adversely affected when the peak ac longitudinal current through the regulating diode approaches the dc powering current. The carrier will fail when the peak ac longitudinal current exceeds the dc powering current through the regulation diode.

4.1.3 Classification System. A method of classifying telecommunication facilities in a given route will allow different environmental criteria. The classification scheme will have four components. The four components are as follows:

- (1) Circuit sensitivity to power fault conditions
- (2) Length consideration
- (3) Ability to inure (accepting an undesirable situation)
- (4) Fault duration

The power system produces two environments: the normal operating condition and the fault condition. Some telecommunication systems and circuits may tolerate interruption during a fault and others may not. For the purpose of this guide, those that may tolerate a fault-caused interruption will be classified "B"; those that may not are classified "A."

Induced voltage is proportional to the length of the exposure. A length or zone qualifier will preclude an unreasonable economic burden on short exposures. The three zones will be defined as follows:

- Zone 1 = 0-15 kft
- Zone 2 = 15-50 kft
- Zone 3 > 50 kft

The inure classification will be for those facilities where a customer will not have access to conductors and the telecommunications utility is willing to condition these to operate safely at interference levels of 50-100 steady-state V rms to ground.

i = inure (50-100 steady-state V rms to ground)
c = customer access (< 50 steady-state V rms to ground)

This classification will be designated by the telecommunication facility owner.

Energy dissipation is dependent upon a fault duration or clearing time. The fault condition must have the time specified and will be designated in seconds, reflecting the maximum time of fault current flow. Energy dissipation is determined by the power company and will indicate the magnitude of the energy in the environment.

Usually the fault duration at a particular location is the time required for the nearest line side protective equipment to operate and isolate a fault, assuming the maximum calculated symmetrical fault current at the fault location. When estimating the fault energy ($I^2 \cdot t$) for repeated reclosure operation on power lines, the following worst case assumptions may be made:

(1) The time to be used for each reclosure cycle is the time from the onset of the fault until the operation of the breaker.

(2) For distribution circuits the fault currents and times for each reclosure cycle may be identical.

(3) For transmission circuits the fault currents and times for each reclosure cycle may be different.

(4) The total $I^2 \cdot t$ is the sum of the $I^2 \cdot t$'s of all the reclosure cycles.

Further information on fault duration may be found in IEEE Std 367-1987 [4]. The telecommunications company will classify a route by circuit by components (1) through (3).

4.1.4 Interface. Calculated or measured levels of induction can be assessed at an interface between the power and telecommunications utilities systems. These levels reflect

(1) The limiting magnitude and waveshape distortion generated by the power system.

(2) The levels that may cause telecommunication system safety, failure, or service degradation problems.

The interface is specified and expressed in terms of a 100 ft, 22 gauge insulated probe wire

with grounded ends. The wire is placed on the ground parallel to the power line and at a radial distance of

(1) 50 ft to the geometric mean location of the power line phase conductor distance, where power lines are less than 69 kV.

(2) 75 ft to the closest power line phase conductor, where power lines are equal to or greater than 69 kV.

For the purpose of voltage or noise measurements, the probe wire is opened and the meter inserted. To keep errors small (less than 0.1 dB for the noise measurement), the meter impedance should be more than 100 times the impedance of the probe wire grounds. For the determination of the current to be used in energy dissipation analysis, currents will be calculated by Ohm's Law, assuming a perfect voltage source equivalent to the measured value and a shorted loop with an internal impedance of 1.6 Ω .

4.1.5 Acceptable Environment Thresholds.

With the 100 ft probe wire as the interface and the classification scheme and limiting considerations defined, Table 1 has been constructed to set voltage thresholds at 60 Hz. These levels, either measured or calculated on the interface, are based upon the 50 V safety threshold.

No individual harmonic should exceed the customer-sensitive steady-state 60 Hz voltage level as read from Table 1 and multiplied by the reciprocal of the harmonic raised to the 2.7 power (see [B3]). The limiting values of Eq 1 for Zones 1, 2, and 3 are listed in Table 2. When this threshold is exceeded, coordination between the affected parties is suggested. Refer to Sections 5 and 6.

$$V = V_p (n)^{(-2.7)} \quad (\text{Eq 1})$$

where

V = the resultant voltage for harmonic n

V_p = the maximum voltage at 60 Hz on the probe wire for the indicated zone from Table 1

n = the harmonic number

Typically no harmonic will generally exceed the 60 Hz measured value multiplied by the reciprocal of the harmonic number raised to the 1.7 power. The values of Eq 2 are listed in Table 2.

$$V_d = V_m (n)^{(-1.7)} \quad (\text{Eq 2})$$

where

V_d = the distortion limit derived from the measured voltage at 60 Hz on the probe wire

V_m = the measured value of 60 Hz on the probe wire

n = the harmonic number

4.1.6 Susceptiveness of Communications Facilities. The susceptiveness of the telecommunication facility should be maintained at a level that would preclude interference in the presence of an electrical environment set by Table 1 and Table 2.

Table 1
Acceptable 60 Hz rms Voltage
Thresholds on Probe Wire Interface

(a) Safety and Circuit Degradation						
Class	A	A	A	B	B	B
Zone	1	2	3	1	2	3
	(V)	(V)	(V)	(V)	(V)	(V)
Steady-state	0.3333	0.1000	0.0379	0.3333	0.1000	0.0379
i	0.6667	0.2000	0.0758	0.6667	0.2000	0.0758

(b) Cable Destruction				
Cable Dielectric Insulation	Gauge	Zone 1	Zone 2	Zone 3
PIC	19	12.0	3.6	1.36
	22	9.3	2.8	1.06
	24	8.0	2.4	0.91
	26	6.4	1.9	0.73
Paper	19–24	6.6	2.0	0.76
	26	6.4	1.9	0.73

(c) Equipment Destruction				
Fault Duration (cycles)	(s)	Energy Dissipation		
		$I^2 \cdot t$	$I^2 \cdot t$	
		16 (V)	80 (V)	
5	0.0833	22.17	49.57	
10	0.1667	15.68	35.05	
20	0.3333	11.09	24.79	
40	0.6667	7.84	17.53	
80	1.333	5.54	12.39	
160	2.667	3.92	8.76	
320	5.333	2.77	6.20	
640	10.67	1.96	4.38	

NOTE: $I^2 \cdot t$ all zones and classes same.

i = inure

c = customer accessible

Class A = may not tolerate interruption

Class B = may tolerate interruption (self-restoring)

Zone 1 = 0–15 kft

Zone 2 = 15–50 kft

Zone 3 > 50 kft (calculation based on 132 kft)

4.2 Methods of Measurement. This portion of the guide will address those measurements on telecommunication cable, loop antenna, probe wire, power supply lines, and customer power equipment that are needed for mitigation. In addition, the type of measurement equipment required in each measurement will be explored along with methods for analyzing the raw data results.

4.2.1 Test Equipment and Units. Oscilloscopes, spectrum analyzers, voltmeters, frequency selective voltmeters, and noise measuring sets produce readings in different formats and possibly in different units. To produce equivalent readings, different test sets must apply a similar terminating impedance to the circuit and have similar frequency response to a complex waveform. Test equipment designed for use in telecommunication circuit measurements should typically have an internal circuit termination, a longitudinal balance above 75 dB (or 14 dB better balance than the circuit to be measured), a measurement unit of dBrn, dBm, C-message, and 3 kHz flat weighting, and a noise-to-ground termination of 100 000 Ω . Other types of test equipment may be used that are of a general nature for these tests, if an appropriate technique of connection and result analysis is used.

In fact, the use of spectrum analyzers and oscilloscopes may greatly enhance the analysis of a complex waveform. The C-message frequency response individual weightings are listed in Table 3.

Volts (V), dBm, dBrn, and dBv are the most common units used by this type of test equipment. The definition of decibel is ten times the common log of the ratio of two powers:

$$\text{dB} = 10 \cdot [\log (\text{power } 1 / \text{power } 2)] \quad (\text{Eq } 3)$$

If there is an identical circuit terminating impedance, the definition may be changed to twenty times the ratio of two voltages or currents.

$$\text{dB} = 20 \cdot [\log (\text{voltage } 1 / \text{voltage } 2)] \quad (\text{Eq } 4)$$

$$\text{voltage } 1 = 10^{(\text{dB} / 20)} \cdot \text{voltage } 2 \quad (\text{Eq } 5)$$

When the reference power is 1 mW and the impedance is 600 Ω (an impedance commonly used in voice band telecommunication practice) the reference voltage is 0.775 V and the unit is dBm (decibel referenced to 1 mW). When the reference power is 1 pW with a 600 Ω impedance,

Table 2
Circuit Degradation
(Voltage by Harmonic on the Probe Wire Interface)

n	f (Hz)	$n^{(-1.7)}$	(dB)	$n^{(-2.7)}$	V_1 (V)	V_2 (V)	V_3 (V)
1	60	0.010E+02	-0.0	0.010E+02	0.033E+01	0.010E+01	0.038E+00
2	120	0.031E+01	-10.2	0.015E+01	0.051E+00	0.015E+00	0.058E-01
3	180	0.015E+01	-16.2	0.051E+00	0.017E+00	0.051E-01	0.020E-01
4	240	0.095E+00	-20.4	0.024E+00	0.079E-01	0.024E-01	0.090E-02
5	300	0.065E+00	-23.7	0.013E+00	0.043E-01	0.013E-01	0.049E-02
6	360	0.048E+00	-26.4	0.079E-01	0.026E-01	0.079E-02	0.030E-02
7	420	0.037E+00	-28.6	0.052E-01	0.017E-01	0.052E-02	0.020E-02
8	480	0.029E+00	-30.6	0.036E-01	0.012E-01	0.036E-02	0.014E-02
9	540	0.024E+00	-32.3	0.027E-01	0.088E-02	0.027E-02	0.010E-02
10	600	0.020E+00	-33.9	0.020E-01	0.066E-02	0.020E-02	0.076E-03
11	660	0.017E+00	-35.3	0.015E-01	0.051E-02	0.015E-02	0.058E-03
12	720	0.015E+00	-36.6	0.012E-01	0.041E-02	0.012E-02	0.046E-03
13	780	0.013E+00	-37.7	0.098E-02	0.033E-02	0.098E-03	0.037E-03
14	840	0.011E+00	-38.8	0.080E-02	0.027E-02	0.080E-03	0.030E-03
15	900	0.010E+00	-39.9	0.067E-02	0.022E-02	0.067E-03	0.025E-03
16	960	0.090E-01	-40.8	0.056E-02	0.019E-02	0.056E-03	0.021E-03
17	1020	0.081E-01	-41.7	0.048E-02	0.016E-02	0.048E-03	0.018E-03
18	1080	0.073E-01	-42.5	0.041E-02	0.014E-02	0.041E-03	0.015E-03
19	1140	0.067E-01	-43.3	0.035E-02	0.012E-02	0.035E-03	0.013E-03
20	1200	0.061E-01	-44.1	0.031E-02	0.010E-02	0.031E-03	0.012E-03
21	1260	0.057E-01	-44.8	0.027E-02	0.090E-03	0.027E-03	0.010E-03
22	1320	0.052E-01	-45.5	0.024E-02	0.079E-03	0.024E-03	0.090E-04
23	1380	0.048E-01	-46.1	0.021E-02	0.070E-03	0.021E-03	0.080E-04
24	1440	0.045E-01	-46.8	0.019E-02	0.062E-03	0.019E-03	0.071E-04
25	1500	0.042E-01	-47.4	0.017E-02	0.056E-03	0.017E-03	0.064E-04
26	1560	0.039E-01	-47.9	0.015E-02	0.050E-03	0.015E-03	0.057E-04
27	1620	0.037E-01	-48.5	0.014E-02	0.045E-03	0.014E-03	0.052E-04
28	1680	0.035E-01	-49.0	0.012E-02	0.041E-03	0.012E-03	0.047E-04
29	1740	0.033E-01	-49.6	0.011E-02	0.037E-03	0.011E-03	0.043E-04
30	1800	0.031E-01	-50.1	0.010E-02	0.034E-03	0.010E-03	0.039E-04
31	1860	0.029E-01	-50.5	0.094E-03	0.031E-03	0.094E-04	0.036E-04
32	1920	0.028E-01	-51.0	0.086E-03	0.029E-03	0.086E-04	0.033E-04
33	1980	0.026E-01	-51.5	0.079E-03	0.026E-03	0.079E-04	0.030E-04
34	2040	0.025E-01	-51.9	0.073E-03	0.024E-03	0.073E-04	0.028E-04
35	2100	0.024E-01	-52.3	0.068E-03	0.023E-03	0.068E-04	0.026E-04
36	2160	0.023E-01	-52.7	0.063E-03	0.021E-03	0.063E-04	0.024E-04
37	2220	0.022E-01	-53.1	0.058E-03	0.019E-03	0.058E-04	0.022E-04
38	2280	0.021E-01	-53.5	0.054E-03	0.018E-03	0.054E-04	0.021E-04
39	2340	0.020E-01	-53.9	0.051E-03	0.017E-03	0.051E-04	0.019E-04
40	2400	0.019E-01	-54.3	0.047E-03	0.016E-03	0.047E-04	0.018E-04
41	2460	0.018E-01	-54.6	0.044E-03	0.015E-03	0.044E-04	0.017E-04
42	2520	0.017E-01	-55.0	0.041E-03	0.014E-03	0.041E-04	0.016E-04
43	2580	0.017E-01	-55.3	0.039E-03	0.013E-03	0.039E-04	0.015E-04
44	2640	0.016E-01	-55.7	0.037E-03	0.012E-03	0.037E-04	0.014E-04
45	2700	0.015E-01	-56.0	0.034E-03	0.011E-03	0.034E-04	0.013E-04
46	2760	0.015E-01	-56.3	0.032E-03	0.011E-03	0.032E-04	0.012E-04
47	2820	0.014E-01	-56.7	0.031E-03	0.010E-03	0.031E-04	0.012E-04
48	2880	0.014E-01	-57.0	0.029E-03	0.096E-04	0.029E-04	0.011E-04
49	2940	0.013E-01	-57.3	0.027E-03	0.091E-04	0.027E-04	0.010E-04
50	3000	0.013E-01	-57.6	0.026E-03	0.086E-04	0.026E-04	0.098E-05
51	3060	0.013E-01	-57.9	0.025E-03	0.082E-04	0.025E-04	0.093E-05
52	3120	0.012E-01	-58.1	0.023E-03	0.077E-04	0.023E-04	0.088E-05
53	3180	0.012E-01	-58.4	0.022E-03	0.074E-04	0.022E-04	0.084E-05
54	3240	0.011E-01	-58.7	0.021E-03	0.070E-04	0.021E-04	0.080E-05
55	3300	0.011E-01	-59.0	0.020E-03	0.067E-04	0.020E-04	0.076E-05
56	3360	0.011E-01	-59.2	0.019E-03	0.063E-04	0.019E-04	0.072E-05
57	3420	0.010E-01	-59.5	0.018E-03	0.060E-04	0.018E-04	0.069E-05
58	3480	0.010E-01	-59.8	0.017E-03	0.058E-04	0.017E-04	0.066E-05
59	3540	0.098E-02	-60.0	0.017E-03	0.055E-04	0.017E-04	0.063E-05
60	3600	0.095E-02	-60.3	0.016E-03	0.053E-04	0.016E-04	0.060E-05
61	3660	0.092E-02	-60.5	0.015E-03	0.050E-04	0.015E-04	0.057E-05
62	3720	0.090E-02	-60.7	0.014E-03	0.048E-04	0.014E-04	0.055E-05
63	3780	0.087E-02	-61.0	0.014E-03	0.046E-04	0.014E-04	0.053E-05
64	3840	0.085E-02	-61.2	0.013E-03	0.044E-04	0.013E-04	0.050E-05

V_1 = Zone 1 threshold voltage (0–15 kft)
 V_2 = Zone 2 threshold voltage (15–50 kft)
 V_3 = Zone 3 threshold voltage (> 50 kft)

n = number of harmonic
 f = frequency of harmonic
dB = the decibel reduction equivalent of n raised to the -1.7 power

Table 3
C-Message Weighting

Harmonic <i>n</i>	<i>f</i> (Hz)	(dB)	Voltage Multiplier
1	60	-55.7	0.00167
2	120	-35.5	0.01667
3	180	-29.6	0.03333
4	240	-21.2	0.08750
5	300	-16.5	0.15000
6	360	-13.1	0.22222
7	420	-10.2	0.30952
8	480	-8.0	0.39583
9	540	-6.2	0.48889
10	600	-4.5	0.59667
11	660	-3.3	0.68485
12	720	-2.3	0.76667
13	780	-1.3	0.86154
14	840	-0.8	0.91190
15	900	-0.3	0.96667
16	960	-0.2	0.97708
17	1020	0.0	1.00000
18	1080	0.0	1.00000
19	1140	-0.1	0.98772
20	1200	-0.2	0.97667
21	1260	-0.4	0.96032
22	1320	-0.5	0.94394
23	1380	-0.7	0.92319
24	1440	-0.7	0.90278
25	1500	-1.0	0.89067
26	1560	-1.2	0.87051
27	1620	-1.3	0.86049
28	1680	-1.5	0.84048
29	1740	-1.5	0.84138
30	1800	-1.5	0.84111
31	1860	-1.5	0.84086
32	1920	-1.5	0.84063
33	1980	-1.5	0.84141
34	2040	-1.5	0.84118
35	2100	-1.5	0.84095
36	2160	-1.5	0.84074
37	2220	-1.5	0.84054
38	2280	-1.5	0.84123
39	2340	-1.5	0.84103
40	2400	-1.5	0.84083
41	2460	-1.5	0.84065
42	2520	-1.6	0.83175
43	2580	-1.7	0.82171
44	2640	-1.9	0.80379
45	2700	-2.2	0.77630
46	2760	-2.5	0.75000
47	2820	-2.8	0.72411
48	2880	-3.2	0.69167
49	2940	-3.5	0.66803
50	3000	-4.0	0.64467

the reference voltage is 0.0000245 V and the unit is dBrn (decibel reference noise). When using a measuring set incorporating a C-message network to measure dBrnC, the reference of 1 pW must be taken at 1000 Hz. The unit of dBv uses a reference of 1 V. Therefore, the common unit is the volt and may be converted to any unit for equivalence using the volt as a reference. For example:

Unit	Impedance (Ω)	Voltage 2 (V)	Power (W)
dBrn	600	24.5 (10^{-6})	(10^{-12})
dBm	600	0.775	0.001
dBv	1000	1.0	0.001

NOTE: See Appendix B for further explanation.

4.2.2 Communication Cable Measurements. The following four direct cable measurements provide information on the inductive influence:

(1) Longitudinally induced voltage to ground on cable pair

(2) The metallic voltage across the cable pair

(3) The longitudinal current on the pair

(4) The longitudinal shield current

Figure 1 is the universal test set configuration that may be used with Figs 3-7.

Voltage-to-ground measurements are typically made at the customer end with the central office end of the cable terminated to ground using a dial-up balanced termination or the equivalent shown in Fig 2. The customer end of the cable pair should be terminated to ground through 100 000 Ω . This may be done internally on some test equipment or may be accomplished using the termination shown in Fig 3. This termination in Fig 3 also allows for the simultaneous measurement of noise to ground and noise metallic.

The noise metallic measurement must be calibrated by the frequency response of the repeat coil or transformer. Note also that the repeat coil allows for measurement with a test set that is not a balanced input. When this termination is built, note that a precision of 0.0035% is required to measure balances up to 75 dB. The longitudinal termination in Fig 3 incorporates

Fig 1
Test Equipment Configuration