

IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines

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Abstract: The inductive environment that exists in the vicinity of electric power and wire-line telecommunications systems and the interfering effects that may be produced are addressed. An interface that permits either party, without need to involve the other, to verify the induction at the interface by use of a probe wire is presented. This recommended practice does not apply to railway signal circuits.

Keywords: communication lines, electric supply, inductive coordination

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Introduction

(This introduction is not a part of IEEE Std 776-1992, IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines.)

During the five years since IEEE Std 776-1987 was published, the guide has provided a useful tool for those faced with inductive coordination problems. Questions have arisen about the stringent harmonic distribution used on the probe-wire interface described in table 2. This version of IEEE Std 776 provides flexibility in the use of harmonic distributions in table 2 to match the variety of existing environments and conditions. The general section was also rewritten in an effort to make it more understandable. Other sections have also been improved editorially. These efforts and contributions were made by Dick Nelson, Harold Held, Bill McCoy, Charlie Nelson, Chrys Chrysanthou, and David Boneau.

Since the publication of joint reports of the National Electric Light Association and the Bell System during and following the 1920s, the joint responsibility of inductive coordination between power and telecommunication companies has generally been accepted. However, the need has long been recognized for one document that defines the components of interference, provides specific procedures to predict levels of interference, provides specific methods to demonstrate cause and effect relationships, and defines a threshold for initiating coordination to mitigate interference. The Longitudinal Induction Working Group, which is under the direction of the Inductive Coordination and Electrical Protection (ICEP) Subcommittee of the Transmission Systems Committee of the Communications Society, has struggled to produce a fair and equitable approach to fill this need under the leadership of three different chairs. These chairs were, first, Harold C. Held, retired from Illinois Bell Telephone Company; second, the late James R. Wilson, formerly affiliated with South Central Bell Telephone Company; and third, David Lee Boneau of Southwestern Bell Telephone Company. Major contributions to the document were made by James R. Wilson, George Benz of Southern New England Telephone Company, and David Boneau. Members of the Oklahoma Power and Communications Association (originally the Oklahoma Inductive Coordination Association) furthered the development of the document by field testing and assuring the validity of the various calculations and measurement techniques. Many others have reviewed and helped to formulate a guide that is usable by both power and telecommunication company personnel.

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Contents

1. Scope.....	1
2. References.....	1
3. General	2
3.1 Inductive interference	2
3.2 Need for coordination	3
3.3 Mutual responsibility of parties involved	3
4. The inductive environment	3
4.1 Guidelines for an acceptable environment.....	3
4.2 Methods of measurement	12
4.3 Methods of prediction	22
5. Coordination within the inductive environment	29
5.1 General Coordination Methods.....	29
5.2 Specific coordination methods.....	30
6. Administrative methods and procedures.....	32
6.1 Intercompany meetings and contacts	32
6.2 Mitigation of specific interference cases	32
7. Bibliography	34
Annex A Example calculations	35
A.1 Prediction calculations	35
A.2 Mitigation calculations.....	49
Annex B Decibel, power, and C-message noise	52

IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines

1. Scope

This recommended practice addresses the inductive environment that exists in the vicinity of electric power and wire-line telecommunications systems and the interfering effect 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 recommended practice in calculating induction between power and telecommunication lines, the concept of an interface is developed. This recommended practice permits either party, without need to involve the other, to verify the induction at the interface by use of a probe wire. This recommended practice does not apply to railway signal circuits.

2. References

This standard shall be used in conjunction with the following publications:

IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (ANSI).¹

IEEE Std 367-1987, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault (ANSI).

IEEE Std 487-1992, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations (ANSI).

IEEE Std 789-1988, IEEE Standard Performance Requirements for Communications and Control Cables for Application in High Voltage Environments (ANSI).

IEEE Std 820-1984 (Reaff 1992), IEEE Standard Telephone Loop Performance Characteristics (ANSI).

IEEE Std 1137-1991, IEEE Guide for the Implementation of Inductive Coordination Mitigation Techniques (ANSI).

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3. General

3.1 Inductive interference

Inductive interference is defined as an effect, arising from the characteristics and inductive relations of electric supply and telecommunication systems. It is of such character and magnitude that it 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:

- a) An inductive influence
- b) A coupling mechanism between two electrical systems or circuits, one of which produces the influence
- c) 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 recommended practice 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

Inductive influence is defined as those characteristics of an electric supply circuit that determine the character and intensity of the inductive field that it produces. The voltage and current 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 magnitude 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

Coupling is defined as the transfer of energy from one system to another. 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 within a grounded metallic sheath or shield, capacitive coupling generally may be considered negligible. Therefore, the coupling mechanism of primary concern will generally be the mutual inductance between an electric supply circuit or circuits and a telecommunications facility. The primary factors affecting coupling are separation of the systems, frequency of the magnetic field, and earth resistivity.

3.1.3 Susceptiveness

Susceptiveness is defined as those characteristics that determine the extent to which the service rendered by a telecommunications circuit can be adversely affected by a given longitudinal voltage or current. The existence of an inductive field and coupling with a metallic telecommunication circuit will cause longitudinal voltage to be induced in the telecommunication circuit. However, interference does not occur unless the circuit is susceptible to the induced voltage and resulting current. One kind of interference is the introduction of an unwanted signal (noise) into the circuit. The susceptiveness of the circuit to noise depends on the quality of the cable shield, the amplitude and 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) voltage is converted to metallic (differential-mode) voltage.

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. In addition, safety thresholds are to be considered.

3.2 Need for coordination

The continued successful coexistence of systems for the transmission, distribution, and utilization of electric power and telecommunications depends upon the ability of their providers to resolve problems of interference between the systems. The need for coordination between providers 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 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 these concerns are as follows:

- a) Ecological considerations, which encourages the placement of facilities on joint or adjacent rights-of-way
- b) Higher-capacity power systems serving larger loads
- c) Degradation of power quality due to the growth of nonlinear power loads
- d) The use of more susceptible electronic devices and equipment for telecommunication and signaling systems

These concerns emphasize the need for continued cooperative inductive coordination.

3.3 Mutual responsibility of parties involved

Inductive coordination is a cooperative effort in the location, design, construction, operation and maintenance of power and telecommunications systems. These efforts 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.

4. The inductive environment

4.1 Guidelines for an acceptable environment

This portion of the recommended practice will address the following:

- a) Areas of concern
- b) Threshold considerations
- c) Suggestion of a classification system
- d) Definition of the interface
- e) Establishment of an acceptable environmental threshold for positive action
- f) Susceptiveness criteria for telecommunications plant

4.1.1 Areas of concern

Three areas of consideration are as follows:

- a) Safety from electrical shock due to personal contact with telecommunications conductors
- b) The destruction of plant facilities as a result of dielectric breakdown or energy dissipation
- c) 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 susceptiveness of the telecommunication system.

4.1.2 Threshold considerations

The following is a list of threshold considerations from various standards on the telecommunications system (see table 1):

- a) *Safety.* 50 V rms continuously induced with respect to ground at 60 Hz on telecommunication facilities has historically been considered an upper threshold by many telecommunications companies in North America. 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.
- b) *Damage of installed cable.* IEEE Std 487-1992² 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 AWG
1.4 kV rms for 22 AWG
1.2 kV rms for 24 AWG
0.96 kV rms for 26 AWG

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.

- c) *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 A²s ($I^2 \cdot t$).
- d) *Circuit degradation.* IEEE Std 820-1984 states that the recommended level of noise to ground is less than or equal to 80 dBrnC. The reference also states that 81–90 dBrnC levels are considered acceptable and those in excess of 90 dBrnC are not recommended on telephone voice frequency circuits.
- e) *Circuit failure*
 - 1) The supervision on some voice frequency circuits may be adversely affected when the longitudinal current exceeds 5 mA.
 - 2) 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.

²Information on references can be found in clause 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 (V)	2 (V)	3 (V)	1 (V)	2 (V)	3 (V)
Steady State	0.3333	0.1000	0.0379	0.3333	0.1000	0.0379
	0.6667	0.2000	0.0758	0.6667	0.2000	0.0758

i = inure*c* = customer accessible

Class A = may not tolerate interruption

Class B = may tolerate interruption (self restoring)

(b) Installed cable damage				
Cable dielectric insulation	Gauge	Zone 1 (V)	Zone 2 (V)	Zone 3 (V)
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	9–24	6.6	2.0	0.76
	26	6.4	1.9	0.73

Zone 1 = 0–15 kft (0–4572 m)

Zone 2 = 15–50 kft (4572–15 240 m)

Zone 3 > 50 kft (15 240 m) (calculation based on 132 kft or 40 234 m)

(c) Equipment destruction			
		Energy dissipation $I^2 \cdot t$ 16	
Fault duration (Cycles)	Time (s)	(V)	(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	1.3330	5.54	12.39
160	2.6670	3.92	8.76
320	5.3330	2.77	6.20
640	10.6700	1.96	4.38

NOTES

1— $I^2 \cdot t$ is the same for all zones and classes.

2—Exposures are assumed to be uniform in all zones.

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:

- a) Circuit sensitivity to power fault conditions
- b) Length consideration
- c) Ability to inure (accepting an undesirable situation)
- d) Fault duration

4.1.3.1 Circuit sensitivity

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 recommended practice, those that may tolerate a fault-caused interruption will be classified “B”; those that may not are classified “A.”

4.1.3.2 Length

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 (0–4572 m)
- Zone 2 = 15–50 kft (4572–15 240 m)
- Zone 3 > 50 kft (15 240 m)

4.1.3.3 Inure

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

- i* will designate inure (50–100 steady-state V rms to ground)
- c* will designate customer access (< 50 steady-state V rms to ground)

This classification will be designated by the telecommunication facility owner.

4.1.3.4 Fault duration

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:

- a) The time to be used for each reclosure cycle is the time from the onset of the fault until the operation of the breaker.
- b) For distribution circuits, the fault currents and times for each reclosure cycle may be identical.
- c) For transmission circuits, the fault currents and times for each reclosure cycle may be different.

- d) 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.

The telecommunications company will classify a route by circuit by components (a) through (c) as listed in 4.1.3.

4.1.4 The interface

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

- a) The limiting magnitude and waveshape distortion generated by the power system
 - b) 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 (30.48 m) 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:
- 50 ft (15.24 m) to the geometric mean location of the power-line phase conductor distance, where power lines are less than 69 kV.
 - 75 ft (22.86 m) 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 $1.6 \, \Omega$.

4.1.5 Acceptable environment thresholds

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

Two harmonic distributions have been set for determining the thresholds of voltages induced on the probe wire. These two distributions form an envelope. In the 1987 version of IEEE Std 776, all harmonics were to fall below a voltage value that was taken as a percentage of 50 V. First, a distance based on the zone was divided into 100 and multiplied by 50 V for the 60 Hz threshold. Then a reduction or distribution factor was multiplied by the 60 Hz voltage limit to determine the individual harmonic voltage limit. The distribution factor was determined by raising the order of each harmonic to -2.7 . Another factor was also defined by raising the order of each harmonic to -1.7 . This distribution factor was to be used to identify an abnormal harmonic based on the actual measured value at 60 Hz. Experience has shown that these limits are more stringent than required above the 17th harmonic. In addition, the distribution factor derived from an exponent of -2.7 was based on a harmonic sum of all the harmonics exceeding the threshold. To mitigate the inequalities imposed in the 1987 version, the criteria for the threshold distributions will be set as follows:

- a) For 3 or less harmonics:
 - 1) Maximum voltage for harmonics 2 through 17 (frequency 120 Hz through 1020 Hz) should be less than the voltage derived from the distribution factor based on an exponent -2 . All other harmonics from 2 through 17 must be below the voltage level derived from the distribution factor based on an exponent of -2.7 .
 - 2) Maximum voltage for harmonics 18 through 50 (1080 Hz through 3000 Hz) should be less than the voltage derived from the distribution factor based on equation 3A. All other harmonics must

- be below the voltage level derived from the distribution factor based on equation 3B from harmonics 18 through 50.
- 3) Maximum voltage for harmonics 51 (3060 Hz) and above should not exceed the voltage level determined at 3000 Hz.
 - b) For more than 3 harmonics:
 - 1) Maximum voltage for harmonics 2 through 17 (frequency 120 Hz through 1020 Hz) should be less than the voltage derived from the distribution factor based on an exponent -2.7 Hz.
 - 2) Maximum voltage for harmonics 18 through 50 (1080 Hz through 3000 Hz), should be less than the voltage derived from the distribution factor based on equation 3B.
 - 3) Maximum voltage for harmonics 51 (3060 Hz) and above, should not exceed the voltage level determined at 3000 Hz from equation 3B.

For harmonics (n) 2 to 17 (< 3 harmonics)

$$V_d = V_p \times n^{-2} \quad (1)$$

where

- V_d is the distortion limit derived from the measured voltage at 60 Hz on the probe wire with only 3 harmonics above the limit set by -2.7 for harmonics 2–17 (frequency 120 Hz–1020 Hz)
- V_p is the maximum voltage at 60 Hz on the probe wire for the indicated zone from table 1
- n is the order of the harmonic

For harmonics (n) 2 to 17 (> 3 harmonics)

$$V_d = V_p \times n^{-2.7} \quad (2)$$

where

- V_d is the resultant voltage for harmonic n
- V_p is the maximum voltage at 60 Hz on the probe wire for the indicated zone from table 1
- n is the order of the harmonic

For harmonics (n) 18 to 50

For extension of n^{-2}

$$V_d = V_p \times \frac{1}{17^2 + n^{1.2}} \quad (3A)$$

For extension of $n^{-2.7}$

$$V_d = V_p \times \frac{1}{17^{2.7} + n^{1.2}} \quad (3B)$$

where

- V_d is the distortion limit derived from the measured voltage at 60 Hz on the probe wire between 1020 Hz and 3000 Hz
- V_p is the maximum voltage at 60 Hz on the probe wire for the indicated zone from table 1
- n is the order of the harmonic

Typically, no harmonic will exceed the 60 Hz measured value multiplied by the reciprocal of the harmonic number raised to the 1.7th power.

$$V_d = V_m \times n^{-1.7} \quad (4)$$

where

- V_d is the distortion limit derived from the measured voltage at 60 Hz on the probe wire
 V_m is the voltage at 60 Hz measured on the probe wire
 n is the order of the harmonic

Table 2 contains a listing of the voltage threshold levels by zone.

**Table 2—Circuit degradation
(voltage by harmonic on the probe wire interface)**

n	f (Hz)	< 3 Harmonics (equation 1)					> 3 Harmonics (equation 2)				
		$n^{-2.0}$	(dB)	V_1 (V)	V_2 (V)	V_3 (V)	$n^{-2.7}$	(dB)	V_1 (V)	V_2 (V)	V_3 (V)
1	60	1.000E+00	0	0.333E+00	0.100E+00	0.379E-01	0.100E+01	0	0.333E+00	0.100E+00	0.379E-01
2	120	2.500E-01	-12	0.833E-01	0.250E-01	0.948E-02	0.154E+00	-16	0.513E-01	0.154E-01	0.583E-02
3	180	1.111E-01	-19	0.370E-01	0.111E-01	0.421E-02	0.515E-01	-26	0.172E-01	0.515E-02	0.195E-02
4	240	6.250E-02	-24	0.208E-01	0.625E-02	0.237E-02	0.237E-01	-33	0.789E-02	0.237E-02	0.898E-03
5	300	4.000E-02	-28	0.133E-01	0.400E-02	0.152E-02	0.130E-01	-38	0.432E-02	0.130E-02	0.491E-03
6	360	2.778E-02	-31	0.926E-02	0.278E-02	0.105E-02	0.792E-02	-42	0.264E-02	0.792E-03	0.300E-03
7	420	2.041E-02	-34	0.680E-02	0.204E-02	0.773E-03	0.523E-02	-46	0.174E-02	0.523E-03	0.198E-03
8	480	1.563E-02	-36	0.521E-02	0.156E-02	0.592E-03	0.364E-02	-49	0.121E-02	0.364E-03	0.138E-03
9	540	1.235E-02	-38	0.411E-02	0.123E-02	0.468E-03	0.265E-02	-52	0.884E-03	0.265E-03	0.101E-03
10	600	1.000E-02	-40	0.333E-02	0.100E-02	0.379E-03	0.200E-02	-54	0.665E-03	0.200E-03	0.756E-04
11	660	8.264E-03	-42	0.275E-02	0.826E-03	0.313E-03	0.154E-02	-56	0.514E-03	0.154E-03	0.585E-04
12	720	6.944E-03	-43	0.231E-02	0.694E-03	0.263E-03	0.122E-02	-58	0.406E-03	0.122E-03	0.462E-04
13	780	5.917E-03	-45	0.197E-02	0.592E-03	0.224E-03	0.983E-03	-60	0.327E-03	0.983E-04	0.372E-04
14	840	5.102E-03	-46	0.170E-02	0.510E-03	0.193E-03	0.804E-03	-62	0.268E-03	0.804E-04	0.305E-04
15	900	4.444E-03	-47	0.148E-02	0.444E-03	0.168E-03	0.668E-03	-64	0.223E-03	0.668E-04	0.253E-04
16	960	3.906E-03	-48	0.130E-02	0.391E-03	0.148E-03	0.561E-03	-65	0.187E-03	0.561E-04	0.213E-04
17	1020	3.460E-03	-49	0.115E-02	0.346E-03	0.131E-03	0.476E-03	-66	0.159E-03	0.476E-04	0.180E-04

Table 2—Circuit degradation (Continued)
(voltage by harmonic on the probe wire interface)

n	f (Hz)	< 3 Harmonics (equation 1)					> 3 Harmonics (equation 2)				
		$\frac{1}{17^2+n^{1.2}}$ (equation 3A)	(dB)	V_1 (V)	V_2 (V)	V_3 (V)	$\frac{1}{2^{17^{2.7}+n^{1.2}}}$ (equation 3B)	(dB)	V_1 (V)	V_2 (V)	V_3 (V)
18	1080	3.114E-03	-50	0.104E-02	0.311E-03	0.118E-03	0.469E-03	-67	0.156E-03	0.469E-04	0.178E-04
19	1140	3.094E-03	-50	0.103E-02	0.309E-03	0.117E-03	0.469E-03	-67	0.156E-03	0.469E-04	0.178E-04
20	1200	3.073E-03	-50	0.102E-02	0.307E-03	0.116E-03	0.468E-03	-67	0.156E-03	0.468E-04	0.177E-04
21	1260	3.052E-03	-50	0.102E-02	0.305E-03	0.116E-03	0.468E-03	-67	0.156E-03	0.468E-04	0.177E-04
22	1320	3.032E-03	-50	0.101E-02	0.303E-03	0.115E-03	0.467E-03	-67	0.156E-03	0.467E-04	0.177E-04
23	1380	3.012E-03	-50	0.100E-02	0.301E-03	0.114E-03	0.467E-03	-67	0.156E-03	0.467E-04	0.177E-04
24	1440	2.991E-03	-50	0.997E-03	0.299E-03	0.113E-03	0.466E-03	-67	0.155E-03	0.466E-04	0.177E-04
25	1500	2.971E-03	-51	0.990E-03	0.297E-03	0.113E-03	0.466E-03	-67	0.155E-03	0.466E-04	0.176E-04
26	1560	2.951E-03	-51	0.984E-03	0.295E-03	0.112E-03	0.465E-03	-67	0.155E-03	0.465E-04	0.176E-04
27	1620	2.931E-03	-51	0.977E-03	0.293E-03	0.111E-03	0.465E-03	-67	0.155E-03	0.465E-04	0.176E-04
28	1680	2.911E-03	-51	0.970E-03	0.291E-03	0.110E-03	0.464E-03	-67	0.155E-03	0.464E-04	0.176E-04
29	1740	2.891E-03	-51	0.964E-03	0.289E-03	0.110E-03	0.464E-03	-67	0.155E-03	0.464E-04	0.176E-04
30	1800	2.872E-03	-51	0.957E-03	0.287E-03	0.109E-03	0.463E-03	-67	0.154E-03	0.463E-04	0.176E-04
31	1860	2.852E-03	-51	0.951E-03	0.285E-03	0.108E-03	0.463E-03	-67	0.154E-03	0.463E-04	0.175E-04
32	1920	2.833E-03	-51	0.944E-03	0.283E-03	0.107E-03	0.462E-03	-67	0.154E-03	0.462E-04	0.175E-04
33	1980	2.814E-03	-51	0.938E-03	0.281E-03	0.107E-03	0.462E-03	-67	0.154E-03	0.462E-04	0.175E-04
34	2040	2.795E-03	-51	0.931E-03	0.279E-03	0.106E-03	0.461E-03	-67	0.154E-03	0.461E-04	0.175E-04
35	2100	2.776E-03	-51	0.925E-03	0.278E-03	0.105E-03	0.461E-03	-67	0.154E-03	0.461E-04	0.175E-04
36	2160	2.757E-03	-51	0.919E-03	0.276E-03	0.104E-03	0.460E-03	-67	0.153E-03	0.460E-04	0.174E-04
37	2220	2.738E-03	-51	0.913E-03	0.274E-03	0.104E-03	0.460E-03	-67	0.153E-03	0.460E-04	0.174E-04
38	2280	2.720E-03	-51	0.907E-03	0.272E-03	0.103E-03	0.459E-03	-67	0.153E-03	0.459E-04	0.174E-04
39	2340	2.702E-03	-51	0.900E-03	0.270E-03	0.102E-03	0.458E-03	-67	0.153E-03	0.458E-04	0.174E-04
40	2400	2.683E-03	-51	0.894E-03	0.268E-03	0.102E-03	0.458E-03	-67	0.153E-03	0.458E-04	0.174E-04
41	2460	2.665E-03	-51	0.888E-03	0.267E-03	0.101E-03	0.457E-03	-67	0.152E-03	0.457E-04	0.173E-04
42	2520	2.648E-03	-52	0.882E-03	0.265E-03	0.100E-03	0.457E-03	-67	0.152E-03	0.457E-04	0.173E-04

Table 2—Circuit degradation (Continued)
(voltage by harmonic on the probe wire interface)

n	f (Hz)	< 3 Harmonics (equation 1)					> 3 Harmonics (equation 2)				
		$\frac{1}{17^{2.7} + n^{1.2}}$ (equation 3A)	(dB)	V_1 (V)	V_2 (V)	V_3 (V)	$\frac{1}{2^{17^{2.7} + n^{1.2}}}$ (equation 3B)	(dB)	V_1 (V)	V_2 (V)	V_3 (V)
43	2580	2.630E-03	-52	0.877E-03	0.263E-03	0.997E-04	0.456E-03	-67	0.152E-03	0.456E-04	0.173E-04
44	2640	2.612E-03	-52	0.871E-03	0.261E-03	0.990E-04	0.456E-03	-67	0.152E-03	0.456E-04	0.173E-04
45	2700	2.595E-03	-52	0.865E-03	0.260E-03	0.984E-04	0.455E-03	-67	0.152E-03	0.455E-04	0.173E-04
46	2760	2.578E-03	-52	0.859E-03	0.258E-03	0.977E-04	0.455E-03	-67	0.152E-03	0.455E-04	0.172E-04
47	2820	2.561E-03	-52	0.853E-03	0.256E-03	0.971E-04	0.454E-03	-67	0.151E-03	0.454E-04	0.172E-04
48	2880	2.544E-03	-52	0.848E-03	0.254E-03	0.964E-04	0.454E-03	-67	0.151E-03	0.454E-04	0.172E-04
49	2940	2.527E-03	-52	0.842E-03	0.253E-03	0.958E-04	0.453E-03	-67	0.151E-03	0.453E-04	0.172E-04
50	3000	2.510E-03	-52	0.837E-03	0.251E-03	0.951E-04	0.453E-03	-67	0.151E-03	0.453E-04	0.172E-04

V_1 = Zone 1 threshold voltage (0–15 kft) (0–4572 m)
 V_2 = Zone 2 threshold voltage (15–50 kft) (4572–15 240 m)
 V_3 = Zone 3 threshold voltage (> 50 kft) (15 240 m)

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

4.1.6 Susceptiveness of communications facilities

The susceptiveness of the telecommunications 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.

4.2 Methods of measurement

This portion of the recommended practice will address those measurements on telecommunications cable, loop antenna, probe wire, power-supply lines, and customer-power equipment. 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 (NMS) 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, dBm, dBrn, and dBv are the most common units used by this type of test equipment. The definition of decibel is 10 times the common log of the ratio of two powers:

$$\text{dB} = 10 \times \left[\log \left(\frac{\text{power}_1}{\text{power}_2} \right) \right] \quad (5)$$

If there is an identical circuit terminating impedance, the definition may be changed to 20 times the ratio of two voltages or currents:

$$\text{dB} = 20 \times \log \left[\frac{V_1}{V_2} \right] \quad (6A)$$

$$V_1 = 10^{\frac{\text{dB}}{20}} \times V_2 \quad (6B)$$