



IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters—10 Hz to 3 kHz

IEEE Power Engineering Society

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Abstract: Specifications that should be provided to characterize instrumentation used to measure the steady state rms value of magnetic and electric fields with sinusoidal frequency content in the range 10 Hz to 3 kHz in residential and occupational settings as well as in transportation systems are identified. The instrumentation, recommended calibration methods, and sources of measurement uncertainty are also described.

Keywords: calibration, electric field strength meters, magnetic flux density, measurements, measurement uncertainty, quasi-static fields, specifications

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Introduction

(This introduction is not part of IEEE Std 1308-1994, IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters-10 Hz to 3 kHz.)

This recommended practice identifies instrument specifications that should be provided to characterize field meters that are used to measure the root-mean-square (rms) values of electric and magnetic fields in residences, the work place, and transportation systems. Because of recent interest in power frequency and other extremely low frequency fields in the above environments, and because of the growing number of commercially available field meters, a need has developed for establishing specifications for instrumentation used to measure fields in the various mentioned settings. In addition to identifying field meter specifications that should be provided, this document includes descriptions of instrumentation, recommends methods of calibration, describes sources of measurement uncertainty, and provides guidance on determining total uncertainty. As noted in 1.2 of the Overview, while field meter specifications are identified, specific frequencies and field levels that should be used for calibration purposes and limits on measurement uncertainty are not recommended in this document. Rather, it is left to standards that describe measurement protocols for the different environments to indicate specific calibration points and uncertainty requirements.

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1. Overview

1.1 Scope

This recommended practice identifies specifications that should be provided to characterize instrumentation used to measure the steady state rms values of magnetic and electric fields with sinusoidal frequency content in the range 10 Hz to 3 kHz in residential and occupational settings as well as in transportation systems. The dynamic ranges of interest are 0.01 μT (0.1 mG) to 10 mT (100 G) and 1 V/m to 30 kV/m for magnetic and electric fields, respectively. In addition, this recommended practice

- Defines terminology
- Describes general characteristics of fields
- Surveys operational principles of instrumentation
- Indicates methods of calibration
- Identifies significant sources of error

While field meter specifications are identified, frequencies and field levels that should be used for calibration purposes, and limits on measurement uncertainty are not recommended in this standard. Rather, it is left to standards that describe measurement protocols for different environments to indicate specific calibration points and uncertainty requirements.

NOTE—For example, IEEE Std 644-1994 [B15]¹ limits the total uncertainty during calibrations of magnetic and electric field meters used in the vicinity of ac power lines to $\pm 3\%$.

However, sources of uncertainty during calibration and measurements are identified and guidance is provided on how they should be combined to determine total measurement uncertainty.

Throughout this recommended practice, the words “magnetic flux density” and “magnetic field” will be considered synonymous. In regard to electric field measurements, this recommended practice considers electric field meters that only measure the unperturbed electric field strength at a point in space (i.e., the electric field prior to the introduction of the field meter) or on conducting surfaces. Measurement protocols are not provided. Protocols for measuring electric and magnetic fields near power lines and video display terminals are described in IEEE Std 644-1994 [B15] and IEEE Std 1140-1994 [B16], respectively. Protocols for measuring only power frequency electric fields are described in IEC Publication 833 1987 [B11].

1.2 General

The increasing interest in characterizing quasi-static magnetic and electric fields in a number of environments has led to the development and marketing of many field meters with a range of specifications. Sources of quasi-static fields include devices that operate at power frequencies and produce power frequency and power frequency harmonic fields, as well as devices that produce fields that are independent of the power frequency. Examples in the latter category include video display terminals (vertical scan magnetic field), electric railroads (16.7 Hz and 25 Hz), mass transportation systems (0 Hz to 3 kHz depending on characteristics of adjustable speed drive), commercial airplanes (400 Hz), induction heaters (50 Hz to 3 kHz), and electric automobiles. Because of differences in the characteristics of the fields from sources in the various environments, e.g., frequency content, polarization, nonuniformity, and magnitude, the instrumentation requirements for measurements in the various environments will differ. While a variety of instrumentation exists to characterize these parameters, this recommended practice only pertains to the instrumentation to the extent that they measure the root-mean-square (rms) levels of the magnetic and electric fields.

2. References

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

IEEE Std 100-1992, IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).²

IEEE Std 539-1990, IEEE Standard Definitions of Terms Relating to Corona and Field Effects of Overhead Power Lines (ANSI).

¹ The numbers in brackets correspond to those bibliographical items listed in annex C.

² IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3. Definitions

For additional definitions, see IEEE Std 100-1992³ and IEEE Std 539-1990.

3.1 ac electric field strength meter: A meter designed to measure ac electric fields. Three types of electric field strength meters are available—free-body meter, ground-reference meter, and electro-optic meter.

3.2 average sensing rms detector: A detector circuit that rectifies the signal from the probe and is calibrated to give the correct rms value of a sinusoidal field at some given frequency. *See:* true rms detector.

NOTE—If there are harmonics in the field, a field meter with an average sensing rms detector will not indicate the true rms value of the field if the signal from the probe is proportional to the time derivative of the field. If the detector contains a stage of integration, the error is reduced. The error will also be a function of the phase relation between the harmonic and fundamental field components [B20], [B34].

3.3 coil probe: A magnetic flux density sensor comprised of a coil of wire that produces an induced voltage proportional to the time derivative of the magnetic flux density.

NOTES:

1—To eliminate effects due to electric field induction, it is essential that the coil of wire be shielded.

2—Since the induced voltage is proportional to the time derivative of the magnetic flux density, the detector circuit of the sensor often contains an integrating stage to recover the waveform of the magnetic field. The integrating stage is also desirable, particularly for measurements of magnetic field strength with harmonic content, since this stage (i.e., its integrating property) eliminates the excessive weighting of the harmonic components in the voltage signal produced by the probe.

3—This probe can also be used to measure static (dc) magnetic flux density if the probe is rotated at a known rate.

3.4 crosstalk: The noise or extraneous signal caused by ac or pulse-type signals in adjacent circuits (measurement of power frequency magnetic fields).

3.5 electro-optic field meter: A meter that measures changes in the transmission of light through a fiber or crystal due to the influence of the electric field.

NOTE—While there are several electro-optic methods that can be used for measuring electric fields, e.g., the Pockels effect, the Kerr effect, and interferometric techniques, this recommended practice only considers electro-optic field meters that utilize the Pockels effect.

3.6 free-body meter: A meter that measures the electric field strength at a point above the ground and that is supported in space without conductive contact to earth.

NOTE—Free-body meters are commonly constructed to measure the induced current between two isolated parts of a conductive body. Since the induced current is proportional to the time derivative of the electric field strength, the meter's detector circuit often contains an integrating stage in order to recover the waveform of the electric field. The integrated current waveform also coincides with that of the induced charge. The integrating stage is also desirable particularly for measurements of electric fields with harmonic content because this stage (i.e., its integrating property) eliminates the excessive weighting of the harmonic components in the induced current signal.

3.7 frequency response (bandwidth): The change in response (reading) of a field meter to a field of constant amplitude but different frequencies.

NOTE—The range of frequencies over which the field meter response is constant to within 3 dB is often referred to as the bandwidth of the field meter.

³ For information on references, see clause 2.

3.8 fluxgate magnetometer: An instrument for measuring magnetic fields by making use of the nonlinear magnetic characteristics of a probe or sensing element that has a ferromagnetic core.

3.9 ground reference meter: A meter that measures the electric field at or close to the surface of the ground, frequently implemented by measuring the induced current or charge oscillating between an isolated electrode and ground. The isolated electrode is usually a plate located level with or slightly above the ground surface.

NOTE—Ground reference meters measuring the induced current often contain an integrator circuit to compensate for the derivative relationship between the induced current and the electric field.

3.10 Hall-effect probe: A magnetic flux density sensor containing an element exhibiting the Hall-effect to produce a voltage proportional to the magnetic flux density.

NOTE—Hall-effect probes respond to static as well as time varying magnetic flux densities. Due to saturation problems sometimes encountered when attempting to measure small power frequency flux densities in the presence of the substantial static geomagnetic flux of the earth, Hall-effect probes have seldom been used under ac power lines.

3.11 magnetic flux density meter: A meter designed to measure the magnetic flux density.

NOTE—Several types of meters are in common use, e.g., field meters with air core coil probes, meters with Hall-effect probes, and meters that combine two coils with a ferromagnetic core as in a fluxgate magnetometer.

3.12 maximum value of magnetic field: (measurement of power frequency electric and magnetic fields from ac power lines). At a given point, the root-mean-square (rms) value of the semi-major axis of the magnetic field ellipse.

3.13 measurement uncertainty: (test, measurement, and diagnostic equipment). The limits of error about a measured value between which the true value will lie with the confidence stated.

NOTE—Uncertainty of measurement comprises, in general, many components. Some of these components may be estimated on the basis of the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. Estimates of other components can be based on experience or other information.

3.14 pass band: (1) (data transmission) A range of frequency spectrum that can pass at low attenuation. (2) (circuits and systems) A band of frequencies that pass through a filter with little attenuation (relative to other frequency bands such as a stop band).

3.15 quasi-static field: A field that satisfies the condition $f \ll c/l\pi\sqrt{2}$, where f is the frequency of the field, c is the speed of light, and l is a characteristic dimension of the measurement geometry, e.g., the distance between the field source and the measurement point.

NOTE—Power frequency magnetic and electric fields near power lines and appliances are examples of quasi-static fields.

3.16 resultant magnetic field: The magnetic field given by the expression

$$B_R = \sqrt{B_x^2 + B_y^2 + B_z^2} \quad (1)$$

where

B_x , B_y , and B_z are the rms values of the three orthogonal field components.

NOTE—The resultant magnetic field is also given by the expression:

$$B_R = \sqrt{B_{\max}^2 + B_{\min}^2} \quad (2)$$

where

$B_{\max}$ and $B_{\min}$ are the rms values of the semi-major and semi-minor axes of the magnetic field ellipse, respectively.

The resultant B_R is always $\geq B_{\max}$. If the magnetic field is linearly polarized, $B_{\min} = 0$ and $B_R = B_{\max}$. If the magnetic field is circularly polarized, $B_{\max} = B_{\min}$ and $B_R = 1.41 B_{\max}$.

3.17 spot measurement (point-in-time measurement): A measurement that is performed at some instant and point in space that does not provide information regarding temporal or spatial variations of the field.

3.18 survey meter: A lightweight battery operated meter that can be held conveniently by hand in order to conduct survey type measurements.

3.19 true rms detector (see average-sensing rms detector): A detector that contains a circuit component that performs the mathematical operation

$$\sqrt{\frac{1}{T} \int_0^T [v(t)]^2 dt} \quad (3)$$

to a periodic signal, $v(t)$

where

T is the period of the signal.

NOTE—If there are harmonics in the field and $v(t)$ is proportional to the time-derivative of the field, the detector circuit must also contain a stage of integration prior to the rms operation in order to avoid error [B13], [B34]. This type of detector gives the true rms value of a field containing harmonics provided that the frequency response of the detector is flat over the frequency range of interest. If significant levels of harmonics are present in $v(t)$, particular attention should be given to the possibility of amplifier saturation effects if the integration follows one or more stages of amplification.

4. General characteristics of magnetic and electric fields

Magnetic and electric fields produced by power lines, appliances, and transportation systems can be characterized according to their magnitude, frequency, waveform (harmonic content), degree of polarization, spatial variation, and temporal variation. These characteristics are described briefly because of their importance in specifying requirements for instrumentation used to measure the fields.

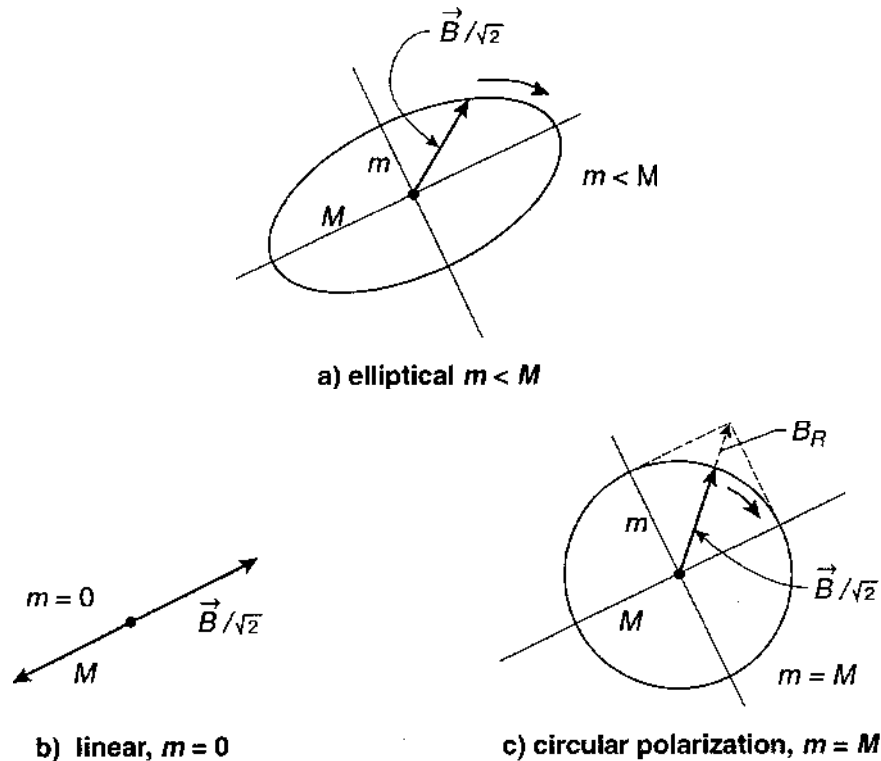
NOTE—This recommended practice does not consider transient temporal variations, i.e., events that are fast compared to the period of the magnetic and electric fields.

Several of the above field parameters can be introduced by considering magnetic fields produced by three phase power lines. Some of the same parameters are also used to characterize electric fields. In general, the magnetic field at a point can be represented as a rotating vector that traces an ellipse for every cycle of the currents in the conductors as shown schematically in figure 1a) [B4]. The rms magnitude and direction of

the semi-major axis, given by M in figure 1a), indicates the magnitude and direction of the maximum magnetic field. Similarly, the rms magnitude and direction of the semi-minor axis, given by m in figure 1a), describes the minimum magnetic field. Such fields are said to be elliptically polarized.

Because magnetic fields in environments away from power lines also can be produced by multiple current sources that are not necessarily in phase, elliptically polarized magnetic fields can occur in many settings (e.g., homes, work place). Depending on the geometry and currents in the conductors, the degree of magnetic field polarization at a point can vary from linear ($m = 0$) to circular ($m = M$) as shown in figures 1b) and 1c). This discussion of polyphase fields assumes that there are no harmonics in the field. The polarization state of fields with significant harmonic content is more complicated [B34].

Near ground level, the magnitude of the magnetic field from a three-phase transmission line changes slowly as a function of height of the measurement point above ground. For example, for a typical 500 kV line, the change in the magnetic field magnitude near ground level is less than 2% for a 10% change in the measurement height for locations underneath the line. The uniformity increases at more distant points. For locations far from the line, the magnitude of the magnetic field from a single circuit three-phase line with balanced or nearly balanced currents decreases approximately as $1/d^2$, where d is the lateral distance from the line (d is assumed to be much greater than the conductor spacing) [B29]. As the current imbalance increases, the decrease in magnetic field magnitude changes from a $1/d^2$ to a $1/d$ dependence [B29], [B37]. The magnetic field from balanced double-circuit three-phase lines with low reactance phasing (i.e., for identical or nearly identical load currents for both circuits) decreases as $1/d^3$ where d is again much larger than conductor spacing. The temporal variations of the magnetic field is a function of load current variations, e.g., during heavy usage of electrical energy, the load currents increase and produce greater magnetic fields (the concurrent sagging of the conductors also can contribute to greater field levels).



Oscillating and rotating magnetic field vectors that have been reduced in magnitude, i.e., divided by $\sqrt{2}$, at any instant for the cases of a) elliptical $m < M$, b) linear $m = 0$, and c) circular polarization $m = M$. The resultant, B_R , and the maximum magnetic field, M , are equal only for the case of linear polarization. The largest difference between the resultant and maximum magnetic field occurs for circular polarization, i.e., B_R exceeds M by 41%.

Figure 1—Oscillating and rotating magnetic field vectors

Other commonly encountered sources of magnetic fields are straight conductors (e.g., home wiring and grounding systems/electrodes) and approximately circular turns of wire (e.g., found in transformers, motors, video display terminals) with single phase currents. The magnetic field lines and vectors at representative points from such sources are shown schematically in figures 2a) and 2b). The magnetic fields are linearly polarized and the time-dependence of the oscillating vectors depends on the waveform of the currents. Sinusoidal currents produce sinusoidal magnetic fields free of harmonics and nonsinusoidal currents (e.g., the sawtooth wave forms from television deflection coils) produce non-sinusoidal magnetic fields that can be rich in harmonics [B13]. The magnitudes of magnetic fields produced by currents in a straight wire and a circular loop of wire decrease as $1/r$ [B9] and $1/r^3$ [B35], respectively, where r is the distance from the field source (in the latter case it is assumed that r is much greater than the radius of the circular loop of wire).