



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

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

IEEE Std 1308™-2023
(Revision of IEEE Std 1308-1994)

STANDARDS

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

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Abstract: Specifications that should be provided to characterize instrumentation used to measure the steady state root mean square (rms) value of magnetic and electric fields with sinusoidal frequency content in the range 10 Hz to 3 kHz are identified. The instrumentation, recommended calibration methods, and sources of measurement uncertainty are also described.

Keywords: calibration, electric field strength meters, IEEE 1308™, magnetic flux density meters, measurement uncertainty, measurements, quasi-static fields, specifications

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Introduction

This introduction is not part of IEEE Std 1308-2023, IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters—10 Hz to 3 kHz.

This recommended practice is a revision of IEEE Std 1308TM-1994 (reaffirmed 30 September 2010), which identifies specifications for field meters used to measure steady state rms values of magnetic and electric fields. The following revisions have been made and are intended to improve the usefulness of the document:

- a) Electric field strength meters are discussed before magnetic flux density meters similar to associated IEEE Std 644TM [B17].⁶
- b) Definitions are updated according to IEEE Std 539TM-2020 and recently accepted standards within the Corona and Field Effects Working Group.
- c) Figures in this recommended practice are copied from IEEE Std 1308-1994.
- d) Equations in this recommended practice are copied from IEEE Std 1308-1994 and IEEE Std 539-2020, with vector quantities shown in bold-italics.

The format of this revision is significantly changed to correspond to the new IEEE standard formatting.

⁶ The numbers in brackets correspond to those of the bibliography in [Annex A](#).

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

1. Overview

1.1 Scope

This recommended practice identifies specifications that should be provided to characterize instrumentation used to measure the steady state root mean square (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 addresses the following:

- 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.

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.

1.2 Purpose

The 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. Because of differences in the characteristics of the fields from sources in the various environments, for example, 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 rms levels of the magnetic and electric fields.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{7, 8}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

This standard does not contain any normative references.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁹ Additional definitions related to corona and field effects can be found in IEEE Std 539™ [B16].¹⁰

ac electric field strength: The electric field strength produced by ac power systems as defined by its space components along three orthogonal axes. For steady-state sinusoidal fields, each space component is a complex number or phasor.

The magnitudes of the components, expressed by their root-mean-square (rms) values in volts per meter (V/m), and the phases need not be the same. *See also:* **maximum value of the electric field strength; phasor; resultant electric field, vertical component of the electric field strength.**

NOTE 1—The space components (phasors) are not vectors. The space components have a time-dependent angle, while vectors have space angles.¹¹

For example, the sinusoidal electric field strength, E , can be expressed in rectangular coordinates as

$$\vec{E} = \hat{a}_x E_x + \hat{a}_y E_y + \hat{a}_z E_z \quad (1)$$

The space component in the x direction is

⁷ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁸ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

⁹ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

¹⁰ The numbers in brackets correspond to those of the bibliography in Annex A.

¹¹ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

$$E_x = \operatorname{Re}(E_{x0} e^{j\phi_x} e^{j\omega t}) = E_{x0} \cos(\phi_x + \omega t) \quad (2)$$

The magnitude, phase angle, and time-dependent angle are given by E_{x0} , ϕ_x , and $(\phi_x + \omega t)$, respectively. In this representation, the space angle of the x- component is specified by the unit vector $\hat{a}_x$.

NOTE 2—The magnitudes and the phase angles of the space components need not be the same.

An alternative general representation of a steady-state sinusoidal electric field strength can be derived algebraically from Equation (1). In this case, the electric field strength is a vector rotating in a plane where it describes an ellipse for which the rms value of the semi-major axis represents the magnitude and direction of the maximum value of the electric field strength, and whose semi-minor axis represents the magnitude and direction of the field a quarter cycle later (see [B1] and [B5]). This representation is perhaps more useful in characterizing power-line electric fields where the electric field's strength values along the direction of the line are small and can usually be neglected. Thus, the electric field strength vector from a power line with parallel conductors is assumed to sweep out an ellipse in a vertical plane perpendicular to the direction of the power line.

For nonparallel conductors, the electric field strength vector describes an ellipse, but the plane of the ellipse may not be vertical. This ellipse may degenerate into a straight line. *See also: single-phase ac fields; polyphase ac fields.*

The use of the term *ac electric field* is deprecated.

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.

ac power-line fields: Power frequency electric and magnetic fields produced by ac power lines.

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 (see [B23] and [B39]).

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.

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

NOTE 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 flux density. The integrating stage is also desirable, particularly for measurements of the magnetic flux density 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.

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

crosstalk: The noise or extraneous signal caused by ac or pulse-type signals in adjacent circuits.

electric field strength meter: An instrument used to measure electric field strength.

electric flux density (D): A vector quantity related to the charge displaced within the medium by an electric field. The electric flux density is that function whose divergence is the charge density.

electric potential difference: The line integral of the scalar product of the electric field strength vector and the unit vector along any path from one point to the other, in an electric field resulting from a static distribution of electric charge. *Syn: electrostatic potential difference.*

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. *Syn:* **optical field strength meter.**

NOTE 1—Several electro-optic methods can be used for measuring electric fields, e.g., the Pockels effect, the Kerr effect, and interferometric techniques.

NOTE 2—Optical electric field strength meters can be used to implement free-body or ground reference measurements.

NOTE 3—When optical fibers are used, the probe is inherently electrically isolated from ground.

field uniformity: The extent to which the magnitude and direction of the field strength, or flux density, are the same at all points within a defined region.

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.

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 strength. The integrated current waveform also coincides with that of the induced charge. The integrating stage is also desirable, particularly for measurements of electric field strength with harmonic content, because this stage (i.e., its integrating property) eliminates the excessive weighting of the harmonic components in the induced current signal.

frequency: The number of complete cycles of sinusoidal variation per unit time.

NOTE 1—Electric and magnetic field components have a fundamental frequency equal to that of the power line voltages and currents.

NOTE 2—For ac power lines, the most widely used frequencies are 60 Hz and 50 Hz.

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.

ground reference meter: A meter that measures the electric field strength 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 strength.

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 density. 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.

harmonic content: Distortion of a sinusoidal waveform characterized by the magnitude and the order of the Fourier series terms that describe the wave.

NOTE—For power lines, the harmonic content is typically small and of little concern for the purpose of field measurements, except at points near large industrial loads (saturated power transformers, rectifiers, aluminum and chlorine plants, etc.), where certain harmonics may reach 10% of the line voltage. Power equipment such as dc-to-ac and ac-to-dc converters also may produce harmonics. Laboratory installations may also have voltage or current sources with significant harmonic content.

magnetic flux density: The vector quantity, often denoted as **B**, of zero divergence at all points, which determines the component of the Coulomb-Lorentz force that is proportional to the velocity of a moving charge. *See also:* **single-phase ac fields; resultant magnetic field; polyphase ac fields; phasor; maximum value of magnetic field.**

NOTE 1—In a zero electric field, the force, **F**, is given by

$$\mathbf{F} = q\bar{\mathbf{v}} \times \mathbf{B} \quad (3)$$

where

$\bar{\mathbf{v}}$ is the velocity of the electric charge q

The vector properties of the magnetic flux density produced by currents in power-line conductors are the same as those given for the **ac electric field strength**. The unit for the magnitude of the magnetic flux density components is the tesla (T).

NOTE 2—Some documents may refer to the magnitude of the magnetic flux density using gauss for the units. The unit gauss is related to the unit tesla by the equation $1 \text{ T} = 10^4 \text{ gauss}$.

NOTE 3—For time-varying (ac) fields, values are expressed as their rms values unless stated otherwise.

NOTE 4—Though they are used often, the use of *magnetic field* or *magnetic flux density field* is deprecated in favor of magnetic flux density.

magnetic flux density meter: A meter designed to measure the magnetic flux density. These meters may use any of several types of flux density sensors or probes.

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.

maximum value of the electric field strength: At a given point, the rms value of the semi-major axis magnitude of the ac electric field strength ellipse. *See also:* **ac electric field strength.**

NOTE 1—The maximum value of the field strength is sometimes referred to as the *peak field strength* when performing measurements of the field strength. The use of the term *peak field strength* or *peak field* is discouraged when referring to the maximum rms value of the field strength.

NOTE 2—It is the largest rms value of the field strength that can be measured at that point with a single-axis meter. The maximum value of the field strength takes into consideration the phase angles of the field strength components.

maximum value of the magnetic field: At a given point, the rms value of the semi-major axis magnitude of the magnetic flux density ellipse. *See also:* **magnetic flux density.**

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.

pass band: (A) (data transmission) A range of frequency spectrum that can pass at low attenuation. (B) (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).

peak value of the field strength: At any given point, the largest instantaneous magnitude (positive or negative excursion) of the time-varying quantity.

NOTE 1—The peak value of the field strength (electric field strength or magnetic field strength) is sometimes used when referring to the maximum value of the field strength when performing field strength measurements. This misuse should be avoided to prevent confusion.

NOTE 2—This definition can be applied to the *peak value of the electric flux density*, D , and to the *peak value of magnetic flux density*, B , as well.

perturbed field: A field that is changed in magnitude or direction, or both, by the introduction of an object.

NOTE 1—The electric field at the surface of the object is, in general, strongly perturbed by the presence of the object. At power frequencies, the magnetic field strength is not, in general, greatly perturbed by the presence of objects that are free of magnetic materials. Exceptions to this are regions near the surface of thick electric conductors where eddy currents alter time-varying magnetic fields.

NOTE 2—The electric field strength at ground level under dc transmission lines is generally increased due to the presence of monopolar space charge having the same polarity as the nearest conductor. This increase is generally termed *field enhancement*.

phasor: A complex number expressing the magnitude and phase of a time-varying quantity. Unless otherwise specified, it is used only within the context of steady-state alternating linear systems. In polar coordinates, it can be written as $Ae^{j\phi}$, where A is the amplitude or magnitude (usually rms, but sometimes indicated as peak value) and ϕ is the phase angle. The phase angle ϕ should not be confused with the space angle of a vector. *See also:* **ac electric field strength; magnetic flux density.**

polyphase ac fields: Fields whose space components may not be in phase. These fields are produced by polyphase power lines. The field at any point can be described by the field ellipse—that is, by the magnitude and direction of the semi-major axis and the magnitude and direction of its semi-minor axis. *See also:* **ac electric field strength; magnetic flux density.**

NOTE—Such fields are sometimes referred to as being elliptically polarized. Certain power line geometries can produce circularly polarized fields. For polyphase power lines, the electric or magnetic field at large distances (≥ 15 m) away from the outer phases (conductors) can frequently be considered a single-phase field because the minor axis of the field ellipse is only a fraction ($< 10\%$) of the major axis when measured at a height of 1 m above ground level.

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 are examples of quasi-static fields.

resultant electric field: The resultant electric field is given by

$$Q_R = \sqrt{Q_x^2 + Q_y^2 + Q_z^2} \quad (4)$$

where

Q_x , Q_y , and Q_z are the rms values of the three orthogonal field strength components

NOTE—The resultant electric field is also given by the expression

$$Q_R = \sqrt{Q_{\max}^2 + Q_{\min}^2} \quad (5)$$

where

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