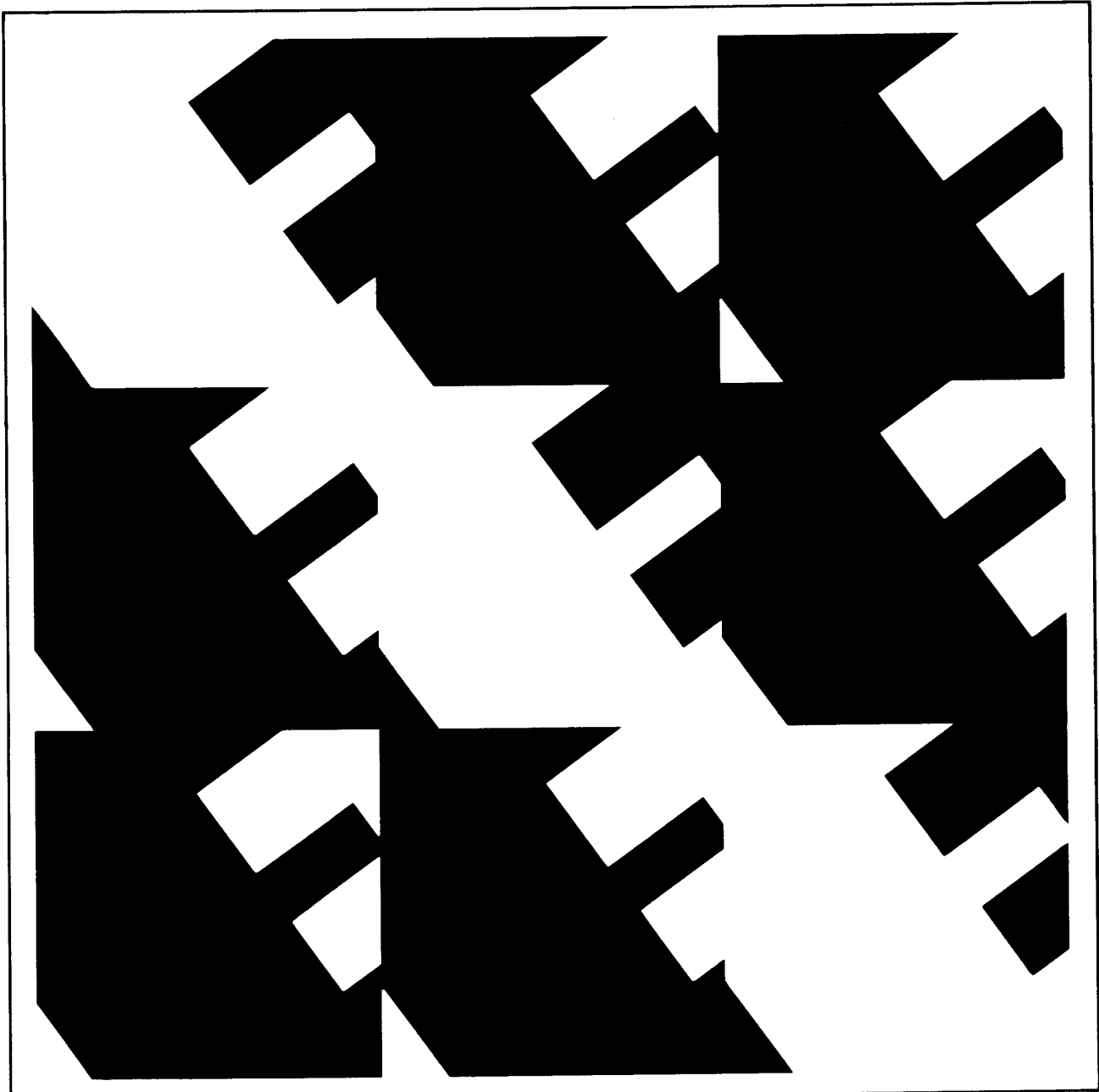


IEEE Standard Methods for Measuring
Electromagnetic Field Strength for
Frequencies Below 1000 MHz in
Radio Wave Propagation



IEEE Std 302-1969



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA

SH01917

ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge, and have conducted experimental work on which many of the IEEE publications are based.

The following members of the Wave Propagation Committee of the IEEE Antennas and Propagation Group were the main contributors to this publication:

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Reaffirmed May 21, 1981

IEEE Standards Board

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IEEE Standard Methods for Measuring ELECTROMAGNETIC FIELD STRENGTH FOR FREQUENCIES BELOW 1000-MHz IN RADIO WAVE PROPAGATION

1. INTRODUCTION

1.1 General. Most measurements with which radio wave propagation is concerned involve the measurement of field strength. Standard methods for the measurement of this fundamental quantity for frequencies below 1000 megahertz are described.

1.2 Symbols and Units. The general symbols used are given in the following list, together with units to be used in those equations containing numerical coefficients. When more specific or restrictive meanings are indicated by subscripts, etc., they are further defined after the equation in which used. In some cases a symbol definition is repeated where used, merely for convenience.

- C = Capacitance (farads).
- d = Distance from transmitter to receiver (meters).
- D = Conductor diameter of dipole antenna (meters).
- E = Root-mean-square electric field strength of a radio wave (volts per meter).
- f = Frequency (hertz).
- H = Root-mean-square magnetic field strength (amperes per meter).
- h = Height above ground of antenna center of radiation (meters).
- I = Root-mean-square antenna current (amperes).
- K = Calibration factor of a commercial field-strength meter.
- l_D = Effective length of dipole antenna (meters).
- L_D = Physical length of a linear dipole antenna (meters).
- l_L = Effective length of loop antenna (meters).
- l_v = Effective length of grounded vertical antenna (meters).
- L_v = Physical length of grounded vertical antenna (meters).
- N = Number of turns.
- P = Power (watts).
- Q = 2π times the ratio of energy stored to energy dissipated per cycle (Q is normally expressed as ratio of inductive reactance to resistance at resonance).
- R = Resistance (ohms).
- r_t = Radius of the transmitting loop antenna (meters).
- r_r = Radius of the receiving loop antenna (meters).
- S = Area of the transmitting or receiving loop antenna (square meters).
- V = Root-mean-square voltage (volts).
- α = Attenuator ratio (equal to or greater than unity).
- λ = Wavelength (meters).

- ϵ_r = Relative permittivity of the ground, i.e., the ratio of permittivity (dielectric constant) of ground to that of vacuum.
- σ = Ground conductivity (mhos per meter).
- c = Velocity of propagation of an electromagnetic wave in a vacuum [$(2.997925 \pm 0.000003) \times 10^8$ meters per second].
- Z_0 = Impedance of free space ($4\pi c \times 10^{-7} = 376.7304 \pm 0.0004$ ohms).

Unless otherwise stated, units are assumed to be those of the International System. For convenience several relationships and prefixes are tabulated below.

- | | |
|--|----------------------|
| 1 inch = 0.0254 meter | |
| 1 mile = 1609.344 meters | |
| 1 meter = 0.0006213712 mile | |
| 1 square inch = 0.00064516 square meter | |
| 1 square meter = 1550.0031 square inches | |
| pico (p) = 10^{-12} | deka (da) = 10^1 |
| nano (n) = 10^{-9} | hecto (h) = 10^2 |
| micro (μ) = 10^{-6} | kilo (k) = 10^3 |
| milli (m) = 10^{-3} | mega (M) = 10^6 |
| centi (c) = 10^{-2} | giga (G) = 10^9 |
| deci (d) = 10^{-1} | tera (T) = 10^{12} |

2. METHODS OF MEASURING FIELD STRENGTH

2.1 General. Two general methods are applicable to the measurement of field strength [1]–[4]. One consists of measuring the voltage induced in a standard antenna by the field to be measured and computing the field strength from the measured voltage and the dimensions and form of the standard antenna. The other consists of comparing voltages produced in an antenna by the field to be measured and by a standard field, the magnitude of which is computed from the dimensions of the transmitting antenna, its current distribution, the distance of separation, and effect of the ground. The measuring sets for the two methods are of the same general form. For the standard-antenna method there are special requirements for the receiving antenna and the voltage-measuring equipment. Field-strength measurements or surveys are often made using commercially available meters that have been previously calibrated* in a known field determined by either of these methods.

* A public calibration service is maintained by the National Bureau of Standards for field-strength meters in the frequency range of 30 hertz to 1000 megahertz. For information write:

Coordinator, Calibration Services
Radio Standards Engrg. Div.
National Bureau of Standards
Boulder, Colo. 80302

2.1.1 Standard-Antenna Method. In the standard-antenna method [2], [3], [5], the receiving antenna is of some standard form such that the voltage induced in it by a wave of given field strength and polarization may be computed readily [5]. The ratio of this voltage to the component of the field producing it is called the effective length of the antenna, i.e.,

$$l = V/E. \quad (1)$$

The method of coupling the standard antenna to the voltage-measuring instrument is generally such that the voltage measured is not the voltage induced in the antenna by the field but bears a fixed ratio to it. The ratio of the voltage measured to the voltage induced in the antenna by the field is called the voltage-transfer ratio; its magnitude is dependent upon the point of introduction of the calibrating voltage into the measuring circuit. Separate determination of this ratio may be required in some instances.

A standard voltage source is provided, usually as part of the field-strength measuring apparatus, for calibrating the voltmeter. The term "voltmeter" is here used to mean the radio receiving portion of the equipment. The calibrating voltage may be fixed or it may be adjustable over a wide range. It may be inserted in series with the standard antenna or at some point in the coupling circuit, or it may be applied to the input terminals of the voltmeter in place of the coupling circuit. When a fixed calibrating voltage is employed, the voltmeter is calibrated at a fixed sensitivity level, and a calibrated attenuator is employed in conjunction with the voltmeter in order to measure voltages over the wide range required. Alternatively, the attenuator may be included in the standard voltage source. The calibrating voltage is then itself variable over a wide range and the voltmeter is calibrated at sensitivities corresponding to the voltages being measured. In either case, the measurement resolves itself into the comparison of two voltages, the known voltage and the voltage produced by the field, generally introduced at different points in the measuring circuit. The method used in determining the voltage-transfer ratio is generally dependent upon the particular form of antenna and the circuit arrangement employed.

The field strength is computed on the basis of the effective length of the antenna, the voltage-transfer ratio, the voltage from the standard voltage source, and the attenuator ratio. In some instances it may be difficult to calculate accurately the effective length of the antenna being used. In such cases the product of the effective length and the voltage-transfer ratio can be determined directly from a single measurement of the terminal voltage of the antenna when placed in a standard field. The reciprocal of this product is sometimes called the antenna coefficient. This is the procedure usually followed in the calibration of commercial field-strength meters. In this case the value of the "antenna coefficient" determined usually includes the gain factor of the receiver.

2.1.2 Standard-Field Method. In the standard-field method the standard field may be set up by a local transmitter. The field at the receiving antenna may be computed from the dimensions of the transmitting antenna its current and current distribution, the distance, and the effect of the ground, or may be determined by direct measurement with a standard antenna [1]–[3]. The measuring equipment associated with the receiving antenna generally consists of a sensitive frequency-selective voltmeter having an output indicator. While it is possible to adjust the strength of the standard field to equality with the field to be measured by varying the distance of the local transmitter, it is usually more convenient to include an attenuator in the measuring equipment for comparing the voltages produced by the known and unknown field, and hence the two fields. When the angles of arrival of the standard and measured fields differ, a correction must be applied for any resultant difference in the voltages caused by directivity of the receiving antenna and effects of the ground.

2.1.3 Simplifications and Precautions. The problem of field-strength measurement is generally complicated by the varying nature of the field resulting from variability of the transmission medium [6]–[9], by the complex nature of the emission [10], [11], and by the influence of the ground and of disturbing structures [11]–[15]. Simplifying approximations are introduced into measurement methods to keep the measuring apparatus from becoming unduly complex or unduly difficult to use or to facilitate analysis of the data.

In the case of ionospheric- or tropospheric-wave fields, a really complete measurement would involve determination of:

- (a) the field strength of the vertical, longitudinal, and lateral electric and magnetic field components in each wave arriving at the receiving point;
- (b) the phase angles between the different components;
- (c) the direction of arrival of each wave component.

Fortunately, considerable practical information may be obtained by measuring only the vector components of the field [16], which are used for communication. Simple forms of receiving antennas thus become useful, the type of antenna used being dependent upon the component of the field to be measured.

A simplification in the measurement of complex emissions may be achieved by removing the modulation so that a single-frequency field (the carrier) is measured. In emissions without a carrier wave, such as a single-sideband wave, it is sometimes desirable to restrict the modulation to a single frequency, so that a single-frequency field is again measured. Occasions arise, however, when it is necessary to retain the normal modulation; for example, when considering the interfering effect of the cross-modulation products of an amplitude-modulated wave or the interfering effect of single-sideband emission. When measuring