

NBS CIRCULAR *517*

**Calibration of Commercial  
Radio Field-Strength Meters  
at the National Bureau of Standards**

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[Continued on cover page 3]

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# Calibration of Commercial Radio Field-Strength Meters at the National Bureau of Standards

Frank M. Greene



National Bureau of Standards Circular 517

Issued December 1951

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For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.  
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# Calibration of Commercial Radio Field-Strength Meters at the National Bureau of Standards

By Frank M. Greene

A brief description is given of the standards and methods used in the calibration of commercial radio field-strength meters at the National Bureau of Standards in the frequency range 10 kc to 300 Mc. A calibration consists in part of measuring the over-all linearity of the field-strength meter at one or more frequencies and radio-frequency input voltage levels, and in measuring the internal attenuator ratios at one or more frequencies in terms of precision dissipative-type step attenuators, as well as precision mutual-inductance attenuators, depending upon the frequency being used. The remainder of the calibration consists in determining the so-called antenna coefficient or correlation factor of the set relating field strength to the output meter reading. Below about 30 Mc this is done only for sets using loop antennas in terms of a quasi-static magnetic field produced by a single-turn balanced transmitting loop. Above this frequency for sets using only dipole antennas a locally generated radiation field is used and is evaluated in terms of the electromotive force induced in a horizontal receiving dipole. The accuracies of the various parts of the calibration are discussed for different portions of the above frequency range.

## 1. General

The National Bureau of Standards offers a calibration service<sup>1</sup> for certain types of radio field-strength meters in the frequency range 10 kc to 300 Mc. The calibration consists in measuring the over-all linearity of the instrument at one or more frequencies and radio-frequency (r-f) levels, measuring the internal attenuator ratios at one or more frequencies, and measuring the so-called antenna coefficient or correlation factor relating field strength to the output meter reading under

specified conditions of set gain at specified frequencies. All measurements are made in terms of sinusoidal voltages or currents.

In developing the equations used in this paper for determining field strength, the practical rationalized mks units have been used. This is in agreement with recent international action.

<sup>1</sup> For further information and calibration fees, write to Director, National Bureau of Standards, Washington 25, D. C.

## 2. Measurement of Linearity and Attenuator Ratios

Those quantities involving only r-f voltage ratios are measured in terms of precision dissipative step attenuators or precision mutual-inductance (waveguide-below-cutoff) attenuators, depending on frequency. Use is made of two types of dissipative attenuators comprising "Pi" or "T" sections, one employing wire-wound resistance elements for frequencies below 1 or 2 Mc, the other using coaxial sections of evaporated or deposited metal film for frequencies up to 300 Mc. These step attenuators are standardized on direct current and their ratios determined to within 0.1 percent. Frequency corrections are determined by comparing one standard attenuator used at signal frequency against another used at the intermediate frequency in a receiver. Cross checks are made against the standard mutual-inductance attenuator at frequencies above about five megacycles.

This type of attenuator<sup>2</sup> serves as a primary reference standard, since the attenuation is a function only of its linear dimensions which can be precisely determined. The TE<sub>1,1</sub> mode of excitation is used, the higher order unwanted modes being reduced by means of a strip filter. Errors resulting from the finite conductivity of the cylinder wall, and from the proximity of the operating frequency to the cut-off frequency are less than 0.1 db in a 60-db range in the HF band (3 to 30 Mc) and the VHF band (30 to 300 Mc) and can usually be neglected.

Since the over-all linearity of a field-strength meter will in general be a function of both frequency and r-f input level, it is necessary to determine this dependence. Fortunately, this effect

<sup>2</sup> R. E. Grantham and J. J. Freeman, A standard of attenuation for microwave measurements, Trans. AIEE 67, 535 (1948).



FIGURE 1. Calibration of the internal attenuators and linearity of a commercial field-strength meter.

is usually limited to the highest attenuator steps in those types of sets having intermediate-

frequency attenuators only. The departure from linearity has been found in general to be less than 2 percent if the signal voltage applied to the mixer grid does not exceed about 5 percent of the injected local oscillator voltage. For practical and economical reasons it is necessary to limit linearity checks on the attenuator steps in question to one or two frequencies as specified by the user.

For those sets also employing r-f attenuators in the antenna input circuit it is necessary to ensure that these ratios are measured under actual operating conditions. Those r-f attenuator steps which may be affected by the changing source impedance of the antenna, or the changing input admittance of the first r-f stage with frequency, are measured with the antenna placed in a field which can be attenuated in known ratios.

The voltage linearity and attenuator ratio measurements made on field-strength meters are usually certified to  $\pm 2$  percent. The equipment used is shown in figure 1.

### 3. Measurement of Antenna Coefficients From 10 kc to 30 Mc

At the present time the National Bureau of Standards certifies only field-strength meters using loop antennas below about 30 Mc. The calibration is made in terms of a standard free-space quasi-static magnetic field produced by a single-turn, unshielded, balanced, transmitting loop of known radius and with a known current flowing. The current is measured by means of a vacuum thermocouple<sup>3</sup> at the loop center, which was previously standardized on direct current, the d-c output of the thermocouple being measured by means of a precision slide-wire potentiometer. The frequency error of the type of thermocouple used for this purpose has been found to be less than 1 percent at frequencies even as high as 100 Mc when used in a balanced circuit with the thermocouple at essentially ground potential.

The magnitude of the field strength produced by a single-turn circular transmitting loop is given by eq (1) for the case of coaxial transmitting and receiving loops as shown in figure 2. The actual value of the quasi-static magnetic field,  $H$ , produced by the loop is expressed in terms of the equivalent electric component,  $E$ , that would exist in a free-space radiation field. The relationship used is  $E=ZH$ , where  $Z$  is the impedance of free space ( $Z=376.7$  ohms).

$$|E| \cong \frac{60\pi r_1^2 I}{(d^2 + r_1^2 + r_2^2)^{3/2}} \sqrt{1 + \left(\frac{2\pi d}{\lambda}\right)^2} \quad (1)$$

where

$E$  = equivalent free-space electric field strength in rms volts per meter

$r_1$  = radius of transmitting loop, meters. To keep a uniform current in the transmitting loop make  $2\pi r_1 < \lambda/8$

<sup>3</sup> This refers to a four-terminal unit having an r-f heater electrically insulated from the thermocouple.

$r_2$  = radius of receiving loop, meters. If receiving loop is rectangular use equivalent radius of circle having same area  
 $d$  = axial spacing (meters) between coaxial loops (make  $d > 7r_1$  and  $d > 7r_2$ )  
 $I$  = transmitting loop current, rms amperes  
 $\lambda$  = free-space wavelength in meters.

The value of field given by eq (1) is essentially independent of frequency up to about 5 Mc, above which the frequency correction term under the radical (the induction-field component) begins to become appreciable for the spacing used in the NBS standard ( $d \cong 1.25$  m). The value of field strength used for calibration is of the order of 0.1 v/m, ( $r_1=0.1$  m,  $I=0.1$  amp).

The magnitude of the field,  $|E|$ , predicted by eq (1) was verified at several frequencies up to 30 Mc by measuring the electromotive force,  $e$ , induced in a single-turn untuned balanced receiving loop immersed in the field. The relationship used was

$$|E| = \frac{e}{l_L} \quad (2)$$

where  $l_L$  is the effective length of the single-turn loop in meters.

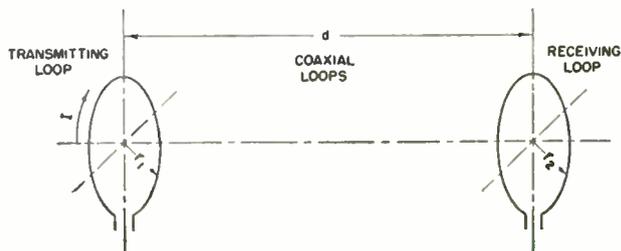


FIGURE 2. Loop-antenna calibration.

$$l_L = \frac{2\pi A}{\lambda}, \quad (3)$$

where  $A$  is the loop area in square meters, and  $\lambda$  is the operating wavelength in meters. Agreements were obtained between these two methods of determining the field to within 3 percent.

It is known that the case of the field-strength meter will distort the field being measured. There is reason to believe that this distortion will not be the same when the instrument is placed in the above quasi-static field ( $E \propto 1/d^3$ ) as when placed near the ground in a radiation field, ( $E \propto 1/d^2$ ), where usually  $1 \leq x \leq 2$  for plane earth depending upon frequency, distance, and the ground constants.<sup>4</sup> It is believed that this difference is probably not great. Previous comparisons of instruments calibrated in both types of fields have agreed to within considerably better than 5 percent at broadcast frequencies. However, orientation of the receiving loop antenna relative to the instrument case must be specified since if later used in other positions an error of as much as 5 to 10 percent may be introduced into subsequent measurements depending upon the height of the loop above the case.<sup>5</sup> This error is usually negligible if this height is greater than the loop diameter. It does not appear feasible to attempt to establish standard radiation fields using the standard-field method at frequencies much below 30 Mc because of the difficulties in accurately taking into account the ground effects.

In calibrating a field-strength meter by means of eq (1), the setup is made in a cleared space as shown in figure 3 such that a distance of at least two or three times the loop spacing,  $d$ , exists to the nearest sizable metallic objects and to the ground. Their effect in distorting the field can be estimated by moving up metal objects of similar size and noting the effect on the value of the received field. For the above distance and spacing the effect of small objects on the value of field was usually found to be less than 1 percent.

It may be found necessary to shield thoroughly the r-f generator and transmission line to the loop to reduce leakage fields, also to correct the current calibration of the thermocouple for harmonics in the r-f supply. It is preferable that the r-f generator output be balanced to ground at least for frequencies above 1 or 2 Mc.

The "antenna coefficient,"  $K$ , is evaluated by the relation

$$K = \frac{E_1}{A_1} \times \frac{f}{M_1}, \quad (4)$$

where

$E_1$  = standard field given by eq (1) usually expressed in microvolts per meter

<sup>4</sup> K. A. Norton, The calculation of ground-wave field intensity over a finitely-conducting spherical earth, Proc. IRE **29**, 623 to 639 (Dec. 1941).

<sup>5</sup> H. Diamond, K. A. Norton, E. G. Lapham, On the accuracy of radio field-intensity measurement at broadcast frequencies, J. Research NBS **21**, 795 (1938) RP1156.

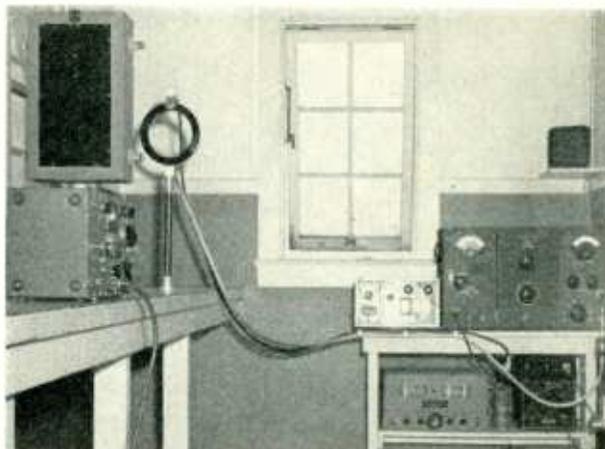


FIGURE 3. Determining the loop-antenna coefficient of a commercial field-strength meter.

$A_1$  = true attenuator ratio used

$M_1$  = output meter reading corrected from linearity data

$f$  = frequency, usually in kc or Mc. This frequency factor is introduced arbitrarily as a convenience to make  $K$  (theoretically) independent of frequency, since  $M_1 \propto f$ .

In using the field-strength meter later for actual measurements, the unknown field in microvolts per meter is given by

$$E = \frac{KM_2A_2}{f}, \quad (5)$$

where  $K$  is given by eq (4), and

$M_2$  = output meter reading corrected from linearity data

$A_2$  = true attenuator ratio used

$f$  = frequency in same units as used in eq (4).

While the instrument actually measures the magnetic component,  $H$ , of the unknown field, the indication is given in terms of the electric component,  $E$ , that would exist if the measurement were being made in free space, from the relationship,  $E = ZH$ , previously given. When the meter is used to measure field strength near the ground, however, this relationship is in general no longer valid. Consequently, the indicated value for the electric component may be subject to question in some cases unless the effect of the ground at the measurement site is considered; the magnetic field is however always correctly given by converting the electric field strength reading by the above simple free-space relation.

The accuracy of antenna coefficients is usually certified to  $\pm 3$  percent below 5 Mc and  $\pm 5$  percent between 5 and 30 Mc for sets using loop antennas.



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