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NIST Calibration Procedure for Vertically Polarized Monopole Antennas, 30 kHz to 300 MHz

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CONTENTS

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This report describes the theoretical basis and test procedure for vertically polarized monopole antenna calibrations at the National Institute of Standards and Technology (NIST). The standard field method applies the theoretical equations of a vertical monopole antenna to calculate the vertical electric field. This method is used at the NIST open field site in the frequency range of 30 kHz to 300 MHz. The uncertainty in the antenna factor of the antenna under test (AUT) is now ± 1 dB.

Key words: antenna factor; calibration; electromagnetic field; monopole antenna; open field site; standard field.

1. INTRODUCTION

The purpose of this report is to provide documentation for the method, equipment, and facility employed by NIST for calibrating vertically polarized monopole antennas over the frequency range of 30 kHz to 300 MHz. The facility is located at the Department of Commerce Boulder Laboratories, Boulder, Colorado.

The method used at NIST for calibrating vertically polarized monopole antennas is called the standard field method [1-4]. This method involves establishing reference cw fields at specified field strength levels for specified distances from the transmitting monopole on the NIST open-field site. This measurement site is used over the frequency range of 30 kHz to 300 MHz for vertically polarized antennas.

At the NIST field site a thin cylindrical monopole antenna is used to transmit a cw electromagnetic field. The voltage supplied to the transmitting antenna is measured. The field strength is calculated in terms of this applied voltage, the length and diameter of the transmitting antenna, the distance between the transmitting antenna and the AUT, and the height of the AUT above the ground plane. The ground plane is assumed to be perfectly conducting.

2. THEORETICAL BASIS

The geometry for a thin cylindrical monopole antenna located over a perfect ground is shown in figure 1. The monopole has length ℓ and is assumed to have a sinusoidal current distribution [5]. The monopole radiates vertical and horizontal electric field components, E_z and E_ρ, and a horizontal magnetic field component, H_ϕ. Only the vertical electric field E_z (in V/m) is required for calibration of vertically polarized monopole antennas, and it is given by [5]

$$E_z = \frac{-j30I_0}{\sin(\beta\ell)} \left[\frac{e^{-j\beta r_1}}{r_1} + \frac{e^{-j\beta r_2}}{r_2} - 2\cos(\beta\ell)\,\frac{e^{-j\beta r_0}}{r_0}\right], \tag{1}$$

where $r_1 = [d^2 + (z - \ell)^2]^{1/2}$,

$r_2 = [d^2 + (z + \ell)^2]^{1/2}$,

$r_0 = [d^2 + z^2]^{1/2}$,

$\beta = 2\pi/\lambda$,

I_0 (in A) is the base current of the monopole, and λ is the free-space wavelength. All distances and the wavelength are given in meters. By image theory the EM fields in the half space above the ground plane are the same as the fields of a center-fed dipole of length 2ℓ in free space. The expression for E_z in eq (1) assumes a sinusoidal current distribution on the monopole [5], and this assumption is valid for $\ell \leq \lambda/4$.

The input impedance of the monopole Z_{mon} (in Ω) is one half that of a dipole of length 2ℓ in free space:

$$Z_{mon} = Z_i/2, \tag{2}$$

where Z_i (in Ω) is the dipole impedance as given by Schelkunoff's mode theory [6, eq (108) on page 433]. At sufficiently low frequencies ($\ell \leq \lambda/8$), the monopole is electrically short, and the impedance can be calculated from its capacitive reactance X:

$$Z_{mon} \approx jX \approx 1/(j\omega C_a). \tag{3}$$

The monopole capacitance C_a is given by [6]

$$C_a \approx \frac{55.63\ \ell}{\ell n(\ell/a) - 1}, \tag{4}$$

where a is the monopole radius and C_a is in pF if ℓ is in m.

The monopole impedance as given by eq (2) has been verified experimentally by measurements with a commercial vector impedance meter. Calculated and measured values of the monopole reactance at low frequencies are shown in table 1. The monopole length is 2.5 m, and the radius is 0.813 mm. At all frequencies the measured reactance was within 5 % of the calculated reactance.

The base current of the monopole is difficult to measure directly; so the base voltage V_0 (in V) is measured. The base current is then calculated from

$$I_0 = V_0/Z_{mon}. \tag{5}$$

The vertical electric field as given by eq (1) has been compared with measurements made with a small probe which had been calibrated in the known field of a TEM cell. The agreement between the calculated and measured electric field was within ± 1 dB.

3. STANDARD FIELD METHOD FOR CALIBRATING MONOPOLES

3.1 Description of the Equipment

The NIST field site facility is designed around a grounded flat screen mesh on a slab of concrete 30 m wide by 60 m long. A tunnel under this concrete slab leads to a room approximately 3 m by 3 m in size, where the rf source and other equipment are located. Several small (15 cm) diameter tunnels leading from this room to various locations under the ground screen convey rf transmission cables and ac power cords to devices operating on the ground screen. The cables, being underground, do not interfere with the EM fields. The NIST standard transmitting antennas consist of telescoping monopoles, with adjustable length. Monopole antennas should be used as gain standards only on large, highly conductive ground screens [7]. Figure 2 shows the NIST field site with the locations of the transmitting and receiving antennas.

The length of the transmitting monopole is adjustable from 0.25 m to a maximum of 2.5 m. The electrical length of the fully extended antenna is 1/4 wavelength at 30 MHz, but only 0.00025 wavelength at 30 kHz. At frequencies above 30 MHz, the antenna length is reduced to 1/4 wavelength. At frequencies below 30 MHz, the antenna length is kept at its maximum of 2.5 m. The base diameter of the monopole is 0.5 cm, and the diameter decreases to a minimun of 0.13 cm with the monopole fully extended. Figure 3 shows a picture of a standard transmitting monopole antenna and mount.

The transmitted signal is produced by a signal generator, amplifier, low-pass filter, low-loss transmission line, and the transmitting monopole. Figure 2 shows the equipment used for a calibration at the field site. An rf voltmeter with a 50 Ω tee connector is used to measure the level of the transmitting voltage. A generic list of equipment used on the ground screen is given in table 2. The cables used are 50 Ω coaxial with type N connectors.

3.2 Test Procedure

NIST tests monopoles and field strength meters or receiving probes at specified frequencies and heights above the ground. When a device to be tested arrives, the serial numbers are logged, a test number is assigned, and a test folder is issued. The unit is inspected to see if it is operating correctly. Before the actual testing is done, a review of the anticipated data and procedure details are clarified. The dimensions of the AUT are measured and logged for use in the calculations. The test data are usually reported in terms of the antenna factor, antenna gain, or antenna output, such as detected voltage. The most common is antenna factor.

All of the serial numbers on the AUT and equipment are recorded, and a sketch is made of the calibration set up. If the test requires an unusual arrangement, a photograph of the system is taken. Header titles are written for each column of data to be taken (along with units), and any pertinent information is noted on the data sheet(s). A sample data sheet is given in figure 4.

If the distance between the transmitting and receiving antennas is not specified, the distance is usually set at 15 to 25 m. If the antenna height above ground is not specified, the AUT is placed at the height of its normal operation, which for monopoles is on the ground plane. The equipment is connected as shown in figure 2. The rf voltmeter and spectrum analyzer are calibrated by the NIST microwave calibration service (test 61190S) [8] and verified before each test by means of calibrated power meters.

A standard EM field is generated by the NIST transmitting monopole in terms of the monopole base current and distance to the AUT. The standard field is calculated at the center of the AUT from eq (1). The output of the AUT is measured with a calibrated spectrum analyzer or in terms of the AUT's meter dial indication. The antenna factor is then determined by the ratio of the calculated (standard) field strength to the AUT response, as described in Section 3.3. A sample test report is shown in the Appendix.

3.3 Antenna Factor

The antenna factor K is defined as

$$K = |E_z/V_{50}|, \tag{6}$$

where E_z = calculated field strength, μV/m, and

V_{50} = AUT voltage pickup across the 50 Ω load, μV.

The value of the vertical component E_z of the electric field is computed from eq (1). It is assumed that the horizontal distance d is large enough that E_z is constant over the length of the AUT.

The antenna factor of the AUT is usually given in dB and is calculated from the expression

$$K_{dB} = E_{dB} - V_{dB} - L_{dB} \tag{7}$$

where K_{dB} = antenna factor of the AUT, dB,

E_{dB} = calculated vertical electric field strength, dBμV/m,

V_{dB} = AUT voltage across the 50 Ω load, dBμV, and

L_{dB} = cable loss between the AUT and the 50 Ω receiver, dB.

The theoretically expected antenna factor of a receiving monopole above a perfect ground, connected to a 50 Ω receiver, is given by

$$K = |1 + \frac{Z_{mon}}{50}|/h_{eff}, \tag{8}$$

where Z_{mon} is given by eq (2). The effective height h_{eff} of the receiving monopole is given by [5]

$$h_{eff} = \frac{1 - \cos(\beta \ell_r)}{\beta \sin(\beta \ell_r)}, \tag{9}$$

where ℓ_r is the length of the receiving monopole. At low frequencies where the receiving monopole is electrically short, $\beta \ell_r \ll 1$, $h_{eff} \approx \ell_r/2$, and $K \approx Z_{mon}/(25\ \ell_r)$.

For example, consider a 1 m monopole of 0.5 cm diameter at frequencies below 10 MHz where the monopole is electrically short. Then $h_{eff} \approx 0.5$ m and the capacitance $C_{mon} \approx 11$ pF. Thus the impedance and the antenna factor are given by $Z_{mon} \approx -j(\frac{14470}{F,MHz})$ and $K \approx \frac{579}{F,MHz}$, where F,MHz is the frequency in megahertz. This example shows that the antenna factor of an electrically short monopole is inversely proportional to frequency.

3.4 Calibration Uncertainty

For calibrations at the NIST field site, at frequencies from 30 kHz to 300 MHz, the following error estimates apply.

(1) A source of error is the uncertainty of the standard field value at the open field site. This is due mainly to uncertainty in the value of the base current in the transmitting monopole. Also, signals from radio stations and other transmitting antennas may cause additional errors. These additional errors can be avoided by viewing the spectrum analyzer or receiver and stopping the measurement during any extraneous signals. The estimated possible error in the standard field is ± 0.4 dB.

(2) Another source of error is the disturbance of the field caused by interconnecting cables, nearby buildings, etc. This error has been checked and is estimated to be less than ± 0.2 dB.

(3) Other sources of uncertainty are associated with antenna alignment, measurement of antenna separation distance, and NIST calibrations of the spectrum analyzer and rf voltmeter. The error due to these sources is estimated to be less than ± 0.4 dB.

The overall uncertainty of the calibration is the sum of those listed above, ± 1.0 dB.

A comparison of calculated and measured antenna factor for a vertical monopole antenna is shown in figure 5 for frequencies from 150 kHz to 15 MHz. The measurements were performed on a cylindrical monopole with a length of 1 m and a radius of 0.4 cm. The transmitting monopole had a length of 2.5 m and a radius of 0.813 mm, and the antenna separation was 20 m. The calculated value of the antenna factor was obtained from eq (8). The difference between the calculated and measured values is less than 1 dB at all frequencies from 150 kHz to 15 MHz.

4. CONCLUSIONS

NIST provides calibration of vertically polarized monopole antennas over the frequency range of 30 kHz to 300 MHz. A standard (known) field is established using a vertical monopole antenna over the NIST ground screen. The present uncertainty in the measured antenna factor is the sum of ± 0.4 dB for uncertainty in the standard field, ± 0.2 dB for disturbance in the field due to nearby objects, and ± 0.4 dB for other sources of uncertainty for a total uncertainty of ± 1.0 dB.

5. REFERENCES

[1] IEEE standard methods for measuring electromagnetic field strength for frequencies below 1000 MHz in radio wave propagation. IEEE No. 302; 1969.

[2] IEEE standard test procedures for antennas. ANSI/IEEE Std. 149-1979; 1979.

[3] Nahman, N.S.; Kanda, M.; Larsen, E.B.; Crawford, M.L. Methodology for standard electromagnetic field measurements. IEEE Trans. Instr. and Meas., IM-34: 490-503; 1985.

[4] Kanda, M.; Larsen, E.B.; Borsero, M.; Galliano, P.G.; Yokoshima, I.; Nahman, N.S. Standards for electromagnetic field measurements. Proc. IEEE, 74: 120-128; 1986.

[5] Jordan, E.C.; Balmain, K.G. Electromagnetic Waves and Radiating Systems. Englewood Cliffs, N.J.: Prentice-Hall; 1968.

[6] Schelkunoff, S.A.; Friis, H.T. Antennas, Theory and Practice. New York: Wiley; 1952.

[7] FitzGerrell, R.G. Limitations on vertically polarized ground-based antennas as gain standards. IEEE Trans. Ant. Propagat., AP-23: 284-286; 1975.

[8] NBS calibration services users guide 1986-88. Nat. Bur. Stand. (U.S.) Spec. Pub. 250, 1986 Edition; 1986.

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NATIONAL ENGINEERING LABORATORY
Boulder, Colorado 80303

SPECIAL TEST

Broadband Active Monopole Antenna
Manufacturing Company
Model ABC, Serial No. xxx

Submitted by:

Submitting Company
City, State 12345-6789

I. Description of Calibration

The Submitting Company electric-field antenna is an active broadband monopole antenna system designed to operate in the 30 kHz to 300 MHz frequency range.

The antenna factor to be used for measuring the vertical component of an electric (E) field was determined by immersing the receiving antenna under test (AUT) in a known field 10 meters from the NIST transmitting monopole. A block diagram of the instrumentation used for this calibration is given in the attached figure. The receiving antenna output was connected to a calibrated cable and 50 Ω spectrum analyzer. This spectrum analyzer was used as a frequency-selective voltmeter to measure the pickup at each frequency tested.

The calibration of vertical monopole antennas at NIST is done at an outdoor field site which has a 30 m x 60 m (100 ft x 200 ft) conducting screen mesh stretched over a concrete slab. An underground room is located beneath the concrete for the transmitter and monitoring instrumentation. The strength of the calibrating field is calculated at each frequency in terms of the base current in a thin transmitting vertical monopole antenna. The vertical component of E field, as a function of base current and position, is given by the equation

$$E_z = \frac{30 I_o}{\sin(\beta \ell)} \left[\frac{e^{-j\beta r_1}}{r_1} + \frac{e^{-j\beta r_2}}{r_2} - 2\cos(\beta \ell)\, \frac{e^{-j\beta r_o}}{r_o} \right] \qquad (1)$$

Page 1 of 4
Test No. ABCDEF
Date of Test:

where

E_z = vertical component of standard E field, RMS V/m,

I_o = monopole antenna base current, A,

ℓ = height of transmitting monopole, m,

β = 2π/wavelength, m^{-1},

r_1 = distance from top of transmitting monopole to field point, m,

r_2 = distance from image of top of monopole (in ground) to field point, m,

r_o = distance from bottom of monopole to field point, m.

The above equation is number (10-72) on page 323 of Jordan [1].

The base current of the transmitting monopole antenna is calculated by the equation

$$I_o = \frac{V_o}{Z_{in}} \tag{2}$$

where

V_o = measured base voltage of the transmitting monopole antenna, V,

Z_{in} = magnitude of the monopole input impedance, Ω.

A 2.5 meter transmitting monopole was used to generate a standard field at each frequency. At frequencies below one-tenth of the self-resonant frequency, the radiation resistance is negligible and the input impedance is only capacitive reactance. The capacitance of a thin electrically-short whip can be calculated from the formula

$$C = \frac{55.63\ell}{\ln\left|\frac{\ell}{a}\right| - 1} \tag{3}$$

where

C = monopole input capacitance, pF,

ℓ = monopole height, m,

a = monopole radius, m.

The above equation is twice that of eqn (11) on page 306 of Schelkunoff [2].

At frequencies above 1/10 the self-resonant frequency, the input impedance of the monopole (Z in) was calculated from Schelkunoff's "mode" theory using equation (108) on page 433 of reference [2]. A check of the calculated E field was made at each frequency with a passive whip antenna with a known antenna factor. The rf voltage on the transmitting monopole ranged from 0.5 volts at 300 MHz up to 80 volts at 30 kHz.

The antenna factor (K), in dB, was determined by the equation

$$K = E_o - V \tag{4}$$

where

E_o = field strength calculated from equation (1), expressed in dBmV/meter,

V = voltage delivered to the calibrated 50 Ω spectrum analyzer, in dBmV.

II. Calibration Data

The measured values of antenna factor (K) with the antenna rod fully extended are given in the following table

Table 1. Antenna Factor of the Active Monopole Antenna, Model ABC, Serial No. xxx.

Frequency (MHz)	Antenna Factor (dB)
0.030	5.1
0.100	8.2
0.500	5.9
1.00	5.7
5.00	5.5
10.0	4.9
30.0	3.9
100.0	2.1
300.0	1.0

Active Monopole Antenna
Manufacturing Company
Model ABC, Serial No. xxx

An unknown field strength (E) may be measured with the calibrated monopole antenna by the expression $E = K + V$. The data in this report are for use in making cw measurements only, and not necessarily valid for broadband interference.

The calibration uncertainty of the antenna factors given is ± 1.5 dB.

III. References

[1] "Electromagnetic Waves and Radiating Systems," E. C. Jordan, Prentice-Hall, Inc., 1950.

[2] "Antennas, Theory and Practice," S. A. Schelkunoff and H. T. Friis, John Wiley & Sons, Inc., 1952.

For the Director
National Institute of Standards
and Technology

Motohisa Kanda, Ph. D.
Group Leader, 723.03
Fields Characterization Group
Electromagnetic Fields Division

Test performed by:

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Page 4 of 4
Test No. ABCDEF
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Reference: P.O. No. 12345

Table 1. Reactance of a Vertical Monopole (ℓ = 2.5 m, a = 0.813 mm)

Frequency (MHz)	Theoretical Reactance (Ω)	Measured Reactance (Ω)
0.5	- 16 093	- 16 100
1.0	- 8 046	- 8 225
2.0	- 4 023	- 4 100
5.0	- 1 609	- 1 600
7.5	- 1 073	- 1 020

Table 2. List of equipment for the open-field site

- 50 Ω signal generator, 30 kHz to 300 MHz.
- Amplifier, 50 dB gain maximum.
- Rf voltmeter with coaxial tee connector, 300 V maximum.
- Calibrated spectrum analyzer, covering the frequency range.
- Assorted low pass filters, attenuators, and low loss cables with type N connectors.

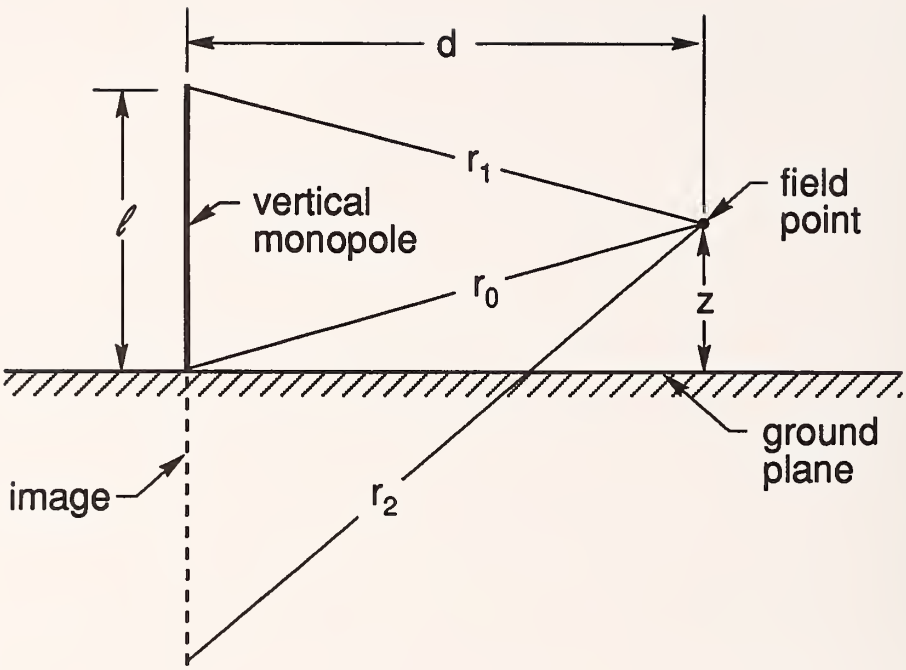

Figure 1. Geometry for a transmitting vertical monopole over a ground plane.

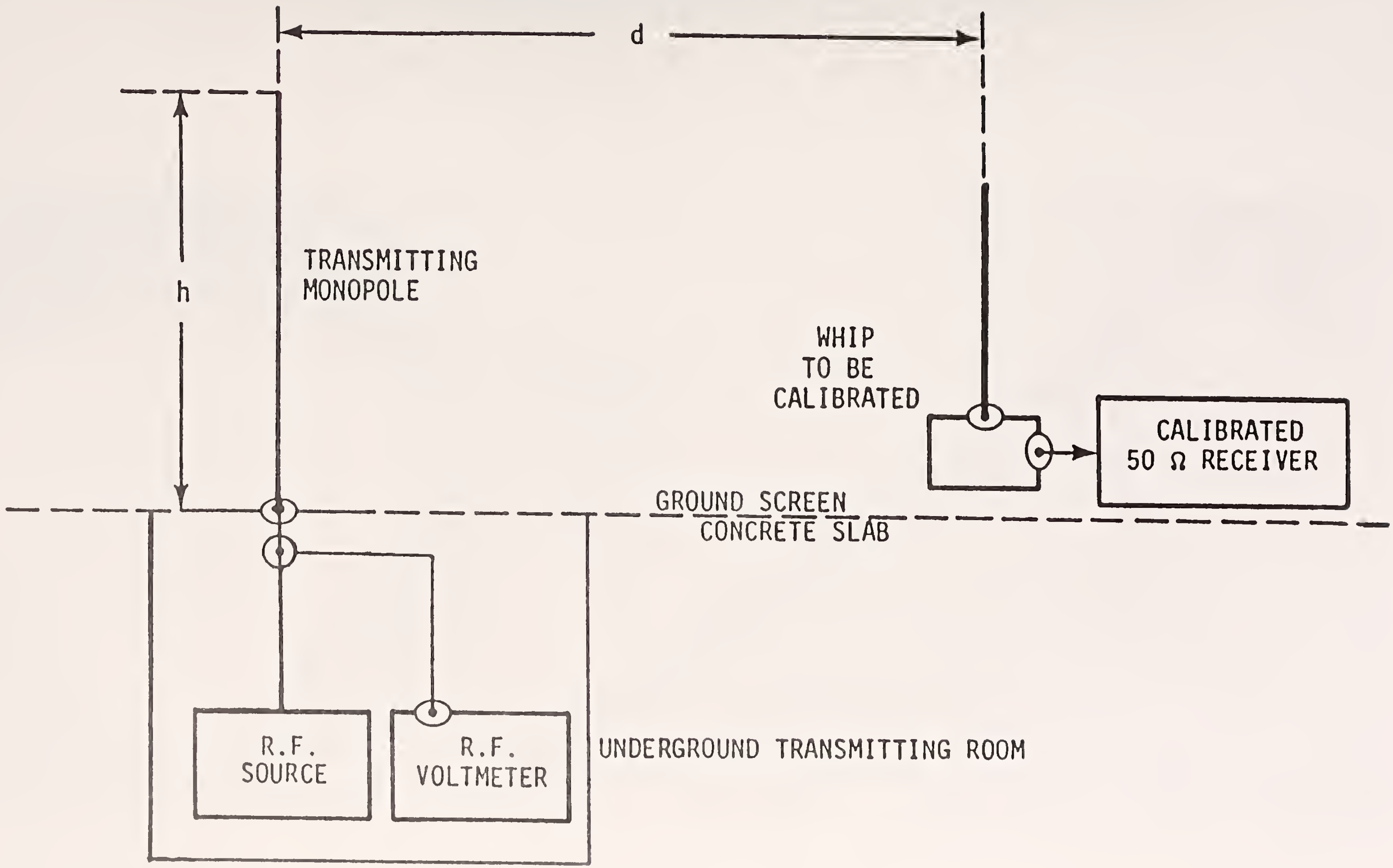

Figure 2. Field site instrumentation for calibrating monopole antennas.

Figure 3. The transmitting monopole antenna and the ground screen mount.

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KIND OF MEASUREMENT Sample Only

INSTRUMENT TESTED vertical monopole antenna

d = 20 m receive height = 1.1 m

Frequency (MHz)	AC voltage (V)		AUT Output (µV)	Xmit monopole length (sections)			
0.01	40.0		44.1	4			
0.05	2.3		95.4	4			
0.1	4.9		98.7	4			
0.5	45.0		61.0	4			
1	30.0		60.2	4			
5	1.4		63.8	4			
10	0.3		67.5	4			
50	0.6		67.5	2			
100	0.1		308.6	1			

Figure 4. Sample data sheet for vertical monopole antenna calibrations.

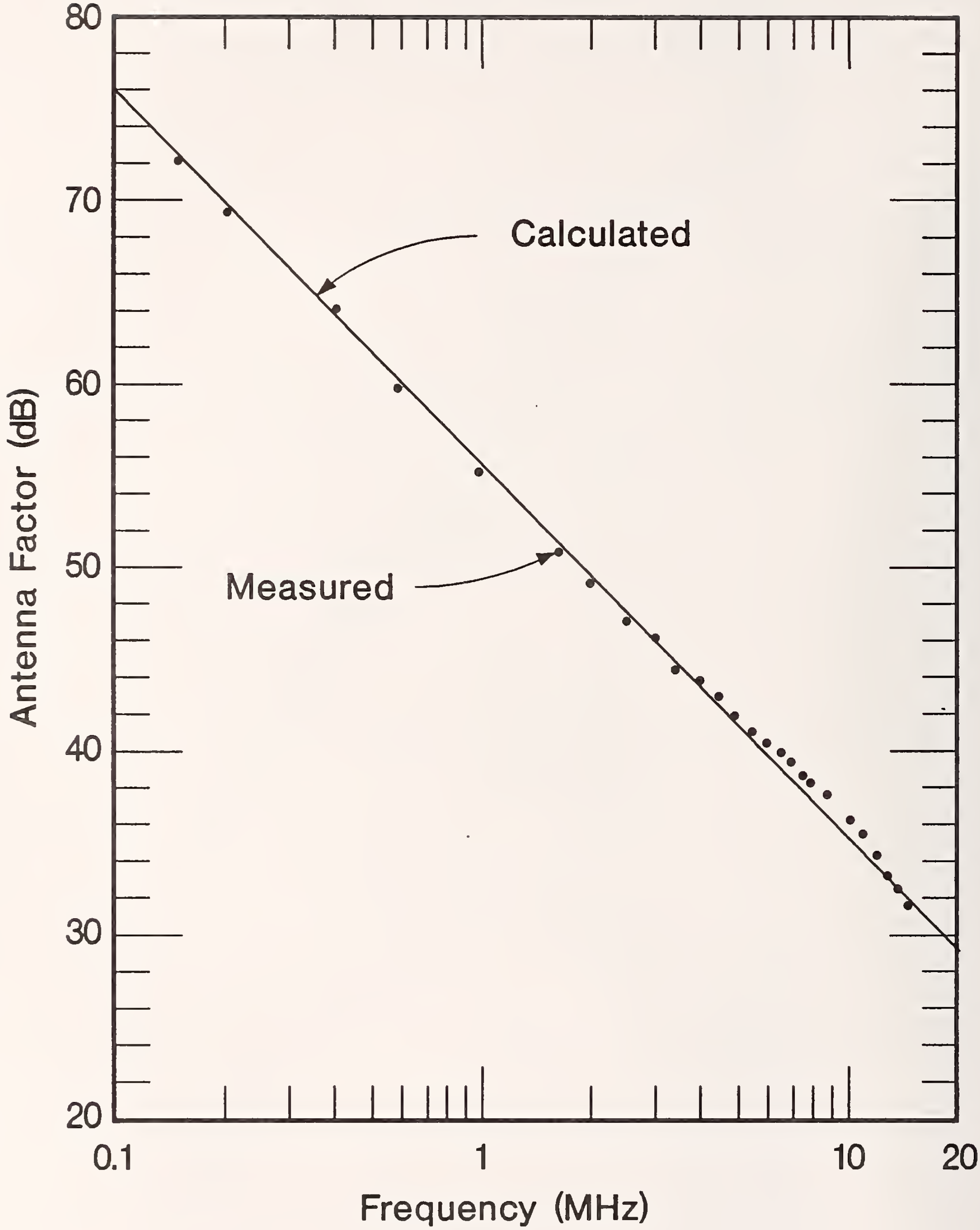

Figure 5. Comparison of calculated and measured antenna factors for a 1 m vertical monopole.

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KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

antenna factor; calibration; electromagnetic field; monopole antenna; open field site; standard field

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