CALIBRATION TECHNIQUES FOR SMALL ANTENNAS IN LIMITED SPACE

A three-antenna method can be used to verify the far-field calibration of antennas at a relatively short range and correct the antenna factor for near-field use.

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The user of small antennas in a limited space, such as for TEMPEST and interference testing in shielded enclosures, is often in doubt concerning the accuracy of the measured results because of the short radiation paths involved. Antennas for these uses are generally calibrated in the far field, but used in the near field where the phase front is not planar. Since the available antennas, though relatively small, nevertheless subtend a substantial arc over which the impressed signal may not be uniform, the effective antenna factor may be somewhat different from that for a plane wave. Frequently the need arises to verify the far-field calibration at a relatively short range, and/or correct the antenna factor for near-field use.

The discussion that follows assumes that the troublesome matter of room characteristics such as resonances and multipath reflections can somehow be suppressed or avoided. The discussion also assumes that the antennas and sources are sufficiently separated that their driving point impedances are not significantly altered by the mutual impedance.

In the absence of a standard calibrated antenna, one must first perform a calibration procedure. The easiest method for most workers is the so-called three-antenna method which does not require knowledge of the gain or antenna factor of any of the antennas. To be accurate, the method depends upon the precision with which the path loss between the sending and receiving antennas can be calculated. The three-antenna method has been described by numerous writers,[1-4] and considerable attention has been given the more elusive problem of short-range calibration.[5-6] In view of the abundance of literature on the method, it will not be treated thoroughly here; instead a modification for short-range use will be offered.

The three-antenna method basically determines the gain product and gain ratio of two of the three antennas. From these the individual gains and antenna factors can be determined by way of the calculated path loss between the source and receiving centers. Calculation of the path loss at short range is the problem because of the presence of the near-field components at the receiving location. Distances of one to perhaps 3 meters, and frequencies down to 1 kHz or less are considered. The third antenna is merely an auxiliary to provide a signal for comparison of the two being calibrated.

The antennas to be calibrated are assumed to have simple patterns of low directivity and near-field characteristics similar to those of an infinitesimal electric or magnetic dipole. The tangential field of either has a complex functional dependence upon distance which is expressed as

$$1/\rho_c = (r^{-1} - jr^{-2} - r^{-3}), \qquad (1)$$

where

r = kR
R = Distance
k = $2\pi/\lambda$
λ = wavelength

The absolute value of ρ_c is

$$\rho = (r^{-2} - r^{-4} + r^{-6})^{-1/2}, \qquad (2)$$

which approaches r as the distance from the source increases. One has only to replace r with ρ in the Friis equation for transmission of power between two antennas to obtain a practical equation for short range transmission. Letting p represent the ratio of received power, P_r, to the transmitted power, P_t, one has

$$p = G_1G_2/4r^2 \qquad (3)$$

(Friis, long range)

$$= G_1G_2/4\rho^2 \qquad (4)$$

(Friis, short range).

The quantity p is measured by a precision attenuator substituted for the two antennas and the transmission path which permits the gain product G_1G_2 to be reckoned through a calculation of the more representative factor ρ. The gain ratio G_1/G_2 is determined by comparing the response of the two antennas in the same field. Proximity to the source is not so critical in the gain ratio measurement because both antennas will respond proportionally to the field as long as they are approximately the same size. Setting

$$G_1 = G_2 (G_1/G_2) \qquad (5)$$

and solving simultaneously with equation (4) yields

$$G_1 = 2\rho (pG_1/G_2)^{1/2} \qquad (6)$$

and

$$G_2 = 2\rho (pG_2/G_1)^{1/2} \qquad (7)$$

In practice, the quantities are usually expressed in decibels. The results obtained here are more nearly the values of the far-field gains than would have been obtained by using field divergence proportional only to 1/r. Of course, ρ is only about 0.2 dB different from r at a distance of three radian lengths, but this is a long distance at 1 kHz. A more detailed treatment of this method is available.[5] Since the results here are far-field power gains relative to an isotrope, the corresponding far-field antenna factors can be found from the well known equation,

$$AF = 9.734/ \lambda G^{1/2} \text{ (E-field)} \qquad (8)$$

The far-field magnetic field antenna factor is 1/377 times the electric field antenna factor. Equation (8) applies to a 50-ohm termination. In applying the three antenna method, a good practice is to make the range distance at least twice the length of the longer antenna.

Further correction can be done mathematically as suggested below for a ferrite rod receiving antenna (Figure 1). This is an untuned magnetic-field sensing device designed specifically for accurate measurement of magnetic field intensity at practically all radian distances from the source, at frequencies from 300 Hz to 100 MHz. The entire range is covered in a SINGLE BAND. A worst-case situation is considered: a small magnetic source, represented by an infinitesimal magnetic dipole is placed at a small distance, s, from the center of the antenna. The distance at very low frequencies, is appreciably less than one electrical radian length. Within this region, both the radial and tangential components of the magnetic field exist. These vary in any radial direction predominantly as $1/r^3$, and as the sine and cosine respectively of the angle Θ measured from the boresight direction. Phase variation will be ignored over the length of the rod because of the long wavelength. Also ignored will be the other field components which vary as 1/r and $1/r^2$, and that the field impressed near the ends of the rod does not contribute to the resultant as strongly as that at the center. This is due to flux leakage between the ends of the rod and the coupling coil at the center.

The first case examined is a tangential field measurement wherein the ferrite rod is positioned in the broadside direction parallel to the axis of the source dipole, as shown in Figure 2. Using the above assumptions, and taking the line integral of the axial component of the magnetic field along the length of the rod, the resultant impressed field is found. Dividing this by the rod length and the tangential magnetic field intensity at the center of the rod, the ratio, R_t, of the apparent field intensity to the actual tangential field intensity at the center of the antenna is found. Thus

$$R_t = (3 \tan\Theta_1)^{-1} \cdot [\sin\Theta_1 (\cos^2\Theta_1 + 2)] \qquad (9)$$
$$\Theta_1 = \tan^{-1} (b/s).$$

In this derivation, the projection of the radial component of the field onto the rod has been neglected because it is very small and diminishes rapidly toward the center of the rod. The ferrite rod of the antenna is 24 inches or 0.61 meter long. At a distance s of one meter, for example, equation (9) yields R_t = 0.929, or -0.64 dB. The far-field antenna factor should therefore be increased by 0.64 dB to improve the accuracy of the measurement.

The case for the radial field measurement at close range is somewhat more severe. The geometry is shown in Figure 3. By the same process of integrating the $1/r^3$ field over the radially disposed rod, one finds the ratio R_r of the indi-

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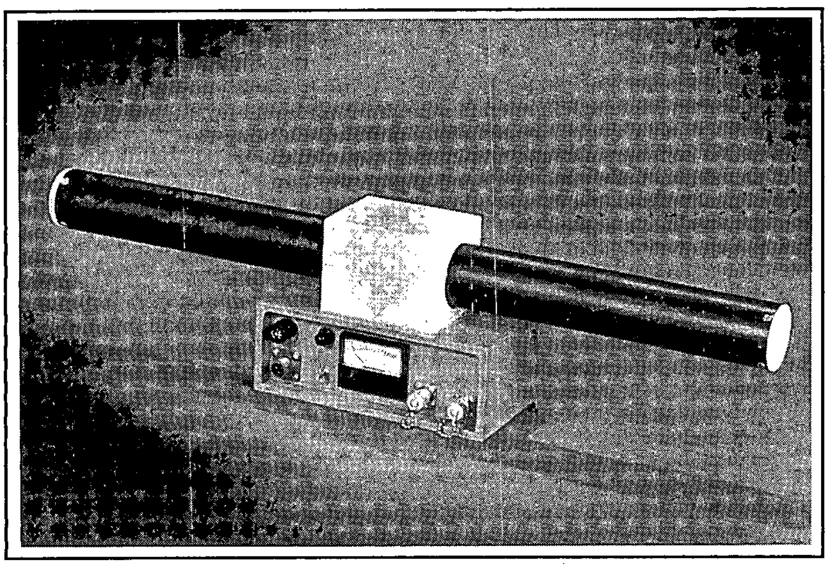

Figure 1. Model BBH-3100/A, Untuned Magnetic Field Antenna.

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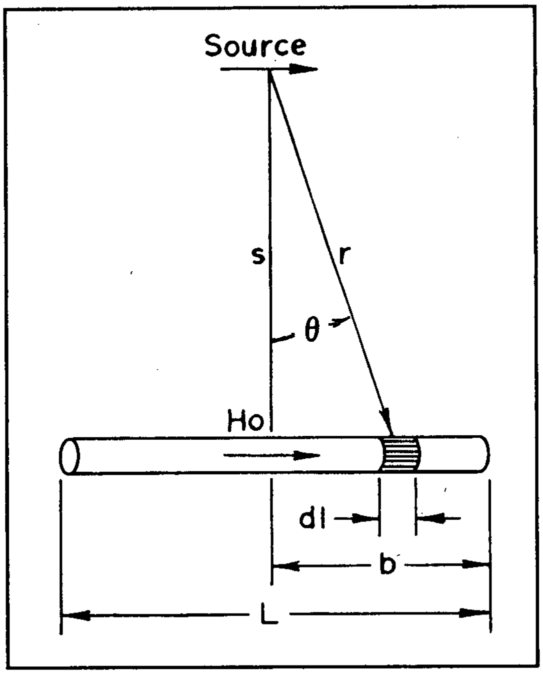

Figure 2. Geometry for Tangential Field Measurement.

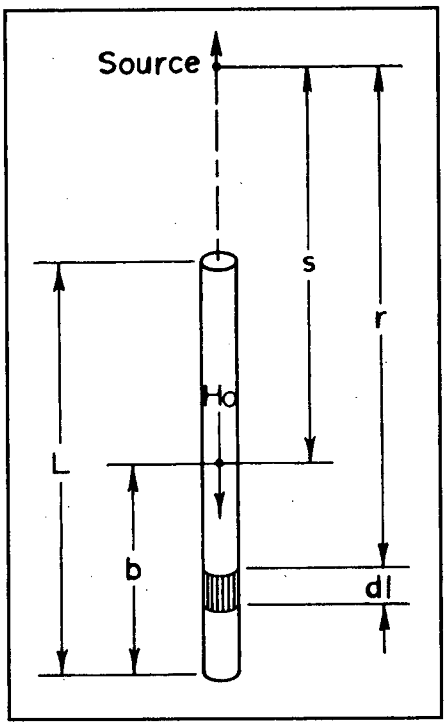

Figure 3. Geometry for Radial Field Measurement.

cated radial field to the actual radial field at the center of the rod to be

$$R_r = s^4/(s^2 - b^2)^2, \qquad (10)$$

which, for s = 1 meter, yields R_r = 1.216, or 1.7 dB. The rod is thus developing a stronger received signal than its antenna factor would indicate. Hence the far-field antenna factor should be decreased by 1.7 dB.

An air-core loop functions in precisely the opposite manner. It will measure the radial component of the magnetic field component more accurately than it will the tangential component. The problem of calculating a correction factor for an air-core loop is more difficult than it is for the ferrite rod because of its two-dimensional geometry.

The three-antenna method has been shown to work with reasonable accuracy at close range. By calculation, the far-field antenna factor of a given antenna can be corrected to yield more accurate results of measurement in the near field. These comments are offered not as a precision cure for a well-known problem, but as an easy means of improving accuracy at close range. ■

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