Correspondence

A Technique to Measure Accurately Antenna Efficiency

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***Abstract*—A technique is described to determine accurately antenna efficiency by comparing integrated isotropic levels of two antennas, one of which is a lossless reference antenna. Standard automated antenna-range instrumentation was utilized to obtain isotropic levels of Apollo scimitar antennas to ±0.1 dB by reducing or eliminating sources of error due to specular ground reflections as well as results based on a single measurement.**

Introduction

Antenna-efficiency measurements have consistently been troublesome, especially in the VHF and UHF bands for omnidirectional-type antennas, where efficiency values approach 100 percent and standard-gain reference antennas are not readily available. Assumption of losslessness for a half-wave or quarter-wave vertical monopole over a perfectly conducting ground plane has been shown to be valid for proper diameter-to-wavelength ratios.[1]

The relationship

$$G = kD$$

expresses the ratio of antenna gain to directivity by the efficiency factor k, where G may be defined as the ratio of the test antenna maximum radiation to the hypothetical isotropic radiator with the same power input. Comparison of the test antenna to the isotropic antenna is normally accomplished by first comparing it to a reference antenna of known gain, such as a standard-gain horn or dipole, at VHF or UHF frequencies. D, unlike G, is independent of copper, dielectric, or mismatch loss; otherwise, it is identical to G.

Directivity

Directivity is determined precisely and automatically by standard antenna-range instrumentation, such as a positioner programmer in conjunction with a pattern integrator and spherical integrator converter. The total directivity is obtained by one calculation from the integrator reading.

Maximum directivity in terms of the radiation intensity, $\Phi(\theta, \phi)$, is

$$D = \frac{\Phi_{\max}}{\frac{1}{4\pi}\int_0^{\pi}\left[\int_0^{2\pi}\Phi(\theta,\phi)d\phi\right]\sin\theta\, d\theta}.$$

Digital output from the integrator, proportional to the ϕ integral within the brackets, is obtained for each 360° of ϕ rotation. The θ integral is approximated by ϕ cuts at select increments of θ which are weighted by $\sin\theta$ to determine a number I_1 proportional to the total integral. I_2, proportional to $\Phi_{\max}$, is obtained by recording a sample of the radiation intensity in the direction of $\Phi_{\max}$.[2]

Therefore

$$D = k_1 \frac{I_2}{I_1}$$

where k_1 is a known constant, and D is measured to within a combined instrumentation error of ±1 percent or ±0.05 dB.

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[1] R. G. FitzGerrell, "Radiation efficiencies of half-wave dipole antennas," *IEEE Trans. Antennas Propagat.* (Commun.), vol. AP-13, pp. 326–327, Mar. 1965.
[2] H. R. Fulmer and R. E. Mosely, "Determination of antenna directivity by the pattern integration method," *The Essay*, Aug. 1960.

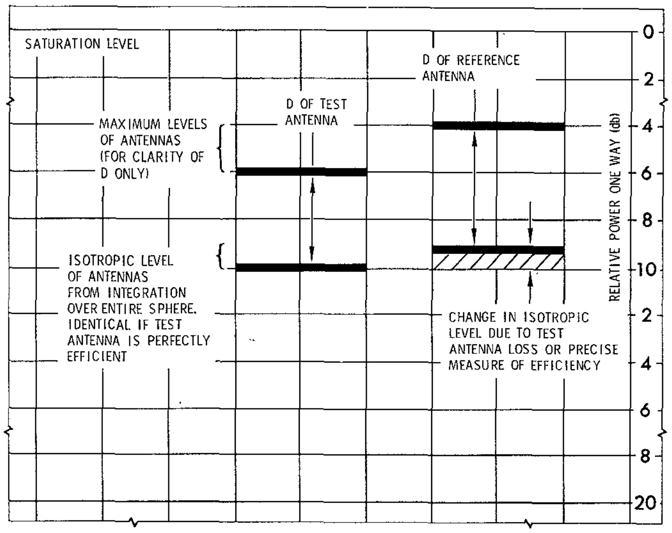

Fig. 1. Antenna power levels.

Gain

Although accurate methods have been developed for measurements of antenna gain,[3] most antenna ranges experience difficulty eliminating errors in VHF gain measurements emanating from the following causes.

1) Specular ground reflections causing significant interference at the test antenna aperture for the aspect angle under test. Test antennas with omnidirectional-type patterns are most susceptible to this form of interference.

2) Determining direction of maximum radiation due to an omnidirectional pattern.

3) Basing result on a single measurement (maximum test antenna intensity).

4) Substitution-type errors due to connector mating, mismatches, etc.

Isotropic Level Technique

A technique that reduces or eliminates the first three sources of error is based on measurements over the entire radiation sphere to obtain antenna isotropic levels. It is similar to measurement of directivity, except that accurate determination of the maximum radiation intensity is not required.

When the approximate gain levels of both the test and reference antennas are known, the rectangular pattern recorder is adjusted below the 0-dB or saturation level, as shown in Fig. 1. The antennas are successively programmed in two orthogonal polarizations to obtain relative isotropic levels with the same power input. Any downward change in isotropic level from the reference antenna to the test antenna is a direct indication of test antenna efficiency, compensating for VSWR mismatch if necessary.

The antenna instrumentation manufacturer gives a combined maximum instrumentation error of ±1 percent or ±0.05 dB for determination of directivity. The technique accuracy of ±0.1 dB was established as double the instrumentation accuracy since two

[3] H. V. Cottony, "Techniques for accurate measurement of antenna gain," in *National Bureau of Standards Circular 598*, Nat. Bur. Stand., Colo., 1958.

integration runs are performed. The quoted accuracy subsequently was verified by performing efficiency and directivity measurements, as described herein, to determine gain ($G = kD$) of UHF standard-gain horns, data that were traceable to the National Bureau of Standards. The elevation cut increment was also changed from 5° to 2° resulting in insignificant variations to the measured efficiency.

Conclusion

This method has been used successfully to determine efficiency levels of scimitar-type antennas to ±0.1 dB which were mounted on a perfectly conducting flat ground plane and compared to quarter-wave vertical monopoles. The scimitar antenna efficiencies were found to be as low as 80 percent due to the amount of ablator material covering the blade surface.

Accurate measurement of antenna efficiency is achieved by use of precise instrumentation to obtain isotropic levels from integration over the entire radiation sphere in both polarizations. Errors from a single or one-shot measurement are thereby substantially reduced.

Acknowledgment

The author wishes to thank W. H. McQuerry and R. B. Silberberg for discussions leading to the isotropic level approach.

Computer Program Descriptions

Digitized Antenna Measurements of the Directive Gain

PURPOSE: This program computes a circularly symmetrical averaged-directive gain pattern from measurements carried out in E and H planes combined with cross-polarization measurements if desired.

LANGUAGE: Fortran IV.

AUTHOR: C. Kramer, Eindhoven University of Technology, Eindhoven, The Netherlands.

AVAILABILITY: ASIS—NAPS Document No. NAPS-01642.

DESCRIPTION: The measured E-plane values may be obtained in different ways; viz., either one antenna position may be measured several times (KK), or all the points of the pattern are measured in succession, and this cycle is repeated several times (LL) to decrease the influence of interference, e.g., noise. Calibrating point (II) are added to the tape before and after each measurement cycle. The average (n) calibration values are used to compute a calibration curve by means of a polynomial equation

$$y = \sum_{i=0}^{n-1} a_i x^i.$$

The program proceeds to convert the measured values in dB relative to the estimated directivity (GG).

If during the measurements a discrepancy appears in the measured values at $\theta = 0°$ and $\theta = 360°$, the average is taken into account. To obtain a symmetrical pattern the maximum value of the nonsymmetrical pattern has to be found. Various points in the mainlobe on either side of the maximum and at equal distances (HS) are compared until the difference is less than a specified value of accuracy (SN).

Using the calculated symmetry axis and the existing calibration curve, the circularly symmetrical averaged and normalized cross-polarized field is added to the main polarized field. The directive gain pattern is now integrated using a subroutine (QSF) with the Newton Cotes formulas and compared with 4π. The same procedure is carried out for the H plane. An absolute-symmetrical directive gain pattern defined to isotropic level is finally obtained by averaging the total E- and H-plane fields, and by carrying out the pattern integration dith respect to 4π.

Manuscript received March 11, 1971.
For program listing order document NAPS-01642 from ASIS National Auxiliary Publications Service, c/o CCM Information Corporation, 909 Third Avenue, New York, N. Y. 10022; remitting $2.00 per microfiche or $5.00 per photocopy.

A Numerical Method for Calibrating Microwave Cavities for Plasma Diagnostics—Part II

PURPOSE: This program generates calibration curves for TE_{0np} and TM_{0n0} cylindrical microwave cavities used in plasma diagnostics.

LANGUAGE: Fortran IV

AUTHORS: M. E. Fein, L. A. Schlie, J. T. Verdeyen, and B. E. Cherrington, Gaseous Electronics Laboratory, Department of Electrical Engineering, University of Illinois at Urbana-Champaign, Urbana, Ill. 61801

AVAILABILITY: ASIS—NAPS Document No. NAPS—01681.

DESCRIPTION: The development and description of these programs is given in "A numerical method foi calibrating microwave cavities for plasma diagnostics —Part I," by M. E. Fein, L. A. Schlie, J. T. Verdeyen, and B. E. Cherrington, this issue, pp. 22–30. The program listing, the data card specifications, and a sample output have been deposited with NAPS. This corresponds to the data plotted in the referenced article.

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For program listing, order NAPS-01681 from ASIS National Auxiliary Publications Service, c/o CCM Information Corporation, 909 Third Avenue, New York, N. Y. 10022; remitting $2.00 per microfiche or $5.00 per photocopy.