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Digitized Antenna Measurements

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***Abstract*—A low-cost automated measuring method is presented to determine the directive gain and relative phase of microwave antenna feed systems in digital form. Using large existing computer facilities, the output data may be used as input data to compute secondary patterns of arbitrary reflector antennas. The use of stepping motors is a key for cheaper and easier operations.**

INTRODUCTION

IN MODERN ANTENNA engineering, especially for long-range radar, radio astronomy, satellite communications ground stations, or multibeam antenna systems for satellites, it is very important to know the antenna pattern as regards amplitude and phase and its polarization in all directions. Mostly, the current distribution method is used to calculate the entire radiation pattern of bodies of revolution.

Silver [1, p. 420] has developed a number of formulas enabling one to calculate the secondary pattern of a paraboloid with the source at the focus, while Rusch [2], [3] has demonstrated that the same technique may be used for a hyperboloid or ellipsoid. It is not the purpose of this paper to go into details with regard to the complicated equations used for calculation, but it appears that in all equations the directive gain $D(\theta, \phi)$ [4] and its relative phase pattern of the primary feed play an important role. Other applications, such as designing double reflector systems [5] with high efficiency, require detailed information with regard to the feed pattern. Sometimes the performance of an antenna system may be predicted by using "theoretical" feeds, the class of circular symmetrical feed patterns defined by

$$D(\theta) = 2(n + 1) \cos^n \theta$$

having become very popular.

The Eindhoven University of Technology, Eindhoven, The Netherlands, now possesses several computer programs to calculate secondary patterns of paraboloids, hyperboloids, and ellipsoids excited by this theoretical feed pattern at their focuses. Moreover, programs are available to design double reflector systems with the same "theoretical" feed system. However, in most cases one wants to know the performance of an antenna with a practical feed system. In the past, antenna patterns have been plotted on paper and presented as graphs, the field strength, power density, and phase being represented relative to a reference value, mostly the peak of the beam.

If the directivity of such an antenna is required, an accurately calibrated gain standard has to be used. These measurements are not only time consuming but also unsuitable for use in the computer programs previously discussed. This paper presents some inexpensive digital techniques in antenna measurements both for amplitude and phase. Digital techniques are particularly useful in applications involving large quantities of data, such as antenna measurements. The results, in the form of punched paper tape are available immediately after the measurements, which permits direct entry into a computer (see computer programs [6]).

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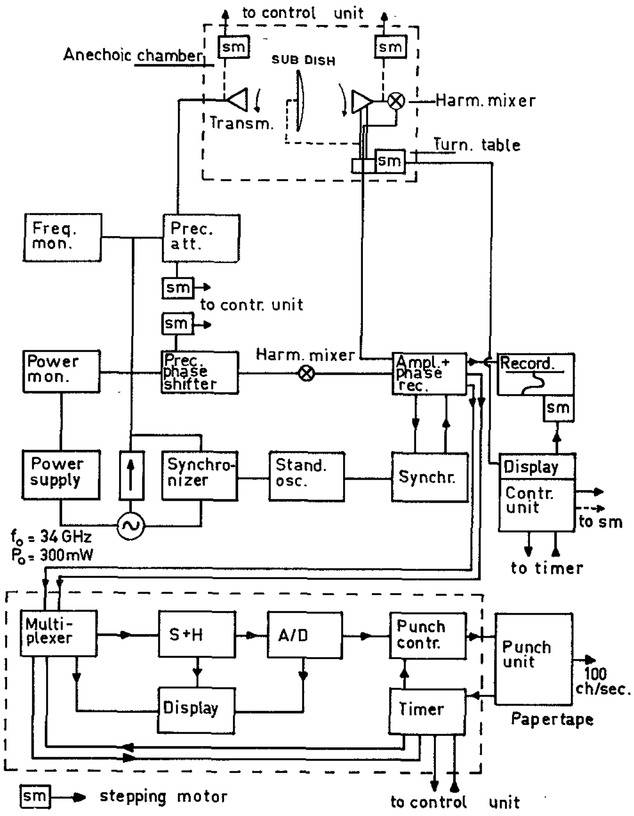

Fig. 1. Measuring arrangement.

The Measuring Arrangement and Data Processing

The measuring arrangement (Fig. 1) comprises a turntable in an anechoic chamber on which the antenna feed system has to be mounted. The turntable is driven by a stepping motor. A second stepping motor is coupled to a recorder, and, after analog-to-digital conversion, a puncher is used punching the digitized amplitude and phase data in paper tape. The use of stepping motors has the advantage that the turntable, recorder, and puncher are kept synchronous by means of a controlling unit without the need of servo systems. Further, the antenna positioning is found directly in digital form by counting pulses without the need of analog-to-digital convertors. The incremental angle of the turntable is adjustable with a minimum of 0.1° so that the measurement in one plane of $D(\theta, \phi)$ for $0<\theta<360°$ delivers a maximum of 3600 measuring points. Further, it is possible to measure detailed parts of the antenna pattern around a given direction (θ, ϕ) by the use of preset counters. The measurements can be repeated continuously, each time provided with calibration values by means of a precision attenuator and a phase shifter, both stepping-motor driven. After measurements, the results and calibration values are processed by a computer.

For amplitude measurements this computer is programmed in such a way that a calibrating and averaging procedure may be started. With n calibrating points, a polynomial equation

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

is generated by the computer making possible a correction of the measured values in order to compensate nonlinearities in the receiver.

This calibrating procedure has the advantage that no precision receivers are required and that a larger dynamic range is obtained. The averaging procedure may be started after the radiation pattern has been measured several times in one ϕ plane or, if an average is required, of measurements in different ϕ planes (i.e., $\phi=0°$, $\phi=90°$). If desired it is also possible to measure separately the cross-polarized components $D_c(\theta, \phi)$ of the pattern and compensate this afterwards. When the main axis ($\theta=0°$) has been found and the averaging procedure carried out, the phase pattern, which is measured with a similar procedure as the amplitude, may be computed and plotted [6]. The best fit phase center is found in accordance with methods discussed before [7, p. 63]. It has already been indicated by Silver [1, p. 425] that for every directive gain pattern

$$\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} [D_p(\theta, \phi) + D_c(\theta, \phi)] \sin \theta d\phi d\theta = 4\pi$$

$D_p(\theta, \phi)$ being the directive gain with principal polarization, and $D_c(\theta, \phi)$ the directive gain with cross-polarization. After integrating the power pattern over all solid angles, using the Newton–Cotes formulas [8, eq. (25.4.13)] the total pattern is compared with 4π. A factor is then found to determine the isotropic level of 0 dB. In this way a pattern is obtained over 180°, which is circularly symmetrical and defined with respect to the 0-dB level.

Taking the cross-polarization into account, this procedure now enables the computer to calculate the directivity [4] of the feed or antenna system without comparison with a standard gain horn. An illustrative example of one of the possibilities of this method is demonstrated by Figs. 2, 3, and 4.

Fig. 2 is a measured H-plane pattern, and Fig. 3 a measured E-plane pattern. The cross-polarization has been measured, but is not shown in these figures. The result of the averaging procedure over the E and H planes is illustrated by Fig. 4, resulting in a circularly symmetrical pattern over 180° together with the cross-polarization. The computer program for these amplitude measurements is described elsewhere in this issue [13]. All in all, 26 752 measuring points have been processed. The same figure also contains information on power distribution per unit solid angle. It appears that the power lost by cross-polarization does not exceed about 0.1 percent.

The total dynamic measuring range is at least 60 dB, although absolute measurements at this level are unreliable, as the reflectivity of the anechoic chamber is

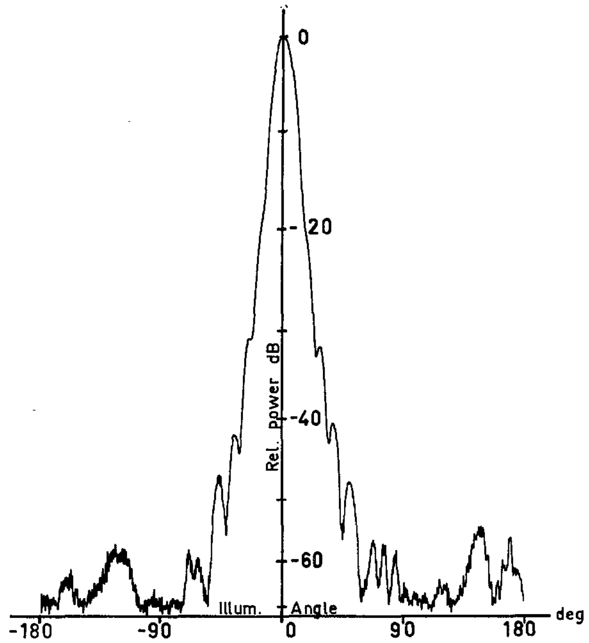

Fig. 2. Measured H-plane pattern.

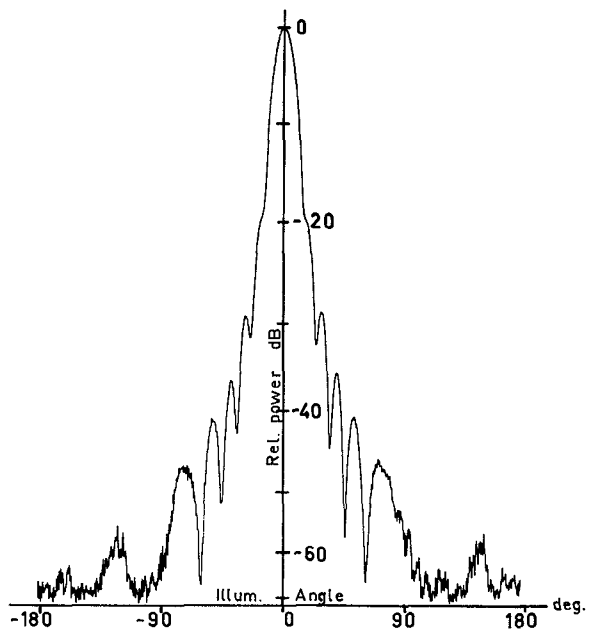

Fig. 3. Measured E-plane pattern.

about −55 dB at a measuring frequency of 34 GHz. Improvement is possible if the measurements are repeated several times with slight displacement of transmitter or antenna feed.

Although complete system error analysis is beyond the scope of this paper, and although error analysis also depends upon the applications, the following remarks may be made. Error sources in azimuth angle presentation are due to improper orientation of the turntable axis, gear errors, stepping motor errors, and turntable vibrations during operation. However, these errors can be kept within 0.02° root sum square.

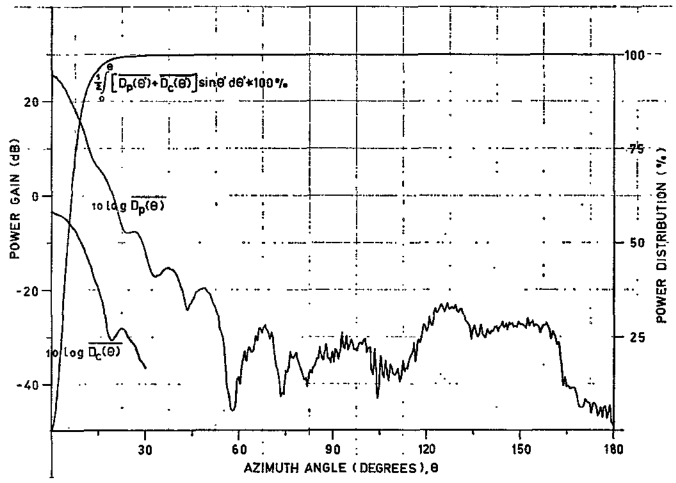

Fig. 4. Averaged antenna feed pattern and its power distribution.

At high-signal levels, the attenuater calibration and setting, the receiver short-term stability, the source stability, and the analog-to-digital conversion will cause errors. At low signal level the main error sources are reflections from the anechoic chamber, leakage along the transmission lines, and receiver noise. The influence of randomly varying error sources is partly diminished by carrying out the measurements several times. An impression of the overall system accuracy may be obtained by comparing the result of the measured directivity of a standard gain horn with the specified directivity. The difference appears to be less than 0.15 dB.

Conclusions

The new digitized measuring range for microwave antennas offers several interesting applications.

1) The directive gain of a feed horn may be found without the time-consuming comparison with a standard gain horn.

2) It is possible to obtain an average pattern in one ϕ plane, resulting from measurements in different ϕ planes, in absolute coordinates calculated by the computer. In this way orientation problems of patterns with respect to their main axis are overcome.

3) It is possible to carry out cross-polarization measurements rapidly.

4) Not only antenna feeds may be measured and the results processed, but also scaled models of paraboloids with focal-point illumination, scaled models of Cassegrainian antennas, or subreflector systems can also be measured.

5) The output tape of the measuring range with the digital information is, after processing, suitable as input data for the main scattering program for paraboloids [1, p. 420] or hyperboloids and ellipsoids [2], [3]. The output tape may also be used as input data for the calculation of antenna-noise temperature [9], or shaped-Cassegrainian systems [5], [10], [11].

6) The method described enables a rapid comparison

between a measured primary or secondary antenna pattern and a calculated one.

7) Rapid insight is obtained with regard to the power distribution of $D(\theta, \phi)$ per unit solid angle.

8) Spillover may be computed directly without the use of time-consuming methods, such as planimeters or special plotting papers [12].

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Frequency-Domain Characterization of Microwave Delay Lines

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Abstract—Techniques for evaluating delay lines with an automatic network analyzer are described. Extremely precise values of the delay can be obtained by an iterative process which uses final measurement frequencies spaced by integral multiples of the reciprocal delay.

The magnitude of leakage and triple-delayed transmissions are determined from measurements which are also necessary to obtain accurate values of insertion loss.

Introduction

UPON INITIAL consideration, one might suppose that delay lines should be characterized in the time domain. However, computer-controlled frequency-domain measuring equipment can evaluate delay lines rapidly. The computer permits an efficient set of test frequencies to be determined from preliminary measurements and transforms the results back into time-domain characteristics.

The automatic equipment, exemplified by the Hewlett-Packard 8542A system, sets a signal generator to a discrete, digitally prescribed frequency for each measurement. (The microwave path of this system, located at Computer Metrics, Inc., Rochelle Park, N. J., was revised to extend the dynamic range by 20 dB.) In most applications of this equipment, measurements are taken at equally spaced frequencies over the range of interest. In delay-line measurements such frequency choices will often result in poor estimates of delay and attenuation. Undelayed leakage and triple-delayed signals (arising from multiple reflection within the delay medium) give the transmission function a fine structure in the frequency domain. The errors are analogous to the "aliasing" errors incurred in sampling a time function too infrequently in relation to the high-frequency content of the time function.

The equipment mentioned requires about 250 ms to set the signal generator at each new frequency. It is generally impractical to measure throughout a frequency band at frequencies spaced closely enough to avoid the aliasing errors. However, appropriately chosen close-spaced groups of frequencies permit determination of the true delay and attenuation, and also

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