A Modulated Scattering Technique for Measurement of Field Distributions*

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Summary—Electric field distributions can be measured accurately by passing a short metal dipole through the field and recording the wave scattered by the dipole. Ordinarily the method is difficult to use since the scattered signal is small, critical tuning adjustments are required, and careful attention to stability is necessary. However, by placing a nonlinear impedance at the center of the dipole and applying an audio voltage through slightly conducting threads, the scattered wave can be modulated. This makes it possible to relax the tuning and stability requirements and at the same time to increase the sensitivity of the measurements.

INTRODUCTION

RADIO-FREQUENCY fields are generally measured with a dipole or other type of probe. Such measurements are often of questionable accuracy because the fields are distorted by the cable which must be connected to the probe. Recently an alternative method of measuring field distributions has been developed by Justice and Rumsey.[1] The research reported herein consists of the development of a modification of the scattering technique of Justice and Rumsey. The technique will be discussed as a method of measuring fields near antennas; however, it has also been applied to the measurement of fields in waveguides. Since this scattering technique is not yet widely known, a brief description of it is appropriate.

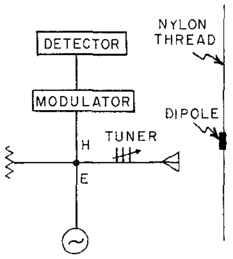

Fig. 1—Apparatus for electric field measurements with scattering technique.

The method uses a hybrid junction as shown in Fig. 1 with the collinear arms terminated in the antenna and a resistive load. The E and H arms of the junction are connected to the signal source and the receiver. If the impedance of the load is equal to that of the antenna, no power is transmitted from the signal source to the receiver. In practice the antenna must be tuned until the isolation between signal source and receiver is about 100 db. A thin, linear conductor having a length of one-half wavelength or less is then introduced at a point in the field of the antenna. This dipole is supported by thin nylon strings which cause negligible disturbance to the field. A current is induced on the dipole proportional to the component of the incident electric field parallel to its axis; that is, if the dipole is parallel to the y-axis, the current is proportional to E_y at that point in the absence of the dipole. Because of the current flowing on the dipole, a signal is radiated or scattered. This produces a reflected wave at the antenna input terminals as well as in other portions of space surrounding the scatterer. This reflected wave at the antenna terminals is separated by the hybrid junction and produces a voltage at the terminals of the receiver. It can be shown[1] that the voltage produced at the receiver terminals with the scatterer at a given position is proportional to the square of the tangential electric field intensity at the same position in the absence of the scatterer. Thus the amplitude and phase of the field at each point can be determined by measuring the phase and amplitude of the received signal.

This scattering technique distorts the fields less than conventional probing methods since no cable is connected to the dipole. Fields in solid dielectric bodies can be measured with the scattering system by passing the dipole through a fine hole in the dielectric.

The scatterer must be short to indicate the field at a point, and it must be slender to discriminate against orthogonal polarization. Hence, the scattered signal is small. It will be shown that measurements with the scattering method are subject to errors from slight detuning of the hybrid junction and hence to frequency drift and temperature drift. Since the hybrid junction tuning is frequency sensitive, a monochromatic signal source is required. For this reason the source shown in Fig. 1 is operated unmodulated to avoid frequency modulation which generally occurs when a kylstron is amplitude modulated. Care must be taken to prevent motion of any bodies (other than the dipole) in the antenna field during measurements.

However, a method will be described for amplitude modulating the scattered wave. This will make it possible to relax tuning and stability requirements, at the same time increasing the sensitivity of the measurements.

A MODULATED DIPOLE SCATTERER

The scattering from a dipole can be amplitude modulated in several ways. The most practical method appears to be to place a nonlinear impedance in series with

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[1] R. Justice and V. H. Rumsey, "Measurement of electric field distributions," submitted for publication in *Trans.-PGAP*.

the dipole at its center, and to modulate the impedance electronically. A Transitron type T7G subminiature germanium diode was somewhat arbitrarily selected as a nonlinear impedance. Cotton thread, made slightly conducting with a trace of Aquadag, was used not only to support the diode scatterer but also to connect an audio modulating voltage to it as shown in Fig. 2. Any field distortion due to the presence of the thread should be negligible because of its high resistance (500,000 ohms per foot) and small diameter (0.02 inch) even if the thread is parallel to the electric field vector, which is the worst case. In measurements of linearly polarized antennas the thread is aligned perpendicular to the electric field to minimize the rf currents on the thread and hence scattering by the thread.

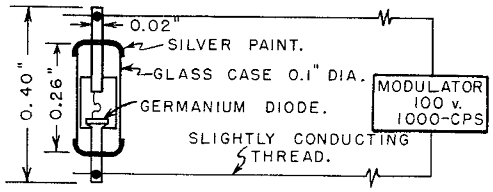

Fig. 2—Modulated diode scatterer.

The dipole was resonated to the operating frequency (9,400 mc) by applying silver paint over a small area of each end of the glass case of the diode as in Fig. 2. As a result, the modulated diode scatters as strongly as an ordinary dipole 0.4-inch long and 0.02-inch in diameter. The modulation produced by the system shown in Fig. 2 was found to be satisfactory; the scattered wave is nearly 100 per cent modulated.

In the usual scattering system the dipole should have a length-to-diameter ratio of at least 50 to satisfy polarization requirements.[1] However, linear polarization should be more easily achieved with a modulated dipole since the diode at the center will modulate only the axial component of current flowing on the dipole. Any circumferential component of current will be unmodulated and hence will produce no depolarization, as will be shown. By rotating the antenna in Fig. 1 and observing the signal level in the receiving arm of the hybrid junction, it was found that the modulated scatterer discriminated between orthogonal linear polarizations by at least 32 db. Of course, when modulation is applied to the scatterer the waveguide modulator[2] shown in Fig. 1 is not used and the signal source is unmodulated.

Error Analysis

To analyze certain errors involved in the usual scattering system shown in Fig. 1, let E_s denote the signal arriving at the detector by way of scattering from the dipole. If E_t is the electric field intensity component tangential to the dipole,

$$E_s \propto E_t^2. \tag{1}$$

[2] J. H. Richmond, "Measurement of time-quadrature components of microwave signals." *Trans. IRE*, vol. MTT-3 pp. 13–15; April, 1955.

Generally there will also be an undesired signal E_u arriving at the detector even in the absence of the dipole. Such a signal will be present if the hybrid junction is imperfectly balanced.

Now, in the usual scattering method both the desired and undesired signals are modulated, and the resultant signal E arriving at the detector is

$$E = [E_s \cos \omega t + E_u \cos (\omega t + \beta)]m(t). \tag{2}$$

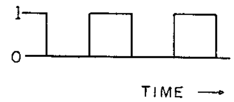

Fig. 3—Assumed modulation function $m(t)$.

Here $m(t)$ denotes the modulation function which may be taken to have the form shown in Fig. 3. ω is the microwave angular frequency, and β is the phase angle of signal E_u. The error caused by signal E_u is maximum when β is zero or π, in which cases the detector indicates amplitudes

$$|E| = E_s \pm E_u. \tag{3}$$

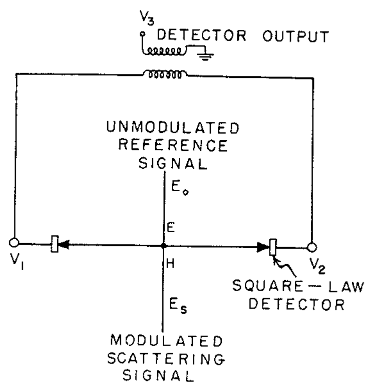

Fig. 4—Simplified diagram of coherent detector.

Thus, if the unbalance signal E_u is 20 db smaller than E_s, the measurement of E_s will have a possible error of ± 10 per cent. The measurement of the electric field distribution E_t may be in error by as much as ± 5 per cent.

It will now be shown that errors from unbalance signals can be eliminated if a modulated scatterer is employed. In order to eliminate these errors and at the same time increase the sensitivity of the field distribution measurements, it is assumed that a coherent detector[2] such as shown in Fig. 4 will be used. Modulation will be introduced at no point in the system other than at the dipole.

An unmodulated signal E_0 direct from the microwave signal source is delivered to the E arm of a hybrid junction. The modulated scattering signal E_s is applied to the H arm of the hybrid junction. Some unmodulated unbalance signal E_u will undoubtedly accompany the scattered signal. Each of the two collinear arms of the hybrid junction is terminated with a square-law detector. The resultant signals E_1 and E_2 arriving at detectors 1 and 2 are

$$E_1 = E_0 \cos \omega t + E_u \cos (\omega t + \beta) + E_s \cos (\omega t + \alpha) m(t) \quad \text{(4a)}$$

$$E_2 = E_0 \cos \omega t - E_u \cos (\omega t + \beta) - E_s \cos (\omega t + \alpha) m(t). \quad \text{(4b)}$$

The minus signs occur because of the properties of the hybrid junction. The power P_1 arriving at detector 1 will be proportional to E_1^2. The only modulated components of this power are given by

$$P_1 = [E_s^2 \cos^2 (\omega t + \alpha) + 2E_0E_s \cos \omega t \cos (\omega t + \alpha) + 2E_uE_s \cos (\omega t + \beta) \cos (\omega t + \alpha)] m(t). \quad (5)$$

The audio response V_1 of detector 1 is found by averaging P_1 over one rf cycle:

$$V_1 = \tfrac{1}{2}E_s^2 + E_0E_s \cos \alpha + E_uE_s \cos (\alpha - \beta). \quad \text{(6a)}$$

Similarly,

$$V_2 = \tfrac{1}{2}E_s^2 - E_0E_s \cos \alpha + E_uE_s \cos (\alpha - \beta). \quad \text{(6b)}$$

The coherent detector response V_3 is obtained by subtracting V_2 from V_1 as is done by the audio transformer in Fig. 4. Hence

$$V_3 = 2E_0E_s \cos \alpha. \quad (7)$$

Thus, the coherent detector response is independent of the phase or amplitude of any unbalance signal. In contrast with the usual scattering technique, the modulated scatterer method is immune to errors from unbalance signals.

If the phase of signal E_0 is now shifted by 90 degrees, one obtains

$$V_3 = 2E_0E_s \sin \alpha. \quad (8)$$

Thus it is possible to measure the real and imaginary components[2] of the scattered signal E_s. The coherent detector also makes it convenient to plot phase distributions automatically.[3]

The coherent detector is unusually sensitive,[2] with sensitivities of −125 dbw being readily obtainable at 9,400 mc. Of course, coherent detection can be used with the usual type of scattering technique, but in this case it will not reduce the errors indicated by (3) because both the scattered signal and the unbalance signal are modulated and hence cannot be distinguished. With the usual type of scattering technique, the extra sensitivity obtained by employing coherent detection would not enable one to accurately measure weaker scattered signals unless the tuning and stability were improved to the point where the unbalance signal could be kept more than 20 db below the weakest scattered signal to be measured.

Experimental Results

It was desired to verify experimentally this predicted immunity of the modulated scattering system to errors from unbalance signals. A system similar to Fig. 1 was used with the modulated dipole of Fig. 2 and the coherent detector of Fig. 4. The electric field distribution was measured with the scattering method along a path near the aperture of a horn antenna. The measurement was repeated with various controlled amounts of unmodulated signal mixed in with the scattered signal where it was delivered to the detector. No error was detectable until the unmodulated signal E_u was increased to 15 db above the *maximum* scattered signal E_s, or 35 db above the minimum scattered signal for which accurate comparisons were made. Since in the usual scattering technique the unbalance signal must be 20 db below the *minimum* scattered signal to be measured accurately, it may be stated that the use of a modulated scattering system decreases the required hybrid junction isolation by 55 db. In the above experiment the detecting elements were type 1N23 crystals. Perhaps even better performance could be obtained by using bolometers, since the immunity to unbalance errors depends on the use of square-law detecting elements. The performance also depends on equalizing the gain of the two detecting elements in the coherent detector before subtraction takes place in the audio transformer (Fig. 4). More accurate equalization than was used in the above experiment could readily be arranged.

Electric field distributions measured with the modulated diode were compared with measurements made with an ordinary dipole of the same length. No detectable differences appeared in the two patterns. From these measurements and data on modulated diodes in waveguides, it is evident that the echo area of a modulated diode is constant for all reasonable levels of rf power. That is, no errors should arise from the nonlinear properties of the diode at least for rf signal levels below 10 mw delivered to the diode.

Conclusions

The scattering technique of measuring antenna near-field distributions is capable of unusual accuracy if the required tuning adjustments are carefully performed and if the equipment stability is adequate. The rigid tuning and stability requirements may be relaxed if the usual dipole scatterer is replaced with a modulated diode scatterer and coherent detection used. The coherent detector has the additional advantages of increased sensitivity and adaptability to automatic phase plotting.

Modulated diode scatterers are linearly polarized to within the required degree of accuracy. Their echo area is constant for rf signal levels likely to be encountered in antenna near-field measurements. Field distributions measured with a modulated diode show no errors when compared with measurements with ordinary dipole scatterers. The required hybrid junction isolation is reduced at least 55 db by use of a modulated scatterer.

Acknowledgment

Discussions with T. E. Tice and other members of the Antenna Laboratory contributed to this research.

[3] J. Bacon, "An automatic X-band phase plotter," *Proc. NEC*, Chicago, Ill. vol. 10 and pp. 256–263; October, 1954.