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PROBES FOR MICROWAVE NEAR-FIELD MEASUREMENTS

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Probes for Microwave Near-Field Measurements*

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Summary—**To be satisfactory for microwave near-field measurements, a probe must have desirable polarization characteristics, must have an aperture small enough to indicate the field at a point, must deliver sufficient signal voltage to permit accurate measurement, and yet must not seriously distort the fields. The design of a probe may be simplified if the fields to be measured are known to be almost linearly polarized or to consist only of a traveling wave. Comparison of measurements made with various probes has led to the development of a small open-ended waveguide probe which is simple to construct and has given excellent results.**

THE OBJECT of this paper is to discuss the results of a limited investigation of radio-frequency probes suitable for near-field measurements at X-band.

A probe for accurately measuring the field intensity distribution near a radio-frequency source must meet the following requirements.

1. Any distortion of the fields by the probe and associated equipment must not seriously affect the accuracy of the measurements.
2. The aperture of the probe must be small enough to measure essentially the field at a point.
3. The probe must have the desired polarization to a high degree of accuracy.
4. The probe must deliver a signal voltage large enough to permit accurate measurement.

It will be noted that the probe may be permitted to distort the fields considerably providing that the effects of such distortion on the measurements are kept small.

The aperture size requirement on probes has been analyzed by Woonton,[1] who concluded that a probe should be no longer than one-half wavelength and no more directive than a half-wave dipole.

It is usually desired to measure some linearly polarized component of the field, and therefore the probe should be linearly polarized.

It is apparent that the performance of any given probe may depend on the environment in which it is placed. Also, the design of a probe may be simplified if one has a knowledge of certain characteristics of the fields to be measured. For example, if the fields are known to have a slow spatial variation, the probe aperture size can be increased. If the field is known to consist mainly of a traveling wave, the probe may be oriented in such a way as to minimize error due to distortion of the field by the probe. If the polarization of the field is essentially linear, the polarization requirements on the probe can be relaxed. A smaller probe may be feasible if the transmitter power or receiver sensitivity can be increased.

In short, it is more realistic to select the probe which is most satisfactory for the particular type of measurements of interest than to seek a "universal" probe to be used in all situations.

Dipole probes are perhaps the most popular type for near-field measurements. The dipole is generally connected to a coaxial line through a balun. The dipole and balun must be carefully designed and constructed to obtain satisfactory results. Small horns or open-ended waveguides are also used as probes. These require no balun and are quite simple to construct.

In recent years this laboratory[2] has developed an alternative method of measuring near fields. A short, slender metal wire supported on fine nylon thread is passed through the field. The wave scattered by the wire back into the transmitting antenna is separated from the transmitted wave by a tuned hybrid junction. The signal appearing in the receiving arm of the hybrid junction is proportional to the square of the electric field intensity component tangential to the wire. The scattering technique distorts the fields less than any known direct probing system since no cable or waveguide is connected to the scatterer. Fields in waveguides and in solid dielectric bodies can be measured with the scattering system, whereas direct probing would encounter serious difficulties.

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. Furthermore, great care must be taken to properly tune the hybrid junction and to obtain a monochromatic signal from the klystron or other signal source. Thus direct probing is often much simpler and is to be preferred where it is adequate.

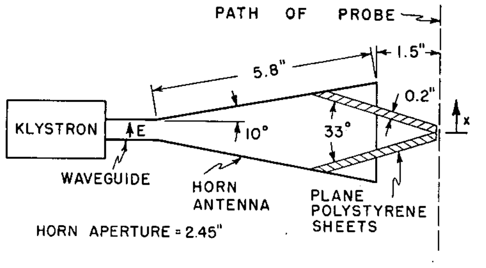

Fig. 1—Experimental arrangement for investigating probes.

To investigate the near-field measurement problem, a field was set up which was typical of the fields we wish to measure. This was accomplished by placing a wedge-shaped dielectric shell in front of a horn antenna and choosing a straight line probing path perpendicular to the horn axis as indicated in Fig. 1. The horn was connected to a type X-13 Varian klystron tuned to 9,375 mc ($\lambda_0 = 3.2$ cm $= 1.26$ inches). The field distribution was

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[1] G. A. Woonton, "On the Measurement of Diffraction Fields," Eaton Elec. Res. Lab., McGill Univ., Montreal, Quebec, Can., Symposium on Microwave Optics, vol. 2; June, 1953.

[2] R. Justice and V. H. Rumsey, "Measurement of electric field distributions," submitted for publication in TRANS. IRE, PGAP.

recorded by automatic phase[3] and amplitude plotters as the probe was moved along the probing path by a motor. The phase measurements were made with a balanced coherent detector using type 1N23 crystals. A Sperry type 821 barretter was used as a square-law detector for the amplitude measurements.

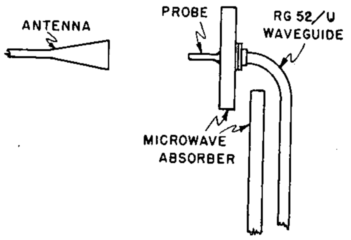

Fig. 2—Orientation of probe 4 and waveguide feed.

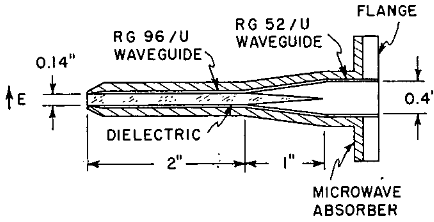

Fig. 3—Cross section of probe 4 showing waveguide transition.

These measurements were repeated using several types of probes, including a small horn and three sizes of open-ended waveguide. The orientation of a probe with its waveguide feed is indicated in Fig. 2. The outside surfaces of the probes were covered with microwave absorber to reduce distortion of the fields. It was necessary to fill the smaller waveguide probes with dielectric materials to permit transmission of energy through them. Waveguide transition sections, tapered in both dimensions, were used to couple the two smallest probes to standard X-band waveguide as shown in Fig. 3. Pertinent information on each probe is listed in Table I.

TABLE I

Probe Number	Description	Aperture Size (inches)		Dielectric filler
		E plane	H plane	
1	horn	1.13	0.90	air
2	open-ended waveguide	0.40	0.90	air
3	open-ended waveguide	0.18	0.42	fiberglas ($\epsilon=4$)
4	open-ended waveguide	0.14	0.28	mycalex ($\epsilon=11.5$)

TABLE II

Scatterer Number	Length (inches)	Diameter (inches)
1	0.5	0.005
2	0.3	0.05

The measurements were repeated with the scattering technique, using scatterers of different lengths. The dimensions of the scatterers are in Table II, above.

It will be noted from Table II that a larger diameter of wire was used for the shorter scatterer. This was necessary in order to obtain a signal large enough to record accurately. Since the polarization of the field was essentially linear, and the scatterer was oriented with the same polarization as the transmitting horn, no loss of accuracy was anticipated due to the increased diameter of the scatterer. Useful measurements could not be made with scatterers less than 0.3 inch long with the present equipment, although the length could be reduced if the transmitter power or receiver sensitivity were increased.

Fig. 4 shows the field distribution as measured by the scattering method. It is noted that the shorter scatterer gave the higher peaks and deeper nulls. Presumably the shorter scatterer is the more accurate one, and hence the results obtained with it are replotted in Fig 5 (next page) for comparison with the probes.

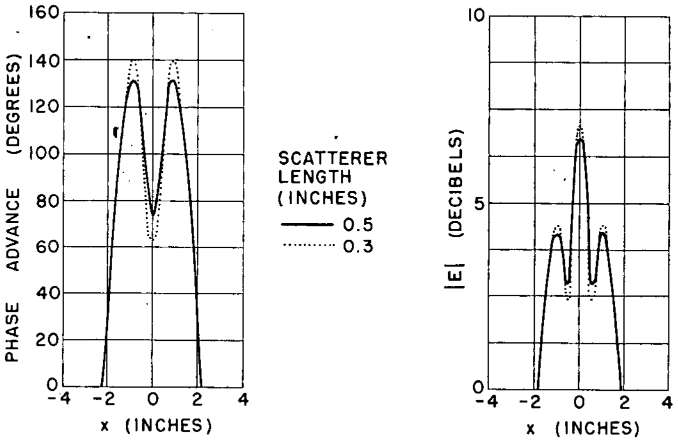

Fig. 4—Phase and amplitude distributions as measured with scatterers.

The averaging effect which takes place in the aperture of probe 1 (the small horn) is obvious in both the amplitude and phase patterns of Fig. 5. Otherwise, the phase patterns are in good agreement.

The amplitude patterns show quite strikingly the steady increase in resolution as the probe aperture dimensions are reduced. The shortest scatterer which could be used had an E-plane dimension twice that of the smallest probe. As a result, the scatterer reduced the peaks by 3 db and increased the level at the nulls by 2 db as compared with probe 4. Although probe 4 has a much smaller aperture than probe 3, these two probes yielded patterns which are in close agreement. It is therefore felt that no additional improvement in accuracy would be obtained by further reduction in the aperture size.

In order to further test the accuracy of probe 4, this probe was used to measure the fields near the horn antenna shown in Fig. 6 (facing page). E denotes electric field intensity and α its phase. For convenience in making calculations,[4] $|E| \cos \alpha$ and $|E| \sin \alpha$ were recorded

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[3] J. Bacon, "An Automatic *X*-Band Phase Plotter," Proc. NEC Conf. Chicago, Ill.; October, 1954.

[4] J. H. Richmond, "Simplified calculation of antenna patterns, with application to radome problems," submitted for publication in TRANS. IRE, PGMTT.

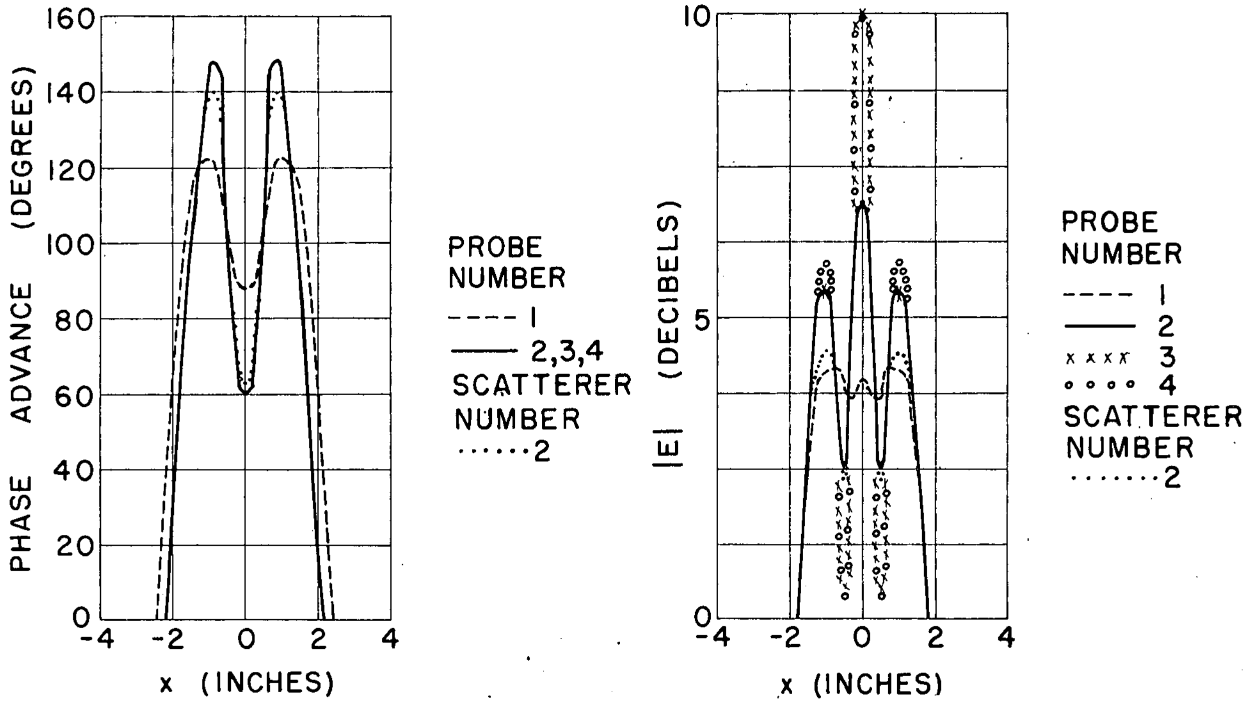

Fig. 5—Phase and amplitude distributions as measured with various probes and scatterer 2.

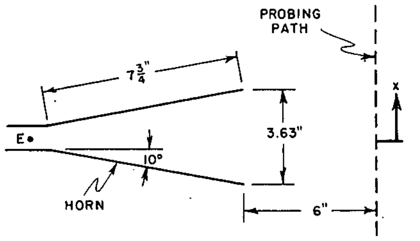

Fig. 6—Horn antenna used to test probe 4.

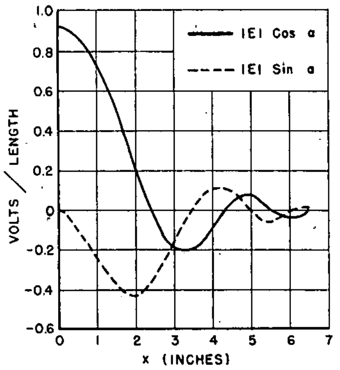

Fig. 7—Time-quadrature components of electric field of horn as measured with probe 4.

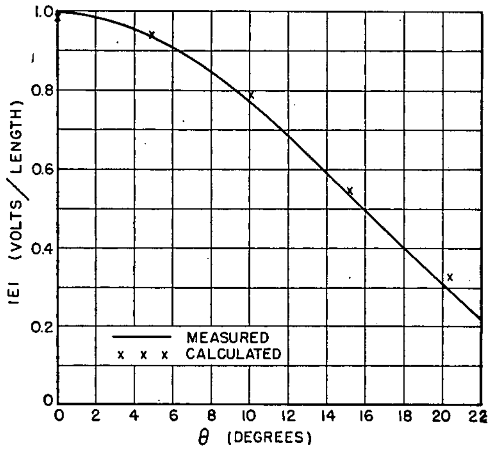

Fig. 8—Comparison of measured far-field pattern of horn and calculations based on near-field measurements with probe 4.

using a coherent detector.[5] These measured near fields, shown in Fig. 7, were used to predict the *H*-plane far-field pattern of the horn. Good agreement was obtained with the measured far field as is evident in Fig. 8. The far field was measured and calculated only through the main lobe since only this portion was of interest. The slight difference between the calculated and measured far-field patterns is due partly to imperfect far-field measurements and certain approximations[4] which were made to simplify the calculations. Equally good success was obtained in far-field calculations for a parabolic reflector antenna,[4] based on near-field measurements with probe 4.

By using probe 4 to measure the field of a rotatable dipole it was found that the probe discriminated between cross linearly polarized waves by at least 38 db.

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[5] J. H. Richmond, "Measurement of time-quadrature components of microwave signals," TRANS. IRE, pp. 13–15, this issue.