A NEW FIELD-PROBING TECHNIQUE FOR MILLIMETER-WAVE COMPONENTS

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Abstract: A new technique for probing the fields in the vicinity of a millimeter-wave circuit or antenna, using a dielectric waveguide is described. This technique is expected to be particularly useful for frequencies greater than 100 GHz, where effects of manufacturing inaccuracies, and minute material defects may lead to hard-to-trace faults.

Introduction: At millimeter-wave frequencies, especially above 100 GHz, almost all testing of circuits is carried out via waveguide ports, measuring S-parameters. This gives no indication of the field pattern in the circuit, and circuit debugging is very difficult. One consequence is that integration of many components on the same substrate is rarely attempted at higher millimeter-wave frequencies. To alleviate this problem a probe based on a dielectric waveguide is demonstrated, which picks up the field from a small tip, and couples it to a rectangular waveguide. This can be connected to a power detector or one port of a network analyzer. The probe tip can be moved in a precisely controllable fashion by a 3-axis micro manipulator. Although similar probing is routinely carried out at lower frequencies, in a slotted waveguide for example[1], it will be demonstrated that the dielectric waveguide based probe has some advantages.

Description: The structure of the probe is shown in Fig.1. The copper strip at the end of the dielectric rod is the element which picks up the field, and couples it to the dielectric waveguide of square cross-section. This in turn leads into a standard rectangular waveguide through a simple tapered transition. This structure, and the dimensions and material used were arrived at after a number of alternatives were tested in a manner subsequently described, and were found unsatisfactory. Fig. 2a shows a microphotograph of the tip of such a probe, suitable for G-band (140 - 220 GHz),and Fig. 2b shows the tapered end which goes inside the metal waveguide. The dielectric rod was made as narrow as possible (0.010" x 0.010"), and the material chosen had permittivity = 20. Ideally, the probe positioned at some point (x,y,z) as shown in Fig.3 should couple power into the waveguide proportional to $E_X(x,y,z)$, but in practice, the fields in some volume surrounding this point will affect the coupled power. To find out if this volume is small enough to be acceptable, some tests were carried out.

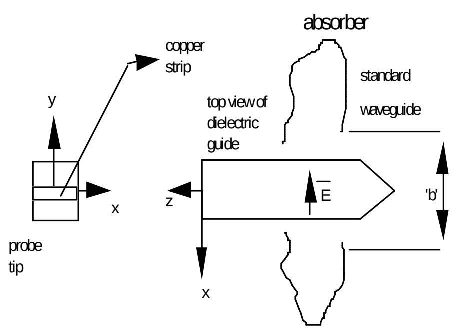

Fig.1. Structure of probe.

Experiments: Fig. 4 shows the setup and co-ordinate system for probing the fields near a

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waveguide mouth radiating into space. This structure was also simulated using H.F.S.S. (the well-known finite-element method based software) to determine the actual field strength as a function of position.

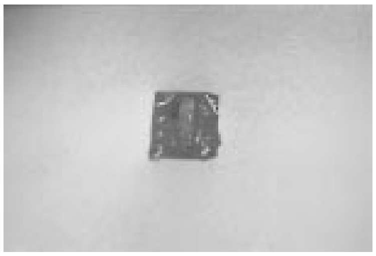

Fig. 2a. Microphotograph of probe tip.

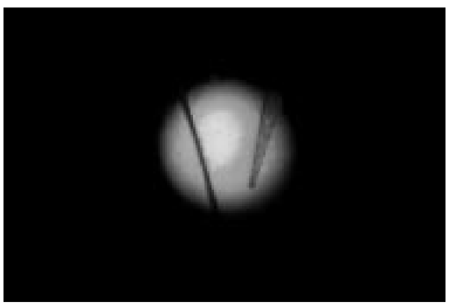

Fig. 2b. Tapered end of dielectric, which forms the transition to metal waveguide; a hair is shown on the left to the same scale.

Fig. 5a shows the z-variation of $|E_X|$ as predicted by H.F.S.S., as well as the field strength indicated by the probe. These are both normalized a peak value of 1, since this experiment aims at measuring the *shape* of the field pattern and not the absolute values. It is seen that the probe output is fairly close to the actual field pattern shown by H.F.S.S., but there is still scope for improvement. Fig. 5b, and Fig. 5c show the x and y variation respectively (for z=0.012"), and it is seen that these patterns are also predicted with reasonable accuracy. The deviation in Figs. 5b and 5c are probably caused by inaccurate knowledge of the z-value for these, as the waveguide mouth is hard to pinpoint in practice. This experiment shows that the probe gives a fairly accurate picture of the electric field in the plane normal to the dielectric rod, as well as a reasonable pattern of the field variation normal to this plane. Also the results could be used as a calibration for obtaining the absolute field values in other measurements, since the absolute values are given by the simulation results if the power input to the waveguide is known. The power picked up by the probe is quite small , so the comparison could not be extended to locations further from the waveguide mouth. More power could be collected by a thicker probe, but the field patterns degrade. This is a trade-off involved in designing such a probe.

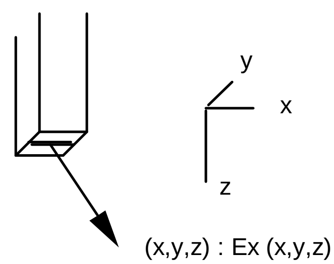

Fig. 3. Co-ordinates used

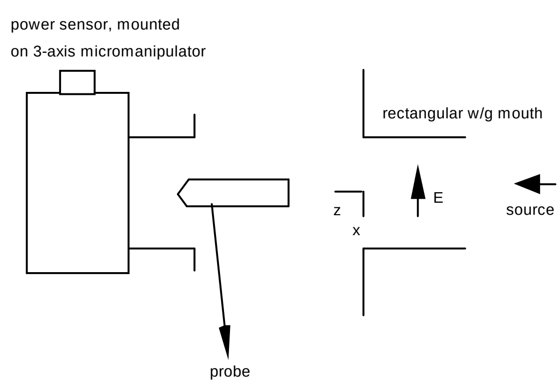

Fig. 4. Setup for probing near a waveguide mouth.

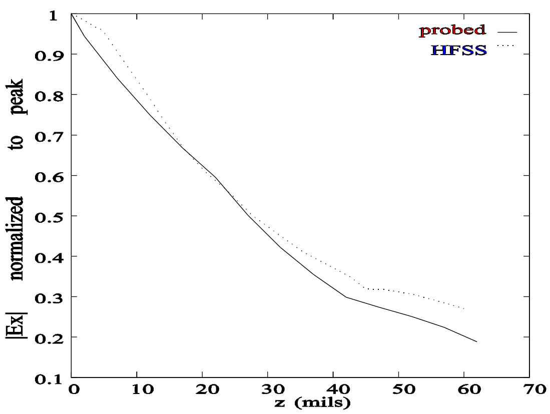

Fig. 5a Z-variation of electric field.

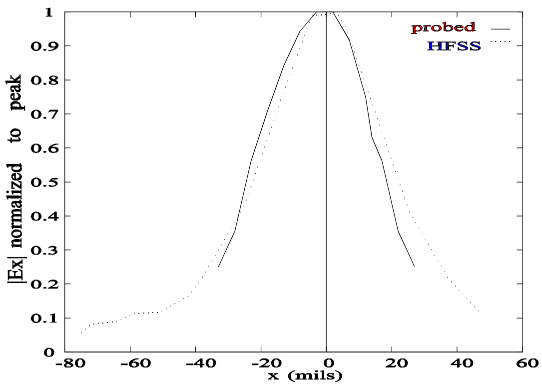

Fig. 5b. X-variation of electric field.

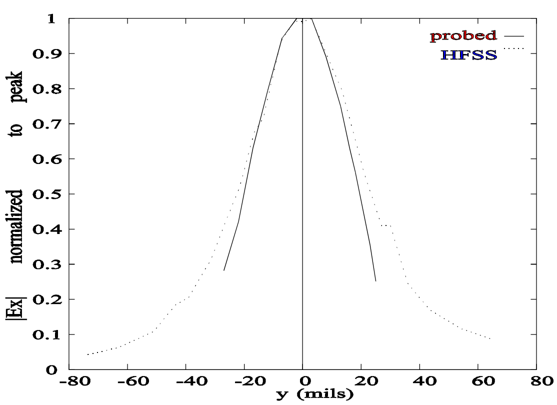

Fig. 5c. Y-variation of electric field

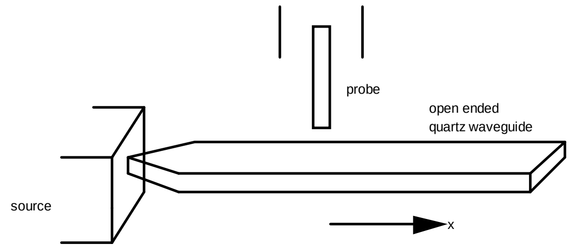

Fig. 6. Probing a dielectric waveguide.

The preceding data was related to the measurement of radiated fields. The probe however is also capable of measuring the field pattern for guided fields. To demonstrate this, the setup shown in Fig. 6 was used. The quartz rod shown is a single mode dielectric waveguide in this frequency range (when the symmetry of the setup is taken into account). The probe was moved along the length of the rod approximately 0.005" above its surface. Since the quartz rod is open-ended, there is a standing-wave pattern along its length. The VSWR of this pattern is dependent on the radiation from the open end, and this depends on the frequency. This is shown in Fig. 7, where the probed field strength is plotted for 3 frequencies.

Knowing that the separation of the peaks is half a guide wavelength, the propagation constant of this waveguide was calculated. This is compared to the calculated result based on the well-known effective dielectric constant approach [2], in Fig. 8. The discrepancy is small ($<$ 3%), and the uncertainty in the probe positioning, particularly the height above the rod, which could not be maintained in a precisely horizontal position, is quite likely to cause this error, as well as the irregular variation in the peak value. It should be emphasized that more precise measurement of the propagation constant is possible by other means such as measuring the beam pointing angle of a leaky-wave antenna as described in [3]. The present measurement however is, we believe, the first direct measurement of the field pattern in a dielectric waveguide at this frequency.

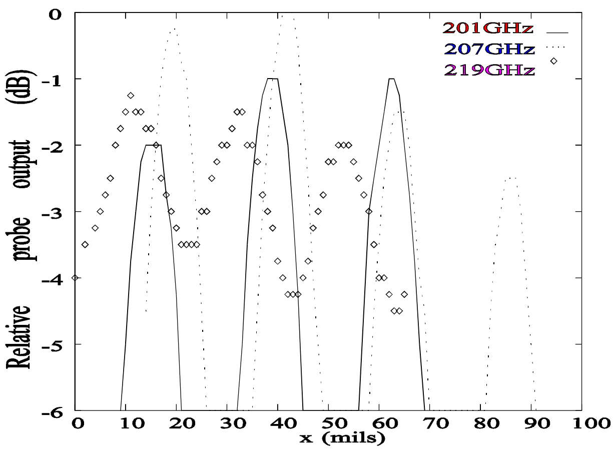

Fig. 7. Standing wave patterns at three frequencies.

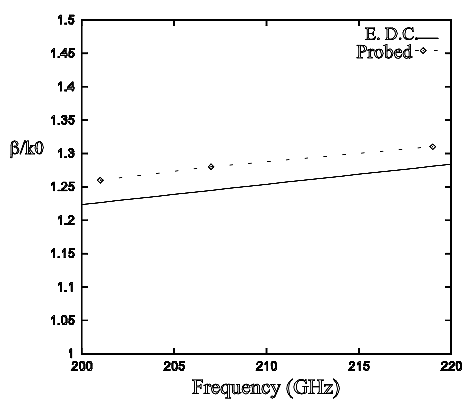

Fig.8. Normalized propagation constant

Conclusion: The dielectric waveguide based probe described has been demonstrated to be a useful tool for field pattern measurements at higher millimeter-wave frequencies. Although a chip Schottky diode can also be used as an effective probe, the structure presented maintains phase information as well, and is easy to fabricate. The main disadvantage is the fragility and frequency-sensitivity of this type of probe. For many measurements ,however, such as near-field measurement of leaky-wave antennas, and devices combining millimeter-waves and optical signals, especially for localizing faults, this probe is expected to be quite suitable.

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References:

[1] D.M.Pozar, *Microwave Engineering* , Addison-Wesley Publishing Company.

[2] T. Itoh, "Inverted Strip Dielectric Waveguide For Millimeter-wave Integrated Circuits" , *IEEE Transactions on MTT,* Nov. 1976.

[3] Chung-Yi Lee, Ananjan Basu, John Liao, June Wong, Bijan Houshmand and Tatsuo Itoh, "Millimeter Wave Dielectric Leaky-wave Antennas", *Conference Proceedings of ISSSE, 1995.*