5.1: A NEW TECHNIQUE FOR MULTIMODE POWER MEASUREMENT*

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A new and simple technique is described for measuring the total power flow in an overmoded waveguide. A problem arises when measuring spurious emissions of microwave transmitters and low-loss transmission in the millimeter and submillimeter regions. In many instances, the power is split between two and ten modes. Conventional power-measuring devices are based on one propagating mode. By converting the overmoded wave to an approximate plane wave, the total power flow in an overmoded waveguide can be determined by averaging the squared magnitudes of electric field along the waveguide perimeter. The electric field is sampled by a set of fixed probes (Figure 1). Unlike an earlier fixed-probe technique [1], this technique does not require a digital computer to reduce the data and can operate at higher peak-power levels. It is applicable to all uniform transmission lines. However, this paper discusses in detail only the rectangular waveguide.

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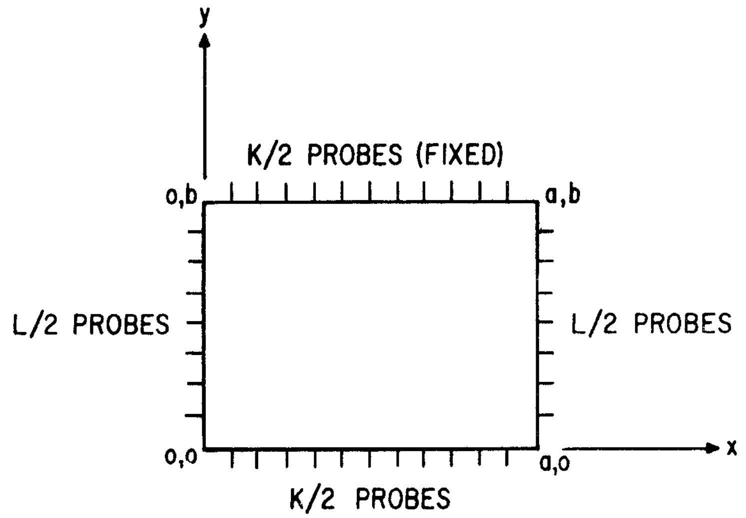

Fig 1. Cross section of enlarged waveguide with fixed probe.

To implement the measurement, the nonplanar (E_z and H_z components are present) overmoded waveguide field must be converted to a plane wave. This is done by connecting the regular overmoded waveguide to a long tapered section. The taper connects the regular waveguide to a section of waveguide having a and b dimensions each three times larger. Figure 2 shows a taper used to connect an S-band waveguide to the oversize section. For an ideal taper, the enlarged waveguide will have negligible E_z and H_z components; the maximum power-measuring error that results from this assumption is 0.25 db. This implies that the power flow can be obtained by integrating the longitudinal component of the Poynting vector over the cross section. This expression is given by

$$P = \frac{1}{\eta} \int_0^b \int_0^a \left(|E_x|^2 + |E_y|^2 \right) dxdy \qquad (1)$$

where η is the free-space intrinsic impedance ($120\,\pi$) and a and b are the dimensions of the oversize waveguide.

This equation suggests that power could be rigorously determined by using moving probes that sample only E_x and E_y components over the entire cross section. Although this form of measurement is feasible and in fact has been developed [2], the moving probe perturbs the field more than the set of fixed probes. Furthermore, the moving probe handles considerably less power and requires a complex mechanical arrangement. The fixed-probe technique overcomes these disadvantages but is not quite as rigorous. Fortunately, accuracy is within ±1 db for most applications.

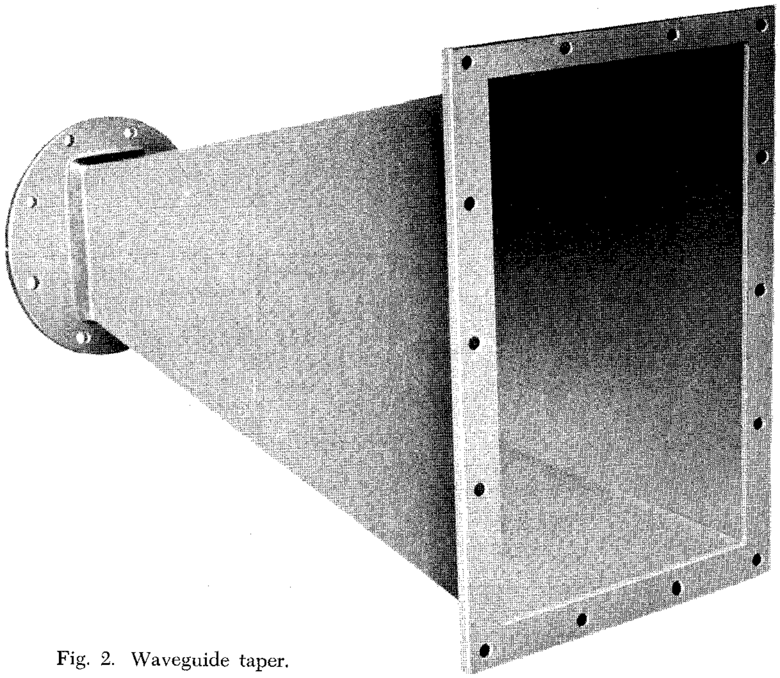

Fig. 2. Waveguide taper.

A mathematical analysis of the fixed-probe data indicates that the following expression is a measure of power flow:

$$P_a = \frac{ab}{2\eta}\left[\frac{1}{K}\sum_{k=1}^{K}\left|E_{y_k}\right|^2 + \frac{1}{L}\sum_{\ell=1}^{L}\left|E_{x_\ell}\right|^2\right] \qquad (2.)$$

where

$\left|E_{y_k}\right|^2$ and $\left|E_{x_\ell}\right|^2$ = sampled squared magnitudes of electric field,

K and L = respective number of broad- and narrow-wall fixed probes.

This expression is related to the true power P of equation 1 by

$$P = P_a + \text{error terms}. \qquad (3)$$

The error terms arise out of cross products of different modal field amplitudes and phases. They are real numbers that can be either positive or negative with equal probability depending on the time phases of the modal amplitudes. Therefore, we can average out the total error by redistributing the modal time phases and taking fixed-probe readings under several different modal phase conditions. This is done by using a line stretcher in the standard size (dispersive) waveguide.

Figure 3 is a block diagram of the equipment used. The power to be measured is fed into the enlarged waveguide fixed-probe section (Figure 4) through a long taper (3 feet for S band). A line stretcher is used in

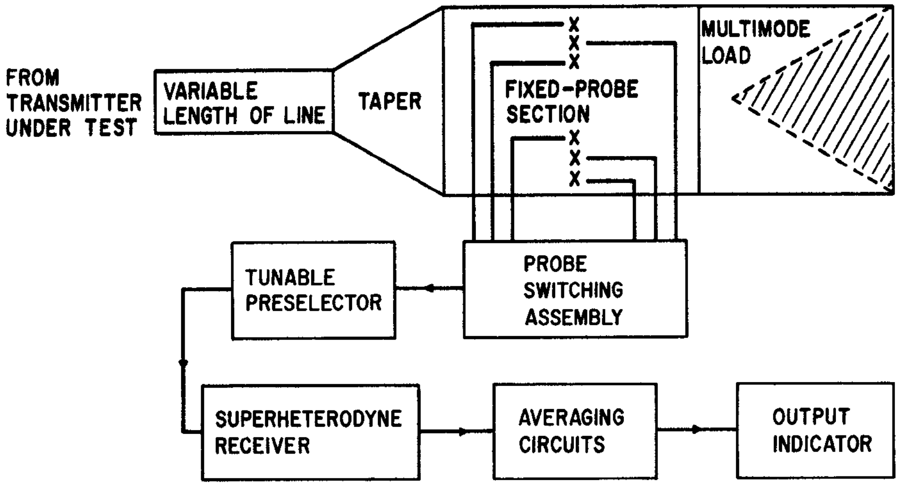

Fig. 3. Block diagram of equipment for fixed-probe technique.

the standard waveguide. The probe outputs are fed to an RF switching assembly that individually switches each probe to a tunable superheterodyne receiver. The output indicator records the average value of all probe readings. Thus, by calibrating the receiver, we can determine the absolute values of $|E|^2$ from output readings. The error term is eliminated by varying the line stretcher and recording the average output indication over its full excursion.

Experimental verification of this technique has been obtained by launching multimode fields of known power levels and correlating them with fixed-probe measurements. Good accuracy (less than ±1 db) has been obtained for multimode fields in rectangular waveguides. Figure 5 shows a typical field distribution that was measured using this technique. The measurement was made at 7000 Mc with the wave launched in a standard S-band waveguide and then tapered to the enlarged waveguide fixed-probe section. The field was measured on all four walls. The E_y components are plotted; the E_x components were much lower and had only a 5-per cent effect on the power calculation. The power resulting from this field distribution agreed with the true power reading within ±0. 9 db.

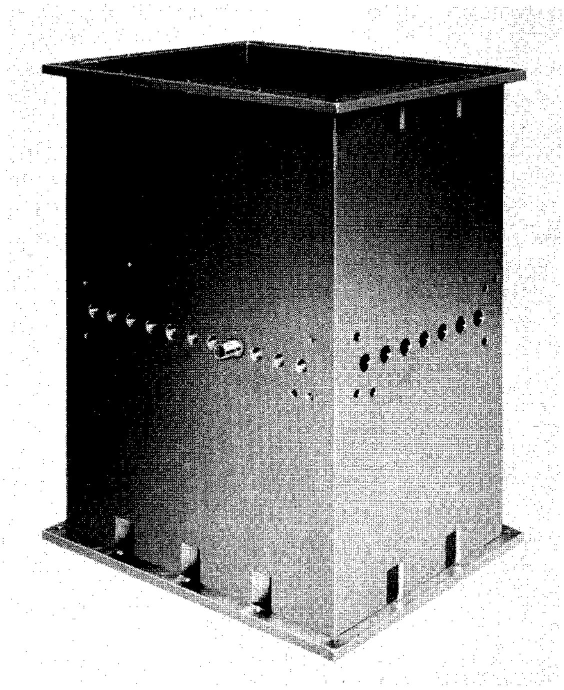

Fig. 4. Fixed-probe test unit.

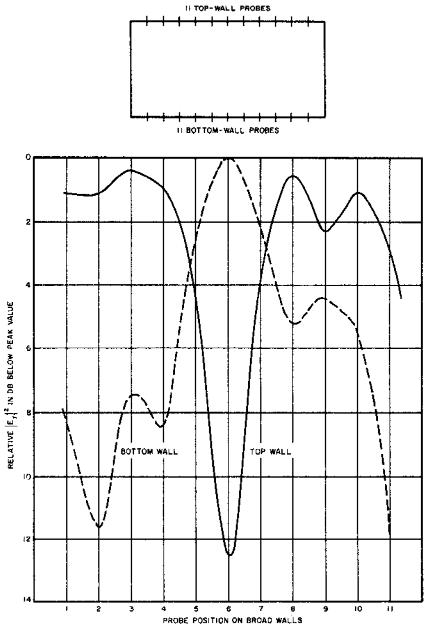

Fig. 5. Field distribution for multimode power measurement.

1. V. G. Price, "Measurement of Harmonic Power Generated by Microwave Transmitters," Trans. IRE MTT-7, 116-120 (1959).

2. O. Hincklemann, D. Levinson, J. Goldberg, J. Taub, and R. Sleven, "First Quarterly Report on New Methods for Measuring Spurious Emissions," Airborne Instruments Laboratory Report No. 1112-I-1, Contract AF 30(602)-2511 (Aug. 1961).