

A NOVEL CAVITY RESONATOR MEASUREMENT  
METHOD FOR LEAKY WAVEGUIDES

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**ABSTRACT**

In this novel cavity resonator method for measuring the phase and leakage constants of leaky waveguides, power is sent in transversely, in a reversal of the leakage process itself. The cavity therefore requires no coupling holes, and the method is accurate and convenient to use, as shown in an illustrative example.

**1. Introduction**

A leaky waveguide loses energy along its length because of the leakage of power away from the guide; the propagation wave-number of the leaky waveguide is therefore characterized as  $\beta - j\alpha$ , where  $\alpha$  represents the leakage per unit length (in addition to any metal or dielectric loss that may be present). In order to accurately measure the leakage constant  $\alpha$ , it is usually necessary to probe a substantial length of the leaky guide. One therefore needs a long guide (particularly if the leakage per unit length is small), and a moveable probe. What is worse is everyone's experience that the power that leaks is easily scattered around, so that the moveable probe picks up spurious radiation that interferes with the precision of the measurements. The new cavity resonance measurement procedure presented here eliminates all of these problems. With this new method, one works with a short section of the leaky structure, feeds it from the side in the leakage polarization, and varies the frequency through resonance. The measured resonance frequency and the  $Q$  of this cavity are related to the  $\beta$  and  $\alpha$  sought.

The novel cavity resonator measurement method to be described below was motivated by the frustrations and annoyances produced by the above-mentioned spurious radiation

encountered with the direct probing procedure. It was also developed in connection with a specific class of leaky waveguides, the dielectric strip guides for millimeter waves, such as the insular guide, rib guide, etc., but it is applicable to a much wider class of leaky waveguides. The description of the new method is phrased in the context of a leaky dielectric strip guide, and the specific numerical results are also presented for that type of guide. It should be understood, however, that the waveguide chosen should be viewed as an example, and that the method is more widely applicable.

**2. Description of the New Measurement Method**

The leaky waveguide chosen for the description of the measurement method is the dielectric rib waveguide for millimeter waves, shown in Fig. 1. When the hybrid mode carried by the waveguide is TE-like, with the primary electric field component oriented as shown in Fig. 1, the mode is usually leaky, with the leakage occurring in the form of a TM surface wave supported by the dielectric layers on the sides of the guide [1,2]. The basic mode propagates in the  $z$  direction along the dielectric strip (or rib), and the leaking surface wave propagates away on each side at an angle  $\theta$  from the  $z$  axis. The strip region has width  $W$ . These features are summarized in Fig. 1.

To construct the resonant cavity on which the new measurement procedure is based, we place a length  $a$  of the guide shown in Fig. 1 between parallel vertical metal plates, where the metal plates extend in the  $x$  and  $y$  directions, as seen in Fig. 2. In that cavity, between the plates, we thus have a strip of dielectric of width  $a$  extending along the  $x$  direction, with its center portion, of "length"  $W$ , having a somewhat greater height, since it corresponds to the strip or rib of the

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original rib waveguide. If the mode on the original dielectric rib waveguide in Fig. 1 were purely bound, the fields in the x direction away from the rib would be evanescent; if the mode is leaky, and a TE-like mode is present, then a TM surface wave would leak away in the outside region. When the short-circuiting parallel plates are introduced, this propagating wave, if it could be excited, would be changed into a standing wave with corresponding properties.

The new measurement approach employing the resonant cavity now reverses the process. A pair of TM waves is sent from one end between the parallel plates, in the x direction, toward the central section of greater dielectric height. Actually, this pair of TM waves is the lowest hybrid mode with a vertical electric field only, and is termed an LSM mode in the xz plane or an  $E^{(y)}$ -type mode; it is also identical with the standard dominant mode in H guide. In the measurement procedure, the frequency is then varied through resonance. The angle  $\theta_g$  of the pair of TM surface waves that comprise the incident wave between the plates varies as the frequency is changed, in accordance with

$$\cos \theta_g = \frac{k_z}{k_o} = \frac{\lambda_o}{2a} \quad (1)$$

At an appropriate frequency, the angle  $\theta_g$  becomes equal to the leakage angle  $\theta$ , and the incident wave excites a resonance in the central section. The fields in that central section would then increase substantially, particularly for the TE portion of the modal field (the inverse of the leakage situation). Hence, a probe sensitive to that polarization is placed in the midplane of the central region, oriented in the x direction, as seen in Fig. 2, and the power detected is found to peak sharply when the frequency of excitation corresponds to the condition for resonance.

The quantities to be measured are, therefore, the width  $a$  of the structure, the frequency  $f_o$  at resonance, and the  $Q$  of the resonance. Alternatively, one could measure directly  $\Delta f$ , the frequency separation between half power points, since  $Q = f_o/\Delta f$ . From these measured values, we may readily obtain  $\beta$  and  $\alpha$  for the leaky guided mode on the dielectric rib waveguide.

The relation for  $\beta$  is extremely simple:

$$\beta = k_z = \pi/a \quad (2)$$

We may alternatively wish to know  $\epsilon_{eff}$  for the guided mode, where

$$\epsilon_{eff} = \left(\frac{\beta}{k_o}\right)^2 = \left(\frac{c}{2af_o}\right)^2 = \left(\frac{15}{af_o}\right)^2 \quad (3)$$

where the last form is valid when  $a$  is in cm and  $f_o$  is in GHz. It can be shown that the leakage constant  $\alpha$  can be written in terms of the measured cavity  $Q$  as

$$\alpha = \frac{\pi}{2aQ} \quad (4)$$

or, if one wishes to express  $\alpha$  in terms of nepers per wavelength,

$$\alpha \lambda_o = \frac{15\pi}{aQf_o} = \frac{\pi a \Delta f}{15} \epsilon_{eff} \quad (5)$$

where  $a$  is in cm and  $f_o$  or  $\Delta f$  is in GHz.

### 3. Why This Cavity Resonator Method is Different

The idea of employing a resonant cavity to measure the propagation characteristics of a mode on a waveguide is of course quite old, but such application has generally been to purely bound modes. A resonant cavity has also been proposed for the measurement of the properties of a leaky mode [3], where the application was to a rectangular waveguide with its side wall perforated to permit leakage. That cavity was comprised of a length of the leaky waveguide placed between metal plates, but it was excited by coupling holes located in these metal plates at the two ends of the cavity. That method of excitation is the standard one; it yields good results, but the coupling holes introduce an extra contribution to the radiation  $Q$  and may therefore reduce the accuracy of the results.

As seen from Fig. 2, the arrangement here is different. In the other methods, including that in [3], the guide section is excited longitudinally, by coupling holes in the metal planes. Here, the structure is excited transversely, by sending in the wave that would have leaked in the reversed situation. No extra coupling holes are needed.

It should be added that the method of transverse excitation used here would not work if the waveguide were not leaky. If the mode were purely bound, with an evanescent transverse field decay, the exciting mode in the resonant cavity arrangement would need to be below cutoff.

### 4. Numerical Comparisons with Theory for Specific Rib Waveguides

The measurement method described above was applied to several dielectric rib waveguide structures under conditions of leakage to verify its utility and its accuracy. The basic waveguide was the one shown in Fig. 1 for the field excitation shown; for the different structures, all dimensions

remained the same except for the waveguide width  $W$ . Six different guide widths were chosen, ranging from  $W = 0.80\text{cm}$  to  $W = 1.50\text{cm}$ . The dielectric constant was  $\epsilon_r = 2.54$ . In the cavity resonator arrangement shown in Fig. 2, dimension  $a$  was  $1.58\text{cm}$ , and the probe used was a miniaturized coaxial monopole that came down vertically but had its exposed end bent horizontally in the manner shown in the mid-plane in Fig. 2. The metal outer conductor of the miniature coaxial line was covered with absorbing material.

To check the accuracy of the measurements, we also made theoretical calculations of the  $\beta$  and  $\alpha$  of the waveguides corresponding to the six different guide widths  $W$ . The method used was the mode-matching procedure [1], where ten modes (five TE and five TM) were taken in each region in the guide cross section.

Comparisons between these theoretical calculations and the results of the measurements, on use of relations (3) and (5), are presented in Figs. 3 and 4. The comparisons in Fig. 3 for the effective dielectric constant, or equivalently for  $(\beta/k_0)^2$ , indicate that the measurements are consistently very slightly higher than the theoretical values. The discrepancy is only of the order of 1%, however, and it could be due to a small error in measuring distance  $a$ , or in the nominal value of  $\epsilon_r$ , which could then affect the theoretical values.

The comparisons shown in Fig. 4 for  $\alpha\lambda_0$ , the leakage attenuation per wavelength, seem to be very good, considering the error sources present, even after taking into account the fact that the plot is on a logarithmic scale. The higher measured values could be accounted for by the presence of small dielectric losses and metal wall losses which are not included in the theoretical results.

We conclude from our experience with this new resonant cavity measurement method that it is convenient to use, and that it yields accurate results when compared with theoretical values. When compared with direct probing procedures, with which we also have experience, the resonant cavity method allows the use of a much simpler set-up, and it permits more accurate measurements in general because it eliminates the spurious radiation problems that arise in the direct probing of leaky structures.

#### REFERENCES

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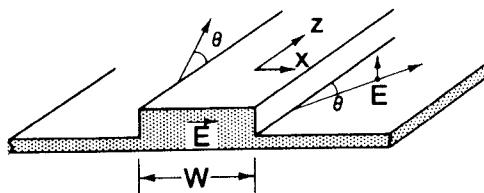


Fig. 1 The dielectric rib waveguide for millimeter waves, an example of a leaky waveguide. This guide can leak when the mode is TE-like, with the primary electric field component shown. Leakage then occurs away from the center rib at angle  $\theta$  in the form of a TM surface wave.

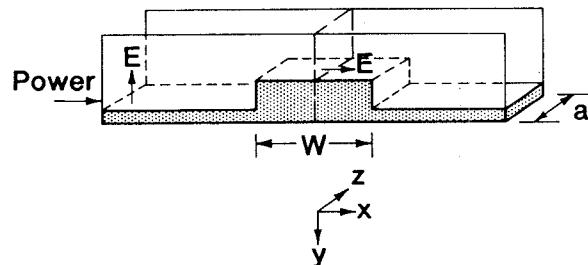


Fig. 2 The resonant cavity measurement arrangement, where a length  $a$  of the leaky waveguide in Fig. 1 is placed between parallel metal plates and the structure is excited from one side.

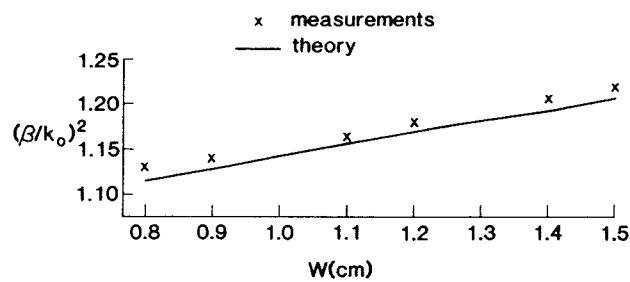


Fig. 3 Comparisons between measured and theoretical values of  $\epsilon_{\text{eff}}$  ( $= (\beta/k_0)^2$ ) as a function of guide width  $W$ .

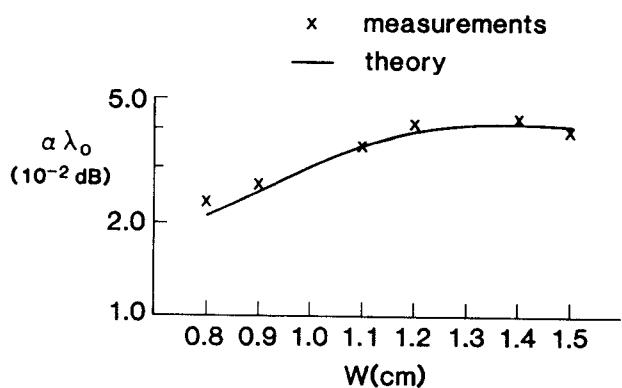


Fig. 4 Comparisons between measured and theoretical values of  $\alpha \lambda_0$ , the leakage constant per wavelength, as a function of guide width  $W$ .

#### ACKNOWLEDGMENT

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