effect of injected power and frequency on the phase transient characteristics is also examined. Criteria are also derived regarding the fast switching of Gunn oscillators and primary importance has been given to the case of devices with strong voltage dependent susceptance characteristics.

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Measurements of Dispersion Characteristics and Field Distributions in Rectangular-Dielectric Waveguide and Its Modifications

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Abstract—**The author has previously numerically analyzed transmission characteristics of several dielectric waveguides by applying generalized telegraphist's equations. The technique may be applicable to a wide class of dielectric waveguides with arbitrary dielectric profile and cross section. In this paper, the dispersion characteristics and the field distributions in rectangular-dielectric waveguides and in single material fibers have been measured at X-band frequencies to verify the validity of the analysis. Good agreement between measured and calculated results shows that the analysis is useful to study the transmission characteristics of dielectric waveguides.**

I. INTRODUCTION

DIELECTRIC waveguides are very attractive transmission lines for integrated circuits in millimeter and submillimeter wave frequencies. At present, exact analytical treatments of many three-dimensional waveguides except for the cylindrical-dielectric waveguide can not be expected. If we expect more accurate solutions than those obtained by approximate analytical methods [1], [2], they can be solved only by the numerical method such as the point-matching method [3], or by enclosing the dielectric waveguide with metallic walls [4]. The author has previously proposed a numerical method based on generalized telegraphist's equations, which may be applicable to a wide class of dielectric waveguides with an arbitrary dielectric profile and cross section [5], and has numerically analyzed transmission characteristics of rectangular-dielectric waveguides, cladded rectangular-dielectric waveguides, insulated-image guides, strip-dielectric guides, and single-material fibers [6].

The purpose of this paper is to determine experimentally the dispersion characteristics and the field distributions in these waveguides. This is of great importance in verifying the validity of the analysis based on generalized telegraphist's equations. As far as the author knows, experimental results of field distributions within dielectric waveguides for comparison have rarely been reported. In this paper, we report

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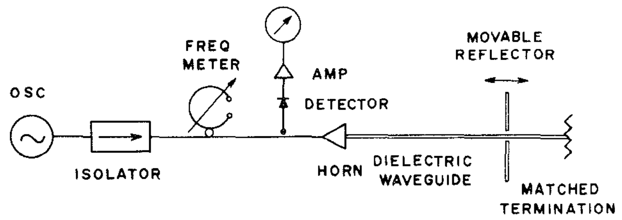

Fig. 1. Block diagram of the experimental setup to measure the propagation constant in dielectric waveguides.

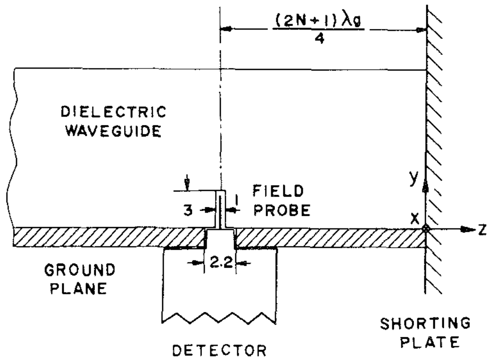

Fig. 2. Field probe to measure the transverse electric field distribution on the ground plane.

the dispersion characteristics in rectangular-dielectric waveguides and cladded rectangular-dielectric waveguides and the field distributions in rectangular-dielectric waveguides and single material fibers measured at X-band frequencies. The agreement between experimental and calculated results is fairly good, and the validity of the analysis is confirmed.

II. Experimental Procedure

Fig. 1 shows a block diagram of the experimental setup to measure the propagation constant k_z in dielectric waveguides. In the actual experiment, we utilize dielectric image lines to simplify the support problem. The oscillator operates at X-band frequencies. The launching horn is used to couple the dielectric waveguide and the microwave circuits. The surface wave on the dielectric waveguide is partially reflected by the metallic plate of the movable reflector, and it forms the standing wave. The reflection is inversely dependent on the frequency, that is, the lower the frequency, the more the reflection. Sliding the reflector, the standing-wave pattern measured by the detector is periodically changed. The guide wavelength λ_g is determined by doubling its period. The normalized propagation constant k_z/k_o is given by

$$\frac{k_z}{k_o} = \frac{\lambda}{\lambda_g} \tag{1}$$

where λ is the free-space wavelength. In this experiment, the reflector can be moved over regions up to 12 cm so that good results can be expected. In order to prevent the disturbance of the standing-wave pattern by the reflected wave through the movable reflector, the matched termination is connected at the end of the dielectric waveguide and absorbs the power through the movable reflector. The matched termination is constructed by tapering the dielectric waveguide as a dielectric rod antenna and painting aquadag on its sides.

Fig. 2 shows the field probe to measure the transverse electric field distribution on the ground plane. In this case, the transverse electric field component is E_y. E_y component is picked up by the field probe through holes drilled in rows 5.0 mm apart in the x direction. The distance between the field probe and shorting plate is $(2N + 1)\lambda_g/4$ (where N is integer) to obtain the maximum field at the position of the probe. The field probe is one of the standing-wave detectors and is connected through the hole of 2.2 mm in diameter on the ground plane. On the other hand, the holes drilled in the dielectric are 1.0 mm in diameter and 3.0 mm in height. In order to avoid the disturbance of field distribution by holes on the ground plane, every hole except one under measurement is closed.

III. Experiment and Discussion

Three materials have been used to fabricate dielectric waveguides: 1) Polypropylene ($\varepsilon_r = 2.25$), 2) ABS resin ($\varepsilon_r = 2.80$), and 3) Paraffin wax ($\varepsilon_r = 2.20$). Dielectric constants of 1) and 2) were experimentally determined by using the cavity-perturbation method and 3) was quoted from [7]. These materials were selected from two standpoints of ease of fabrication and dielectric constant. The rectangular-dielectric waveguide and the single material fiber were made of polypropylene. For the cladded rectangular-dielectric waveguide having a core of higher dielectric constant than the cladding, the core and the cladding were made of ABS resin and paraffin wax, respectively. In the experiment, we utilized image lines electrically equivalent to those waveguides. The dielectric rod was fixed on the ground plane (brass) by an adhesive. All experiments were carried out at X-band frequencies (6.7–12.2 GHz).

Fig. 3 shows the experimental and theoretical results of dispersion characteristics for the E^y_{11} mode in the rectangular-dielectric waveguide and cladded rectangular-dielectric waveguide. In this case, the rectangular-dielectric waveguide has the square cross section as shown in the inset in Fig. 3. In the calculation based on generalized telegraphist's equations, a 50×50 matrix was used. In Fig. 3, the result derived by Marcatili [1] for the rectangular-dielectric waveguide is also presented. For both waveguides, theoretical results based on telegraphist's equation agree well with the experiments over a wide range, including the transition region $k_z/k_o = 1.0$. In the case of the rectangular-dielectric waveguide shown in Fig. 3, the cutoff frequency of the next higher order mode is $k_oc = 2.0$. Marcatili's approximation breaks down when the electromagnetic field is not well confined within the waveguide.

Figs. 4 and 5 show experimental and theoretical results of $E_y(x,0)^2$ distribution for the E^y_{11} mode in the rectangular-dielectric waveguide and single material fiber, respectively, at $k_oc = 3.0$. $E_y(x,0)^2$ distribution is normalized to $E_y(0,0)^2$. The experiment was carried out at 9.61 GHz for the rectangular-dielectric waveguide and at 10.22 GHz for the single material fiber. In both figures, two other theoretical

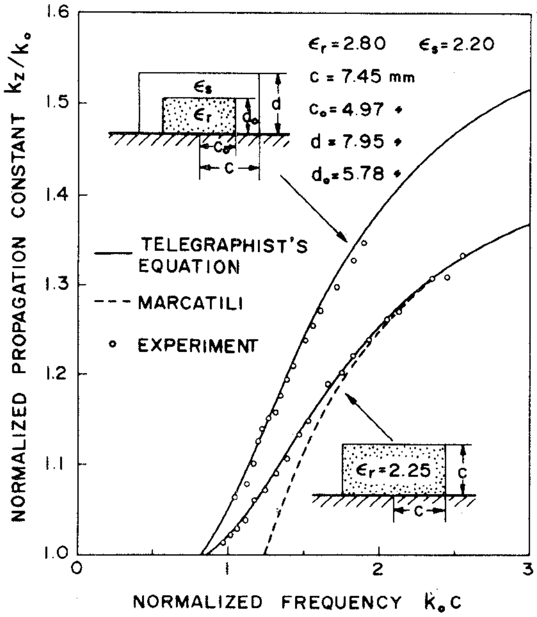

Fig. 3. Experimental and theoretical results of dispersion characteristics for the E_{11}^y mode in the rectangular-dielectric waveguide and cladded rectangular-dielectric waveguide.

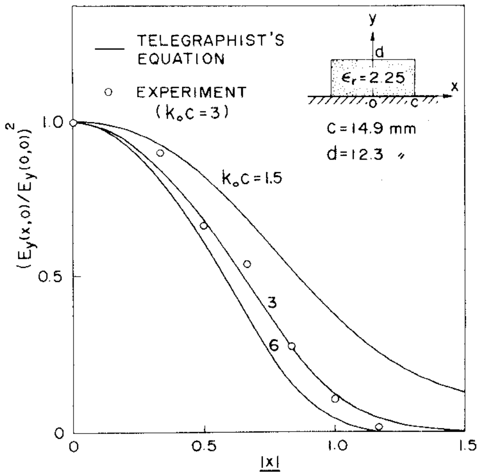

Fig. 4. Experimental and theoretical results of $E_y(x,0)^2$ distribution for the E_{11}^y mode in the rectangular-dielectric waveguide.

results for different frequencies are also presented. In the calculation, a 98 × 98 matrix was used. Normalized propagation constants in the rectangular-dielectric waveguide at $k_0c = 1.5$, 3.0, and 6.0 are 1.099, 1.342, and 1.453, respectively. On the other hand, normalized propagation constants in the single material fiber at $k_0c = 1.5$, 3.0, and 6.0 are 1.324, 1.444, and 1.484, respectively. The agreement between experimental and theoretical results is good.

As mentioned above, agreement between theory and experiment shows that our analysis gives good results for open-dielectric waveguides, even though our analysis is based on a closed waveguide model. Therefore, our analysis

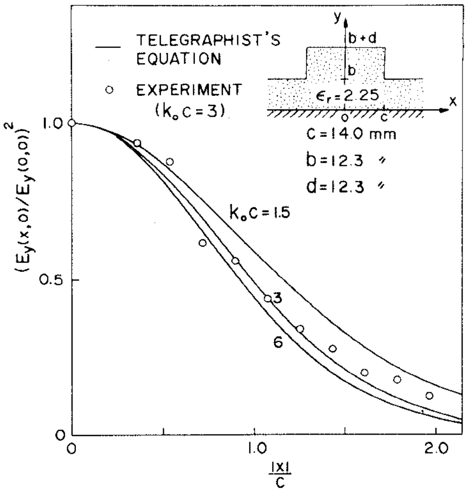

Fig. 5. Experimental and theoretical results of $E_y(x,0)^2$ distribution for the E_{11}^y mode in the single material fiber.

is useful to study new waveguides and to check new analytical techniques for their applicability.

IV. Conclusion

Dispersion characteristics and field distributions in rectangular and other dielectric waveguides have been measured at X band. The measured results agree with those obtained via our theory based on generalized telegraphist's equations. Therefore, the method is useful to study new waveguides and to check new analytical techniques for their applicability.

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