POWDER CORE DIELECTRIC WAVEGUIDES

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A powder-filled groove in the surface of a teflon substrate has been demonstrated as a dielectric waveguide at 94 Ghz. Guide wavelengths measured for combinations of guide dimensions and powders agree within 10% of values predicted by Marcatili's approximate theory. Attenuation constants of 0.2 to 0.3 dB/cm were measured for barium tetra-titanate.

A powder-filled groove in the surface of a teflon substrate has been demonstrated as a dielectric waveguide at 94 Ghz. This guide appears to be an attractive medium for low-cost, complex mm-wave components and integrated circuits. We have also demonstrated flexible dielectric waveguides by filling hollow low dielectric constant polymer tubes with low loss, high dielectric constant powders. This technique was used successfully at 10 Ghz and at 94 Ghz. However, the groove guide was used for guide wavelength and attentuation measurements since it proved easier to pack uniformly than the thin tubes used at 94 Ghz (18, 19, 20, 21 AWG teflon spaghetti). In addition, the cross-sectional dimensions of standard teflon spaghetti vary too much with length to give accurate measurements.

A rectangular groove was milled into the surface of a low-loss (TFE teflon) substrate and was filled with a high dielectric constant powder to form the core of a dielectric waveguide (Fig. 1). With this configuration, the powder could be packed from the top to assure a sufficiently uniform density along the length of the groove. Rectangular grooves with cross-sectional dimensions varying less than 0.002 inches from the specified values could be milled with relative ease. This degree of dimensional accuracy was found to be sufficient at 94 Ghz to produce a guide wavelength uniform within our measurement accuracy.

The guide wavelength and loss per unit length were measured for the fundamental vertically polarized mode of various powder-filled rectangular groove waveguides using the set-up shown in Fig. 1. On each end of the substrate the dielectric-filled groove was extended with a thin-walled trough of substrate material. This trough fitted snugly into the end of a slightly flared section of metal wavequide to couple to the dielectric guide. Lossy inserts made from Emerson and Cumming MF-110 absorber were placed at non-periodic intervals in the teflon substrate 3 mm from the groove to attenuate any substrate modes that might have been excited at the coupling point.

To measure the guide wavelength, a metal perturber was held mechanically just above the surface of the powder. This perturber reflects a small fraction of the powder travelling along the waveguide toward the feed, where it interferes with the reflection from the input coupler. The amplitude of this interference changes as the relative phase between these two signals changes. Thus, as the perturber was moved along the length of the groove, a sequence of maxima and minima in reflected power was sensed with a -10dB directional coupler and a Schottky diode. The guide wavelength is twice the distance the perturber is moved between successive minima.

The guide wavelengths for various combinations of guide dimensions and dielectric powders were compared to the values predicted by Marcatili's approximate theory (1) for the fundamental vertically polarized mode. In order to use Marcatili's theory, the dielectric constants of the powders were needed. The density of the powder in the groove was determined by weight measurement, and previously measured curves of dielectric constant versus density were used to find the effective dielectric constant of the powder packed into the groove. The dielectric constants of the powders were measured at 10 Ghz using the shorted-waveguide technique. These measurements were made at 10 Ghz because of the difficulty of controlling the length of a powder sample sufficiently accurately to measure its dielectric constant at 94 Ghz. For low-loss dielectrics we do not expect much change in dielectric constant between 10 and 94 Ghz.

To determine the loss-per-unit length of a groove waveguide, the power transmitted from end to-end was measured by a detector connected to the flared section of metal waveguide surrounding the trough on the far end of the substrate (Fig. 1). E/H tuners were used to match the coupling sections. The power detected at the far end could not be significantly increased by adjusting the E/H tuners, so we assume that the couplers are well matched. In addition, removing the lossy substrate inserts did not affect the power received at the far end, indicating that little

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power is lost to substrate modes. A third detector connected to a small horn antenna was used as a movable probe to determine that an insignificant amount of power was radiated from the couplers or guide. Finally, the power reflected from the feed coupling was -20dB down from the incident power. Taken together, these observations indicate that almost all of the incident power was coupled into the dielectric waveguide, so that the difference between the incident power and the power detected at the far end represents dielectric waveguide loss. The loss per unit length is then this loss divided by the length of the dielectric waveguide.

A second method for measuring loss-per-unit length along the powder-filled groove was used as a rough check. A detector with a short section of metal waveguide attached and positioned just above the groove was used as a probe. The probe-to-groove spacing had to be maintained accurately as the probe was moved along the groove. The slope of the detected power (dB) versus distance along the groove also gives the loss-per-unit length in dB/m.

A comparison between the measured values of the guide wavelength with those predicted for the Ey11 mode by Marcatili's approximate theory is given below for various powders in a teflon substrate at 94 Ghz.

Type of Powder	Width of groove (mm)	Depth of groove (mm)	Powder Density (g/cm3)	Dielectric Constant	λg (meas.) (mm)	λg (Marcatili) (mm)
1	1.14	1.22	1.69 ±.05	4.43 ±.25	1.86	2.00 ±.07
1	0.94	0.94	1.95 ±.07	5.78 ±.35	1.86	1.96 ±.08
2	1.12	1.12	1.77 ±.04	5.0 ±.4	2.06	1.9 ±.1
3	1.14	1.12	1.82 ±.03	4.68 ±.12	2.18	1.98 ±.04
3	1.04	1.04	1.95 ±.03	5.29 ±.15	2.12	1.93 ±.04

Powder 1 is nickel-aluminum-titanate (Trans-Tech D-30).

Powder 2 is barium tetra-titanate (Trans-Tech D-38).

Powder 3 is barium tetra-titanate (Trans-Tech D-8512).

The uncertainty in the guide wavelength predicted by Marcatili's theory is estimated from the uncertainty in the dielectric constant of the powder.

The results of measurements of the loss per unit length along a straight powder-filled groove in a teflon substrate are given below.

Type of Powder	Width of groove (mm)	Depth of groove (mm)	Density of Powder (g/cm3)	Technique	Loss (dB/cm)
1	1.14	1.22	1.44	movable detector	0.57 ±.08
1	1.14	1.22	1.44	end-to-end transmission	0.48
1	1.14	1.12	1.44	end-to-end transmission	0.43
3	1.14	1.12	1.82	end-to-end transmission	0.21
3	1.04	1.04	1.95	end-to-end transmission	0.27

Additional measurements are in progress and will be reported at the meeting.

(1) E.A.J. Marcatili, "Dielectric Rectangular Waveguide and Directional Coupler for Integrated Optics," Bell Syst. Tech. J. Vol. 48, pp. 2071-2102: Sept. 1969.

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