PROBE MEASUREMENTS OF GUIDE WAVELENGTH IN RECTANGULAR SILICON DIELECTRIC WAVEGUIDE

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Abstract

A probe method for determining the guide wavelength within a dielectric (silicon) waveguide is presented. The experimental results are compared to previously measured experimental values obtained with resonant silicon dielectric cavities and to the theoretical values as determined by Marcatili's theory. There is good agreement between the two experimental methods. The theoretical predicted slope of guide wavelength versus frequency is nearly equal to the slope of the experimental curve. The theoretical and experimental values however, differ, particularly at lower frequencies.

Introduction

Considerable work has been completed on the study of dielectric waveguides [1-4]. Very little however, has been reported on experimental confirmation of theoretical predictions. This report presents a probe method for determining the guide wavelength within a dielectric (silicon) waveguide. A probe, supported by a carriage of a slotted section, is used, from which the slotted metallic waveguide has been removed. In addition, provisions were made to move the probe precisely in vertical and transverse directions. The data obtained is compared to previous experimental[5] and theoretical values as determined by Marcatili[6]. The guide wavelength was chosen as the primary parameter for measurement because of its importance in designing dielectric waveguide components.

Experimental Procedures

Figure 1 shows the experimental X-Band set-up used in making the measurements. The portion called "Dielectric Test Circuit" in an enlarged form, is illustrated in Figure 2. The "Coaxial Probe", illustrated in Figure 2, was used to sample the vertical electric fields at various positions just above the dielectric waveguide. Note the dielectric waveguide was terminated by a large aluminum block to enhance the standing wave in the dielectric (silicon) waveguide. The probe was supported by a carriage of a slotted section, from which the slotted metallic waveguide had been removed; this provided calibrated longitudinal movements of the probe. In addition, two micropositioners provided a calibrated movement of the probe in the vertical and transverse directions giving the probe an overall 3-dimensional calibrated movement. The dielectric waveguide was a piece of rectangular silicon whose resistivity was 10,000 ohm cm and whose dimensions were 7 mm wide, 3.5 mm high, and approximately 10 cm long. A teflon saddle positioned this dielectric waveguide on a copper plate, 2.29 cm wide and approximately 1/3 cm high; these dimensions permitted the insertion of the copper plate with the dielectric waveguide into the standard rectangular X-Band metallic waveguide (RG-52/U). Thus, the combination of the dielectric waveguide and copper piece, were inserted into the X-Band waveguide approximately 1.0 cm and a copper sheet was placed around the dielectric waveguide so that only the microwave energy within the dielectric waveguide could come out of the X-Band metallic waveguide, as shown in Figure 2.

At each frequency, the half-guide wavelengths were measured along the length of the silicon and the average mean value, as well as the standard deviation, were calculated. An X-band oscillator, with 1000 Hz square wave AM modulation was used, limiting the frequency band from 8.0 to 12.4 GHz. A standard Standing Wave Indicator measured the signal, picked up by the probe, and detected by a broad-band coaxial detector.

Experimental Results

The experimental results are illustrated in Figure 3; the average mean value of guide wavelengths are plotted as solid points with the standard deviation shown by the vertical line through the solid points. In addition, the hollow points in Figure 3 illustrate the experimental value of guide wavelength obtained previously[5], wherein the length of the silicon cavity was increased by adding small slabs of silicon with the same cross sectional dimensions as the cavity, and the resonant frequency was measured. Theoretical values of the guide wavelength, calculated from the theory of Marcatili[6], are drawn as a dashed curve. Agreement between the two experimental methods is self-evident in Figure 3 within the frequency range from 9.75 to 12.4 GHz, giving confidence in the experimental methods of measurement.

At 9.36 GHz, the vertical electric field was measured as a function of distance in the transverse direction, at a fixed height; the result is plotted in Figure 4. The logarithm of the electric field is plotted in Figure 5 as a function of the distance. Note, in Figure 4 and Figure 5, the relative position of the dielectric waveguide and the copper plate are shown with respect to the plotted electric field and logarithm of the electric field, respectively. In addition, in Figures 4 and 5, the distance in the transverse direction is given in the units, mils (1 mil = 0.001 inch).

Discussion and Conclusions

The agreement of the two experimental methods, namely, the probe measurements and the cavity length variation, is evident in the plot of Figure 3. The theoretical values of guide wavelength generally falls below the experimental points, indicating that the calculated values of guide wavelength are somewhat smaller than the measured values. At the higher frequencies however, the discrepancy between the theoretical and experimental values should be practically negligible. From probe measurements, the E^y_{11} mode was found to exist in the dielectric waveguide, namely, the trigonometric variation of the electric field in the 3-dimensions, the longitudinal, the transverse and the vertical directions. Assuming a cosine function for the electric field as a function of the transverse distance, in Figure 4 we note that only two-thirds of the transverse half-wavelength resides within the dielectric waveguide, since the magnitude of the electric field at the edge of the dielectric, is approximately one-half of the electric field in the center of the dielectric. Although the theory recognizes the fact that for the fundamental mode, E^y_{11}, the transverse variation should be less than a one-half wavelength; the theory is incomplete in that it does not predict quantitatively by what portion the half-wavelength should be reduced. The attenuation outside the dielectric waveguide in the transverse direction, was calculated from Figure 5 to be 0.048 db/mil (0.22 nepers/mm); this value is one-third the attenuation as obtained from the theory.

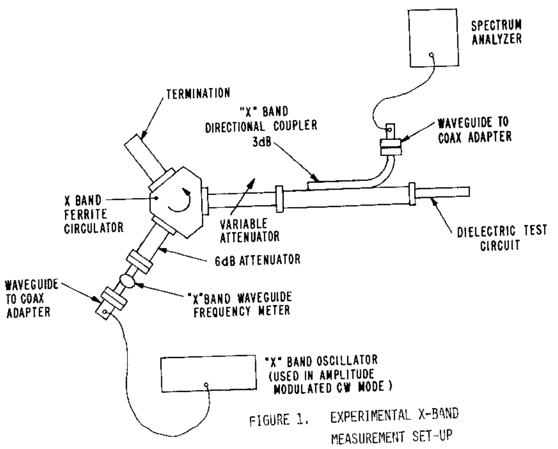

FIGURE 1. EXPERIMENTAL X-BAND MEASUREMENT SET-UP

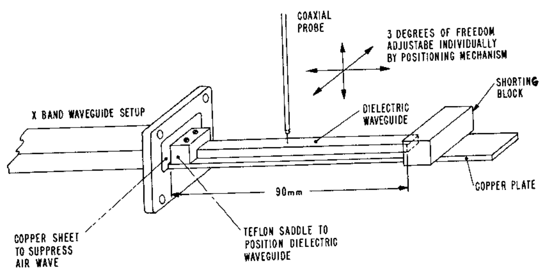

FIG 2 DIELECTRIC TEST CIRCUIT

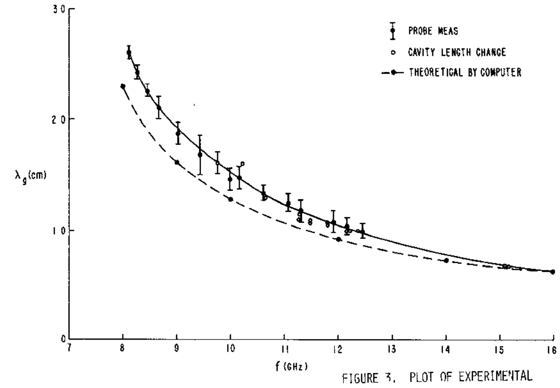

FIGURE 3. PLOT OF EXPERIMENTAL AND THEORETICAL GUIDE WAVELENGTHS VERSUS FREQUENCY

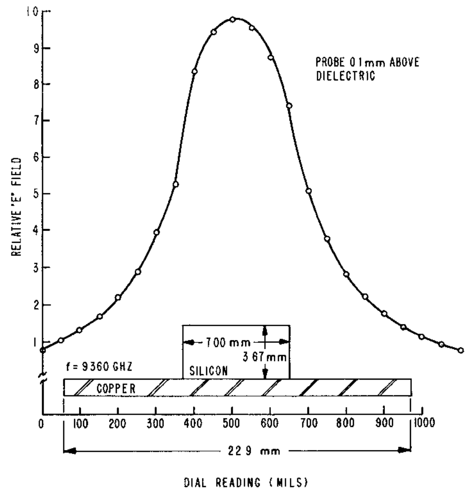

FIG. 4 "E" FIELD (TRANSVERSE) IN SILICON DIELECTRIC WAVEGUIDE

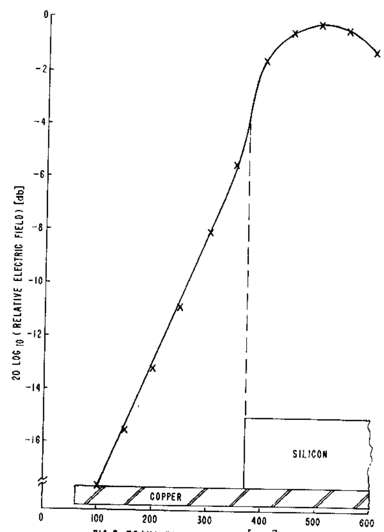

FIG 5 TRANSVERSE DISTANCE [MILS]

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