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DESIGN, CONSTRUCTION, AND MEASUREMENT OF A 3 dB DIELECTRIC DIRECTIONAL COUPLER

by

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TABLE OF CONTENTS

LIST OF FIGURES

DESIGN, CONSTRUCTION, AND MEASUREMENT OF A 3 dB DIELECTRIC DIRECTIONAL COUPLER

M. Abouzahra and L. Lewin

Abstract

A previously developed theory on coupling between curved transmission lines is used to design and construct a 3 dB dielectric directional coupler. The accuracy of the theoretical results for a 3 dB coupler designed at 94 GHz is confirmed by experiment. Well-balanced outputs for the coupler, and a directivity of better than 40 dB are obtained. Though a substantial amount of insertion loss in the experimental model is found, this loss is believed to be largely dielectric loss. Design and performance data are presented.

I. Introduction

The problem of coupling between curved dielectric guides has been investigated and reported on by many authors(1-8). A theoretical treatment of the coupling theory and its application to the design of a broad-band 3 dB directional coupler have been undertaken and four research reports have been issued(9-12).

It is the purpose of this work to utilize our previous theoretical work to design, construct, and test a 3 dB dielectric directional coupler. An appropriate choice of parameters for the design of a 3 dB coupler has been reported(12). These parameters are used to construct and test an experimental model designed at 94 GHz. This report is in three sections; the first section presents a description of the experimental model; the second section describes the scheme of the measurement and presents the experimental findings; finally, conclusions are presented in the third section.

II. Description of the experimental model

The 3 dB dielectric directional coupler model is composed of two Teflon waveguides sandwiched between two parallel conducting plates. The Teflon guides are cut in the form of continuously curved guides and then placed between the two parallel conducting plates. Teflon is chosen for the waveguide material of the 3 dB coupler because of its expected low loss and ease of fabrication. The geometry of the proposed 3 dB dielectric coupler is shown in Fig. 1.

Transitions from metal to dielectric waveguides are made by using a tapered dielectric waveguide and an improved horn. In order to achieve a smooth transition, symmetric tapering must be insured.

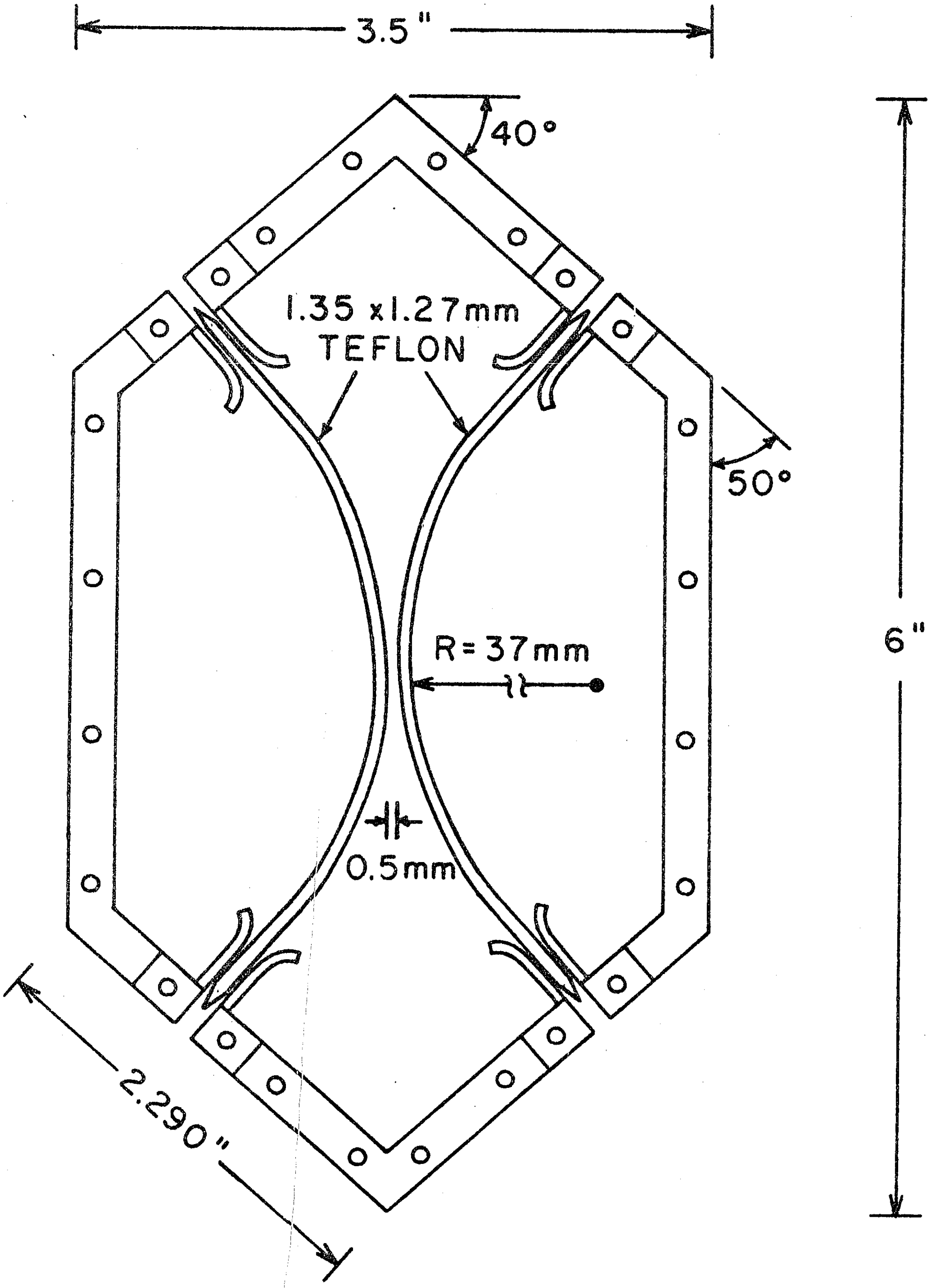
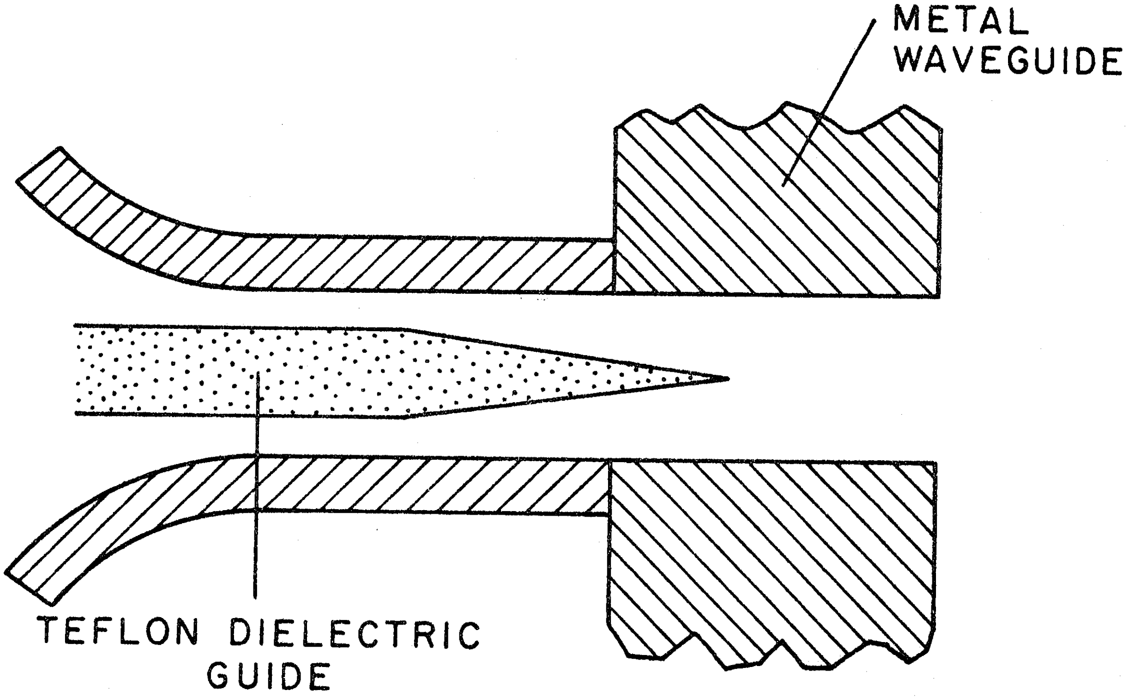


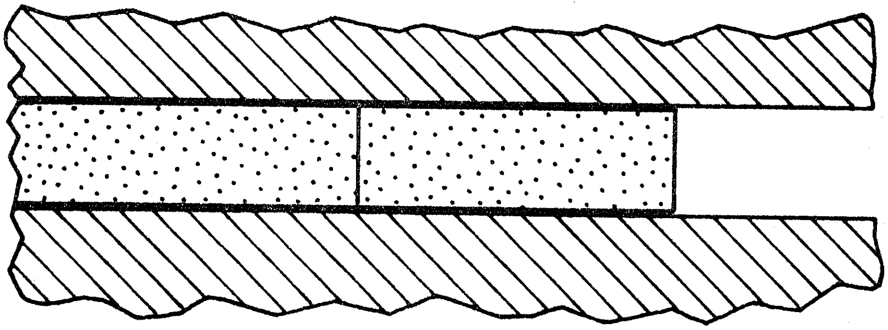
Fig. 1. The geometry of the proposed 3 dB dielectric directional coupler.

The length of each tapered section of the dielectric guides is chosen to be about $3\lambda_g$. The linearly tapered section of the dielectric guide is inserted into the waveguide section of the horn. On the basis of an earlier investigation by Trinh et. al.(13) the flare angle θ of the horn, is chosen to be in the H-plane and fixed at 35 degrees. The length of the horn's variable width is about $3\lambda_g$. The metal-to-dielectric transition is illustrated in Fig. 2. The radius of curvature of the dielectric waveguides is chosen to be significantly large (about 12λ) so that radiation losses are negligible. The intention of not using straight sections is to avoid the reflection coming from the discontinuity between the straight and curved parts(8) and to obtain a broad bandwidth. This comes about through the achievement of a tight coupling region at the closest approach of the curved sections.

In order to hold the dielectric waveguides in place a low-loss adhesive (5-minute Epoxy) was used. However, the measurements indicated the existence of a substantial amount of insertion loss which at the time was thought to be caused by the bonding material. In an attempt to eliminate these losses the adhesive was removed and some other mechanical supporting techniques were employed. The dielectric waveguides were held in place by means of a movable spacer and fish-tail supports, as shown in Fig. 3. The fish-tail supports and the movable spacer were removed after fixing the top plate, which in turn held the two dielectric guides in place. Indeed, this mechanical technique turned out to be very reliable in the short run, even though it did not resolve the insertion loss problem.



TOP VIEW



SIDE VIEW

Fig. 2. Dielectric waveguide to metal waveguide transition.

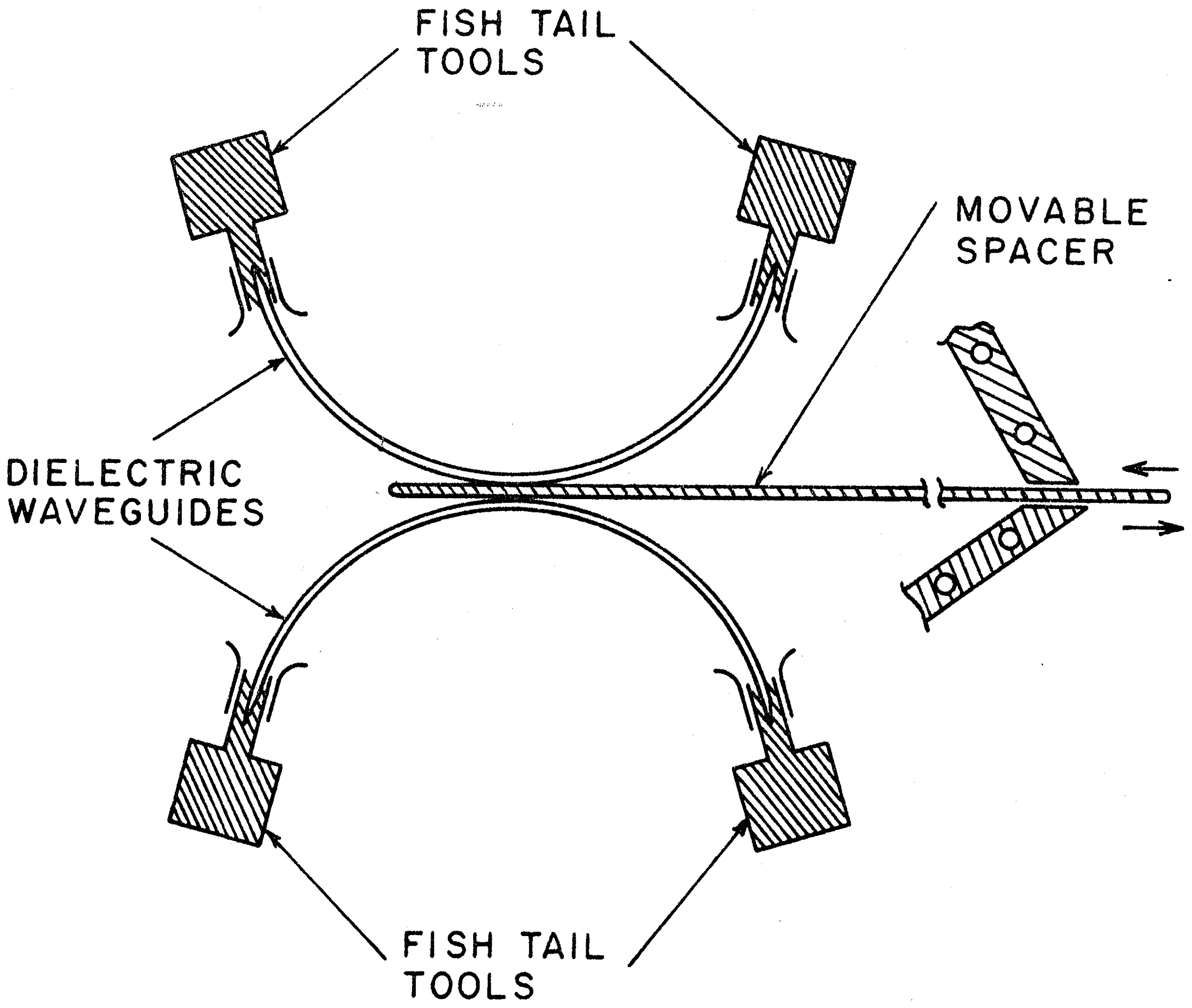


Fig. 3. Mechanical technique used to locate the dielectric waveguides in place.

The experiment was carried out at 95 GHz and the fundamental TE_o mode was launched. The guiding medium was teflon with $\varepsilon_r = 2.05$ and an expected $\tan \delta = 4 \times 10^{-4}$ (low frequency value). The guide dimensions are 1.35 x 1.27 mm, and the curved sections are separated by a minimum distance of 0.5 mm. The bending radius of the curved guides is about 37 mm. Sheets of absorbing material (Eccosorb) are inlaid inside the coupler (close to the conducting walls and at an appreciable distance from the dielectric guides) so that resonances are eliminated. The overall dimensions of the 3 dB coupler is 3.5" x 0.75" x 6".

III. Measurements and performance

Coupling between two dielectric waveguides is achieved by placing them in close proximity. The coupling process takes place via the sidewalls of the sandwiched dielectric guides. The degree of coupling is controlled by the length and the width of the gap. Utilizing our theoretical treatment a computer program was written and data were generated. Fig. 4 shows the theoretical performance of the coupler.

In order to test the accuracy of the theoretical results some measurements were made in the frequency range 94.25 - 95.5 GHz. A broadband klystron was not available and hence the expected 20 GHz calculated bandwidth could not be confirmed. The reflection loss of the transition regions was measured and found to be less than 0.03 dB. The outputs of the coupler (for the case where adhesive was used) were measured at 95 GHz and found to be 8.5 dB below the input. The directivity of the coupler was measured at about 40 dB below the input. Because the outputs were well below the 3 dB level, it had been thought that this substantial amount of insertion loss could be caused in part

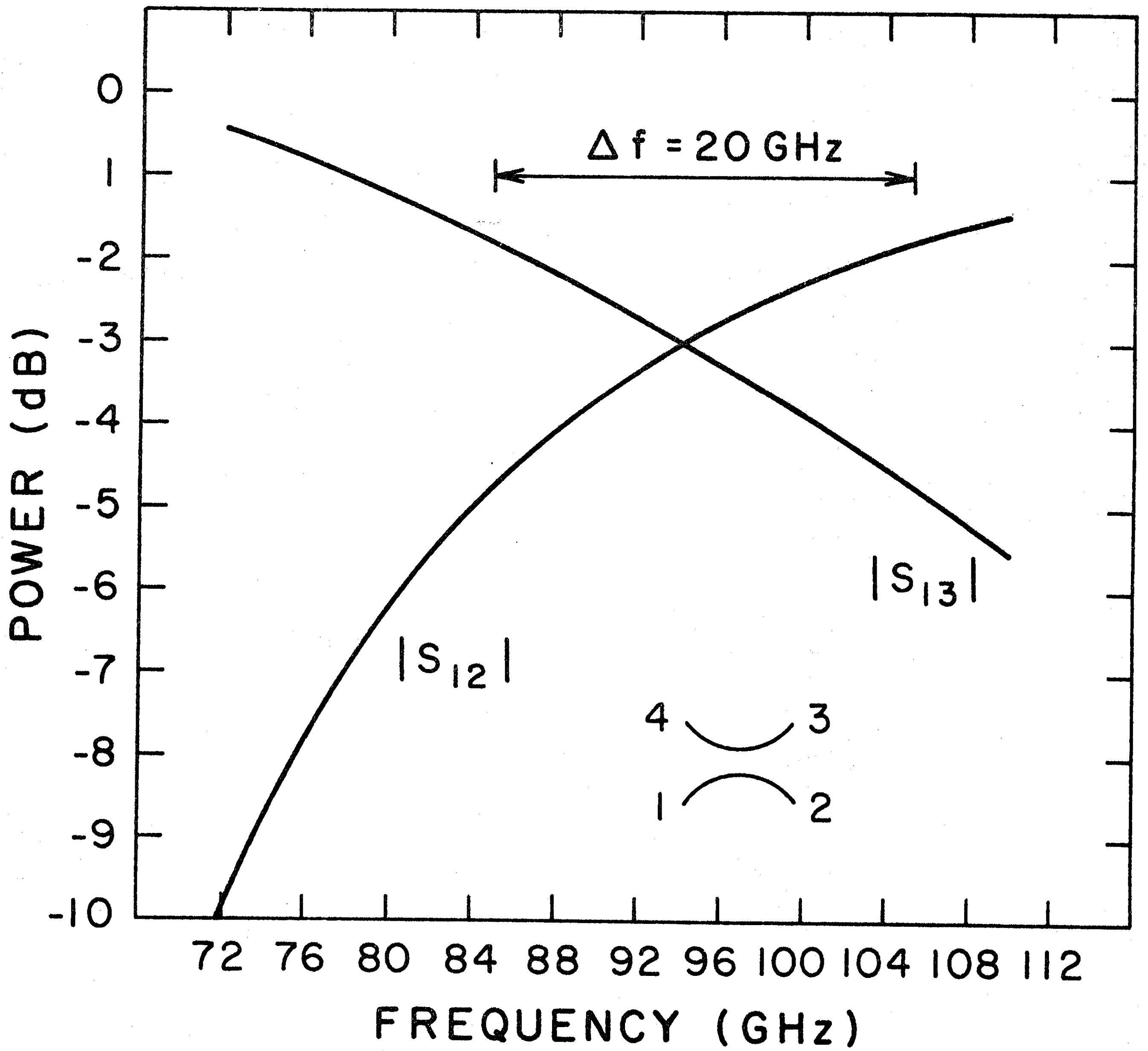


Fig. 4. Theoretical power/frequency characteristics of the proposed 3 dB dielectric directional coupler.

by the adhesive. As a result, the bonding material was removed and an alternative means of mechanical support was introduced. A movable spacer and some fish-tail-like tools, as demonstrated in Fig. 3, were used to locate the dielectric prior to clamping between the plates.

Repeating the measurements at 95 GHz the outputs of ports 2, 3, and 4 were 7.4, 7.4, and 40 dB below the input respectively. Therefore the replacement of the adhesive material reduces the insertion loss by only 1 dB. Theoretical calculations indicate that the dielectric loss (for $\tan \delta = 4 \times 10^{-4}$) and the conductor loss should be no more than 0.45 dB and 0.27 dB respectively. The transition loss of the mode launcher could be of the order of 1.0-1.5 dB per transition pair (13,14), figures which are consistent with our measurements.

In order to measure the dielectric loss, losses for two dielectric waveguides of different length were measured, and the loss of the shorter one was subtracted from that of the longer one. Thus the loss of the two horn launchers was eliminated and the transmission loss only was obtained. The accuracy of the measurement was within 0.1 dB, and the transmission loss found was 2.8 dB per coupler length. Subtracting the transmission loss and the 1.5 dB horn launcher loss from the measured 7.4 dB gives a net output of 3.1 dB. The well-balanced performance of the coupler is shown in Fig. 5 for the frequency range 94.25-95.5 GHZ. The balance is, if anything, better than the theoretical prediction.

In an attempt to confirm our dielectric loss measurements, an extensive research in the literature was carried out. The ITT handbook (15) reported an increase in the value of $\tan \delta$ (for Teflon) by a factor of 4 as frequency increases from 3 GHz to 25 GHz. Recently, W. Bridges

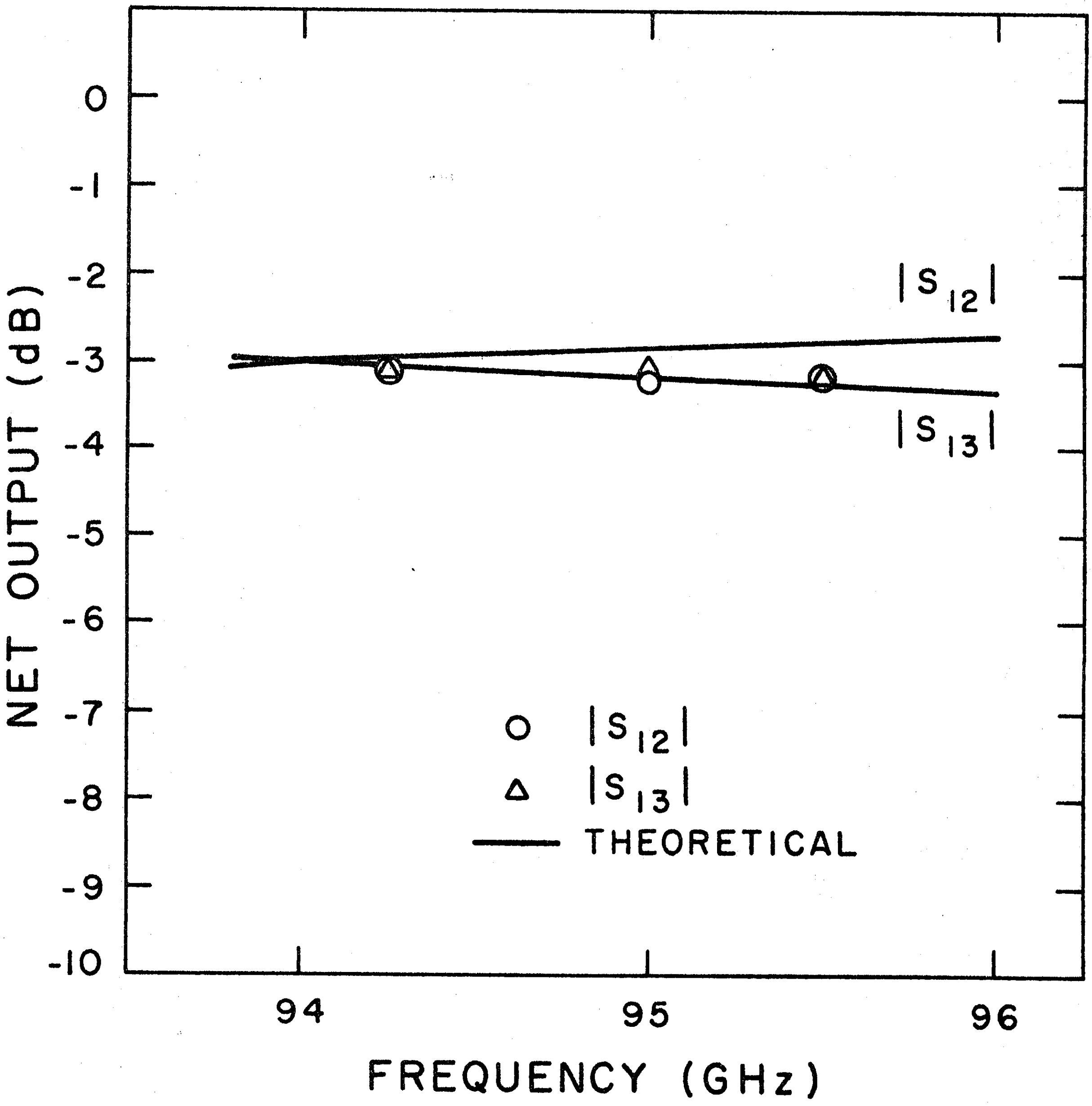


Fig. 5. Measured and theoretical outputs of the 3 dB coupler. The measured values do not include material and coupling losses.

et.al.(16) reported the measurement of tan δ for Teflon at 94 GHz. These measurements indicate that the value of tan δ, for Teflon, is 10 times larger than the low frequency value. No specific explanations were given other than stating that in general dielectric losses are expected to be larger for higher frequencies due to lattice absorbtion. In addition, the authors tend to believe that this discrepancy might also be caused by measurement error or sample imperfections. Moreover, during the conduction of some measurements on a microstrip structure F. Lalezari(17) detected a sharp increase in the dielectric loss as the frequency approached the millimeter region.

At any rate, based on our measurements as well as the above mentioned references we believe that a substantial amount of the insertion loss (about 3 dB) is caused largely by a sharp increase of tan δ with frequency.

IV. Conclusions

The design method, theoretical characteristics, and experimental results for a 3 dB directional coupler, using curved dielectric waveguides sandwiched between two parallel plates, are presented. A well-balanced coupler is achieved, though considerable losses were found. These losses are believed to be caused largely by the Teflon's behaviour at high frequency. The directivity of the coupler is better than 40 dB. Unfortunately, a broadband source was not available and consequently no confirmation of the expected 20 GHz theoretical bandwidth is obtained. However, the performance of the coupler at 94.25-95.5 GHz has been found to be quite flat. Apart from the insertion loss the experimental results are in close agreement with the theoretical predictions.

Acknowlegement

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