MULTIMODE WAVEGUIDE COMPONENTS FOR MILLIMETER-WAVE INTEGRATED CIRCUITS

R. Mittra and S. Bhooshan

Coordinated Science Laboratory
and
Department of Electrical Engineering
University of Illinois
Urbana, Illinois 61801

ABSTRACT

In this paper, we report the results of an investigation of multimode, planar dielectric waveguides for integrated circuit application at millimeter wavelengths. Two multimode devices have been fabricated and tested using the inverted strip guide (ISG), and a comparison between the theoretical and experimental results is given.

Introduction

Working with planar dielectric guides at millimeter wavelengths, one is often faced with the choice of using either multimoded guides or reducing the size to such small dimensions as to make fabrication extremely difficult[1]. The inverted strip guide (ISG), shown in Fig. 1(a) is an example of such a guide, which was first proposed by Itoh, and is particularly well suited to integrated-circuit applications[2]. The above guide has its dispersion characteristics shown in Fig. 1(c), where only the $E^y_{p,q}$ modes are considered. The purpose of this paper is to investigate the effects of multimoding on the performance of passive devices fabricated with the ISG. The multimoding effect was studied for two passive devices which were fabricated with the homogeneous and inhomogeneous ISGs, and tested over a range of frequencies. Experimental results were compared with the computed results which ignored the presence of the second mode in the guide. An analysis of the single and coupled ISGs (Fig. 1(a) and 1(b)) is given in reference 2.

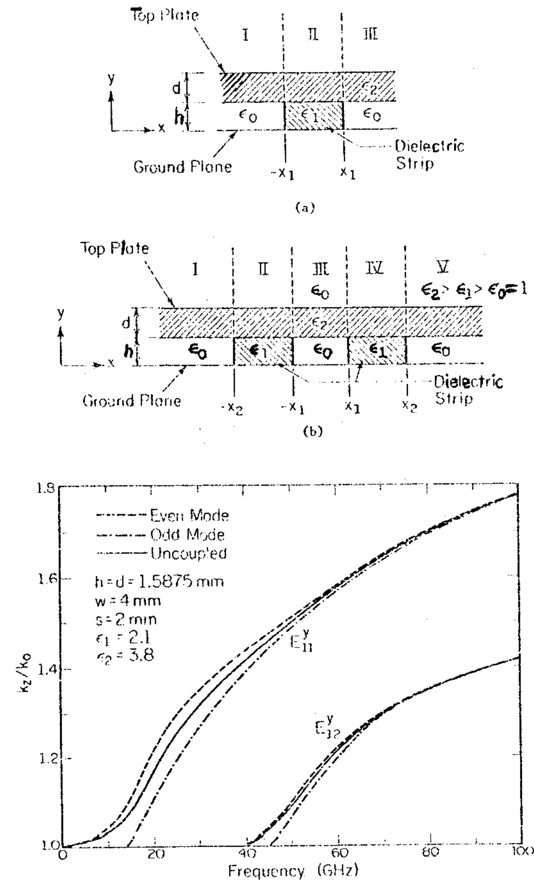

Figure 1: (a) Cross-section of inverted strip guide
(b) Cross-section of coupled ISG
(c) Dispersion characteristics of the guide.

Design Equations

Distributed Line Directional Coupler

One of the devices, which was fabricated and tested, was the distributed line directional coupler[3], shown in Fig. 2. Its operation can be understood if

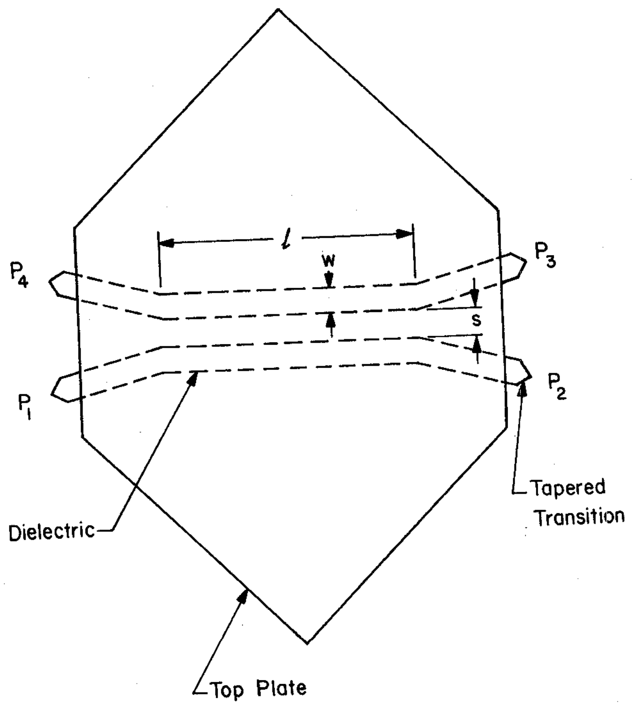

Figure 2: Top view of the directional coupler with four connecting guides.

it is considered as a section of coupled ISG with a separation s and length ℓ. Port 1 is excited by an electric field of strenght E_1, and the coupled energy is tapped off at port 3. Under the assumption that there are no reflections, no energy exits through port 4. If $E_{(1)}(z)$ and $E_{(2)}(z)$ are the electric fields at a distance z along the two guides, then:

$$E_{(1)}(z) = E_e\, e^{-jk_e z} + E_o\, e^{-jk_o z} \quad (1)$$

$$E_{(2)}(z) = E_e\, e^{-jk_e z} - E_o\, e^{-jk_o z} \quad (2)$$

for $0 \leq z \leq \ell$, with the conditions $E_{(1)}(0) = E_1$ and $E_{(2)}(0) = 0$. E_e and E_o are the amplitudes of the even and odd modes; k_e and k_o are the corresponding propagation constants. If the length of coupling is ℓ, and the even and odd amplitudes are equal, then,

$$\frac{P_3(\ell)}{P_2(\ell)} = \frac{E_{(2)}(\ell)}{E_{(1)}(\ell)} = \tan^2 \left[(k_e - k_o) \frac{\ell}{2} \right] \quad (3)$$

Single-Pole Ring Resonator

The second device used for experimentation was the ring resonator[4], whose geometry is shown in Fig. 3(a).

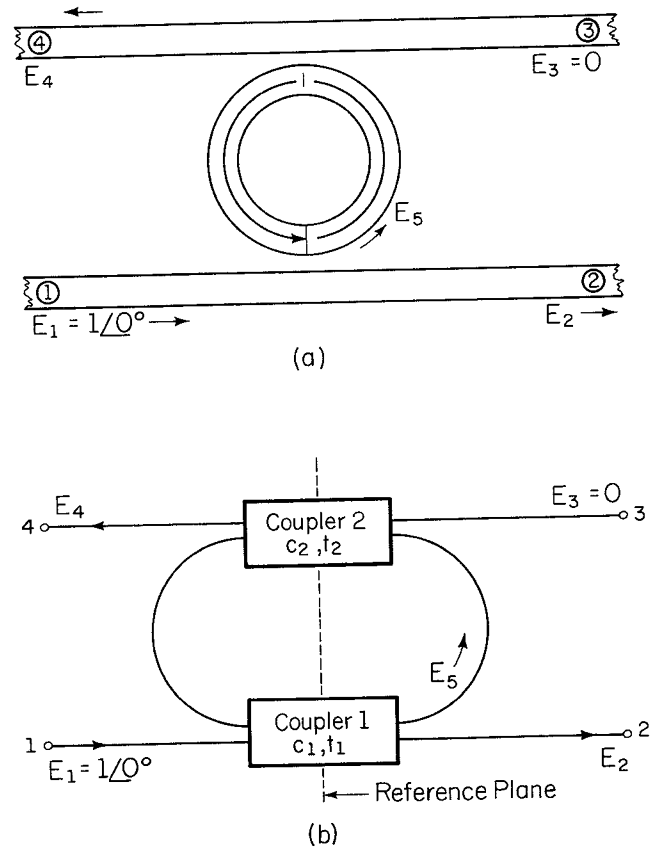

Figure 3: (a) Idealized ring resonator
(b) Schematic of ring resonator.

To understand its operation, the sections of the guide on either side of the ring are assumed to behave as identical couplers. It is further assumed that they are perfectly matched and that a traveling wave exists in the ring. These assumptions yield the following:

$$E_1 = 1e^{j0} \qquad E_3 = 0 \qquad E_5 = \frac{c}{1 - t^2\, e^{-j\beta_g \ell}}$$

$$E_2 = \frac{t(1 - e^{-j\beta_g \ell})}{1 - t^2\, e^{-j\beta_g \ell}} \qquad E_4 = c\, E_5\, e^{-j\beta_g \ell/2} \quad (4)$$

where c and t are the coupling and transmission coefficients of each coupler respectively; β_g is the propagation constant in the guide; and ℓ is the mean circumference of the ring, which is taken as the geometric mean of the inner and outer circumference of the ring. For perfect rejection between ports 1 and 2, we must have $E_2 = 0$. Hence, the resonance condition is:

$$\ell = n\lambda_g \qquad n = 1,2,\ldots \quad (5)$$

Experimental Results

Figure 4 shows the metal-to-dielectric guide transition, which was sued to excite the dielectric guide. A short taper of about 4.5 mm was used on the strip, as shown. Each component was fabricated with two different types of ISGs; where the top guiding layer was either quartz or teflon.

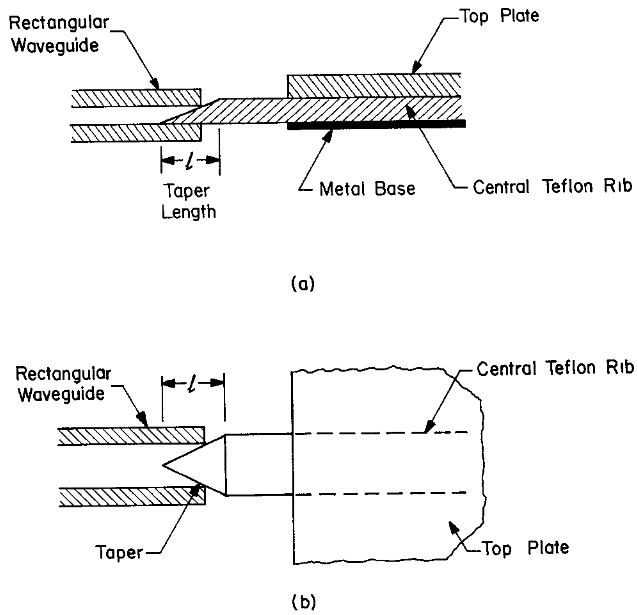

Figure 4: (a) Cross-section of side view of metal-dielectric guide transition
(b) Top view of metal-dielectric guide transition.

Figures 5 and 6 show the comparison of theoretical and experimental results for the direction coupler for various separations, s, for the two types of guides. These results show good agreement between the computed and experimental values, particularly for larger separations.

Next, measurements were made for P_3/P_2 over a range of frequencies. Tables 1 and 2 show the results of these measurements. Here the "deviation" refers to the maximum deviation from the mean over the frequency range.

Table 3 shows the comparison between the theoretical and experimental results for the ring resonator. The results show good agreement between the experimental value for the resonant frequency and those determined analytically.

Conclusions

It has been shown that passive devices can be designed and fabricated under the assumption that a single mode, e.g., E^y_{11} mode, dominates their performance because, for the excitation used, it is possible to confine most of the energy to the dominant mode.

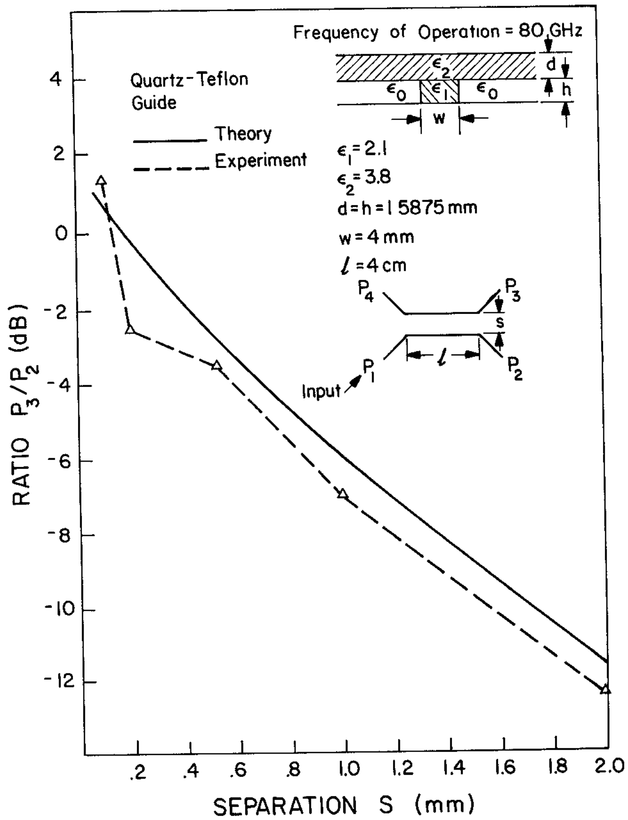

Figure 5: Comparison of theoretical and experimental results for the Quartz-Teflon distributed directional coupler.

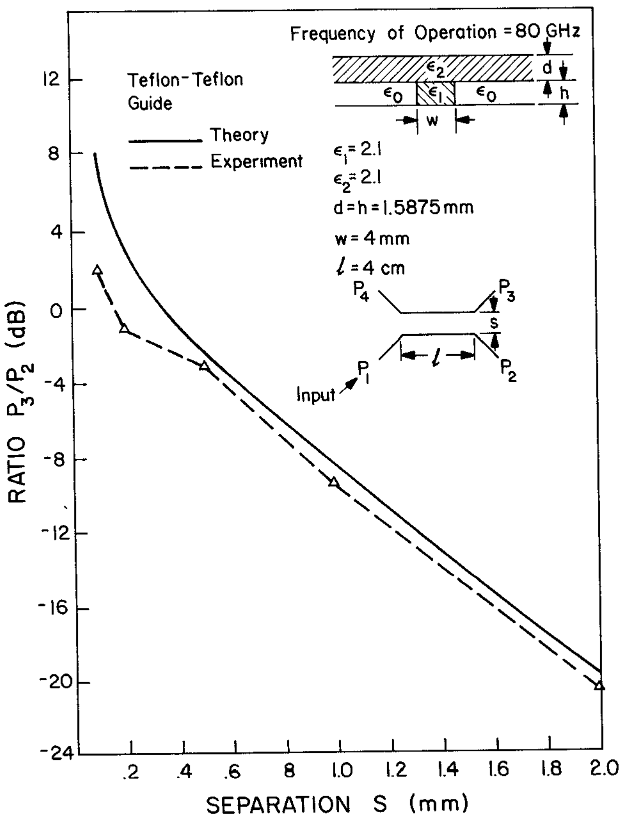

Figure 6: Comparison of theoretical and experimental results of the Teflon-Teflon distributed directional coupler.

TABLE 1. QUARTZ-TEFLON COUPLER RESULTS (79-83 GHz)

SEPARATION S, mm	THEORETICAL P_3/P_2 (dB)		EXPERIMENTAL P_3/P_2 (dB)	
	MEAN	DEVIATION	MEAN	DEVIATION
0.2	-4.686	±0.388	-3.8	±0.5
1.0	-7.903	±0.312	-7.5	±0.5
2.0	-13.270	±0.173	-12.5	±1.0

TABLE 2. TEFLON-TEFLON COUPLER RESULTS (79-83 GHz)

SEPARATION S, mm	THEORETICAL P_3/P_2 (dB)		EXPERIMENTAL P_3/P_2 (dB)	
	MEAN	DEVIATION	MEAN	DEVIATION
0.5	-2.995	±0.724	-1.125	±0.63
1.0	-8.836	±0.486	-8.5	±0.25
2.0	-19.458	±0.175	-20.0	±2.00

TABLE 3. COMPARISON OF THEORETICAL & EXPERIMENTAL RESULTS FOR THE RING RESONATOR
h=d=1.5875 mm a=15 mm $\bar{r}$ = 16.882 mm
w= 4 mm b=19 mm ε_1= 2.1

TYPE OF GUIDE	RESONANT FREQUENCY, GHz		DIFFERENCE, GHz (EXPT.-THEORY)
	THEORETICAL	EXPERIMENTAL	
QUARTZ-TEFLON ε_2 = 3.8	78.60 80.00 81.40 82.80	78.71 80.19 81.53 82.95	0.11 0.19 0.13 0.15
TEFLON-TEFLON ε_2 = 2.1	77.80 79.60 81.60 83.50	78.10 79.74 81.75 83.40	0.30 0.14 0.15 -0.10

REFERENCES

1. D. Marcuse, Theory of Dielectric Optical Waveguides, New York: Academic Press, 1974.
2. T. Itoh, "Inverted Strip Dielectric Waveguide for Millimeter-Wave Integrated Circuits," IEEE Trans. Microwave Theory Tech., vol. MTT-24, pp 821-827, Nov.'76
3. R.S. Rodokas, "Analysis of Inverted Strip Dielectric Waveguides and Passive Devices for Millimeter-Waves", Coordinated Science Laboratory Report R-774, July 1977, University of Illinois at Urbana-Champaign.
4. B.J.Levin and J.E.Kutzer, "Hybrid Millimeter-Wave Integrated Circuits," Final Report, Contract number DAAB 07-74-C-0577, U.S.Army Electronics Command Report ECOM-74-0577-F, July 1975.