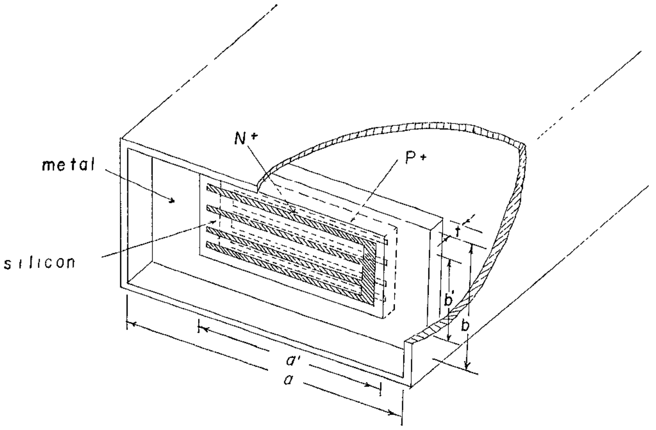

Fig. 1. Iris-mounted window.

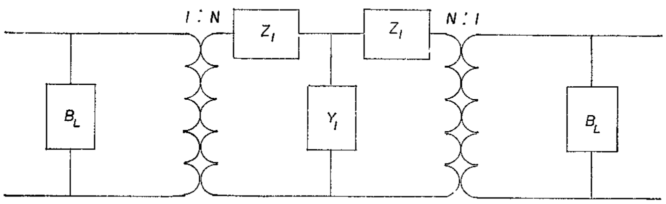

Fig. 2. Circuit-model schematic.

ture ratio. The overall effects of the iris mounting can be evaluated without considering the line structure.

The electrical characteristics of this network represent the electromagnetic characteristics of the iris and can be easily evaluated for any material properties, iris geometry, and frequency with simple linear circuit theory. For example, the resonant frequency f_0 is defined as the frequency at which the susceptance of the network equals zero $(b=0)$ and the loaded Q can be approximated by $Q=[f_0/4]\partial b/\partial f|_{f_0}$ where f_0 is the resonant frequency. The insertion loss and fraction of incident power dissipated in the device can be predicted in a similar fashion using the lumped model.

The average power handling capability of the window is limited by dissipation of RF power in the window, and consequently the temperature rise per watt of power dissipated at the center of the window. If the temperature at the perimeter of the window is held constant, solution of Laplace's equation shows that the temperature at the center of the iris per watt of incident power is proportional to the fraction of incident power dissipated and a function of the iris aspect ratio for equivalent window structures

III. Results and Conclusions

The accuracy of the electromagnetic model of the iris was checked by measuring several passive X-band models of the switch. The results (Fig. 3) show good agreement between predicted and actual characteristics.

When comparing the characteristics of a 7.5-mil X-band iris-mounted window to a 7.5-mil window filling the guide, the tradeoffs in window design become apparent. An iris-mounted window designed to have a loaded Q of 1 and a resonant frequency of 10.3 GHz (0.252 in$\times$0.52 in) is about $\frac{1}{3}$ the volume of the full-guide structure and gives 11 dB greater isolation for a bias current equal to that which creates a 1-Ω plasma in the iris structure. At zero bias (300 $\Omega\cdot$cm) the midband insertion loss of the iris-mounted window is only 0.1 dB greater than that of the full-guide window. The only significant drawback of the iris structure is its 20-percent 0.5-dB bandwidth. This is a 50-percent reduction in bandwidth from the full-guide structure.

Since their aspect ratios are similar, the iris-mounted window has a comparable thermal resistance to a full-guide window. However, comparison of the fractional dissipations in the critical high-plasma-density region shows that the iris-mounted window is capable of handling more than twice the average incident power of the full-guide structure with equal bias currents. However, this advantage is only realized when the structure is used as an on–off switch since the fractional dissipation approaches 0.5 for both windows near resistivities of 10 $\Omega\cdot$cm.

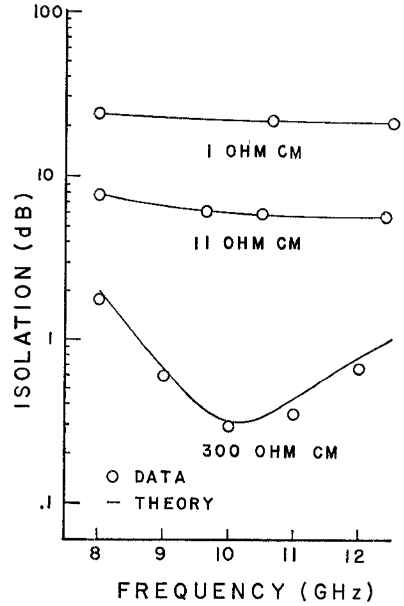

Fig. 3. Experimental and theoretical isolation versus frequency for a passive 0.008-in $\times$0.51-in $\times$0.24-in silicon iris-mounted window in X-band waveguide.

The iris-to-guide field ratio of 2.31 indicates that the maximum allowable peak power is only 20 percent of that for the full-guide structure. However, with encapsulation of the line structure the full-guide switch withstood 220 kW [4] of peak power without degradation of switching characteristics. Since the breakdown field of silicon is seven times that of air, it appears that the iris switch can withstand peak fields as large as the breakdown fields in air-filled guide. However, encapsulation will reduce the bandwidth slightly.

The iris-mounted window is significantly superior when used as a switch in both isolation and average power handling capability where the reduction in bandwidth is tolerable. Also the iris-mounted window is most attractive at frequencies below X band where fabrication of a full-guide window is not practical.

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Loss Calculations of Coupled Microstrip Lines

R. HORTON

***Abstract*—Loss calculations have been performed to yield useful data relevant to the complementary odd and even modes propagating along a pair of identical coupled microstrip lines.**

The calculations are based on methods applied to the single-line case and indicate substantial differences in attenuation occurring between the odd and even modes for particular geometries.

An insight into the characteristics of coupled microstrip lines has been available for some time now through the efforts of such workers as Bryant and Weiss [1], Chen [2], and Napoli and Hughes [3], providing useful data to be employed in the design of directional couplers, filters, etc., to be fabricated in such a medium in the absence of conductor and dielectric losses.

Nevertheless, in practice such losses do occur, and the real part

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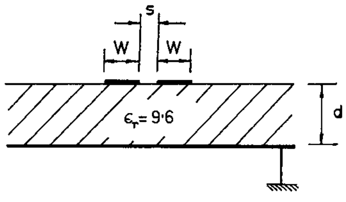

Fig. 1. Geometry of a pair of identical coupled microstrip lines.

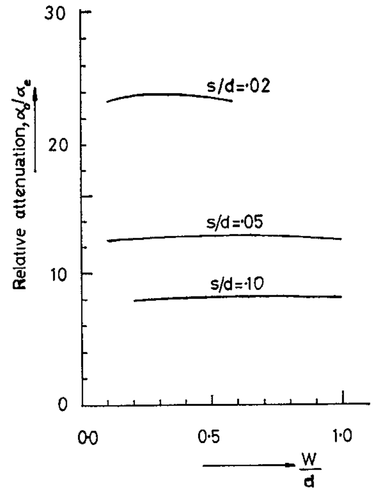

Fig. 2. Relative conductor attenuation of the odd and even mode.

of the resulting complex propagation constant has been shown to be quite significant in the case of coupled rectangular bars, between ground planes, by Horton [4], where he develops expressions for both odd- and even-mode attenuation coefficients. In the particular example cited, the total loss of a matched coupled section then becomes the mean of these two odd- and even-mode attenuations. Tripathi [5] has pursued this approach to obtain the immittance parameters associated with coupled sections, thus availing the virtue of cascading of sections.

However, although the case of losses suffered by a single microstrip line has been investigated by Horton *et al.* [6], [7] and Pucel *et al.* [8], a knowledge of the losses incurred by both odd and even modes in a pair of symmetrical coupled microstrip lines still requires evaluation if the methods of Tripathi are to be satisfactorily employed.

In order to evaluate the odd- and even-mode attenuation coefficients, the current distributions associated with each mode were first evaluated, under the assumptions of quasi-TEM propagation and loss-free conditions, by an image technique, much the same way as in [6], but with the further premise that the odd mode is that field solution defined by $+1$ V and -1 V on the respective conductors, of equal width W, while the even mode is that field solution defined by $+1$ V on each of the two conductors. The geometry assumed is shown in Fig. 1, where d represents the substrate thickness and S the strip separation. The substrate material evaluated was alumina with a dielectric constant of 9.6 and a thickness of 0.025 in.

The current distributions and their associated charge distributions were then used to provide the odd- and even-mode impedances, and, via a numerical integration, and odd- and even-mode attenuation copper losses, presuming that the fields calculated in the loss-free case remain unchanged in the presence of losses.

A rough estimation of dielectric losses suffered revealed them to be of much less significance than conductor losses, and as the present techniques employed are unsuitable for these purposes, they were neglected.

Fig. 2 depicts the relative attenuation encountered in each conductor, due to conductor loss, of the two modes and can be seen to indicate a substantial difference between the two, especially when the lines are tightly coupled. Furthermore, this difference is not severely affected by width W. Absolute values of attenuation can be obtained from Fig. 3, which presents the even-mode copper loss per unit length. It should be noted that the attenuation in Fig. 3 has been normalized with surface resistivity by the term R_s, where

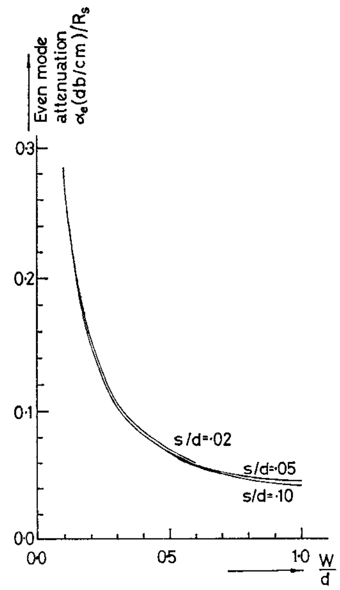

Fig. 3. Conductor attenuation per unit length of the even mode.

$$R_s = \left(\frac{\pi f \mu_0}{\sigma}\right)^{1/2} \times 100.$$

This normalization has the implication that a few skin depths of conductor material have been assumed at the operating frequency, which in turn avoid overlapping of the fields penetrating the upper and lower surfaces of the strip and allows normalization of the frequency.

In the calculations performed, the thickness of strips assumed was 6 μm and the above normalization ought to provide useful working information above about 5 GHz.

Due to the absence of corroboration of the results by other sources of theoretical or practical information, the only justification which can be proposed is in the extreme case of a very wide separation of the strips, where it can be seen from Fig. 2 that both the odd and even mode approach the same attenuation. This value of attenuation can be approximately established using Fig. 3 and compares well with the data available for the single strip, quoted in the references earlier.

In conclusion, although adequate information on coupling properties exists in the literature, as quoted, for the lossless case, the need for data of the attenuation coefficients of both modes provides the additional knowledge required for a more complete description of practical circuits.

Acknowledgment

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