A 3-dB INTERDIGITATED COUPLER ON FUSED SILICA*

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Abstract

This paper presents a simple model that describes the odd/even impedances and phase velocities of an interdigitated structure. Complete design information is given for a 3-dB interdigitated coupler on fused silica. Experimental data are presented for a coupler centered at 10 GHz and another at 13.5 GHz. The coupler features extremely low dissipative loss (of the order of 0.1 dB) and an excellent power split (within 0.3 dB over a 25- to 30-percent bandwidth).

Introduction

The use of low-dielectric substrates (e.g., fused silica) instead of high-dielectric substrates (e.g., alumina or sapphire) allows significant reduction in substrate thicknesses at no sacrifice in loss. For a given substrate thickness, the finger width of the Lange[1] type 3-dB coupler on fused silica is 2.5 to 3.0 times greater than that of the same coupler realized on alumina. The advantage offered in terms of improved producibility and decreased loss is thought to be significant.

Equivalent Wave Structure

A cross-sectional view of the interdigitated structure is shown in Figure 1. Alternate fingers are assumed at the same potential. If it is assumed that the fringing fields are influenced only by nearest neighbors and that, to a first order, they are independent of finger width, then it can be shown that

$$C_{12} \cong 1/2\ (C_{OD} - C_{EV}) \tag{1}$$

$$C_{OUT} \cong C_{EV} \tag{2}$$

$$C_{IN} \cong 2\ C_{EV} - C_S \tag{3}$$

where C_S is computed for a single finger, and C_{OD} and C_{EV} are computed for a single pair of fingers.[2] The equivalent odd/even capacitances are then

$$C_{EVEQ} = 3\ C_{EV} - C_S \tag{4}$$

$$C_{ODEQ} = 3\ C_{OD} - C_S \tag{5}$$

The equivalent inductances are found by removing the dielectric and computing the equivalent capacitances, C'_{EVEQ} and C'_{ODEQ}, for $E_R = 1$. (Primed quantities denote the case $E_R = 1$; unprimed quantities are calculated with the dielectric in place.) With the dielectric removed, the interdigitated structure will support a TEM mode with odd/even phase velocities equaling the speed of light, c. In particular,

$$L'_{EVEQ} = 1/C'_{EVEQ}\ c^2 \tag{6}$$

$$L'_{ODEQ} = 1/C'_{ODEQ}\ c^2 \tag{7}$$

The equivalent inductances are unaffected by the dielectric so that L_{EVEQ} and L_{ODEQ} are also given by equations (6) and (7).

The equivalent odd/even impedances and effective dielectric constants are given by

$$Y_{EVEQ} = \left\{\left[3\sqrt{\varepsilon_{EV}}\ Y_{EV} - \sqrt{\varepsilon_S}\ Y_S\right]\left[\frac{3Y_{EV}}{\sqrt{\varepsilon_{EV}}} - \frac{Y_S}{\sqrt{\varepsilon_S}}\right]\right\}^{1/2} \tag{8}$$

and

$$\varepsilon_{EVEQ} = \frac{3\sqrt{\varepsilon_{EV}}\ Y_{EV} - \sqrt{\varepsilon_S}\ Y_S}{3\ \frac{Y_{EV}}{\sqrt{\varepsilon_{EV}}}\quad \frac{Y_S}{\sqrt{\varepsilon_S}}} \tag{9}$$

where Y_{EV} ($= 1/Z_{EV}$) and ε_{EV} are computed for a single pair of fingers,[2] and Y_S ($= 1/Z_S$) and ε_S are computed for a single finger. Y_{ODEQ} and ε_{ODEQ} are found by interchanging "OD" and "EV" in equations (8) and (9). Ou[3] has given a similar analysis, but without the phase velocity information. A numerical solution[4] has also become available.

Coupler Analysis, Design, and Realization

The effort reported here has been devoted to developing a 3-dB coupler on 0.015-inch-thick fused silica. Applications are intended for the 11- to 14-GHz range. Since communications bandwidth requirements are typically quite modest, it was decided to tailor the coupling for the most equal power split.

The finger width and space values imply Y_S and ε_S for a single finger and Y_{OD}, ε_{OD}, and Y_{EV}, and ε_{EV} for a single pair. The interdigitated structure as an equivalent pair of coupled lines is then described by equations (8) and (9). The interdigitated structure can be simulated as a circuit element by using the techniques of References 5 and 6 and a microwave computer package that allows analysis of 4-port networks.

Figure 2 is a drawing of the coupler. Experimentation was necessary to minimize joint effects. Wire bonds are made with 0.001-inch-diameter wire according to the connections shown in Figure 2. It can be seen in Figure 3 that the line lengths between launchers and coupler have been minimized. The metallization is chrome-gold with the gold plated up to 4.0 microns.

The dimensions and equivalent wave properties for the two reported couplers are given in Table 1. The 10-GHz coupler demonstrates a 0.3-dB difference bandwidth of 30 percent (Figure 4) and the 13.5-GHz coupler demonstrates a 0.3-dB difference bandwidth of 25 percent (Figure 6). These measurements include the launchers. Any reasonable budgeting of launcher loss would indicate that the dissipative loss of the coupler is of the order of 0.1 dB. Isolation and return loss for the two couplers (Figures 5 and 7) are in excess of 20 dB over the same bandwidths.

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Conclusions

It is believed that the low loss and good performance of the reported couplers may make then useful in balanced mixers and amplifiers for the X and K_U bands. The simple model is thought to provide useful and accurate insight into the circuit performance of the interdigitated structure.

Acknowledgment

W. J. Getsinger contributed important suggestions to this project. E. Bainbridge, R. Barber, W. Chang, W. More, and L. Sparrow provided technical support.

References

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Table 1. Coupler Properties on 0.015-Inch-Thick Fused Silica

Coupler Center Frequency (GHz)	W (in.)	S (in.)	L (in.)	Z_{EVEQ} (ohms)	Z_{ODEQ} (ohms)	ε_{EVEQ}	ε_{ODEQ}
10	0.005	0.0009	0.170	117	19	2.84	2.38
13.5	0.005	0.001	0.128	116	20	2.84	2.38

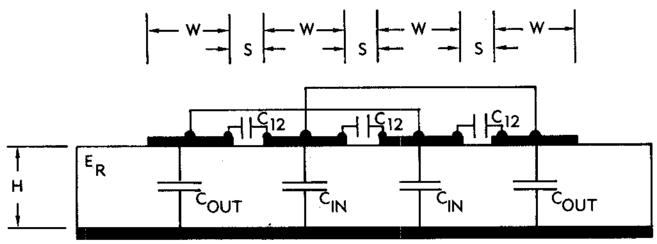

Figure 1. Interdigitated Structure

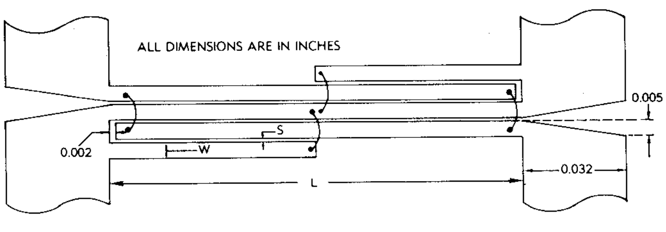

Figure 2. 3 dB Interdigitated Coupler on 0.015 Inch Fused Silica

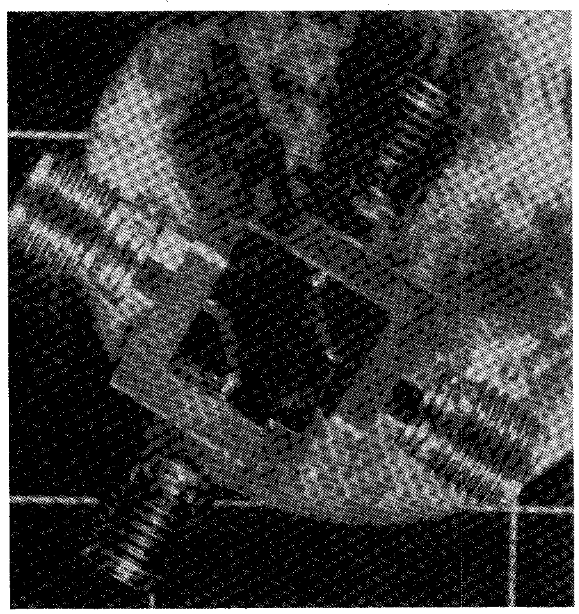

Figure 3. Packaged Coupler

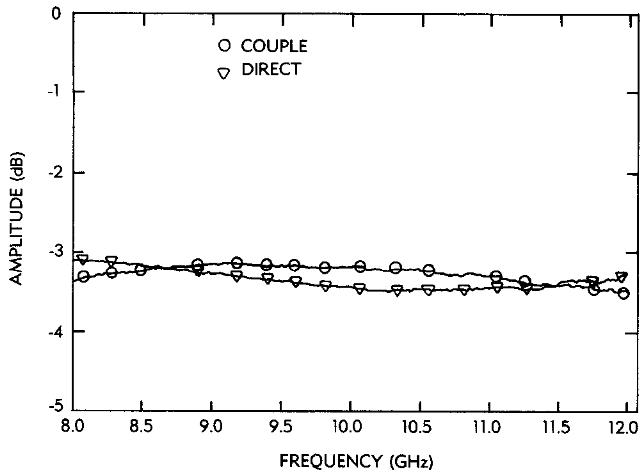

Figure 4. Power Split for the 10 GHz Coupler

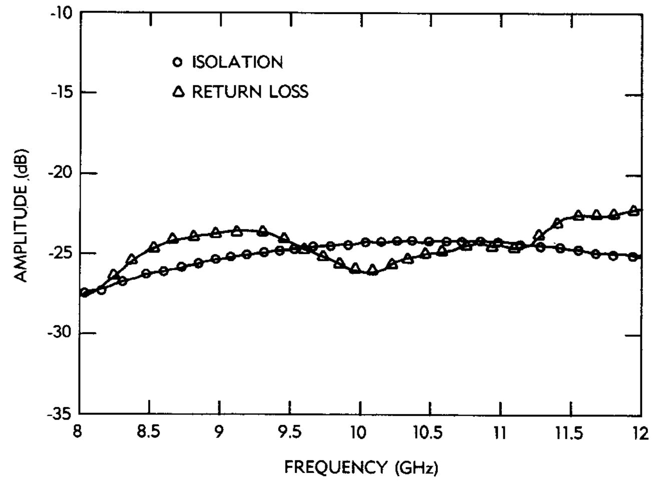

Figure 5. Isolation and Return Loss for the 10 GHz Coupler

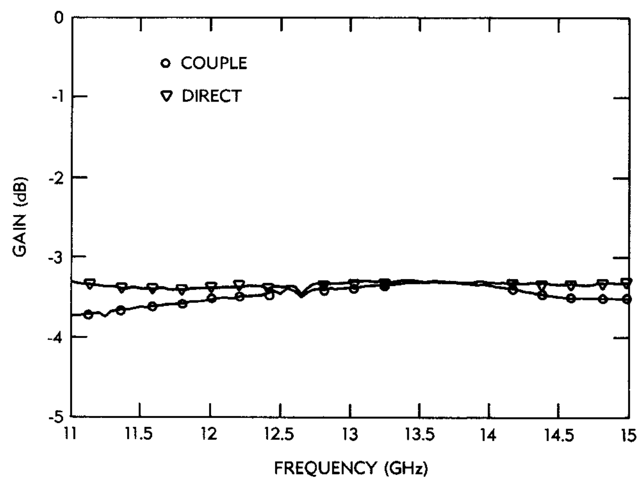

Figure 6. Power Split for the 13.5 GHz Coupler

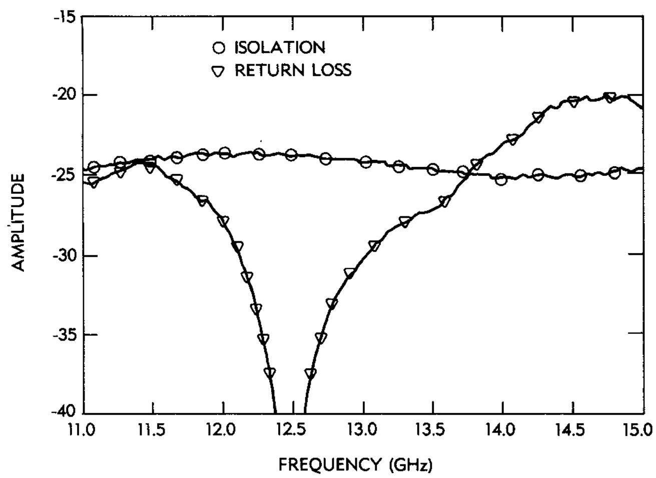

Figure 7. Isolation and Return Loss for the 13.5 GHz Coupler