Integrated Directional Coupler for 90 and 180 GHz

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***Abstract*—This letter presents coplanar integrated directional couplers for 90 and 180 GHz with a 60-GHz (120-GHz) bandwidth and up to 20-dB directivity. A three-dimensional (3-D) field simulator has been used to calculate the complex propagation constants and the impedances of the two modes. For the first time, the comparison of simulated and measured S-parameters up to 230 GHz shows the validity of the design approach and the capability of integrated coplanar couplers.**

***Index Terms*—Coplanar couplers, coupled transmission lines, diretional couplers, millimeter-wave couplers, nonlinear transmission lines (NLTL's).**

I. Introduction

To DECREASE the cost and increase the bandwidth of microwave instrumentation, integrated directional couplers must be developed. With a high-directivity coplanar directional coupler, the complete integration of an S-parameter test set in a single integrated circuit becomes feasible [1]. For accurate and fast simulation of the couplers, a scalable model is used. After simulating the complex propagation constants and the impedances, the layout can be scaled to each center frequency, using the theory of TEM line directional couplers.

II. Simulation

Propagation in coupled lines is described by the frequency-dependent impedances and propagation constants of the even and odd modes [2], [3]. Using a three-dimensional (3-D) simulator [4] we have calculated these parameters for three coplanar coupled line structures. A symmetric structure was chosen with a ground-line spacing of 16.5 μm, a line width of 17 μm, and three different line–line spacings (5, 16.5, and 33 μm). The metal conductor thickness is 3 μm and the substrate dielectric constant is 12.9 (GaAs). Because of the symmetry, only the fields in one half of the structure are considered, which enhances accuracy. From the propagation constants the effective dielectric constants are calculated. Figs. 1 and 2 show the calculated effective dielectric constants and the mode impedances. From Figs. 1 and 2, it is apparent that the even- and odd-mode effective dielectric constants, and

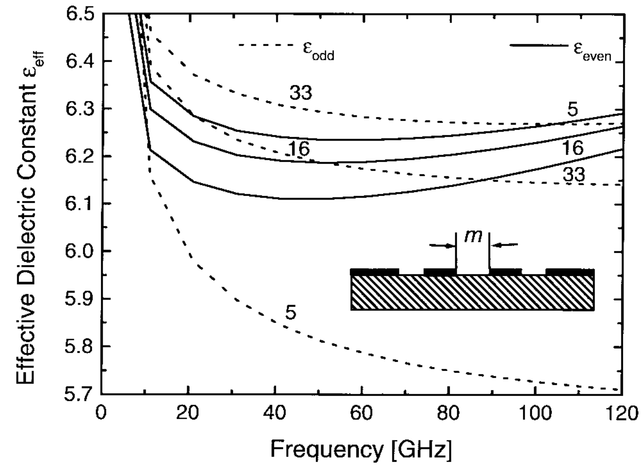

Fig. 1. The effective dielectric constants of the even and odd mode in dependence on the frequency for coplanar lines with different coupled line spacings m.

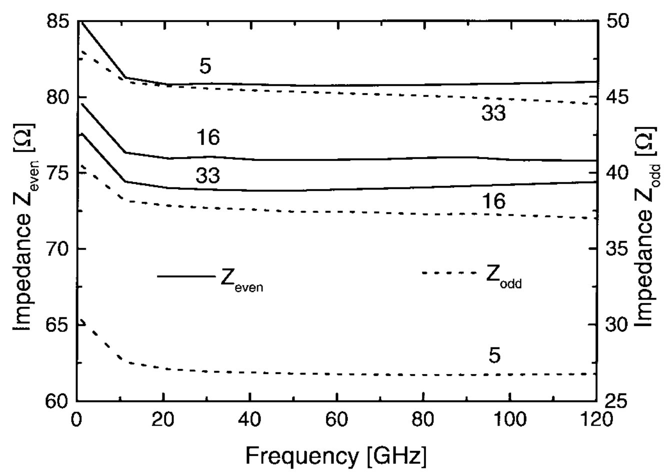

Fig. 2. The impedances of the even and odd mode in dependence on the frequency for coplanar lines with different middle spacings.

the mode impedances, are nearly frequency-independent, as is important for high-directivity broad-band line couplers. This is in marked contrast to microstrip couplers, which show strong frequency-dependent mode parameters.

From the calculated values of Z_{even}, Z_{odd}, $\varepsilon_{r,\mathrm{even}}$, and $\varepsilon_{r,\mathrm{odd}}$, the coupler S-parameters can be calculated for any coupler length. The time-consuming ($\mathrm{Z_{even}}$, $\mathrm{Z_{odd}}$, $\varepsilon_{r,\mathrm{even}}$, $\varepsilon_{r,\mathrm{odd}}$) calculation must be performed only once, hence an easy scalable model is formed. This can be incorporated into a circuit simulation tool.

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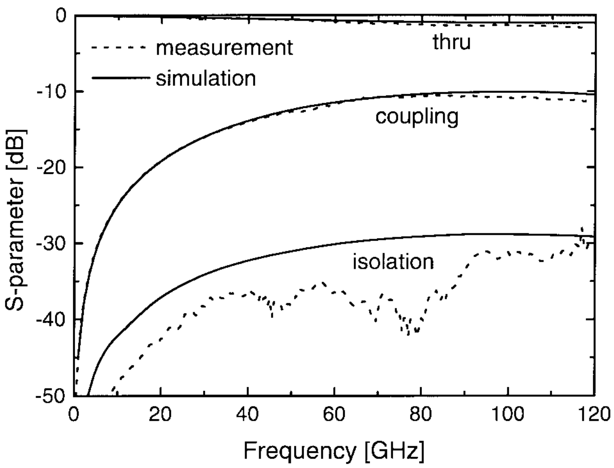

Fig. 3. Measured and simulated S-parameters of the 10-dB coupler with a center frequency of 90 GHz.

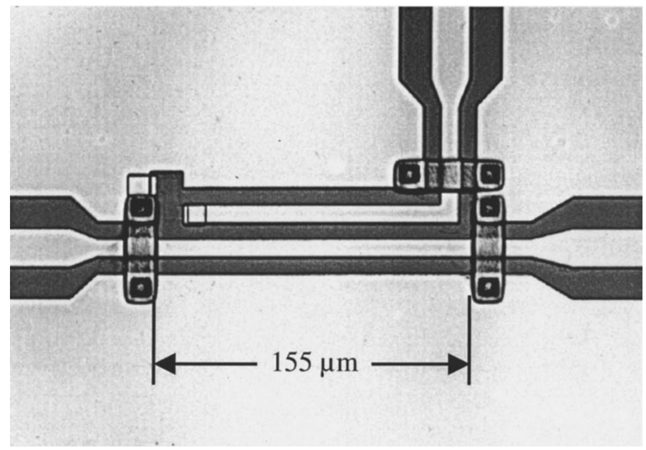

Fig. 4. Microphotograph of the 10-dB coupler with a center frequency of 180 GHz.

III. VERIFICATION

To verify the simulations, the couplers have been fabricated on GaAs and measured over a broad frequency range. With a length of 310 μm, the coupler attains a center frequency of 90 GHz. NiCr resistors are used for the termination. The measurements up to 120 GHz have been performed using a commercial on-wafer S-parameter test-set (HP 8510XF). Fig. 3 shows the very good agreement between the simulation and measurement of the 10-dB coupler with 16.5-μm line–line spacing.

The predicted isolation is less accurate, because this parameter is very strongly dependent on the calculated mode impedances. This coupler achieves a bandwidth of more than 60 GHz. The return loss is $<$19 dB up to 120 GHz and the directivity is 20 dB. Other couplers with 5- and 33-μm line–line spacing have 7- and 13-dB coupling, return loss, and directivity better than 15 dB, and show very good agreement between simulation and measurement. Of the three designs, the 10-dB coupler has the best directivity and the smallest phase mismatch between the two modes (Fig. 1).

We have also fabricated a directional coupler for 180-GHz and 10-dB coupling. In addition to characterization with the HP8510, this coupler is characterized in the frequency domain (120–230 GHz) using active probes based on these coplanar couplers and nonlinear transmission lines (NLTL's) [5], [6]. Fig. 4 shows a microphotograph of the coupler. The calibration planes of the two-port measurement are on the contact pads, which are not on the picture. The third port is terminated with a 50-Ω on-chip resistor. In this process the n^+ layer of the GaAs is used for the termination resistor. To avoid the influence of the transition from the CPW to the coupled lines, all dimensions of this coupler were reduced by 2 : 1. Simulated and measured parameters (Fig. 5) of this coupler show good agreement. The peak coupling is only 11 dB due to increased losses at higher frequencies. Furthermore the bandwidth is 120 GHz, the directivity is better than 13 dB up to 220 GHz and the return loss is 17 dB up to 200 GHz.

With the same process an additional coupler with the same lateral dimensions as the 180-GHz coupler but with a length of 310 μm has been fabricated. Fig. 6 shows the simulation and measurement up to 230 GHz of this coupler and verifies the scalability of the model.

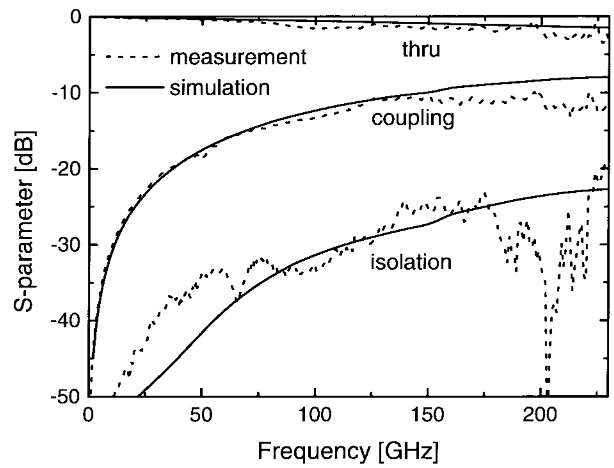

Fig. 5. Measured and simulated S-parameters of the 180-GHz coupler with a coupling length of 155 μm. All dimensions are reduced by 2 : 1 compared to the 90-GHz coupler (Fig. 3).

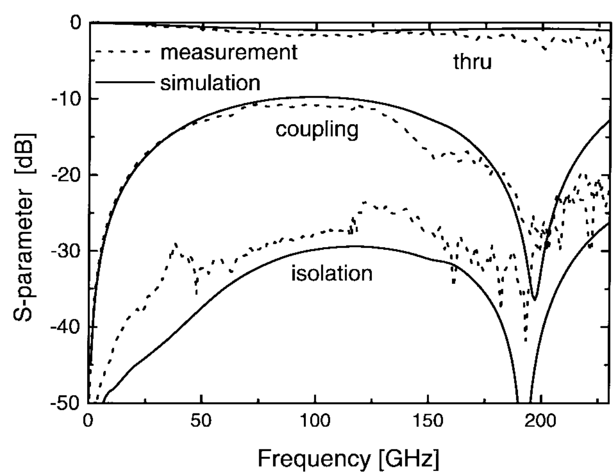

Fig. 6. Measured and simulated S-parameters of the 90-dB coupler with a coupling length of 310 μm. Only the lateral dimensions are reduced by 2 : 1 compared to the 90-GHz coupler (Fig. 3).

IV. Conclusion

Based on simulated S-parameters, various design approaches for broad-band coplanar directional couplers have been investigated. The calculation of the impedances and complex propagation constants of the two modes forms the basis for a model, which can be easily scaled to any desired center frequency. The comparison of simulated and measured S-parameters in a frequency range up to 230 GHz, verifies the model for coplanar directional couplers.

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