Directional Couplers Between Doubled-Sided Substrate Microstrip Lines Using Virtually-Terminated Coupling Slots

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***Abstract*— A new planar multilayer quadrature coupler is proposed. This new multilayer coupler consists of two microstrip lines that are coupled through two virtually-terminated narrow slots in a common ground plane. Experimental results are in fairly good agreement with a theory. With the advantages of compact size and simple design procedure, this new component should have many applications in multilayer microwave integrated circuits.**

I. Introduction

The increasing complexity of microwave systems has led to the need for high-density interconnects in MIC's and MMIC's. Three-dimensional or multilayer components have become an attractive way of dealing with complex microwave integrated circuits. A double-sided directional coupler using broadside slot-coupled microstrip lines has been proposed by Tanaka *et al.* [1], [2]. Compared to the conventional parallel coupled stripline directional coupler, this three-dimensional coupler can be used for tight coupling in a more compact size. Schwab and Menzel [3] reported another multilayer directional coupler using transverse slot-coupled microstrip lines. The coupling structure consisted of four square slots in a common ground plane between two microstrip lines. Design of the above multilayer directional couplers requires either a finite element method (FDM) or a spectral domain method combined with a commercial microwave CAD program.

This letter proposes a simple vertical-interconnect quadrature directional coupler that consists of two microstrip lines coupled through two virtually-terminated narrow slots in a common ground plane. By applying the design equations for the quasi-lumped quadrature coupler developed by O'Caireallain and Fusco [4], [5], the positions and dimensions of two virtually-terminated narrow slots in the common ground plane can be easily determined. Experimental results verified the design concept and showed a fairly good agreement with theory.

II. Circuit Design and Measurements

Fig. 1 shows the general circuit of the quasi-lumped quadrature directional coupler. The coupler consists of two parallel uniform transmission lines connected together with lumped admittances. Ports 2 and 3 are the output ports, and port 4 is the isolated port. Port 1 is used for excitation. The conditions imposed for perfect match, isolation and coupling are given by [4] as

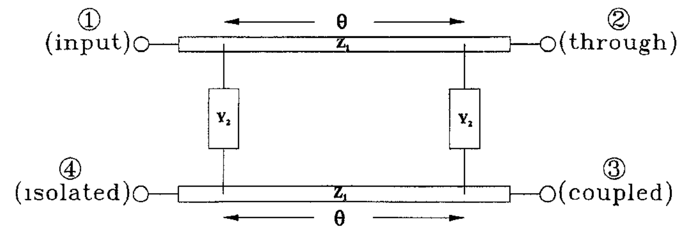

Fig. 1. General quasi-lumped quadrature directional coupler.

$$1 + jY_2 Z_1 \tan\theta = 0 \tag{1}$$

and

$$k = \frac{1}{Y_2^2 Z_1^2}, \tag{2}$$

where k is the power coupling ratio between port 2 and port 3, Z_1 is the characteristic impedance of the transmission line, and Y_2 is the admittance of the shunt elements. For 3-dB coupling, the coupling factor k is equal to 1 and the electrical length θ of the parallel transmission line is 135° for inductive coupling and 45° for capacitive coupling.

Fig. 2 shows the three-dimensional view of the vertical-interconnect quadrature coupler. The coupling structure has two transverse narrow slots in a common ground plane between two microstrip lines. Each of the coupling slots is terminated with a virtual open on both ends. The separation between the coupling slots is determined by (1) and (2). For a 3-dB coupler design, the electric length of the separation between two coupling slots is 45°. The length is equivalent to $1/8\lambda_g$, where λ_g is the guide wavelength.

According to these design equations, a vertical-interconnect quadrature coupler was built on a RT/Duroid 6010.8 substrate with the following dimensions:

substrate thickness: $h = 1.27$ mm

microstrip line width: $w_m = 1.12$ mm

slotline line width: $w_s = 0.175$ mm

virtual slotline open diameter: $d_s = 6$ mm

separation between two coupling slots: $l_m = 5.35$ mm.

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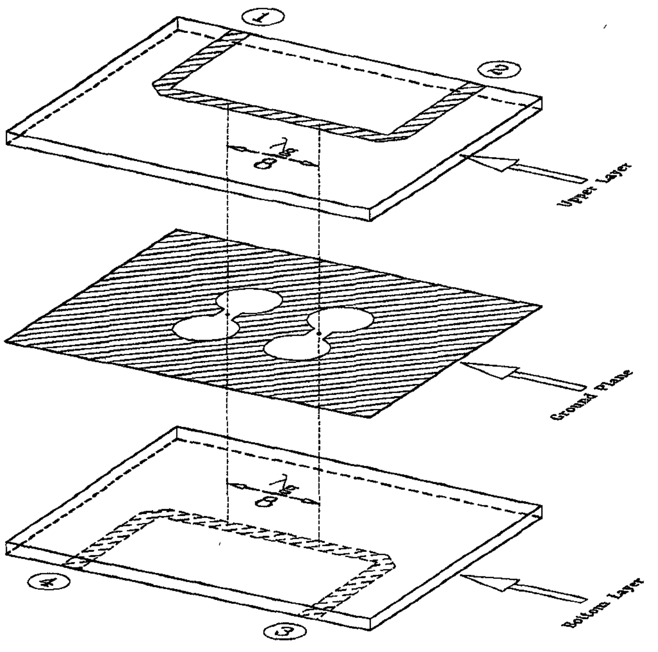

Fig. 2. 3–D view of the vertical interconnect quadrature directional coupler.

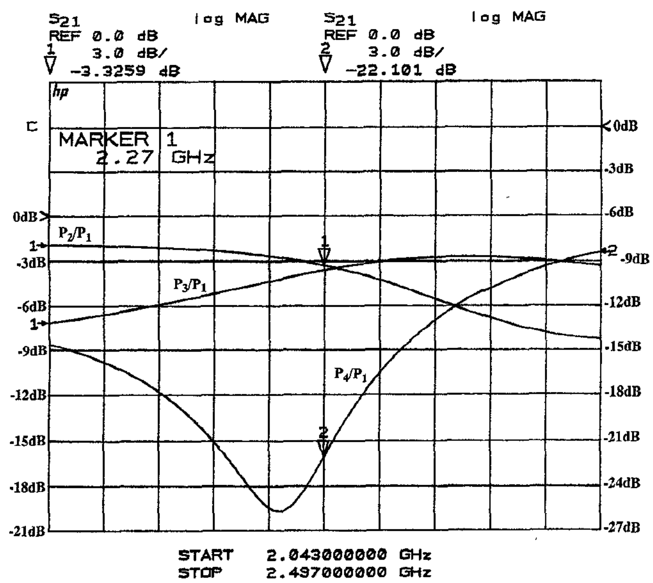

Fig. 3. Measured frequency responses of transmission, coupling, and isolation for a multilayer quadrature directional coupler.

Fig. 3 shows the measured results of transmission, coupling and isolation. The input power P_1 is split equally into P_2 and P_3 with an insertion loss of 0.5 dB at the frequency of 2.3 GHz. The isolation between port 1 and port 4 is greater than 15 dB. Fig. 4 shows the phase balance between transmission and coupling ports. Phase quadrature is maintained at 90° ±2.5° over a bandwidth of 14%.

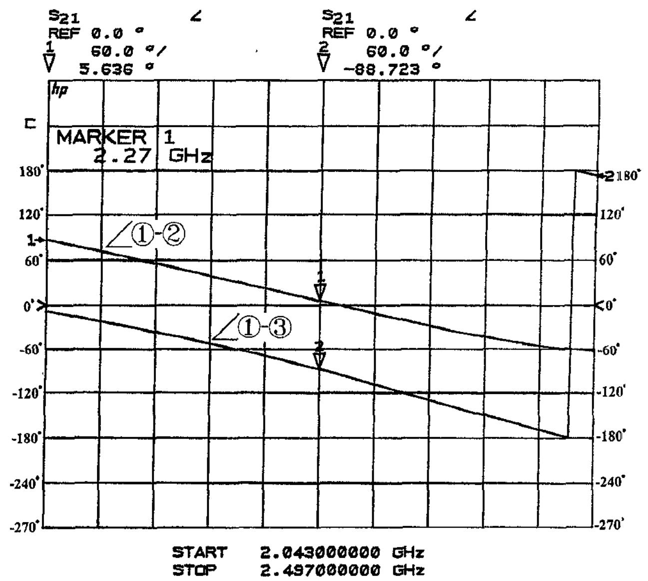

Fig. 4. Measured phase balance of a multilayer quadrature directional coupler.

III. Conclusion

A new quadrature directional coupler consisting of vertical-interconnect microstrip lines coupled by two virtually terminated narrow slots is presented. This three-dimensional coupler is compact and simple in construction compared to the conventional quarter-wavelength microstrip hybrids. Preliminary results show the existence of narrow-band quadrature characteristics and verify the validity of quasi-lumped design equations. Further analysis and modeling of multihole couplers are required to improve the bandwidth.

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