Slot-Coupled Double-Sided Microstrip Interconnects and Couplers

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ABSTRACT

This paper presents a broad-band slot-coupled microstrip vertical interconnect and a microstrip double-layer quadrature coupler. The interconnect demonstrates less than 1 dB insertion loss over a 2.6 octaves bandwidth from 1.39 GHz to 8.5 GHz. The coupler shows an isolation of greater than 15 dB and phase quadrature of $90^o \pm 2.5^o$ over 14% bandwidth.

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. Slot coupling was recently successfully used to interconnect two microstrip lines on two different layers [1]. This technique used the conventional quarter-wavelength cross-junction microstrip to slotline transition. However, the sensitivity of the slot length caused deterioration of the coupling efficiency and resulted in the complexity of the vertical interconnect design. Also the quarter-wavelength cross-junction limited the operating bandwidth and inherited some ripple effects caused by reflections from the open and short stubs. To overcome the above drawbacks and obtain a better coupling performance, this paper presents a new microstrip vertical interconnect by using virtually-terminated microstrip line to sandwich-slotline transitions. This vertical interconnect has a much wider bandwidth, lower loss, and higher coupling efficiency.

A double-sided directional coupler using broadside slot-coupled microstrip lines has been proposed by Tanaka *et al* [2]. Compared to the conventional parallel coupled stripline directional coupler, the 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 paper proposes a simple microstrip double-layer quadrature coupler. The new quadrature coupler 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.

BROAD-BAND MICROSTRIP VERTICAL INTERCONNECTS

Figure 1 shows the physical configuration of the microstrip vertical coupling structure. The microstrip lines on two vertical layers are parallel to each other and coupled by a narrow slot on the common ground plane. The RF signal comes in from one of the two microstrip lines, coupled by the interconnect slot, and then goes out from the other microstrip line. Each input microstrip line is terminated by a virtual circle short near the edge of the interconnect slot. The virtual microstrip short provides broadband and high magnetic coupling from microstrip lines to sandwich-slotline. The coupling slot on the common ground plane is also terminated by two virtual circle opens near the edges of the virtual microstrip shorts. These two virtual sandwich-slotline open circuits enforce the maximum electromagnetic power flow through the

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coupling slot. The line widths of the microstrip feeds and the interconnect slot are optimized by the equivalent transmission line model in [6].

Figure 2 shows the measured frequency response of insertion loss for the broad-band microstrip vertical interconnect. The bandwidth of less than 1 dB insertion loss is from 1.39 GHz to 8.5 GHz. The inband flatness is measured within 0.6±0.3 dB. As shown in the measured results of Figure 2, the sandwich-slotline length does not effect the coupling bandwidth. Furthermore the virtually-terminated sandwich-slotline will not excite resonances which cause the ripple problems in the conventional quarter-wavelength cross-junction, because the virtual circle open has a broader bandwidth than the quarter-wavelength short stub and can conduct maximum power flow through the guided direction.

MICROSTRIP DOUBLE-LAYER QUADRATURE COUPLERS

Figure 3 shows the general circuit of the quasi-lumped quadrature 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

$$1 + jY_2 Z_1 \tan\theta = 0 \qquad (1)$$

and

$$k = \frac{1}{Y_2^2 Z_1^2} \qquad (2)$$

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.

Figure 4 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 Equations (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 $\lambda g/8$, where λg is the guide wavelength.

Figure 5 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 2.3 GHz. The isolation between port 1 and port 4 is greater than 15 dB. Figure 6 shows the phase balance between the transmission and coupling ports. Phase quadrature is maintained at $90^\circ \pm 2.5^\circ$ over a bandwidth of 14%.

CONCLUSIONS

This paper presented two slot-coupled microstrip double layer couplers. The broad-band microstrip vertical interconnect used virtually-terminated microstrip to sandwich-slotline transitions and demonstrated broad bandwidth, low loss, and high efficiency coupling. The interconnect showed less than 1 dB insertion loss over a bandwidth of more than 2.6 octaves which covered the L, C, and S bands. The other microstrip double-layer quadrature coupler consisting of two parallel microstrip lines coupled by two virtually-terminated narrow slots illustrated an isolation of greater than 15 dB and phase quadrature of $90^\circ \pm 2.5^\circ$ over a bandwidth of 14%. Due to the advantages of compact size, light weight, high density, and good isolation, these three dimensional, noncontacting RF couplers are very suitable for multilayer and large scale MIC's and MMIC's applications.

ACKNOWLEDGMENTS

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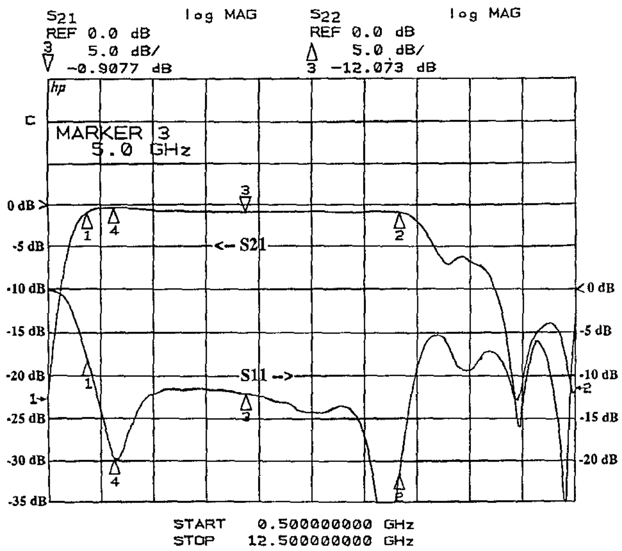

Figure 2 Frequency responses of the insertion loss and return loss for a microstrip vertical interconnect. Marker 1 reads $|S_{21}|$= -0.97 dB at 1.4 GHz. Marker 2 reads $|S_{21}|$= -0.98 dB at 8.5 GHz. Marker 3 reads $|S_{21}|$= -0.91 dB at 5.0 GHz. Marker 4 reads $|S_{21}|$= -0.38 dB at 2.0 GHz.

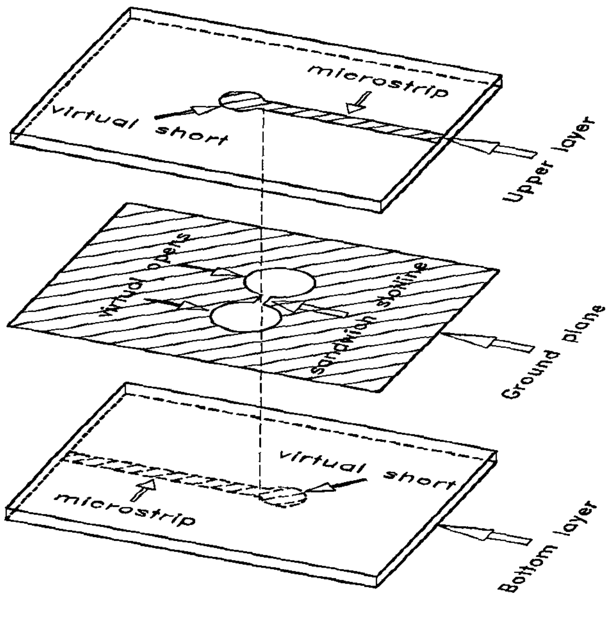

Figure 1 3-D configuration of the virtually-terminated microstrip vertical interconnect.

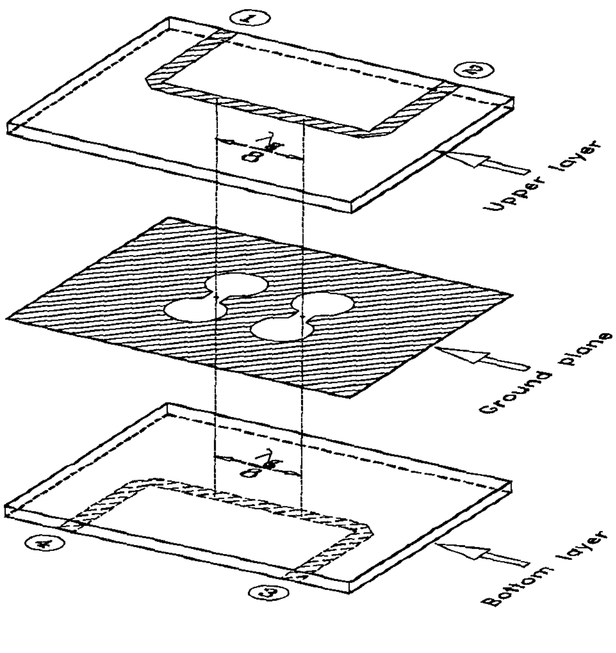

Figure 4 3-D view of the microstrip double-layer quadrature coupler.

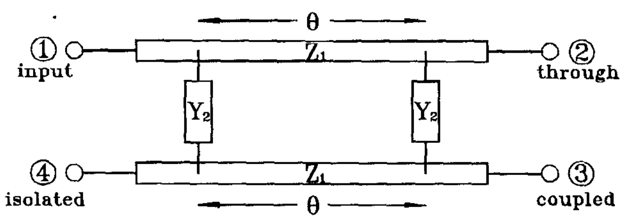

Figure 3 quasi-lumped quadrature directional coupler.

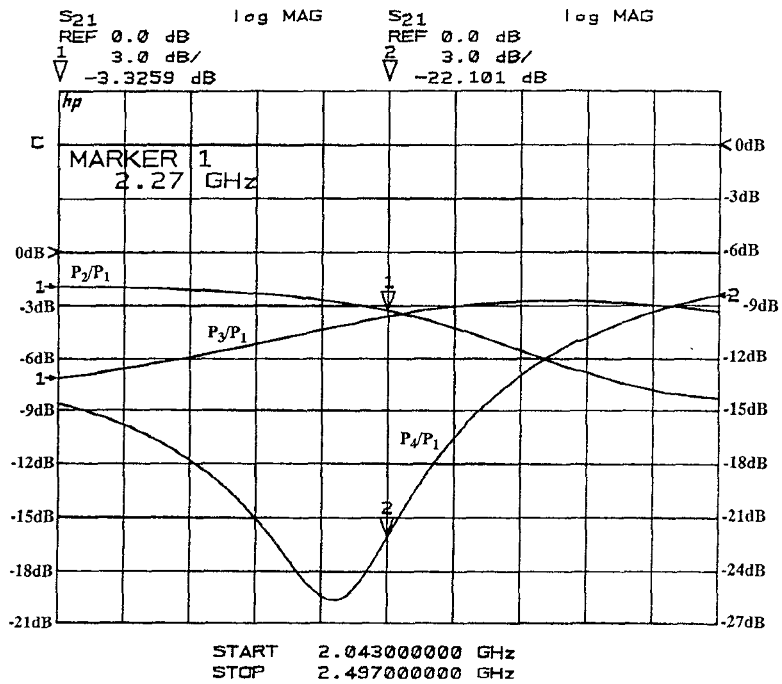

Figure 5 Measured transmission, coupling, and isolation of a microstrip double-layer quadrature coupler.

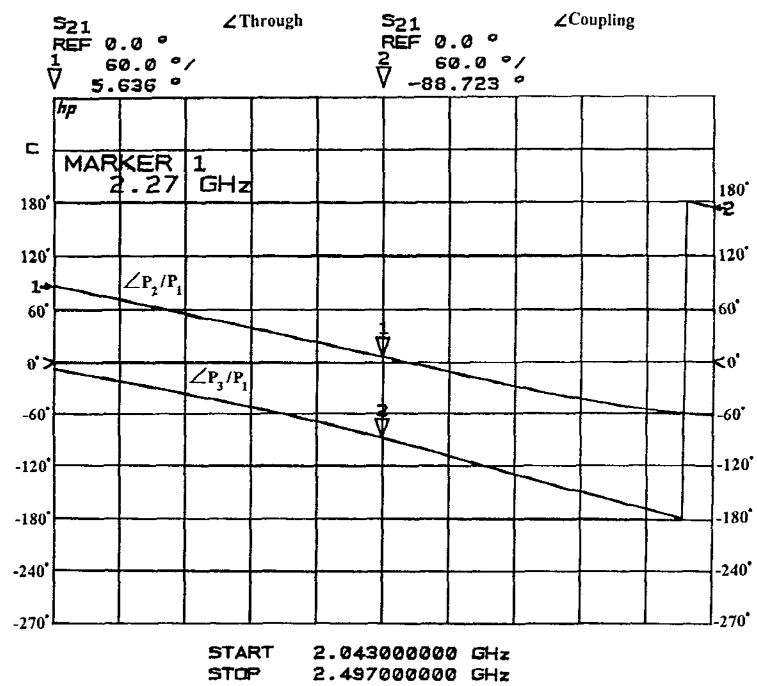

Figure 6 Measured phase balance of a microstrip double-layer quadrature coupler.