A 3-D Broadband Dual-Layer Multiaperture Microstrip Directional Coupler

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***Abstract*—A three–dimensional (3-D) broadband dual-layer multiaperature microstrip directional coupler is presented in this paper. The dual-layer, multiaperature directional coupler consists of two-layer back-to-back substrates with 15 small coupling apertures on the center ground plane. A novel rectangular multiaperature coupling structure with very small width is used to greatly extend the bandwidth and operating frequency of the coupler. The ±2.4 dB coupling variation bandwidth of the couplers is more than 1.5 octaves from 9.79 to 29.55 GHz. The insertion losses, return losses at all ports and directivities, are better than 1.7 dB, 10.26 dB, and 10.3 dB over the bandwidth, respectively. The measurements agree well with the simulations.**

***Index Terms*—3-D structure, directional coupler, multilayer circuits, packaging and integration.**

I. Introduction

In the recent decade, engineers developed various RF/microwave modules with high performance, light-weight, and compact-size [1], [2]. The modules had widespread application in telecommunications, radar, and information systems. Light-weight and compact-size RF/microwave circuits are especially critical in hand-held, airborne and satellite communication systems. The three–dimensional (3-D) RF/microwave circuits with multilayer substrates have been developed for reducing size and weight of the RF/microwave modules and increasing their integration scale [3]. The 3-D RF/microwave circuits have had many applications in the device, circuit, and module integration although the development of the 3-D RF/microwave circuits is just beginning.

The multilayer microwave circuits developed in the past also included the dual-layer directional coupler. But, the previous reported couplers only operated over a narrow bandwidth of less than 2 GHz and at low operating frequencies below 11 GHz [4]–[8]. The dual-layer couplers presented in this paper utilize a novel rectangular multiaperature structure with very small width. The couplers operate over a much wider bandwidth and at a much higher frequency compared with the previous ones. The coupling coefficients of the couplers are designed to be 6, 11, and 30 dB. Measured results show that the bandwidth with ±2.4 dB coupling variation is more than 1.5 octaves from 9.79 to 29.55 GHz and the directivities are more than 10.3 dB even for the coupler with a small coupling of 30 dB. The ±1.5 dB coupling bandwidth of the couplers is more than 1 octave from 14 to 29 GHz. The simulations and measurements further show that the 30 dB coupler works well at a broader bandwidth of more than 2 octaves from 7.13 to 33.92 GHz if a more relaxed coupling variation of ±5 dB is allowed.

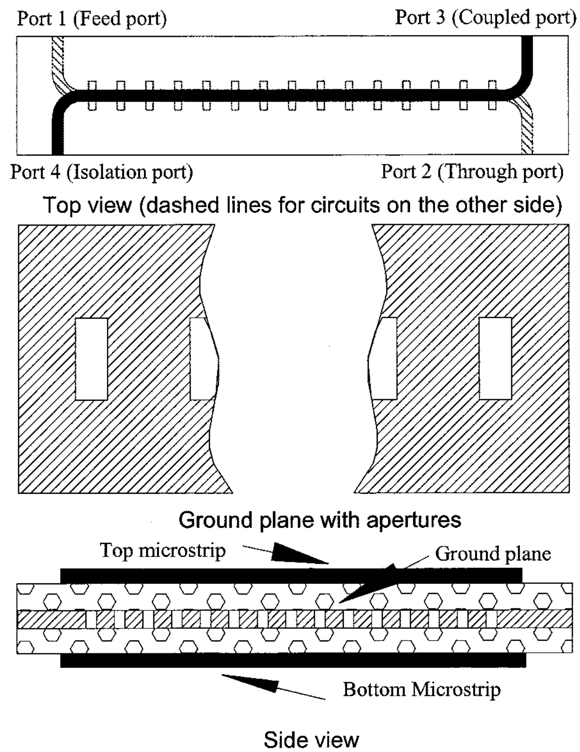

Fig. 1. Layout of the dual-layer multiaperature coupler.

II. Configurations and Theory

The circuit layout of a dual-layer multiaperature directional coupler is shown in Fig. 1. The coupling coefficient C and directivity of the coupler D in dB can be defined as [9]

$$C = -20Log\left|\frac{E_3}{E_0}\right| = -20Logk - 20Log\sum_{n=0}^{N} a_n^2 b_n \quad (1)$$

$$D = -20Log\left|\frac{E_4}{E_3}\right| = -C - 20Logk - 20Log(S) \quad (2)$$

where

$$S = \left|\sum_{n=0}^{N} a_n^2 b_n e^{-j\beta(n\pi/\beta_0)}\right| \quad (3)$$

where E_0 is the input electric field at Port 1 and E_3 are E_4 electric field at Port 3 and 4, β is the propagation constant of the

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TABLE I
DIMENSIONS $a_n \times b_n$ OF THE APERTURES

		$a_0 \times b_0$	$a_1 \times b_1$	$a_2 \times b_2$	$a_3 \times b_3$	$a_4 \times b_4$	$a_5 \times b_5$	$a_6 \times b_6$	$a_7 \times b_7$
Dimensions	30 dB coupler	5×11	5×14	5×21	5×16	5×22	5×16	5×23	5×17
(mil×mil)	11 dB coupler	5×23	5×28	5×41	5×32	5×43	5×33	5×45	5×33
	6 dB coupler	5×33	5×41	5×61	5×46	5×63	5×47	5×64	5×47

dual-layer multiaperature coupling structure, β_0 is the propagation constant at the center frequency, k is a constant to be determined, and a_n and b_n are the width and length of the nth aperture, respectively. Assuming that N is an even number (an odd number of apertures) and the coupler is symmetrical ($a_0 \times b_0 = a_N \times b_N, a_1 \times b_1 = a_{N-1} \times b_{N-1}, a_2 \times b_2 = a_{N-2} \times b_{N-2}, \ldots$), couplers with different responses will be achieved by equaling S to different N-degree polynomials, respectively

$$S = 2\sum_{n=0}^{N/2} a_n^2 b_n \cos(N-2n)\theta = K\left|P_N\left(\sec\theta_m \cos\theta\right)\right| \quad (4)$$

where K and θ_m are constants to be determined and polynomial $P_N(\sec\theta_m \cos\theta)$ may be a binomial (maximum flat), or Chebyshev polynomial, etc. Multiaperature, dual-layer microstrip directional couplers with different coupling coefficients can be designed with the above method and small-hole coupling theory.

III. SIMULATIONS AND MEASUREMENTS OF MULTI-APERTURE COUPLERS

Three fifteen-aperture ($N = 14$) dual-layer microstrip couplers with Chebyshev responses are designed. Aperture dimensions $a_n \times b_n (n = 0, 1, 2, \ldots, 7)$ of the couplers with different coupling coefficients and constant K are determined by solving (4) and using the method of the multi-section matching transformer [9]. The couplers are simulated by Agilent HFSS Electromagnetic Simulator [10]. The coupling coefficients of the 15-aperture couplers are designed to be 6, 11, and 30 dB, respectively. The couplers' structure is shown in Fig. 1. The 15-aperture dual-layer directional couplers are fabricated on 10-mil-thick Rogers 5880 Duroid substrates with dielectric constant of 2.2. Experiments show that the larger the width a_n and length b_n of the apertures are, the stronger the coupling is. The variation of length b_n does not significantly affect the directivity and bandwidth of the couplers. But, increasing width a_n beyond 8 mils would reduce the directivity and bandwidth.

Aperture dimensions of the couplers are shown in Table I. The widths a_n of all apertures are fixed at 5 mils. The distance ℓ between the two neighboring apertures is 100 mils. The width of each aperture is chosen to be 5 mils mainly because this is the minimum dimension that could be accurately etched. The simulations show that the operating frequency and bandwidth of the couplers can be increased if the apertures with smaller width a_n are used. The simulated and measured results for these three couplers are shown in Figs. 2–5. The measured results indicate that the ±2.4 dB coupling variation bandwidth is from 9.79 to 32.78 GHz for the 30 dB coupler, as shown in Fig. 2 and from 9.6 to 31.45 GHz for the 11 dB coupler, as shown in Fig. 3, and from 9.41 to 29.55 GHz for the 6 dB coupler, as

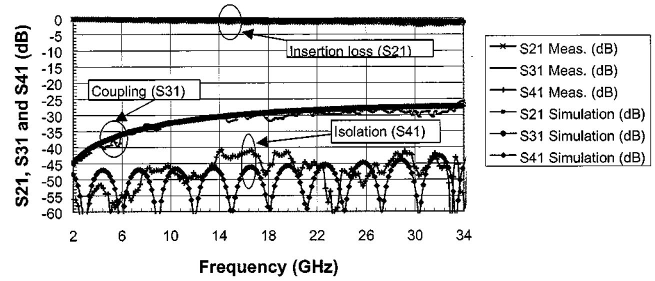

Fig. 2. Insertion loss, coupling, and isolation of the 30 dB coupler.

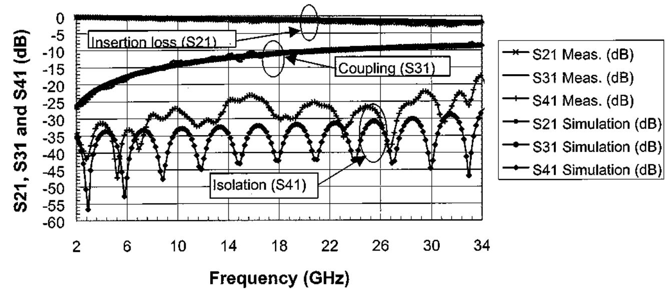

Fig. 3. Insertion loss, coupling, and isolation of the 11 dB coupler.

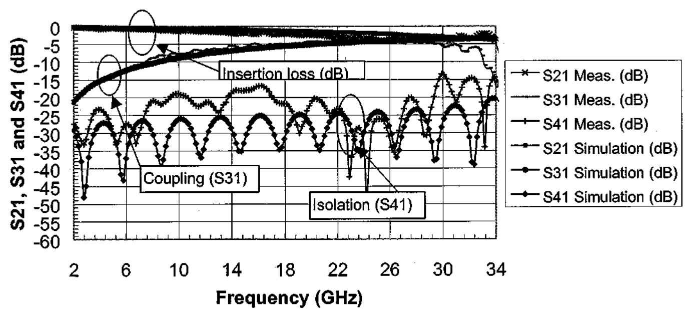

Fig. 4. Insertion loss, coupling, and isolation of the 6 dB coupler.

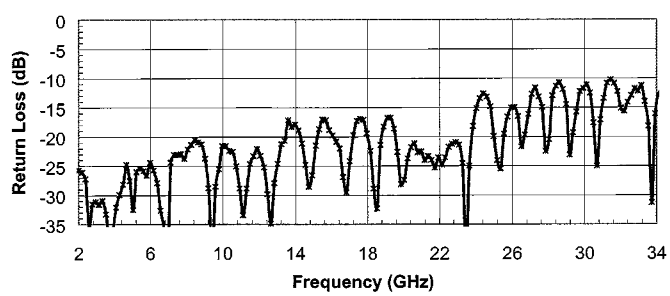

Fig. 5. Measured S33 of the 11 dB coupler.

shown in Fig. 4. The bandwidths of all these three couplers with a ±2.4 dB coupling variation are more than 1.5 octaves. The 1.5 dB coupling bandwidth of the couplers is more than 1 octave from 14 to 29 GHz. Measured isolations of the 6, 11, and 30 dB couplers shown in Figs. 2–4 are more than 10.3, 11.52, and 11.1 dB, respectively. Figs. 2–4 show that measured insertion losses are less than 1.7 dB. Measured return losses of these three couplers are better than 12, 10.2, and 11 dB, respectively, over the bandwidth. Fig. 5 shows the measured return loss S33 of the 11 dB coupler. The performance of the return losses of the couplers at the other ports is similar with the one shown in Fig. 5. The measurements agree well with the simulations.

IV. Conclusion

This paper describes several microstrip 3-D multiaperature broadband couplers with dual-layer substrates. The couplers with 6, 11, and 30 dB coupling coefficients are fabricated and tested. The novel rectangular multiaperature coupling structure with very small width is proposed in this paper. The structure significantly extends the bandwidth and operating frequency of the couplers. The simulated and measured results demonstrate that these couplers have good performance over a very broad bandwidth. The couplers should have many applications in microwave circuits, modules, and systems using multilayer packaging.

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