DESIGN OF A MINIATURIZED STRIPLINE-TO-MICROSTRIP-LINE COUPLER

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Abstract: A new design methodology for a stripline-to-microstrip-line coupler using apertures in their common ground plane is presented. The design is based on a cosine distribution of aperture sizes and allows the component to be realized within one fifth of a wavelength while maintaining a broadband performance. Various key points of the design such as aperture dimensions and the number of apertures are discussed. The theory is validated by measurements.

I. INTRODUCTION

One of the main application-oriented differences between stripline and microstrip-line technology is their power handling capability [1]. If the performance of a stripline circuit at moderate power level is to be monitored through signal extraction by a weak coupler, it is often appropriate to design the control circuit in low-power microstrip technology to take advantage of its easier manufacturing and integration process. With respect to the design of a stripline-to-microstrip-line coupler in UHF and VHF bands, the standard proximity coupling approach is inconvenient due to its quarter-wavelength section lengths. Therefore, a concept built on aperture coupling through a common ground plane has been presented in [2]. This eliminates the quarter-wavelength restriction of proximity designs.

This paper focuses on a new design, which further reduces component size to one fifth of a wavelength by proposing a specific taper of apertures. As shown in Fig. 1, coupling is achieved through apertures in the common ground plane of the two technologies. Since these couplers exhibit generally weak coupling, increasing a single aperture dimension will not extend coupling beyond a certain level, thus saturating the amount of coupling. This property sets the limit for the maximum aperture dimension. Coupling values and bandwidth are improved by utilizing multiple apertures in some sort of a tapered-size arrangement. It will be demonstrated that our new design guidelines result in aperture arrangements of shorter overall component size while competing well with the broadband performance of the traditional designs.

One of the important specifications of the coupler is its directivity, which, in aperture couplers, depends on the shape of the aperture. In order for a single aperture to achieve strong backward coupling and minimize forward coupling, circular apertures will be used here. For details on this specific subject, the reader is referred to [3].

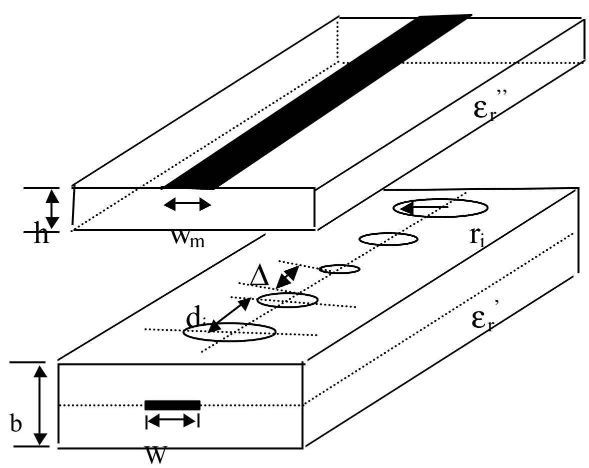

Fig. 1. *Aperture-coupled stripline-to-microstrip-line coupler.*

II. THEORY AND DESIGN

Bethe's coupling theory [4, 5] assumes that the field over the aperture is uniform. If the aperture dimensions are too large, this assumption fails, and the calculated and measured results will start to deviate from each other. This is shown in Fig. 2 where the saturation sets in at approximately 2 GHz. From this value, we find that the maximum aperture diameter, for which the assumption of uniform field holds, is about eight percent of the guided wavelength. If the aperture dimension is too small, the coupling will vary drastically with frequency. Therefore, the ideal dimensions for the aperture are deemed to be between one and eight percent of the guided wavelength. Note that these limits may vary slightly with substrate thickness and dielectric constant.

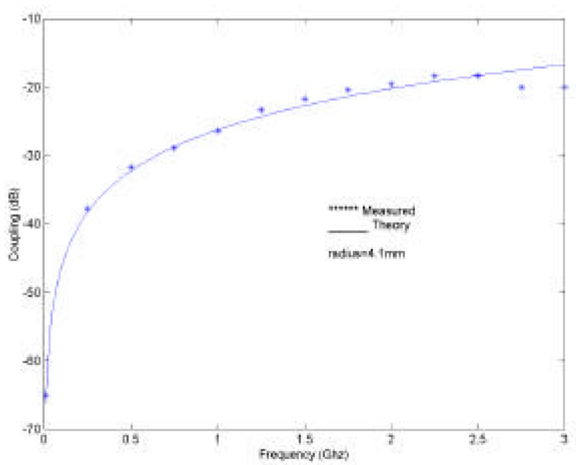

Fig. 2. Calculated and measured coupling of a single circular aperture in the common ground plane between stripline and microstrip line according to Fig. 1.Refer to Table I for circuit parameters.

Now consider a stripline with dielectric constant ε_r' and ground-to-ground spacing b, and a microstrip line with an effective dielectric constant ε_{reff}'', e.g. [6], and thickness h, as shown in Fig. 1. The characteristic impedance of the microstrip line is z_c, the width of the stripline is w, and r is the radius of the aperture. For a single aperture coupler, the radius of the aperture for desired coupling C (dB) could be written as

$$r = (\varphi)^{1/3} \tag{1}$$

where

$$\varphi = \frac{180\lambda h^2 b\sqrt{F(m)}\,10^{\frac{-C(dB)}{20}}}{z_c\left[\frac{\varepsilon_r'\varepsilon_{reff}''}{\varepsilon_r'+\varepsilon_{reff}''}+2\sqrt{\varepsilon_r'\varepsilon_{reff}''}\right]} \tag{2}$$

$$F(m) = \frac{8}{\left(\frac{b}{2}\right)^2}\int_{-\frac{b}{2}}^{\frac{b}{2}}\int_{-\infty}^{\infty}\frac{dxdy}{\left|1-m^2\cosh^2\left(\frac{\pi(x+jy)}{b}\right)\right|} \tag{3}$$

and

$$m = \sec h\left(\frac{\pi w}{2b}\right) \tag{4}$$

If the calculated aperture dimension exceeds the maximum aperture dimension, more than one aperture is required to realize the desired coupling. In order to minimize the size component, we select a constant minimum distance Δ as the gap between the aperture edges. If N apertures with radii r_i (i=1…N) are used, then

$$\varphi = \left|\sum_{i=1}^{N} r_i^3 e^{-j(\beta_{gs}+\beta_{gms})d_{1i}}\right| \tag{5}$$

where

$$d_{1i} = (r_1+r_i)+2\sum_{k=2}^{i-1} r_k + (i-1)\Delta \tag{6}$$

$$d_{11} = 0$$

$$\beta_{gs} = \frac{2\pi}{\lambda}\sqrt{\varepsilon_r'} \tag{7}$$

$$\beta_{gms} = \frac{2\pi}{\lambda}\sqrt{\varepsilon_{reff}''} \tag{8}$$

For uniform apertures, (5) can be solved and d_{1i} gives the spacing of the apertures from the center of the first aperture.

The radii of the apertures need not be identical and can vary according to any functional form. Let δr be the minimum radius of the aperture, and let the radii follow a functional form F.

$$r_i = R\left[F\left(\frac{\pi(i-1)}{N-1}\right)+\delta r\right] \tag{9}$$

By substituting (9) in (5), the multiplication factor R can be deduced. The distances between aperture centers can then be calculated as described above.

The response of the coupler with frequency is (theoretically) periodic. The bandwidths of these couplings are variable, and the first coupling band will have larger bandwidth compared to any other band. If the predicted diameter of the apertures is larger than the specified saturation limit, more apertures will be required to realize the desired coupling. The center frequency of the coupling band can be tuned by adjusting the inter-aperture spacing. Coupling can be tuned by slightly modifying the aperture radius. The number of coupling bands within a broadband frequency range will increase with inter-aperture spacing within a band of frequencies.

III. RESULTS

As has already been shown in Fig.2, there is excellent agreement between the calculated and measured performance of a single aperture stripline-to-microstrip-line coupler.

In Fig.3 and Table 1, we investigate bandwidth and component size of couplers with different types of patterns of the aperture size. All three couplers are designed for 20 dB coupling at 1 GHz. The various parameters are described in Table I. As can be seen from Fig. 3, the sinusoidal distribution of aperture radii (conventional design with largest aperture in the center) provides the largest bandwidth (89.1 percent). However, it is almost twice as long (30 % of λ_g; c.f. Table I) as the cosine design (smallest aperture in the center), which is only 0.17 λ_g long but achieves only an 81 percent bandwidth (Table I and Fig. 3). The design with uniform distribution of aperture size appears to be a very good compromise between the cosine (largest bandwidth) and sinusoidal (smallest coupler) design.

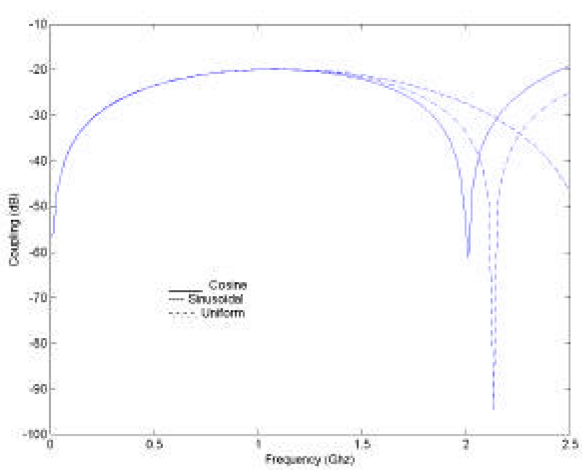

Fig. 3. Bandwidth comparison of stripline-to-microstrip-line couplers with five apertures and different patterns of aperture size; cosine taper (solid line), sinusoidal taper (dashed line) and uniform apertures (dash-dotted line).

In order to provide the design engineer with all dimensions used in this comparison, Table I also includes the aperture dimensions as obtained from the guidelines presented in Section II.

Table I

f= 1GHz, C = 20 dB, N = 5, b = 1.6 mm, h = 0.8 mm
$Z_c = 50\ \Omega$, $\varepsilon_r' = \varepsilon_r'' = 2.32$.

Distribution	Radius (mm)	Distance* (mm)	Bandwidth ± 1 dB	Length** λ_g
Cosine	4.06	0	81%	17%
	3.27	9.32		
	1.35	15.94		
	3.27	22.56		
	4.06	31.89		
sinusoidal	1.54	0	89.1%	30%
	3.72	12.88		
	4.62	31.08		
	3.72	49.29		
	1.54	62.17		
uniform	3.47	0	83.6%	19.8%
	3.47	9.64		
	3.47	19.27		
	3.47	28.91		
	3.47	38.54		

*Note that the distance is measured from the center of the first aperture to the center of the respective next aperture.
** Length is measured from left edge of left-most aperture to right edge of right-most aperture.

To verify the design procedure, a coupler with six uniform apertures with 4.1mm radii and 10.2 mm aperture spacing has been designed, fabricated and measured. Fig.4 demonstrates excellent agreement between measured and predicted results. It also validates the fact that inter-aperture (mutual) coupling is not a major factor in this type of design. Moreover and as a result of the assumption of weak coupling, the input return loss is not been included in the design process. Indeed, return loss values observed during measurements have been better than 15 dB.

IV. CONCLUSIONS

New design guidelines for stripline-to microstrip-line couplers achieve component miniaturization down to approximately one fifth of a wavelength. The procedure is straightforward. Design examples and measurements verify the theoretical approach.

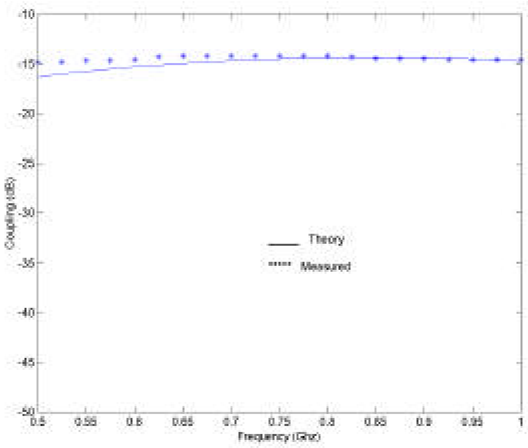

Fig. 4. *Measured (**) and calculated (solid line) performance of stripline-to-microstrip-line coupler with six identical apertures centered at 0.75 GHz.*

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