A HYBRID COUPLER FOR MICROSTRIP CONFIGURATION

By

Samuel Hopfer

General Microwave Corporation

155 Marine Street

Farmingdale, New York 11735

ABSTRACT

A hybrid coupler for microstrip, modelled along the lines of the "re-entrant coupled section"[1] of a coaxial system, is described. Complete design information is available, leading to the realization of these circuits up to 18 GHz with good accuracy.

Introduction

The work reported in this paper was initiated several years ago with the intent of developing an alternate to the microstrip hybrid coupler, known as the "Lange Coupler."[2] The latter suffered from several shortcomings, especially a lack of sufficient design information and the difficulty of realizing this circuit as a low-loss device of good reproducibility at frequencies up to 18 GHz and beyond.

Design Approach

Although the design concept pursued in this development (the "re-entrant coupled section" introduced by Cohn and Wehn[1] for coaxial systems) is an old one, its application to the microstrip configuration is, to the extent of our search of the literature, quite new. A particular embodiment of the above concept is shown in Figures 1 and 2. Analyzing the coupled structure in terms of the odd and even-mode impedances Zoo and Zoe, respectively, the former should approximately be given by

$$Z_{oo} \simeq Z'_{oo} \quad (1)$$

where Z'_{oo}, is the odd-mode impedance of the structure inside the floating shields B, but with infinite ground planes in place of the shields of finite width W'. Similarly, the even-mode impedance is approximately given by

$$Z_{oe} \simeq Z'_{oe} + Z_{AB} \quad (2)$$

where Z'_{oe} is the even-mode impedance of the same structure as defined above for Z'_{oo} and where Z_{AB} is the impedance of an equivalent two-conductor microstrip configuration of strip width W', thickness b, and elevation h. The above equations, in conjunction with the analytic information available in the literature[3] for Z'_{oo}, Z'_{oe}, and Z_{AB} as well as the standard relationships of coupled structures, suffice to determine the cross-sectional dimensions in Figure 2.

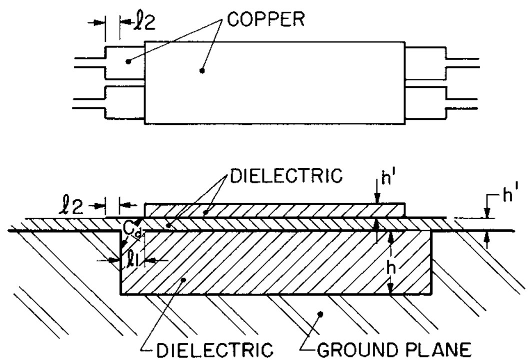


Figure 1. Hybrid Coupler

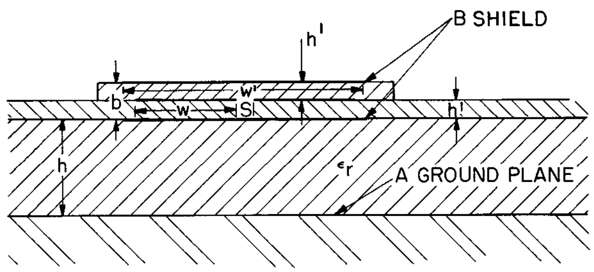


Figure 2. Hybrid Coupler Cross Section

The longitudinal dimensions are affected by the step discontinuity in the ground plane which should be compensated for. This compensation is achieved by extending the coupled strips of width W beyond the shielded region for a length $\ell_1 + \ell_2$ as shown in Figure 1. In terms of ℓ_1, which is somewhat arbitrary and, in our case, chosen to be equal to b, ℓ_2 is approximately given by

$$\ell_2 = \ell_1 \frac{(1/\rho_1 - \rho_1) - vcZ_0}{1/\rho_2 - \rho_2} \tag{3}$$

where ρ_1 and ρ_2 refer to ratios of the different Z_0s appearing in the transition region, v is the phase velocity in the ℓ_2 region, and C_d is the discontinuity capacity indicated in Figure 1, and approximately given by

$$C_d = \frac{2\epsilon W}{\pi} \ln \csc \frac{\pi h'}{2(h+h')} \tag{4}$$

While the above equations define relative dimensions of the coupled structure, the absolute dimensions are subject to some choice. In practice, it is convenient to choose the dielectric constant ϵ_r of the material, the thickness h' of the microstrip transmission line, the separation s of the coupled lines and, to some extent, the width W' of the shields. The design considerations for these choices, although of considerable importance, are beyond the scope of this summary. A typical set of parameters used in most of our applications is as follows:

ϵ_r = 2.18 (Duroid)
h' = 0.007"
s/b = 0.5
W' = 2W + s+b

Construction

The construction of hybrid couplers as parts of microwave integrated circuits starts by fitting dielectric slabs into rectangular depressions in the metallic ground plane. The dielectric substrate, containing rf circuitry on the top and a shield on the bottom, is then placed over the ground plane. Finally, the upper shields are put in place. With all parts referenced to a common set of alignment pins, the assembly becomes routine and is reproducible within close tolerances. Figure 3 shows an assembly of 18 hybrid couplers used in the recent design of an analog phase shifter for the 8-18 GHz band.

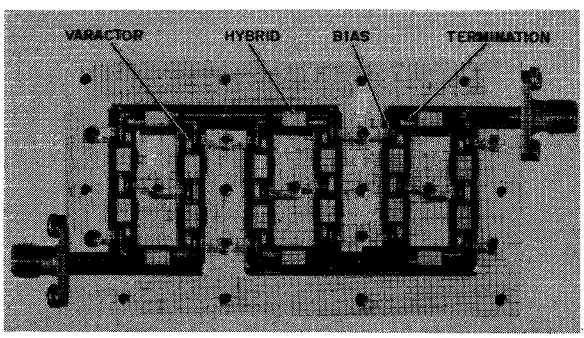


Figure 3. Top View of Phase Shifter

Performance

Since the major application of the microstrip hybrid coupler is that of a component in an integrated circuit assembly, it is highly desirable to infer its performance from data obtained with the coupler in situ. A critical parameter of the design is the midband coupling coefficient c. Its criticalness becomes evident when the direct and coupled arms of the hybrid are terminated in identical but totally reflecting impedances and the fourth port is properly terminated. Under these conditions, the magnitude of the input scattering coefficient S_{11} can be shown to be given by

$$|S_{11}| = 1 - \frac{2c^2 \sin^2\theta}{1 - c^2\cos^2\theta} \tag{5}$$

A plot of (5) is shown in Figure 4 for the 8-18 GHz band, indicating the nulls of the reverse spectrum at 9.4 and 16.6 GHz, respectively, which correspond to the 3-dB coupling points. Since the magnitude of S_{11} changes very rapidly in the vicinity of the null and the reflection experiences a phase reversal, the super-position of such a reflection on other, usually smaller, reflections is easily recognizable. To illustrate the use of (5), consider the rf portion of a PIN diode attenuator optimally designed for the 8-18 GHz band as shown in Figure 5. The input and output hybrids are seen to be connected by transmission lines containing shunt-mounted PIN diodes. Figure 6a shows $|S_{11}|$ with the device in a very low attenuation state indicating mainly the reflections from the input connector assembly, the input impedance match of the hybrid and the effects of the finite directivity of the reflectometer system. Figure 6b, on the other hand, shows $|S_{11}|$ with the PIN diodes heavily biased and thus producing the conditions to which Figure 4 can be applied. Inspection of Figure 6b indicates that the hybrid is slightly under-coupled, that is, c = 0.719 instead of 0.741, the value for which it was designed. This situation results from housing the hybrid in a channelled

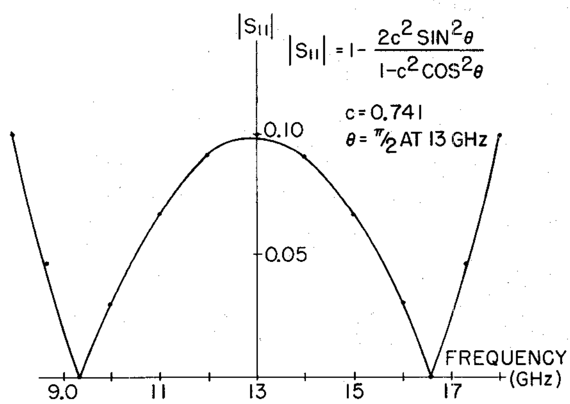


Figure 4. S_{11} Vs. Frequency Plot

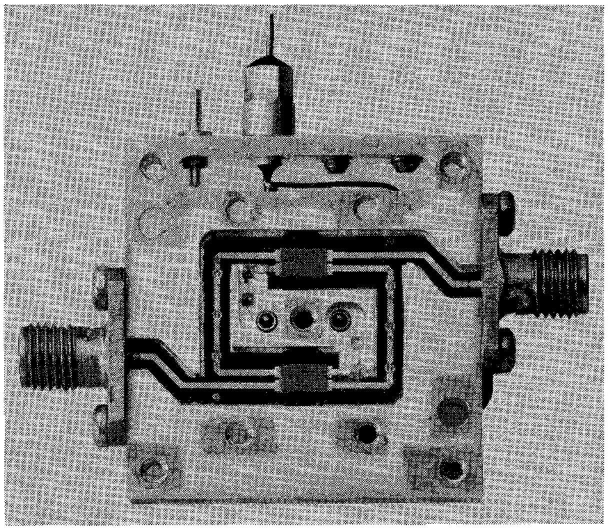
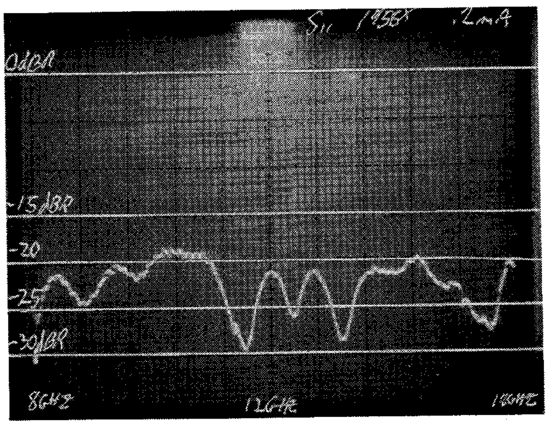
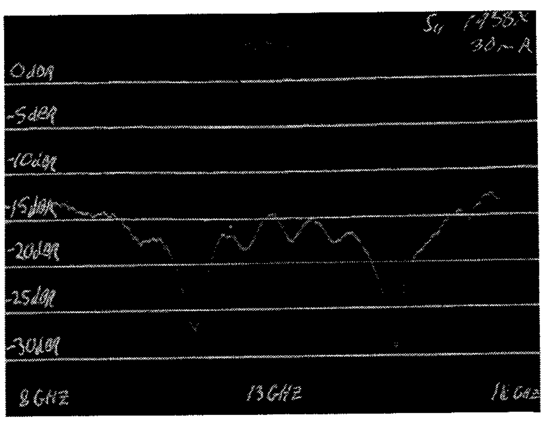


Figure 5. Model 1958 PIN Diode Modulator



a



b

Figure 6. $|S_{11}|$ Plots

metallic enclosure rather than in the assumed configuration of the infinite ground plane. In this case, the even-mode impedance is decreased while the odd-mode impedance remains substantially unchanged thus producing the undercoupled condition. In practice, this loading effect which amounts to about 6 percent, in the present case, is either directly taken into account in the original design, or corrected for after assembly by an appropriate decrease in the thickness of the top shield.

The insertion loss of the hybrid itself, based on measurements of numerous single and multiple hybrid structures, is estimated to be less than 0.25 dB for the 8-18 GHz band. This figure includes a finite directivity loss of between 0.05 and 0.1 dB as measured on a separate four-port device. The small difference of approximately 5 percent in the phase velocities of the odd and even modes makes this performance possible.

References

[1] S.B. Cohn and S.L. Wehn, "Microwave hybrid coupler study program," Second Quarterly Progress Report, Contract DA 36-2395c-87435, Rantec Corp., Calabasas, CA. (November 1961).

[2] J. Lange "Interdigitated stripline quadrature hybrid," IEEE Transactions Microwave Theory and Techniques, Vol. MTT-17, pp. 1150-1151, December 1969.

[3] G.L. Matthaei, L. Young, and E.M.T. Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-Hill Book Company, New York 1964.