TAPERED ASYMMETRIC MICROSTRIP MAGIC TEE

M. H. Arain
N. W. Spencer
Autonetics Group, Rockwell International
Anaheim, California 92803

Abstract

The design of a very compact decade (1 to 10 GHz) bandwidth, -8.34 dB microstrip coupler and magic tee is described. The coupling factor is calculated. The construction of the device is described and its feasibility demonstrated.

Introduction

This paper describes the design and development of an asymmetric broadband microstrip magic tee. Such devices are required for many microwave assemblies, including balanced mixers and monopulse bridge. Asymmetric tapered line magic tees are inherently broadband in nature.

The theory of these circuits has been described by Arndt[1] and Tresselt[2], while such a circuit in stripline configuration was developed by Du Hamel and Armstrong[3]. However, up to now it has been difficult to produce satisfactory circuits of this type in microstrip configuration, because of the following limitations. First, the planar structure of microstrip makes it difficult to obtain desired tight coupling. Secondly, inhomogenity restricts the directivity of such circuits to a rather low value. These limitations have made it difficult to produce microstrip hybrid circuits with wide bandwidth.

Now these difficulties have been overcome in the asymmetric microstrip tapered line magic tee described here. This device consists of two -8.34 dB coupler cascaded in tandem to form a -3 dB coupler. Reference lines added to each side of the device give a phase relationship of 180 and 0 deg at the output ports. Good directivity has been obtained by means of a top ground plane located above the circuit and separated from it by air.

Analysis of -8.34 dB Coupler

The asymmetric high pass-8.34 dB directional coupler is shown schematically in Figure 1. It consists of two transmission lines which are coupled nonuniformly along the coupling Section ℓ. The coupling factor k(z) changes continuously along the longitudinal direction Z. It is defined by even and odd mode impedances Zoe and Zoo respectively (Eq 1).

$$k(Z/\ell) = \frac{Zoe\ (Z/\ell) - Zoo\ (Z/\ell)}{Zoe\ (Z/\ell) + Zoo\ (Z/\ell)} \qquad (1)$$

It is assumed that the four ports of the coupler are terminated in a characteristic impedance Zo and that the relationship defined by Eq (2) holds along the coupling section.

$$Zoe\ (Z/\ell) \cdot Zoo\ (Z/\ell) = Z_o^2 \qquad (2)$$

The coupling factor k (Z/ℓ) and the low frequency cutoff $(\ell/\lambda)_c$ for the coupler are determined from Eqs (3) and (4).

$$\ell = (\ell/\lambda)_c \frac{\lambda_{omax}}{\sqrt{\epsilon_r}} \qquad (3)$$

$$k\ (Z/\ell) = \sum_{m=o}^{6} K_m\ (Z/\ell)^m \qquad (4)$$

where $\sqrt{\epsilon_r}$ is the relative permitivity of the dielectric. λ_{omax} and K_m are the free space wavelength and the coupling factor coefficient respectively. Each of these parameters, which can be determined from Arndt's Table[4] corresponds to a given mean coupling value and voltage ripple δ. From Arndts table for a -8.34 dB coupler corresponding to 0.5 percent voltage ripple, the low cut off frequency $(\ell/\lambda)_c$ is found to be 0.409 and the coupling factor coefficients are found to be 0.6687, -1.0507, -0.7719, 2.3164, -1.0692, -0.3929, and 0.3044. Then from (3) it will be seen that for a low end cut-off frequency of 1 GHz, the physical length of the coupling section is 2.05 in.

In doing the computation, the total physical length of the coupler is divided into 10 equal sections. The even and odd impedances that correspond to the previously determined k(Z) are determined from Eqs (1) and (2), and the physical circuit dimensions are determined using the computer program subroutine provided by Smith[5] for computation of even and odd mode fringing capacitances of coupled microstrip lines in suspended substrates.

The circuit was fabricated on a 0.025 in. thick alumina substrate with a top ground plane separated from the circuit by an air space of 0.025 in. The gap width tapers down from 0.070 in. at the loosely coupled end to 0.00018 in. at the tightly coupled end. The circuit was tested initially on an automatic network analyzer. Satisfactory results were obtained over a 5:1 frequency bandwidth.

In an additional analysis, the coupler was tested on a time domain reflectometer, which measures the coupling amplitude along the coupled lines. Coupling was observed beyond the actual coupled section. It is believed that this undesirable coupling was caused by the surface waves and the standing wave modes, which can occur in the rectangular package. To correct this undesirable condition the width of the circuit package was reduced from 1 to 0.15 in. by decreasing the length of the uncoupled transmission line. After this change had been made, the measurements were repeated and it was observed that the overall response of the coupler was improved. This directional coupler is shown in Figure 2 with the top cover removed. The coupling, isolation and the return loss of this directional coupler are shown in Figures 3, 4 and 5.

Magic Tee

The magic tee was constructed by cascading two -8.34 dB couplers in tandem and adding the phase reference lines on each side of the device in order to obtain the 180 or 0 deg phase relation at the output ports. To connect the two -8.34 dB couplers in tandem, the coupled lines are made to crossover at the tightly coupled region by bridging one line with gold ribbon. Notice that the coupled sections as well as the reference lines are separated by metal walls in order to reduce the undesired standing wave modes in the box.

The magic tee circuit finally designed for the 1 to 10 GHz frequency band is shown in Figure 6 with the top ground plane removed. The characteristics of this device, obtained experimentally, are shown in Figure 7 through 9. Figure 7 compares power at the two equal power output ports. The average power deviation is less than 0.5 dB over the 1 to 9 GHz frequency band. Figure 8 shows the isolation, which is greater than 15 dB upto a 9 GHz and greater than 10 dB over the rest of the frequency region. Finally, Figure 9 represents the phase deviation of the two equal phase and 180 deg out of phase output ports.

Conclusion

This work has demonstrated the feasibility of designing a decade wide magic tee, using microstrip and a top ground plane. The coupling factor k(z), which changes continuously along the length of the coupler, was calculated for this device using the coupling coefficient prepared by Fritz Arndt[1] for equal ripple high pass directional couplers. The line and gap widths were determined by using the computer subroutine of Smith[5]. The coupled sections and the reference lines were separated by metal walls in order to reduce the standing wave modes in the box.

Acknowledgment

The authors wish to thank F. A. Pizzarello and D. E. Stiegler for their efforts in fabricating the circuits.

References

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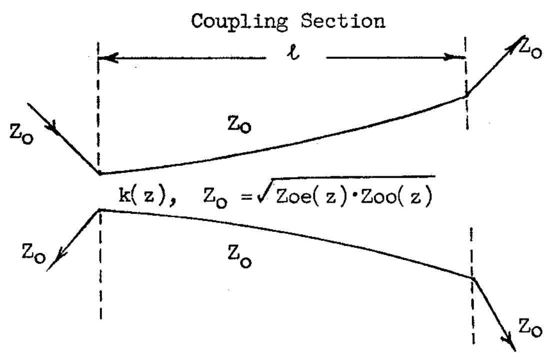

Figure 1. High-Pass Transmission Line Directional Coupler

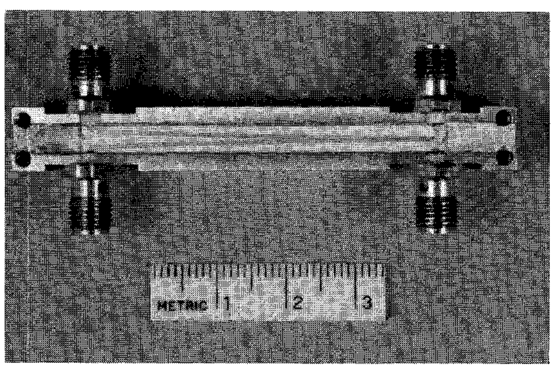

Figure 2. Tapered Asymmetric Directional Coupler

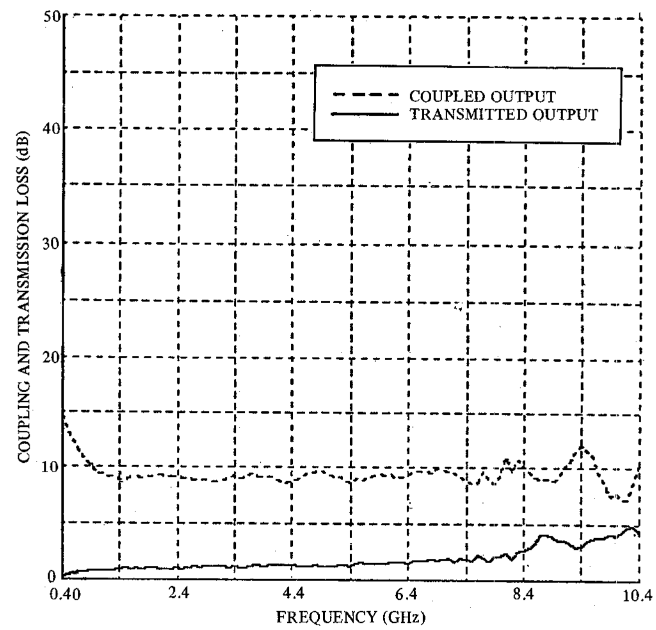

Figure 3. Coupling and Transmission Loss of -8.34 dB Coupler

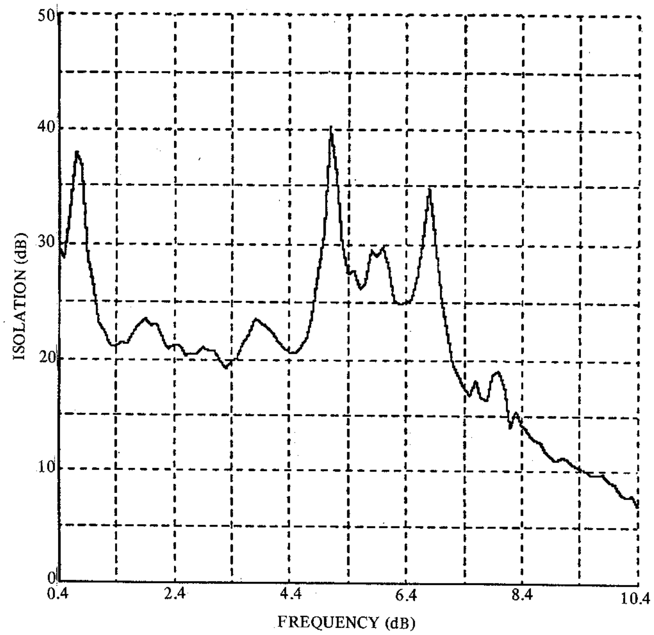

Figure 4. Isolation of -8.34 dB Coupler

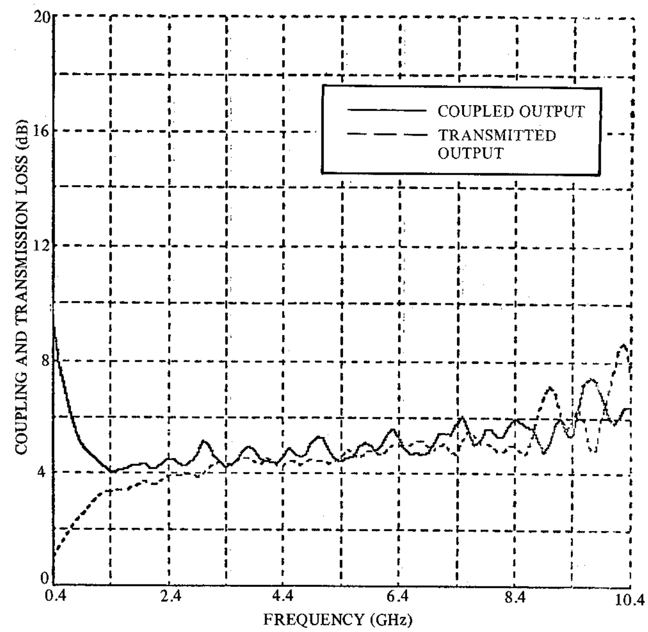

Figure 7. Coupling and Transmission Loss of Magic Tee

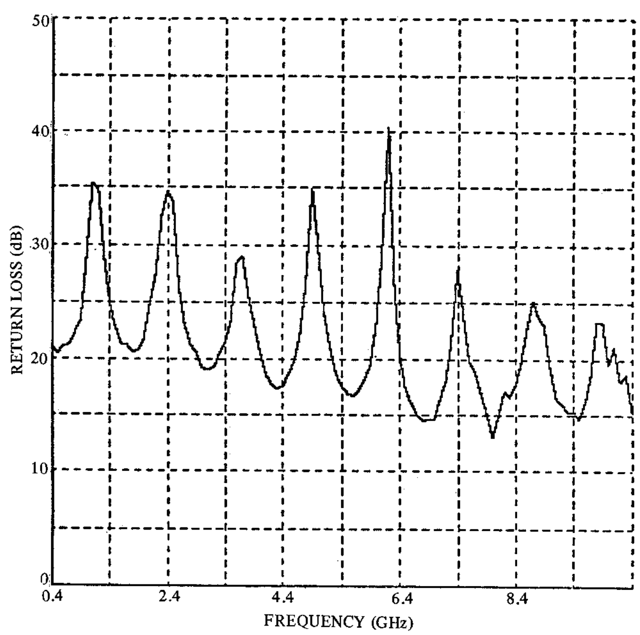

Figure 5. Return Loss of -8.34 dB Coupler

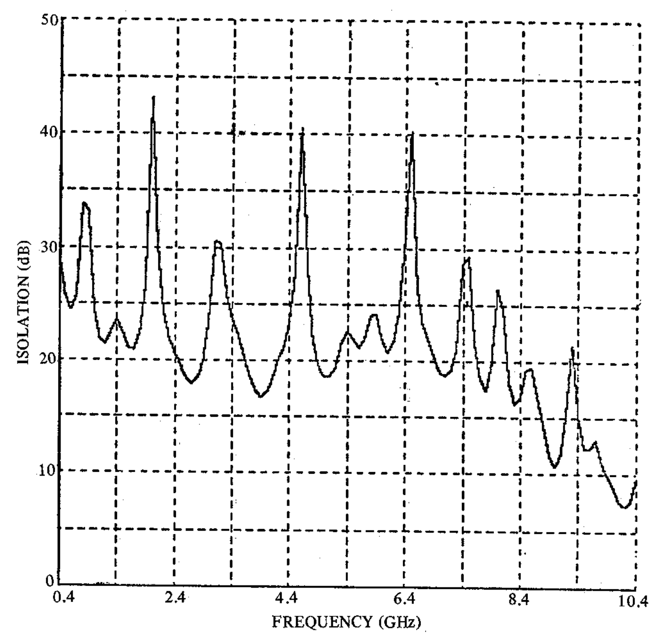

Figure 8. Isolation of Magic Tee

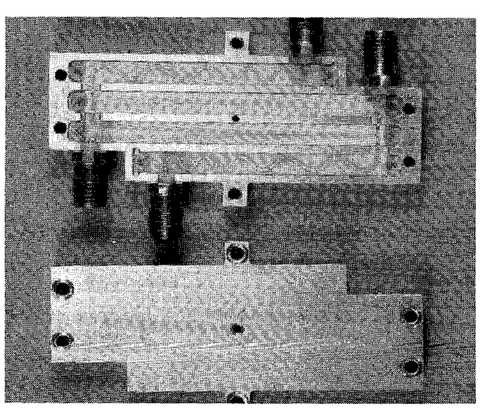

Figure 6. Tapered Asymmetric Magic Tee

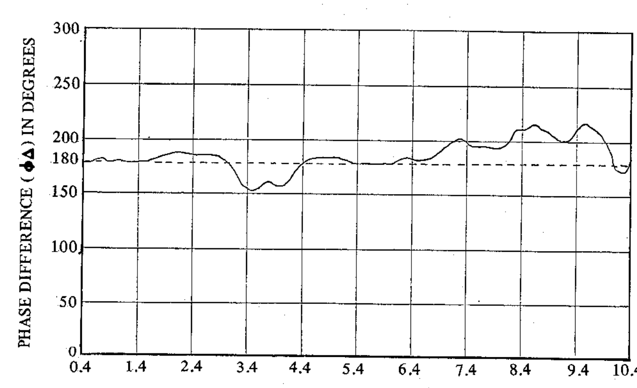

Figure 9. Phase Performance of Tapered Asymmetric Magic Tee