A NEW CLASS OF BRANCH-LINE DIRECTIONAL COUPLERS

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Abstract

The branch-line directional coupler consists of two parallel transmission lines connected by quarter wavelength shunt branches spaced one quarter wavelength apart. This paper describes a new class of branch-line directional couplers in which the shunt transmission line branches are replaced by shorted coupled transmission line pairs. The new circuit overcomes the limitations of the conventional circuit which may require for the shunt branches, unrealizable high impedance transmission line sections for loose coupling values and for some wideband multi-section designs.

Introduction

Directional couplers are widely used in microwave frequency applications such as power division and combining, phase shifters, sampling circuits, mixers and others. For microstrip applications, couplers that may be realized in planar form as a printed circuit are desirable. Among the structures commonly used is the branch-line coupler [1], [2]. This type of coupler is easily realizable in planer microstrip for tight coupling values (such as 3 dB) but its useful bandwidth is limited. The bandwidth may be increased by adding more branches but the impedance values of the outer branches become unrealizable for most microstrip designs. Also, loose coupling values (8 dB or higher) are impractical for most microstrip designs because of the high impedance values required for the shunt branches. Wideband coupling, for a large range of coupling values, may be achieved with quarter-wave coupled line couplers, [3] but for tight coupling values line widths and line spacings become extremely small and may not be practical for some microstrip designs. Loose coupling is easily obtained with coupled line structures but because of unequal phase velocities for the even and odd modes, the coupler directivity is significantly degraded and may not be acceptable for many applications. A new class of Branch-line directional couplers, which is described in the sections to follow, overcomes some of the above limitations and can be designed for a wide range of coupling values with high directivity over moderately wide bandwidths.

The Conventional Branch Line Coupler

The conventional branch line coupler circuit is shown in Figure 1. It consists of a main transmission line which is coupled to a secondary line by two quarter wavelength transmission line sections spaced one quarter wavelength apart. A signal applied at port 1 is ideally coupled to port 2 (thru port) and port 4 (coupled port) and uncoupled at port 3 (isolated port). the coupling is determined by the impedances of the shunt and series branches which must satisfy the conditions below. For a matched directional coupler, the normalized impedance relationships are as follows:

$$Z_m = \frac{Z_B}{\sqrt{1+Z_B^2}} \tag{1}$$

where

$$Z_B = \frac{E_2}{E_4} \tag{2}$$

For most coupling values, the coupler directivity is better than 20 dB over a 10% bandwidth and the coupling variation is less than 0.25 dB over that band. For wider bandwidths, additional branches may be added as shown in figure 2.

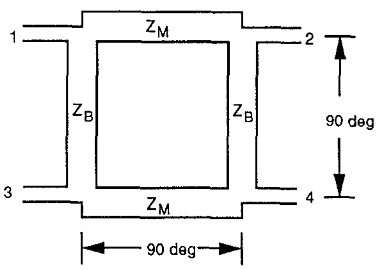

Figure 1. Conventional Branch-line Coupler

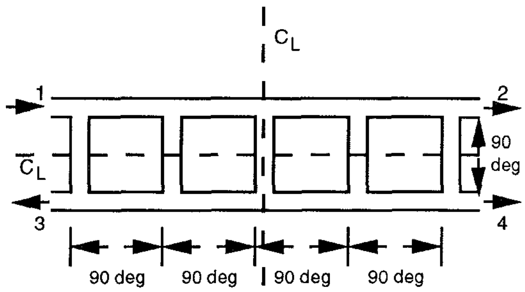

Figure 2. Multi-section Branch-line Coupler.

The New Class of Branch-Line Couplers

The circuit described herein is one of a new class of branch-line couplers in which the shunt branches are replaced by coupled transmission line pairs one quarter wavelength long which are shorted to ground at the ends as shown in figure 3. The shorted coupled line pair can be made electrically equivalent to the original shunt branches by properly selecting the even and odd mode impedances (admittances) of the coupled line pair. Figure 4 shows the equivalent circuit of the shorted coupled line pair [4]. At the design center frequency, the shorted stubs are 90° long and appear as open circuits shunting the transmission line, thus the circuit reduces to a simple 90° section of transmission line of normalized characteristic admittance equal to

$$Yo = \frac{Yoo - Yoe}{2} \qquad (3)$$

where Yoo and Yoe are the normalized odd and even mode admittances of the coupled line pair. By choosing Yoe as low as possible, the circuit can be made to approximate a single section of transmission line over a moderately wide frequency band.

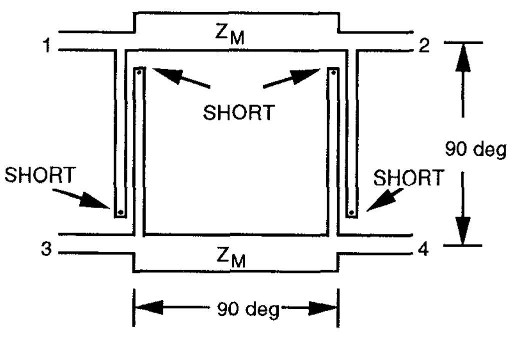

Figure 3. A New Branch-line Coupler.

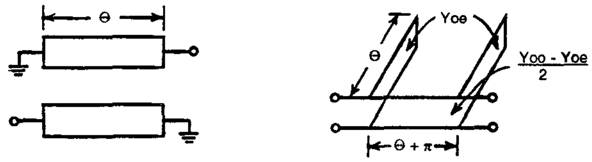

Figure 4. Shorted Coupled Line Pair and Equivalent Circuit.

The practical range of realizable characteristic impedances for the transmission line equivalent of the shorted coupled line pair is determined by the substrate thickness, dielectric constant and practical limits for line widths and spacings. High impedances (with virtually no upper limit) are easier to realize than low impedances. Low impedance sections require very tightly spaced lines which are limited by etching capabilities. For coupled lines spaced 1 mil on a 25 mil substrate, the low impedance limit is about 115-120 ohms for a dielectric constant of 2.0. These values are suitable for loose coupling values of about 8 dB or greater for a 50 ohm coupler. A dielectric constant of 10 allows for low impedance values of about 70 ohms minimum which are suitable for loose couplings or tight couplings (3 dB) in a higher than 50 ohm system of about 60 ohms. Using a dielectric constant of 16, both loose coupling and tight coupling (3 dB) for 50 ohm couplers are achievable.

Comparison to Conventional Circuits

Figures 5 and 6 show the computed responses for a conventional 20 dB coupler and a design from the new class of branch-line couplers respectively. The conventional circuit requires a shunt arm impedance of 500 ohms which is not realizable for a practical microstrip design. The series arm impedance is 49.97 ohms. The computed isolation is greater than 40 dB over the normalized frequency range from 0.94 to 1.06 (12% bandwidth) and greater than 35 dB from 0.9 to 1.10 (20%). The directivity (the ratio of the energy at the coupled port to the energy of the isolated port) is greater than 20 dB and 15 dB over the 12% and 20% bands respectively. In the new design, the 500 ohm shunt arm transmission line sections are replaced by shorted coupled line pairs whose even and odd mode impedances are 100 ohms and 71 ohms respectively. This design achieves a directivity of 20 dB over an 8% bandwidth and a 15 dB bandwidth of 14%. The return loss over the 14% bandwidth is better than -40 dB. Although the bandwidth of the design from the new class of couplers is slightly narrower than that of the conventional design, the new design is realizable for most microstrip circuits. For the example chosen, a microstrip circuit on a 0.025 inch alumina substrate is easily realized with a pair of coupled lines 0.005 inches wide spaced 0.024 inches apart.

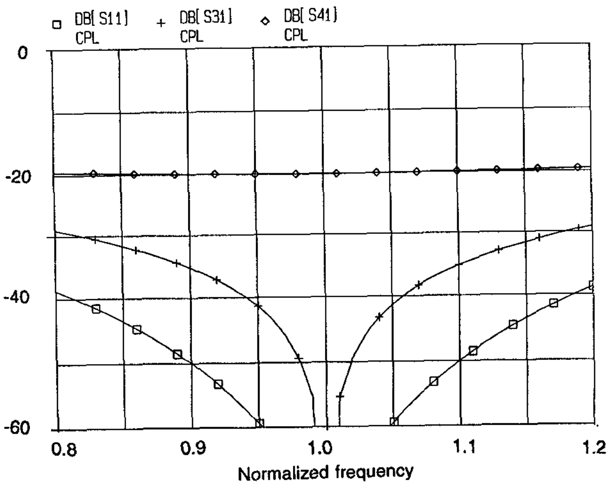

Figure 5. Responses of a Conventional 20 dB Branch-Line Coupler.

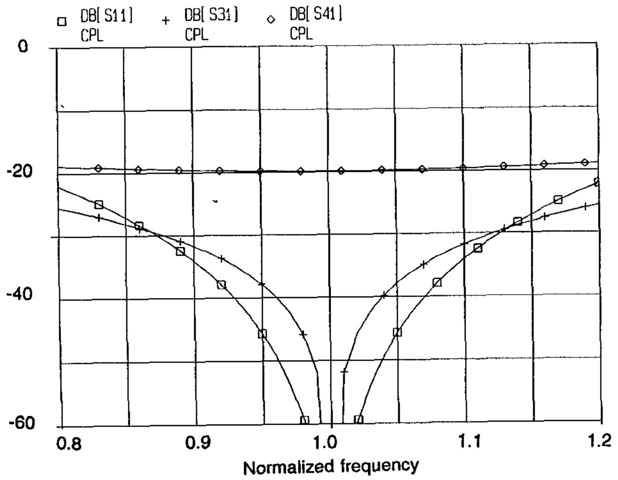

Figure 6. Responses of A New 20 dB Branch-Line Coupler

Figure 7 shows a circuit for a conventional multisection (4 branches) wideband tight coupling design. This design requires shunt arm impedances of 255 ohms and 65 ohms for the outer and inner branches respectively. The 255 ohm shunt arm impedance for the outer branches is not realizable for a practical microstrip design. A coupler design from the new class of couplers can be made to achieve comparable performance to the conventional circuit with a set of shorted coupled line pairs in the shunt branches with even and odd mode impedances of 100 ohms and 56 ohms respectively for the outer branches and 100 ohms and 25 ohms respectively for the inner branches.

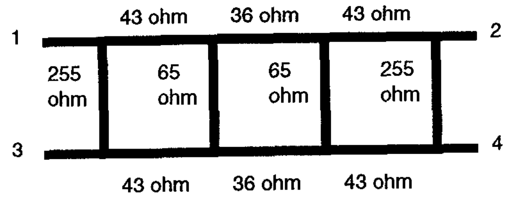

Figure 7. Conventional Multi-Section 3 dB Branch-line Coupler

Figure 8 and 9 show the computed responses the conventional and new designs respectively. The conventional design achieves better than 30 dB of isolation and return loss over the frequency range of 0.84 to 1.16 (32%) with the power split of 3 dB ±0.25 dB. The new design achieves the same 30 dB bandwidth (32%) with a power split of 3 dB ± 0.30 dB over that band. The 20 dB isolation bandwidth is slightly narrower at about 40%.

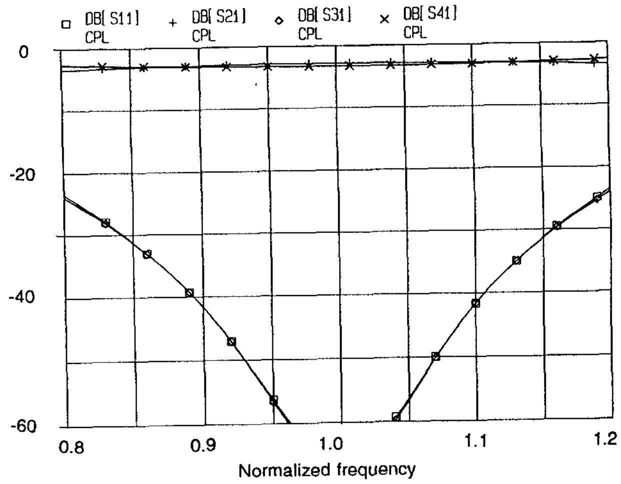

Figure 8. Responses of Conventional Multisection 3 dB Coupler.

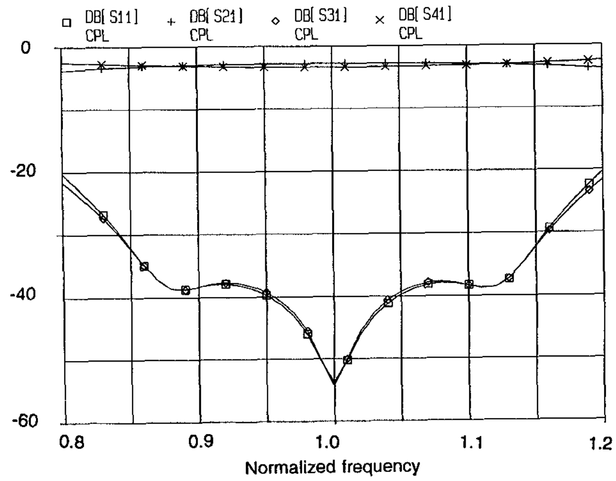

Figure 9. Responses of A New Multi-Section 3 dB Coupler.

Experimental Results

To confirm the performance of a design from the new class of branch-line couplers a 20 db microstrip coupler was built and tested. The circuit was designed for 0.025 inch alumina substrate that operates at a nominal center frequency of 2.0 GHz. The dimensions of the coupled line sections are 0.005 inch line widths spaced 0.024 inches apart. A photograph of the test coupler is shown in figure 10. Measurements were taken with a HP8510 network analyzer over the frequency band from 1.6 GHz to 2.4 GHz. The results are shown in figures 11 and 12. The isolation is greater than 40 dB over a 0.16 GHz bandwidth (8%) and greater than 25 dB over a 0.28 GHz bandwidth (14%). The coupling measured 20.3 dB at the center of the band and to within less than 0.3 dB over the 14% bandwidth. The measured performance agrees very closely to the predicted responses. The return loss measured better than 30 dB over the 14% bandwidth.

Figure 10. 20 dB Test Coupler.

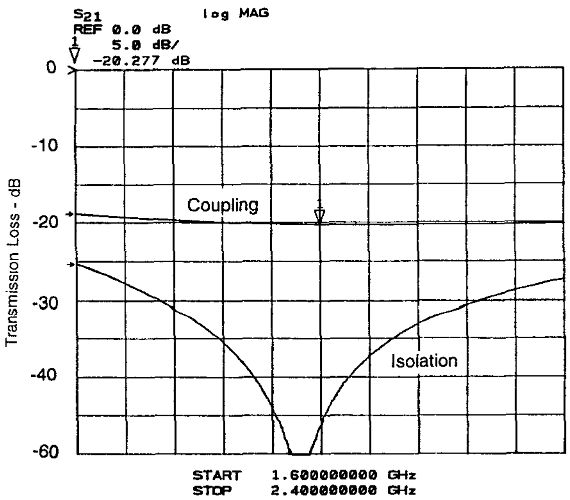

Figure 11. Measured Coupling and Isolation of 20 dB Test Coupler.

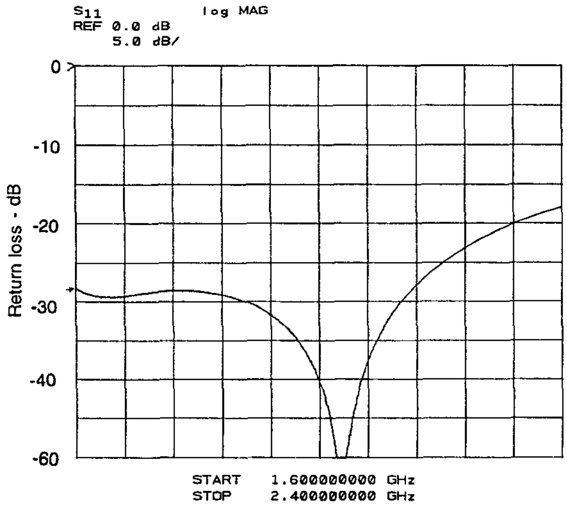

Figure 12. Measured Return Loss of 20 dB Test Coupler.

Summary and Conclusions

A new class of branch-line coupler is presented in which the shunt transmission line branches of the conventional coupler are replaced by shorted coupled transmission line pairs. The new class of couplers allows for the realization of a wider range of designs for both loose coupling and wideband tight coupling values than the conventional coupler. The performance of couplers from the new class is comparable to the performance of conventional couplers with only a slight decrease in bandwidth for most designs. Experimental results of a 20 dB microstrip test coupler show measured performance very close to predicted performance.

References

[1] C.G. Montgomery, R.H. Dicke, and E.M. Purcell, "Principles of Microwave Circuits", McGraw Hill, New York, 1948.

[2] R. Levy and L.F. Lind, "Synthesis of Symmetrical Branch-Guide Directional Couplers", IEEE Trans. Microwave Theory and Techniques vol. MTT-16, No. 2 February 1968, pp 80-89.

[3] Shimizu and Jones, "Coupled-Transmission-line Directional Couplers" IEEE Trans. Microwave Theory and Techniques Vol. MTT-6, NO. 4, October 1958 pp. 403-410.

[4] Matthaei, Young and Jones, "Microwave Filters, Impedance Matching Networks, and Coupling Structures", McGraw Hill, New York, pp 217-229.