A NOVEL BRANCH-LINE COUPLER DESIGN FOR MILLIMETER-WAVE APPLICATIONS

Paul Meaney

Alpha Industries,Inc. TRG Millimeter Wave Division
651 Lowell Street; Methuen, MA 01844

Abstract

By taking advantage of the odd function nature of the branch line coupler to increase its series line length to 3/4 wavelength, it is possible to make a microstrip three-branch coupler that works over a full millimeter waveguide band. This design also uses orthogonal inputs and minimizes discontinuities to improve the input match.

Introduction

The 3dB directional coupler is an important element in many millimeter-wave components (Figure 1a)[1]. It has applications in many important areas such as balanced mixers, amplifiers, PIN switches, detectors and patch antennas. In balanced mixers it can provide the proper orientations for the RF and LO inputs to give the proper mixing conditions.[2] With amplifiers, the microstrip 3 dB directional coupler can be used in a zero-degree crossover configuration to provide better input and output matches, and raise the 1 dB compression point of the amplifier. In the same way it can improve the input and output matches, and the power handling capability of the PIN switches. With balanced detectors it can improve the input match and the detector sensitivity. In the area of patch antennas, the microstrip 3 dB directional coupler can be used in monopulse comparators[3] and with circularly polarized antennas. Producing all of these components in microstrip can reduce the overall size, weight and cost, while maintaining highly reproducible components.

Microstrip is an excellent transmission medium for all the reasons mentioned above. However, it does have its restrictions. One of those is realizing a characteristic impedance outside the range of 25 Ω to 140Ω when working with 10 mil Duroid 5880®. Another problem which arises at millimeter wave frequencies is the shrinking aspect ratios of the quarter-wavelength lines. As the quarter wavelength dimensions shrink at higher frequencies, the lengths of the lines can actually get shorter than the widths. This has a direct effect on the input match, bandwidth and isolation of the coupler.

Other problems which arise with the branch-line couplers, are the mutual coupling between the input lines and discontinuities at the inputs. As the quarter wavelengths get shorter, and the input lines come closer together; consequently the mutual coupling of the input lines increases. This has a detrimental effect on the coupler's performance. At high frequencies the discontinuities become more pronounced, and also restrict the coupler's performance.

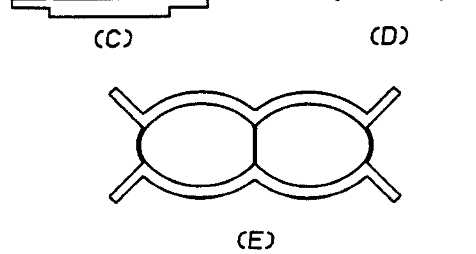

Figure 1. Various 90 Degree Branch-Line Couplers.

CH2848-0/90/0000-0585$01.00 © 1990 IEEE

1990 IEEE MTT-S Digest

Many attempts have been made to improve the isolation and return loss over broad bandwidths of the branch line couplers. Several of these involve adding extra branch-line sections to improve the bandwidth (Figure 1b).[4,5,6] These run into physical limitations because of the very high impedances needed in the branch sections. Even these techniques do not work at millimeter-wave frequencies because of the small aspect ratios. One design overcame this problem, by using three-quarter wavelength sections in the hybrid (Figure 1c).[7] This worked well, but over a limited bandwidth. Others tried to overcome the mutual coupling of the input lines. One design had the input lines at 90° to each other and the branch-line coupler in the shape of a circle.[4] This is very similar to how the rat-race hybrid's input lines are implemented (Figure 1d). Input matching stubs can also be used to improve the input match.

Design

This new design uses all of these existing ideas to form a new branch-line coupler (Figure 1e). This coupler has all its inputs at orthogonal to each other. It has also eliminated most discontinuities on the hybrid. These two factors act to improve the input match. It uses a three-branch coupler to take advantage of the broad-banding effect of extra branch-lines. Where it is really different is that it uses three-quarter wavelength lines for the series lines and quarter wavelength lines for the shunt lines. In terms of a Fourier Series, the series lengths are odd functions. This means that these lengths can be any odd multiple of a quarter-wavelength to give the required conditions for coupling. Using an even number of quarter wavelengths would not work here. The disadvantage of using the longer lengths is the narrowing of the usable bandwidth. The shunt lines are also odd functions, but because of their narrow line widths, they do not need to be lengthened to improve their aspect ratios. The series lengths are much lower in impedance and consequently have much wider widths. This is where the longer lengths are needed to create reasonable aspect ratios. The usable bandwidth is reduced by using the longer line lengths; but what is lost due to the longer lengths, is compensated by having realizable aspect ratios.

Experimental Results

A branch-line coupler using the above design techniques and CAD software to get the desired linelengths was designed for use at Ka-Band. The hybrid was printed on the same Duroid 5880® substrate as the transition to waveguide to minimize and input discontinuities. The substrate used was a piece of 10 mil Duroid 5880®. In the optimization of this circuit, certain design criterion were used: 1) Good return loss, 2) High isolation, and 3) Equal coupling across the widest possible band. The numbers from the computer model accomplish just this as can be seen in Figures 2, 3 and 4. The return loss is 10dB or better over 90% of the band and the isolation is 10dB or better over the whole band. The difference in the coupling of the two coupled parts is fairly small (1dB or better) over about 75% of the band, and never gets worse than 2dB over the full board.

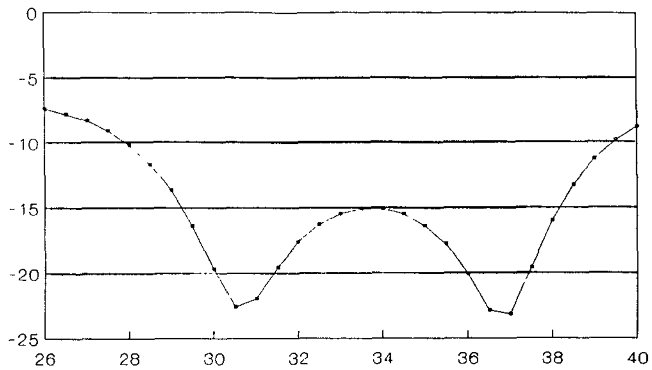

Figure 2. Return Loss of 90 Degree Branch-Line Coupler (Computer Model).

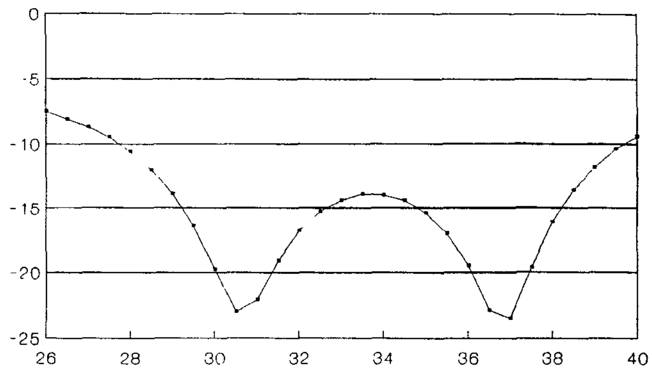

Figure 3. Isolation of 90 Degree Branch-Line Coupler (Computer Model).

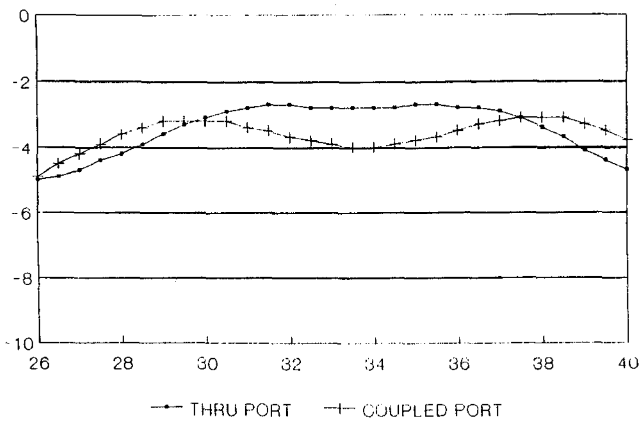

Figure 4. Insertion Loss of Thru and Coupled Ports (Computer Model).

Figure 5 shows the actual circuit with the four antipodal finline transitions at each input. As can be seen in Figures 6, 7 and 8, the actual results agree quite well with the numbers from the computer model; the only major difference being that the actual circuit was tuned a little low in frequency. Figure 6 shows good return loss across the band; figure 7 shows good isolation across the band; and Figure 8 shows fairly equal coupling across the band. The coupling levels degrade slightly at the high end, mostly because the circuit was designed a little low in frequency. Except for the circuit being tuned a little low, this means that the actual impedances and line lengths correlate very well with those predicted by the computer model.

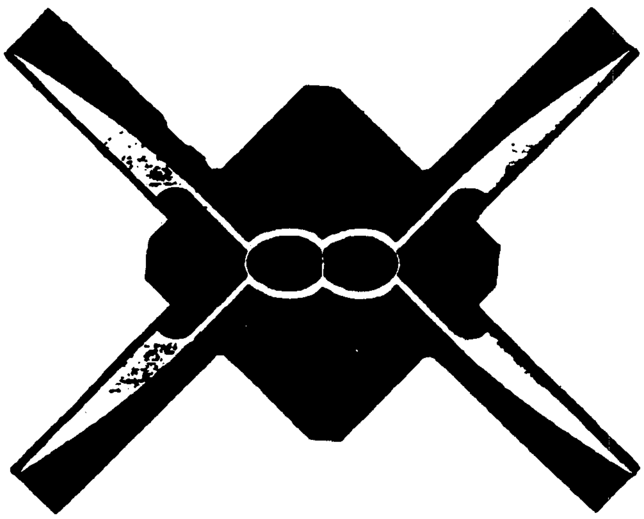

Figure 5. Picture of 90 Degree Branch-Line Coupler with Antipodal Finline to Microstrip Transition at each of the four input ports.

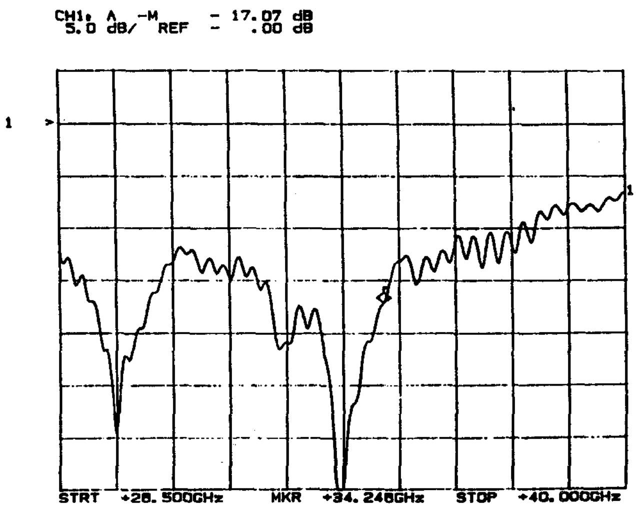

Figure 6. Return Loss of 90 Degree Branchline Coupler (Actual Measurement).

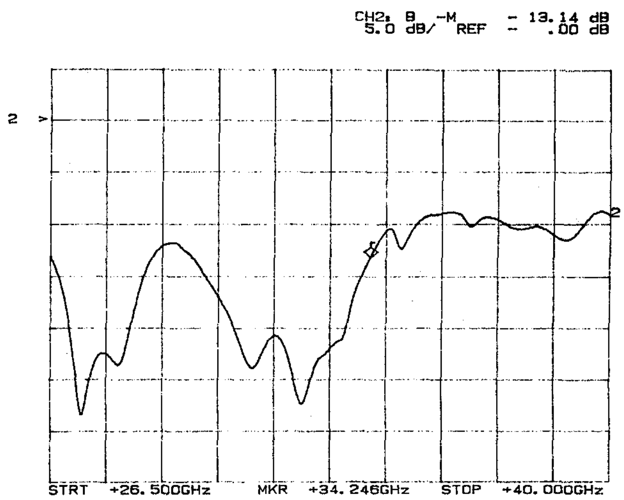

Figure 7. Isolation of 90 Degree Branch-Line Coupler (Actual Measurement).

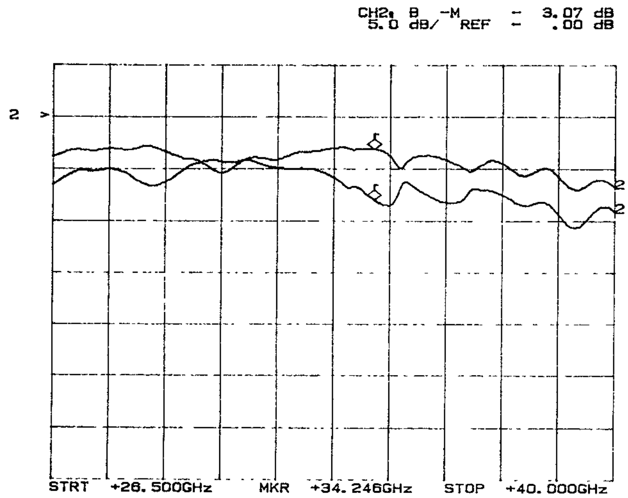

Figure 8. Insertion Loss of Thru and Coupled Ports (Actual Measurement).

Conclusion

A three branch-line coupler with three-quarter wavelength series lengths has been designed to work from 26.5 to 40 GHz. It takes advantage of the odd mode nature of the series lines to increase the line lengths. What is lost in bandwidth because of the 3/4 wavelength series lines is acceptable because of what is gained by having higher aspect ratios and by using a three branch-line coupler design. These same design rules will scale well to designs all the way up to W-Band.

REFERENCES

1. C.G. Montgomery, R.H. Dicke, and E.M. Purcell, "Principle of Microwave Circuits". New York: McGraw Hill, 1948.
2. Bernd Adelseck et al., "A Monolithic 60 GHz Diode Mixer and IF Amplifier in Compatible Technology", IEEE Trans. Microwave Theory and Tech., Vol. MTT-37, No. 12, December, 1989, pp. 2142-2147.
3. Charles M. Jackson and Jeffrey Newman, "Low Cost, Ka-Band Microstrip Patch Monopulse Antenna", Microwave Journal, Vol. 30, No. 7, July 1987, pp. 125-131.
4. R. Levy and L.F. Lind, "Synthesis of Symmetrical Branch-guide Directional Couplers", IEEE Trans. Microwave Theory and Tech. Vol. MTT-16, No. 2, Feb. 1968, pp. 80-89.
5. David Rubin, "Millimeter-wave Hybrid Coupled Reflection Amplifiers and Multiplexers", IEEE Trans. Microwave Theory and Tech., Vol. MTT-30, No. 12, Dec. 1982, pp. 2156-2162.
6. Masahiro Muraguchi et al., "Optimum Design at 3 dB Branch-Line Couplers using Microstrip Lines", IEEE Trans. Microwave Theory and Tech., Vol. MTT-31, No. 8, August 1983, pp. 674-678.
7. T. H. Oxley, and D. A. Williams, "Millimeter-Wave Hybrid Microstrip Subsystems", IEEE Trans. Microwave Theory and Tech., Vol. MTT-33, No.12, Dec. 1985, pp. 1542-1546.