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A COMPACT PLANAR MICROSTRIP-SLOTLINE SYMMETRICAL JUNCTION COMPARATOR CIRCUIT

G. P. Riblet

Microwave Development Laboratories, Inc.
11 Michigan Drive
Natick,MA 01760 U.S.A.

ABSTRACT

In this paper it is shown that the common 8 port comparator circuit may be constructed as a fully symmetrical junction device. As an example a planar symmetrical comparator circuit which makes use of microstrip and slotline transmission lines is described. Its diameter may be a wavelength or less at mid-band.

INTRODUCTION

Some common microwave components can be constructed as symmetrical junction devices. A good example is the waveguide junction circulator. On the other hand the waveguide differential phase shift circulator is not a junction device. In this contribution it is shown that the 8 port comparator may also be constructed as a fully symmetrical circuit. Two examples of symmetrical comparator circuits are given in the paper. The most common use of the comparator circuit is to determine the azimuth and elevation of a target. This circuit is most frequently constructed using four 180^0 hybrids.

THE SYMMETRICAL 8 PORT

A schematic diagram of the 8 port circuit is given in figure 1. The solid lines represent microstrip lines on the top of the circuit board. The dashed lines represent slotlines in the ground plane on the bottom of the circuit board. The circuit of figure 1 is symmetrical under reflection R_X in the XZ plane, under reflection R_Y in the YZ plane and under the reflection R_Z which interchanges ports 1 and 2, 3 and 4, 5 and 6, 7 and 8. Using these symmetry operators, it may be shown that the scattering matrix S has the form

$$S=\begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} & S_{17} & S_{18} \\ S_{12} & S_{11} & S_{14} & S_{13} & S_{16} & S_{15} & S_{18} & S_{17} \\ S_{13} & S_{14} & S_{11} & S_{12} & S_{17} & S_{18} & S_{15} & S_{16} \\ S_{14} & S_{13} & S_{12} & S_{11} & S_{18} & S_{17} & S_{16} & S_{15} \\ S_{15} & S_{16} & S_{17} & S_{18} & S_{11} & S_{12} & S_{13} & S_{14} \\ S_{16} & S_{15} & S_{18} & S_{17} & S_{12} & S_{11} & S_{14} & S_{13} \\ S_{17} & S_{18} & S_{15} & S_{16} & S_{13} & S_{14} & S_{11} & S_{12} \\ S_{18} & S_{17} & S_{16} & S_{15} & S_{14} & S_{13} & S_{12} & S_{11} \end{pmatrix} . \quad (1)$$

There are only 8 independent S matrix entries $S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17}$ and S_{18}.

For this symmetrical matrix linear S matrix element - S matrix eigenvalue relations can be derived once the S matrix eigenvectors are known. It can be shown that the constant 8 x 8 matrix A consisting of the orthogonal eigenvectors is

$$A=\frac{1}{2\sqrt{2}}\begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{pmatrix} . \quad (2)$$

The linear S matrix element - S matrix eigenvalue relations may now be derived using the expression [1]

$$S = A \cdot S_d \cdot A \quad (3)$$

where S_d is the diagonal matrix consisting of the 8 S matrix eigenvalues S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8. For a lossless device such as that of figure 1 these eigenvalues must have unit amplitude. This is because they are the reflection coefficients of the reactive terminations of each of the eigenexcitations. The linear S matrix element - S matrix eigenvalue relations which follow from (3) are

$$\begin{aligned} 8S_{11} &= S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8 \\ 8S_{12} &= S_1 + S_2 + S_3 + S_4 - S_5 - S_6 - S_7 - S_8 \\ 8S_{13} &= S_1 + S_2 - S_3 - S_4 + S_5 + S_6 - S_7 - S_8 \\ 8S_{14} &= S_1 + S_2 - S_3 - S_4 - S_5 - S_6 + S_7 + S_8 \\ 8S_{15} &= S_1 - S_2 + S_3 - S_4 + S_5 - S_6 + S_7 - S_8 \\ 8S_{16} &= S_1 - S_2 + S_3 - S_4 - S_5 + S_6 - S_7 + S_8 \\ 8S_{17} &= S_1 - S_2 - S_3 + S_4 + S_5 - S_6 - S_7 + S_8 \\ 8S_{18} &= S_1 - S_2 - S_3 + S_4 - S_5 + S_6 + S_7 - S_8 . \end{aligned} \quad (4)$$

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THE MICROSTRIP-SLOTLINE PLANAR JUNCTION COMPARATOR

The coupling properties of this circuit can be determined from equations (4) if the eigenreflection coefficients S_i (i=1, 2, 3, 4, 5, 6, 7, and 8) or eigenadmittances Y_i are known. The eigenadmittances Y_1, Y_2, Y_3, Y_4, Y_5, Y_6, Y_7 and Y_8 can be found by placing open circuits and short circuits along the x and y symmetry axes and around the middle of the ring in the 8 possible combinations. Let Y_m be half the characteristic admittance of the microstrip lines and Y_s be twice the characteristic admittance of the connecting slotlines. Furthermore, let B be the susceptance at the input due to the four slotline sections that are terminated in short circuits. Define $T = \tan\theta$ where θ is the electrical length from port 1 or 2 on the ring to either the x or y axis. It may be shown then that

$$Y_1 = Y_m \cdot T \;;\; Y_2 = -Y_m/T \;;\; Y_3 = Y_m \cdot T \;;\; Y_4 = -Y_m/T$$

$$Y_5 = -Y_s/T + B \;;\quad Y_6 = Y_s T + B \;;$$

$$Y_7 = Y_s T + B \;;\quad Y_8 = -Y_s/T + B.$$

Note that $Y_3 = Y_1$, $Y_4 = Y_2$, $Y_8 = Y_5$, and $Y_7 = Y_6$ so that $S_3 = S_1$, $S_4 = S_2$, $S_8 = S_5$, and $S_7 = S_6$. Equations (4) can then be rewritten as

$$\begin{aligned} 4S_{11} &= S_1 + S_2 + S_5 + S_6 \\ 4S_{12} &= S_1 + S_2 - S_5 - S_6 \\ S_{14} &= S_{13} = 0 \\ 4S_{15} &= 4S_{16} = S_1 - S_2 \\ 4S_{17} &= S_5 - S_6 \\ 4S_{18} &= -S_5 + S_6 \;. \end{aligned} \quad (5)$$

At the center frequency the short circuited slotline stubs will be a quarter wavelength long so that B=0. Furthermore if $Y_m = Y_s$, then at the center frequency $Y_6 = Y_1$ and $Y_5 = Y_2$. Consequently, $S_6 = S_1$ and $S_5 = S_2$. Equations(5) further simplify to

$$\begin{aligned} 2S_{11} &= S_1 + S_2 \\ S_{12} &= S_{13} = S_{14} = 0 \\ 4S_{15} &= 4S_{16} = 4S_{18} = -4S_{17} = S_1 - S_2 \;. \end{aligned} \quad (6)$$

If $Y_m = Y_s = 1$ corresponding to the 25Ω microstrip line and 100Ω slotline in figure 1, then $S_2 = -S_1$. At a reference plane where $S_2 = 1$ the S matrix at the center frequency becomes

$$S = \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 1 & -1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & -1 \\ 0 & 0 & 0 & 0 & -1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & -1 & 0 & 0 & 0 & 0 \\ -1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 1 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (7)$$

Like the 8 port comparator circuit, this circuit has two sets of 4 matched mutually isolated ports with equal power division from the other set of four ports. However, the phases aren't the same. For the comparator circuit the S matrix S_c is given by

$$S_c = \frac{1}{2}\begin{pmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 \\ 0 & 0 & 0 & 0 & 1 & -1 & +1 & -1 \\ 0 & 0 & 0 & 0 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (8)$$

Port 1 is the sum port while ports 2, 3 and 4 are difference ports. However, the above matrix S may be converted to that of the comparator circuit S_c given by equation (8) by including a 180^0 phase shifter at both ports 3 and 7.

In figure 1 the susceptance B of a short circuited slotline stub is zero when it is a quarter wavelength long. If pairs of stubs are separated by three quarters of a wavelength as in the figure, then their reflections will tend to cancel at mid-band. In this way a bandwidth of about 35% for 20 dB isolation can be obtained. The circumference of the ring will be three wavelengths at the center frequency. This circumference may be made arbitrarily small for a constant center frequency by resonating the four short circuited slotline stubs with capacitors of capacitance C across the slotlines as in figure 2. A particularly interesting case occurs when the diameter is a wavelength. Then two resonators will be separated by a quarter wavelength and their reflections will again tend to cancel each other. The size of this planar junction comparator will be the same as that of the ring 180^0 hybrid(2) four of which may be used to construct a comparator.

EXPERIMENTAL MODEL

An experimental version of figure 1 has been built and tested. The circuit board was 1/32 of an inch thick with a dielectric constant ε = 2.22. The design center frequency was about 4 GHZ. Microstrip impedances were calculated using standard formulas. Slotline impedances were calculated using formulas given in reference 3. Figure 3 gives the measured return loss, isolation (1-2), isolation (1-3), coupling (1-5), and coupling (1-7) from D.C. to 6 GHZ. In agreement with equations 5, the isolation to port 3 is high (>30dB) over the entire frequency range. The coupling to port 5 is very flat and slightly more than 6 dB. This is not too surprising since from equations 5 flat coupling to this port depends only on an accurate 25 Ω microstrip impedance. For the same reason the measured return loss and isolation (1-2) are very nearly the same. Figure 4 gives theoretical isolation (1-2) and theoretical coupling (1-7) over this frequency range assuming a center frequency of 4.5 GHZ. The theoretical and experimental curves agree very well if the slotline stub impedance is assumed to be 77 Ω's corresponding to a normalized admittance of Y=1.3. In this preliminary version there appears to be more than 1 dB additional insertion loss in the slotlines then in the microstrip lines.

REFERENCES

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

[2] W.V.Tyminski and A.E.Hylas, "A Wide-Band Hybrid Ring for U.H.F.," Proceedings IRE, Vol. 41, pp.81-87, January 1953.

[3] R. Janaswamy and D. H. Schaubert, "Characteristic Impedance of a Wide Slotline on Low-Permittivity Substrates," IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-34, pp.900-902,August 1986.

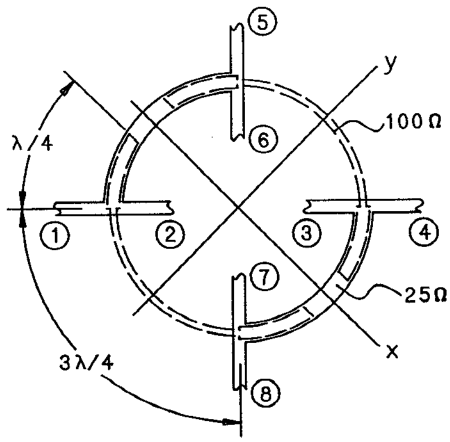


Figure 1 Symmetrical planar 8 port junction comparator circuit using a microstrip-slotline technique.

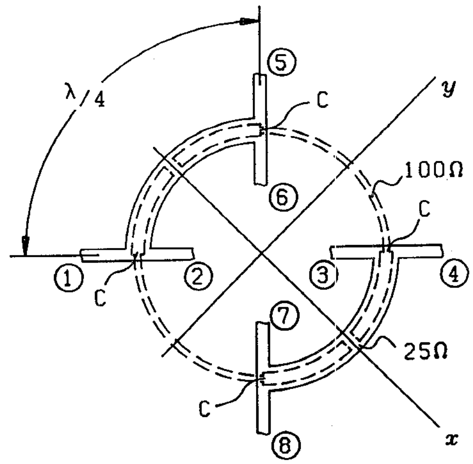
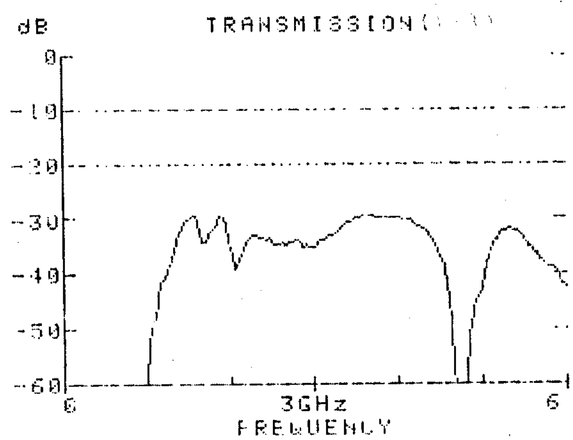
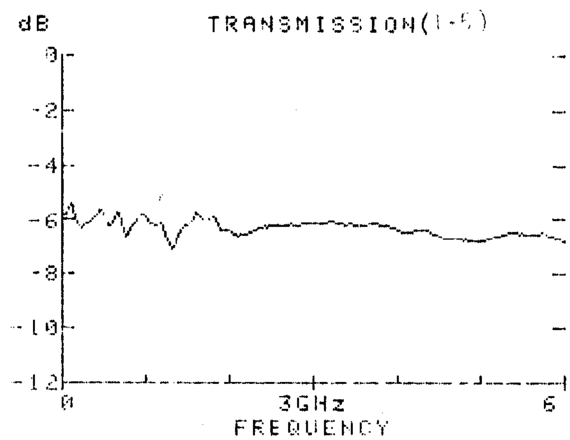
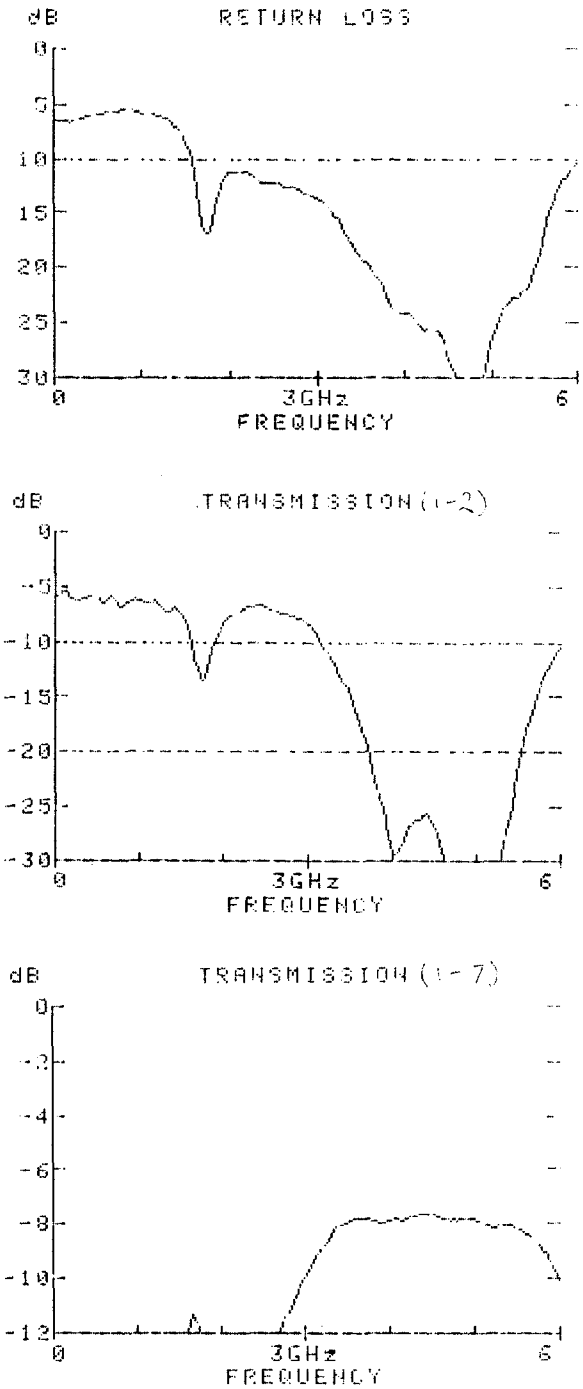


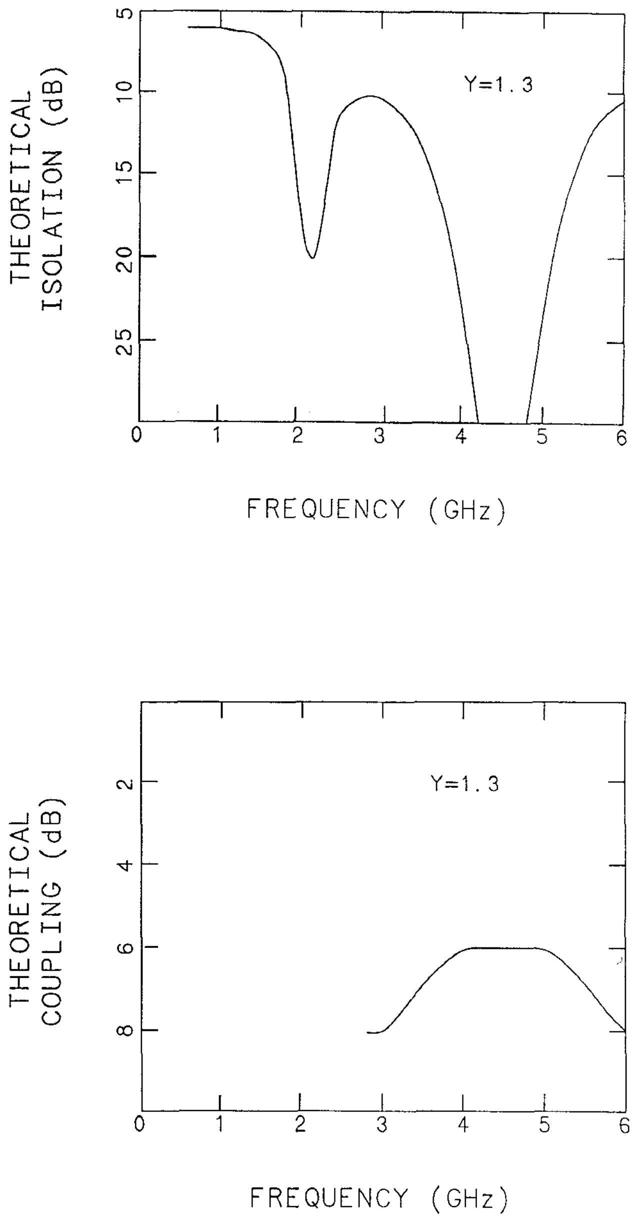
Figure 2 Symmetrical planar 8 port junction comparator circuit with a circumference of one wavelength at mid-band.







Figures 3a,b,c,d,e Experimental isolation (1-3), Coupling (1-5), return loss, isolation (1-2), and coupling (1-7) from D.C. to 6 GHz.



Figures 4a,b Theoretical isolation (1-2) and theoretical coupling (1-7) assuming a slotline stub impedance of 77Ω's.