A TRANSMISSION-LINE-TYPE EIGHT-PORT HYBRID

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Abstract

A novel transmission-line-type eight-port hybrid is proposed and investigated theoretically and experimentally. A bandwidth comparable with that of a branch-line 3 dB hybrid is obtained for moderate values of characteristic admittances of line sections. This circuit is useful for applications to a comparator circuit in a four-port monopulse radar system and a four-way power combiner/divider with four input/output arms isolated from one another.

Introduction

Recently, several eight-port microwave networks have been developed with a view to utilizing as a comparator circuit in a four-port monopulse radar system for determining both azimuth and elevation information [1], [2]. These networks are very similar to a conventional 3 dB hybrid in the following ways apart from the number of input/output ports:

1)Eight ports are split into two groups of four ports isolated from one another.

2)An input power at an arbitrary port is divided into four equal parts among four ports belonging to the other group.

A circuit having the properties, which here is described as an eight-port hybrid, also is applicable as a four-way power combiner/divider with sub-arms isolated, and will be useful for new applications such as a power combining system of four oscillators.

In this paper, we consider a novel transmission-line-type eight-port circuit shown in Fig. 1. This circuit has the property that four alternative ports are isolated and power incident in one of the isolated ports couples into four ports belonging to the other group by quarters, and hence is a variety of eight-port hybrids. First, a circuit configuration is illustrated and a scattering matrix at a center frequency is derived by taking advantage of the symmetrical configuration of the network. Next, the frequency characteristics of the scattering parameters are calculated. Finally, a test circuit is fabricated using a microstrip line, and its scattering parameters are measured to confirm theoretical results.

Construction and properties

Fig. 1 illustrates schematically a circuit configuration to be considered and the dimensions inclusive of the characteristic admittances of each line section. The values of the line admittances are normalized by that of the input/output ports. The cross transmission lines in the center of the circuit do not intersect with each other. Since the circuit possesses two-fold symmetry about the two planes AA′ and BB′, it can be analyzed by reducing the eight-port network to four kinds of two-port networks, that is, quarter-circuits cut out of the eight-port network along the planes AA′ and BB′ with a magnetic or electric boundary. Furthermore, the symmetry tells us that this circuit is characterized by seven independent scattering matrix parameters, S_{11}, S_{21}, S_{31}, S_{41}, S_{51}, S_{61} and S_{81}. When the scattering parameters of the four two-port networks having the ports 1 and 2 are denoted by S_{ij}^{ee}, S_{ij}^{eo}, S_{ij}^{oe} and S_{ij}^{oo}, the scattering parameters of the whole circuit are given as

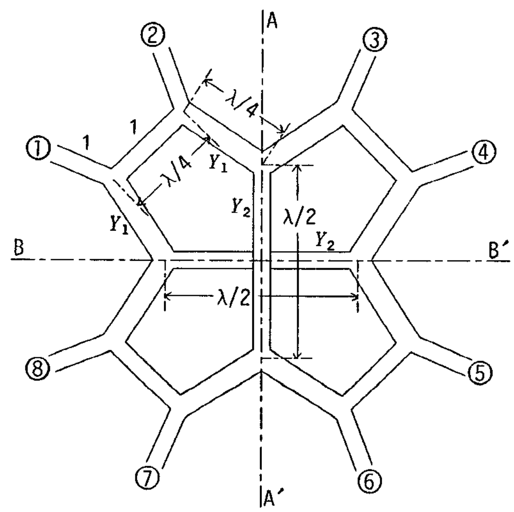

Fig. 1. Schematic configuration of a newly proposed eight-port hybrid.

$$S_{11}=(S_{11}^{ee}+S_{11}^{eo}+S_{11}^{oe}+S_{11}^{oo})/4 \quad (1a)$$
$$S_{21}=(S_{21}^{ee}+2S_{21}^{eo}+S_{21}^{oo})/4 \quad (1b)$$
$$S_{31}=(S_{21}^{ee}-S_{21}^{oo})/4 \quad (1c)$$
$$S_{41}=(S_{11}^{ee}+S_{11}^{eo}-S_{11}^{oe}-S_{11}^{oo})/4 \quad (1d)$$
$$S_{51}=(S_{11}^{ee}-S_{11}^{eo}-S_{11}^{oe}+S_{11}^{oo})/4 \quad (1e)$$
$$S_{61}=(S_{21}^{ee}-2S_{21}^{eo}+S_{21}^{oo})/4 \quad (1f)$$
$$S_{71}=S_{31} \quad (1g)$$
$$S_{81}=(S_{11}^{ee}-S_{11}^{eo}+S_{11}^{oe}-S_{11}^{oo})/4 \quad (1h)$$

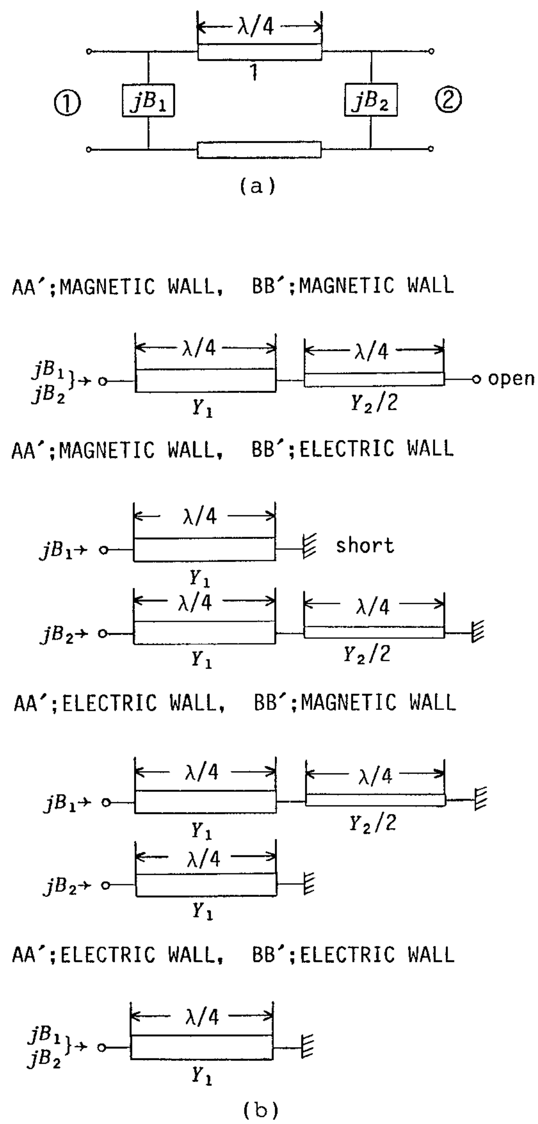

Fig. 2. (a) An equivalent circuit of quarter-circuits. (b)Two shunt susceptances for four kinds of excitations.

where the superscript e or o of the two-port scattering parameters represents an even or odd excitaion with regard to the two planes, and the first superior corresponds to AA' and the second to BB'. Moreover, we use the relation that $S_{21}^{eo}=S_{21}^{oe}$ also.

Fig. 2 (a) exhibits an equivalent circuit of the two-port networks and (b) the shunt susceptances jB_1 and jB_2 for four kinds of excitations. From Fig. 2, we can easily derive the two-port scattering parameters at a center frequency as follows:

(1)AA';magnetic wall, BB';magnetic wall

$B_1=B_2=0$

$$S_{11}^{ee}=0, \qquad S_{21}^{ee}=-j \quad (2a,b)$$

(2)AA';magnetic wall, BB';electric wall

$B_1=0, \quad B_2=\infty$

$$S_{11}^{eo}=1, \qquad S_{21}^{eo}=0 \quad (3a,b)$$

(3)AA';electric wall, BB';magnetic wall

$B_1=\infty, \quad B_2=0$

$$S_{11}^{oe}=-1, \qquad S_{21}^{oe}=0 \quad (4a,b)$$

(4)AA';electric wall, BB';electric wall

$B_1=B_2=0$

$$S_{11}^{oo}=0, \qquad S_{21}^{oo}=-j \quad (5a,b)$$

Substituting (2), (3), (4) and (5) into (1), we obtain

$$[S]=\frac{1}{2}\begin{bmatrix} 0 & -j & 0 & 1 & 0 & -j & 0 & -1 \\ -j & 0 & -1 & 0 & -j & 0 & 1 & 0 \\ 0 & -1 & 0 & -j & 0 & 1 & 0 & -j \\ 1 & 0 & -j & 0 & -1 & 0 & -j & 0 \\ 0 & -j & 0 & -1 & 0 & -j & 0 & 1 \\ -j & 0 & 1 & 0 & -j & 0 & -1 & 0 \\ 0 & 1 & 0 & -j & 0 & -1 & 0 & -j \\ -1 & 0 & -j & 0 & 1 & 0 & -j & 0 \end{bmatrix} \quad (6)$$

As can be seen from the above derivation, the circuit acts as an eight-port hybrid independently of the values of Y_1 and Y_2. Furthermore, if 90° and -90° phase changers are connected with ports 4 and 5, and 1 and 8, respectively, the circuit has a comparator phase property.

Frequency dependences of scattering parameters

The frequency characteristics depend on the two characteristic admittances Y_1 and Y_2. Fig. 3, 4 and 5 show the computed magnitudes of the scattering parameters as a function of frequency for various values of the admittances. Fortunately, a comparison of these characteristics indicates that a desirablle performance can be obtained for the moderate admittances, Y_1=1.1 and Y_2=1.0, as shown in Fig. 3. The relative bandwidth is about ten percent under the condition that tolerance limits for maximum return loss, minimum isolation and maximum deviation of coupling factors are -20dB, 20dB and 0.5dB, respectively. This bandwidth is comparable with that of a four-port branch-line 3 dB hybrid.

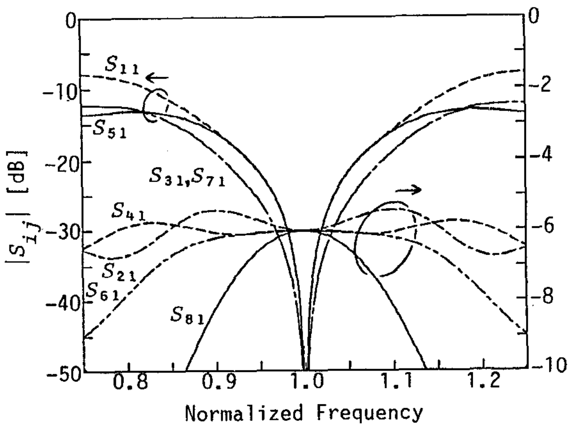

Fig. 3. Theoretical magnitude of S-parameters as a function of frequency for Y_1=1.1 and Y_2=1.0.

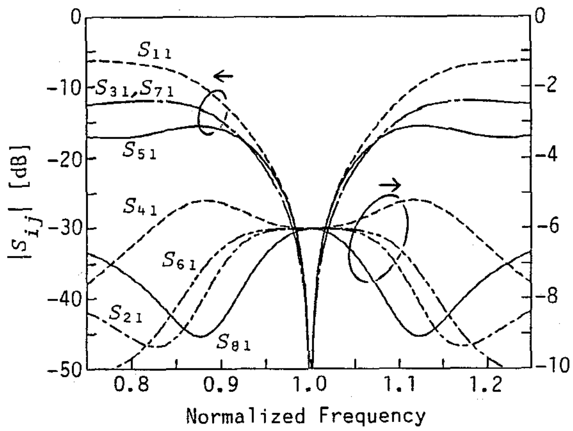

Fig. 4. Theoretical frequency dependence of S-parameters for Y_1=1.4 and Y_2=1.0.

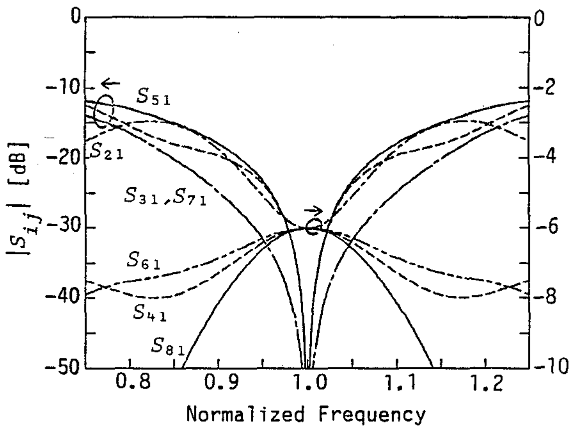

Fig. 5. Theoretical frequency dependence of S-parameters for Y_1=0.8 and Y_2=1.0.

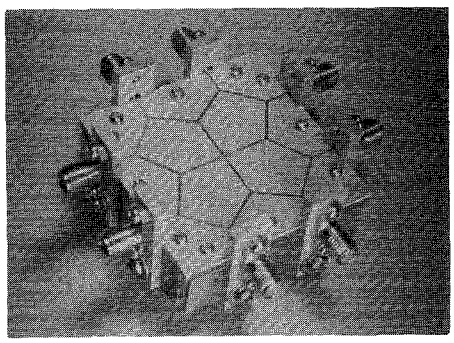

Fig. 6. A photograph of the experimental circuit.

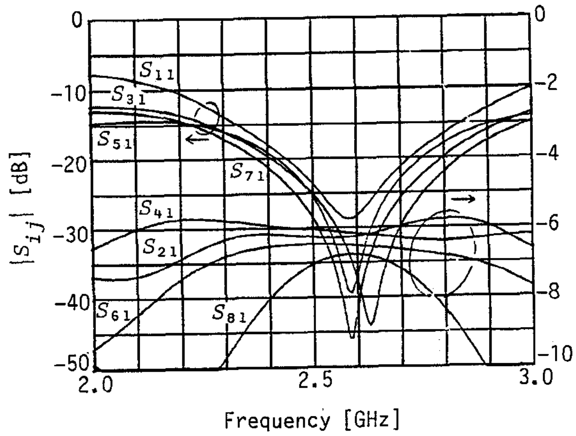

Fig. 7. Measured S-parameters of the circuit in Fig. 6.

Experimental results

A microstrip circuit having the parameters in Fig. 3 was fabricated on a 1/40-inch-thick Epsilam-10 (3M brand) with a dielectric constant of 10.3. The design center frequency was 2.5 GHz. A photograph of a circuit built as a trial is shown in Fig. 6. Fig. 7 exhibits X-Y recordings of the return loss, the isolations and the couplings made with HP's 8510B network analyzer. These experimental results approximately agree with the theoretical results except that coupling factors for each output port are a little unbalanced. The deterioration is presumably caused by uncomplete property of the crossover. In case of using a coaxial line or a multi-layered thin film microstrip line [3], we will not encounter this problem.

Conclusion

A new transmission-line-type eight-port hybrid has been proposed and the frequency characteristics of the scattering parameters have been shown. The bandwidth is comparable with that of a four-port branch-line hybrid for moderate characteristic admittances of the transmission-line sections. A further increase in the bandwidth of the eight-port hybrid would be an important subject for more practical purpose.

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References

[1]G. P. Riblet: "Compact planar microstrip-slotline symmetrical ring eight-port comparator circuits," *IEEE Trans. Microwave Theory Tech.*, **MTT-38**, 10, pp.1421-1426, Oct. 1990.

[2]T. Kawai, K. Iio, I. Ohta and T. Kaneko: "A branch-line-type eight-port comparator circuit," 1991 *IEEE MTTS Dig.* **2**, Z-6, pp.869-872, June 1991.

[3]S. Banba, T. Hasegawa and H. Ogawa:"Multilayer MMIC branch-line hybrid using thin dielectric layers," *IEEE Microwave & Guided Wave Letters*, **1**, 11, pp.346-347, Nov. 1991.