A BRANCH-LINE-TYPE EIGHT-PORT COMPARATOR CIRCUIT

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Abstract

A novel method of constructing an eight-port comparator with four branch-line 3 dB quadrature hybrids is described theoretically and experimentally. A relative bandwidth of up to 20 percent (for return loss and isolation better than 20 dB) is obtained by addition of simple external circuits. A strong point of the present comparator is to be manufactured on the same face of a substrate using a planar transmission line such as a stripline or a microstrip line.

Introduction

An eight-port comparator is used in a monopulse radar system for determining both azimuth and elevation information. In addition, the circuit is applicable as a 4-way power combiner/divider with sub-arms isolated from one another. Generally, the eight-port comparator is constructed with four 180° hybrids. Riblet has proposed a compact circuit which is successfully composed of microstrip lines and slotlines on the face and the back of a substrate. On constituting principle, it also is regarded as a circuit synthesized from four microstrip-slotline magic T's.

In this paper, we consider a circuit constructed with four branch-line 3-dB couplers. First, after deriving admittance relations between the branch line sections for a matching and an equal-power splitting condition of a basic construction, we analyze the frequency dependence of the scattering parameters. Next, we try to increase the bandwidth and show that the relative bandwidth is widened up to 20 percent for return loss and isolation better than 20 dB by appropriate matching. Finally, we obtain experimental corroboration by measuring the scattering parameters of a band-widened circuit. The present circuit can be manufactured in the same plane using a planar transmission line.

Construction

If four branch-line 3-dB couplers are connected in a manner illustrated in Fig. 1 and the reference planes of the output ports are appropriately adjusted, the whole circuit is expected to act as an eight-port comparator. 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} from its symmetrical configuration. Considering the two fold symmetry about the two

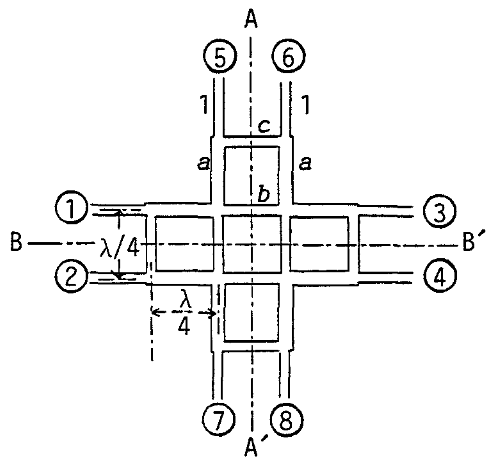


Fig. 1. Schematic configuration of a basic circuit.

planes AA' and BB', moreover, we can derive the S-parameters at a center frequency as follows:

$$S_{11}=S_{41}=-\alpha\beta/\delta \quad (1a)$$
$$S_{21}=S_{31}=j\beta\gamma/\delta \quad (1b)$$
$$S_{51}=-(\alpha^2+\gamma^2-a^2\gamma)/\delta \quad (1c)$$
$$S_{61}=S_{71}=ja^2\alpha/\delta \quad (1d)$$
$$S_{81}=(\alpha^2+\gamma^2+a^2\gamma)/\delta \quad (1e)$$

where $\alpha=a^2c-bc^2+b$, $\beta=a^2c-bc^2-b$, $\gamma=-a^2+2bc$ and $\delta=2(\alpha^2+\gamma^2)$. In the above, a , b and c represent the characteristic admittances of each branch line section normalized by that of the output ports. Eqs. (1a) and (1b) indicate that if

$$\beta=0 \quad (2)$$

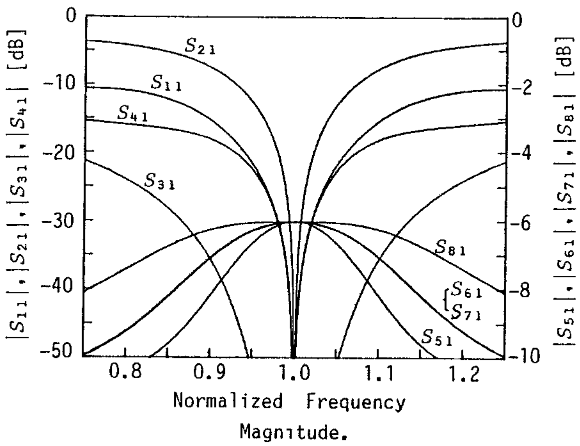
all ports are matched and ports 1, 2, 3 and 4 are isolated from one another. Furthermore, if

$$\gamma=0, \quad \alpha^2=a^4 \quad (3a,b)$$

all of four outputs emerging from ports 5, 6, 7 and 8 equal. Eqs. (2) and (3) are reduced to the following admittance relations:

$$a^2=2b, \quad c=1 \quad (4a,b)$$

The branch line admittances are not necessarily required to be $\sqrt{2}$ and 1 as an ordinary branch-line cou-



admittances of branch line sections
a=1.0, b=0.5, c=1.0

Fig. 2. Theoretical magnitude of S-parameters as a function of frequency for a basic circuit.

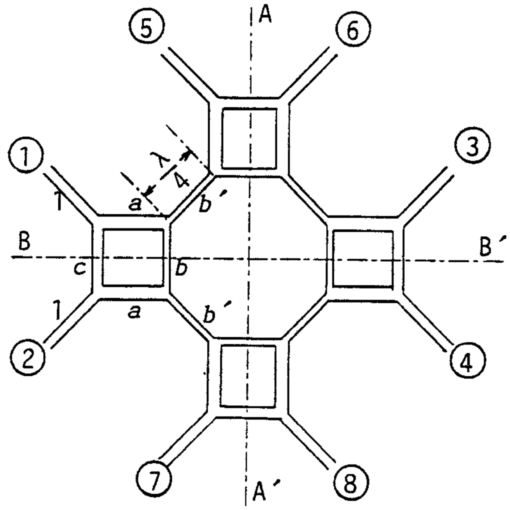


Fig. 3. A modified circuit configuration with coupling sections.

pler. When the above (4) is satisfied, the scattering matrix of the circuit at a center frequency can be written as

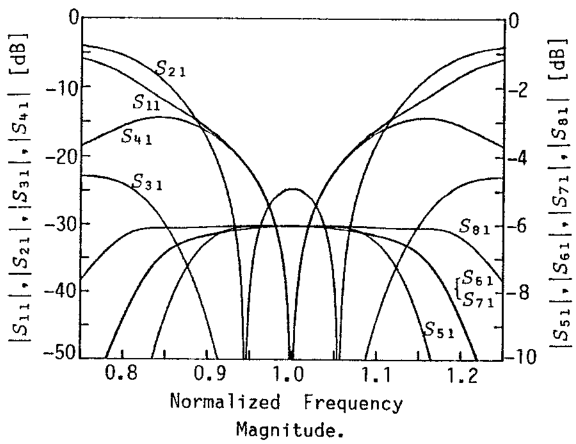
$$[S] = \frac{1}{2}\begin{bmatrix} 0 & 0 & 0 & 0 & -1 & j & j & 1 \\ 0 & 0 & 0 & 0 & j & 1 & -1 & j \\ 0 & 0 & 0 & 0 & j & -1 & 1 & j \\ 0 & 0 & 0 & 0 & 1 & j & j & -1 \\ -1 & j & j & 1 & 0 & 0 & 0 & 0 \\ j & 1 & -1 & j & 0 & 0 & 0 & 0 \\ j & -1 & 1 & j & 0 & 0 & 0 & 0 \\ 1 & j & j & -1 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad (5)$$

In order that this circuit have a comparator phase property, as can be seen from (5), 90° and -90° phase shifters are required at ports 1 and 5, and 4 and 8, respectively.

Fig. 2 shows the computed frequency dependence of the S-parameters for a=1.0 and b=0.5. For the purpose of avoiding the impairing effect of the parasitic reactances associated with junctions of strip conductors, low admittances are chosen for a and b. Excepting an isolation (S_{31}) and a coupling (S_{81}), the bandwidth is a little narrower than a single branch-line coupler owing to undesirable interaction between the four couplers.

Improvement on the bandwidth

In this section, we try to broaden the frequency performance. When the four couplers are connected using transmission line sections with an admittance equal to b, the property of the circuit at a center frequency does not change. Now, let the admittance(b') of the connecting line sections slightly increase from b with the aim of broadening the characteristics. Then, as il-



admittances of branch line sections
a=1.0, b=0.5, c=1.0, b'=0.53

Fig. 4. Theoretical magnitude of S-parameters as a function of frequency for the circuit pictured in Fig. 3.

lustrated in Fig. 3, if the length of the coupling sections is chosen as a quarter-wavelength, the frequency characteristics are computed as Fig. 4. The frequency dependences of the couplings and the isolation between ports 1 and 2 are considerably improved but the return loss (S_{11}) and the other isolation (S_{41}) are little broadened.

Furthermore, in order to band-widening those S-

parameters, quarter-wavelength transformers and shunt short-circuited stubs quarter-wavelength long are added at each output port as shown in Fig. 5. By properly choosing the admittances of the line sections in a manner such as the literature [2], we can obtain a band-widened characteristics. Fig. 6 exhibits the admittance values and the theoretical scattering parameters as a function of frequency. The bandwidths of all the S-parameters are considerably widened and the bandwidth for return loss and isolations better than 20 dB comes up to about 20 percent.

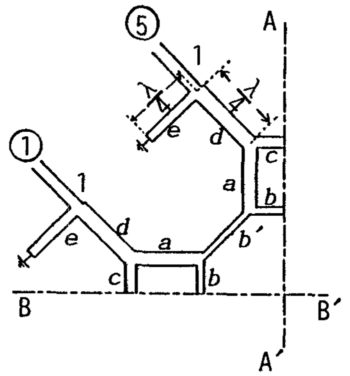


Fig. 5. A Broadband version of the branch-line comparator.

Experimental results

A triplate circuit with broadband characteristics shown in Fig. 6 was fabricated on a 1/16-inch-thick Rexolite 1422 with a dielectric constant of 2.53. The design center frequency was 3.0 GHz. In the actual construction, moreover, the short-circuited stubs were replaced by open-circuited stubs having twice the length and half the admittance. The photograph of the circuit pattern is shown in Fig. 7. Fig. 8 exhibits X-Y recordings of the return loss, the isolations, couplings and the phase differences between the outputs made with a network analyzer. These experimental results substantially agree with the theoretical results except that the frequency characteristics collectively move to a little higher frequencies due to the parasitic reactances at the junctions.

Conclusions

An eight-port comparator constructed of four branch-line 3 dB couplers has been studied theoretically and experimentally. By adding external circuits consisting of a quarter-wavelength transformer and a shunt stub, and appropriately choosing the admittances of each line sections, a bandwidth of 20 or more percent has been obtained.

A more detailed design with consideration for the parasitic reactances would be an important subject for further work.

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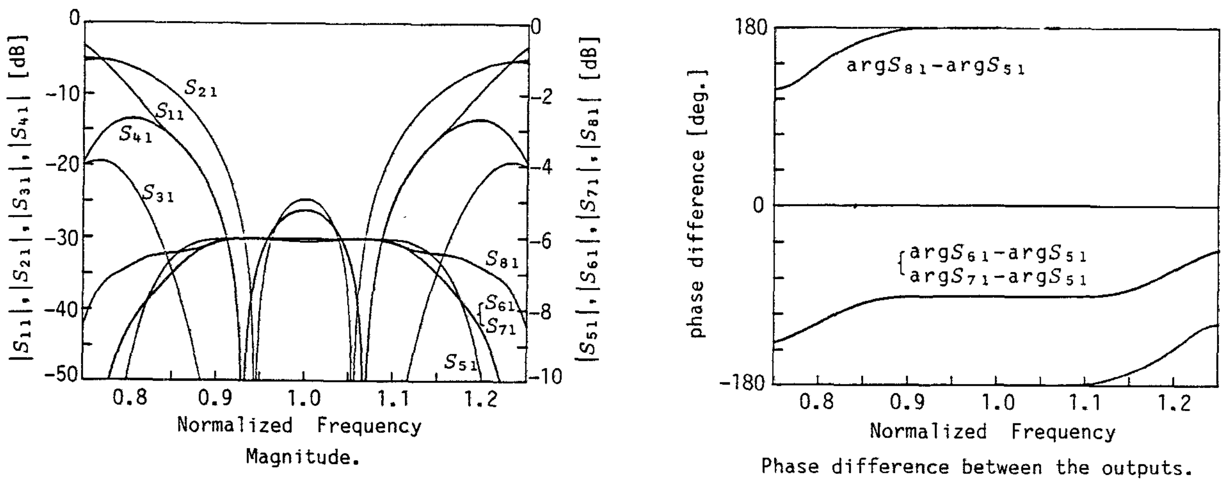

admittances of branch line sections
a=1.0, b=0.5, c=1.0, b'=0.53, d=1.05, e=2.0

Fig. 6. Theoretical S-parameters of the band-widened circuit pictured in Fig. 5.

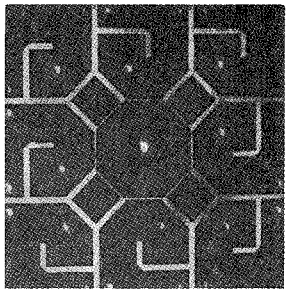

Fig. 7. A photograph of the experimental circuit pattern.

References

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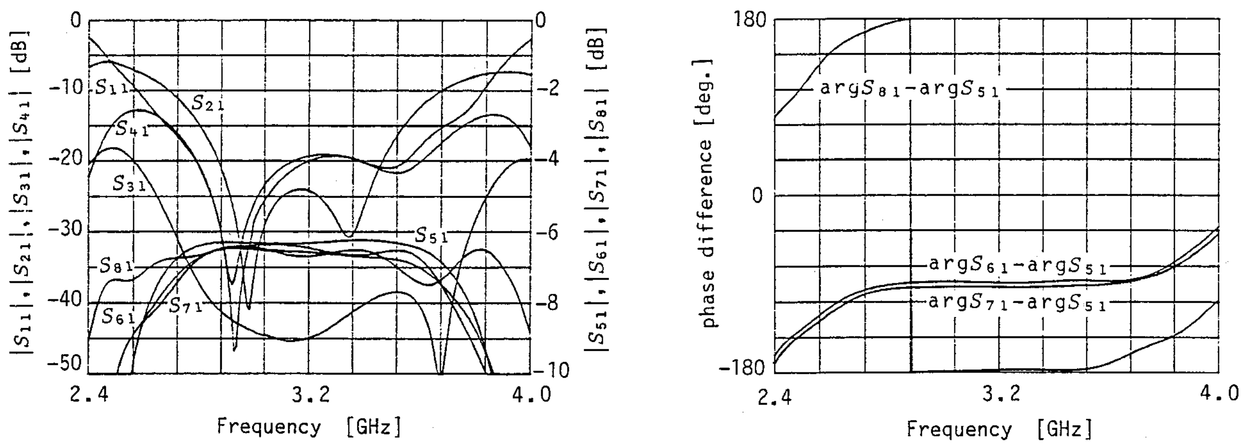

Magnitude.

Phase difference between the outputs.

Fig. 8. Measured *S*-parameters of the band-widened circuit.