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MULTIPLE-PORT POWER DIVIDERS/COMBINERS CIRCUITS USING CIRCULAR MICROSTRIP DISC CONFIGURATION

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ABSTRACT

A generalized method for evaluating the S-parameters of a multiport center-fed circular microstrip disc power divider/combiner circuit is presented. The method is based on the planar circuit approach in which the two-dimensional Green's function of a circular segment is used. Various symmetrical power divider/combiner circuits are designed and tested. The effect of introducing shorted posts between the circumferential ports on the reduction of radiation losses is discussed. Experimental results verifying the design methodology and the optimization procedure are given.

INTRODUCTION

Symmetric n-way power-dividers and power-combiners have recently received considerable attention [1-2]. These circuits have the advantage of not giving either amplitude nor phase power-division imbalance at all frequencies, thus making them very useful in many RF applications. Indeed power dividers have found extensive use in the design of multi-element antenna feed systems. Also multiple-port power combiners have been widely used in combining multiple oscillators or amplifiers in a single module, thus yielding higher power capabilities.

Recently the use of a circular microstrip center-fed disc structure as an n-way power divider/combiner has been reported [2]. However, no design formulas nor any theoretical treatment were given. In this paper, a generalized theoretical formulation and several experimental results for this new structure will be presented. The geometry of this power divider/combiner circuit is illustrated in Fig. 1. At the center of the disc is the coaxially fed port which is the input port for the power-divider design and the output port for the power-combiner design. The other n-ports are microstrip line ports symmetrically located around the circumference of the circular disc.

The theoretical analysis developed in this paper is based on the planar circuit approach which uses the disc's two-dimensional impedance Green's function to derive the impedance-matrix. In order to efficiently optimize the design, and interpret the results as well, the impedance-matrix is transformed into the more familiar scattering-matrix representation. The validity of this approach and the feasibility of the design have been verified experimentally. The influence of introducing shorted posts (between the circumferential ports) on the reduction of the excessive radiation losses is investigated.

METHOD OF ANLAYSIS

The analysis to be reported in this paper is based on the planar circuit two-dimensional approach. In this approach the fringing field at the disc circumference is accounted for by replacing the physical disc by a larger disc surrounded by a perfect magnetic wall. The effective radius of this larger disc is obtained from [3]. The detailed analysis is very similar to that of the four-port and five-port microstrip disc circuits discussed previously in [4-5]. The two-dimensional impedance Green's function for a circular segment with magnetic walls is available from [6]. This function has been used to derive the impedance matrix for the center fed n-port circular microstrip structure shown in Fig. 1.

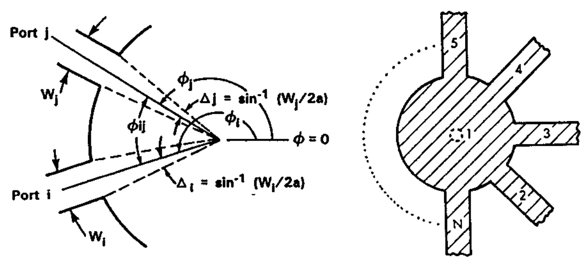

Fig. 1. (a) Parameters of the circumferential ports.
(b) Circular microstrip disc structure with a single coaxially-fed port at the center and (N-1) microstrip ports along the circumference.

Port 1 is located at the centre of the disc and its width W_1 is a cylindrical surface of extent

$2\pi\rho_0$, where ρ_0 is the radius of the coaxial feed center conductor. The Z-matrix element Z_{11} of this port is:

$$Z_{11} = \frac{j\omega\mu d}{\pi a_e^2} \sum_{m=1}^{\infty} \frac{J_0^2\,(k_{0m}\rho_0)}{[k_{0m}^2 - k^2]J_0^2\,(k_{0m}a_e)} \tag{1}$$

The other diagonal terms of the impedance matrix (i.e., Z_{ii} $(i\neq 1)$) are found to be

$$Z_{ii}(i\neq 1) = \frac{2j\omega\mu d a_e^2}{\pi W_i^2} \sum_{n=0}^{\infty} \sum_{m=1}^{\infty}$$

$$\frac{\sigma_n\{1-\cos[2n\sin^{-1}(w_i/2a_e)]\}}{n^2(a_e^2 - \frac{n^2}{k_{nm}^2})(k_{nm}^2 - k^2)} \tag{2}$$

Off-diagonal terms in the first row (or the first column) are given by

$$Z_{1j} = \frac{j\omega\mu d}{\pi a_e^2} \sum_{m=1}^{\infty} \frac{J_0(k_{0m}\rho_0)}{(k_{0m}^2 - k^2)J_0(k_{0m}a_e)} \tag{3}$$

The summation with respect to n does not appear in equations (1)and (3) since,

$$\int_{\phi_i=0}^{2\pi} \cos[n(\phi_i-\phi_j)]d\phi_i = \begin{cases} 2\pi \text{ for } n=0 \\ 0 \text{ otherwise} \end{cases} \tag{4}$$

The other off-diagonal terms are given by

$$Z_{ij}(i\neq 1,\ j\neq 1) = \frac{2j\omega\mu d a_e^2}{\pi W_i W_j} \sum_{n=0}^{\infty} \sum_{m=1}^{\infty}$$

$$\frac{\sigma_n}{n^2[a_e^2 - \frac{n^2}{k_{nm}^2}][k_{nm}^2 - k^2]} \tag{5}$$

$$\cdot\{\cos[n(\Delta_i-\Delta_j)]-\cos[n(\Delta_i+\Delta_j)]\}\cos(n\phi_{ij})$$

where

$$\Delta_{i,j} = \sin^{-1}(W_{i,j}/2a_e)$$

The two expressions given in equations (2) and (5) are identical to those corresponding expressions derived in [4,5]. The impedance matrix obtained from equations (1) through (5) is then converted into the more familiar S-matrix representation.

Finally, it should be mentioned that for all the results reported in this paper we have assumed that the circumferential ports are symmetrically located around the disc. The widths $W_i(i\neq 1)$ of these ports have been taken to be equal to the effective widths $(\eta_0 h/Z\cdot\ \varepsilon_{re})$ of the microstrip lines connected to these ports. Additionally, the frequency variation of Z_0 and W_e (the effective width of the microstrip lines) has been taken into account.

NUMERICAL RESULTS

The method of analysis described in the previous section has been used to analyse various multiport power-divider geometries. A representative example is the center-fed four-way power-divider shown in Fig. 2 insert. The S-parameters of this configuration has been calculated over the frequency range 1 GHz to 20 GHz and are plotted in Fig. 2. These results are based on a circular disc with a 7.50 mm radius. The substrate in this case is assumed to be 31 mil thick and has a dielectric constant ε_r=2.2. The characteristic impedance of the output ports are assumed to be 50Ω.

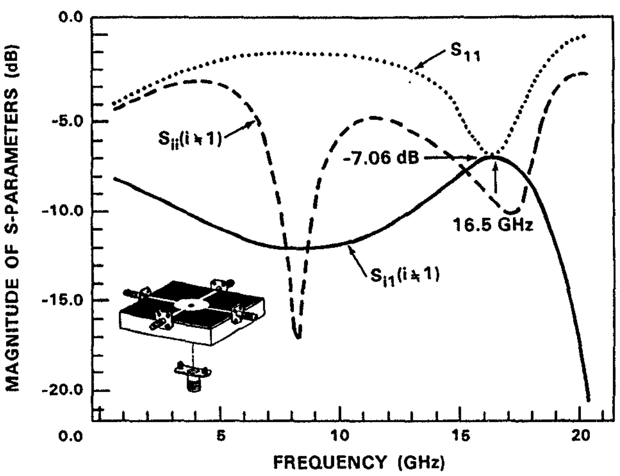

Fig. 2. Theoretical results for a center-fed 4-way power divider (disc radius = 7.50 mm).

Inspection of the computed results reveals that the return loss S_{11} of the feed port is minimum at 16.5 GHz. This frequency is near 15.43 GHz which is the resonance frequency of the (0,1) mode of the circular disc cavity structure. The transmission coefficient from the center port to any of the circumferential ports (at 15.43 GHz) is -7.06 dB. For an ideal power-divider this value should be -6.0 dB. The dependence of the transmission coefficient on the characteristic impedance of the output ports has been studied. The results clearly indicate that both the reflection and the transmission coefficients improve monotonically when Z_0 for the output ports is varied from 60Ω to 30Ω. Obviously, when a characteristic impedance as low as 30Ω is used, the implementation of an impedance transformer becomes essential. This of course would require a modification of the analysis to accomodate the use of the transformer. This aspect will be discussed later in the concluding section.

EXPERIMENTAL RESULTS

Typical experimental results for the 4-way power divider are shown in Fig. 3. When compared with the theoretical results the main discrepency is in the value of the transmission coefficient (Experiemntal -9.03 dB, theoretical -7.06 dB). This is attributable to a possible radiation loss from the open portions of the disc circumference. Furthermore this point is reinforced when we compare the measured performance of the 3, 4, 5, 8 and 10-way power dividers with their corresponding ideal theoretical values as indicated in Table 1.

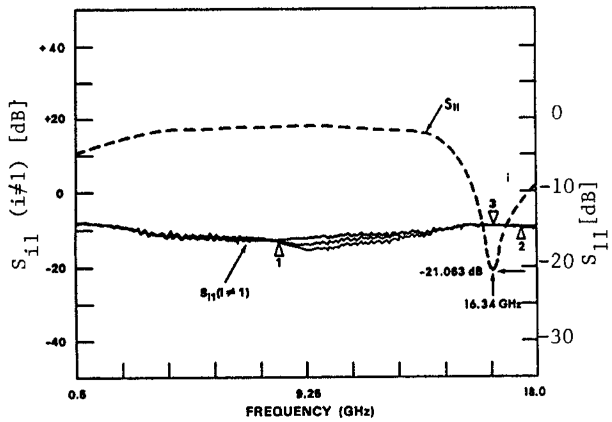

Fig. 3. Typical measured results for a 4-way center-fed microstrip disc power divider (disc radius = 7.5 mm).

We note that the extra loss observed experimentally decreases when the number of external ports is increased. When the number of output ports is increased, the open region at the circumference decreases and the radiation loss is expected to decline.

N-way Divider	S_{21} (Expt)	S_{21} (Ideal)	Extra Loss*	Operating Frequency
N = 3	-10 dB	-4.77 dB	5.23 dB	14.4 GHz
N = 4	-9 dB	-6.0 dB	3.0 dB	14.4 GHz
N = 5	-9.0 dB	-7.0 dB	2.0 dB	14.4 GHz
N = 8	-10 dB	-9 dB	+1.0 dB	15.025 GHz
N = 10	-11 dB	-10 dB	+1.0 dB	15.98 GHz

* Extra Loss = S_{21}(Ideal) - S_{21}(Expt.)

Table 1. Transmission coefficient values for 3, 4, 5, 8 and 10 way power dividers with 0.865 cm disc radius.

POWER-DIVIDERS CIRCUITS WITH SHORT-CIRCUITED PORTS

One of the techniques that has been successfully used for reducing the extra transmission loss (attributed partly to radiation) is to add extra shorted ports around the circumference. An example of this modified configuration is shown in Fig. 4 insert (for a 3-way power-divider). Ports numbered 5, 6 and 7 shown in this figure represent short circuits from the disc to the ground plane at those locations. In practice, these are realized by 20 mil diameter 'fuzz' buttons drilled into the substrate and soldered on top of the metallizations.

Preliminary experimental results for a 3-way power divider with three extra shorted ports are shown in Fig. 4. The transmission coefficient value is now only -6.24 dB which implies that the extra loss is reduced from 5.23 dB (as shown in Table 2) to only 1.47 dB. This confirms that the extra insertion loss is mainly caused by the radiation at the open edges of this disc.

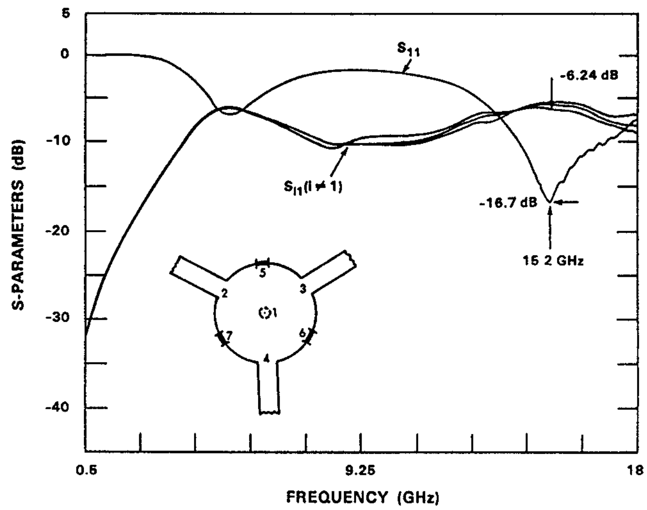

Fig. 4. Experimental results for a 3-way power divider with extra shorted ports.

POWER-COMBINER CIRCUITS WITH OUTPUT PORT AT THE CENTER

The basic requirements on the power-combiner circuit are different from those on the power-divider circuits. In terms of the configuration shown in Fig. 1., a power-combiner operation is possible provided that ports 2 through N (i.e., S_{22}, S_{33}, ... S_{NN}) are matched and isolated from one another as well. Furthermore, the use of electrically symmetric designs, such as the one at hand, is an effective way for eliminating the frequency-dependent imbalances in the combiner and hence increase its combining efficiency.

Initial investigations have shown that these conditions may be achieved by slight modifications in the design. Experiments on a three way combiner with three shorted ports located between each of the circumferential ports have shown that it is possible to obtain input reflection as low as -30 dB and at the same time achieve an isolation of better than 27 dB between the input ports. More detailed theoretical and experimental results for this case will be reported at the Symposium.

CONCLUDING REMARKS

Preliminary theoretical results and experimental results on the use of circular microstrip disc structures for designing multiport power divider and combiner circuits have been very encouraging. The planar circuit approach (starting from the Green's function of a circular segment with a magnetic wall) has been used successfully for analysing such circuits. The validity of this theoretical approach has been verified experimentally.

These investigations are currently being extended in the two directions. Firstly, modified power-divider circuits are being designed with lower impedance at the output ports which requires the incorporation of quarter wave impedance matching sections. The junction effect, at the interface between the circular disc and the output impedance matching sections, needs to be taken into account using a two-dimensional circuit analysis approach. The $\lambda/4$ impedance transformers are treated as separate additional rectangular segments. These segments are connected to the disc via multiple ports and to the output lines via a single port as shown in Fig. 5. Secondly, its performance of the power divider/combiner circuits are currently being optimized through the introduction of additional shorted ports around the disc circumference.

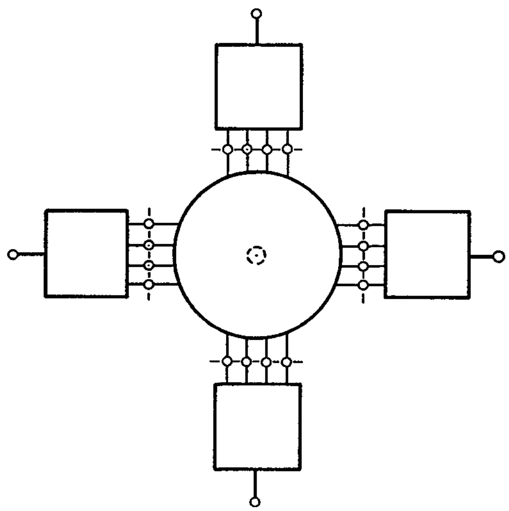

Fig. 5. Two dimensional planar circuit analysis of the modified power divider circuits.

Detailed theoretical and experimental results on multi-way power-divider and power-combiner circuits will be presented at the Symposium.

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REFERENCES

[1] Adel A. M. Saleh, "Planar Electrically Symmetric N-Way Hybrid Power Dividers/Combiners", IEEE Trans Microwave Theory Tech, Vol. MTT-28, June 1980, pp. 555-563.

[2] E. Belohoubek, et al, "30-way Power Combiner for Miniature GaAs FET Power Amplifiers", 1986 IEEE MTT-S Int. Microwave Symposium Digest, pp. 515-518.

[3] I. Wolff and N. Knoppik, "Rectangular Microstrip Disc Capacitors and Resonators", IEEE Trans. Microwave Theory Tech, Vol. MTT-22, No. 10, October 1974, pp. 857-864.

[4] M. Abouzahra, and K. C. Gupta, "Analysis and Design of Five-Port Circular Disc Structure for Six-Port Analyzers", 1985 IEEE MTT International Microwave Symposium Digest, pp. 449-452.

[5] K. C. Gupta, and M. Abouzahra, "Analysis and Design of Four-Port and Five-Port Microstrip Disc Circuits", IEEE Trans. Microwave Theory Tech, Vol. MTT-33, December 1985, pp. 1422-1427.

[6] K. C. Gupta, et al, Computer-Aided Design of Microwave Circuits, Antech House, Dedham MA, 1981, p. 249.