Z-2

Use of Circular Sector Shaped Planar Circuits for Multiport Power Divider-Combiner Circuits

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ABSTRACT

A novel sector shaped circuit configuration is proposed for designing planar power dividers-combiners that are compatible with microstrip circuits. Interesting experimental results on 2, 3, 4, and 5-way power divider circuits are presented. Impedance matrix expressions for annular sectors have been derived and used in the two-dimensional analysis of these circuits.

INTRODUCTION

Passive power divider and power combiner circuits are used extensively at microwave and millimeter-wave frequencies. When these circuits are realized in planar (microstrip-type) configurations, two particular circuit types are often used. These types are: the symmetric geometry with radially oriented lines[1-2], and the fan-out, Wilkinson type, geometry[3]. The use of circular disk planar segments for designing symmetrical power combiner-divider circuits has been discussed in a recent paper[4]. The present paper explores the use of the sector shaped planar segments for designing power divider-combiner circuits.

One system application that motivated this investigation is the need for replacing the lossy corporate feed structures used in feeding a linear array of antenna elements. A circular disk geometry with output lines extending radially in all directions is not appropriate for this purpose. On the other hand, a sector geometry with the almost linearly aligned output ports (Figure 1) is topologically more suitable. Also, the sector geometry shown in Figure 1 is truly planar as there is no need for the vertically oriented feed port which is used in the circularly symmetric configuration[4]. This of course makes it easy to integrate

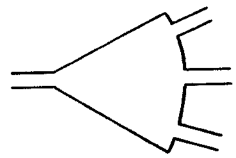

Figure 1: Geometry of a sectorial power divider/combiner circuit.

these circuits in the same plane and on the input and output sides as well. Furthermore, these power divider-combiner circuits could be cascaded in a fan-out or a fan-in manner as shown in Figure 2. Another promising feature offered by these circuits is the flexibility in obtaining unequal output power levels at various ports. This characteristic can be used for the amplitude tapering often required in antenna arrays. The power output at the various output ports (Figure 1) can be controlled by adjusting the locations and/or widths of the microstrip lines connected to these ports.

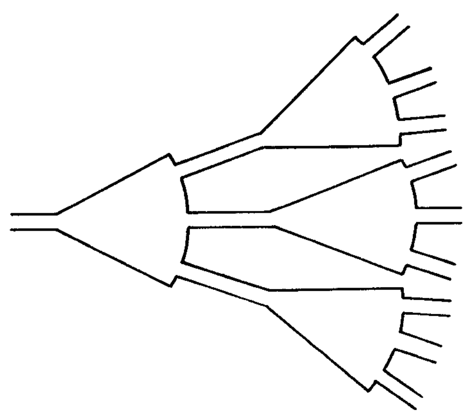

Figure 2: Cascading of sectorial power divider combiner circuits.

This paper reports experimental results and a theoretical analysis procedure for sector shaped power divider-combiner circuits. Several

2-way, 3-way, 4-way and 5-way power divider circuits have been designed and fabricated. The experimental performance is very encouraging.

EXPERIMENTAL RESULTS

A number of sector shaped power divider-combiner circuits have been designed, constructed and tested. A photograph of some of these circuits is shown in Figure 3. These circuits were fabricated on 1/32 inch thick duroid[R] (ε_r = 2.2) substrates and tested over a frequency range of 1.5 to 26.5 GHz. Some of the typical results are summarized in this section.

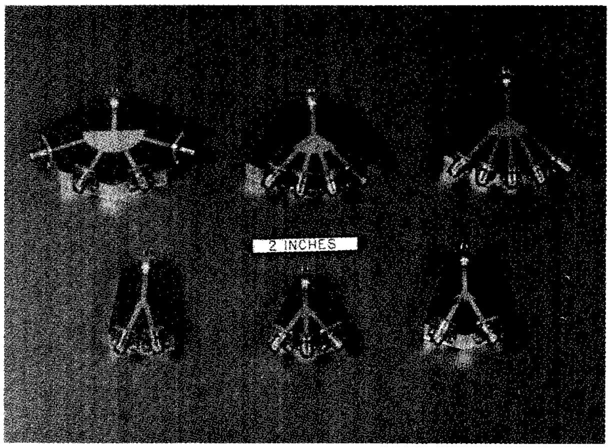

Figure 3: Photograph of several multi-way power divider/combiner sectorial circuits.

A 4-way power divider circuit using a 90° sector is shown in the Figure 4 inset. This circuit can be used as a power divider in two different frequency bands. This is because S_{11} is less than -12 dB in the frequency bands 8 to 10 GHz and 14.5 GHz to 18.5 GHz. In the lower frequency band, the power output levels at the four ports are about equal (being slightly less than -6 dB). In the upper band (14.5-18.5 GHz), the power division is unequal, with the outputs at the outer ports 2 and 5 being smaller than those at the inner ports.

A 5-way power divider has been designed using 90° sector planar circuit. The configuration and the measured S-parameters of this power divider are shown in Figure 5. Again, as in the case of the 4-way circuit shown in Figure 4, there are two different frequency bands of operation. Considering -12 dB as an acceptable level for the input reflection coefficient S_{11}, the lower band is found to extend from 7.7 to 10.5 GHz while the upper frequency band is found to be wider and extends from 15.4 GHz to 22 GHz.

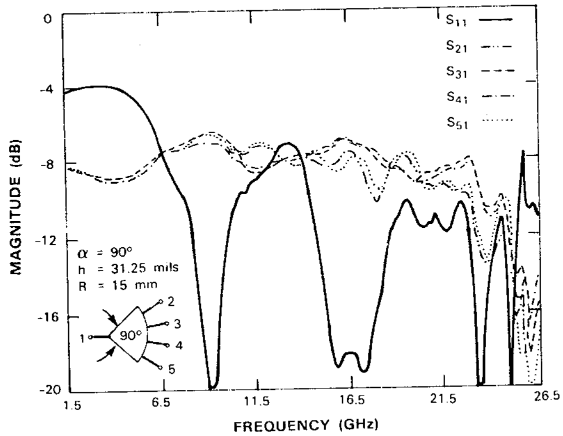

Figure 4: S-parameters of a four-way power divider using a 90° sector

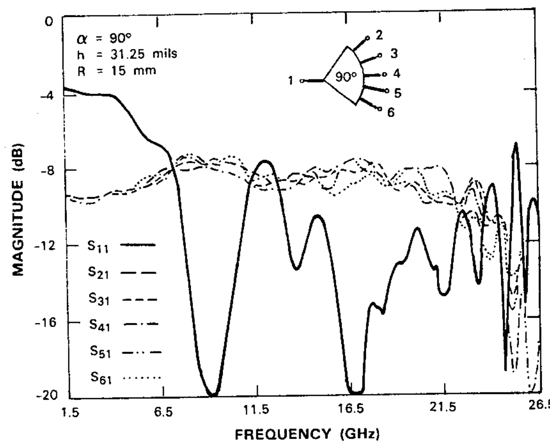

Figure 5: S-parameters of a five-way power divider using a 90° sector.

THEORETICAL ANALYSIS OF SECTORIAL CIRCUITS

The planar circuit analysis approach previously used[4] for circular disk power divider circuits is also applicable to circuits with sectorial geometry. For the configurations considered, the planar circuit analysis approach can be implemented in two different ways. As shown in Figure 6, the geometry can be decomposed into an annular sector 'B' and a rectangular segment 'A'. Characterization of the overall configuration is obtained by using the segmentation formula [5] after evaluating the Z-matrices of the A and B circuits. This procedure is approximate because the curved edge of the sector is being connected to the straight edge of a rectangle. This implementation will yield more accurate results for smaller sector angles (such as 22.5°, 30° and 45°).

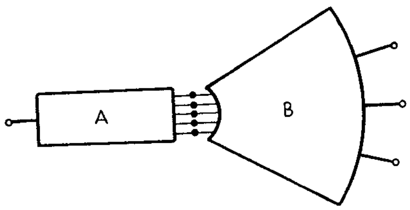

Figure 6: An illustration of the segmentation method for analysing annular sectorially shaped power dividers.

The second implementation is shown in Figure 7. The Z-matrix of a truncated sector is obtained by first evaluating the Z-matrices of the complete circular sector and the triangular segment X, and then invoking the desegmentation formula[5]. The resulting Z-matrix for the truncated sector Z, is combined with the Z-matrix of a rectangular segment (through segmentation formula) to obtain the overall Z-matrix of the desired configuration. Since the Green's functions for isosceles triangles are only available for 90° and 60° apex angles, sectorial circuits with only these two configurations can be analyzed by this method.

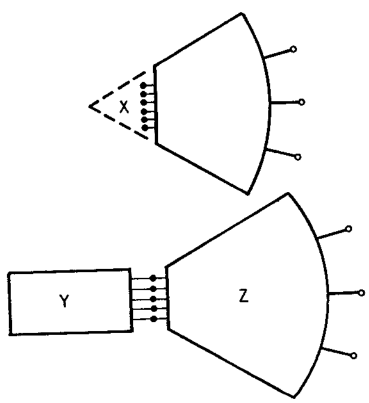

Figure 7: An illustration of the segmentation and desegmentation methods for analysing circular sectorially shaped power dividers.

The two-dimensional impedance Green's functions are only available for sectorial segments having a sector angle α equal to sub-multiples of π-radians (180°). Thus, the Green's function approach can be used for sectors with α = 180°, 90°, 60°, 45°, 30°, 22.5°, etc.. However, the Z-matrix expressions for these sectors have not been reported in the literature. In this paper the two-dimensional planar circuit approach is used to determine the values of the individual elements of the Z-matrix of an annular sectorial segment.

The self and transfer impedance terms for ports located along the outer circumference $\rho=b$, are given by

$$Z_{ij}=\frac{2j\omega\mu d b^2}{\alpha W_i W_j}\sum_{n=0}^{\infty}\sum_{m=1}^{\infty}\frac{\sigma_n\{\cos(n_s\phi_{ij})+\cos[n_s(\phi_i+\phi_j)]\}}{n_s^2[(b^2-\frac{n_s^2}{k^2_{mn_s}})-(a^2-\frac{n_s^2}{k^2_{mn_s}})A^2_{mn_s}](k^2_{mn}-k^2)}$$

$$\cdot\ \{\cos[\frac{n_s}{2}(\Delta_i-\Delta_j)]-\cos[\frac{n_s}{2}(\Delta_i+\Delta_j)]\} \qquad (1)$$

where

$$\sigma_n=\begin{cases}1 & n=0\\ 2 & \text{otherwise}\end{cases}$$

$$A_{mn_s}=F_{mn_s}(a)/F_{mn_s}(b) \qquad (2)$$

$$F_{mn_s}(\rho)=N'_{n_s}(k_{mn_s}a)J_{n_s}(k_{mn_s}\rho)$$

$$-\ J'_{n_s}(k_{mn_s}a)N_{n_s}(k_{mn_s}\rho). \qquad (3)$$

Furthermore, the values of the wave number k_{mn_s} are solutions of

$$J'_{n_s}(k_{mn_s}a)N'_{n_s}(k_{mn_s}b)$$

$$-\ J'_{n_s}(k_{mn_s}b)N'_{n_s}(k_{mn_s}a)=0 \qquad (4)$$

and $n_s=n\pi/\alpha$, $\Delta_{i,j}=W_{i,j}/b$ where $W_{i,j}$ represent the curvilinear widths of the ports measured along the outer circumference, ϕ_i the angular location of the i^{th} port measured from one of the straight edges, and ϕ_{ij} denotes the angular distance between ports i and j.

When some ports are located along the inner circumference $\rho=a$, the corresponding self and transfer impedance elements of the Z-matrix are determined from

$$Z_{ij} = \frac{2j\omega\mu d a^2}{\alpha W_i W_j} \sum_{n=0}^{\infty} \sum_{m=1}^{\infty} \frac{\sigma_n \{\cos(n_s \phi_{ij}) + \cos[n_s(\phi_i + \phi_j)]\}}{n_s^2 [(b^2 - \frac{n_s^2}{k_{mn_s}^2}) B_{mn_s}^2 - (a^2 - \frac{n_s^2}{k_{mn_s}^2})](k_{mn_s}^2 - k^2)} \cdot \{\cos[\frac{n_s}{2}(\Delta_i - \Delta_j)] - \cos[\frac{n_s}{2}(\Delta_i + \Delta_j)]\} \quad (5)$$

where $B_{mn_s} = 1/A_{mn_s}$.

When some of the ports are located at the edge of the inner circumference ($\rho=a$) and the others are located along the edge of the outer circumference ($\rho=b$), all the elements of the impedance matrix for this planar segment can be determined from (1), (5) and

$$Z_{ij} = \frac{2j\omega\mu d a b}{\alpha W_i W_j} \sum_{n=0}^{\infty} \sum_{m=1}^{\infty} \frac{\sigma_n \{\cos(n_s \phi_{ij}) + \cos[n_s(\phi_i + \phi_j)]\}}{n_s^2 [(b^2 - \frac{n_s^2}{k_{mn_s}^2}) B_{mn_s} - (a^2 - \frac{n_s^2}{k_{mn_s}}) A_{mn_s}](k_{mn_s}^2 - k^2)} \cdot \{\cos[\frac{n_s}{2}(\Delta_i - \Delta_j) - \cos[\frac{n_s}{2}(\Delta_i + \Delta_j)]\} \quad (6)$$

where in (6) W_i represents ports located along the inner circumference ($\rho=a$) and W_j represents ports located along the outer circumference ($\rho=b$).

CONCLUDING REMARKS

The results reported in this paper indicate that the sectorial planar geometry is a promising configuration for the design of planar multiway power divider-combiner circuits. It may be noted that the experimental results shown in this paper are based on the initial ad hoc designs of these circuits. It should be possible to improve the performance of these circuits by selecting optimum values for the various design parameters (such as the widths and locations of the various ports). The two-dimensional analysis reported in Section 3 is well suited for a computer-aided optimization of these circuits. Detailed results based on this approach will be reported at the Symposium.

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REFERENCES

[1] A. Fathy and D. Kalokitis, "Analysis and Design of a 30-way Radial Combiner for the Ku-band Applications," RCA Rev., Vol. 47, pp. 487-508, December 1986.

[2] S. J. Foti, R. P. Flam, and W. J. Scharpf, "60-way Radial Combiner Uses No Isolators," Microwaves and RF, pp. 96- 118, July 1984.

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

[4] M. D. Abouzahra and K. C. Gupta, "Multiple-Port Power Divider/Combiner Circuits Using Circular Microstrip Disc Configurations," IEEE Trans. Microwave Theory Tech., Vol. MTT-35, pp. 1296-1302, December 1987.

[5] K. C. Gupta, R. Garg, and R. Chadha, Computer-Aided Design of Microwave Circuits, Dedham, MA: Arbech House, 1981, Chapter 11.