INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.5, NO.6, NOVEMBER 2010

In-Phase Microstrip-Square Power Combiner/Divider

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***Abstract*- A six-port microstrip-square power combiner/divider showing in-phase quasi-equal-amplitude transmission characteristics is presented. The circuit has one input port and five output ports equidistantly spaced. A matching between the microstrip square impedance and the equivalent impedance of the five parallel (shunt connected) outputs is achieved. As the microstrip square decreases in size its bandwidth augments and the relation of the width of the output ports to the separation between them diminishes, thereby reducing the cross-talk effects and converting the circuit into an appropriate device for high-speed interconnect applications. As an extension of the possible applications, a three-port equal-power splitter is also presented. A 2-D FDTD electromagnetic simulation method is used for obtaining the transmission scattering parameters.**

***Index Terms*- Power combiner/dividers, microstrip squares, FDTD electromagnetic simulation, high-speed interconnect applications.**

I. INTRODUCTION

Solid circular- [1], triangular- [2, 3] and square-like [4] power dividers have been presented in the past. In-phase quasi-equal-amplitude transmission is common characteristic of most of these dividers. Another feature only shared by the triangular- and square-like dividers is the plane co-linear location of the output ports. Since coupling between parallel close miscrostrip lines can be desirable or undesirable depending on a specific application, a judicious choice of the space separation between the output ports has to be made. Thus, for instance, coupling on a parallel coupled line coupler is not only desired but also necessary. On the contrary, coupling between close interconnect traces indubitably leads to cross talk which is a spurious phenomenon that must be reduced or even eliminated for preserving the signal integrity [5, 6].

Power combiner/dividers are microwave circuits extensively used in modern digital high-speed interconnects. An excellent candidate to interconnect multiple-input/multiple-output devices is the microstrip-square power divider. A six-port (one-input/five-output) microstrip-square power divider that has very closely matched transmission factors, both in amplitude and phase, was presented in [4]. This structure is taken here as the basis for generating and simulating four sequenced microstrip-square power dividers that, as the size of the geometry reduces, show how the relative separation between the output ports augments, representing a less harmful cross-talk effect.

II. SIGNAL SEPARATION PROPERTIES

Figure 1 shows the basic geometry of a six-port microstrip-square power divider.

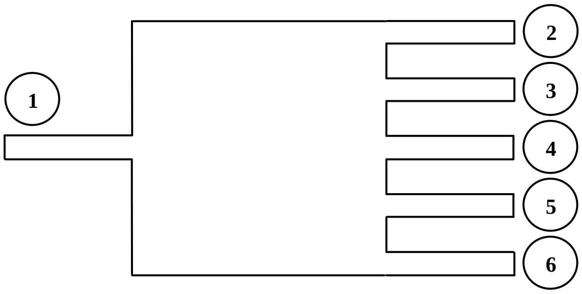

Fig. 1. Geometry of a six-port microstrip-square power divider.

The dividers were simulated by considering that a polytetrafluoroethylene PTFE substrate with $\varepsilon_r = 2.2$ and $H = 0.07874\,cm$ was used. Table 1 shows the dimensions and the impedances of the squares and their connection lines (input/output ports) for each one of the four dividers.

Table 1: Dimensions and impedances of the dividers.

Divider No.	Squares		Connection Lines	
	Side (mm)	Impedance Ω	Width (mm)	Impedance Ω
1	41.630	4.558	7.346	21.694
2	29.386	6.353	4.898	30.113
3	17.142	10.501	2.449	49.915
4	8.571	19.581	0.735	98.347

The S_{ij} scattering transmission parameters are shown in Figs. 2, 3, 4 and 5 for the dividers 1, 2, 3 and 4 respectively. As can be seen from these figures, very sharp magnitude responses are obtained at two resonant frequencies where the values are maxima. The shunt impedance of ports 2 to 6 is matched to the square's impedance in such a way that the magnitude minima of the S_{11} scattering reflection parameter at port 1 are at the same resonant frequencies.

The maxima of divider number 1 are at 1 GHz ($S_{21} = S_{61}$ = -6.849 dB, $S_{31} = S_{51}$ = -10.032 dB and S_{41} = -10.418 dB) and at 3.17 GHz ($S_{21} = S_{61}$ = -5.787 dB, $S_{31} = S_{51}$ = -9.095 dB and S_{41} = -9.571 dB).

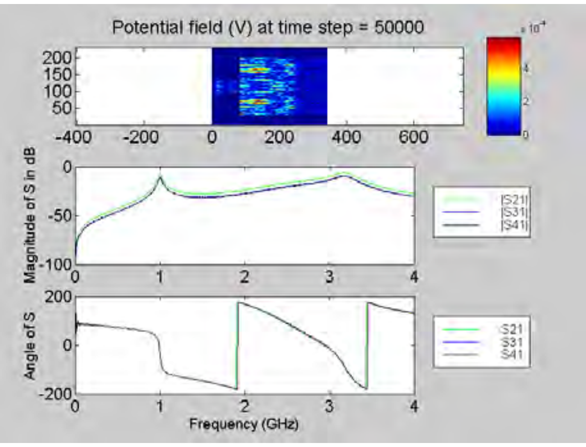

Fig. 2. Transmission scattering parameters for a microstrip-square power divider 41.630 *mm* wide.

The maxima of divider number 2 are at 1.43 GHz ($S_{21} = S_{61}$ = -7.16 dB, $S_{31} = S_{51}$ = -10.477 dB and S_{41} = -10.853 dB) and at 4.44 GHz ($S_{21} = S_{61}$ = -5.567 dB, $S_{31} = S_{51}$ = -9.194 dB and S_{41} = -9.720 dB).

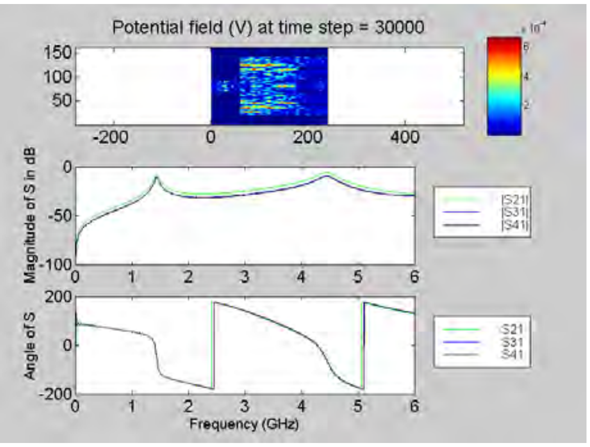

Fig. 3. Transmission scattering parameters for a microstrip-square power divider 29.386 *mm* wide.

The maxima of divider number 3 are at 2.51 GHz ($S_{21} = S_{61}$ = -7.825 dB, $S_{31} = S_{51}$ = -11.258 dB and S_{41} = -11.591 dB) and at 7.56 GHz ($S_{21} = S_{61}$ = -5.257 dB, $S_{31} = S_{51}$ = -9.209 dB and S_{41} = -9.746 dB).

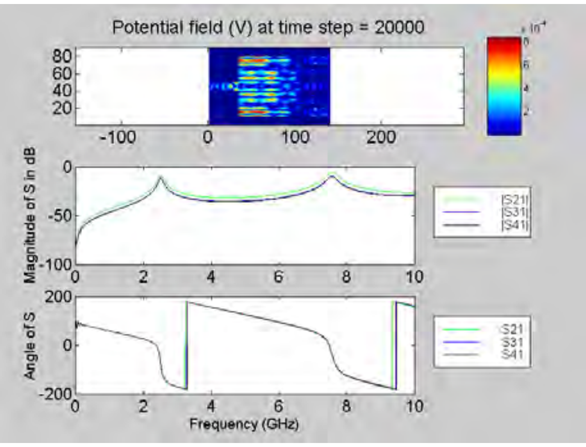

Fig. 4. Transmission scattering parameters for a microstrip-square power divider 17.142 *mm* wide.

The maxima of divider number 4 are at 5.24 GHz ($S_{21} = S_{61}$ = -10.427 dB, $S_{31} = S_{51}$ = -13.422 dB and S_{41} = -13.614 dB) and at 15.57 GHz ($S_{21} = S_{61}$

= -5.371 dB, S_{31} = S_{51} = -8.884 dB and S_{41} = -9.219 dB).

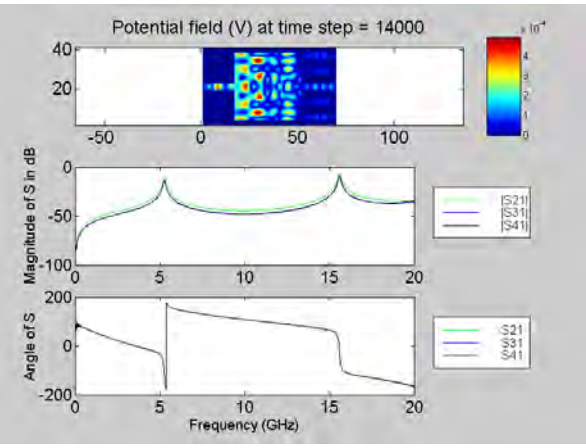

Fig. 5. Transmission scattering parameters for a microstrip-square power divider 8.571 *mm* wide.

III. THREE-PORT EQUAL-POWER SPLITTER

Other possible application of the in-phase divider [7] is that of the three-port equal-power splitter. A 3 dB power splitter is a fundamental part of several passive and active circuits as the signal separation structures [8] and the balanced amplifiers [9]. As a three-port, the equal-power splitter can't be simultaneously matched at all the three ports if the structure is considered as lossless and reciprocal [10]. Mandatorily, one of these conditions has to be released in order to achieve a physically realizable circuit. In the next section an energy conservation analysis will prove that the 3 dB power splitter can be assumed as lossless, thereby the splitter have to be nonreciprocal in order to get a concomitant matching in all ports. The power-splitter is considered as made on a PTFE substrate with the same characteristics as those given in the previous section.

Fig. 6 shows the S_{ij} scattering transmission parameters for a power-splitter with the following dimensions and impedances: a square 6.106 *mm* wide (25 Ω) and connection lines 2.449 *mm* wide (50 Ω).

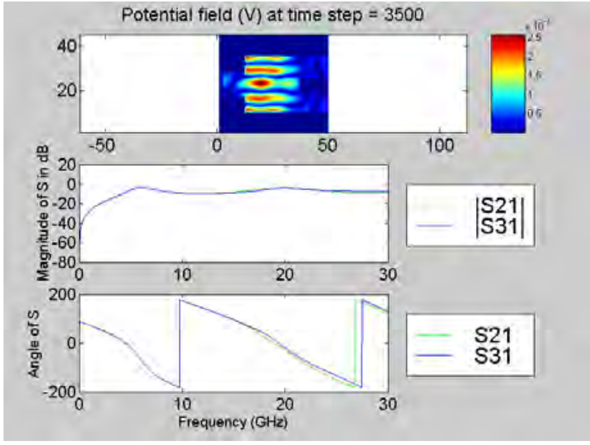

Fig. 6. Transmission scattering parameters for a microstrip-square three-port equal-power splitter 6.106 *mm* wide.

From the numerical results, it can be noted that a very good equal-power division (S_{21} = -3.239 dB, S_{31} = -3.220 dB) and almost a perfect relative phase ($|\angle S_{21}|$ - $|\angle S_{31}|$ = 0.129^o) is attained at a frequency of 6.03 GHz. Of course, this is possible only if a good matching between the microstrip square impedance and the equivalent impedance of the two shunt connected output ports is achieved.

The 3 dB bandwidth is found to be of 46.932 %, this is, from 4.9 to 7.73 GHz at a central frequency of 6.03 GHz, as shown in Fig. 7.

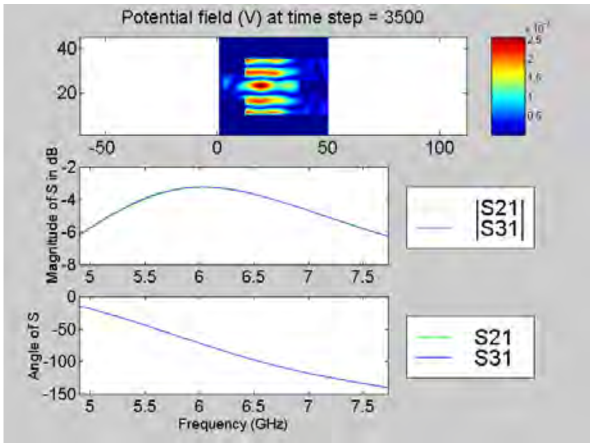

Fig. 7. The 3 dB bandwidth for a microstrip-square three-port equal-power splitter 6.106 *mm* wide.

IV. ENERGY CONSERVATION AND POWER BALANCE

A brief discussion on the energy conservation and power balance was presented in a previous paper [7]. That paper presented as well the energy conservation (EC) criterion for the six-port microstrip-square power dividers. The same criterion is addressed here for the three-port equal-power splitter on the basis of well matched termination ports.

The magnitude of the S_{ij} scattering parameters and the energy conservation are all shown in Fig. 8. As can be seen from this figure, the energy conservation is only slightly busted at the first resonant frequency and then growths beyond one, showing an unbalance of power that can be disregarded because is out of the 3 dB operation band.

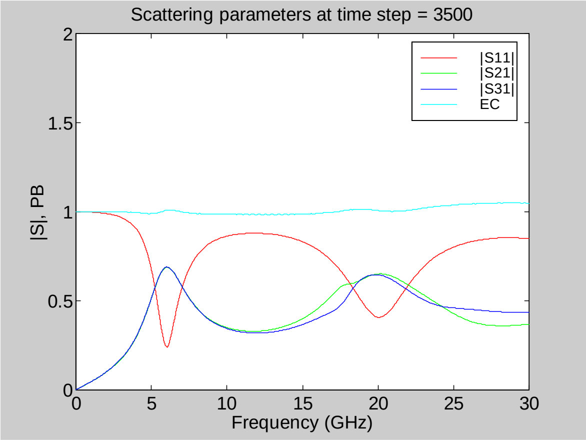

Fig. 8. Energy conservation criterion for a microstrip-square three-port equal-power splitter 6.106 *mm* wide.

V. CONCLUSION

Some well-behaved microstrip-square power dividers which may find application in printed circuit board and integrated high speed interconnects were presented. Also, a three-port equal-power splitter was described as an appropriate one for signal separation purposes. On one hand, the energy conservation analysis showed that low losses exist even at the resonant frequencies, and that a good power distribution among the output ports is achieved guarantying an excellent power balance. On the other hand, the fine results prove that it is not necessary to use complex electromagnetic simulation methods for analyzing these useful but uncomplicated networks which can be investigated by simple two-dimensional techniques as the FDTD one treated in [11].

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