Progress In Electromagnetics Research, Vol. 114, 383–393, 2011

SEVEN PORTS POWER DIVIDER WITH VARIOUS POWER DIVISION RATIOS

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Abstract—A seven ports network is proposed to act as a six-way power divider/combiner. The proposed network structure consists of a set of $\lambda/4$ planar transmission lines at the design frequency and does not require any isolating resistor. The power divider is capable of providing various power ratios by judicious choice of the transmission lines characteristic impedances. Design equations are derived for arbitrary power ratios. Simulation results obtained from the ADS software proved the possibility of achieving preset power ratios with fairly linear phase response over a certain bandwidth. The latter depends on the chosen power ratios. Measured results of manufactured power dividers agree well with simulations and theory.

1. INTRODUCTION

Power dividers and combiners are indispensable components in microwave circuits. They are used in many applications such as the reflectometers, radar system and feeding networks for antenna arrays. Power combiners are used to combine the outputs of semiconductor chips for high power oscillators and amplifiers.

The well-known Wilkinson power divider is a 2-way or generally N-way divider [1]. However, it has the disadvantage that it requires a floating common node to connect all isolation resistors, which rules out the planar geometry for $N > 2$ and causes difficulty in fabrication. This difficulty is alleviated in the modified design by Gysel [2], but both Wilkinson and Gysel dividers suffer from small operating bandwidth [3, 4]. recently novel dual band Wilkinson power dividers have been proposed [5–7]. Unequal Wilkinson power divider with dual-band operation was introduced in [8]. A miniaturized Wilkinson power

Received 30 January 2011, Accepted 3 March 2011, Scheduled 5 March 2011
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divider using nonuniform transmission line has been proposed [9]. A modified version of Gysel power divider with increased bandwidth that reaches 62% has been recently demonstrated [10]. A two way power divider with unequal power division has been recently proposed [11]. It has the property that the power ratio is independent on the characteristic impedances of the transmission lines but dependent only on their electrical lengths. Power divisions of 2:1 and 4:1 have been achieved using this divider over 20% bandwidth.

A three way power divider that does not need isolating resistors has been proposed in [12]. It comprises a six ports structure with one input port, three output ports and two isolated ports. The structure can be designed to have various power ratios. More recently a three way power divider with Ultra Wide-Band (UWB) performance has been proposed [13, 14]; it is built on a three dielectric layer structure which are coupled through slot coupled microstrip lines. Power division ratios of 1:1:1, 2:1:1 and 4:2:1 have been achieved with this structure over 3–10 GHz bandwidth. A three way unequal power divider has been recently introduced and it enjoys compact size and dual-band operation [15]. A 4-way power divider is realized using spatial power combining and two 1:2 power divider [16]. A six way equal power divider that does not need isolating resistors has been reported in [17]. It comprises two stages power division and uses coupled line sections. A three way triple band power divider has recently been proposed [18] to operate in the 900/1800/2400 MHz bands.

In this paper, we present a novel six way planar power divider that does not need any isolating resistors. The proposed divider is a seven ports structure capable of producing various power ratios over a wide bandwidth by properly adjusting the connecting line's characteristic impedances. In Sections 2 and 3, the theory and design of the proposed power divider for arbitrary power division ratios are given. Simulation results are obtained using Agilent's Advanced Design System (ADS) facility and are presented in Section 3. The discussion of the simulation results are given in Section 4. Power dividers with different power ratios are built and measured in Section 5. Comparison between measured and simulated results are given and followed by concluding remarks.

2. THEORY

The proposed power divider is a 7-ports planar circuit as shown in Fig. 1. Port 7 is used as an input port while ports 1 to 6 as the output ports which are assumed matched, hence there are no reflection from these ports. This circuit is symmetrical about the line joining ports 2,

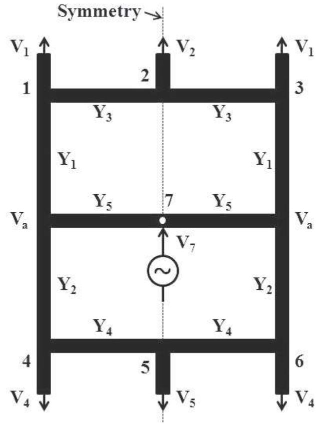


Figure 1. Seven ports power divider. The transmission lines joining adjacent ports are $\lambda/4$ long at the center frequency.

7, and 5. The transmission lines joining adjacent ports are $\lambda/4$ long at the center frequency.

Due to symmetry, we have $V_1 = V_3$, and $V_4 = V_6$. In the following we derive the amplitude levels of the outgoing waves from ports 1 to 6, when a unit wave is incident from port 7. The line characteristic admittances are given by Y_1, Y_2, Y_3, Y_4, and Y_5 as shown in Fig. 1. The output line admittance at all ports is denoted by Y_o. Considering node (1) and equating the total currents entering the node by zero, we get:

$$-jY_3V_2 - jY_1V_a - Y_oV_1 = 0 \tag{1}$$

Defining normalized admittances $y_1 = Y_1/Y_o$, and $y_3 = Y_3/Y_o$, (1) is rewritten as:

$$-jy_3V_2 - jy_1V_a - V_1 = 0 \tag{2}$$

Doing the same at nodes, 2, 7, 4, and 5, we get:

$$-2jy_3V_1 - V_2 = 0 \tag{3}$$

$$V_7 - 2jy_5V_a = 0 \tag{4}$$

$$-jy_2V_a - jy_4V_5 - V_4 = 0 \tag{5}$$

$$-2jy_4V_4 - V_5 = 0 \tag{6}$$

Equations (2)–(6) are solved for V_1, V_2, V_4, V_5, in terms of V_7 to get:

$$S_{17} = S_{37} = \frac{V_1}{V_7} = \frac{-y_1}{2y_5(1+2y_3^2)} \tag{7}$$

$$S_{27} = \frac{V_2}{V_7} = -2jy_3S_{17} \tag{8}$$

$$S_{47} = S_{67} = \frac{V_4}{V_7} = \frac{-y_2}{2y_5(1+2y_4^2)} \tag{9}$$

$$S_{57} = \frac{V_5}{V_7} = -2jy_4 S_{47} \tag{10}$$

In order to have matching at port 7; $S_{77} = 0$, an additional relation should be satisfied, namely

$$2|S_{17}|^2 + |S_{27}|^2 + 2|S_{47}|^2 + |S_{57}|^2 = 1$$

leading to the following condition:

$$2y_5^2 = \frac{y_1^2}{1+2y_3^2} + \frac{y_2^2}{1+2y_4^2} \tag{11}$$

Equations (7) to (10) mean that for a unit incident power at port 7, the output powers out of ports 1 to 6 are given by:

$$\begin{aligned} P_1 &= P_3 = |S_{17}|^2 = \frac{y_1^2}{4y_5^2(1+2y_3^2)^2} \\ P_4 &= P_6 = |S_{47}|^2 = \frac{y_2^2}{4y_5^2(1+2y_4^2)^2} \\ P_2 &= 4y_3^2 P_1 \quad \text{and} \quad P_5 = 4y_4^2 P_4 \end{aligned} \tag{12}$$

The special case $y_3 = y_4$ simplifies the expression of the power ratios; namely in this case:

$$P_1 : P_2 : P_4 : P_5 = 1 : 4y_3^2 : \left(\frac{y_2}{y_1}\right)^2 : \left(\frac{2y_2y_3}{y_1}\right)^2 \tag{13}$$

Next, we consider three design examples.

3. DESIGN EXAMPLES

3.1. Equal Power Division

In this design $P_1 = P_2 = P_4 = P_5$. Using (13), this requires that $y_3 = y_4 = 1/2$ and $y_1 = y_2$, while $y_5 = \sqrt{\frac{2}{3}}y_1$. For $Z_o = 1/Y_o = 50\,\Omega$, then $Z_3 = Z_4 = 2Z_o$, $Z_1 = Z_2$ and $Z_5 = \sqrt{\frac{3}{2}}Z_1$. See (11). As an example: $Z_2 = 50\,\Omega$,$Z_1 = Z_2 = 50\,\Omega$, and $Z_3 = Z_4 = 100\,\Omega$, hence $Z_5 = 61.2374\,\Omega$.

3.2. Unequal Power Division with 1:2:1:2 Power Ratios

In this design $P_1 : P_2 : P_4 : P_5 = 1 : 2 : 1 : 2$. This corresponds to $y_3 = y_4 = \frac{1}{\sqrt{2}}$ and $y_1 = y_2$, while $y_5 = \frac{y_1}{\sqrt{2}}$. Example: $Z_1 = Z_2 = 50\,\Omega$, and $Z_3 = Z_4 = \sqrt{2}Z_o = 70.711\,\Omega$ and $Z_5 = 70.711\,\Omega$.

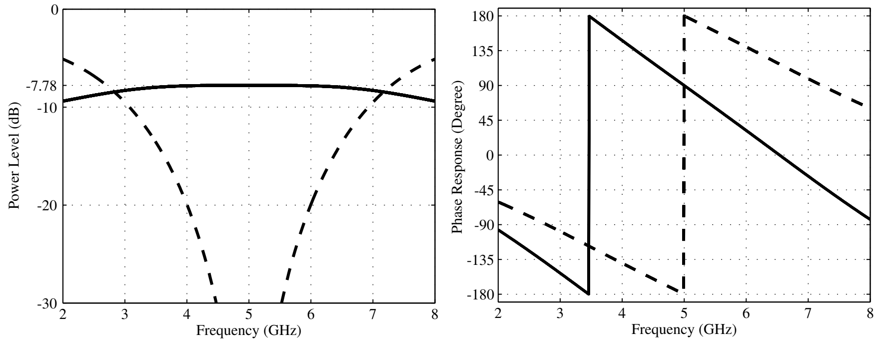


Figure 2. Simulation results for an ideal power divider with 1:1:1:1 power ratio. (a) Solid curve is the output power level in dB relative to input power at the 6 output ports ($P = -7.78\,\mathrm{dB}$) and dashed curve is the reflection coefficient $|S_{77}|^2$. (b) Solid line is the phase responses of S_{27} and S_{57}. Dashed line is the phase response at ports S_{17}, S_{37}, S_{47}, and S_{67}.

3.3. Unequal Power Division with 1:4:2:8 Power Ratios:

In this design $P_1 : P_2 : P_4 : P_5 = 1 : 4 : 2 : 8$. This corresponds to $y_3 = y_4 = 1$ and $y_2 = \sqrt{2}y_1$, while $y_5 = \frac{1}{\sqrt{2}}y_1$. Hence: $Z_3 = Z_4 = Z_o$, $Z_1 = \sqrt{2}Z_2$ and $Z_5 = \sqrt{2}Z_1 = 2Z_2$. Example: $Z_2 = 50\,\Omega$, $Z_1 = 70.711\,\Omega$, $Z_3 = Z_4 = 50\,\Omega$, and $Z_5 = 100\,\Omega$.

4. DISCUSSION OF SIMULATION RESULTS

The seven ports power divider was simulated with ideal transmission lines using Agilent's advanced design system (ADS) software. The simulated results for the three different power dividers (different power ratios) in Section 2 are discussed. The power in ports 1 to 6 for the equal power divider is equal to 1/6 or $-7.78\,\mathrm{dB}$ at the center frequency relative to the input power. The bandwidth can be defined either by the input reflection coefficient or by the flatness of the targeted output power from the output ports 1 to 6. In this paper the input reflection coefficient $|S_{77}|^2$ out of port 7 was chosen; this is to make sure that there is minimum reflection loss. Defining the bandwidth of the power divider as the bandwidth in which the input reflection coefficient $|S_{77}|^2$ is below $-10\,\mathrm{dB}$, it is found that the bandwidth in Fig. 2(a) covers the range 3.05–6.9 GHz which amounts to 77% around 5 GHz center frequency. (See Table 1). The phase response in Fig. 2(b) shows a

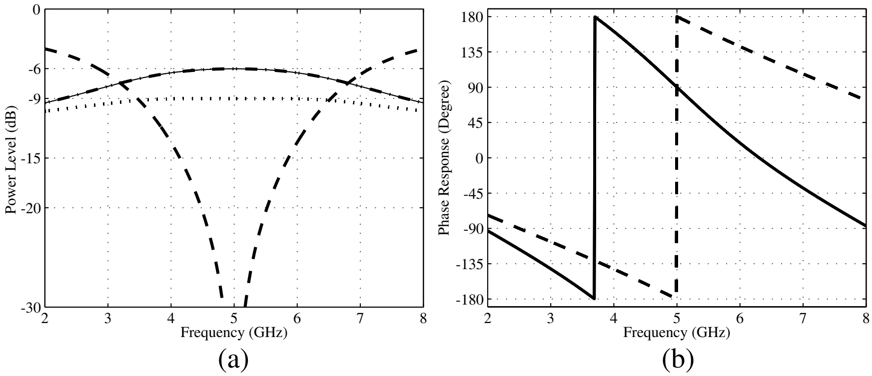


Figure 3. Simulation results for an ideal power divider with 1:2:1:2 power ratios in dB relative to input power. (a) Solid curve is the output power level at P_2 and $P_5 = -6$ dB. Dotted curve is the output power level at P_1 and $P_4 = -9$ dB. Dashed curve is the reflection coefficient $|S_{77}|^2$. (b) Solid line is the phase response of S_{27} and S_{57}, and dashed line is the phase response at ports S_{17}, S_{37}, S_{47}, and S_{67}.

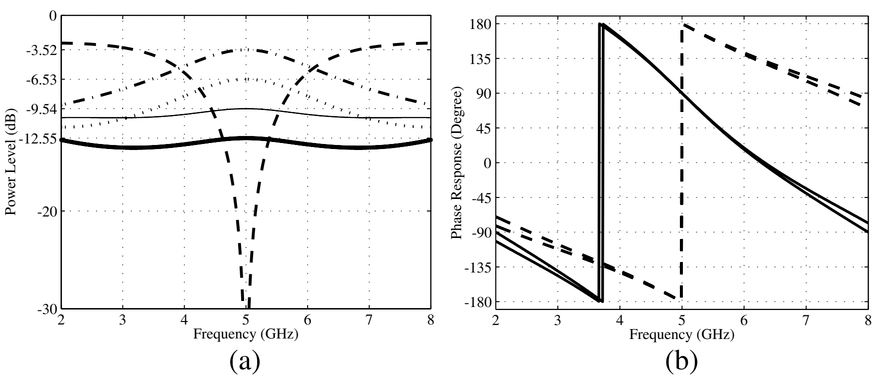


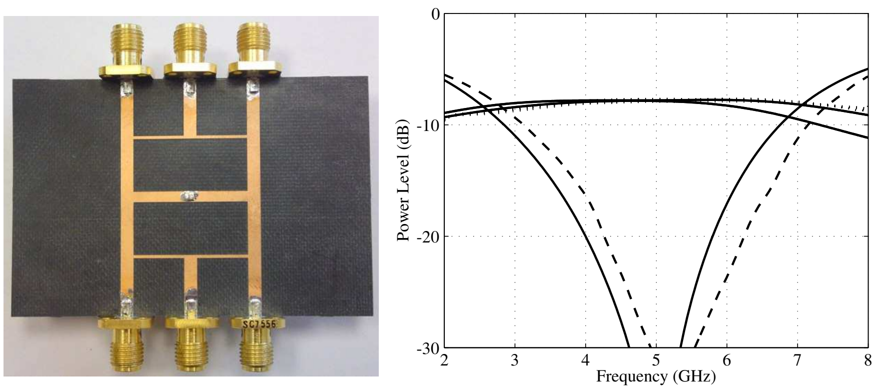
Figure 4. Simulation results for an ideal power divider with 1:4:2:8 power ratios. All output powers are normalized relative to input power. (a) Dashed-dotted curve is the output power level at $P_5 = -3.52$ dB, dotted curve is the output power level at $P_2 = -6.534$ dB, solid curve is the output power level at $P_4 = -9.544$ dB, thick solid curve is the output power levels at $P_1 = -12.55$ dB, and dashed curve is the reflection coefficient $|S_{77}|^2$. (b) Solid lines are the phase responses of S_{27} and S_{57}, dashed lines are the phase responses at ports S_{17}, S_{37}, S_{47}, and S_{67}.

Table 1. Performance of the power dividers.

Power Divider	Parameter	Value	BW percentage
1:1:1:1	-10 dB Bandwidth of $\lvert S_{77}\rvert$	3.85 GHz	77%
	Amplitude Variation	0.46 dB	
1:2:1:2	-10 dB Bandwidth of $\lvert S_{77}\rvert$	2.78 GHz	56%
	Amplitude Variation (P_2 and P_5)	0.83 dB	
	Amplitude Variation (P_1 and P_4)	0.12 dB	
1:4:2:8	-10 dB Bandwidth of $\lvert S_{77}\rvert$	1.06 GHz	21%
	Amplitude Variation (P_5)	0.57 dB	
	Amplitude Variation (P_4)	0.59 dB	
	Amplitude Variation (P_2)	0.23 dB	
	Amplitude Variation (P_1)	0.24 dB	

linear change with frequency within the bandwidth, which means a constant time delay or zero delay distortion. It should be noticed that the phase of port 2 and 5 is delayed by 90°.

Considering the power divider corresponding to Fig. 3 for 1:2:1:2 ratios, we find that for a unit incident power at port 7, $P_2 = P5 = 1/4$ (-6 dB) and $P_1 = P4 = P_3 = P6 = 1/8$ (-9 dB). It can be seen that



(a) (b)

Figure 5. Power divider with 1:1:1:1 power ratio. (a) A photograph of the fabricated structure. (b) Simulation (ADS Momentum) and measurement results. Dashed lines are measured and solid lines are simulated power levels.

the −10 dB bandwidth covers the range 3.61–6.39 GHz or 56% around the center frequency. (See Table 1). Within this bandwidth, the power level in ports 2 and 5 varies by about 0.83 dB, while the power level in ports 1 and 4 varies by about 0.12 dB. Note that the phase response is almost linear within this bandwidth, which imply zero delay distortion. Finally consider the power divider with 1:2:4:8 ratios, $P_1 = P_3 = 1/18$ (−12.55 dB), $P_4 = P_6 = 1/9$ (−9.54 dB), $P_2 = 2/9$ (−6.53 dB), and $P_5 = 4/9$ (−3.52 dB) for a unit incident power at port 7 (See Fig. 4). The −10 dB bandwidth is 21% and the phase response is fairy linear within the bandwidth. Table 1 summarizes the bandwidths of the three designs and the variation of power levels over this bandwidth.

5. SIMULATION AND EXPERIMENTAL RESULTS

The equal power divider and the two unequal power dividers are manufactured and are shown in Figs. 5(a), 6(a), and 7(a). The substrate used in all the designs is Roger's Duroid 5880 with dielectric constant of 2.2 and thickness of 0.787 mm. Measured results are given in Figs. 5(b), 6(b), and 7(b) along with simulations obtained for real transmission lines using Agilent's full-wave EM simulation software (ADS-Momentum). Good agreements is noticed between measured and simulated results. It is noticed that the bandwidth over which the power levels in the port remain constant depends on the design power ratios. Maximum bandwidth occurs for the equal power divider.

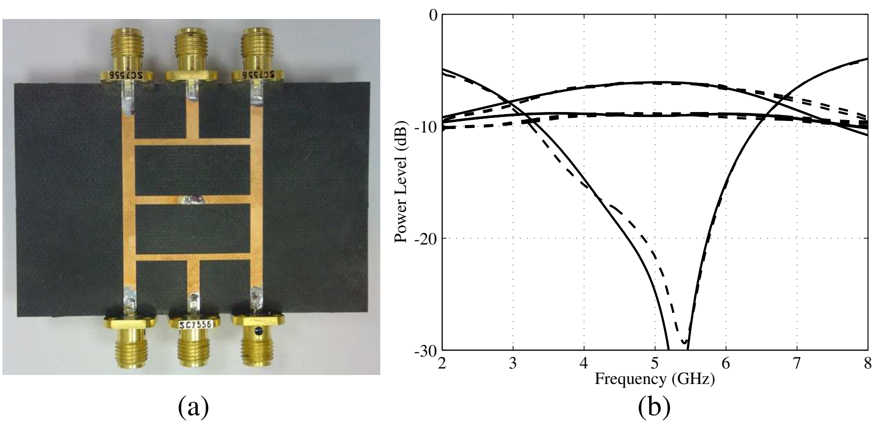
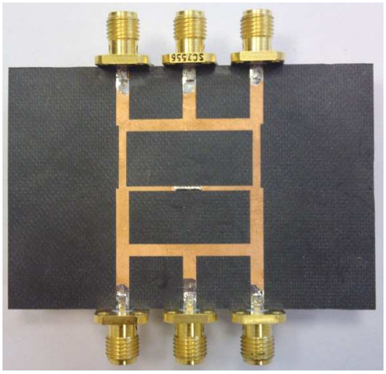
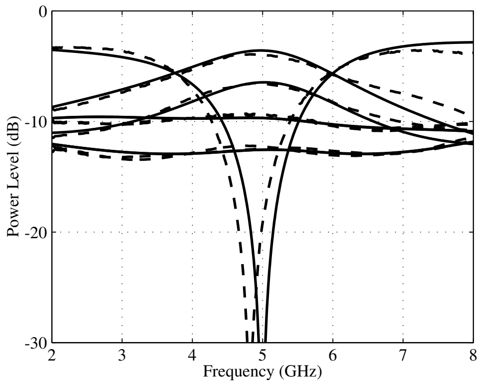


Figure 6. Power divider with 1:2:1:2 power ratio. (a) A photograph of the fabricated structure. (b) Simulation (ADS Momentum) and measurement results. Dashed lines are measured and solid lines are simulated power levels.



(a)



(b)

Figure 7. Power divider with 1:4:2:8 power ratio. (a) A photograph of the fabricated structure. (b) Simulation (ADS Momentum) and measurement results. Dashed lines are measured and solid lines are simulated power levels.

6. CONCLUSION

A six way power divider/combiner has been proposed. The power divider is implemented on a seven port planar network of $\lambda/4$ transmission lines. Design equations are derived to determine the transmission lines characteristics impedances for given power ratios. Power dividers of equal and unequal ratios (1:2:1:2, and 1:4:2:8) have been manufactured and measurements are taken. The measured and simulated results show fairly constant power levels and time delays over bandwidths that ranges from 21% to 77% depending on the designed power ratios.

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