ELectronics EXpress

IEICE Electronics Express, Vol.9, No.6, 596–601

# A variable power divider with 1:3 and 3:1 power division ratios

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**Abstract:** A variable power divider to be 3:1 and 1:3 power division ratios with the good inputmatching characteristic is proposed and fabricated. The proposed power divider has an ungrounded copper plane under two power-dividing lines. The power-dividing line becomes a microstrip line or a coplanar line based on the operating conditions of the ungrounded copper plane. The fabricated power divider at a center frequency of 1.5 GHz stably provides power division ratios of 3.2:1 and 1:3.2, with $S_{11} < -20$ dB over the frequency range 0.97–2.22 GHz.

**Keywords:** variable power divider, coplanar power divider, unequal power divider

**Classification:** Microwave and millimeter wave devices, circuits, and systems

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## 1 Introduction

Most receiving systems are supplied with a sufficient input power to restore a stable original signal, regardless of the variation in the communication environment. The input signal power except the minimum power needed to restore the original signal is surplus energy. If the power divider in the receiving system can change the power division ratio according to the input signal strength, this surplus energy can be used as new energy in the receiving system.



DOI: 10.1587/elex.9.596
Received February 21, 2012
Accepted February 28, 2012
Published March 25, 2012

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Research on power dividers with adjustable power division ratios is nearly nonexistent compared to fixed-ratio power dividers [1, 2]. The reasons are simple. First, there has been little need to change power division ratios in a power divider while the system works. Second, it is very difficult to build a variable power divider with stable operating characteristics. Since a change of the power division ratios means a change of the impedance ratio between power-dividing lines for power division, it is difficult to maintain stable port-matching characteristics and to transmit the input signal without distortion.

This study suggests a new variable power divider that can change the power division ratios without changing the input-matching characteristic. The proposed power divider using an ungrounded copper plane under the power-dividing line should have good input-matching characteristics over a wide frequency range, regardless of the power division ratio. The detailed construction and operating characteristics of the proposed power divider follow.

## 2 The proposed power divider

### A. Structure of the proposed power divider

Figure 1 (a) shows a block diagram of a two-way variable power divider with 50-$\Omega$ input and output impedance. If a Wilkinson power divider is used only for power distribution, no resistor is required between the two output ports [3]. The impedance of the power-dividing lines in a two-way power divider is determined by the power division ratios and port-matching characteristics. For good port-matching characteristics due to the power division ratio, the impedance of power-dividing lines "A" and "B" is easily calculated, as shown in Table I. For example, if the impedance of "A" and "B" is 57.9 and 100.2 $\Omega$, respectively, the combined impedance of the two power-dividing lines becomes 50.25 $\Omega$ and the power division ratio of the two output ports must be 3:1. If the impedance of "A" and "B" changes to 100.2 and 57.9 $\Omega$, the power division ratio becomes 1:3, without changing the combined impedance. Here, the electric length of "A" and "B" must be $\lambda/4$ of the operating frequency.

A variable power divider that can change power division ratios in the circuit can be implemented by changing the impedance of the power-dividing line. This can be accomplished in two ways. The first inserts an additional component in the transmission line, such as a diode, capacitor, or inductor. This is relatively easy to implement, but signal distortion as magnitude and phase characteristic changes in the operation frequency band and intermodulation distortion will occur. The second uses the impedance change of the power-dividing line. This method can divide the input signal without signal distortion, although its implementation is difficult. This paper proposes a variable power divider that uses an ungrounded copper plane under two power-dividing lines for the impedance change of the power-dividing line. If a PIN diode (or Schottky diode) is placed between the ground and the ungrounded copper plane, the power-dividing microstrip line has two differ-


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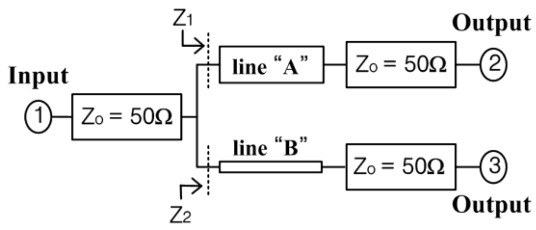
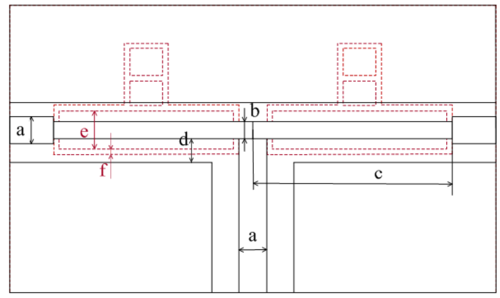



(a)




(b)

**Fig. 1.** Structure of the proposed power divider; (a) Block diagram of a general unequal power divider, and (b) Circuit diagram of the proposed power divider

**Table I.** Power division ratios ($P_1$:$P_2$) due to the impedance of power-dividing lines "A" and "B"

| A [Ω] | B [Ω] | $Z_1$ [Ω] | $Z_2$ [Ω] | $Z_1//Z_2$ [Ω] | $P_1$:$P_2$ |
|---|---|---|---|---|---|
| 52.4 | 165.8 | 55 | 550 | 50.0 | 11:1 |
| 54.8 | 122.5 | 60 | 300 | 50.0 | 5:1 |
| 55.9 | 111.8 | 62.5 | 250 | 50.0 | 4:1 |
| 57.9 | 100.2 | 67 | 201 | 50.25 | 3:1 |
| 59.2 | 93.5 | 70 | 175 | 50.0 | 2.5:1 |

ent impedances according to the diode's operation state. The ungrounded copper plane is floating plane when the diode is in the OFF state and the ungrounded copper plane is the ground when the diode is in the ON state. If the ungrounded copper plane is the ground, the power-dividing line becomes a microstrip line. And, if the ungrounded copper plane is floating, the power-dividing line becomes a coplanar line [4]. The impedance of the coplanar line exceeds the impedance of a microstrip line of the same line width.

Figure 1 (b) shows a circuit diagram of the proposed power divider. The black lines are microstrip lines on the upper surface of the substrate and the purple lines are both the ungrounded copper plane and the plane for voltage control via the diode on the lower surface of the substrate. The 50-Ω microstrip line in the middle of the upper surface is the input port, and the two 50-Ω microstrip lines at both ends of the upper surface are output ports. The proposed power divider can change power division ratios with good port-matching characteristics because one of two ungrounded copper planes is the ground and the other is floating. The length and width of the power-dividing line are determined as follows. Since the $\lambda/4$ electric length of the microstrip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line differs from the $\lambda/4$ electric length of the coplanar line, the length of the power-dividing line is set a reasonable length between the two lengths. The width of the power-dividing line determines the impedance of the microstrip or coplanar line. Since the power-dividing line operates alternately as a microstrip or coplanar line according to the power division ratio, the impedance of these lines that has optimum input-matching characteristics is paired. These impedance values are also heavily dependent on the substrate dielectric constant and thickness.

**B. Fabrication and measurement of the proposed power divider**

The proposed power divider was fabricated on TLX-9 laminate (h = 20 mil, $e_r = 2.5$; Taconic) at a center frequency of 1.5 GHz. Since the $\lambda/4$ electric length of the microstrip and coplanar lines using "linecalc" in ADS was 34.7 and 40.5 mm, respectively, the length of the power-dividing line was set at the geometric mean, 37.5 mm. The width of the power-dividing line was determined as follows. First, the width of the microstrip line according to the impedance was calculated for TLX-9 substrate. Then, the impedance of a coplanar line equivalent to each acquired width was calculated. Finally, the line width with a combined impedance of about 50 Ω for two power-dividing lines was determined. As a result, a line width of 1.05 mm corresponded to 59.4 and 100.6 Ω for the microstrip and coplanar lines, respectively. Then, the fabricated power divider with a combined impedance of 52.5-Ω for two power-dividing lines can operate with a 3:1 power division ratio. The size of the ungrounded copper plane and the distance between the ungrounded copper plane and the ground affects the impedance of the coplanar line. The dimensions of the fabricated power divider in Figure 1 (b) were set at **a** = 1.38, **b** = 1.05, **c** = 37.5, **d** = 0.67, **e** = 4, and **f** = 1.5 mm by considering the minimum length and distance that has little effect on the coplanar line. Two HSMP-4810 PIN diodes (Agilent Technologies) were connected at both ends of the ungrounded copper plane. If the power divider operated at a fixed frequency or within a narrow frequency band, the parasitic capacitance and inductance of the diode could be removed by changing the location of the diode on the ungrounded copper plane and inserting an offset microstrip line between the ungrounded copper plane and the diode. But, if the power divider operated over a one-octave range, the fabricated power divider had the best result when two diodes were connected at both ends of the ungrounded copper plane. The fabricated power divider is shown in Figure 2 (a) and (b).

The operating characteristics of the fabricated power divider were determined using an Agilent Technologies N5230A network analyzer. Figure 2 (c) shows $S_{11}$, $S_{21}$, $S_{31}$, and $S_{32}$ for the fabricated 3:1 power divider when the diode at the 2-port was ON and the diode at the 3-port was OFF. Conversely, Figure 2 (d) shows the operating characteristics for the reverse power division ratio of 1:3, *i.e.*, with the diode at the 2port OFF and the diode at the 3-port ON. The power divider with the 3:1 power division ratio exhibited $S_{11} < -25$ dB and a magnitude difference ($S_{21}/S_{31}$) of $5.1 \pm 0.5$ dB over 1.09–2.04 GHz. The reverse power divider with the 1:3 power division ratio exhibited $S_{11} < -22$ dB and a magnitude difference ($S_{31}/S_{21}$) of $5.0 \pm 0.3$ dB


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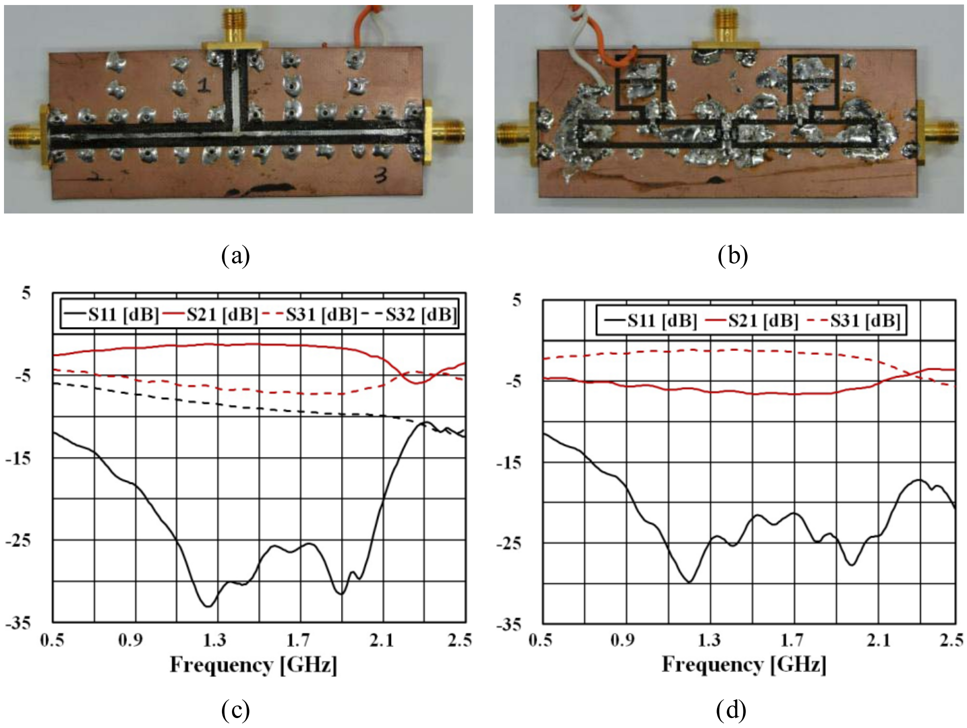


**Fig. 2.** The photograph ($87 \times 35\,\mathrm{mm}^2$) and operating characteristics of the fabricated power divider: (a) Front side of the fabricated power, (b) Reverse side of the fabricated power, (c) Case 1 ($S_{21}$: ON, $S_{31}$: OFF), and (d) Case 2 ($S_{21}$: OFF, $S_{31}$: ON)

over 1.01–2.2 GHz. Based on these results, the fabricated power divider had actual power division ratios of 1:3.2 and 3.2:1, with $S_{11} < -20\,\mathrm{dB}$ over the frequency range 0.97–2.22 GHz. In here, the ungrounded copper plane acted as neither a perfect ground nor a perfect floating because the HSMP-4810 diode used in the fabricated power divider had an impedance of about $3\,\Omega$ in the ON voltage state and about $9000\,\Omega$ in the OFF voltage state. If the diode is 0-Ω or ∞-Ω according to an applied voltage without parasitic capacitance and inductance, the fabricated power divider will have better results. Nevertheless, the fabricated power divider could be stably divided between ratios of 3.2:1 or 1:3.2 for input powers with a low insertion loss over a one-octave range.

## 3 Conclusion

A variable power divider was proposed and fabricated using an ungrounded copper plane under power-dividing lines. Since the operating state of an ungrounded plane changes the impedance of the power-dividing line, the proposed power divider can change power division ratios without signal distortion. The fabricated power divider had variable power division ratios of 3.2:1 and 1:3.2 similar to theoretical values, with low insertion loss and good input-matching characteristics over a one-octave range.

If it uses the detector circuit to measure the voltage according to the


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input signal strength, the proposed power divider can automatically change the power division ratio according to the input signal strength. And, the power division ratio of the proposed power divider is heavily dependent on the substrate dielectric constant and thickness. Using various substrates and types of ungrounded plane, the proposed power divider is easily implemented at various power division ratios. A variable power divider with various power division ratios will help to use surplus energy in receiving systems.


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