# A novel power divider with continuous power division

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# A NOVEL VARIABLE POWER DIVIDER WITH CONTINUOUS POWER DIVISION

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**ABSTRACT:** *In this article, a novel variable power divider based on varactor diodes is introduced and described in detail. Its main components are 3-dB couplers, varactor diodes, and lumped elements. The proposed power divider is initially studied using the even- and odd-mode techniques. Then, based on the derived equations and as an experimental verification, the proposed varactor-based power divider operating at the center frequency of 2.5 GHz is fabricated and its performance is measured. It is shown that the power divider offers a maximum insertion loss of about 1.8 dB with a minimum dynamic range of over 6 dB in the frequency range from 2.3 to 2.7 GHz. The results are discussed.*  Microwave Opt Technol Lett 55:1684–1677, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27603

**Key words:** *3-dB couplers; lumped elements; varactor diode*

## 1. INTRODUCTION

Variable control devices play an important role in modern communication systems. Examples of such devices—variable phase shifters, couplers, and attenuators are essential in the radio frequency (RF) front end of a typical transceiver chain. The control signal usually takes the form of either voltage or current, depending on the characteristics of the active device used.

Power dividers [1] are frequently used in a variety of microwave circuits, such as antenna feeding networks, point-to-point radio, and in Doherty amplifier architectures [2]. The use of variable power dividers in Doherty amplifier architectures is beneficial from many aspects. For example, a variable power divider at the input of the Doherty amplifier allows the use of fixed periphery carrier and peaking amplifiers to achieve different power backoff levels at which peak power added efficiencies are achieved.

The major problem in the realization of variable power dividers, either in the lumped or distributed form, lies with the feasibility of high-impedance lines necessary for an asymmetric power split. Previously, this problem has been partially solved by using varactor diodes in the circuit of a defected ground plane [3] at the expense of undesired electromagnetic couplings between closely spaced ports. In another approach [4], the classical circuit of a Wilkinson power divider given in Ref. 1, was loaded with varactor diodes to achieve a variable power ratio. However, the main drawback of this approach is a great number of varactors used (four) and a low-power division ratio of 5 dB.

A different approach towards the design of variable power dividers was given in Ref. 5. Here, an arrangement of four 3-dB hybrid couplers with a fixed 90° phase shifter and four movable short circuits was used to obtain a variable power division operation. An interesting circuit configuration has been reported in Ref. 6. Here, the variable power divider consists of two 3-dB hybrid couplers connected in cascade through a varactor diode shunted the quarter-wavelength transformer. Unfortunately, in this case, the size of the proposed divider prohibits its use at a lower GHz frequency range, due to the increased length of the quarter-wavelength transformer.

In this article, the operation of a variable power divider is achieved by using a balanced circuit consisting of two 3-dB hybrid couplers connected in cascade through shunted varactor diodes [7]. Due to the absence of distributed elements in the proposed design, the resulting circuit is very compact and lends itself easily to a generic microwave monolithic integrated circuit process.

The proposed divider was first analyzed using the even- and odd-mode techniques, upon which its general four-port matrix was derived. Then, as an experimental verification, a variable power divider operating at 2.5 GHz is fabricated on a commercially available RO4350B substrate [8]. The results are discussed.

## 2. THEORY AND ANALYSIS

Figure 1 shows the schematic of the proposed variable power divider. It consists of two 3-dB, 90° couplers connected in cascade through shunted varactor diodes in the direct and coupled arm, respectively. The direct port of the second 3-dB, 90° coupler is connected to a termination resistor $R$.

The even- and odd-mode analysis [9] is carried out under the assumption that the 3-dB couplers are ideal and the varactor diode can be represented by dc bias controlled admittance $Y$. The $S$-parameters matrix obtained in this way for the circuit of Figure 1 is given as

$$[S] = \begin{pmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{pmatrix} \tag{1}$$

where

$$S_{13} = S_{24} = S_{31} = S_{42} = T_s = \frac{j2}{2 + Z_0 Y} \tag{2}$$

and

$$S_{14} = S_{23} = S_{32} = S_{41} = R_s = -\frac{jZ_0 Y}{2 + Z_0 Y}. \tag{3}$$

In Eqs. (2) and (3), $T_s$ and $R_s$ represent the transmitted and reflected signals, whereas $Z_0$ is the characteristic impedance of the interconnecting transmission line. It can be shown that, if the admittance $Y$ of the varactor diode is purely imaginary, the power conservation condition is satisfied, that is,

$$\sum_{n=1}^{4} |S_{ni}|^2 = |T_s|^2 + |R_s|^2 = 1 \tag{4}$$

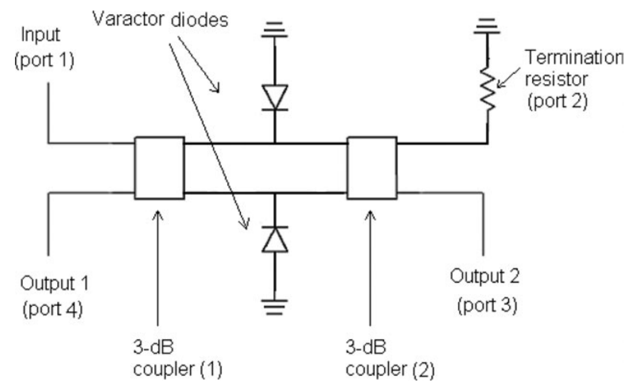


**Figure 1** Varactor based continuously variable power divide (bias circuit excluded for brevity)

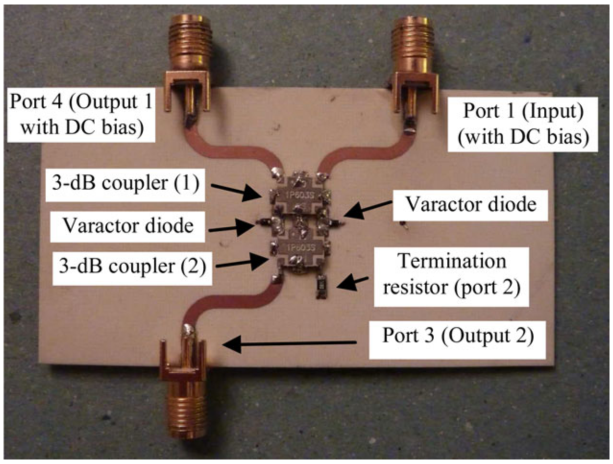


**Figure 2** Photograph of varactor-based variable power divider. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

This infers that the circuit of Figure 1 can be used as a continuous, variable power divider, where the distribution of input RF power is controlled by the reactance of the varactor diode. Further, it can also be shown that the differential phase shift between the transmitted and reflected signals is always equal to 90°, which can also be inferred from the circuit schematic of Figure 1.

### 3. RESULTS

Based on the equations derived in the previous section, and the circuit schematic of Figure 1, a continuously variable power divider has been designed and fabricated for operation at a center frequency of 2.5 GHz.

In the fabrication, a commercially available dielectric material, RO4350B from Rogers Corp. [8] was used, on which the circuit of the power divider was mounted. This material has the following characteristics: $\varepsilon_r = 3.66$, $h = 762$ $\mu$m, and $\tan\delta = 0.0031$. As a 3-dB coupler, a quadrature surface mount hybrid coupler 1P603S from Anaren [10] is used. This device operates across the frequency range of 2.3–2.7 GHz, with a maximum insertion loss of 0.3 dB. The varactor diode used in the circuit of the reflection load is a hyperabrupt diode from Aeroflex–Metellics [11], with part number MHV-500. According to the manufacturer's datasheet, the capacitance of the varactor die

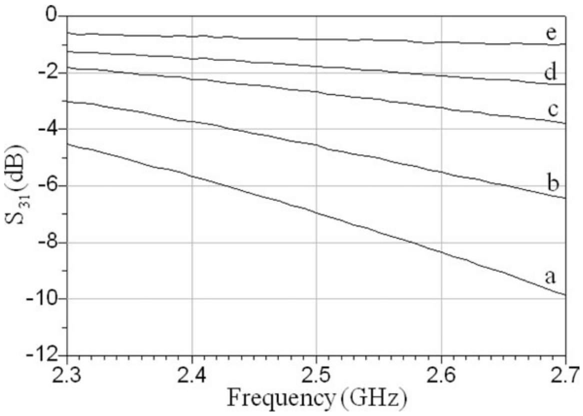


**Figure 4** $S_{31}$ of power divider of Figure 2 for different dc bias voltages: (a) 1.4 V, (b) 2.2 V, (c) 3.5 V, (d) 5.1 V, and (e) 20 V

varies from $C_{min} = 0.5$ pF to $C_{max} = 2.5$ pF, having a negligible parasitic resistance.

As a next step, the power divider of Figure 2 is fabricated and its *S*-parameters are measured for different settings of the dc bias voltage, which was conveniently supplied through a wideband bias tee. The *S*-parameters of the fabricated power divider, measured at dc bias voltages of (b) 1.4 V, (c) 2.2 V, (d) 3.5 V, (e) 5.1 V, and (f) 20 V, are presented in Figures 3–6.

As evident from Figures 3 and 4, the variation of power division between Ports 3 and 4 is obtained in the frequency range dictated by the 3-dB couplers. The minimum dynamic range obtained between the fully ''ON'' and fully ''OFF'' states is about 6 dB; however, this dynamic range can be extended by the appropriate choice of the varactor diode and the 3-dB couplers. The insertion losses of $S_{41}$ and $S_{31}$ are of about 1.8 dB and are partly due to the losses of the coupler (about 0.3 dB per coupler) and partly due to the parasitic resistance losses of the varactor diode. As elaborated earlier, these losses can be mitigated by the appropriate choice of the diode and 3-dB couplers.

The measured return losses ($S_{11}$, $S_{22}$, and $S_{33}$) are below 13 dB regardless of the dc bias conditions, due to the matched impedance property of 3-dB hybrid couplers, as shown in Figure 5. The measured phase difference between the transmitted ($T_s$) and reflected signals ($R_s$) shown in Figure 6 deviates from the theoretically predicted value of 90°. The measured magnitude of the phase variation for the proposed power divider is ±11°. The

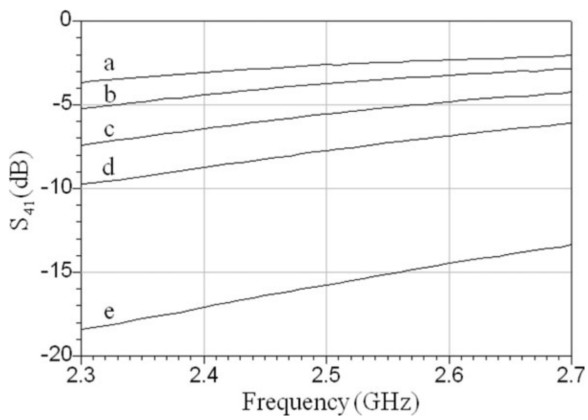


**Figure 3** $S_{41}$ of power divider of Figure 2 for different dc bias voltages: (a) 1.4 V, (b) 2.2 V, (c) 3.5 V, (d) 5.1 V, and (e) 20 V

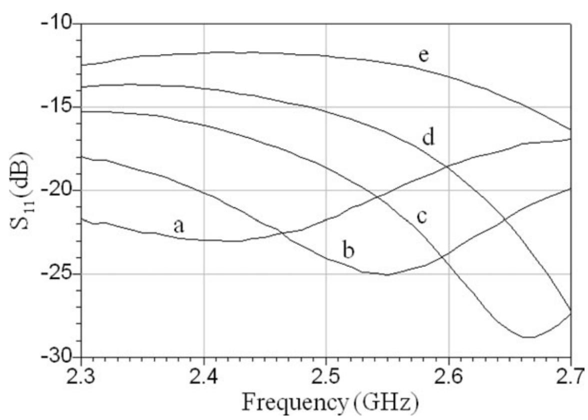


**Figure 5** $S_{11}$ of power divider of Figure 2 for different dc bias voltages: (a) 1.4 V, (b) 2.2 V, (c) 3.5 V, (d) 5.1 V, and (e) 20 V

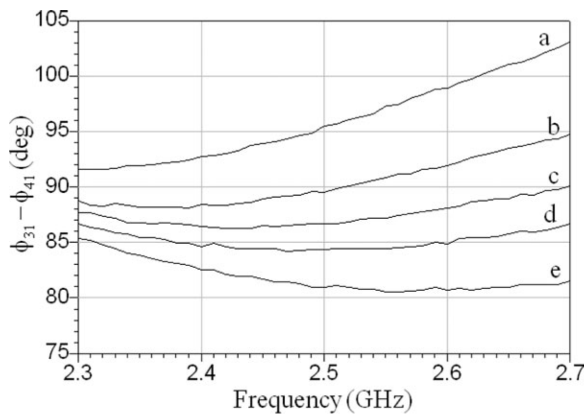


**Figure 6** Phase difference of transmitted and reflected signal of power divider of Figure 2 for different dc bias voltages: (a) 1.4 V, (b) 2.2 V, (c) 3.5 V, (d) 5.1 V, and (e) 20 V

phase difference is attributed to the unbalanced characteristics of the varactor diodes and 3-dB couplers.

## 4. CONCLUSION

A novel and compact variable power divider based on 3-dB couplers and varactor diodes is proposed in this article. The variable power divider is initially studied using the even- and odd-mode techniques. Then, based, on the obtained equations a variable power divider operating in the frequency range 2.3–2.7 GHz was fabricated and measured. The measured results reveal that the proposed structure offers a dynamic range of minimum 6 dB, whereas the reflection losses are greater than −13 dB, regardless of the dc bias conditions. It is, however, believed that the dynamic range can be extended by using balanced varactor diodes in the circuit of the reflective loads. The proposed structure is, particularly, suitable for the implementation in the circuit of a variable input power for the Doherty amplifier, due to its inherent 90$^o$ and continuous input power distribution.

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# A COMPACT HIGH DIRECTIONAL BEAM ANTENNA FOR WiMAX AND WiFi APPLICATION

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**ABSTRACT:** *A high directional beam antenna for wireless interoperability microwave access (WiMAX) and wireless fidelity (WiFi) is proposed. With a single circular radiator and a full ground plane, the antenna has successfully achieved a high directional gain of 6.7 dBi. Moreover, the proposed antenna is compact with a square substrate dimension of 50 × 50 mm$^2$. The implementation of the slot with a dimension of 0.8 × 10 mm$^2$ at the center of the radiator has resulted the circular current distribution that leads to the antenna efficiency of up to 87%. The patch antenna performed under tolerable $S_{11}$ of −10 dB covering operating frequencies of 2.36 GHz up to 2.40 GHz. Parametric study of the narrow slot size, coaxial port position, and the substrate size have been conducted in order to achieve the best antenna dimension with an optimum performance. The measured radiation patterns of the proposed single antenna show a top main beam of 0° and a peak side-lobe level of −17.6 dB, exhibiting a good agreement with the simulated results. Both simulation and measurement results prove that this optimized circular antenna is reliable for IEEE 802.16d fixed WiMAX, IEEE 802.16e mobile WiMAX, and WiFi application.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:1686–1680, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27638

**Key words:** *high directional; compact antenna; WiMAX antenna*

## 1. INTRODUCTION

The rapid growth of the wireless communication system due to the high demand for better capacities of broadband service and transmission speed to support multimedia, image, and video/audio streaming is exceptionally crucial. Moreover, the need of the new technology with the ability to overcome the absence of the communication infrastructure is the main concern over the past several years. Therefore, wireless interoperability microwave access (WiMAX) is the great of choice. WiMAX is capable to extend the internet access coverage up to 40 km for IEEE 802.16d fixed WiMAX and up to 3 km for IEEE 802.16e mobile WiMAX. However, WiMAX and wireless fidelity (WiFi) are perfectly compatible companions. WiMAX/WiFi synergies enable integration of both wireless technologies into notebooks and mobile devices. Therefore, with dual-mode WiMAX/WiFi from the dongle, your notebook and other mobile devices can use both WiMAX and WiFi technologies.

However, as the proposed microstrip antenna is specially made to be functioning in dual frequencies of WiMAX and WiFi mobile dongle, limitation of the conventional microstrip patch antenna in terms of size, gain, and complex structure has attracted huge intention among the researchers [1–3]. A bidirectional multiband of the fractal antenna is capable to operate in a digital communication system, WiMAX, IMT, and WLAN as discussed in [4]. However, the size dimension of 53.37 × 75.2 mm$^2$ is considered bulky to be fixed in a small receiver's dongle. The gain of 3 dBi also leads to the bad signal reception.