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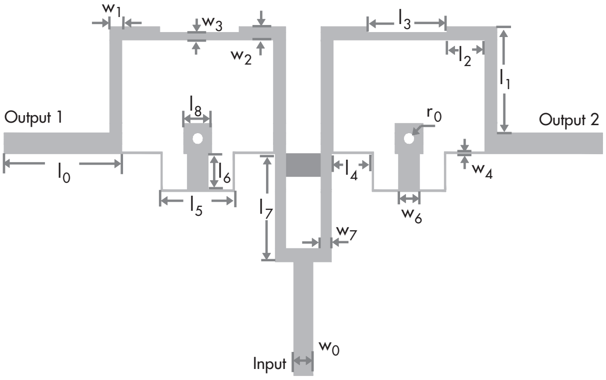
Miniature Resonator Guides UWB Divider

A ring-multiple-mode-resonator (RMMR) structure enables a compact, two-way power divider to achieve consistent performance.

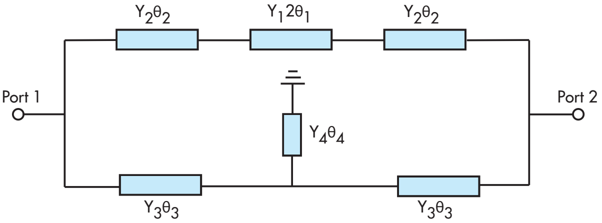
Ultrawideband (UWB) communications systems offer great promise for effective, short-range communications at relatively high data rates. To develop such systems, of course, various active and passive components are essential—e.g., amplifiers and filters, respectively. In support of these UWB communications applications, a compact UWB power divider was designed and fabricated with microstrip circuit technology using a ring-multiple-mode-resonator (RMMR) approach. To better understand the circuit design, the proposed resonator was studied by means of even- and odd-mode analyses.

By introducing the RMMR to a Wilkinson power-divider circuit layout, it was possible to design and fabricate a novel, compact microstrip UWB power divider. Simulated results and measured responses for the UWB power divider show close agreement, with low insertion loss and good return loss at all three ports and high isolation between the two output ports across the full UWB bandwidth of 3.1 to 10.6 GHz. The compact power divider measures just 20 × 30 mm.

Power dividers are essential passive microwave components widely used in both wired and wireless communications systems, as well as in satellite-communications (satcom) and radar systems. A two-way power divider provides an even division of input power into slightly less than one-half the power at the two output ports (after accounting for some losses due to circuitry, dielectric substrates, and connectors).



1. This layout represents the proposed UWB power divider.

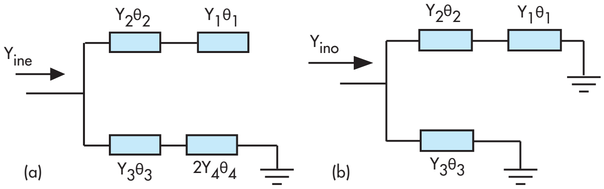


2. This is a schematic diagram of the proposed square RMMR.

Power dividers can be designed for more than two output ports, with the corresponding power division ratio determined by the number of output ports. Power dividers are also used in measurement systems; some performance characteristics, such as amplitude and phase consistency and flatness across the frequency range, can be critical.[1-8]

Conventional power dividers have been designed for octave and wider bandwidths once input and output ports have been properly matched to the system characteristic impedance (typically 50 Ω). That being said, UWB applications can place greater bandwidth demands on components such as power dividers. In 2002, the United States Federal Communications Commission (FCC; www.fcc.gov) proposed the frequency range from 3.1 to 10.6 GHz for UWB applications in the U.S.

A variety of commercial and industrial designs have been developed for research and practical use, and UWB devices and components with wide stopband characteristics have been the focus of many research efforts. Such circuits must be capable of providing good harmonic suppression and passband characteristics.



3. These equivalent-circuit models for the square RMMR were used to design the UWB power divider: (a) odd-mode circuit model and (b) even-mode circuit model.

A number of different power-divider configurations have been proposed for the extended bandwidth necessary to cover UWB applications. For example, cascading multisection matching networks at two output ports can provide broad bandwidth, but also increases the total size of the power-divider circuit and requires an increased number of resistors for higher isolation.

To serve the needs of emerging UWB systems, an in-phase power divider with bandpass response was developed[3] based on a multilayer microstrip-slotline coupling structure. The power divider employed a broadside coupling structure via a multilayer slot configuration and includes one narrow notch band.[4] Ring resonators were also used as part of the design to achieve miniaturization.[5-8]

A number of power-divider approaches were previously reviewed, so as to narrow down a design strategy suitable for achieving acceptable UWB performance. A four-way UWB coaxial-waveguide power divider was designed with a coaxial taper transition, oversized coaxial waveguide, and four coaxial probes.[5] In addition, an UWB power divider employing a ring-cavity multiple-way configuration was developed.[6]

A triband power divider was designed with the aid of network theory and even- and odd-mode analysis techniques, although the structure was complex. The design approach can be adapted to microstrip, which is relatively simple to implement and relatively low in cost.[7] Yet another power divider was created with a harmonic-suppressed ring resonator in a planar structure. However, it was relatively limited in bandwidth, with a frequency range from 1.41 to 2.68 GHz.

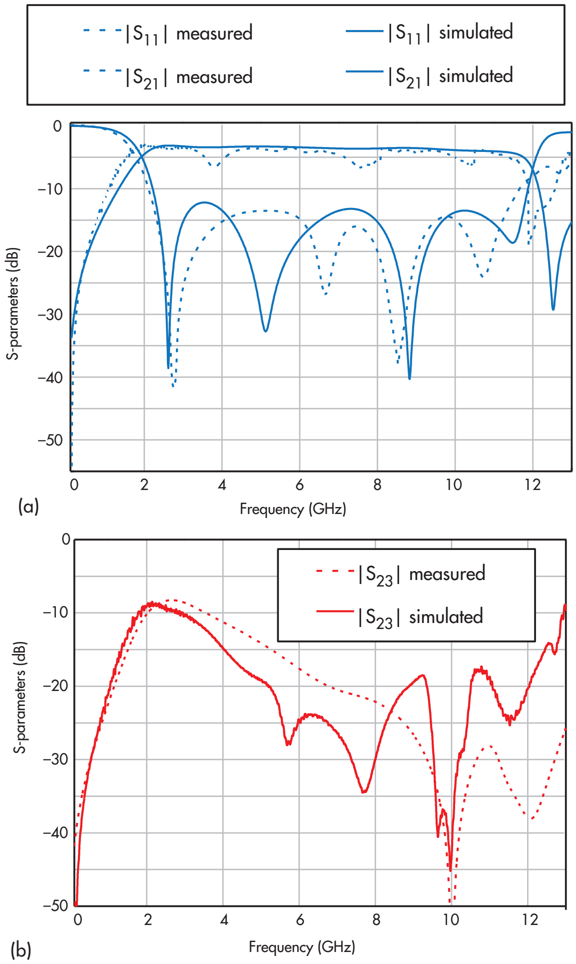
It was thought that a power divider based on a RMMR structure might provide the performance and bandwidth needed for UWB applications. The resonance behavior of the RMMR was first analyzed through application of electrical theory, then by studying the two pairs of resonance modes. Following this, the RMMR was incorporated into a basic Wilkinson power-divider circuit to achieve increased bandwidth, with computer simulations showing good results.

Finally, to validate the design approach, a microstrip power divider with RMMR was designed and fabricated. Measurement results reveal a wide bandwidth from 2.1 to 11.7 GHz with better than 10-dB return loss and quite good passband response, as evidenced by passband insertion loss of less than 3 dB.

Figure 1 shows the layout of the proposed UWB power divider. Isolation resistor R was placed at the end of transmission line L_1. The microstrip line $L_0 = \lambda_g/4$ (where λ_g is the guided wavelength at 6.85 GHz) is used to achieve good impedance match at port 1. Meander transmission lines were also used in this design to further reduce the size of the power divider. *Figure 2* shows the layout of the equivalent circuit for the square ring resonator.

The electromagnetic (EM) simulation software HFSS 13.0 from Ansoft Corp. (www.ansoft.com) was used to investigate the impact of using different dimensions on the performance of the UWB power divider. The power divider was fabricated on 0.508-mm-thick RO4350B printed-circuit-board (PCB) laminate from Rogers Corp. (www.rogerscorp.com). The circuit material exhibits a relative dielectric constant of 3.48 in the z-direction (thickness) of the material at 10 GHz, with loss tangent of 0.0027 at 10 GHz.

The following dimensions were used for the UWB power divider: $L_0 = 6$ mm; $L_1 = 5.7$ mm; $L_2 = 2$ mm; $L_3 = 6.7$ mm; $L_4 =$



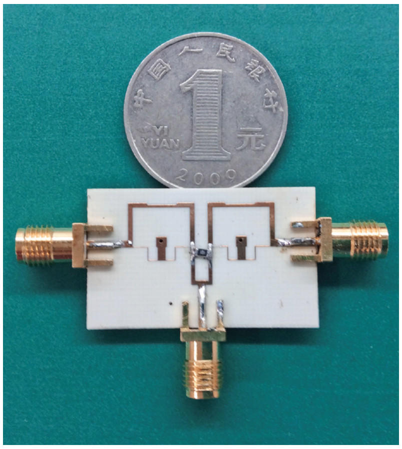
4. These plots provide views of the simulated and measured performance levels of the UWB power divider: (a) S_{11} and S_{21} magnitudes and (b) S_{23} magnitude.

> "With its strong performance and compact size, this power divider is a good candidate for UWB communications systems and in UWB radar imaging applications."

4.2 mm; $L_5 = 1.5$ mm; $L_6 = 4.5$ mm; $L_7 = 10$ mm; $W_0 = 1.1$ mm; $W_1 = 2$ mm; and $W_2 = 0.1$ mm. The total size of the power-divider circuit was 20 × 30 mm^2.

The even- and odd-mode analysis method can be applied to this proposed UWB power divider for studying the symmetry properties of the power divider. The simple schematic of the square RMMR is shown in *Fig. 2*, while the odd- and even-mode equivalent circuits are shown in *Figs. 3(a) and (b)*.

From port 1 to port 2, two transmission paths with characteristic admittances Y_2 and Y_3 were introduced, and a shorted stub with characteristic admittance Y_4 and electrical length λ_4 was connected by means of shunt in the center of the second transmission path. The characteristic impedance at port 1 is 50 Ω. When even/odd-mode signals are excited or introduced from ports 2 to 1, a virtual open/short appears along the center of the square ring resonator.



5. This photograph shows the fabricated UWB power divider with RMMR.

In the even mode, the stepped impedance stub is divided by one-half along the plane of symmetry. In the odd mode, the plane of symmetry can be considered as a ground plane, with no current flowing through the isolation resistor.

The even-/odd-mode input admittance Y_{ine}/Y_{ino} of *Fig. 3* can be computed via Eqs. 1 and 2:

$$Y_{ino} = -jY_3 \cot\theta_3 - \frac{Y_1 \cot\theta_3 - jY_2 \tan\theta_2}{Y_2 + Y_1 \cot\theta_1 \tan\theta_2} \quad (1)$$

$$Y_{ine} = jY_2 \frac{Y_1 \tan\theta_1 + Y_2 \tan\theta_2}{Y_2 \tan\theta_2 - Y_1 \tan\theta_1 \tan\theta_2} - jY_3 \frac{Y_4 \cot\theta_4 + 2Y_3 \tan\theta_3}{2Y_3 + Y_4 \cot\theta_4 \tan\theta_3} \quad (2)$$

Due to the symmetry of the square RMMR structure, resonant frequencies can be calculated when $Y_{ine}/Y_{ino} = 0$ from the one end of the even- and odd-mode circuit.[2] Thus, it cannot directly solve the expressions for the two pairs of resonant modes.

Moreover, another two odd-mode resonator frequencies, $f_{odd1}(\theta_1 = 120$ deg., $4f_0/3)$ and $f_{odd2}(\theta_1 = 180$ deg., $2f_0)$, can be realized. The bandwidth of the power divider increases as Z_1 increases and decreases as f_0, θ_2, and Z_2 increase. In this way, the bandwidth of the RMMR power divider can be conveniently controlled by changing the characteristic matrix values Y_1 and Y_4 and keeping Y_2 and Y_4 fixed. By properly tuning the dimensions of the RMMR, the desired bandwidth of the UWB power divider can be achieved.

Measurements on the fabricated power divider were performed with the aid of a model 8722ES microwave vector network analyzer (VNA) from Agilent Technologies (now Keysight Technologies; www.keysight.com). The measurements are compared to the simulated responses in *Fig. 4*. As shown, the fabricated UWB power divider features a wide passband from 2.1 to 11.7 GHz. The return loss is better than −10 dB across the passband, with insertion loss close to 3 dB across that same wide frequency range, which ensures good transmission performance across the passband of interest.

The isolation between the two output ports is better than 10 dB across the full UWB frequency range. Some deviations between simulations and measured results were expected, mainly due to reflections from connectors and the characteristics of the PCB material. The overall size of the fabricated divider was only 20 × 30 mm^2, which corresponds to a compact electrical size of $0.46\lambda_g \times 0.69\lambda_g$. With its strong performance and compact size, it becomes a good candidate for UWB communications systems as well as in UWB radar imaging applications. **mw**

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