X-band broadband substrate integrated rectangular waveguide power divider

K. Song, Y. Fan and X. Zhou

A novel broadband substrate integrated rectangular waveguide (SIRW) power divider is presented. Based on the equivalent-circuit method, broadband impedance matching about the current probe circuit has been achieved. A four-way SIRW power divider operating at X-band has been designed, fabricated and measured. Good agreement between simulated and measured results is found. The measured 15 dB return loss bandwidth is demonstrated to be about 40%, and its 1 dB insertion loss bandwidth is 4.2 GHz. This broadband SIRW power divider can be used widely in microwave and millimetre-wave circuits and system.

Introduction: The development of modern microwave and millimetre-wave communication systems requires high quality and high density circuit integration and packaging. Size and cost are two of the most critical requirements of these systems. This has stimulated a rapid development of many low-cost and compact passive components. Power dividers, which have been widely used as a key element in multiplexers, couplers, antenna feeding systems and power-combining systems, have been studied intensively for decades. However, conventional technologies for designing high-quality power dividers, including a metal rectangular waveguide or microstrip line, are either too expensive or unable to provide the required performance. Recently, a convenient and interesting planar integration scheme called substrate integrated waveguide (SIW) has attracted much interest. Many passive components, such as filters, antennas, circulators, power dividers etc., which are based on SIW or similar technologies, have been studied by researchers in [1–4].

A novel radial cavity SIW power divider has been presented by the authors [5], and it has demonstrated favourable characteristics. However, since the radial cavity SIW power divider is a resonant structure, it has only narrow bandwidth. In this Letter, we present the design and development of a novel broadband microwave and millimetre-wave substrate integrated rectangular waveguide (SIRW) power divider. The characteristics of such a design of SIRW power divider are its broadband, low cost, low profile, low loss etc., and its ease of integration into microwave and millimetre-wave integrated circuits.

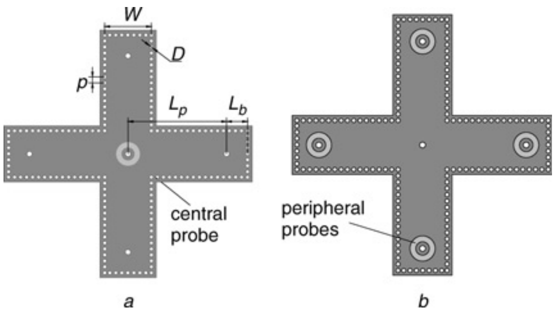

Fig. 1 *SIRW power divider*

a Top view
b Bottom view

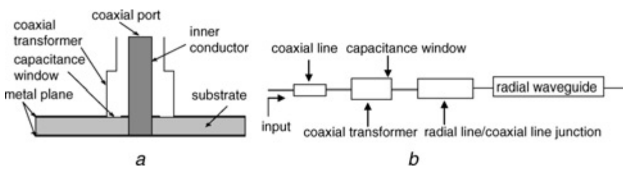

Fig. 2 *Equivalent-circuit model of current probe circuit*

Analysis and design of SIRW power divider: A four-way SIRW power divider is shown in Fig. 1, which originates from the conventional metal rectangular waveguide power divider. The SIRW is a type of dielectric-filled rectangular waveguide that is synthesised on a planar substrate with arrays of metallic vias to realise walls. As shown in Fig. 2*a*, the SIRW power divider is centrally fed using a stepped coaxial line transformer that can provide broadband impedance matching from the coaxial line to the radial line. We utilise the equivalent-circuit model (shown in Fig. 2*b*) to analyse the current probe. The stepped impedance transformer is a step discontinuity. Both the transformer discontinuity and the capacitance window can be modelled as capacitive reactances [6]. The junction discontinuity model of the coaxial line/radial line junction is based on Williamson's equivalent circuit [7], and the equivalent circuit for the current probe is shown in Fig. 3. The capacitive reactance of the stepped impedance transformer discontinuity and the capacitance window are jB and jB_c, respectively [6]. The input radial line is assumed to be excited only by the dominant *E*-mode, with its input admittance given in [6]. The parameters of the coaxial line/radial line junction R, jB_1, jB_2, and jB_3 can be obtained from [7].

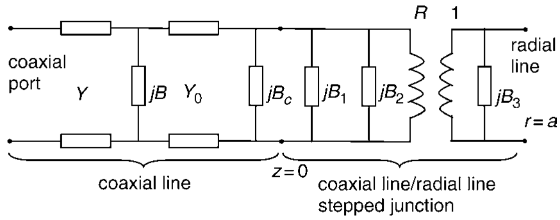

Fig. 3 *Equivalent circuit of current probe circuit*

After finishing the broadband matching of the current probes, an equivalent-circuit method can be used to design the SIRW power divider. The equivalent width *W*, the diameter of the via *D*, and the period of the vias *p* of the SIRW are easily obtained from [8]. The distance between the central probe and the peripheral probe is $L_p \approx n \cdot \lambda g/2$, while the distance between the peripheral probe and the short walls is $L_b \approx \lambda g/4$. Then, the dimensions of the SIRW power divider can be specifed.

Experimental results: A four-way SIRW power divider has been designed and fabricated. It is built with a substrate of thickness of 0.5 mm, with relative dielectric constant of 3.2 and dielectric loss tangent of 0.004 at 9.5 GHz. The commercial software CST Microwave Studio based on finite integration is used to simulate and optimise the power divider. The final dimensions of the SIRW power divider are (shown in Fig. 1): $L_p = 18.7$ mm, $L_b = 6.8$ mm, $W = 22$ mm, $p = 0.8$ mm, $D = 0.5$ mm. The coaxial probe inner conductor diameter is 1.3 mm, and the outer conductor diameter is 4.2 mm.

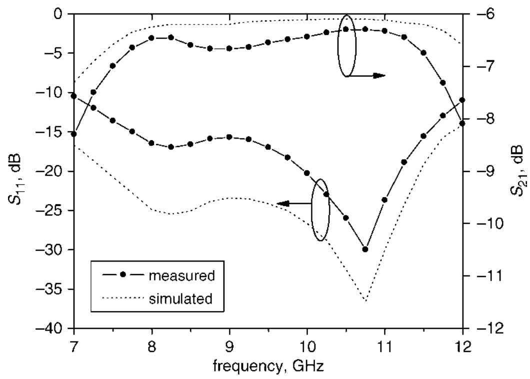

Fig. 4 *Simulated and measured results*

The simulated and measured results of S_{11} and S_{21} are shown in Fig. 4. The measured results include the influence of the SMA connectors at input and output ports. Thus there are some disagreements with the simulated results. The measured and simulated 15 dB return loss bandwidths were found to be approximately 40 and 50%, respectively. The bandwidth at which the minimum insertion loss increases by 1 dB was found experimentally to be about 4.2 GHz (from 7.5 to 11.7 GHz), which should be greater than 5 GHz by simulation. The higher insertion loss in the measured response is due to the insert loss of SMA connectors, measurement error, and the dielectric loss. It can also be seen from Fig. 4 that there has been little shift in frequency, which validates the accuracy of the design and simulation of the four-way SIRW power divider. In general, the measured and simulated results agree relatively well over the entire design band.

Conclusions: A broadband SIRW power divider suitable for microwave and millimetre-wave applications has been designed and tested. To realise the broadband impedance matching from the coaxial line to the radial line of the current probe, a stepped coaxial line transformer has been used. The stepped coaxial line transformer was analysed using the equivalent-circuit method. For verifying the design of a SIRW power divider, a four-way SIRW power divider has been fabricated and tested. Test results were compared with simulation. Experiments on the four-way power divider demonstrate a broadband operating frequency of 4.2 GHz. The SIRW power divider can be fabricated on the basis of our standard PCB process or LTCC circuits, and can be used in compact broadband microwave and millimetre-wave systems.

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