Broad-Band Power Divider Based on the Novel Split Ring Resonators

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Abstract **—** A broad-band power divider, based on proposed novel split ring resonators, with the use of surface-mount components, is presented in this paper. This paper is focused on the design of generalized novel split ring resonators in a fully planar configuration. This novel split ring resonator exhibits multiple, alternating backward and forward-transmission bands, and is therefore promising for the synthesis of wideband microwave components. The equivalent circuit models, including parasitic parameters, of the structures is presented (based on electrically small planar resonators), the detailed procedure for the synthesis of these resonators by using the proposed circuit model, is illustrated. It is shown that excellent results in both performance and size can be obtained through the proposed approach, fully compatible with planar technology.

Index Terms - Equivalent circuit models, power divider, and split-ring resonators (SRRs).

I. INTRODUCTION

In the past several years, the feasibility to take advantage of the unusual properties of the so-called metamaterial technology has led to a great deal of research activity [1-5]. At microwave frequency bands, the propagation medium is generally fabricated from transmission lines, loaded by split-ring resonators (SRRs) or implemented in a dual configuration with respect to a conventional one, namely with lumped series capacitances and shunt inductances [6-7]. The intense work carried out in the research group of Barcelona, Spain, is particularly representative of the SRR technology with several proposals, notably in terms of configurations on the basis of split-ring resonator and complementary split-ring resonator schemes [8].

On the other hand, the power divider and combiner are very important components for microwave power amplifiers [9]. Recent years, there has seen a worldwide effort to develop broadband power dividers due to the trend of wideband mobile systems [10-11]. Several power dividers based on the SRRs have been proposed. However, they are either high insertion loss or narrow band between output ports. To address this issue, this paper presents a novel broad-band power divider based on the SRRs but with improved performance compared with those previously mentioned work.

II. SYNTHESES OF BULK METAMATERIAS

Among much geometry proposed to date, edge-coupled split ring resonators (EC-SRR) has been studied in great detail for the design of such artificial media. The split ring structure can support resonant wavelengths much larger than the diameter of the ring [12]. The EC-SRR structure changes the real part of magnetic permeability from positive to negative values, when signals with frequencies higher than the resonance frequency propagate through it. This negative

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permeability can be employed with negative dielectric constant originating from another structure to produce negative refractive index materials [13]. In other words, the physical dimension is much smaller than the resonant wavelength, thus offering a quasi-static resonant effect and allowing very compact components designs.

When the EC-SRR shown in Fig. 1 (a) is excited by a time-varying external magnetic field directed along the z-axis, the cuts on each ring (which are placed on the opposite side of the EC-SRR) force the electric current to flow from one ring to another across the slots between them, in a form of a strong displacement current. The slots between the rings therefore behave as a distributed capacitance, and the whole EC-SRR has the equivalent circuit. EC-SRRs can be modeled as an LC resonant tank by virtue of the distributed capacitance (denoted as C) between concentric rings and inductance (denoted as L) of overall rings, as shown in Fig. 1 (b). The L is the SRR self-inductance and C is the capacitance associated with each EC-SRR half. The capacitance is $C = \pi r C_{\mathrm{pul}}$, where r is the mean radius of the EC-SRR, and C_{pul} is the per unit length capacitance along the slot between the rings. The total capacitance of this circuit is C/2 considering taking into account the series connection of the capacitances of both EC-SRR halves. R is the actual electromagnetic loss of the microstrip. Taking into account the circuit model, its resonance frequency can be expressed as,

$$w_0 = 1/\sqrt{LC} \ . \tag{1}$$

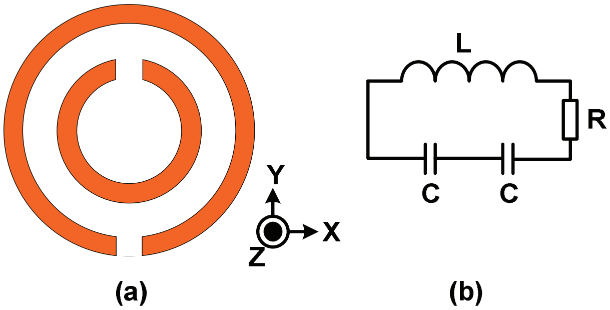


Fig. 1. (a) The typical edge-coupled split ring resonator (EC-SRR) and (b) its equivalent circuit model.

Spirals are well-known resonators in planar microwave circuitry. They can be used for the design of negative magnetic permeability and left-handed media [14]. This design also provides a strong magnetic dipole at resonance, thus being useful for metamaterial design. The electrical size can still be reduced by increasing the number of turns. This property is a clear advantage, as it implies a smaller electrical size at resonance. We have found that the printed circuit in Fig. 2 (a) has the same size as the one in Fig. 1 (a), but its resonant frequency is approximately one-half lower, which is shown in equation (2). From the equivalent circuit in Fig. 2 (b), it indicates that the resonance frequency of the 2-SR $w_{0[2\text{-SR}]}$ would be half of the resonance frequency of the EC-SRR $w_{0[\text{EC-SRR}]}$ with the same size [15]. Thus, the 2-SR is much easier to design and implement in RF and microwave circuits,

$$w_{0[2-SR]} = \frac{1}{2} w_{0[EC-SRR]} \ . \tag{2}$$

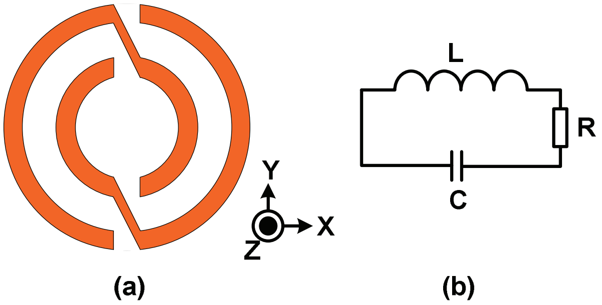
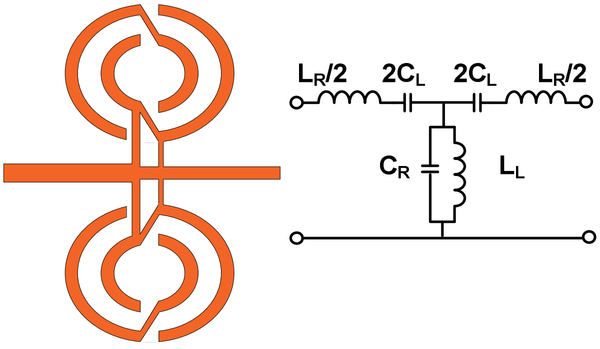


Fig. 2. (a) Typical two-turns spiral resonator (2-SR) and (b) its equivalent circuit model.

Based on microstrip technology, the layout and the canonical lumped circuit model corresponding to the proposed new 2-SR unit cell are characterized in Fig. 3 (losses have been excluded). Figure 3 (b) depicts the circuit model of the symmetrical unit cells shown in Fig. 3 (a). The LH contribution capacitance across the slot between the rings has been introduced into the model as C_L. The LH contribution, L_L represents the inductance generated by the 2-SR self-inductance. Similarly, the right-handed (RH) contribution contains the distributed shunt capacitance C_R and series inductance L_R, which are made by distribution parameters effect from the transmission line. To validate the use of the proposed new 2-SR unit cell for compact circuit design, a power divider implemented by means of an impedance inverter is designed and tested [16]. Apart from power dividers, this unit cell will find applications in the designs of compact impedance matching, filter and many other passive circuits [17].



(a) (b)

Fig. 3. Layout and canonical lumped circuit models of the new 2-SR unit cell; (a) the new 2-SR unit cell and (b) its equivalent circuit.

III. POWER DIVIDER DESIGN

The geometry of the proposed novel wideband power divider is shown in Fig. 4. This power divider printed is on a 0.254 mm thick RT5880 (substrate with dielectric constant $\varepsilon_r = 2.2$ and loss tangent $\tan\delta = 0.0009$) with overall dimension of 15×14.97 mm^2. The size of inner-square (R_1, R_2) should be adjusted to determine the central frequency of power divider as shown in Fig. 5. For fixed R_1 and R_2, the resonance frequency could be increased by decreasing length of branch (h), as shown in Fig. 6. It can also be obtained from Fig. 6 that the return loss of the power divider increases with increasing the branch length. These optimization works were managed by using commercial 3-D electromagnetic software high frequency structure simulator (HFSS) [18].

IV. RESULTS DISCUSSION

To validate the proposed design, the novel two-turns spiral SRR unit cell based power divider was fabricated. The photograph of the fabricated component is shown in Fig. 7. The prototype has been characterized and its relevant measured scattering parameters (return losses and transmission coefficients) are shown in Fig. 8. By comparing the measured and simulated scattering parameters in Fig. 8, well agreement between simulated and measured results is obtained for the novel wideband microstrip power divider. However, the measured central frequency (5.4 GHz) is slightly higher than the simulated one (5.25 GHz). This shift is attributed to fabrication tolerances, connectors, and the substrate properties [19-21]. The measured return loss is below -20 dB, and the measured insertion loss, at each branch, is approximately -3.2 dB at the central frequency. The slightly higher loss of approximately 0.2 dB is due to inaccuracies in fabrication of the structure. Figure 9 shows simulated electric field distribution at simulated central frequency (5.25 GHz) on the proposed broad-band power divider. It can be seen that the proposed power divider achieves equal power dividing performance at the operating frequency. The measured results show that this novel unit cell can be used in the design and fabrication of miniaturized RF and microwave circuits [22, 23].

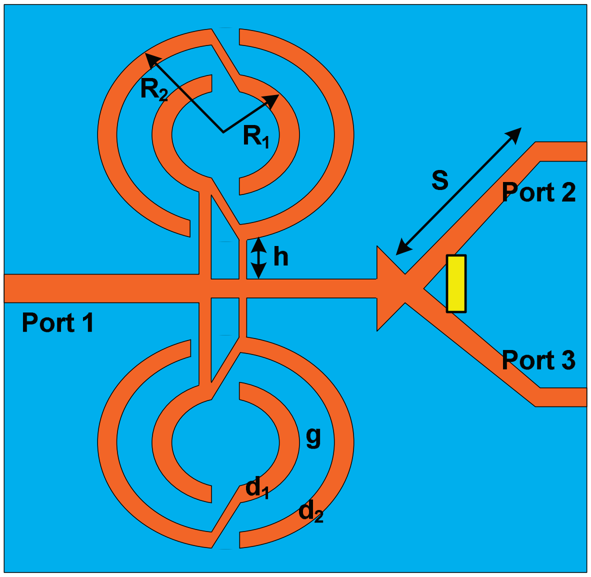
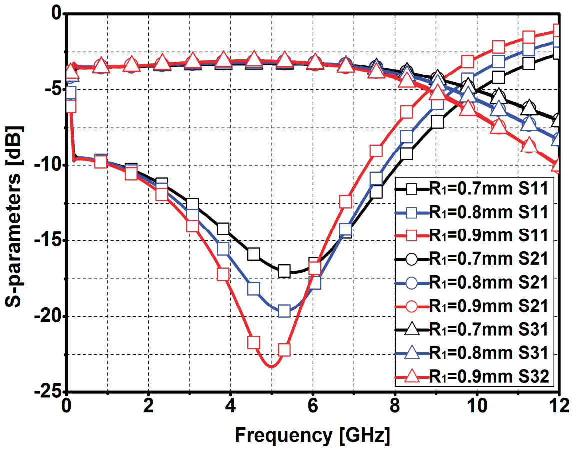
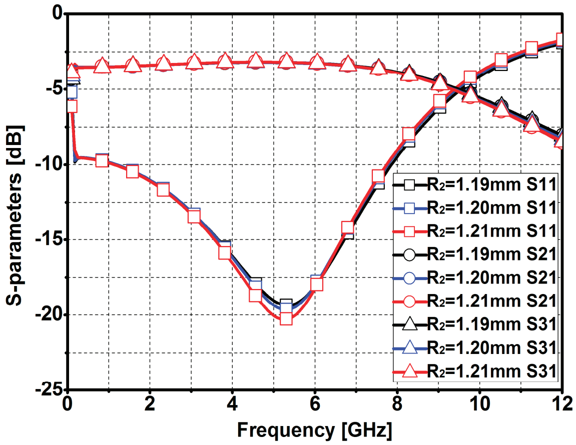


Fig. 4. Geometry of compact power divider, dimensions are R1 = 0.9 mm, R2 = 1.29 mm, d1 = 0.2 mm, d2 = 0.2 mm, g = 0.19 mm, h = 1.02 mm, S = 10.9 mm, W = 15 mm, and L = 14.97 mm.



(a)



(b)

Fig. 5. S-parameters of (a) different radius of R1 and (b) different radius of R2.

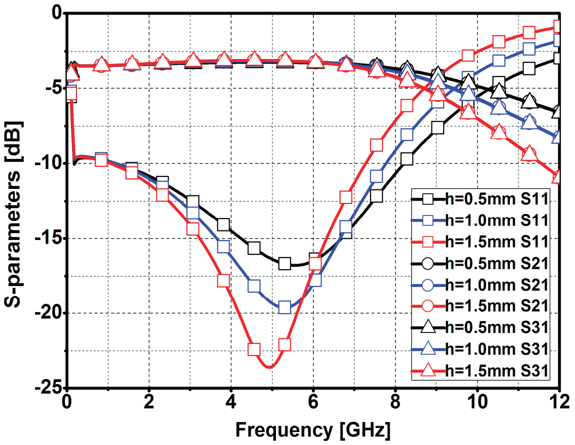


Fig. 6. S-parameters of different height of squares (h).

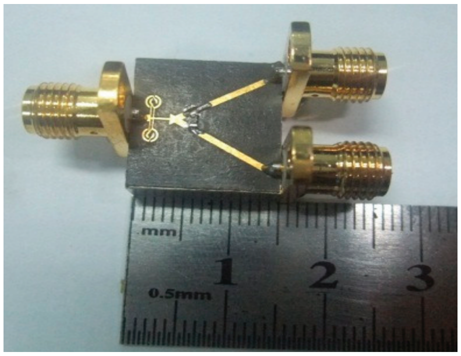


Fig. 7. Photograph of the proposed power divider.

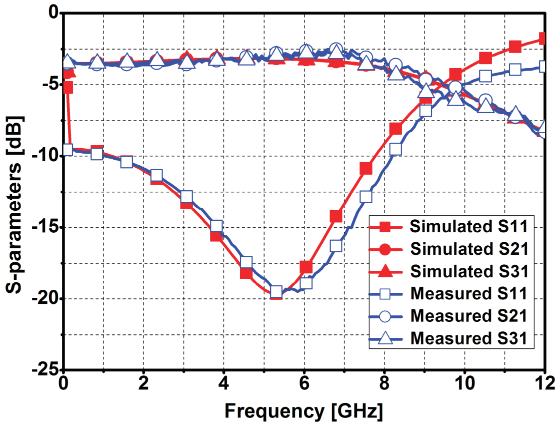


Fig. 8. Measured and simulated frequency responses for the thrus (S21 and S31), and the return loss (S11) of the wideband power divider.

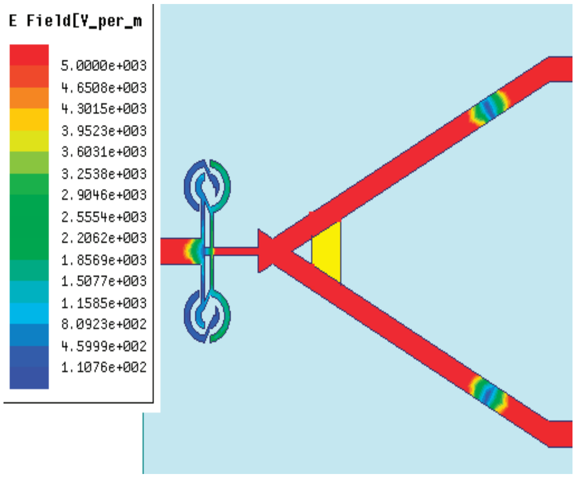


Fig. 9. Simulated electric field distriution at simulated central frequency (5.25 GHz) on the proposed wideband power divider.

V. CONCLUSION

A novel Wilkinson power divider using novel two-turns spiral resonator (2-SR) was proposed. The power divider not only shows excellent performance in a wide band, but also has compact size due to the use of proposed two-turns spiral SRRs cells. The new model developed is suitable for the design of compact broad-band microwave components, as has been demonstrated through the design and fabrication of a power divider. It can be easily implemented in microwave integrated circuit.

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