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Implementation of a compact microstrip power divider using novel split ring resonator

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ABSTRACT

A compact planar wide-band power divider for microwave wireless applications is presented. The miniaturization of the compact broadband power divider is implemented by using a novel co-directional split ring resonator (SRR) structure. The SRRs are etched on the conduct signal strip, which can be easily fabricated and integrated in planer microwave circuits. The proposed power divider has a compact size of only 15 × 14.97 mm^2. The measurement results show that the proposed power divider offers a wide bandwidth from 1 GHz to 7 GHz (S11 < −10 dB) successfully. The proposed power divider demonstrates equal dividing and good matching in all the relevant bands.

1. Introduction

In the past decade, the use of the unusual properties of the so-called metamaterial technology has led to a great deal of research [1], which makes it possible to reduce the size and tailor the performance of microwave components, such as, phase-shifters, couplers, power dividers and filters. Recently, ideas have been proposed to achieve both negative permittivity and permeability in a given frequency range by an appropriate engineering of the dispersion characteristics [2]. Nowadays, the propagation of microwaves is 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 [3]. The former approach is resonant in essence via the SRR technology and thus suitable for a narrowband operation [4]. In contrast, the latter approach exhibits broader transmission bands resulting from their composite left and right-handed characteristics [5]. 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 SRR and complementary split-ring resonator schemes (CSRR) [6].

In this paper, a compact broadband power divider based on the novel SRR structure is presented. By selecting a series rather than a corporate feed topology, the corporate-fed networks can be collapsed into a single feed line, reducing significantly the overall area of the structure [7,8]. Thus, series dividers are more compact and exhibit lower conductor, dielectric, and radiation losses compared with corporate dividers, leading to higher overall efficiencies when used in antenna arrays [9]. However, for conventional transmission line (TL)-based series dividers, the ratio of power delivered to each port varies with frequency due to the inherent frequency dependence of the TLs [10]. This work incorporates one-dimensional (1-D) metamaterial phase-shifting lines to implement a broadband 1:1 series power divider, providing equal power split to two output ports over a significantly larger band-width compared with conventional TL series dividers [11]. In addition, the proposed power divider is very compact, scalable in size, and can be extended to an arbitrary number of ports, therefore it is well suited for various applications including planar antenna feed networks and power-combining amplifiers [12–16].

2. Synthesis of novel SRR

The SRR was initially proposed by Pendry, consists of two concentric metallic split rings, as printed on a microwave dielectric circuit board (Fig. 1). When it is excited by a time-varying external magnetic field directed along the z-axis, the cuts on each ring (which are placed on opposite sides of the EC-SRR) force the electric current to flow from one ring to another across the slots between them, taking the form of a strong displacement current [17]. The slots between the rings therefore behave as a distributed capacitance, and the whole EC-SRR has the equivalent LC circuit as shown

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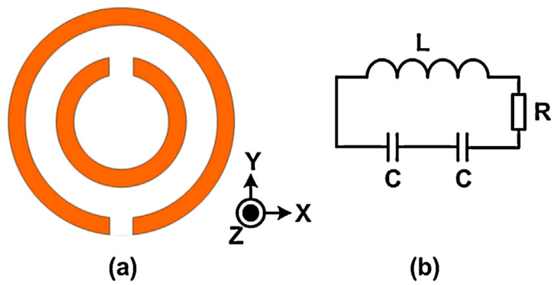

Fig. 1. Quasi-static circuit model for the EC-SRR. (a) Sketch of the resonator. (b) Equivalent circuit for the determination of the frequency of resonance, where C is the capacitance across the slots on the upper and lower halves of the EC-SRR: $C=\pi r C_{pul}$.

in Fig. 1, where L is the EC-SRR self-inductance and C is the capacitance associated with each EC-SRR half [18]. This capacitance is represented as $C=\pi r C_{pul}$, 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 $C/2$ which takes in account the series connection of the capacitances of both EC-SRR halves. Thus, neglecting losses, the equation for the total current I on the circuit is given by

$$\left(\frac{2}{jwc}+jwl\right) I = \Sigma \tag{1}$$

where Σ is the external excitation.

The traditional design of the SRR-structure is an open resonator as shown in Fig. 1, which is composed of two metal broken rings with the oppositely oriented gaps. The traditional split ring resonators were first introduced by J. Martel et al. in 2004. As seen from the layout, it is based on the SRRs which is obtained by cutting off parts of the rings, forming resonator, and increasing their length outwards [19]. The equivalent model of this structure is a series connection of inductance L and capacitance C with the microstrip line.

Currently, a majority of traditional edge-coupled SRRs possess fixed and often narrow-band response, which can be determined by capacitance between the rings due to their different induced charge distributions [20]. In contrast, when the inner ring is placed along the same direction as the outer ring (as depicted in Fig. 2), the capacitance coupling between the rings is drastically reduced due to their similar induced charge distributions. Thus, the co-directional SRR can exhibit broad distinct fundamental magnetic resonance frequencies for each ring. Simulations show that the edge-coupled SRR can only provide narrow distinct band gap, while the co-directional modified SRRs bring out broad-band fundamental magnetic resonance frequencies [21].

The unit cell of the co-directional SRR-based artificial microstrip line and its lumped element equivalent Π-circuit model are illustrated in Fig. 3 (losses have been excluded). This model is valid under the assumption that the electrical size of co-directional SRRs is small. The co-directional SRRs (etched on the top plane)

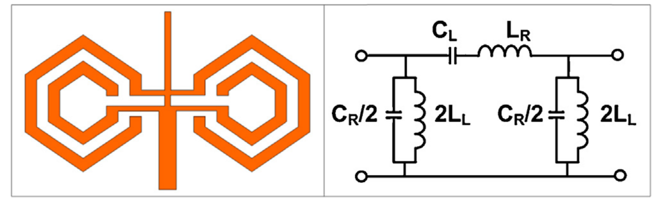

Fig. 3. Layout and canonical lumped circuit models of the new split SRR unit cell.

are described by parallel resonant tanks (with inductance L_L and capacitance C_L). The series gaps, which are etched vertical the co-directional SRRs to enhance line-to-SRRs linking, are represented by the capacitance C_R. While the line inductance, L_R, was made by distribution parameters effect from the transmission line, in order to simplify the analysis of the equivalent circuit and the synthesis of the devices, since the series impedance was clearly dominated by C_R in the region of interest.

Based on the co-directional SRR, a new unit cell implemented in a microstrip transmission line configuration is proposed in this paper, which is shown in Fig. 3. The novel resonators are directly connected to the microstrip line at the same metallization level. By tuning the physical parameters of the resonator structures, the strong magnetic coupling between line and rings emerges at the resonance frequency of SRRs. This impedes signal propagation in the proximity of the resonant frequency. The equivalent circuit shows that the geometry of this structure allows further degree of freedom in design. Microstrip or coplanar circuits built up by using SRR configurations require multilevel processing, both at the top level and the ground level. Contrary to these structures, the proposed structure here requires single level processing and avoids the use of complex processing steps. Thus, it is much easier to design and to implement in RF and microwave circuits.

To validate the use of the proposed new co-directional SRR unit cell for compact circuit design, a power divider implemented by means of a impedance inverter is presented in Fig. 4 [22]. Apart from power dividers, the unit cell is also suitable for applications in the design of compact impedance matching for many passive circuits [23]. Based on microstrip technology, the layout and the canonical lumped circuit model corresponding to the proposed new double-split SRR unit cell are characterized in Fig. 3 (losses have been excluded).

3. Power divider design

Here we reasonably assume that perimeter of the ring is smaller than a half-wavelength, and the capacitance associated with the cuts on each ring can be neglected. Under such assumptions, the current on each ring vanishes at each cut, and the angular dependence of the current on each ring can be assumed to be linear (so that the total current on both rings is constant). Such assumptions also imply that the voltage across the slots is constant in both co-directional SRR halves. A more detailed circuit model, which takes into account the gap capacitance and a transmission-line model for the slot between the rings, has been reported. It has been

Fig. 2. The proposed typical co-directional SRR.

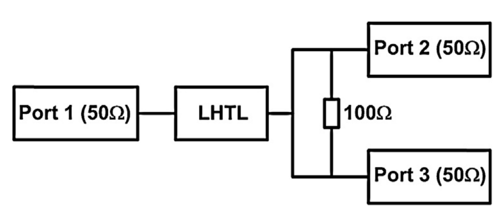

Fig. 4. Schematic of the proposed power divider.