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Wideband three section branch line coupler using triple open complementary split ring resonator and open stubs

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ABSTRACT

This paper presents the design of a wideband three section branch line coupler using three cascaded open complementary split ring resonator structures and open stubs connected between them. The slow wave effect offered by the open complementary split ring resonator is utilized to achieve size reduction. The low impedance lines of the conventional three section branch line coupler are replaced by the proposed structure which is 50–52% less in length. The fabricated prototype gives a bandwidth of 53% and occupies an area of 17.46% of the conventional one.

1. Introduction

Branch line coupler (BLC) is a common component widely used in wireless communication systems. The advantage of the branch line coupler is that, it divides power equally/ unequally with quadrature phase between the output ports. The branch line couplers have applications in the design of microwave elements, such as mixers, amplifiers, phase shifters and antenna array feed networks. The main drawback of a single section BLC is its short bandwidth (10–20%) [1]. In order to increase the bandwidth, several sections have to be cascaded. At lower frequencies, the cascaded sections occupy larger area. Therefore size reduction of these wideband devices is very much essential to produce compact systems. Several methods have been reported to achieve size reduction of these devices. Microstrip line along with defected ground structure (DGS) was used to design three section BLC [3]. In [4], four branch and five branch BLC is realized using photonic bandgap structure (PBG) and DGS. The limitation of DGS based design is that, there is a need of etching on both sides of the substrate, which requires additional position calibration and a minimum space underneath, resulting in an increase in the circuit volume. A wideband branch line coupler using symmetrical four strip interdigitated coupler is reported in [5]. This coupler has a wideband performance of 62% at the center frequency and the size is reduced up to 60 % when compared to the conventional coupler. Recently, symmetrical/asymmetrical T-shaped transmission line, pi-shaped transmission line, combination of both T-shape and pi-shape transmission lines and fractal shaped geometries have been used to design various single and multiple section couplers [6–10]. In [9], the quarter-wavelength low impedance transmission lines of the conventional three-section BLC is replaced by unequal length shunt open-stub units and a size reduction of 70.7% is achieved.

In this paper, a three section BLC is realized by replacing the quarter-wavelength low impedance transmission lines by cascaded open complementary split ring resonator structures and open stubs connected between them.

2. Open complementary split ring resonator

Open complementary split ring resonator is a sub wavelength resonator first proposed by F. Aznar et al. for realizing a compact low pass filter [11]. It is widely used to design various compact filters and power divider/combiner [12–14]. The layout of OCSRR is shown in Fig. 1. The resonance behaviour and transmission characteristics of OCSRR are already explained in [15]. By changing the dimensions of OCSRR, resonance frequency can be easily varied.

3. Realizing low impedance lines using OCSRR

OCSRR is designed and embedded in a 50 Ω microstrip line on RT duroid substrate having dielectric constant $\varepsilon_r = 2.33$ and substrate thickness of 0.787 mm, the layout is shown in Fig. 2. Let *'a'* be the length of OCSRR and *'l'* be the length of microstrip line embedded with OCSRR.

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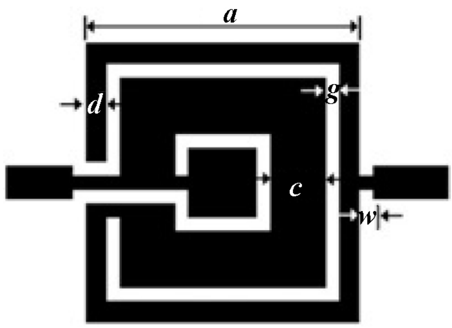

Fig. 1. Layout of open complementary split ring resonator.

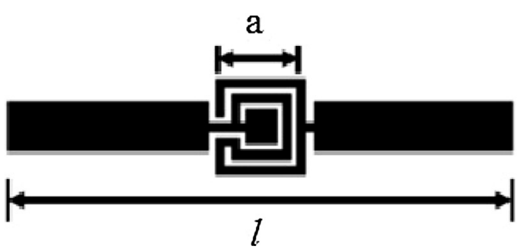

Fig. 2. Layout of microstrip line embedded with OCSRR.

The simplified transmission line model to calculate the characteristic impedance of OCSRR embedded microstrip line is shown in Fig. 3. The impedance of the OCSRR embedded microstrip line is calculated using the equations given in [16].

$$S_{11}[\mathrm{dB}] = 20\log|\Gamma| \quad (1)$$

$$Z_{in} = Z_0\frac{1+|\Gamma|}{1-|\Gamma|} \quad (2)$$

$$Z_{OCSRR} = \sqrt{Z_{in}Z_0} = Z_0\sqrt{\frac{1+|\Gamma|}{1-|\Gamma|}} \quad (3)$$

To replace any conventional transmission line having certain impedance and phase using reduced length OCSRR embedded line, the OCSRR embedded line must have the same impedance and phase similar to the conventional line at the design frequency. Consider a 54 Ω (which is one of the impedance value of the conventional three section branch line coupler) quarter wavelength transmission line with physical length of 59.71 mm at the design frequency of 0.9 GHz. To replace this conventional line with OCSRR embedded line, Z_{OCSRR} and phase must be 54 Ω and 90°. To obtain Z_{OCSRR} as 54 Ω, the required S_{11} value is −22.3 dB. It is calculated from the Eqs. (1)–(3). Inorder to achieve the desired S_{11} value, the OCSRR embedded microstrip line is simulated by adjusting the parameters 'a' and 'l'. The parameter 'a' of the OCSRR is varied while keeping the remaining dimensions constant (d = 0.4 mm, c = 0.4 mm, g = 0.25 mm, w = 0.3 mm) because it is the dimension that can be varied in larger amount and has larger effect on the transmission characteristics of OCSRR. Table 1 shows the possible impedance values that can be achieved with single OCSRR embedded microstrip line. It is observed that −22.3 dB is not achieved. Difficulties in realizing low impedance line using single OCSRR embedded microstrip line are, the structure of OCSRR is deforming as the parameter 'a' is decreased beyond 3.2 mm and physical length is increasing. Due to this size miniaturization is not possible. In order to decrease the electrical length, slow wave factor has to be increased. The slow wave factor is improved by cascading the OCSRR structures. Fig. 4 shows the layouts of double and triple OCSRR embedded microstrip lines.

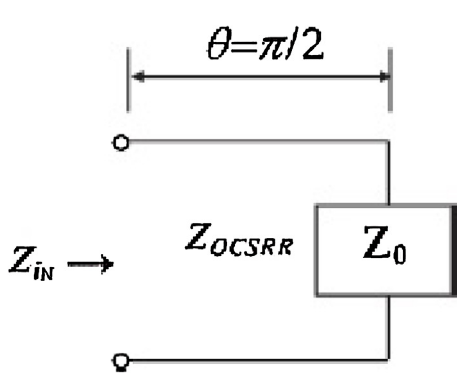

Fig. 3. Simplified transmission line model to determine the characteristic impedance of OCSRR embedded line.

Table 1
Impedance values that can be achieved using single OCSRR.

S. No	a (mm)	l (mm)	Phase (degree)	S_{11} (dB)	Impedance (Ω)
1	5	44	−89.70	−11.15	66.45
2	4.5	47	−90.25	−12.34	63.97
3	4	49	−90.27	−13.69	61.67
4	3.5	51.6	−89.02	−15.26	59.52
5	3.2	53	−90.85	−15.45	59.29

The slow wave factor of microstrip line embedded with and without OCSRR structure is calculated from the Eq. (4) given in [17] and plotted in Fig. 5.

$$\text{Slow wave factor (SWF)} = \frac{\lambda_0\Delta\theta}{360L_P} + \sqrt{\varepsilon_{eff}} \quad (4)$$

where L_P is the physical length of the microstrip line, λ_0 is the guided wavelength, $\Delta\theta$ is the phase difference (in degrees) of microstrip lines with and without OCSRR, ε_{eff} is the effective permittivity.

From Fig. 5 it is observed that the slow wave factor of triple OCSRR embedded in a 50 Ω microstrip line is high and it can be used to realize a 54 Ω transmission line. Table 2 shows the possible

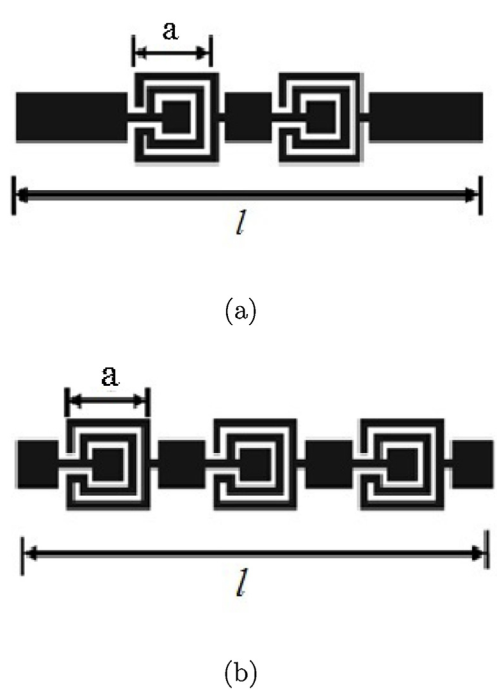

Fig. 4. Layout of (a) double OCSRR embedded microstrip line; (b) triple OCSRR embedded microstrip line.