

# CPW bandstop filter using slot-type SRRs

J. Kim, C.S. Cho and J.W. Lee

The bandstop characteristic of a slot-type split-ring resonator (SRR) on a substrate used for microwave frequencies is presented for a bandstop filter. Analogously to the conventional strip-type SRR, the slot-type SRR is very attractive for notching unwanted band because of its small dimension and high  $Q$  operation. In addition, the complementary SRR can be easily applied for coplanar configuration, which is favourable to MMIC designs. Based on the simulation and measurement results, the slot-type SRR for the bandstop filter is very effective in rejecting unwanted frequency in terms of its selectivity and size.

**Introduction:** The split-ring resonator (SRR) was originally introduced by Pendry *et al.* [1] to construct the left-hand materials. The electromagnetic waves in these materials behave corresponding to the left-handed rule, the reverse manner with respect to the conventional rule for right-handed materials. The SRR is of prime interest because of its resonant behaviour. The SRR can be considered as an electronically small resonant structure with a high  $Q$ , which means that it is a very attractive structure to construct filters that need to notch or pass certain frequencies sharply. The SRR has the resonance and anti-resonance properties that can pass or stop the flow of the electromagnetic field that is polarised and localised along the SRR array, because the SRR has a resonance permeability and antiresonance permittivity [2].

In this Letter, the SRR is used to reject unwanted frequency for a bandstop filter because of its high  $Q$  characteristic and small size. However, it is not easy to apply a conventional strip-type of SRR in a coplanar configuration. Therefore, a slot-type SRR is proposed for coplanar configuration in this Letter. Since the slot-type SRR takes a complementary form of strip-type SRR, it can be used to generate a resonance, while properly maintaining a coplanar configuration.

**Design of slot-type SRR:** The SRR is generally composed of two concentric split-ring strips, which are under main investigation by researchers to implement the left-hand materials. In this research, we take advantage of its theory and experimental results that have been already proven and realised. Instead of the strip-type SRRs, the slot-type SRR is proposed for bandstop applications in this work since the slot-type SRR can be applied for a coplanar configuration. Moreover, it provides a high  $Q$  characteristic, similar to the strip-type SRR.

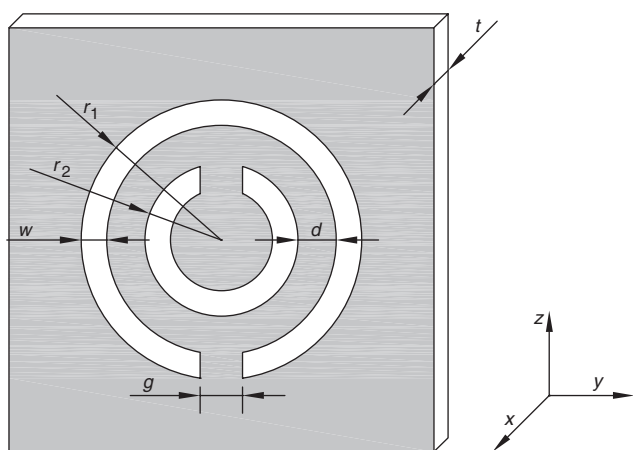


Fig. 1 Geometry of proposed slot-type SRR

Publications about the SRR, regarding both the theoretical and experimental aspects [3, 4], are utilised as design guidelines to design the geometry of the slotted complementary form of the SRR on a conducting plane. If a wave polarised in the axis of  $y$  propagates in the  $z$ -direction, as in Fig. 1, the SRR can be symmetrical about the axis of  $z$ . Under this condition, using the same approach as in [5], the resonance

frequency can be postulated as

$$\omega_0 = \sqrt{\frac{2}{\pi r_0 L_0 C}} \tag{1}$$

where  $L_0$  is the inductance per unit length between the annular slots,  $C$  is the total capacitance of the SRR, and  $r_0$  is the average radius of the two annular slots.

Corresponding to the resonance frequency, its equivalent LC circuit was modelled as shown in Fig. 2. We can take (1) into account to obtain the dimensions of the SRRs at the beginning stage of design and then tune the geometry for the final design. The average circumferential length of the slotted rings is shorter than a half wavelength at resonance. The average circumferential length of the SRR is dominant in determining the resonant frequency. The behaviour of the slotted complementary SRR is very similar to that of the SRR. The complementary SRR can create the strongest resonance when parallel polarisation occurs, since the parallel polarisation means that the E-field is parallel with the  $y$ - $z$  plane and the H-field is aligned with the centre axis ( $x$ ) of the complementary SRR.

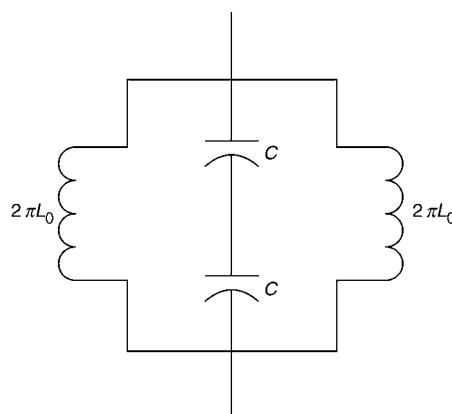


Fig. 2 Equivalent circuit model for proposed slot-type SRR

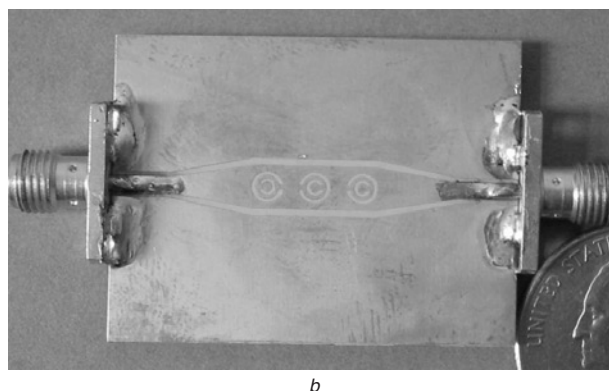
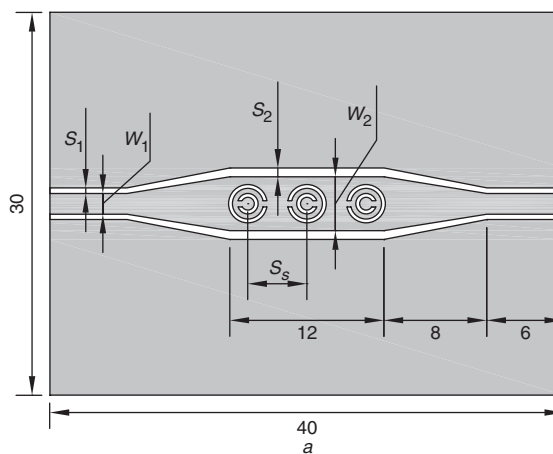


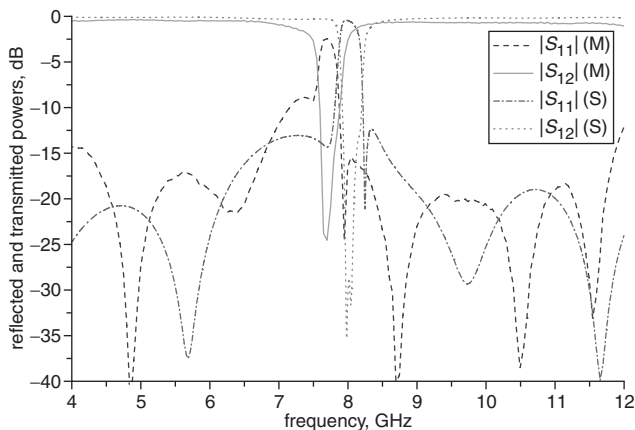
Fig. 3 Geometry of CPW bandstop filter

a Dimensions (mm)  
b Fabricated filter

*CPW bandstop filter:* A new design of a bandstop CPW filter is presented in this Letter. The SRR has a favourable aspect in its size, which can be designed as small as one-tenth of the resonance wavelength. Bandstop filters based on the SRR have been reported but the coplanar configuration cannot be maintained any longer in the design since the SRRs are located on the back of the conductor plane of a CPW line [6]. As in this Letter, a coplanar design can be achieved using slot-type SRRs instead of strip-type SRRs.

The size of the CPW filter shown in Fig. 3a is  $40 \times 30$  mm, with dimensions  $S_1 = 0.45$  mm,  $W_1 = 1.6$  mm,  $S_2 = 0.71$  mm,  $W_2 = 4.2$  mm, which are calculated for a  $50 \Omega$  line. Although the central strip became wider to place the SRRs, the impedance of the line was maintained as  $50 \Omega$ . From the guidelines mentioned above, the dimensions of the slotted SRR were obtained as  $r_1 = 1.5$  mm,  $r_2 = 0.8$  mm,  $w = 0.35$  mm,  $d = 0.35$  mm,  $g = 0.5$  mm and  $S_s = 4.7$  mm in order to have the stop-band from 7.8 to 8.2 GHz. The spacing between the SRRs is about  $\lambda/4$  of the centre line of the CPW at 8 GHz. According to [3], the frequency selectivity for multiple SRRs becomes strongest when the spacing between SRRs is  $\lambda/4$  at the resonance frequency. The design was fabricated on RO3010 ( $\epsilon_r = 10.2$ ) with  $t = 0.635$  mm by photo-etching, as shown in Fig. 3b.

*Experiment results:* To verify the performance of the proposed approach, the CPW bandstop filter was fabricated and measured. Simulation results with ADS-Momentum and the measurements are shown and compared in Fig. 4. The measurements show that the stop-band occurs around 0.25 GHz bandwidth with the reference level of  $|S_{21}| = -10$  dB and the centre frequency of the stopband is 7.7 GHz. Compared with the simulated results, the stopband performance is in good agreement with the measurement but the centre frequency is slightly shifted from 8 to 7.7 GHz. The sharp selectivity was observed in both the simulation and the measurements. Typical characteristics of SRRs, a small real estate and a sharp selectivity, were observed in the experiment results for the band stop filter. The complementary form of the SRR was applied to reject the unwanted frequency while maintaining the coplanar configuration. These new coplanar bandstop designs can be favourable for various applications in monolithic designs.



**Fig. 4** Reflected and transmitted powers of bandstop filter  
M: measurement, S: simulation by ADS-Momentum

*Conclusion:* A slot-type SRR has been successfully designed for rejecting unwanted frequency band (7.7 GHz in this work) using a small real estate and high  $Q$  operation. A sharp selectivity obtained using the complementary type of SRR is attractive for other applications such as MMICs and antennas.

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