In this section the propagation characteristics of a microstrip line loaded with an array of SRR as superstrate are investigated. The presence of SRRs over the microstrip line leads to rejection of a narrow band in the vicinity of its resonant frequency. The width and attenuation of the rejected frequency band depends on the height of the superstrate as well as its relative position with respect to the microstrip line.
5.1 Introduction

The split ring resonators (SRRs) have been used in planar circuit technology for the design of novel printed microwave components; particularly in band reject filters. SRRs would be excited by a time varying magnetic field with significant component parallel to the ring axis. Therefore, in microstrip configurations, SRRs have to be etched at the top metal level, in close proximity to the central strip to guarantee efficient magnetic coupling, while in the CPW structures they must be etched underneath the slots (Martin et al., 2003). SRR particles coupled to the conventional microstrip line where the excitation is by the H-field generated by the line have been investigated by Falcone, (Chap. 5, pp.102-104, 2005). The SRR structure when etched on the same plane of the microstrip line limits the performance due to inefficient magnetic coupling resulting in low stop band attenuation. A more efficient way of coupling is to load the microstrip line with substrate containing SRR array with reduced number of unit cells.

In this section the SRR array as superstrate for bandstop filter application is described. This method also enables the selection of different structures and designs according to the frequency requirements. The variation in coupling strength with the thickness of the superstrate as well as the lateral position of the SRR array from the microstrip line is studied. At the resonant frequency of these particles, due to the electromagnetic coupling between the transmission line and the SRRs, current loops are generated on them and the signal propagation is inhibited.

- **Split ring resonator (SRR)**

SRRs are planar structures with two concentric conducting rings with slits etched on opposite sides (Fig. 5.1). It can be considered as an externally driven LC circuit with a resonant frequency that can be tuned by varying the dimensions.
A time varying magnetic field applied parallel to the axis of SRR induces rotating currents in the rings, which produces its own magnetic flux to enhance or oppose the incident field. Due to splits in the rings, the SRR unit can be made to resonate at wavelengths much larger than the diameter of the rings. This would not happen in closed rings. The purpose of the second split ring inside and the slit opposite to the first is to generate a large capacitance in the small gap region between the rings, which enables current flow by means of new displacement current. The dimension of the structure is smaller than the free space wavelength resulting in low radiative losses and so very high quality factor.

5.1.1 Transmission characteristics of SRR loaded microstrip Line

The SRR unit cell designed to resonate at 3.7 GHz is placed on a microstrip line as shown in Fig. 5.2. The characteristic of the filter is studied by electromagnetically coupling the SRR unit cell to a microstrip transmission line. The level of rejection depends on the coupling between feed line and resonator and also on the number of resonators. When placed symmetrically above the line (position X₁), no H-field lines penetrate through the axis of the resonator to induce resonance. Thus, the signal propagates from the input port to output port without any attenuation. The H-field lines can have perpendicular incidence on the SRR resonator, when the superstrate is shifted laterally with respect to the transmission line centre along the x-axis(X₁ through X₃). At
X₁, field lines, both electric and magnetic, interact with the SRR to induce resonance leading to signal inhibition at the resonant frequency. Thus, maximum attenuation level in the rejection band is obtained when placed at position X₃.

![Fig. 5.2 SRR unit cell at various positions with respect to microstrip line](image)

In Fig. 5.3, S₂₁ plots for different lateral positions of the superstrate are plotted. It is clearly seen that at X₁ the resonance disappears since the SRR is placed symmetrically above the microstrip line.

![Fig. 5.3 Simulation results of SRR superstrate at different lateral positions](image)

The attenuation increases with the position X₂ through X₃ and decreases at X₄ since it is away from the transmission line. To validate the above fact, current density plots have been obtained by simulation at 3.7GHz by placing the SRR at positions X₁ and X₃ and shown in Fig. 5.4. At X₄ (Fig. 5.4a), i.e., symmetrically above the microstrip line, the signal propagation is not interrupted as the H-field lines never
penetrate through the SRR axis to excite it. At $X_3$ (Fig. 5.4b), the SRR particle is adequately excited by the H-field lines at the air-dielectric interface resulting in resonance producing strong attenuation at the resonant frequency.

![Fig. 5.4 Current density plots for SRR loaded transmission line at position $X_1$ and $X_3$.](image)

The frequency response of the single SRR loaded transmission line can be further enhanced by increasing the number of SRR resonators on the superstrate. The effect of number of SRR resonant cells on the attenuation is also studied by increasing the number cells at the optimized position ($X_3$). With the size constraints in mind, a minimum number of SRR resonators providing appreciable attenuation are optimized.

![Fig. 5.5 Transmission characteristics of SRR loaded transmission line with varying number of SRR resonators](image)
As depicted in Fig. 5.5, a minimum of 5 SRR cells are required to attain an attenuation of -30dB. The superstrate has the advantage of flexibility of easy coupling gap adjustment and resonator/circuit replacement or modifications. Added advantage of this type of flexible EM coupling is that resonating circuits can be replaced or additional notch resonators can be added, easily without affecting the underlying feed line and port connections, thus achieving properties like multi-frequency operation without much difficult.

- **SRR array based microstrip bandstop filter**

This section is devoted to design microstrip band reject filter based on the rejection properties of SRR array. When loaded with SRR array, the microstrip line behaves as compact, high Q band reject filters with deep stop band in the vicinity of its resonant frequency. If properly coupled to the host microstrip line, these particles produce rejection levels required in most of practical applications (i.e. >20dB).

A prototype of the SRR array of five unit cells was fabricated by means of etching the pattern on a substrate of relative permittivity $\varepsilon_r=2.0$, thickness $t = 0.5, 1, 1.5$ and 2 mm for investigating the variation of the transmission characteristics with height above the microstrip line. A 50 $\Omega$ microstrip line is fabricated on commercially available FR4 substrate ($\varepsilon_r = 4.36, h = 1.6$ mm).

The SRR array was placed over the microstrip line as shown in Fig.5.6 (lateral view). The transmission and reflection coefficients were measured with the aid of Agilent E8362B PNA network analyzer. The effect of lateral of the SRR array over the microstrip line was studied by placing the superstrate of a particular thickness at different lateral positions along the X-axis ($X_1, X_2, X_3, X_4$) and the transmission characteristics are shown in Fig.5.7.
Fig. 5.6 SRR superstrate loaded microstrip line filter (p=8mm, N=5, $r_1=1.6\text{mm}$, $r_2=2.7\text{mm}$, $c=.9\text{mm}$, $d=.2\text{mm}$ and $s=1\text{mm}$)

Fig. 5.7 Measured S-parameters of microstrip line loaded with SRR array superstrate at different positions (t=0.5mm)

- **Effect of height above the transmission line**

In order to verify the dependence of thickness, arrays fabricated on different superstrates were placed at the optimum position $X_3$ and measured. The $S_{21}$ plots are shown in Fig. 5.8. It was observed that the maximum stop band attenuation occurred for minimum value of superstrate thickness (t=0.5mm).
SRR based microstrip bandstop filter

![Graph showing measured S21 parameters](image)

**Fig. 5.8** Measured S21-parameters of microstrip line loaded with SRR array superstrate at different heights.

The photograph of the superstrate loaded filter is shown in Fig. 5.9(a). The characteristics of the optimum filter measured in Agilent HP 8510C VNA is shown in Fig. 5.9(b). At the resonant frequency (f=3.7 GHz, approx.) S21 of -32dB is obtained with 5 SRR elements.

![Photograph of the superstrate loaded filter](image)  ![Graph showing measured S parameters](image)

**Fig. 5.9** (a) Photograph of the superstrate loaded filter (b) Measured S parameters of the optimized filter
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- **Superstrate arrays of different element shapes**

As mentioned earlier, this superstrate method has the additional advantage of flexibility of easy coupling gap adjustment and resonator/circuit replacement or modifications. This method also enables the selection of different structures and designs according to the frequency requirements. Some of the resonator arrays fabricated to illustrate the filtering characteristics when placed over the transmission line at the optimized position to attain maximum coupling and rejection are shown in Fig. 5.10 with their frequency response.

(a) Spiral resonator-Square.

(b) Spiral resonator- Circular
Fig 5.10. Measured transmission characteristics of microstrip line loaded with (a) & (b) Spiral resonators (c) Square SRRs (d) & (e) Open loop resonators
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The resonators in Fig. 5.10 (a&amp;b) are spiral resonators (SRs) which allow significant reduction in the electrical size of unit cell compared to other ring resonators. It is verified that the resonant frequency of SRs are one half that of its SRR counterparts. The characteristic in Fig. 5.10(c) is based on square split ring resonator array with its split axis along the x-direction, to attain narrow bandwidth. The filters in Fig. 5.10 (d) and (e) are based on open loop resonator array which are simpler to design and fabricate.

5.2 Conclusion

The transmission characteristics of microstrip line loaded with SRR particles as superstrate are presented. SRR, in the proximity of a microstrip line, inhibits the signal propagation at frequencies determined by its dimensions. Amount of notching and width of the stop band formed are functions of the superstrate height and its relative position with respect to the microstrip line. The frequency of the stop band may be varied by changing the dielectric constant of the superstrate. Our investigation shows that periodic arrangement of SRR over the transmission line gives a band reject filter with appreciable attenuation and low insertion loss.

References
