Miniaturization of Slot Loop Antenna Using Split-Ring Resonators

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Introduction

In recent years, the need for antenna miniaturization stems from the fact that most mobile platforms have a limited space for all of the required antennas in ever increasing wireless systems. Intuitively, substrates with high dielectric constants can be used for miniaturization. However these structures easily excite surface waves, thus degrading the performance of the antenna. Another approach for reducing the antenna size is to change the boundary condition of the antenna, either using a shorting pin on a patch [1] or replacing the two short circuits at the end of the resonant slot by inductive or capacitive loadings [2]. Slow wave concept is also a common approach for miniaturizing the antennas. Using the lump elements with periodical arrangement is presented in [3]. The significant reduction in size is obtained, however at the cost of poor performances. In this paper, we propose a miniaturizing method without using lump elements. In general, Split-ring resonators (SRRs) are used to form the left-hand transmission line [4]-[8] and we take advantage of its equivalent inductance and capacitance to achieve the slow wave behavior and reduce the size of the slot loop antenna.

Antenna Design

The Split ring resonator (SRR) was first proposed in [4]. It consists of two concentric metallic split rings as shown in Fig. 1(a). When excited by a time-varying external magnetic field directed along the z -axis, its equivalent circuit can be drawn as that shown in Fig. 1(b), where L_s is the self-inductance and C_s is the capacitance associated with each SRR half. Using the above LC characteristics of SRR, we propose a miniaturized slot loop antenna with equal slot width by adding the SRRs underneath the slot as shown in Fig. 2 to reduce the antenna size. The magnetic field in the slot loop can excite SRRs and the equivalent circuit of a unit cell of the antenna with size l shown in Fig. 2(b) is shown in Fig. 3. Its dispersion relation is given by [8]

$$\cos(\beta l) = 1 - \frac{LaCa\omega^2}{2} + \frac{Ca/C_s'}{4(1 - \omega_0^2/\omega^2)} \quad (1)$$

where La and Ca are the per-section inductance and capacitance of the slot loop antenna, respectively, $C_s' = L_s/\omega_0^2 M^2$ is the equivalent capacitance, in which M is the mutual inductance between slot loop and SRR and ω_0 is the angular resonant frequency of the SRR. Eq. (1) suggests that for slow waves, the operating frequencies would be lower than the resonant frequency of the SRR. Also, the self inductance L_s of SRR is a key parameter to control the percentage of size reduction.

Simulation and Measurement Results

The proposed antenna is implemented and tested. The dielectric substrate used is FR4 with dielectric constant $\epsilon_r = 4.3$, loss tangent $\tan\delta = 0.02$, and thickness $h = 0.8$ mm. The antenna is matched to a 50- Ω CPW feedline with $S = 4$ mm and $G = 0.3$ mm. The size of the unit cell of the SRR is $l = 6$ mm. All other parameters are listed in Table I. The simulated and measured return losses of the slot loop without SRRs are plotted in Fig. 4(a), and those of the slot loop with SRRs are plotted in Fig. 4(b). Good agreement between simulation and measurement is obtained. All simulations in this work were carried out using *Ansoft* HFSS 10.0. The measured impedance bandwidths (return loss > 10 dB) of the slot loop without and with SRRs are 19.5% (3.15-3.83 GHz) and 15.8% (2.57-3.01 GHz), respectively. The slot loop without SRRs loaded shows wider bandwidth than that of the miniaturized design at the expense of a relatively larger antenna size. The size reduction is about 20% as the resonant frequency being decreased from 3.5 to 2.81 GHz. Radiation patterns of the slot loop without and with SRRs measured at 3.5 and 2.81 GHz are shown in Figs. 5 and 6, respectively. Both antennas have slot-dipole-like radiation patterns within their respective bands. The simulated and measured peak gains of the slot loop without SRRs are about 3.02 and 3.95 dBi, respectively. After adding the SRRs, the simulated and measured peak gains of the antenna are about 2.83 and 4.53 dBi, respectively.

Conclusion

A CPW-fed slot loop antenna with SRR-loaded has been presented. By adding SRRs underneath the slot loop, miniaturized characteristics can be realized. Simulation and measurement results have shown that the proposed antenna with SRR-loaded have good impedance matching characteristics. Also, the cross polarization in each plane of the pattern is lowered. At the same time, the proposed antenna maintains the value of the gain.

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TABLE I. Design Parameters of The Proposed Antenna (unit: mm)

L	L_1	L_2	r	c	d	t	l
50	18.75	23.5	2.75	0.3	0.3	5.5	6

Fig. 1. (a) Geometry of SRR and (b) its equivalent circuit.

Fig. 2. Geometry of the proposed antenna. (a) Top side. (b) Bottom side.

Fig. 3. Equivalent circuit of a unit cell of the slot loop coupled by SRR.

Fig. 4. Simulated and measured return losses (a) Slot loop without SRRs (b) Slot loop with SRRs.

Fig. 5. Measured and simulated radiation patterns of the slot loop without SRRs at 3.5 GHz.

Fig. 6. Measured and simulated radiation patterns of the slot loop with SRRs at 2.81 GHz.