A small antenna for the handheld device using a split-ring inspired resonator with tunability

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Abstract

A tunable small antenna using a split ring resonators (SRR) combined with an inductor is presented, and its resonant frequency depends on the size and shape of the SRR, and the added inductor values. The small antenna adjusted to 50 Ω without any matching network with the total efficiency of 82%

Keywords : Antennas for handheld device, Split-ring resonator

1. Introduction

Recently, as the wireless communication system has rapidly developed, the antennas have been not only used in various manners, but have also been reduced in size. In general, however, since a small antenna has a large reactance and a very small radiation resistance, it is difficult to accomplish the impedance matching. Accordingly, the small antenna has a very narrow impedance bandwidth and low efficiency. In order to achieve the impedance matching of the small antenna, an additional matching network is required in a feeding system of a small antenna. The matching network integrated with the antenna increases a cost and a time-consuming as well as the complexity. Furthermore, the efficiency deteriorates due to the supplementary loss resistance of the matching network. The loss resistance reduces the efficiency of the small antenna, and also increases the entire size of the antenna [1- 3].

A general antenna has an electrical half wavelength with respect to a resonant frequency. Since the electrical length of the antenna is decided depending on the resonant frequency, the size of the antenna having the primary resonant mode is changed in accordance with the resonant frequency. In particular, as the operation frequency decreases, the size of the antenna increases. To solve such a problem, a meander antenna has been proposed [4]. However, since the antenna having the fixed electrical resonant length should be formed in a limited small space to reduce the size of the antenna, the complexity and loss of the antenna inevitably increases. Therefore, there is demand for a method for implementing a small antenna, which may easily obtain the impedance matching without an additional matching network, minimize the size and the complexity of the antenna, and increase the antenna efficiency.

In this paper, we have presented a tunable high efficiency small antenna using an SRRs, which does not require an additional impedance matching network. Furthermore, since a lumped inductor connects the SRRs between a ground, it is possible to easily control the resonant frequency of the small antenna. All simulation is performed by the commercial software of CST microwave studio (MWS).

2. Analysis and measured results

Fig. 1a illustrates the proposed small antenna using the SRRs. SRRs includes via formed through the dielectric substrates (εr=3.4) with the thickness of 1.53mm to connect the upper SRR and lower SRR. The feed line has a characteristic impedance of 50 Ω and transfers the signal to the SRRs to excite the antenna. And, the inductor connected between the SRRs and ground controls the resonant frequency of the antenna. The designed antenna has a resonant frequency of 1.925 GHz, and has a size of 0.03 λ at the operating frequency which is 16.6 times reduced than a general half-wave length antenna. Therefore, it is possible to implement a much smaller antenna. Fig. 1b shows the equivalent circuit of the proposed small antenna. The R_S corresponds to the characteristic impedance of the feed line of 50 Ω. And, the C_P is the capacitance formed between the feed line and ground due to discontinuity. The C_S denotes a series gap capacitance generated between the feed line and the SRRs. The L_A is the loop inductance of the SRR and L_P is the added lumped inductor to control the resonant frequency. The R_L is the total resistance composed of the radiation resistances (R_r) and loss resistances (R_O). In general, R_r, R_O, L_A are mainly decided by the shape and size of the SRRs , which are given by [5]:

$$\text{Rr (radiation resistance)}=320N^2\pi^4A^2/\lambda^4\ (\Omega) \tag{1}$$

$$R_O\ \text{(loss resistance)} = (NP/2W)(\pi f\mu_0/\sigma)^{1/2}\ (\Omega) \tag{2}$$

$$L_A\ \text{(loop inductance)} = (2N^2\ \mu_0 a/\pi)[\ln(a/b)-0.774]\ (H) \tag{3}$$

where A is the area of the SRRs, N is the number of turns of the SRRs, P is the perimeter of the SRRs, W is the trace width of the SRRs, a is the radius of the SRRs, and b is the radius of the trace of the SRRs. The proximity effect can be more important than the skin effect when loss resistances are extracted, but it is more complex to model since it is influenced by the geometry of the antenna. So, we ignore the proximity effect and the dielectric loss to simplify the analysis. The predicted circuit values of R_r, R_O, L_A are 0.13 Ω, 0.23 Ω, 13.13 nH, respectively. In the small antenna using the SRRs, SRRs has the very small total resistance R_L, and the large loop inductance L_A. Therefore, the impedance matching is difficult to achieve and the bandwidth become narrow. To complete the impedance matching at the given frequency, the values of the capacitances for the impedance matching are derived from the calculated R_r, R_O, L_A, which are given by:

$$C_S=1/[2\pi f(2\pi f(LA+LP)-R_SR_L((R_S-R_L)/(R_S^2R_L))^{1/2}\ )]\ (F) \tag{4}$$

$$C_P=((R_S-R_L)/(R_S^2R_L))^{1/2}\ /(2\pi f)\ (F) \tag{5}$$

The two capacitors C_S and C_P easily realize the impedance matching in the small antenna without the additional matching circuit which is generally required in the conventional small antenna. Therefore, the antenna is simplified and much smaller, which makes it easy to design and implement the antenna. Furthermore, the inductance values of the inductor L_P easily control the resonant frequency and the bandwidth is changed by the total resistance value, referring to Figs. 2. Fig. 2 shows variations in the resonant frequency corresponding to the control of R_L and L_P by simulating the equivalent circuit illustrated in Figs. 1b. The small antenna using the SRRs has a resonant frequency of 1.93 GHz. When the inductance values of the L_P are set to 1.2 nH and 2.7 nH, the resonant frequencies of the antenna are changed to 1.84 GHz and 1.75GHz, respectively. Therefore, the small antenna using the SRRs combined with L_P easily manuplates the resonant frequency. In addition, the bandwidth of the antenna is affected by the total resistance of R_L, namely, the bigger value of R_L exhibit larger bandwidth compared to the smaller R_L. R_L is increased when the radiation occur at the ground plane since the radiation resistance of R_r is improved. It is important note that the ground size affects only both the efficiency and bandwidth of the antenna; however, it does not have little effect on the resonant frequency. The radiation efficiency can be written as:

$$\text{Radiation efficiency}= R_r/(R_r+R_O) \tag{6}$$

The comparison of the measured and simulated return losses are given in Fig. 3. The measured return losses are a little frequency upshift compared to the simulated results since the commercial inductor (L_P) offer ±5% tolerance when lumped inductor is attached between the SRRs and the ground, but two results agree well with each other. The radiation patterns of the proposed antenna are shown in Fig. 4. The proposed small antenna has an omni-directional radiation pattern in x-y plane since the ground is operated as dipole antenna, Furthermore, the small antenna using the SRR structure has a high total efficiency of 82%.

3. Conclusions

In this paper, we have proposed the antenna using SRRs to reduce the size of the antenna. Added inductors between the SRRS and ground are helpful to control the resonant frequency. In addition, both the radiation efficiency and bandwidth are improved by utilizing the radiation resistance generated from the ground. Good agreement between the measured and theoretically predicted behaviors ensures the validity of our design and prediction method.

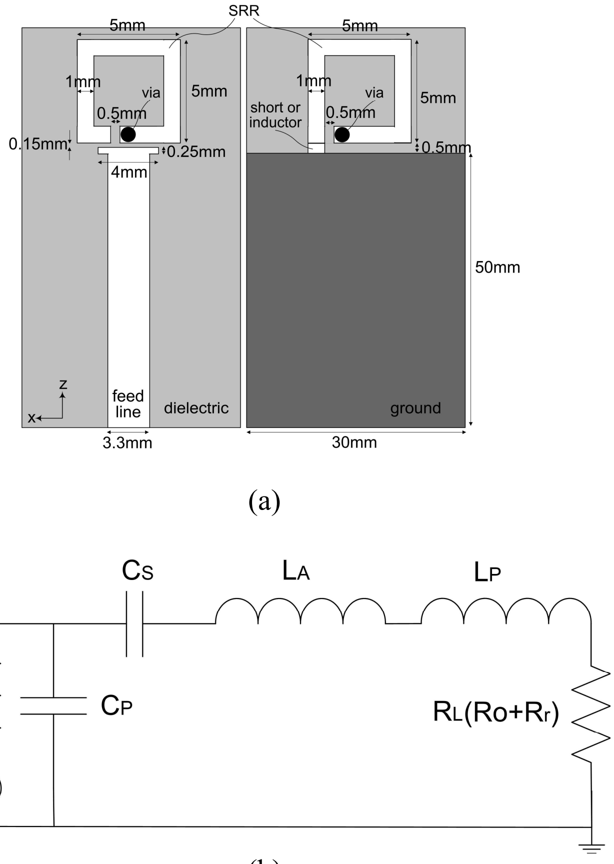


Figure 1: Configuration of the proposed antenna. (a) geometry of the small antenna using SRRs, (b) equivalent circuit of the antenna

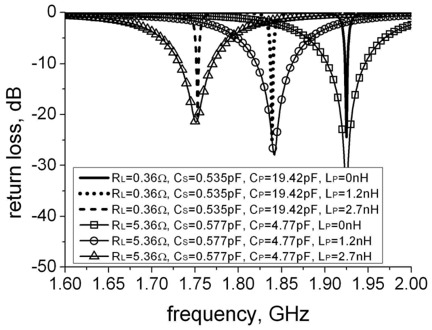


Figure 2: Variation of return losses and bandwidths.

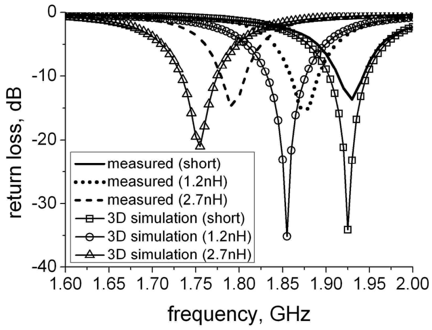
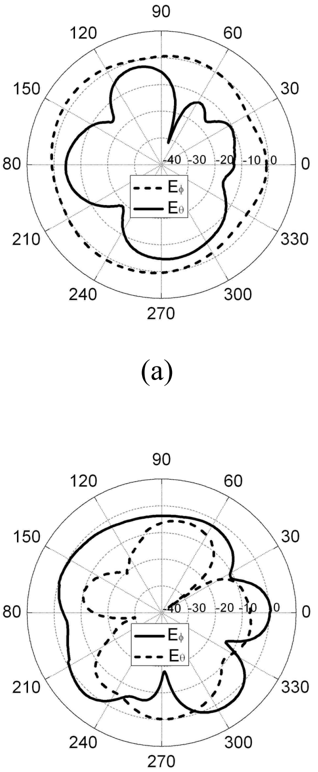


Figure 3: Comparison of the predicted and measured return loss.



(a)

(b)

Figure 4: The measured radiation patterns of the antenna at 1.93GHz. (a) x-y plane, (b) y-z plane.

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