Mutual Coupling between Parasitic Elements of Split Ring Resonator on Antenna

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Abstract— The parasitic elements on antenna have become an important issue in improving the antenna performance in various wireless devices. These elements are mostly used as radiator and resonator in antenna. However, an investigation of the mutual coupling between parasitic elements is rare to be found in metamaterial resonator antenna studies. From this unusual approach, this paper presents the new mutual coupling structure of parasitic elements with the split ring resonator (SRR) on antenna. The suggested antenna consists of two rectangular SRRs and conventional monopole antenna. These resonators play the role of the parasitic element in antenna. In order to operate these SRRs, linear monopole antenna is used as an active antenna which can provide the time-varying magnetic field with normal direction. In metamaterial technology, a negative effective permeability can be generated at resonant frequency via periodic arrangement of these SRRs which are electrically small LC resonant elements with a high quality factor. Fundamentally, mutual coupling phenomenon has been observed between adjacent resonators, so that the antenna with two resonators has the same effect on parasitic elements, too. In this study, the coupling coefficient between two parasitic element resonators on antenna is obtained from scattering parameter simulation results. On the basis of the electromagnetic field characteristics and the result of antenna parameter, this study will be exquisite from the previous studies of antennas that utilize the SRR.

1. INTRODUCTION

The split ring resonators (SRRs) have attracted considerable attention in microwave engineering. These SRRs as the metamaterial resonator are understood as artificially effective medium that exhibits some unique electromagnetic properties. They have received significant attention and have enabled numerous applications over the past decade, especially for the antenna design. Various design techniques for antenna have already been studied and developed based on the SRR [1–3]. Those studies proposed the antenna characteristics of wide bandwidth, multi-band, miniaturization, band rejection, and high directivity.

Recently, the parasitic elements are important components for antenna design, such as band rejection element, parasitic impedance stub, and resonance element. Typical parasitic elements in antenna technology have been used to improve the antenna performance. These elements act as resonators or electromagnetic coupler with antenna radiator [4–6]. The parasitic element SRR behaves as resonator which is operated by excited field, so that mutual coupling effect between the SRRs can be calculated. The conventional mutual coupling effect for resonator has been commonly obtained from coupling theory of coupling structure. In this paper, we investigated the mutual coupling effect between the SRRs as parasitic element of antenna.

2. ANTENNA CONFIGURATION

The SRR structure, which was proposed by Pendry as a metamaterial resonator in 1999 [7], is a core element in the mutual coupling effect of resonators in this study. This structure exhibits a negative-permeability medium within a local frequency range, which has resulted in the extensive development of microwave circuit and antenna using the SRR for improving electromagnetic performance. A typical SRR is made using two metallic split-ring strip, which behaves as an electrically small LC resonant tank having a high quality factor. This unusual electromagnetic property can be excited by an incident time-varying magnetic field with normal direction. Figure 1 shows the geometry and dimensions of the proposed element of the SRR. The physical parameters of the SRR are: $c = 0.9\,\text{mm}$, $d = 0.3\,\text{mm}$, $g = 0.5\,\text{mm}$, $L1 = 11.9\,\text{mm}$. The resonance frequency of the SRR depends on its geometrical parameters. Figure 2 shows the geometry and dimensions of basic monopole antenna. As shown in Figure 2, the basic monopole antenna was designed by forming the conventional linear monopole antenna on the finite ground plane and using the coaxial feeding. This antenna has a length of pole $L2 = 13.5\,\text{mm}$, diameter of pole cylinder $a = 2.5\,\text{mm}$. The length of monopole antenna is approximately $\lambda/4$ of $5.5\,\text{GHz}$. Figure 3 shows the geometry and dimensions of the monopole antenna with two SRRs. The inserted SRRs are fabricated on a dielectric substrate of Rogers 4003 (thickness $h = 0.812\,\text{mm}$, relative permittivity $\varepsilon_r = 3.38$, loss tangent $\delta = 0.0023$). The geometry and dimension of two SRRs are same.

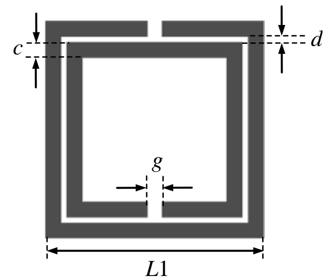

Figure 1: Geometry of the SRR.

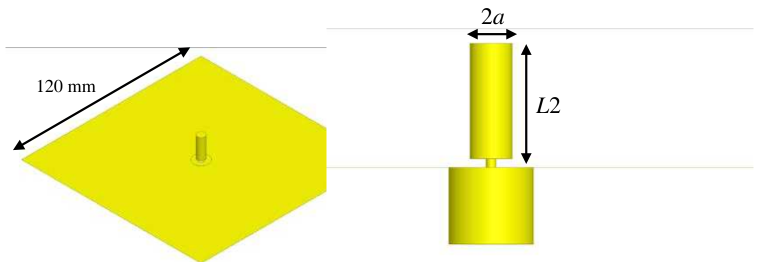

Figure 2: Geometry and dimension of the basic monopole antenna.

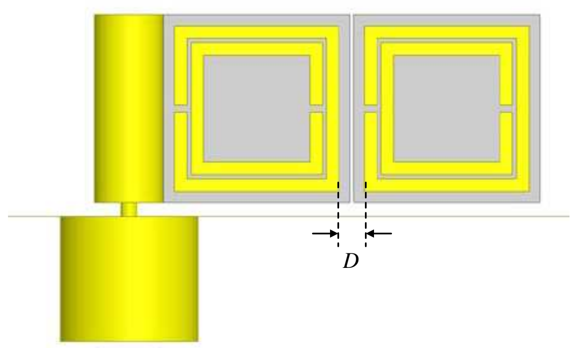

Figure 3: Geometry and dimension of the monopole antenna with SRR.

3. SIMULATION AND DISCUSSION

Figure 4 shows the simulated return loss ($S11$) results of the proposed antenna. The return loss results were computed by 3D EM simulator of HFSS of Ansys Corporation. From the result shown in Figure 4, it is observed that an impedance bandwidth with good matching for $S11 < -10\,\text{dB}$ is from 36 to 5 GHz. Two SRRs in this antenna perform as two LC resonators which radiate and store the electromagnetic field energy, so that there are mutual coupling between them. Thus, we can find two resonance frequencies corresponding to electric coupling and magnetic coupling. Figure 5 shows the mutual coupling phenomenon between two SRRs with simple circuit model.

As two adjacent resonators make mutual coupling, it is necessary to consider the coupling coefficient of the proposed structure. To verify the effect of mutual coupling, we can calculate the coupling coefficient k, defined as Equation (1)

$$k_{ij} = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} \tag{1}$$

In this paper, the coupling coefficient k was derived for two cases of distance between two SRRs. The calculated coupling coefficient k for $D = 1.65$mm, was 0.042, and $D = 1.85$mm was 0.091. Considering the coupling coefficient k of the proposed structure, it is evident that the SRR as parasitic element of antenna exhibits a mutual coupling phenomenon, so that the calculation of coupling coefficient is possible.

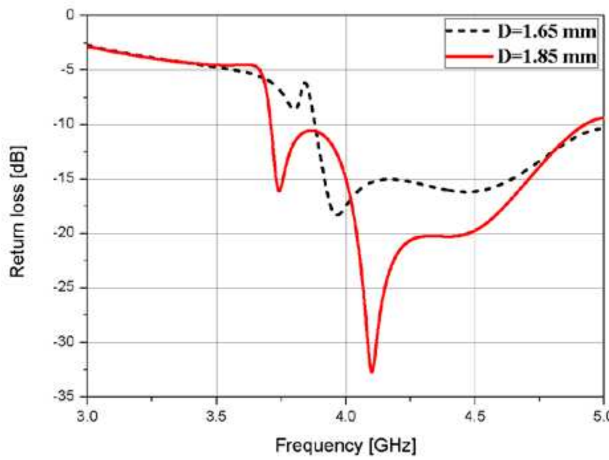

Figure 4: Return loss results of proposed antenna with two SRRs.

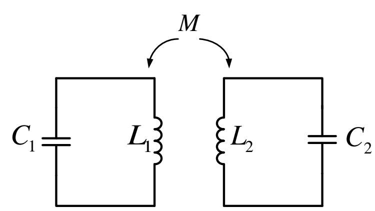

Figure 5: Simple circuit model for mutual coupling between two SRRs.

4. CONCLUSIONS

This paper explains the coupling effect between two SRRs as parasitic element of monopole antenna. A conventional linear monopole antenna is used for verification And two SRRs are inserted on ground plane. To verify the coupling effect between two parasitic element SRRs, we show the coupling coefficient calculated. From these results, this study is helpful to design the antenna using the parasitic element of resonator type.

ACKNOWLEDGMENT

This work was supported by ICT R&D program of MSIP/IITP. [B0101-15-1369, Development of small basestation supporting multiple streams based on LTE-A systems].

REFERENCES

1. Alici, K. B. and E. Ozbay "Electrically small split ring resonator antennas," *Journal of Applied Physics*, Vol. 101, No. 8, 083104(1)–083104(4), 2007.
2. Alici, K. B. and E. Ozbay, "Radiation properties of a split ring resonator and monopole composite," *Physica Status Solidi B*, Vol. 244, No. 4, 1192–1196, 2007.
3. Kim, D. O. and C. Y. Kim, "CPW-fed ultra-wideband antenna with triple-band notch function," *Electronics Letters*, Vol. 46, No. 18, 1246–1248, 2010.
4. Alici, K B., A. E. Serebryannikov, and E. Ozbay, "Radiation properties and coupling anaylsis of a metamaterial based, dual polarization, dual band, multiple split ring resonator antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 8–9, 1183–1193 2010.

5. Gemio, J., J. Parrón, P. de Paco, G. Junkin, J. Marin, and O. Menéndez, "A split-ring-resonator loaded monopole for triple band applications," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 2–3, 241–250, 2010.
6. Ntaikos, D. K., N. K. Bourgis, and T. V. Yioultsis, "Metamaterial-based electrically small multiband planar monopole antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 963–966, 2011.
7. Pendry, J. B, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 11, 2075–2084, 1999.