A Metamaterial Absorber for Reducing False Image in 24GHz Automotive Radar System

Eun Jeong, Jinpil Tak, and Jaehoon Choi
Department of Automotive Electronic Control Engineering, Hanyang University,
222 Wangsimni-ro, 133-791, Seoul, Republic of Korea
sasasa4466@gmail.com

***Abstract*—In this paper, a metamaterial absorber for reducing false image in automotive radar system is proposed. The unit cell of the proposed absorber consists of an electric LC (ELC) resonator and a ground plate. The ELC resonator is composed of two symmetric Spiral Split Ring Resonators (SSRRs) with slightly different absorbing band. The aim of this absorber is to improve the performance of 24 GHz automotive radar by absorbing scattered wave in the vicinity of the radar receiver. The proposed absorber exhibits the first peak at 23.1 GHz with an absorption of 93 % and exhibits the second peak at 24.1 GHz with an absorption of 96 %. Total full width at half maximum (FWHM) is 7.7% (1.85GHz) at 24 GHz.**

***Index Terms*—Metamaterials, electromagnetic wave absorber, spiral split ring resonator, radar false image absorber**

I. INTRODUCTION

Electromagnetic (EM) absorbers are widely used in many applications such as stealth technology, anechoic chamber, and various electromagnetic interference (EMI) control systems [1]-[3]. Recently, the operating environment of modern vehicle becomes more and more complex by adopting various intelligent electronic systems. Automotive radar is one of the most important sensors in an intelligent vehicle. In order to improve the performance of radar systems, EM wave absorbers are necessary to reduce radar false image. They can be mounted in the vicinity of the radar receiver to absorb unwanted scattered waves [4]-[5].

EM absorbers are mainly classified into three types. The most common EM absorber is an attenuation type. It usually has pyramid-shaped array to absorb and scatter EM waves. It has high absorption in broadband and is commonly used in an anechoic chamber. However, the absorber is bulky and easily damaged. Therefore, it is not suitable for portable or automotive applications [6]-[7]. Another type is conductive loss or magnetic loss type. It is made of a composites of carbon fiber, ferrite, and so on. It also has high absorption in broadband [8]-[9], but it is quite expensive. The third type is resonance type. Metamaterials (MTMs) are artificial electromagnetic structures which have effective negative permittivity, permeability, and refractive index [10]-[11]. MTM absorber is one of the most interesting metamaterial applications because it has great potential for various systems. It is an electric resonant type absorber, in general, which is also called frequency selective surface (FSS) absorber.

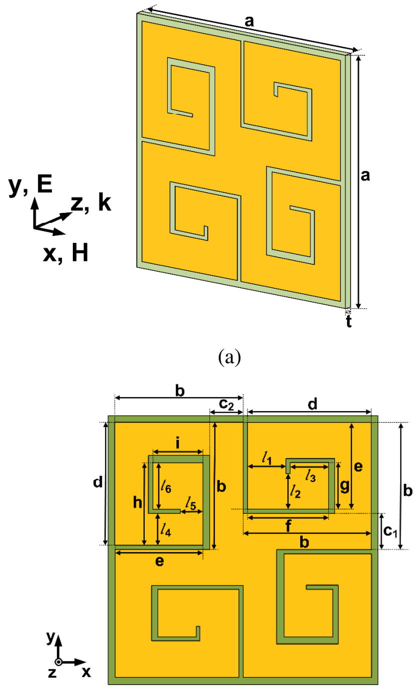


Fig. 1. Geometry of the proposed FSS absorber (a) perspective view of the unit cell with FR4 substrate t=0.2mm and incident TEM wave, (b) top view of the unit cell with detailed dimensions of Table 1.

The first step of FSS absorber unit cell design is deciding substrate. Then, on the top side of the substrate, resonant patch is designed depending on the target application [12]. At the resonant frequency, the reflected wave is reduced by matching the impedance of an absorber to that of an air. The transmitted wave is absorbed by a lossy substrate [13]-[14]. Many researchers pay great attention to the dual band MTM absorber because it inherently has narrow bandwidth [15]. By placing the ground on the back of the substrate, FSS absorber design is finished.

In this paper, a bandwidth-enhanced double resonance absorber is proposed. The unit cell of the proposed FSS absorber operates at 24 GHz. In vehicular environments, 24 GHz radar is used for a core sensor of the safety system such as collision avoidance or blind spot detection. The proposed absorber can be used for a false image absorber of an automotive radar.

TABLE I. THE DIMENSIONS OF ABSORBER UNIT CELL

Parameters	Dimension	Parameters	Dimension
a	6	h	1.85
b	2.85	i	1.1
c_1	0.81	l_1	0.86
c_2	0.74	l_2	0.81
d	2.75	l_3	0.85
e	1.95	l_4	0.71
f	1.8	l_5	0.5
g	1.05	l_6	1.05

[Unit: mm]

II. DESIGN OF AN ABSORBER UNIT CELL AND RESULTS

A. Design concepts

Fig. 1 shows the unit cell geometry of the proposed FSS absorber. The absorber consists of an ELC resonator, ground, and FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with a thickness of 0.2 mm. ELC absorber consists of two symmetric spiral split ring resonators (SSRRs) which are located at the top left and the bottom right sides for 23.1 GHz band. The other two symmetric SSRRs for 24.1 GHz band are located at the top right and the bottom left sides as shown in Fig. 1(b). In this absorber, two SSRRs pairs provide slightly different resonances at the neighborhood of 24 GHz to broaden the bandwidth. The two resonance frequencies of a unit cell can be controlled independently.

On the back of the substrate, the full ground is placed for zero transmitted wave. But the existence of a ground plane at the back causes the back reflected wave. In general, a thick dielectric substrate is used to solve this problem [16]. In our case, however, the proposed absorber needs to be designed using a thin substrate with flexibility since it has to be attached to the curved surface of a car bumper. In order to analyze the absorption characteristics, the incident TEM wave is excited along the z-axis as shown in Fig. 1(a).

The absorption coefficient of an absorber $A(\omega)$ is calculated as $A(\omega) = 1 - T(\omega) - R(\omega)$, where the transmission coefficient $T(\omega) = S_{21}^2$ and reflection coefficient $R(\omega) = S_{11}^2$. In this design, however, the transmitted wave is blocked by the conductive ground on the back of the substrate. The reflected wave contains back-reflected wave from the ground. Therefore, the absorption coefficient $A(\omega)$ is determined only by the reflection coefficient as $A(\omega) = 1 - R(\omega)$.

B. Parametric study

Fig. 2 (a) and (b) show the simulated absorption coefficients for various design parameters l_1 and l_4. As l_1 increases, the high frequency band shifts to higher frequency side while the low frequency band is minimally affected. As l_4 increases, the low frequency band shifts toward a higher frequency side while the high frequency band is not changed.

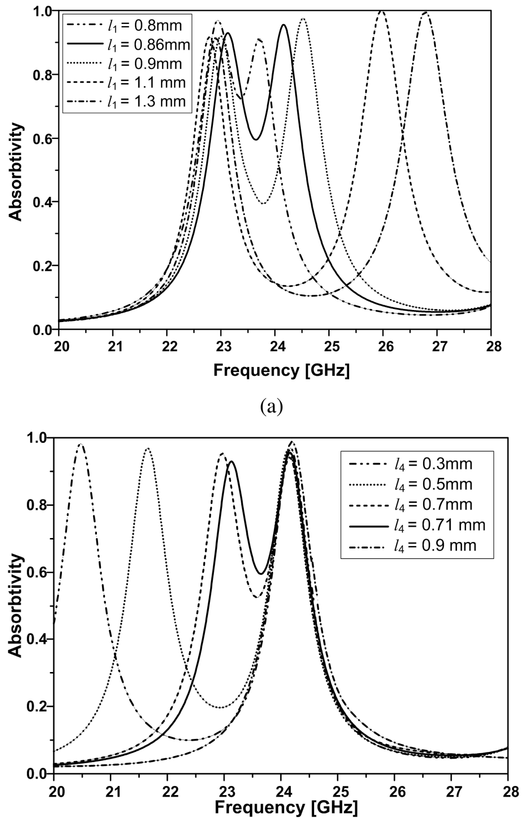


Fig. 2. Simulated absorption characteristics for (a) various l_1 (b)various l_4

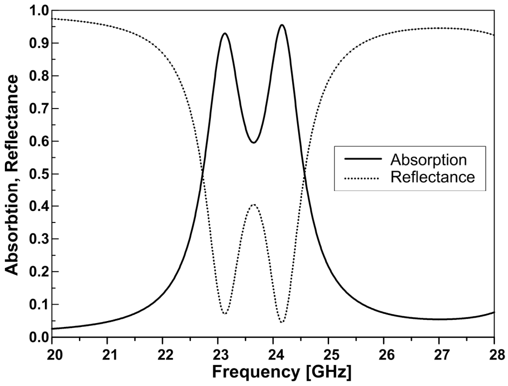
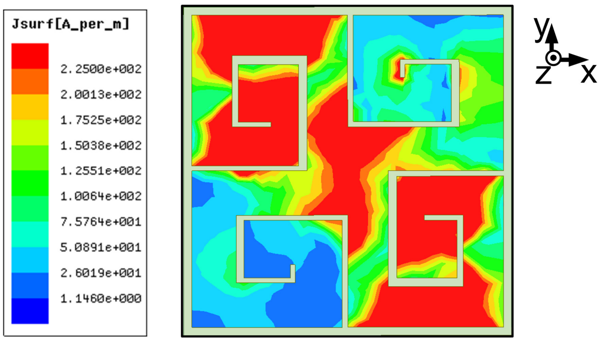
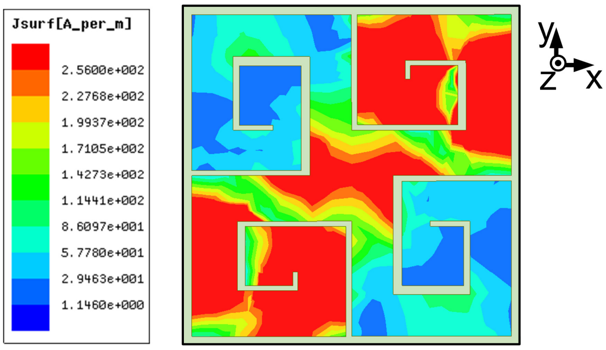


Fig. 3. Simulated absorption and reflectance characteristics of proposed absorber

Fig. 3 shows the simulated absorption characteristics of the unit cell of the proposed absorber. The optimized geometrical dimensions are listed in Table I. Peak absorptions of approximately 93 % and 96 % are obtained at 23.1 GHz and 24.1 GHz, respectively. The proposed absorber has two absorption peaks by using double-resonance, the lowest valley between two absorption peaks has 60 % of absorptivity. Consequently, the proposed absorber provides an enhanced bandwidth with full width half maximum (FWHM) of 1.85 GHz. The fractional bandwidth of the proposed absorber is 7.7 % at 24 GHz. The reflectances are 0.07 and 0.04 at 23.1 GHz and 24.1 GHz, respectively.



(a)



(b)

Fig. 4. Simulated current distribution on the unit cell of the proposed absorber (a) at 23.1 GHz, (b) at 24.1 GHz

C. Results

The simulated current distributions on the unit cell are given in Fig. 4. Fig. 4 (a) and (b) verify that the proposed absorber unit cell is properly operating at each resonance frequency. The low frequency resonance is generated by SSRRs located at the top left and the bottom right sides. The high frequency resonance is strongly generated by the top right and the bottom left sides. At the resonant frequencies, reflectance is minimized because of the good impedance matching between absorber and free space and the dielectric loss by a absorber substrate.

III. Conclusions

In this paper, the unit cell design of a metamaterial absorber using double resonance is proposed. The electric LC resonator and full ground are designed on both sides of the thin FR4 substrate. The proposed absorber exhibits two absorption peaks with absorption ratio 93% and 96% at 23.1 GHz and 24.1 GHz, respectively. It has a FWHM of 1.85 GHz which is equivalent to a fractional bandwidth of 7.7 % at 24 GHz. The absorption mechanism is explained by impedance matching between absorber and air, total reflection on the ground, and dielectric loss of substrate. The proposed metamaterial absorber can be used for a 24GHz automotive radar to prevent false image phenomena due to the unwanted external EM waves.

Acknowledgment

This research was supported by the MSIP(Ministry of Science, ICT&Future Planning), Korea, under the ITRC(Information Technology Research Center) support program (IITP-2015- H8501-15-1006) supervised by the IITP(Institute for Information&communications Technology Promotion)

References

[1] W.F. Bahret, "The beginnings of stealth technology", *IEEE Transactions on Aerospace and Electronic Systems*, vol. 29, no.4, pp. 1377-1385, 1993.

[2] W.H. Emerson, "Electromagnetic wave absorbers and anechoic chambers through the year", *IEEE Transactions on Antennas and Propagation*, vol. 21, no.4, pp.484-490, 1973.

[3] K. Matsumoto, "Wave absorber based on rubber sheet with circular lattice for installing between ETC lanes", *The 9th European Conference on Wireless Technology*, pp. 261-264, 2006.

[4] J. Wenger, "Automotive mm-wave radar: status and trends in system design and technology", *IEE Colloquium on Automotive Radar and Navigation Techniques*, 1998.

[5] D.W. Hahn, K.S. Lee, "Microwave absorber for 24GHz short range automotive radar system", *IEEE Vehicle Power and Propulsion Conference*, pp. 1023-1026, 2012.

[6] O. Bucci and G. Franceschetti, "Scattering from wedge-tapered absorbers," *IEEE Transactions on Antennas and Propagation*, vol. 19, no. 1, pp. 96–104, 1971.

[7] B. DeWitt andW. Burnside, "Electromagnetic scattering by pyramidal and wedge absorber," *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 7, pp. 971–984, 1988.

[8] C.P. Nep, "Optimization of carbon fiber composite for microwave absorber", *IEEE Transactions on Electromagnetic Compatibility*, vol. 46, no. 1, pp.102-106, 2004.

[9] F. Zekun, "Wide-band electromagnetic wave absorber of rubber-ferrite", *2002 3rd International Symposium on Electromagnetic Compatibility*, pp. 420-423, 2002.

[10] V.G. Veselago, "The electrodynamics of substances with simultaneously negative values of ε and μ", *Soviet Physics Uspekhi*, vol. 10, no. 4, pp. 509-514, 1968.

[11] D. R. Smith, J. B. Pendry, and M. C. K. Wiltshire, "Metamaterial and negative refractive index," *Science*, vol. 305, no. 5685, pp. 788-792, 2004.

[12] A. Porch, D. V. Morgan, and R. M. Perks, "Electromagnetic absorption in transparent conducting films," *Journal of Applied Physics*, vol. 95, no. 9, pp. 4734-4737, 2004.

[13] J. Lee and S. Lim, "Bandwidth-enhanced and polarization-insensitive metamaterial absorber using double resonance," *IET Electronics letters*, vol. 47, no. 1, pp. 8-9, 2011.

[14] J. Lee, M. Yoo, and S. Lim, "A Study of Ultra-Thin Single Layer Frequency Selective Surface Microwave Absorbers With Three Different Bandwidths Using Double Resonance," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 1, pp. 221-230, 2015.

[15] P. V. Tuong, J. W. Park, J. Y. Rhee, K. W. Kim, W. H. Jang, H. Cheong, and Y. P. Lee, "Polarization-insensitive and polarization-controlled dual-band absorption in metamaterials," *Applied Physics Letters*, vol. 102, no. 8, 2013.

[16] C.G.Hu, X. Li, Q. Feng, X.N. Chen, X.G. Luo, "Investigation of the role of the dielectric loss in metamaterial absorber", *Optics Express* , vol. 18, pp. 6598-6603, 2010.