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Dimensionally Adjustable Metamaterial Signal Absorber Design for Microwave S-Band Applications

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Abstract – In this study, the signal absorption of metamaterials was discussed and for this aim, a design capable of perfect signal absorption was realized. The suggested structure consists of a copper resonator on the front surface of the dielectric material and completely copper on the back surface. Accordingly, the suggested design was designed with a finite integration technique (FIT) based simulation program and numerical results were obtained. According to the results obtained from the suggested absorber design, the metamaterial absorber is able to absorb the incoming signal at a rate of 99.88% at a frequency of 3.2091 GHz. In addition, the suggested absorber design can be adjusted parametrically, and the absorption frequency and high absorption rate can also be adjusted in the microwave S-band (2–4 GHz).

Keywords – Metamaterial, Absorber, S-Band, Perfect Absorption, Dimensional Adjustment

I. Introduction

Metamaterials are materials that are not exist directly in nature, artificially designed and exhibit extraordinary electromagnetic properties [1]–[3]. These materials have a wide range of applications, thanks to the great opportunities they offer to control the absorption, transmission, and reflection of electromagnetic waves [4]. Some of the application areas can be listed as filters [5], image processing [6], super lenses [7], signal absorption [4], invisibility cloak [8], sensors [9], antennas [10]. Metamaterials provide a gain increase in materials with their extraordinary electromagnetic properties [11].

In this study, electromagnetic signal absorption of metamaterials is discussed. In order to realize signal absorption with metamaterial, when an electromagnetic signal is applied to the material/ surface, it is expected that the material will not transmit and reflect the incoming signal in the resonance frequency range, that is, absorb it [12]. Since there will not be 100% absorption, this value is required to be at least around 99% after the losses are removed. In this study, high absorption rate in microwave S-band (2–4 GHz) is presented with the suggested design. In addition, with the dimensional adjustability of the presented design, the high absorption rate can be shifted to other frequencies.

II. Materials and Method

A. Theory

The absorption rate in metamaterials is related to the transmission and reflection scattering parameters (S_{11} and S_{21}, respectively). In order to have an excellent absorption rate, the electromagnetic signals reflected and transmitted from the material must be zero or close to zero. The following equation is used to calculate the absorption value (A) of the absorbers [4], [9], [12].

$$A = 1 - |S_{11}|^2 - |S_{21}|^2 \quad (1)$$

In order to obtain the value of A as 1 in Eq. (1), that is, to ensure perfect absorption, it is necessary to set both the parameters S_{11} and S_{21} to 0 as mentioned before. Therefore, a grounded substrate layer (i.e., the back surface covered with metal) is used to simplify the design [4]. In this way, S_{21} parameter will approach 0, and the approximation of

S_{11} parameter to 0 will also be realized with the resonator design [4], [13].

B. *Absorber Design*

Based on the considerations in the theory section, the metamaterial absorber structure shown in Fig. 1 is suggested. The absorber design consists of a dielectric substrate and a copper resonator surface on the front of this substrate and a completely copper surface coating on the back. For absorber design in the x–y plane, FR-4 material with a size of 10 mm × 10 mm ($l_s \times l_s$) and a thickness of 1.6 mm (t_s) (loss tangent 0.025 and relative dielectric constant 4.3) was used as dielectric substrate. The thickness (t_c) of the copper material (conductivity 5.8×10^7 S/m) on the front and back surfaces of the FR-4 is 35 μm. The resonator structure on the front of the FR-4 substrate is designed by forming a Z-shaped structure within a square structure with a width (w) of 1 mm and a side of 9 mm (l_c). Then, these two structures were combined and a 1.05 mm high (g) slit was made from the right and left sides of the square shape. While creating the Z-shape, the structure with a length of 6 mm (l_b) and a width of w was rotated 45° counterclockwise to form a cross bar. In addition, the upper and lower bar of the Z-shape is also 5 mm (l_a) long.

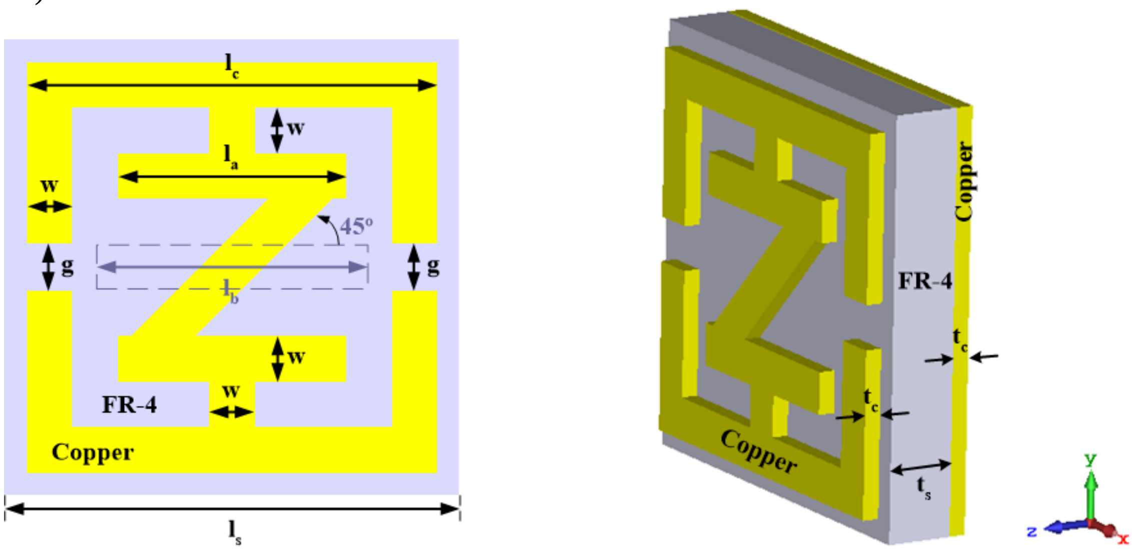

Fig. 1 The front and 3-dimensional appearance of the designed metamaterial absorber, respectively

III. Simulations and Performance Analysis

The metamaterial absorber design, whose geometry and dimensions are given in Fig. 1, was designed with the 3D electromagnetic simulation program CST Microwave Studio and simulations were carried out in the frequency range of 1–5 GHz. Boundary conditions are assigned periodically in the simulations and S_{11} and S_{21} parameters of the design are firstly found. Then, the absorption values of the absorber were obtained from these parameters with the help of Eq. (1).

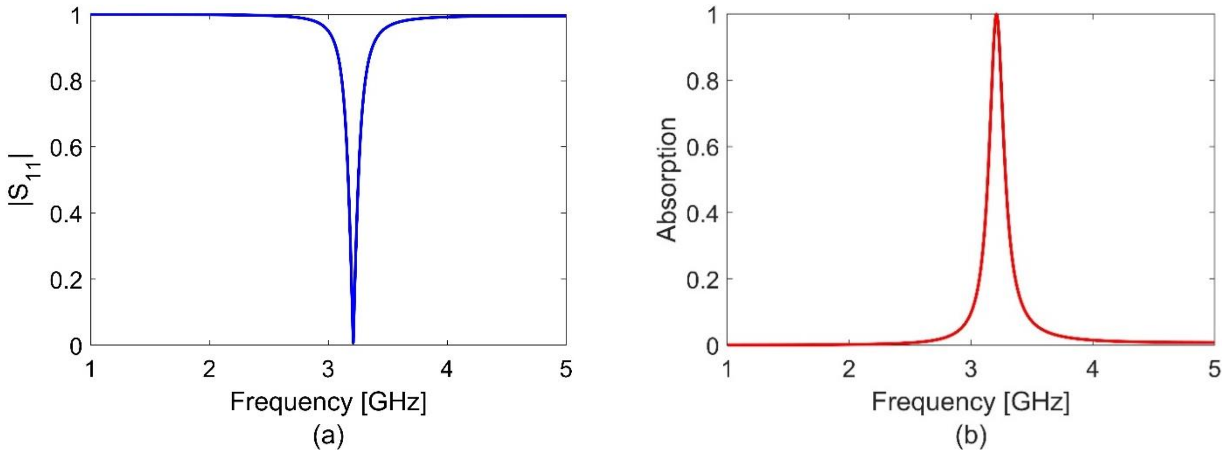

Fig. 2 (a) $|S_{11}|$ and (b) A values for the designed metamaterial absorber

According to the data obtained in Fig. 2(a), the S_{11} parameter has its smallest value ($|S_{11}| = 0.0071$) at a frequency value of 3.2091 GHz (Due to the fully metal-coated surface, it has not been graphed for simplicity, since $S_{21} \approx 0$). At this frequency value, according to Fig. 2(b), it is noted that the suggested metamaterial absorber performs a signal absorption value of 0.9988 (99.88%). It should be noted that changes were made to the dimension parameters so that the suggested final design could give this result. In other words, some sections of the designed absorber were changed parametrically in order to obtain the best absorption value, and an absorption value of 99.88% was obtained at a frequency of 3.2091 GHz. Accordingly, the parametric evaluations of w, g, and l_c values are given in Fig. 3 and Table 1.

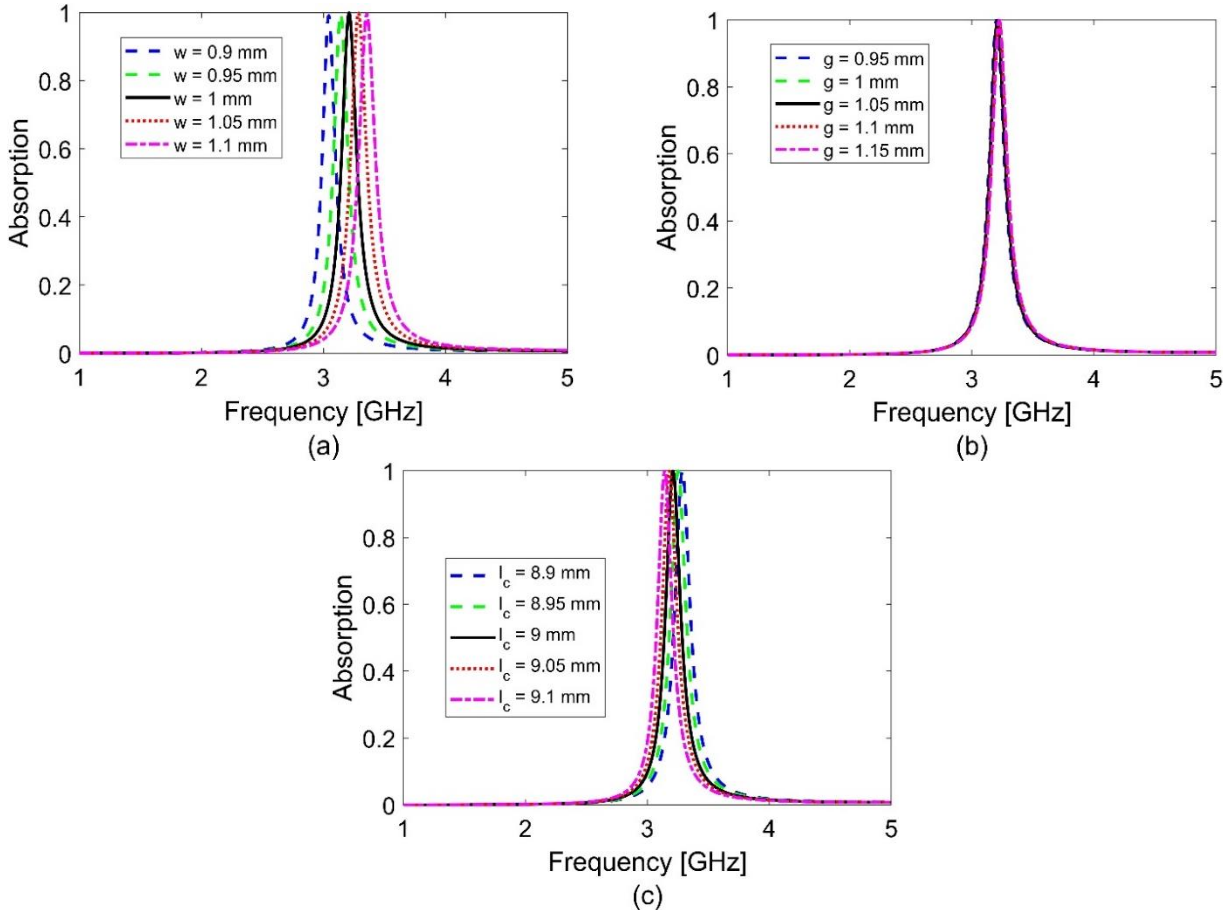

Fig. 3 Variation of the absorption values with frequency, obtained by changing (a) the w dimension to 0.9–1.1 mm, (b) the g dimension to 0.95–1.15 mm, and (c) the l_c dimension to 8.9–9.1, keeping other parameters constant

Table 1. The maximum absorption values obtained by changing the dimensions of w, g, and l_c respectively, with other parameters remaining constant, and the frequencies at which this absorption occurs

w = 0.9 mm		**w = 0.95 mm**		**w = 1 mm**		**w = 1.05 mm**		**w = 1.1 mm**	
f	A	f	A	f	A	f	A	f	A
3.044 GHz	0.9904	3.140 GHz	0.9971	3.2091 GHz	0.9988	3.288 GHz	0.9977	3.356 GHz	0.9950
g = 0.95 mm		**g = 1 mm**		**g = 1.05 mm**		**g = 1.1 mm**		**g = 1.15 mm**	
f	A	f	A	f	A	f	A	f	A
3.204 GHz	0.9988	3.212 GHz	0.9984	3.2091 GHz	0.9988	3.22 GHz	0.9982	3.224 GHz	0.9988
l_c = 8.9 mm		**l_c = 8.95 mm**		**l_c = 9 mm**		**l_c = 9.05 mm**		**l_c = 9.1 mm**	
f	A	f	A	f	A	f	A	f	A
3.288 GHz	0.9983	3.252 GHz	0.9987	3.2091 GHz	0.9988	3.18 GHz	0.9987	3.144 GHz	0.9980

When the parametric analysis in Fig. 3 and Table 1 is examined, it is once again confirmed that the best absorption value in the 1–5 GHz frequency range occurs at w = 1 mm, g = 1.05 mm, and l_c = 9 mm, and at 3.2091 GHz in the microwave S-band. In addition, when the absorption values in Table 1 are examined, it is seen that these values vary between 0.9904 and 0.9988 in the close range and do not fall below 99%. these absorption values, which are above 99%, indicate that the suggested metamaterial absorber structure can be parametrically adjusted and the absorption frequency can be adjusted in the microwave S-band with high absorption values. These absorption values, which are above 99%, indicate that the suggested metamaterial absorber structure can be parametrically adjusted and the absorption frequency can be adjusted in the microwave S-band with high absorption values. In other words, high absorption can be achieved in wider microwave bands by performing parametric analyzes with other dimensional parameters.

IV. CONCLUSION

In this study, the suggested metamaterial-based absorber structure and simulation results are examined in a broad perspective. According to the performed design and numerical data analysis, a design that can absorb the incoming signal at a rate of 99.88% at the frequency of 3.2091 GHz in the microwave S-band is suggested. In addition, parametric analyzes show that by changing the dimension parameters of the suggested absorber design, the absorption frequency and value can be changed in such a way that a high absorption value can be obtained in the microwave S-band. As a result, the suggested design with its dimensionally adjustable feature is adaptable to different frequencies with its excellent absorber feature in many fields such as communication, image processing, medical and military technologies.

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