Design and Investigation of Characteristic Structure Split Ring Resonator Circular of Microwave Metamaterial Absorber Parameter in X-band Frequency

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Abstract—This paper explained the design and investigation of the characteristic structure of split ring resonator circular in the parameter of microwave metamaterial absorber in X-band frequency. The result showed that bigger value of inner radius circular geometry obtained the resonance frequency shifted to bigger such as 9.20 GHz to 9.30 GHz, and maximum absorption rate increased from 88.9% to 93.35%. When the inner radius smaller and the outer higher, represented the resonance frequency shifted to lower, 11.13 GHz to 9.94 GHz, and the maximum absorption rate decreased from 85% to 78.27%. In another condition, the lower gap variation affected resonance frequency shifted to lower 9.30 GHz to 9.13 GHz but maximum absorption rate increased 88.64% to 89.2%, thus opposite.

Keywords—Absorption rate, Resonance frequency, a split ring resonator, Gap width, geometrical radius circular, X band

I. INTRODUCTION

For last years, the microwave metamaterial absorber technology was interested in the researcher, actually in the microwave field. This reason indicated that microwave has an advantage and unique feature in many applications, such as microwave, terahertz, infrared and optic [1][2], and [3]. In 1968, a physicist, who named Victor Vaselago pioneered in electrodynamic isotropy research field also obtained dielectric constant and magnetic permeability which negative, so metamaterial began [4]. In 1999, a physicist from Great Britain, John Pendry, proved metamaterial theory from Vaselago to make a combination between coal wire and structure split ring resonator, which basically to obtain negative dielectric constant, thus resonator ring to make negative permeability [4].

Metamaterial absorber is an artificial composite structure which consists of two metal layers of the electric resonator, another side is a ground plane, and the middle is dielectric layer [5]. Split ring resonator is a structure represented electrical circuit about resonance frequency shifted [6][7], and [8]. In this research, will explain a design and characteristic investigation of structure split ring resonator circular in microwave metamaterial absorber parameter, which means to know about the effect of wide radius characteristic in geometrical circular and also gap width of microwave metamaterial absorber parameter such as resonance frequency absorption rate.

This research is expected that the result of an investigation between characteristic circular radius width and a gap width of microwave metamaterial absorber can be applied in any research fields, such as to apply microwave, mutual coupling, radar cross section, airborne and chamber room. From the background that presented, this research will purpose “Design and Investigation of Characteristic Split Ring Resonator Circular in Microwave Metamaterial Absorber Parameter in X-band”.

II. DESIGN OF STRUCTURE UNIT CELL SPLIT RING RESONATOR CIRCULAR

A. Calculation of Structure Unit Cell Split Ring Resonator Circular

In this chapter explaining the dimensional calculation of structure unit cell split ring resonator circular used equivalent circuit approach [9]. The Sub-wavelength of structure unit cell split ring resonator circular characterized in inductance (L) and capacitance (C). The geometrical structure unit cell is shown in Figure 1.

Figure 1. Geometrical Unit Cell Split Ring Resonator Circular [9].

LC circuit of resonance frequency represented in Eq. (1)

\[ f_0 = \frac{1}{2\pi\sqrt{LC}} \]  

(1)

The inductance can be approximated in that of a closed ring [9].

\[ L = \mu_0 R_m \left( \ln \frac{R_m}{h+w} - 0.5 \right) \]  

(2)
\( \mu_0 \) is the permeability of free space and \( R_m \) is the mean radius of the ring, \( R_m = R + \frac{w}{2} \).

Here, there are two capacitances in this research, gap and surface capacitance which shown in Eq. (3). The gap capacitance divided in material and vacuum capacitance.

\[
C = C_{\text{gap}} + C_{\text{surf}} \tag{3}
\]

B. Absorbed Rate Calculation

From reference [10], microwave metamaterial absorber performance is shown in Eq. (4-5).

\[
A(\omega) = 1 - R(\omega) - T(\omega) \tag{4}
\]

\[
A(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2 \tag{5}
\]

Where:

- \( A(\omega) \) = Absorption rate
- \( R(\omega) \) = Reflection coefficient
- \( T(\omega) \) = Transmission coefficient
- \( |S_{11}| \) = Magnitude of \( S_{11} \)
- \( |S_{21}| \) = Magnitude of \( S_{21} \)

III. SIMULATION DESIGN OF MICROWAVE METAMATERIAL ABSORBER

C. Unit Cell Structure Split Ring Circular Design of Microwave Metamaterial Absorber

In this chapter, processing unit cell structure design split ring resonator circular used software Computer Simulation Technology (CST) studio. The material specification in this research is decided in Table 1.

| Parameter                      | Specification                  |
|--------------------------------|--------------------------------|
| Material                       | FR-4 Epoxy                     |
| Dielectric constant \( \varepsilon_r \) | 4.3                            |
| Substrate thickness \( h \)    | 0.8 – 3.2 mm                   |
| Copper thickness               | 0.035 – 0.07 mm                |

Simulation design of structure unit cell split ring circular is shown in Figure 2.

![Figure 2. Simulation Design of Geometrical Structure Unit Cell Split Ring Resonator Circular.](image)

From Table 2, presenting some dimensional specifications of the structure unit cell split ring circular is established in the resonance frequency, therefore the simulation design in this process will be taken in two X-band frequency samples, 9.23 GHz, and 10.14 GHz.

| No | Dimensional Structure Unit Cell Split Ring Resonator Circular | Frekuensi (GHz) |
|----|--------------------------------------------------------------|-----------------|
|    | Value (mm)                                                   |                |
| 1  | Substrate length \( (s) \)                                  | 0.85            |
|    | Substrate thickness \( (h) \)                               | 0.8             |
|    | Inner radius \( (R) \)                                      | 2.825           |
|    | Outer radius \( (R_o) \)                                    | 3               |
|    | Radius width \( (w) \)                                     | 0.175           |
|    | Gap width \( (g) \)                                        | 0.5             |
|    | Substrate length \( (s) \)                                  | 6.85            |
|    | Substrate thickness \( (h) \)                               | 0.8             |
| 2  | Inner radius \( (R) \)                                      | 2.625           |
|    | Outer radius \( (R_o) \)                                    | 2.8             |
|    | Radius width \( (w) \)                                     | 0.175           |
|    | Gap width \( (g) \)                                        | 0.5             |

In Table 3, the validation calculating of dimensional structure unit cell split ring circular used LC method which noticed about radius dimension, thick substrate, wide radius and wide gap are equal with dimension in Table 2.

| No | Dimensional Specification Used LC Method | L \( (\mu \text{H}) \) | C \( (\text{pF}) \) | Frekuensi (GHz) |
|----|-----------------------------------------|-----------------------|-----------------|-----------------|
|    | Variable                                | Value (mm)            |                 |                |
| 1  | \( R \)                                 | 2.825                 |                 |                |
|    | \( w \)                                 | 0.175                 | 9.78            | 0.031           |
|    | \( h \)                                 | 0.8                   |                 |                |
|    | \( g \)                                 | 0.5                   |                 |                |
| 2  | \( R \)                                 | 2.625                 |                 |                |
|    | \( w \)                                 | 0.175                 | 8.86            | 0.038           |
|    | \( h \)                                 | 0.8                   |                 |                |
|    | \( g \)                                 | 0.5                   |                 |                |

D. Absorption rate

Basically, the absorption rate chart can be obtained from the correlation among scattering parameters which are determined by \( S_{11} \) and \( S_{21} \). The absorption values will work well in 80% required by \( S_{11} \) ≤ -5 dB and magnitude \( S_{21} \) is 0 which assumes power blocked [11]. The result of \( S_{11} \) graph and absorption rate from each resonance frequency is shown in Figure 3.

![Figure 3. \( S_{11} \) Parameter Chart in Frequency 9.21 GHz.](image)

\( S_{11} \) parameter rate chart in resonance frequency 9.21 GHz with minimum value -9.5 dB is shown in Figure 3.
Figure 4. Parameter Chart $S_{11}$ in Frequency 10.1 GHz.

$S_{11}$ parameter rate chart in resonance frequency 9.21 GHz with minimum value -8.92 dB is shown in Figure 4. Absorption rate chart for each resonance frequency is referred in 5 and 6.

Maximum absorption rate chart in frequency 9.21 GHz is 88.9% shown in Figure 5 and in frequency 10.1 GHz is 87.22% as shown in Figure 6.

Figure 5. Absorption Rate Chart in Frequency 9.21 GHz.

Figure 6. Absorption Rate Chart in Frequency 10.1 GHz.

IV. PARAMETRIC ANALYSIS OF THE PROPOSED UNIT CELL STRUCTURE SPLIT RING RESONATOR CIRCULAR

In this chapter, the design of unit cell split ring resonator circular is investigated in a characteristic parameter such as the width of the inner and outer geometric circular and gap width.

A. Inner Radius Variation (Ri) in Geometrical Circular

The effect of characteristic inner radius width (Ri) in a geometrical circular in microwave metamaterial absorber parameter is analyzed. There are two conditions, increasing and reducing the value of the inner radius. The former in 9.2 GHz and the later 8.4 GHz. For the specification, dimensional and various inner radius (Ri) in the geometrical circular are shown in Table 4 and 5.

| Ri (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|-----------------------------|------------------------|----------------------------|
| 2.825   | 9.20                        | -9.52                  | 88.90                      |
| 2.86    | 9.21                        | -10.1                  | 90.23                      |
| 2.895   | 9.23                        | -10.76                 | 91.68                      |
| 2.93    | 9.30                        | -11.77                 | 93.35                      |

Absorption rate chart $S_{11}$ and parameter shown in Figure 7 and 8.

Figure 7. $S_{11}$ Parameter Graph of Increasing Various Inner Radius (Ri) in Geometrical Circular.

| Ri (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|-----------------------------|------------------------|----------------------------|
| 2.975   | 8.41                        | -10.37                 | 90.84                      |
| 2.8    | 8.49                        | -8.54                  | 85.3                       |
| 2.625   | 8.65                        | -7.19                  | 80.9                       |
| 2.45    | 8.89                        | -6.31                  | 76.65                      |

Absorption rate chart $S_{11}$ and parameter shown in figure 9 and 10.

Figure 8. Absorption Rate Chart of Increasing Various Inner Radius (Ri) in Geometrical Circular.

TABLE 4.
VARIOUS VALUES OF INCREASING INNER RADIUS (Ri) IN GEOMETRICAL CIRCULAR

| Ri (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|-----------------------------|------------------------|----------------------------|
| 2.825   | 9.20                        | -9.52                  | 88.90                      |
| 2.86    | 9.21                        | -10.1                  | 90.23                      |
| 2.895   | 9.23                        | -10.76                 | 91.68                      |
| 2.93    | 9.30                        | -11.77                 | 93.35                      |

Figure 7. $S_{11}$ Parameter Graph of Increasing Various Inner Radius (Ri) in Geometrical Circular.

TABLE 5.
VARIOUS VALUES OF DECREASING INNER RADIUS (Ri) IN GEOMETRICAL CIRCULAR

| Ri (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|-----------------------------|------------------------|----------------------------|
Figure 9. $S_{11}$ Parameter Graph of Decreasing Various Inner Radius ($R_i$) in Geometrical Circular.

Figure 10. Absorption Rate Chart of Decreasing Various Inner Radius ($R_i$) in Geometrical Circular.

B. Variation value of outer radius in (Ro) geometrical circular

In this chapter, the effect of characteristic outer radius (Ro) width in a geometrical circular in microwave metamaterial absorber parameter is analyzed. There are two conditions, such as increasing outer radius (Ro) of the resonance frequency of 11.1 GHz, and decreasing 10.1 GHz. The dimensional specifications of various outer radius (Ro) in the geometrical circular are shown in Table 6 and 7.

![Figure 11. $S_{11}$ Parameter Graph of Increasing Outer Radius (Ro) in Geometrical Circular.](image)

| Ro (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|----------------------------|-----------------------|----------------------------|
| 2.6     | 11.13                      | -8.24                 | 85                         |
| 2.7     | 10.69                      | -7.51                 | 82                         |
| 2.8     | 10.29                      | -7.00                 | 80                         |
| 2.9     | 9.94                       | -6.62                 | 78.27                      |

Absorption rate chart $S_{11}$ and parameter shown in Figure 11 and 12.

![Figure 12. Absorption Rate Chart of Increasing Various Outer Radius (Ro) in Geometrical Circular.](image)

| Ro (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|----------------------------|-----------------------|----------------------------|
| 2.8     | 10.14                      | -8.93                 | 88.9                       |
| 2.76    | 10.33                      | -9.40                 | 88.53                      |
| 2.72    | 10.46                      | -10.19                | 90.24                      |
| 2.68    | 10.84                      | -11.03                | 92.18                      |

Absorption rate chart $S_{11}$ and parameter shown in Figure 13 and 14.

C. Various Values of Geometrical Circular Gap Width

By this chapter, the effect of characteristic gap width in unit cell structure split ring circular in microwave metamaterial absorber parameter. The specification of gap width unit cell structure circular shown in Table 8.

![Figure 13. Absorption Rate Chart of Decreasing Outer Radius (Ro) in Geometrical Circular.](image)

| Xg (mm) | Absorption Frequency (GHz) | Minimum $S_{11}$ (dB) | Maximum Absorption Rate (%) |
|---------|----------------------------|-----------------------|----------------------------|
| 0.5     | 9.20                       | -9.54                 | 88.9                       |
| 0.3     | 9.13                       | -9.63                 | 89.20                      |
| 0.4     | 9.16                       | -9.59                 | 89.13                      |
| 0.6     | 9.25                       | -9.49                 | 88.77                      |
| 0.7     | 9.30                       | -9.44                 | 88.64                      |

Absorption rate chart $S_{11}$ and parameter shown in figure 15 and 16.
V. CONCLUSIONS

The design and characteristic investigation of structure split ring circular in microwave metamaterial absorber parameter in X-band frequency are established. From table IV, various values of increasing inner radius (Ri) resulted in higher resonance frequency and shifted to the higher frequency and maximum absorb rate increased. Nevertheless, from table V showed that decreasing inner radius (Ri) resulted in opposite. Table VI informed that various values of increasing outer radius (Ro) resulted resonance frequency shifted to a lower frequency and maximum absorption rate decreased, so did opposite in table VII. Moreover, table VIII showed that various values of decreasing gap width resulted in resonance frequency shifted to lower frequency but maximum absorption rate increased. We can obtain that the results of the investigation between structure split ring resonator circular and LC equivalent circuit resulted in frequency shifted higher in smaller L and bigger C, and opposite.

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