Wide Angle and Polarization Insensitive Circular Ring Metamaterial Absorber at 10 GHz

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***Abstract*-This report presents a design of wide angle and polarization insensitive circular ring metamaterial absorber working at 10 GHz. The structure is designed on lossy FR4 substrate sandwiched by thin copper layers. From the simulation, the circular ring metamaterial absorber can operates at wide incident angle, where they maintain high absorbance, which is more than 87% for incident angles as large as 70^{o}. Due to the geometrical properties, this kind of absorbance is insensitive to any polarization state.**

I. Introduction

Metamaterials are composite structured materials, structured at sub-wavelength scales, and depend on the structure to give rise to electromagnetic resonances. [1]. The unique properties of metamaterials have attracted much attention among researchers. Then, many sub-areas of metamaterials have been developed such as artificial magnetic conductor [2], frequency selective surface [3], electromagnetic band gap [4] and left-handed metamaterials [5]. Metamaterials generally appear as periodic elements that are a combination of many unit cell and they work in sub-wavelength of their operating frequency. Due to this characteristic, they can be fabricated using very thin substrate and small surface area compared to their operating wavelength. Metamaterials, until this moment have shown that they can improve the performance of other electromagnetic devices, especially antenna [6] and filter [7] if these structures are combined together. For example, using left-handed metamaterial, the gain of microstrip antenna can be increased [6].

AMC (artificial magnetic conductor) type of metamaterial has been widely used in antenna design to improve the radiation pattern of antennas, especially for horizontal dipole antenna. This kind of antenna obtains poor radiation pattern due to the appearance of out-of-phase image current on the ground plane that may cancel the real current of the antenna. Using AMC structure as artificial ground plane, they provide in-phase image current that may reinforces the real current and improves the radiation pattern of the antenna [8]. AMC ground plane in this case acting as a reflector of the antenna structure where it reflects most of the backward radiation.

In reverse, there are increasing much interest on metamaterials as electromagnetic absorber [9] other than electromagnetic reflector. To obtain this, the material properties such as permittivity and permeability are manipulated so that they can obtain high absorption. Perfect absorbance achieved when both reflectance and transmittance value are simultaneously 0. To obtain this, proper structure should be used to ensure the electromagnetic waves do not reflected or pass through the structure. This involves the impedance matching between the absorbing structures with the free space impedance. Theoretically, the maximum absorber occurs when the surface impedance of the metamaterial absorber is the same as free space impedance (377Ω).

II. Proposed Design of Circular Ring Metamaterial Absorber

The conventional electromagnetic absorbers use thick substrate for their design. For example, the usage of Salisbury screen as an electromagnetic absorber need to be designed with the thickness of λ/4 compared to the operating frequency [10]. The thickness of electromagnetic absorber can be reduced using planar substrate like FR4 board. In this report, the circular ring metamaterial absorber as shown in Figure 1 is designed using lossy FR4 substrate, which has substrate thickness, h of 0.8 mm (0.027λ_o), relative permittivity of 4.6 and tangent loss of 0.019. The structure consists of single copper ring, which has inner radius, r_i of 2.56 mm and outer radius, r_o of 2.80 mm. The width of the ring is 0.24 mm with average circumference of circle of 16.85 mm. At the back of the structure, the full copper layer is used to minimize the transmission. The size of unit cell of the absorber is 9 mm x 9 mm. The ring shape is selected due to their symmetrical property for all rotational angles. That means the absorbance properties will remain the same for all rotational angles and make this structure insensitive to any polarization state.

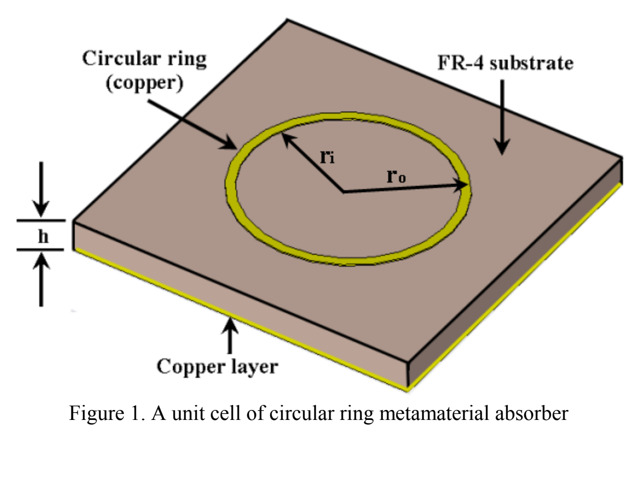

Figure 1. A unit cell of circular ring metamaterial absorber

III. SIMULATION RESULT AND DISCUSSION

The structure as shown in Figure 1 is simulated using CST software with floquet solver. The structure, which is in a unit cell, is simulated by setting the boundary condition to be in periodic boundary condition while the top and bottom boundary to be open add space. The simulated result is given in term of S_{11} (reflection) and S_{21} (transmission).

A. Reflectance, Transmittance and Absorbance

Reflectance, R(ω) is a measure of the reflection ability of the structure with the incident electromagnetic waves. This value can be obtained by $R(\omega)=|S_{11}|^2$ where the S_{11} magnitudes is given from simulation. The small value of reflectance indicated that the structure is not a reflector. For example, R(ω)=1 means that the structure reflect all the electromagnetic waves while R(ω)=0 means otherwise. But to ensure the structure is a good absorber, the value of transmittance, T(ω) should be determined. Transmittance is a measure of transmission ability of electromagnetic waves through the structure. This value can be determined by $T(\omega)= |S_{21}|^2$ where the S_{21} magnitudes are obtained from simulation result. The small value of transmittance shows that the structure may not let the electromagnetic waves to pass through the structure. For many absorbance designs, the small value of transmittance can be easily obtained using full metal plane at the bottom of the absorbance structure. To determine the absorbance value, A(ω) this formula can be used; A(ω)=1-R(ω)-T(ω) where all value is linear. If both R(ω) and T(ω) are simultaneously 0, A(ω)=1 indicates that the metamaterial structure can absorb 100% of incident electromagnetic waves.

Figure 2 shows the simulated result of circular ring metamaterial absorber in term of absorbance, reflectance and transmittance for normal incident EM waves. From the figure,

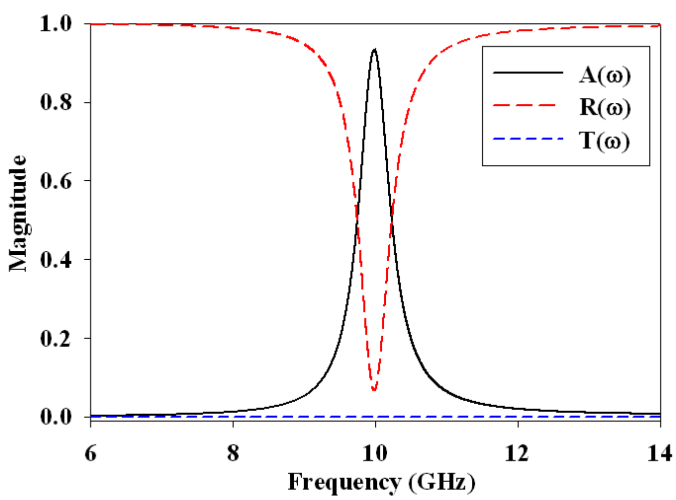

Figure 2. Simulated reflectance, transmittance and absorbance

T(ω) is 0 for all frequency range since the full copper layer that is used in the design will prevent the incident electromagnetic waves to pass through the structure. So the absorption is only depend on the value of R(ω). Through optimization and other design consideration, R(ω)=0.069 (6.9%) is achieved and then gives A(ω)=0.931 (93.1%). The full width half maximum, FWHM is given by 0.51 GHz (9.74 GHz-10.25GHz).

B. Current Distribution and Surface Current

To better understand the physical mechanism of the circular ring metamaterial absorber, the power loss distribution on the metals and surface current distribution is simulated. Figure 3 shows the power loss distribution for E-field and H-field of circular ring metamaterial absorber. For E-field, the concentration of power loss distribution is high at +y and –y-axis of the ring structure since it is parallel to the electric component of the incident EM waves. For H-field, the concentration of power loss distribution is high at +x and –x-axis of the ring structure since it is parallel to the magnetic component of EM waves.

The surface current distribution is then investigated for the structure. On the circular ring shape, the dipolar respond is noticed where the current is going up and down on the ring at the left side and the right side of the ring as shown in Figure 4. There is also a magnetic response associated by circulating displacement currents between the two metallic elements. Most currents are concentrated at the two sides of the copper layer indicate that the major loss for this absorber comes from copper losses compared to dielectric loss which is occur in the dielectric substrate between the metal layers.

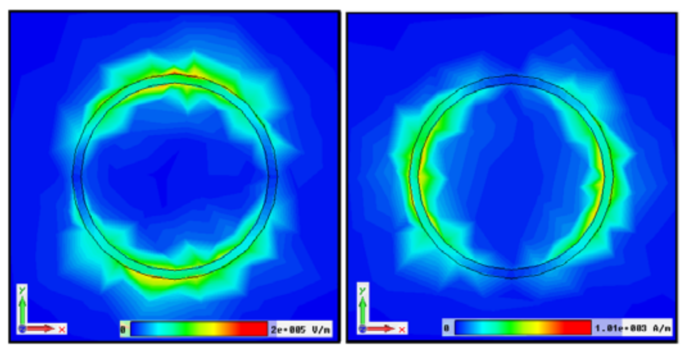

Figure 3. Power loss distribution for E-field (left) and H-field (right)

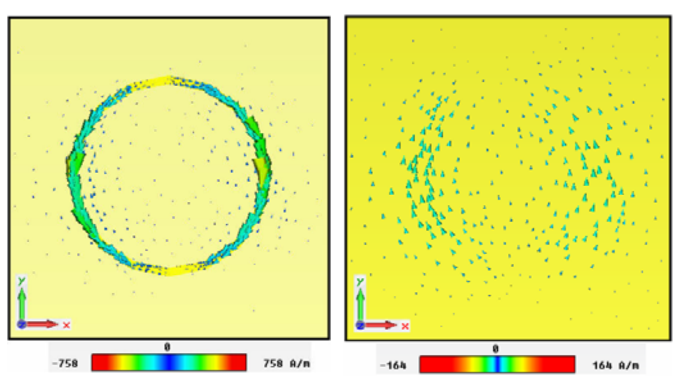

Figure 4. Surface current on ring structure at the top substrate (left) and copper plane at the bottom substrate (right)

C. *Effect of Absorbance for different Angle of Incident EM Waves*

From the previous result, the circular ring metamaterial absorber shows that it has good absorbance for normal incident of EM waves and the geometrical property make this structure insensitive to all polarization angles. To determine the absorbance characteristic of this kind of absorber for different angles of incident EM waves, simulation is done for TE and TM polarization incident waves. For TE polarization incident waves, the angles of incident of EM waves are varied where the electric component of EM waves always tangential to the surface of the metamaterial absorber. For TM polarization incident waves, the magnetic component of EM waves should be tangential to the surface of absorber for all incident angles of EM waves.

Figure 5 shows the magnitude of absorbance of circular ring metamaterial absorber for TE polarization incident waves. The angle of incident is varied from normal incident (0^0) to an angle where the absorbance drops to 0.5 (50%). The magnitudes of absorbance for 0^0, 20^0, 40^0, 60^0, 70^0 and 82^0 are 0.9310, 0.9494, 0.9889, 0.9781, 0.8775, and 0.5471 respectively. It shows that the circular ring structure manages to maintain high absorbance (more than 87%) for large incident angles (70^0) of EM waves for TE polarization incident waves.

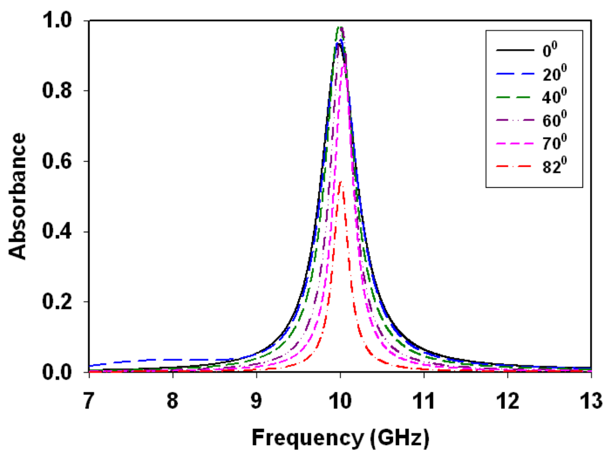

Figure 5. Absorbance for TE polarization incident waves

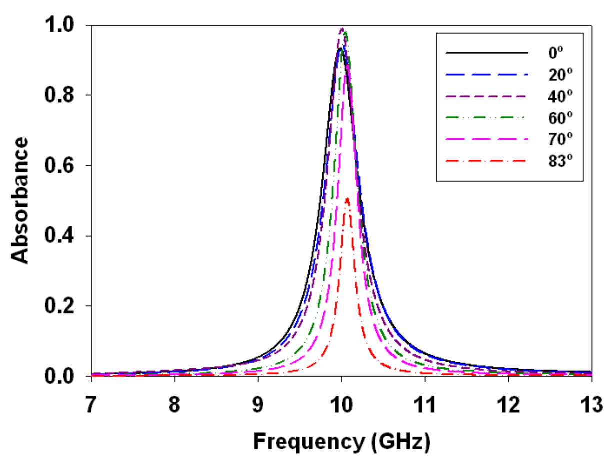

Figure 6. Absorbance for TM polarization incident waves

Figure 6 shows the magnitude of absorbance of circular ring metamaterial absorber for TM polarization incident waves. The angle of incident is varied from 0^0 to 83^0. The magnitudes of absorbance for 0^0, 20^0, 40^0, 60^0, 70^0 and 83^0 are 0.9310, 0.9440, 0.9882, 0.9785, 0.8840, and 0.5056 respectively. The result shows that this structure can maintain high absorbance (more than 88%) for large incident angles (70^0) of EM waves for TM polarization incident waves. The results for TE and TM polarization incident waves are almost the same due to the characteristic of the structure that is highly symmetrical.

IV. CONCUSION

In this report, a circular ring matamaterial absorber, which is independent from any polarization state and working at wide incident angles of electromagnetic waves, has been presented. Peak absorbance of 93.1% with 0.51GHz FWHM has been achieved for normal incident waves. The investigation of power loss distribution and surface currents in the unit cell of the structure reveals the behavior of power loss for both E-field and H-field.

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