Polarization Angle Independent Metamaterial Absorber in both of C- and X-Bands

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Abstract ─ In this study, perfect metamaterial absorbers (MAs) based on circle- and square-shaped configurations that are numerically and experimentally designed and analyzed in both of C- and X-band. The proposed models have very simple designs and present perfect absorption for all polarization angles. A sensor application of the suggested model (for circle-shaped) is also presented to introduce further feature of the structure. Moreover, the suggested models can be easily reconfigured for THz and infrared frequency regimes to enable myriad potential applications such as sensors, defense systems and stealth in the next studies.

Index Terms ─ Absorber, metamaterial, sensor.

I. INTRODUCTION

Metamaterials have been rapidly a great deal of interest by the electromagnetic community due to present unusual EM properties, such as negative refraction. Also, they have many potential application areas such as sensing [1], cloaking [2], super lens [3], antenna [4], polarization rotator [5], and absorber [6]. These materials are manmade and can be artificially manufactured at the desired frequency regimes of the EM spectrum from MHz [7], GHz [8], sub-THz [9], THz [10], sub-PHz [11], near-IR [12] to the near optical frequency region [13].

Moreover, the concept of MA has great attention during the recent years by the researchers because of having crucial importance applications, especially for military areas. There are many MA studies in literature in order to achieve perfect absorption at a certain frequency range such as ultra-thin [14], extremely broad band [15], tunable [16], based on chiral metamaterial [17], multi-band [18], based on isotropic resonators [19]. Unlike the others, this study focuses on microwave absorber that has very simple design, easy fabrication and introduces wide band perfect absorption for all polarization angles and so on at certain frequency regime. Additionally, electric field and surface current distributions of the proposed model at the resonance frequencies are separately examined to realize its' physical operation mechanism. Obtained numerical and experimental results are realized and compared according to the other MA studies in literature.

II. NUMERICAL AND EXPERIMENTAL SETUP OF THE PROPOSED MODEL

In order to achieve perfect absorption for all polarization angles, firstly we proposed two different symmetric geometric shaped, and then to have very simple designs and easy fabrication process, we created circle-with gap and square-shaped. After these processes, we optimized the aimed models of circle- with gap and square-shaped to obtain perfect absorption. So, the proposed structures are created with the best dimension values. The proposed resonators are designed of copper with the conductivity of 5.8001 S/m and thickness of 0.035 mm. The substrates are chosen as FR4 (flame resistant); thickness, loss tangent, and relative permittivity of 1.6 mm, 0.02 and 4.2, respectively. Figures 1 (a), 2 (a) and 1 (b), 2 (b) shows dimensions of the optimized resonators and numerical setups picture, in order. It can be seen that the periodic boundary conditions (x,y) with floquet port (z) are used in the simulation study for both of study. The numerical studies are performed with a commercial full-wave EM solver (CST

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Microwave Studio) based on finite integration technique.

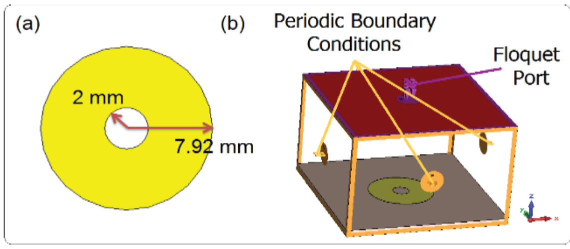

Fig. 1. Proposed perfect circle with gap-shaped MA: (a) dimensions, and (b) numerical setup.

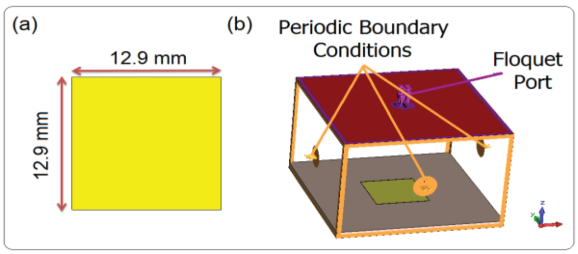

Fig. 2. Proposed perfect square-shaped MA: (a) dimensions, and (b) numerical setup.

The S-parameter (scattering parameter) defines device characteristics using the degree of scattering when an electromagnetic wave is applied. Scattering as a general term means reflection back to the incident direction or transmission to other directions. All linear characteristics of electromagnetic material or electronic device can be defined in terms of the degree of scattering (S-parameter).The input/output ports of a system can be numbered and the S-parameter is defined as Sij; i.e., "Incident at port j→ Obtained at port i." Reflection and transmission cases are valid when i=j and i≠j, respectively. Hence, in an n-port system, n^2 times S-parameters can be defined. Besides these S-parameters can be aligned as a matrix and referred as S-matrix (scattering matrix). The absorption behavior of the proposed MA can be calculated by $A(\omega)=1-R(\omega)-T(\omega)$, where $A(\omega)$,$R(\omega)=|S_{11}|^2$ and $T(\omega)= |S_{21}|^2$ are the absorption, reflection, and transmission, in order. Therefore, to achieve perfect absorption, reflection and transmission EM waves must be very close to zero. This provided by impedance matching at the resonance frequency. It is well known that metamaterials can be characterized by a complex frequency dependent electric permittivity $\varepsilon(\omega)=\varepsilon_1(\omega)+i\varepsilon_2(\omega)$ and a complex frequency dependent magnetic permeability $\varepsilon(\omega)=\mu_1(\omega)+i\mu_2(\omega)$. Reflectivity can also be reduced (near-zero) when the effective permittivity $\varepsilon(\omega)$ and permeability $\mu(\omega)$ have minimum values. Therefore, $\varepsilon(\omega)$ and permeability $\mu(\omega)$ can properly be adjusted to absorb both the incident electric and magnetic fields to achieve perfect absorption [14-19].

After numerical results, the fabricated structure is also experimentally tested to verify numerical results. Therefore, the absorption measurement setup is installed. The measurement is carried out by using R&S ZVL6 Vector Network Analyzer (VNA) and two horn antennas with the range of 4 GHz to 6 GHz in C-band. In the measurement, one horn acts as a transmitter and the other one detects the transmitted or reflected wave. Firstly, free space measurement without sample is carried out to obtain calibration data for the VNA. The sample is then inserted into the experimental measurement setup and *S*-parameters measurements are performed. The fabricated sample and devices for measurements setup are shown in Fig. 3.

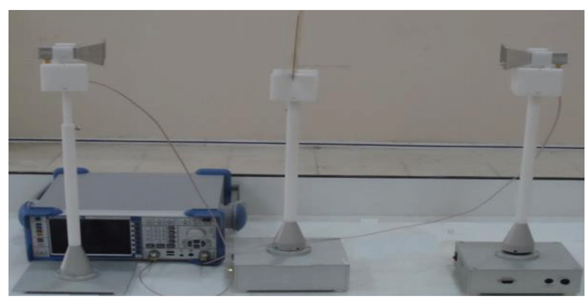

Fig. 3. A picture from the measurement setup.

III. NUMERICAL AND MEASUREMENT RESULTS

Figures 4 and 5 show numerical and measured results for proposed perfect MA. It can be seen that the simulation maximum absorptions of 99.98% is obtained at the resonance frequency of 4.69 and 4.99 GHz, and the corresponding reflection magnitude is 0.0001 at the resonance frequencies for both of structures, respectively. Also, the measured maximum absorption of 98.67% and 99.78% is observed at the resonance frequency of 4.69 GHz and 5.00 GHz for circle with gap- and square-shaped MAs, in order. The simulation results are in good agreement with the experimental ones. The suggested structures have potential applications of long-distance radio telecommunications in relation with C-band and it will also be a very good candidate for the applications of satellite communication transmissions, some Wi-Fi devices, some cordless telephones, some weather radar systems and so on.

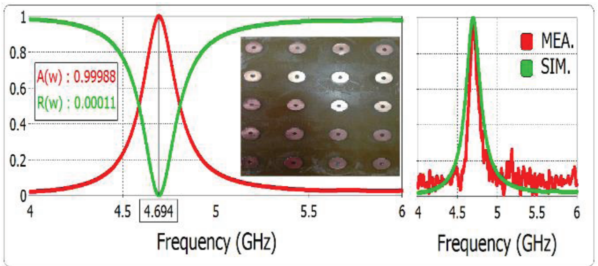

Fig. 4. Simulated reflection and absorption values in C-band Inset: fabricated picture and measured absorption spectrum of the proposed circle with gap-shaped MA at certain frequency regime.

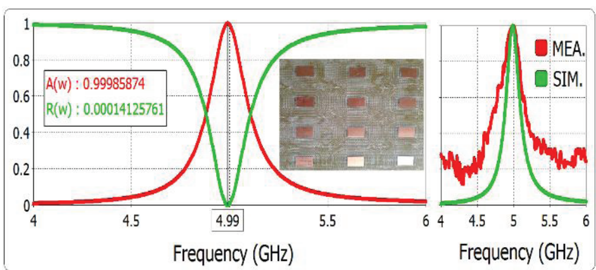

Fig. 5. Simulated reflection and absorption values in C-band Inset: fabricated picture and measured absorption spectrum of the proposed square-shaped MA at certain frequency regime.

Besides, bandwidth calculations are performed to show the performance of the structure in C-band. The fractional bandwidth (FBW) is calculated as FBW=$\Delta f/f_0$, where Δf is the half power bandwidth and f_0 is the center frequency. These parameters are found as Δf=0.23-0.25 GHz, f_0=4.69-4.99 GHz and FBW≈4.90%-5.01%, for circle with gap- and square-shaped MAs, respectively. This means that the proposed structure has approximately 230-250 MHz bandwidth range referring to 4.90%-5.01- FBW which is very well for many applications. For example, a patch antenna needs around 3% FBW. Therefore, the proposed model would provide enough margins to work with. These computations confirm performance quality of the suggested MA.

Moreover, we performed numeric studies using the suggested structures for X-band frequency regimes. Since the proposed models introduce flexibility to adjust its metamaterial features, the structure is easily rescaled for infrared and visible frequency regions. Maximum absorptions for X-band frequency regime is numerically obtained around 99.68% and 99.99% at the resonance frequency of 10.6 GHz and 8.51 GHz, for circle- and square-shaped, respectively as shown in Figs. 6 and 7.

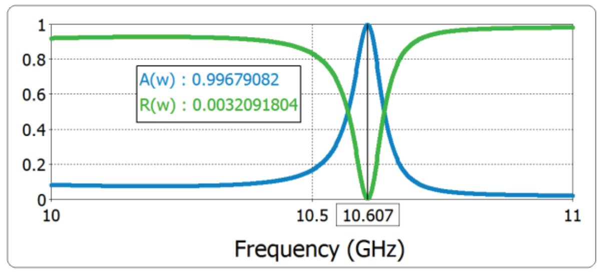

Fig. 6. Simulated reflection and absorption values in X-band for the proposed circle with gap-shaped MA.

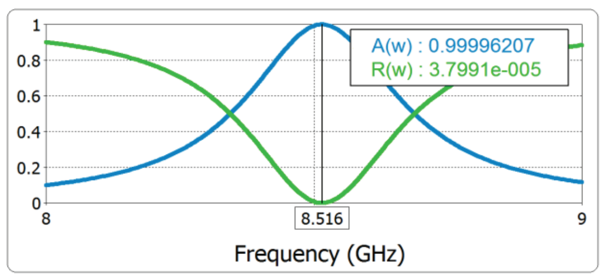

Fig. 7. Simulated reflection and absorption values in X-band for the proposed square-shaped MA.

As next investigation, we examined the effect of the polarization angle on the absorption behavior of the proposed perfect MA in both C-band and X-band as shown in Figs. 8 and 9, respectively. Both of obtained numerical results show that when the polarization angle is increased from 0^o to 90^o with 30 degree step and both of absorptions do not change. The suggested MAs perfectly keep polarization angle independency. These features provided by the symmetric-shaped of the proposed models and also the suggested very simple geometry MAs respond the same electric field for all polarization angles at the resonance frequencies.

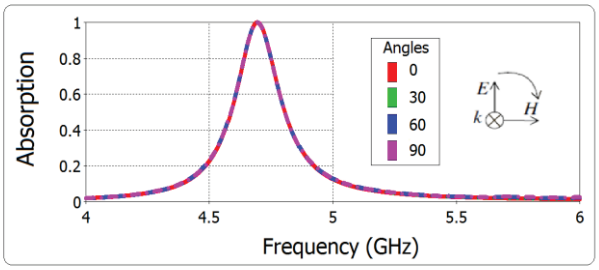

Fig. 8. Simulated absorptions at different polarization angles in C-band.

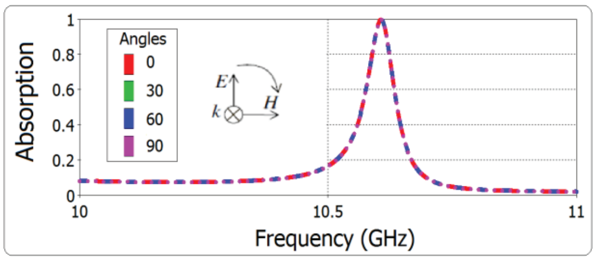

Fig. 9. Simulated absorptions at different polarization angles in X-band.

Additionally, we examined and discussed the electric field and surface current distributions at the resonance frequency of 4.69-4.99 GHz in order to show physical operation mechanism of the proposed circle with gap- and square-shaped perfect MAs, respectively (Figs. 10 and 11). It can be seen that the electric field is concentrated at the right- and left-side of the circle resonator. For square-shaped MA, the electric field is concentrated at the up- and below-side. So, the structure behaves as an electrical dipole for the all applied polarization angles. Also, the current circulation excites magnetic response and as a result an absorption phenomenon increases for surface current distribution.

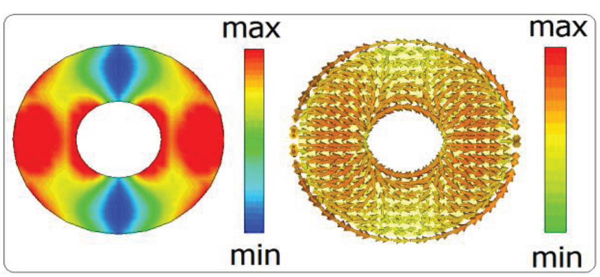

Fig. 10. Electric field and surface current distribution at the resonance frequency of 4.69 GHz of circle with gap-shaped.

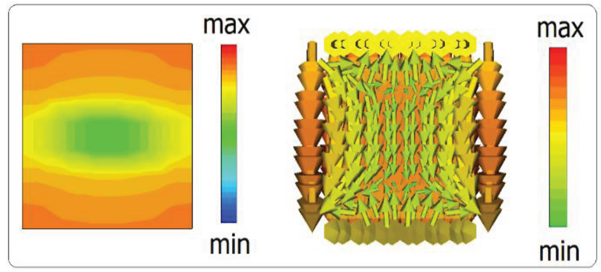

Fig. 11. Electric field and surface current distribution at the resonance frequency of 4.69 GHz of square-shaped.

With this regard, to show performance quality of the suggested MAs according to the current MA studies in literature, proposed models are compared with other MA studies as shown in Table 1. It can be understood that many MA studies show polarization angle independency only in some angles or do not in any [5-8]. Although, some of them provide perfect absorption for all polarization angle, their *FBW* values are low and/or proposed geometry is complex and/or have inflexible geometry design.

Table 1: Performance comparison of MAs

Absorber	Freq. (GHz)	A(w)	FBW	Indep.***
PropCirc.	4.69	99.98%	4.9%	Yes
PropSqu.	4.99	99.98%	5.01%	Yes
[20]	11.5	96%	4.0%	No
[21]	10.14	97%	4.7%	S.A.**
[22]	10.45	99.9%	4.2%	No
[23]	10.07	98%	N.C.*	Yes

*N.C.= not calculated **S.A.= some angles
***Indep: independency

However, the suggested MA has many advantages according to the many MA studies in literature such as perfect absorption, polarization independencies, wide band, flexibility and very simplicity are some of the important advantageous of the proposed MA.

IV. SENSOR APPLICATION OF THE SUGGESTED MODEL

The proposed perfect circle with gap-shaped MA can also be used for sensor applications by located dielectric layer on the front face of the absorber with indicated distance, as shown in Fig.

12. With this regard, the effect of distance between dielectric layer (FR4) and front-face of the proposed MA is investigated and evaluated as detailed, as shown in Fig. 12. The distance (all other parameters of design and simulation are remained constant) is varied from 1.5 mm to 3.5 mm by 0.5 mm step. The reflection results of the simulations for different dielectric thickness are shown in Fig. 12. It can be seen that reflection magnitude values change with the variation of dielectric thickness (for 1.5 mm-dielectric (0.42) and for 3.5 mm-dielectric (0.02), the resonance frequency shifts to lower frequencies when the thickness of the dielectric is increased. The reason of this downward shift can be explained by the variation of the capacitance of the overall structure. The increment of the thickness of dielectric-FR4 leads to increase capacitance, therefore resonance frequency slide downward with increased dielectric thicknesses. Hence, the proposed structure can also be used as a pressure sensor beside absorber applications. One of the most important properties of the proposed MA based sensor is polarization angle independency and its easily obtainable frequency range. These are the superiority of the proposed system.

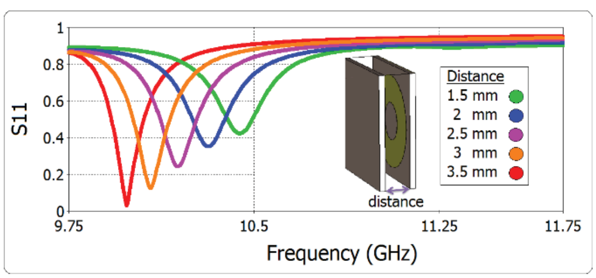

Fig. 12. Reflection values for different distance values of the over-layer in X-band.

V. CONCLUSION

In this study, very simple designs of perfect MAs numerically and experimentally are designed and investigated as detailed. The proposed models are also realized in X-band, too. Obtained numerical and experimental results show that the structures have many advantages such as perfect absorption, polarization angle independency, wide band, very simple design, and so on according to the current MA studies in literature. Also, they can be tuned the dimensions to achieve perfect absorption in other frequency regimes because of the symmetric-shaped, and realized for different application areas such as stealth and defense systems. Moreover, the suggested structures can be implemented/adopted tunable MA applications to use applications of some Wi-Fi devices, some cordless telephones, and some weather radar systems and so on.

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