Experimental Investigation on Absorption Power of Electromagnetic Wave Absorber Based on Patch Pattern

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***Abstract*—This paper presents the experimental investigation of electromagnetics (EM) wave absorber based on patch pattern to analyze its absorption power. Three different patch patterns of EM wave absorber were used in the investigation, namely square resonator pattern, ring resonator pattern, and split ring resonator pattern. The investigation was performed in an anechoic chamber using a horn antenna connected to a Vector Network Analyzer (VNA) to measure reflected wave from the proposed EM wave absorber. The horn antenna and the measured EM wave absorber was separated around 1.5 m to comply a far-field region of measurement. At the frequency of 3 GHz, the absorption powers in an ideal condition for the EM wave absorber with square resonator pattern, ring resonator pattern, and split ring resonator pattern are –12.05 dB, –14.33 dB and –14.26 dB, respectively. The investigation results showed that the realized EM wave absorber with ring resonator pattern has better total impedance compared to other patterns indicated by the value of absorption power.**

***Index Terms*—absorption power; electromagnetics (EM) wave absorber; experimental investigation; ring resonator; split ring resonator; square resonator.**

I. INTRODUCTION

There are some techniques implementable to construct electromagnetics (EM) wave absorber. One of them is using planar transmission line which contains of dielectric substrate and metal pattern as its patch and fully metal conductor as its groundplane. The working mechanism of planar transmission line-based EM wave absorber is similar to the common EM wave absorber, where it absorbs the incident waves come into the dielectric and reflected all the transmission waves propagate in the dielectric. All the reflected wave occurred due to the use of full metal groundplane [1]. The EM wave absorber developed based on microstrip technology by configuring a periodic pattern of patches in 2D arrangement on a dielectric substrate has been implemented to compose high impedance surface (HIS) [2]. In fact, the microstrip technology which is usually applied for the antenna design [3], has also been involved for developing other devices including wave absorber, wave reflector, and active device [2], [4]–[6]. By configuring microstrip patch in a specific pattern, it affects the capacitance and/or inductance on the patch surface and produces an optimum impedance which is matched with the impedance of vacuum [1], [4].

Study on square patch and ring resonator has been proposed to analyze the EM wave absorber performance at the frequency of X-band [7]. The single layer of square patch has deficiency in the term of absorption and ring resonator patch has better performance of absorption. Moreover, Split Ring Resonator (SRR) and/or Complementary Split Ring Resonator (CSRR) were also involved in the design of EM wave absorber [8]. It is well-known that SRR is frequently used to miniaturize a microwave devices [9]–[13]. A size miniaturization of antenna by using SRR and CSRR has been achieved up to 22% with similar radiation characteristic [9]. The array of SRR was also implemented to miniaturize waveguide antenna up to 44.5% reduction [11]. Other than utilizing SRR/CSRR, a compact antenna could also be achieved by employing a half-mode substrate integrated waveguide (HMSIW) structure [14].

As a pattern in EM wave absorber, SRR has been characterized by varying its physical parameters that could vary the frequency response [15]. In order to design an EM wave absorber which relates to its frequency application, it may consist of specific pattern to absorb the wave. Moreover, an experimental validation process is one of important stage in the development of EM wave absorber. There are various methods to validate the EM wave absorber performance. It can use transmission-line-based measurement, open ended rectangular waveguide (OERW), and other advanced measurement techniques [16]. While for validating the performance of EM wave absorber, it is usually carried out by measuring the scattering parameter using free space measurement techniques [17].

In this paper, an experimental investigation on absorption power of EM wave absorber is proposed using three different patch patterns. The investigation is performed in an anechoic chamber using one port free space measurement technique. A horn antenna connected to a Vector Network Analyzer (VNA) is used to measure reflected wave from the EM wave absorber. In general, the paper is organized as follows: Section II describes the absorption power of EM wave absorber, Section III presents the experimental configuration, Section IV discusses the result of experiment which is contain of absorption power and the phase of absorption power, and the last section is the conclusion.

II. Analytical Approach on Absorption Power of EM Wave Absorber

Fig. 1 is a model for analyzing the absorption power of EM wave absorber excited using a horn antenna. The antenna is separated by transmission medium form the EM wave absorber. The transmission power is denoted by P_1^+ and the received power by the EM wave absorber is P_2^+, where the relation between P_1^+ and P_2^+ is expressed in (1).

$$P_2^+ = P_1^+ - P_{pathloss} \tag{1}$$

In one port analysis, the transmitted power and reflected power P_3^+ and P_3^- can be neglected. Hence, the absorption power of EM waves absorber can be calculated using (2).

$$P_{Absorber} = P_2^+ - P_2^- \tag{2}$$

and P_1^- as power transmitted by the pathloss will equal to (3),

$$P_1^- = P_2^- - P_{pathloss} \tag{3}$$

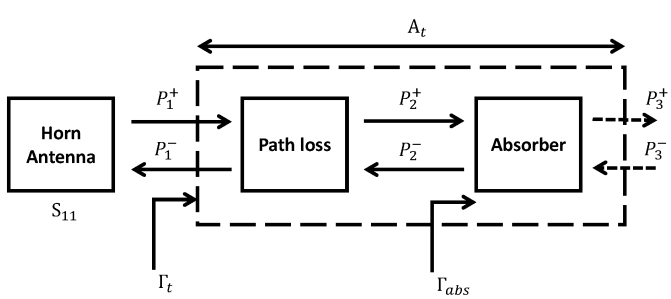


Fig. 1. Model for analyzing absorption power of EM wave absorber.

If the reflected power by the EM wave absorber is S_{11}, then the reflected power, then P_1^- can be described by (4).

$$P_1^- = S_{11} P_1^+. \tag{4}$$

The attenuation as a consequence of the distance between a horn antenna and the EM wave absorber as well as the frequency of transmitted wave can be determined by (5) [18].

$$\frac{W_T}{W_R} = \frac{A_{et} A_{er}}{\lambda^2 r^2}. \tag{5}$$

where W_T is the transmitted power, W_R is the received power, A_{et} is the effective aperture of antenna transmitter, A_{er} is the effective aperture of antenna receiver, λ is the wavelength, and r is the distance between transmitter and receiver. Since horn antenna is a directional antenna and can act as a transmitter antenna, the aperture efficiency of horn antenna is equal to 0.51 [19]. Meanwhile, the aperture efficiency of EM wave wave absorber can be approached by physical aperture.

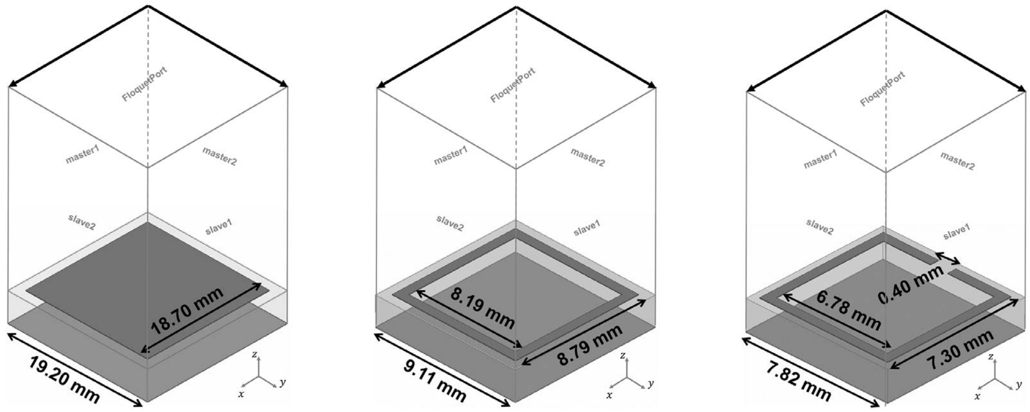
III. EM Wave Absorber Configuration and Experimental Characterization

This section describes the electromagnetic waves pattern design using a single unit cell to simplify the simulation process, realization of proposed EM wave absorber, and experimental characterization for investigating the performance of each patch patterns.

A. Electromagnetic Waves Absorber Configuration

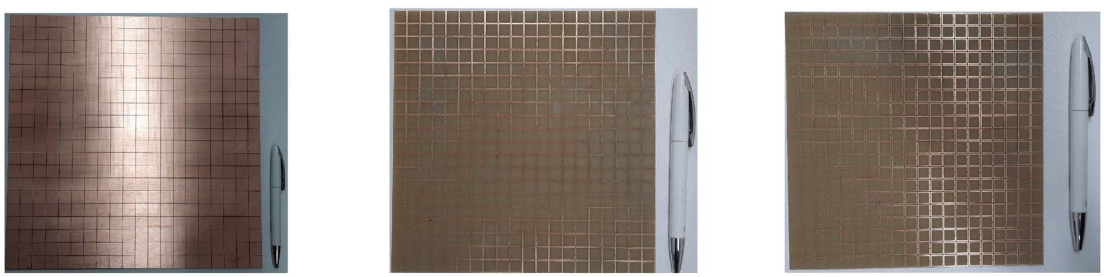
The proposed EM wave absorber is configured using three different patch patterns, namely square resonator pattern, ring resonator pattern, and split ring resonator pattern. A unit cell is designed by a 3D simulation software and simulated using master-slave boundary condition with a Floquet port excitation method. This configuration can simplify the simulation since it can make an infinite array for asymmetric pattern configuration like SRR pattern. The patch patterns are made of metal conductor deployed on an FR4 Epoxy dielectric substrate with the thickness of 1.6 mm and the relative permittivity of 4.4.

Fig. 2 depicts a single unit cell of EM wave absorbers using square resonator, ring resonator, and split ring resonator as its patch pattern. In order the proposed EM wave absorber workable at the frequency of 3 GHz, the unit cell with square resonator pattern is designed to have 18.70 mm length of patch and 19.20 mm length of dielectric substrate. Furthermore, the unit cells with ring resonator and with split ring resonator have 9.11 mm and 7.82 mm lengths of dielectric substrate, respectively. The ring resonator pattern has 0.60 mm ring thickness with the separation between unit cell of 0.64 mm. While the split ring resonator pattern has 0.52 mm ring thickness and 0.40 mm ring split with the separation between adjacent unit cells of 1.04 mm. The disparity of unit-cell size among all designs are related to the characteristic of split ring resonator as a miniaturization method in microwave devices [20].



(a) (b) (c)

Fig. 2. Unit cell of patch pattern, (a) square resonator, (b) ring resonator, (c) split ring resonator.



(a) (b) (c)

Fig. 3. Realized EM wave absorber using 20×20 unit cells, (a) square resonator, (b) ring resonator, (c) split ring resonator.

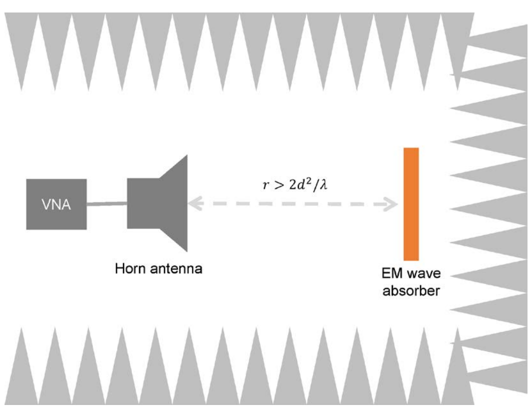


Fig. 4. Schematic of experimental characterization.

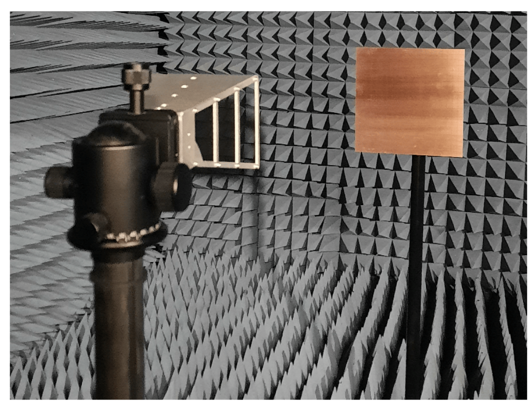


Fig. 5. Experimental measurement setup in an anechoic chamber.

The pictures of realized EM wave absorber deployed on an FR4 Epoxy dielectric substrates are shown in Fig. 3. Each pattern of EM wave absorber was realized using 20×20 unit cells. The dimensions of EM wave absorber with square resonator pattern, ring resonator pattern, and split ring resonator pattern are 384.00 mm × 384.00 mm, 182.20 mm × 182.20 mm and 156.40 mm × 156.40 mm, respectively. Since the size of square resonator for a single unit cell is the largest one, so the realized EM wave absorber with square resonator pattern has the largest dimension among others.

B. Experimental Investigation

A schematic of experimental characterization is illustrated in Fig. 4 which is related to the model for analyzing absorption power of EM wave absorber in Fig. 1. An EM wave absorber is installed in front of a horn antenna that has directional beam pattern. The horn antenna and the EM wave absorber are placed with the distance that comply with far field regions in order to achieve an adequate excitation to the EM wave absorber. The reflected wave is received by horn antenna and displayed on Vector Network Analyzer (VNA).

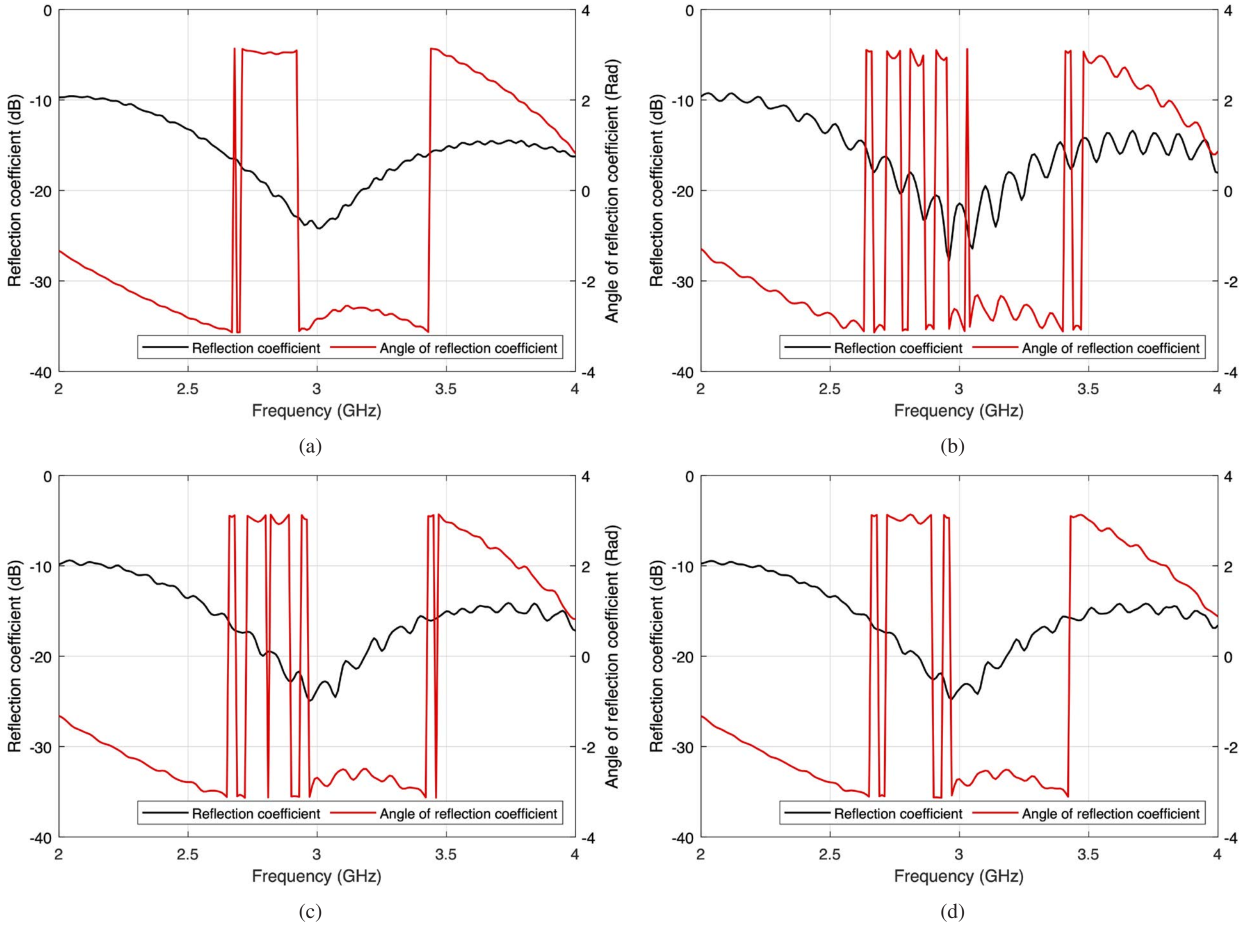


Fig. 6. Measurement result for reflection coefficient and angle of reflection coefficient, (a) commercially cone absorber, (b) square resonator, (c) ring resonator, (d) split ring resonator.

An experimental measurement setup for obtaining the performance of realized EM wave absorber is shown in Fig. 5. A horn antenna is connected to a VNA to measure the reflected wave from EM Wave absorber. The realized EM wave absorber is positioned in front of the antenna installed on a non-conductor pole. This experimental characterization is performed in an anechoic chamber so that the reflected wave which may appear due to the reflection from some other objects can be neglected.

There are four scenarios to characterize the performance of each patch patterns. The first scenario is the ideal condition. This scenario is set with no prototype absorber attached in front of the antenna. So, the VNA will measure an ideal reflection. In the second scenario, the third scenario, and the fourth scenario, the realized EM wave absorbers with square resonator pattern, ring resonator pattern, and split ring resonator patter are positioned 1.5 m in front of the antenna. This condition is to comply a far-field region of measurement using the horn antenna.

The orientation of horn antenna which is related to its polarization needs to be set in parallel with the orientation of realized EM wave absorber. This is required in order to achieve maximum absorption power. It should be noted that the absorption power will degrade in case the horn antenna orientation has different orientation or is perpendicular to the realized wave absorber orientation, especially the split ring resonator pattern. The VNA will measure reflected waves from realized EM wave absorber. To determine the absorption power of EM wave absorber, the effect of transmission medium should be disposed. The loss of transmission medium can be calculated by considering the distance between horn antenna and EM wave absorber, as well as the frequency of transmitted wave to EM wave absorber and reflected back to the horn antenna.

IV. Result and Discussion

The measured reflected waves from the EM wave absorber, as depicted in Fig. 6, is used to obtain the actual absorption power which is determined by (2). It recorded an S_{11} data as a measurement of reflected wave to be then transformed into power transmitted in logarithmic scale. The received power by the EM wave absorber, P_2^+, can be calculated by (1) with the attenuation is given by (4). For obtaining the power received by the horn antenna, P_1^-, it can be solved by finding the correlation between P_1^+, S_{11} and P_1^-.

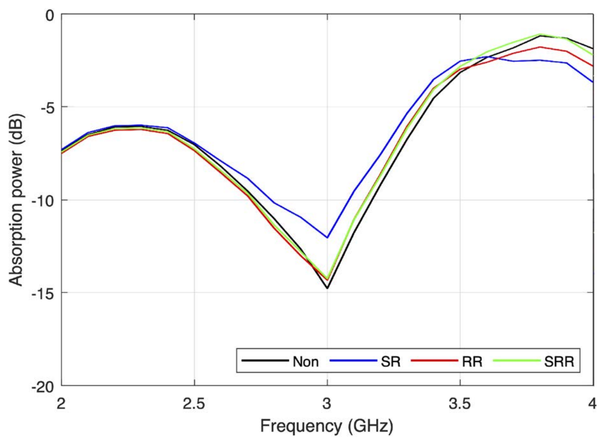


Fig. 7. Magnitude of absorption power for different patch patterns.

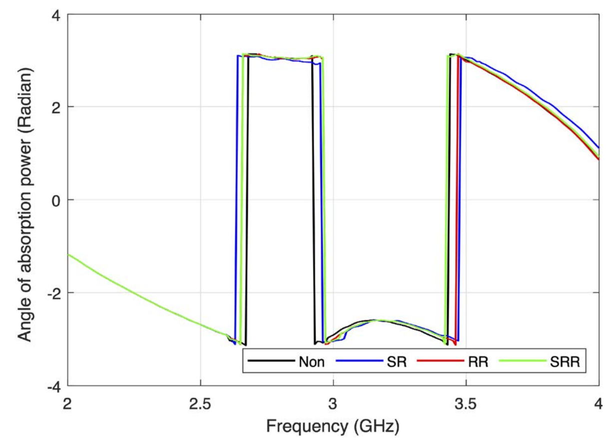


Fig. 8. Phase of absorption power for different patch patterns.

Fig. 7 plots the absorption power magnitude of EM wave absorbers for three different patch patterns. The graphs are obtained by disposing the loss of transmission medium which emerges due to the transmitted wave from the horn antenna to the EM wave absorber and the reflected wave at the reverse direction. In actual, the VNA measured reflection coefficient which consists of the medium losses and the absorption power of EM wave absorber.

The absorption power of realized EM wave absorber with square resonator pattern, ring resonator pattern, split ring resonator pattern and the ideal condition have similar response each others in the frequency range of 2 GHz to 2.5 GHz. Since the EM wave absorber has been designed to work at the frequency of 3 GHz, the absorption power has divergent in the frequency range of 2.5 GHz to 3.5 GHz. At this frequency range, the scenario of adequate condition has highest absorption power followed by the EM wave absorber with ring resonator pattern, split ring resonator pattern, and square resonator pattern.

At the frequency of 3 GHz, the absorption powers in an ideal condition, EM wave absorber with square resonator pattern, ring resonator pattern, and split ring resonator pattern are –14.79 dB, –12.05 dB, –14.33 dB and –14.26 dB, respectively. These results show that the EM wave absorbers with ring resonator pattern and split ring resonator pattern have an optimum total impedance which match with the impedance of vacuum to absorb EM wave compared to the one with square resonator patten.

The phase of absorption power of EM wave absorber for different patch patterns is depicted in Fig. 8. In general, it has similar phase of absorption power at the frequency range of 2 GHz to 2.5 GHz for all scenarios. The absorption power for the ideal condition has the phase shifted at the frequency of 2.68 GHz, 2.93 GHz, and 3.44 GHz. The second scenario for EM wave absorber with square resonator pattern has the phase shifted at the frequency of 2.64 GHz, 2.96 GHz, and 3.48 GHz. The third and fourth scenario for EM wave absorber with ring resonator pattern and split ring resonator pattern, both patterns have the phase shifted at the frequency of 2.66 GHz, 2.97 GHz and 3.47 GHz.

From the results shown in Figs. 7 and 8, it is seen that realized EM wave absorbers with square resonator pattern, ring resonator pattern, and split ring resonator pattern have the optimum performance at the frequency range of 2.5 GHz to 3.5 GHz. The performances are shown by the shifting of absorption power magnitude as well as the phase. The absorption power of EM wave absorber with ring resonator pattern has the optimum performance since it has the optimum impedance. Therefore, it can be inferred that the impedance of EM wave absorber is significantly affected by the patch pattern applied in the configuration.

Furthermore, the EM wave absorber with ring resonator pattern has wide area to absorb the wave in comparison to the one with square resonator pattern or split ring resonator pattern. The EM wave absorber with square resonator pattern has a separation of 1 mm of adjacent unit cell, while the EM wave absorber with split ring resonator has a separation of 0.52 mm of adjacent unit cell with 6.78 mm $\times$ 6.78 mm of dielectric area. It can be compared to the area of dielectric substrate which is 8.19 mm $\times$ 8.19 mm with separation of 0.64 mm adjacent unit cell. The patch pattern of EM wave absorber not only affects the total impedance, but also influences the absorption power.

V. Conclusion

The experimental investigation on absorption power of EM wave absorber based on patch pattern has been presented. A single port free space experimental characterization has been used to measure the absorption power of EM wave absorber with three different patch patterns. The proposed EM wave absorber was realized using 20$\times$20 unit cells for each patch pattern on an FR4 Epoxy dielectric substrate. It has been shown that the optimum absorption power was achieved by the EM wave absorber with ring resonator pattern at the frequency range of 2.5 GHz to 3.5 GHz. This is due to the pattern has an optimum surface impedance and a wide area to absorb the incoming EM wave.

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