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Absorption performance of biomass hollow pyramidal microwave absorber using multi-slot array technique

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ABSTRACT

Electromagnetic interference (EMI) is an undesired electromagnetic (EM) wave by nearby electronic devices, process equipment, and measuring instruments. In this work, a novel multi-slot technique is applied to the hollow biomass pyramidal microwave absorber to study its absorption properties thoroughly. Two different slot arrangements in horizontal and vertical configuration are designed for the proposed microwave absorbers. Both slot design concepts have identical shape and size. This work aims to study, compare and analyze the absorption performance of the proposed designs at L, S, C and X frequency bands. The biomass material is used to form as absorbent material. The characteristics performance of the multi-slot design on biomass hollow pyramidal microwave absorbers are measured by using naval research laboratory (NRL) Arch space-free method. The frequency range set up for the measurement is in between 1 GHz to 12 GHz. The multi-vertical slots design exhibits better absorption performance at C-band and X-band which is -63.67 dB and -46.78 dB respectively while the multi-horizontal slots design provides better absorption performance at S-band which is -16.92 dB. The results shows that both design performances are frequency-dependent since horizontal slots design improve maximum absorption performance at low frequency while vertical slots design delivers better performance at high frequency.

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1. INTRODUCTION

The discovery of electromagnetic (EM) waves has enhanced transmission technology development. During the wireless device advancement in industry 4.0, many researchers have carried out the development of high-performance electromagnetic wave absorbers to prevent electromagnetic interventions in electronic devices. Rapid development of technology devices may result in severe interruptions to those applications and, as a result, considerable EM pollution [1]. This exposure to EM radiation can have a significant impact on the performance of equipment, human health, information and environmental pollution [2], [3].

Microwave absorbers with high efficiency are becoming increasingly attractive and important to address the issues caused electrical equipment electromagnetic interference (EMI). Through broad bandwidth absorption, the basic material is employed to efficiently reduce EM signal reflection [4]–[6]. In order to optimize the performance of microwave absorbers, the design must be improved at specified parameters such as high absorption, wide frequency band, lightweight and thin thickness [7]. Design improvements can be achieved by establishing slot array, multilayer structures or physically assembling of different types of absorbers [7]–[10].

Apart from microwave absorber, electromagnetic shielding is also another common technique to solve electromagnetic pollution. Electromagnetic shielding is designed as a barrier to the penetration of the radiation passing through any medium by reflectivity or absorption mechanism [11]. These materials prevent electromagnetic radiation from affecting electrical equipments by suppressing the electromagnetic wave signal, which results in better quality performance without affecting their function and lasting performance. With the excellent performance obtained from biomass material, the use of coconut carbon as radiation absorbing material (RAM) is an alternative advantage in this project that can meet green technology and reduce reflectivity by the microwave absorber [12]. Carbon is known as the semiconductor material which allows for a low load flow [5], [7], [13], [14].

There are a few design concepts for electromagnetic wave absorbers. The three main processes, including reflection, absorption and penetration that are carried out by an electromagnetic wave incident via the absorption material, as shown in Figure 1 [11]. During the absorption process electromagnetic energy is transformed to different energy types under the influence of electromagnetic loss fillers. Therefore, the incident wave cannot be reflected or penetrated by the materials [11], [15].

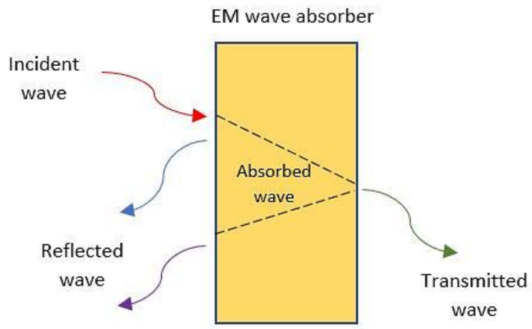


Figure 1. The general processes of incident EM wave through an EM absorber

An absorber with optimal electromagnetic wave absorption capability must meet two fundamental characteristics. One of them is that the absorber should have proper impedance matching in order to allow the incoming EM wave to be transported into the absorber during the transmission process [11], [16]. Another one is that the absorber should have a strong ability to dissipate EM waves. The common way of fulfilling the impedance requirement is to adjust the permittivity and permeability values to be closed to each other. The absorbing performances can also be improved by modifying the absorber design using various approaches such as slot array, multi-layer gradient structure, periodic structure and others [9], [11], [17].

The material and the shape of an absorber are the two important parameters in constructing it. The market offers a variety of the commercial shapes, including pyramidal, wedge, hybrid-type, walkway, convulated, multilayer and oblique. Earlier researches on microwave absorber design concentrated on pyramidal shape with novel configurations of absorbing transition geometry [4], [18], [19]. The interest in pyramidal is as a result of its common usage in the industry compared to the other shapes. The base of the pyramid and the pyramidal component it self are two important design requirements for a microwave absorber [19]. Numerous studies with various base shapes have been undertaken and pyramidal absorber with square based shape has been shown to have excellent absorption at frequencies up to 10 GHz as proven in simulation and experimental measurements [20]–[22]. The form of a pyramidal absorber could be solid or hollow in design. Most of the investigations reported earlier involved solid forms but recently, studies on hollow is being carried out since the structures will be beneficial in reducing the overall weight of the absorbing material used within an anechoic chamber facility [23], [24]. The slot array, which comprises of capacitive cells, acts as a capacitor in the low frequency domain but, after the first resonance, its impedance becomes inductive [25]. The slot shape impacts the values of the parameters L and C. In this work, the dielectric substrate (carbon) acts as an inductor [26].

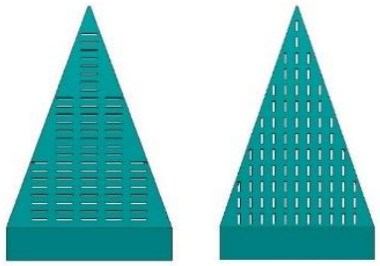
A slot is defined as a radiating element that is used to excite the electromagnetic wave. Based on the frequency of the field, a slot is designed to reflect, transmit or absorb electromagnetic fields [27], [28]. The currents flow around the slot, accumulating the charge on one side, resulting in the formation of an electric field to form across the slot. The field across the gap is affected by the current passing through the slot. The slots can be excited and radiated by placing a slot in the path of the currents. Depending on the nature of array element, an incoming plane wave is either transmitted (passband) or reflected (stopband), entirely or partially [29], [30]. This occurs when the electromagnetic wave coincides with the resonance frequency of the slot feature [31]. As a result, the slot is capable of passing or blocking the electromagnetic wave of a specific frequency range in free space [29], [30], [32].

Based on slot antenna theory, this project focuses on the characteristics of rectangular slotted array on biomass hollow pyramidal microwave absorber, considering the shape, size and arrangement of the slotted array. Rectangular slot has been chosen primarily due to its excellent performance in antenna gain and bandwidth [33]–[35]. This paper proposes a new alternative method to improve the absorption performance by creating rectangular multi-slot array at different orientation on hollow pyramidal microwave absorbers. Measurements are performed in a condition close to free space environment to reduce the microwave absorber reflected wave. The proposed size of the identical slots is 0.3 cm width x 2.5 cm length.

2. RESEARCH METHOD

2.1. Design of microwave absorber

Figure 2 shows the design of multi-slot on biomass hollow pyramidal microwave absorber. The microwave absorbers are designed in a pyramidal shape due to its effective cross section towards electromagnetic wave. The single pyramid design parameter is set to 20 cm (length)x20 cm (width)x40 cm (height) while the base height is 6 cm. Both designs have identical rectangular slot of size 0.3 cm width x 2.5 cm length implemented on biomass hollow pyramidal microwave absorber. The proposed absorber design is configured with two different slots arrangement which are horizontal and vertical as shown in Figure 2(a) and 2(b).



(a) (b)

Figure 2. Multi-slot on biomass hollow pyramidal microwave absorber, (a) horizontal and (b) vertical

2.2. NRL arch free space measurement

In general, a network analyzer is used for measurements on an naval research laboratory (NRL) Arch to provide both the stimulus and the measurement. A calibration is performed by measuring the resultant power reflecting off the metal plate over a broad frequency range. This is established as the 'perfect' reflection or 0 dB level. The material under test is then placed on the plate and the reflected signal is measured in dB. Time domain gating may be used to eliminate antenna cross talk and to reduce the error introduced by room reflections. The measurement was performed to determine the absorption performance as shown in Figure 3.

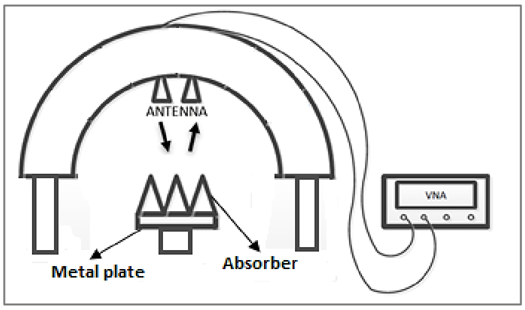


Figure 3. NRL arch free space measurement

Basically, the NRL arch is a vertical semicircular framework, made of wood. The absorption measurement is carried out at 0° to observe the effect of the slot array towards absorption at the desired frequency range 1 GHz to 12 GHz. An antenna is connected to a microwave transmitter and the other is connected to a microwave receiver in the NRL arch at a constant distance from the material under test. The microwave energy is sent through the transmitting horn, is transferred to the material, absorbed partially and dispersed into the receiving horn.

3. RESULTS AND DISCUSSION

This research examined rectangular pattern slot with horizontal and vertical orientation. Slot size was calculated based on 4 GHz, 8 GHz and 12 GHz state frequencies. This research is intended to study the effect of multiple slots with different slots arrangements towards absorption performance over frequency 1 GHz to 12 GHz. The measurement of absorption performance of multiple slots in horizontal and vertical array design on biomass hollow pyramidal microwave absorber are shown in Figure 4. Meanwhile, the analysis results of the multiple slots in different arrangement are presented in Table 1. This table shows that the average, minimum and maximum absorption performance achieved by both design. For average absorption performance, the design of multiple vertical slots exceeds the multiple horizontal slots design at -3.45 dB at S-band and -25.22 dB at X band. Meanwhile, horizontal slots design has an average absorption performance of -2.95 dB and -17.26 dB at L-band and C-band respectively, higher than multiple vertical slots design. The graph in Figure 5 indicates that both designs of multiple slots show different absorption performances at certain frequency band. Multiple slots with vertical array design obtain the maximum absorption performance of -63.67 dB at 5.37 GHz throughout the frequency range of 1 GHz to 12 GHz. The minimum and maximum absorption performance for both designs are illustrated in Figure 5.

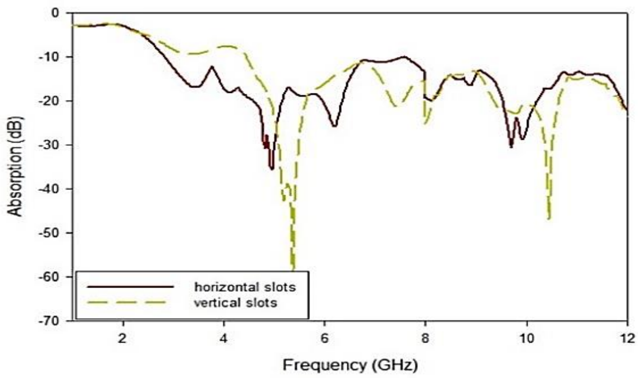


Figure 4. Absorption performance of horizontal and vertical slots

Table 1. Minimum, maximum and average absorption performance of horizontal and vertical slots

Band	Frequency (GHz)	Design	Absorption (dB) Min	Max	Average
L-band	1-2	Multiple horizontal slots	-2.68	-3.04	-2.95
		Multiple vertical slots	-2.56	-3.17	-2.77
S-band	2-4	Multiple horizontal slots	-3.08	-16.92	-3.21
		Multiple vertical slots	-3.31	-9.41	-3.45
C-band	4-8	Multiple horizontal slots	-10.04	-35.63	-17.26
		Multiple vertical slots	-7.62	-63.67	-7.63
X-band	8-12	Multiple horizontal slots	-13.04	-30.62	-19.26
		Multiple vertical slots	-13.31	-46.78	-25.22

Statistical analysis is used to compare the results of minimum and maximum absorption performance achieved by multiple slots horizontal and vertical array design. For minimum absorption performance, multiple vertical slots design provides better absorption than multiple horizontal slots design at S-band and X-band, -3.31 dB and -13.31 dB respectively. In the meantime, multiple horizontal slots design contributes to better L-band and C-band minimum absorption with performance of -2.68 dB and -10.04 dB respectively. As shown in Figure 5, there is a significant difference of maximum absorption performance at S-band, C-band and X-band between horizontal slots and vertical slots designs. On the other hand, because of the narrow frequency range from 1 GHz to 2 GHz for L band, the difference of maximum absorption performance between multiple horizontal and vertical slots is too small. The bar chart above illustrates that the maximum absorption performance obtained by vertical slots design are -63.67 dB at C-band and -46.78 dB at X-band, which provide better performance than multiple horizontal slots design. Meanwhile, horizontal slots design contributes to higher maximum absorption performance than vertical slots design at S-band which is -16.92 dB. As observed in the results, the absorption performance at L-band and S-band is lower than C-band and X-band due to the nature of pyramidal microwave absorber response commonly achieved by commercial product. It is observed that the multiple horizontal slots design gives better performance at low frequency due to the wider slot length of the incoming incident wave. In contrast, multiple vertical slots design performs better at high frequency because it has a narrow slot length for the incoming incident wave. In previous research, studies were conducted on the optimization of pyramidal microwave absorbers utilizing the slot technique. The comparison of maximum absorption performance between the proposed designs and previous designs at X-band are tabulated in Table 2.

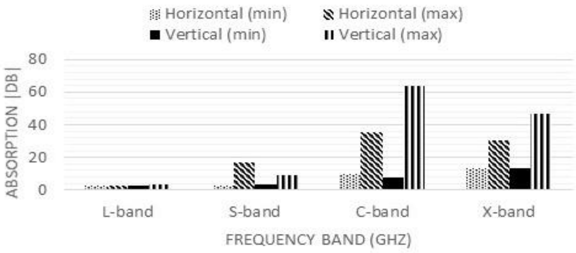


Figure 5. Minimum and maximum absorption performance of horizontal and vertical slots

Table 2. Maximum absorption performance of proposed designs and previous designs at X-band

Band	Frequency (GHz)	Author	Designs	Max. Absorption (dB)
X-band	8-12	M. I Fazin	Multiple horizontal slots	-30.62
			Multiple vertical slots	-46.78
		A. Hasnain	Slot array absorber	-11.80
		A. Syahmi	Slotted triangle	-38.56
			Isosceles slotted triangle	-20.65

Another statistical analysis is used to compare the results of maximum absorption performance as shown in Figure 6. The results show that the maximum absorption performance of multiple horizontal slots and multiple vertical slots is -30.62 dB and 46.78 dB respectively. According to the previous researchers, a noteworthy finding is that the innovative methodology of slot radial array design on pyramidal microwave absorber is demonstrated to improve the absorption performance [9]. The absorption performance of pyramidal microwave absorber with slotted design is enhanced from -10.3 dB to -11.8 dB. In another study, this achievement was improved by using other methods, for example, the slotted triangle on pyramidal microwave absorber, that was investigated to analyse the performance after applying the sierpinski triangle slot design. It was discovered that the best absorption performance is up to -38.56 dB at frequency ranging from 11 GHz to 12 GHz [14]. Meanwhile, another studied on the effect at selective point on the microwave absorber surface with un-slotted and inverted triangle slotted has shown the best absorption performance obtain is -20.65 dB which is higher than un-slotted design [10]. Overall, it is observed that the proposed design of multiple vertical slots obtained the highest absorption performance as compared to previous designs.

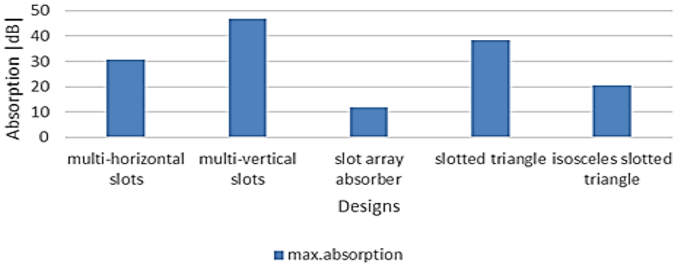


Figure 6. Comparison of maximum absorption performance of proposed designs and previous designs at X-band

4. CONCLUSION

A novel rectangular multiple slots hollow pyramidal microwave absorber with different orientation at the desired frequency band have been investigated and presented. The best absorption by the multiple horizontal slots design is achieved at low frequency S-band, which is -16.92 dB while the best absorption from multiple vertical slots design is at high frequency C-band and X-band, which is -63.67 dB and -46.78 dB respectively. From the results, it has been proven that the proposed design has achieved better absorption as compared to the previous works. This study has shown that the frequency band absorption performance can be varied by adjusting the slot orientation. The absorption performance at the low frequency band has been observed to be better for horizontal orientation due to the wider open slot length that correspond to the large incoming incident wavelength which resulted in attenuation of the energy at low frequency. In the meantime, a narrow open slot length of vertical orientation has been observed to give better absorption performance at high frequency band because of the expected higher attenuation correspond to the smaller incident wavelength at high frequency. Generally, both designs of absorbers with different slot orientations have been observed to efficiently absorb undesirable electromagnetic wave at certain frequency. The absorption is apparently be affected by the slot length adjustment, indicated that multiple slots at different orientation is capable to absorb unwanted electromagnetic effectively. Therefore, the observed performance of the proposed designs have provided a clear indicator that the slot orientation and slot length at incoming incident wave are the new techniques to improve the absorption performance of pyramidal microwave absorbers. Apart from that, this study will serve as the baseline reference for future research and understanding on the role of rectangular slot array on hollow pyramidal microwave absorber.

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