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Effect of Slot Array at Different Angles towards the Performance of Hollow Pyramidal Microwave Absorber

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ABSTRACT

This paper presents the performance of electromagnetic wave absorption at different angles with novel slot array design implemented on hollow pyramidal microwave absorber. The size of pyramidal shaped absorber is selected to comply with the industrial standard and can operate at the frequency range between 1 GHz to 12 GHz. Initially, six designs slot array on hollow pyramidal microwave absorber are fabricated using biomass carbon. Their electromagnetic wave absorption at 0˚, 30˚ and 60˚ angles are measured to analyze their performance. The performance results show that the absorption rates are sensitive to angle of measurement. The observation shows that the designs of slot array at S, C and X frequency bands give better absorption performance of up to 60˚. The overall results for all slot array design at different angles are analyzed and compared.

Key words: Slot array, microwave absorber, absorption performance, electromagnetic wave

1. INTRODUCTION

Microwave absorber is an important element in Anechoic Chamber. An RF Anechoic Chamber is a protected room whose walls have been secured with Microwave Absorber that absorb such an extensive amount of the undesirable signal [1]. Electromagnetic wave absorbers and anechoic chamber are used throughout the world in performing antenna and reflectivity measurements [2]. The creation of non-reflection room is required to remove all the unwanted signal from interrupting the system operation. Most of the absorbers are working in broad frequency range and typically made from blocks of absorbing materials and used for interferes with the reflection of the electromagnetic waves passing through the absorber [3].

Some researchers have mentioned that carbon has a significant function in microwave absorption [4], [5]. Carbon is an excellent microwave absorber as it is easily heated by microwave energy. Carbon is ideal for converting microwave energy into thermal energy because signal is blocked when they pass through carbon [6], [7]. A proper RF absorber models are developed based on information, for instances absorbers reflectivity and reflection coefficient [8][9]. The permittivity, permeability and the frequency of the material can control the reflectivity, R. The reflectivity can be expressed in dB unit as following the equation (1) below.

$$R = 20\log|\Gamma| \quad (1)$$

In broadcast communications, the proportion of the amplitude of the reflected wave to the amplitude of the incidence wave is considered as reflection coefficient. The reflection coefficient, Γ can be defined as the following equation (2) below.

$$\Gamma = \frac{Z_1 - 1}{Z_1 + 1} \quad (2)$$

Dielectric constant is equivalent to relative permittivity (εr) or the absolute permittivity (ε) comparative with the permittivity of free space (ε_0) [9], [10]. The dielectric constant of a material influences on electromagnetic signals travel through the material. If the dielectric constant has a high value, it can make the signal such as radio waves or light travel more gradually [11], [12]. Further improvement of the absorber reflectivity is possible by implementing the slot array technique in antenna design on the hollow pyramidal microwave absorbers. Commonly, slots are popular among antenna technology to increase the gain, bandwidth, RFID and multiband applications. [13]–[16]. This has encouraged the researchers to identify and research the design of the slot array antenna implementation on the hollow pyramidal absorber[17]–[19]. In this paper, slot array is invented to the hollow pyramidal microwave absorbers. The study involve analyzing the reflectivity performances based on measurement angles and the frequency bands. This study is important to determine the relationship between slot array patterns effecting the performance at different angle of wave incident.

2. STRUCTURE OF PYRAMIDAL ABSORBER

The reflectivity is an important parameter of radiation absorbing material (RAM). Absorption performance is the result from many reflections that take place between the pyramids. Because a single pyramid is relatively large compared to wavelengths, the sides of the pyramid usually reflect incident wave. Thus, some part of the wave can cause a lot of reflection before it gets to the solid absorption base, and the remaining waves are then reflected. The reflectivity performance is determine by comparing the magnitude of the reflection with the magnitude of the incident waveform, where the absorber is considered an infinite plane [20]. Figure 1 below shows the comparison design of commercial absorber and slotted absorber.

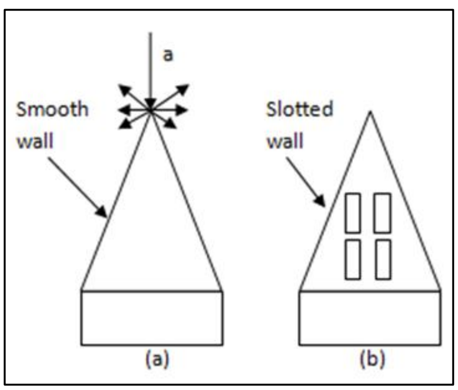

Figure 1: Side view profile of (a) commercial absorber (b) slotted absorber

The pyramidal absorber produce poor reflectivity performance when pyramid length is less than a quarter wavelength, $\lambda/4$. The absorber would scatter just a restricted sum of energy of the incidence wave [20]. The incident energy at low and excessive top frequencies are in general attenuated with the aid of using $\lambda/4$ resonances, corresponding to the wavelength of $\lambda/4$ and $3\lambda/4$ separately. In evaluation to flat absorber, pyramidal shape obtain more interdependent results for broadband absorption. Furthermore, the pyramid kept up its absorption bandwidth in a wide incident angle, 50° for transverse electric (TE) polarization and 60° for transverse magnetic (TM) polarization has been reported in [21]. The impedance mismatching contributes to the bad absorption performance

In this study, the slotted array design technique is applied on the hollow pyramidal microwave absorbers in order to diminish dissipating from the tips and edges of pyramid. The creation of slotted array design is to improve the impedance matching as well as the absorber performance at what has been proven in slotted array antenna designs. Generally, it is necessary to study the absorption required for an application depends on the specification at the test facility. For example, the absorption required to achieve the performance of a particular space varies by size and shape of its protected shields. Therefore, the designed absorbers applied are similar with the conventional absorbers in terms of size and shape to satisfy the reflectivity criteria in the chamber. Figure 2 below shows the dimension of hollow pyramidal absorber from side view and top view.

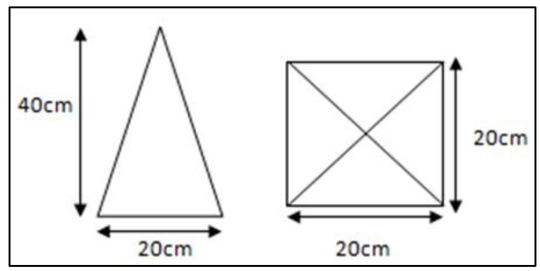

Figure 2: The dimensions of pyramidal absorber from frequency between 1GHz to 12GHz from side view and top view

3. ABSORBER MEASUREMENT

The initial proposed design and investigation of this study are simulated by using CST Microwave Studio. Then, the slotted array design of pyramidal absorber is fabricated and measured under free space arch to experimentally obtain the performance. Prior to the experimental design, the resistivity must be considered to ensure that the material is in a semiconductor state. In order to achieve the best result, the value of resistivity must be closed to 1MΩ [18]. This is the value to obtain semiconductor material.

After obtaining the appropriate resistivity value, the measurement technique starts by placing a metal plate on the middle point of the arch to measure the reflection. The loss electromagnetic wave propagation is a feature indicates that the portion of energy loss in the propagation path. The propagation path is the way which electromagnetic waves move, ranging from the transmitter to the receiver [22]. The horn antenna is placed at a normal incident, 0˚ of microwave absorber as shown in this paper [23]. Next step, the sample of absorber is place on the metal plate, and the reflection is measured. The same process is repeated again for 30˚ and 60˚. The reflection coefficient is define when the proportion of the sample reflection to the metal plate reflection [5].

When the incidence and reflected electrical field, Ei and Er, and magnetic waves Hi and Hr enter vertically to the incident plane at random angle, θi, in the reflection plane, the propagation constant, γ can be characterized as the equation 3 following below.

$$\gamma = \sqrt{jw\mu(\sigma + jw\varepsilon)} \approx \sqrt{jw\mu\sigma} \quad (3)$$

4. RESULT AND DISCUSSION

A. Comparison of Non-Slot and Single Slot on Hollow Pyramidal Absorber

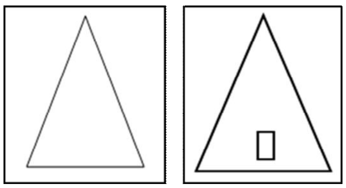

Figure 3: Non-slot and single slot on hollow pyramidal absorber

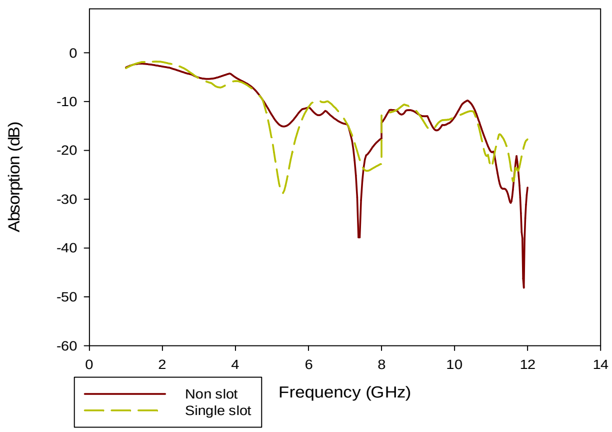

Figure 4: The absorption performance between non-slot and single slot at 0°

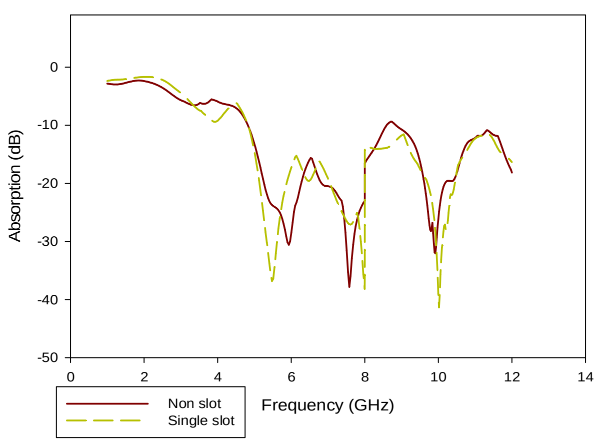

Figure 5: The absorption performance between non-slot and single slot at 30°

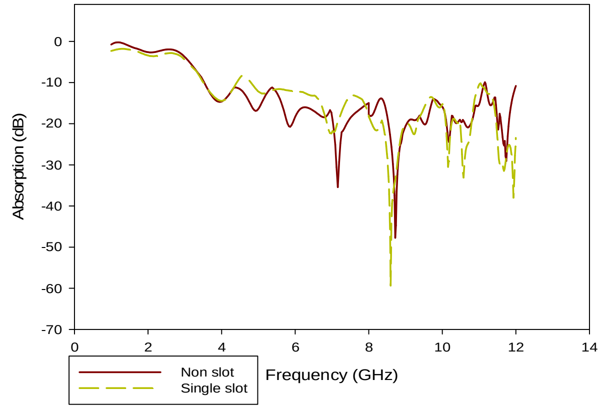

Figure 6: The absorption performance between non-slot and single slot at 60°

Figure 3 shows the design of non-slot and single slot on hollow pyramidal microwave absorber. The results are taken at 0°, 30° and 60° as shown in Figure 4, 5 and 6. Both designs are compared to each other to analyze the significant absorption performance different throughout the frequency bands.

B. Comparison of Two Array Slots (Model A) and (Model B) on Hollow Pyramidal Absorber

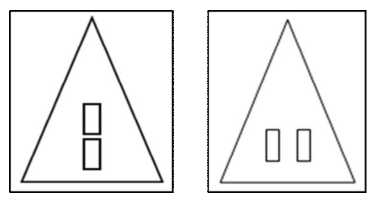

Figure 7: Two array slots (Model A) and (Model B) on hollow pyramidal absorber

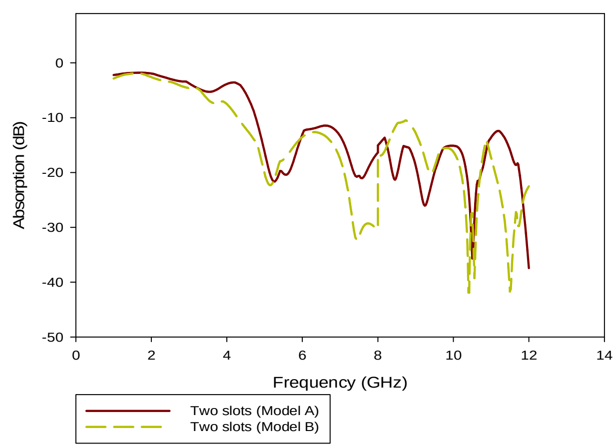

Figure 8: The absorption performance of two slots array (Model A) and (Model B) at 0°

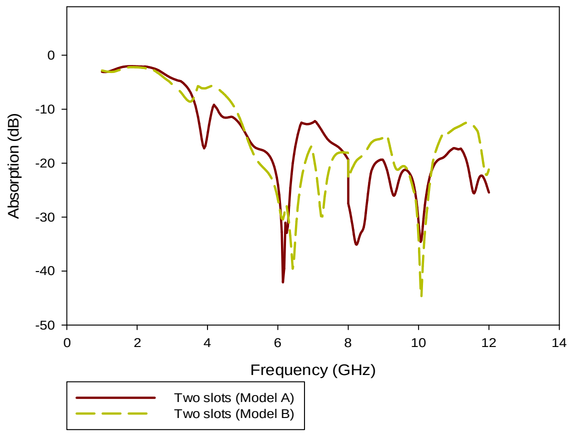

Figure 9: The absorption performance of two slots array (Model A) and (Model B) at 30°

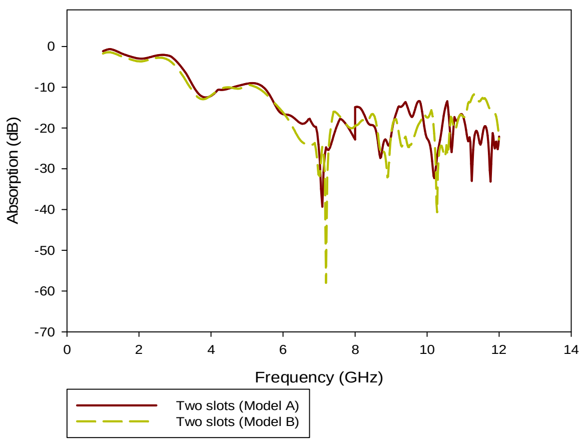

Figure 10: The absorption performance of two slots array (Model A) and (Model B) at 60°

Figure 7 shows the design of two different slots array on hollow pyramidal microwave absorber. The results are taken at 0°, 30° and 60° as shown in Figure 8, 9 and 10. Both slots array designs are compared to each other to analyze the significant absorption performance different throughout the frequency bands.

C. Comparison of Four Array Slots (Model C) and (Model D) on Hollow Pyramidal Absorber

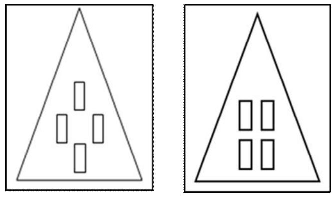

Figure 11: Four slots array (Model C) and (Model D)

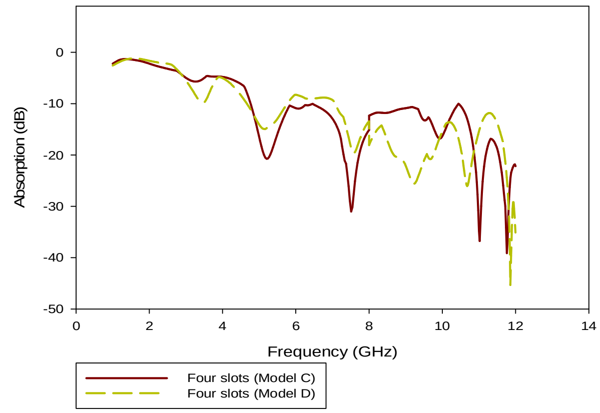

Figure 12: The absorption performance of four slots array (Model C) and (Model D) at 0°

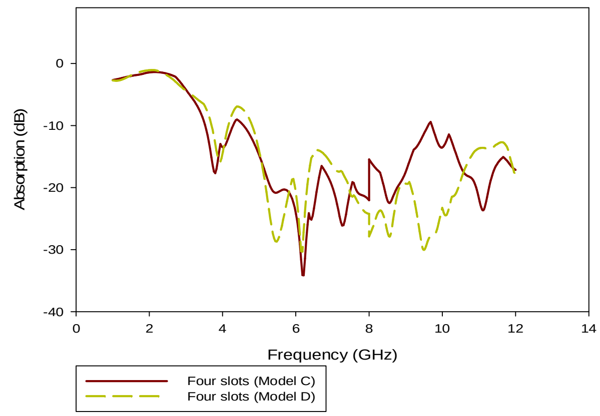

Figure 13: The absorption performance of four slots array (Model C) and (Model D) at 30°

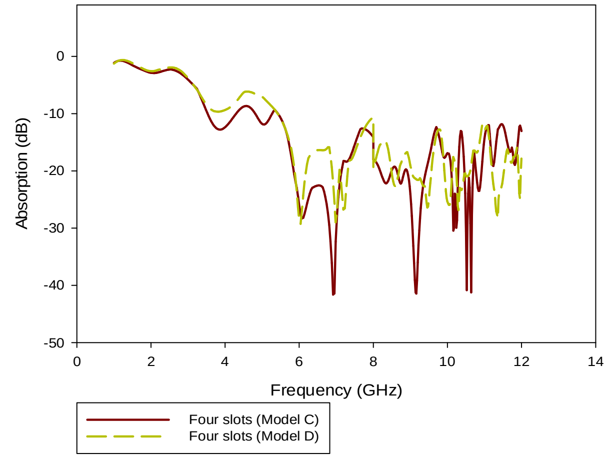

Figure 14: The absorption performance of four slots array (Model C) and (Model D) at 60°

Figure 11 shows the design of four slots array at different pattern on hollow pyramidal microwave absorber. The results are taken at 0°, 30° and 60° as shown in Figure 12, 13 and 14. Both slots array designs are compared to each other to analyze the significant absorption performance different throughout the frequency bands.

Table 1: Minimum and maximum absorption performance of slots design at 0˚

Design	Frequency (GHz)	L band (1-2)		S band (2-4)		C band (4-8)		X band (8-12)	
	Reflectivity (dB)	Min	Max	Min	Max	Min	Max	Min	Max
Non-Slot		-1.17	-2.96	-3.99	-5.27	-10.91	-38.37	-9.11	-47.61
Single Slot		-1.83	-3.27	-1.93	-7.08	-5.84	-28.89	-10.88	-26.32
Two Slots (Model A)		-1.52	-2.25	-1.08	-3.28	-11.51	-21.65	-12.39	-37.09
Two Slots (Model B)		-1.88	-2.32	-4.08	-7.82	-12.86	-32.18	-10.45	-42.04
Four Slots (Model C)		-1.01	-2.54	-4.08	-5.61	-9.79	-31.08	-10.01	-38.97
Four Slots (Model D)		-0.50	-1.72	-2.93	-10.21	-5.02	-19.94	-11.96	-45.43

Table 2: Minimum and maximum absorption performance of slots design at 30˚

Design	Frequency (GHz)	L band (1-2)		S band (2-4)		C band (4-8)		X band (8-12)	
	Reflectivity (dB)	Min	Max	Min	Max	Min	Max	Min	Max
Non-Slot		-2.32	-3.20	-2.10	-6.72	-5.83	-37.44	-9.13	-32.18
Single Slot		-1.45	-1.88	-1.67	-9.35	-15.27	-37.66	-11.54	-41.38
Two Slots (Model A)		-1.88	-2.98	-2.10	-17.24	-9.35	-41.82	-17.24	-34.81
Two Slots (Model B)		-1.88	-2.98	-5.83	-8.91	-17.24	-39.41	-12.64	-44.69
Four Slots (Model C)		-1.86	-2.22	-2.04	-17.72	-9.15	-33.93	-9.52	-23.73
Four Slots (Model D)		-1.13	-2.59	-2.41	-14.99	-6.97	-30.29	-12.61	-30.29

Table 3: Minimum and maximum absorption performance of slots design at 60˚

Design	Frequency (GHz)	L band (1-2)		S band (2-4)		C band (4-8)		X band (8-12)	
	Reflectivity (dB)	Min	Max	Min	Max	Min	Max	Min	Max
Non-Slot		-0.29	-1.76	-2.62	-11.05	-11.15	-35.26	-9.98	-46.72
Single Slot		-1.46	-3.52	-2.64	-13.60	-8.51	-21.67	-11.55	-59.34
Two Slots (Model A)		-1.17	-2.64	-2.35	-12.05	-8.80	-39.07	-13.52	-33.20
Two Slots (Model B)		-1.76	-3.52	-2.64	-12.64	-8.80	-57.29	-12.35	-40.83
Four Slots (Model C)		-0.79	-2.54	-2.10	-13.08	-8.48	-28.65	-12.64	-41.38
Four Slots (Model D)		-0.35	-2.32	-1.88	-9.57	-6.05	-41.60	-12.86	-28.00

In the literatures, there are researchers stated that the slot radial array was found to be one of the method to improve the reflectivity performance [18]. Therefore, it is expected that a single slot design should offered better performance than non-slot design on hollow pyramidal absorber. In the measurement of this study, the comparison between single slot design and non-slot design has been analyzed as in Table 1,2, and 3 at 0˚, 30˚ and 60˚. At 0˚, the results show that the single slot design have slightly better performance than non-slot design at low frequency band of L-band and S-band. At C and X frequency band, non-slot design however achieved better absorption than single slot design. Meanwhile, at measurement angle of 30˚ and 60 ˚, a single slot and non-slot design have slight difference in absorption performance at all bands. However, in average, the specific performance indicated that a single slot design obtain better absorption than non-slot design at frequency band of C and X frequency band. This result indicates that single slot design is capable to improve the absorption performance of a microwave absorber.

On the other hand, it is apparent from Table 1, 2 and 3, the performance between two slots array design in Model A and Model B shows that there is an improvement in term of absorption when compared to single or non-slot designs. At 0˚, 30˚ and 60˚, it is observed that the absorption performance between two slots array of Model A and Model B at L band has uncorrelated differences. However, Model B achieved an averagely better absorption performance compared to Model A at S, C and X frequency band. In addition, the result shows that the angle of incidents on slot array design is sensitive to the reflectivity behavior, thus become an important role to be analyzed further to achieve better performance.

On top of that, Table 1, 2 and 3 show that there is an uncorrelated difference between the four slots array designs (Model C) and (Model D) at L low frequency band at 0˚, 30˚ and 60˚. However, specific observation shows that at 0˚, four slots array design (Model C) obtained better absorption performance than four slots array design (Model D) at S frequency band. Meanwhile, at X-band, Model D obtained better absorption performance than Model C. Apart from that, at 30˚, Model C obtained a better absorption performance at S and C frequency band. However, at X band, Model D obtained better absorption performance than Model C. Finally at 60˚, Model D obtained better absorption performance at the frequency band C-band while Model C obtained better absorption performance at X-band.

Overall, it is observed that apart from the variation of slot array designs and slot numbers, angles of measurement are also a crucial factor to determine the absorption performance of a pyramidal microwave absorber. These analysis results are very important to guide researchers in the study to improve the performance using slotted array technique or measurement angle.

5. CONCLUSION

In summary, the effects of measurement angle from incident wave and the application of slotted array technique on pyramidal microwave absorber for its absorption performance are presented. The absorption performance is observed to be very sensitive to different angles in the desired frequency range of 1-12 GHz. The sensitivity is also influenced by the variety of slot array designs applied to the absorber. It was also concluded that, there is a certain slot design that is suitable for certain angles of measurement that act as a potential combination to achieve better absorbing performance.

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