

Rice Husk Truncated Pyramidal Microwave Absorber using Quadruple P-Spiral Split Ring Resonator (QPS-SRR)

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Abstract: There are many types of agricultural waste being potentially used in the pyramidal microwave absorber, among which are rice husk, sugarcane baggase and others. This paper analyzes the use of rice husk as a truncated pyramidal microwave absorber with an integrated of split ring resonator structure. It also ascertains the effect of the Quadruple P-Spiral Split Ring Resonator (QPS-SRR) on the truncated pyramidal microwave absorber design. The QPS-SRR structure is located at the top part of the truncated pyramidal microwave absorber to improve the reflection loss value. This absorber is fabricated using agricultural waste of rice husk, polyester resin and hardener agent of Methyl Ethyl Ketone Peroxide (MEKP). The QPS-SRR truncated pyramidal microwave absorber is simulated using CST Microwave Studio simulation software. The study and simulation are performed in the frequency ranges between 10.50 GHz to 14.50 GHz. The addition of SRR has improved the pyramidal microwave absorber from - 34.81 dB to - 51.171 dB in the range of 11.00 GHz to 11.25 GHz. Thus, it is recommended that the design of agricultural waste microwave absorber be integrated with the SRR structure which can lead in reducing the fabrication cost.

Key words: Split Ring Resonator, Pyramidal microwave absorber, Rice husk, Reflection loss

INTRODUCTION

Rice husk is one of the potential agriculture wastes or agriculture residues that can be applied in the truncated pyramidal microwave absorber as its main material. It is also highly porous, lightweight material, and has a high external surface area (Kumar, A., 2012). About 35 percent of carbon that exists in the rice husk serves as the important element that can help the high absorption rate for the absorber (Muthadhi A. and S. Kothandaraman, 2007).

Different absorber materials, sizes and shapes are used for the microwave range frequency between 1 GHz to 40 GHz. For a low frequency range which is below 1 GHz, the popular absorber used is ferrite tiles (Amano, M. and Y. Kotsuka, 2003). Polyurethane and polystyrene are widely used as the main fabricated material in the measurement laboratory and the commercial market. The *VHP-8-NRL* microwave absorber from Eccosorb (TDK, RF Solution Inc., 2008) is an example of a microwave absorber design which uses urethane foam as its based material with carbon loaded at the top of the pyramid. The *TDK ICT-030* microwave absorber (Emerson, and Cumming, 2008) is also currently a popular microwave absorber in the market that uses carbon plus non-flammable material. There are many shapes of microwave absorber used in research, including pyramids (Nornikman, H., 2010), wedges (Johansson, M., 2005) or hybrid absorber (Chung, B.K. and H.T. Chuah, 2003). The Pyramidal shaped is the most popular fabricated microwave absorber in the market because of its reflection loss performances.

This microwave absorber is installed in an anechoic chamber to eliminate the unwanted reflected electromagnetic signal. It can reduce the affected anechoic chamber reflection to a manageable level. The high performance microwave absorber is needed to ensure efficient testing measurement for the antenna placed in the anechoic chamber. There are four possible bounce paths in anechoic chamber, namely floor, ceiling, and the two walls. The multipath problem in an anechoic chamber is potentially worse than an outdoor ground-plane range. Therefore, the microwave absorber provides the best reflection loss performance due to its ability to absorb the microwave signal (Knott, E.F., 1985).

The Split Ring Resonator (SRR) structure is a combination of the concentric ring metal and wires (Pendry, J.B., 1999). This work continued with Smith by first metamaterial structure fabricated (Smith, D.R., 2000). The

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SRR unit cell can be transformed by an equivalent circuit using a capacitor and an inductor element (Bilotti, F., 2011). In this case, the gap between the rings can be shown by a capacitor while the long strip can be represented by the inductor. Figure 1 shows the double rings of SRR and single ring of SRR with its equivalent circuit. The other shapes available are spiral (Wickenden, D.K., 2006), Minkowski (Xu, H.X., 2011) and H-shape (Machac, J., 2008). The basic parameters investigated in the split ring resonator are ring thickness, inner diameter, the gap of the ring, and the gap between two rings. The SRR structure has the capability to improve performance in many devices and application, for example antenna (Marques, R., 2003), filter (Dong, Y. and T. Itoh, 2011), frequency selective surface (FSS) (Ghaderi, M., 2011) and microwave absorber (Nornikman, H., 2010).

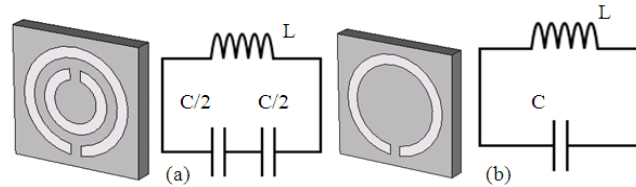


Fig. 1: Split ring resonator and its equivalent circuit, (a) double SRR, (b) single SRR.

The aim of this paper is to develop the microwave absorbers using agricultural waste of rice husks. The design incorporates the Quadruple P-shaped Split Ring Resonator (QPS-SRR) in designing the hybrid truncated pyramidal microwave absorber. This SRR structure deems to improve the reflection loss and reduce the cost of fabrication of the microwave absorber.

METHODS AND MATERIALS

Development of Rice Husk Microwave Absorber:

There are four main steps to develop the pyramidal microwave absorber. First, mix the fabricated particle board using mixed rice husk with resin and a hardener agent. Next, define the dielectric properties of the particle board using the free space method. Then, fabricate the pyramidal microwave absorber using the molds and hand press machine. Finally, measure the reflection loss performance of the microwave absorber using the radar cross section method.

Figure 2 (a) shows the raw rice husk that is taken from a paddy field in Kuala Perlis, Malaysia. Figure 2 (b) shows the particle board or the based part of the pyramidal microwave absorber that has been fabricated using the mixture of rice husk, polyester resin and Methyl Ethyl Ketone Peroxide (MEKP) as the hardener agent. The mixture is done by mixing the palm oil with unsaturated polyester resin and 3% methyl ethyl ketone peroxide (MEKP), to make a layer type microwave absorber (Anas, Y.A., 2005). The dimension of this particle board is 20 cm length x 20 cm width x 2 cm thickness.

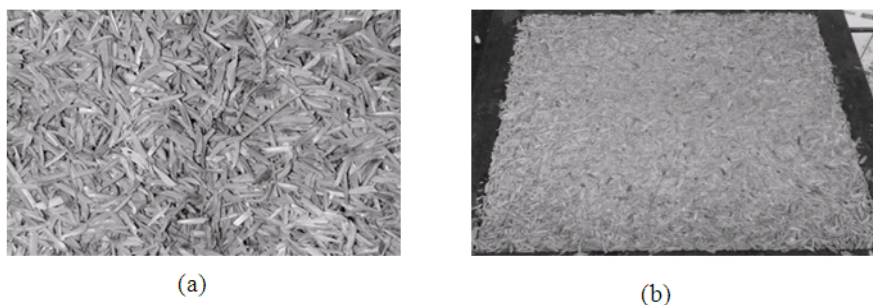


Fig. 2: (a) Raw rice husk (b) Fabricated rice husk particle board for measuring dielectric properties.

An important element before selecting the material is the dielectric properties (include dielectric constant and loss tangent) of the material. There are various techniques used to define dielectric properties of materials namely free space, transmission line, resonant cavity and dielectric probe. The measurement of dielectric constant and loss tangent must consider the type of the material such as liquid, solid, or semi-solid.

Permittivity or dielectric constant is a measurement used to define the electrostatic energy which is stored within the materials (depending on the material). The dielectric constant is equivalent to relative permittivity (ϵ_r) or the absolute permittivity (ϵ) relative to the permittivity of free space (ϵ_0) (Bekefi, G. and A.H. Barrett, 1987). Equation (1) shows the formula of permittivity of free space while equation (2) shows the formula of the wavelength. Equation (3) shows the loss tangent formula.

$$\varepsilon = \varepsilon_r \varepsilon_o \quad (1)$$

$$\lambda = \frac{c}{f \sqrt{\varepsilon}} \quad (2)$$

Where c = speed of light = $3 \times 10^8 \text{ ms}^{-1}$

$$\tan \delta = \frac{\varepsilon_r''}{\varepsilon_r'} \quad (3)$$

Where ε_r' = real part component of permittivity and
 ε_r'' = imaginary component of permittivity

The permittivity of different material affects the velocity of microwave signals when it moves through the material. The high value of dielectric constant causes the decrease of wave velocity due to the density of the material. By varying the dielectric constants of the designed absorber will vary the absorber dimensions and reflection losses. The large value of dielectric constant results in the signal to travel slower.

The materials, after going through the process, are hardened and transformed to a board, which are then used to measure the dielectric constant, ε_r and the loss tangent, $\tan \delta$ of the rice husk using the free space measurement technique, as shown in Figure 3. The equipment used are the Agilent E8362B PNA network analyzer installed with Agilent 85071E Material Measurement software, two horn antennas, coaxial cables, and the particle board as the material under test (MUT). In the initial step, the calibrations of the coaxial cable, reference board sample and length between two antennas (transmitter and receiver) are performed. The aim of the calibration is to remove undesired errors, such as noise in the coaxial cable and to ensure measurement accuracy. The full two-port calibration is used for both reflection and transmission part measurements. The Agilent 85052D Economy Mechanical 3.5 mm calibration kit with SOLT (Short – Open – Load – Trough) standard is used in this calibration setup.

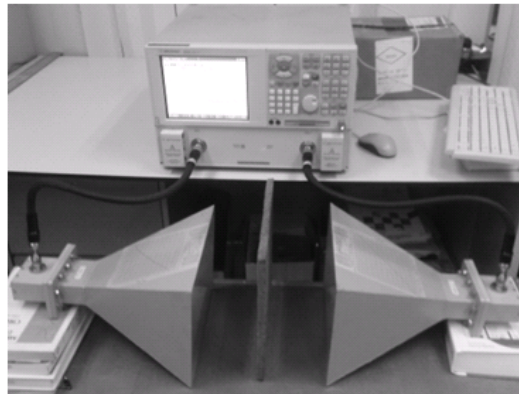


Fig. 3: Free space measurement technique setup for measuring dielectric properties.

The dielectric constant value of the reference board sample will be displayed at the Agilent 85071E Material Measurement software at the PNA network analyzer. From the measurement conducted earlier, it shows $\varepsilon_r = 2.9$ and $\tan \delta = 0.107$. The reference dielectric constant in the commercial sector is $\varepsilon_r = 1.00059$. Fig. 4 illustrates the fabrication of pyramidal part using the same mixture with the particle board. This absorber fabricated uses a pyramidal shaped mold. The pyramidal shape has two main parts: the base part with a 5 cm length x 5 cm length x 2 cm thickness or height, and the pyramid part with 13 cm height. These parts are glued together using a special glue.

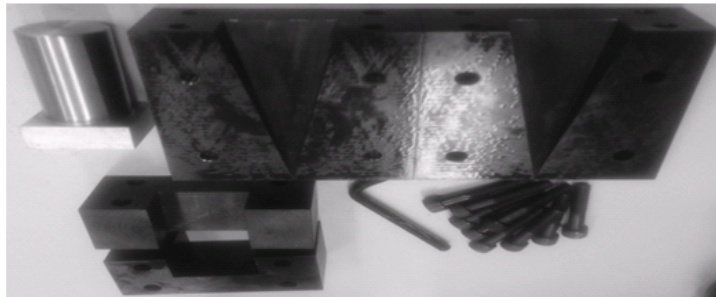


Fig. 4: Pyramidal shape mold for fabricating pyramidal shaped microwave absorber

The reflection loss performance is measured using the radar cross section technique: a pair of horn antennas, reference metal, signal generator, network analyzer, and coaxial cables, as shown in Figure 5. Radar cross section is defined as the area that can be perfectly reflected back when an electromagnetic wave is transmitted from its source to its target position (Rezende, M.C., 2001). The reference metal is placed in between the rice husks pyramidal microwave absorbers and the plywood board. The optimum distance between the horn antennas and plywood board is determined from the experiment. The signal analyzer is connected to the transmit horn antenna for transmitting the input microwave signal, and the receiver horn antenna will collect the microwave signal.

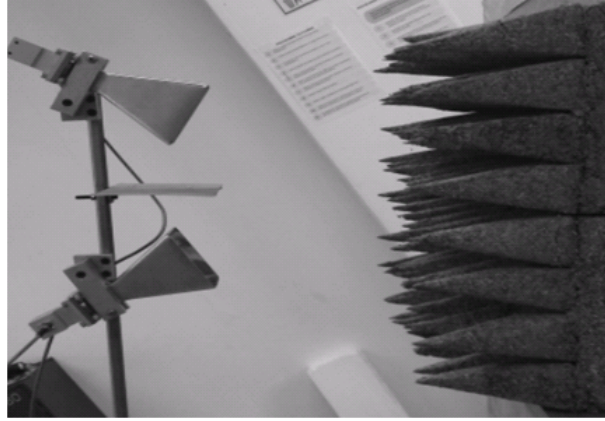


Fig. 5: Radar cross section setup for reflection loss measurement of truncated pyramidal microwave absorber

Design of QPS-SRR Structure:

Figure 6 (a) shows the single QPS-SRR and the QPS-SRR structure. The width of the single P-spiral SRR structure is 2.67 mm on the left and 1.21 mm on the right. The length dimension of this split ring resonator structures is 1.7 mm on the top side and 2.18 mm on the bottom side. The ring thickness is 0.24 mm. Figure 6 (b) shows the complementary unit of QPS-SRR.

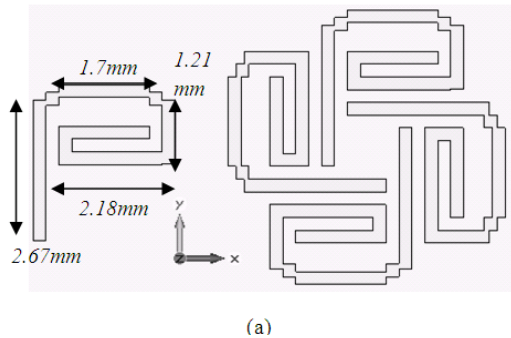


Fig. 6: (a) Single unit of P-spiral SRR and substrate

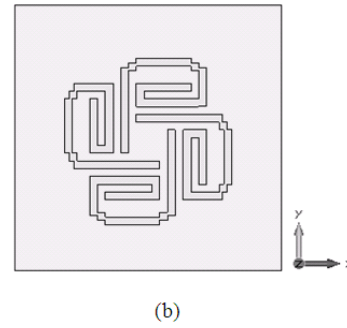


Fig. 6: (b) Complementary of QPS-SRR in FR-4 quadruple unit of P-spiral

Figure 7 shows the single, double and triple unit of QPS-SRR in CST Microwave Studio simulation setup. The red square zone is the waveguide port 1 and waveguide port 2 refer to the reflection coefficient, S_{11} and transmission coefficient, S_{21} .

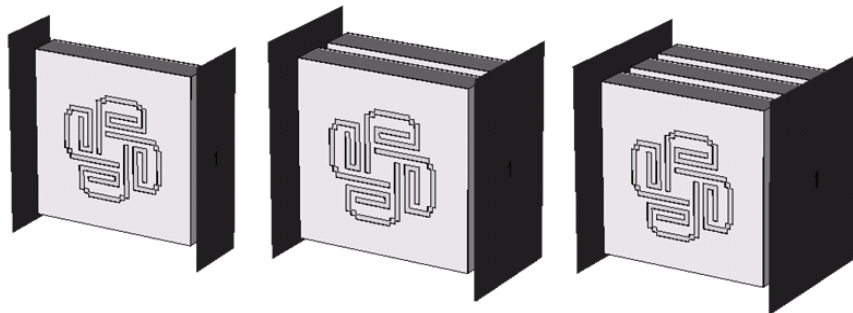


Fig. 7: S_{11} and S_{21} simulation setup of single, double, and tripe QPS-SRR in CST Microwave Studio simulation software.

Figure 8 shows the reflection loss simulation setup on the hybrid truncated pyramidal microwave absorber using rice husk incorporated with QPS-SRR on the top of the truncated part. The location of this QPS-SRR is 130 mm from the base part of the absorber. The dimension of copper is 8.32 mm width x 8.32 mm length with 1.6 mm FR4 substrate thickness and 0.035 mm copper thickness. The source signal comes from the waveguide port (red square zone). There are approximately four parameters which affect the reflection loss of the pyramidal microwave absorber such as the dielectric constant of the material of the microwave absorber, distance between source signal and the microwave absorber, the angle between the waveguide port and microwave absorber and the location of the SRR structure on the microwave absorber.

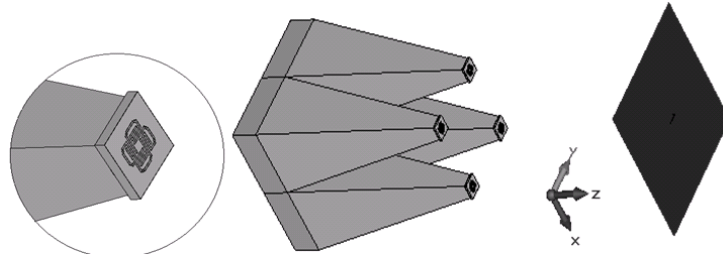


Fig. 8: Simulation setup of truncated pyramidal microwave absorber in CST.

RESULTS AND DISCUSSION

Figure 9 shows the transmission coefficient, S_{11} and reflection coefficient, S_{21} for single, double and triple QPS-SRR in a CST simulation setup. The resonant frequency of these structures are - 30.503 dB at - 13.216 GHz (single QPS-SRR), - 29.49 dB at 12.992 GHz (double QPS-SRR), and - 34.502 dB at 12.896 GHz.

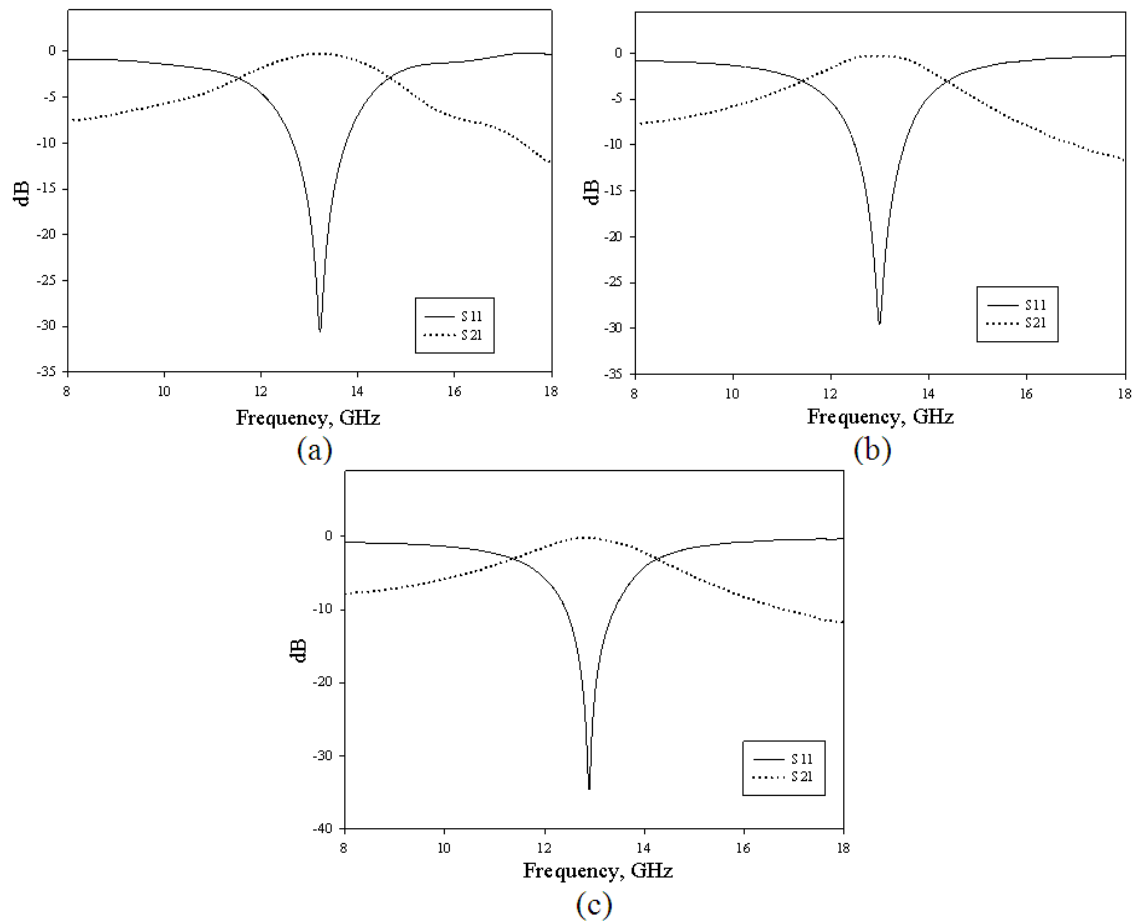


Fig. 9: Transmission coefficient, S_{11} and reflection coefficient, S_{21} result, (a) single QPS-SRR, (b) double QPS-SRR, (c) triple QPS-SRR.

Figure 10 and 11 show the reflection loss of truncated pyramidal microwave absorber with different units of QPS-SRR. The graph below illustrates the reflection loss in the frequency range of 10.500 GHz to 14.500 GHz. The highest point is shown by 2 QPS-SRR absorber with -60.269 dB in the frequency of 12.906 GHz.

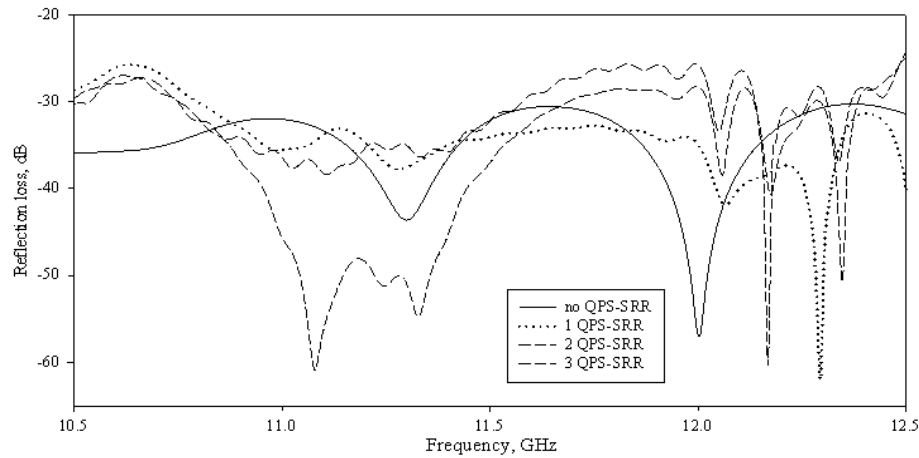


Fig. 10: Reflection loss of truncated pyramidal microwave absorber with different QPS-SRR in the range frequency of 10.5 GHz to 12.5 GHz.

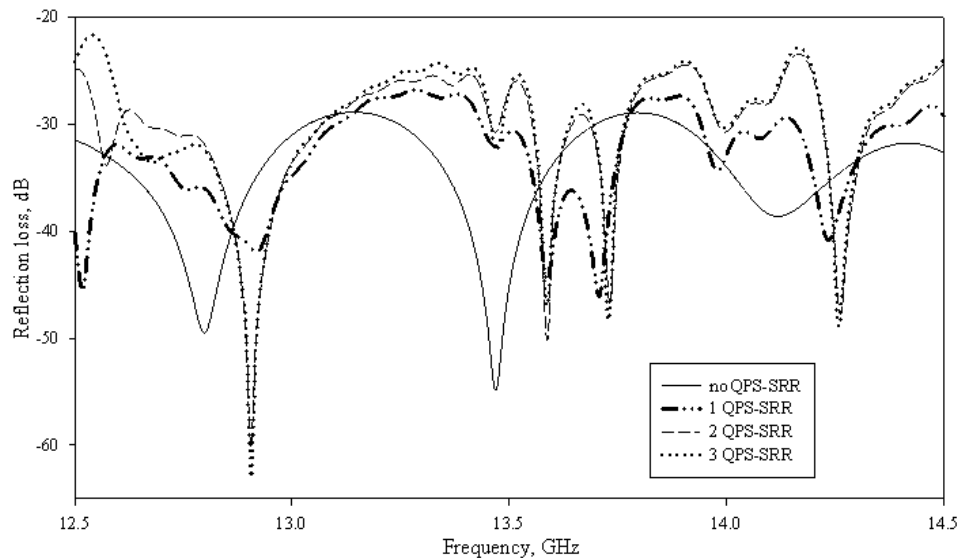


Fig. 11: Reflection loss of truncated pyramidal microwave absorber with different QPS-SRR in the range frequency of 12.5 GHz to 14.5 GHz.

Table 1 shows the average reflection loss of truncated pyramidal microwave absorber using QPS-SRR structure. It is divided into 16 regions with a frequency range of 0.25 GHz each which shows the improvement of the reflection loss at the B, C, D, and E regions with -36.122 dB, -51.171 dB, -46.224 dB and -32.00 dB. These regions show the significant impact of the addition of double unit of QPS-SRR at the truncated pyramidal microwave absorber. The results show the wider bandwidth of -40 dB return loss in the frequency range of 10.951 GHz to 11.500 GHz (bandwidth = 0.549 GHz).

From the aforementioned work in (Nornikman, H., 2010), it is proven that the agricultural waste, for example, rice husk has the potential to be used in designing the truncated pyramidal microwave absorber. The main materials for commercial microwave absorber are not environmentally friendly and hazardous. This is due to the usage of 100% based chemical materials such as polystyrene and polyurethane which can increase the pollution into the environment compared to the rice husk pyramidal microwave absorber that uses only $>10\%$ of chemical based material and liquids.

The fabricated microwave absorber successfully can operate in the microwave range frequency between 10.5 GHz to 14.5 GHz. The reflection loss results obtained in the rice husks pyramidal microwave absorbers are significantly better than -10 dB (i.e., the threshold dB for the characteristics of microwave absorber). In this paper, the addition of QPS-SRR has significantly improved more reflection loss compared to the previous work.

The result is acceptable especially in the frequency range between 10.75 GHz to 11.75 GHz (region B, C, D, E). The fabricated absorber price is cheaper than the commercial pyramidal microwave absorber such as TDK—ICT-030 and VHP-8-NRL.

Table 1: Reflection loss performance with different number of QPS-SRR at the truncated pyramidal microwave absorber.

Region	Frequency range (GHz)	Average reflection loss			
		No SRR	Single SRR	Double SRR	Triple SRR
A	10.50-10.75	- 35.511	- 26.955	- 28.139	- 28.746
B	10.75-11.00	- 32.801	- 32.404	- 36.122	- 33.917
C	11.00-11.25	- 34.810	- 34.687	- 51.171	- 36.765
D	11.25-11.50	- 38.103	- 35.785	- 46.224	- 34.826
E	11.50-11.75	- 30.994	- 33.323	- 32.000	- 28.922
F	11.75-12.00	- 38.569	- 36.601	- 31.177	- 29.139
G	12.00-12.25	- 38.228	- 38.791	- 33.250	- 31.874
H	12.25-12.50	- 30.716	- 37.344	- 31.451	- 29.367
I	12.50-12.75	- 35.481	- 35.104	- 29.675	- 28.711
J	12.75-13.00	- 39.533	- 38.324	- 38.554	- 38.930
K	13.00-13.25	- 29.518	- 30.016	- 28.964	- 28.662
L	13.25-13.50	- 38.666	- 28.477	- 26.658	- 26.066
M	13.50-13.75	- 33.869	- 37.563	- 33.563	- 32.930
N	13.75-14.00	- 30.425	- 29.563	- 27.179	- 26.869
O	14.00-14.25	- 36.926	- 32.614	- 27.948	- 27.603
P	14.25-14.50	- 32.688	- 31.475	- 30.797	- 30.341

Conclusion:

In conclusion, rice husk microwave absorber has successfully been developed and measured by using the compression and radar cross section methods. It shows that the QPS-SRR has a high potential to be used to improve the average reflection loss of microwave absorber design up to 17 dB. This improvement can lead to a better antenna measurement accuracy in an anechoic chamber. Future direction will lead other researchers to explore further in coating the pyramidal microwave absorber using different percentages of carbon powder mixed with different agricultural waste.

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