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# STUDY AND SIMULATION OF AN EDGE COUPLE SPLIT RING RESONATOR (EC-SRR) ON TRUNCATED PYRAMIDAL MICROWAVE ABSORBER

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**Abstract**—Split ring resonator (SRR) structure can potentially be incorporated onto the truncated pyramidal microwave absorber. This study considers three different patterns of edge couple split ring resonator (EC-SRR) designs. Each EC-SRR design is then placed onto the truncated pyramidal microwave absorber. Outer split gap dimension widths of the EC-SRR are varied, and the various $S_{21}$ performances are compared. This EC-SRR truncated pyramidal microwave absorber is simulated using CST Microwave Studio simulation software. The study and simulation are performed in low frequency range (0.01 GHz to 1 GHz) as well as in microwave frequencies range (1 GHz to 20 GHz). Simulation results of this EC-SRR show improvement of reflection loss and $S_{11}$ performance in the high frequency range of the pyramidal truncated microwave absorber.

## 1. INTRODUCTION

Microwave absorbers can eliminate the reflected signal and are used in radio frequency (RF) anechoic chamber. Carbon is the main element used in a microwave absorber, as it provides the best reflection loss performance due to its ability to absorb the microwave signal. $\varepsilon$ (epsilon) is the absolute permittivity of the dielectric, which is a measure of the electrostatic energy stored within it and therefore

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dependent on the material. Dielectric constant is equivalent to relative permittivity ($\varepsilon_r$) or the absolute permittivity ($\varepsilon$) relative to the permittivity of free space ($\varepsilon_0$). Equation (1) shows the formula of permittivity of free space while Equation (2) shows the formula of the wavelength.

$$\varepsilon = \varepsilon_r \varepsilon_o \tag{1}$$

$$\lambda = \frac{c}{f\sqrt{\varepsilon}} \tag{2}$$

where $c$ = speed of light = $3 \times 10^8 \mathrm{ms}^{-1}$.

There are many ways to increase the pyramidal microwave absorber performance such as using the material with high carbon, using the new hybrid pyramidal shape, making an array pyramidal microwave absorber and adding the metamaterial structure on the pyramid. In this work, split ring resonator (one of metamaterial structure types) is used to increase the microwave absorber performance. Other matermaterial structures that can be used are artificial magnetic conductor (AMC) [1], electromagnetic band gap (EBG) [2], and photonic band gap (PBG) [3].

In microwave application, there are many applications that use split ring resonator (SRR) design such as the design of metamaterial antennas, microwave absorbers, mixers, filters and oscillators [4]. Many papers show the improved performance by employing the SRR in the design [5–19]. SRR can be incorporated onto a microwave absorber [20]. It has the potential to increase the reflection loss or $S_{11}$ results of the microwave absorber.

Metamaterial or left handed material is an artificial material that does not exist in the real nature [21]. Matermaterial has categorized structure or design that has simultaneously negative permeability and permittivity. The metamaterial structure can significantly miniaturize the design size. It also achieves better reflection loss or return loss performances than a normal design without metamaterial structure [22] and improves antenna gain [23, 24]. The metamaterial artificial left-handed materials (LHMs) were initially discovered by Veselago [25]. Only after 3 decades, researchers in the field manage to apply the materials in practical applications. The first artificial metamaterial was fabricated by Smith et al. in 2000 [26]. Their design is based on Pendry split ring resonator-base artificial negative magnetics permeability media [27]. Split ring resonators (SRRs) design is used to produce the negative magnetic permeability.

Commercial microwave absorbers are designed to be made of plastic foamed-based materials like polystyrene or polyurethane with impregnating carbon as its mixed material. Beside that, there are also many researches on alternative materials, such as carbon nanotube

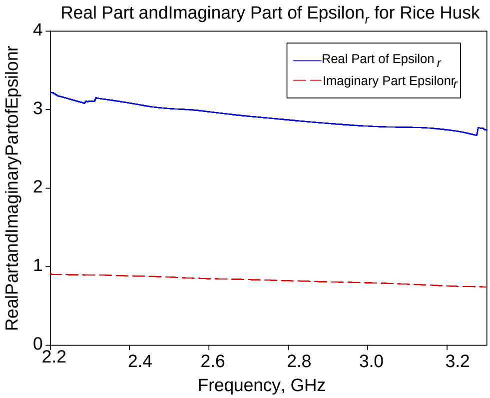


**Figure 1.** Real and imaginary parts of Epsilon$_r$ (dielectric constant) for rice husk.

composite [28], ferrite absorber [29], ferroxide film [30] and other polymers materials. Agricultural residue like rice husk, a byproduct of paddy (*Oryza sativa*), has potential to apply as the based material in the microwave absorber fabrication. Figure 1 shows the dielectric constant that has been measured in the laboratory using dielectric probe technique. The dielectric constant for rice husk is $\varepsilon_r = 2.9$. This dielectric constant has been measured using dielectric probe technique [31–33].

## 2. SPLIT RING RESONATOR (SRR) UNIT CELL

The split ring resonator can be applied in many designs, such as antennas [34, 35], microwave absorber [36–38], filters [39], frequency selective surface [40]. There are many types of split ring resonator, which have been designed by researchers, such as edge couple SRR (EC-SRR), broadside-couple SRR (BC-SRR), nonbianistropic SRR (NB-SRR), Spiral SRR (S-SRR), open split ring resonator (O-SRR). Edge-coupled SRR (EC-SRR) was initially designed by Pendry in [41] and Smith et al. [42]. Since 1999, researchers have proposed many structures for metamaterial designs using split ring resonators (SRRs). These structures are used to produce the negative dielectric constant (permittivity) and negative permeability design. This structure can improve reflection loss ($S_{11}$) performances compared to the normal design [43].

Figure 2 shows the front view and ground view of the EC-SRR design. The front part of the EC-SRR has two rings, an inner ring

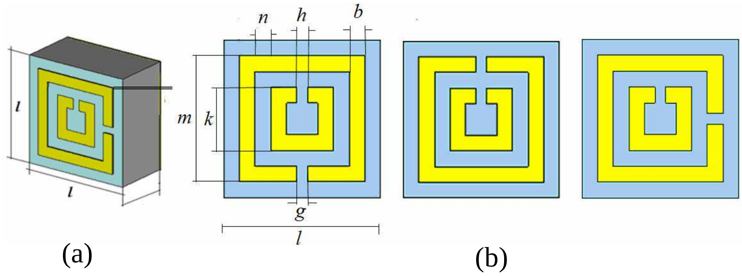


**Figure 2.** (a) The perspective view of single unit of EC-SRR structure. (b) Plan view of single unit of EC-SRR structure with three different pattern: Pattern $A$, Pattern $B$, and Pattern $C$. The SRR dimensions are as follows: Copper thickness, $t = 0.0035\,\text{cm}$, Taconic *TLX 906207* substrate thickness, $t_{board} = 0.1615\,\text{cm}$, side length, $l = 0.32\,\text{cm}$, width of inner ring split gap, $h = 0.04\,\text{cm}$, width of outer ring split gap, $g = 0.04\,\text{cm}$, width of copper line, $b = 0.03\,\text{cm}$, length of outer copper line, $m = 0.28\,\text{cm}$, length of inner copper line, $k = 0.16\,\text{cm}$ and gap between inner and outer ring, $n = 0.02\,\text{cm}$.

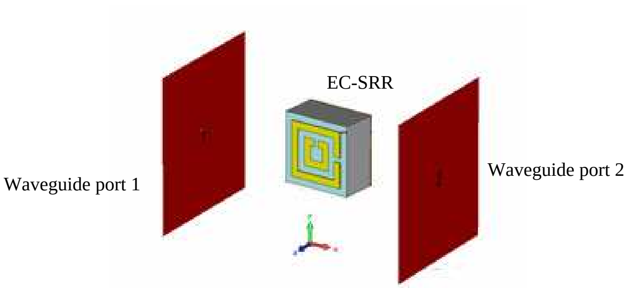


**Figure 3.** The simulation setup of single array of edge couple split ring resonator in CST Microwave Studio simulation software.

and outer ring, while the back part has a wire with dimension of $0.01\,\text{cm} \times 0.3\,\text{cm}$. Figure 3 shows the simulation setup run in CST Microwave Studio. The simulation consists of two sources of signal ports, namely waveguide port 1 and waveguide port 2. The EC-SRR is positioned right at the center between the two ports. CST Microwave Studio software is used to do the simulation to determine the performance of the EC-SRR on the microwave absorber. This EC-SRR is designed on Taconic *TLX 906207* board with dielectric constant of $\varepsilon_r = 2.5$. The three patterns are differed by changing the length of gap between the outer rings of the SRR. The performance of each SRR pattern, which has a different outer ring split gap width, is analyzed and compared. The gap values, $g$, chosen for comparison are 0.02 cm, 0.04 cm, 0.06 cm, and 0.08 cm, respectively. All patterns have the same dimension of 0.32 cm width $\times$0.32 cm length and $\times$0.1685 cm thickness.

There are many parameters that affect the performance or the result of the Split Ring Resonator such as the dimension of EC-SRR, N-number of SRR, split ring gap, thickness of the substrate used and others. In this study, three types of square shape EC-SRR patterns are designed to be incorporated into the truncated pyramidal microwave absorber.

## 3. THE TRUNCATED PYRAMIDAL MICROWAVE ABSORBER DESIGN

The design of the pyramidal microwave absorbers has been performed by Nornikman et al. [44–46]. Performances of three different stages of truncated pyramidal microwave absorber are studied. The stages are conventional truncated pyramidal microwave absorber stage, truncated pyramidal microwave absorber with single SRR stage, and truncated pyramidal microwave absorber with array SRR stage. Figure 4 shows the dimension of truncated pyramidal microwave absorber, which has two main elements, the pyramidal base part and the pyramidal body part. This paper discusses the designs of the normal truncated pyramidal microwave absorber, SRR truncated pyramidal absorbers, SRR array truncated pyramidal microwave absorber and reports the respective reflection losses This microwave absorber is designed using

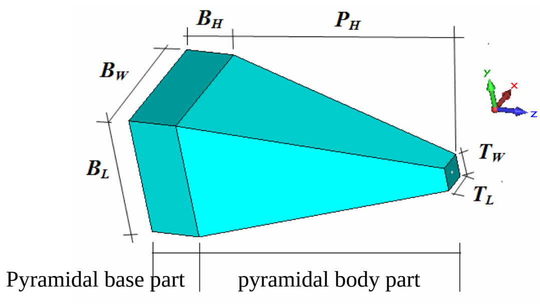


**Figure 4.** The dimensions of the truncated pyramidal microwave absorber; based length, $B_L$ = 5 cm, based width, $B_W$ = 5 cm, based height, $B_H$ = 2 cm, pyramid height, $P_H$ = 13 cm, top width, $T_W$ = 1 cm, and top length, $T_L$ = 1 cm.

CST Microwave Studio software.

Table 1 shows the differential dimension for the three different absorbers. TDK and VHP are commercial pyramidal microwave absorbers. They are currently available in the market. TDK absorber is designed by using a mixture of carbon and nonflammable material and VHP absorber by urethane foam. The truncated microwave absorber used in this study is made of agricultural waste, which is rice husk mixed with Urea Formaldehyde as its resin or bonding agent. It has a dielectric constant of $\varepsilon_r = 2.9$.

**Table 1.** The differential dimension for TDK, VHP absorber and new design of truncated pyramidal microwave absorber.

| Part | Symbol | Absorber dimension (cm) | | |
|---|---|---|---|---|
| | | TDK | VHP | Truncated |
| Pyramidal width | $P_W$ | 10 | 6.8 | 5 |
| Pyramidal length | $P_L$ | 10 | 6.8 | 5 |
| Pyramidal height | $P_H$ | 25 | 17.8 | 13 |
| Base width | $B_W$ | 10 | 6.8 | 5 |
| Based length | $B_L$ | 10 | 6.8 | 5 |
| Based height | $B_H$ | 5 | 2.5 | 2 |
| Top width | $T_W$ | - | - | 1 |
| Top length | $T_L$ | - | - | 1 |

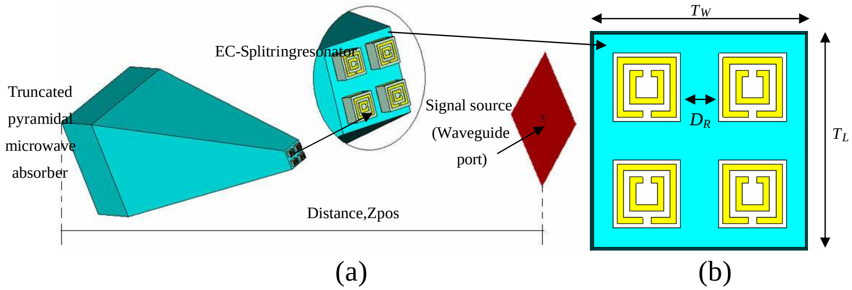


**Figure 5.** (a) The location of edge couple split ring resonator at the top of pyramidal microwave absorber (perspective view), Distance, $Z_{pos} = 30\,\text{cm}$, (b) The array of EC-SRR structure (plan view), distance between two SRR, $D_r = 0.18\,\text{cm}$, top length, $T_L = 1\,\text{cm}$, top width $= T_W = 1\,\text{cm}$.

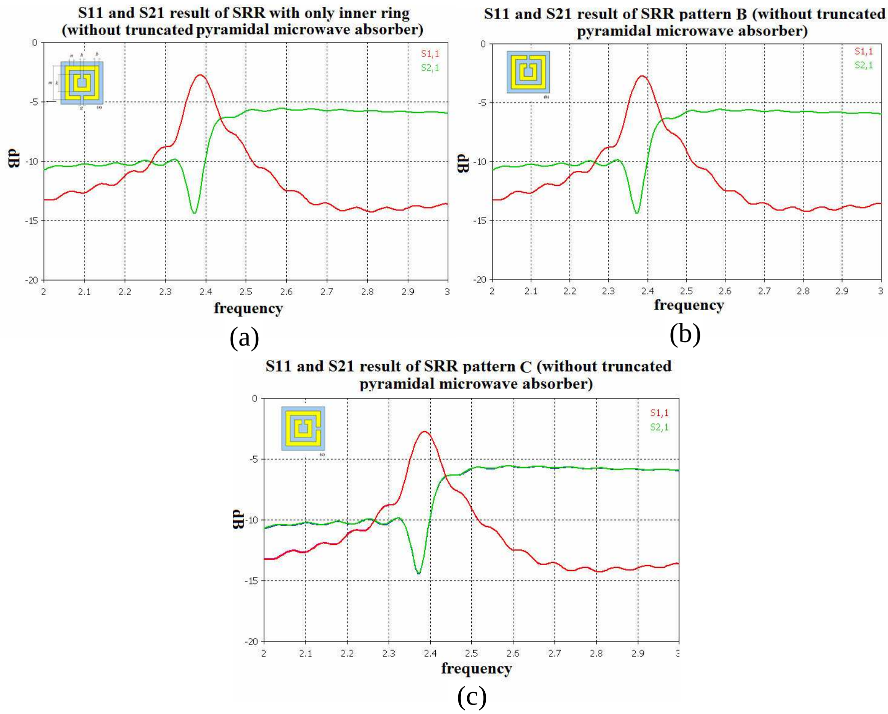


**Figure 6.** The $S_{11}$ and $S_{21}$ results for unit cell of EC-SRR designs (stand-alone SRR, without truncated pyramidal microwave absorbers): (a) SRR with only inner ring, (b) SRR Pattern $A$, (c) SRR Pattern $B$, (d) SRR Pattern $C$.

Basically, the dimension of this absorber is based on TDK ICT-030 and Eccosorb VHP-8-NRL but with modified dimension. Both TDK and VHP are pyramidal microwave absorbers with sharp corner at the top of the pyramid. In this work, the truncated pyramidal microwave absorber has 1 cm width $\times 1$ cm length surface at the top of the pyramid. The dimension of the truncated microwave absorber has been miniaturized as compared to the *TDK ICT-030* and Eccosorb *VHP-8-NRL* absorber. It significantly reduces the cost of mold fabrication.

Figure 5 shows the schematic diagram of the truncated pyramidal microwave absorber with the corresponding EC-SRR and source port location. The EC-SRR unit is placed at the top of the truncated pyramidal microwave absorber. The port is located at 30 cm away from the base absorber. The distance between pyramidal microwave absorber and source signal port, $Z_{pos}$, also affects the reflection loss performance of absorber [47].

# 4. RESULTS

## 4.1. $S_{11}$ and $S_{21}$ Result of Split Ring Resonator

Figure 6 shows $S_{11}$ and $S_{21}$ performance results of the SRR (stand-alone, without truncated pyramidal microwave absorber) for three different EC-SRR patterns (patterns $A$, $B$ and $C$). The frequency ranges from 2 to 3 GHz. At 2.37 GHz, $S_{21}$ result for pattern $A$ is $-14.418$ dB, $-14.421$ dB for pattern $B$, and $-14.381$ dB for pattern $C$. It shows that all SRR patterns produce almost similar $S_{21}$ and $S_{11}$ results.

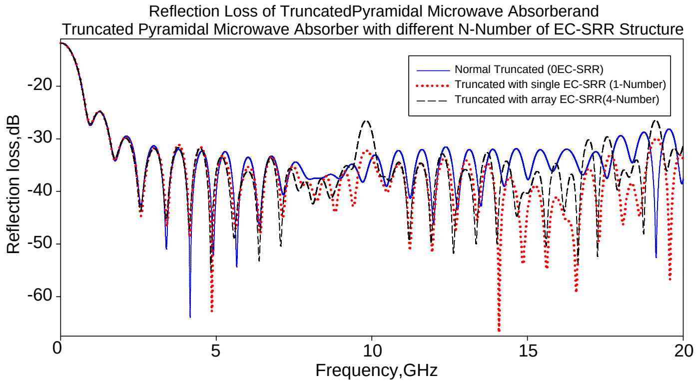


**Figure 7.** Reflection loss of normal truncated pyramidal microwave absorber and truncated pyramidal microwave absorber with EC-SRR structure split ring gap, $g = 0.04$ cm.

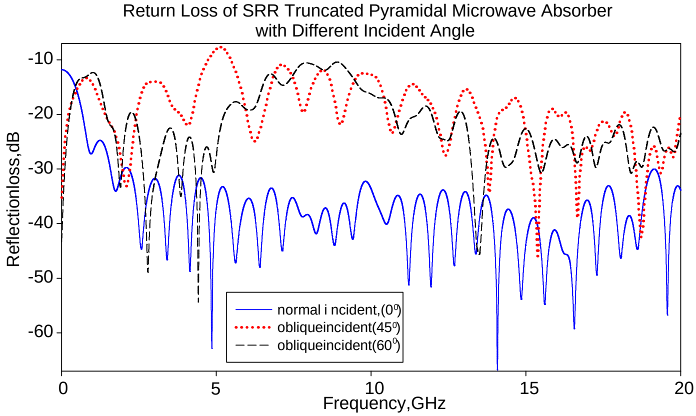


**Figure 8.** Reflection loss of normal truncated pyramidal microwave absorber with different incident angle. Split ring gap, $g = 0.04$ cm.

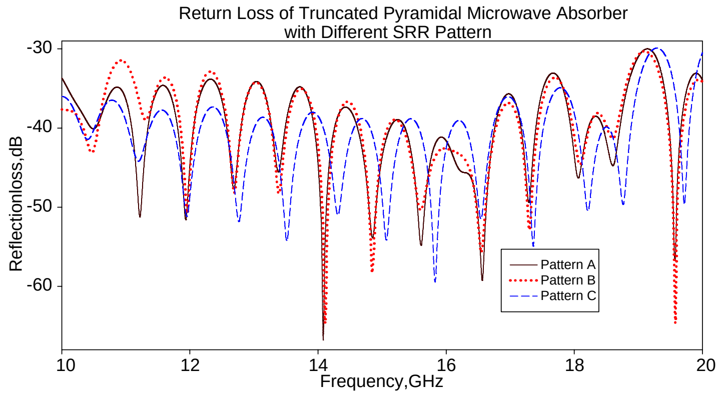


**Figure 9.** The reflection loss of truncated pyramidal microwave absorber with different SRR pattern. Split ring gap, $g = 0.04\,\text{cm}$.

**Table 2.** Average reflection loss of conventional truncated pyramidal microwave absorber, absorber with single and EC-SRR array.

| Frequency range (GHz) | Average reflection loss (dB) | | |
|---|---|---|---|
| | Normal truncated absorber | Absorber with single EC-SRR | Absorber with EC-SRR array |
| 0.01–1 | −17.788 | −17.724 | −17.732 |
| 1–10 | −35.870 | −36.433 | −36.170 |
| 10–15 | −35.437 | −39.582 | −38.362 |
| 15–20 | −33.469 | −40.200 | −36.017 |
| 0.01–20 | −34.247 | −37.219 | −35.754 |

## 4.2. Effect of N-number of EC-SRR

Figure 7 and Table 2 show the reflection loss of conventional truncated pyramidal microwave absorber, absorber with one EC-SRR, and absorber with SRR array. Truncated pyramidal microwave absorber with single SRR has the best result among the three designs. The graph shows that the reflection loss of all three designs are better than −30 dB from the frequency range of 1.58 GHz to 20 GHz. The best point for this design is shown by absorber with single EC-SRR at frequency of 5.29 GHz with −66.774 dB. All three designs of the microwave absorber show similar performances in the low frequency range of 0.1 GHz to 1 GHz. In this frequency range it shows the worse reflection loss performance than the other frequency ranges.

**Table 3.** Average reflection loss of truncated pyramidal absorber with different incident angle.

| Frequency range (GHz) | Average reflection loss (dB) | | |
|---|---|---|---|
| | Normal incident (0°) | Oblique incident (45°) | Oblique incident (60°) |
| 0.01–1 | −17.724 | −17.737 | −18.392 |
| 1–10 | −36.433 | −16.541 | −19.762 |
| 10–15 | −39.582 | −19.329 | −23.871 |
| 15–20 | −40.200 | −25.967 | −26.066 |
| 0.01–20 | −37.219 | −19.664 | −22.311 |

**Table 4.** The average reflection loss of truncated pyramidal microwave absorber with different SRR pattern.

| Frequency range (GHz) | Average reflection loss (dB) | | | |
|---|---|---|---|---|
| | No SRR structure | SRR pattern $A$ | SRR pattern $B$ | SRR pattern $C$ |
| 0.01–1 | −17.788 | −17.724 | −17.735 | −17.876 |
| 1–10 | −35.870 | −36.433 | −36.664 | - 36.868 |
| 10–15 | −35.437 | −39.582 | −38.900 | - 41.404 |
| 15–20 | −33.469 | −40.200 | −40.305 | −40.742 |
| 0.01–20 | −34.247 | −37.219 | −37.176 | −38.008 |

### 4.3. Effect of Incident Angle

Figure 8 and Table 3 show the return loss of SRR truncated pyramidal microwave absorber with different incident angles. Three different incident angles are considered in this section, i.e., normal incident of 0° or straight line, 45° of oblique angle, and 60° of oblique angle. It is shown that the normal incident achieves the better reflection loss performance than the other incident angles. The average return losses (between 0.01 GHz and 20 GHz) for 450 and 600 are only −19.664 dB and −22.311 dB compared to the normal incident with −37.219 dB.

### 4.4. Effect of EC-SRR Pattern

Figure 9 and Table 4 show the reflection loss for pyramidal microwave absorber with different SRR patterns. In the frequencies ranging from 1 GHz to 10 GHz, $S_{11}$ value for the SRR truncated pyramidal microwave absorbers is around 1 to 2% larger than the result obtained for the conventional truncated pyramidal microwave absorber. For the frequencies ranging from 10 GHz to 15 GHz, better overall reflection loss performances are observed than the conventional truncated pyramidal microwave absorber. SRR pattern A shows a 9.38% larger result, SRR pattern $B$ a 7.65% larger result, and SRR pattern $C$ a 13.98% larger result.

For the high frequencies ranging from 15 GHz to 20 GHz, larger reflection loss values for the three SRR patterns are observed than the results obtained using the conventional truncated pyramidal microwave absorber. For SRR pattern $A$, the reflection loss result is larger by 20.11%, for SRR pattern $B$ 20.43% larger, and for SRR pattern $C$ 21.73% larger. For comparison, SRR pattern $C$ shows the best performance among all the analyzed SRR patterns. Overall, in the frequencies ranging from 0.01 to 20 GHz, EC-SRR pattern $C$ achieves $-38.008$ dB of reflection loss result compared to the conventional truncated pyramidal microwave absorber which achieves $-34.247$ dB of reflection loss result.

## 4.5. Effect of Split Ring Gap

Figure 10 and Table 5 show the reflection loss of the truncated pyramidal microwave absorber of SRR with different split gap dimensions, $g$ values. From Table 5, it can be seen that the minimum value of the split gap ($g = 0.02$ cm) provides a better reflection loss result performance than the other wider ring gap dimensions. It achieves an average return loss of $-37.432$ dB for 0.01 GHz to 20 GHz.

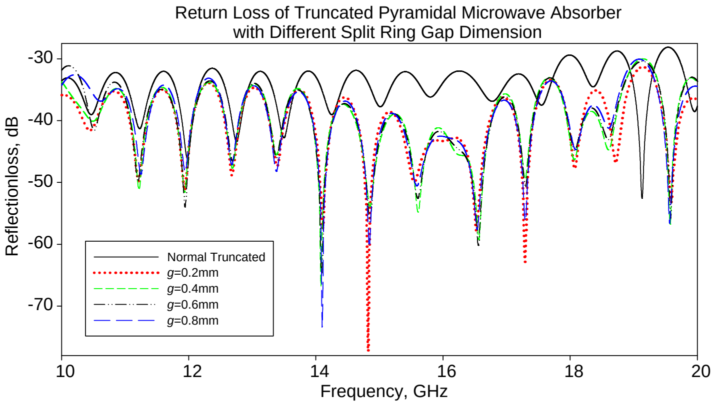


**Figure 10.** The reflection loss of truncated pyramidal microwave absorber with different ring gap dimension.

**Table 5.** The average reflection loss of truncated pyramidal microwave absorber with different ring gap dimension.

| Frequency range (GHz) | Average reflection loss with ring gap dimension, $g$ (cm) | | | |
|---|---|---|---|---|
| | 0.02 cm | 0.04 cm | 0.06 cm | 0.08 cm |
| 0.01–1 | −17.685 | −17.724 | −17.716 | −17.732 |
| 1–10 | −36.518 | −36.433 | −36.598 | −36.727 |
| 10–15 | −39.847 | −39.582 | −39.234 | −39.033 |
| 15– 0 | −40.637 | −40.200 | −40.146 | −40.286 |
| 1–20 | −37.432 | −37.219 | −37.195 | −37.237 |

## 5. CONCLUSION

An edge-couple split ring resonator (EC-SRR) design incorporated into the truncated pyramidal microwave absorber has been presented in this paper. The incorporation of the EC-SRR increases the reflection loss performance of the truncated pyramidal microwave absorber, especially in high frequency range (15 GHz to 20 GHz). It is also shown that pattern $C$ of the EC-SRR design has the best results amongst all the three EC-SRR designs analyzed. The outer split ring gap width of $g = 0.02$ (i.e., the minimum value of split gap analyzed) results in the best reflection loss performance.

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