This chapter highlights the results of the scattering measurements carried out on different targets such as flat plate cylinder, dihedral corner reflector and circular cone, loaded with metallo-dielectric structures based on fractal geometries. The scattering characteristics of the above targets with different parameters are measured for TE and TM polarizations in C, X and Ku frequency bands.
Reduction of Radar Cross Section (RCS) of targets is of great importance in the design of low detectable targets. The conventional methods of RCS reduction are shaping of targets, use of absorbing materials, passive cancellation and active cancellation. It is also possible to reduce the RCS of targets by modifying its scattering properties so that the scattered energy is diverted away from the radar. This can be achieved by loading dielectric backed metallisations (metallo-dielectric structures) on the target surface.

The results of the scattering measurements carried out on different targets loaded with metallo-dielectric structures based on fractal geometries are described in this chapter. The investigations were carried out in the frequency range 4.5 GHz – 16 GHz. As mentioned in the previous chapter, the following targets which form the basic building blocks of any complex target are investigated.

- Flat plate
- Cylinder
- Dihedral corner reflector
- Circular cone

Fractal based metallo-dielectric structures (MDS) etched on dielectric substrates of different thickness are loaded over these targets. The parameters of the MDS were optimized to produce large reduction in backscattering. The results of the backscattering measurements for TE and TM polarizations of the incident electromagnetic waves are presented and compared with that of the original target.
• TE – polarizations: Magnetic field perpendicular to the plane of incidence
• TM – polarizations: Electric field perpendicular to the plane of incidence

4.1 FLAT PLATES LOADED WITH FRACTAL BASED METALLO-DIELECTRIC STRUCTURES (MDS)

Measurement results of the flat plates loaded with fractal based MDS is presented in this section. The following types of fractal structures were investigated.

➢ Different iterated stages of Sierpinski carpet fractal geometry
➢ Sierpinski carpet fractal geometry with different patch shapes
➢ Sierpinski gasket based metallo-dielectric structure
➢ Fractal geometries with varying lacunarity

The scattering characteristics of the above targets were measured for TE and TM polarizations in C, X and Ku bands to study the following.

• Variation of backscattered power with frequency
• Variation of backscattered power with angle of incidence.
• Angular distribution of the scattered power
• Change in backscattered power with dielectric thickness, fractal geometry, patch shape and dielectric constant
• Effect of loading superstrates
4.1.1 Different Iterated Stages of Sierpinski Carpet Fractal Geometry

Here, the backscattering measurements were taken for both TE and TM polarized fields incident normally on the target. The first iterated stage of Sierpinski carpet fractal geometry and the scattered power measured for different dielectric thickness compared to that of flat plate of same dimension is shown in figure 4.1. Measured results for the second, third and fourth iterated stages are shown in figures 4.2-4.4.

![Figure 4.1](image1)

**Figure 4.1** (a) First iterated stage of Sierpinski carpet fractal geometry
(b) Variation of backscattered power with frequency for different dielectric thickness (h)
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The backscattered power is measured for normal incidence in the range of frequencies covering C, X and Ku bands. The measurement is repeated for different iterated stages of the Sierpinski carpet fractal geometry. The dielectric thickness is also varied in each case, and the results are shown in figures 4.1-4.4.

![Diagram of Sierpinski carpet](image)

**Figure 4.2 (a)** Second iterated stage of Sierpinski carpet

**Figure 4.2 (b)** Variation of backscattered power with frequency for different dielectric thickness (h)
Experimental Results

Figure 4.3 (a) Third iterated stage of Sierpinski carpet
(b) Variation of backscattered power with frequency for different dielectric thickness (h)
Figure 4.4 (a) Fourth iterated stage of Sierpinski carpet fractal geometry
(b) Variation of backscattered power with frequency for different dielectric thickness (h)
Experimental Results

It is found that there is no appreciable reduction in backscattered power for the first and second iterated stages. A maximum reduction in backscattered power of -32 dB is obtained at 10.5 GHz for the third iterated stage for a substrate of thickness $h = 4$ mm. It is clear from figure 4.4 that the backscattering obtained for the fourth iterated stage is less than that for the third stage.

![Figure 4.5 Backscattered power variations with angle of incidence for the third iterated stage, $h = 4$ mm, $f = 10.5$ GHz](image)

Since the third iterated stage is giving maximum reduction in backscattered power, it is investigated further. Backscattering is measured for different angles of incidence by rotating the target keeping the transmitter and receiver antennas stationary. The result of this measurement is shown in figure 4.5. It is found that the backscattering is
minimum at normal incidence, for this particular thickness. Maximum backscattered power of -10 dB is obtained at an angle of incidence of 5°.

For a particular angle of incidence, backscattering reduction is obtained by the redistribution of scattered power in other directions. This angular distribution of the scattered power is measured for normal incidence by moving the receiver antenna around the target, keeping the transmitter antenna and target stationary. The power scattered from the structure at various angles is shown in figure 4.6. It is found that the scattered power is distributed symmetrically with respect to the normal in both the azimuth and elevation angular ranges, due to the symmetry in the structure of the target. Maximum backscattered power of -7 dB is obtained for a scattering angle of 10°.

![Figure 4.6 Distribution of scattered power along the azimuth for normal incidence for the third iterated stage, h = 4 mm, f =10.5 GHz](image-url)
4.1.2 Sierpinski carpet with different patch shapes

From the previous section it is concluded that the third iterated stage of the Sierpinski carpet fractal structure is giving maximum reduction in backscattered power over a considerable range of frequencies. Therefore this fractal geometry constructed with patches of different shapes as generator and is used for studying the scattering characteristics as described below.

4.1.2.1 Cross

Sierpinski carpet geometry with patches of the shape of Cross is shown in figure 4.7.

![Figure 4.7 Third stage of the Sierpinski carpet fractal with Cross as the generator](image)
Figure 4.8 (a) & (b) Backscattering characteristics with frequency for different substrate thickness for the structure with cross shaped generator
Experimental Results

Backscattered power is measured in different frequency bands for this structure for different substrate thickness and the results are shown in figures 4.8 (a) and (b). A maximum reduction in backscattered power of -17.6 dB is obtained at 8.65 GHz, for a dielectric thickness $h = 4$ mm.

4.1.2.2 Octagon

Octagonal shaped patches are used to construct fractal based metallo-dielectric structure as shown in figure 4.9.

![Figure 4.9 Sierpinski carpet with octagon as the generator](image)

Figure 4.9 Sierpinski carpet with octagon as the generator
Figure 4.10 (a) & (b) Backscattered power variations with frequency for different substrate thickness for the structure with octagonal patches
Experimental Results

Measurement results for the structure in figure 4.9 are shown in figures 4.10 (a) and (b). A maximum reduction in backscattered power of -35.5 dB is obtained at 8.15 GHz for a substrate thickness of 5 mm.

4.1.2.3 Hexagon

Metallo-dielectric structure constructed with hexagonal patches is shown in figure 4.11.

Figure 4.11 Sierpinski carpet with hexagon as the generator

Since the patch shape is not symmetric, scattering measurements are done for both TE and TM polarizations. The experiment is conducted for a large variation of substrate thickness and the measured results for TE polarization is shown in figure 4.12 (a) and (b). An appreciable reduction in backscattered power is obtained at 9.9 GHz for a dielectric thickness of h = 5 mm. A bandwidth (- 10 dB) of 2.82 GHz is achieved.
Figure 4.12 (a) & (b) Backscattered power variations with frequency for different substrate thickness for the structure with hexagonal patches for TE polarisation
Experimental Results

TM polarization is also showing similar results with the maximum reduction obtained at a slightly different frequency. From figure 4.13 (a) and (b), a maximum reduction in backscattered power of -38 dB is obtained at 8.24 GHz for a substrate thickness of 5 mm. A bandwidth of 2.13 GHz below -10 dB is achieved. Also, this structure is giving a reduction in backscattered power over an appreciable range of frequencies in X-band.

From figure 4-13(b), it is observed that a reduction in backscattered power of about 45 dB is obtained at 13.04 GHz for a thickness $h = 10$ mm apart from the dip at 8.24 GHz. The observations indicate that the metallo-dielectric structure can be optimized to give minimum backscattering at a different frequency by varying the thickness of the substrate. The variation of backscattered power with angle of incidence for the hexagonal shaped fractal for the two frequencies giving minimum backscattering is shown in figure 4.14 (a) and (b).
Figure 4.13 (a) & (b) Backscattered power variations with frequency for different substrate thickness for the structure with hexagonal patches for TM polarisation
Figure 4.14 (b) Variation of backscattered power with angle of incidence
(a) $f = 8.24$ GHz  $h = 5$ mm
(b) $f = 13.04$ GHz  $h = 10$ mm
4.1.2.4 Circle

Third iterated stage of the Sierpinski carpet structure with circular patches as the generator is shown in figure 4.15.

![Sierpinski carpet with circle as the generator](image)

**Figure 4.15** Sierpinski carpet with circle as the generator

The reduction in backscattered power with frequency for various substrate thickness for this case is shown in figures 4.16 (a) and (b). This structure is found to give backscattering reduction to an appreciable range of frequencies. The minimum thickness at which an appreciable reduction in backscattered power obtained is \( h = 5 \) mm. The frequency of minimum backscattering is 7.77 GHz. A bandwidth of 2.57 GHz below \(-10\) dB is achieved for this structure.
Figure 4.16 (a) & (b) Variation of backscattered power with frequency for the structure with circular patches
Figure 4.17 (b) Backscattered power variations with angle of incidence
(a) $f = 7.77 \text{ GHz}$ $h = 5 \text{ mm}$
(b) $f = 13.28 \text{ GHz}$ $h = 10 \text{ mm}$
Effect of the angle of incidence on the backscattering for this structure at the two frequencies of minimum backscattering are plotted in figures 4.17 (a) and (b).

4.1.2.5 Diamond

In this case, diamond shaped patches are used as generator to construct the metallo-dielectric structure and the geometry is shown in figure 4.18.

Figure 4.18 Sierpinski carpet with diamond as the generator
Figure 4.19 (a) & (b) Backscattered power variations with frequency for different substrate thickness for the structure with diamond shaped patches.
Experimental Results

The backscattered power measured at different frequencies for different substrate thickness is shown in figure 4.19 (a) and (b). It is observed that, no considerable reduction in the backscattered power is obtained for this structure.

4.1.2.6 *Purina square*

Sierpinski carpet with patches of the shape Purina square is shown in figure 4.20. Figure 4.21 (a) and (b) shows the variation of backscattered power with frequency for substrates of various thickness.

![Sierpinski carpet with Purina square as the generator](image)

**Figure 4.20** Sierpinski carpet with Purina square as the generator

The observations indicate that a maximum reduction in backscattered power of -23 dB is obtained at 14.26 GHz for a dielectric thickness of height, \( h = 9 \) mm.
Figure 4.21 (a) & (b) Variation of backscattered power with frequency for the structure with patches of the shape Purina square
4.1.2.7 Star

The third iterated stage of the Sierpinski carpet fractal geometry with patches of the Star shape is shown in figure 4.22.

![Sierpinski carpet with star as the generator](image)

**Figure 4.22** Sierpinski carpet with star as the generator

Since this the structure is not symmetric, the measurements are taken for TE and TM polarization of the incident field. The results are shown in figures 4.23 (a) and (b).

It is observed that for both cases, the maximum reduction in backscattered power is obtained for a dielectric thickness of 4 mm. Variations of backscattered power with frequency is almost identical for both polarizations.
Figure 4.23 (a) & (b) Variation of backscattered power with frequency (TE – Polarization) for the structure with Star shaped patches.
Figure 4.24 (a) & (b) Variation of backscattered power with frequency (TM – Polarization) for the structure with Star shaped patches.
4.1.2.8 Cross bar fractal tree

Figure 4.25 shows the metallo-dielectric structure based on the Sierpinski carpet geometry with crossed bar fractal tree shaped patches.

![Cross bar fractal tree](image)

**Figure 4.25** Sierpinski carpet with Crossed bar fractal tree as the generator

From the experimental results shown in figures 4.26 (a) and (b) it is observed that this structure is not giving appreciable reduction in the backscattered power.
Figure 4.26 (a) & (b) Variation of backscattered power with frequency for the structure with patches of the shape crossed bar fractal tree dipole
4.1.2.9 Sierpinski carpet array

Array of second iterated Sierpinski carpet fractal geometry is shown in figure 4.27.

![Sierpinski carpet array](image)

**Figure 4.27** Array of second iterated stage of Sierpinski carpet

Results of the scattering measurements for this structure are shown in figure 4.28 (a) and (b). A maximum reduction of backscattered power of -24.5 is obtained at 8.775 GHz for a substrate thickness of 5 mm.
Figure 4.28 (a) & (b) Variation of backscattered power with frequency for the Sierpinski carpet array.
4.1.3 Sierpinski gasket based metallo-dielectric structure

This section describes the use of Sierpinski gasket based metallo – dielectric structure for backscattering reduction. Figure 4.29 shows the metallo-dielectric structure based on Sierpinski gasket.

![Figure 4.29 Sierpinski gasket based metallo-dielectric structure](image)

Backscattering characteristics of this structure is shown in figure 4.30 (a) and (b). Here, a reduction of up to -31 dB at 8.8 GHz is achieved for a substrate thickness of 5 mm. Further increase in substrate thickness gives reduction in backscattering at a lower frequency but with less bandwidth.
Figure 4.30 (a) & (b) Backscattering characteristics of Sierpinski gasket based metallo-dielectric structure.
Backscattering at different angles of incidence is studied and plotted in figure 4.31. It is observed that a maximum backscattered power of $-3.4$ dB is obtained for an angle of incidence of $10^\circ$.

Figure 4.31 Variation of backscattered power with angle of incidence $h = 5$ mm, $f = 8.8$ GHz.
4.2 EFFECT OF LOADING SUPERSTRATES

For a given fractal geometry and patch shape, the frequency at which maximum reduction in backscattering is obtained depends on the substrate thickness. Once the structure is constructed, further tuning of the frequency can be achieved by loading superstrates. This section presents the measurement results of superstrate loaded metallo-dielectric structure.

The cross sectional view of superstrate loaded metallo-dielectric structure is shown in figure 4.32. Superstrates of various thickness are loaded over the metallo-dielectric structure and the backscattered power is measured in order to study the frequency tuning effect. It is found that the frequency of minimum backscattering can be tuned to a large range by varying the thickness of the superstrates. Also, the superstrate can act as a radome.

![Figure 4.32 Cross sectional view of superstrate loaded metallo-dielectric structure](image)

$h =$ substrate thickness, $t =$ superstrate thickness
4.2.1 Superstrate loading on Sierpinski carpet fractal geometry

The Sierpinski carpet based metallo-dielectric structure is loaded with superstrates of various thickness \( t \) and the backscattering is measured. This is repeated for the structure fabricated on substrates of different thickness \( h \).

![Graph showing variation of backscattered power with frequency with superstrate loading on Sierpinski carpet structure, \( h = 3 \) mm.](image)

**Figure 4.33** Variation of backscattered power with frequency with superstrate loading on Sierpinski carpet structure, \( h = 3 \) mm.

Results shown in figure 4.33 indicate that as the superstrate thickness is increased, the frequency giving minimum backscattering decreases. The frequency of minimum backscattering at 13.75 GHz without superstrate \( (t = 0) \) can be shifted up to 10.4 GHz by loading superstrate of thickness \( t = 1.5 \) mm. Appreciable reduction is obtained at
the 'tuned' frequencies. Further increase in superstrate thickness lowers the frequency but backscattering is found to be increasing.

![Graph](image)

**Figure 4.34** Variation of frequency of minimum backscattering with superstrate thickness for third iterated stage of Sierpinski carpet structure

The frequency tunability by superstrate loading is clearly indicated in figure 4.34 Here, superstrates are loaded over metallo-dielectric structure fabricated on substrates of different thickness $h = 2.6 \text{ mm}, 3 \text{ mm} \text{ and } 3.5 \text{ mm}$. 

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Experimental Results

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4.2.2 Superstrate loading on Sierpinski gasket fractal geometry

Effect of superstrate loading is studied on Sierpinski gasket geometry also. As before, when the structure is loaded with superstrate, the frequencies of minimum backscattering are shifted downwards with increase in superstrate thickness as shown in figure 4.35.

![Graph showing relative backscattered power vs frequency for different superstrate thicknesses on the Sierpinski gasket structure.](image)

**Figure 4.35** Power measured for different superstrate thickness on the Sierpinski gasket structure
Figure 4.36 shows the shift in frequency of minimum backscattering as the superstrate thickness is varied.

![Graph showing variation of frequency of minimum backscattering with superstrate thickness, for Sierpinski gasket structure](image)

**Figure 4.36** Variation of frequency of minimum backscattering with superstrate thickness, for Sierpinski gasket structure

From the experimental results, it is clear that the backscattering reduction can be obtained at a wide range of frequencies by loading superstrate of proper thickness.
4.3 FRACTAL GEOMETRIES WITH VARYING LACUNARITY

Scattering properties of metallo-dielectric structure based on Sierpinski carpet structures having same fractal dimension with different lacunarity values is investigated. Figure 4.37 (L1-L6) shows the Sierpinski carpets with dimension 1.9152 and varying lacunarity.

Figure 4.37 Sierpinski carpets with varying lacunarity (D = 1.915)
Experimental Results

Figure 4.38 Variation of backscattered power with frequency for optimum dielectric thickness for carpets with varying lacunarity in C band.

Figure 4.38 shows the variation in relative backscattered power with frequency in C-band for the structures shown in figure 4.37. The substrate thickness is varied for each structure and the thickness giving minimum backscattering in the band is found out. A reduction in backscattered power of 44 dB is achieved at 6.46 GHz for a dielectric thickness $h = 7$ mm for the structure L3. It is also noted that the backscattered power is below $-20$ dB for a wide band of 5.54 GHz to 6.84 GHz. Similarly, the results of the measurements in X and Ku bands, are shown in figure 4.39 and 4.40. The backscattered power is reduced up to $-42$ dB at 8.34 GHz and $-44$ dB at 15.22 GHz in X and Ku frequency.
bands. It is found that the structure L3 is giving maximum reduction in backscattered power in all the three frequency bands for different values of h. Hence, the reduction in backscattered power can be obtained in any of the three bands by varying the substrate thickness with the same design.

Figure 4.39 Backscattered power variations with frequency for optimum dielectric thickness in X band

Figure 4.40 Variation of backscattered power with frequency for optimum dielectric thickness in Ku band
Experimental Results

![Figure 4.41 Backscattered power variations with angle of incidence for L3 in C band](image)

**Figure 4.41** Backscattered power variations with angle of incidence for L3 in C band

![Figure 4.42 Backscattered power variations with angle of incidence for L3 in X band](image)

**Figure 4.42** Backscattered power variations with angle of incidence for L3 in X band
Figure 4.43 Backscattered power variations with angle of incidence for L3 in Ku band

The backscattered power for different angles of incidence for the structure L3 measured in different frequency bands are presented in figures 4.41 - 4.43. The results indicate that the backscattering is minimum at normal incidence and maximum backscattering occurs at the blazing angle. The blazing angles in C, X and Ku bands are 27°, 20° and 11° respectively. Studies also indicated that the backscattered power is distributed symmetrically with respect to the normal in both the azimuth and elevation angular ranges. Since the structures are symmetric, this property is observed for both TE and TM polarizations.
4.4 RCS REDUCTION OF 3D STRUCTURES

As mentioned earlier, basic building blocks of any complex targets are flat plates, cylinders, cones and corner reflectors. Result of loading fractal based metallo-dielectric structure on these objects are described in the next section.

4.4.1 METALLIC CYLINDER

A metallic cylinder loaded with the metallo dielectric structure is shown in figure 4.44.

![Figure 4.44 Hollow metallic cylinder loaded with fractal based metallo-dielectric structure, L = 30 cm, r = 9.55 cm](image)

The measurements are done for both TE and TM polarization of the incident field for vertical and horizontal orientation of the cylinder for different angles of incidence.
TE-Polarization

**Figure 4.45** Variation of backscattered power from the structure for different dielectric thickness, TE polarization

**Figure 4.46** Backscattered power variations with angle of incidence, $f = 10.18$ GHz, $h = 4$ mm, TE polarization
Figure 4.45 illustrates the variation of the backscattered power with frequency for TE polarization of the incident field for different dielectric thickness. The reduction in backscattering varies with the thickness of the substrate material and a reduction of $\sim 35$ dB is obtained at 10.18 GHz for a dielectric thickness of $h = 4$ mm. The frequency of minimum backscattered power is also changing with thickness of the substrate.

Backscattered power for different angles of incidence for the configuration giving minimum backscattered power is plotted in figure 4.46. It is found that, at an angle of incidence of $15^\circ$, backscattering is maximum. Distribution of scattered power for normal incidence is shown in figure 4.47.

![Graph]

**Figure 4.47** Angular distribution of scattered power for normal incidence, TE polarization, $f = 10.18$ GHz, $h = 4$ mm
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TM-Polarization

Backscattered power at different frequencies for TM polarization of the illuminated wave is plotted in figure 4.48. Maximum reduction in the backscattered power of -35 dB is obtained at 9.78 GHz for dielectric thickness $h = 4$ mm.

![Figure 4.48](image)

**Figure 4.48** Backscattered power variations with frequency for TM polarization

![Figure 4.49](image)

**Figure 4.49** Variation of backscattered power with angle of incidence $f = 9.78$ GHz, $h = 4$ mm, TM polarization
Experimental Results

In this case also, reduction in backscattered power is obtained at multiple frequency bands. Figure 4.49 shows the backscattered power for different angles of incidence. Maximum backscattered power is obtained at an angle of incidence of 70°.

![Graph showing backscattered power at different angles of incidence.]

**Figure 4.50** Angular distribution of scattered power for normal incidence, TM polarization, $f = 9.78$ GHz, $h = 4$ mm

Distribution of scattered power for normal incidence is shown in figure 4.50. Experimental results obtained for the cylinder oriented horizontally as shown in figure 4.51 for both TE and TM case are given below.
Figure 4.51 Fractal structure loaded cylinder, horizontally oriented

TE-Polarization

Figure 4.52 Variation of backscattered power with angle of incidence
\( f = 9.78 \) GHz, \( h = 4 \) mm, TE polarization

The graph of variation in backscattered power with angle of incidence for the frequency giving minimum backscattered power and
substrate thickness is shown in figure 4.52. It is seen that a maximum backscattered power of -5.5 dB is obtained at an angle of incidence of $5^\circ$. Figure 4.53 shows the distribution of scattered power when the incidence is normal.

Figure 4.53 Scattered power measured at different angles for normal incidence, $f = 9.78$ GHz, $h = 4$ mm, TE polarization, cylinder horizontal
TM polarization

The variation of backscattered power with angle of incidence for TM polarization is depicted in figure 4.54. A maximum backscattered power of -6.6 dB is obtained at an angle of incidence of 50°.

Figure 4.54 Variation of backscattered power with angle of incidence $f = 10.18$ GHz, $h = 4$ mm, TM polarization, cylinder horizontal
Figure 4.55 shows the distribution of scattered power when the incidence is normal.

![Graph](image_url)

**Figure 4.55** Scattered power measured at different angles for normal incidence, $f = 10.18$ GHz, $h = 4$ mm, TM polarization
4.4.2 DIHEDRAL CORNER REFLECTOR

A dihedral corner reflector loaded with Sierpinski carpet based metallo-dielectric structure is shown in figure 4.56.

![Dihedral corner reflector loaded with fractal based metallo-dielectric structure, L = 30 cm](image)

**Figure 4.56** Dihedral corner reflector loaded with fractal based metallo-dielectric structure, $L = 30$ cm

The scattering from a corner reflector is strongly dependent on the corner angle. It gives a large backscattering when the corner angle is $90^\circ$ and is less at other angles. Hence the measurements are carried out for corner reflectors for a wide range of corner angles ($\alpha$) from $60^\circ$ to $175^\circ$ loaded with metallo-dielectric structures. This is repeated for different substrate thickness for both TE and TM polarizations.

The backscattered power at different frequencies for corner angle $\alpha = 60^\circ$ is plotted in figure 4.57 (a) for different dielectric thickness. As can be observed, compared to a plain corner reflector a reduction in backscattered power of $-31.6$ dB is achieved at $f = 9.9$ GHz for an
dielectric thickness of $h = 2$ mm. It is also observed that there is an increase in backscattering (3.96 dB) at $f = 8.5$ GHz compared to a plane corner reflector. The measurements are repeated for different acute angles of the corner reflector and the results for TE polarization are shown in figures 4.57 (a)-(f).

**Figure 4.57** Variation of backscattered power against frequency for acute angles of the dihedral corner reflector for TE polarization
(a) $\alpha = 60^\circ$ (b) $\alpha = 65^\circ$ ................. contd
Chapter 4

Relative backscattered power (dB)

Frequency (GHz)

- h = 2 mm
- h = 3 mm
- h = 4 mm
- Plain dihedral corner

\( \alpha = 70^0 \)

(e)

Relative backscattered power (dB)

Frequency (GHz)

- 2mm
- 3mm
- 4mm
- Plain dihedral corner

\( \alpha = 75^0 \)

(d)
Experimental Results

(e) Relative backscattered power (dB)

(f) Relative backscattered power (dB)

\( \alpha = 80^0 \)

\( \alpha = 85^0 \)

Frequency (GHz)
It is observed from figure 4.57 (a) – (f) that there is an enhancement in backscattering at certain frequencies for corner angles in the range $60^0 - 85^0$.

In the case of $90^0$ plain dihedral corner reflector, a large RCS is obtained due to the multiple reflections from the two mutually orthogonal flat surfaces dominating the backscattered pattern. This is reduced when the metallo-dielectric structure is loaded over the flat surfaces.

![Graph showing backscattered power variations against frequency](image)

**Figure 4.58** backscattered power variations against frequency for a right angled dihedral corner reflector, TE polarization

The variation of backscattered power with frequency for corner angle $\alpha = 90^0$ is shown in figure 4.58 for different dielectric thickness. A maximum reduction in backscattered power of $-32.8$ dB is achieved at $f = 9.05$ GHz for substrate thickness $h = 4$ mm. It is clear that by loading
Experimental Results

metallo-dielectric structures, the back scattered power is reduced to a considerable extend for $\alpha = 90^\circ$.

![Graph](image.png)

**Figure 4.59** Backscattered power variations with angle of incidence for $f = 9.05$ GHz, TE polarization

Backscattered power measured for different angles of incidence for the dihedral corner with corner angle $90^\circ$ loaded with the metallo-dielectric structure of thickness $h = 4$ mm at $f = 9.05$ GHz is shown in figure 4.58. It is observed a maximum backscattered power of -3.43 is obtained for an angle of incidence of $40^\circ$.

The backscattered power measurements for obtuse angles ($\alpha = 95^\circ - 175^\circ$) are shown in figure 4.60 (a) – (q) for different dielectric thickness.
Figure 4.60 Variation of backscattered power against frequency for obtuse angles of the dihedral corner reflector for TE polarization
(a) $\alpha = 95^0$ (b) $\alpha = 100^0$ .................contd
Experimental Results

(c) Relative backscattered power (dB)

(d) Relative backscattered power (dB)

- $h = 2 \text{ mm}$
- $h = 3 \text{ mm}$
- $h = 4 \text{ mm}$
- Plain dihedral corner

$\alpha = 105^0$

$\alpha = 110^0$
(e) Relative backscattered power (dB)

\[ \alpha = 115^0 \]

(f) Relative backscattered power (dB)

\[ \alpha = 120^0 \]
Experimental Results

(g) Relative backscattered power (dB) vs Frequency (GHz) for different heights (h) and angles (α).

(h) Relative backscattered power (dB) vs Frequency (GHz) for different heights (h) and angles (α).

- h = 2 mm
- h = 3 mm
- h = 4 mm
- Plain dihedral corner

α = 125°

α = 130°
Experimental Results

(k)

(l)
\[ \alpha = 155^0 \]

\[ \alpha = 160^0 \]

Relative backscattered power (dB)

Frequency (GHz)

\( h = 2 \text{ mm} \)
\( h = 3 \text{ mm} \)
\( h = 4 \text{ mm} \)
Plain dihedral corner
Experimental Results

\( \alpha = 165^0 \)

\( \alpha = 170^0 \)
From the observations it is found that loading fractal based metallo-dielectric structure reduces the backscattering from a corner reflector of corner angle $90^\circ$. For other angles, an enhancement in backscattered power is observed compared to a plain corner reflector. The backscattered power is maximum for certain acute and obtuse angles. An enhancement in backscattered power of around 20 dB is obtained for corner angles $\alpha = 80^\circ$ and $105^\circ$. 
TM polarization

The measurement results for acute angles of the corner reflector for TM polarization are shown in figures 4.61 (a) - (f).

![Graph showing variation of backscattered power against frequency for acute angles of the corner reflector for TM polarization](image)

**Figure 4.61** Variation of backscattered power against frequency for acute angles of the dihedral corner reflector for TM polarization

(a) $\alpha = 60^0$  
(b) $\alpha = 65^0$  
(contd)
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(c) Graph showing relative backscattered power (dB) vs. frequency (GHz) for different heights (h = 2 mm, h = 3 mm, h = 4 mm) at an angle of incidence α = 70°. The graph includes a dotted line for a plain dihedral corner.

(d) Graph showing relative backscattered power (dB) vs. frequency (GHz) for different heights (h = 2 mm, h = 3 mm, h = 4 mm) at an angle of incidence α = 75°. The graph includes a dotted line for a plain dihedral corner.
Experimental Results

(e)

(f)
As in the case of TE polarisation, $90^\circ$ corner reflector gives backscattering reduction when loaded with metallo-dielectric structures. Results plotted in figure 62 indicates a reduction of $\sim 40$ dB at 8.03 GHz for $h = 4$ mm.

Backscattered power measured for different angles of incidence for TM is given in figure 4.63. It is observed a maximum backscattered power of $-12.27$ dB is obtained for an angle of incidence of $15^\circ$.
Experimental Results

Figure 4.63 Variation of backscattered power with angle of incidence for \( f = 8.03 \) GHz for TM polarization

The backscattered power measurements for obtuse angles \((\alpha = 95^\circ \text{ to } 175^\circ)\) are shown in figures 4.64 (a) – (q) for different dielectric thickness.

Figure 4.64 Variation of backscattered power against frequency for obtuse angles of the dihedral corner for TM polarization
(a) \( \alpha = 95^\circ \) ................................. contd
Experimental Results

(d) Relative backscattered power (dB) vs. Frequency (GHz) for different heights and dihedral corner angles.

(e) Relative backscattered power (dB) vs. Frequency (GHz) for different heights and dihedral corner angles.
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(f)

(g)
Experimental Results

(h)

(i)

Relative backscattered power (dB)

Frequency (GHz)

-30
-20
-10
0
10
20

5 6 7 8 9 10 11 12 13 14 15 16

-30
-20
-10
0
10
20

5 6 7 8 9 10 11 12 13 14 15 16

h = 2 mm
h = 3 mm
h = 4 mm
Plain dihedral corner

\( \alpha = 130^0 \)

\( \alpha = 135^0 \)
Chapter 4

(j) Relative backscattered power (dB) vs. Frequency (GHz)

(k) Relative backscattered power (dB) vs. Frequency (GHz)
Experimental Results

![Graph (l)](image)

![Graph (m)](image)
Experimental Results

(p) Relative backscattered power (dB)

Frequency (GHz)

(h = 2 mm, h = 3 mm, h = 4 mm, Plain dihedral corner)

\( \alpha = 170^0 \)

(q) Relative backscattered power (dB)

Frequency (GHz)

(h = 2 mm, h = 3 mm, h = 4 mm, Plain dihedral corner)

\( \alpha = 175^0 \)
In the case of TM polarizations also it is found that loading fractal based metallo-dielectric structure reduces the backscattering from a corner reflector of corner angle $90^\circ$. There are enhancements in backscattered power for certain acute and obtuse angles. Maximum increase in backscattered power is observed for corner angles $\alpha = 80^\circ$ and $120^\circ$. 
4.4.3 CIRCULAR CONE

The scattering characteristic of a circular metallic cone loaded with metallo-dielectric structure based on the array of Sierpinski carpet fractal geometry is described in this section. A schematic of the structure is shown in figure 4.65.

![Metallic circular cone loaded with array of Sierpinski carpet fractal geometry, radius = 11 cm, L = 22 cm.](image)

**Figure 4.65** Metallic circular cone loaded with array of Sierpinski carpet fractal geometry, radius = 11 cm, L = 22 cm.

The variation of backscattered power with frequency for different substrate thickness is shown in figure 4.66. A plain metallic plate having the same area as that of the base of the cone is used as the reference target. The measured results indicate that by loading fractal based structure over the cone the backscattered power can be reduced to a considerable extent. A maximum reduction in backscattered power of 25.5 dB with respect to metallic cone is obtained at $f = 8.1275$ GHz for a dielectric thickness $h = 1.2$ mm.
Figure 4.66 Variation of relative backscattered power with frequency for different dielectric thickness

Figure 4.67 Variation of relative backscattered power with angle of incidence, $f = 8.127$ GHz
The variation of backscattered power with angle of incidence at $f = 8.127$ GHz is shown in figure 4.67. A reduction of backscattered power of $\sim 25$ dB is obtained with respect to a metallic cone for normal incidence. Maximum backscattered power of $-10.92$ dB is obtained for an angle of incidence of $5^\circ$. Scattered power distribution for normal incidence is shown in figure 4.68. It is seen that the distribution is symmetric with respect to normal due to the symmetry in the nature of the structure.

\textbf{Figure 4.68} Backscattered power received at different scattering angles for $f = 8.127$ GHz