SIMULATION STUDIES ON RCS SIGNATURE PATTERNS OF CORNER REFLECTORS

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Abstract
By reducing signatures, stealth technology has established new paradigms for disguising one's existence from observers. However, it is often necessary to enhance the signature to detect the target in unfavorable conditions and also to identify our boat/sailboat. One such signature that allows a target to be recognized or classified even at greater distances is the radar cross section (RCS) and it is enhanced by using retro-reflectors. One of the most often utilized retro-reflectors is the corner reflector. Because of its high Radar Cross Section (RCS) and broad RCS pattern, it is useful for calibrating radar systems and creating effective structure decoys. The present paper deals with the study of RCS signature patterns of corner reflectors. This study is carried out using MATLAB Coding and MATLAB GUI, and the results from the developed program are compared with the statistical data obtained from RCS Prediction tool GALILEO EME/SHIP EDF available with NSTL.

Keywords: RCS, Corner Reflectors, 3dB Beam width

I. Introduction

As one of the most effective radar reflectors, corner reflectors increase the radar cross section (RCS) of airborne and ground-based targets. Decoys with corner reflectors are progressively replacing older approaches for RF-seeking missile systems. A decoy's purpose is to confuse an opponent's tracking abilities. They are simple to use, do not need much knowledge about possible threats, and pose no threat to other vessels. Corner Reflectors offer a great deal of room for development as a weapon against threats in the far future. The capacity to mass-produce corner reflectors with equivalent theoretical RF performance and the capability to fold them down into compact packages and deploy them swiftly on command has been crucial to the success of this endeavor.

The corner reflectors are placed on the ship's upper decks and are deployed over the ship's side as necessary. They expand to produce a big radar reflecting array composed of corner reflectors that float on the water's surface. Sailboats and buoys are very poor radar targets. Therefore, radar reflectors, i.e., corner reflectors, are used to aid in detecting these targets. These reflectors may be attached to the top of buoys or incorporated into the structure [1].

II. Prediction of RCS

The importance of RCS prediction cannot be overstated. Discrimination using RCS is used in almost all radar systems. As a result, reliable discrimination algorithms need an accurate prediction of the target RCS. The development of RCS reduction methods is also aided by measuring and locating the scattering centers (sources) for a certain target. There are two types of RCS prediction strategies: exact and approximate [3].

Even for simple geometric objects, the exact RCS prediction methods are notoriously difficult to implement. This is because they involve finding the solutions to differential or integral equations that characterize the scattered waves from an object under the correct boundary conditions. The equations of Maxwell are what rule over these sorts of boundaries. It is typically challenging to comprehend and design accurate answers using digital computers, even when they are achievable. Since exact RCS prediction is challenging, approximate methods have emerged as viable substitute [3].

Most of the approximate methods work well enough in the optical region, but they all have their advantages and disadvantages." For complicated and long-range targets like airplanes, ships, and missiles, approximate approaches are often the first and only place of call when trying to estimate RCS. The approximations may be validated and verified using experimental data whenever they become available. "Geometrical optics (GO), physical optics (PO), the geometric theory of diffraction (GTD), the physical theory of diffraction (PTD), and the method of moments (MoM) are all examples of widely used approximate techniques [2].

III. SIMULATION STUDY

There are primarily two kinds of corner reflectors: Dihedral and Trihedral. The square or rectangular plate dihedral and the circular dihedral are two common dihedrals. The three plates that make up a trihedral may be any one of three conventional shapes. They could be square, circular, or triangular. Analyzing the RCS signature patterns of all the corner reflectors will reveal which patterns provide the best result. The formulas utilized for the study provided in [4] represent the primary response of each reflector.

Modern users have grown accustomed to more sophisticated interaction with programs using windows containing menus, buttons, drop-down lists, etc. This way of interacting with a program is called a graphical user interface. MATLAB has a facility called GUIDE (Graphical User Interface Development Environment) for creating and implementing GUIs [5]. Using the RCS formulae in relation to the azimuth angle, a model is developed in the graphical user interface (GUI) of MATLAB to analyze the RCS signature pattern of various corner reflectors.

The outcomes are compared with the statistical data obtained by Galileo EME/Ship EDF RCS Prediction tool available at NSTL. The Ship EDF /Galileo EME software provides a simulation environment and concurrent design approach for EM design of naval targets for RCS application in a wide frequency range 1GHz to 40GHz. Advanced electromagnetic solvers like physical optics, the physical theory of diffraction, and the method of moments are available for accurate EM computation. Here physical optics is used. In this software, the exact geometrical details of the target to be predicted are modeled using Micro-station or AutoCAD. Then the geometrical model is subjected to electromagnetic meshing, depending on the frequency of operation. The meshed file is used for the computation of RCS. The type of analysis, the frequency of operation, the method to be used, azimuth details, etc., are some inputs the user needs to define/specify. The results are given below:

A. *Square Dihedral Corner Reflector with Dimensions* $1m \times 1m$ *at 9.4GHz*

(i) Using Developed Tool:

Fig. 1 shows the initial GUI, it shows all the uicontrols which are required to get desired requirement. This GUI is used to find the radar cross section of different types of corner reflectors at normal incidence and how the RCS varies with Azimuth angles.

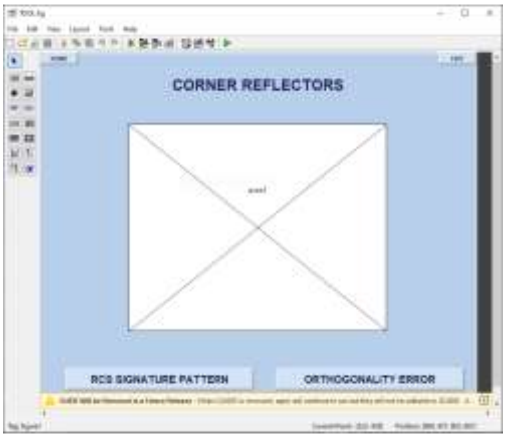


Fig. 1 Initial GUI

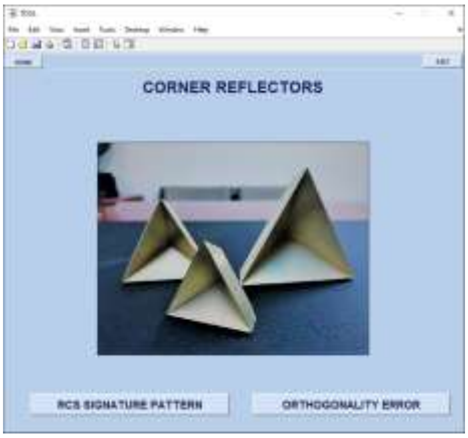


Fig. 2 GUI after execution

After the Home screen is displayed, select the RCS SIGNATURE PATTERN.

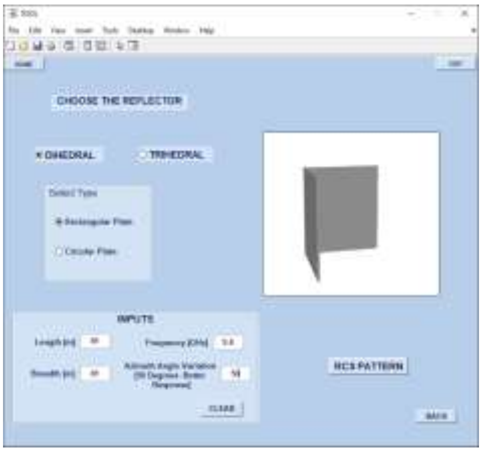


Fig. 3 GUI for Square/Rectangular Plate Dihedral

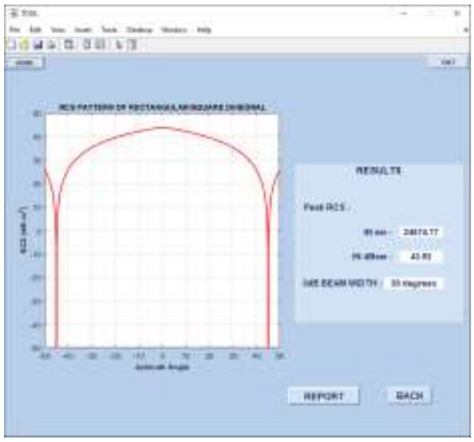
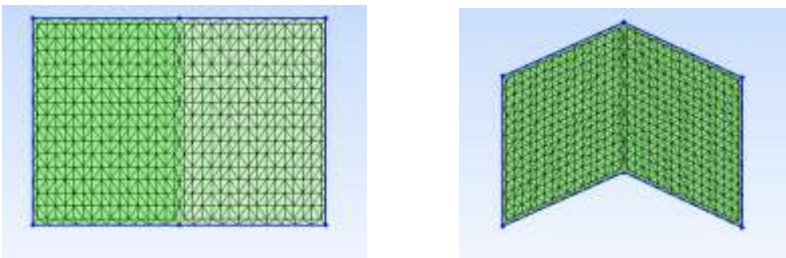


Fig. 4 GUI for RCS variation for Square dihedral (1m x 1m) at frequency of 9.4GHz

Fig. 3 displays the Square/Rectangle Dihedral Corner Reflector and Input Data UIcontol of the selected shape. After choosing the Plate type, length, breadth, frequency, and azimuth variation should be provided. Thereafter, click on RCS PATTERN. Fig. 4 depicts the Square Dihedral RCS pattern variation, results contain the peak RCS in dBsm (decibel relative to one square meter) and sm (square meters), 3dB beam width, and Cartesian plot for RCS pattern.

(ii) Using RCS Prediction software:

A Dihedral reflector of both length and breadth 1m (a=b=1m) is considered and its RCS analysis is conducted in GalileoEME after meshing it the wire length of 0.1m at the frequency of 9.4 GHz.



(a) (b)

Fig. 5 Dihedral of a=b=1m with mesh (a) Right view (b) 3d view

Fig. 6 Polar plot of the RCS of a Dihedral at 9.4 GHz, HH, Reflection order = 2, Azimuth Angle – -50^0 to 50^0

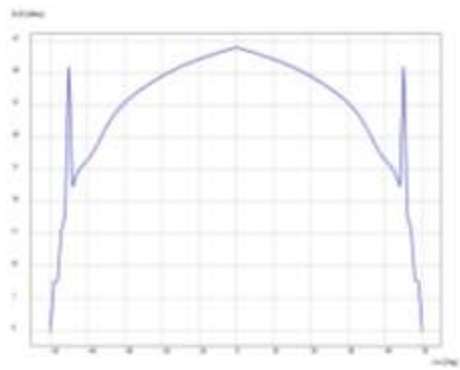


Fig. 7 Cartesian plot of the RCS of a Dihedral at 9.4 GHz, HH, Reflection order = 2, Azimuth Angle – -50^0 to 50^0

(iii) Comparison of Statistical Data between NSTL'S Software and developed Program:

TABLE 1
RCS Statistic Data of a Square Dihedral

Measurement	RCS Prediction Software	From Developed Program
	(dBsm)	(dBsm)
Maximum RCS	43.955	43.9591
Mean RCS	41.102	40.4755

Comparison between RCS prediction software and developed MATLAB program reveals, there is a good compromise between these two results for Square Dihedral. Mean RCS is calculated for Azimuth angle -30° to 30°.

B. Circular Dihedral Corner Reflector with Diameter 1m at 9.4GHz

(i) Using Developed Tool:

Fig. 8 displays the Circular Dihedral Corner Reflector and Input Data UIcontol of the selected shape. After choosing the Plate type, length, breadth, frequency, and azimuth variation should be provided. Thereafter, click on RCS PATTERN.

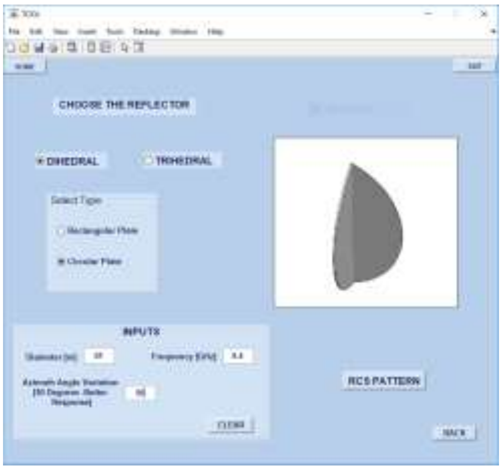


Fig. 8 GUI for Circular Plate Dihedral

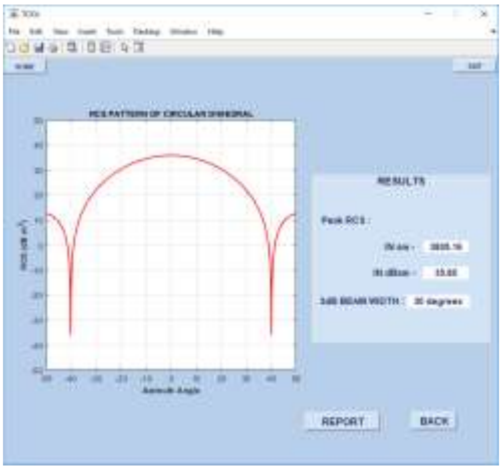
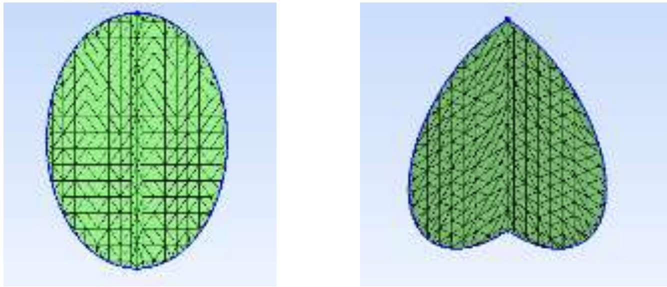


Fig. 9 GUI for RCS variation for Circular Dihedral (1m) at frequency of 9.4GHz

Fig. 9 depicts the Circular Dihedral RCS pattern variation, results contain the peak RCS in dBsm and sm, 3dB beam width, and Cartesian plot for RCS pattern.

(ii) Using RCS Prediction software:

A Circular Dihedral reflector of diameter 1m is considered and its RCS analysis is conducted in GalileoEME after meshing it the wire length of 0.1m at the frequency of 9.4 GHz.



(a) (b)

Fig. 10 Circular Dihedral of diameter 1m with mesh (a) Right view (b) 3d view

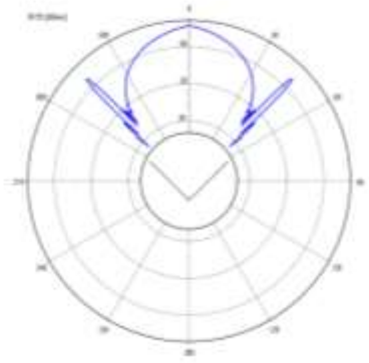


Fig. 11 Polar plot of the RCS of a Circular Dihedral at 9.4 GHz, HH, Reflection order = 2, Azimuth Angle – -50^0 to 50^0

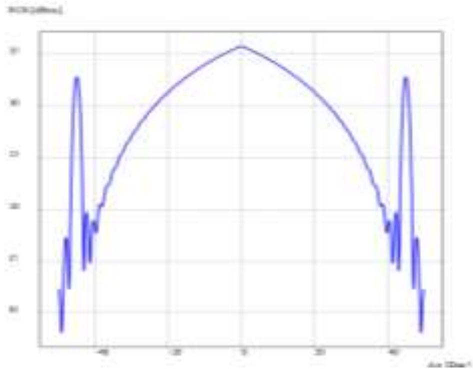


Fig. 12 Cartesian plot of the RCS of a Circular Dihedral at 9.4 GHz, HH, Reflection order = 2, Azimuth Angle – -50^0 to 50^0

(iii) Comparison of Statistical Data between NSTL'S Software and developed Program:

TABLE 2
RCS Statistic Data of a Circular Dihedral

Measurement	**RCS Prediction Software**	**From Developed Program**
	(dBsm)	**(dBsm)**
Maximum RCS	35.803	35.8037
Mean RCS	32.974	31.93

Comparison between RCS prediction software and developed MATLAB program reveals, there is a good compromise between these two results for Circular Dihedral Corner Reflector.

C. Square Trihedral Corner Reflector with Side length 1m at 9.4GHz

(i) Using Developed Tool:

Clicking Home will bring up the home screen, as seen in Fig. 2, choose the RCS pattern once more or just click BACK to return to the previous screen. Then choose trihedral and select Square Plate. The displayed images are simple images created with AUTOCAD. Fig. 13 displays the Square Trihedral Corner Reflector and Input Data UIcontol of the selected shape. After choosing the Plate type, length, breadth, frequency, and azimuth variation should be provided. Thereafter, click on RCS PATTERN.

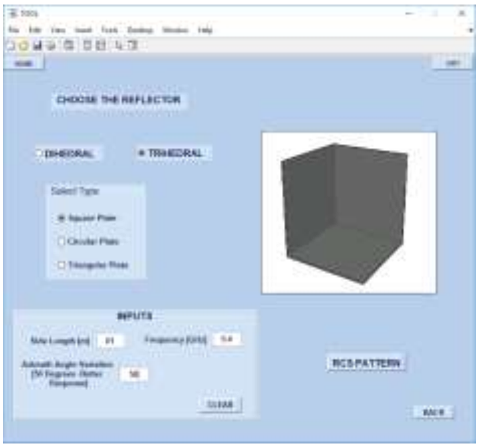


Fig. 13 GUI for Square Plate Trihedral

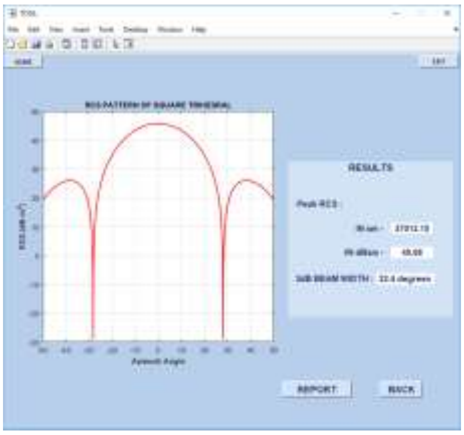
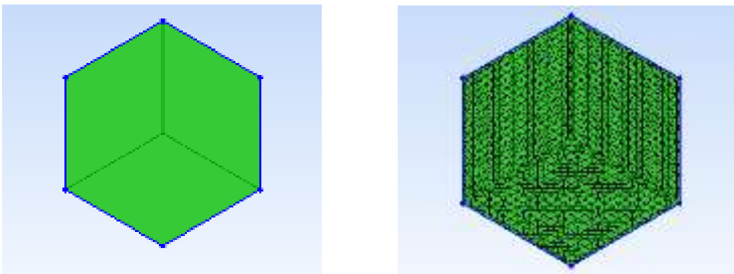


Fig. 14 GUI for RCS variation for Square Trihedral (1m) at frequency of 9.4GHz

Fig. 14 depicts the Square Trihedral RCS pattern variation, results contain the peak RCS in dBsm and sm, 3dB beam width, and Cartesian plot for RCS pattern.

(ii) Using RCS Prediction software:

A Square Trihedral reflector of side length 1m is considered and its RCS analysis is conducted in GalileoEME after meshing it the wire length of 0.1m at the frequency of 9.4 GHz.



(a) (b)

Fig. 15 Square Trihedral of side length1m Right view (a) without mesh (b) with mesh

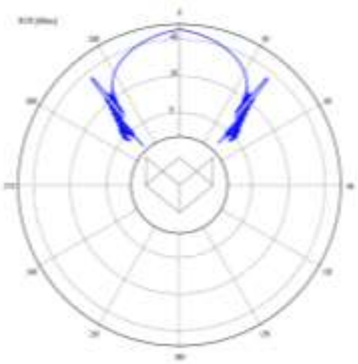


Fig. 16 Polar plot of the RCS of a Square Trihedral at 9.4 GHz, HH, Reflection order =3, Azimuth Angle – -50^0 to 50^0

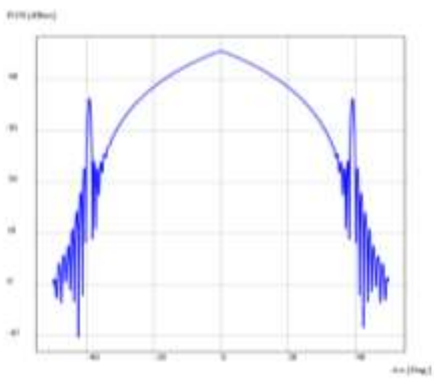


Fig. 17 Cartesian plot of the RCS of a Square Trihedral at 9.4 GHz, HH, Reflection order = 3, Azimuth Angle – -50^0 to 50^0

(iii) Comparison of Statistical Data between NSTL'S Software and developed Program:

TABLE 3
RCS Statistic Data of a Square Trihedral

Measurement	RCS Prediction Software (dBsm)	From Developed Program (dBsm)
Maximum RCS	45.653	45.6834
Mean RCS	41.645	40.3687

Comparison between RCS prediction software and developed MATLAB program reveals, there is a good compromise between these two results for Square Trihedral.

D. Triangular Trihedral Corner Reflector with Side length 1m at 9.4GHz

(i) Using Developed Tool:

Clicking BACK returns to the previous screen. Then choose trihedral and select Triangular Plate. Fig. 18 displays the Triangular Trihedral Corner Reflector and Input Data UIcontol of the selected shape. After choosing the Plate type, length, breadth, frequency, and azimuth variation should be provided. Thereafter, click on RCS PATTERN.

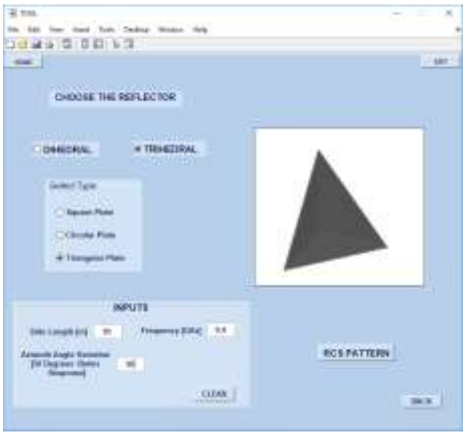


Fig. 18 GUI for Triangular Plate Trihedral

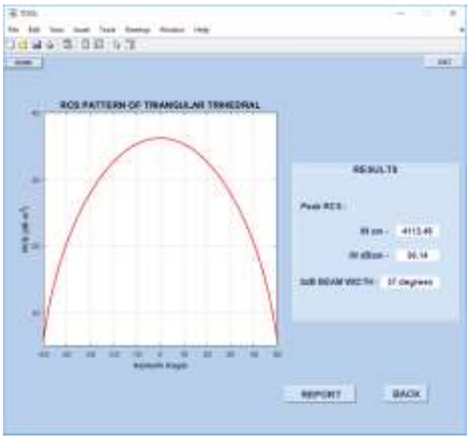
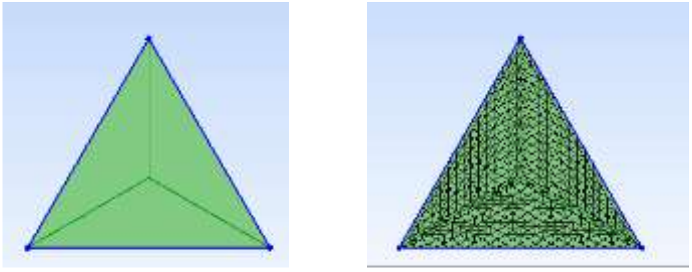


Fig. 19 GUI for RCS variation for Triangular Plate Trihedral (1m) at frequency of 9.4GHz

Fig. 19 depicts the Square Trihedral RCS pattern variation, results contain the peak RCS in dBsm and sm, 3dB beam width, and Cartesian plot for RCS pattern.

(ii) Using RCS Prediction software:

A Triangular Trihedral reflector of side length 1m is considered and its RCS analysis is conducted in GalileoEME after meshing it the wire length of 0.1m at the frequency of 9.4 GHz.



(a) (b)

Fig. 20 Triangular Trihedral of side length1m Right view (a) without mesh (b) with mesh

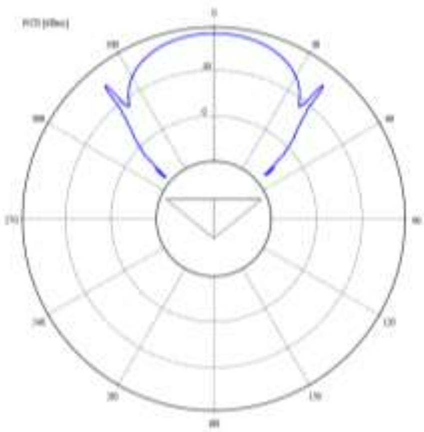


Fig. 21 Polar plot of the RCS of a Triangular Trihedral at 9.4 GHz, HH, Reflection order =3, Azimuth Angle – -50^0 to 50^0

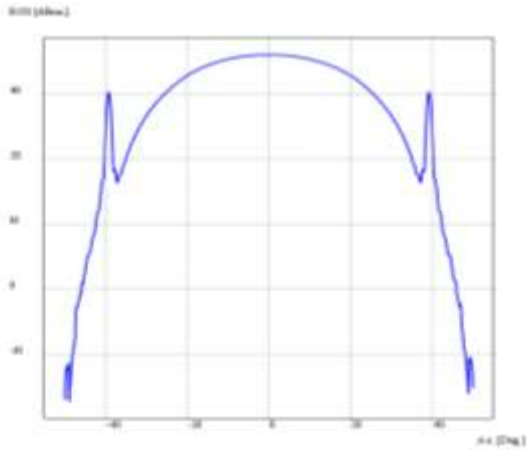


Fig. 22 Cartesian plot of the RCS of a Triangular Trihedral at 9.4 GHz, HH, Reflection order=3, Azimuth Angle – -50^0 to 50^0

(iii) Comparison of Statistical Data between NSTL'S Software and developed Program:

TABLE 4
RCS Statistic Data of a Triangular Trihedral

Measurement	RCS Prediction Software	From Developed Program
	(dBsm)	**(dBsm)**
Maximum RCS	36.146	36.141
Mean RCS	34.152	33.4426

Comparison between RCS prediction software and developed MATLAB program reveals, there is a good compromise between these two results. The difference in RCS values is mainly because the RCS prediction software at NSTL optimizes the number of reflections and considers edge and tip diffractions. Similarly, we can obtain statistical results for each corner reflector with various frequencies. We can notice the effective RCS generally decreases as the aspect varies away from the reference axis.

TABLE 5
RCS Statistic Data of Corner Reflectors

Reflector Type	Frequency	RCS Prediction Software RCS_{max} (dBsm)	From Developed Program RCS_{max} (dBsm)
Circular Dihedral (diameter=1m)	3.3GHz	26.678	26.7115
	5.5GHz	31.131	31.1484
	10GHz	36.341	36.3412
Square Dihedral (1m×1m)	3.3GHz	34.802	34.9531
	5.5GHz	39.255	39.2843
	10GHz	44.492	44.4777
Square Trihedral (side length=1m)	3.3GHz	36.562	36.5912
	5.5GHz	40.998	41.0281
	10GHz	46.191	46.2209
Triangular Trihedral (side length=1m)	3.3GHz	27.351	27.0487
	5.5GHz	31.507	31.4857
	10GHz	36.677	36.6785

For constant dimensions, as frequency increases we can notice RCS is increasing. From these results, we can conclude the trihedral with a square plate has the largest RCS and smallest response width, whereas the triangular trihedral has the smallest RCS and widest response width.

IV. CONCLUSION

The RCS signature patterns are simulated to represent the required Corner Reflector geometries under varying frequency and azimuth parameters. A GUI was designed in MATLAB for this analysis and successfully validated through simulation data. The final results obtained are found to be matching for the GUI and RCS Prediction software Galileo EME/Ship EDF. Therefore this GUI model can be used to evaluate the performance of radars for corner reflectors.

REFERENCES

[1] Nima. *The American Practical Navigator: Bowditch*. 2002nd ed., Paradise Cay Publications, 2010.
[2] Mahafza, Bassem, and Atef Elsherbeni. *MATLAB Simulations for Radar Systems Design*. 1st ed., Chapman and Hall/CRC, 2003.
[3] "Estimation of Radar Cross Sectional Area of Target Using Simulation Algorithm." *International Journal of Research Studies in Electrical and Electronics Engineering*, vol. 4, no. 2, 2018, https://doi.org/10.20431/2454-9436.0402003.
[4] SaratPulapa, Rama, et al. "Corner Reflectors Pattern Study With and Without Orthogonality Errors." *2015 13th International Conference on Electromagnetic Interference and Compatibility (INCEMIC)*, IEEE, July 2015, https://doi.org/10.1109/incemic.2015.8055879.
[5] Hahn, Brian, and Dan Valentine. *Essential MATLAB for Engineers and Scientists Fourth Edition*. Amsterdam, Netherlands, Amsterdam UP, 2009.