SCATTERING BY A SIMPLIFIED SHIP DECKHOUSE MODEL

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ABSTRACT

To gain a greater insight into the design of surface ships with reduced radar cross-section characteristics, a structure resembling a ship deckhouse was physically modeled and measured. The structure was represented as a truncated pyramid. Six scaled pyramids were fabricated, all identical except for the radii of the four vertical (slanted) edges. The pyramids were measured at the University of Massachusetts, Lowell Research Foundation, submillimeter laser compact range. Measurements were made at scaled X-band using a laser-based system that operates at 585 GHz with the pyramids scaled at a ratio of 1:58.5. These shapes were measured at 0.75 degrees depression angles on a smooth metal ground plane at both HH and VV polarizations. The goal of this study was to determine if small changes in the radius of the curvature of the slanted edges could significantly affect the radar cross-section of the pyramid. In this paper the results of measurements of the pyramids will be presented. The data are compared with computer code predictions and the differences are discussed.

1. INTRODUCTION

The design of surface ships with reduced radar cross-section (RCS) is facilitated by an assessment of the separate contributions to the RCS by the individual ship sub-structures (masts, deckhouse, etc.). Even though typical structures on a ship deck are usually comprised of complex geometrical configurations, the essential physics of scattering can be captured by identifying and modeling only the dominant contributions to RCS as simplified geometrical surfaces (plates with rounded or sharp edges, cylinders, dihedrals, etc.). For example, to the first approximation a ship deckhouse can be modeled as a truncated pyramid on a conducting plane (Fig. 1).

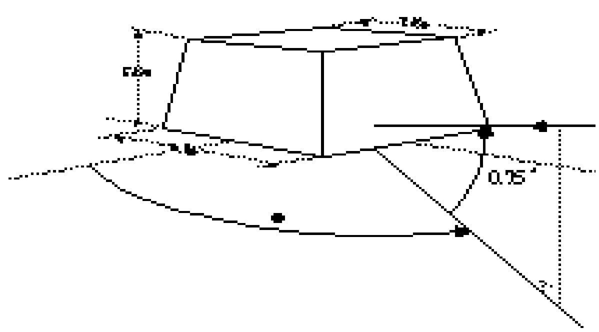

FIGURE 1. THE PYRAMID MODEL

Assuming the direction of the incident field nearly horizontal (~1° depression angle), the peak of the large RCS contributed by the flat pyramid sides can be substantially reduced by slanting the sides with respect to the vertical. Unfortunately, the slants cannot preclude enhancement of the RCS at all azimuth angles. Indeed, the results of our investigation showed that at azimuth angles of 45°, 135°, 225°, and 315° (Fig. 3) a unique triple peak structure appears. It will also be shown that only a very slight rounding of the edge is necessary to eliminate this scatter.

The RTS computer code was chosen for the initial investigation into the pyramid shape. A physical measurement was desired to backup the computer predictions and the submillimeter compact range was chosen as the lowest cost, physical measurement alternative due to the size of the full-scale pyramid and the ground-plane requirement.

This paper describes an experimental effort using scale-model measurements and computer predictions to investigate the effects of edge radii. The results from both techniques are presented and comparisons are discussed.

2. THE PYRAMID MODEL

The full-scale dimensions of the pyramidal structure modeling the deckhouse are shown in Fig. 1. The pyramid sides are tilted at 10° with respect to vertical. The nominal scaled frequency is 10 GHz and the direction of incidence is fixed at a depression angle of .75°, but variable in azimuth. In the numerical simulations and scale model measurements both the ground plane and the pyramid are modeled as metallic surfaces, which can be assumed as perfect conductors.

Five pyramid scale models with a scaling ratio of 1:58.5 were constructed with edge radii of 0.049, 0.846, 1.66, 3.37 and 5.1 wavelengths. The pyramids were fabricated from solid aluminum stock using CNC milling. Dimensional tolerances were specified to ± 0.001¯ (<λ/20). Each pyramid weighed about 13 lb. The back-scattering cross-section was measured at the scaled frequency of 585 GHz at the University of Massachusetts, Lowell Research Foundation submillimeter compact range, described in the following section.

3. SUBMILLIMETER COMPACT RANGE

The essential components of the compact range are represented schematically in Fig. 2. This system is described in detail in [1]. The heart of the compact range is a 585 GHz transceiver. The transceiver is based on a pair of continuous-wave (CW), optically-pumped, molecular gas lasers, one used as the transmit source, and the other, offset by 500 KHz, serves as the receiver local oscillator (LO). The transmit power available for this measurement was about 5mW.

The receiver consists of a pair of liquid-helium cooled InSb detectors used as the low-noise input mixers. The two mixers are utilized in a coherent heterodyne receiver system which is capable of providing vector measurements. Quasi-optical techniques are used to transport the radiation in the receiver.

A 45" diameter, 250" focal length, diamond turned aluminum mirror is used as the main antenna mirror. For this measurement, the system was configured to produce an 8" full-width, half-max (FWHM) measurement beam at the target. This was sufficient to uniformly illuminate the prism and its image in the ground plane. In a CW system, background and stray signals from sources such as target interactions with the anechoic chamber are indistinguishable from the desired target return. To provide a means to reject these unwanted signals, target modulation was implemented. By precisely moving the target along the optic axis of the measurement system, a doppler shift is imposed on the signals scattered from the target. The frequency of this shift is proportional to the modulation velocity and can be used to isolate the target signal from the stationary background, as well as most of the target-chamber interactions, which will have a different doppler shift.

4. THE RTS COMPUTER CODE

At the frequency of interest scattering by the pyramidal structures can be treated quite accurately by a combination of the Geometrical Theory of Diffraction (GTD) and Physical Optics(PO). Several computer codes exist that incorporate these techniques. The simulation discussed in Section 5 are based on the RTS code developed by the Naval Research Laboratory. Two computer models were developed. Both codes treat the pyramid as a group of connected large flat plates. The differences were in how the edges were modeled.

The first computer model incorporated the rounded edges by butting partial verticle cylinders to the flat plates to create the desired shape. Due to current limitations in the code, this method proved inadequate. The second approach generated the curved edges with a large number of small rectangular flat plates, each small compared to the wavelength. This model showed better agreement with the experimental data. Interestingly, a similar result was noted when these two techniques were used with the TRAK [2] code.

The value of cross-checking measurements and predictions was realized with this task. The error in using a cylinder to represent the edge for the current versions of these codes would probably have gone unnoticed if the predictions had not been compared with the scale-model technique.

5. COMPARISON OF THE RTS AND MEASUREMENT RESULTS

The RCS measurement and simulation results are plotted in Figures. 3 - 10 for four pyramid models, designated in the figures as models #1 - #4. The correspondence between the model designation and the edge radius employed is as follows:

Model #	1	2	3	4
Edge Radius (wavelengths)	.049	.846	1.66	3.37

The edge radius in model #1 was chosen sufficiently small, so as to approximate an ideal wedge. Indeed, in the corresponding RTS calculations for model #1 a zero edge radius is assumed.

The raw measured data taken at intervals of 0.02° in azimuth were medianized over a 2.0° window. The RTS data were sampled at 1.0° intervals and likewise medianized over a 2.0° window. Because only the medianized data is presented, it should be noted that some differences in the data are due to different widths of peaks which resulted in different median levels even though the peak values themselves were identical. The reason for the differences in the widths is currently unexplained.

The RCS results for vertically polarized incident and vertically polarized received waves are plotted in Figs. 3 - 6. Starting with Fig. 3, we note the peaks corresponding to scattering by the inclined flat pyramid sides at 0°, 90°, and 180°; agreement between medianized measured and RTS results are reasonably close.

At 45° and 135°, the triple peak mentioned in the Introduction is noted. It has been deduced that the left and right peaks of this triplet occur when the left and right edges rotate into a plane perpendicular to the measurement beam and the edge diffraction is observed. Due to the shallow depression angle, and assuming a clock-wise rotation, the left edge is normal and therefore visible slightly before 45° and the right edge is visible slightly after 45°. It should also be noted that because of the ground-plane, the image of the right edge is also visible before 45° coincident with the real left return and the reverse is true.

The central peak of this triplet, which occurs at exactly at 45°, is due to an edge-dihedral formed between the left and right edges with the ground-plane. As expected, since the magnitude of the edge diffraction is a function of its radii, these peaks diminish as the curvature is increased. Here again, measurement data and calculations exhibit good agreement. A discrepancy between calculation and measurement is noticed in regions between the peaks. The measurement data is higher than predicted by RTS due partly to target/chamber interactions, partly due to the scattering from the small gap between the ground-plane and the pyramid and partly due to the effects of higher order diffraction which is not accounted for in the RTS code. We expect to examine these issues in more detail in the future.

Figs. 4 - 6 show the RCS as the edge radius is progressively increased to 3.37 wavelengths (model #4, Fig. 6). We note that the general trend shows a progressive reduction in the effective edge scattering (45°, 135°) as the edge radius is increased. Qualitatively this result is, of course, not surprising, since at high frequencies a curved boundary affords a weaker scattering center than a sharp edge. The surprising part is that the RTS code tends to overestimate the scattering relative to the measured data. (The exception appears to be Fig. 6) . It should be noted that when these predictions were first run using the plate/cylinder model, the opposite effect was predicted. The magnitude of the triple peak actually increased significantly. When this large discrepancy between the code and measurements was first noted, both techniques were examined closely. The target modulation technique was added to the UML system to improve the ability to reject stray scattering. The data improved, but the basic results remained unchanged. When the possible invalidity of using the cylinder to model the edge was noted by the authors of the RTS code, the pyramid was remodeled using the multi-plate model. The agreement between the two systems was then very good.

Figs. 7 - 10 show RCS plots for horizontal incident and horizontal received polarizations. Starting with Fig. 7 we note that the measured RCS reaches a plateau at about -15 dBsm, whereas the RTS results drop to nearly -30 dBsm. Note, however, that the agreement at the dihedral scattering angles (45°. , 135°) between RTS and the measured data is quite good. Clearly, the explanation that the discrepancy between measured and simulated results are due to scattering from the pyramid/ground-plane gap appears more plausible here than in case of vertical polarization (Fig. 4). As the edge radius is increased (Figs. 8 - 10), the measured data continue to be dominated by this scattering, whereas the RTS results, as expected, show a progressive reduction of the RCS at the edge scattering angles.

6. CONCLUSIONS

RTS calculations and scale-model measurements support the conclusion that sharp corners on the pyramid/ground-plane configuration result in increased RCS at the 45° sectors for both horizontal and vertical polarizations . These edge scattering effects can be essentially eliminated by using edge radii of a fraction to a few wavelengths. However, increasing the radii beyond this will result in increased baseline scattering in areas between peaks, which may not be acceptable.

The submillimeter laser compact range has been demonstrated to be a convenient test-bed for studying the RCS of simplified ship structures. For the deckhouse model examined in this paper, the results for the RCS for vertical polarization are in good agreement with RTS code predictions. The principal discrepancies are in the low RCS regime, where the the current groundplane technique may be limiting the minimum measurable RCS. Scattering from the gap between the pyramid and the ground-plane is suspected. Future data analyses will attempt to identify and isolate the sources of these discrepancies.

This exercise also demonstrates the value in using different techniques to cross-check results. Computer codes are constantly improving and becoming an important tool for low RCS design. Compact range technology is also under constant improvement and has an important place in radar development. Continual verification of each method for accuracy through cross-checks from alternative techniques has been shown to be important and should be included as a standard testing phase.

8. REFERENCES

[1] Coulombe, M. J. et al, "A 585 GHz Compact Range for Scale Model Measurements", Proc. of the Antenna and Measurement Techniques Association, October 1993.

[2] J.L.Davis et al. " TRACK 4.1 User's Manual" , Georgia Tech Research Institute, July 1990.

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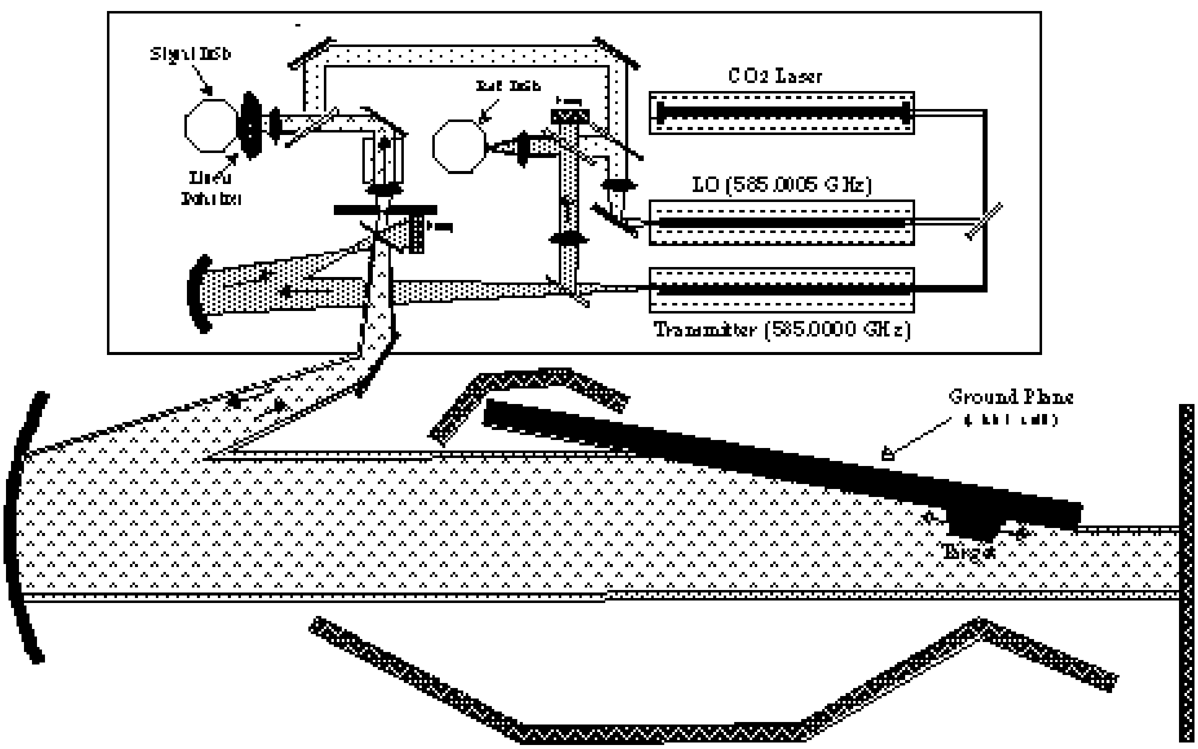

Figure 2. Sumillimeter Compact Range

FIGURE 3 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 1 VERTICAL POLARIZATION

FIGURE 4 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 2 VERTICAL POLARIZATION

FIGURE 5 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 3 VERTICAL POLARIZATION

FIGURE6 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 4 VERTICAL POLARIZATION

FIGURE 7 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 1 HORIZONTAL POLARIZATION

FIGURE 8 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 2 HORIZONTAL POLARIZATION

FIGURE 9 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 3 HORIZONTAL POLARIZATION

FIGURE 10 COMPARISON OF MEASURED AND COMPUTED(RTS) RCS PYRAMID 4 HORIZONTAL POLARIZATION