VERIFICATION METHOD FOR THE SERRATION DESIGN OF CATR REFLECTORS

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ABSTRACT

Serrations are used on Compact Antenna Test Range reflectors to reduce the effects of edge diffraction. It has been found that the traditional triangular shape for these serrations is not optimal and that more continuous shapes should perform better. To verify this, RCS measurements were performed on test targets consisting of strip reflectors terminated by end sections of various shapes. The RCS vs. angle data were corrected for the field irregularities caused by the measurement range and then converted to the induced current distributions on the targets, from which the fields in front of the targets were calculated using Physical Optics. These fields are equivalent to the test-zone fields of an actual Compact Range. The results are compared with theoretical data. The agreement is very good.

Keywords: Compact Antenna Test Range design, edge treatments, serration shape.

1. INTRODUCTION

Compact Antenna Test Ranges (CATRs) operate on the principle of Geometrical Optics: one or two reflectors are used to collimate a spherical wavefront into a planar wavefront. Since the reflector(s) cannot be infinitely large, the wavefront is only approximately planar. The uniformity of the test-zone fields depends on the diameter of the reflector(s) and on the separation between the reflector and the test zone. Furthermore, diffraction occurs at the edges of the reflector(s) which has to be controlled such that the level of diffracted energy that reaches the test zone is minimized. Traditionally, serrations have been used to achieve this and they still offer the most successful solution.

Recently, it has been found [1] that the traditional triangular shape is not optimal and that more continuous shapes such as the cosine^x-shape offer a better performance. In particular, if the argument of the cosine varies between 0 and 90 degrees over the length of the serration, then the cosine$^{1.6}$-shape was found to be the best.

In order to verify this result and to try to find possible second-order effects, experiments were performed on reflectors having different serration shapes.

2. TEST PROCEDURE

The most straightforward test procedure to investigate the effects of serrations would be to manufacture reflector antennas, e.g. parabolic dishes with different edge treatments and then probe the aperture fields in front of the antennas. However, this would require expensive reflector manufacturing plus a linear scanner.

Therefore, an indirect method was employed, making use of available hard- and software. Two narrow strip reflectors were manufactured, terminated by either triangular or cosine-shaped end sections. The exponent for the cosine was 1.6. This shape will simply be referred to as "cosine" in this paper. The reflectors were used as RCS targets and the RCS was measured vs. aspect angle. By doing a Fourier transformation, the reflectivity distribution across the target is obtained. The reflectivity distribution is proportional to the one-dimensional induced-current distribution, i.e. integrated over the vertical coordinate. The fields in front of the target are then calculated using Physical Optics (PO).

3. TEST TARGETS

The two test targets are shown in Figure 1. The measurements were done at frequencies of 9 GHz and 16 GHz. This compares with an actual CATR reflector of 2.50 m width, having serrations of 30 cm length, at frequencies of 3.6 GHz and 6.4 GHz. On such a system, the test zone location would be at a distance of approx. 5 m in front of the reflector. For the test targets, this implies that the location of the "test zone" is at 2 m distance from the targets.

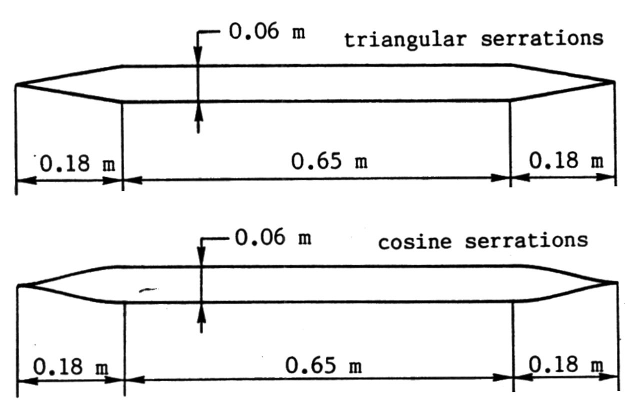

Figure 1: Test targets.

4. THEORETICAL RESULTS

Because of the small height of the test reflectors, theoretical PO analysis is possible using a one-dimensional model in which the serrations are represented by a tapered current distribution [2].

Figures 2 and 3 show the theoretical amplitude and phase distribution at 2 m distance from the test reflectors. From Figure 2 it can be concluded that at 9 GHz, the triangular serrations actually perform better than the cosine serrations. At 16 GHz (Figure 3), however, the cosine shape is better, especially in the center of the test zone.

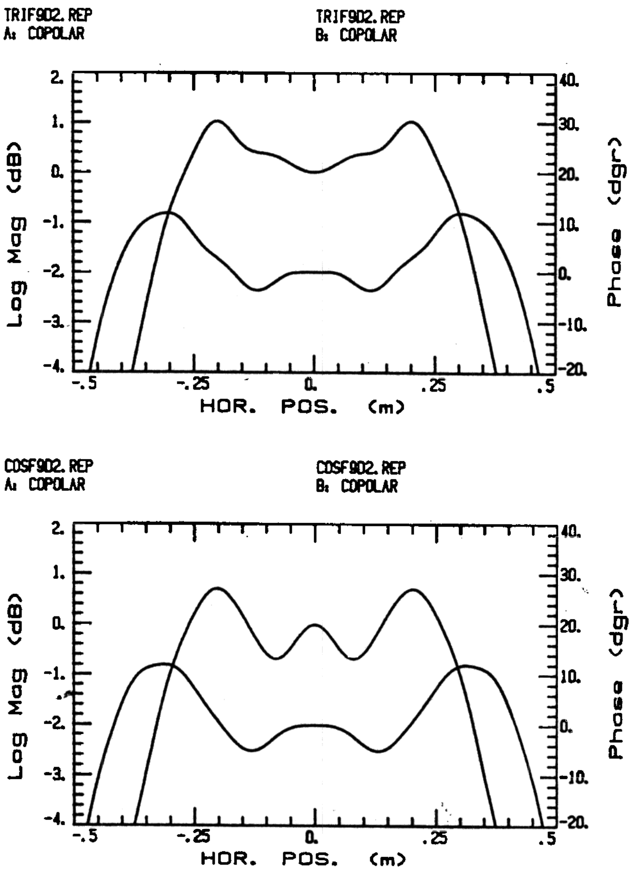

Figure 2: Predicted test-zone fields at 9 GHz. Top: triangular serrations; bottom: cosine serrations.

A good measure of the performance is provided by the spectral components: the test-zone field is decomposed into plane waves arriving in the test-zone from varying angles [3,4]. The largest plane-wave component is coming from 0 degrees: this is the desired plane wave. The other components are lower in level and represent the amplitude and phase variations in the test zone. They should obviously be as low as possible. Such a plane-wave spectrum can be calculated for any test-zone diameter. Since a Compact Range is expected to perform well for any antenna or target diameter up to the specified test-zone dimension, the spectral components are calculated for a large number of diameters and superimposed in a single plot. An example of such a plot is shown in Figure 4.

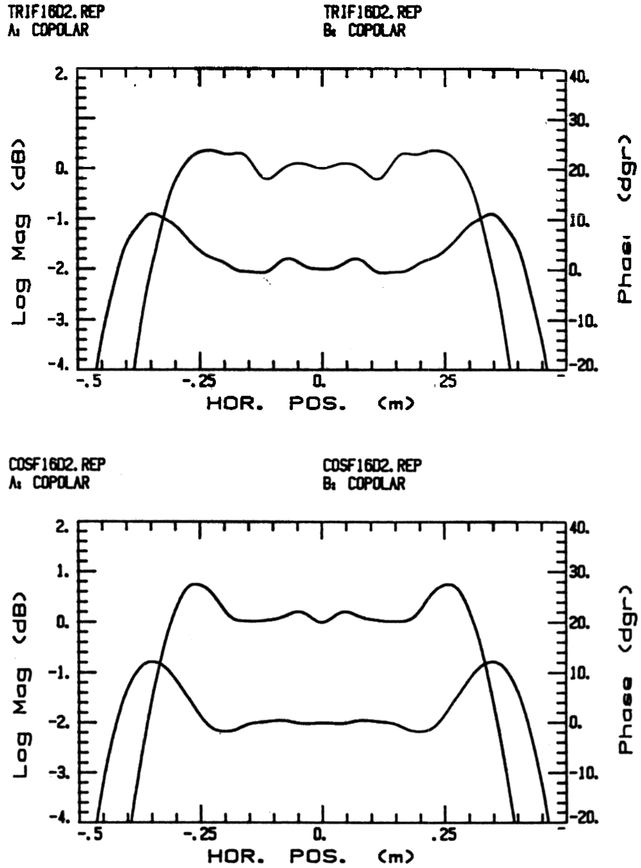

Figure 3: Predicted test-zone fields at 16 GHz. Top: triangular serrations; bottom: cosine serrations.

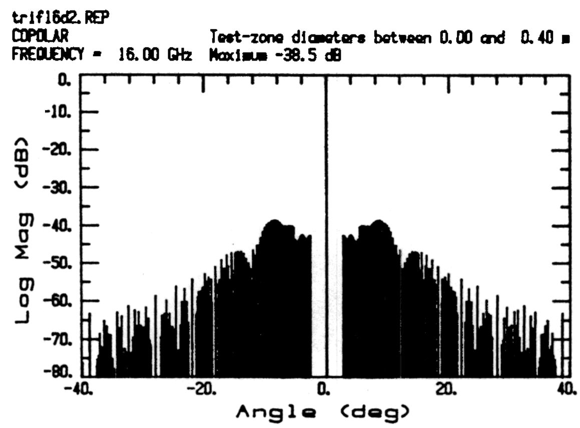

Figure 4: Example of spectral component plot.

The maximum level of any unwanted plane wave (relative to the primary plane wave), for any test zone diameter up to a maximum, is used here to compare the performance. Table 1 gives the maximum spectral component for the test-zone fields shown in Figures 2 and 3, for diameters up to 0.4 m.

Table 1: Maximum spectral components in dB.

serration shape	frequency 9 GHz	16 GHz	30 GHz
triangular	-33.0	-38.5	-46.1
cosine	-30.1	-43.9	-57.0

At 9 GHz, the triangular shape is 3.1 dB better, while at 16 GHz the cosine shape is 4.4 dB better.

It must be realized that at low frequencies a large ripple will occur across the test zone, regardless of the shape of the serrations or indeed any edge treatment whatsoever, simply because the reflector size is limited, in this case to 20 wavelengths at 9 GHz (excluding the serrations).

The reason why the triangular serrations perform better at the low frequencies is that the transition between the reflector (constant current) and the surrounding space (no current) is not as steep. A more gradual transition could also be realized by increasing the length of the serrations.

At high frequencies, both the reflector itself and the serrations are large in terms of wavelengths and the lowest ripple is obtained by making the current distribution at the reflector edge continuous in all derivatives. This would call for a cosine-squared shape.

Thus, the optimum serration shape and length are functions of the desired frequency range[6]. Further analysis has shown that the cosine$^{1.6}$-shape offers the best compromise at most frequencies. As the entry in Table 1 for 30 GHz shows, the improvement for this shape increases considerably with rising frequency.

5. ACCURACY REQUIREMENTS

As can be seen from Figures 2 and 3, the differences in expected performance between the two serration shapes are less than 0.5 dB in amplitude and 4 degrees in phase. This implies that the measurement accuracy for the current distribution on the targets must be better than this in order to be able to tell the difference between the targets.

Additionally, the surface accuracy of the reflectors must be taken into consideration. For example, the surface deviation that produces a 4 degree phase error at 16 GHz is only 0.1 mm. It was found that the test targets did indeed have a maximum surface deviation of approximately 0.1 mm.

Finally, the targets have to be mounted extremely carefully so that no coupling to the positioner occurs, since any coupling would produce ripples in the calculated test-zone fields. A styrofoam column was used for the measurements. The front surface of the reflectors was aligned with the front of the column.

6. DATA PROCESSING

The measurements were performed on a model 3025 CATR. Due to the use of extremely wideband feeds (2-18 GHz), the performance at both 9 and 16 GHz was not optimal, leading to more ripple than desired at 9 GHz and some amplitude and phase taper at 16 GHz.

In order to obtain the above-mentioned test-zone field purity needed for these measurements, the RCS measurements vs. angle were corrected using a Quiet Zone correction technique employing a reference measurement of a bar [5]. The Fourier transform of the reference measurement gives the test-range field distribution which is then used to correct the test-target measurements using deconvolution techniques. The resulting accuracy in the current distribution on the test targets is better than +/- 0.1 dB in amplitude and +/- 2 degrees in phase. This includes the effects of chamber stability, target support etc.

The complete data processing scheme is shown in Figure 5. An example of a measured and a corrected RCS pattern is given in Figure 6.

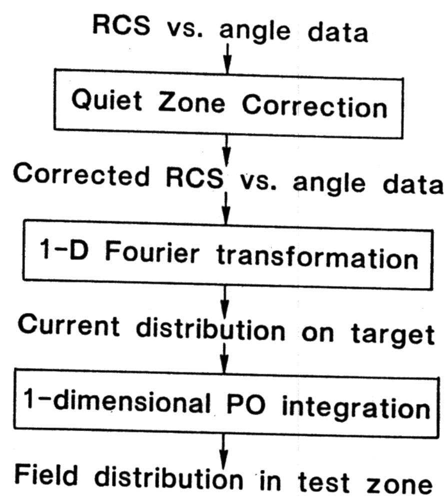

Figure 5: Data processing scheme.

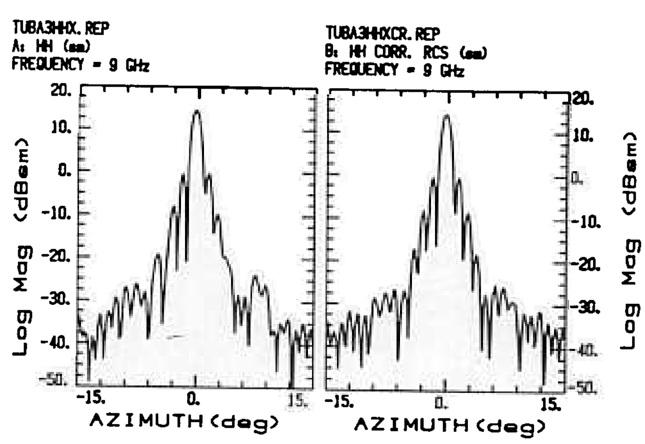

Figure 6: Example of RCS patterns. Left: measured pattern; right: corrected pattern.

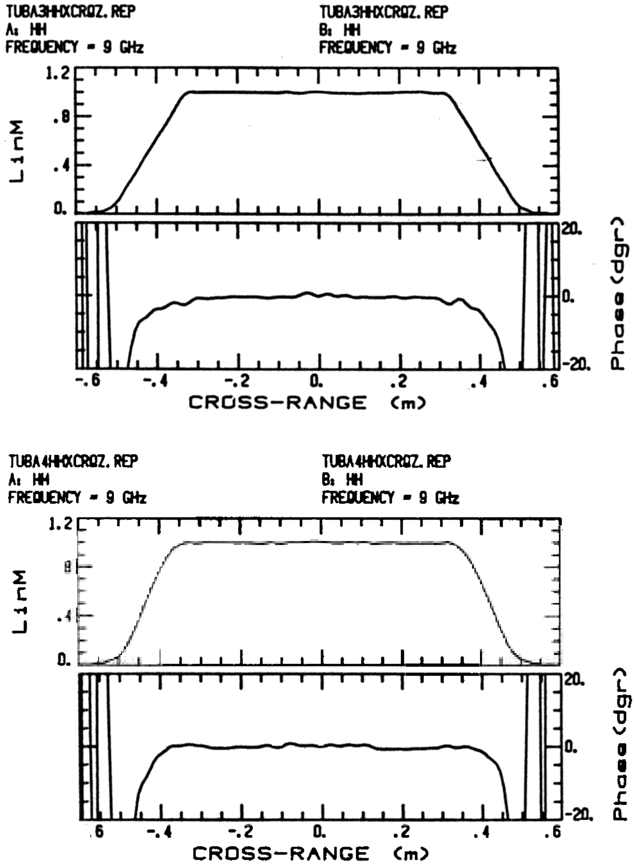

Figure 7: Current distributions on test targets, HH polarization, 9 GHz. Top: triangular serrations; bottom: cosine serrations.

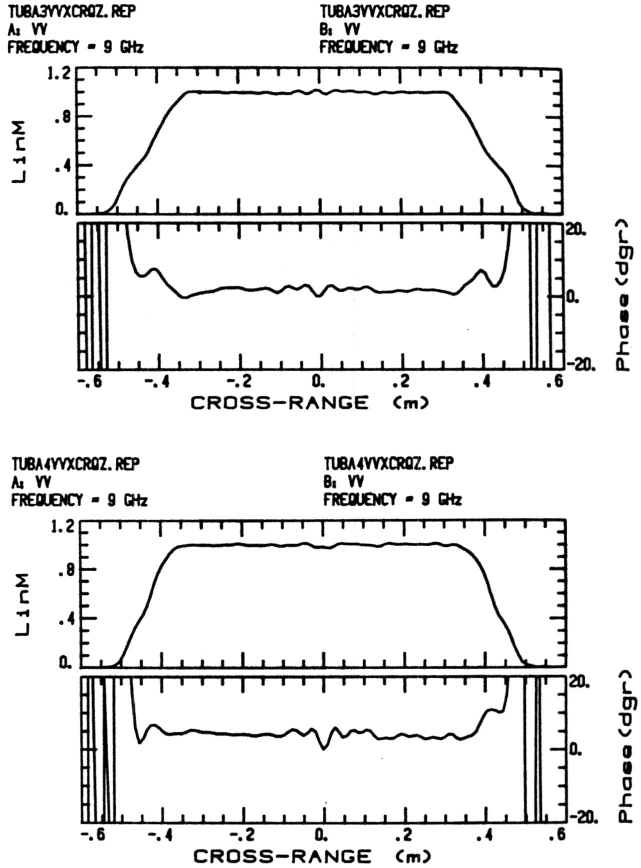

Figure 8: Current distributions on test target, VV polarization, 9 GHz. Top: triangular serrations; bottom: cosine serrations.

The current distribution on the targets are compared in Figure 7 for horizontal polarization, and in Figure 8 for vertical polarization. In these vertical-split displays the top graph is the linear magnitude and the lower graph is the phase in degrees.

At 16 GHz, the current distributions are almost the same as at 9 GHz and therefore they are not shown here. Note that, in Figure 7, the amplitude distribution for the triangular serrations has an almost perfect triangular shape and thus closely matches the theoretical result. The latter is also true for the cosine serrations. For vertical polarization (Figure 8), however, the amplitude distribution over the serrations deviates slightly from the theoretical response.

Comparing the phase responses, the phase distribution over the serrations tilts slightly downwards for horizontal polarization, while for vertical polarization the phase increases over the serrations. This phenomenon occurs for both serration shapes and for both frequencies. Since the current density is low at the ends of the target, the influence of this phase curvature on the test-zone fields is quite small.

The phase curvature in the central part of the reflectors can be attributed to curvature in the reflector surface.

In general, however, these current distributions correspond very closely to the theoretical functions. The test-zone fields in front of the target can thus also be expected to agree closely with the theoretical results.

7. TEST-ZONE FIELDS

The fields at a distance of 2 m from the test targets, obtained by PO integration over the current distribution, are shown in Figures 9 and 10.

In Figure 10a some oscillation in the amplitude and phase distribution is observed. This could be caused by the variations in the amplitude distribution across the serrations, as observed in the previous section. Otherwise, the results are in close agreement with the theory. As predicted, at 9 GHz the triangular serrations perform better, while at 16 GHz the cosine shape is superior, although not by as much as predicted.

The maximum spectral components were calculated, again for test-zone diameters up to 0.4 m; these are tabulated in Table 2.

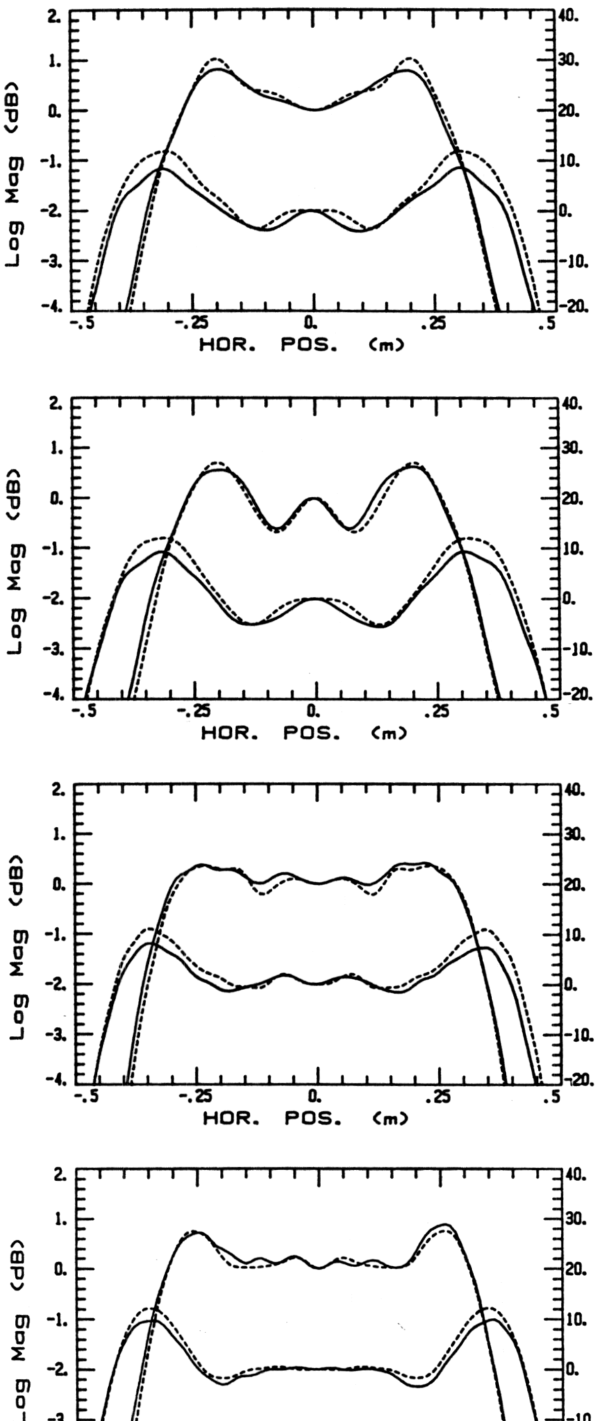

Figure 9: Test-zone fields, horizontal polarization.
From top to bottom:
a) 9 GHz, triangular serrations
b) 9 GHz, cosine serrations
c) 16 GHz, triangular serrations
d) 16 GHz, cosine serrations
Solid lines: derived from measurement;
dashed lines: theoretical

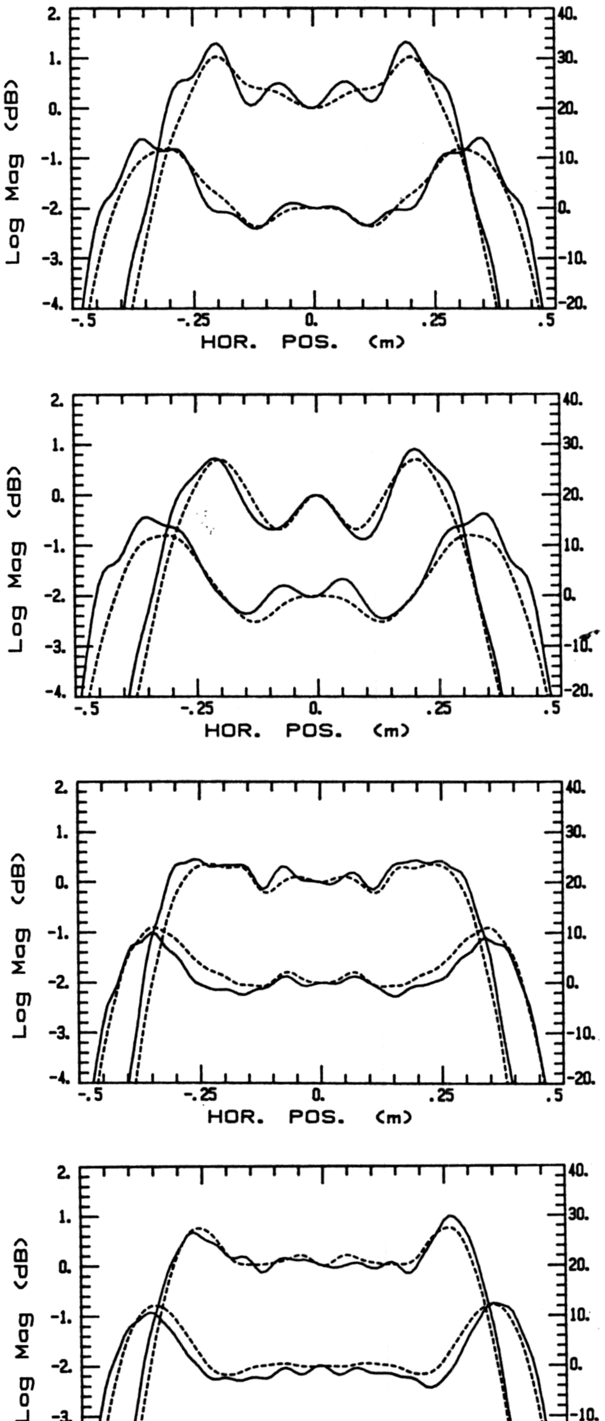

Figure 10: Test-zone fields, vertical polarization.
From top to bottom:
a) 9 GHz, triangular serrations
b) 9 GHz, cosine serrations
c) 16 GHz, triangular serrations
d) 16 GHz, cosine serrations
Solid lines: derived from measurement;
dashed lines: theoretical

Table 2: Maximum spectral components derived from measured results.

serration shape	frequency (GHz)	polarization HH	VV	theoretical value
triangular	9	-32.9	-32.9	-33.0
	16	-38.6	-37.1	-38.5
cosine	9	-30.9	-29.3	-30.1
	16	-38.5	-39.7	-43.9

At 9 GHz, the maximum spectral components are within 1 dB of the theoretical value, which can be considered to be an excellent result. At 16 GHz, the cosine serrations perform slightly better than the triangular serrations. The theoretical level of -44 dB for the cosine serrations is not obtained, however. Possible causes for this are:
1) measurement uncertainties, giving rise to a noise floor prohibiting measurements below -40 dB;
2) insufficient surface flatness of the test reflectors;
3) the phase and amplitude irregularities across the serrations for vertical polarization.

Since the spectral components for vertical polarization are not higher than those for horizontal polarization, it must be concluded that these polarization-dependent phenomena are not significant.

8. CONCLUSIONS

Compact Antenna Test Range reflectors with serrations having a cosine$^{1.6}$-shape perform better than those with triangular serrations. However, at low frequencies (near the low-frequency operating limit of the CATR), triangular serrations give better results.

The theoretical results were confirmed by RCS measurements on test targets. Accuracy enhancement techniques were employed to improve the spectral purity of the measurement system to the required level. The current distributions on the targets closely correspond to the theory. Polarization-dependent phenomena were found to be limited to a few degrees of phase error.

The "test-zone" fields in front of the test targets were calculated from the current distributions using Physical Optics. The agreement with the theoretical amplitude and phase distributions was remarkably good.

As a result of this study, March Microwave Systems now equips its Compact Antenna Test Range reflectors with cosine-shaped serrations.

9. ACKNOWLEDGEMENT

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10. REFERENCES

[1] E.B. Joy and R.E. Wilson: "Shaped edge serrations for improved Compact Range performance", Proc. 1987 AMTA meeting, pp. 55-60.

[2] H.F. Schluper: "Compact Antenna Test Range analysis using Physical Optics", Proc. 1987 AMTA meeting, pp. 309-312

[3] H.F. Schluper, V.J. Vokurka: "Troubleshooting limitations in indoor RCS measurements", Microwaves & RF, Vol. 26, No.5, May 1987, pp. 154-163.

[4] J.C. Bennett and K.S. Farhat: "Wavefront quality in antenna pattern measurements: the use of residuals", IEE Proc., Vol. 134, Pt. H, No. 1, Feb. 1987, pp. 30-34

[5] J. van Damme: "Correction technique on indoor RCS measurements", M. Sc. thesis ET-16-86, Feb. 1987, Eindhoven University of Technology.