COMPACT ANTENNA TEST RANGE ANALYSIS USING PHYSICAL OPTICS

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INTRODUCTION

March Microwave Systems B.V. is manufacturer of the dual-cylindrical reflector Compact Antenna Test Range (CATR) that was designed by Vokurka [1] (see Fig. 1). The analysis of the test-zone fields of such a design is necessary to be able to optimize the geometry.

The main modeling techniques that could be used for such an analysis are the Geometrical Theory of Diffraction (GTD), Physical Optics (PO), Physical Theory of Diffraction (PTD) and the Method of Moments (MM).

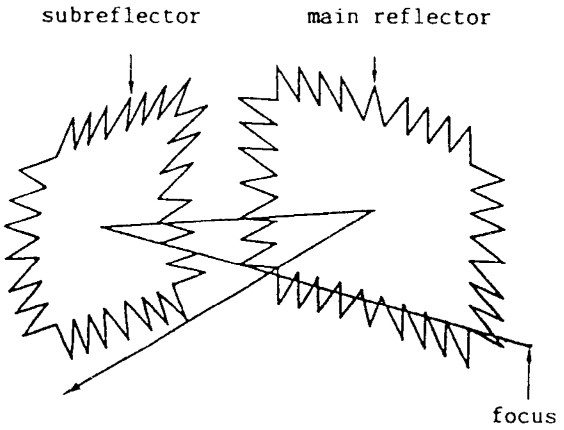

Fig. 1: Dual-reflector CATR geometry.

GTD is an extension of Geometrical Optics (GO) that ncludes the effects of the edges of the reflector. Basically, it is a ray tracing technique that gives very accurate results. For our purpose, however, it is rather cumbersome since the Compact Range to be analyzed has a total of approx. 80 serrations, giving 160 diffracting edges. The number of ray-tracing operations would be enormous.

Physical Optics is based on the integration of the currents on the surface of the reflector. PTD is an extension of PO that includes the edge currents on the surface that are induced near the boundaries of the surface.

The Method of Moments is an exact technique that ncludes all diffractions, but is numerically inefficient or large structures such as we want to analyze.

The purpose of this study was to start the analysis with Physical Optics, to examine its accuracy and to extend the analysis method to PTD in case the PO model failed.

THEORY

Complete PO analysis involves calculating first the field at the subreflector surface. This is the far field of the primary feed, which is modeled as a Huygens source. A tapered feed pattern can easily be included; also, the feed could be displaced from the focal point. The field that is reflected from the subreflector is evaluated at the main reflector using

$$\vec{H}(\vec{r}) = \nabla_r \times \int_S \left[\hat{n} \times \vec{H}(\vec{r}\,')\right] \cdot \frac{1}{4\pi} \frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}\, ds \tag{1}$$

where $\vec{r}$ is a point on the main-reflector surface,
$\vec{r}\,'$ is a point on the subreflector surface,
$H(r)$ is the feed pattern at the subreflector,
$\hat{n}$ is the unit vector normal to the surface,
S is the surface of the subreflector.

The integral is evaluated in a number of points on the main reflector. A continuous representation is then obtained using cubic spline interpolation.
The field in the test zone is calculated using

$$\vec{E}(\vec{r}) = \frac{1}{j\omega\varepsilon_0} \nabla_r \times \nabla_r \times \int_S \left(\hat{n} \times \vec{H}(\vec{r}\,')\right) \cdot \frac{1}{4\pi} \frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}\, ds \tag{2}$$

where $\vec{r}$ is a point in the test zone,
$\vec{r}\,'$ is a point on the main reflector,
$\hat{n} \times \vec{H}$ is the induced current on the main reflector,
S is the surface of the main reflector.

The integrations in (1) and (2) are over the entire reflector surface, including all the serrations. They can be written as the contribution from the solid reflector plus the sum of the contributions from each serration. Although this technique leads to a relatively short computer program, the computation time is rather long, especially at higher frequencies. For a single scan in the test zone, it varies between approx. 8 hours and several days.

ONE-DIMENSIONAL APPROXIMATION

If the test-zone field is only required along a vertical or horizontal scan, the reflector surface can be approximated in such a way that only two line integrations are required.

For vertical field computations, both reflectors are modeled as narrow strip reflectors, see Fig. 2. The reflector surface tapers off linearly towards the end to simulate the serrated edge.

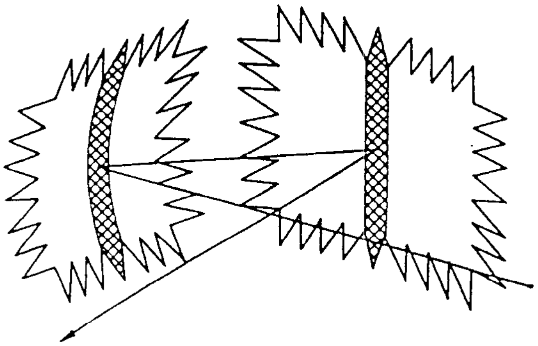

Fig. 2: Vertical strip model.

With this strip-reflector geometry, the wave in the test zone is essentially a cylindrical wave instead of a plane wave. The field intensity decreases with the distance to the reflector instead of being constant. However, the relative distribution along a vertical line in the test zone is predicted very accurately.

Figures 3, 4 and 5 show a comparison of measured and predicted amplitude in the test zone of CATR model 3025 at 5, 10 and 17 GHz, respectively. The main reflector height is 2.50 m, including serrations of 30 cm length. The agreement is very good, generally within 0.3 dB at all frequencies.

Using the one-dimensional approximation, the computation time for a single scan in the test zone is reduced to typically 5 minutes.

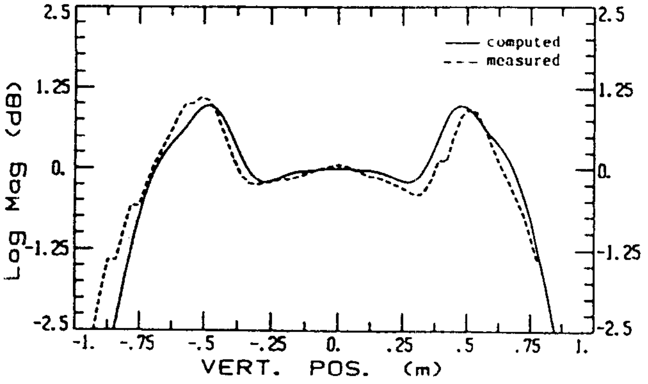

Fig. 3: Test-zone fields, vertical plane, 5.0 GHz.

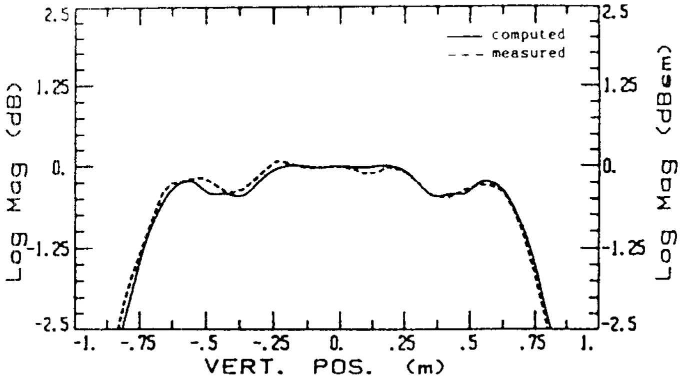

Fig. 4: Test-zone fields, vertical plane, 10.0 GHz.

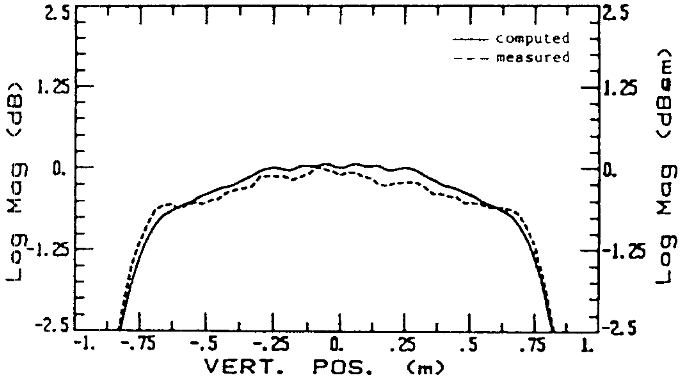

Fig. 5: Test-zone fields, vertical plane, 17.0 GHz.

For horizontal field computations, a horizontal strip model is used, see Fig. 6. However, this model has to be modified since a horizontal strip does not collimate in the vertical direction as the subreflector is required to do. Consequently, the wave reflected from the subreflector is spherical instead of cylindrical. This problem is solved by using reflectors of infinite height. The surface integration in the vertical direction can be solved analytically using the method of stationary phase. This gives the required term to transform the above-mentioned spherical wave into the required cylindrical wave.

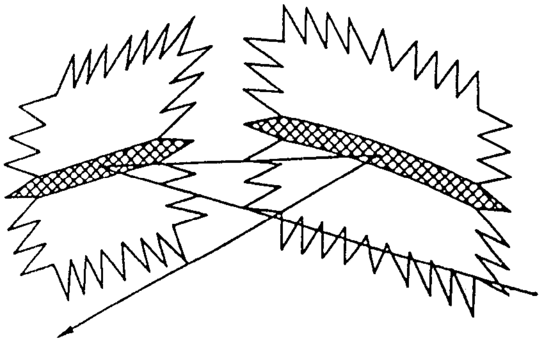

Fig. 6: Horizontal strip model.

A comparison between measured and predicted amplitude in the test zone, again for frequencies of 5, 10 and 17 GHz is shown in Figs. 7, 8 and 9.

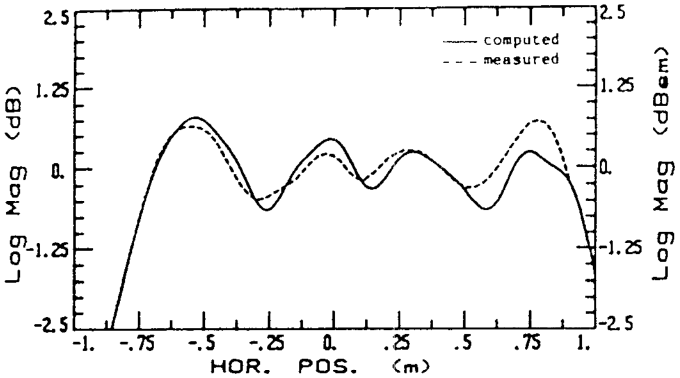

Fig. 7: Test-zone fields, horizontal plane, 5.0 GHz.

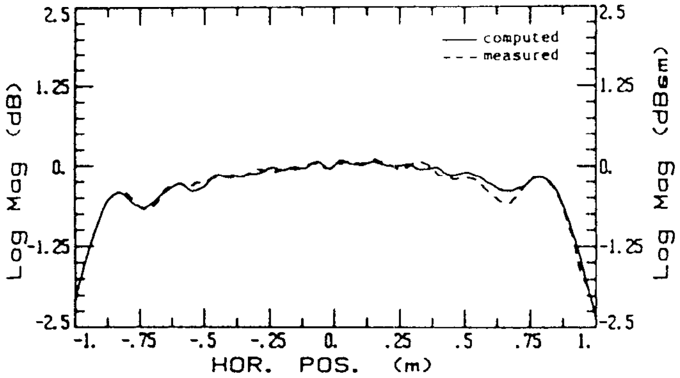

Fig. 8: Test-zone fields, horizontal plane, 10.0 GHz.

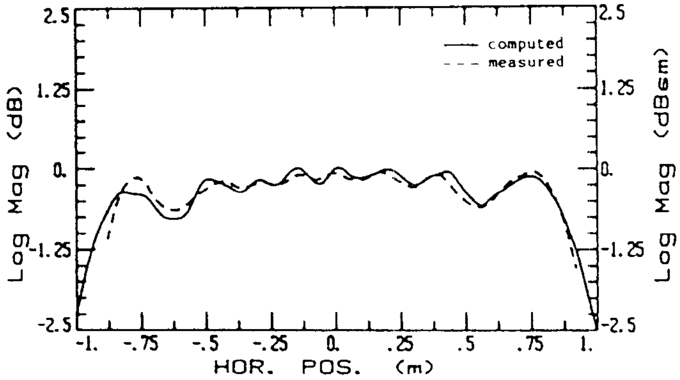

Fig. 9: Test-zone fields, horizontal plane, 17.0 GHz.

The projected size of the main reflector (model 3025) is 2.07 m excluding serrations, and 2.58 m including the serrations. Again, the agreement is very good.

These results show that the contribution from parts of the reflector that are not included in the strip-reflector model to the fields in the test zone is small.

They also show that Physical Optics is accurate for our application and that the inclusion of edge diffracted currents (PTD) is not required.

FIELD OUTSIDE TEST ZONE

For predicting background levels in RCS applications, it is important that the fields outside the test zone can be calculated. This will predict the field intensity near the walls of the anechoic chamber. Figure 10 shows the comparison between a measured and a calculated vertical scan in the test zone. The prediction is accurate to a level of -30 dB. Below this level, interference from the ceiling of the chamber can be seen. In this case, the ceiling was 10 cm to the right of the right margin of the figure.

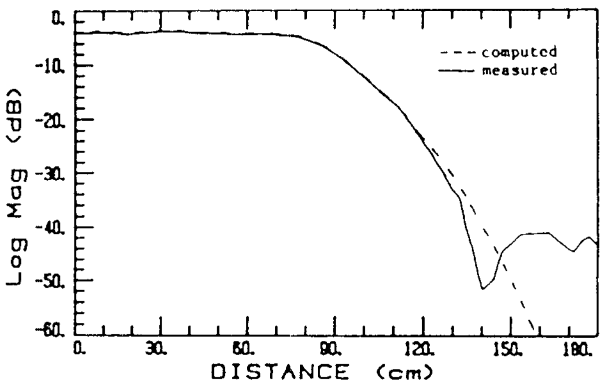

Fig. 10: Test-zone fields, vertical plane, 10.0 GHz.

We can conclude that the PO prediction is accurate outside the test zone region as well, at least down to levels of -30 dB.

ROLLED EDGE CALCULATIONS

The Physical Optics model can be used for all edge treatments that can be described mathematically. As an experiment, a reflector with a blended rolled edge treatment was analyzed. The field was calculated for a one-dimensional reflector with a solid part of 1.83 m, terminated on both sides with blended rolled edges with a length of 1.19 m each, resulting in a reflector dimension of 4.21 meters. The result at a distance of 6 m from the reflector is shown in Fig. 11 (4 GHz).

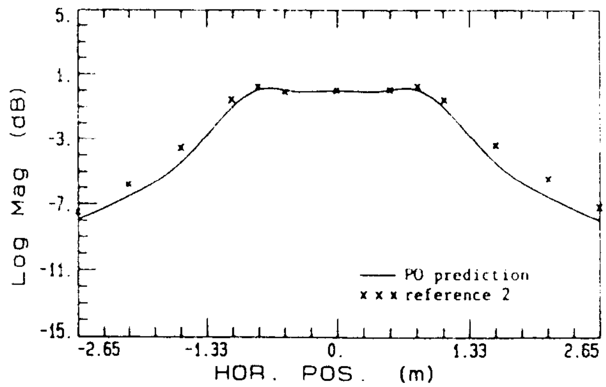

Fig. 11: Comparison of two prediction methods.

This result is compared with that of a parabolic reflector of approximately the same (projected) dimensions [2], shown as dots (space-loss taper removed). The agreement is remarkable for such a simple model. The ripple in the test zone, the size of the test zone and the behaviour outside are accurately predicted by the Physical-Optics model.

COMPARISON

The test zone fields of the blended rolled-edge reflector were compared with the results from a single reflector with serrations having the same dimensions as the rolled edge. The results at frequencies of 1, 2, 4 and 10 GHz are shown in the following Figures.

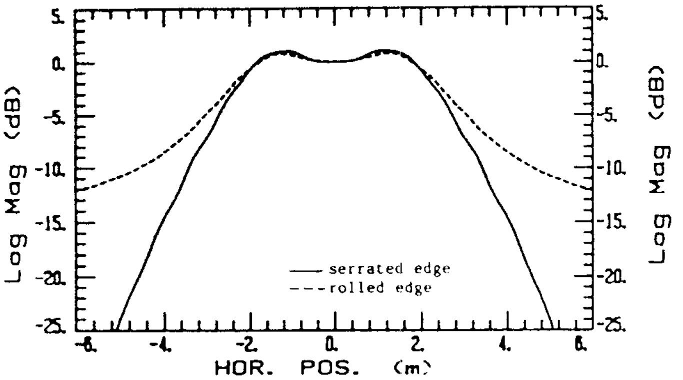

Fig. 12: Serrated and rolled edge comparison, f = 1.0 GHz.

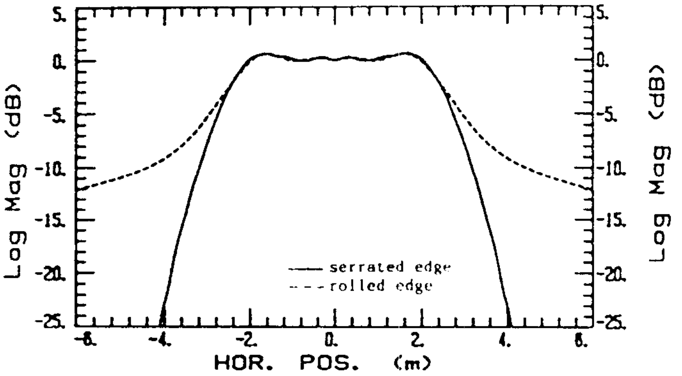

Fig. 13: Serrated and rolled edge comparison, f = 2.0 GHz.

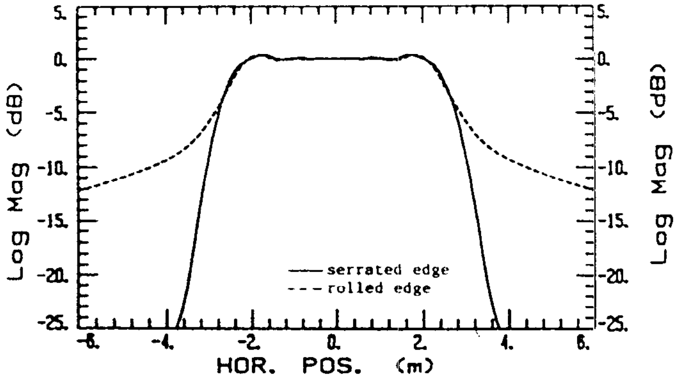

Fig. 14: Serrated and rolled edge comparison, f = 4.0 GHz.

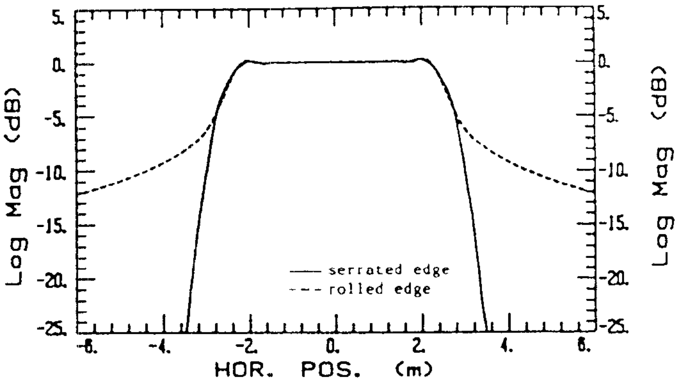

Fig. 15: Serrated and rolled edge comparison, f = 10.0 GHz.

At the lowest frequencies (1 & 2 GHz), the ripple in the test zone is the same for both models. At higher frequencies, the ripple is smaller for the rolled-edge reflector.

Outside the test zone, the behaviour for the rolled edge design is the same at all frequencies. For the reflector with serrations however, the field falls off much more rapidly at high frequencies than it does at the low frequencies. Even at 1 GHz the difference between the two designs is evident.

CONCLUSION

Physical Optics is a very powerful tool in the analysis of the field in and beyond the test zone of the Compact Range. There is no need to include the edge diffracted fields (PTD) in the computations since the agreement with measured data is very good.

The accuracy of the one-dimensional models described is very good. The combination of PO and 1-D model for the dual-cylindrical Compact Range results in a fast and accurate analysis.

Other reflector shapes such as rolled edges can be analyzed as well. It is expected that the PO technique is also applicable to predict the effect of surface irregularities on the reflectors, as long as the irregularity can be described mathematically.

REFERENCES

1. Vokurka, V. J., "Seeing double improves indoor range", Microwaves & RF, Vol. 24, No. 2, February 1985, pp. 71-94.

2. Burnside, W. D., and Dominek, A. K., "Blended surface concept for a Compact Range reflector", Proceedings AMTA conference 1985, pp. 10.1-10.10.