GUIDELINES FOR THE DESIGN OF THE SERRATIONS OF A COMPACT RANGE

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1. Introduction

Compact ranges based on reflector technology may be based on different designs: single offset reflector, dual offset reflector compensated for cross polarisation or an offset dual reflector system consisting of two orthogonal parabolic cylinders. In all cases it is necessary to make a special treatment of the edges of the reflectors in order to reduce the diffraction effects. Other factors that influence the performance is the feed taper, the surface accuracy, the distance to the quiet zone, etc.

Two different techniques are used for the edges, as for example discussed by Lee and Burnside [1]. The one is the so-called rolled edge where the reflector at the edge is gradually bended backwards such that the reflected rays are directed away from the quiet zone. The other method is to use serrations and it is the scope of the present paper to present simple design relations for the serration parameters such as the length, width and shape.

2. Serration length

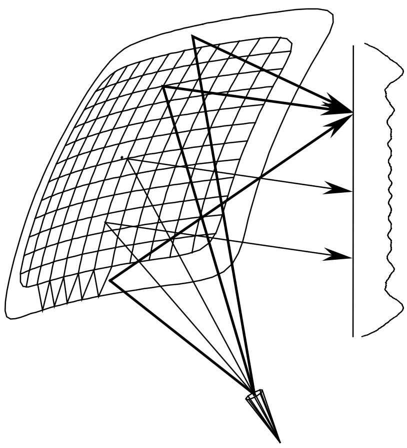

Figure 1 Typical compact range using an offset paraboloid

Figure 1 shows a typical compact range based on an offset paraboloidal reflector illuminated by a feed at the focus. The rim is supplied with serrations. The figure also shows the field in a vertical cut through the quiet zone. At the one end of the pattern the field is slowly varying due to interference between the plane wave from the reflector and the diffraction from the nearest edge. Moving towards the centre the ripples become faster because also the other edges will interfere with the plane wave. At the same time the ripples become smaller due to the angular dependence of the edge diffractions.

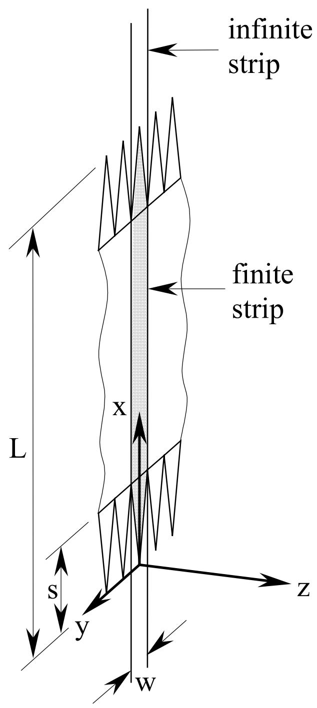

Figure 2 Plane serrated reflector infinite along y-direction

The performance is clearly very dependent on the amplitude and angular distribution of the edge diffractions. It is the purpose of the present section to isolate and quantify this contribution. To do this a plane serrated reflector illuminated by a plane wave is examined, as illustrated in Figure 2. The reflector is infinite in the y-direction. The pattern cut along x for a fixed value of z will be the same as for a narrow strip of width w. If the strip is infinitely long the pattern will be constant along x and this is the field we wish to generate by the compact range. The field from the finite strip will approximate the infinite field as long as the field point is in front of the strip but when the field point approaches the ends the two fields will start to diverge. The difference between the two fields is therefore a measure of the errors introduced by the finite length. We will denote this difference field the “edge distortion field”. The field from the finite strip is calculated by Physical Optics (PO). In order to separate the two ends a very long strip is investigated such that the area of interest is concentrated in the one end and the contributions from the other end are negligible.

Figure 3 shows the edge distortion field for a particular example: the serration length s = 1 (s is used as the unit for linear dimensions throughout this paper), the length of the finite strip is L = 100. The frequencies are selected such that the wavelength is λ = s/4, s/8, s/16, s/32 and s/64. The field is calculated in a pattern cut along x for the constant value of the distance to the field point z = 15. The field from the infinite strip is normalised to 0 dB.

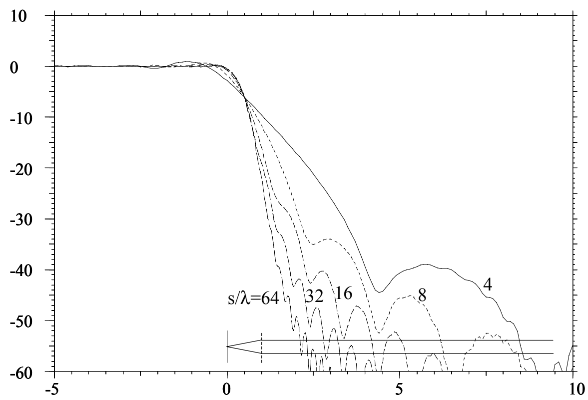

Figure 3 The edge distortion contribution as a function of the distance from the edge, the distance to the quiet zone is 15

The results in Figure 3 show that the distortion field decreases as the field point moves into the region of the finite strip, more quickly at higher frequencies. One notes also that the field has decreased by 6 dB for x = 1/2 independent of the frequency.

Ripples in the quiet zone below, say ±0.1 dB, requires that the distortion field shall be below -40 dB. A general result for design purposes is shown in Figure 4 where the -40 dB contour curves for the distortion field are given as a function of the distance z to the quiet zone and the distance x from the edge into the quiet zone.

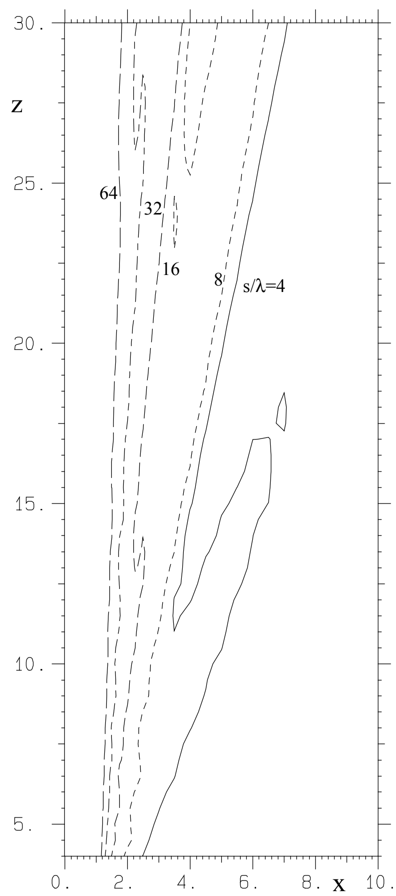

Figure 4 The –40 dB contour curves for the distortion field as a function of the distance from the edge, x, and the distance to the quiet zone, z

3. Computational approach

It is clear that the simple strip approach in the previous section does not provide information about the variation of the field in the quiet zone in the direction orthogonal to the strips. For typical compact ranges this effect is very small and is neglected. As a consequence the actual width w of each serration is not included in the analysis.

The fact that the field from an edge only varies orthogonal to the edge is important from a computational point of view because it greatly simplifies the analysis when several edges are involved in a real compact range design. It is possible in TICRA’s reflector antenna program GRASP8 to simulate serrations on a reflector edge. The serrations are defined by means of two rim specifications, one for the tip and one for the foot of the serrations.

The electrical influence of the serrations is simulated by modifying the PO surface currents that would exist for an unserrated reflector. This modification is carried out by multiplying the surface currents by a weight factor which is unity for a point inside the inner rim and which gradually decreases from one to zero when the point moves from the inner to the outer edge.

For triangular serrations the rate of decrease is selected linear and for cosine-shaped serrations a cosine rate of decrease is available. It must be noted that the number of serrations or the actual position of the individual elements is not taken into account. The above described technique for the analysis of serration effects is extremely simple but yet it has proven to provide very good results for practical applications.

4. Serration edge shape

The results presented in the previous sections were related to a triangular shape of the serrations, i.e. the serration width decreases linearly with the distance from the foot to the tip of the serration. Another popular shape of the serration is the cosine which provides a more smooth transition from the solid area inside the reflector to the empty area outside the reflector. The width of the serrations is here given by $w(1 + \cos(\pi x/s))/2$, where x is the distance measured from the foot to the tip.

The effects of triangular and cosine shaped serrations are compared in Figure 5 by showing the distortion field, similar to Figure 3, in a pattern cut in the distance of z = 15 in front of the strip. Only the two frequencies corresponding to λ = s/4 and s/64 are considered but in addition the results with no serrations are also included.

At the low frequency, λ = s/4, there is some difference between the linear and the cosine serration. The latter decreases more slowly as the field point moves into the quiet zone. At the high frequency the difference between the two edge shapes is very small.

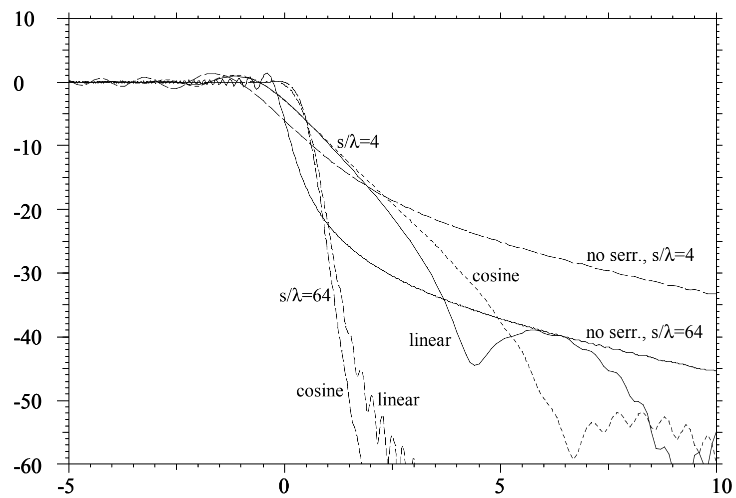

Figure 5 Comparison of the distortion field for triangular and cosine shaped serrations. The distance to the quiet zone is 15.

5. Tilt at the serration basis

The reflector surfaces in a real compact range are curved. The results obtained in the previous sections with a plane reflector illuminated by a plane wave rely on the assumption that the surface shape in the serrated region is the same as in the solid area, typically a paraboloid. In this and the following section we will consider the effects of realistic deviations from this ideal assumption.

If the serrations are manufactured separately and attached to the rim of the solid part of the reflector afterwards, it is likely that the serration is tilted slightly relative to the nominal orientation. Again the strip approach is used to calculate the effects. The example to be investigated is: L = 10, s = 1 and the field is calculated in a plane cut, z = 15, in front of the strip. The result is illustrated in Figure 6 for three frequencies, both for the nominal orientation of the serrations and when they are tilted 2º backwards. The absolute values on the ordinate axis are arbitrary and the three frequencies are separated for better readability. It is seen that the tilt of the serrations gives rise to increased ripples, especially at the higher frequencies, and it reduces the size of the quiet zone. In practice not all the serrations are misaligned in the same direction and with the same amount, and this will reduce the overall effect of this type of distortion.

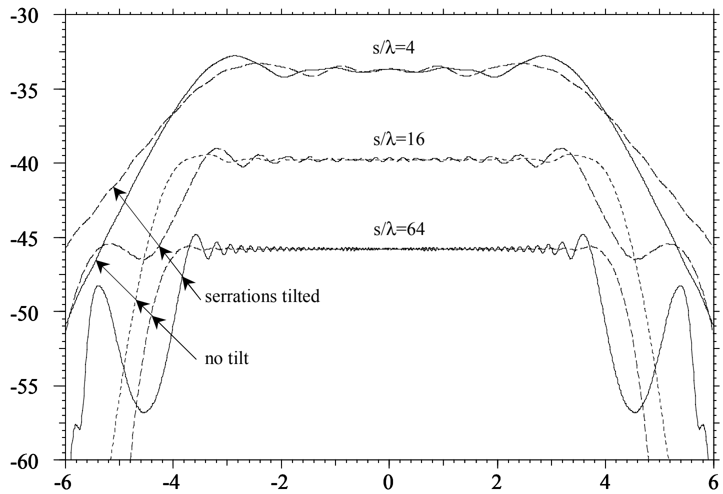

Figure 6 The field in the quiet zone in the distance 15 in front of the reflector with and without a 2° tilt of the serrations. The compact range parameters are s = 1, L = 10.

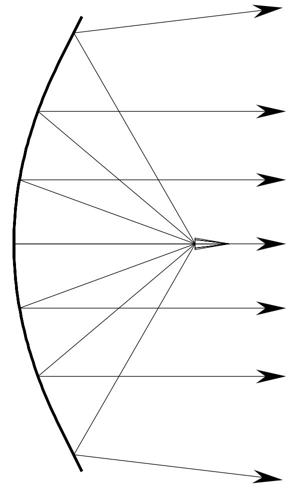

Figure 7 Parabolic cylinder with plane serrations

6. Serration surface shape

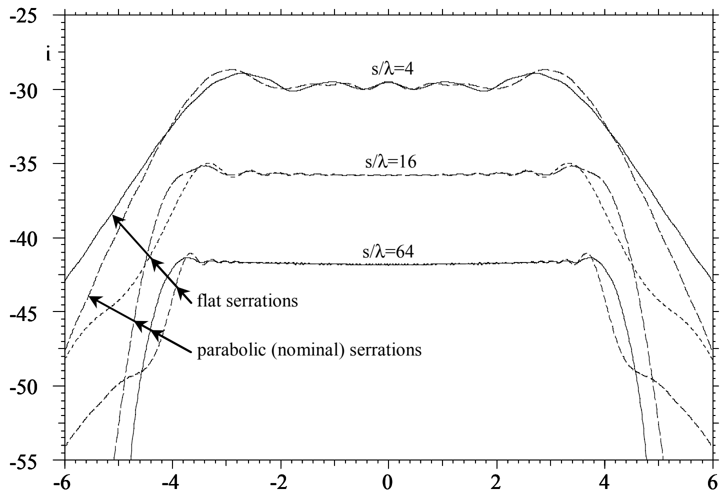

Figure 8 The field in the quiet zone in front of the reflector in Figure 7. Compact range dimensions: L = 10, s = 1. Distance to quiet zone z = 15.

From a mechanical point of view it is simpler to replace the curved surface serrations with plane triangles. The idea is illustrated in Figure 7 where the solid part of a parabolic cylinder is 8 units and supplied with plane serrations 1 unit long. The figure shows that the plane serrations cause the rays to diverge in the outer region of the range.

Figure 8 shows the field in the quiet zone 15 units in front of the reflector both for serrations with the parabolic cylinder surface and for plane triangular serrations. The example shows that the changes in the quiet zone are very modest and that the simple, plane triangles can be a viable and practical solution in many cases. For doubly curved reflectors the same idea can be used, but in this case the triangular plates must be bent in one dimension to fit the rim of the solid part of the reflector.

7. References

[1] The-Hong Lee and Walter D. Burnside,
"Performance trade-off between serrated edge and blended rolled edge compact range reflectors",
IEEE Trans. Antennas and Propagation, Vol. 44, January 1996