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POLARISATION DEPENDENT SCATTERING FROM THE SERRATIONS OF COMPACT RANGES[1]

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ABSTRACT

Serrations are often applied at the edges of compact-range reflectors in order to reduce the scattering from the edges into the quiet zone. At low frequencies the serrations show different scattering of the field at the two polarisations: parallel to and perpendicular to the serration teeth.

This has been verified by modelling a range by the Method of Moments (MoM). The size of the range reflectors is about 7.5 m by 10 m which make the reflectors difficult to handle by MoM even at a frequency which is low for the range, viz. 1.7 GHz, in which case the reflectors are each 2400 wavelengths squared.

A narrow strip, horizontal or vertical, across the reflector and closed by a single serration tooth at each end is shown to give a good prediction of the field along a line parallel to the strip in the quiet zone. By this simple model of the range it has been demonstrated that the quiet-zone field depends highly on the polarisation. When the polarisation is parallel to the teeth the quiet-zone field has ripples which are 0.3 dB peak-to-peak, but for the perpendicular polarisation the field variations are 0.8 dB peak-to-peak.

The results are compared to quiet-zone fields determined by Physical Optics (PO).

Keywords: Compact range modelling, Methods of Moments, Physical Optics, Serrations design.

1. Introduction

In measurements carried out at the Compact Payload Test Range (CPTR) at the European Space Research and Technology Centre (ESTEC) it was experienced that gain measurements at linear polarisations gave different results depending on the polarisation of the range feed. The measurements were carried out at 1.2 GHz which is a low frequency for this range. That the quiet-zone field in such a case is not an ideal uniform field is well known and that the gain measured at different positions in the range may give different results is known as well. However, it is not common knowledge that the performance of a range with serrated reflectors at low frequencies depends on the polarisation of the range.

Due to the size of a compact range the electromagnetic modelling is usually based on Physical Optics (PO) [1]. This method, however, gives results which are essentially independent of the polarisation. This is due to the fact that the scattering is determined from surface currents which are given by the incident field in magnitude and direction.

The modelling may instead be based on the very accurate Method of Moments (MoM). A MoM model will, further, reveal the accuracy of the PO model.

In MoM the scatterers are divided into small segments – small in terms of wavelengths – having currents which mutually interact. The result is accurate values for the currents and then also for the radiated field. However, the limitations in computer storage and computer time limit the size of the structures it is possible to handle.

Thus the MoM model presented is a low-frequency modelling of a part of the CPTR and it will be illustrated with examples at 1.7 GHz. Finally it is illustrated how the large difference in gain measurements at 1.2 GHz in the CPTR may arise.

In the interpretation of the field in the quiet zone it is useful to apply terms from the Geometrical Theory of Diffraction, GTD. Thus, the quiet-zone field may be considered as a nearly constant main field, viz. the field optically reflected through the range reflectors, disturbed by diffractions in the reflector edges.

2. Modelling

The applied PO modelling of the serrations is based on the principle that the PO currents over the serrated area are determined as for a solid surface but tapered by a weight decreasing from one to zero. The weight function follows the geometry of the solid area of the serrations [2].

[1] The work presented here has been carried out for the European Space Agency (ESA) on ESTEC Contract 18802

From the PO modelling it is found that the horizontal and the vertical serrations influence the quiet-zone field nearly independently [3]. Thus the ripples in a horizontal cut of the quiet zone are controlled by the vertical edges of the reflectors and these horizontal ripples may be determined, by PO or MoM, from a simplified structure, a horizontal strip with one tooth, representing the serrated edge, at each end. The quiet-zone field in a vertical cut is determined by a similarly modelled vertical strip.

The model is further simplified by letting the strip being part of a plane reflector illuminated by a plane wave. Hereby, the imperfections in the quiet-zone field are not influenced by an offset reflector geometry. The strip has a size corresponding to a similar strip on the main reflector of the CPTR but projected on the aperture plane.

The terminology applied for the polarisation is s-polarisation for polarisation parallel to the strip and p-polarisation for the polarisation perpendicular to the strip. The plane wave illuminates the strip in either of the two polarisations. Only the co-polarised currents and field components will be reported here.

The examples are calculated by GRASP9 [2].

2.1 Strip geometry

The modelled strip has a length of 8800 mm from tip to tip and the teeth at each end have the length 786 mm. The width of the strip is 300 mm. The wavelength, λ, at 1.7 GHz is 176 mm.

The strip is shown in Figure 1(a) with the MoM mesh in black lines. A high order polynomial expansion is applied in the MoM of GRASP for the currents within each patch. Hereby larger patches than for conventional MoM can be applied.

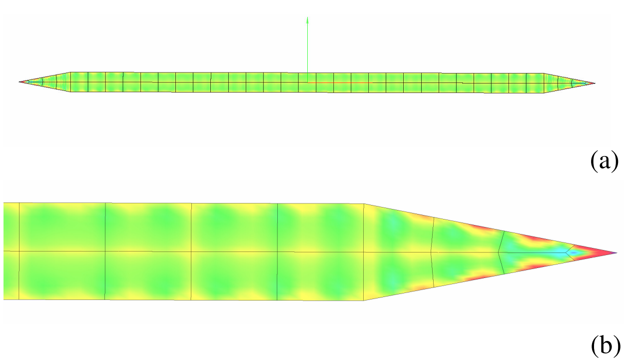

Figure 1 – The s-polarised current component on the strip illuminated by the s-polarised plane wave. (a) full strip, and (b) details of the right end. Colour code for the currents: blue is zero changing over green and yellow to red which is maximum. The same colour scale is applied to all current plots.

2.2 Polarisation parallel to the strip

The co-polar currents induced on the strip when it is illuminated by a strip-polarised (s-polarised) plane wave are shown in colours in Figure 1(a). The current distribution is rather uniform except upon the teeth. The right end of the strip with its tooth is shown in Figure 1(b) in high resolution.

It is seen that resonances occur in the geometry. Along the length of the strip where it has full width we find current maxima at every 185 mm (1.05λ). Perpendicularly we find two periods over the 300 mm wide strip with maxima along the edges and the centre line of the strip.

Most interesting, however, are the currents on the teeth. The currents have four strong maxima along the edges of each tooth with the most intensive currents at the tip. These currents generate the ripples in the field over the quiet zone, Figure 2.

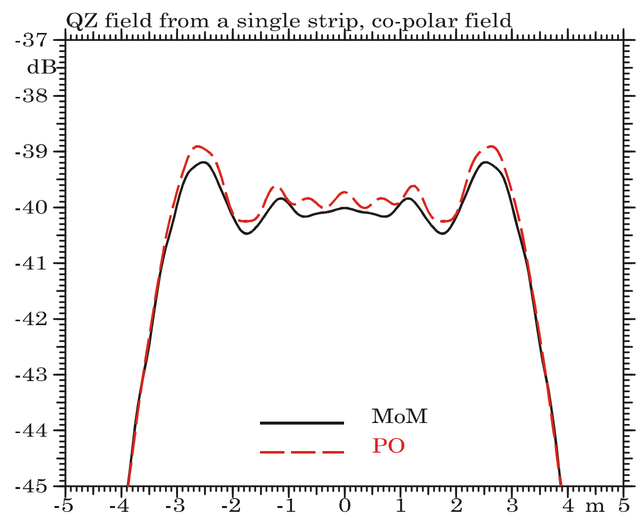

Figure 2 – The s-polarised quiet-zone field determined by MoM from a strip illuminated by s-polarisation (full line) with comparison to PO (dashed).

The PO field determined over a similar strip is also shown. A good agreement is found between the field of the PO model and field of the MoM model in the sense that the peak-to-peak field variations agree over the full quiet zone. The variations of the MoM field in the central part of the zone are small because, accidentally, the edge effects are in phase quadrature to the optically reflected main field in this region.

2.3 Polarisation perpendicular to the strip

When the polarisation of the incident plane wave is changed to a polarisation perpendicular to the strip (p-polarisation) the currents on the strip perform quite differently as shown in Figure 3. The currents on the central part of the strip are uniform along the strip but have two maxima across the strip and null along the upper and lower edges.

The currents on the teeth, however, behave differently in an important way. The currents are still forced to zero at the edges but as the edges narrow along a tooth, first two and next only one current maximum is possible across the tooth and, finally, only negligible currents exist near the tip.

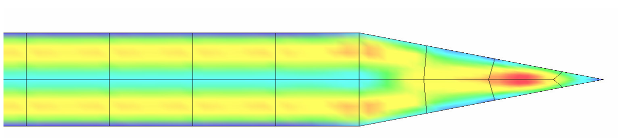

Figure 3 – The p-polarised current component upon the right end of the horizontal strip illuminated by the p-polarised plane wave.

The quiet-zone field of this current distribution is shown in Figure 4. The figure indicates that the ripples in the quiet-zone field are much larger than for the s-polarisation. The PO field, however, is practically the same as for the s-polarisation.

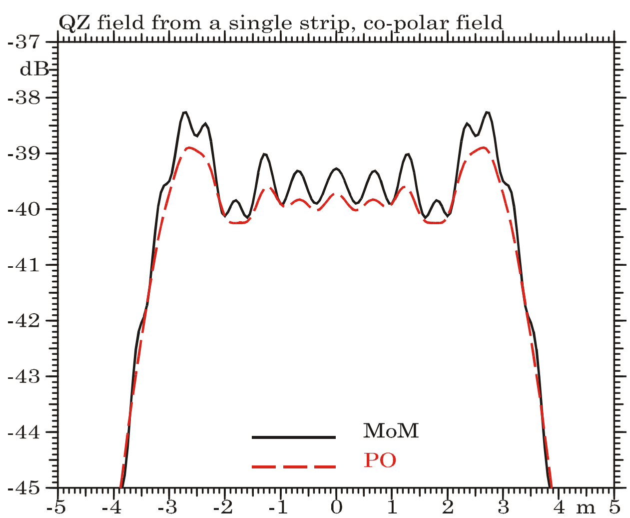

Figure 4 – The p-polarised quiet-zone field determined by MoM from a strip illuminated by p-polarisation (full line) and compared to PO (dashed).

The ripples are more violent for this case (p-polarisation) due mainly to the one intense current spot near the tip of the teeth in the serrations. In the previous case (s-polarisation) several current spots occurred on each tooth blurring the common disturbance of the quiet-zone field.

2.4 Coupling to neighbour teeth

In the calculations above a strip with only one tooth at each end was investigated. This simple model will introduce artificial edge effects along the central part of the strip, and all mutual coupling with the remaining part of the serrated reflector is neglected.

To investigate the accuracy of the single-strip model, a triple strip, which is three times as wide as the single strip, is then analysed with MoM, cf. Figure 5. The currents on the centre strip will now closely resemble the currents on the corresponding part of the serrated reflector. To isolate the radiation properties of the centre strip, the currents on the outer strips are neglected when the field in the quiet zone is determined.

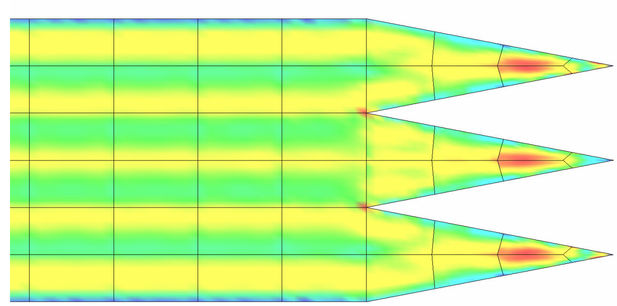

Figure 5 – The p-polarised current component upon the right end of a triple strip illuminated by the p-polarised plane wave.

In Figure 5 the currents on the three strips are shown (p-polarisation). Notice how the currents on the central strip deviate from the currents on especially the outer halves of the outer strips as the currents are forced to zero on the long outer edges of the central part of the structure. This was also the case for the currents on a single strip, Figure 3, while the centre strip does not exhibit this behaviour.

When we determine the quiet-zone field from the currents on the centre strip only we get the pattern shown as a dashed curve in Figure 6. For comparison the pattern for the single strip, curve in full line in Figure 4, is inserted. The difference between the patterns is very small. For the s-polarised field the curves deviate slightly more, but still within ±0.1 dB. In conclusion, the single strip model is deemed reliable for a good and simple prediction of the quiet-zone field.

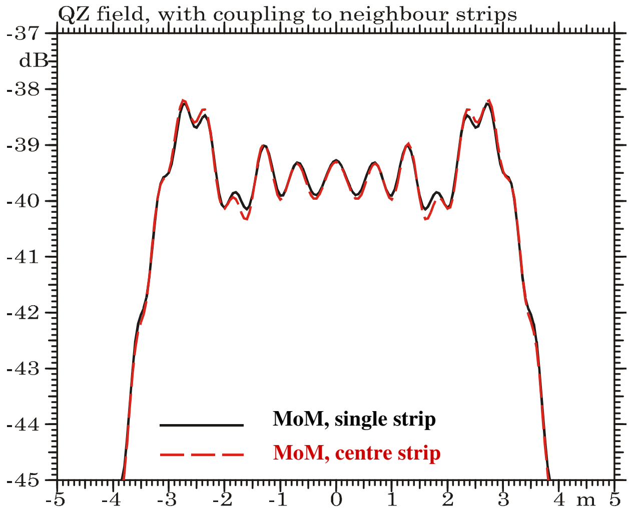

Figure 6 – The p-polarised quiet-zone field determined by MoM on a single strip (full line) and on three strips of which only the currents on the central strip are applied in the field determination (dashed). The latter curve is raised by 0.6 dB.

2.5 Modelling of curved teeth edges

The teeth of the serrations have so far been modelled as isosceles triangles. However, the edges of the teeth are not straight but shaped like a cosine function raised to the power of 1.6. The influence of this shape is investigated in this section. We will only consider the polarisation perpendicular to the strips, p-polarisation.

The currents on a single strip are shown in Figure 7. A comparison to the currents on the tooth with straight edges, Figure 3, shows that the peak current on the tooth are moved slightly inwards in agreement with the strip being more narrow near the tip.

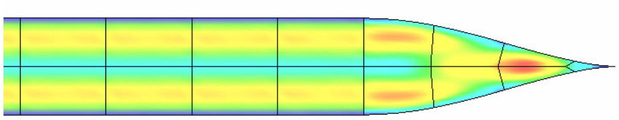

Figure 7 – Modelling of the teeth with curved edges, co-polar current component when illuminated by the p-polarised plane wave.

The corresponding quiet-zone field is shown in Figure 8. The field variations in the quiet zone have the same amplitude as in the case with straight-edged teeth (shown in full line) because the disturbances in the field are still dominated by the single current maxima near the tips of the teeth.

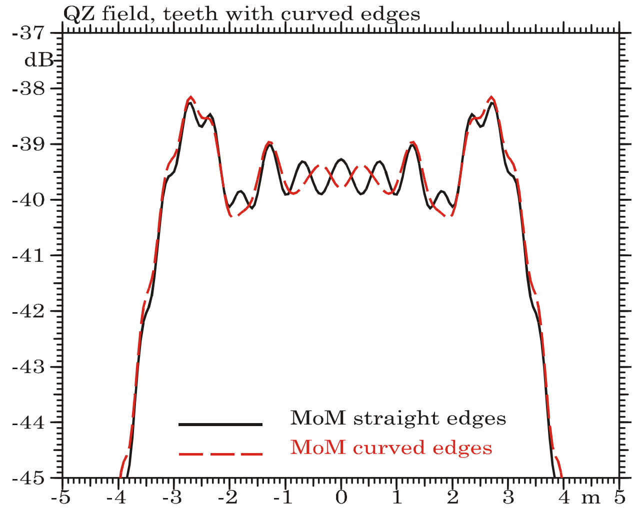

Figure 8 – The p-polarised quiet-zone field determined by MoM on a horizontal strip with curved teeth edges (dashed) compared to the reference case with straight-edged teeth (full line).

The ripples in the quiet-zone field have changed in position due to the fact that the current maxima on the teeth have moved inwards when the teeth edges are curved.

2.6 Conclusion on strip modelling

The quiet-zone field is generated by reflectors which first of all generate a uniform optically reflected field in the quiet zone. This field cannot be generated without some edge effects, and the figures with the MoM-determined current distributions, especially on the teeth of the serrations, show that distinct current maxima are generated along the edges of the teeth for the s-polarisation while the p-polarisation at low frequencies causes only one strong current maximum at the teeth where the width is 10-20% more than half a wavelength. This single current maximum causes a severe edge effect.

The single strip renders a good prediction of the quiet-zone field. The model may be improved in the details by including the neighbour strips in the model and by modelling the detailed shapes of the teeth.

3. MoM compared to PO at high frequencies

It requires a large computer to apply the MoM for high frequencies, but it is possible to apply the model for a single strip at 5.1 GHz which is three times the frequency applied hitherto. In the following we will therefore show the scattering at 5.1 GHz from a horizontal strip of the same geometry as described in Section 2.1.

Only results for p-polarisation will be presented as the results for s-polarisation agree with PO.

3.1 Polarisation perpendicular to the strip

The currents on the strip for p-polarisation are shown in Figure 9. Compared to the case for 1.7 GHz, Figure 3, we see a similar pattern in the currents but with a faster variation corresponding to the shorter wavelength of the higher frequency. Again a characteristic intense current spot appears near but inside a tooth width of λ/2, and here also inside tooth widths of additional odd multiples of λ/2.

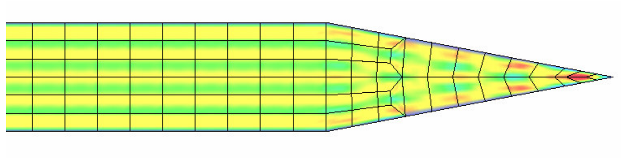

Figure 9 – Modelling of the horizontal strip at 5.1 GHz, co-polar current component when illuminated by the p-polarised plane wave.

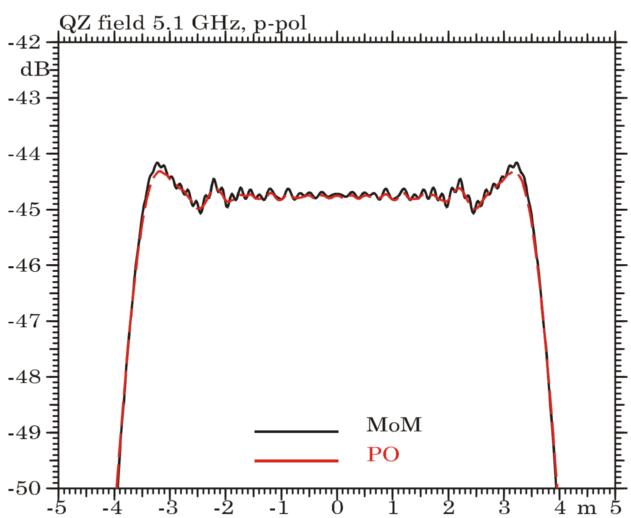

Figure 10 – The p-polarised quiet-zone field determined by MoM and PO at 5.1 GHz.

As previously discussed one current spot (at each end of the strip) causes ripples in the field across the quiet zone while many current spots smear out this effect causing a more calm quiet zone. This is seen in the quiet-zone field at 5.1 GHz in Figure 10. The deviation from the constant field is less than at 1.7 GHz. However, the p-polarised field still has higher ripples than predicted by PO, but as the ripples in general are low the difference is small at 5.1 GHz and the PO prediction is found in reasonable agreement with the MoM result.

3.2 Conclusion on MoM versus PO modelling

The higher the frequency the less is the difference between the quiet-zone field for s-polarisation and p-polarisation and, further, the difference between PO and MoM models. The PO model applied for 5.1 GHz gives results which are accurate within a tenth of a dB in the quiet-zone field. In conclusion, for this range the PO model may be applied for frequencies above 5 GHz while it is less accurate at lower frequencies where the MoM model should be applied.

4. Range modelling

Measurements in the CPTR at 1.232 GHz showed considerable polarisation dependent results for vertical displacements in the quiet zone. Thus, gain variations of 4.7 dB at horizontal polarisation and 1.3 dB at vertical polarisation were found for a 200 mm displacement of a directive antenna of diameter 1300 mm.

In order to determine the quiet-zone field of the range by MoM, the range reflectors were modelled as strips. To obtain the field in a vertical cut the reflectors are each modelled as a central vertical strip as shown in Figure 11.

The field of the feed illuminates the strip representing the subreflector and the hereby scattered field illuminates the strip of the main reflector. The coupling between the two reflectors have thus been neglected.

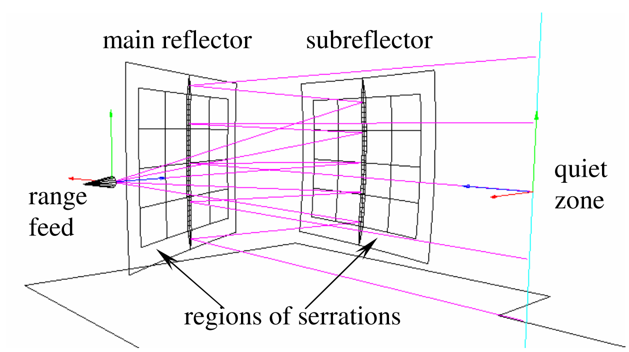

Figure 11 – The range modelled by two vertical strips in MoM and by full reflectors in PO. Some ray paths from the range feed to the quiet zone are shown.

The quiet-zone fields determined are shown in Figure 12. The figure shows the quiet-zone field for horizontal as well as for vertical polarisation. The horizontal polarisation (p-polarisation) shows the most severe ripples in the field, 4.5 dB peak to peak in the central part of the quiet zone while the corresponding ripples of the vertical polarisation (s-polarisation) are at 1.6 dB. These results agree well with the measurements.

A comparison to the quiet-zone field determined by PO is also shown in Figure 12. The PO field depends on the polarisation with less than 0.05 dB and therefore only the vertical polarisation is shown. It is seen that the field variation is well determined by PO for polarisation parallel to the teeth of the serrations while the ripples are higher for polarisation perpendicular to the teeth.

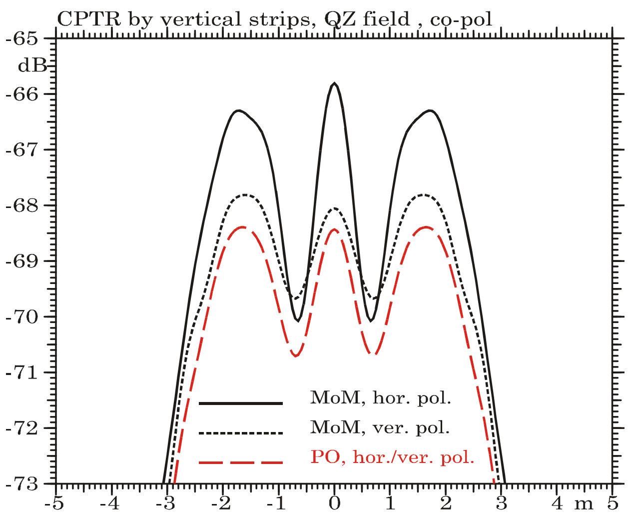

Figure 12 – A vertical cut in the quiet-zone field determined by MoM when the CPTR reflectors each are modelled as a vertical strip.
Horizontal polarisation, p-polarisation (full line), vertical polarisation, s-polarisation (dotted) and comparison to PO (dashed).

5. Conclusion

The quiet-zone field of a compact range has been modelled by MoM and it has been found that the faster PO model is reliable at high frequencies, i.e. when the teeth of the serrations at their base are wider than 5 wavelengths. At these frequencies it is found that the scattering in the serrations is independent of the polarisation.

The MoM model further reveals the interesting result that for low frequencies the scattering in the serrations increases significantly more than predicted by PO but only for the polarisation perpendicular to the teeth of the serrations.

This is explained from the peaks in the currents on the teeth of the serrations. At low frequencies the width of a tooth allows only a single current peak to exist perpendicular to the tooth. This peak is positioned where the tooth is slightly wider than half a wavelength. When the teeth are not wide enough to allow further peaks to exist, the current peaks of the serrated edge all lie on a straight line positioned where the width of the teeth is about half a wavelength. Thereby a virtual edge is generated and this edge causes an increased diffraction into the quiet zone.

For polarisation parallel to the edges of the teeth the resonance causes more than a single current maximum as the number of maxima is now determined by the length of the teeth. The many maxima along the edges of the teeth blur the diffractions which disturb the quiet zone. This conclusion is under the assumption that the teeth are long and narrow as is the case for most ranges.

The MoM model is based on modelling the reflector as a single strip with a tooth at each end. This results in a reliable field determination in the quiet zone in a cut parallel to the strip. The currents on the strip and its teeth depend on the existence and modelling of a continued reflecting surface with more teeth, but it has been shown that the field is nearly independent of this neighbour effect.

The MoM model further appears to have little sensitivity to the precise shape of the teeth and their edges. Thus all teeth may be modelled as isosceles triangles. However, with the ever increasing capabilities of computers it will soon be possible to model the full reflector with its actual serrations in MoM. Results at the lowest frequency are expected to be available at the Conference.

6. REFERENCES

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