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MODELLING OF THE ANTENNA-TO-RANGE COUPLING FOR A COMPACT RANGE

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Abstract

Two ways of modelling a compact range design are presented, and the coupling to a given antenna under test (AUT) is determined and compared to the AUT far field.

The compact range models are both based on physical optics (PO). The first model applies a simple presentation of the serrations of the range reflector while the second model is based on a new feature of GRASP8, which allows a detailed description of the triangles of the range serrations.

The AUT measurement is modelled by an accurate coupling analysis between the current elements on the compact range reflector and the antenna under test. This coupling pattern is compared to the real far-field pattern and the differences are discussed.

By including known range imperfections in the AUT-to-range coupling a better agreement to the measured patterns may be obtained.

All computations are carried out by GRASP8.

Keywords: Antenna measurements, compact range, measurement errors, modelling, antenna coupling.

1. Introduction

The purpose of testing an antenna in an antenna test range is in general to verify that the specifications for the radiation pattern of the antenna are fulfilled. The measured pattern is therefore compared to the specifications and, if available, to numerical results.

An important factor in evaluating the pattern deviations is the range accuracy. This factor involves not only instrument accuracies but also the ability of the range to produce the real antenna far field. The latter is interfered by components such as incompleteness of the quiet-zone field for the case of a compact test range or near-field effects and specular ground reflections for the conventional far-field range.

If these contributions could be removed, the range accuracy would be improved considerably. Alternatively, these contributions could be included in the numerical modelling and, consequently, reduce the deviation between the measured and the modelled pattern.

In the following, an example of a compact-range measurement will be given. The geometry of the compact range is given in Section 2, and in Section 3 the performance of the quiet-zone field is presented. The range performance is determined by physical optics (PO) and two different ways of modelling the PO currents in the serrated area of the range reflector, a simple and a rigorous, are discussed. The latter is based on a new PO modelling in GRASP8 [1] that includes the detailed geometry of the range serrations.

Finally, in Section 4, a measurement of the AUT in the range is simulated by an accurate determination of the coupling between the PO currents on the range reflector and the AUT. The coupling pattern is compared to a directly determined far-field pattern of the AUT and the differences are discussed.

2. The compact range

The AUT is measured in a compact range as illustrated in Figure 1. The range consists of a single offset paraboloidal with focal length 6 m. The rim is rectangular and the size projected on a plane orthogonal to the beam axis is 3.9 x 3.9 m including 0.6 m serrations, Figure 1b. The centre of the

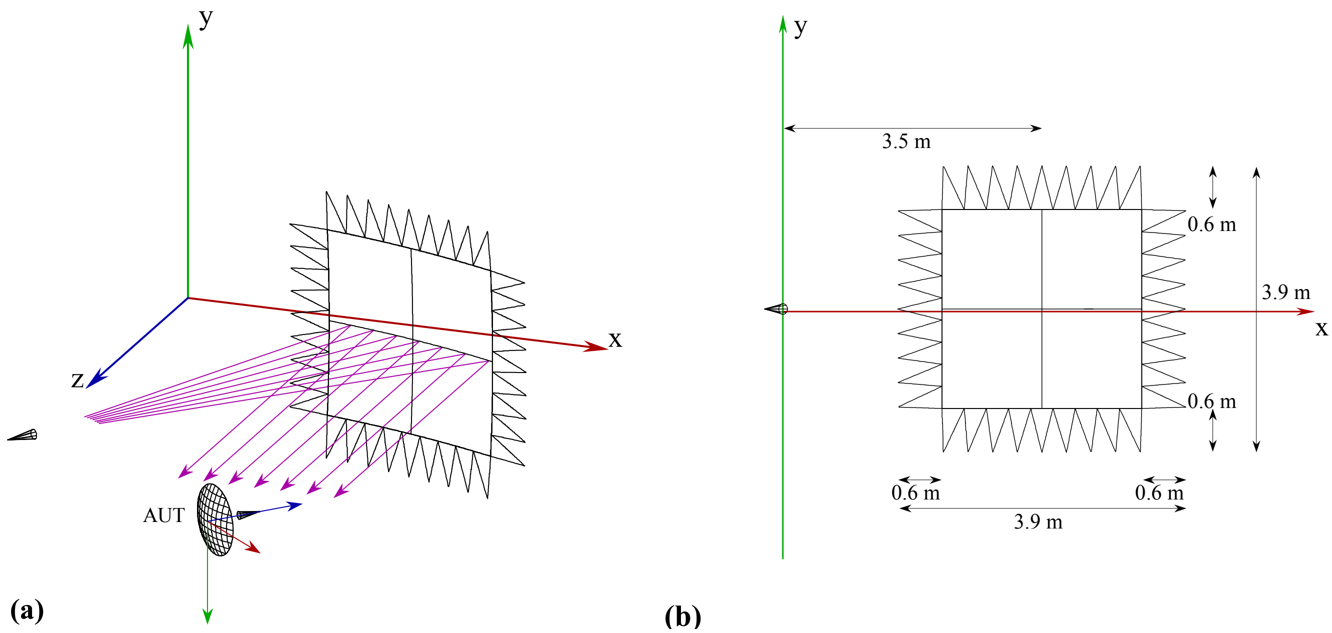

Figure 1 - Single reflector compact range layout; perspective view with a set of horizontal rays illuminating the AUT rotated 30º from boresight (a) and front view (b).

reflector is located 3.5 m from the parabolic axis. The figure also shows a range coordinate system with origin at the paraboloid vertex.

The symmetry plane of the reflector system is selected horizontally. The AUT is placed 8 m in front of the reflector in the quiet zone which is specified to have a cross section of 1.8 m × 1.8 m. The computations in the following example are carried out at 4 GHz at which the quiet zone is specified to have amplitude ripples less than ±0.6 dB.

3. Performance of the quiet zone

The quiet-zone field generated by geometrical optics.

The quiet-zone field is primarily generated by a geometrical optics (GO) field from the feed reflected in the range reflector. A few GO rays are shown in Figure 1a. The GO quiet-zone field is depicted in Figure 2 in an area of 1.8 m × 1.8 m around its centre; the range is horizontally polarised. Both the co- and cross-polar components are shown and they are both normalised with respect to the co-polar maximum. It is seen that the co-polar component is almost rotational symmetric and with a taper of 0.5 dB from the centre to the edge. This taper is caused by the taper of the range feed. The cross-polar component, which is unavoidable in a single reflector system, is symmetric about the horizontal plane and it is below –30 dB in most of the area.

The quiet-zone field determined by physical optics.

The real quiet-zone field has ripples, which are caused by the finite size of the reflector. This edge effect of the reflector is reduced by a proper design of the serrations of the edge.

The effect of the serrations may successfully be evaluated by physical optics (PO) [2, 3, 4], improved with inclusion of physical theory of diffraction (PTD) [5, 6, 7].

To include the influence of the serrations in the calculations two different PO approaches are applied here, a “simple” and a “rigorous” approach.

In the simple approach [1,8], the serrations are specified by two rims, an outer rim representing the tip of the serrations and an inner rim representing the foot of the serrations. The usual PO surface currents in the serrated region are then tapered with a weight varying from unity at the inner rim to zero at the outer rim according to the geometry of the serrations. This approach is approximate but simple and it is therefore very useful for range design work where many parameters have to be explored.

In the rigorous approach, the PO field for each serration element is computed separately and they are all added to the field from the solid part of the reflector to generate the total field. The integration grid is automatically generated by GRASP8. This method is more complicated and it is there-

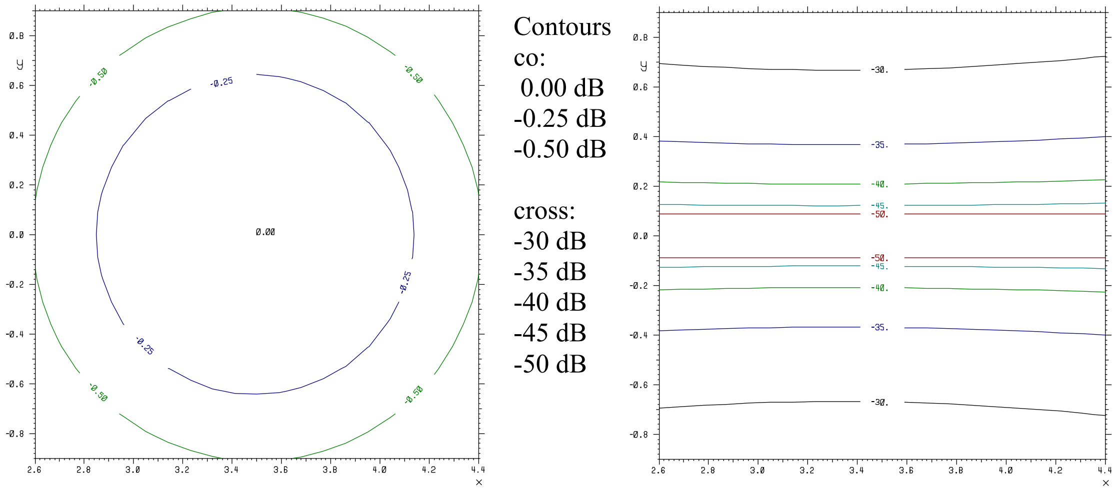

Figure 2 - Co-polar (left) and cross-polar (right) quiet-zone illumination as determined by GO.

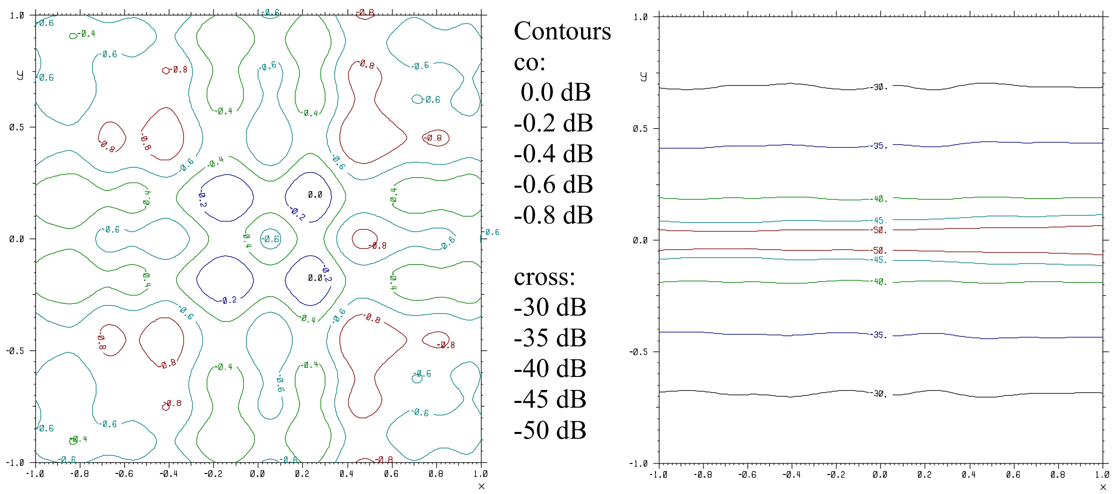

Figure 3 - Co- and cross-polar components of the quiet-zone field at 4 GHz using the simple PO method.

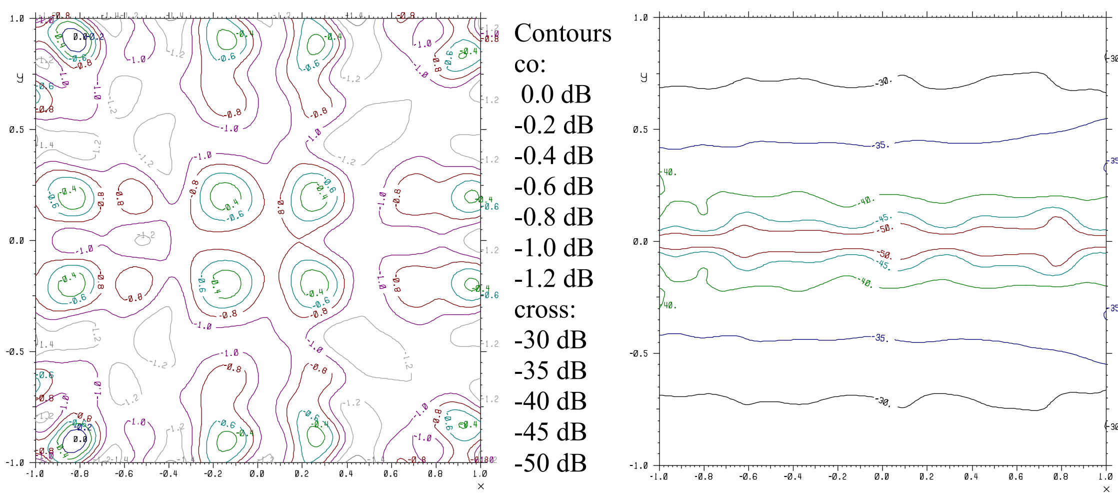

Figure 4 - Co- and cross-polar components of the quiet-zone field at 4 GHz using the rigorous PO approach

fore mostly used to check results obtained with the simple method.

The quiet-zone field by simple PO

Calculating the quiet-zone field at 4 GHz using the simple approach yields the field shown in Figure 3. Both the co- and cross-polar fields are normalised with respect to the co-polar maximum. It is seen that the quiet zone fulfills the requirement of maximum field variations of ±0.6 dB within 1.8 m × 1.8 m. Figure 3 also shows that the cross-polar field at 4 GHz is 30 dB or more below the co-polar component in the major part of the quiet zone.

The quiet-zone field by rigorous PO

The simple PO does not require specific information about the serration details. The rigorous approach, however, needs the detailed design for all the serration elements, cf. Figure 1b. The calculated quiet-zone performance at 4 GHz using the rigorous approach is shown in Figure 4. Note that the peak amplitude occurs at the left corners outside. By comparison to Figure 3 it is seen that the amplitudes of the ripples in a quiet zone of diameter 1.8 m are now slightly increased but still within the specifications. This shows that some margin is necessary when evaluating a compact range using the simple PO approach.

Comparison of the quiet-zone field

The contour plots show that a cut to illustrate the worst-case ripples shall be diagonal. Such cuts are shown in Figure 5 for both amplitude and phase based on both the simple PO and the rigorous PO.

The differences between the two methods are small. Again, it is seen that the rigorous PO method produces slightly higher ripples, namely ±0.53 dB, than the simple PO method, ±0.48 dB, in amplitude and ±2.5º, respectively ±2.3º in phase. Further, the rigorous PO method results in a pattern with finer details.

4. Simulation of a real measurement

We now know the performance of the quiet zone and shall model a real measurement in the range as the coupling between the AUT and the compact-range reflector.

The AUT is selected as a linearly polarised, front-fed paraboloidal reflector antenna with diameter D = 1 m and focal length f = 0.5 m. The far-field pattern for this antenna can be calculated with high accuracy.

The AUT is rotated around a vertical axis in the set-up of Figure 1a, and for each angular position the coupling between the AUT and the compact range reflector is calculated by the simple PO method. The result is shown in green in Figure 6 and compared to the accurate far-field

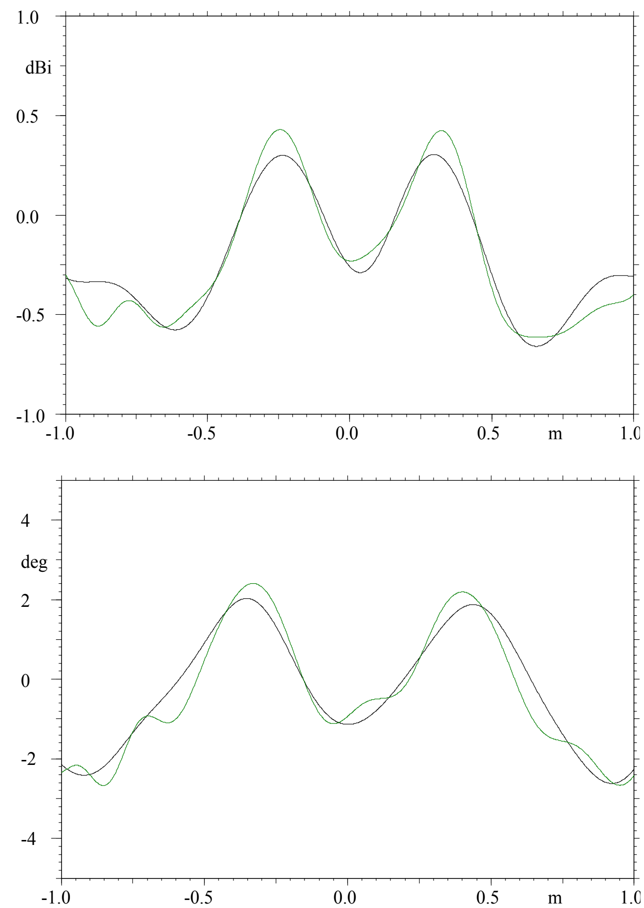

Figure 5 - Diagonal cut through the field in the quiet zone by simple PO (black) and rigorous PO (green); amplitude (top) and phase (bottom).

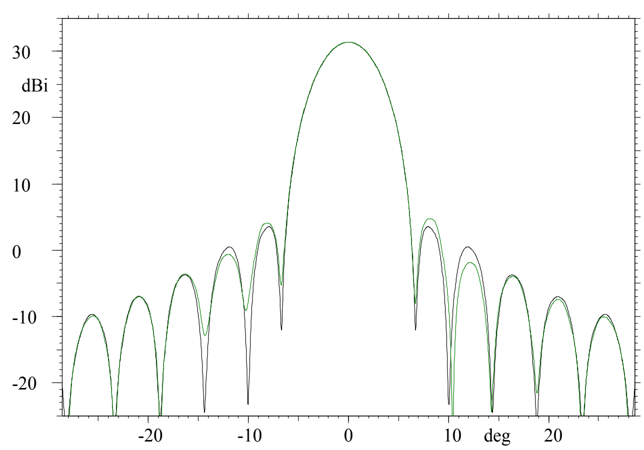

Figure 6 - Accurate far-field pattern (black) for the AUT compared to the coupling pattern which will be measured in the compact range (green).

pattern shown in black. The two patterns are equalised for the boresight direction and it is seen that the two patterns agree very well apart from the two first side lobes. This disagreement is due to the diffractions in the serrations of the range reflector, the same diffractions, which caused the ripples in the quiet-zone field.

When the main beam is measured, the diffractions are received by side lobes at about -30 dB. The diffractions are thus suppressed by 30 dB. However, when the first and second side lobes are measured, the main beam points towards an edge. The undesired diffracted signal is then amplified 30 dB, which results in the pattern deviations on these lobes.

When evaluating the measurements it is thus important to compare the measured patterns to the coupling patterns, not to the expected far-field patterns. The found difference is up to ±2.5 dB on a side lobe at -31 dB.

5. Computing time

The computing time for generating the contour plot of the quiet-zone field by the rigorous PO method (Figure 4) is less than one minute. The rigorous method is fast compared to a method of moment calculation for which a cut calculation took 3.5 hours [9] for an 18λ by 18λ reflector (the reflector in this paper is 52λ by 52λ).

The coupling determination is heavier, the pattern computation of Figure 6 required 1 hour (on a 750 MHz Pentium III).

6. Conclusion

The quiet-zone field of a compact range has been determined by two methods, a simple and a rigorous, both based on PO. In the simple method, the PO currents induced in the serrated area of the range reflector are weighted according to the solid area of the serrations. In the rigorous method each tooth of the serrations are modelled according to its actual geometry.

Both methods give a qualitative correct quiet-zone field, but the simple method tends to give smaller ripples within the quiet zone, namely ±0.48 dB compared to ±0.53 dB for the rigorous method in the presented example at 4 GHz. The phase ripples are found to ±0.23º and ±0.25º, respectively. The simple method may therefore give too optimistic results.

The consequences of the quiet-zone field not being a perfect plane wave has been determined by a coupling analysis in which the coupling between the range and an AUT has been calculated for a scan of the AUT in the range. The coupling is, for each AUT position, determined as a superposition of the coupling between the PO current elements on the range reflector and the AUT.

By comparison to a directly computed AUT far-field pattern the accuracy of a range measurement can be evaluated. For the given example where the quiet-zone field is constant within ±0.27 dB over the area of the AUT aperture, it is found that a side lobe at -31 dB can be measured with an accuracy of ±2.5 dB.

As these deviations can be predicted, they may be included in antenna evaluation and verification tests. By comparing the measured patterns to coupling patterns instead of to far-field patterns, higher accuracy and reliability of the tests may be obtained.

The calculations are carried out by the coupling module of GRASP8.

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