A Detailed PO / PTD GRASP Simulation Model for Compensated Compact Range Analysis with Arbitrarily Shaped Serrations

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***Abstract*—Compensated compact ranges offer accurate testing techniques for large devices under test. The quiet zone field performance is affected by diffracted field components from the sub and main reflector edges even though they are equipped with serrations in order to reduce this effect. The size, shape, and alignment of the serrations have a strong influence on the range performance and are important design parameters. For performance estimation and optimization, detailed EM simulation models are required. Integral equation methods like the Method of Moments (MoM) with Multilevel Fast Multipole (MLFMM) acceleration promise accurate simulation results. However, the memory requirements limit simulations nowadays to lower frequencies due to the electrical size of the compact range reflectors. For example, the main reflector of Astrium's Compensated Compact Range CCR 120/100 including serrations is 1860 λ by 1600 λ in size at 40 GHz. Asymptotic methods are suitable for objects of this size, however, the accuracy has to be investigated and is related to the degree of detail in the model.**

A detailed simulation model based on the Physical Optics (PO) / Physical Theory of Diffraction (PTD) method is developed in GRASP. Each serration is realized as an individual scatterer and can thus be modeled with arbitrary shape and orientation. Different modeling techniques have been applied in order to realize an accurate simulation model with acceptable runtime. In this paper, the simulation model will be described in detail and a comparison of the quiet zone fields will be drawn with the MoM / MLFMM tool Feko as well as with quiet zone probing measurements.

I. INTRODUCTION

Antenna radiation patterns are commonly characterized by near-field [1] or compact range [2] measurements. Compact test ranges consist of a feed antenna together with one or more reflectors. The feed radiates a spherical wave towards the range reflector which converts the wave into a plane wave. In this way it is possible to emulate a plane wave field in the so-called quiet zone (QZ) as in the far field but in close proximity to the feed and the device under test (DUT). Further advantages of compact ranges are convenient end-to-end payload testing capabilities for satellite applications [3]. However, the conversion of the feed pattern into a plane wave field will not be ideal since the reflectors have a finite extent. Diffracted field components will originate from the reflector edges and corners and will superimpose the desired reflected signal in the QZ. This will result into ripples in the QZ field. In order to minimize the diffracted signals, so-called serrations are installed at the reflector edges and corners (as shown in Figure 2). Serrations are metal plates which have an optimized shape in order to direct the diffracted signals away from the QZ. The quality of the plane wave field in the QZ is dominated by the size, shape, and alignment of the serrations which are therefore important design and optimization parameters.

The range performance can be optimized in the design process by simulations. Different simulation techniques are available, e.g. full wave and asymptotic analysis, which have different numerical complexity and achievable accuracy. Full wave simulations like the Method of Moments (MoM) with Multilevel Fast Multipole (MLFMM) acceleration allow very accurate simulation results at the cost of high memory consumption for electrically large structures. However, the compact range reflectors have an electrical size of e.g. 1860 λ by 1600 λ for a frequency of 40 GHz. These dimensions allow full wave simulations only in the lower GHz region. Asymptotic methods like Physical Optics (PO) together with the Physical Theory of Diffraction (PTD) possess significantly lower memory requirements and have the advantage of becoming more accurate the larger the structures are. The achievable accuracy also depends on the degree of detail that is implemented in the simulation and determines the runtime of the simulation. Therefore a good compromise has to be found in order to obtain the required accuracy at acceptable runtime.

In this paper a detailed PO / PTD simulation model is developed in GRASP [4] which allows numerical simulation of compact ranges with arbitrarily shaped serrations at low memory costs and acceptable runtime. Therefore, a Matlab parser is written which generates the required huge number of objects for the GRASP simulation using range parameters as well as contour data of the serrations as input data. In section II Astrium's compensated compact ranges are introduced. In section III the detailed GRASP PO / PTD simulation model is presented. In the results section IV the detailed GRASP model is compared to a full wave analysis carried out with Feko [5], to simplified PO simulation with GRASP, and finally to measured QZ fields. This is done at a frequency where the full-wave solution is still durable. The paper is concluded in section V.

II. ASTRIUM'S COMPENSATED COMPACT RANGES

Astrium is one of the leading manufacturers for highly accurate compensated compact range (CCR) facilities. A CCR consists of a parabolic main reflector (MR) and a hyperbolic sub reflector (SR). The reflectors are designed to fulfill the Mizugushi criterion and thus realize the main advantage of having no system inherent cross-polarization. Astrium primarily offers the models CCR 75/60 and CCR 120/100 having a main reflector size of 7.5 m times 6.0 m and 12.0 m times 10.0 m, respectively. This results in a quiet zone of 5 m and 8 m diameter. A principal top view of a CCR is shown in Figure 1; a picture of a CCR of type 120/100 is shown in Figure 2.

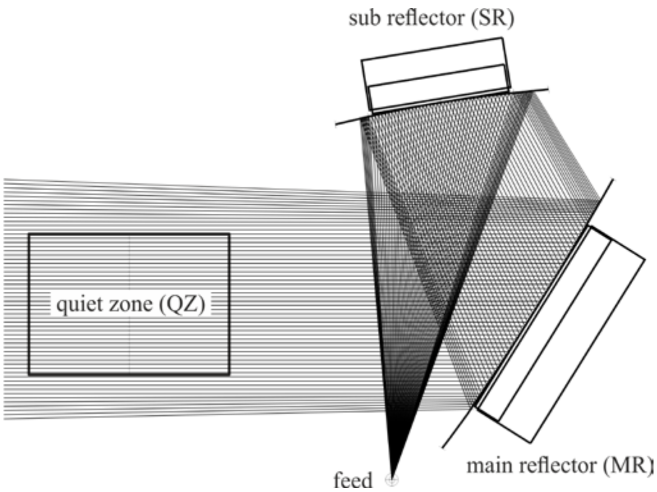

Figure 1. Top view of a CCR with center QZ.

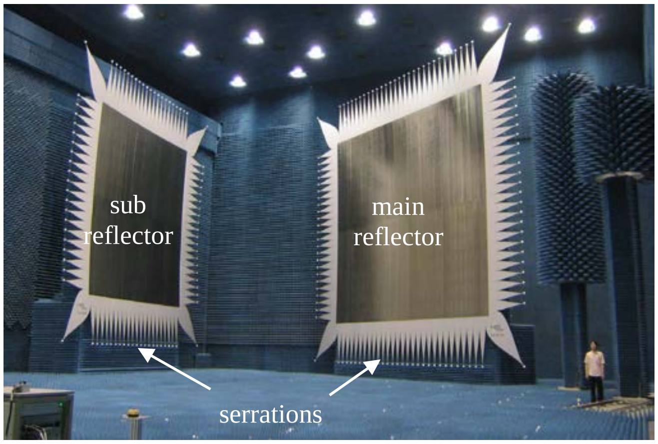

Figure 2. Astrium's CCR 120/100.

III. DETAILED GRASP PO / PTD SIMULATION MODEL

The model developed in this paper will solve the EM field problem by the PO / PTD method implemented in GRASP. All relevant objects, sub reflector, main reflector, serrations, and base sections, are modeled as individual scatterers with their own surface, rim, and coordinate system. The base sections connect reflector and serrations. The simulation is carried out by repeatedly computing the PO / PTD currents on an object due to an excitation. E.g. the currents on the sub reflector are computed due to illumination by the feed. In the next step the sub reflector currents are used to illuminate the main reflector. Finally the fields caused by the main reflector currents are computed in the QZ. This has to be repeated for all combinations of reflectors and serrations and the field components in the QZ have to be summed up.

The GRASP software package is commonly applied to model reflectors of circular and rectangular shape. However, the compact range reflectors and especially the serrations have a complicated rim which is typically not canonic. This requires that sub reflector, main reflector, all serrations, and base sections are modeled as individual scatterers with their own scatterer object, surface, coordinate systems, and a numerically defined rim. For the CCR 75/60 in total 132 serrations have to be modeled. Due to the large number of objects, they have to be created in an automated way. This is realized by a Matlab script which reads the range parameters, e.g. reflector dimensions, focal lengths, etc., as well as the serration rim points from text files as shown in Figure 3. The Matlab parser processes the data and generates the input files for the GRASP simulation:

- ***.tor file** which contains the information on all GRASP objects to be generated, e.g. scatterers, surfaces, rims, coordinate systems, field points etc.
- ***.tci file** which contains all analysis steps to be executed by GRASP, e.g. current and field computations.
- **Rim files** for all serrations and base sections which contain numerical rim coordinates.
- **Surface files** for all base sections which contain numerical surface data.

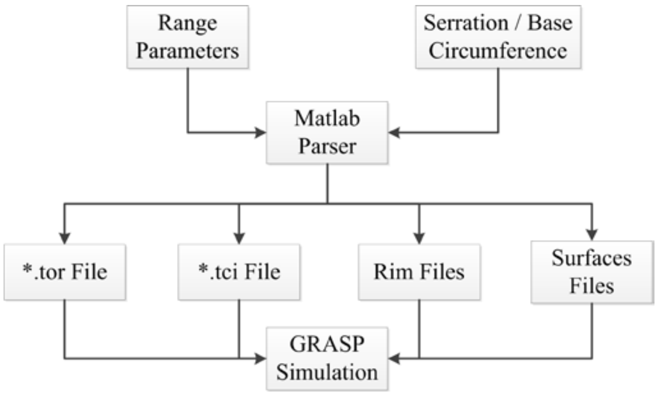

Figure 3. GRASP model generation.

A screenshot of the model is shown in Figure 4. The sub reflector is shown on the left side, the main reflector on the right side. The green, red, and blue arrows belong to the global and local coordinate systems.

In the GRASP simulation model different measures have been applied in order to reduce the runtime to an acceptable level:

- Reflectors and serrations are subdivided into an inner and an outer scattering object as seen in Figure 5. The inner scatterer with canonical (rectangular or triangular) rim allows a fast integration. The outer scatterer with a numerically defined rim as well as a hole corresponding to the inner scatterer, uses an alternative integration technique which is much faster than the standard integration for numerically defined rims. This alternative integration technique is, so far, only available for scatterers with a hole, therefore reflectors and serrations are subdivided into two pieces.

- The standard accuracy for automatic grid determination is reduced from -80 dB to -40 dB for serrations and base sections. This is possible since the field contributions are much smaller than those of the reflectors and results in a faster determination of the integration grid and less grid points to be processed in the following steps.

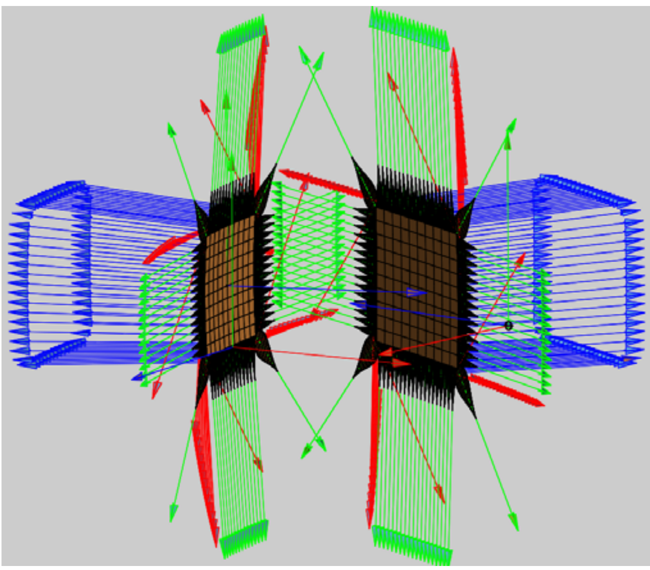

Figure 4. Detailed GRASP CCR simulation model including serrations.

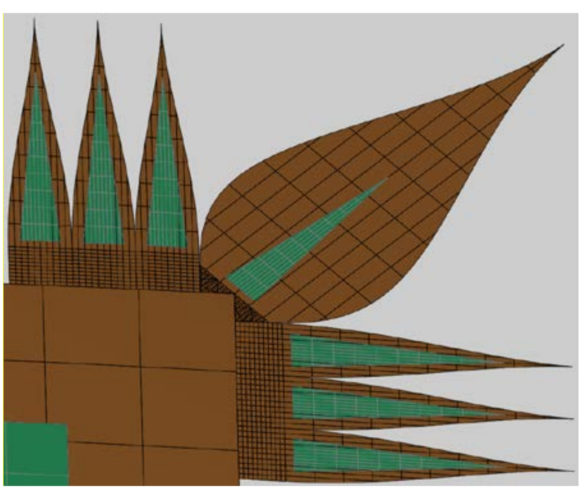

Figure 5. Modeling of reflector and serrations with inner and outer scattering object. Inner objects shown in green.

IV. RESULTS

The presented GRASP simulation model for the CCR is tested and compared to different simulation models as well as to measured QZ data. The simulations with the detailed GRASP model contain the following field contributions:

- Feed → SR → MR → QZ,
- Feed → SR serrations → MR → QZ,
- Feed → SR → MR serrations → QZ,
- Feed → SR serrations → MR serrations → QZ,
- Feed → SR → QZ,
- Feed → SR serrations → QZ.

The field values are computed in a similar way to the QZ probing measurements. The measurements are carried out with a probe antenna mounted on a linear scanner which is mounted on a rotational positioner (shown in Figure 6). Four cuts C1-C4 are measured with angular increments of 45° as shown in Figure 6.

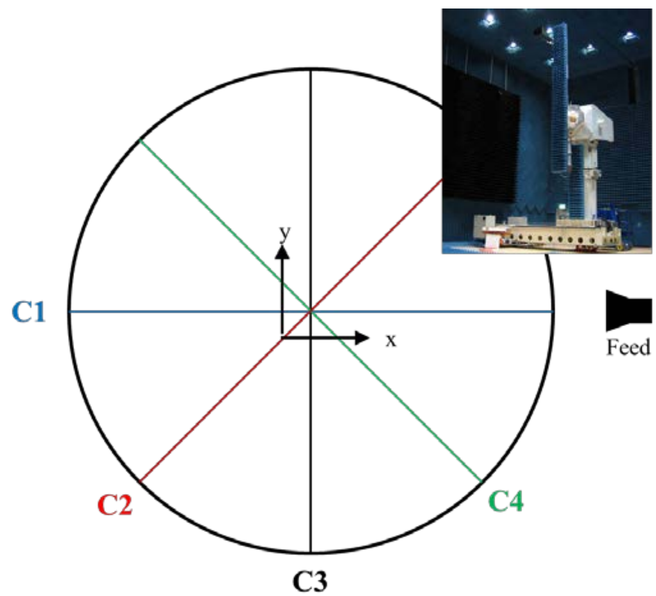

Figure 6. Cut definition for QZ field evaluation; scanner setup in CCR. x is pointing towards the feed, y is pointing upwards, and z is pointing away from the main reflector.

A. *Feko and GRASP Comparison*

The proposed simulation model is compared to a full wave simulation using the MLFMM solver of Feko as well as to a simplified GRASP PO simulation which models the serrations by a built-in model. In the Feko simulation the complete CCR reflectors including serrations are modeled by triangles and only the scattered part of the field is evaluated. Furthermore the feed pattern in Feko is restricted to an angular range which will illuminate the sub reflector only; main reflector and QZ are not directly illuminated. In the simplified GRASP simulation SR and MR are modeled as one scatterer each both having a rectangular rim. The serrations are considered using a built-in model which applies a taper function to the PO current distribution. The serrations are defined by a second rim together with the type of taper function, i.e. linear or cosine.

1) CCR 75/60 6 GHz

A CCR 75/60 is simulated at 6 GHz for the three different simulation models as described above. 6 GHz is close to the upper frequency limit of the Feko MLFMM solver using a workstation with 256 GB RAM. The results are shown in Figure 7 - Figure 10 for C1 and C3 cuts as defined in Figure 6 in magnitude and phase. The QZ has a diameter of 5 m which corresponds to the range from -2.5 m to 2.5 m in the corresponding figures.

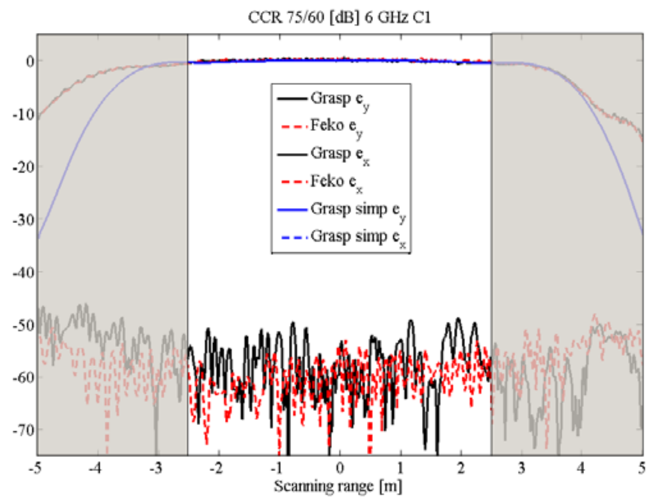

Figure 7. Comparison of different simulation models for CCR 75/60 QZ data at 6.0 GHz. Cut C1, magnitude [dB].

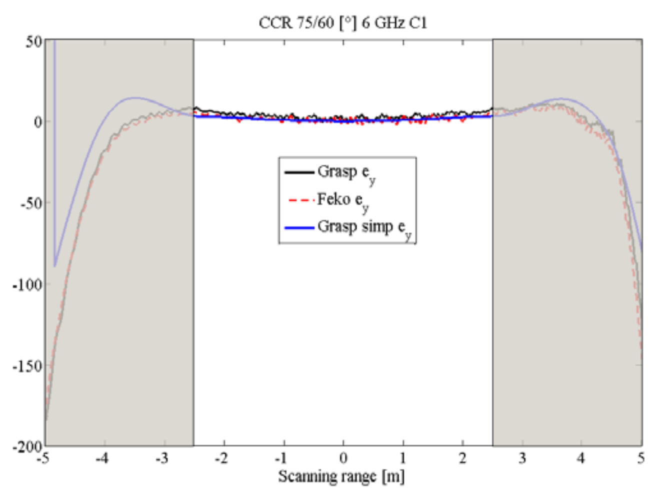

Figure 8. Comparison of different simulation models for CCR 75/60 QZ data at 6.0 GHz. Cut C1, phase [°].

The copolar pattern cuts (e_y component) show a good agreement between the proposed technique and the full wave Feko solution in amplitude and phase. The crosspolar pattern cuts (e_x component) have a similar level and behavior. One has to keep in mind that the full wave solution contains all possible interactions whereas the proposed GRASP analysis contains the above listed field components only. Further it has to be considered that the crosspolar pattern level is very low compared to the copolar pattern level. Therefore, one would expect a general agreement between both simulations but not an exact overlap for the crosspolar component.

The simplified GRASP solution using the built-in serration model shows deviations from the other simulations, especially for the crosspolar component, which is on the order of -300 dB in the C1 cut (Figure 7). This is due to the simplified serration model which does not properly model the diffraction effects at the individual serrations.

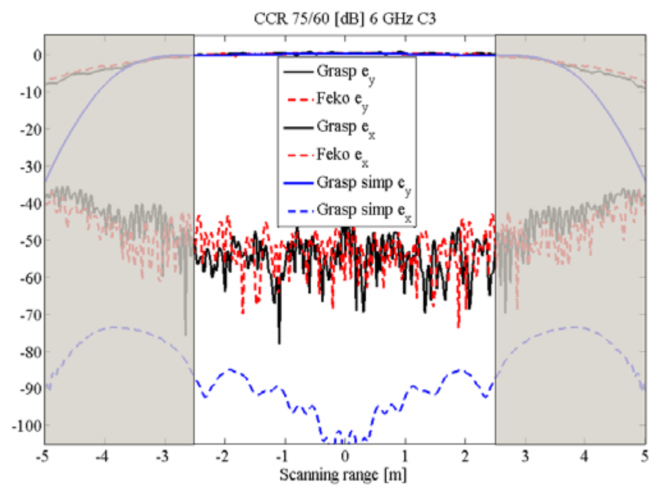

Figure 9. Comparison of different simulation models for CCR 75/60 QZ data at 6.0 GHz. Cut C3, magnitude [dB].

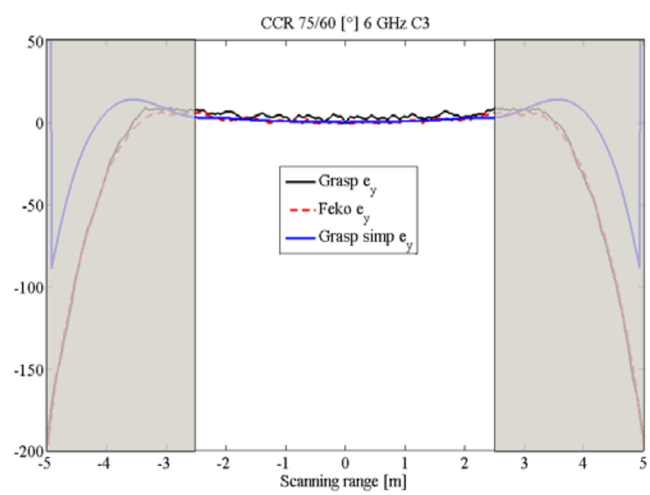

Figure 10. Comparison of different simulation models for CCR 75/60 QZ data at 6.0 GHz. Cut C3, phase [°].

2) CCR 75/60 6 GHz Bended Serrations

Besides the size and the shape of the serrations it was found that the quality of the QZ fields also strongly depends on the accuracy of the serration installation and alignment. Due to gravity effects especially the upper serrations have a bending moment downwards and therefore have to be carefully fixed. In order to estimate the effect of the serration bending moment simulations have been carried out with the presented GRASP model and have been crosschecked with a Feko full wave simulation at a suitable frequency. The serrations are bended significantly in order to consider a worst case scenario. The bending in the GRASP model is realized by introducing a linear term in the second order polynomial used to model the serrations surface. The results are shown in Figure 11 - Figure 14 for C1 and C3 cuts in magnitude and phase.

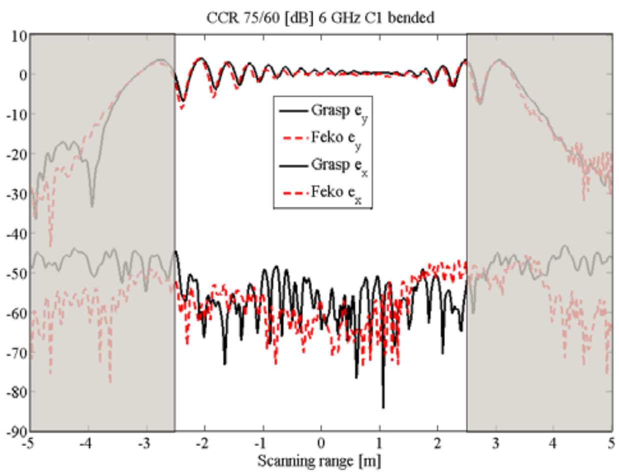

Figure 11. Comparison of GRASP and Feko results for CCR 75/60 at 6.0 GHz, bended serrations. Cut C1, magnitude [dB].

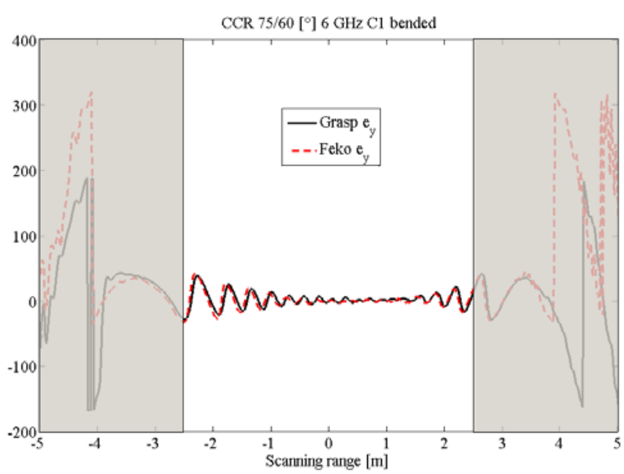

Figure 12. Comparison of GRASP and Feko results for CCR 75/60 at 6.0 GHz, bended serrations. Cut C1, phase [°].

As for the case without bending the presented model and Feko solutions show a good agreement. Furthermore, it can be seen that the bending moment of the serrations caused by gravity can have a significant contribution and thus requires proper installation and alignment of the serrations.

B. Measurement Comparison

The proposed simulation model is also compared to measured QZ probing data. In this case it has to be considered that the QZ measurements use a standard gain horn as receiving antenna in the QZ. This will result in a certain averaging effect of the field data as compared to the simulation data which does not include the probe influence so far and thus shows electric near-field values. Furthermore, the simulation considers only those field components as described above. Reflections from the chamber which are still possible even though the chamber is equipped with absorbers, multiple reflections between the reflectors and the QZ, as well as any other kind of disturbances are not included in the simulation model and might lead to a certain deviation between simulated and measured results.

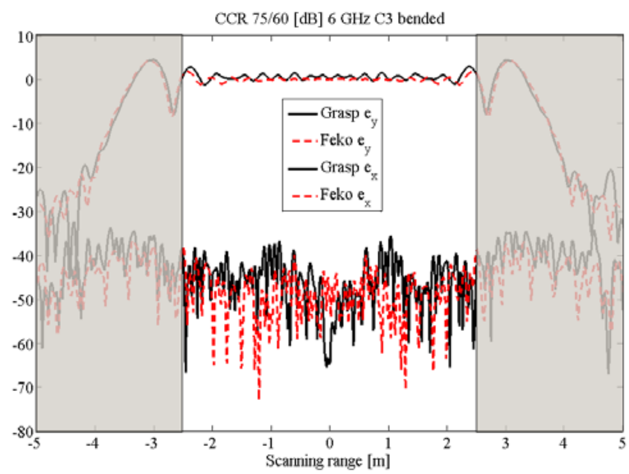

Figure 13. Comparison of GRASP and Feko results for CCR 75/60 at 6.0 GHz, bended serrations. Cut C3, magnitude [dB].

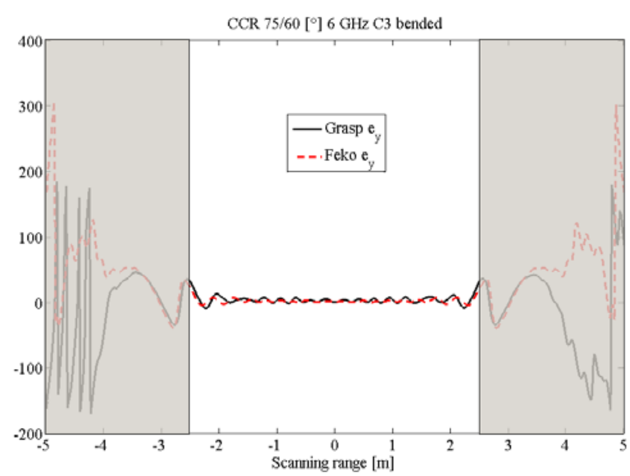

Figure 14. Comparison of GRASP and Feko results for CCR 75/60 at 6.0 GHz, bended serrations. Cut C3, phase [°].

The QZ probing measurements were conducted in a CCR 120/100 facility at a frequency of 15.1 GHz. The QZ has a diameter of 8 m which corresponds to the range from -4 m to 4 m in the corresponding figures. The measured data is restricted to the QZ size due to the available scanner, the simulated data is shown from -10 m to 10 m. The feed data in the simulation was taken from spherical measurements of the actual feed pattern which have been converted to spherical wave coefficients. The results are shown in Figure 15 - Figure 18 for C1 and C3 cuts in magnitude and phase.

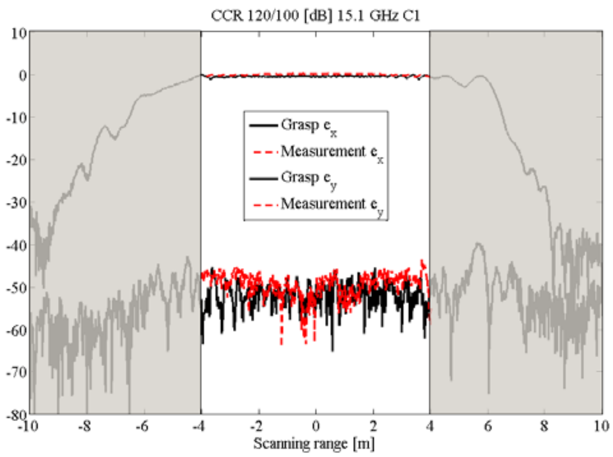

Figure 15. Comparison of simulated and measured CCR 120/100 QZ data at 15.1 GHz. Cut C1, magnitude [dB].

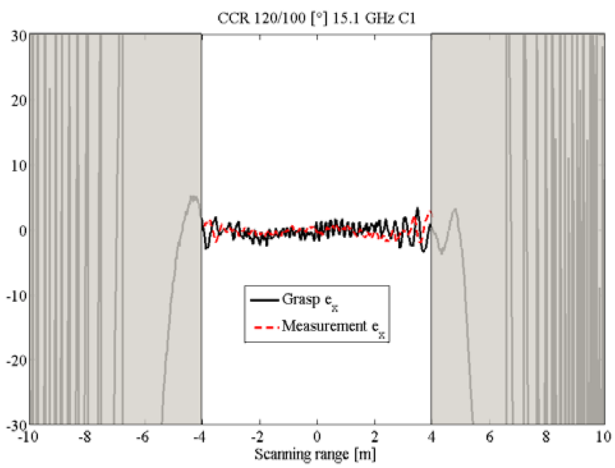

Figure 16. Comparison of simulated and measured CCR 120/100 QZ data at 15.1 GHz. Cut C1, phase [°].

Considering the deviations of the proposed simulation model from the real CCR facility, promising results could be achieved.

V. Conclusions

A detailed GRASP PO / PTD simulation model for a compensated compact range has been presented. The model allows to simulate the reflector serrations with an arbitrary shape. Especially for higher frequencies the memory requirements are considerably lower than for full wave simulations, e.g. by MoM with MLFMM acceleration. Compared to a simplified GRASP PO approach the achievable accuracy is much higher and the results are comparable to full wave analysis. Therefore, the presented model enables accurate simulations and optimization of compensated compact ranges in frequency ranges that are not suitable for full wave analysis due to the high computational demands. The model showed good performance for CCR reflectors of 100 λ upwards; smaller sizes are under consideration.

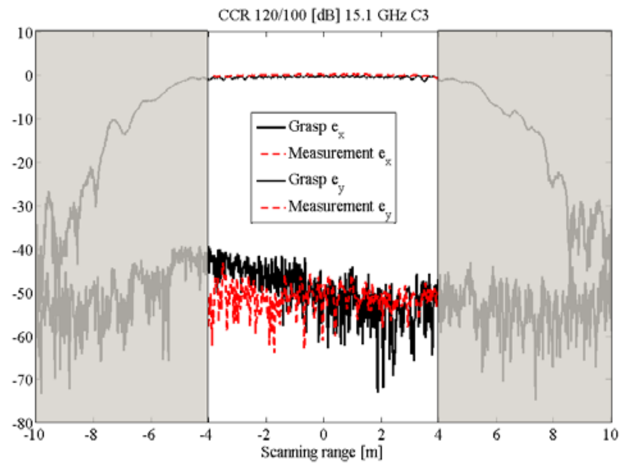

Figure 17. Comparison of simulated and measured CCR 120/100 QZ data at 15.1 GHz. Cut C3, magnitude [dB].

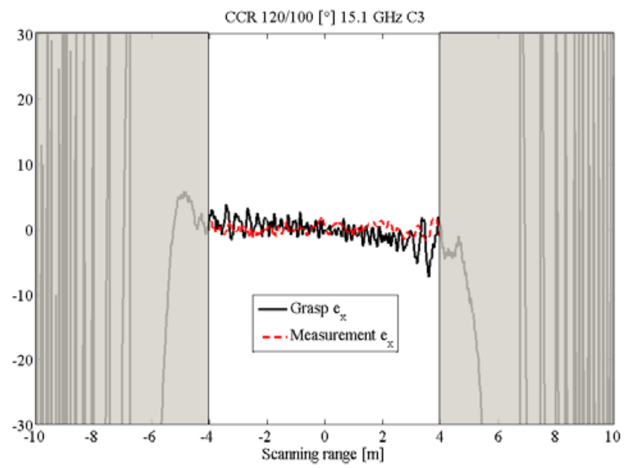

Figure 18. Comparison of simulated and measured CCR 120/100 QZ data at 15.1 GHz. Cut C3, phase [°].

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