Baffle and SERAP Design for Compact Antenna Test Ranges

C. Cappellin[1], P. H. Nielsen[1], D. Trenta[2], L. Rolo[2]
[1]TICRA, Copenhagen, Denmark, Email:cc@ticra.com, phn@ticra.com
[2]ESA/ESTEC, Noordwijk, The Netherlands, Email: damiano.trenta@esa.int, luis.rolo@esa.int

***Abstract*—A baffle and SERAP (Serration Radiation Protection) are designed to improve the quiet zone of the ESTEC Compact Payload Test Range (CPTR). The baffle has the purpose of preventing the feed to radiate in the quiet zone, while the SERAP prevents the feed to illuminate the main reflector serrations which create diffraction visible in the quiet zone. The baffle and SERAP are cylindrical structures covered by pyramidal absorbers, and their design is obtained with a general and computationally fast approach, which provides the radius of the cylinders and their location from the CPTR walls.**

***Index Terms*— measurement, quiet zone, high frequency methods, absorbers.**

I. INTRODUCTION

Compact Antenna Test Ranges (CATR) allow radiation pattern far-field measurements of an antenna under test (AUT) in an in-door and controlled environment and are thus widely used and preferred relative to traditional outdoor far-field measurement ranges. Moreover, CATR measurements do not need probe correction and near-to-far field transformation, achieving faster measurement time and easier mechanical alignment relative to spherical, cylindrical or planar near-field antenna measurements. These numerous advantages are however counter balanced by the lack of a well-defined estimation of the accuracy of the measured AUT pattern.

When measured in receive mode, the AUT is illuminated by an incident quasi-plane wave, called quiet zone field, generated by the single or double reflector system of the CATR. The antenna pattern measured in a CATR is the result of the interaction between the AUT aperture field and the quiet zone field [1-2]. Under ideal conditions, the quiet zone field is a perfect plane wave with uniform amplitude and constant phase. In practice, the quality of the feed, the finite surface accuracy of the reflectors and the diffraction from their edges introduce ripples on the uniform distribution of the quiet zone field in amplitude and phase, affecting the measured AUT pattern.

The ESTEC CPTR is a compensated dual reflector CATR taken into operation in the early 90's and operating from 3.4 GHz to 20 GHz. It is constituted by a paraboloid as main reflector and a hyperboloid as sub reflector, both with serrations, which generate a quite zone (QZ) of 5 m x 5 m x 7 m [3]. It was found during previous studies [4], that the main sources of the ripples in the quiet zone of the ESTEC CPTR are two: the first one is given by the direct illumination of the feed in the quiet zone, and the second one by the illumination of the main reflector serrations by the feed, which create a triple reflected ray visible in the quiet zone, as shown in Fig. 1. These two unwanted field contributions can be shadowed by two absorbing structures, of proper size and correctly positioned, called baffle and SERAP, respectively, with the resulting effect of improving the quality of the QZ.

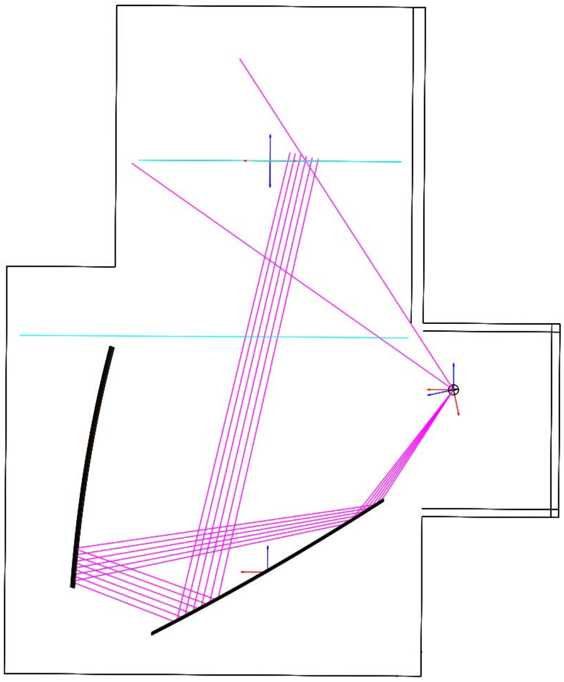

Fig. 1. GRASP model of the ESTEC CPTR and drawing of the direct (40°-45°) and triply reflected ray (47°-69°) of the feed.

The purpose of the present paper is to describe a general and computationally fast approach to design a baffle and SERAP for a certain CATR, on the basis of the room geometrical characteristics and the known feed patterns. The design approach is summarized in Section II, and later applied in Section III to the ESTEC CPTR. Conclusions are finally drawn in Section IV.

II. BAFFLE AND SERAP DESIGN APPROACH

The baffle and SERAP are designed to reduce as much as possible the direct illumination of the feed in the quiet zone and on the main reflector serrations, respectively, while accounting for the general size constraints of the room and the specific feed patterns. In practice, the baffle and SERAP are constituted by cylindrical structures covered by pyramidal absorbers working in the frequency range of the CATR.

To arrive at the optimal design and position of the baffle and SERAP, the following procedure is followed.

First, a GRASP model [5] of the CATR room is developed, by considering the optics of the CATR, the height of the serrations, the position of the existing walls and the radiation patterns of the feeds of the CATR. With this model, the nominal QZ is calculated with Physical Optics (PO) on the main and sub reflector. The reflector serrations are treated by the GRASP continuous model, by which the induced PO currents are slowly tapered to zero at the serrations tip. Later on, the direct illumination from the feed and the triply reflected ray are added to the nominal performances of the QZ to have a measure of their contribution on the QZ. These steps are performed at all frequencies of interest, and the frequency for which the QZ pattern is degraded the most is found and used in the subsequent steps.

The effect of the baffle and SERAP is then first modelled by a suitable tapering of the feed pattern up to a certain angle, after which the feed pattern is set to zero. This determines the limited angles of the feed pattern for both the direct and the triple ray radiation and coincides with assuming the baffle and SERAP as perfect absorbing structures that perfectly shadow the feed pattern. These direction angles are then used to generate the initial positions and sizes of the baffle and the SERAP. In doing that, the baffle and the SERAP are modelled as serrated plates with size equal to the diameter of the cylinder and serration lengths equal to the height of the absorbers needed on the two structures. Their shadowing effect is computed by PO. After an adjustment of the position of the cylinders or their radius, the optimal positions of the baffle and SERAP and the size of their cylinder are finally obtained.

The approach described above is computationally very efficient and provides the physical understanding of the radiation phenomena of the CATR, which are essential for a correct design and positioning of the SERAP and baffle. Moreover, the proposed approach is general and can be used for a given CATR, once its optics and feed patterns are known. It is noted that a more detailed RF modelling of the QZ performance of the CATR is possible, see [6], if the detailed geometry of each serration is known in surface and rim. A full wave analysis of the baffle and SERAP has also recently been proposed, see [7]. The resulted analysis is computationally very demanding and requires, to provide accurate results, the knowledge of the measured transmission and reflection coefficients of the absorbers covering the baffle and SERAP, for normal and oblique incidence. These parameters are in general not known from typical data sheets and have not been considered in [7]. The inaccuracies, which are introduced in the modelling of the SERAP and baffle when the oblique incidence parameters are not known, are indeed high. High enough to speculate whether the full wave simulation presented in [7] makes sense. Moreover, the correct full wave modelling of the absorbers of the baffle and SERAP requires multiple concentric dielectric regions with increasing ε'_r and tan δ. These simulate the absorbing boundary condition and avoid reflections from free space to the dielectric region, which otherwise occur when a single layer of dielectric material is considered [7].

III. BAFFLE AND SERAP FOR THE ESTEC CPTR

A. GRASP modelling of the ESTEC CPTR

A GRASP model of the ESTEC CPTR was developed by considering the detailed drawing of all walls (inner side of the shielding), the feed room specifications, the size of the absorbers existing in the vicinity of the feed, the position of the QZ and the optics of the CPTR, see Fig. 1.

The Planar Near Field rail, present in the same room, is 30 cm away from the serration of the sub reflector and crosses the anechoic chamber parallel to the quiet zone, as it is visible in Fig. 1. Five feed patterns, covering the frequency range from 2 GHz to 20.5 GHz were provided by ESA.

The initial RF performances of the QZ, where both the direct illumination of the feed in the QZ and on the main reflector serrations are added to the nominal QZ, are listed in TABLE I. It is seen that the largest QZ degradation of ±0.5 dB and ±3.9° is at 20.5 GHz, while at 2 GHz the performances are considered too pour. The computed QZ field at 20.5 GHz is shown in Fig. 2- Fig. 3 in amplitude and phase, respectively.

TABLE I. MAXIMUM QZ FIELD VARIATIONS OF AMPLITUDE AND PHASE

Frequency	Max amplitude variation	Max phase variation
2 GHz	±1.9 dB	±13°
5.9 GHz	±0.25 dB	±2.3°
9 GHz	±0.40 dB	±3.0°
16 GHz	±0.45 dB	±2.9°
20.5 GHz	±0.52 dB	±3.9°

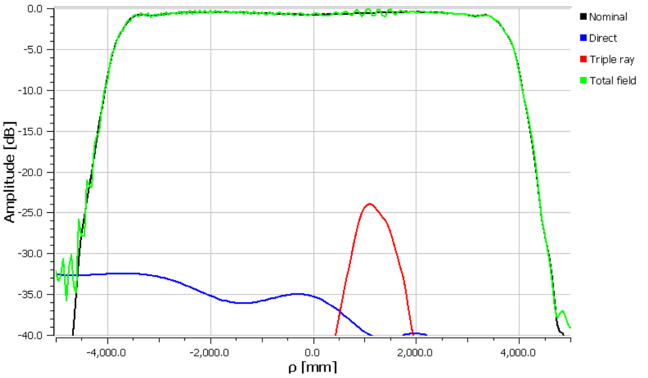

Fig. 2. Amplitude of the quiet zone field at 20.5 GHz: in green the total field, in black the nominal contribution of the sub and main reflector radiation, in blue the direct feed illumination and in red the triply reflected ray.

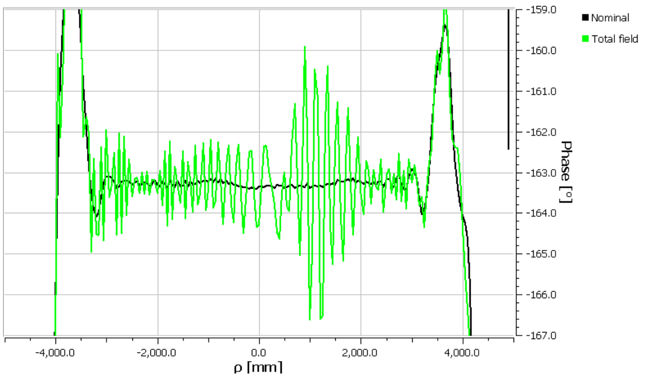

Fig. 3. Phase of the quiet zone field at 20.5 GHz: in green the total field, in black the nominal contribution of the sub and main reflector radiation.

B. Designed baffle and SERAP and improved performances

The GRASP model developed in Section A is then used to design the baffle and SERAP. The baffle and SERAP are initially assumed perfect absorbers and their shadowing effect on the feed pattern is simulated by setting to zero the pattern after a certain angle. The obtained RF performances in the QZ at 20.5 GHz for six pattern truncation angles are listed in TABLE II.

TABLE II. MAXIMUM VARIATIONS OF AMPLITUDE AND PHASE IN THE QZ IN FUNCTION OF THE FEED PATTERN TRUNCATION

Max. variation	Direct ray		Triple ray	
Truncation angle	amplitude	phase	amplitude	phase
30°	0 dB	0°	0 dB	0°
35°	0 dB	0°	0 dB	0°
40°	0 dB	0°	±0.41 dB	±2.7°
45°	0 dB	0°	±0.54 dB	±3.4°
50°	±0.14 dB	±0.9°	±0.52 dB	±3.3°
55°	±0.17 dB	±1.5°	±0.53 dB	±3.4°

The table shows that the influence of the direct ray and the triply reflected ray vanish with a feed truncation angle of 45° and 35°, respectively.

To make a detailed design of the baffle and SERAP we proceed as follows. The function of the baffle is to shadow the direct illumination of the QZ from the feed, and we have seen that the influence of the direct ray vanishes with a feed truncation angle of 45°. The function of the SERAP is to shadow the direct illumination of the main reflector and thereby reduce the field from the triply reflected ray, and we have seen that the triply reflected ray vanishes with a feed truncation angle of 35°. Therefore, the baffle edge is initially placed near the line of the 45° feed ray, and the SERAP edge is initially placed near the line of the 35° feed ray. The computation of the baffle and SERAP effect is finally performed by modelling the baffle and SERAP as serrated plates with normal in the truncation angle direction and with serrations of the same length as the absorbers (18’’). The tips of the serrations are on the line of the truncation angle. This results in a baffle given by a cylinder of radius of 243 mm, covered by 18” absorbers, giving a total outer radius of 700 mm. After optimizing the position of the cylinder, it is found that the baffle center is positioned at (x, z) = (5.42 m, 7 m) in the QZ coordinate system. The SERAP is given by a cylinder of radius of 343 mm, covered by 18” absorbers. This leads to a total outer radius of 800 mm. After optimizing the position of the cylinder, it is found that the baffle center is positioned at (x, z) = (5.46 m, 11.22 m) in the QZ coordinate system. A summary of the geometrical characteristics of the designed baffle and SERAP is given in TABLE III. while a drawing of the two designed structures in the ESTEC CPTR is shown in Fig. 4.

TABLE III. DETAILS OF THE DESIGNED BAFFLE AND SERAP

Geometry	Radius		Center position in QZ coor		Height
	Inner	Outer	x	z	
Baffle	243 mm	700 mm	5.42 m	7.0 m	2.8 m
SERAP	343 mm	800 mm	5.46 m	11.2 m	5.6 m

The height of the baffle and SERAP is selected to 2.8 m and 5.6 m, respectively, see Fig. 5. The SERAP height is the same as the height of the feed room to shadow the rays from the feed to both the top and bottom of the main reflector. The baffle is closer to the feed, giving a smaller illumination region on the baffle surface. Therefore, the baffle height can be reduced to half the height of the SERAP. To fully cover the feed room, and be on the conservative side, the height of the baffle can however be increased to 5.6 m.

The final RF performances of the QZ in amplitude and phase ripple with the designed the baffle and SERAP are listed in TABLE IV. together with the initial performances of the existing CPTR. It is seen that the improvement is significant at 20.5 GHz, and also visible at 2 GHz. The baffle and SERAP are planned to be manufactured and installed during the first half of 2019.

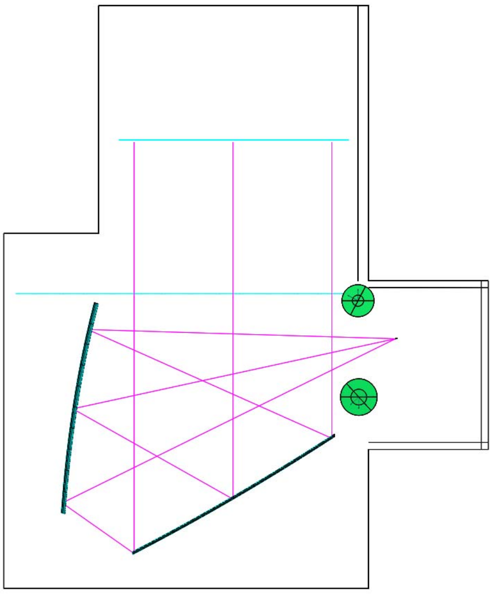

Fig. 4. Optimised baffle and SERAP positioned in the CPTR.

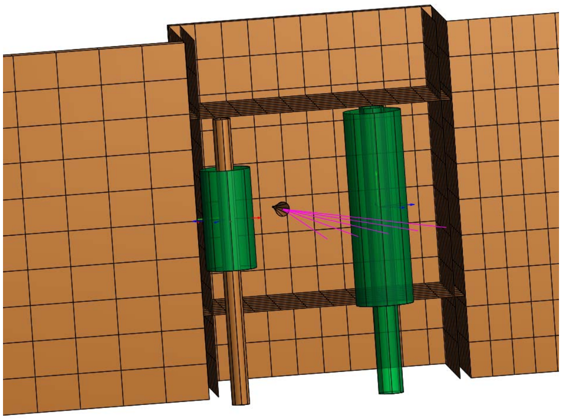

Fig. 5. SERAP and baffle in the CPTR, with view of the feed room.

TABLE IV. SUMMARY OF THE QZ RF PERFORMANCES: WITH THE DESIGNED BAFFLE AND SERAP AND WITHOUT

Max RF variation	Without baffle and SERAP		With baffle and SERAP	
Frequency	Max. amplitude	Max phase	Max. amplitude	Max phase
2 GHz	±1.9 dB	±13°	±0.3 dB	±2.4°
20.5 GHz	±0.52 dB	±3.9°	±0.002 dB	±0.05°

IV. CONCLUSIONS

An understanding of the radiation phenomena of the ESTEC CPTR, and a computation of its nominal QZ performances were provided. A baffle and SERAP (Serration Radiation Protection) were then designed to improve the quiet zone. The baffle has the purpose of preventing the feed to radiate directly in the quiet zone, while the SERAP prevents the feed to illuminate the main reflector serrations which create diffraction visible in the quiet zone. The baffle and SERAP are cylinders of 243 mm and 343 mm radius, respectively, covered by pyramidal absorbers with height of 18''. Their design was made following a general and computationally efficient approach, which provides a physical understanding of the radiation phenomena of the CATR under consideration and can thus be applied to any CATR, once its optics and feed patterns are known.

REFERENCES

[1] A. D. Yaghjian, “Efficient computation of antenna coupling and fields within the near-field region”, IEEE Transactions on Antennas and Propagation, Vol. AP-30, No. 1, Jan. 1982, pp. 113-128.

[2] C. Cappellin, S. B. Sørensen, M. Paquay, A. Østergaard, ”An accurate and efficient error predictor tool for CATR measurements”, Proc. EuCAP 2010, Barcelona, Spain, April 2010.

[3] Antenna Measurements Facilities at ESTEC, https://esamultimedia.esa.int/docs/space_engineering/Antenna_Measurement_Facilities.pdf

[4] F. Jensen, K. Pontoppidan, “Modeling of the antenna-to-range coupling for a compact range”, Proceedings of Antenna Measurements Technique Association, Symposium, AMTA, Denver, CO, USA, pp. 387-391, October 2001.

[5] GRASP software, https://www.ticra.com/software/grasp/

[6] O. Borries, P. Meincke, E. Jørgensen, H.-H.Viskum, F. Jensen, C. H. Schmidt, “Design and validation of compact antenna test ranges using computation EM” Proceedings of AMTA, Long Beach, California, October 2015.

[7] T. M. Gemmer, C. H. Schmidt, A. Geise, J. Migl, “Full-wave analysis of compensated compact ranges including absorber structures”, Proceedings of EuCAP, Davos, Switzerland, April 2016.