Performance Comparison Between Serrated Edge and Rolled Edge Reflectors Inside CATR Facilities

A. Muñoz-Acevedo*, S. Burgos+, M. Sierra-Castañer*

* Grupo de Radiación, Dpt. Señales, Sistemas y Radiocomunicaciones, Universidad Politécnica de Madrid (UPM)
Av. Complutense s/n, Ciudad Universitaria, 28040 Madrid, Spain
{alfonso, mscastaner}@.gr.ssr.upm.es
+*Antena Systems Solutions (ASYSOL)*
Office 01, Centro de Empresas, Parque Científico y Tecnológico UPM,
Campus de Montegacedo, 28223 Pozuelo de Alarcón , Madrid, Spain
sburgos@.asysol.com

***Abstract*— CATR facilities are attractive antenna measurement facilities. Main reasons which contribute to this fact lie on its inherent reduced volume, on-the-fly measurements and the extension of both to a wide range of frequencies. However, these features rely on the assumption that the field collimation scheme is able to generate a plane wave distribution (quiet zone) where the AUT is to be placed and operated in RX mode. Unfortunately, electromagnetic theory states that this field distribution is not possible to be generated by a finite size scatterer operated as the collimator of a nonzero wavelength time-harmonic propagating field. This is the background of this paper, where two well-known electromagnetic field collimators will be discussed: the serrated edge reflector and the blended rolled edge reflector. To reach this purpose, electromagnetic hybrid analysis techniques developed at Technical University of Madrid will be applied.**

I. INTRODUCTION

Reflector-based compact ranges make use of field reflecting surfaces following a disposition which pursues a wave transformation from spherical wavefront to planar wavefront. To this purpose, ad-hoc conformal techniques are carried out over each one of the reflectors involved in the process. These techniques mainly affect the edge of the reflectors and the feeder antenna scheme [1]. While the first group of techniques deal with the reflector's behaviour as a field diffracting device, the conformal feed techniques beat the amplitude tapper introduced by the spherical wavefront propagation towards a parabolic reflector.

In this paper, we will focus on the reflector edge treatment techniques. Two classical concept approaches to them are the serrated edge reflectors and the rolled edge reflectors. Following the theoretical constraint involving the feasible planarity of the diffracted wavefront, the two concepts will be discussed.

II. ELECTROMAGNETIC ANALYSIS

A. *Formulation background*

Regardless of which edge conformation alternative is object of our analysis, the main feature of any reflector operated as a field collimator is its necessarily huge size, in terms of wavelength. While this fact sets limits to its lower frequency of operation within certain quiet zone planarity criteria, it also makes a well-behaved field collimator an intrinsically EM task difficult to cope with. This background has made CATR design and EM analysis techniques development parallel tasks at Technical University of Madrid. These EM analysis techniques aim to fulfil three practical principles which serve design tasks: accuracy, computational efficiency and flexibility.

In general lines, results accuracy and computational efficiency evolute inversely one respect to the other [2]. Our approach to this bottleneck is to increase the computational efficiency of the formulated problem by choosing assumptions which are acceptable within a CATR facility [3,4,5], as well as using a hybrid approach to the analysis problem which makes use of different order physics depending on the assumptions drawn. Tangential contributions to the computational speedup rely on closed-form expressions [6] and FFT-based operations at certain modules of the hybrid formulation. Accuracy is reached through a careful choice of the simplifying assumptions, as well as the use of higher order physics in addition with simpler approaches, where necessary.

B. *Hybrid approach*

Here, a GO-PWS formulation of the analysis approach will be used to analyse an offset fed reflector. The scattering problem is only of interest in the forward half-space of the reflector, and is divided in two regions of propagation. The field propagated from the feed towards to the reflector can be assumed to be in farfield when it reaches the scatterer. PO's high frequency hypothesis is taken to calculate the induced currents in the typically high f/D ratio reflectors used inside CATRs. They are projected [7] towards a maximally close planar domain and spatially sampled, following a Nyquist criterion at the frequency of interest.

This discretized information is used to perform FFT computations and, thus obtain the plane wave spectrum distribution which characterizes the facility. From this point, the field distribution can be easily and efficiently calculated in any space of the forward half-space of the reflector. A dense formulation of this approach, applied to the serrated-edge reflector can be found at [3,4,5]. The use of this analysis approach for rolled edge geometries is for first presented here and is still on its first developments.

III. PERFORMANCE MONITORS

A. *Spectral fields monitors*

As pointed out in the introduction, the on-the-fly operation of a compact range relies on the planarity of the quiet zone. Antenna measurements theory states that the AUT's measured radiation pattern is obtained from the vectorial convolution between its actual pattern and the arrival signals from its environment [8,9].

Whenever the quiet zone distribution is not a plane wave, or contains spurious polarization components, its vectorial spectral representation will not be the delta and, thus, the measured pattern will not be the exact AUT pattern. This discrepancy is a quantitative figure of the performance for a particular CATR.

With this in mind, the maximum projected surface of the antenna over the quiet zone bounds the planar acquisition domain that affects the range performance. Commercial CATR specifications set root mean square and peak values for field ripple within a certain spatial range, which is a figure of both the quality and extension of the so accepted quiet zone. If the projected surface of the antenna exceeds this region, no warranty can be offered about the measurement's accuracy. However, if this projected surface is substantially smaller than the specified QZ extension, the field quality within that region may be locally higher than specification figures.

Figure 2 depicts the immersion of an AUT with circular projected surface (continuous line) inside a QZ generated by a sample blended rolled edge reflector. The dotted line bounds the specified QZ, while the dashed line stands for the region where the QZ fields affect the measurement performance for this particular AUT. Given that the convolution deals with vectorial complex fields, pattern measurements require a vectorial QZ field characterisation both in amplitude and phase. In Fig. 2, both **x** and **y** components of **E** field are normalized the peak value of the co-polar field (y-polarized).

Following this approach, a spectral monitor for a particular facility and an AUT would be the 2-dimensional FFT of the fields inside the minimum size window.

B. *Spatial fields monitors*

Following the specifications' notation, the performance of a CATR can also be described in terms of rms and peak values in amplitude and phase. These figures stand for the spatial planarity of the complex wavefront in the quiet zone region. While it offers a clear idea of this planarity, it is less meaningful in the transformed modal domain, where the convolution occurs between the AUT pattern and the incoming wavefront.

When defining this ripple figures, two main effects contribute to the general non planarity of the facility: spherical

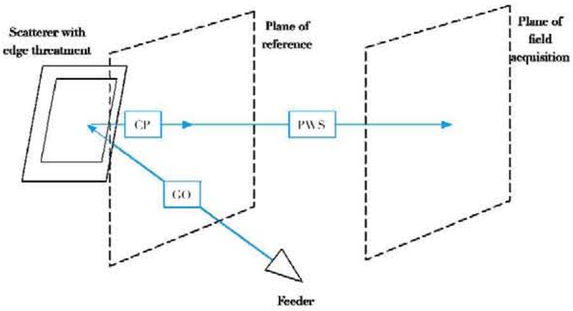

Fig. 1 EM hybrid analysis approach for edge threatened reflectors

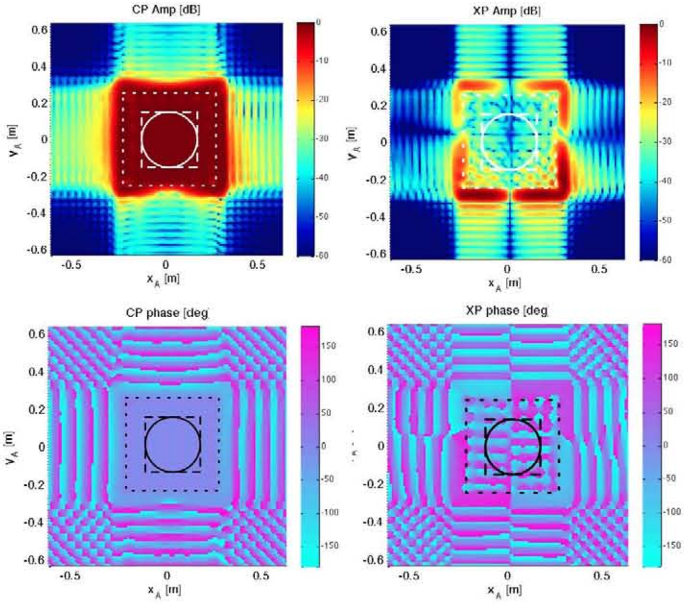

Fig. 2 Vectorial characterisation of QZ generated by rolled edge reflector. Amplitude distributions of **y** (a) and **x** (b) polarized field and their respective phases in (c) and (d) subfigures.

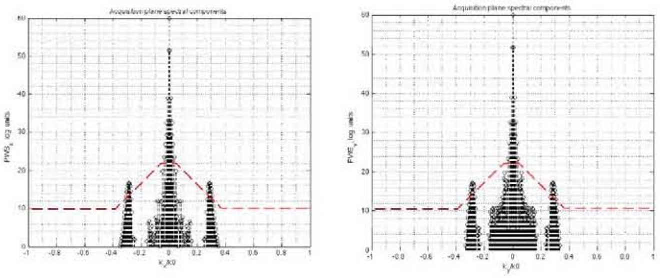

Fig. 3 PWS spectral modes of the whole acquisition plane: vertical (a) and horizontal (b) cuts for **y**-polarized distribution.

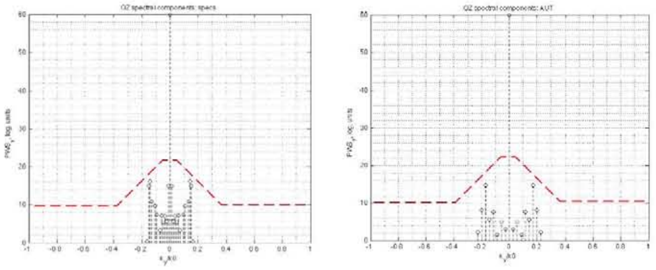

Fig. 4 PWS spectral modes of the specifications domain (a) and AUT domain (b) for **y**-polarized distribution.

wave propagation scheme towards the reflector and diffraction effects generated by it. The first term is known as taper contribution, or GO field, and is independent of the frequency of operation as well as the upper bound of the achievable planarity of the facility. On the other side, the diffraction term is directly influenced by the edge treatment scheme.

C. *Stray signal monitors*

A complementary point of view of quiet zone performance lays on the stray signal concept. It expresses the QZ fields as the summation of the desired plane wave distribution and a stray signal distribution. This stray signal contribution includes orthogonal polarization contributions, diffraction effects and feed scheme influence over amplitude taper. The addition of contributions from several independent factors of design make this kind of monitors a useful tool for a first approach to the problem, but a quite non-practical way to optimize a reflector, due to its intrinsic inability to isolate field contributions.

In spite of the ambiguity of a stray signal monitor, it can be implemented to focus on one particular design aspect. In [11], this idea is used to evaluate the stray contributions of the diffracted rays over the quiet zone, reaching design conclusions through PO-PTD analysis.

IV. EDGE TREATMENT TOWARDS ANALYTICAL MODELLING

The design variables which influence QZ performance deal, both for serrated edge as well as blended rolled edge reflectors, with two sets of variables. On one side, the former parabola is defined with its focal length and the desired feed scheme. These variables influence mainly the amplitude taper introduced by the spherical wave propagation from the feed towards the reflector. Preferred configurations regarding these degrees of freedom choose high focal distance over diameter facilities, which minimize the amplitude tapper of the incident wavefront over the reflector. Corner-fed offset reflectors are able to maximize the compactness of the CATR, reducing the separation between reflector and AUT below the focal distance, as mandatory in single offset-fed facilities. The projected surface of a blended rolled edge reflector following simple offset feeding and corner feeding is depicted in Fig. 5. The projected location of the focus is depicted with a red square.

On the other side, the edge treatment variables handle the diffraction scheme that is expected to minimize the field ripple within the desired QZ region. For serrated edge reflectors, these variables are: the number of serrations, their size, shape and distribution scheme [11,5]. Regarding rolled geometries, these parameters handle the blending scheme and involve the major and minor axis of the rolling ellipse, in addition with blending schemes, in the case of blended rolled edge geometries [12,13].

At Technical University of Madrid, the research line involving CATR design through edge-treated reflectors focuses on analytical analysis-design skills. A summary of these families of analytical parameters can be found in Table 1, and discussed in [5,11,12,13].

TABLE I CONFORMAL EDGE MODELING

Edge treatment aspect	**Serrated edge**	**Blended rolled edge**
Size	Serration depth, Number of serrations	Rolling ellipse
Shape	Different order Cosine-shape serrations.	Junction rim topology: concave/convex
Conformation.	Modulation schemes for serrations	Blended-rolled edges

TABLE II CATR FACILITY DEFINITION

Parameter	**Constraint**
Frequency of operation	60 GHz
Focal distance	1.3 m
Feed scheme	Corner fed (0.2 m clearance in both X/Y dimensions)
Acquisition plane	1.5 m away from the reflector
Feed scheme	y-polarized field, with -3.0 dB taper at 20 deg. from peak. Low crosspolar level.
QZ specs.	1.0 dB peak-peak, 10 deg peak-peak
Reflector size	Max. width/height: 0.6 m
Absorber material	Assumed to be perfectly absorbing at 60 GHz.

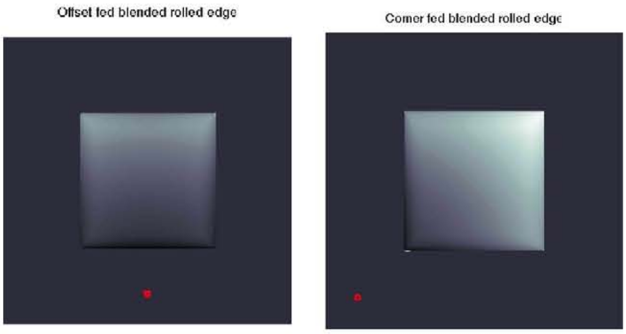

Fig. 5 Feeding schemes: offset fed sample rolled edge reflector (a) and corner fed alternative (b), with same focal length as subfigure (a).

V. NUMERICAL RESULTS

Following the explained methodology of analysis, sample feasible reflectors from the two main discussed alternatives will be tested. The CATR in which it should be used is defined by the parameters in Table 2. Within this design framework, the performance comparison aims to evaluate which edge treatment alternative is able to maximize the QZ size within specifications.

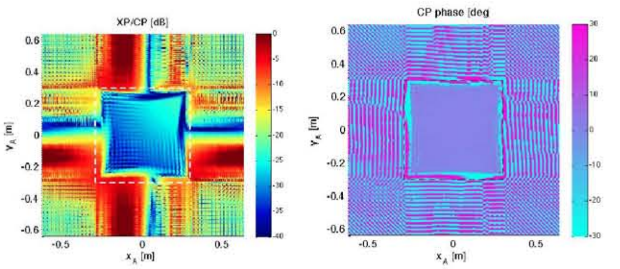

Fig. 6 Fields in XY grid for blended rolled edge: crosspolar figure (a) and co-polar phase distribution (b).

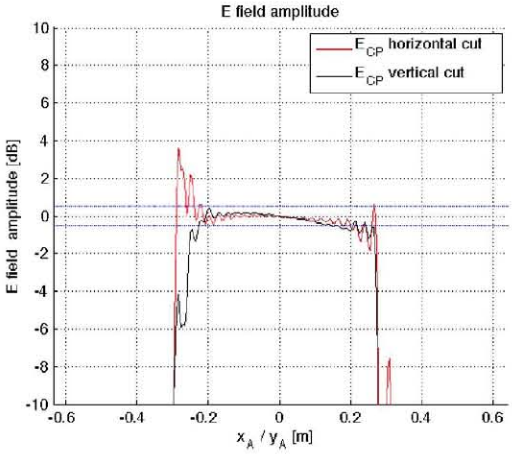

Fig. 7 Amplitude cuts for blended rolled reflector.

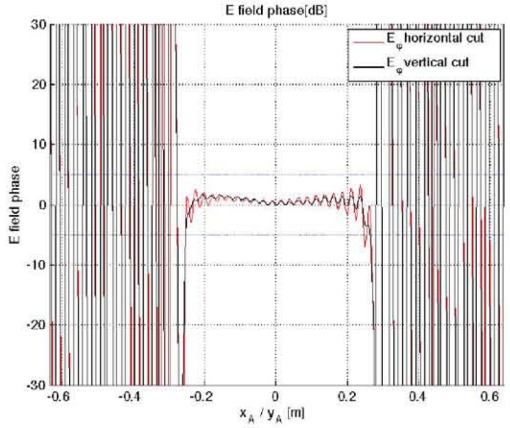

Fig. 8 Phase cuts for blended rolled reflector.

A. *Blended rolled edge*

The design alternative for the reflector under study follows literature conclusions regarding optimal blended rolled edge reflectors. Further explanation about the election of the design parameters can be found at [12]. Figure 6 depicts an overview of amplitude and phase acquisitions showing the crosspolar level (x-polarization) related to the co-polar (y-polarization) fields, as well as a phase evaluation for the y-polarized field.

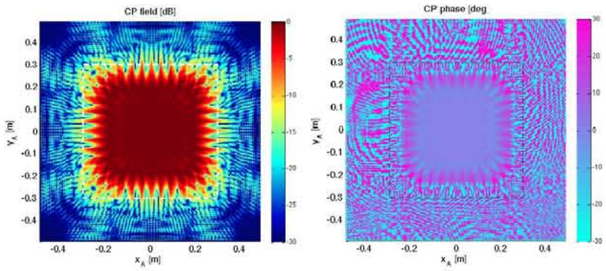

Fig. 9 Fields in XY grid for blended rolled edge: co-polar normalized magnitude (a) and co-polar phase distribution (a).

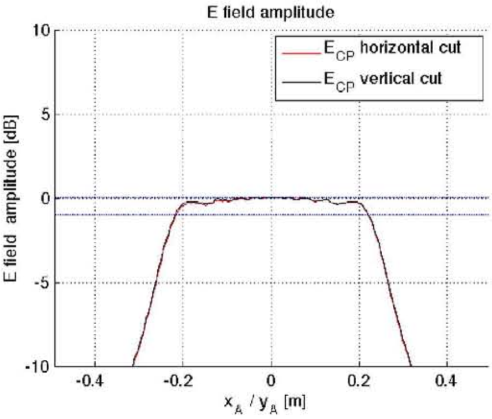

Fig. 10 Amplitude cuts for serrated edge reflector.

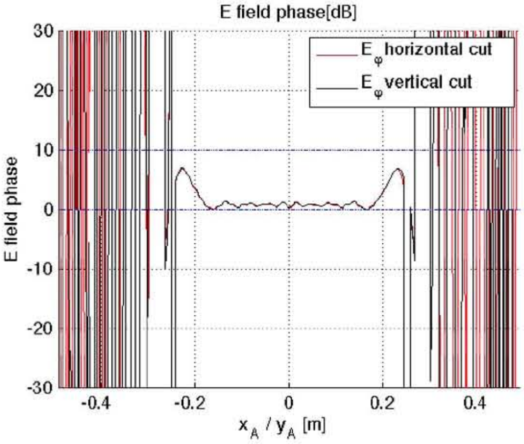

Fig. 11 Phase cuts for serrated edge reflector.

B. *Serrated edge*

The sample chosen reflector is the design alternative taken at Technical University of Madrid for its mmWave facility. The design has cosine-shape serrations which follow a modulation scheme [5] and is optimized for a wide frequency margin of operation between 30 GHz-300 GHz. The serration height is chosen to be one sixth of the maximum width of the projected surface, which is a rule of thumb that solves the tradeoff between the QZ size and its field quality. The mechanical

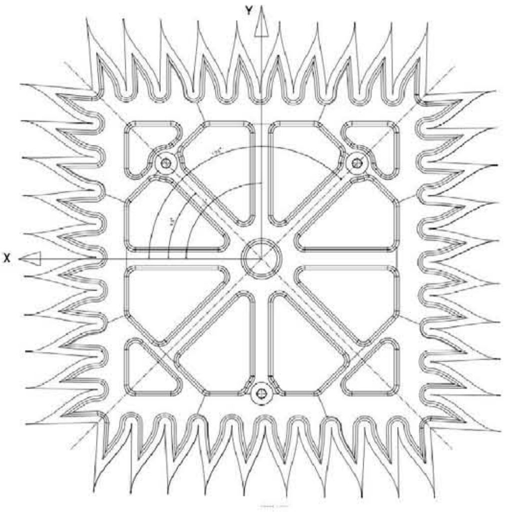

Fig. 12 Mechanical design of the serrated edge reflector.

design of this reflector, from the structural point of view is depicted in Fig. 12.

VI. CONCLUSIONS. FUTURE WORK

This paper has presented two well-known implementation alternatives for field collimating structures. Parting from the evidence that general conclusions are difficult to reach, a design prototype of each alternative has been chosen and QZ fields have been calculated. Each prototype is assumed to be a high performance candidate among its respective family of reflectors, so the unitary simulations must be seen as sub-optimal approaches of both serrated-edge and blended rolled-edge alternatives.

On the other hand, the analysis algorithm accuracy is determined by the high frequency hypothesis assumed to evaluate the projected currents. A deeper study of both blended rolled and serrated edge geometries would also require the use of higher order physics (MoM over the reflector's surface or PTD along its edge) to evaluate these geometries.

Bearing in mind these contour conditions, it can be seen from the detailed amplitude/phase cuts that the serrated edge reflector achieves wider and purer quiet zone fields for a given maximum reflector size and a fix focal distance. This electrical analysis must be seen as a contribution to the whole cost figure, which should also include the feasibility of the reflector, its economical cost, and the long-term structural consistence of the structure.

Future work consists on the development of higher order Electromagnetic Physics formulations, which can improve the accuracy of the proposed analysis skills, and thus offer more realistic results of the fields inside the quiet zone. To this purpose, these formulations should be followed by a model which must be able to evaluate the effect of typical surface distortions over the reflector's surface.

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