Digitally Reconfigurable Approach to Compact Antenna Test Range Design

C.G. Parini[1], R. Dubrovka[2], S.F. Gregson[3]
[1] Queen Mary University of London, London, UK, c.g.parini@qmul.ac.uk
[2] Queen Mary University of London, London, UK, r.dubrovka@qmul.ac.uk
[3] Nearfield Systems Inc. Torrance, CA, USA, sgregson@nearfield.com

Abstract—**The efficiency of use of the parabolic reflector of a single offset reflector compact antenna test range (CATR) is affected largely by the illumination provided by the range feed and the reflector edge treatment. Thus, when these factors are taken together it is commonly found that the realized quiet zone (QZ) diameter is typically as little as 30% of the diameter of the reflector for the commonly encountered case of a single offset CATR. Furthermore, single offset CATR performance is known to degrade as the wavelength of the illuminating fields becomes more comparable with the physical dimensions of the reflector because the physical optics (PO) assumption needed for collimation of the reflected field becomes less effective. Different reflector edge treatments such as rolled or serrated edges are commonly employed to taper the intensity of the reflected fields at the reflector aperture boundary, seeking to minimize the level of diffracted fields in the quiet-zone (QZ). Such strategies mean that at higher frequencies the transverse dimensions of the QZ are unnecessarily reduced thereby decreasing the spatial efficiency of the CATR and limiting the effective bandwidth of the antenna test system. In this paper we report preliminary results that begin to investigate the alternative strategy for controlling the signal illuminating the CATR reflector by utilising a shaped beam feed antenna. Building on our previously reported work of efficient CATR computational electromagnetic simulation, we report the use of an array feed whose excitation is optimized to achieve maximum QZ size for a given reflector dimension thereby minimising the cost of a new test system or increasing the capacity of an existing one. We illustrate the concept by employing the technique with a sector-shaped, single offset reflector CATR by examining the impact that this has on the amplitude taper and the amplitude and phase peak-to-peak ripple. We demonstrate that a 9-element array feeding an un-serrated rim reflector can attain a useable QZ size approaching 50% the size of the 80λ diameter main reflector.**

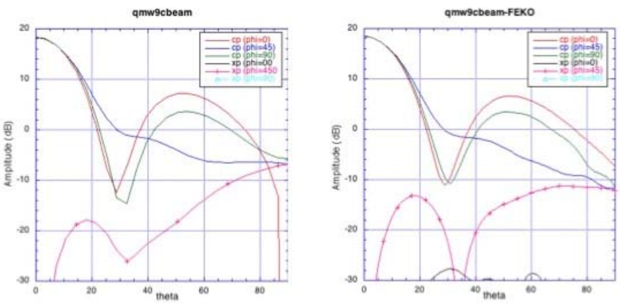
Index Terms— **Compact Antenna Test Range, Quiet-Zone, Feed Array, Reflector Efficiency.**

I. Introduction

The single-offset compact antenna test range (CATR) is a widely deployed technique for broadband characterization of electrically large antennas at reduced range lengths [1]. The nature of the curvature and position of the offset parabolic reflector as well as the edge geometry ensures that the resulting collimated field is comprised of a pseudo transverse electric and magnetic (TEM) wave. Thus, by projecting an image of the feed at infinity, the CATR synthesizes the type of wave-front that would be incident on the antenna under test (AUT) if it were located very much further away from the feed than is actually the case with the coupling of the plane-wave into the aperture of the AUT creating the classical measured "far-field" radiation pattern. The accuracy of a pattern measured using a CATR is primarily determined by the phase and amplitude quality of the pseudo plane-wave incident on the AUT aperture, with this being restricted by two main factors: amplitude taper (which is imposed by the pattern of the feed), and reflector edge diffraction, which usually manifests as a high spatial frequency ripple in the pseudo plane-wave [2]. It has therefore become customary to specify CATR performance in terms of amplitude taper, and amplitude & phase ripple of this wave over a volume of space, termed the quiet zone (QZ). Unfortunately, in most cases it is not directly apparent how a given QZ performance specification will manifest itself on the resulting antenna pattern measurement. However, with the advent of powerful digital computers and highly-accurate computational electromagnetic (CEM) models, it has now become possible to extend the CATR electromagnetic simulation to encompass the complete CATR AUT pattern measurement process thereby permitting quantifiable accuracies to be easily determined prior to actual measurement. An extensive study of the accuracy of this approach was reported by the authors in [3].

Amplitude and phase ripple of the quiet zone is still the dominant performance criteria of a given CATR facility with an industry standard being ±0.5dB and ±5° amplitude and phase ripple respectively defining the QZ dimension [1]. These performance criteria are usually determined experimentally by probing the QZ with a planar scanner using either plane-polar or plane-rectilinear acquisition geometries. In a recent paper [4] the authors have detailed the CEM simulation of the measurement of a CATR QZ using arbitrary but known near-field probes using both the Plane Wave Spectrum (PWS) and Reaction Integral (RI) based modelling techniques. These models include effects associated with cross polarisation and polarisation purity of the respective scanning field probes and so it is possible to utilise measured *or* simulated patterns for the field probe to predict the "measured" QZ performance.

In [5] the authors presented results of a preliminary design study using an array of waveguide elements as the feed to optimally control the illumination of the CATR reflector. Two techniques were considered, reflector edge serrations and the alternative strategy of tapering the reflected field at the edge of



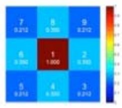


Fig.1 Comparison of radiation pattern cuts for a 25 element array feed using both CEM model (right) and the modal mutual coupling approach (left). Element excitations shown on the inset right.

the CATR aperture using a shaped beam such that the edges coincide with "ideally" a pattern null.

The aim of the array approach is to maximize uniformity of illumination over some portion of the reflector whilst also providing the field intensity windowing needed to minimize edge diffraction effects thereby enabling greater aperture efficiency to be achieved for a given reflector size [1]. The work in [5] demonstrated a new efficient CATR computational electromagnetic simulation that enables a feed array (including mutual coupling effects) to encompass the design optimization loop. As an example of this work Fig. 1 compares the radiation pattern cuts of a 9 element rectangular array (shown inset to the figure, the aperture dimension of the array element is 0.933λ square, giving a dimension of the overall 9 element array of 2.96λ) computed using a CEM tool (FEKO) and our fast array feed calculation based on modal approach that implicitly includes the effect of mutual coupling. The agreement is excellent the slight differences being associated with the fact that our model assumes the elements are set in a metal ground plane whereas the CEM model includes just the real thickness of the array element walls. Comparing processing times for the two methods using a high end PC was 30 minutes for the CEM case and 1 second for our modal mutual coupling approach. More details about the fast array model can be found in [5]. By employing this fast array model with a simple genetic optimiser we can change the array element excitation to give a feed pattern that would offer near uniform illumination across the main part of a CATR reflector thereby minimising the amplitude taper within the CATR QZ.

As an example of the initial results of using the optimiser a 9-element rectangular horn array feed was used with a sector shaped CATR (based on the 3m CATR that forms the 8GHz to 60GHz CATR facility at Queen Mary University of London's (QMUL) Antenna Measurement Laboratory), and Fig. 2 compares simulated CATR field results using both this array feed and a conventional corrugated horn. In this case the simple target array feed pattern was that of constant amplitude illumination across ±7° degrees, which represents the centre 1m of the CATR reflector's projected cross-sectional aperture in the AUT test-zone. Fig. 3 summarises QZ results for untreated reflector edge using both corrugated horn and array feed comparing amplitude taper and ripple (top), and phase ripple (bottom). Clearly these results indicate that, due to reflector edge diffraction, the QZ ripple is too high for this CATR facility to operate at an 8GHz target frequency with either the corrugated horn or array feed. However, we now use our prediction software to demonstrate how the use of reflector edge serrations can drastically improve the CATR QZ performance.

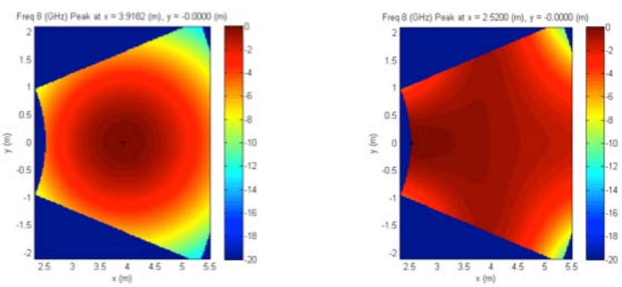


Fig 2 Simulated CATR field for corrugated horn feed (left) compared to 9 element array feed (right)

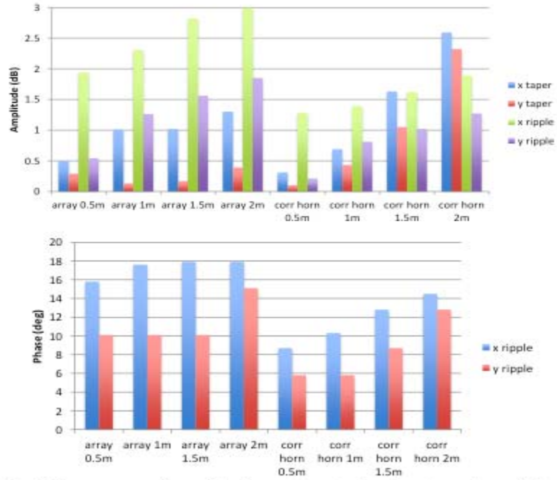


Fig.3 Summary of results for untreated reflector edge with both corrugated horn and array feed comparing amplitude taper and ripple (top) and phase ripple (bottom).

In Fig. 4 we show the simulated CATR field after serrations were applied to the reflector edge, with serrations 7λ in depth at the sides and ranging from 7λ to 17λ along the reflector top and bottom edges, where diffraction is likely to be strongly cumulative in the QZ. Fig. 5 shows summary results for the QZ amplitude taper and ripple and QZ phase ripple, the scaling is identical to that for the untreated reflector results of Fig. 3 and so can be directly compared. Clearly, significant improvement in both phase and amplitude ripple is seen, and if we take as a usability criteria of a maximum amplitude taper

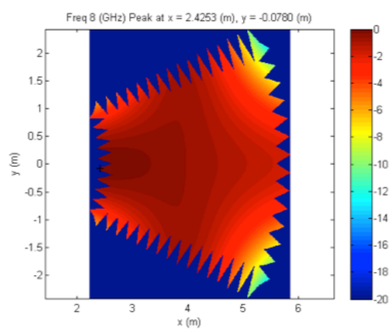


Fig 4 Simulated CATR field for 9 element array feed with serrated reflector edge.

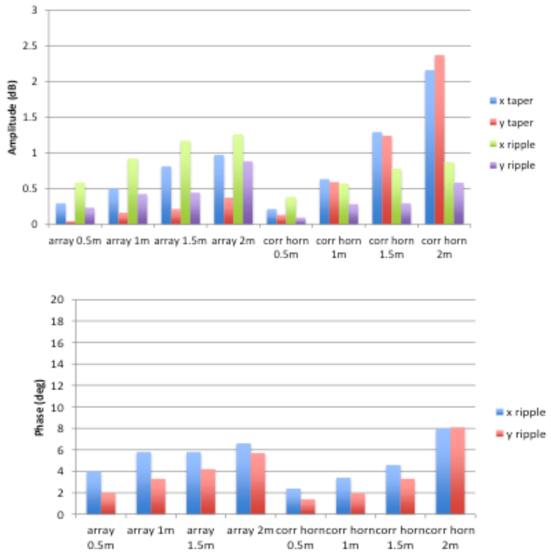


Fig 5. Summary of results for serrations on the reflector edge with both corrugated horn and array feed comparing amplitude taper and ripple (top) and Phase ripple (bottom).

and ripple of 1dB and maximum phase ripple of 10° then the QZ for the array is now close to 2m whereas that for the corrugated horn is around 1.5m due to the far higher amplitude taper confirming the expected improvement in the efficiency with which the CATR reflector is illuminated by the array feed. We have not attempted to optimise the serrations for this case as the aim was simply to demonstrate what can be done with an array feed compared to a conventional horn.

In the remainder of this paper we aim to further demonstrate the potential of array feeding a CATR reflector by considering a larger array and more complex target functions for the array feed optimiser.

II. UNIFORM ILLUMIATION TARGET FUNCTION WITH SERRATED REFLECTOR

Building on the promising results of Figs 4 & 5 the use of a 25-element array (5x5) was investigated, the array elements

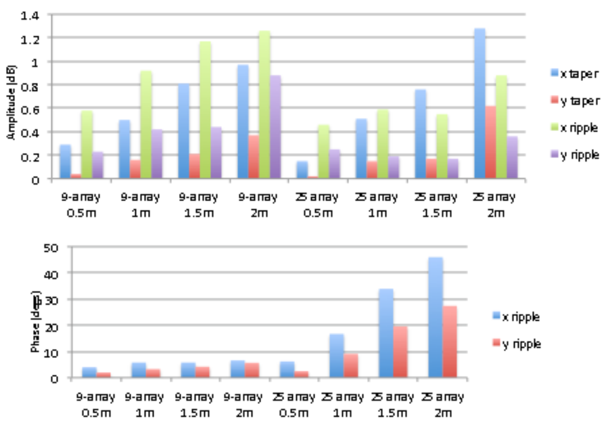


Fig 6. Summary of results for serrations on the reflector edge with 9 element and 25 element array feed comparing amplitude taper and ripple (top) and Phase ripple (bottom).

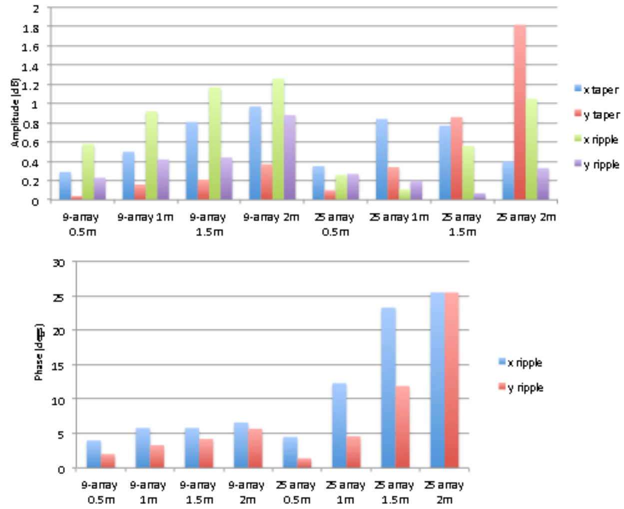


Fig 7. As fig 6 but with 25 element array feed using target function accounting for 1/r amplitude taper and increased iteration count (16,000). Amplitude taper and ripple (top) and Phase ripple (bottom).

being the same size as those used in the 9-element array, and the target pattern comprising the same constant amplitude illumination across ±7° degrees. Fig. 6 shows summary results for the QZ amplitude taper and ripple and QZ phase ripple for both the 9-element and 25-element arrays. Although the 25-element array offers improved amplitude ripple and taper the phase ripple rapidly exceeds that required of the QZ. This is probably not surprising as the simple optimiser has no phase constraints and so the large number of degrees of freedom offered by the larger array means the phase is not directly constricted. In Fig. 7 we show results where the 25-element case has a target function that removes symmetry in the horizontal plane and thus allows for a target pattern that takes account of the 1/r amplitude taper across the reflector [1], in addition the optimiser was run for a very extended time (16,000 iterations – taking *circa* 5 hours of processing time – compared to the nominal 3,000 – taking a matter of a few minutes – used in all the above cases). Here the 25-element amplitude and phase ripple are improved but the main issue of lack of phase constraint still predominates.

III. SHAPED PATERN AMPLITUDE TARGET FUNCTION FOR PLAIN RIM REFLECTOR USE.

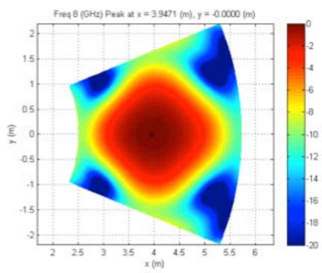


Fig. 8 Reflector amplitude for target function that is constant out to 7° and then Gaussian down to -20dB at reflector edge.

In this section we investigate amplitude target patterns that are shaped to minimise the illumination of the reflector rim and avoid the need for edge serrations. As a starting point Fig. 8 shows the reflector field amplitude for a shaped beam that is constant out to 7° and then tapers off in

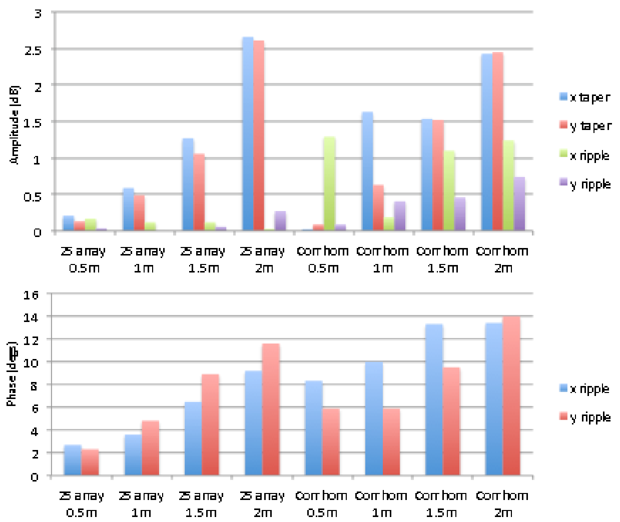


Fig 9 Summary of results for the shaped target function used in figure 8, compared to the corrugated horn feed. Amplitude taper and ripple (top) and Phase ripple (bottom).

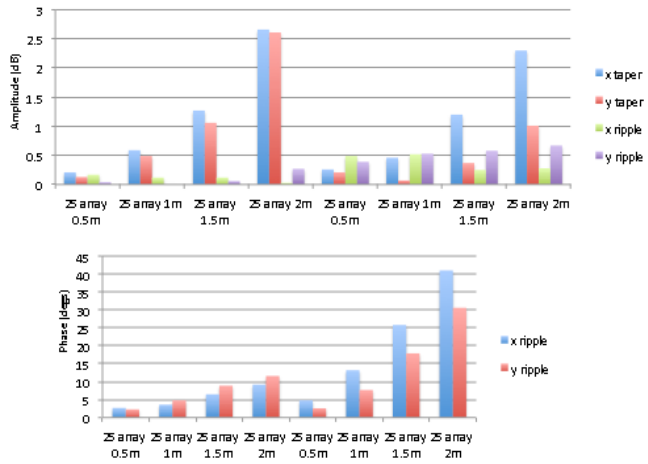


Fig 11 , Summary of results for the symmetrical back-projected target function used in figure 10 – right hand side, compared to the Gaussian target pattern of Fig.8 – left hand side. Amplitude taper and ripple (top) and Phase ripple (bottom).

a Gaussian manner to reach -20dB at the reflector edge. Fig. 9 summarises the results and compares them with those for the conventional corrugated horn feed. Whilst the corrugated horn feed does not meet the QZ amplitude ripple for even a 0.5m QZ, the use of the shaped beam array shows that a QZ of nearly 1.5m is possible within the ±0.5dB and ±5° criteria. This is a significant achievement and demonstrates that an array feed and a plain rim CATR reflector *can* achieve a QZ that is 50% the size of the 80λ diameter main reflector, as opposed to the 30% efficiency that is more typically achieved.

We next investigate an amplitude target function that is specified at the QZ and which is than back-projected to obtain the desired feed target pattern. We used a simple QZ target pattern of uniform illumination over ±6° and then Gaussian roll-off to the reflector edge and assumed that it was symmetrical in *x* and *y*. The resulting optimised 25-element feed yielded the reflector field amplitude shown in Fig. 10, and a summary of the performance, compared with Gaussian target pattern of Fig. 8, is shown in Fig. 11. Here, we see slightly improved amplitude performance because of the tighter control but the phase performance is poorer, again because we are applying no phase constraint at this point. In Fig. 12 we compare the result of Fig. 11 with the result for the identical case but with the array excitation phase quantised to just 0° or 180° since these are easily achieved, broadband phase changes. As expected this simple constraint on the phase has considerably reduced the QZ phase ripple to well below ±5° for a small increase in amplitude ripple. In this case the QZ size is about 1.25m and very similar to the result for Fig. 9.

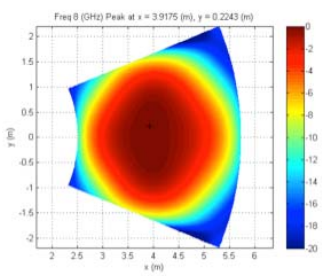


Fig 10. Reflector amplitude illumination from 25-element array with symmetrical back –projected target function

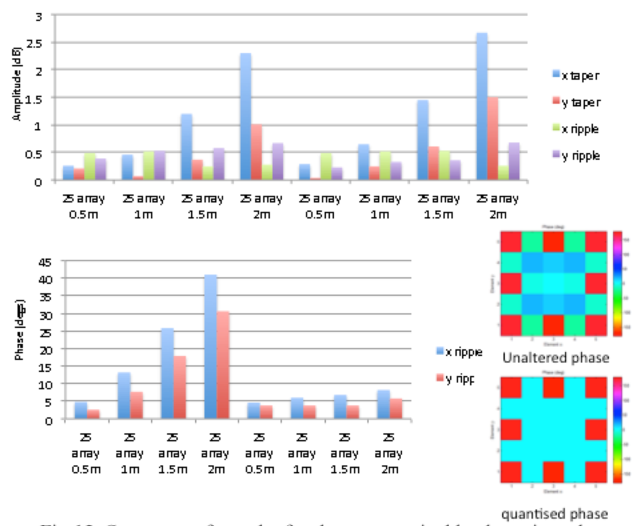


Fig 12. Summary of results for the symmetrical back-projected target function used in figure 10. left hand side= array excitation phase unaltered; right hand side= array excitation phase quantised to 0° and 180° . Inset figure shows array excitation phase unaltered (top) and quantised (bottom).

IV. Summary And Conclusions

In this paper we have presented preliminary results of an on-going study to investigate the use of an array feed with a single offset reflector CATR aiming to improve and enlarge the QZ offered by a given reflector. At this stage of our research we have employed a simple optimisation process and used several amplitude only optimisation criteria. To demonstrate the flexibility of the approach we have chosen to apply the method to a sector shaped single offset CATR reflector. Firstly we considered the case of a serrated edge reflector and attempted to maximise the QZ size compared to a conventional corrugated horn feed. Both 9 element and 25 element arrays were investigated and we have demonstrated that improved QZ size can be achieved by employing an array but that the lack of phase constraint in our optimisation is limiting performance.

We then demonstrated that shaping the illumination with a 25-element array, such that the rim of the un-serrated reflector has low illumination, can produce a useable QZ size approaching 50% the size of the 80λ diameter main reflector. In contrast no usable QZ was possible with this plain rim reflector and a conventional corrugated horn feed thus clearly demonstrating the potential power of this method. Finally we considered several improved amplitude target functions based on specifying directly the desired QZ field and then back projecting this to determine the desired feed target function. No significant improvements were seen and the need to address phase constraints in our optimisation was nicely demonstrated by the improved results obtained when the optimised array phase excitation was simply quantised to 0° and 180° (Fig. 12). Applying a weighted phase constraint to the array feed optimisation process will be reported in a future publication. The potential power of the array feed approach is that we can optimise the feed excitation for each operating frequency maximising the QZ volume for a given CATR facility without increasing the size of reflector or test chamber.

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