Reflectarray Compact Antenna Test Range Concept

Christophe Granet¹, Min Zhou², Stig B. Sørensen², Ken W. Smart³, John S. Kot⁴, John Ness⁵

¹ Lyrebird Antenna Research, Sydney, Australia, Christophe.Granet@lyrebirdantennas.com

² TICRA, Copenhagen, Denmark, mz@ticra.com, sbs@ticra.com

³ CSIRO Astronomy and Space Science, Sydney, Australia, Ken.Smart@csiro.au

⁴ YK Engineering Research, Sydney, Australia, John.Kot@yker.com.au

⁵ EM Solutions, Brisbane, Australia, John.Ness@emsolutions.com.au

Abstract— This paper presents a concept for a reflectarraybased compact antenna test range. To demonstrate the concept, a 2.6m square reflectarray operating at Ka-band has been designed to emulate an offset reflector. Preliminary results indicate that a Quiet Zone >45% of the size of the reflectarray can be achieved.

Index Terms—antenna, CATR, horn, optimization, reflectarray, measurement.

I. INTRODUCTION

Lyrebird Antenna Research (LAR) and YK Engineering Research (YKER) have been collaborating with EM Solutions (EMS) for a number of years to design high performance SATCOM-on-the-Move (SOTM) antenna terminals at various frequency bands.

One of the issues faced by EMS when trying to measure the SOTM terminals is that there are only a small number of antenna facilities in Australia able to measure the radiation pattern of the antennas, and the measurement is usually done using the Spherical Near Field (SNF) technique. Basically, a large number of measurement samples are collected on a virtual sphere around the antenna over a long period of time and a large amount of post processing is necessary to obtain the gain and radiation pattern of the antenna. Testing large antennas in terms of wavelengths using the SNF technique can be very frustrating as if somehow, a scan fails, it is an involved process to recover useful data and complete the scan and data set. Typically linear probes are used for SNF, requiring two sets of measurements to be taken and these measurements need to be post-processed later. The SNF procedure is also inefficient if verification measurements only are required rather than full field patterns for final approval.

The simplest way to test a SOTM antenna would be to use the far field (FF) method, either by direct satellite measurement or by the use of a far-field antenna test range (FFATR). The only FFATR in Australia is that of the CSIRO (Marsfield), but it can only test at a maximum distance of 40m or so. This distance is not large enough for most SOTM applications where far field distances of 100m or more are usually required (for example, a Ka-band 1m antenna at 30 GHz needs a far field distance of at least 200m). EMS sometimes uses a local quarry as a FFATR for preliminary tests, but this is hardly a practical solution and it is limited to a distance of about 70m and this method has major practical issues. Direct measurement by satellite is also very limited as often one can only measure using the beacon of a given satellite. These measurements are restricted to one or two frequencies and have limited dynamic range. To measure the transmit beam requires coordination with the satellite operator and an additional earth station. Unless done on an elevated site, the measurements are also subject to reflections from buildings

If a FFATR could be used, the antenna pattern cuts of the SOTM terminal could be measured in minutes by simply pointing the antenna to the source on boresight and rotating the antenna using the integrated pedestal and antenna control system. This would really simplify the measurement campaign and allow for quick feedback to debug the system if needs be.

One way to "simulate" a FFATR is by using what is generally called a Compact Antenna Test Range (CATR). A number of companies around the world sell or have access to CATRs, but there is none suitable for measuring SOTM antennas in Australia.

CSIRO has a 1.5m-square CATR, developed in-house, that is capable of measuring antenna systems up to 0.5m in diameter from 20 GHz to 200 GHz, but it has not been used for a number of years now. However, it would not be large enough to measure the SOTM terminals EMS is currently developing.

LAR was involved in the design of the CSIRO CATR [1] and has recently collaborated with Queen Mary University London (QMUL) to improve the performance of their CATR [2]. Both these CATRs are single-offset reflector systems as they are the cheapest CATRs that can be produced. Figure 1 shows the schematics of the CSIRO CATR and Figure 2 the actual CATR. Dual-reflector or sometimes tri-reflector CATRs are commercially available, but these are very expensive solutions usually reserved to strict tests for flight hardware (satellite platforms) or military hardware.

Traditional single-offset reflector CATRs from commercial vendors are usually also expensive, require edge treatment on the reflector and need to be enclosed in an anechoic chamber because the source horn illuminating the reflector of the CATR has usually only a -2 dB to -3 dB taper at the edge of the reflector. The rule of thumb is that for a CATR reflector diameter D, the quiet zone of a commercial CATR is only about D/3 or often less (<30%), depending on the frequency. With the technique in [1] and [2], the available quiet zone can be >40% or even up 60% or more, depending on the edge taper chosen and the F/D chosen.

The CSIRO CATR [1], was designed using a different technique, utilizing a very different type of source horns to avoid expensive edge treatment on the reflector.



Figure 1: CSIRO CATR schematics.



Figure 2: Photo of the CSIRO CATR.

We consider that it may be possible to use the horn antenna optimization technology used in [1] and [2] and the reflectarray technology optimization of a company like TICRA [3][4] to basically generate a modular CATR.

The basic concept is explained below.

II. REFLECTARRAY CATR CONCEPT

For some applications, people use reflectarrays instead of reflector antennas. Both technologies have their pluses and minuses. The main issue with reflectarrays is their bandwidth as they are usually made up of a large number of printed resonant elements although, significant work has been published to alleviate this limitation. The advantage is that a reflectarray can be printed flat and cheaply on a PCB board, compared to the expensive manufacture of a reflector antenna made out of aluminium, as in Figure 2.

A basic single offset reflectarray geometry is shown in Figure 3.



Figure 3: Photo of a reflectarray designed by TICRA.

The single-offset reflector CATR idea of [1] and [2] is narrow band by nature as the optimized horn can only work effectively over about a 10% bandwidth (the reflector itself is of course, wide band, covering 20 GHz to 200 GHz). This 10% is also the typical bandwidth of a reflectarray.

It is possible to combine the horn design technology of [1] and [2] with an optimized reflectarray design from TICRA. Therefore it should be possible to design a modular, cheap, CATR that would be able to measure the type of SOTM terminals EMS needs to measure over a 10% bandwidth.

A typical Ka-band antenna covers 19.20 - 21.20 GHz (9.9% bandwidth) at Ka-Rx and 29.00 - 31.00 GHz (6.7% bandwidth) at Ka-Tx. At X-band, X-Rx covers 7.25 - 7.75 GHz (6.7% bandwidth) and X-Tx covers 7.90 - 8.40 GHz (6.2% bandwidth). At Ku-band, Ku-Rx covers 10.7 - 12.75 GHz (17.50% bandwidth) and Ku-Tx covers 13.75 - 14.50 GHz (5.3% bandwidth).

So a different reflectarray design would be needed for Ka-Rx, Ka-Tx, X-Rx, X-Tx, possibly two to cover Ku-Rx and one to cover Ku-Tx. A corresponding source horn for each of these bands would also be needed of course, but only one horn "design" is needed. The manufacture of the different source horns can be done by direct scaling of the original design, like in [1].

Using the theoretical radiation pattern of the optimized source horn [1], it is possible to design a suitable reflectarray of a dimension large enough to generate a 1.0-1.5m diameter CATR quiet zone, given a reflectarray size of about 2.0-2.6m square. Basically, the reflectarray design would simulate the behaviour of an single-offset parabolic reflector and generate as best as possible, a plane wave.

The manufacture of the flat reflectarray would be cheap as it can be printed on ordinary PCB in modular form and assembled as a flat structure. The source horns can also be manufactured cheaply if the smooth-walled spline-profile technology is used [1], [2].

Alignment of the different components would be important but should not be too difficult especially if the highest frequency of operation is 31 GHz.

The overall concept is shown in Fig 4. Note that the geometry is shown with the source horn below the reflectarray (like the CSIRO CATR configuration) but a "side" configuration, like that of the QMUL CATR could also be considered.

A different reflectarray and source horn combination would be needed for each sub-band, but the same mounting structures could be used for each reflectarray and source horn. Hence, the modular aspect of this reflectarray CATR concept. A number of standard gain horns (SGH) would be needed to have a gain comparison.



Figure 4: Sketch of the reflectarray CATR.

Note that because this concept uses source horns providing low illumination at the edge of the reflectarray, such a CATR could be less susceptible to external interference than a standard CATR, It is possible such a system would not need to be housed in a full anechoic chamber. This assumption would need to be verified later.

III. DEFINITION OF A CATR QUIET ZONE

Extract from [2]: Amplitude and phase ripple of the QZ is still the dominant performance criteria of a given CATR

facility with an industry standard of: 1dB amplitude taper, ± 0.5 dB amplitude ripple and $\pm 5^{\circ}$ phase ripple [5]. The amplitude taper is measured as the variation of a 2nd degree polynomial function that is obtained by means of, typically, a least squares best fit through the amplitude data over a cut through the QZ with the value being reported in dB. The amplitude ripple is measured by determining the variation of the amplitude about the 2nd degree polynomial fit with this also being expressed in dB. The phase ripple is characterized by the deviation from a best-fit straight line over the quiet zone and is expressed in degrees. These linear cuts are typically acquired across horizontal, vertical or inter-cardinal cuts that are transverse to the z-axis of the range and are repeated at various z positions down range. The maximum dimensions within a volume of space, typically a circular or elliptical shaped cylinder, throughout which this specification can be achieved, determines the size of the CATR quiet-zone (QZ) [5]. Amplitude taper and amplitude ripple parameters are illustrated in Figure 5 with the phase ripple being analogous to the amplitude ripple These field properties are shown (without a taper). generally characterized as part of the CATR range installation using a procedure based upon a field probe scanner comprising a probe antenna mounted on a linear translation axis [5][6]. The final facility acceptance is typically predicated upon the vendor being able to successfully demonstrate that these requirements have been met or exceeded.



Figure 5: Illustration of CATR amplitude taper and amplitude ripple specifications in the QZ.

IV. PRELIMINARY DESIGN STUDY

The first proof of concept we have considered is a reflectarray CATR to cover the Ka-Rx band, i.e., 19.20 - 21.20 GHz.

CSIRO has an existing corrugated horn [1] (manufactured and tested) that could be used and LAR has also scaled the smooth-walled horn designed for [2] and designed an optimized corrugated horn to cover this frequency band. Potentially, these three different horn designs could be used to optimize the reflectarray. As a first proof of concept, the Ka-Rx reflectarray CATR tries to emulate an offset parabolic reflector 2.6m-square with a focal length of 5.6m, an offset of 0.5m and a feed pointing angle of 18.19deg. Now, the half subtended angle of the reflector would be about 13°, which is suitable for all three horn designs. However the well characterized, existing horn (CSIRO), will be used initially. The theoretical radiation pattern of the horn at 20.2 GHz in the 45°-plane in co-polar and cross-polar is shown in Figure 6.



Figure 6: Pattern of the horn at 20.2 GHz.

The design of the reflectarray, follows the direct optimization technique (DOT) described in [3]. In the DOT, one optimizes all the array elements in the reflectarray simultaneously to fulfill certain radiation specifications. Since the direct relation between optimization variables (geometrical parameters) and optimization goals (radiation specifications) is maintained, one has better control of the antenna performance as compared to traditional phase-only approaches, and as a result, designs with enhanced performance can be obtained.

For this preliminary study, a reflectarray that consists of rectangular patches printed on a single layer Duroid substrate will be used. The substrate has a thickness of



Figure 7: Optimized reflectarray geometry.



Figure 8: Co- and cross-polar QZ fields in the two principal planes 7m away from the reflectarray center.

0.787mm with a dielectric constant of 2.2 and loss tangent of 0.0009. A square unit-cell with a side length of 7.4mm is considered, corresponding to half a wavelength at 20.2 GHz.

The reflectarray is optimized to emulate an offset reflector (pencil beam design) and the optimized reflectarray geometry is shown in Figure 7. As optimization variables, the two side lengths of each patch are included. The number of array elements is 124,605 resulting in a total number of optimization variables of almost 250,000. The optimization takes just a few minutes on a standard laptop computer.

Figure 8 shows the simulated QZ field (co- and crosspolar) along the two principal cuts 7m away from the reflectarray centre. In Figs. 9 and 10, the amplitude and phase of the QZ field and their best fit curves are shown in the two cuts in a range of 1.2m in both x and y. It is seen that the amplitude taper is less than 1dB, with peak-to-peak amplitude and phase ripples less than ± 0.5 dB and ± 5 deg, respectively. This corresponds to a QZ >45% of the size of the reflectarray.

This essentially shows that it is possible to generate a relatively large QZ using a reflectarray. Of course, bandwidth is an important factor and the performance using a reflectarray consisting of rectangular patches printed on a single-layer Rogers substrate is not optimal. To this end, more sophisticated cell geometries, e.g., like the ones presented in [4], are needed. These advanced cells combined with low cost epoxy PCBs positioned a given height above the ground plane (supported by spacers or foam) can provide cheap and low-loss designs with enhanced bandwidth performance.

Furthermore, in this preliminary design, the reflectarray is optimized for its far-field which is not a performance parameter of interest in this application. It is expected that a larger QZ can be achieved if the reflectarray is optimized directly to fulfill the QZ requirements instead of the far-field specifications. These topics are subject to future investigations and research.



Figure 9: QZ amplitude (top) and phase (bottom) and their best fit curves along x.

V. CONCLUSIONS

This paper presents a concept to develop a reflectarraybased compact antenna test range. To demonstrate the concept, a 2.6m square reflectarray operating at Ka-band has been designed to emulate an offset reflector. Preliminary results indicate that a Quiet Zone >45% of the size of the reflectarray can be achieved. This concept validation can open the door to more research and potentially the manufacture and test of a prototype and possibly, commercialization of the concept.

REFERENCES

- [1] S.J. Barker, C. Granet, A.R. Forsyth, K.J. Greene, S.G. Hay, F. Ceccato, K.W. Smart, P. Doherty. "The development of an inexpensive high precision mm-wave compact antenna test range", Proceedings of AMTA, Newport, Rhode Island, USA, Oct. 30 Nov. 4 2005, pp. 337-340.
- [2] C.G. Parini, C. Granet, R. Dubrovka, S.F. Gregson, J. Kot, "Smooth-Walled Spline-Profile Horn Feed to Enlarge Compact Antenna Test Range Quiet Zone", 2018 12th European Conference on Antennas and Propagation (EuCAP'2018), 5 pages.



Figure 10: QZ amplitude (top) and phase (bottom) and their best fit curves along y.

- [3] M. Zhou, S.B. Sørensen, O.S. Kim, E. Jørgensen, P. Meincke, and O. Breinbjerg, "Direct optimization of printed reflectarrays for contoured beam satellite antenna applications," IEEE Trans. Antennas. Propag., vol.61, no.4, pp.1995-2004, April 2013.
- [4] M. Zhou, O. Borries, and E. Jørgensen, "Design and optimization of a single-layer planar transmit-receive contoured beam reflectarray with enhanced performance", IEEE Trans. Antennas. Propag., vol.63, no.4, pp.1247-1254, April 2015
- [5] C.G. Parini, S.F. Gregson, J. McCormick, D. Janse van Rensburg "Theory and Practice of Modern Antenna Range Measurements", IET Press, 2014, ISBN 978-1-84919-560-7.
- [6] C.G. Parini, R. Dubrovka, S.F. Gregson, "CATR Quiet Zone Modelling and the Prediction of 'Measured' Radiation Pattern Errors: Comparison using a Variety of Electromagnetic Simulation Methods" AMTA October 2015.