Improving the Cross-Polar Discrimination of Compact Antenna Test Range using the CXR Feed

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***Abstract*— The polarization purity of an antenna system is an important performance parameter. Accurate polarization testing, requires a significantly higher polarization purity of the test system than the test object. The Compact Antenna Test Range (CATR) is widely used for antenna system testing purposes [1]. It provides convenient testing, directly in far-field conditions of the antenna placed in the Quiet Zone (QZ). Polarization performance is often a motivation for choosing the complex and expensive CATR based on compensated dual reflectors rather than a single reflector. Recently, a novel Cross-polar Reduction (CXR) feed has been presented. It is based on conjugate matching of the undesired cross-polar QZ fields to improve the polarization purity of the single reflector CATR [2-3]. A dual-polarized proof-of-concept demonstrator with a limited bandwidth of 1.25:1 has been validated experimentally by QZ probing in standard side-fed and corner-fed CATR configurations. A numerical investigation of the final CXR feed on a full 1.6:1 bandwidth was presented in [4]. It was shown that cross-polar discrimination can be improved 8-10 dB with respect to standard feeds.**

In previous papers, the CXR feed concept has been discussed and demonstrated using limited scope demonstrators and numerical analysis. In this paper, the QZ cross-polar reduction properties of the CXR feed is measured in a standard corner-fed CATR in both orthogonal polarization over the full 1.6:1 bandwidth. The advantages of the CXR in general measurement scenarios are investigated by measurement of an antenna with low cross-polarization level at different QZ positions and frequencies. It is shown that a cross-polar discrimination improvement up to 10dB is achievable.

Keywords*— *Compact Range, Quiet Zone, Cross Polarization Compensation

I. Introduction

An important performance parameter of an antenna system is the polarization purity. Compact Antenna Test Ranges (CATRs) provide convenient far-field conditions testing but the Geometrical Optics (GO) effect induced by the offset CATR parabolic single reflector causes variation of the polarization tilt angle in the Quiet Zone (QZ), and it is null in a sub-region along the plane of symmetry of the reflector optics. Therefore, accurate polarization measurements, in single reflector CATR, can only be achieved when the Antenna Under Test (AUT) is positioned at the center of the QZ and its size is at least 10 times smaller than the CATR reflector [2]. Consequently, the accurate measurement of cross-polar performance is rather difficult for physically large antennas in single reflector CATR.

Arrays, reflectors and antennas mechanically offset in the QZ, when mounted on structures such as a satellite are examples of such antennas. Reflector geometry adjustment, post-processing and hardware modifications have been presented in the literature to improve the cross-polar measurement accuracy of single reflector CATR for such measurements. An overview of such techniques can be found in [3]. Recently, the application of conjugated matched feeds providing cross-polar reduction has been presented [2-4].

A new, dual polarized CXR feed, based on conjugate matching of the undesired cross-polar field in the QZ on a full wave-guide band, has recently been developed, manufactured and tested. In previous papers, the CXR feed concept has been discussed and demonstrated using a limited scope demonstrator and numerical analysis. In this paper, we show for the first time, the exhaustive testing of the dual polarized feed in a 10-16GHz bandwidth. Measurements and QZ probing are performed in a single reflector corner-fed CATR at the RWTH Aachen University in Germany. Accuracy improvements, achieved in the measurement of antennas with low cross-polar level will also be illustrated by a measurement example.

II. The CXR Feed

The CXR conjugate matched feed is shown in Figure 1. , consists of a 3-element array of wideband horn in dual linear polarization with integrated feeding network.

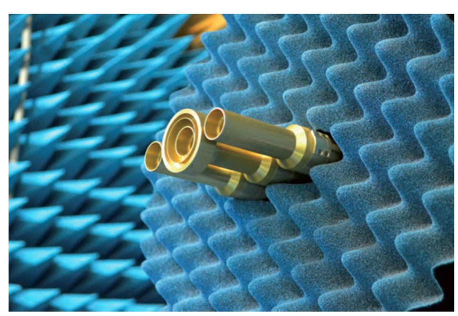


Figure 1. The CXR, conjugate matched feed providing 1.6:1 bandwidth in dual linear polarization. The feed is suitable for both side and corner-fed single reflector CATR configurations.

The CXR consist of a central corrugated horn with a high polarization purity similar to standard CATR feed. The feed is based on a compact waveguide orthomode junction [7]. The feeding network create the conjugate field matching taking advantage of the array characteristics and a suitable excitation of the two cross-polarized side-elements.

The full band, dual polarized CXR covers the frequency from 10-15GHz (nominal band) and 10-16GHz (extended band) as presented in [4]. The optimum wide-band excitation coefficients and the overall dimensions of the central and lateral elements have been determined by Physical Optics (PO) simulation of the CATR QZ performance and embedded element patterns from full-wave simulation of the entire array [5]. The OMJ on the center element is based on a self-diplexing concept [6-7]. Further details on the feed and optimization effort are given in [4]. The resulting dimensions of the full band CXR conjugate matched feed are summarized in Table I.

TABLE I. CXR FEED DIMENSIONS

Dimensions	Center element	Side-elements
Aperture inner diameter	49.0 mm	23.9 mm
Inter-element distance	-	76.0 mm

III. CATR System And Quiet Zone Probing

The CATR at RWTH Aachen University is shown in Figure 2 and has been designed and installed by Orbit/FR, a MVG company [6]. It is based on a corner-fed single reflector with a parabolic section of 1.7m x 1.7m and serrated edges. The resulting size of the cylindrical QZ is 1.1m x 1.1m. The operational frequency range is 2 to 75GHz. The positioner system is configured as roll-over-azimuth with elevation squint and AUT pick-up, all mounted on a cross-range slide. RF-instrumentation is based on a ZVA24 Vector Network Analyzer (VNA) with 85320 series external mixers. The CATR is fed by high-performance, linearly polarized, axisymmetric, corrugated horns. The feeds are mounted on a 4-axes positioner system. An optimized geometry, absorber baffle limits the direct leakage from the feeds towards the QZ. The range is housed in a shielded chamber of 9m x 5m x 5m (L x W x H).

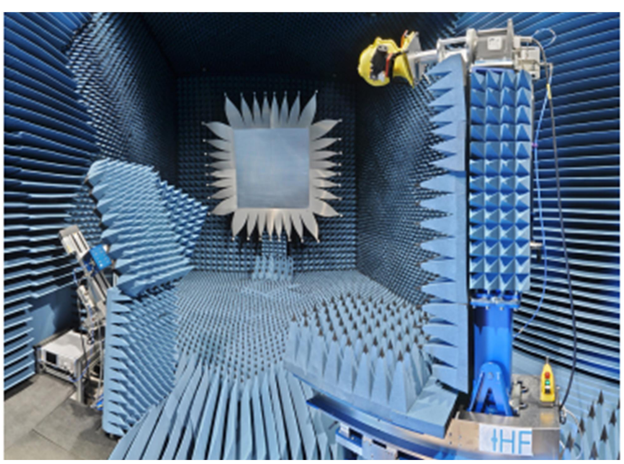


Figure 2. Corner-fed single reflector CATR at RWTH Aachen University from Orbit/FR, a MVG company [6].

The QZ field probing measurements were performed using a linear field probe scanner in combination with the cross-range slide for 2D planar scanning with a spatial sampling of $\Delta_x, \Delta_y = 10\ \text{mm} \leq \lambda_{min}/2$ as shown in Figure 3.

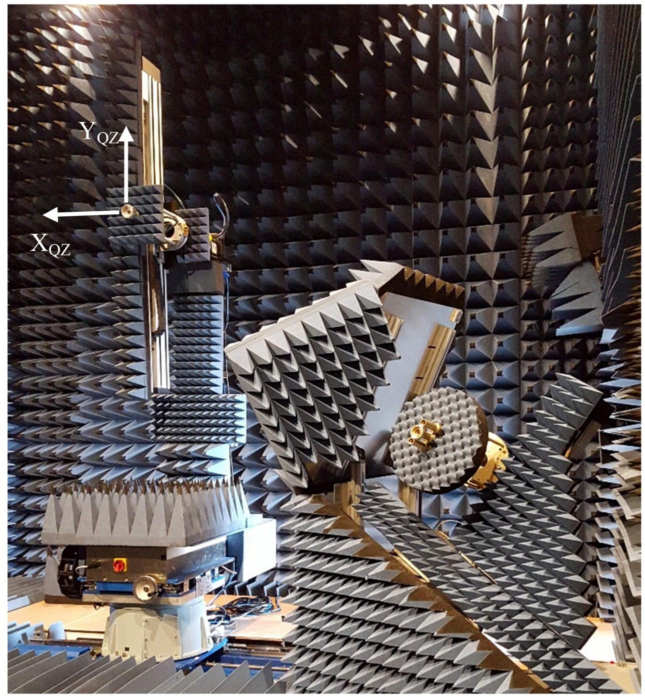
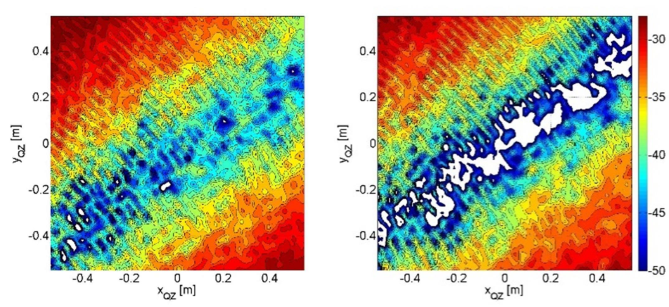


Figure 3. Field probe scanner (*Left*) with the Orbit/FR AL-2309-AL-10.0-SL probe and CXR feed (*Right*).

A standard single-linear polarized CATR feed (Orbit/FR AL-2309-10.0-SL) with medium gain and high polarization purity (>50dB) was selected as probe. The QZ field probing was performed initially with the CXR center element to establish the reference QZ cross-polar performance. The radiation characteristics of the center element are very similar to standard CATR feed for this optics. The measured QZ cross-polar field distribution for this range in both polarizations are shown in Figure 4. The distribution show the expected distribution with a null in the symmetry plane of the reflector.

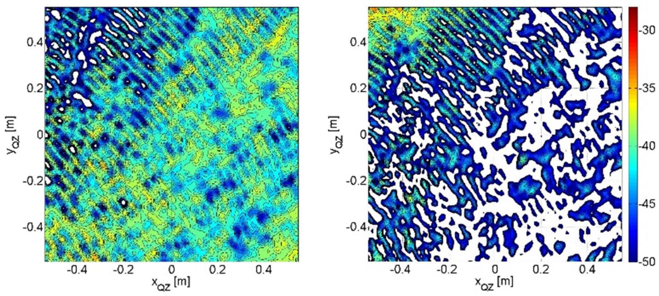


(a) (b)

Figure 4. Field probing at 10GHz, standard CATR feed. QZ cross polar discrimination contours with 1dB amplitude steps. Horizontal polarization (a). Vertical polarization (b).

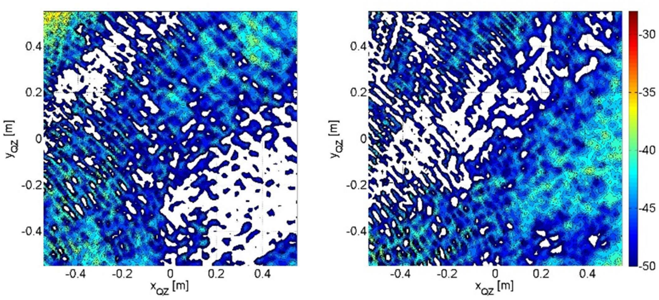
IV. CXR PERFORMANCE FROM QUIET ZONE PROBING

The QZ field probing was repeated with the CXR feed in the full 10-16GHz bandwidth. Contour plots of the QZ cross polar discrimination with the CXR feed at 10, 13 and 15GHz, are shown in Figure 5 to Figure 7.



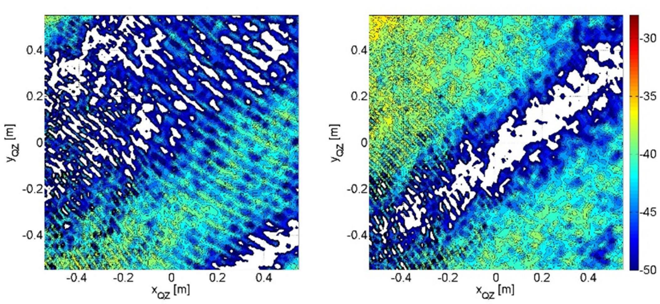
(a) (b)

Figure 5. Field probing at 10GHz with CXR feed. QZ cross-polar discrimination, 1dB amplitude steps. Horizontal polarization (a). Vertical polarization (b).



(a) (b)

Figure 6. Field probing at 13GHz, CXR feed. QZ cross-polar discrimination, 1dB amplitude steps. Horizontal polarization (a). Vertical polarization (b).

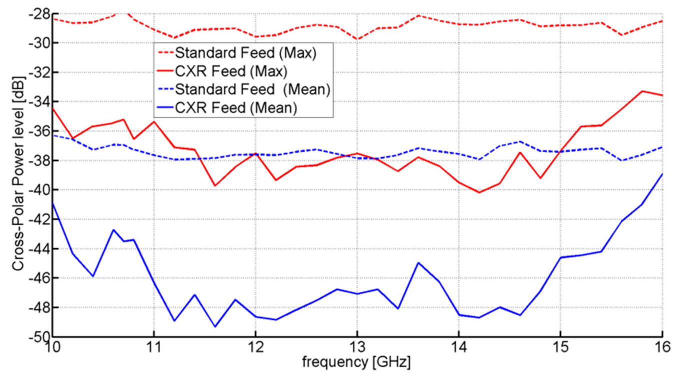


(a) (b)

Figure 7. Field probing at 15GHz, CXR feed. QZ cross-polar discrimination, 1dB amplitude steps. Horizontal polarization (a). Vertical polarization (b).

In it observed, that the overall cross-polar field component in the QZ was homogenized over the nominal 1.5:1 bandwidth, for both polarization, using the CXR feed. In particular, the maximum cross-polarization level at the edges of the circular QZ region is reduced by more than 10dB.

The measured QZ performances can conveniently be expressed by maximum and mean value over the QZ as a function of frequency as shown in Figure 8. The significant reduction of both maximum and mean cross-polarization level throughout the QZ has be achieved by the CXR conjugate matched feed.



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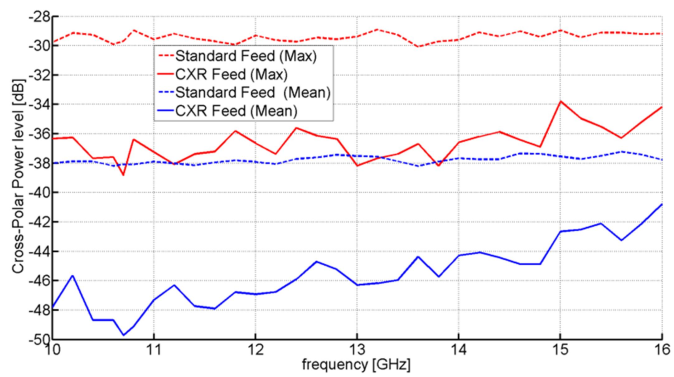


(b)

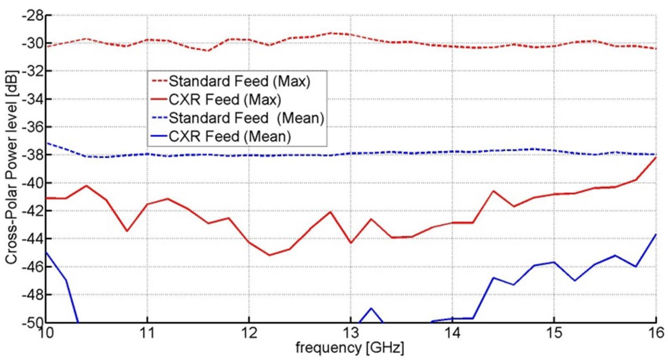
Figure 8. Comparison of measured QZ cross-polar discrimination. Mean / Maximum levels over frequency. Standard feed vs CXR conjugate matched feed. Horizontal polarization (a). Vertical polarization (b).

It can be observed from the field probing maps, that, although minimum, the center element of the CXR contributes with a non-negligible primary cross-polar field. This affects the GO cross-polarization distribution and consequently, leads to minor degradation in the cross-polarization compensation by the CXR.

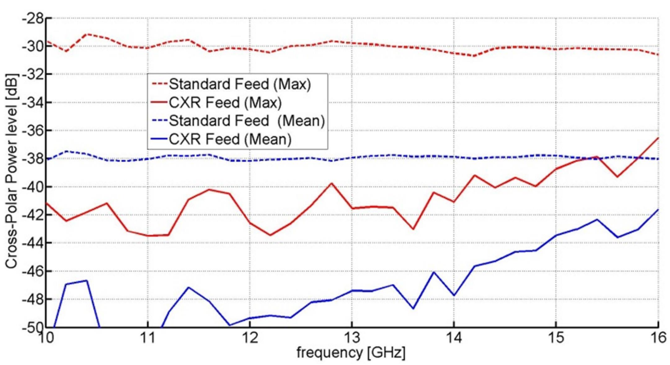
V. CXR PERFORMANCE FROM SIMULATION

The cross-polar performance for the CXR in this geometry has been determined by Physical Optics (PO) simulation of the CATR with embedded element patterns from full-wave simulation of the entire array [5]. The simulated performances are shown in Figure 9. Minor degradations between the simulations and measurements are observed when comparing Figure 8 and Figure 9. The small performance degradation in the measurements is due to measurement error and room scattering but also to deficiencies in the manufacturing of the center CXR element, resulting in slightly increased high primary cross-polar field at some frequencies, and slight differences between radiation patterns of the side-elements.

The simulations show that the performance degradation increases with frequency. The nominal bandwidth of the CXR is 10-15GHz with very good performance and with good performance in the extended 15-16GHz frequency range. The frequency range limitations are imposed by the fixed excitation coefficients of the lateral cross-polar reduction feeds with frequency and the array factor of these elements. The performance is a trade-off between cross polar reduction level and frequency bandwidth.



(a)



(b)

Figure 9. Comparison of simulated QZ cross-polar discrimination. Mean / Maximum levels over frequency. Standard feed vs CXR conjugate matched feed. Horizontal polarization (a). Vertical polarization (b).

VI. SR40-A Radiation Pattern Measurement

An electrically large reference antenna has been selected for the verification measurements. The SR40-A [6] located in the CATR QZ is shown in Figure 10. This AUT is a vertical linearly polarized, super elliptical, offset reflector antenna (F/D=0.5) with a wideband dual-ridge horn feed covering 4 to 40GHz. The parabolic rim of this antenna is about 400mm x 400mm. For the measurements, the condition of 10 times larger CATR reflector diameter than AUT dimension is not fully respected.

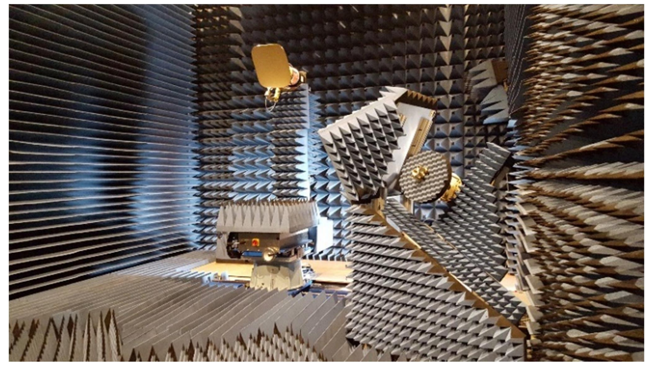


Figure 10. Reference antenna, SR40-A with SH4000 in the CATR at RWTH Aachen University.

This reference antenna has well-known radiation pattern characteristics [3] [8], with high polarization purity and a deep null in the volumetric cross-polar pattern, almost perfectly aligned with the antenna mechanical axis (within 0.05). These characteristics, along with the electrical size, make this AUT well suited for the verification experiment.

To investigate the accuracy improvement of the CXR feed concept on the cross-polar measurement, the cross-polar pattern of this reference antenna was measured at different frequencies of the extended band, using both the CXR and the standard AL-2309-10.0-SL for comparison. The AUT was furthermore placed at two different locations in the QZ. The centered position is the reference position in which the cross polar measurements is expected to be more accurate. The offset position of -0.3m in the QZ is selected to challenge the CXR. This latter position emulates a measurement scenario in which the AUT is located in an area of the QZ with worse cross-polarization discrimination. The displacement was achieved by using the cross-range slide, so that the complete positioner, hence the center of rotation, was displaced. The volume of the QZ occupied by the AUT during azimuthal rotation is therefore the same.

The measured cross-polar performance of the reference antenna, while positioned favorably in the QZ center, shows very low cross-polar levels for both CXR and standard feed configuration over the full operational band. For the sake of brevity, only the center frequency cross polar patterns are presented in Figure 11. These results completely confirm the findings in the facility comparison campaign of this reference antenna as reported in [8].

However, the quality of the cross-polar measurement of the reference antenna while positioned in an unfavorable offset position of the QZ is highly affected by the feed choice. In this position the antenna is placed in a part of the QZ where the induced cross polarization by the offset geometry is higher. As presented in Figure 12. , the measured cross-polar pattern is degraded by approximately 10dB with the standard feed. The measurement with the CXR is very similar to the reference onset measurement. The measurement with the CXR feed confirms the expected invariance to the QZ position and further confirms the conjugate matched feed concept.

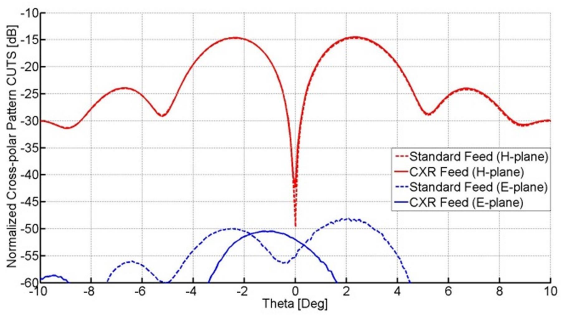


Figure 11. E- and H-plane measured cross polarization at 13GHz. AUT centered in the QZ. Standard feed (*Dashed*). CXR Conjugate matched feed (*Solid*).

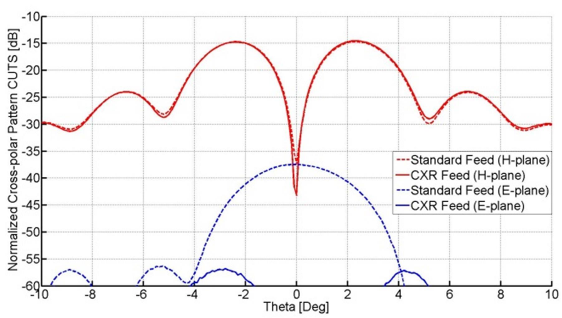


Figure 12. E- and H-plane measured cross polarization at 13GHz. AUT offset by -0.3m. Standard feed (*Dashed*). CXR Conjugate matched feed (*Solid*).

VII. Summary and Conclusion

The cross-polarization cancellation properties of a conjugate matched feed for a corner-fed CATR has been investigated. The CXR conjugate matched feed performs a similar cross-polar cancellation as the second reflector in the more complex and expensive dual compensated CATR. The cross-polar accuracy improvement with the new feed concepts has been investigated by QZ probing and measurement of an antenna with low cross-polar level in different QZ positions.

The QZ probing shows no co-polar degradation of the QZ field as compared to standard CATR feed. A homogenization of the cross polar QZ field has been achieved. With the new concept, the cross-polarization measurement accuracy is independent of AUT size and position in the QZ. Consequently, the full QZ has become available for accurate cross-polar characterization of antennas in single reflector CATR. This is a significant improvement in the accurate measurement of large antennas, such as arrays, reflectors or antennas naturally offset in the QZ since mounted on a structure such as a satellite.

The advantages of the CXR conjugate matched feed concept is further investigated by measurement of a low cross-polarized antenna in different QZ positions. The aim is to investigate cross polarization levels of more than 50dB below peak. For offset QZ measurements, an improvement on cross-polar discrimination of approximately 10dB has been achieved with the conjugate matched feed.

The CXR feed reported in this paper covers the frequency range from 10 to 16GHz (WR-75 waveguide band) with simultaneous cross-polar cancellation capabilities in both orthogonal polarizations. The CXR feed is easily reconfigurable to different CATR geometries (side/corner-fed) and maintains its effectiveness even in short focal length CATRs.

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