CALIBRATION AND VERIFICATION MEASUREMENTS IN COMPENSATED COMPACT RANGES UP TO 500 GHZ

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Abstract

Compensated Compact Ranges (CCR) represent a high standard of state-of-the-art test facilities with a fast and real time measurement capability up to the sub-mm wave range. Future scientific and earth observation instruments of ESA/ESTEC such as MASTER, PLANCK and HERSCHEL are working within this frequency ranges and require a high measurement accuracy for large antenna apertures.
Within the ADMIRALS study for ESA/ESTEC, transmit and receive modules up to 500 GHz and an appropriate large offset reflector antenna with precise surface accuracy in form of a Representative Test Object (RTO) were applied. Related tests in the CCR 75/60 of Astrium were performed in order to qualify the test facility and verify the antenna measurements with theoretical pattern calculations.
The present paper shows measurement results with the highly accurate Plane Wave Scanner (PWS) of Astrium GmbH and the RTO. Through the measurements performed, the accuracy of the plane wave field as well as pattern accuracy in the quiet zone of the CCR 75/60 have been qualified up to 500 GHz.

Keywords:
mm-Wave Antenna Measurements, Compact Ranges

1. Introduction

Earth observation and limb sounder missions, requiring high spatial resolutions, need large antenna apertures compared to the wavelengths of its operating frequencies. The ESA/ESTEC missions MASTER for investigation of the upper atmosphere chemistry as well as PLANCK and HERSCHEL for astronomy investigations use antenna apertures up to 2,2 and 3,5 m [1]. The highest operating frequencies of the instruments are in the sub-mm wave frequency range above 100 GHz and up to 857 GHz.
For measurement of these instruments, a test facility with large quiet zone, high positioning accuracy of mechanical components, collimating systems (if applicable) and positioners, as well as RF measurement capability up to operate in this frequency range has to be identified. For this aim, a trade-off between Near-Field and Compact-Range Test Facilities was performed [2]. The results exhibited a preference for the Compensated Compact Ranges (CCR) of Astrium GmbH.
For range qualification, measurements with a 5 m plane wave scanner and for verification of equivalent test objects, measurements with an offset reflector antenna at sub-mm wave frequencies were performed. Characteristic measurement results are shown within this paper. The results will be analyzed and comparative as well as characteristic pattern values will be presented.

2. Test Facility

A trade-off between the Cylindrical Near-Field Test Facility (CNTF) and the Compensated Compact Range (CCR) of Astrium GmbH was performed within Phase I of the study ADMIRALS for ESA/ESTEC [2]. Both facilities have a quiet zone size in the order of 5 to 6 m in diameter and have been qualified up to 100 and 200 GHz [3], respectively. For that aim, the two ranges were identified as potential candidates for measurements of large sub-mm wave space antenna apertures with lowest cost and risk for improvements measures, if deemed necessary.
The results of the trade-off exhibited an almost equivalent measurement accuracy up to 500 GHz for the two facilities. According to the existing highly accurate status [3] and the direct application of existing mm-wave module technology [4], the CCR 75/60 was selected for measurements in the sub-mm wave frequency range within

the ADMIRALS study. A picture of the test facility with the INTELSAT 8 multi-beam antenna, mounted on the DUT positioner is shown in Figure 1.

Figure 1 CCR 75/60 of Astrium GmbH

The plane wave field accuracy in the quiet zone was analyzed in detail for frequencies between 200 and 500 GHz and error budgets for the pattern accuracy were calculated. The results for the CCR 75/60 are summarized in Table 1. The results of the trade-off study as well as explanations of the error contributions can be found in more detail in [2].

Error contribution	**Pattern error [dB] @ - 30 dB level**
Feed polarization	0.15
Feed alignment	0.00
AUT positioning	0.10
Mismatch of AUT	0.03
Multiple reflections	0.15
Room scattering	0.25
Leakage and crosstalk	0.05
Angular distortions	max. 0.48
Receiver non-linearity	0.30
Receiver dynamic range	0.07
Reflector surface	1.30
Serration and billboard	0.01
QZ taper on AUT	0.00
Other errors	0.05
RSS Error level	**1.44**

Table 1 Error Budget for the CCR 75/60 of Astrium GmbH at 500 GHz (3σ values)

Within the facility trade-off, the gain measurement accuracy was also investigated. According to the deficiency of applicable measurement standards, gain measurements in the considered frequency range were not performed. Therefore, related activities are no longer considered within this work.
Possible range improvements have to be identified during probing and pattern measurements. An upgrade can be expected in range temperature and humidity constancy, selection of applicable absorber, absorber layout, positioner accuracy as well as positioning resolution, reflector alignment and serration design.

3. MM-Wave Modules

For the study a frequency range between 200 and 500 GHz with discrete frequency bands had to be investigated. The frequency bands are located at a center frequency of

- 203 GHz
- 322 GHz
- 503 GHz

Therefore, transmit and receive modules for each frequency band had to be procured. With existing technology, a bandwidth up to 4 % for the modules can be expected.
The technical requirements for the modules are mainly derived from the link budget of the CCR 75/60 at the related frequencies. The link budget is shown in Table 2.

Freq. [GHz]	**Free Space Loss [dB]**	**Gain CCR Feed [dBi]**	**Gain Test Ant. [dBi]**	**Rec. Power Level [dBm]**	**Dyn. Range [dB]**	**Rec. Sens. [dBm]**
203	103.7	20	66.1	- 17.6	90	- 108
322	107.7	20	70.0	- 17.7	80	- 98
503	111.6	20	73.8	- 17.8	70	- 88

Table 2 Link Budget for CCR 75/60 of Astrium GmbH (Reflector Size of RTO for Gain Value of Test Antenna Considered; Transmit Power of 0 dBm Assumed)

The main characteristic data for the transmit modules out of the link budget is the transmit power. The amplitude taper of the plane wave in the quiet zone should not extend 1 dB within a Field of View (FoV) of ± 12 degree. The FoV corresponds to the angular illumination range of the subreflector from the feed.
For the receive modules, the necessary sensitivity for expected high dynamic range as well as the feed gain are the most important characteristic data. The required sensitivity value results in an input noise temperature (T) below 3000 K for a resolution bandwidth of lower than 1 kHz for the applied spectrum analyzer used as

measurement system. Further, the mixer conversion loss values should not exceed 15 dB. A minimum signal to noise ratio (S/N) of 12 dB is assumed.
The transmit module consists of a separate Gunn-Oscillator, mixer and PLL (Phase Locked Loop) unit for the 203 GHz/322 GHz and 503 GHz as well as a mixer and corrugated feed horn unit for each of the three frequency bands. The 503 GHz transmit module is shown in Figure 2.

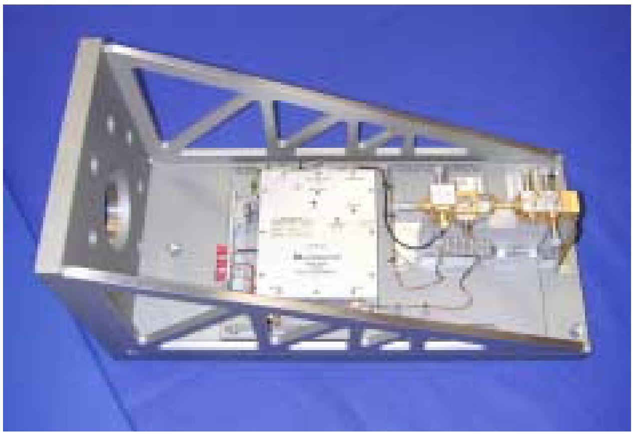

Figure 2 503 GHz Transmit Module

The receive module, shown in Figure 3, contains for each frequency band a Quasi-Optical Network (QON) with a Martin-Puplet Interferometer and subsequent fundamental mixer down to an IF (Intermediate Frequency) of 3.5 GHz.
For reasons of design cost reduction and compatibility, the LO unit for the receive module is identical to the unit, used in the transmit module.

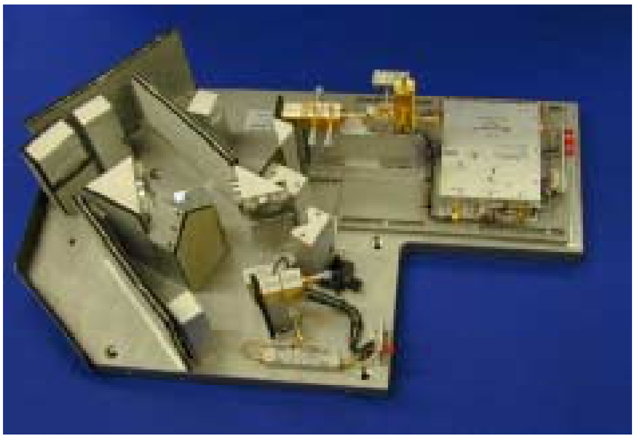

Figure 3 500 GHz Receive Module

The characteristic data of the modules as well as the related design concept can be found in [4].

4. Test Objects

Measurements at 203, 322 and 503 GHz were performed with a high precision plane wave scanner for range qualification and with an offset reflector antenna for range verification.
The plane wave scanner, as shown in Figure 4, has a transversal scanning range up to 5 m and can be rotated 360 degree around the center of Quiet Zone (QZ). For the study, probing was performed with the receive modules directly mounted on the slide of the scanner. This method prevents additional errors according to the small pattern beamwidths as well as ripple integration effects by a reflector aperture when compared to measurements with additional application of a collimating reflector.

Figure 4 5 m Plane Wave Scanner of Astrium GmbH with 500 GHz Receive Module Mounted

For pattern verification up to 500 GHz, a Representative Test Object (RTO) with large antenna aperture and high reflector surface accuracy was applied. The antenna aperture is 1.5 m in diameter with a focal length of 3 m. The receive module is located at the phase center of the paraboloid. The RTO placed on the positioner in the quiet zone is shown in Figure 5.
To prevent bending of the strongback during elevation movement, a very stiff and lightweight construction with maximum deviations up to 0.1 mm for the position of the phase center was designed. The surface roughness of the RTO reflector was measured and peak-to-peak values up to 0.35 µm could be identified. The surface contour accuracy was measured with a RMS value of better than 30 µm.

Figure 5 Highly Accurate Offset Reflector Antenna for Measurements up to 500 GHz as Representative Test Object (RTO) in the CCR

5. Measurement Results

Plane wave probing as well as pattern measurements were performed at the center frequency of the three frequency bands.

To mount the receive modules onto the slide of the scanner, an adapter plate was manufactured. Due to the weight of the modules (approximately 20 kg), no additional polarization positioner could be applied between the slide and the module, which is needed for performing polarization alignment for oblique angular scanner positions. The plane wave probing was therefore performed along horizontal and vertical cuts. The test setup for the measurements is shown in Figure 6.

Exemplary probing data for a horizontal scan in the QZ of the CCR 75/60 of Astrium GmbH at a frequency of 503 GHz are shown in Figure 7a and 7b.

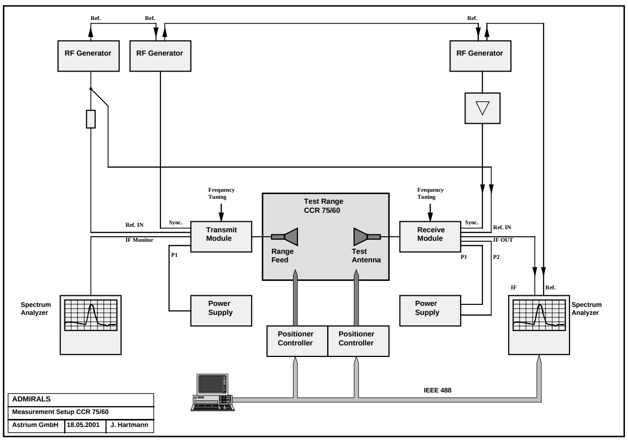

Figure 6 Test Setup for Measurements up to 500 GHz in the CCR 75/60

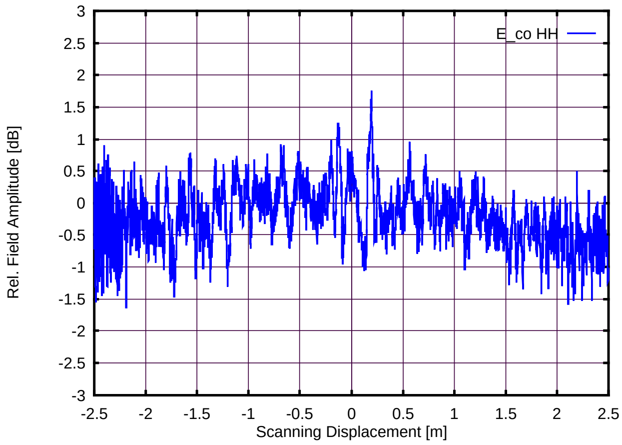

Figure 7a Co-Polar Amplitude for Horizontal Scan (Horizontal DUT Polarization, f = 503 GHz)

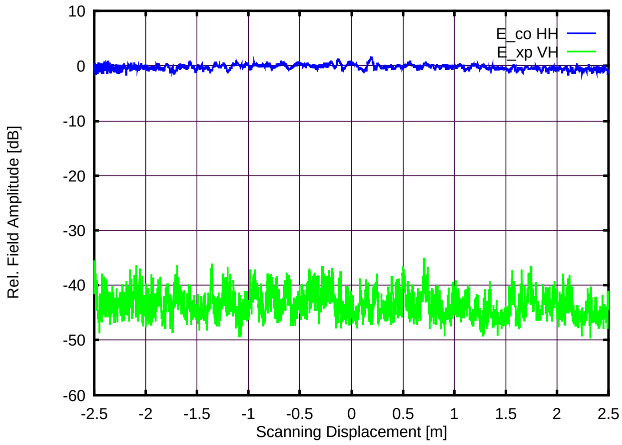

Figure 7b Cross-Polar Amplitude for Horizontal Scan (Horizontal DUT Polarization, f = 503 GHz)

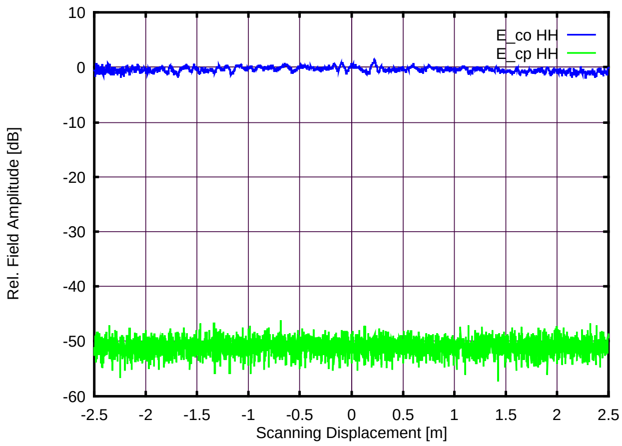

Figure 7c Dynamic Range for Horizontal Scan (Horizontal DUT Polarization, f = 503 GHz)

In Figure 7a, the co-polar field variation is shown. The influence of diffraction effects of the serrations can be observed outside + 2 and - 2 meter. At the centre of the scan, a structural dependent interference can be observed, which can be interpreted as a possible limitation of the alignment accuracy of the reflector segments. Normally, the reflector segments are adjusted and aligned for a operating frequency range up to 40 GHz. The probing results at 500 GHz clearly exhibit, that a higher alignment accuracy for the reflector segments is necessary.
By using highly sophisticated alignment methods, an overall contour accuracy for the large compact range reflectors in the order of 20 µm can be achieved. The maximum co-polar amplitude ripple at 500 GHz can be expected to be in the order of ± 0.5 dB for the whole quiet zone. Therefore, the standard measurement accuracy of the CCR 75/60 test facility can be extended up to sub-mm wave frequencies without reduction of quiet zone field performance and quiet zone dimension.
The achieved dynamic range for probing measurements at 503 GHz is approximately 50 dB, as shown in Figure 7c. For this test, the receive signal was measured with transmitter in off-status.

The summarized data for maximum amplitude ripple of the co-polar field and maximum cross-polar amplitude level for 203, 322 and 503 GHz in the QZ of the CCR 75/60 are given in Table 3.

Frequency	**Max. Co-Polar Amplitude Ripple***	**Max. Cross-Polar Amplitude**
203 GHz	± 0.5 dB	- 40 dB
322 GHz	± 0.75 dB	- 39 dB
503 GHz	± 1.0 dB	- 38 dB

* Taper not included

Table 3 Summarized Probing Results for CCR 75/60 (within 95 % of Quiet Zone)

Characteristic results of pattern measurements with the RTO are shown in Figure 8 for an azimuth cut and in Figure 9 for an elevation cut. According to the DUT aperture size of 1.5 m, the RTO exhibits a 3 dB beamwidth of 0.028 degree at 500 GHz. For this small beamwidth, a highly accurate boresight justification of the RTO is needed [5].
As expected, serration effects around an angular range of approximately 7.5 degree in azimuth and 10 degree in elevation can be observed. The distortion levels are below - 55 dB to - 60 dB and are therefore of minor interest.
Furthermore, the influence of milling tracks and milling steps of the compact range reflectors, as described in [2] with mechanical errors of the collimating system, can be seen in the form of grating lobes. The grating lobes are periodically located at angles of approximately ± 1.6 and ± 1.8 degree. The maximum signal level of this error contributions is below - 50 dB and can therefore also be neglected for pattern evaluation w.r.t. pattern, gain and beam efficiency accuracy.

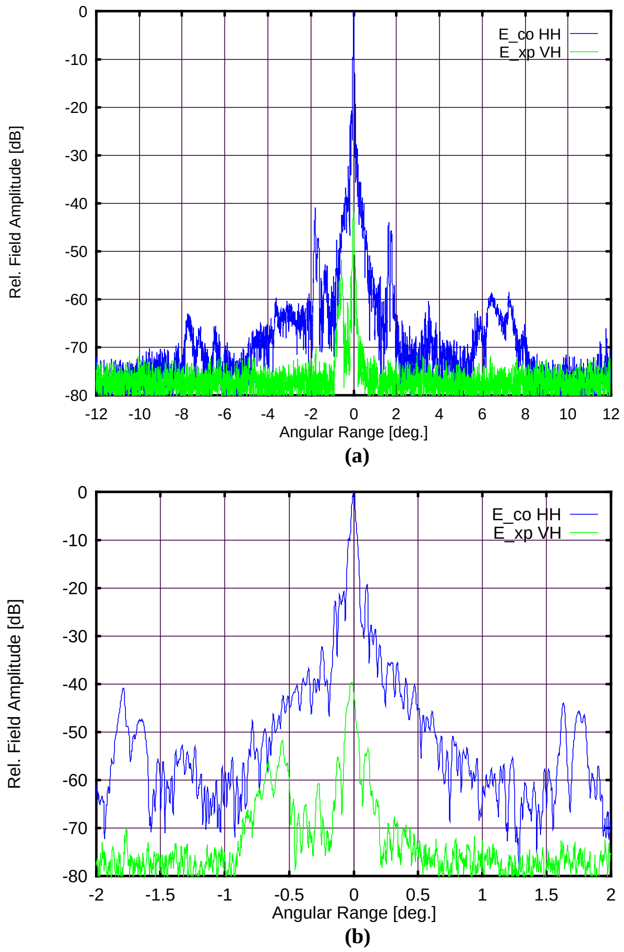

Figure 8 Azimuth Cut with RTO at f = 503 GHz;
(a) Angular Range between - 12 and + 12 degree
(b) Angular Range between - 2 and + 2 degree

The cross-polar level in boresight was measured with a maximum value in the order of - 40 dB. The achieved dynamic range for pattern measurements is in the order of 75 dB at 500 GHz.
The evaluation of the pattern w.r.t. side lobe level, 3 dB beamwidth and beam efficiency results in good agreement between calculated and measured data. According to the very low wavelengths of the operating frequencies, the real geometry data of the reflector have to be applied within the calculations.

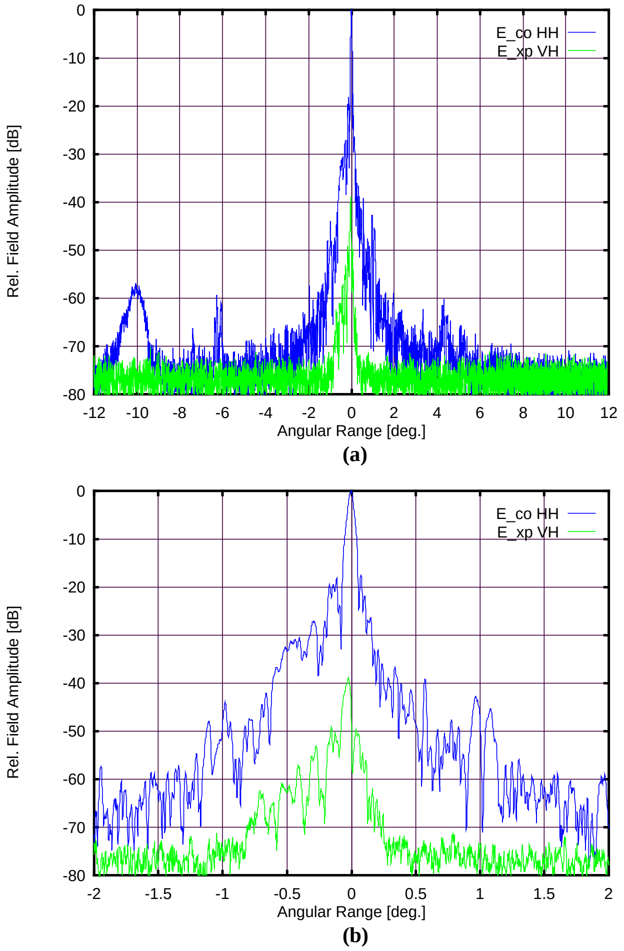

Figure 9 Elevation Cut with RTO at f = 503 GHz
(a) Angular Range between - 12 and + 12 degree
(b) Angular Range between - 2 and + 2 degree

6. Conclusions

Measurement results in the frequency range up to 500 GHz within the CCR 75/60 of Astrium GmbH, Ottobrunn, were presented.

The measurements were performed with a highly accurate 5 m plane wave scanner and a specially designed offset reflector antenna. In relation to space applications with large aperture dimensions, the reflector diameter of the test antenna was defined with 1.5 m. This diameter value is correlated with a 3 dB beamwidth of 0.028 degree at 500 GHz.

The results exhibited a maximum ripple value of the co-polar amplitude of ± 0.5 dB up to ± 1.0 dB and a maximum cross-polar amplitude of - 35 dB up to - 40 dB between 200 and 500 GHz. With highly accurate alignment of the compact range reflector segments applied, a further improvement of the measurement results can be expected.

Du to the unique test setup and the relatively low free space loss in the CCR, dynamic range values of 50 dB for plane wave probing and 75 dB for pattern measurements are possible. The calibration results at 500 GHz exhibited, that a measurement accuracy similar to the accuracy at lower frequencies, for which the CCR 75/60 has already been calibrated, can be achieved. For that aim, a highly sophisticated alignment of the compact range reflector segments has to be performed.

7. References

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