DEVELOPMENT OF HIGHLY ACCURATE MEASUREMENT TECHNIQUES FOR STATE-OF-THE-ART ANTENNA TEST FACILITIES

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Abstract

Contoured multi-beams achieved by multi-feed reflector antennas, realized in modern communication satellites, like Intelsat VIII and IX generations satellite, require an economic measurement of their antenna characteristic. Further, highly accurate, but also fast and therefore real-time measurements are assumed to be applied for the testing of the antenna performance. For that aim, the Compensated Compact Range CCR 75/60, applied at e.g. Space Systems Loral (SSL) in Palo Alto (USA), at ALCATEL in Cannes (France), at the MISTRAL facility in Toulouse (France) and at Astrium GmbH (Germany) was developed and installed by Astrium GmbH. In order to optimize the measurement accuracy of the CCR, detailed error analyses and investigations for improvement measures were performed.
Within this paper, the accuracy analyses and improvement steps will be presented in order to establish accuracy values, which can be realized in state-of-the-art compact range test facilities.

Keywords:
Satellite Antenna Measurement, Compact Range

1. Introduction

The objective of the performed investigations was the development of methods and techniques in order to perform highly accurate antenna measurements of e.g. circularly polarized array-fed reflector antennas in the C-Band [1]. This type of antenna applies to the Intelsat VIII and IX communication satellites. The radiation characteristics of these types of satellite antennas are based on highly accurate beam forming, creating multiple beams for zone and also hemi illumination.
For performance verification of these types of antennas, highly accurate test facilities were taken into consideration, whereas the Compensated Compact Range (CCR) of Astrium GmbH was investigated in more detail. In the following, the test requirements will be given and subsequently, detailed error budgets in combination with range improvement measures as well as their influence on the measurement accuracy will be described.

2. Requirements

This work was motivated by the stringent requirements of Intelsat, for the side-lobe accuracy as well as for the cross-polarization isolation of satellite antennas in the required low amplitude range for frequency re-use. The aim was to analyze and improve the measurement accuracy of antenna test facilities for electromagnetic fields.
At the beginning of the work, a pattern measurement accuracy of ± 2.9 dB @ - 40 dB signal level, relative to the beam peak of the co- and cross-polarized field in the considered C-Band frequency range, was calculated for the CCR 75/60. For gain measurements, an accuracy of ± 0.16 dB was determined. The maximum cross-polarization level of the test facility could be identified

with a level in the order of - 38 dB. These values should be improved to ± 1 dB @ - 40 dB signal (side-lobe) level for the pattern accuracy, ± 0.1 dB for the gain accuracy and - 40 dB for the maximum cross-polarization level.
Due to the several beams (6 zone and 2 hemi beams) of the Intelsat VIII generation satellite in combination with a large number of test frequencies as well as two orthogonal polarized signals, a fast and economic testing had to be applied. Therefore, the testing in a compact range test facility was favored, since it applies far-field measurements without the need of mathematical transformations. For the measurement of cross-polarization levels far below the levels of the applied test antennas, a test facility had to be identified, which reaches at least maximum cross-polarization levels below - 40 dB. Further, a quiet zone with cross-range dimensions of at least 4 to 5 meters for the large antennas was required. The CCR 75/60 of Astrium GmbH (see Figure 1) was selected as the most promising test facility, which matches all of the previous mentioned requirements.

Figure 1 CCR 75/60 with Intelsat VIII Satellite Feed, Reflector and Mockup Structure

3. Error Analyses of the CCR 75/60

As a result of its extensive experience in designing of antenna test facilities and also operating the CCR 75/60 in the test business for approximately 15 years, Astrium has solid understanding of the electromagnetic effects occurring in the facilities. The effects on the measurement accuracy can be grouped into nine categories:

a) RF-Measurement System
b) Feed System
c) Reflector System incl. Serrations and Billboard
d) Direct Leakage Suppression by Baffle
e) Positioning System
f) Antenna Under Test
g) Environmental Impacts
h) Measurement Procedure
i) Computational Impacts

For each of these categories, detailed error contributions can be identified, as shown below. The following Astrium compact range error model is quiet similar to the error model established in [2].

a) RF-Measurement System:
a1) Amplitude Non-Linearity
a2) Amplitude and Phase Drift
a3) Dynamic Range
a4) Settling Time
a5) Frequency Drift
a6) Random Amplitude and Phase Errors
a7) Impedance Mismatch
a8) RF Leakage and Cross-Talk

b) Feed System
b1) Absolute Gain
b2) Radiation Pattern
b3) Polarization
b4) Impedance Mismatch
b5) Mechanical Alignment
b6) Scattering Cross-Section

c) Reflector System including Serration and Billboard
c1) Reflector Dimensions
c2) Reflector Surface Accuracy
c3) Serration Length
c4) Serration Shaping
c5) Serration Alignment
c6) Billboard Shaping
c7) Billboard Edge
c8) Mechanical Alignment

d) Direct Leakage Suppression by Baffle
d1) Non perfect Suppression in Complete Quiet Zone
d2) Disturbing of Feed Pattern (Near-Field Effect)

e) Positioning System
e1) Mechanical Positioning of Feed Scanner
e2) Positioning Accuracy of Turntable
e3) Position Measurement
e4) Feed Alignment
e5) Feed Polarization

f) Antenna Under Test
f1) Mechanical Alignment
f2) Scattering Cross-Section
f3) Impedance Mismatch
f4) Mechanical Stiffness (AUT and MGSE)

g) Environmental Impacts
g1) Temperature
g2) Temperature Spatial Gradient
g3) Electromagnetic Interference
g4) Room/Absorber Scattering

h) Measurement Procedure
h1) Absorber Mounting at Feed Surrounding
h2) Baffle Position
h3) APC/AAPC Calculation
h4) Transversal/Longitudinal Sample Spacing
h5) Gain measurement Procedure

i) Computational Impacts
i1) Data Acquisition Software
i2) Instrument Interface Software
i3) Evaluation Software

In order to determine the locations of error sources and the incidence directions of the related distorting fields into the quiet zone, detailed ray tracing analyses for the Compensated Compact Ranges of Astrium GmbH were performed, as shown in Figure 2.

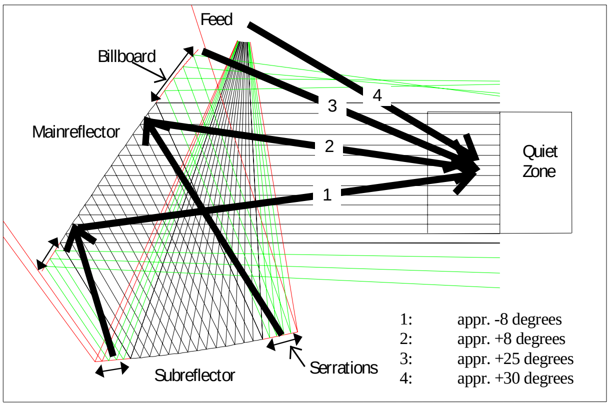

Figure 2 Ray Tracing Analyses of the CCR 75/60

For frequencies up to 40 GHz, the most critical error contributors in compact ranges are generated by diffractions effects from the serrations and the billboard edge (if applied as an option at CCR 75/60) and radiation effects by direct leakage from the feed into the quiet zone. These errors may not be combined in RSS-methods [2], because they interfere with the plane wave field in the quiet zone at different pattern angles. According to the ray trace analyses, shown in Figure 2, the angles of arrival for the four most critical error contributors can be determined as are visualized in the drawing. The predicted angles are calculated from the experience with this type of compact range. The angular values of ± 8 degrees are mean values from different measurements. The angular values depend on the position of the AUT in the quiet zone.
The error budgets are principally based on the investigations performed in [2]. For the pattern measurement accuracy, the worst case error budget is shown in Table 1 and the related error budget for the gain accuracy is shown in Table 2. For determination of the gain error values, it should be noted that the Astrium power measurement method was applied [3].

Error	Level/dB	Error/dB	Dist./dB
Feed xp isolation	-30	**0.05**	-74.82
Feed alignment	-30	**0.00**	-1000
Feed mismatch	-30	**0.02**	-82.77
Reflector, serr., billboard (cp)	-30	**0.03**	-80.16
Reflector, serr., billboard (xp)	-30	**0.03**	-80.16
Direct leakage	-30	**1.00**	-49.27
Quiet zone taper	-30	**0.15**	-65.33
AUT positioning system	-30	**0.02**	-82.77
AUT mismatch	-30	**0.03**	-79.25
Receiver ampl. non-lin.	-30	**0.04**	-76.76
Receiver dynamic range	-30	**0.07**	-71.91
Multiple reflections	-30	**0.06**	-73.24
Room scattering	-30	**0.08**	-70.75
Leakage and cross-talk	-30	**0.05**	-74.82
Other errors	-30	**0.05**	-74.82
Additional xp error	-30	**0.47**	-55.57
RSS Disturber (cp):			**-49.04**
RSS Disturber (xp):			**-48.17**
RSS Error (cp):	-30	**1.02**	
RSS Error (xp):	-30	**1.11**	
RSS Error (cp):	-40	**2.89**	
RSS Error (xp):	-40	**3.12**	

Table 1 Worst Case Error Budget for the Pattern Accuracy in C-Band of the CCR 75/60 for - 30 dB and - 40 dB signal level (3 σ values assumed)

Error	Level/dB	Error/dB	Dist./dB
Feed xp isolation	0	**0.00**	-75.00
Feed alignment	0	**0.00**	-95.62
Feed gain accuracy	0	**0.10**	-38.83
Measurement Method (Feed)	0	**0.02**	-52.77
Measurement Method (DUT)	0	**0.02**	-52.77
Free space losses	0	**0.03**	-49.25
Attenuator calibration	0	**0.05**	-44.82
Quiet Zone taper	0	**0.02**	-52.77
VSWR at DUT	0	**0.03**	-49.25
VSWR at feed	0	**0.02**	-52.77
Multiple reflections	0	**0.08**	-40.75
Room scattering	0	**0.01**	-60.72
Leakage and cross-talk	0	**0.01**	-60.72
Other errors	0	**0.03**	-49.25
RSS Disturber (cp):			**-35.12**
RSS Error (cp):	0	**0.15**	

Table 2 Worst Case Error Budget for Gain Accuracy in C-Band of the CCR 75/60 (3 σ values assumed)

4. Improvement Measures

Distorting fields, which degrade the plane wave field in the quiet zone of compact range test facilities, are mainly caused by the direct leakage of the feed and by diffraction effects at the reflector rim structures. The direct leakage of the feed can be eliminated to a great extent by a well designed baffle or a hard gating system [4], while maintaining the real-time measurement capability. The diffracted fields from the reflector rim can be reduced by serrated or rolled edges, whereas rolled edges cannot be applied in a double reflector compact range. An optimized serration design can lead to a further reduction of this type of error.

Compensated compact ranges exhibit no system inherent cross-polarization and have therefore an excellent cross-polar performance. These type of test facilities represent therefore the highest standard of compact ranges when regarding the measurement accuracy. For that aim, the suggested improvement measures will only be applied at compensated systems. Their use is a pre-condition to fulfill the performance specifications in Chapter 2.
Multi-path propagation of the diffracted fields from the serrations into the quiet zone can be eliminated by hard gating, if the difference of the propagation time between the main field and the distorting fields is > ≈ 4 ns [5]. The triple diffraction/reflection effect, caused by the right edge of the main reflector, can be suppressed by implementation of a billboard [6], as shown in Figure 3, or the newly developed SERAP (Serration Radiation Protection) structure [6]. The SERAP structure is shown in Figure 4.

Figure 3 Billboard at Main Reflector in the CCR 75/60

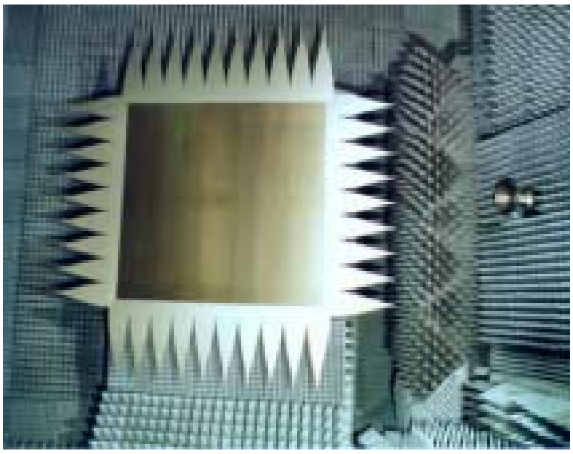

Figure 4 SERAP Structure between Main Reflector and Feed in the CCR 20/17

The distorting fields which emanate from the serrations and propagate along the same ray path as the main field via both reflectors were reduced with a new serration design, as shown in Figure 5.

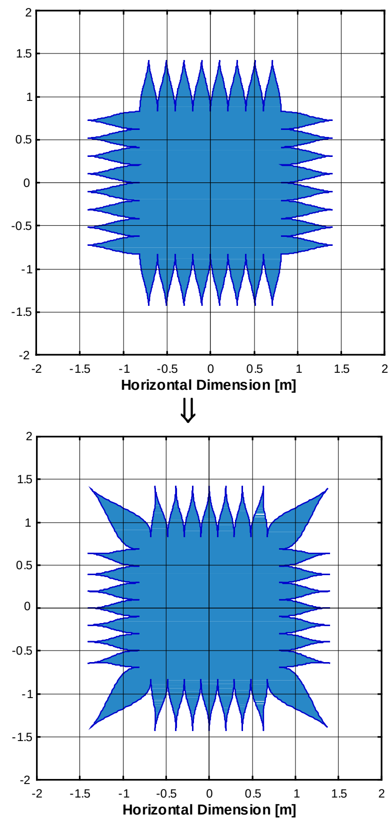

Figure 5 Improvement of Serration for the CCR 20/17

With a GO/UTD analysis tool, the geometrical serration parameters like rim contour, serration length, position tilting, etc. were investigated within a large range of

variation [7]. The quiet zone fields were calculated along single cuts and in full planes, transverse to the incident main field. The optimization, applied for the CCR 20/17 of Astrium GmbH, considered co-polar as well as cross-polar fields for horizontal and vertical polarization within a frequency range from 3 GHz to 30 GHz. The results exhibited an arrangement of the serrations and a serration contour shape, which differs from the formerly used cosine shape.
The improvements were verified with plane wave probing in the quiet zone of the investigated CCR 20/17, which is installed in the laboratory for satellite communications at the Munich University of Applied Sciences.

5. Measurement Results

Comparative measurements were performed before and after installation of the optimized serrations at the sub- and main reflector in the CCR 20/17. They were carried out in the quiet zone with a high precision polar plane wave scanner. The frequency range for the measurements covered the C- and M-band, whereas at several frequencies in each band the co- and cross-polar fields along single cuts and full planes were detected for horizontal and vertical feed polarization.

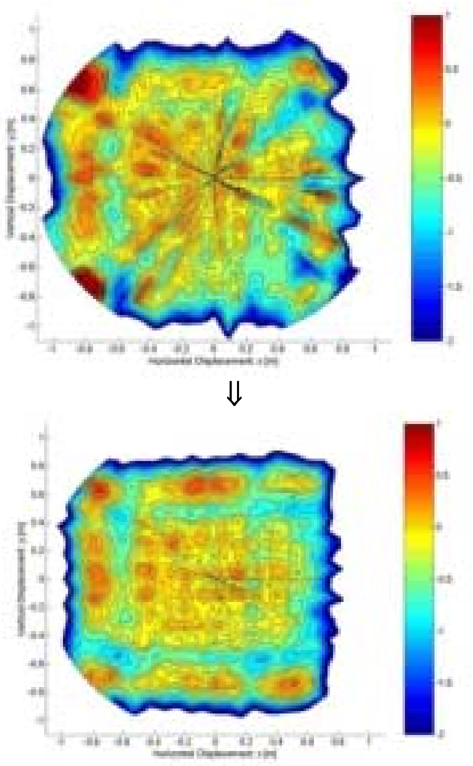

Figure 6 Co-Polar Field in the Quiet Zone of the CCR 20/17 before and after Installation of the Optimized Serrations

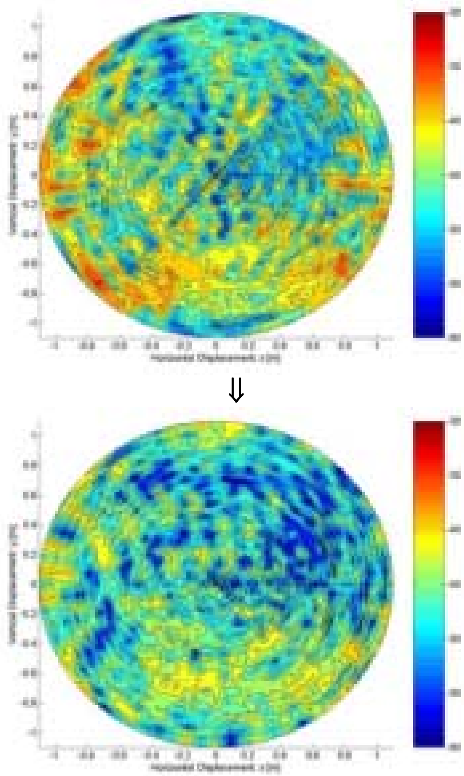

Figure 7 Cross-Polar Field in the Quiet Zone of the CCR 20/17 before and after Installation of the Optimized Serrations

The co- and cross-polar measurement results at 12 GHz and vertical polarization are shown in the Figures 6 and 7.
The improvements resulted in a reduction of the amplitude and phase ripple from originally ± 0.5 dB and ± 3 degree to ± 0.3 dB and ± 2 degree for the co-polar field. A reduction of the cross-polar field from originally - 38 dB to - 43 dB within 95 % of the quiet zone could be achieved. The higher values are only visible at the extreme edge of the quiet zone. Additionally, a more homogeneous field distribution in the quiet zone could be achieved. For all measurements, a special designed compact range feed (Astrium CCR-Feed) with a maximum cross-polarization level of - 50 dB was used.

6. Achievable Performance Characteristics

The measurement accuracy of the CCR of Astrium GmbH, was analyzed and error contributions identified as well as quantitatively summarized within error budgets.
For quantitative consideration of the separate improvement steps, the following reduction of the considered disturber (@ approximately - 45 dB disturber level) for the antenna pattern accuracy can be achieved (3σ values):

- SERAP/Billboard: $\Delta_{Improvement}$ = 3.6 dB
- Hard gating: $\Delta_{Improvement}$ = 1.2 dB*
- Serrations: $\Delta_{Improvement}$ = 2.6 dB**
- AAPC [8]: $\Delta_{Improvement}$ = 3.7 dB**

* For comparative analyses w.r.t. the influence of hard gating, the Baffle was always installed, as its implementation is anticipated, generally. The given improvement value corresponds to the additional suppression of diffracted fields by multi-path propagation via serration zones.

** For comparative analyses w.r.t. the influence of optimized serrations and AAPC, hard gating was always applied.

The improvement values represent relative values based on the fact that all evaluations were performed with measurement data of the CCR 20/17.

The application of the improvement steps is given in the error values in Table 3 below for the side-lobe measurement accuracy of the CCR 75/60. The main errors for the CCR result from diffraction effects at the serrations and from direct leakage of the feed. A reduction of these errors can be performed in order to achieve the required measurement accuracy of ± 1.74 dB @ - 40 dB signal level. For calculation of the overall error, the other error values have to be taken out of Table 1.

Error	Level [dB]	Error [dB]	Dist. [dB]
Reflector system, Serrations, billboard (cp)	-30	0.55	-54.30
Direct leakage	-30	0.04	-76.76
Other errors (Table 1)	- 30	0.22	- 61.68
RSS Disturber (cp):			**-53.55**
RSS Error (cp):	-30	**0.59**	
RSS Error (cp):	-40	**1.74**	

Table 3 Resulting Error of the Side-lobe Measurement Accuracy for the CCR 75/60 after Optimization

7. Conclusions

Within the performed analyses, the measurement accuracy of highly accurate satellite antenna test facilities, like the Compensated Compact Range (CCR) of Astrium GmbH, was investigated for further improvement.

The analyses started with the actual accuracy figures of ± 2.89 dB @ - 40 dB for the pattern and ± 0.16 dB for the gain measurements. As a goal, a maximum error of ± 1 dB @ - 40 dB signal level for the pattern measurement accuracy was considered.

With defined and in detail investigated improvement steps, a reduction of the error levels could be achieved. Besides the already implemented/applied Billboard and AAPC, the application of optimized serrations as well as a fast hard gating system is proposed. The investigations concerning CCR improvement were performed in the small CCR 20/17 at the Munich Univ. of Applied Sciences. For the CCR 75/60, which is usually used for measurement campaigns of commercial satellite antennas of Intelsat, even a further improvement can be expected as given with an improved maximum error level down to ± 1.74 dB @ - 40 dB signal level for the pattern measurement accuracy. The intention of Astrium GmbH is to apply the improvement steps at the CCR 75/60 in the near future.

8. References

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