Paper, presented at: International Conference on Antenna Technologies (ICAT)
23. - 24. February 2005, Ahmedabad, India

DEVELOPMENT OF HIGHLY ACCURATE MEASUREMENT AND DIAGNOSTIC TECHNIQUES FOR SATELLITE ANTENNA TESTING

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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 EADS Astrium GmbH (Germany) was developed and installed. In order to optimize the measurement accuracy of the CCR, detailed error analyses and investigations for improvement measures were performed.

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/hemi illumination.
For verification, highly accurate test facilities were taken into consideration, whereas the Compensated Compact Range (CCR) of EADS Astrium GmbH was investigated in more detail.

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 ± 0.15 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 EADS Astrium GmbH (see Figure 1) was selected as the most promising test facility.

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. For each of the categories, detailed error contributions can be identified.

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.

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 [1], because they interfere with the plane wave field in the quiet zone at different pattern angles. According to the ray trace analyses 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 [1]. For the pattern and gain measurement accuracy, the worst case error budget results are shown in Table 1. For determination of the gain error values, it should be noted that the Astrium power measurement method was applied [1].

Pattern Error	Level dB	Error dB	Disturber dB
RSS Disturber (cp):			**-49.04**
RSS Error (cp):	-30	**1.02**	

Gain Error	Level dB	Error dB	Disturber dB
RSS Disturber (cp):			**-35.12**
RSS Error (cp):	0	**0.15**	

Table 1 Worst Case Error Budgets for the Pattern and Gain Accuracy in C-Band

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 [2], 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 types of test facilities represent therefore the highest standard of compact ranges when regarding the measurement accuracy.
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 [3]. The quiet zone fields were calculated along single cuts and in full planes, transverse to the incident main field.

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.
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 (EADS 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 EADS 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 [4]: $\Delta_{Improvement}$ = 3.6 dB
- Hard gating [2]: $\Delta_{Improvement}$ = 1.2 dB
- Serrations [5]: $\Delta_{Improvement}$ = 2.6 dB
- AAPC [1]: $\Delta_{Improvement}$ = 3.7 dB

7. Conclusions

Within the performed analyses, the measurement accuracy of highly accurate satellite antenna test facilities, like the Compensated Compact Range (CCR) of EADS 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 the 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. During the last years, EADS Astrium GmbH applied the analyzed improvement steps at the CCR 75/60 in Ottobrunn as well as compact range projects for external customers.

8. References

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