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Development of a Highly Sophisticated Test Philosophy for Complex Multifeed Satellite Antenna Testing

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ABSTRACT

The Intelsat-IX spacecraft carries a C- and Ku-Band payload. It provides coverages from five different orbital locations over Atlantic (AOR) and Indian (IOR) ocean regions. The feed arrays for the C-band multifeed offset parabolic reflector antennas were designed, manufactured and tested by EADS Astrium GmbH in Munich, Germany. Design drivers for the antenna subsystem were the high power requirement for the transmit antenna and stringent isolation specification for both transmit and receive antennas. The final designs feature as many as 145 feed horns and up to ten switches. Due to the complexity of the beam forming network and the large number of SCRIMP (Short Circular Ring loaded Horn with Minimized Cross-Polarization) horns at every feed array a special test philosophy was introduced in order to detect any malfunction of the array at an early stage of the antenna assembly and integration. This paper will present details of the applied test sequence starting at the initial beam forming network measurements and the intermediate near-field feed testing under extreme environmental conditions up to the final antenna testing in a compact range at unit and at spacecraft level. The used in-house data evaluation software platform allows the evaluation of any measurement at any stage of the testing sequence independent of the actual applied losses and /or design error allocations.

Keywords: Antenna Measurement, Compact Range, Near-Field, Beam-Forming-Network, Multiple Feed Arrays

1. Introduction

After the successful delivery of the C-Band Hemi/Zone beam antennas as well as the C-Band high performance global beam antennas for the Intelsat VIII satellite family in 1996 EADS Astrium GmbH (at this time Dornier Satellitensysteme GmbH) obtained in 1997 from Space System/Loral the contract for the design, manufacture and testing of the C-Band Hemi/Zone antennas for the following satellite series Intelsat-IX. Space System/Loral was the prime contractor for this program with responsibility for the complete satellite. The program consists of 7 spacecrafts each carrying two C-Band Hemi/Zone antennas. At present, all spacecrafts were launched and the In-Orbit tests were successfully completed.

A complete description of the Intelsat-IX antenna system was presented in [1]. This paper will focus on the Hemi/Zone beam antenna RF tests, starting with Beam Forming Network (BFN) measurements and ending with the antenna spacecraft tests. Intermediate tests were performed in the cylindrical near-field facility, including RF measurements at temperatures of -50°C and +85°C.

The goal of this paper is to present a complete measurement sequence with individual explanations to each type of test and comparisons of typical results of the different measurement facilities and set-ups.

2. Overview of the C-Band Antennas

The Intelsat-IX satellites carry a C-Band and Ku-Band payload. It provides coverage from five different orbital locations over Atlantic (AOR) and Indian (IOR) ocean regions. In the case of the C-Band Hemi/Zone antenna an Equivalent Isotropically Radiated Power (EIRP) of 37 dBW is required which is an 1 dB increase compared to the previous Intelsat-VIII generation.

Design drivers for the antenna subsystem are the high power requirement for the transmit antenna and stringent isolation specification allowing seven fold frequency reuse as well as the partly reconfigureable zone beam coverages which are implemented via switches while the hemi beams are designed to provide the coverage for all five orbital locations with no reconfiguration. The following Figure 1 and Figure 2 show the required hemi beam coverages (solid line) and the achieved Edge of Coverage (EOC) Gain (dotted line) for one geostationary orbit. To fulfil all these requirements the same principle as for previous Intelsat antenna subsystems has been chosen. The transmit and receive antennas are designed as multifeed reflector antennas using an offset parabolic reflector. Key technologies for Intelsat-IX are the low cross-polar SCRIMP horn and the software for predicting the horn behaviour and notably the mutual coupling between horns in the array. The transmit antenna operates from 3.625GHz to 4.075GHz with a super-elliptical reflector at the size of 3.2m in the off-set plane and 2.8m in the symmetry plane. The receive antenna is in principal a scaled down version of the transmit antenna but with circular reflector and the diameter of 2.3m.

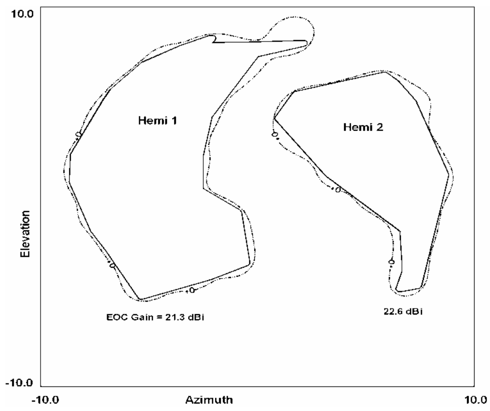


Figure 1: *Hemi Beam Coverages*

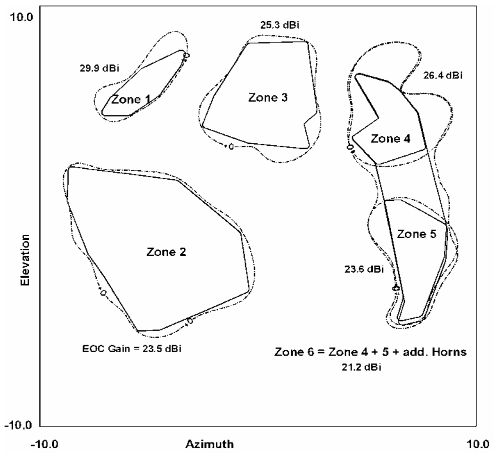


Figure 2: *Zone Beam Coverages*

3. RF Test Philosophy

Due to the circumstances of complexity of one feed array (up to 145 SCRIMP horns) and the large number of feed arrays (16 complete C-Band antennas) of the Intelsat-IX project and the stringent requirements regarding the schedule and the budget a special RF test philosophy was introduced. This should allow to detect any malfunction of the Device under Test (DUT) at an early stage of the manufacturing or at least at an early stage of the final test sequence.

3.1 Test Drivers

Today's development, manufacturing and test of complex satellite antenna systems like the Intelsat-IX antennas are driven by several factors which influence the test requirements and performance.

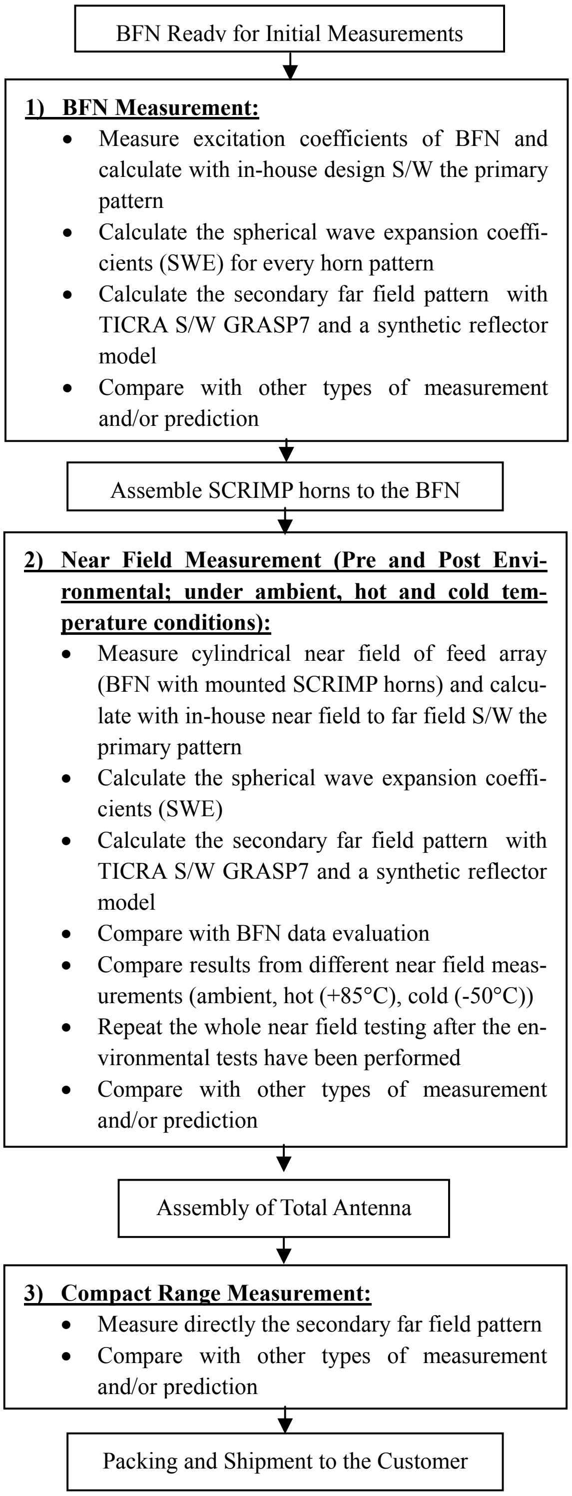
- Short development time: 21 month schedule for 1st flight model from manufacturing start to delivery. The additional flight models followed in frames of appr. 3-4 months each other. This requires a rapid design, manufacturing and testing of the antenna subsystems.
- Low cost: The Intelsat-IX project did not foresee any engineering or qualification model. Only the first model was called Protoflight Model (PFM) at which additional parameters were analyzed and qualified.
- Strict performance monitoring: To detect possible defects in both design and production, tests at many stages were applied and translated to the secondary far field pattern in order to get a statement about the expected final performance.
- Redundant measurements with different measurement techniques: Initial measurement of excitation coefficients at the Beam Forming Network level followed by near field testing and finally far field measurement in the compact range. This excludes fundamental measurement errors and detects possible flaws.

3.2 Test Flow

For that reason Astrium established a testing sequence which consists of three major steps at the unit level test and the final spacecraft testing under responsibility of the prime contractor Space Systems/Loral:

1) Beam Forming Network (BFN) measurements
2) Near field testing before and after the environmental test sequence including testing under thermal conditions.
3) Compact Range measurements with mock-up structure at unit level
4) Compact Range measurements at spacecraft level

Figure 3 shows the complete sequence of performed RF measurement steps which were carried out under the responsibility of EADS Astrium at unit level. The Steps 1 (BFN measurement) and 2 (Near-field measurement) at Figure 3 require a synthetic model of the reflector to calculate the secondary far field pattern. For that reason an extensive use of the well known TICRA software GRASP was made. As the reflector is placed in the



BFN Ready for Initial Measurements

1) BFN Measurement:

- Measure excitation coefficients of BFN and calculate with in-house design S/W the primary pattern
- Calculate the spherical wave expansion coefficients (SWE) for every horn pattern
- Calculate the secondary far field pattern with TICRA S/W GRASP7 and a synthetic reflector model
- Compare with other types of measurement and/or prediction

Assemble SCRIMP horns to the BFN

2) Near Field Measurement (Pre and Post Environmental; under ambient, hot and cold temperature conditions):

- Measure cylindrical near field of feed array (BFN with mounted SCRIMP horns) and calculate with in-house near field to far field S/W the primary pattern
- Calculate the spherical wave expansion coefficients (SWE)
- Calculate the secondary far field pattern with TICRA S/W GRASP7 and a synthetic reflector model
- Compare with BFN data evaluation
- Compare results from different near field measurements (ambient, hot (+85°C), cold (-50°C))
- Repeat the whole near field testing after the environmental tests have been performed
- Compare with other types of measurement and/or prediction

Assembly of Total Antenna

3) Compact Range Measurement:

- Measure directly the secondary far field pattern
- Compare with other types of measurement and/or prediction

Packing and Shipment to the Customer

Figure 3: *Test Sequence of the applied RF tests*

near-field of the feed array additionally a calculation of spherical wave expansion coefficients is mandatory to ensure that the near field effects are properly taken into account. That was performed using the TICRA software SWEP. At the BFN measurement (Step 1) there is one additional calculation necessary in order to derive the element beam pattern out of the measured excitation coefficients of the BFN. Due to the synthetic model a certain Design Error Allocation margin has to be applied to the final calculated pattern. The final compact range measurement (Step 3) including the mock-up structure, simulating the spacecraft scattering, fulfills all requirements of the unit level testing and does not need any additional calculation. The secondary far field pattern is obtained directly out of the measurement. At any step a comparison with the predictions and/or the previously carried out measurement gives a high reliability into the results. An important criterion for a successful measurement campaign under a tight schedule is additionally also a properly running data processing and analysis tool and a common data file standard. This was achieved by using the EADS Astrium in-house software package EVALPRJ for processing, analysis and presentation of the data of all different measurement methods in a common mode.

4. Details of Performed RF Measurement Steps

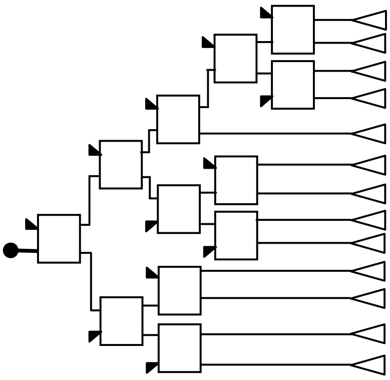
4.1 Initial Beam Forming Network Measurement

As an example Figure 5 shows the structure and coefficients of the BFN for Zone 3. This is the output of an excitation coefficient optimization. The optimization software makes use of the Astrium horn and modeling software which accounts the mutual coupling between the horns, to generate the element beam pattern. The beam forming network for all Hemi and Zone beams is realized in coaxial TEM-line technology and consists of three layers. Figure 4 shows the upper layer of a transmit feed array. The complete BFN is tuned and sealed prior to the installation of the SCRIMP horns with their built-in polarizers. The actual coefficients are measured at all BFN polarizer interface points using a Network-Analyzer in a swept mode over the complete frequency band.

Figure 4: *Upper Layer of the BFN*

The performance of the measured BFN Hemi/Zone beam is then transformed to the primary far field by using the horn and array modeling software from EADS Astrium. This pattern is afterwards converted into spherical wave expansion coefficients which are used as the input for the final calculation over the reflector in order to achieve the secondary far field. The far field performance is the fail/pass criterion for the hardware at this stage.

Figure 6 shows the Co-Polar pattern which was derived from the overlay of the BFN and Compact Range measurements for the Zone 3 Beam. All contour levels are in dB relative to the specified Edge of Coverage (EOC) gain. It is seen that both the mainlobe as well as the sidelobe areas has been modeled very well.



dB	Deg	No
-28.4	60.6	#1
-25.6	42.8	#1
-15.4	67.8	#4
-14.7	57.8	#2
-8.2	44.1	#2
-14.3	42.9	#2
-9.2	8.0	#1
-11.9	32.4	#4
-20.3	58.5	#6
-7.9	62.0	#6
-6.0	56.8	#4
-9.5	93.5	#6
-16.6	90.0	#6

Figure 5: *BFN coefficients of Zone 3*

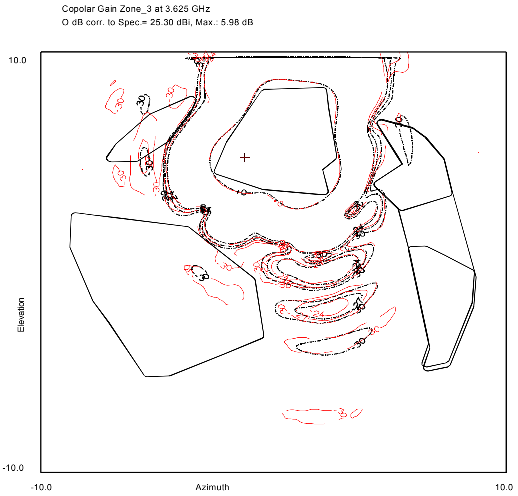


Figure 6: *Comparison of BFN far field data (black) to measured Compact Range data (red) of the Zone 3 beam*

4.2 Intermediate Near-Field Testing at Extreme Temperatures

Usually the reflector is not available at the time of the environmental tests of the feed array assembly. Due to this reason and the requirement of a prediction about the final performance the near field testing of the feed array without reflector is a suitable method. The secondary far field pattern can be calculated again using a synthetic reflector model which allows the calculation of the secondary far field pattern.

Measuring the feed array without the reflector allows additional the chance to apply RF measurements under extreme temperatures which can be carried out at the near field test facility by using a closed but RF transparent climate box on top of the turntable. Figure 7 shows the set-up in the cylindrical near field test facility of EADS Astrium. To allow a wide angle rotation also the complete climate control box is mounted on the turntable. A detailed description of the test range of EADS Astrium is given in [2].

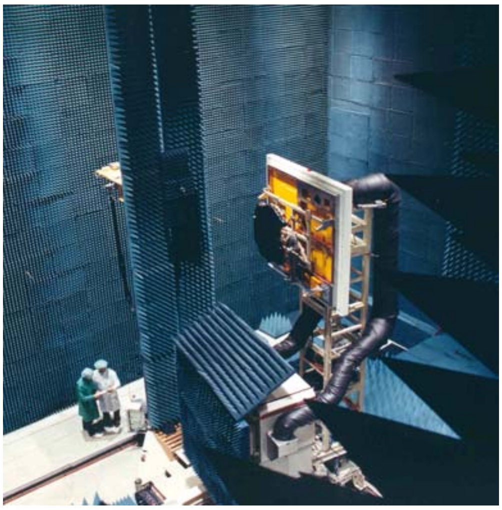


Figure 7: *Set-up with feed array in the climate box at top of the azimuth turntable in the cylindrical near field range*

The secondary far field pattern is derived in three steps according to the given description in the above chapter “Test Flow”. In the first step the primary far field is calculated from the measured cylindrical near field using the Astrium in-house transformation software. The next step, the evaluation of the secondary far field by using a synthetic model of the reflector, is identical to the BFN far field calculation.

Figure 8 shows the Co-Polar results of the Hemi 1 beam from the near field evaluation compared to the final CCR measurements of the complete antenna subsystem including a mock-up structure. Figure 9 compares the Co-Polar pattern results of the Hemi 1 beam before and after the environmental tests and Figure 10 shows the overlay of the applied hot (+85°C) and cold (-50°C) RF-tests in the near field.

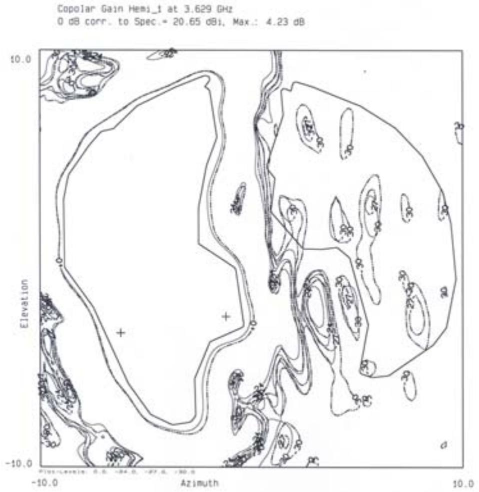


Figure 8: *Overlay of Near Field (Dotted) and Compact Range (Solid) Results of the Hemi 1 beam Co-Polar Pattern*

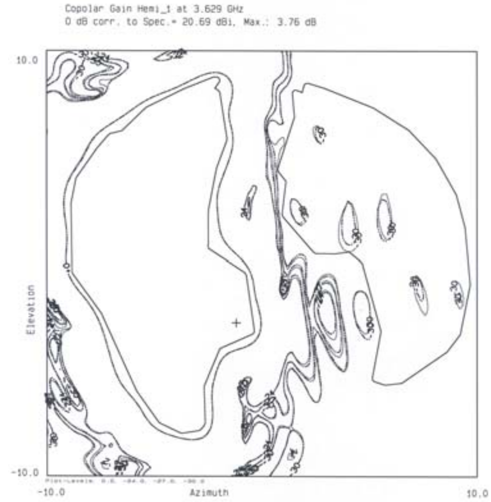


Figure 9: *Overlay of the Pre- (Dotted) and Post Environmental (Solid) Test Results of the Hemi 1 beam Co-Polar Pattern*

The results show in every case of the near field evaluation a close agreement between the overlaid patterns. Also the agreement between the near-field and compact range measurements is very well. This demonstrates that the use of state-of-the-art software and well prepared synthetic reflector models allows the prediction of complex antenna structures from the very first step of the design and also the stable behavior of the antenna design under extreme temperatures.

Figure 10: *Overlay of the RF-Test Results of the Co-Polar Hemi 1 Beam, at Hot (+85°C, Solid) and Cold (-50°C, Cold)*

4.3 Final Compact Range Tests

Unit Level Testing

The radiation characteristic of the complete antenna subsystem (feed array with reflector) was measured directly in the large Compensated Compact Range (CCR 75/60) of EADS Astrium. This measurement was the final subsystem performance testing at which the results had to be compared against the given specification.

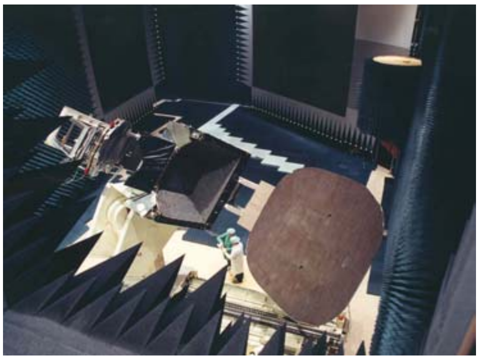


Figure 11: *Transmit Antenna including Mock-Up installed in Compact Range CCR75/60 of EADS Astrium*

The measurements of the first antennas (Protoflight Model, PFM) in the compact range were performed with and without mock-up in order to evaluate the performance of the antenna itself without scattering effects of the mock-up. All following flight models were measured with mock-up. Figure 11 shows a photograph of the installed transmit antenna at the compact range of EADS Astrium.

Spacecraft Level Testing

Due to the unique situation that Astrium carried out also the data evaluation for the spacecraft testing with the same software which was already used during the unit level tests and that the same type of compact range was used it was quite easy to compare the final spacecraft tests with the unit level tests at any stage. Figure 12 gives an image of the installed Intelsat-IX satellite in the CCR of Space Systems/Loral during the payload tests at spacecraft level.

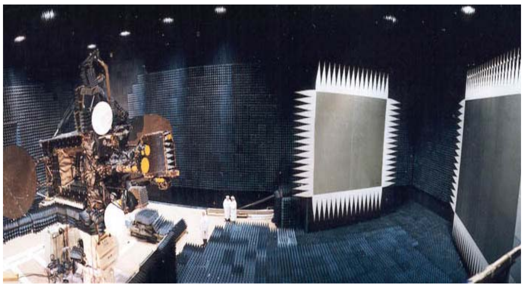


Figure 12: *Satellite installed in Compact Range CCR75/60 of Space Systems/Loral*

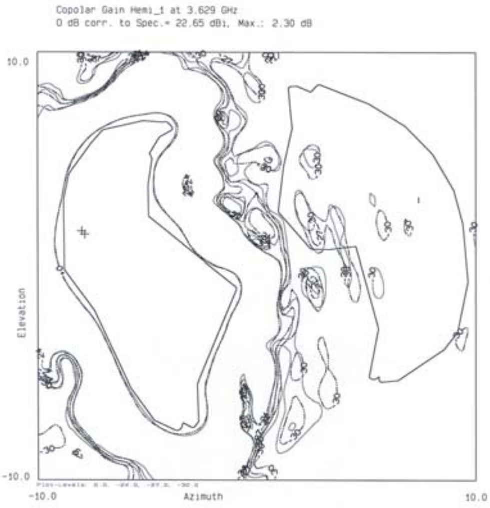


Figure 13: *Comparison of Compact Range Results at Unit Level (Dotted) and System Level (Solid) for Hemi1 beam Co-Polar Pattern*

Figure 13 demonstrates the close agreement between the unit level test at the CCR of EADS Astrium and the system level test at the CCR of Space Systems/Loral. The figure shows the Co-Polar pattern of the Hemi 1 beam for the lowest transmit frequency 3.629GHz and the specified coverage polygons. All levels are given in dB with respect to the Edge of Coverage (EOC) gain specification.

5. Conclusion

The Intelsat-IX antenna measurement program has shown that accurate software modeling techniques coupled with accurate measurement techniques are key requirements for designing and manufacturing high performance multiple beam antennas and deliver these within short time frames dictated by today's commercial satellite programs. It has been demonstrated that measurements over temperature can be performed with very high accuracy. And even the knowledge of the complex excitation coefficients is sufficient to give a prediction about the final secondary far field pattern. This allows very early in the process of a satellite antenna development program a detailed verification of the performance compared to the specification. Monitoring and tracing of the performance along the manufacturing and testing process is possible at any stage.

6. Acknowledgement

EADS Astrium GmbH is indebted to Intelsat and Space Systems/Loral for funding the design and delivery of the C-Band Hemi/Zone feed arrays for the Intelsat-IX satellite fleet.

7. References

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