RCS MEASUREMENTS WITH A HIGH RESOLUTION HARDGATING SYSTEM

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Abstract

In general, the RF test setups of antenna test facilities are designed and optimized for antenna pattern and gain measurements. However, the operation of test facilities, especially the here considered 'Double Reflector Compact Ranges', can be extended, so that they can also be used for RCS testing.
A simple and very practical expansion of the RF antenna test setup - while maintaining the real-time capability - can be achieved with the aid of a hardware gating system. With this type of setup, RCS measurements have successfully been performed in the Compensated Compact Ranges of EADS Astrium. The applied gating system was the high resolution Hard-gating System HG2000 of EADS Astrium, developed together with the Munich Univ. of App. Sciences.
Within this paper, the applied facility and the gating system will be described firstly. Subsequently, the modified test setup and the test results obtained by calibration measurements will be shown. They will give an indication of the achievable resolution for the extended test system w.r.t. object size detection and resulting amplitude dynamic range.

Keywords:
RCS Measurement, Compact Range, Hardgating

1. Introduction

Nowadays, compact range test facilities represent a standard in fast real time and high precision antenna and RCS measurements within a frequency range from 1 to 500 GHz and beyond. With the development of the Compensated Compact Ranges (CCR), a fundamental improvement by suppressing the system inherent cross-polarization was achieved [1].

For Radar Cross Section (RCS) measurements, a high resolution in time domain as well as in Signal-to-Interference-Ratio (SIR) is necessary. RF pulses with an amplitude dynamic range between 70 to 100 dB are required to achieve such a good amplitude resolution.
The Hardgating System, which originally was developed to suppress undesired distorting fields in antenna test facilities [2,3] can also be applied for RCS measurements. The system isolation between the on-to-off state switching status of the PIN-switches can be extended up to 120 ... 140 dB. The spatial resolution of 1.2 m corresponds to the minimum system pulse width, which can be adjusted down to 4 ns. This flexible and adjustable switching capability is preferably applicable for antenna as well as RCS testing.
In the following, investigation results, concerning the application of the proposed Hardgating System for RCS measurements in the CCR's of EADS Astrium will be presented. The System was already installed and implemented in the CCR 20/17 at the Munich Univ. of App. Sciences, in the CCR 75/60 at EADS Astrium as well as several other single and double reflector compact test facilities of EADS Astrium customers. The achieved RCS results rely on measurements with calibration standards like spheres with different diameters or plane, circular and rectangular reflectors.

2. Test Facility

The Compensated Compact Ranges CCR 20/17, CCR 75/60 and CCR 120/100 of EADS Astrium GmbH represent the highest standard of compact antenna RF testing mainly for satellite antennas requiring different sizes of test zones. The CCR's main advantage in antenna - and especially in satellite antenna - testing is the high cross-polar purity up to at least - 40 dB. The remaining cross-polar component of the facility below this value is produced from secondary effects as reflector distortions, rim design and feed performance, only. The CCR 75/60 and CCR 20/17 are shown in Figure 1 and Figure 2.

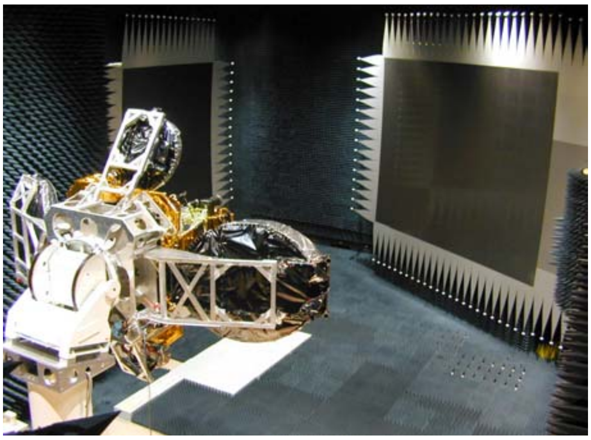

Figure 1 CCR 75/60 of EADS Astrium in Ottobrunn, Germany, with Payload Module Installed on Positioner

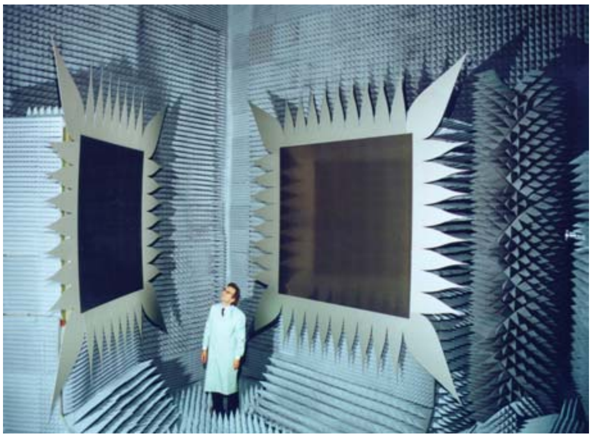

Figure 2 CCR 20/17 at Munich University of Applied Sciences for Research and Development Activities

Up to now, RCS measurements with the aid of hardware gating have already been performed in the CCR 75/60 and in the CCR 20/17.

For mono-static RCS testing, the required single feed is nominally positioned with its phase centre in the focal point of the reflector system.

In case of bi-static RCS testing, a boresight deviation w.r.t. the nominal situation occurs, depending on the relationship of the lateral feed position to the resulting boresight angle. For the CCR 75/60, a slight feed shifting in the order of e.g. ± 200 mm for X-Band feed aperture dimensions, leads to a boresight deviation of only ± 0.3 deg which corresponds to a difference angle of ± 0.6 deg between incident and emanating fields at the target. Such a configuration implies already a 45 degree rotation of the feeds in order to minimize its distances w.r.t the facilities focal point in the azimuth plane. For comparison, the typical boresight deviation value for single reflector ranges with a focal length of 13 m is in the same order of the considered CCR. Nevertheless, the CCR exhibits a much better field quality in the shifted (scanned) quiet zones according to the equivalent large RF focal length which determines the differential path loss. The feed setup for bi-static RCS measurements in the CCR 75/60, realized with a 45 degree rotated twin-feed plate, is shown in Figure 3.

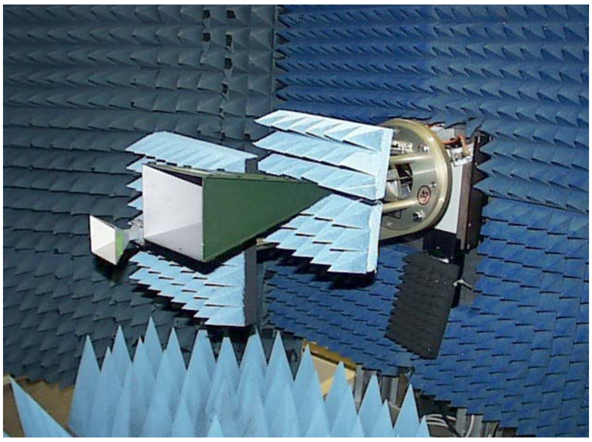

Figure 3 RCS Feed Setup with Twin-Feed Plate and Tx-/Rx-Feed Installed for Bi-static Measurements

3. Hardgating System

The applied gating hardware is the Hardgating System HG2000 of EADS Astrium GmbH. Hardgating was selected in comparison to software gating as it is a real-time measurement method, which does not require high number of time consuming measurements. By that, a time saving factor of 10 to 100 can be achieved [4].

Generally, if hardgating is applied in an antenna test facility, the RF transmit signal is 100 % amplitude modulated with very short pulses in the order of nanoseconds. Considering different ray paths of interfering field contributions, as shown in Figure 4, the transmitted pulses reach the quiet zone at different times. The geometrical location of the scatterers in the spatial domain is deterministically related to the time delayed incidence of their field contributions in the quiet zone in the time domain. The width of the transmitted pulse determines the spatial discrimination of the scatterers which lead to an interfering field contribution in the quiet zone. The pulses are generated with a fast RF switch at the transmit side in the signal path between the generator and feed.

Selective measurements of the plane wave field and the different interfering fields or their suppression, respectively, can be performed by insertion of a second fast RF switch at the receiver side between the test antenna and receiver. This switch generates a 'window' in the time domain in which the detected field of the test antenna is forwarded to the receiver.

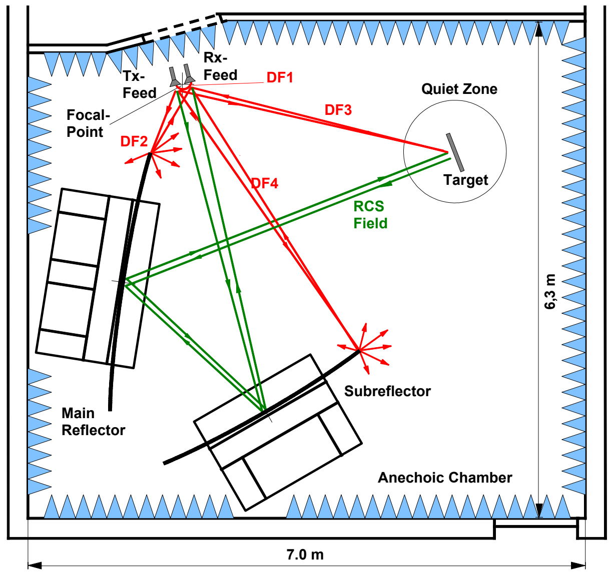

Figure 4 Ground Plane of CCR 20/17 with Significant Ray Paths for Bi-Static RCS Measurements (see also Figure 9)

The Hardgating System HG2000 consists out of a control unit, one transmit and one receive unit. The transmit and receive units contain ultra fast PIN diode switches. The control unit supplies the transmit and receive units with power, synchronisation and data signals. For practical reasons, the connection to each switch unit is realized by one coaxial cable, which transmits all signals. The adjustment of the pulse widths for the transmit pulse and receive window, as well as the position of the receive window, can be performed directly at the control unit or via a standard interface like RS232 or IEEE 488 via PC. The PC software enables the setting of all adjustments and visualization of the pulses in the time domain.
The Hardgating System HG2000 of EADS Astrium, as shown in Figure 5, was mainly developed to fulfil the requirements of single and double reflector compact range test facilities of different sizes. Especially, the second facility type puts high demands on gating as it exhibits relatively small dimensions of the reflectors and distances between feed, reflectors and quiet zone.

Figure 5 Hardgating System HG2000 of EADS Astrium with Control- and Tx-/Rx-Switch Units

For this reason and in order to achieve a high resolution in the spatial domain, the pulse widths can flexibly be adjusted to values within the range of a few nanoseconds. The measurement result of the output signal of a switch unit, allowing a minimal adjustable pulse width of 4 ns, is shown in Figure 6. The specifications of the Tx- and Rx-switch units are separately given in Table 1 for the antenna and the RCS Hardgating System (see Chapter 4).

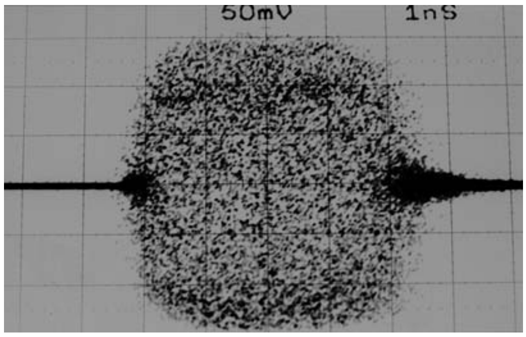

Figure 6 Measured Output Signal of a Switch Unit with an Adjusted Pulsewidth of 4 ns

The mentioned Hardgating System HG2000 has already been applied at several customers' premises for antenna as well as RCS measurement applications.

4. RCS Test Setup

The principle RF test setup for antenna and RCS measurements is typically based on the distributed mixer concept. In order to achieve higher measurement accuracies, a gating technique can additionally be applied for antenna pattern and RCS measurements to suppress unwanted reflecting or distorting fields in the test facility.

In case of using a Hardgating System, the principle test setup for mono-static measurements is shown in Figure 7. The equivalent setup for bi-static RCS measurements is shown in Figure 8.

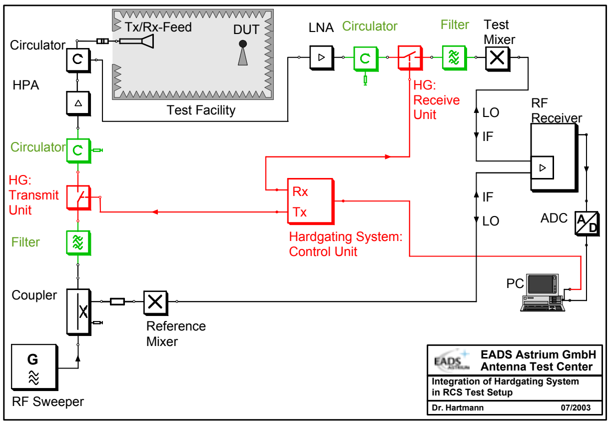

Figure 7 Principle RF Test Setup for Mono-Static RCS Testing Applying a Hardgating System

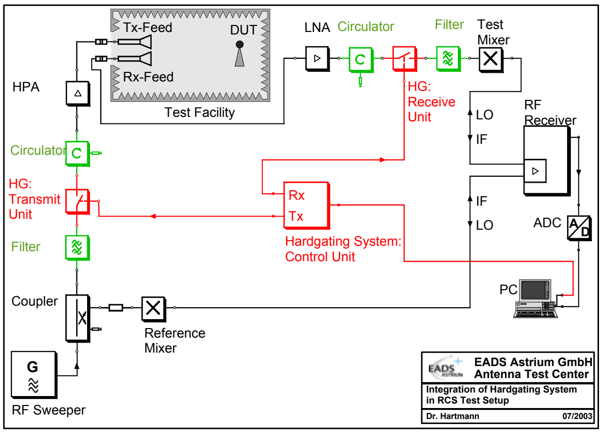

Figure 8 Principle RF Test Setup for Bi-Static RCS Testing Applying a Hardgating System

In the setups, one switch unit is inserted in the Tx signal path and one in the Rx signal path. Both switch units are synchronized, controlled and powered by the central placed control unit of the system and connected via the coaxial synchronization cables.

The setups in Figure 7 and Figure 8 show additionally inserted isolators and filters which are used to prevent reflections in the RF signal path and to reduce the influence of video transients from the switch unit hardware into the RF signal path. For mono-static RCS measurements, the receive signal has to be coupled out via a circulator at the Tx feed and for bi-static RCS measurements a second feed has to be installed via a second feed holder or with a twin-feed plate, as already mentioned in Section 2. In order to achieve a higher signal isolation, different switch units can be applied with isolation values up to 120 dB, as given in Table 1(b).

Parameter	**Limits**
Function	SPST
Frequency	2 - 18 GHz
Insertion loss	3.0 dB max.
Isolation	80 dB min.
SWR	2.0 : 1 max.
Rise/Fall time	1 ns typ.

(a)

Parameter	**Limits**
Function	SPST
Frequency	2 - 18 GHz
Insertion loss	5.0 dB max.
Isolation	120 dB min.
SWR	2.0 : 1 max.
Rise/Fall time	1.3 ns typ.

(b)

Table 1 Specification of the Tx-/Rx-Switch Units for (a) Antenna Pattern and (b) RCS Measurements

5. Facility Analysis

Before starting the RCS measurements, detailed analyses of the test facility have to be performed in order to determine the incidence of target and disturbing signals at the Rx feed in the time domain. Further, the amplitudes of the mentioned signals have to be analyzed in order to establish an error budget for calculating the resulting measurement accuracy for RCS testing with the Hardgating System. The dynamic losses of the setup with the System have to be considered which are determined by the ratio of pulse width to pulse repetition time. Usually, this problem is solved by inserting an equivalent amplifier, preferably an LNA, in the receive path.

For the CCR, the following main field contributions can be identified:

- Feed coupled field (in case of bi-static testing) or Isolator coupled signal (in case of mono-static testing)
- Direct leakage from target
- Reflector distorting fields
- Target field
- Backwall field

The timing diagram valid for the CCR 20/17 is shown in Figure 9. The diagram is related only to the time delay of the pulses in the facility (see Figure 4) without regarding delays within cables and RF components. This constant delay values are already subtracted and do not influence the relative positions of the field contribution to each other.

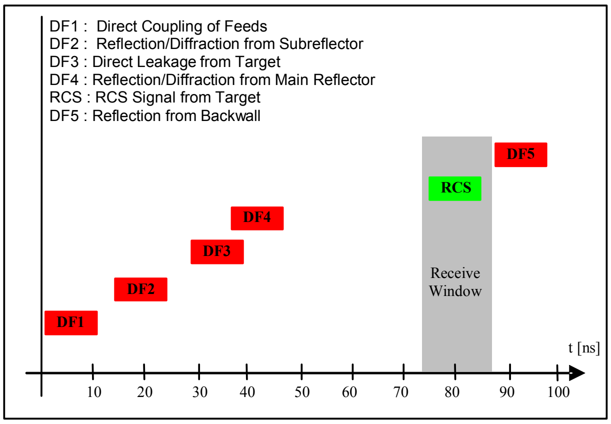

Figure 9 Timing Diagram with different Distorting Fields (DF1..5) and RCS Target Signal (RCS) as well as Receive Window of Hardgating System

For the CCR's of EADS Astrium, detailed error analyses were performed for the antenna pattern and gain measurement accuracy [5]. The main disturber are the diffracted fields from the sub- and main reflector serrations as well as the direct leakage from the feed. For RCS testing, additional disturber are the feed coupled field - in case of bi-static setup - and the disturbing fields from the surrounding of the target and from the backwall. With an optimum setting of the Hardgating System the feed coupled field, the field from the backwall and partly the diffracted fields from the serrations can significantly be reduced as shown in Figure 9. However, also diffracted fields with nearly the same transit time from the feed via the reflectors to the test object exist in compact ranges. These fields lead to an interference with the plane wave field in the quiet zone and to a ripple in amplitude and phase for which equivalent disturber values can be calculated.
For the applied calibration standards (see Chapter 6) and for the considered Ku-Band frequency range, a disturber value of - 28 dB was identified, which leads to a maximum RCS measurement error of ± 0.35 dB in the CCR.

6. Measurement Results

Prior to performing RCS measurements on unknown targets, calibration data have to be generated in order to verify the test setup and to perform the necessary amplitude normalization of the test data itself.
In the RCS test campaigns, described within this paper, the calibration was performed with one sphere, a rectangular plate and a corner reflector. The advantage of the sphere is the possibility to determine its theoretical RCS value exactly. On the other hand, (large) spheres are very difficult to be manufactured and very heavy in weight, whereas the RCS value of small spheres is very low.
The diameter of the used sphere is 0.08 m and the dimension of the calibration plate is 0.1 m x 0.1 m. The dimensions of the corner reflector plates are 0.1 m x 0.1 m so that the height is 0.1 m. The theoretical RCS values can be calculated as follows:

$$\sigma_{Sphere} = -22.99 \text{ dBsm}$$
$$\sigma_{Plate} = 3.39 \text{ dBsm} \quad @\ 12.5 \text{ GHz}$$
$$\sigma_{CornerRefl.} = 6.40 \text{ dBsm} \quad @\ 12.5 \text{ GHz}$$

The RCS measurements were performed in the following sequence:

1. Adjustment of optimum time settings at Hardgating System
2. Measurement of facility environment without target, the so-called "empty-room" measurement
3. Measurement of at least two theoretically and deterministically defined calibration objects
4. Complex subtraction of "empty-room" value from the calibration values
5. Check of measured level difference between two calibration standards
6. Measurement of unknown target
7. Complex subtraction of "empty-room" value from target value
8. Calculation of RCS value by normalization of target value to one of the calibration values

As shown in Figure 10, a pylon out of Styrofoam is centrally placed on the the DUT positioner. The positioner itself is covered with an absorber, which additionally is tilted by 30 degree w.r.t. the upright position.

Figure 10 Mechanical Test Structure for RCS Measurements with Pylon, Positioner and Cover Plate; Lateral Positioner Absorber Plates Removed

The comparative RCS measurement results of the sphere, the plate and the corner reflector are shown in Figure 11 for a test frequency of 12.5 GHz and for co-polarization. A comparison between mono- and bi-static measurement results related to the sphere value is shown in Figure 12.

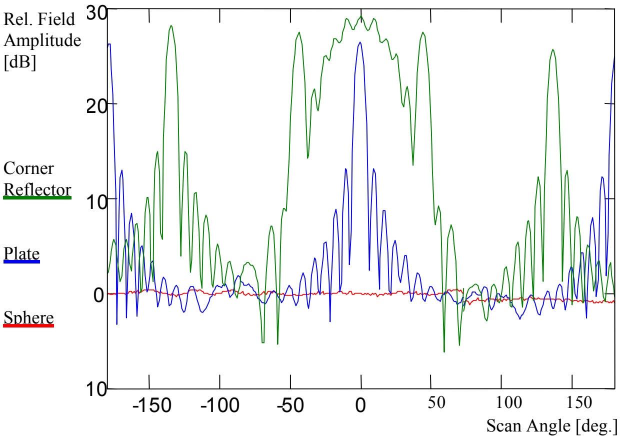

Figure 11 RCS Test Results of Sphere, Plate and Corner Reflector for Bi-static Measurement, VV-Polarization Adjusted

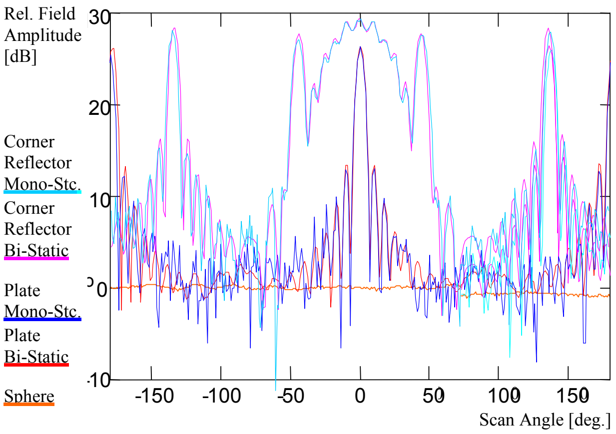

Figure 12 RCS Test Results of Sphere, Plate and Corner Reflector with Comparison of Mono- and Bi-Static Measurement Data

The measurement results of the calibration targets exhibit a good agreement of the amplitude differences between the applied sphere to the rectangular plate and also to the corner reflector as well as between the rectangular plate to the corner reflector. These correlations of the values w.r.t to its theoretical values give at least an indication that the measurement accuracy with the applied RCS test setup including the use of the Hardgating System HG2000 is accurate for testing RCS targets.

7. Conclusions

The standard RF test setup of antenna test facilities can be extended to a RCS setup by applying hardware gating. For two different high performance compact test ranges as the CCR 20/17 at the Munich Univ. of Appl. Sci. and the CCR 75/60 of EADS Astrium in Ottobrunn, Germany, related RCS tests with a Hardgating System were performed. The Hardgating System HG 2000 of EADS Astrium, which originally was designed for improvement of the antenna measurement accuracy [5], was now adapted to the requirements of RCS testing.

Validation measurement results, shown within this paper, exhibit a close agreement of relative measurement values compared to absolute theoretical values of the applied calibration standards like a sphere, a rectangular plate and a corner reflector. A measurement accuracy of better than ± 0.5 dB could be derived with the verification measurements. The accuracy value is determined by the measurement accuracy of the calibration standards on which the targets are normalized. The dynamic range or signal-to-interference (SIR) value was determined to a figure of better than 70 dB.

It can be summarized, that the application of a Hardgating System in a RCS test facility like the CCR leads to a good measurement accuracy and additionally allows a very flexible, time and cost efficient operation of the test facility itself. In future, further investigations are foreseen, in order to optimize the hardgating implementation and to improve the RCS test environment.

8. References

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