

Satellite Payload Parameter Measurements in a Compensated Compact Antenna Test Range

Juergen Habersack, Horst Kress, Willi Lindemer, Hans-Juergen Steiner

Dornier Satellitensysteme GmbH (DSS) / DaimlerChrysler-Aerospace,
P.O. Box 801169, 81663 Munich, Germany

Abstract

Modern Satellite Antennas and Payloads are characterized by a lot of physical parameters like e.g. Radiation Pattern, Gain, EIRP, Flux Density, G/T and PIM, whereas the available time frame for measurements is getting shorter and shorter. The DSS Compensated Compact Range (CCR) allows a time efficient measurement of all payload parameters with high accuracy under controlled environmental conditions. The CCR consists of two doubly curved reflectors, which prevent inherent cross-polarization and create a very high constant amplitude and phase distribution in the quiet zone with a very good scanning performance. Most of the payload parameters can be measured directly or have to be calculated from a set of measurement values. For the G/T measurement of active antennas a new method for the noise power measurement was established. This paper describes the principle test set-ups with the corresponding measurement techniques to improve the measurement accuracy. Error budgets will be presented for pattern and gain measurement.

Keywords: Compact Range, Payload Test, Satellite Test, Transponder Test

1. Introduction

Payload tests on Spacecraft level are mainly based on the following parameters:

- Radiation Pattern, Coverage, Gain
- Beam Efficiency
- Optical Boresight Determination
- EIRP (Equivalent Isotropic Radiated Power)
- Saturated Flux Density
- Amplitude Frequency Response
- G/T, Group Delay
- PIM (Passive Intermodulation)

The large Compensated Compact Range at DASA/DSS with a nominal test zone of 5.5 x 5.0 x 6.0 m and its instrumentation allows the characterization of the above

listed test parameters. A general problem here is the overall size of the satellite of approximately 8 m and the fact that often the antennas are mounted at the opposite sidewalls of the spacecraft. To overcome this problem, the CCR has the special feature to generate multiple quiet zones to be centered around the respective satellite antennas. The multiple quiet zones are generated by lateral movement of the range feed outside the focal point, resulting in a semi-plane wave. The high quality of the scanned plane waves is caused by the long focal length of the compact range reflector layout.

The multiple plane wave capability introduces the opportunity of creating two or more independent quiet zones in different positions, operating at different frequencies and polarizations. A typical CCR test set-up for payload testing is shown in Fig. 8-1.

With this test facility and test configuration payload antenna and transponder tests can be performed in a very short time frame and with a high measurement accuracy.

2. Radiation Pattern

These measurements are carried out with the spacecraft unpowered. The receive and transmit antenna will be measured separately. For this reason the test antenna will be positioned into the quiet zone by moving the test positioner on a linear slide perpendicular to the propagation direction of the plane wave. This application is shown in Fig. 2-1 and 2-2.

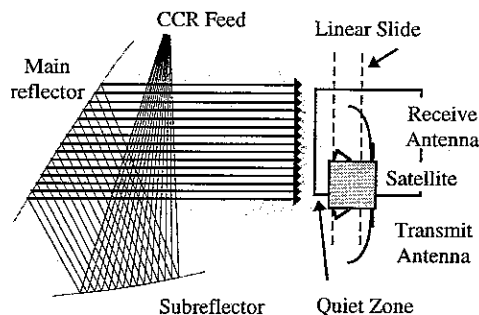


Figure 2-1: Test Configuration for the Pattern Measurement of the Receive Antenna

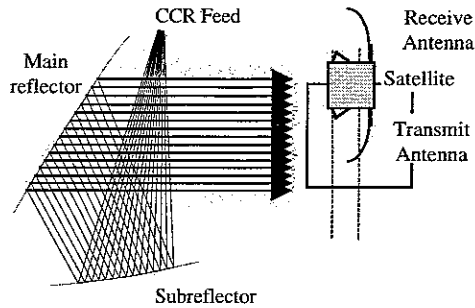


Figure 2-2: Test Configuration for the Pattern Measurement of the Transmit Antenna

In both cases the Compact Range Feed transmits the correspondent receive or transmit frequencies of the satellite. At the antennas the receive signal will be measured via the relevant AIT test coupler. These test couplers are part of the satellite. In Fig. 2-3 the principle test set-up is shown. For the pattern measurement the complete satellite will be moved by the azimuth and elevation axes of the turntable in a raster scan manner, recording received level and position to produce a map of the antenna pattern. Because of the dual polarized Compact Range Feed, both co- and cross-polar pattern can be measured simultaneously. Additional multibeam and multifrequency measurements can be performed.

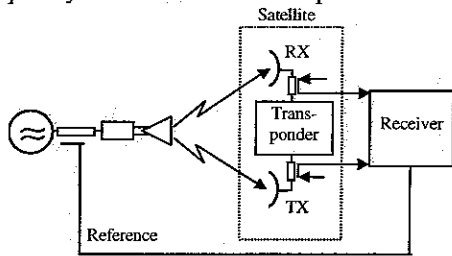


Figure 2-3: Principle Test Set-up for Pattern Measurement of Receive or Transmit Antenna

3. Gain

The antenna gain will also be measured with the spacecraft unpowered. The test configuration is the same as shown in Fig. 2-1 and 2-2 for the receive and transmit antenna. Two different types of gain measurements are possible to perform in the Compact Range. First the well known substitution method using a gain calibrated SGH (Standard Gain Horn) and second the Power Measurement Method (PMM) using a 2 channel power meter. With the first method the gain of the DUT will be related to the gain of the SGH. The SGH has to be positioned at the same area where the AUT is located in the quiet zone. Additional the SGH has to be moved transversal in the quiet zone to get a mean amplitude ripple value. The gain accuracy of the SGH influences directly the gain accuracy of the DUT.

The power measurement method is directly based on Friis transmission formula:

$$G_{DUT} = (P_r + C) / P_t (1/G_{Feed}) (\lambda / (4\pi R))^2$$

- G_{DUT} : gain of DUT
- G_{Feed} : gain of Compact Range Feed
- P_r : receive power by the DUT
- C : coupling of test coupler
- P_t : transmit power at the CCR Feed
- λ : wavelength of the signal
- R : distance between DUT and Feed which is valid for the spherical attenuation of the CCR.

The transmit power P_t at the Compact Range Feed and the receive power P_r at the DUT has to be measured with a power meter. With the knowledge of the feed gain, the coupling of the test coupler and the spherical distance R the gain could be easily calculated. No further change of the test set-up is needed. The distance R between the test antenna and the CCR feed reduces to the distance from the CCR feed to the sub- and main-reflector, and so R can be calculated from the exact dimensions of the CCR. The measurement is therefore independent of the antenna position in the quiet zone. In Fig. 3-1 the test set-up is shown. Power head A is used as reference and power head B will be changed from the CCR feed input to the test antenna test coupler.

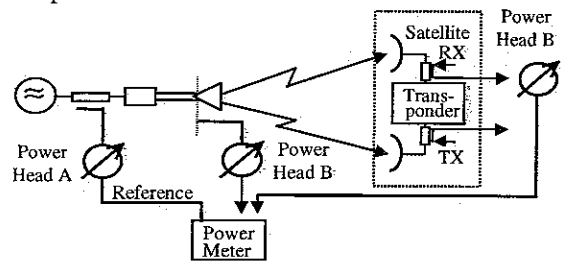


Figure 3-1: Test Set-up for the Gain Measurement with the Power Measurement Method

The gain measurement errors are less than ± 0.2 dB for both measurement methods, but from the practical side of view, it's much easier to use the power measurement method. No additional test set-up and no quiet zone probing is needed.

4. Beam Efficiency

The beam efficiency is defined as an integral value of transmit or receive power in a specified angle region relative to the radiated power of the sphere.

$$\eta_{Beam} = \frac{\int_{\theta=0}^{\phi_n} \int_{\phi=0}^{\theta_n} P(\theta, \phi) \sin \theta \partial \theta \partial \phi}{\int_{\theta=0}^{\pi} \int_{\phi=0}^{\pi} P(\theta, \phi) \sin \theta \partial \theta \partial \phi}$$

ϕ_n, θ_n : specified beam angle

$P(\theta, \phi)$: radiated power

This value has to be calculated after performing a radiation pattern. A typical value for radiometric payloads is in the order of 90 % for the main lobe.

5. Optical Boresight

The RF boresight of an antenna after integration on a satellite has to be identical with the nominal boresight (design direction) with tolerances in the order of 0.01-0.02 deg. To meet this requirement the following tasks have to be done:

1. Internal antenna alignment (i.e. feed, sub-reflector, main reflector w.r.t. each other and to the S/C)
2. Determination of the nominal boresight w.r.t. facility system
3. Determination of RF boresight w.r.t. facility system.

The internal antenna alignment has been pretested and optimized in subsystem tests. The adjustment parameters have been determined and frozen in references like tooling balls or mirror cubes. At system level antenna integration the adjustment values shall be realized by shimming of the feed and reflector or fitting the reflector deployment angle. In some cases not all the axes are adjustable and resulting boresight errors have to be compensated by feed displacement or reflector tilting. Finally the resulting boresight has to be verified by RF tests. The nominal boresight of the antenna is defined by the orientation of vectors w.r.t. S/C system and materialized by two sides of a mirror cube. This allows to pick up this directions by theodolites and compare them with reference directions of the RF measurement facility. Finally the nominal boresight and – if needed – the nominal polarization direction of the antenna are known w.r.t. the references of the facility in coordinates of the antenna positioner. The boresight of the RF measurement facility (CCR) depends on the range feed location. For a range feed located at the focal point of the CCR the RF boresight will be identical with the geometrical boresight of the facility, which once has been measured and is known w.r.t. references (mirror cube, theodolite, a.s.o). The accuracy of this process including calibration errors is in the order of 0.01 deg. For a range feed in scanned location the RF boresight of the facility will be tilted. The angle of arrival (AOA) of a constant phase front defines the RF boresight and can be predicted by commercial software (e.g. GRASP). A calibrated feed

positioner is needed, which allows to locate the range feed precisely at a desired position, and a table with the predicted AOA's. An accuracy of the feed positioner of 1 mm results in a pointing error of approx. 0.003 deg. The accuracy of this process including feed positioner calibration errors and reference accuracy is in the order of 0.015 deg. A Spacecraft with two antennas on the left and right side can be measured with two range feeds in scanned location. The RF pattern of each antenna can be calibrated knowing the nominal boresight defined by the S/C reference and the scanned facility boresight of each range feed. This allows the verification of RF pattern measurements at system level and calibrated end to end tests.

6. EIRP Measurements of the Transmit Antenna

The Equivalent Isotropic Radiated Power (EIRP) is defined as the product of the transmit antenna gain (G_T) at a given direction and the input power (P_T):

$$EIRP = G_T P_T$$

From the radar equation given in chapter 3 the EIRP can be calculated by the following equation:

$$EIRP = P_R / G_R ((4\pi R) / \lambda)^2$$

G_R : gain of Compact Range Feed

P_R : receive power by the DUT

λ : wavelength of the signal

R : distance between DUT and Feed, which is valid for the spherical attenuation of the CCR.

The transmit antenna has to be pointed to the beam maximum. A synthesized CW signal at a level to produce transponder saturation will be fed into the spacecraft via the relevant receive test coupler. The saturation at the transmit test coupler and the receive power at the CCR feed can be measured by power meters. With the knowledge of the CCR gain and the range distance R , the EIRP can be calculated with the same accuracy as for the gain measurement (Fig. 6-1).

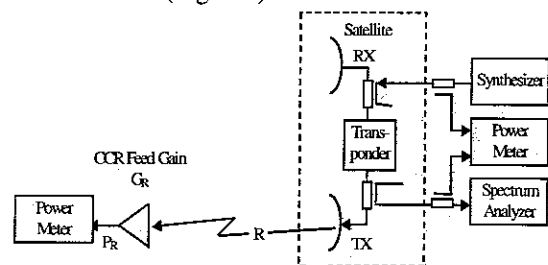


Figure 6-1: Test Set-up for the EIRP Measurement

7. Saturated Flux Density

The Saturation Flux Density (SFD) is defined as the flux

density to saturate the transponder under test:

$$SFD = P_T G_T \left(1 / 4\pi R^2 \right)$$

- G_T : gain of CCR feed
- P_T : transmit power at the CCR feed
- R : distance between DUT and Feed

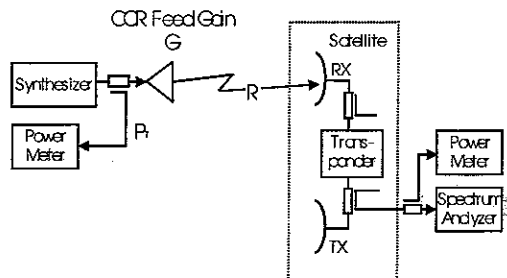


Figure 7-1: Test Set-up for the SFD Measurement

The receive antenna has to be pointed to the beam maximum. A synthesized CW signal at a level to produce transponder saturation will be fed into the CCR feed. The saturation at the transmit test coupler and the transmit power at the CCR feed can be measured by power meters (Fig. 7-1). With the knowledge of the CCR gain and the range distance R, the SFD can be calculated with the same accuracy as for the gain measurement.

8. Amplitude Frequency Response

The Amplitude Frequency Response (AFR) test is one of the most efficient tests to perform in the Compact Range, because this test can be done as close loop test under far field conditions. Scanned plane waves were generated by positioning the CCR feeds outside of the focus. Fig. 8-1 shows the test configuration. The satellite has to be positioned to an angle, where the pattern degradation of the transmit and receive antenna gives the possibility to perform the loop test.

The advantage to make this test in the CCR is the exact knowledge of the measurement distance to calculate the free space losses for the two different frequencies (transmit/receive). The resulting equation for this test is given as follows:

$$AFR = P_T P_R G_T G_R \left(\lambda_T \lambda_R / (4\pi R)^2 \right)$$

- P_T : transmit power
- P_R : receive power
- G_T : gain of transmit CCR feed
- G_R : gain of receive CCR feed
- λ_T : wavelength of transmit frequency
- λ_R : wavelength of receive frequency
- R : distance between CCR feed and

sub- and main-reflector .

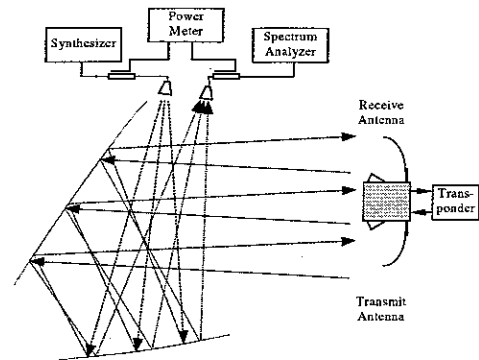


Figure 8-1: Test Set-up for the AFR Measurement

9. Receiver Sensitivity (G/T)

In the following only the test method to be applied for a satellite operating in FIXED-GAIN mode is described. For a satellite operating in ALC mode a slightly different procedure with more test steps is required.

The principle test set-up for G/T is outlined in Fig. 9-1. The needed data reduction for the test is explained in Fig. 9-2 with an active antenna used as DUT (instead of a satellite). For the G/T test, a link budget has to be calculated with the equivalent compact range far field distance and the satellite parameters C/N_0 and EIRP. With typical satellite values the required transmit power in the "uplink" to the satellite is in the range of -45 to -10 dBm. The receive signal power in the "downlink" from the satellite is in the range of -15 to +8 dBm.

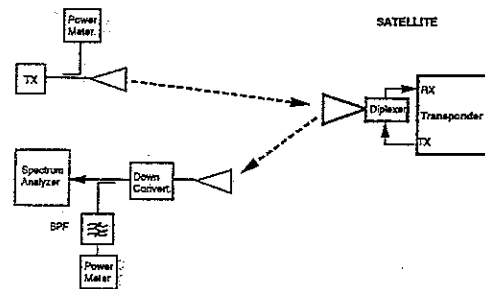


Figure 9-1: G/T-Measurement Principle Test Set-up

Test Method

Sequences:

*RX-STATION

- point antenna **off-satellite** and measure RX-station + environmental noise-power (P1) in bandwidth B
- point antenna **on-satellite** and measure total noise power, including satellite noise contribution (P2) in bandwidth B

*TX-STATION

- switch CW-carrier **on** and increase EIRP to a level

side. For the calibration of the RX-chain group delay the TX-chain of the same station together with a wide-band test translator is used. In both modes of satellite operation (FIXED GAIN or ALC-mode) the reference carrier is transmitted at an $EIRP_G$ which is about 20 dB above the stepped frequency carrier. Thus in ALC-mode the reference carrier sets the transponders point of operation and the measurement of the group delay is not affected by level variations of the stepped carrier over the channel-frequency range. With 20 dB distance between the large reference carrier and the small stepped carrier, a level change of the stepped carrier of ≤ 3 dB will change the transponder gain by $-0.05/+0.03$ dB which can be neglected in its effect on group delay. Above applies for ratios of $(C/N)_{up}$ of +5 dB measured in the channel noise bandwidth. The measurement range for group delay is for the 2.777 MHz test frequency 0 to 180 nsec and for the 277.77 kHz test frequency 0 to 1800 nsec. If a time interval counter is used for the delay measurement a fixed bias offset of about 180 nsec should be introduced in one baseband branch of the receive chain. Thus for relative group delays in the range around 0 to 10 nsec always a reasonable delay value even in presence of noise can be measured. This shortens also the averaging measurement time interval, which is e.g. determined by the ratio of gate time to measured time interval for the counter HP 5345 A. In case of phase meter as indicator this artificial bias is not required as the phase display is centered on 0.

Measurement errors

The error sources affecting the group delay vs. frequency measurement accuracy are in principle:

- the residual group delay variation vs. frequency of the TX-antenna referenced to the TX-feed I/P port
- the residual group delay variation vs. frequency of the RX-antenna referenced to the RX-feed O/P port
- the calibration error of the receive chain (Test translator response etc.)
- the video signal to noise ratio $(C/N_o)_{VIDEO}$ of reference- and measurement tone
- in case of a delay counter e.g. the HP 5345 A the errors are:
 - 1 count error (~ 2 nsec) can be reduced by $1/N$ when averaging over N samples
 - time base error
 - trigger error (function of C/N)

The residual group delay variations vs. frequency of the antenna plus feed can be neglected when comparing the satellite communications channel bandwidth to the passband width of the antenna S/S. The delay measurement error resulting from the counter time base error is negligible when compared to the delay range of ± 180 nsec or ± 1.8 μ sec.

11. PIM

The principle test set up for PIM (Passive Inter-modulation Performance Test) testing is shown in Fig. 11-1. For this test two uplink carriers are radiated into different satellite receive channels. The magnitude of the uplink carriers F_1 and F_2 is chosen so, that the satellite transmit each carrier F_1^* and F_2^* in the downlink with equal $EIRP_{sat}$. Generally any PIM signals if at all, will be generated by the passive components (e.g. wave-guide flanges, O-MUX etc.) within the satellite transmit signal path. The frequency difference between the uplink carriers F_1 and F_2 is chosen w.r.t. the satellite frequency plan in such a way, that a "worst case situation" is produced. This situation is so that a possible PIM - product of the frequency: $PIM - Freq = \pm M^* (F_1^*) \pm N^* (F_2^*)$; (M, N : harmonic order, $M + N =$ odd number) generated by the nominal satellite transmit signals F_1^* and F_2^* , falls into the satellite receive frequency band. This PIM product acts then like an uplink signal into the satellite. It is in the transponder frequency converted and transmitted in the downlink, where it can be detected.

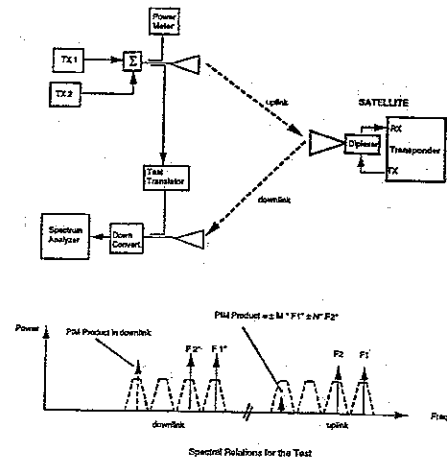


Figure 11-1: PIM-Measurement Principle Set-Up

References

- [1] E. Dudok, J. Habersack, F. Hartmann, H.-J. Steiner, "Payload Test Capabilities of a Large Compensated Compact Range", *Proc. 14th. AIAA International Satellite Systems Conference*, Washington, D.C. March 22-26, 1992
- [2] E. Dudok, H.-J. Steiner, T. Smith, S. Brumley, "Scanned Quiet Zone in a Compensated Antenna Test Range", *Proc. 12th. AMTA Conference 1990*