Paper, presented at: 28th ESA Antenna Workshop on Space Antenna Systems and Technologies
31. May - 3. June 2005, ESA/ESTEC, Noordwijk, The Netherlands

ACCURATE AND EFFICIENT SATELLITE PAYLOAD TESTING IN COMPACT RANGES

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ABSTRACT

Compensated Compact Ranges (CCR) and planar near-field systems represent nowadays the standard for highest accurate measurement of space applications such as satellite antennas and payload systems [1]. According to the additional real-time measurement capability, compact ranges offers a lot of advantages when a high number and high variety of payload test parameters are required to be measured on subsystem as well as on system level. For that aim, a flexible and adaptive configurable payload test matrix was developed at EADS Astrium. With the new developed payload test matrix in combination with the AAMS antenna and payload measurement software of EADS Astrium, payload tests can be performed nearly automatically and extreme time efficient. Further, a 6 m x 6 m area of the facility was equipped with high power absorbers so that auto-compatibility tests can be performed in the CCR up to some kilowatts of satellite transmit-power under save condition. The paper will describe the principle test set-ups, the payload test matrix for an automatic test control as well as modified absorber layout of the CCR at EADS Astrium in Ottobrunn in combination with also performed power flux density calculations.

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

1. INTRODUCTION

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

- Radiation Pattern, Coverage, Gain
- Polarization Isolation (transmit-receive)
- EIRP (Equivalent Isotropic Radiated Power)
- IPFD (Input Power Flux Density)
- G/T (Gain over Noise Temperature)
- AFR (Amplitude Frequency Response)
- Group Delay
- PIM (Passive Intermodulation)
- Auto compatibility

Important payload test parameters, which are required for the link analysis of earth station links via satellite, are the received (IPFD) and transmitted (EIRP) signal as well as the figure of merit (G/T) of the satellite receiver [2]. These parameters allow the calculation of the Carrier Power to Noise Power Spectral Density (C/N_0) which characterizes the RF link performance in terms of signal to noise ratio (S/N) for analog transmission or bit error rate (BER) for digital transmission.

To increase the measurement accuracy and to reduce the measurement time a new Payload Test Unit PTU4001 was developed. The specification, the design criteria and the realized hardware will be described within this paper.

2. EIRP MEASUREMENTS

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 Friis transmission formula given in [1] the EIRP can be calculated by the following equation:

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

G_R: gain of CCR receive feed
P_R: receive power at the CCR receive feed
λ: wavelength of the signal
R: equivalent far-field range distance of the CCR.

The spacecraft 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 CCR transmit feed. With the knowledge of the CCR receive feed gain and the range distance R, the EIRP can be calculated with a high accuracy of less than ±0.2 dB. In Fig. 2-1 a principle test set-up for EIRP measurement in the CCR is shown.

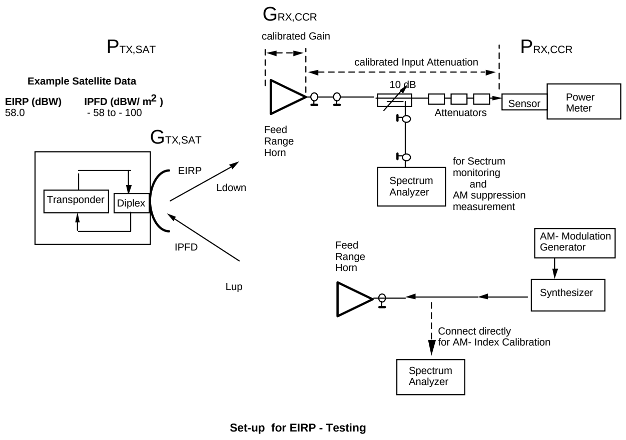


Figure 2-1: Test Set-up for the EIRP Measurement

In order to determine the point of saturation the uplink signal is AM-modulated with an index, which results in AM-sideband levels of about 30 dB below carrier. The test sequence is started with a moderate uplink power level, resulting in a transponder drive level about 20 dB below saturation. The spectrum CCR receive feed is observed with a spectrum analyzer. To reach saturation the CAMP (channel amplifier) gain will be increased in 1 dB steps via satellite EGSE command until the point of maximum AM-suppression is reached. In Fig. 2-2 and 2-3 the received spectrum for AM-modulated carrier at linear region and in saturation is presented.

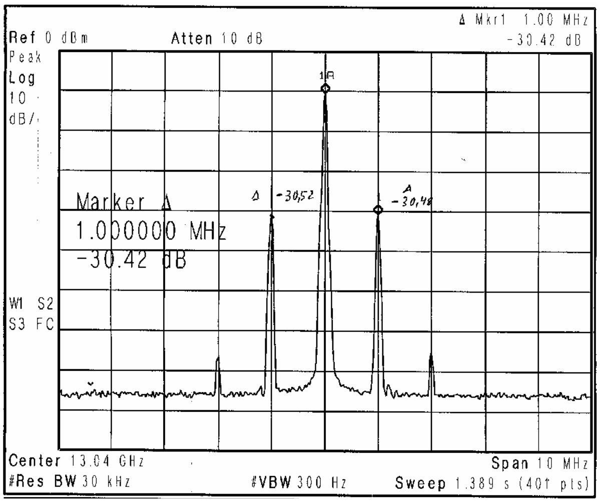


Figure 2-2: AM-modulated signal at linear region

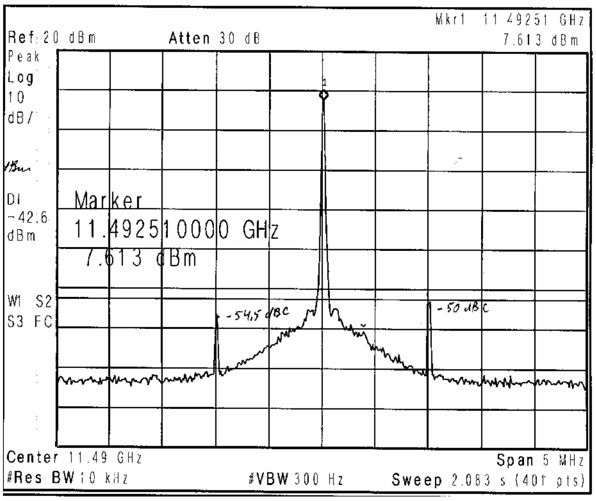


Figure 2-3: AM-modulated signal at saturation

3. INPUT POWER FLUX DENSITY

The Input Power Flux Density (IPFD) is defined as the flux density to saturate the transponder under test:

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

G_T: gain of CCR transmit feed
P_T: transmit power at the CCR transmit feed
R: equivalent far-field range distance of the CCR

The spacecraft 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 transmit feed. With the knowledge of the CCR transmit feed gain, the transmitted power level and the range distance R, the IPFD can be calculated with a high accuracy of less than ±0.2 dB.

The measurement of saturation is performed as described in chapter 2. To reach transponder saturation the transmit power at the CCR transmit feed will be increased in 1 dB steps until the point of maximum AM-suppression is reached.

In Fig. 3-1 a principle test set-up for IPFD measurement in the CCR is shown.

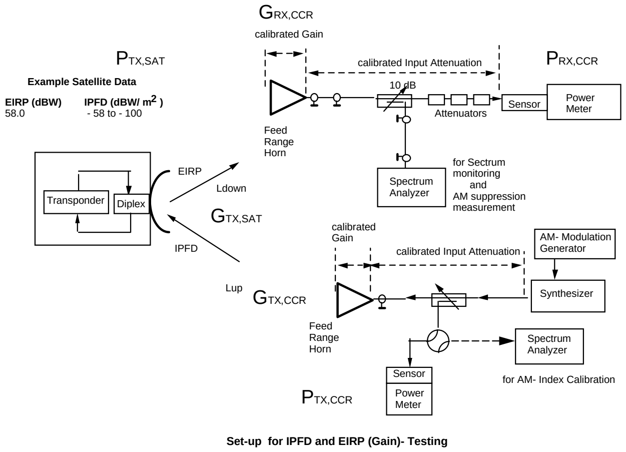


Figure 3-1: Test Set-up for the IPFD Measurement

4. GAIN OVER NOISE TEMPERATURE

The Gain over Noise Temperature (G/T) describes the Figure of Merit of the satellite receiver. The measurement can be performed for two different modes, operating if FIXED GAIN or in ALC mode. As an example the G/T measurement for a satellite operating in FIXED-GAIN mode is described in the following equation:

$$\left.{}^{G}\!/\!{}_{T}\right|_{SAT} = \frac{k \cdot B \cdot LP_{Up}}{EIRP_{TX,CCR}} \frac{P3 - P2}{P2 - P1}$$

k:	Boltzmann constant
B:	measurement noise bandwidth
LP_{Up}:	loss of power for the uplink signal
P1:	RF-equipment noise power level
P2:	RF-equipment + satellite noise power level
P3:	power level with switched on uplink level

For this test the relevant satellite RX-beam has to be pointed in bore-sight. The G/T is determined from three sequential power level measurements. The test set-ups are outlined in Fig. 4-1. 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_o 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.

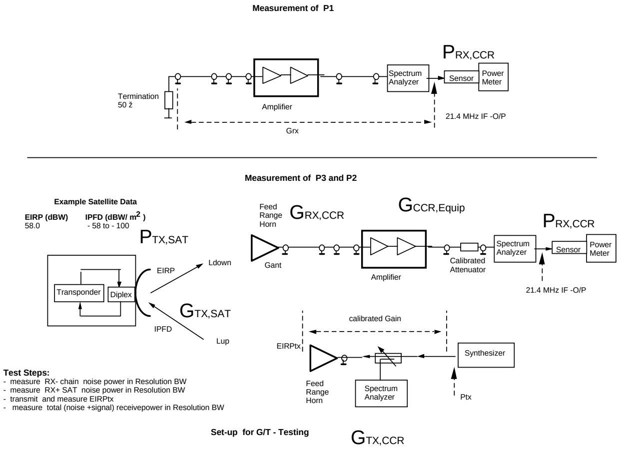


Figure 4-1: G/T-Measurement Principle Test Set-ups

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 that the resulting total receive power (P3) is so that P3/P2 $\geq$2.
- measure and record EIRP

*RX-STATION

- measure total received power (P3) in bandwidth B consisting of RX-station noise, satellite-noise and CW-carrier signal

The significance of the noise power measurement uncertainty vs. integration time can be seen from the following example for 1 MHz and 10 kHz measurement bandwidth and the integration times as available on the HP 438 A power meter. For an RF-measurement bandwidth of 1 MHz, 0.1 sec integration time yields to a noise power uncertainty of ±0.014 dB. For 10 kHz measurement – BW the integration time for the same error would be 10 sec. The minimum useful NPR for the test with respect to accuracy should be ≥0 dB. Thus the receive power should at least be doubled if the satellite noise is added to the ground station noise. Then the uplink signal should be set that the total receive power (signal + satellite noise + G/S noise) is at least two times the total noise power (satellite noise + G/S noise).

5. AMPLITUDE FREQUENCY RESPONSE

The Amplitude Frequency Response (AFR) test is one of the most efficient tests to perform in the CCR, because this test can be done as close loop test under far field conditions.

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:

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

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: equivalent far-field range distance of the CCR

The normal overall transponder gain will be measured if the satellite receive and transmit antenna are identical, with both beams on bore-sight. If the receive and transmit beam are divergent (or if receive and transmit antenna are separated) a lower overall transponder gain will be measured. For the second case scanned plane waves were generated by positioning the CCR feeds outside of the focus. Fig. 5-1 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.

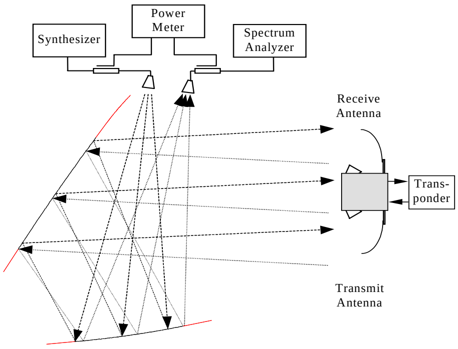


Figure 5-1: Test Set-up for the AFR Measurement

6. PASSIVE INTERMODULATION

The principle test set up for PIM (Passive Inter-modulation Performance Test) testing is shown in Fig. -1. For this test two uplink carriers are radiated into different satellite receive channels. The magnitude of the uplink carriers F1 and F2 is chosen so, that the satellite transmit each carrier F1* and F2* in the downlink with equal EIRPsat. 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 F1 and F2 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 – Frequ = ±M* (F1*) ±N* (F2*); (M,N: harmonic order, M + N = odd number) generated by the nominal satellite transmit signals F1* and F2*, 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.

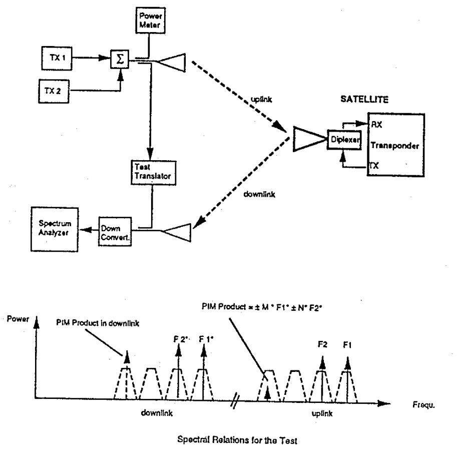


Figure 6-1: PIM-Measurement Principle Set-Up

7. AUTO COMPATIBILITY

For the payload tests like EIRP or PIM only one or two transponder channels are switched on. For the auto compatibility test several channels have to be switched on to transmit RF power in the order of some kilowatts. These tests require special environmental condition like high power absorber, infrared camera for temperature monitoring and last but not least special safety conditions for the personal.

For this test the high power absorber can be positioned in the near-field of the radiated field. In the CCR at EADS Astrium in Ottobrunn a 6 m x 6 m area of the facility was equipped with high power absorbers. These absorbers can be illuminated with RF power up to 1.5 Watt/cm^2. This area is located at a side-wall of the CCR (see Fig. 7-1).

Figure 7-1: High-Power Side Wall in CCR

The spacecraft will to be rotated clockwise 90 degrees for pointing to the high power wall.

Before starting this test, the distribution of the near-field radiation pattern has to be calculated at the distance, were the high power absorber are installed. In Fig. 7-2 an example for such a calculation can be seen. At all four beams the maximum power was calculated to 0.74 Watt/cm^2 which is below the allowed value of 1.5 Watt/cm^2.

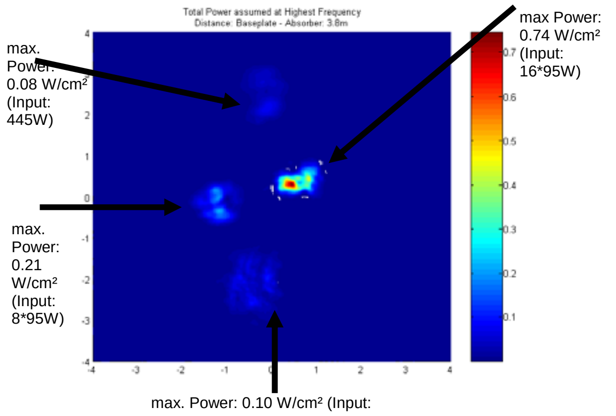


Figure 7-2: High-Power Distribution at Near-Field

8. PAYLOAD TEST UNIT PTU4001

In order to perform the above described payload tests, a Payload Test Unit (PTU 4001) was developed. The PTU 4001 is the heart of the payload testing with flexible software controlled test paths up to 40 GHz and +30 dBm input power.

A picture of the PTU 4001 is shown in Fig. 8-1.

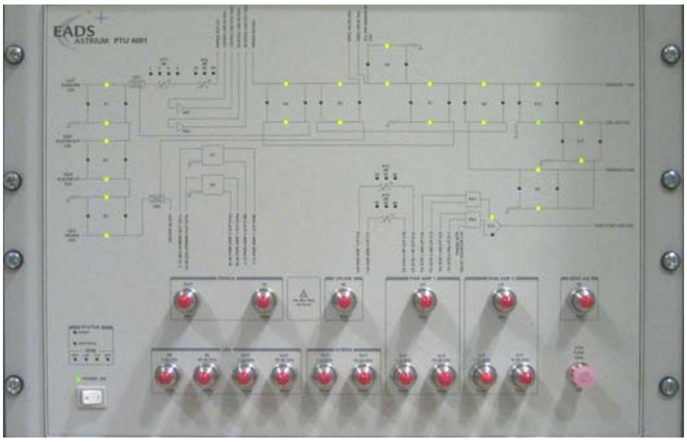


Figure 8-1: Front View of PTU 4001

The test unit is already completely designed and equipped for the following payload tests:

- EIRP
- IPFD
- G/T
- AFR
- PIM
- Group Delay

The functional block-diagram is presented in Fig. 8-2:

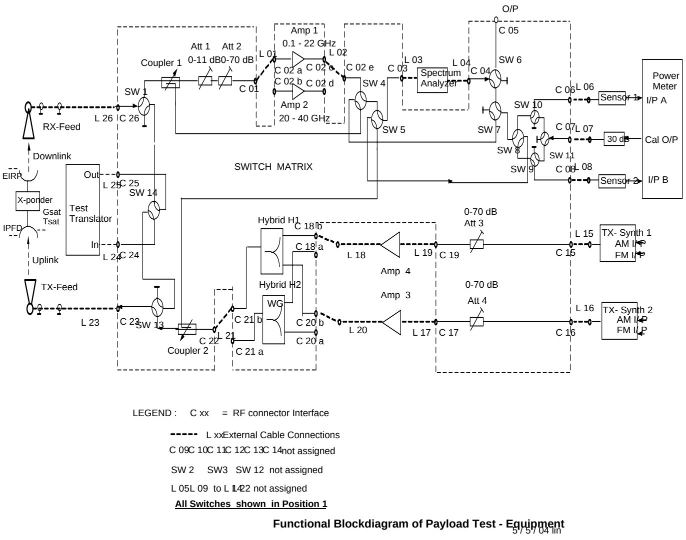


Figure 8-2: Functional block diagram of PTU 4001

8.1 Specification

The PTU4001 was specified to measure the EIRP, IPFD, G/T, PIM, AFR and Group Delay of payload modules and/or satellites integrated into compact ranges and operated within the Quiet Zone. G/T measurements can be performed in fixed gain or ALC mode. All measurements can be performed in remote access configuration to perform the required calibration, the measurements and the evaluation of the payload parameter.

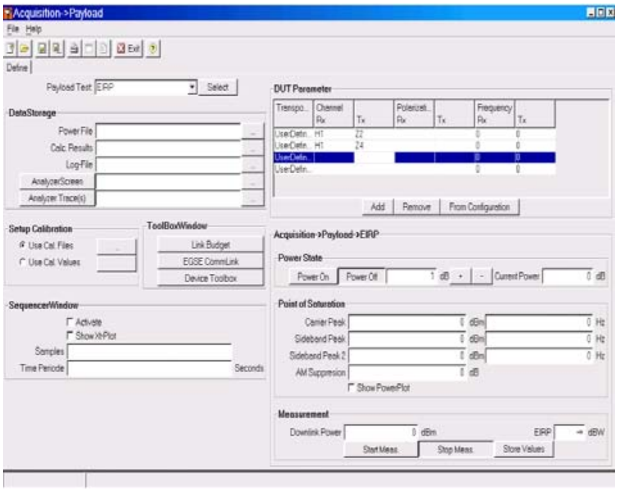
8.2 Design Criteria

- The frequency range has to cover the complete band between 1 to 40 GHz.
- Generic set-ups for payload test parameters.
- Standard device communications for IEEE 488-Bus and LAN to connect individual devices.
- Determining the point of saturation by detecting the minimum sideband level of the applied amplitude modulation at the spectrum analyzer.
- Semi automatic measurement procedure.

8.2 Operation Control

The payload test with the PTU 4001 will be performed under semi automatic test control. The software allows a bi-directional way of working. Either a software guided measurement through the Graphical User Interface (GUI) or by manual operation at the hardware itself with convenient loading of the used test configuration back to the software for archiving purposes.

The software menu for payload testing within the AAMS antenna measurement software of EADS Astrium is shown in Fig. 8-3.



Payload Test: EIRP

Transpo...	Channel Rx	Tx	Polarizati... Rx	Tx	Frequency Rx	Tx
UserDefin...	H1	Z2			0	0
UserDefin...	H1	Z4			0	0
UserDefin...					0	0
UserDefin...					0	0

● Use Cal. Files
○ Use Cal. Values

☐ Activate
☐ Show XtPlot
Samples
Time Periode Seconds

1 dB + - Current Power 0 dB

Carrier Peak 0 dBm 0 Hz
Sideband Peak 0 dBm 0 Hz
Sideband Peak 2 0 dBm 0 Hz
AM Suppresion 0 dB
☐ Show PowerPlot

Downlink Power 0 dBm
EIRP → dBW

Figure 8-3: Software GUI for Payload Tests

9. CONCLUSION

The compact antenna test facility EADS Astrium at Ottobrunn is fully equipped with all needed equipment for antenna, gain and payload tests as well as with the corresponding test software for automatic testing and data processing to perform the state of the art system tests in the frequency range between 1 and 40 GHz. The test set-ups and procedures are optimized for highest accuracy under qualification assurance of ISO 9001.

The highly qualified test team is specialized for optimized test solutions for several test cases under the consideration of required test plan and given test schedule.

References

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[2] E. Dudok, H.-J. Steiner, T. Smith, S. Brumley, “Scanned Quiet Zone in a Compensated Antenna Test Range” , *Proc. 12th, AMTA Conference 1990*