Real Time Satellite Payload Testing in Compact Ranges

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3. Appropriate Test Facility
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Payload Testing – Why?
Payload Testing – Why?

- Payload Testing characterizes parameters which are required for the Link Analysis of Satellite Links via Earth Stations.

- Important Parameters of the Satellite for the Link Analysis are:
  - Received Signal (→ IPFD)
  - Transmitted Signal (→ EIRP)
  - Figure of Merit of the Satellite Receiver (→ G/T)

- This allows a calculation of the Carrier Power to Noise Power Spectral Density (C/N₀) which characterizes the RF link performance.

- The link performance (C/N₀) conditions the quality of the baseband signal delivery to the customer in terms of:
  - Signal to noise ratio (S/N) for analog transmission
  - Bit error rate (BER) for digital transmission
Required Tests
Which tests are required?

- Link Analysis related tests are
  - Equivalent Isotropic Radiated Power (EIRP)
  - Input Power Flux Density (IPFD)
  - Gain over Temperature (G/T)

- Transponder Performance related tests are
  - Amplitude Frequency Response (AFT)
  - Passive Intermodulation (PIM)
  - Group Delay

- EMC related test is
  - Auto-Compatibility
Test Facility
Appropriate Test Facility

- In principle all types of indoor antenna test facilities which are large enough can be utilized for payload tests.

- From the practical point of view:
  - Compact Ranges
  - Near-Field Ranges

These are suitable for payload tests.

- However, only in Compact Range facilities Real-Time tests can be performed.

- Compact Ranges with a large scanning focal length (e.g. a Compensated Compact Range) allow additionally a closed loop testing under radiated mode conditions.

- Combinations of radiated and test coupler test are possible, too.
Appropriate Test Facility (Cont’d)

- Compensated Compact Range test principle for closed loop tests under real time conditions
  - Transmit (Uplink) and Receive (Downlink) signal simultaneously possible utilizing two range feeds and scanned test zones
Appropriate Test Facility (Cont’d)

- Principle of scanned test zones by shifted range feeds
**Appropriate Test Facility – Compact Range**

CCR 75/60:
- Quiet Zone
- Size: $\varnothing = 5.5$ m

CCR 120/100:
- Quiet Zone
- Size: $\varnothing = 8.5$ m

Compensated Compact Range of Astrium GmbH (Ottobrunn/Munich)
Appropriate Test Facility - High Power Test Capability

CCR 75/60
High Power Absorber Area:

Size: 6 m x 6 m

Absorber Type: E&C
HFX-18 (HC)

Reflectivity: > 50 dB (typ.)
Max. RF Power Density: 1.5 W / cm²
Max. Temperature: 200 °C

CCR 75/60 with installed Payload Module on Positioner in QZ;
High Power Absorber Wall at QZ Side
Theory and Measurement Set-Ups at a Glance

\[ EIRP = \frac{P_{RX,CPR} \cdot LP_{Down}}{G_{RX,CPR}} \]

\[ P1 = C_1 + N_{SAT1} + N_{RX,Equip} \]

\[ P3 = \frac{EIRP_2 \cdot G_{RX,SAT}}{LP_{Up} \cdot LP_{Down}} \cdot G_{XPond2} \cdot G_{RX,CPR} \]

\[ G/T_{SAT} = \frac{k \cdot B \cdot LP_{Up}}{EIRP_{TX,CPR}} \cdot \frac{P3 - P2}{P2 - P1} \]

\[ LP_{Down} = \left(\frac{4\pi R}{\lambda}\right)^2 \]
Content of this section

- This section explains the essential aspects of the most important payload test
  - Equivalent Isotropic Radiated Power (EIRP)
  - Input Power Flux Density (IPFD)
  - Gain over Temperature (G/T) @ Fixed Gain Mode of the S/C

- Each test parameter is subdivided into
  - Theory
  - Principle Set-Up
  - Principle Test Procedure
  - Error Budget
**Theory of Test: EIRP (1/5)**

- **Physical Background**
  - The **Equivalent Isotropic Radiated Power (EIRP)** describes the radiated power of the satellite TX antenna in a certain direction.

\[
EIRP = P_{TX,SAT} G_{TX,SAT}
\]

- Usually the EIRP is measured at the **Point of Saturation** of the output amplifier of the Satellite.

- With the knowledge of the gain normalized TX antenna pattern it is sufficient to measure the EIRP\(_{\text{max}}\) at the maximum of the antenna gain.

- With the parameter EIRP\(_{\text{max}}\) the TX antenna pattern can be normalized to absolute EIRP values in [W or dBW].
Principle Set-Up: EIRP (2/5)

Principle Set-Up

\[ EIRP = P_{TX,SAT} G_{TX,SAT} \]

\[ EIRP = \frac{P_{RX,CCR} L_{P_{Down}}}{G_{RX,CCR}} \]

\[ L_{P_{Down}} = \left( \frac{4\pi R}{\lambda} \right)^2 \]
Principle Test Procedure: EIRP (3/5)

Major Steps of the Measurement

- **Calibration**
  - Calibration of measurement set-up (signal paths, range antennas)
  - Calibration of CCR-RX station AM demodulation sensitivity

- **Measurement**
  - CCR-TX station:
    *Transmit AM modulated carrier with level stepped TX Power at CCR Feed*
    *Measure and record TX Power and AM-index*
  - CCR-RX station:
    *Measure AM level for detecting Point of Saturation*
    *Measure RX Power with power meter via spectrum analyzer at Point of Saturation*

- **Calculation of EIRP**
The Output Amplifier of the Satellite is working usually on a partly nonlinear characteristic.

Received Signal @ Linear Region with modulated Carrier

Received Signal @ Non-Linear Region with modulated Carrier
## Error Budget Estimation: EIRP (5/5)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error Source</th>
<th>Value (± dB)</th>
<th>(± Linear)</th>
<th>(± Linear)^2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power Prx</strong></td>
<td>Power Measurement (absolute Power)</td>
<td>0.21</td>
<td>0.05</td>
<td>0.00250</td>
</tr>
<tr>
<td></td>
<td>Mismatch Error</td>
<td>0.11</td>
<td>0.03</td>
<td>0.00064</td>
</tr>
<tr>
<td></td>
<td>Power Sensor Return Loss (dB)</td>
<td>18</td>
<td></td>
<td>0.00000</td>
</tr>
<tr>
<td></td>
<td>Attenuator (Latt) Return Loss (dB)</td>
<td>20</td>
<td></td>
<td>0.00000</td>
</tr>
<tr>
<td></td>
<td>RX- Feed Gain Accuracy</td>
<td>0.15</td>
<td>0.04</td>
<td>0.00123</td>
</tr>
<tr>
<td></td>
<td>Mismatch Error (Feed/L2/Attenuator Latt)</td>
<td>0.12</td>
<td>0.03</td>
<td>0.00081</td>
</tr>
<tr>
<td></td>
<td>TX - Feed Return Loss (dB)</td>
<td>17</td>
<td></td>
<td>0.00000</td>
</tr>
<tr>
<td></td>
<td>Attenuator (L1) Calibration (dB)</td>
<td>0.15</td>
<td>0.04</td>
<td>0.00123</td>
</tr>
<tr>
<td></td>
<td>Grx + L2+ Latt Gain Stability during Test</td>
<td>0.05</td>
<td>0.01</td>
<td>0.00013</td>
</tr>
<tr>
<td></td>
<td>RX- Feed Gain Accuracy</td>
<td>0.20</td>
<td>0.05</td>
<td>0.00222</td>
</tr>
<tr>
<td></td>
<td>Lp Distance Measurement</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00000</td>
</tr>
<tr>
<td></td>
<td>Pointing Uncertainty</td>
<td>0.10</td>
<td>0.02</td>
<td>0.00054</td>
</tr>
<tr>
<td></td>
<td>Influence of Quiet Zone taper on TA aperture</td>
<td>0.10</td>
<td>0.02</td>
<td>0.00054</td>
</tr>
<tr>
<td></td>
<td>Point of Saturation Determination</td>
<td>0.50</td>
<td>0.12</td>
<td>0.01489</td>
</tr>
<tr>
<td></td>
<td>Multiple Reflections</td>
<td>0.08</td>
<td>0.02</td>
<td>0.00035</td>
</tr>
<tr>
<td></td>
<td>Leakage and Crosstalk</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00002</td>
</tr>
<tr>
<td></td>
<td>Set-up Calibration</td>
<td>0.10</td>
<td>0.02</td>
<td>0.00054</td>
</tr>
<tr>
<td></td>
<td>Polarisation Uncertainty (LIN / CIRC)</td>
<td>0.05</td>
<td>0.01</td>
<td>0.00013</td>
</tr>
<tr>
<td>(EIRPsat)</td>
<td><strong>total Error ±(RSS)</strong></td>
<td><strong>0.65</strong></td>
<td></td>
<td><strong>0.16</strong></td>
</tr>
<tr>
<td>(EIRPsat)</td>
<td><strong>worst case Error</strong></td>
<td><strong>1.64</strong></td>
<td><strong>0.46</strong></td>
<td></td>
</tr>
</tbody>
</table>
Theory of Test: IPFD (1/4)

- Physical Background
  - The Input Power Flux Density (IPFD) describes the received power at the satellite RX antenna in a certain direction.
  
  \[
  IPFD_{\text{Saturation}} = \frac{P_{TX,CCR}G_{TX,CCR,\text{max}}}{4\pi R^2}
  \]

  - Usually the EIRP is measured at the Point of Saturation of the output amplifier of the Satellite.

  - With the knowledge of the gain normalized RX antenna pattern it is sufficient to measure the IPFD_{max} at the maximum of the antenna gain.

  - With the parameter IPFD_{max} the RX antenna pattern can be normalized to absolute IPFD values in [W/m² or dBW/m²].
Principle Set-Up: IPFD (2/4)

- Principal Set-Up

**Example Satellite Data**

- **EIRP (dBW):** 58.0
- **IPFD (dBW/ m²):** -58 to -100

**Set-up for IPFD and EIRP (Gain): Testing**

\[
IPFD \mid Saturation = \frac{P_{TX,CCR} G_{TX,CCR,max}}{4\pi R^2}
\]
Principle Test Procedure: IPFD (3/4)

Major Steps of the Measurement

- **Calibration**
  - Calibration of measurement set-up (signal paths, range antennas)
  - Calibration of CCR-RX station AM demodulation sensitivity

- **Measurement**
  - **CCR-TX station:**
    - Transmit AM modulated carrier with level stepped TX Power at CCR Feed
    - Measure and record TX Power and AM-index
  - **CCR-RX station:**
    - Measure AM level for detecting Point of Saturation

- **Calculation of IPFD**
## Error Budget Estimation: IPFD (4/4)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error Source</th>
<th>Value</th>
<th>(± dB)</th>
<th>(± Linear)</th>
<th>(± Linear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power $P_{tx}$</td>
<td>Power Measurement (absolute Power)</td>
<td>0.21</td>
<td>0.05</td>
<td>0.00250</td>
<td></td>
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<td></td>
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<td></td>
<td>0.00000</td>
</tr>
<tr>
<td></td>
<td>TX- Feed Gain Accuracy</td>
<td>0.15</td>
<td>0.04</td>
<td>0.00123</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mismatch Error (Feed/L1)</td>
<td>0.12</td>
<td>0.03</td>
<td>0.00081</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TX - Feed Return Loss (dB)</td>
<td>17</td>
<td></td>
<td></td>
<td>0.00000</td>
</tr>
<tr>
<td>Gtx + L1</td>
<td>Gain Stability during Test</td>
<td>0.05</td>
<td>0.01</td>
<td>0.00013</td>
<td></td>
</tr>
<tr>
<td>Lp</td>
<td>Distance Measurement</td>
<td>0.05</td>
<td>0.01</td>
<td>0.00013</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>0.01489</td>
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<td>Pointing Uncertainty</td>
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<tr>
<td></td>
<td>Set-up Calibration</td>
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<td>0.00054</td>
<td></td>
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<tr>
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<td>Polarisation Uncertainty (LIN / CIRC)</td>
<td>0.05</td>
<td>0.01</td>
<td>0.00013</td>
<td></td>
</tr>
<tr>
<td>(IPFDsat)</td>
<td>total Error ±(RSS)</td>
<td>0.60</td>
<td></td>
<td>0.15</td>
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<tr>
<td>(IPFDsat)</td>
<td>worst case Error</td>
<td>1.28</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Theory of Test: G/T (Fixed Gain) (1/4)

- Physical Background
  - The Gain over Temperature (G/T) describes the Figure of Merit of the Satellite Receiver

\[
\left. \frac{G}{T} \right|_{SAT} = \frac{k \cdot B \cdot LP_{Up}}{EIRP_{TX,CCR}} \cdot \frac{P_3 - P_2}{P_2 - P_1}
\]

- The G/T values is given in [1/K or dB/K]
**Principle Set-Up: G/T (Fixed Gain) (2/4)**

- **Principal Set-Up**

**Measurement of P1**

\[ P1 = k \cdot T_{CCR,RX} \cdot B \cdot G_{RX,Equip} \]

**Measurement of P3 and P2**

\[ P2 = P1 + \frac{k \cdot T_{SAT} \cdot B \cdot G_{Xpond} \cdot G_{CCR,RX} \cdot G_{RX,Equip}}{L_{Down}} \]

\[ P3 = P2 + \frac{EIRP_{TX,CCR} \cdot G_{RX,SAT} \cdot G_{Xpond} \cdot G_{CCR,RX} \cdot G_{RX,Equip}}{L_{Up} \cdot L_{Down}} \]

**Set-up for G/T - Testing**

\[ G/T_{SAT} = \frac{k \cdot B \cdot L_{Up}}{EIRP_{TX,CCR}} \cdot \frac{P3 - P2}{P2 - P1} \]
Principle Test Procedure: G/T (Fixed Gain) (3/4)

Major Steps of the Measurement

- **Prerequisite for Set-up Configuration**
  - Calibrate RX-chain gain \( G_{rx} \)
  - Calibrate Analyzer Gain from RF – input to IF – output in ZERO – span mode
  - Calibrate uplink equipment gain (EIRP tx)

- **Satellite EGSE**
  - Set up communication path configuration
  - Set X-ponder Gain and switch ON TWT

- **CCR**
  - Point SAT- RX – beam to boresight
  - Measure RX-equipment noise power \( P_1 \) (input terminated)
  - Measure with Analyser the receive noise power level \( P_2 \) at the center frequency of the satellite channel (This level should be \( \approx 10 \) dB below the maximum power range)
  - Transmit Low level uplink signal and observe receive spectrum / power meter
  - Increase Uplink Level until the power meter reading for \( P_3 \) (total power: signal + noise) is 3 to 6 dB higher than \( P_2 \)
  - Record downlink receive Level \( P_3 \) and Uplink synthesizer level (EIRPtx)

- **Calculate G/T**
## Error Budget: G/T (Fixed Gain) (4/4)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error Source</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(± dB)</td>
</tr>
<tr>
<td>B</td>
<td>Calibration of Filter Noise, BW</td>
<td>0,13</td>
</tr>
<tr>
<td>EIRP</td>
<td>Power Measurement (absolute Power)</td>
<td>0,21</td>
</tr>
<tr>
<td></td>
<td>Mismatch Error</td>
<td>0,11</td>
</tr>
<tr>
<td></td>
<td>Source Return Loss (dB)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Attenuator (L1) Return Loss (dB)</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>TX- Feed Gain Accuracy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mismatch Error (Feed/Attenuator L1)</td>
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<td></td>
<td>TX - Feed Return Loss (dB)</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Attenuator (L1) Calibration (dB)</td>
<td>0,15</td>
</tr>
<tr>
<td>Power Ratios</td>
<td>ΔP/P = 1/√B*t</td>
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</tr>
<tr>
<td></td>
<td>B (MHz)</td>
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<td></td>
<td>t (sec)</td>
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<tr>
<td></td>
<td>Y1 (dB)</td>
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<tr>
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<td>ΔY1</td>
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<td>Y2 (dB)</td>
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<td>ΔY2</td>
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</tr>
<tr>
<td></td>
<td>ΔY1/(Y1*(Y1-1))</td>
<td>0,01</td>
</tr>
<tr>
<td>Grx + G2</td>
<td>Gain Stability during Test</td>
<td>0,05</td>
</tr>
<tr>
<td>Lp</td>
<td>Distance Measurement</td>
<td>0,00</td>
</tr>
<tr>
<td></td>
<td>Pointing Uncertainty</td>
<td>0,05</td>
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<tr>
<td></td>
<td>Polarisation Uncertainty (LIN / CIRC)</td>
<td>0,05</td>
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<tr>
<td>(G/T)</td>
<td>total Error ±(RSS)</td>
<td>0,37</td>
</tr>
<tr>
<td>(G/T)</td>
<td>worst Case Error</td>
<td>1,03</td>
</tr>
</tbody>
</table>
Equipment, Tools and Software
RF Set-Up Issues

- Complete Payload Test Solutions are available at the market
- However, such an approach is expensive
- Idea: Reuse of Existing Antenna Equipment
  - Commercial payload test equipment solutions cover wide area of tests, but do normally not fit to already existing antenna equipment → Different Setups required!
  - For the typical system payload tests (EIRP, IPFD, G/T, AFR) reuse of already existing antenna equipment (H/W and S/W) is possible → Cost Efficient!
- Change of Setup → Source of Possible Errors
  → Source for Uncertainties
  → Time Consuming
- Solution: Centralized Test Unit (PTU) for Up- and Downlink routing with adapted payload toolbox which fits to the available antenna measurement software
Solutions

- **Payload Test Unit (PTU)**
  - Remote controlled Switch Matrix allows flexible signal routing of the Uplink and Downlink Path
  - Usable for Antenna and Payload Tests
  - Complete Calibration Sequence can be handled via this unit with only a few user interactions
    - High reliability through high quality transfer switches

- **Common Software Test Environment**
  - Payload Toolbox extend already available antenna measurement software
  - Easy to use through common user interface for both types of measurement
  - Use of measured antenna pattern for calibration and / or measurement point detection
Payload Test Unit (PTU) Features

- **Key Items**
  - Measurement of different payload parameters: AFR, EIRP, IPFD, G/T, PIM
  - Measurement of antenna parameter with or without PTU
  - Payload in Fixed Gain or ALC mode

- **Design Criteria**
  - Generic set-up
  - Frequency Range: 1 – 40 GHz
  - Using of standardized and commercial quality equipment for highly accurate and stable measurements
  - Standard Device Communication: IEEE 488 (IEC-, GPIB) – Bus and LAN
  - Determining the Point of Saturation by detecting the minimum sideband level of the applied amplitude modulation
  - Semi-Automatic measurement procedure
Payload Test Unit (PTU) Design (Cont’d)

Downlink Path

Uplink Path
Cost Efficient Payload Test Bench

Payload Test Unit PTU 4001

Payload Test Unit PTU 4002

Power Meter

Spectrum Analyzer
Payload Software Toolbox Design

Test Definition Area

Measurement Area

Direct Hardware Access Area
Payload Software Toolbox Design (Cont’d)

- Payload Toolbox within the AAMS Software
- Point of Saturation Detection Mode
Conclusion
Conclusion

- **Motivation**
  - Satellites requires payload testing prior to the launch
  - Typical Payload Test
    - EIRP, IPFD, G/T, AFR, Auto-Compatibility and PIM
    - Group Delay (if required) is typically carried out on subsystem level

- **Appropriate Test Facility for Real-Time Tess**
  - Compact Range Systems, e.g. the Compensated Compact Range due to the large scanning focal length → Scanned test zones with closed loop testing

- **RF Set-up consists typically of**
  - RF Source(s), Spectrum Analyzer and Power Meter

- **Time Saving Equipment**
  - Payload Test Unit (PTU) and appropriate Software Toolbox
  - Easy Switch of Setup between Calibration and Measurement
  - Time Efficient due to fixed set-ups with pre-calibrated RF paths
Questions

Thank You for Your Attention

Any Questions?