Design of a Combined Beacon Receiver and Digital Radiometer for 40 GHz Propagation Measurements at the Madrid Deep Space Communications Complex

Session: Propagation I

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Motivation & Goals

Experiment Goals

• To **assess the impact** of atmospheric effects on links operating in the Q-band (rain attenuation, scintillation, etc.) in various climatological regions through distributed measurement campaigns.

• To assist the **development of physical models** to improve predictions of atmospheric attenuation within the Q-band.

NASA Motivation

• Preliminary architecture studies of the next generation TDRSS system will require higher downlink bandwidths than available in the current Ku-band allocation.

• The allocation of 4 GHz of contiguous bandwidth in the Q-band provides an opportunity to meet these requirements.

• NASA mission planning benefits greatly from Q-band measurements near NASA frequency allocations at Deep Space Network sites.
Site of Study

**NASA Madrid Deep Space Communications Complex**

*Robledo de Chavela, Spain*

**Alphasat 40 GHz Beacon Receiver**

**Ground Station**
- **Installation Date**: March 2017
- **Latitude**: 40.425433° N
- **Longitude**: 4.251175° W
- **Altitude**: 758 m

**Satellite**
- **Name**: Alphasat
- **Nom. Elevation**: 34.5°
- **Nom. Azimuth**: 139°
- **Beacon Freq.**: 39.402 GHz

**MDSCC, Spain**

*The Madrid Deep Space Communications Complex is in Robledo de Chavela*

Beacon Receiver / Radiometer at the Madrid Deep Space Communications Complex
**Instrumentation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna Gain</td>
<td>45.6 dBi</td>
</tr>
<tr>
<td>Antenna Beamwidth</td>
<td>0.9 deg</td>
</tr>
<tr>
<td>Antenna Tracking Resolution</td>
<td>0.01 deg</td>
</tr>
<tr>
<td>LNA Gain</td>
<td>33 dB</td>
</tr>
<tr>
<td>LNA Noise Figure</td>
<td>2.5 dB</td>
</tr>
<tr>
<td>Beacon Frequency</td>
<td>39.402 GHz</td>
</tr>
<tr>
<td>Final IF</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Measurement Rate</td>
<td>10 Hz and 1 Hz</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>30 dB</td>
</tr>
<tr>
<td>Temperature Control</td>
<td>0.01 deg C (plate) / 1 deg C (air)</td>
</tr>
<tr>
<td>Radiometer Calibration</td>
<td>20 sec / 30 min</td>
</tr>
<tr>
<td>Radiometer Bandwidth</td>
<td>10 MHz</td>
</tr>
</tbody>
</table>
The beacon is downconverted from 39.402 GHz to 70 MHz in two stages at the feed, then transmitted over fiber to the final downconversion (to 5 MHz) and digitization.

A waveguide switch prior to the LNA is used for radiometer calibration via Noise Diode, and calibration is also done via automated tipping once per day.

All LOs are referenced to a common ultra-stable 10 MHz ref. oscillator.

Temperatures are all tightly controlled:

- $T_{\text{LNA}}$ temperature controlled within ±0.1°C
- $T_{\text{RFplate}}$ temperature controlled within ±0.01°C
- $T_{\text{ND}}$ temperature controlled within ±0.5°C
Alignment to the beacon polarization (Linear -45°) plus LNB skew at each site is accomplished through mechanical rotation of the antenna on a custom mount. On the antenna mount, four mounting bolt holes swept from -10° to -80° allow fine adjustment of the polarization to cover all NASA Alphasat sites.
System temperature is tightly controlled to limit gain variation.

A primary thermoelectric cooling (TEC) system controls a cold-plate within the RF enclosure to within ±0.01 °C. All mountable RF components are heatsinked to this plate including LOs, IF amplifiers, and filters. The noise diode is also heatsinked to this plate.

The LNA is mounted directly to the waveguide switch / feed and cannot be heatsinked to the cold plate. Instead, a secondary TEC system controls the LNA to within ±0.1 °C.

The internal air temperature of the enclosure is circulated with a fan and maintains stability within about ±2.0 °C day-to-day with some larger seasonal drift.

The TEC systems use four Tellurex C2-40 tiles (plate) and one C2-25 (LNA) driven by a PWM voltage.

The plate tiles are driven as two parallel pairs of two series tiles.
Temperature Stability

4 Day Temperature Stability

RF Plate Temperature ±0.01 °C
LNA Temperature ±0.1 °C
RF Air Temperature ±2.0 °C
Noise Diode Temperature ±0.5 °C
Under normal operating conditions, the beacon receiver tracks the signal using a modified Quinn-Fernandes frequency estimation algorithm.

When attenuation approaches the noise floor (below a given power threshold), the frequency estimate is replaced by an average of the frequency estimate prior to the fade. This allows for a slight improvement in dynamic range during the beginning and end of deep fades.

Signal lock is immediately regained when the signal reappears above the noise floor.
The digital radiometer measurement is implemented by pre-processing the sampled data before calculating the signal power.

The full bandwidth output from the final-stage filter is Nyquist sampled to obtain the noise power measurement. A digital notch filter is applied, centered on a moving average of past beacon frequency estimates, to remove the signal power. The remaining noise power is then integrated to produce the noise power measurement.

The signal power is obtained by applying a digital band-pass sampling around the beacon frequency, then decimating to reduce the computational demand of the FFT / frequency estimators used to estimate signal power.

### Parameters

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
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<tbody>
<tr>
<td>$f_s$</td>
<td>11.11 MHz</td>
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<tr>
<td>$N$</td>
<td>$2^{20}$ (1,048,576)</td>
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<tr>
<td>Decimation</td>
<td>$2^5$ (32)</td>
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<tr>
<td>BPF Bandwidth</td>
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<tr>
<td>Notch Bandwidth</td>
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<tr>
<td>Filter Type</td>
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<tr>
<td>Filter Order</td>
<td>10</td>
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<tr>
<td>Filter Atten.</td>
<td>100 dB</td>
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</table>
Digital Radiometer Measurement

![Graph showing CH1 Power (dBm) and Mean Noise Power (dBm) over time (UTC).]

- **Rain Fade:** 16 dB
- **Noise Power Variation:** 0.5 dBm
Digital Radiometer Calibration

MDSCC Receiver during tip calibration at 90° elevation angle.
Concluding Remarks & Future Work

Conclusions

• The MDSCC Alphasat terminal has been operational since March 2017, collecting attenuation and scintillation data at an elevation angle of 34.5°. Operation is expected to continue for a minimum of 5 years.
• The integrated digital radiometer provides valuable clear sky reference level but requires calibration – this system used a switching noise diode approach as well as a tip calibration and found that tip calibrations are sufficient and may be preferable to minimize required hardware.

Future Work

• Infusion of data into MDSCC high-frequency operations.
• Antenna wetting resolution – feed cover with hydrophobic coating
Thank You!
Appendix Charts
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