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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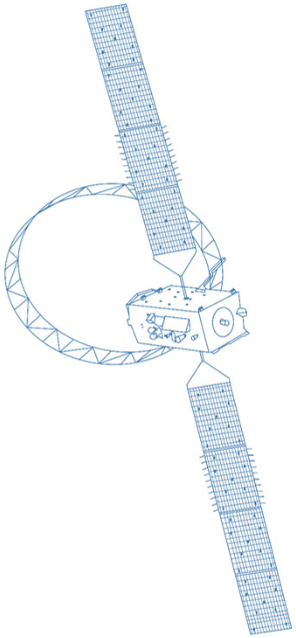
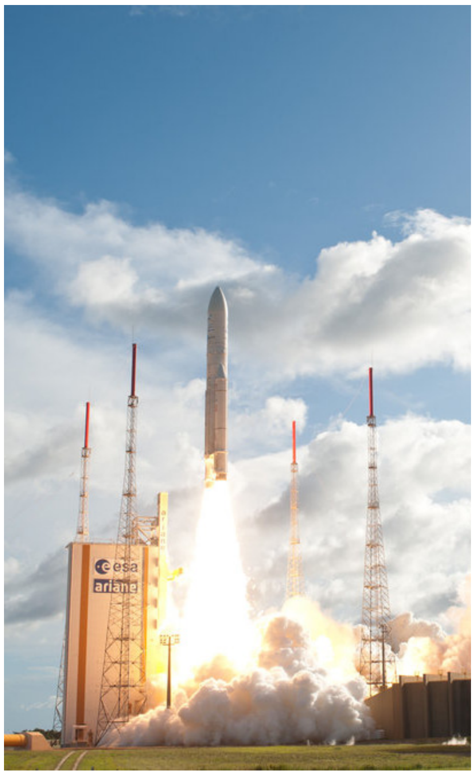
Presentation Overview



Wireframe schematic of the Alphasat satellite carrying the Aldo Paraboni TDP#5 Experiment.

1. Motivation & Experiment Goals
2. Site of Study
3. Instrumentation & System Design
4. Temperature Control
5. System Performance
6. Radiometer Calibration
8. Concluding Remarks

Motivation & Goals



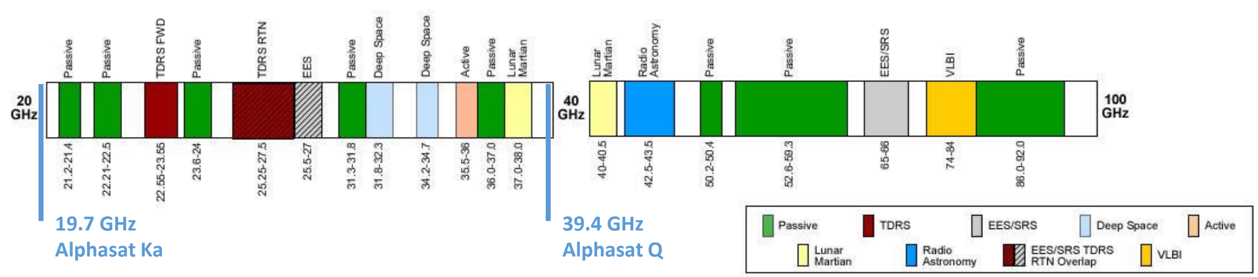
Launch of Alphasat on an Ariane 5, July 2013.
(Photo: ESA / CNES / ARIANESPACE)

Experiment Goals

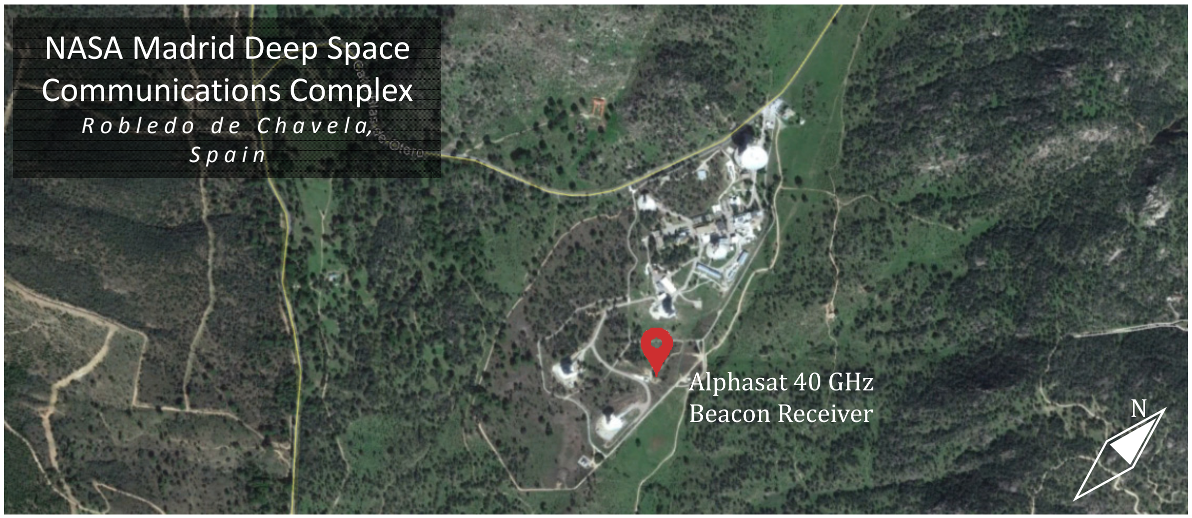
- To **assess the impact** of atmospheric effects on links operating in the Q-band (rain attenuation, scintillation, etc.) in various climatological regions through distributed measurement campaigns.
- To assist the **development of physical models** to improve predictions of atmospheric attenuation within the Q-band.

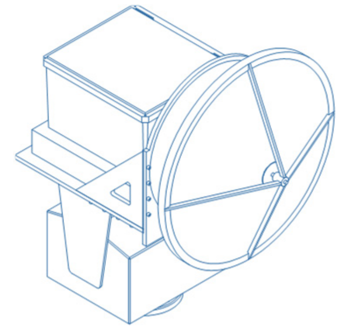
NASA Motivation

- 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





		MDSCC, Spain
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

NASA Alphasat Stations (The Madrid Deep Space Communications Complex is in Robledo de Chavela)*

Beacon Receiver / Radiometer at the Madrid Deep Space Communications Complex

Instrumentation


GRC Beacon Receiver
JPL Interferometer Element


RF Electronics


IF Electronics

Antenna Gain	45.6 dBi
Antenna Beamwidth	0.9 deg
Antenna Tracking Resolution	0.01 deg
LNA Gain	33 dB
LNA Noise Figure	2.5 dB
Beacon Frequency	39.402 GHz

Final IF	5 MHz
Measurement Rate	10 Hz and 1 Hz
Dynamic Range	30 dB
Temperature Control	0.01 deg C (plate) / 1 deg C (air)
Radiometer Calibration	20 sec / 30 min
Radiometer Bandwidth	10 MHz

System Block Diagram

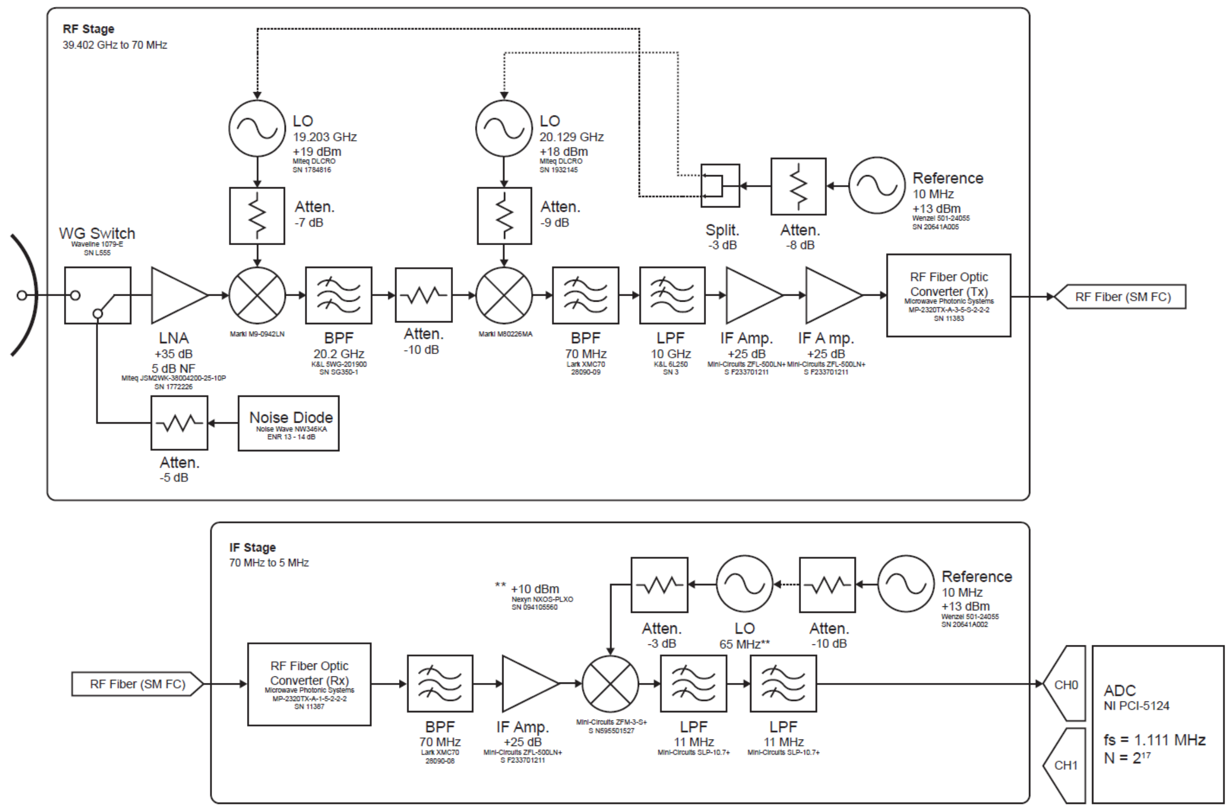
The beacon is downconverted from 39.402 GHz to 70 MHz in two stages at the feed, then transmitted over fiber to the final downconversion (to 5 MHz) and digitization.

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.

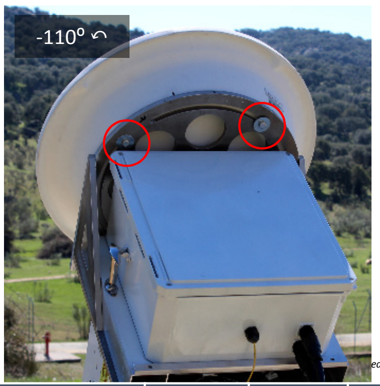
All LOs are referenced to a common ultra-stable 10 MHz ref. oscillator.

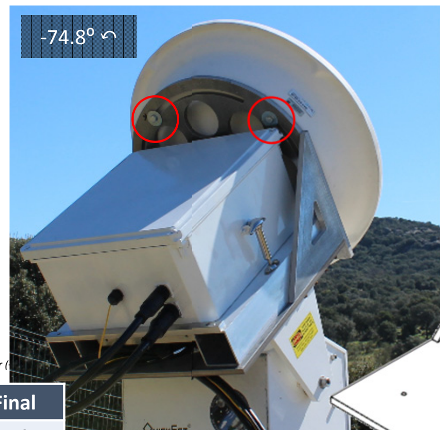
Temperatures are all tightly controlled:

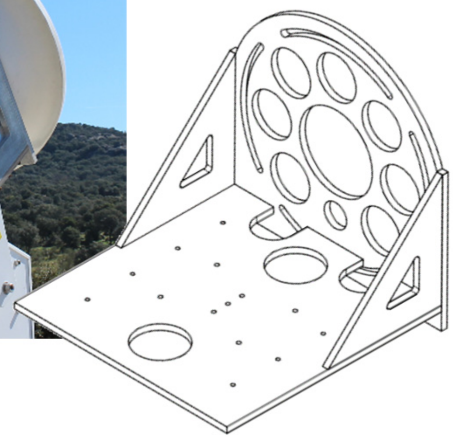
- T_{LNA} temperature controlled within ±0.1°C
- $T_{RFplate}$ temperature controlled within ±0.01°C
- T_{ND} temperature controlled within ±0.5°C



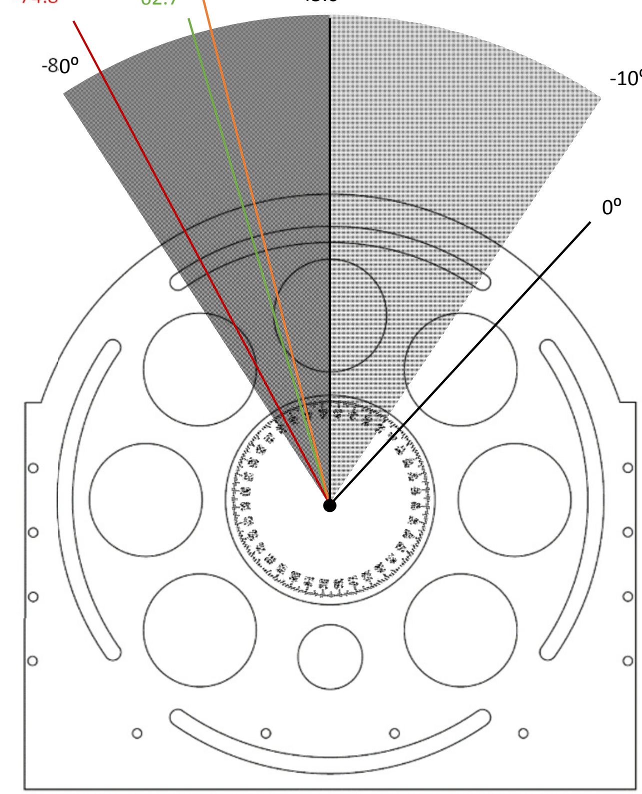
Fine-Tuning Polarization Alignment





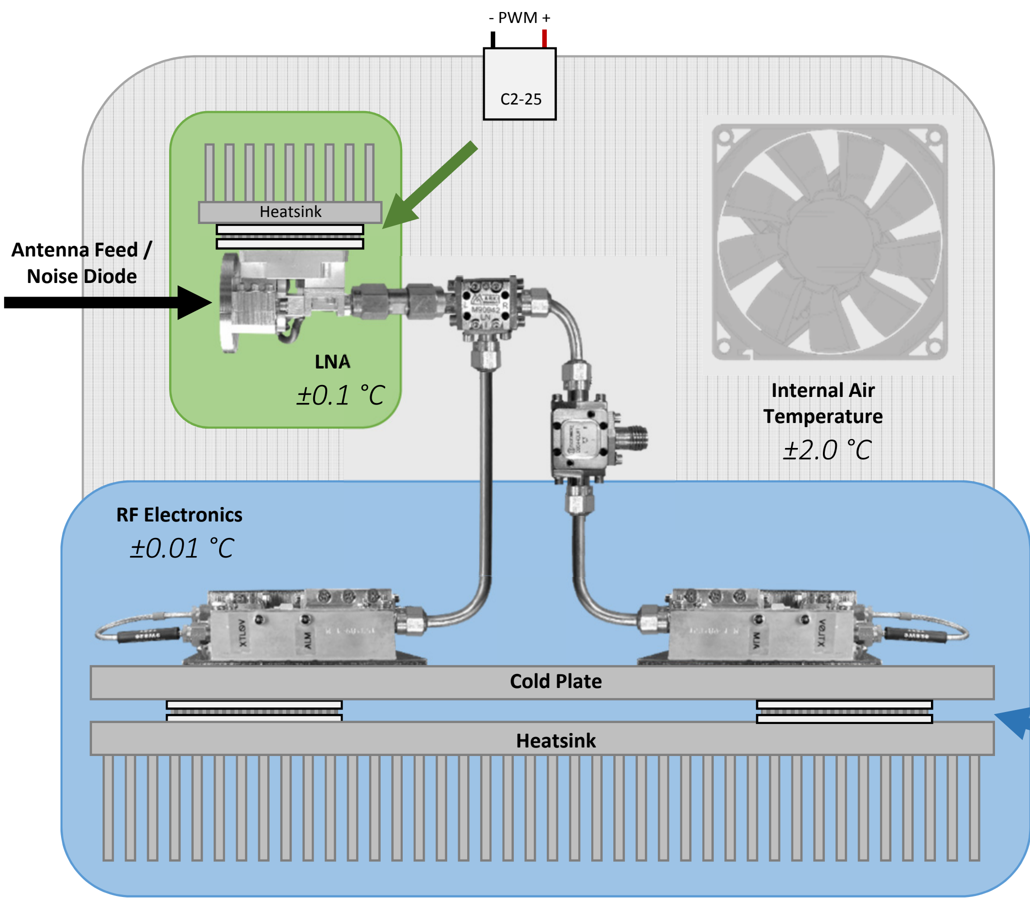


Site	Pol.	Skew	Final
Milan, Italy	-45.0° ↶	-29.8° ↶	-74.8° ↶
Edinburgh, Scotland	-45.0° ↶	-17.7° ↶	-62.7° ↶
Madrid, Spain	**-45.0° ↶**	**-14.8° ↶**	**-59.8° ↶**



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.

Temperature Control System

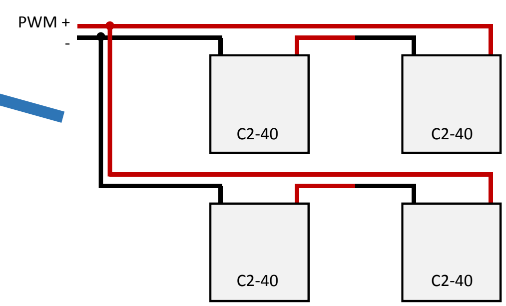


System temperature is tightly controlled to limit gain variation.

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.

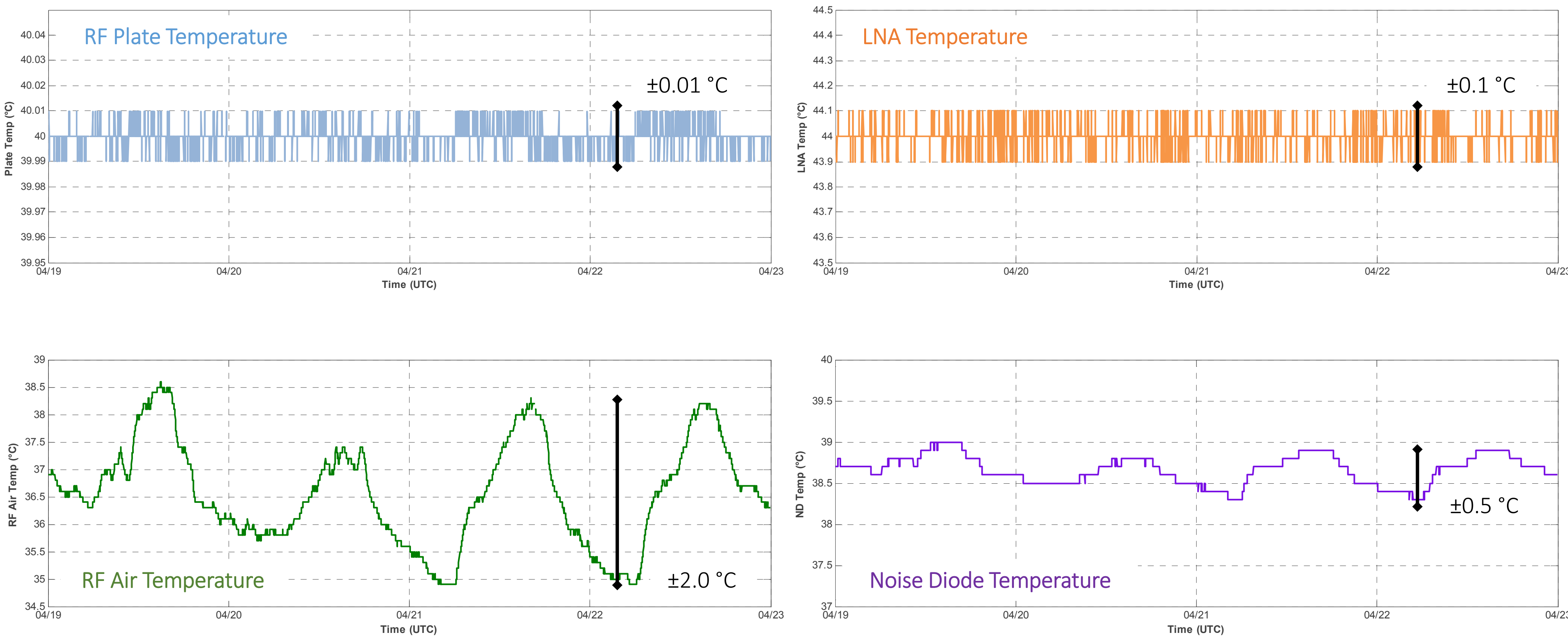


The TEC systems use four Tellurex C2-40 tiles (plate) and one C2-25 (LNA) driven by a PWM voltage.

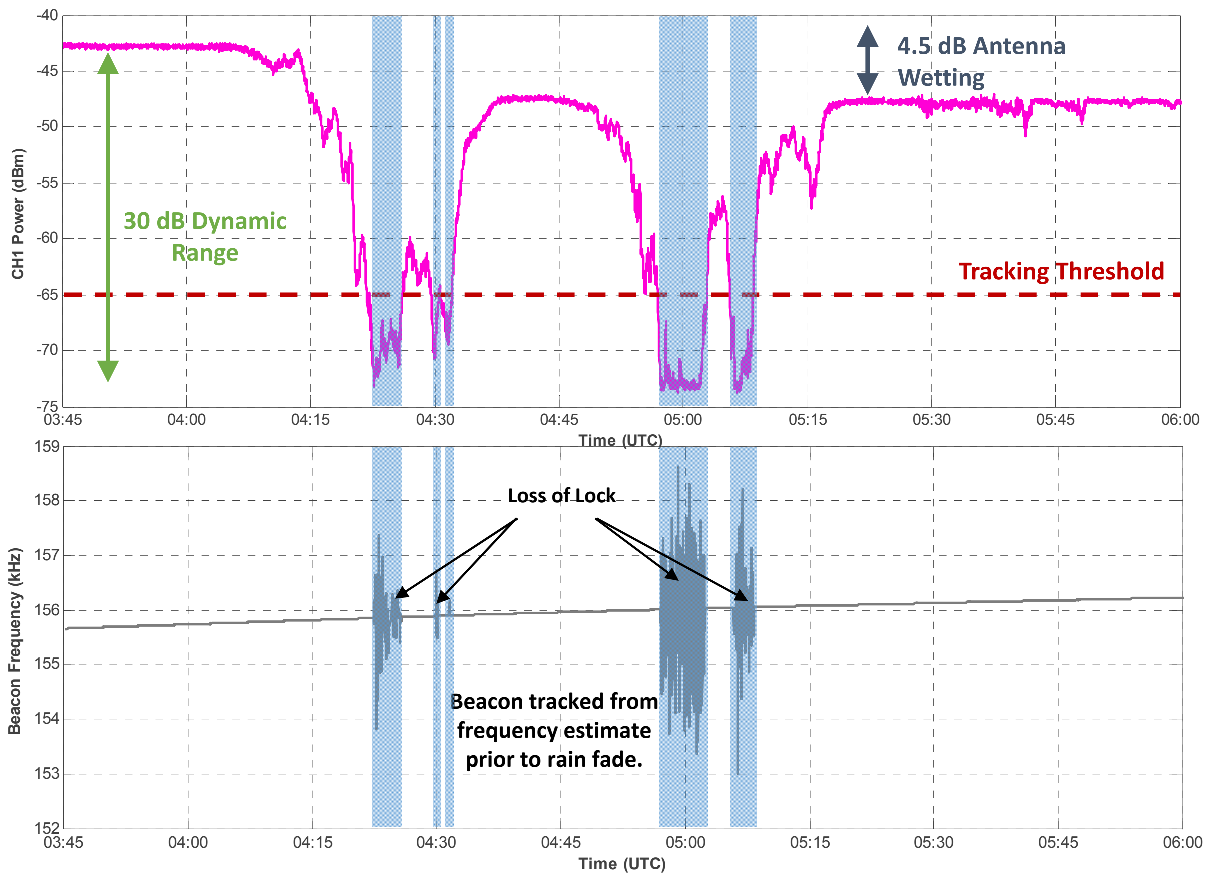
The plate tiles are driven as two parallel pairs of two series tiles.

Temperature Stability

4 Day Temperature Stability



System Performance

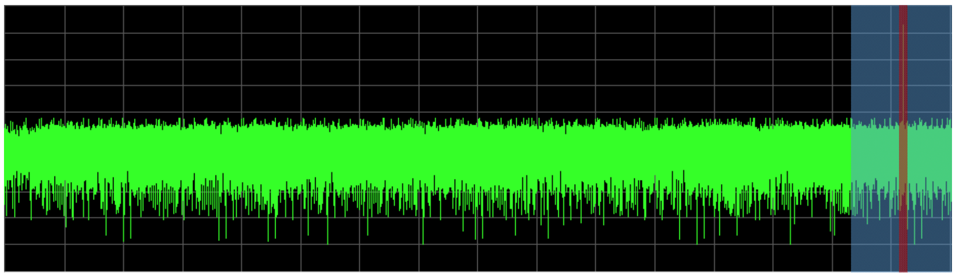


Under normal operating conditions, the beacon receiver tracks the signal using a modified Quinn-Fernandes frequency estimation algorithm.

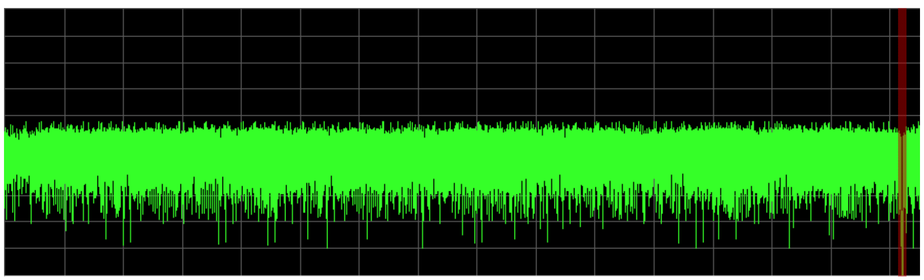
When attenuation approaches the noise floor (below a given power threshold), the frequency estimate is replaced by an average of the frequency estimate prior to the fade. This allows for a slight improvement in dynamic range during the beginning and end of deep fades.

Signal lock is immediately regained when the signal reappears above the noise floor.

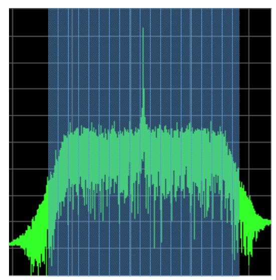
Digital Radiometer Design



Nyquist Sampled Spectrum
($f_s/2$ = 5.55 MHz)



Noise Power Spectrum
Notch Filter @ Beacon Frequency →
Integrate Noise Power



Signal Spectrum
BPF @ Beacon Frequency →
Decimate / Undersample →
Estimate Frequency (QNF) →
Calculate Signal Power

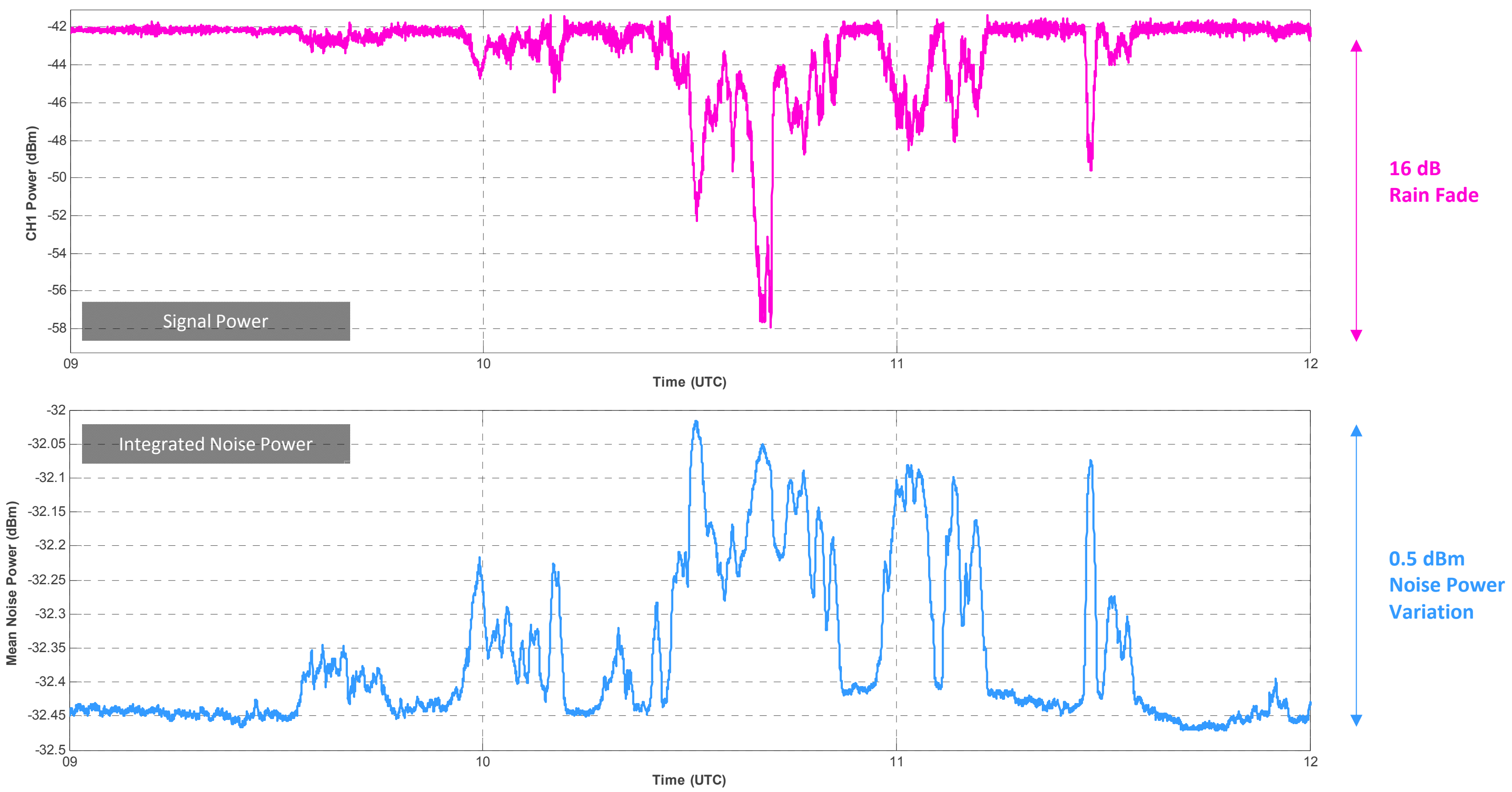
The digital radiometer measurement is implemented by pre-processing the sampled data before calculating the signal power.

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.

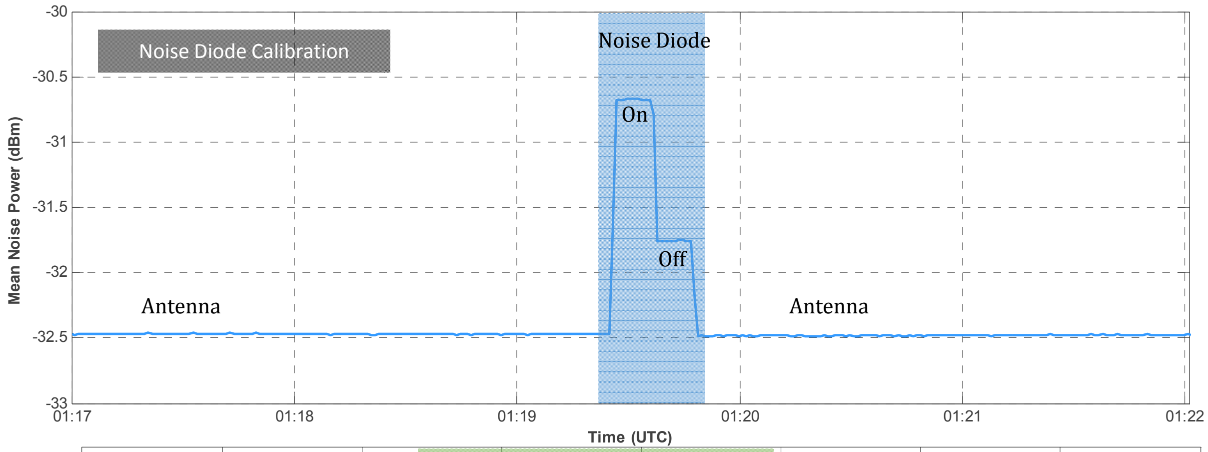
fs	11.11 MHz
N	2^{20} (1,048,576)
Decimation	2^5 (32)
BPF Bandwidth	50 kHz
Notch Bandwidth	2 kHz
Filter Type	Chebyshev II
Filter Order	10
Filter Atten.	100 dB

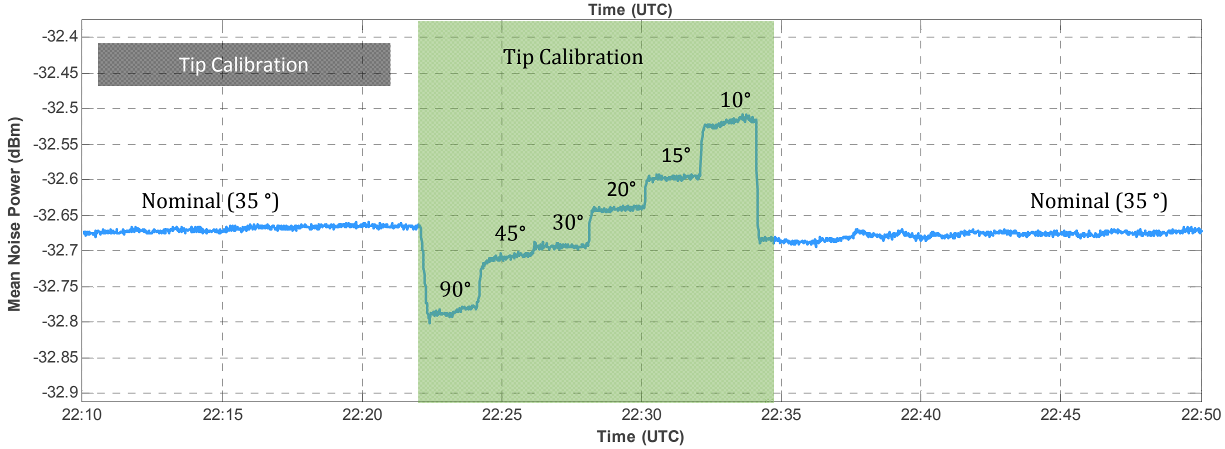
Digital Radiometer Measurement



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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