The SATCROSS Measurement Campaign
Application of the NDSA technique to a Ground-to-Ground Radio Link

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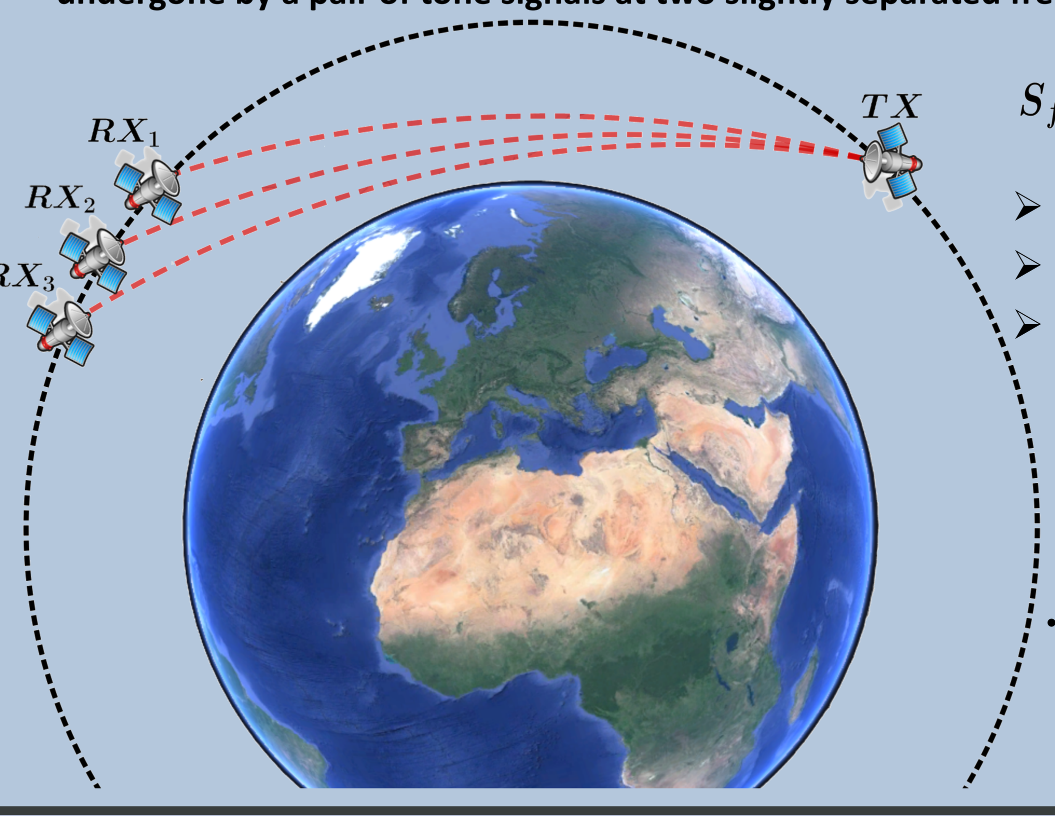
SUMMARY

The measure of water vapor (WV) in the lowest part of the troposphere is a critical issue. A novel technique, which is based on a microwave radio link and the measure of differential attenuation of two signals transmitted at closely spaced frequencies in the Ku-K band, has been recently proposed. In order to prove the potential of this technique, a low-cost microwave link has been designed and the first measurements are being carried out along a ground-to-ground link. Instrument design and characteristics, as well as experimental results, are presented here.

1. THE NDSA CONCEPT

- **NDSA is a method to estimate the Integrated Water Vapor (IWV) along a microwave link in the troposphere.**
- **It is based on the measurement of the *spectral sensitivity S,* related to the differential attenuation undergone by a pair of tone signals at two slightly separated frequencies f_1 and f_2.**



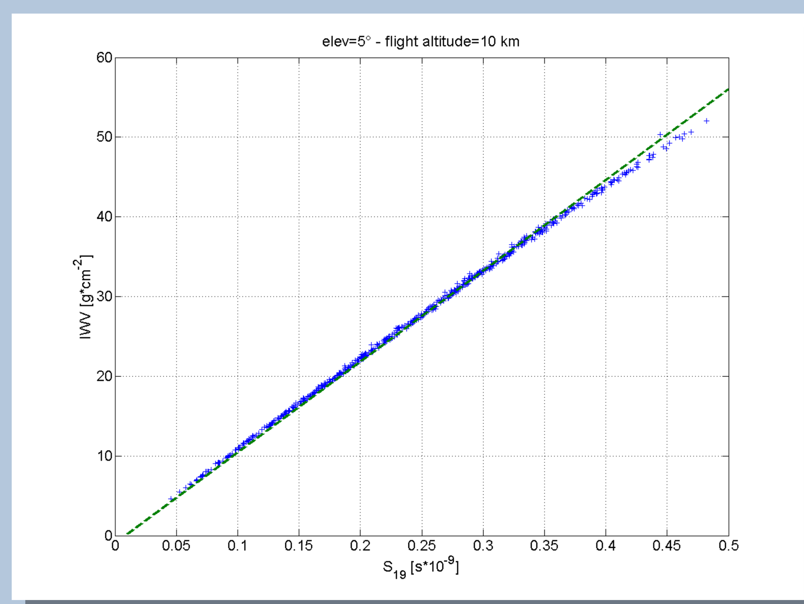
$$S_{f_c} = \frac{A(f_1) - A(f_2)}{(f_2 - f_1)A(f_1)} = \frac{1}{\Delta f}\left(1 - \frac{P_1}{P_2}\right)$$

- $P_{1,2}$: received powers of the two tones at $f_{1,2}$
- $\Delta f = (f_1 - f_2)$: frequency separation
- $f_C = (f_1 - f_2)/2$: center frequency
- *S* is strongly correlated to IWV - it can be directly converted into IWV and the regression is independent of the elevation angle

$$IWV = a_1 S_{f_c} + a_0$$

- F. Cuccoli, L. Facheris: “Normalized Differential Spectral Attenuation (NDSA): a novel approach to estimate atmospheric water vapor along a LEO – LEO satellite link in the Ku/K bands”, *IEEE Trans. Geosc. Rem. Sensing*, Vol. 44, June 2006, pp. 1493-1503

Example of ground-LEO configuration



Simulation of IWV vs. S at 19 GHz for a receiver placed on a platform at 10 km altitude. Each point in the scatter plot refers to a spherically symmetric atmosphere generated through real radiosonde observations

- Proposed measurement configuration

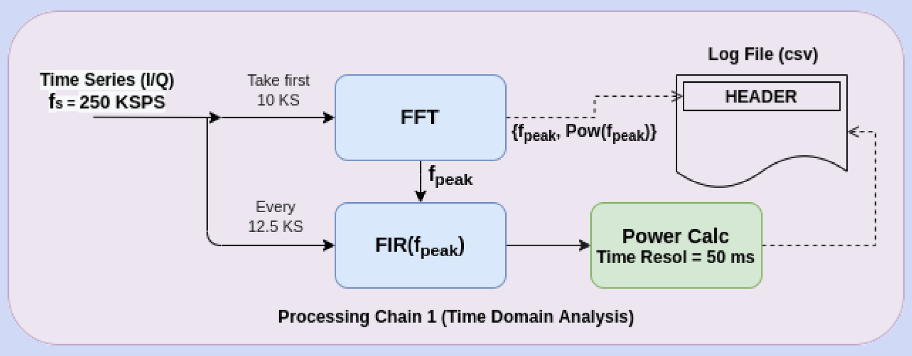
- $f_1 = 18.8$ GHz; $f_2 = 19.2$ GHz
- $\Delta f = 400$ MHz
- $f_C = 19$ GHz
- ✓ $f_C = 19$ GHz is the optimal frequency for an Earth-satellite link that includes the lowest tropospheric shells. The same concept is applicable to aerial platforms such as HAPS or stratospheric baloons

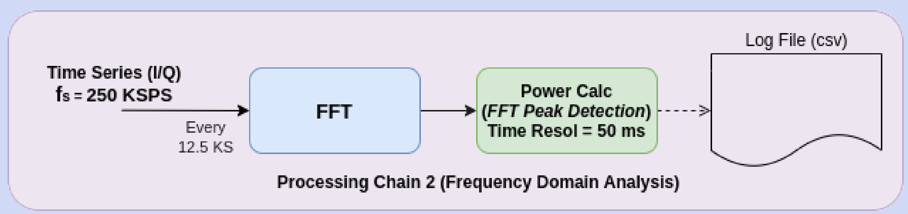
TABLE 1: Coefficients of the IWV-S_{19} linear regression

a_1 $[s^{-1} \cdot g \cdot cm^{-2}] \cdot 10^{-9}$	a_o $[g \cdot cm^{-2}]$	Relative error [%]
114	0.58	3.0

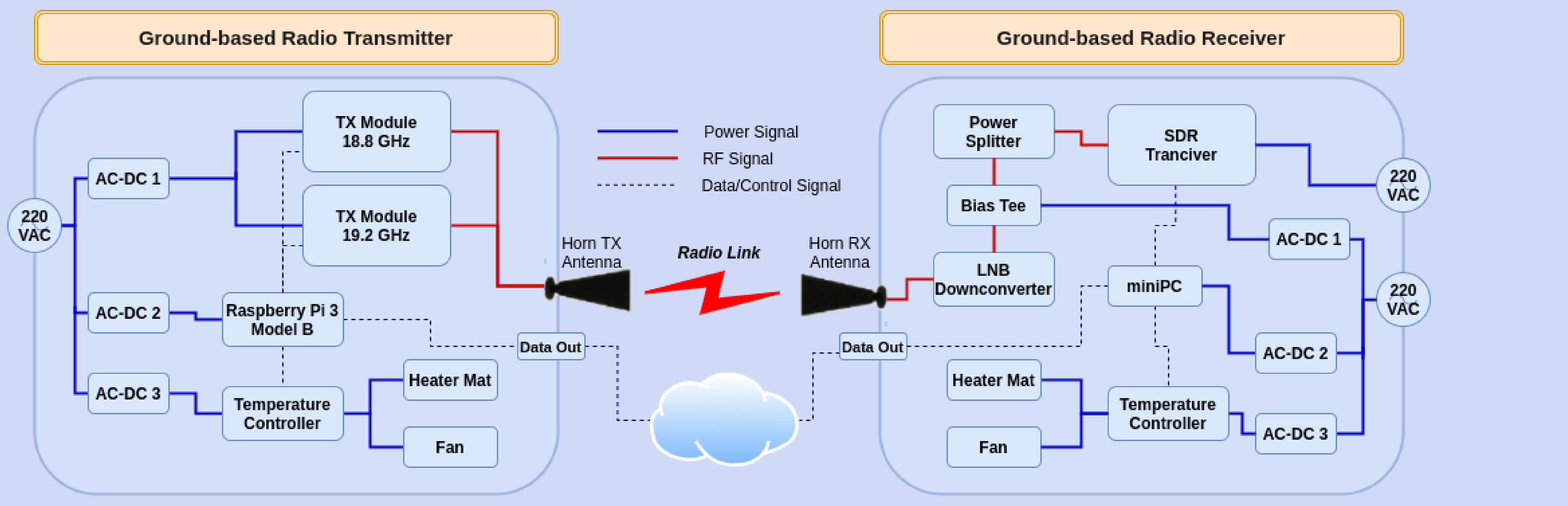
2. THE INSTRUMENT

- An instrument prototype able to perform the first NDSA measurements in ground-ground configuration has been designed and realized.
  - Montomoli at. al. (2021). Integrated Water Vapor Estimation Through Microwave Propagation Measurements: First Experiment on a Ground-to-Ground Radio Link. IEEE Transactions on Geoscience and Remote Sensing. PP. 1-13. 10.1109/TGRS.2021.3067929.
- The first prototype was upgraded with the realization of improved transmitter and receiver units to ensure more accurate measurements of IWV.
- It consists of a synthesized microwave transmitter and a software defined radio microwave receiver operating from 18.2 to 19.2 GHz.
- Two tones separated by 400 MHz are transmitted and sampled at the receiver using 2 independent channels of an SDR Transceiver.



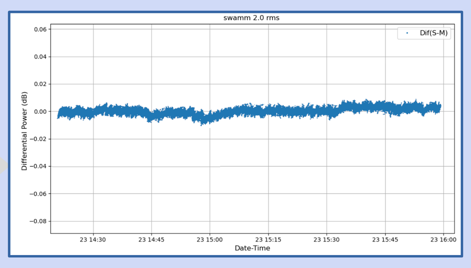


- For more robust measurement results, the signal power is calculated from the received samples using two different processing chains working in parallel.
- RMS based power calculation – every 12500 samples.
- Peak detection of the received signals’ power spectra - every 12500 samples.
- The received signals time resolution is 50 ms in both processing chains.



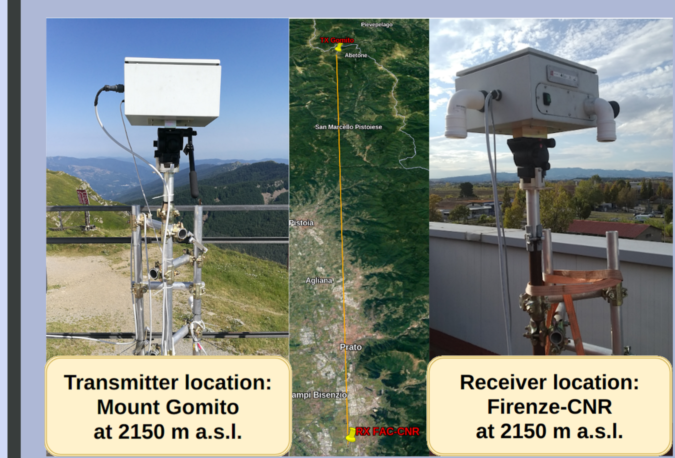
Transmitter characteristics		Receiver characteristics	
TX-Antenna	Corrugated Circular Horn	RX-Antenna	Corrugated Circular Horn
Antenna Gain	21.6 dBi	Antenna Gain	21.6 dBi
Antenna Polarization	Circular	Antenna Polarization	Circular
Antenna HPBW	15.8°	Antenna HPBW	15.8°
Tx frequency range	Fixed: 18.2, 19.2 GHz	LNB-band (RF)	18.2-19.2 GHz
Tx frequency resolution	0.001 Hz	LNB-Noise Figure	1.6 dB
Tx output power (Max))	20 dBm	LNB IF	1.55 - 1.95 GHz
TX Output Frequencies	18.8; 19.2 GHz	ADC RF Bandwidth	10MHz-6GHz

<u>Test in anechoic chamber:</u>
-good RX stability
-incertitude
ΔA<0.02 dB



3. GROUND TO GROUND EXPERIMENT

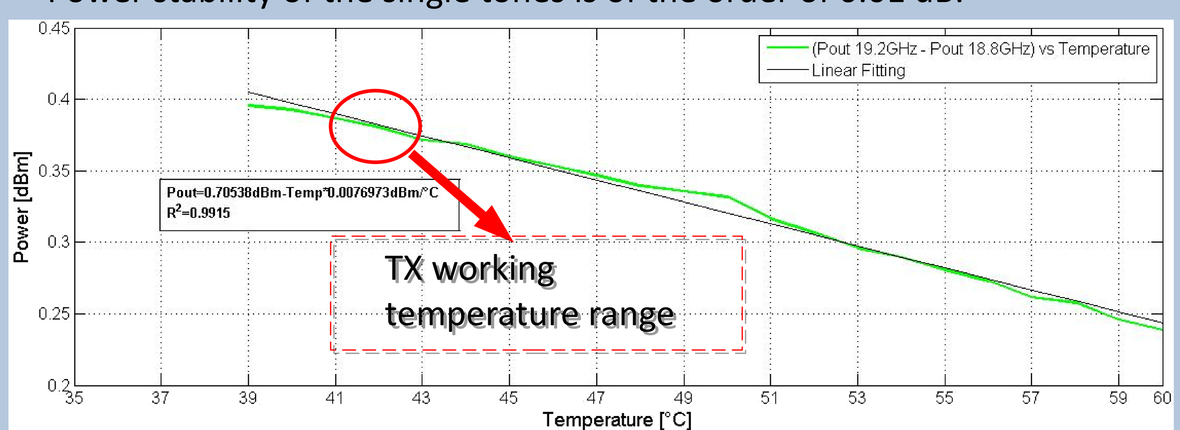
- The measurement campaign started in August and is still going on, to test the instrument and the performance of the NDSA technique.
- The receiver has been installed at sea level and the transmitter on the top of a mountain (around 1900 m a.s.l.) thus obtaining a transect in the troposphere of tens of Km.



4. PRELIMINARY RESULTS

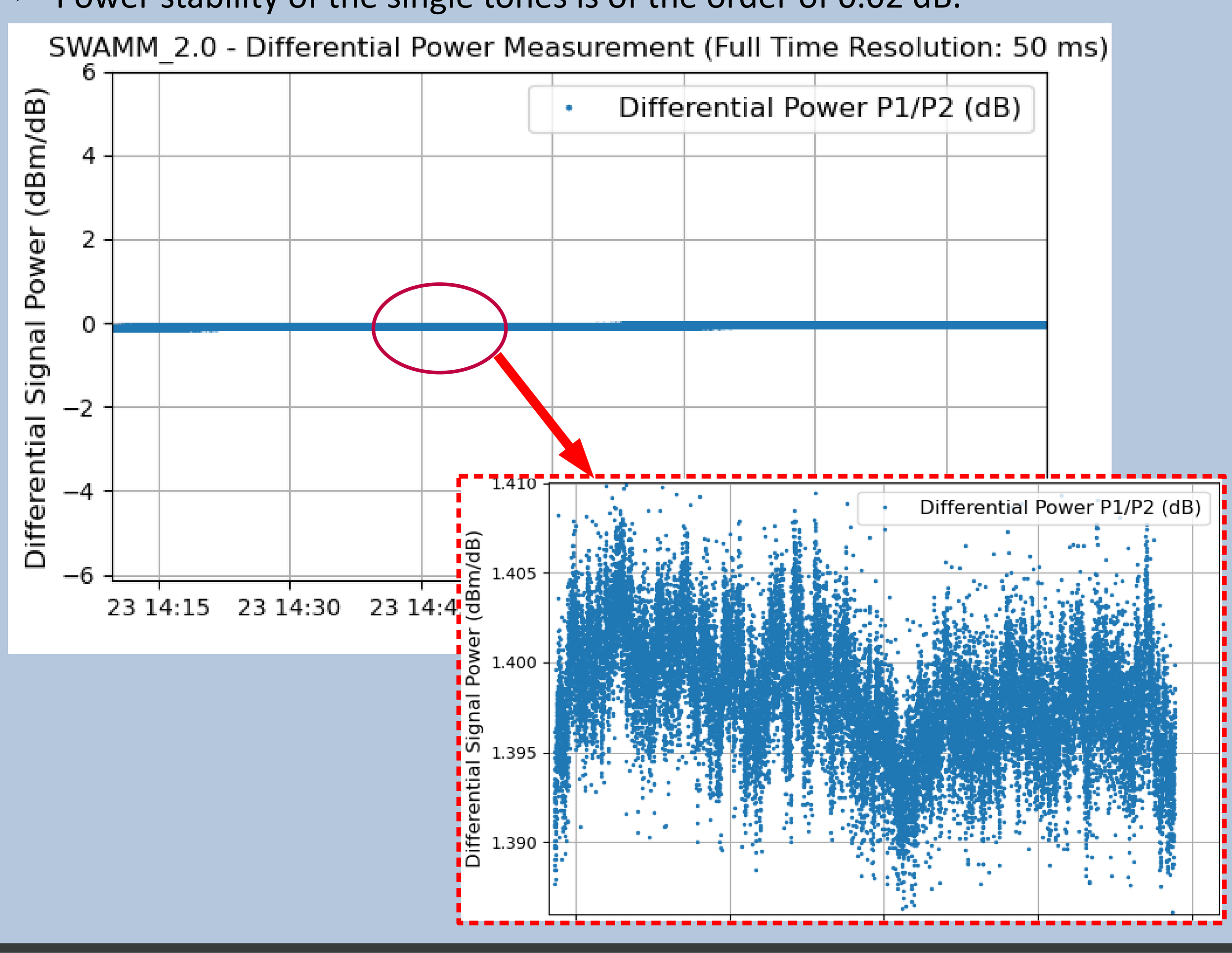
4.1 – Power Stability in Transmission

- The transmission modules provide diagnostic signals for monitoring the stability of the generated signals.
- Power stability of the single tones is of the order of 0.01 dB.



4.2 – Differential Signal Power Stability in Reception

- The system in its definitive configuration was tested and calibrated in an anechoic chamber.
- Power stability of the single tones is of the order of 0.02 dB.



4.3 – In-field Power Measurement

- The measurement campaign started on the end of July and is currently continuing.