2SQCC DIGITAL CORRELATING V-BAND SPECTROMETER FOR CLIMATE MONITORING

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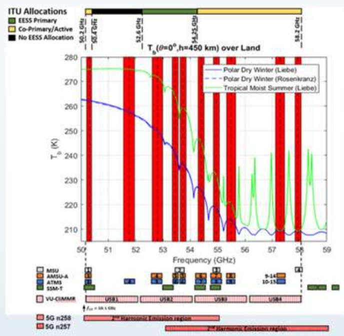
Sponsors: **SpectrumX, CET, NASA**

Science motivation

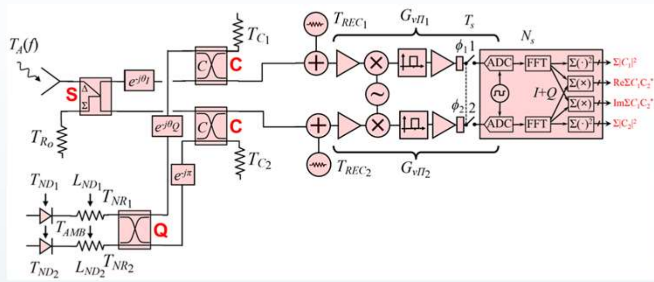
With an overall increase in the anthropogenic radio emissions across the spectrum, radio frequency interference (RFI) detection and mitigation is indispensable for future radiometers and sounders operating in the protected EESS bands [1]. Specifically, second harmonic emissions (if any) from 5G transmitters (n258 and n257 bands) will fall within the bandwidth of different ATMS atmospheric temperature sounding channels operating between 50-58GHz and potentially corrupt atmospheric temperature sounding measurements.

In addition to preventing RFI of anthropogenic origin from corrupting the atmospheric temperature data, quantifying and predicting changes in atmospheric temperature of climatological origin is also a critical earth science need [2]. Without stable and traceable reference instruments, drift and deterioration can obscure trends occurring over several decades. The intrachannel spectral variation of brightness temperature in the conventional sounder channels (~400 MHz) is a major source of inter-satellite sensor calibration errors. Radiometer gain and offset instability during a long scan cycle can further introduce scan "striping" error that has been known to exceed ~0.3 K in some ATMS channels [3].



A digital correlating spectrometer with extremely stable spectral detection to precisely characterize satellite instrument sub-channel spectral variation and kurtosis computation capability to perform real-time radio frequency interference (RFI) detection and mitigation is thus warranted.

2SQCC architecture



$T_A(f)$ is the unknown antenna temperature
T_{C1}, T_{C2} are coupler termination temperatures
T_{REC1}, T_{REC2} are noise temperatures of individual receiver paths
T_{R0} represent noise temperature of waveguide termination (room temperature)
T_{NR1}, T_{NR2} are noise reference temperatures input to the Q-hybrid
θ_I, θ_Q represent phase error in the antenna path and the quadrature reference path
$G_{v\pi1}, G_{v\pi2}$ represent complex receiver path gains (RF & IF gains)
C_1, C_2 are complex FFT outputs of individual receiver path signal voltages

Assuming the path phase difference $\theta_I - \theta_Q = 0$, the observation equation is

$$c_{21} = -\frac{1}{2} G^*_{v\pi_1} G_{v\pi_2} e^{j\theta_I} \left[\underbrace{(1-|C|^2)(T_A - T_{Ro})}_{\text{real}} - j\underbrace{|C|^2 (T_{NR1} - T_{NR2})}_{\text{imaginary}} \right]$$

If $\theta_I - \theta_Q = 0$, the brightness temperature differences $(T_A - T_{Ro})$ and $(T_{NR1} - T_{NR2})$ are orthogonal to each other in the complex correlation space [4]

Comparative Assessment

The observation equation for 2SQCC radiometer architecture is

$$c_{21} = \frac{1}{2} G^*_{v\pi_1} G_{v\pi_2} [(-e^{j\theta_I})(1-|C|^2)(T_A - T_{Ro}) + je^{j\theta_Q}|C|^2(T_{NR1} - T_{NR2})]$$

Two equations, two unknowns*

If the coupler is absent, we get a conventional two-path correlating radiometer

$$c_{21} = \frac{1}{2} G^*_{v\pi_1} G_{v\pi_2} [(-e^{j\theta_I})(T_A - T_{Ro})]$$

Two equations, three unknowns

Either of the diagonal terms of the coherency matrix can be considered as equivalent the output of a single path (1S) total power radiometer

$$c_{11} = |G_{v\pi_1}|^2 [(T_A + T_{Ro}) + T_{REC1}]$$

One equation, three unknowns

If the number of unknowns are more than the number of equations, calibration views are unavoidable.

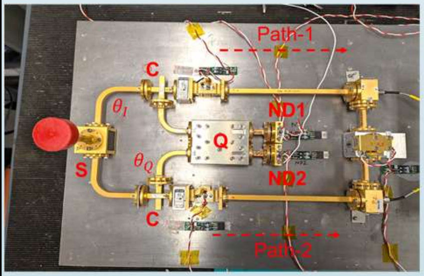
The inversion expression yielding the antenna temperature estimate $\widehat{T_A}$

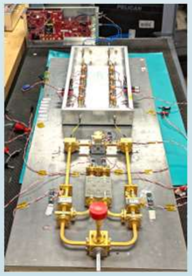
$$\widehat{T_A} = T_{Ro} - \frac{|C|^2}{(1-|C|^2)} \frac{(T_{NR1} - T_{NR2})}{tan(\angle c_{21} + \Delta\varphi_{21} - \theta_I)}$$

Amplifier gain fluctuations do not affect the antenna temperature estimate.

External calibration views are not needed and is continuously calibrating.

Prototype Instrument Development

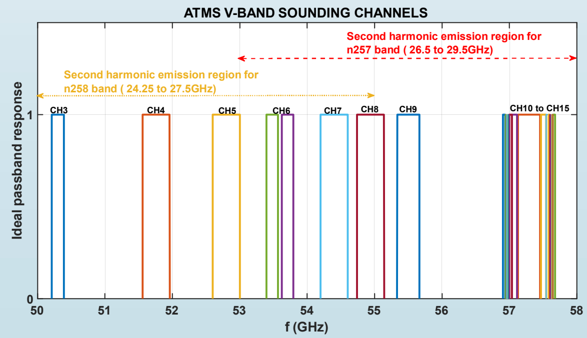




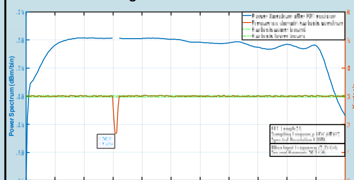
The 2SQCC RF transmission network and front end is realized using WR19 V-band waveguide components. A Gunn diode oscillator tuned to 50.1GHz is used to downconvert 50.1-58GHz spectrum to 0-8GHz IF. Connectorized IF amplifiers and filter pairs are used to observe ~1.2GHz wide sub bands within the 0-8GHz IF bandwidth. A high-speed dual-channel 12-bit ADC card (TI ADC32RF45EVM) and data capture board (TI TSW14J56EVM) operating at 2.4576 GS/s is used to capture coherent ADC samples from the two receiver paths and is processed offline.

A digital spectrometer-based detection scheme is essential to implementing RFI detection and mitigation techniques.

RFI from 5G NR mmwave at V-band

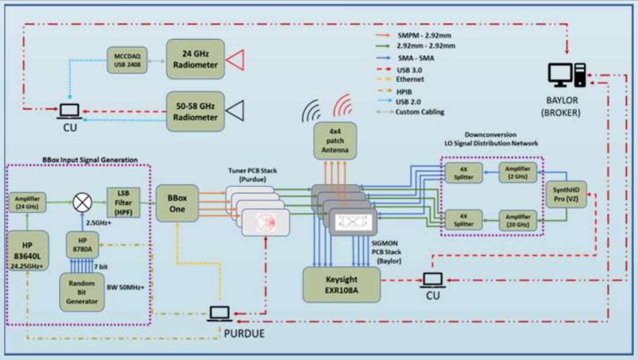


Second harmonic emissions (if any) from 5G transmitters will fall within all 50-58 GHz ATMS sounding channels.



Spectral Kurtosis will used to detect RFI from anthropogenic sources.

Integration with NSF SWIFT AIPAA



The 2SQCC spectrometer will be used with the NSF SWIFT collaborative research project "**Broker-Controlled Coexistence of a 5G Wireless Artificially Intelligent Power Amplifier Array (AIPAA) with Passive Weather Radiometers**" with Baylor University (C. Baylis), and Purdue University (D. Peroulis) and University of Colorado at Boulder as partners [5]. The project aims to design a broker-controlled collaborative system, including a 5G transmitter array with reconfigurable power-amplifier matching networks, to orchestrate and ensure coexistence between active 5G transmitters in the 24-31 GHz band and passive radiometers in the 23.6-24.0 GHz and 50-58 GHz bands.

References

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[2] Santer, B.D et al, "Comparing Tropospheric Warming in Climate Models and Satellite Data. J. Climate",2017
[3] Doherty et al "An Assessment of Data from the Advanced Technology Microwave Sounder at the Met Office",2015
[4] Aravind Venkitasubramony, Doctoral Comprehensive Examination, 2023
[5] Baylis et al "Broker-Controlled Coexistence of 5G Wireless Artificially Intelligent Power Amplifier Array (AIPAA) with Passive Weather Radiometers", NSF Spectrum Week 2024