Name of research institute or organization:

STFC Rutherford Appleton Laboratory

Title of project:

Field test of a total-power radiometer comprising a 340 GHz sub-harmonic image rejection mixer (SHIRM) receiver for atmospheric remote sensing

Part of this programme:

CEOI (Centre for Earth Observation Instrumentation, UK)

Project leader and team:

Simon Rea (project leader), Matthew Oldfield, Daniel Gerber

Project description:

The aim of the project was to perform field measurements of submillimetre wave radiation from the atmosphere and the spectral signatures from various trace gases therein. The measurements are performed by a new generation of heterodyne receiver, currently being developed at RAL Space in the UK. The new receiver technology addresses a fundamental limitation in remote sensing of the atmosphere using the heterodyne detection principle. In heterodyne detection, the atmospheric radio frequency signal (RF) is downconverted to a lower, intermediate frequency (IF) band by mixing the RF signal with a continous wave (CW) signal from a local oscillator (LO). Only at these lower IF frequencies can the atmospheric signal be processed and detected at all.

In heterodyne detection however, two atmospheric RF bands are simultaneously mapped onto the same IF band, which leads to spectral confusion. This forces the observer to make a binary choice: to either accept the spectral confusion, or to add a complex sideband-separating filter into the beam path, thereby inceasing cost, size, weight and most importantly the measurement noise of the receiver. The new "SHIRM" receiver developed at RAL enables the simultaneous detection of both atmospheric side-bands with high isolation without the need for a filter in the beam path. The achievable sideband separation of a SHIRM receiver based on laboratory measurements is of the order of 25 dB. We have however never deployed this type of receiver in the field. To do so, a total-power radiometer comprising the SHIRM receiver was developed and deployed.

In this measurement campaign at the High Alpine Research Station Jungfraujoch we have confirmed the functioning of the sideband-separating mixer by making real atmospheric measurements. In addition to that, the atmospheric measurements also allow us to determine the noise performance of the receiver system, as well as the radiometric stability and the frequency stability. The operating wavelengths in the sub-millimetre wave range are optimized for a satellite-borne platform in low Earth orbit. The current mission candidate for such an instrument is STEAMR, a radiometer originally designed for the PREMIER mission. RAL Space, together with our Swiss University partners at the IAP Uni Bern have a stake in STEAMR.

Only at a very select handful of high-altitude locations worldwide can ground-based measurements at these frequencies be performed. Even at the altitudes of the Jungfraujoch, detection of weak atmospheric signatures can only be successful in the very dry winter months January-March, and even then only on particularly dry days. We were lucky to encounter periods of very high tropospheric transmittance right at the start of our weekly campaign, and then again towards the end (as illustrated by cold temperatures in Figure 1).

An example of measured atmospheric spectra is given in Figure 2 for a 1-hour integration time. The detected species are H2O in the lower side-band, as well as a number of Ozone lines (343 GHz) and the very narrow CO line (345.8 GHz) in the upper sideband. The detection of CO from ground-based observations is a major scientific feat and testimony to the quality of the instrument performance, as well as the unique observation conditions the High Alpine Research Station Jungfraujoch (HFSJ) has to offer.

In Figure 3 we mirror the frequency range of the lower side-band about the LO frequency. This allows a direct inter-comparison of the two radio frequency bands just the way they are mapped on top of each other in IF space. The red arrows indicate that none of the spectral features in either side-band is visible at all in its respective mirror side-band. This confirms, with real atmospheric data, the good side-band suppression of our current generation of SHIRM mixers.

The confirmation of the predicted instrument performance with real field measurements, and the demonstration of low receiver noise and high measurement stability, will be instrumental in supporting our endeavor to impart this new mixer technology in future Space instrumentation (i.e. as part of STEAMR on the Canadian-Swedish ALiSS Mission).

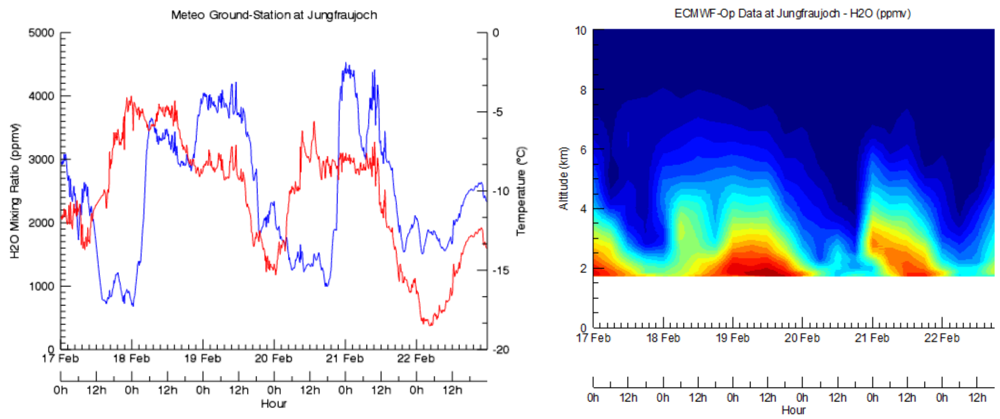

Figure 1. Overview of the meteorological conditions during the measurement campaign. The left panel shows surface temperature (blue) and surface humidity (red) from the Ground Station at HFSJ. The right panel shows the tropospheric humidity profiles over HFSJ from ECMWF Operational Data. We've encountered three windows of good measurement conditions over the course of 1 week.

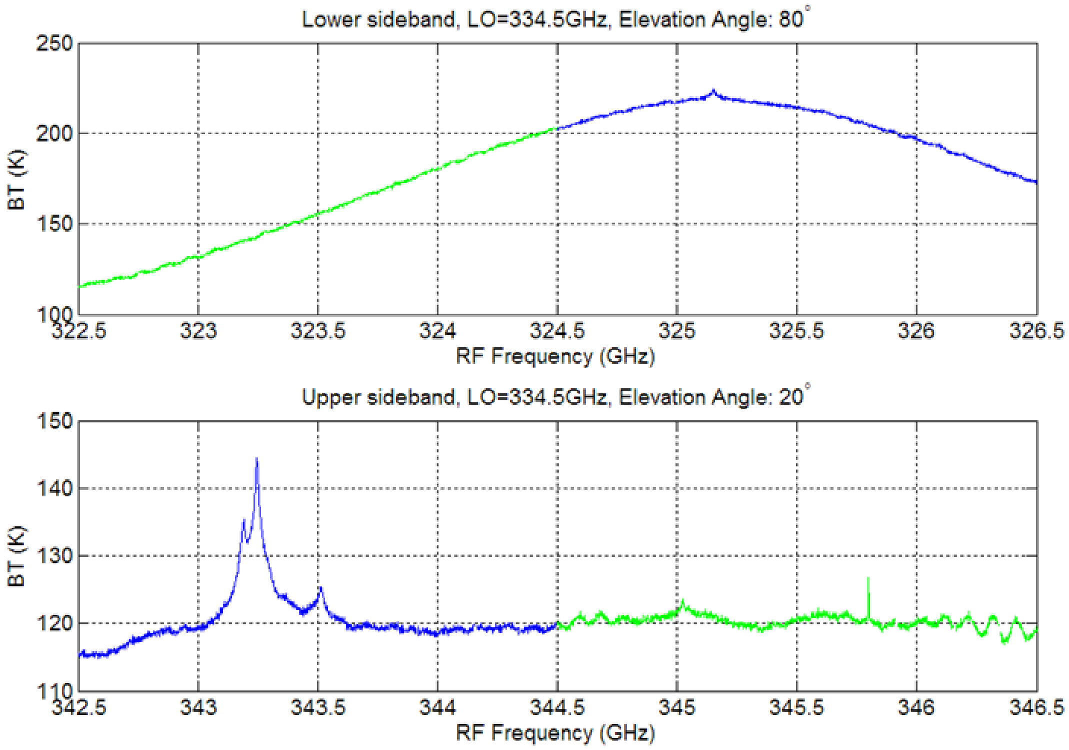

Figure 2. Measured spectra in the lower (top panel) and upper (bottom panel) side-bands. The spectrum is composed of measurements from two separate spectrometers (green and blue parts) symmetrically located around the centre local oscillator frequency at 334.5 GHz.

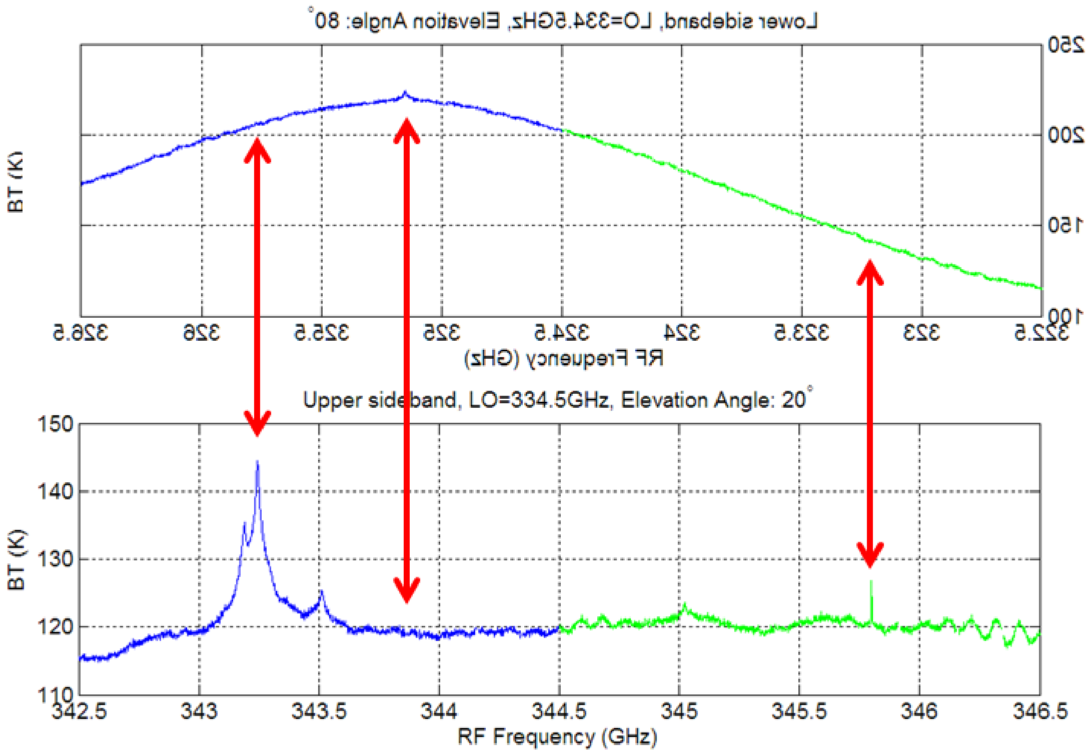

Figure 3. Flipping over the lower sideband gives a direct comparison of the different radio frequencies that are mapped on the same intermediate frequency in heterodyne detection. The inter-comparison of spectral features (red arrows) shows that even strong spectral lines are suppressed beyond detection in the respective mirror side-bands.

Key words:

Atmospheric remote sensing, instrument development, sub-harmonic image-rejection mixer

Collaborating partners/networks:

Institute of Applied Physics, University of Bern (Dr. Axel Murk)

Scientific publications and public outreach 2014:

Results of the measurement campaign have been disseminated at the Annual Science Conference of the CEOI and NCEO at Sheffield, 24-27 June, UK. The results have also been used to strengthen the case for further development of the new receiver technology with the CEOI at various project meetings.

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