DEVELOPMENT AND CHARACTERIZATION OF THE BALLOON BORNE INSTRUMENT TELIS (TErahertz and Submm Limb Sounder): 1.8 THz RECEIVER

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ABSTRACT

The present paper focuses on the 1.8 THz heterodyne receiver developed by DLR (Deutsches Zentrum für Luft- und Raumfahrt). The 1.8 THz channel consists of a hot electron bolometer (HEB) as a highly sensitive mixer, a solid state local oscillator having a compact size, and a diplexer based on a MPI (Martin-Puplett Interferometer) used for coupling RF and LO signal into the mixer. Thus, the size of receiver can be reduced while the stability of the receiver is enhanced since all components are cryogenically operated on a small optical bench (ϕ~26 cm.). The 1.8 THz channel has been integrated into the TELIS flight module cryostat since the end of 2006 and has been fully characterized during 2007/2008. After the first test flight in Teresina, Brazil, in May 2008, the 1.8 THz channel was retested and improved and operated well during the flight campaign in Kiruna, Sweden, in March 2009. The sensitivity improvement of the 1.8 THz heterodyne receiver by about 60% with respect to the prototype developed in 2005 will be discussed. In addition, results of the characterization and some quick look calibrated spectra from the Kiruna campaign will be shown in this paper.

1. INTRODUCTION

In order to investigate atmospheric trace gas distributions associated with, e.g. ozone destruction, TELIS (TErahertz and submillimeter LImb Sounder) has been developed, a new state-of-the-art balloon borne three channel (500, 450-660, 1800 GHz for RAL, SRON and DLR respectively) cryogenic heterodyne spectrometer. The instrument applies state-of-the-art superconducting heterodyne technology operated at 4K and is designed to be compact and lightweight, while providing broad spectral coverage within the submillimeter and far-infrared spectral range, high spectral resolution and long flight duration (~24 hours duration during a single flight campaign). On the same balloon platform, the TELIS instrument is installed together with the MIPAS-B Fourier Transform spectrometer developed by the Institute of Meteorology and Climate research of the Forschungszentrum Karlsruhe, Germany. The combination of TELIS and MIPAS instruments covers all relevant atmospheric species.

Various important atmospheric constituents within the lower stratosphere can be measured. For instance, the vertical profiles of BrO, ClO, O_3 and N_2O are measured by the 500 GHz channel. The high sensitivity 450-660 GHz channel is used to measure the profiles of ClO, BrO, O_3, HCl, ClOOCl, HOCl, H_2O and its three isotopologues, HNO_3, NO, N_2O, NO_3, CH_3Cl, and O_2 for pointing. The profiles of OH, HO_2, HCl, NO, NO_2, O_3, H_2O+isotopologues, O_2 for pointing, HOCl and CO are measured by the 1.8 THz channel.

2. TELIS INSTRUMENT OVERVIEW

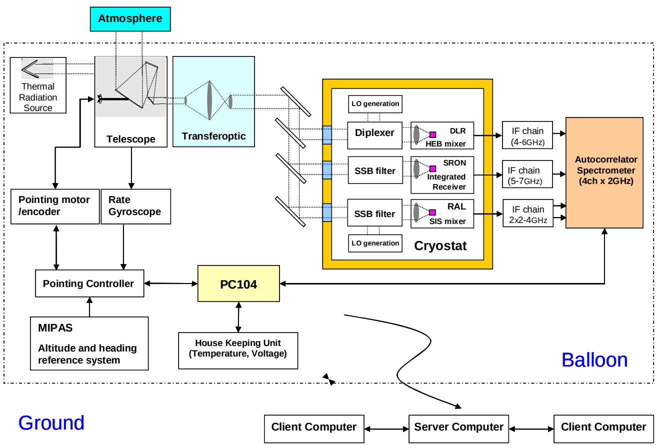

Figure 1: Block diagram representing TELIS instrument

Fig. 1 shows the block diagram of the TELIS instrument. Three heterodyne receivers are installed inside the cryostat. The 450-660 GHz channel developed by Netherlands Institute of Space Research (SRON) utilizes the Super-Integrated-Receiver (SIR) combining the Superconductor-Isolator-Superconductor (SIS) mixer and its quasi-optical antenna, a superconducting phase-locked Flux Flow Oscillator (FFO) acting as LO and SIS Harmonic Mixer (HM for FFO phase locking [1,2]. The 500 GHz channel developed by Rutherford Appleton Laboratory (RAL) is

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a highly compact heterodyne receiver. It uses a SIS mixer and a solid state LO [3]. The details of the 1.8 THz channel are presented in section 4. The atmospheric signal is transmitted from the telescope through the front-end transfer optics where the signals will be separated and coupled to each channel. The Intermediate Frequency (IF) output of each channel is fed to a digital autocorrelator spectrometer having a resolution of about 2MHz and an input frequency range of 2 GHz bandwidth for DLR and SRON channels and 2x2GHz for RAL. All devices of the TELIS instrument are controlled by a computer (based on PC104).

3. OPTICAL FRONT-END OF TELIS

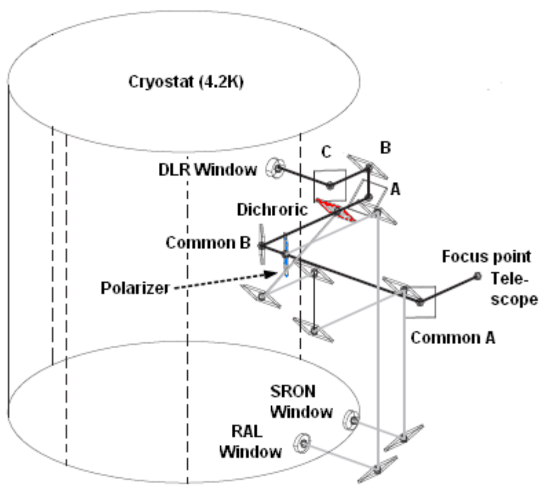

Figure 2: Optical front-end of TELIS [4]

The atmospheric radiation is transmitted by a dual offset Cassegrain telescope through the common transfer-optic as shown in Fig.2. At the polarizer, the reflected beam is coupled to the 500 GHz channel and the transmitted beam having horizontal polarization is directed to the dichroic plate (developed by RAL) used to separate the signals of the 1.8 THz and the 450-660 GHz channels.

4. THE 1.8 THZ RECEIVER

The main target of the 1.8 THz receiver is the OH radical. Further stratospheric species such as HO_2, HCl, NO_2, NO, O_3, H_2O+isotopologues and HOCl and CO will also be measured in the frequency range 1780-1880 GHz. The cryogenic receiver is installed on a 26 cm diameter optical bench. It utilizes a hot electron bolometer (HEB) based on a phonon-cooled NbN technology as mixer. In comparison to the old Schottky diode mixer technology utilized in the THz region the new superconducting mixer technology requires much less local oscillator power and thus allows using a cryogenic solid state local oscillator (LO). Thus, the size of the receiver can be reduced while its stability is enhanced since all components are cryogenically operated on a small optical bench. The 1.8 THz heterodyne receiver operates in double side band mode and a diplexer based on a Martin-Puplett Interferometer (MPI) developed by SRON is used for coupling radio frequency (RF) and LO signal.

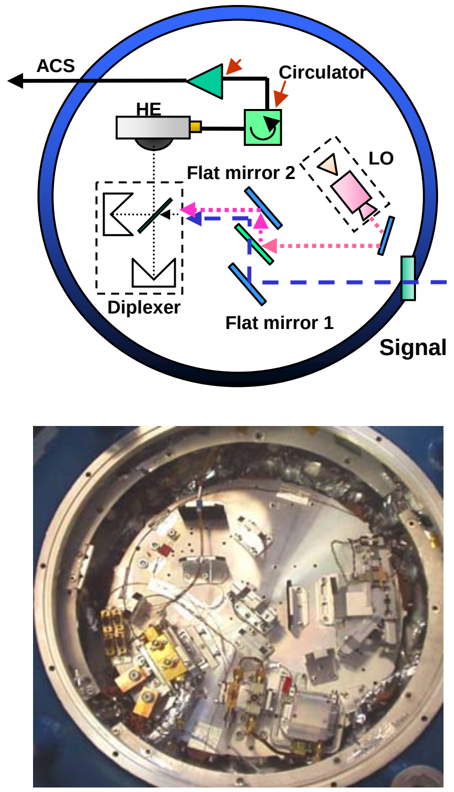

Figure 3: a) The schematic of the 1.8 THz channel. b) The 1.8 THz channel on the optical bench inside the flight module cryostat.

The schematic in Fig. 3a) shows the 1.8 THz channel operating in double side band (DSB) mode. The atmospheric signal transmitted through the transfer optics is fed through the THz cryostat window and blocking filter having a transmittance of about 70%. The horizontally polarized signal passes through the polarizer and is reflected by the flat mirror into the diplexer while the vertically polarized signal from the LO is reflected to the diplexer. Both, signal and LO, are superimposed and horizontally polarized at the output of the diplexer. They are then reflected by two imaging mirrors to the HEB mixer where the RF signal is downconverted to 4-6 GHz (IF). The IF-output signal from the mixer is amplified and sent to the IF backend (outside cryostat) where the digital autocorrelator is located. The performance of the diplexer was tested with the FIR laser in a test cryostat. It has a very low leakage of about 0.7%. The highly sensitive HEB mixer developed by Chalmers University, Sweden, requires very low LO power (about 200 nW). It is a NbN phonon-cooled HEB mixer in which the electron phonon interaction (in the electron energy relaxation process) dominates over the electron diffusion [5]. The HEB mixer operates at about 4.2 K. The HEB together with resistor network, bias tee and double slot antenna are integrated inside the same housing. The solid state local oscillator is heat-sinked to the 77 K shield in order to reduce the LO power dissipation to the optical bench (4 K). Basically, the output LO frequency is generated by a frequency multiplier chain. By multiplying the frequency from a synthesizer (16.5 GHz-17.5 GHz) located at room temperature by 108, 1.8 THz can be generated. By using the solid state LO, the stability of the system is enhanced with respect to the FIR laser source used with Schottky mixers. Furthermore, the frequency can be tuned in the range of 1780-1880 GHz.

3. RESULTS OF CHARACTERIZATION OF 1.8 THZ RECEIVER

The sensitivity of the cryogenic channel is about 60% better than that of the prototype developed in 2005. There are many improvements and design changes in order to enhance the performance of the cryogenic channel. For instance, the diplexer was characterized at 4 K instead of 300 K, the bias of the HEB mixer was better stabilized and the EMC problems in the system were reduced. Along with the full characterization of the 1.8 THz heterodyne receiver, the sensitivity of the cryogenic receiver could be improved much.

The noise temperature spectrum from 4 to 6 GHz of the 1.8 THz channel is shown in Fig. 4. By measuring power from two different blackbodies (300 K and 77 K) and applying the following equations (Eq.1 and Eq.2) the noise temperature can be determined.

$$Y = \frac{P_H}{P_C} = \frac{T_H + T_n}{T_C + T_n} \qquad (1)$$

$$T_n = \frac{T_H - Y \cdot T_C}{Y - 1} \qquad (2)$$

where P_H , P_C is the power measured from hot and cold blackbodies and T_H, T_C are the respective blackbody temperatures. As shown in Fig. 4, the average noise temperature is about 2200 K.

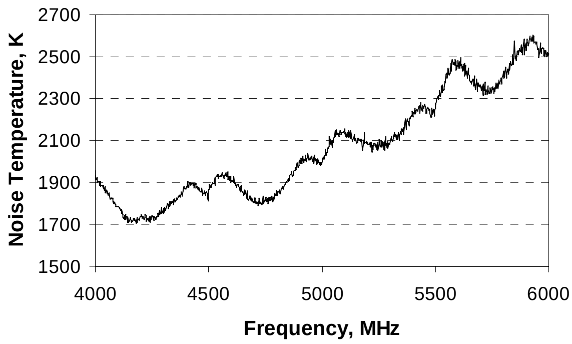

Figure 4: Double sideband noise temperature spectrum of 1.8 THz channel measured with the autocorrelator. LO was tuned at 1830.214 GHz.

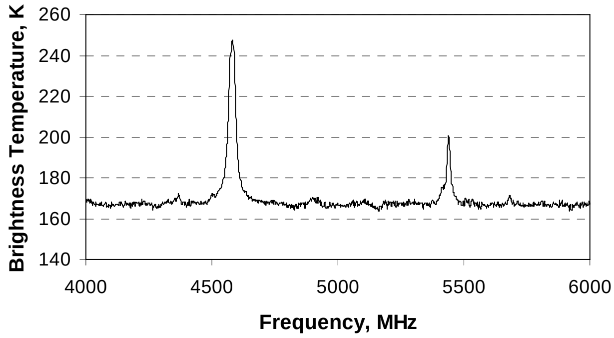

Figure 5: Methanol spectrum measured with the 1.8 THz channel in the laboratory.

Fig. 5 presents the methanol spectrum measured with the 1.8 THz channel in the laboratory in order to characterize the radiometric calibration of the channel and the backend. The LO was set to 1.8428 THz. the cell length is 50 cm, the window material of the cell is polyethylene and the gas pressure 0.4 mbar.

4. EXAMPLES OF SPECTRA FROM THE FIRST SCIENTIFIC FLIGHT IN KIRUNA, SWEDEN

The microwindow selection of the 1.8 THz channel used during the flight in Kiruna is shown in Tab.1. A quick-look result of one measurement performed while the gondola was at 32.17 km and the tangent height was set to 26.5 km is shown in Fig. 6. In this figure a comparison is shown of this quick-look calibrated spectrum (red) with the simulation (green) from the **hi**gh-resolution **tran**smission molecular absorption (Hitran)database+fascode sub arctic winter climatology [6].

Table 1: Microwindow selection of the 1.8 THz channel

Species	**Line center/GHz**	**LO range/GHz**	**Sideband**
OH	1834.75	1829.35-1830.25	USB
OH	1837.8	1842.70-1842.20	LSB
H2 17O	1880.75	1876.55-1875.65	USB
H2 18O	1815.85	1820.05-1820.85	LSB
H2 19O	1840.15	1834.70-1836.00	USB
HDO	1853.9	1858.10-1859.60	LSB
CO	1841.36	1836.10-1836.56	USB

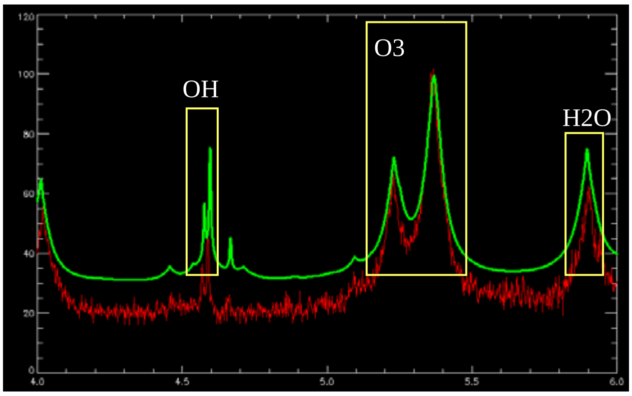

Figure 6: Comparison of the calibrated spectrum measured while the gondola was at 32.17 km and the simulation from the Hitran database. Integration time for complete limb sequence (18 different tangent heights) 30 minutes, 8:30 local time, latitude 66.25°, longitude 27.15°.

5. CONCLUSIONS AND OUTLOOKS

The sensitivity of the 1.8 THz heterodyne receiver is improved about 60 % with respect to the prototype developed in 2005. The 1.8 THz channel was successfully operated in double side band mode in the first scientific flight in Kiruna in March 2009. The next step is to do a post flight characterization of the whole instrument e.g. regarding pointing, side band ratio and the antenna profile before the measured data can be used in the level 2 processing for scientific analysis.

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