The Low-Cost Upper-Atmosphere Sounder (LOCUS)

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Abstract— **The LOw-Cost Upper-atmosphere Sounder (LOCUS) is a mission concept with the aim of observing the mesosphere and lower thermosphere (MLT) region of the Earth's atmosphere from a small space-borne platform in Low-Earth Orbit (LEO). The LOCUS payload consists of a compact terahertz radiometer operating between 0.8–4.7 THz providing global distributions of key MLT species such as atomic oxygen (O), the hydroxyl radical (OH) and nitric oxide (NO) with the aim of increasing our understanding of the chemistry of the region and its effect on climate. This paper presents an overview of the LOCUS mission concept and describes the main technology pre-developments that are in progress in the areas of quantum-cascade lasers (QCL), terahertz Schottky diodes and components, space cryo-coolers and digital spectrometers.**

I. INTRODUCTION

The mesosphere and lower thermosphere (MLT) region of the Earth's atmosphere, from 55–150 km altitude, forms the gateway between the lower atmosphere and the near space environment. A key feature of this part of the atmosphere is the meeting of huge energy fluxes: solar radiation and energetic particles from above, roughly matched by upward energy transfer from gravity waves propagating from the lower atmosphere [1]. It is a region strongly affected by both natural and anthropogenic sources from the Earth's surface, and by solar and space-weather impacts from the space environment above. The MLT is currently cooling at a rate one order of magnitude faster than predicted by models. The rate of cooling is around 5 K yr^{-1}, which is faster, by much greater than one order of magnitude, than the troposphere is warming [2]. The MLT therefore represents an important indicator of global climate change.

Despite the importance of the MLT to our understanding of the Earth system it is a region that has been relatively under-observed. Missions dedicated either solely to MLT observations (e.g. SME, SABER/TIMED, AIM, MAHRSI) or in-part (e.g. MIPAS, SCIAMACHY/ENVISAT, SMR/ODIN, SMILES, MLS/AURA, ACE-FTS, CRISTA) have increased our knowledge of the region, particularly within the last decade. However global measurements of key atmospheric species such as atomic oxygen (O) and the hydroxyl radical (OH) have not been directly made from space, except by the short-lived Space Shuttle experiments MAHRSI and CRISTA/CRISTA2. In addition, continuous observations of NO would provide a new insight into the influence of space weather on climate.

The objective of LOCUS is to detect concentration profiles of O, O_2, O_3, OH, H_2O, HO_2, NO and CO in the MLT on a global scale with high vertical resolution. A terahertz radiometer observing in the limb-viewing geometry and operating in four discrete bands (0.8, 1.1, 3.5 and 4.7 THz) is proposed. An overview of the radiometer concept and critical technology pre-developments in progress are presented.

II. LOCUS PAYLOAD

A top-level schematic of the LOCUS payload is presented in Fig. 1. A primary reflector of diameter 0.45 m is used to couple radiation to the front-end feed cluster whilst providing the required spatial resolution. Periodic calibration of the instrument is performed by viewing an on-board hot blackbody target (not shown) and cold space. The heterodyne receiver front-end including feedhorns is mounted in a cryo-cooler for operation at approx. 100 K. The requirement for cryogenic cooling is driven by the use of QCLs as local oscillator (LO) sources in Bands 1 (4.7 THz) and 2 (3.5 THz). A 300 K receiver stage comprises intermediate frequency (IF) circuitry and high-resolution digital fast Fourier transform (FFT) spectrometers.

Two classes of receiver topology are baselined for the instrument. Bands 1 and 2 shall employ fundamentally-pumped Schottky diode mixers with QCL LO sources. This topology has been selected for the two highest frequency bands taking advantage of advances in the performance of QCL devices. Continuous-wave (CW) emission is now achievable, using QCLs with double-metal waveguides, at heat-sink temperatures in excess of 100 K [3-5]. Furthermore, LO generation directly at the band centre frequency permits an extremely compact receiver solution with low DC power consumption. Bands 3 (1.1 THz) and 4 (0.8 THz) shall employ sub-harmonically pumped Schottky mixers with LO sources based on frequency multiplied microwave oscillators. This receiver topology has been successfully demonstrated to 1.2 THz in support of future planetary missions [6].

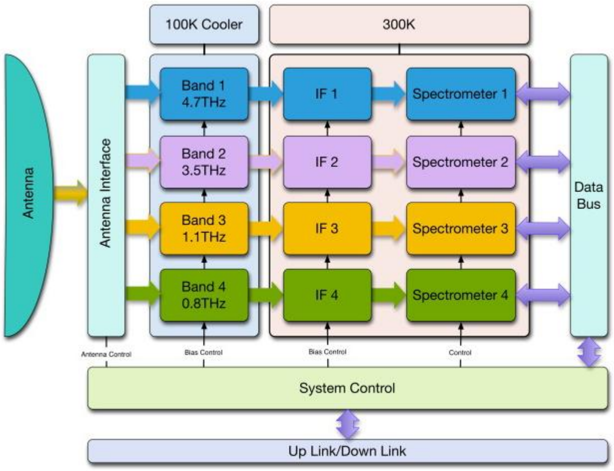

Fig. 1: LOCUS System Schematic

III. TECHNOLOGY PRE-DEVELOPMENTS

Several of the key enabling technologies for LOCUS are the subject of ongoing developments in the UK. QCLs compatible with the Band 1 and Band 2 LOs have been developed with CW output powers in excess of 220 μW and 410 μW respectively, and operating at heat-sink temperatures of up to 60 K and 86 K respectively. Further improvements in output power and operating temperature are targeted through optimisation of device mounting schemes, epitaxial growth, and improved thermal integration through the use of thin substrates. In addition, the packaging of QCL devices into waveguide split-blocks has been successfully demonstrated. This is essential for the coupling of QCL power to the mixers.

Schottky diode technology and associated components operating into the terahertz region are under development. This effort is focussed on a number of areas: sub-micron anode Schottky diodes for operation beyond 1 THz, both as discrete chips and on integrated membrane circuits; fundamental and sub-harmonic mixer topologies for operation at the required LOCUS bands; Schottky-based LO chains based on high-input power frequency doublers and frequency triplers to 600 GHz.

In order to maintain a front-end temperature of approx. 100 K for QCL operation, and as a secondary benefit to improve the noise temperature of the receivers, a high-reliability small-scale Stirling-cycle cooler is under development. The aim is to develop a unit to Technology Readiness Level 5 (TRL-5) capable of 0.5 W heat lift at 80 K with a mass of 0.6 kg and power consumption ~22 W. A CAD image of the cooler is shown in Fig. 2.

LOCUS will spectrally resolve the emission signatures of the MLT species using digital-FFT based spectrometers. Several versions of this spectrometer, based on a Xilinx Virtex-5 field-programmable gate array (FPGA), have been demonstrated. The latest version, using in-phase/quadrature (IQ) input sampling to provide an instantaneous bandwidth of 3 GHz with ~1 MHz spectral resolution has been deployed successfully in a 340 GHz radiometer at the High Altitude Research Station Jungfraujoch (HFSJG) [7]. A ruggedized version of the spectrometer, Fig. 3, is part of an on-going update to the MARSCHALS airborne instrument operated by RAL Space. Effort is now focussed on increasing the TRL of the spectrometer in preparation for a space mission.

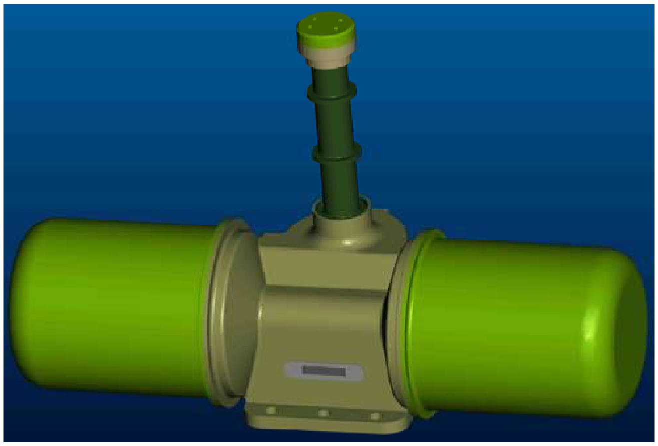

Fig. 2: CAD Image of Small Scale Cooler

Fig. 3: Digital-FFT Spectrometer for Aircraft Deployment

IV. CONCLUSIONS

The LOCUS mission aims to improve our understanding of the MLT region of the atmosphere and its effect on Earth. Detection of key species in the MLT shall be performed using a passive terahertz payload from a limb-viewing geometry in low-Earth orbit. Technology pre-developments in support of the mission are in progress.

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