Terahertz Limb Sounder to Measure Winds and Temperature above 100 km

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***Abstract*— We describe a new instrument, the Terahertz Limb Sounder (TLS) designed to measure upper atmospheric winds and temperature in the altitude regime between 100 and 150 km. It is based on Doppler measurements of the line of neutral atomic oxygen, OI, at 2.06 THz. This measurement takes advantage of a Schottky diode based all solid state receiver.**

I. INTRODUCTION

UNDERSTANDING and characterizing winds in the thermosphere (above ~100 km altitude) is critical for two main reasons. First, how the neutral atmosphere interacts with the ionosphere is fundamental to understanding the mechanisms of drivers and effects in the Earth's atmosphere as well as all other planetary and stellar atmospheres. Second, Reentry and low-orbit space vehicles and debris, strongly affected by thermospheric density and atmospheric motion perturbations from space weather events, are vulnerable to orbital perturbations and potential collisions [1]. Detailed understanding of thermospheric dynamics is lacking because of limited observations. Key dynamical variables (neutral wind speeds, temperature, and atomic oxygen density) are measured with spatial and local time coverage that is insufficient to model the coupled ionosphere and thermosphere.

The atomic oxygen (OI) emissions at 2.06 THz (145.525 µm) and 4.7 THz (63.184 µm) are the two brightest (in terms of photons/cm^2/s) emission lines in the terrestrial thermosphere and have been observed from balloon, sounding rocket and orbital platforms. They provide two ideal emission features for sensing the thermospheric temperature, winds, and atomic oxygen density. We are building a laboratory demonstrator of a room temperature Schottky diode based receiver for the 2.06 THz OI line, similar to our previous 1.2 THz receiver [2]. The receiver (Fig. 1a) consists of a mixer pumped by a local oscillator (LO) source whose fundamental source is a fixed-frequency DRO at 38 GHz. Its output is split and amplified in two separate amplifiers, each giving over a watt of power to pump four 114 GHz triplers through two waveguide power dividers. These in turn pump four 343 GHz triplers whose output is combined into a single 40 mW signal to pump the final 1.03 THz tripler. This provides the LO signal for the subharmonically-pumped 2.06 THz mixer.

At the time of this writing part of the LO system has been assembled (Fig. 1b), and we are awaiting housings for the final 1.03 THz tripler and the mixer.

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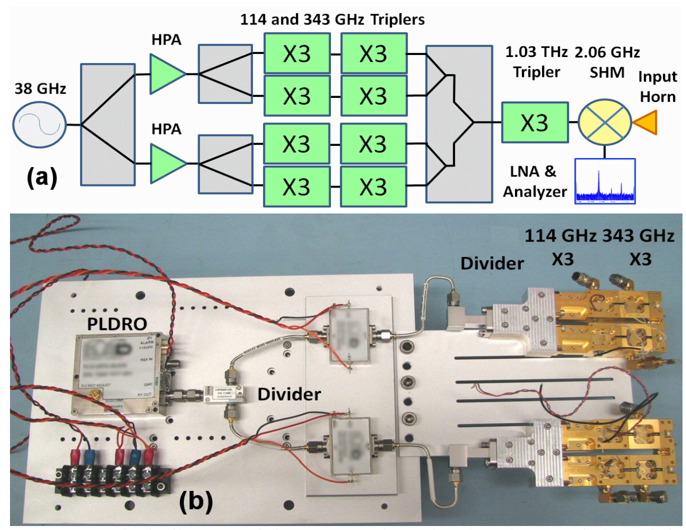

Fig. 1. (a) Block diagram of the TLS receiver showing the LO chain at left, mixer and analyzer at right. (b) LO chain in the lab: the fundamental PLDRO is at left, amplifiers at center and multipliers (excluding 343 GHz combiner, 1.03 THz tripler) at right.

II. 2.06 THz Mixer Design

The mixer (Fig 1c) was originally designed for the 1.8 to 2.0 THz band [3]. The design was modified to extend the frequency coverage to 2.06 THz and to minimize noise and conversion loss over a 20 GHz band centered on 2.06 THz, since the mixer is required to cover only the single OI line, and the system requires the best performance achievable.

The design procedure is the same as that used for the 1.2 THz subharmonically pumped mixers described in [2]. Since the original design operated at a lower frequency, the waveguide matching networks needed to be reduced in size and specifically designed to prevent spurious resonances and over-moding that would degrade performance.

The mixer diodes are fabricated monolithically on a 2-µm thick GaAs substrate, to minimize waveguide loading. The anodes are as small as can be fabricated to minimize capacitance and maximize diode conductance adjustability, but at the cost of high embedding impedances. The high IF impedance is matched using an external matching circuit.

III. 1.03 THz Tripler Design

The 1.03 THz frequency tripler stage of the multiplier chain is a similar to the two-anode 650 tripler described in [2], but utilizes four anodes for additional power handling. For future designs needing even more output power a *dual* version has

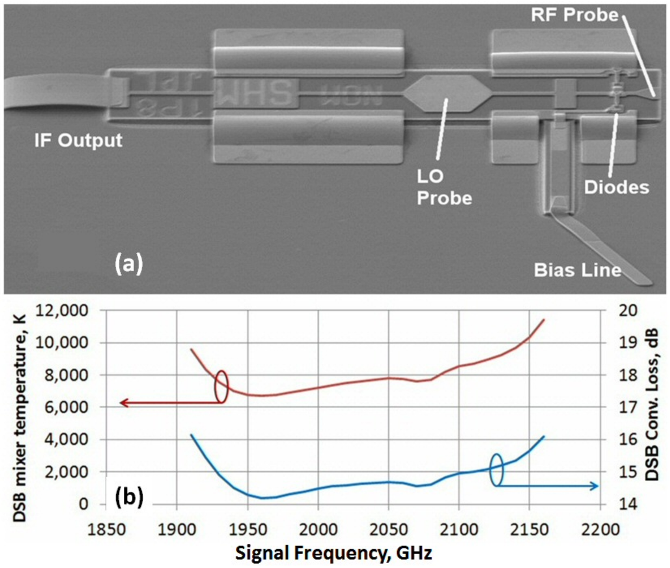

Fig. 2. (a) SEM of 1.8 THz mixer chip to be used at 2.06 THz. (b) Predicted performance of mixer, <8000 K DSB and 15 dB Loss at 2.06 THz.

also been designed, based on the concept for the high-power 105 to 120 GHz tripler [4] (Fig. 2a) used here for the first-stage 114 GHz triplers shown in Fig. 1a. The input signal is power divided to the two triplers in the input guide, and the outputs are combined in a separate Y-guide combiner (not shown). Fig. 2b shows the SEM of the dual version, with the single version very similar to the left half of the dual device.

The diode devices are supported by a very thin 5-µm thick GaAs membrane to reduce the dielectric loading of the chip **Error! Reference source not found.**. The anode size and waveguide matching elements were redesigned for the 950 □ 1100 GHz band. The two pairs of Schottky diodes are connected in series at DC and form a virtual loop trapping the second harmonic and maximizing energy transfer to the third harmonic output signal.

IV. System Considerations

This system has proven a challenge to assemble for several reasons. Since the eventual goal is an instrument that can be deployed on a CubeSat or similar miniature platform, minimum power consumption is a primary requirement. Experience indicates that the higher the frequency of the amplification before the Schottky multiplier chain, the more efficient the LO chain as a whole [5]. Past systems built by the JPL team [6] utilized high-power amplifiers at around 90 GHz, and the ideal would be to have gain at the 343 GHz stage, or even 1030 GHz, technology allowing. This would enable DC plug power consumption below 10 W, versus the approximately 20 W for a W-band amplifier based LO chain.

Amplifiers at 114 GHz would need output power of around 0.5 W, 343 GHz would require around 30 mW, and 1030 GHz would require 1 to 3 mW to generate enough power to pump the mixer. Since these are not available to this effort at this time, our amplification is at 38 GHz. Unfortunately, this requires power combining four separate multiplier chains, at 343 GHz to yield the 30 to 40 mW required to pump the 1030 GHz final tripler stage. The total power consumption is 43 W.

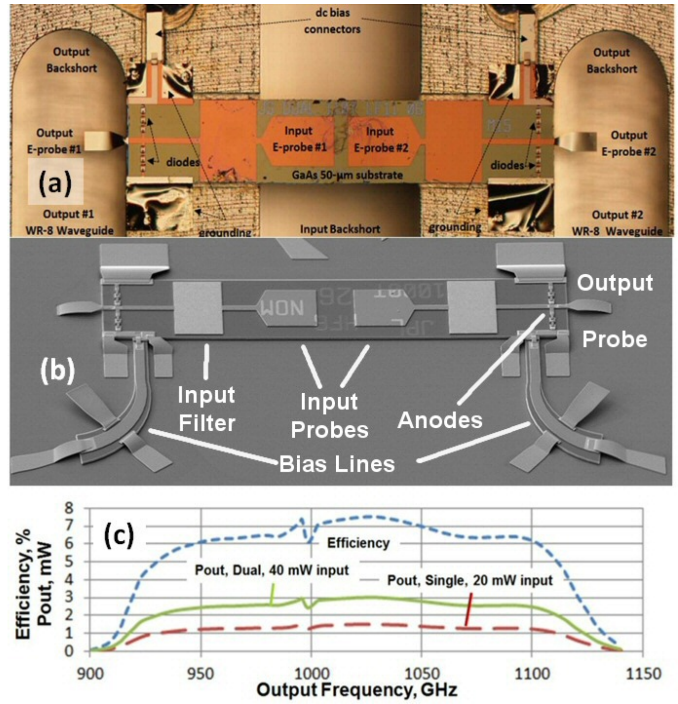

Fig. 3. (a) 114 GHz 1st stage dual tripler [4] (b) SEM of 1.03 THz dual tripler. (c) Predicted efficiency and output power of single tripler with 20 mW input power and dual tripler with 40 mW input power.

In order to minimize the loss of LO power between the output of the 1.03 THz tripler and the mixer, the tripler and mixer will be incorporated into a single block to reduce the length of waveguide and prevent misalignment of the waveguide that may result from use of separate blocks.

V. Summary

The predicted output power of the LO chain is between 1 and 3 mW at 2.03 THz, depending strongly on the power available from the combined 343 GHz pump chains. Harmonic balance and mixer temperature simulations indicate the mixer effective DSB temperature should be about 8,000 K. When built, this will be the highest frequency all solid-state heterodyne receiver of which the authors are aware.

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