Sub-Terahertz Heterodyne Spectroscopy of Carbonyl Sulfide

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***Abstract*— We showed the preliminary results of traditional frequency modulated heterodyne spectroscopy and the phase modulated heterodyne spectroscopy in the J=21 to 22, 22 to 23 and 23 to 24 transitions (267.5GHz to 291.8GHz) of $^{16}O^{12}C^{32}S$ in the ground vibrational state.**

Keywords—molecular clock, heterodyne spectroscopy, phase modulation, frequency modulation, carbonyl sulfide, radio occultation, CubeSats constellation, deep space

I. Introduction

One-way radio occultation enables a simple space mission architecture using a constellation of CubeSats to study Martian and alike planetary atmosphere with high spatial and temporal resolution [1][2][3] The on-board oscillator's noise and drift from 0.1s to 100s greatly impact the radio occultation signal to noise ratio. Ultra-stable oscillators, while fulfilling the required performance for such missions, have a volume of 2-3 Liter, which is too big for a CubeSat. A few common molecules, such as carbonyl sulfide, water, ammonia and hydrogen cyanide, have strong absorption lines in 200-1000GHz range [4] and can calibrate much smaller oscillators with fast free-running frequency drift. Schottky diode-based terahertz electronics can provide sufficient power for the molecular spectroscopy [5] with Watt-level DC power consumption. CMOS-based electronics has shown promising performance in the sub-terahertz range for chip-scale molecular clock [6][7] with less than 0.1Watt power consumption. Both these two electronic platforms and the simplicity of molecular spectroscopy configuration can benefit future deep space CubeSats missions with different performance, power, size and weight requirements on the on-board oscillators.

The simplicity of the clock architecture comes with a price to the achievable signal to noise, especially the electronic noise in the local oscillator, terahertz multiplier/synthesis chain and receiver, which has been witnessed in the early era of atomic/molecular clock development [8]. Phase-modulation heterodyne spectroscopy both in the microwave [9] and optical [10][11] frequency ranges is a promising tool to improve noise performance.

II. Methods/Results

We carried out the sub-THz phase-modulation heterodyne spectroscopy of carbonyl sulfide and compared it with traditional heterodyne spectroscopy. We found that with the current experimental setup (in Fig.1), we are able to acquire high signal-to-noise signals using both the two methods for the J=21 to 22, 22 to 23 and 23 to 24 transitions (in Fig.2,3,4).

Fig. 1. Experiment diagrams for a). Phase modulation heterodyne spectroscopy, and b) Traditional frequency modulation spectroscopy.

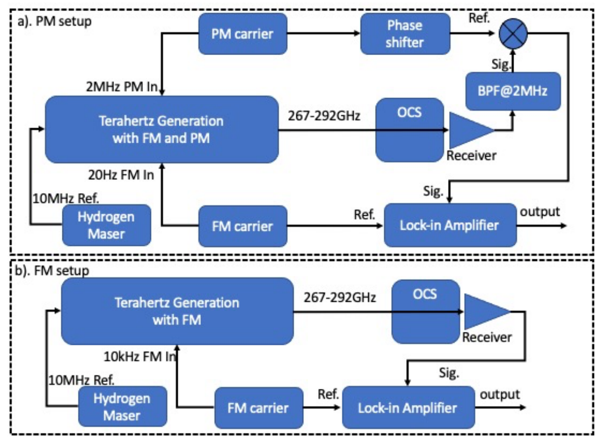
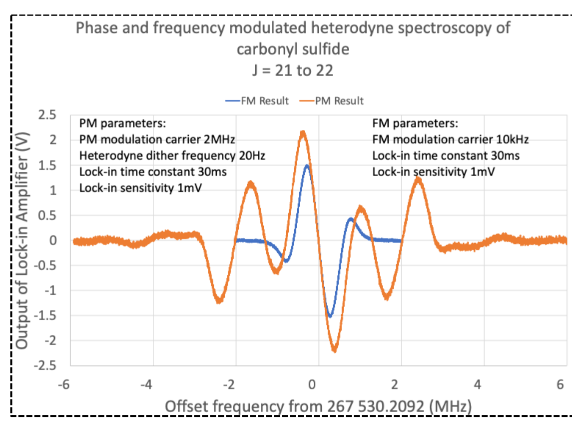


Fig. 2. Carbonyl sulfide J = 21 to 22 ground vibrational state transition with phase modulation and frequency modulation heterodyne methods.



The pressure indicated on the vacuum gauge is at about 0.0128Torr. The actual partial pressure of OCS is smaller than the indicated reading due to non-perfect purging process:

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during the gas filling, unknown level of ambient atmosphere may pre-exist in the gas filling apparatus.

The PM configuration also includes a 20Hz FM with the frequency synthesis scheme. The modulation parameters are not optimized towards the best signal to noise ratios but are reasonably good. Both the modulation and demodulation parameters are kept the same to compare the three different transitions. The sub-THz transmitter has a milli-Watt level power to propagate into a quartz vapor-cell containing the OCS.

Fig. 3. Carbonyl sulfide J = 22 to 23 ground vibrational state transition with phase modulation and frequency modulation heterodyne methods.

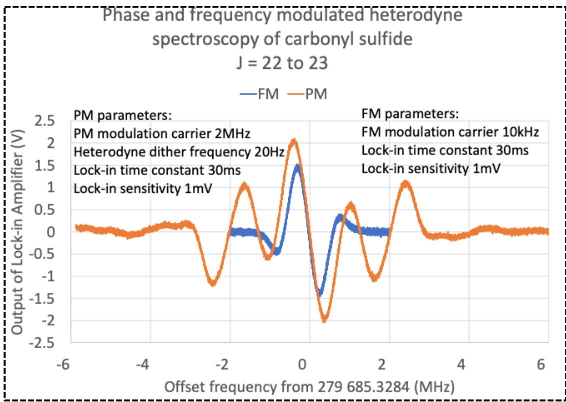
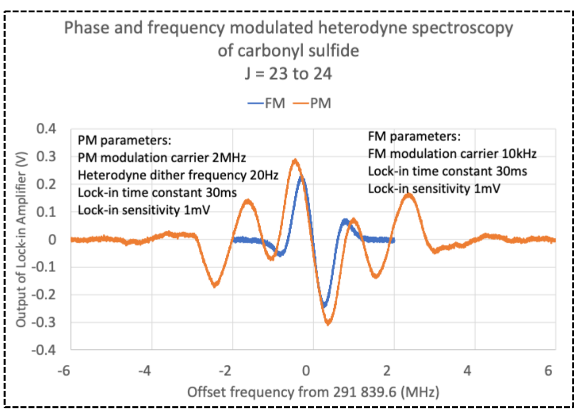


Fig. 4. Carbonyl sulfide J = 23 to 24 ground vibrational state transition with phase modulation and frequency modulation heterodyne methods.



III. DISCUSSION/INTERPRETATION

The results showed that both the frequency modulated heterodyne spectroscopy (FM) and the phase modulated (PM) heterodyne spectroscopy achieved high signal-to-noise ratios (SNR) in the sub-terahertz transitions of carbonyl sulfide. For the SNR difference between the PM and the FM, it could be caused by non-optimized experimental parameters. The SNR for all the three transitions is between 100-300. We also observed higher SNR using a different synthesis scheme that allows higher modulation frequency than 20Hz and the results shall be published elsewhere.

IV. CONCLUSIONS

In summary, we have presented the preliminary results of traditional frequency modulated heterodyne spectroscopy and the phase modulated heterodyne spectroscopy of carbonyl sulfide at sub-terahertz. The high SNR is promising towards applications in deep space inter-satellite radio occultation missions.

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