National Aeronautics and Space Administration

Dual-Tone Local Oscillator (LO) Investigation on Quantum Limited SIS Receivers for the Simultaneous Observation of Isotopic D:H in Solar System Water

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Program: Spontaneous Concept

Project Objective:

NASA's Planetary Decadal Survey has concluded that isotopic measurements of cometary water vapor are a means to unraveling the mysteries involving the origin of Earth's water and the evolution of our solar system. By taking advantage of the HDO (509.3 GHz) ground state and (similar in line strength) $H_2^{18}O$ (547.7 GHz) and $H_2^{17}O$ (552.0 GHz) isotopologues, a potentially very important factor two in observation time can be gained when both lines are observed simultaneously!

We propose to pump the SIS mixer with two LO tones, thereby generating four non-overlapping sidebands. The comet lines are, due to the low pressure, very narrow in bandwidth and will not overlap (no line convolution). Aside from the scientific benefit in reduced integration time, simultaneous observations of HDO and isotopic H_2O lines include common spatial pointing (same beam) reducing systematics thus enhancing the quality of the D:H measurement.

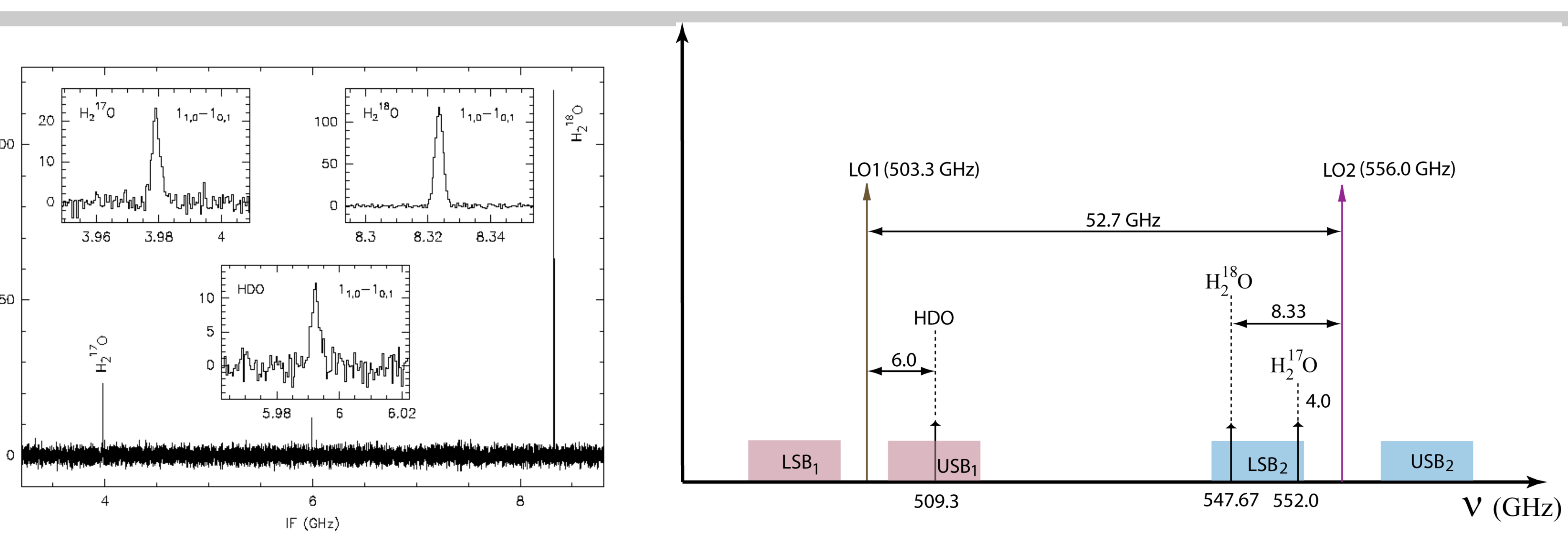

Fig. 1. *Left) Comet 103P/Hartley 2 synthesized 'Dual-tone LO' 1_{10} - 1_{01} ground state folded spectrum of HDO (509.292 GHz), $H_2^{18}O$ (547.676~GHz), and , $H_2^{17}O$ (552.021~GHz) isotopologues. Right) 503.3 GHz and 556.0 GHz LO frequency setup. The individual spectra were obtained with the Heterodyne Instrument for the Far Infrared (HIFI) High Resolution Spectrometer (HRS) in 2010 [1].*

The Method:

The dual-tone concept is investigated with existing hardware from a previous funded strategic RTD. For this task two Gunn Oscillator based 540-615 GHz LO sources are available. Since the developed SIS mixers have near quantum limited sensitivity sensitive, we inject an harmonic tone separated by the HDO and water isotopologues frequencies into the receiver front-end (Δν = 40.7 GHz), thereby simulating the HDO and isotopic H_2O spectral lines. Recording tone signal strength measurements as a function of LO1, LO2, and LO1+LO2 pumping, in addition to standard Hot/Cold continuum calibration establishes the approach and provides a measure of the attainable sensitivity and observing efficiency.

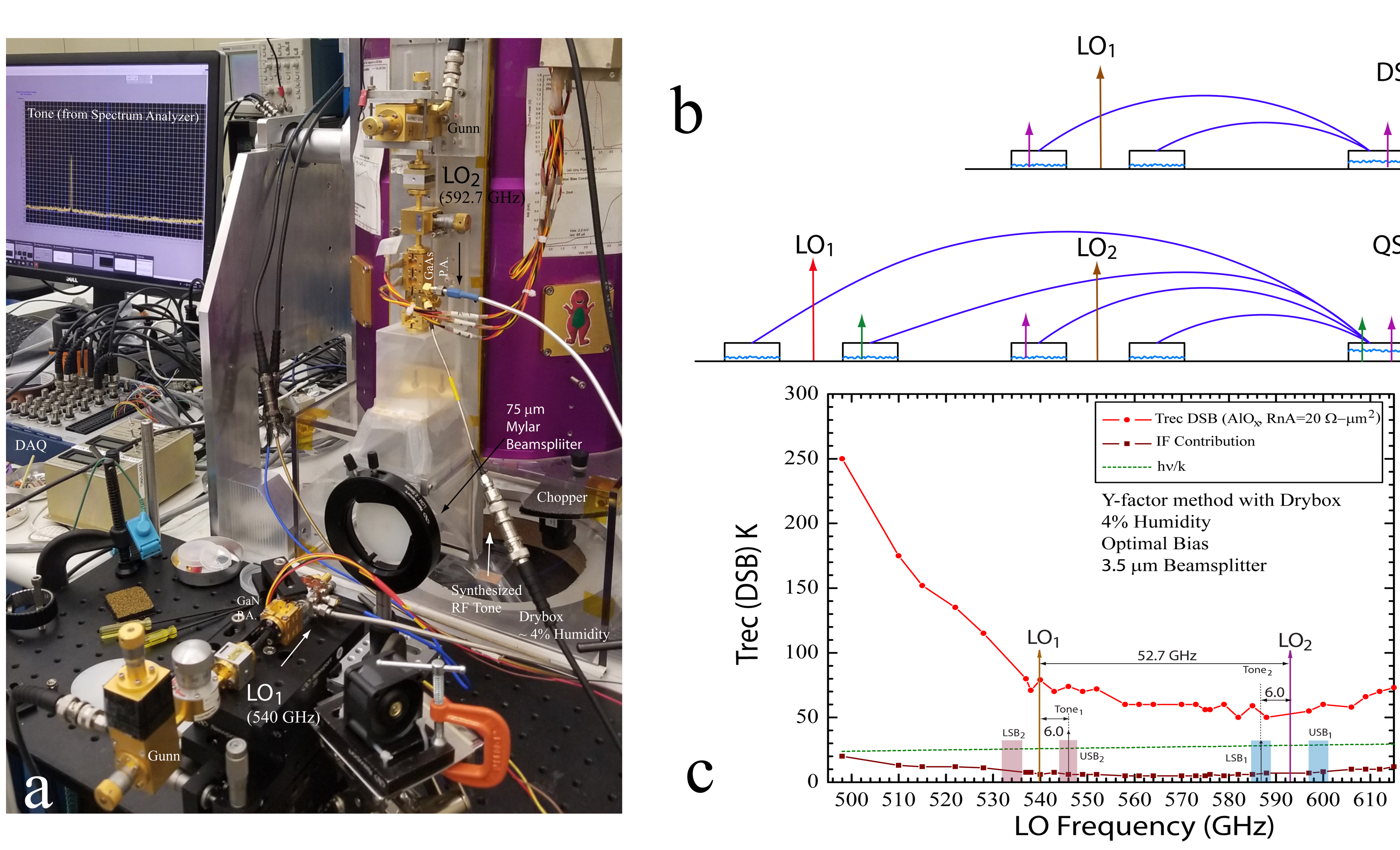

Fig. 2a) Two tone local oscillator (LO) frequency setup. b, c) To minimized mixer intermodulation the two-tone LO frequency separation has been maximized. This causes HDO to fall in the 'lower LO frequency' USB with and $H_2^{17}O$ and $H_2^{18}O$ isotopologues in the 'higher frequency' lower sideband. The required IF bandwidth is 4.5~GHz, which is readily available these days. The two LO's also provide redundancy, can function in a pair, or individually to for example observe the optically thick and $H_2^{16}O$ Ortho ground state line.

References:

[1] P. Hartogh *et al*. ``Ocean-like water in the Jupiter-family comet 103P/Hartley 2", Nature, 21 8 , Vol 478, 13 Oct, 2011.

Benefits to NASA and JPL:

The concept of simultaneous HDO and $H_2^{17}O$ and $H_2^{18}O$ the Water Isotopologues is potentially game-changing in that not only an important factor two in integration time is saved, but importantly will also facilitate high fidelity self-calibrating HDO/H2O ratio measurements on an active outgassing comets near Perihelion.

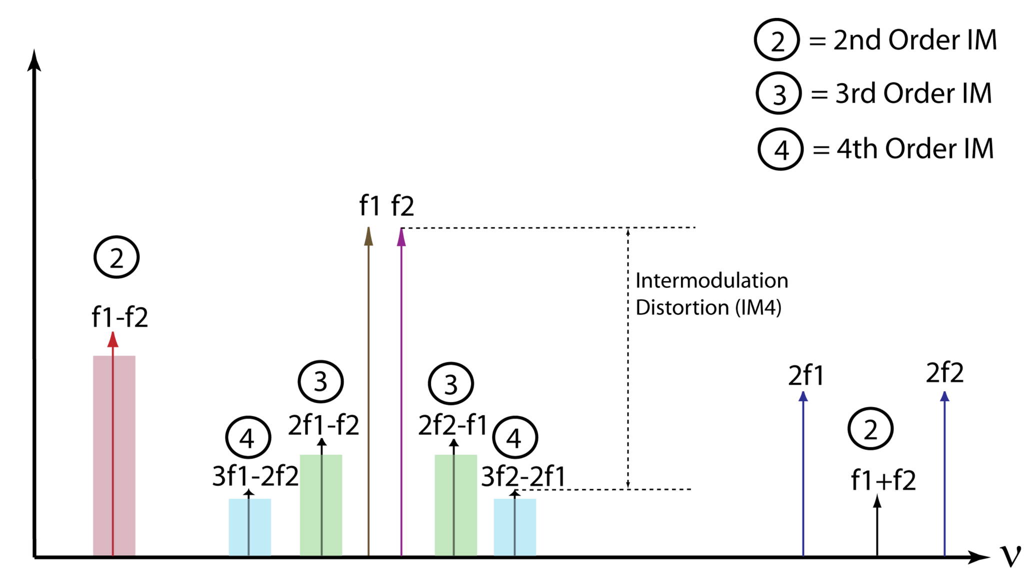

Fig. 3) *Mixer Intermodulation products. For the concept to work the intermodulation products have to be outside the mixer band. In the case of a SIS mixer, this can be accomplished by adjusting the junctions current density (R_nA product) as depicted in the Table to the right.*

2^{nd} ORDER INTERMODULATION (MIXING) PRODUCT

flo1	flo2	|flo1-flo2|	|flo1+flo2|
503.3†	556	52.7	1059.3
503.3††	556	52.7	1059.3

Red is in band, Black is out of band.
† $R_nA = 5.6\ \Omega \cdot \mu m^2$.
†† $R_nA = 20.0\ \Omega \cdot \mu m^2$.
Units in GHz.

TABLE II
3^{rd} ORDER INTERMODULATION PRODUCT

flo1	flo2	2flo1-flo2	2flo2-flo1	2|flo1-flo2|	3|flo1-flo2|
503.3†	556	450.6	608.7	105.4	158.1
503.3†	556	450.6	608.7	105.4	158.1

Blue is marginally in band, Red is in band, Black is out of band.
† $R_nA = 5.6\ \Omega\mu m^2$.
†† $R_nA = 20.0\ \Omega\mu m^2$.
Units in GHz.

TABLE III
4^{th} ORDER INTERMODULATION PRODUCT

flo1	flo2	3flo1-2flo2	3flo2-2flo1	2|flo1-flo2|	3|flo1-flo2|	4|flo1-flo2|
503.3†	556	397.9	661.4	105.4	158.1	210.8
503.3††	556	397.9	661.4	105.4	158.1	210.8

Blue is marginally in band, Red is in band, Black is out of band.
† $R_nA = 5.6\ \Omega\mu m^2$.
†† $R_nA = 20.0\ \Omega\mu m^2$.
Units in GHz.

FY18/19 Result:

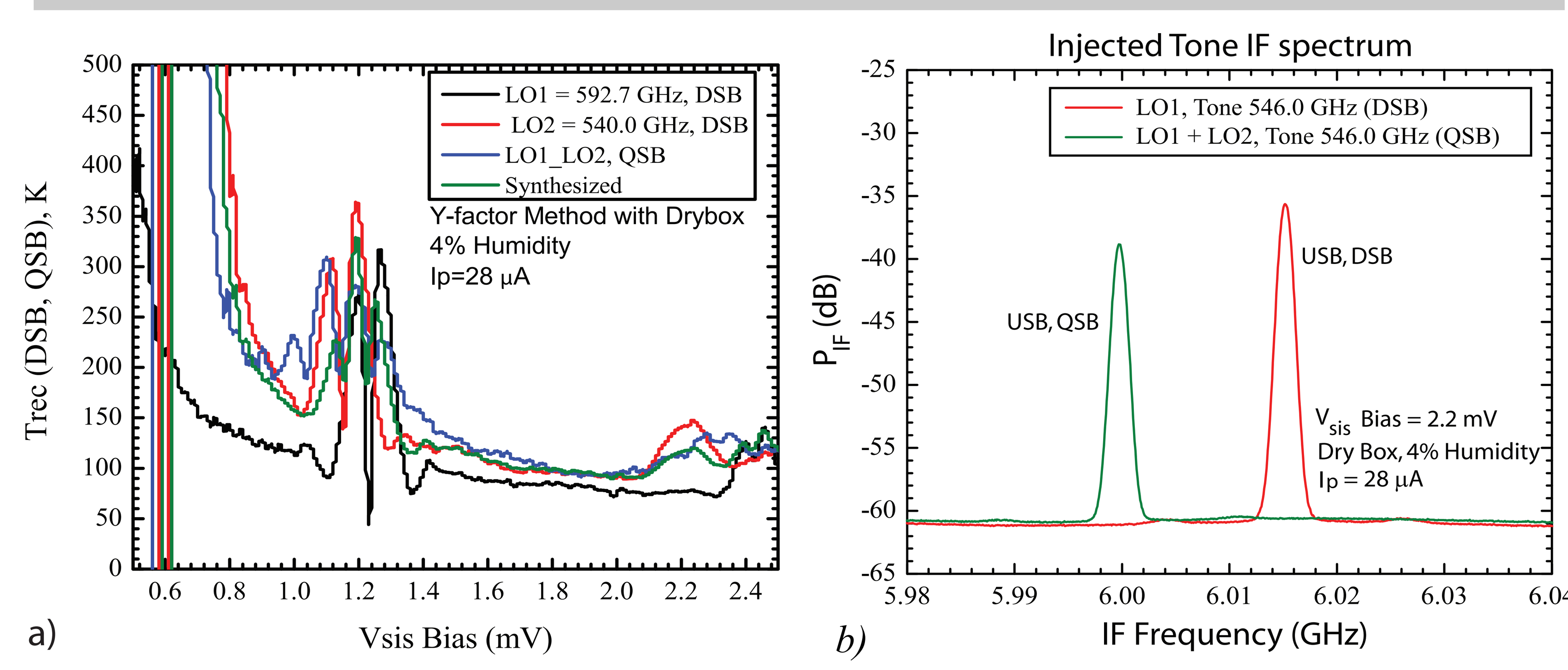

Fig. *4a) Continuum heterodyne response for LO_1, LO_2, LO_1+ LO_2, and synthesized (green) response. b) At a given bias (1.9 mV), the SIS mixer down-converted tonal heterodyne response for both DSB (1 LO) and QSB (2 LO's). The amplitude difference is 3 dB (2 vs 4 sidebands), however when referenced to SSB, as is ordinarily done since the tone is in just one sideband, the IF response is equal.*

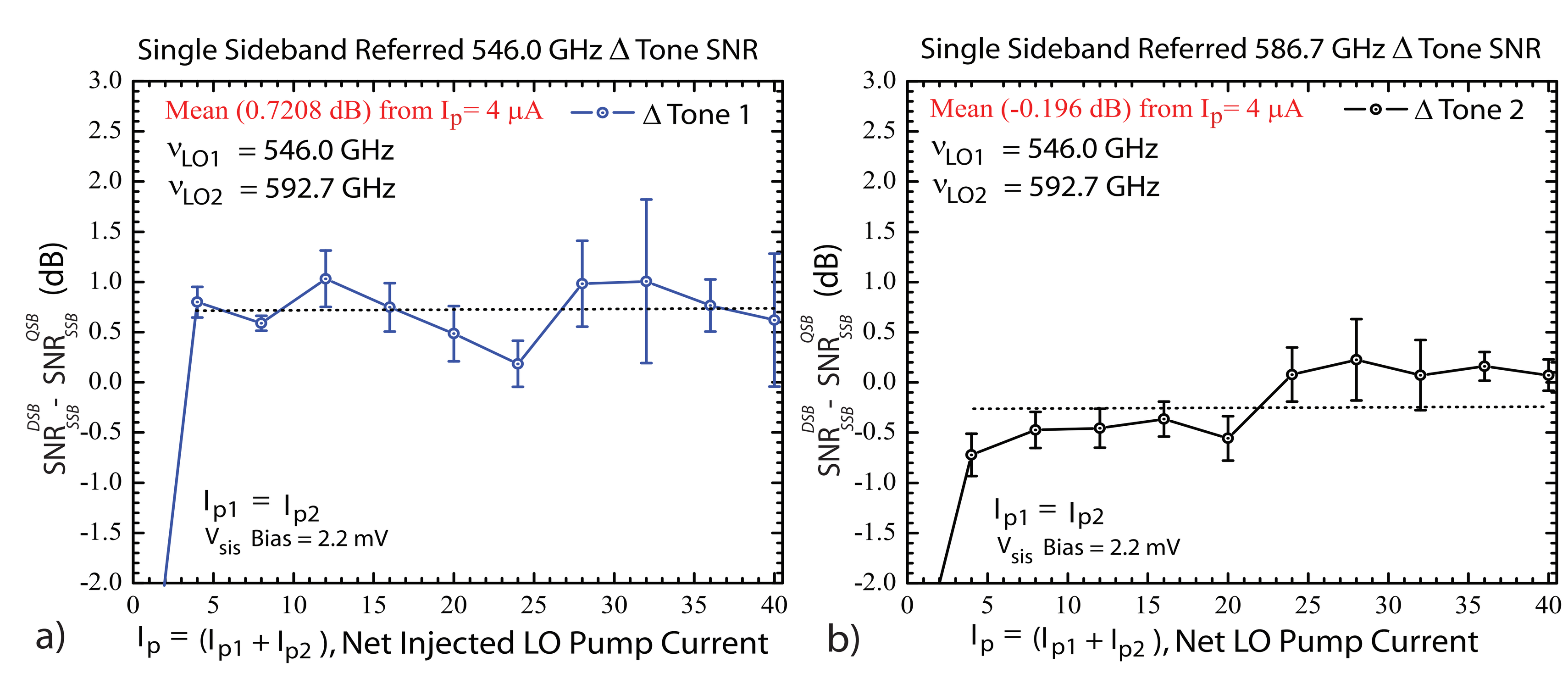

Fig. 5a.) *Change in signal-to-noise (SNR) by going from double-sideband to quad-sideband (SNR_{SSB}^{DSB} - SNR_{SSB}^{QSB}) for the USB_{LO1} 546.0 GHz tone and b) the LSB_{LO2} residing 586.7 GHz tone. The SIS bias was fixed at 2.2 mV with no other bias settings explored. The small difference between QSB and DSB SNR is attributed to the two- or four sideband not having exactly the same mixer conversion gain. The result shows that a QSB mixer can receive multiple widely separated spectral lines w/o loss of efficiency as long as intermodulating mixing products are avoided.*

Publications:

''Dual-tone Local Oscillator SIS Receiver for Efficient Observations of Isotopic D:H Ratio of Water Formation Processes in the Solar System'', J. W. Kooi, D. J. Hayton, P. Goldsmith, D. C. Lis, J. Kawamura, B. Bumble, G. Chattopadhyay, and I. Mehdi. IEEE. Trans Terahertz Science and Tech, in prep.

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