National Aeronautics and Space Administration

Generation of spectrally pure G-band signal via optical rectification

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Objectives:

- Prove that a millimeter wave signal with the single sideband phase noise better than -120 dBc/Hz at 10 kHz offset can be generated via photonic means.
- Find the limitations of the long term stability of the millimeter wave signal generated by the photonic means.
- Identify limitations of the technique and specify improvements necessary to achieve the desirable performance.

Background:

Photonic production of millimeter (mm) wave signals with good spectral purity is fundamentally feasible [1]. The concept was verified multiple times for the microwave signal generation in C-Ka band frequency ranges. Experimental implementation of the generation of mm wave signals, though, faces technical obstacles. The main goal of the proposed effort was to show that the low noise mm wave signals can be generated in the lab setting using high-end equipment available at JPL. The demonstration was intended to pave the way towards further development of the space qualified technology and to allow us to identify JPL scientists who would benefit from the technology development.

High resolution cloud radars call for high spectral purity W- and G-band signals. The ultimate figure of merit is the single sideband phase noise that is better than -120 dBc/Hz at 10 kHz frequency offset. Existing commercial compact W-band dielectric resonator oscillators are capable of delivering signals with frequency noise of -110 dBc/Hz at 10 kHz but are bulky. The advanced laboratory lower frequency oscillators (10L volume and 100W power consumption, e.g. hQPhotonics) can be used to produce the high spectral purity signals that can be multiplied, but they are not suitable for space applications. Same is true for the oscillators involving optical frequency combs. The photonic structure studied in this work can generate a highly spectrally pure reference frequency (and therefore reduced ground clutter contamination over the desired cloud echoes when paired with a highly linear and low phase noise amplifier) while having small size and low power consumption. We expect this technology to become a game changer for Earth observing radars on resource constrained platforms (e.g. SmallSats and CubeSats).

Approach and Results:

We demonstrated generation of spectrally pure millimeter wave signals using optical rectification and validated the concept. We have locked two RIO lasers to two modes of an SLS Fabry-Perot cavity available at the Frequency Standard Test laboratory and generated 6.2 GHz and 18.8 GHz signals. The signals were tested using metrological equipment stabilized to a Hydrogen maser. The scheme of the experimental setup is shown in Fig. 1.

The phase noise and Allan deviation of the photonically generated signals are shown in Figs. 2, 3 and Fig. 4, respectively. The phase noise measured at 10 kHz frequency offset barely changes with the carrier frequency and is limited by -105 dBc/Hz. This number is 15 dB worse than the prediction based on a shot noise limited laser. The reason for the limitation is the relative intensity noise of the lasers, that limits the signal-to-noise ratio of the locking circuitry. We expect that reasonable improvement of the noise will allow us reaching the target goal in the future studies.

The increase of the phase noise in the vicinity of 100 kHz frequency offset is associated with the phase lock loop noise. This noise is not fundamental. It can be completely removed if self-injection locking is utilized instead of the electronic lock.

We also demonstrated generation of W- signals at 78.5 GHz and G-band signals using the lasers. To generate the signals we utilized a commercial high frequency photomixer (Fraunhofer HHI). The power of the signal reached -10 dBm. W-band phase noise characterization was carried out using a custom frequency discriminator setup developed at JPL. We were unable to measure the phase noise of the G-band signal because of equipment unavailability. However, based on the results of the measurements performed at lower frequencies, we expect that the phase noise does not degrade.

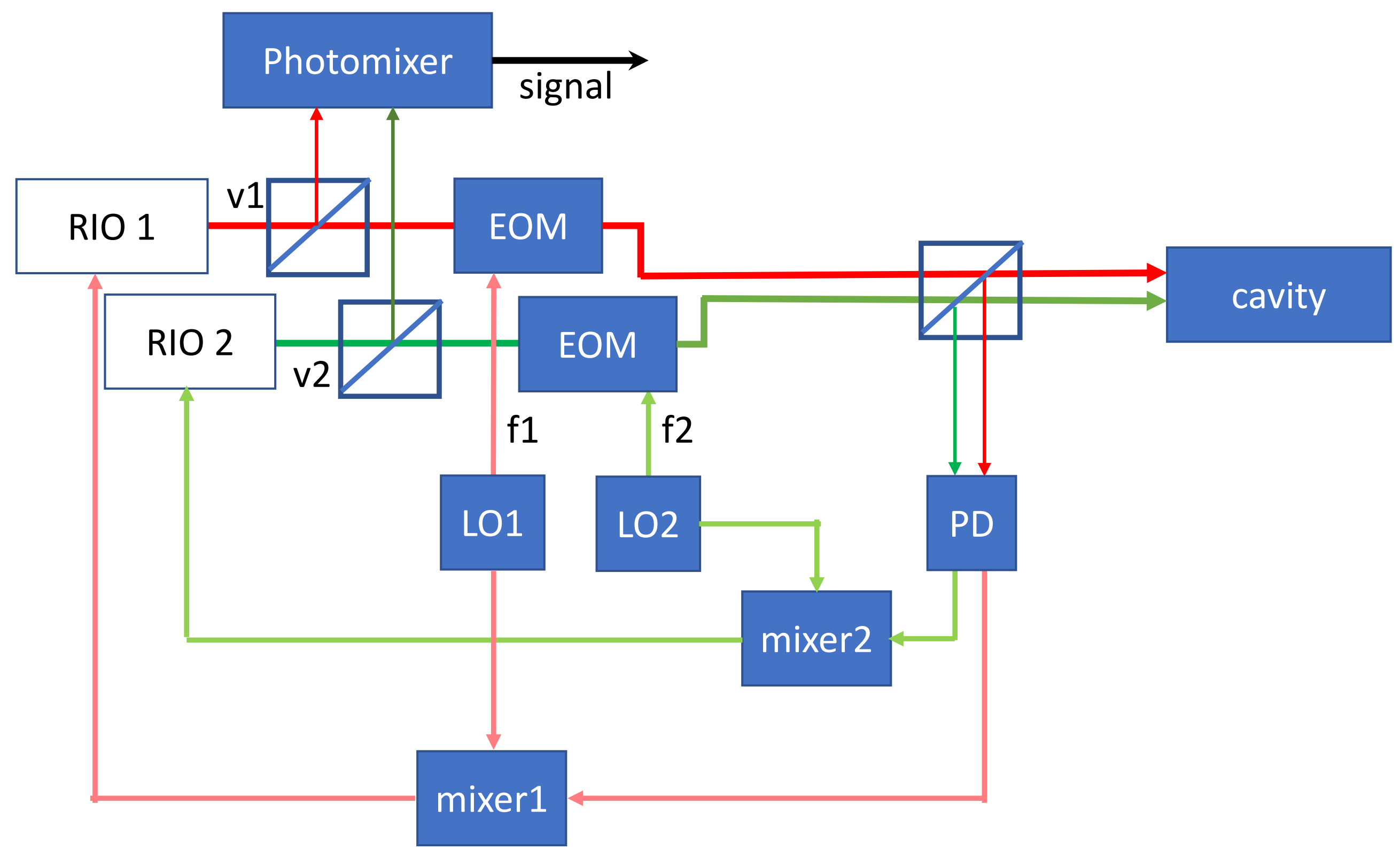

Figure 1: Experimental setup. Two semiconductor lasers are phase locked to different frequency modes of an ultrastable Fabry-Perot optical cavity using Pound-Drever-Hall (PDH) technique. The microwave signal is generated by demodulating the emission of the lasers on a fast photomixer.

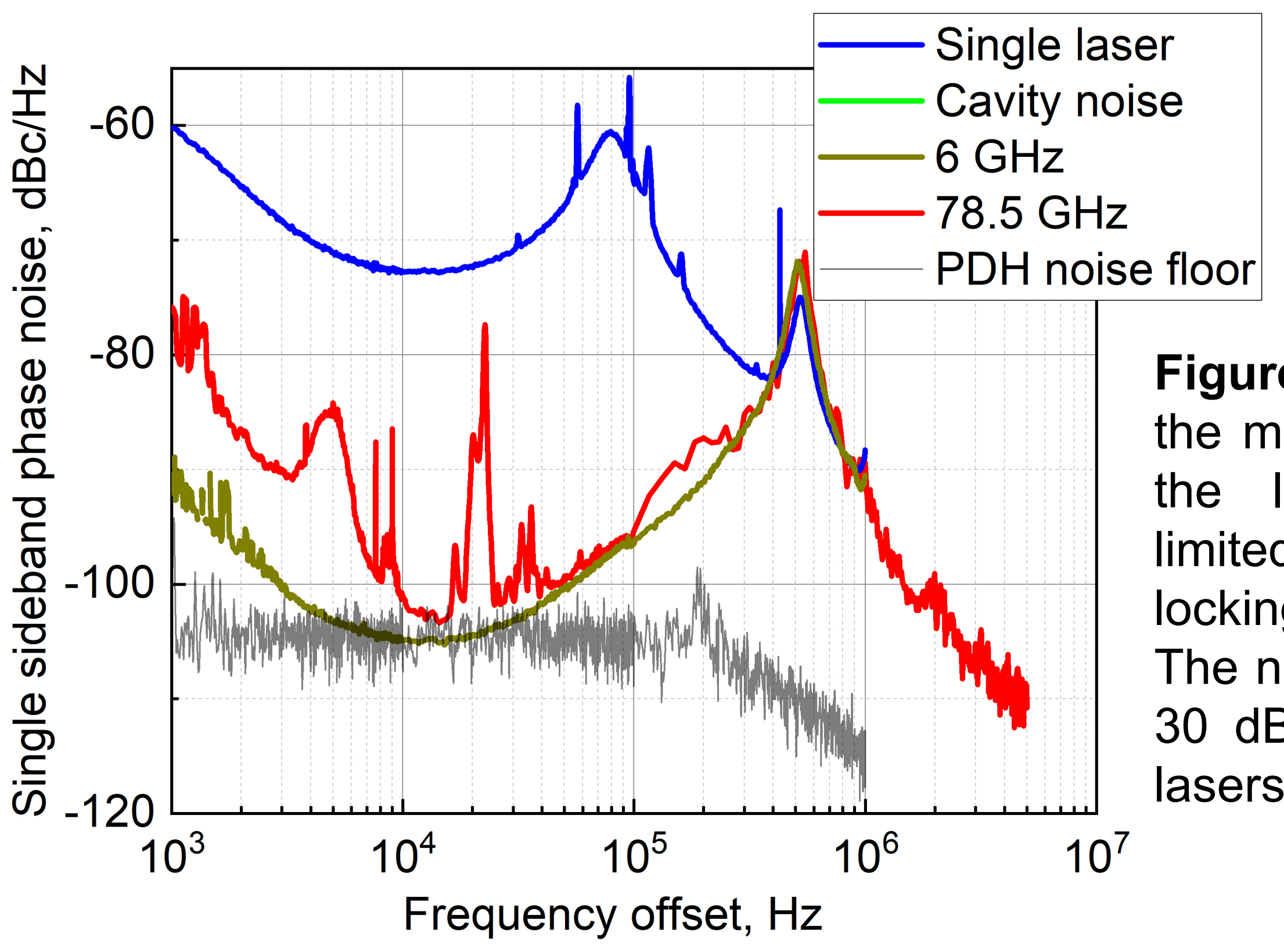

Figure 2: High-offset phase noise of the microwave signals generated by the lasers. The performance is limited by the noise floor of the locking circuit and can be improved. The noise of the microwave signal is 30 dB better than the noise of the lasers measured independently.

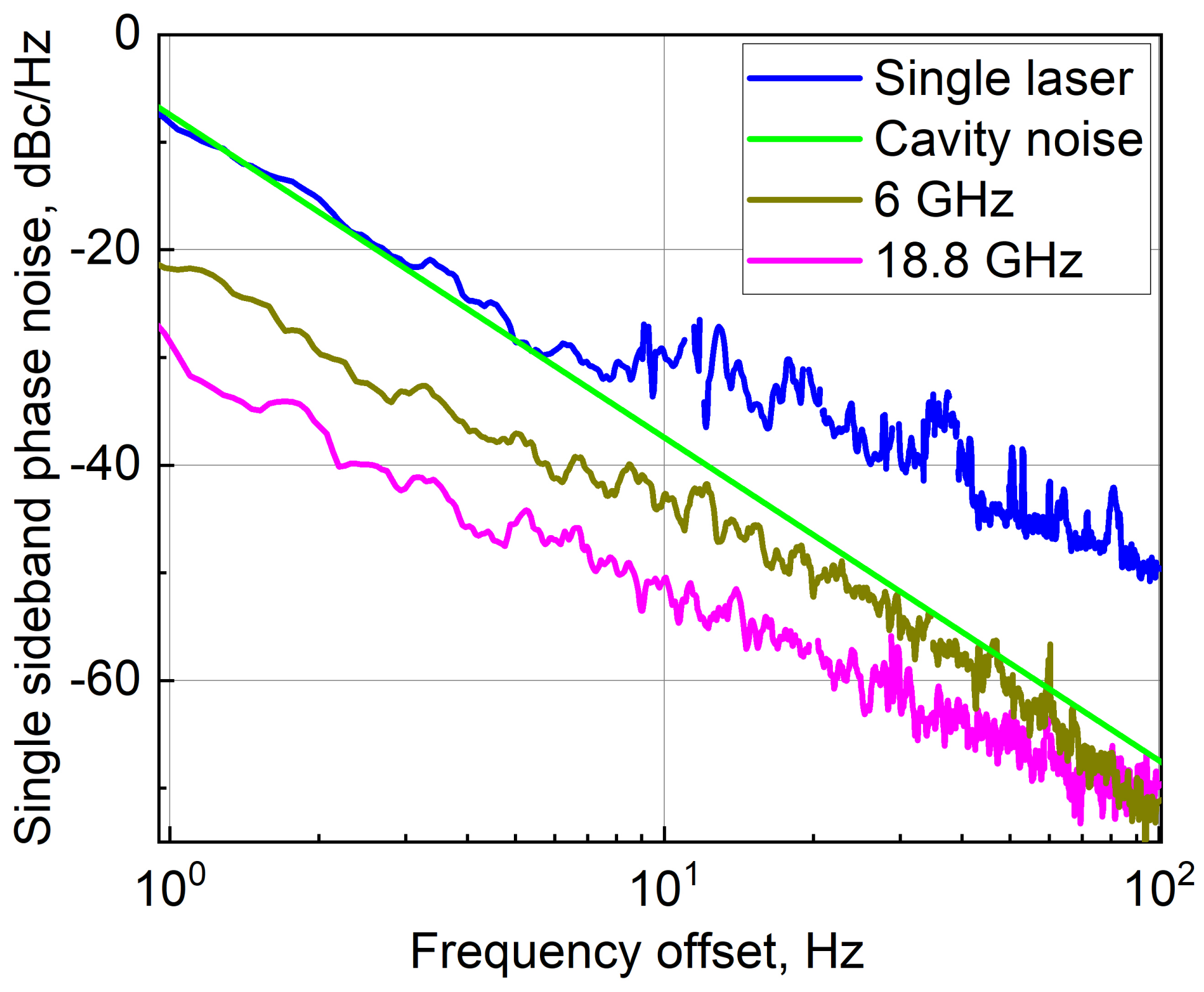

Figure 3: Close-in phase noise of the microwave signals generated by the lasers. The performance is limited by the noise floor of the locking circuit and can be improved. The noise of the microwave signal is more than 10 dB better than the fundamental thermodynamic noise of the optical cavity.

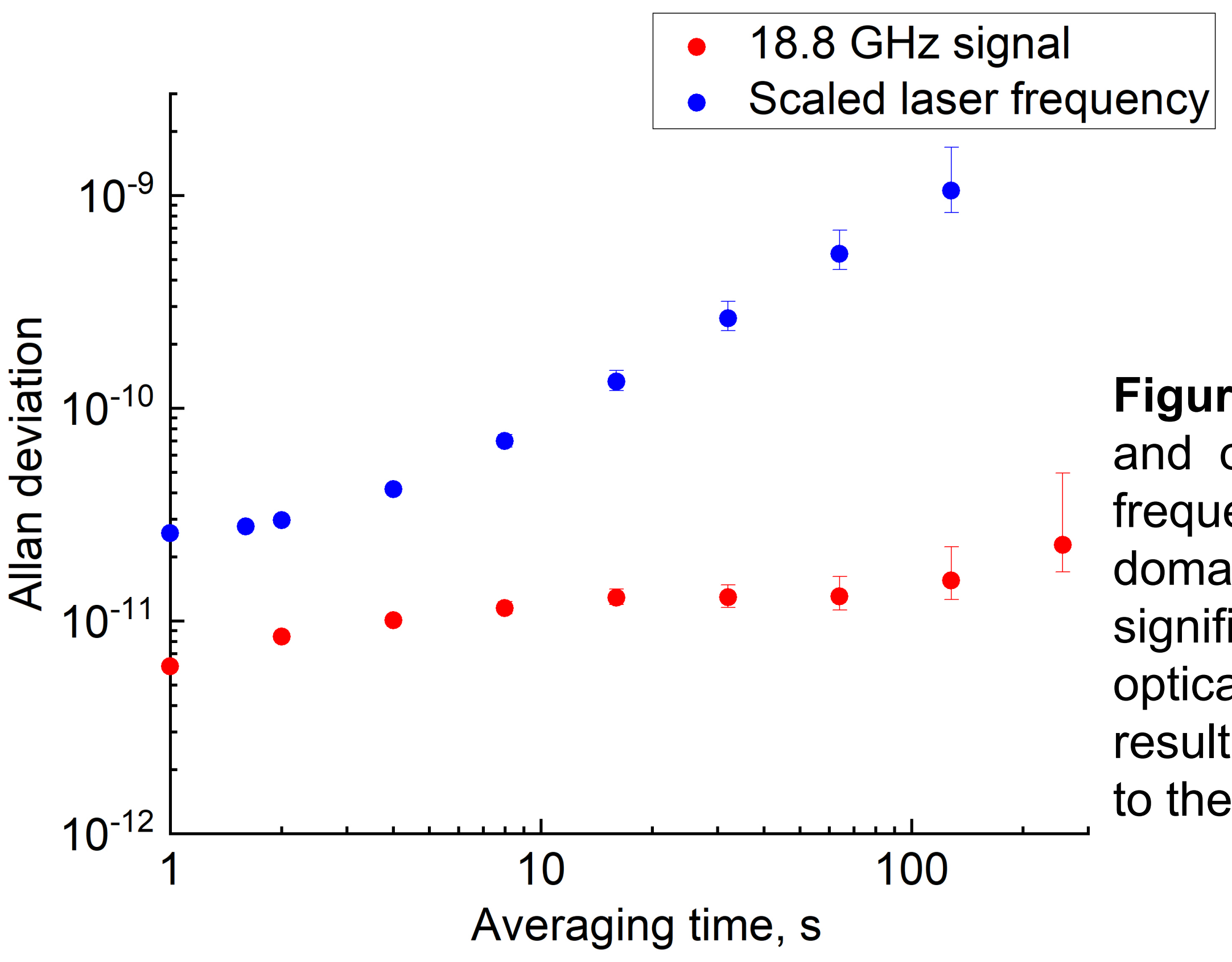

Figure 4: Stability of the microwave and optical frequencies. The optical frequency is scaled to the microwave domain. The microwave signal is significantly more stable than the optical one due to correlation resulting from the locking the lasers to the same optical cavity.

Significance/Benefits to JPL and NASA:

The system will potentially become a convolution of an integrated photonic platform (the lasers and micro-optics) and an ultra-stable cavity system. The development is related to “Miniaturized Systems”, “Instruments and Sensors”, and “Communication and Navigation” sections of the JPL List Strategic Technologies. The oscillators can support flying formations of spacecrafts. The proposed technology has a chance to enable novel instrument designs in advanced planetary seismology, navigation, ranging, and remote sensing. The photonic device could become useful for the high frequency cloud radar development.

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References:

[1] A. Matsko, “Advances in the Development of Spectrally Pure Microwave Photonic Synthesizers,” IEEE Photonics Technology Letters **31** (23), 1882-1885 (2019).

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