National Aeronautics and Space Administration

Technology Development for Orbital Planetary Boundary Layer Humidity Sounding Radar

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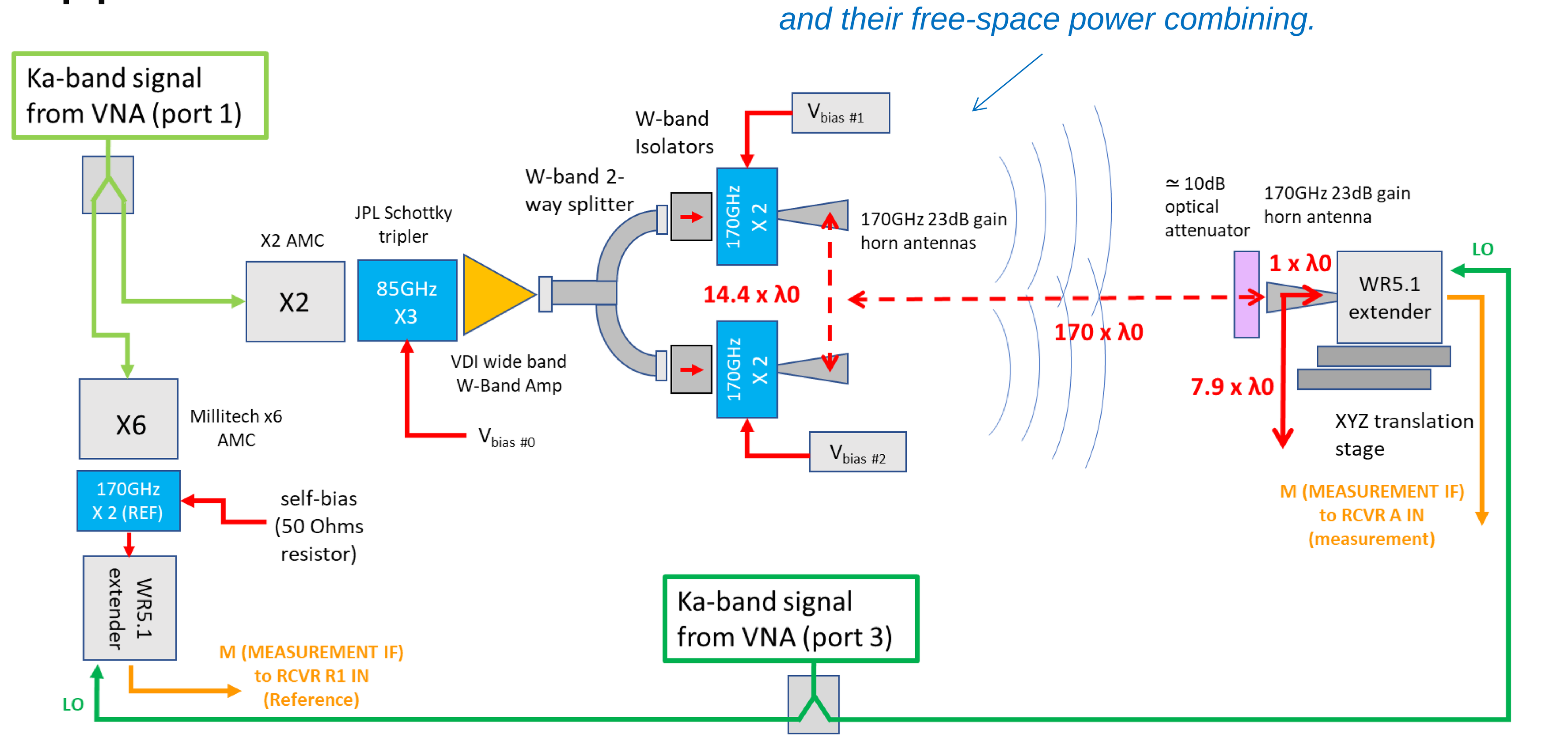
Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Radars 2030**

Background

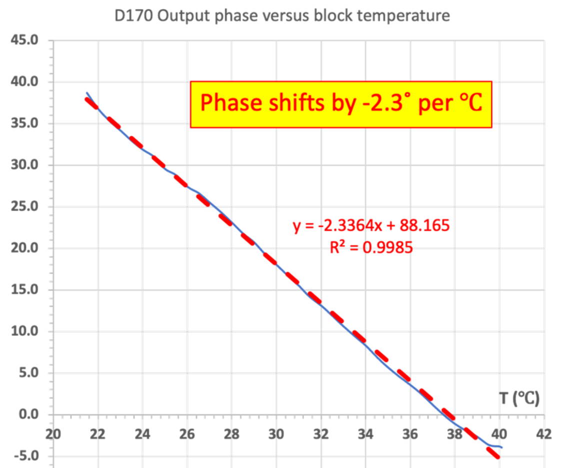
- High resolution water vapor profiles inside of clouds, over both ocean and terrain within the Planetary Boundary Layer (PBL), is identified as a Targeted Observable for Incubation in the 2017 Earth Science Decadal Survey.
- JPL's 155-175 GHz Differential Absorption Radar (DAR) approach offers a novel way of retrieving humidity by measuring cloud scattering brightness varies over frequency near the 183 GHz water absorption resonance.
- To realize a spaceborne DAR system in the 2030s, great improvements in transmit power are required, along with large apertures, in order to measure scattering from clouds at orbital altitudes. Ultra-low phase noise sources above 150 GHz are also highly desirable to maximize the dynamic range of cloud detection above bright ground clutter.

Approach and Results

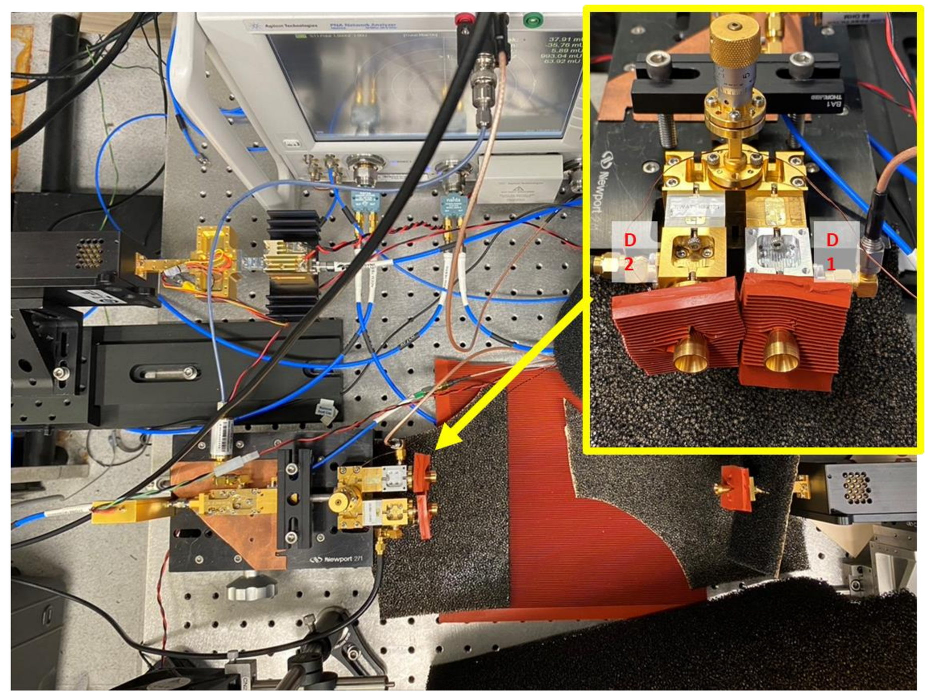
Customized Vector Network Analyzer test-bench to characterize phase-shifting of G-band solid-state sources and their free-space power combining.



Measured phase-shift temperature sensitivity of frequency-doubler and G-band power amplifier together



Photograph of VNA test-bench with two independently phased G-band sources. The phase shift is done in a nearly lossless manner using diode voltage bias adjustment.

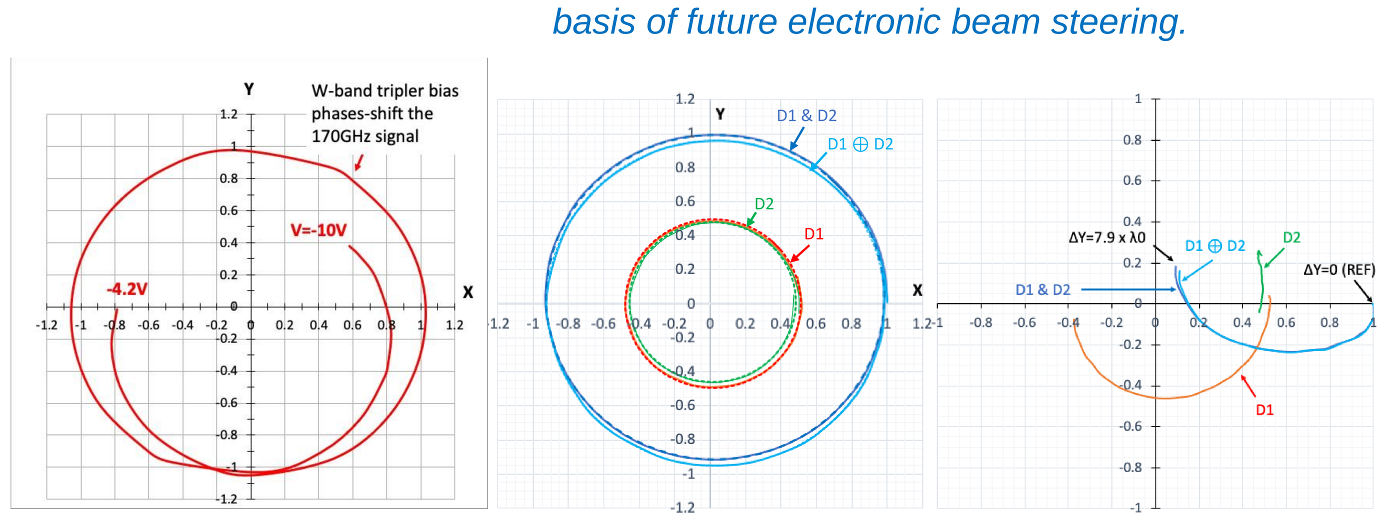


Objectives

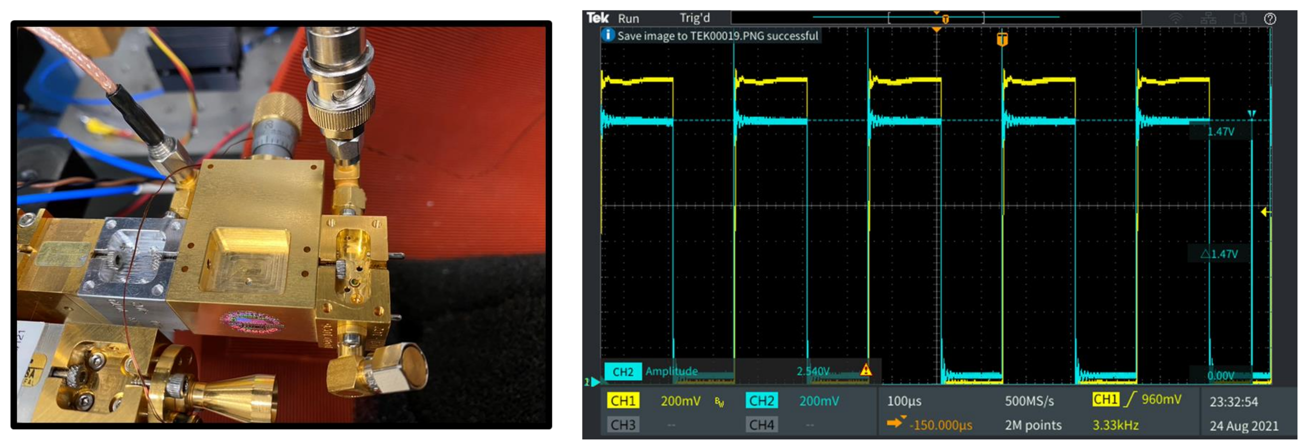
- Phase-shifting and power-combining solid-state G-band sources/receivers
  - *Long-term goals: 100 W transmit power using dozens of independently-phased sources feeding a ~2m array of antennas, 155-175 GHz fast-tuning bandwidth, and ±3° beam steering*
- Use RF photonic source of a compact Brillouin laser to directly generate ultra-low phase noise and tunable sources in the 155-175 GHz band.
  - *Long-term goals: -110 dBc/Hz at 100 kHz offset for 170 GHz carrier, in a compact and stable package*
- Waveguide power-combine newly available commercial InP 170 GHz amplifier MMICS.
- System design for a potential small size/weight/power DAR-demonstrator instrument (11kg, 70W, <5% total-water-column accuracy in very dry atmospheres.

>360 degree phase control of the independent G-band channels demonstrated by adjusting the bias voltages of the frequency multipliers.

Longitudinal (left) / lateral (right) translations of sensor head. The green and red curves are the measured independent signals, while the dark blue curves are their measured vector summation, which is very close to their mathematical addition (light blue curves), demonstrating a fringing effect, the basis of future electronic beam steering.



A JPL-packaged Teledyne-fabricated InP 170 GHz power amplifier was shown to operate efficiently in a pulse mode using drain control at 3 kHz. This is important for a future pulsed radar application.



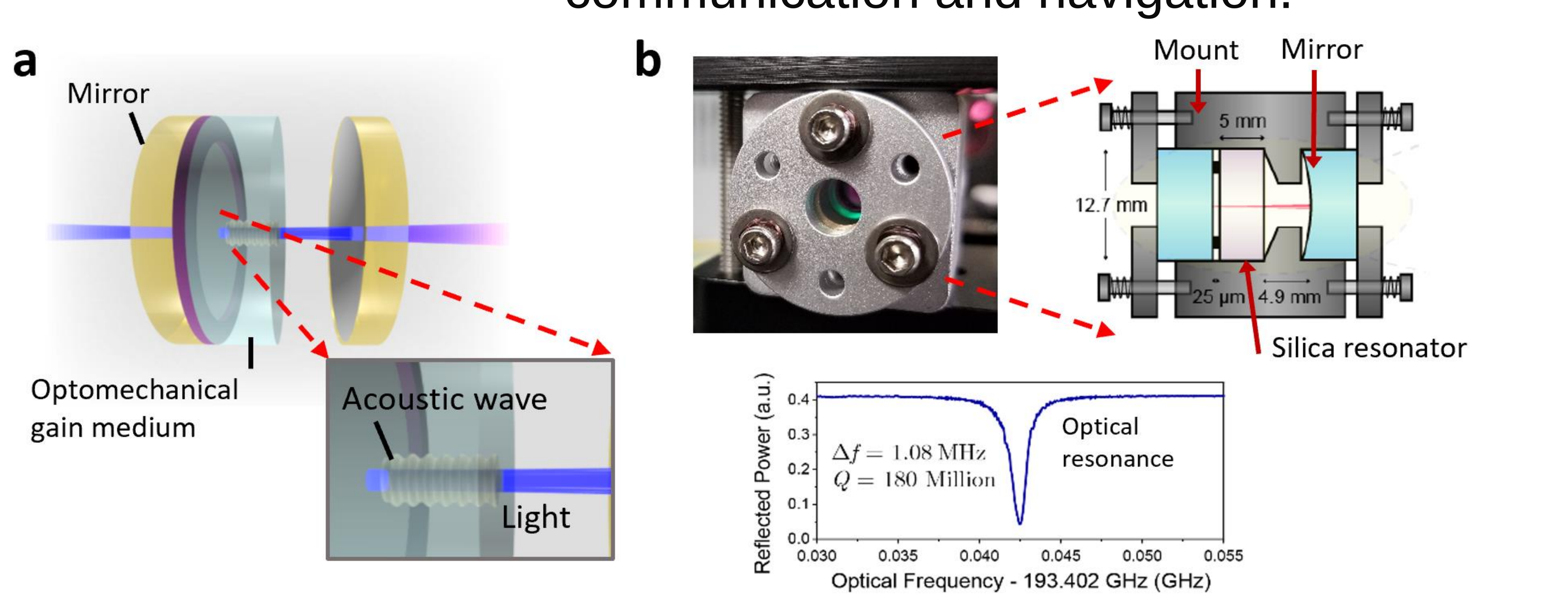
Publications:

[A] Kittlaus, Eric A., Danny Eliyahu, Setareh Ganji, Skip Williams, Andrey B. Matsko, Ken B. Cooper, and Siamak Forouhar. "A low-noise photonic heterodyne synthesizer and its application to millimeter-wave radar." Nature Communications 12, no. 1 (2021): 1-10.

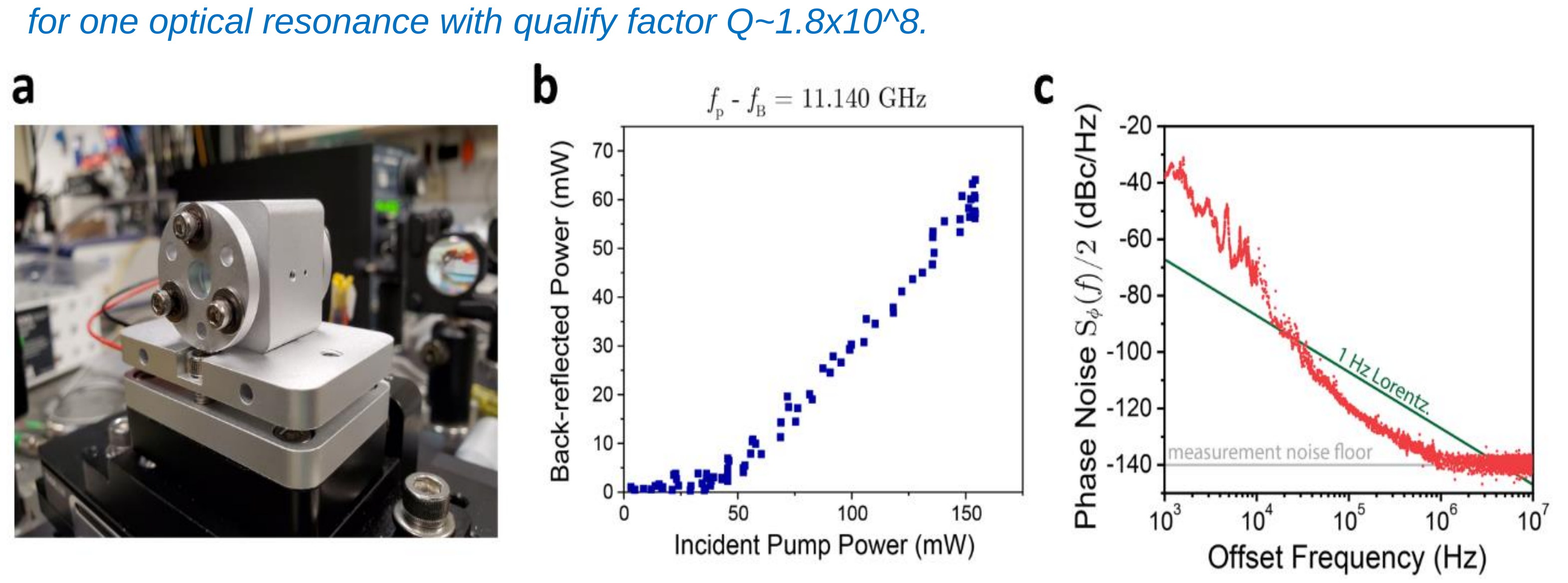
[B] Roy, R., Lebsock, M., and Kurowski, M.: Spaceborne differential absorption radar water vapor retrieval capabilities in tropical and subtropical boundary layer cloud regimes, Atmos. Meas. Tech. Discuss. [preprint], ttps://doi.org/10.5194/amt-2021-111, in review, 2021.

Benefits to JPL and NASA

- Research makes JPL competitive for anticipated NASA investment in technology incubation for PBL science, specifically high-resolution humidity profiling.
- Disruptive breakthroughs could lead to technology demonstrator missions in the near-term (<10 years), and can help in realizing a large PBL missions in the long terms.
- Approaches and techniques we are investigating are promising for a variety of wider applications both within NASA and beyond, ranging from security to communication and navigation.



Bulk cavity Brillouin laser. (a) depicts the principle of operation based on light-sound coupling in an optomechanical cavity. (b) shows the prototype device and dimensions, and experimental data for one optical resonance with qualify factor Q~1.8x10^8.



Characterization of Brillouin laser. (a) shows the laser cavity mounted on a translation stage. (b) shows slope efficiency data for one laser configuration. (c) shows the single-side phase noise around an optical carrier frequency of 193 THz. The measured instantaneous linewidth is around 40 mHz.

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