FY24 Strategic Initiatives Research and Technology Development (SRTD)

Technology Development and Design for an Orbital Differential Absorption Radar on a Future PBL Mission

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Strategic Focus Area: Next Earth Science Decadal Survey: Technology & Architecture for Planetary Boundary Layer (PBL)/ Surface Topography & Vegetation **| Strategic Initiative Leader:** Rashmi Shah

Objectives:

1) Design, fabricate and test a low-loss receiver-protect switch for a high-power G-band radar (20 dBm switch input power).
2) Design, fabricate and test a W-band dielectric resonator oscillator for generation of millimeter-wave signals at G-band with ultra-low phase noise, in order to improve the dynamic range of a high frequency cloud radar.
3) Model the along-track resolution performance of a spaceborne Differential Absorption Radar instrument for humidity sounding in the PBL.

Background:

Earth's Planetary Boundary Layer (PBL) is at the heart of fundamental science challenges, such as: reducing uncertainty in cloud-climate feedback, understanding the sensitivity of extreme weather to a warming world, quantifying the exchanges of energy, water and carbon between the free-atmosphere and the ocean/land surface, and improving forecasts of near surface air quality. A compelling remote sensing technique that has emerged in the last decade is **Differential Absorption Radar** (DAR) for mapping vertical distributions of water vapor inside of clouds. JPL pioneered this method, which relies on advance millimeter-wave radar technology. However, to be competitive for consideration in a future space mission, the added capabilities of lower on-board oscillator noise, receiver immunity to higher transmit power, and better along-track spatial resolution are critical for the application of DAR on a global basis.

Approach and Results:

G-band RF switches: Our approach employs a hybrid switching solution based on reflection, absorption AND frequency multiplication. The demonstrated switch is operating as expected for 0dBm input power with a state-of-the-art isolation of -50 dB. In the OFF-state, the chip biasing should be adjusted for each frequency point of operation. The instantaneous isolation for various biasing conditions indicates that switch is narrowband; depending on the isolation requirement the bandwidth ranges from a few hundreds of MHz to several GHz. This bandwidth is sufficient for radar applications. See NTR 53178.

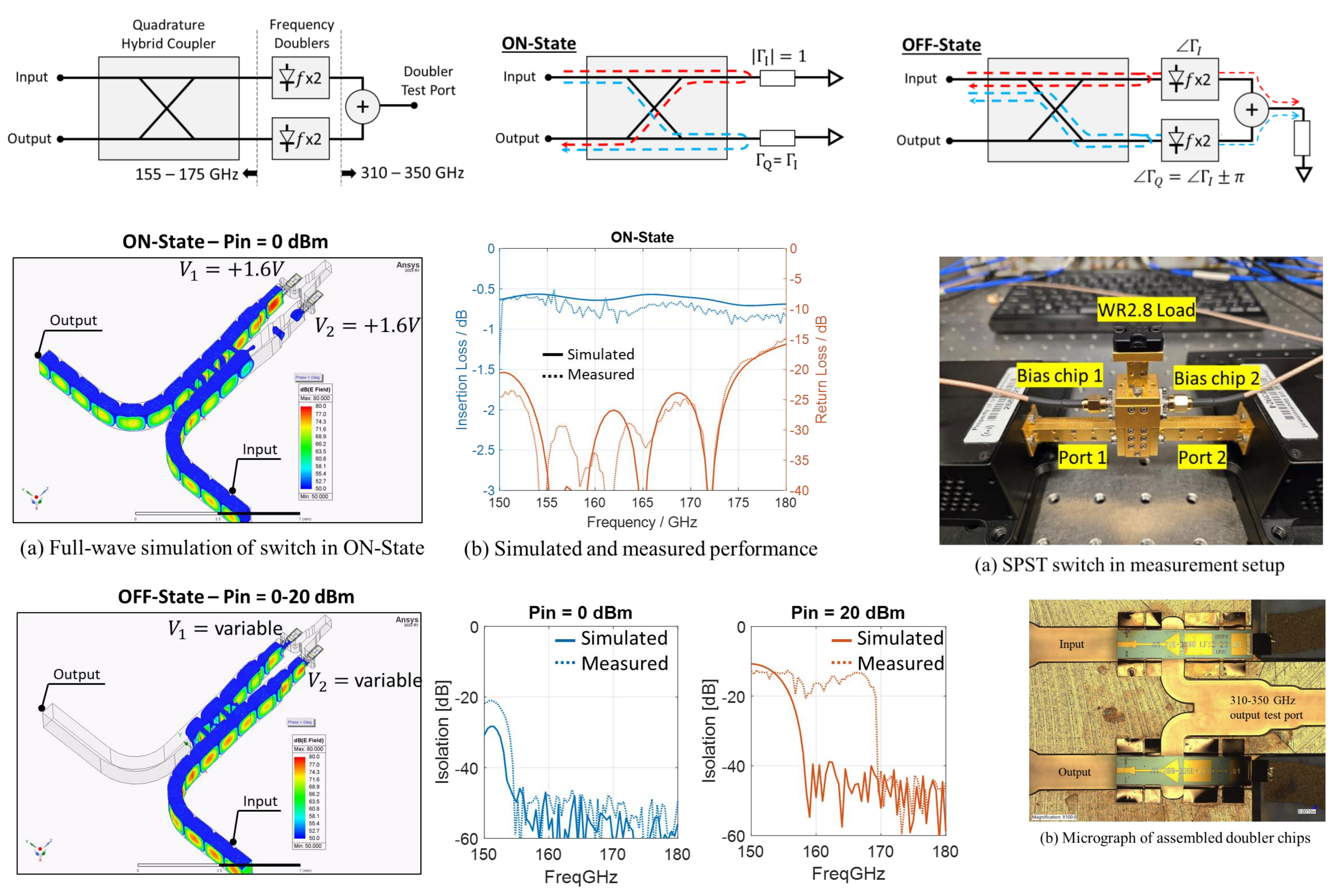
High performance W-band oscillators: Firstly, we demonstrated generation of W-band signals with phase noise better than -110 dBc/Hz at 10 kHz offset and W-band carrier. The breadboard formfactor was less than 1L. This performance corresponds to the quantitative objective of the Project since the oscillator noise does not increase with the carrier frequency. Secondly, we demonstrated Ka-band and W-band sapphire distributed Bragg grating cavities with the record Q-factors. The cavities will be used in FY'25 oscillator systems.

Spaceborne DAR modeling: We developed a semi-empirical model for humidity retrieval accuracy based on airborne data obtained by VIPR, and developed a parameter space where along-track resolution varies from ~10-100 km.

Significance/Benefits to JPL and NASA:

The excellent results of the demonstration of the oscillators using both microwave photonics and microwave approaches is promising for building very high frequency radars that require high dynamic range. The G-band switch can likely be infused on upcoming airborne campaign that VIPR will participate in. Both technologies would benefit an eventual large-scale DAR space mission to study the PBL in the 2030s. Our work also has direct relevance to other mm-wave JPL radar concepts under development, such as DORA for the AOS mission.

G-band Switch Progress:

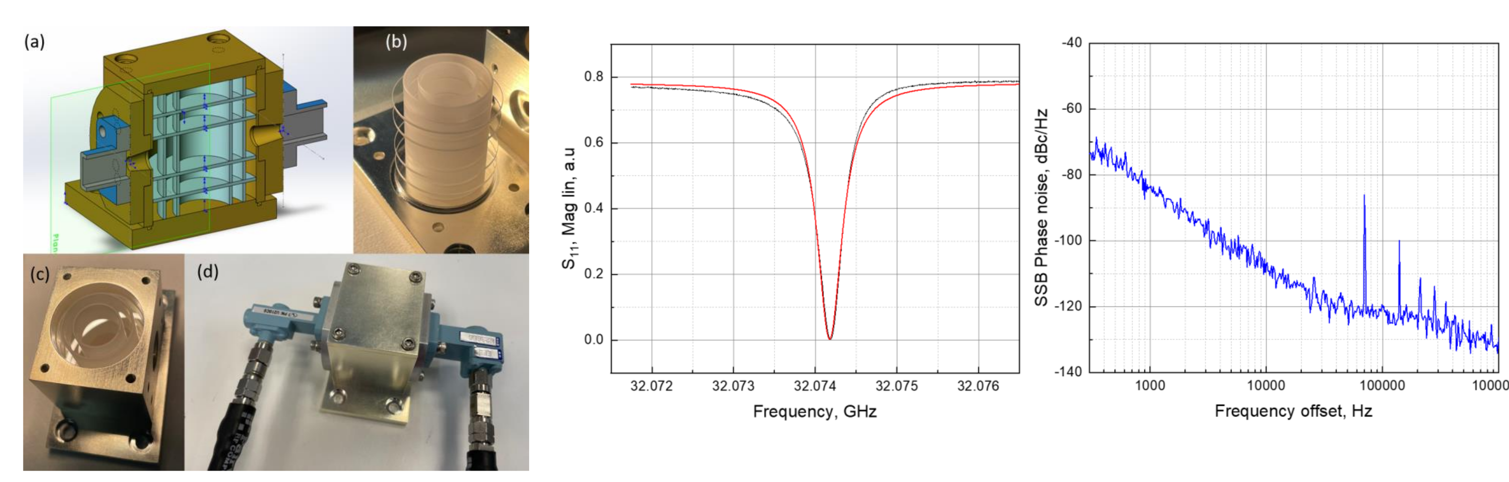


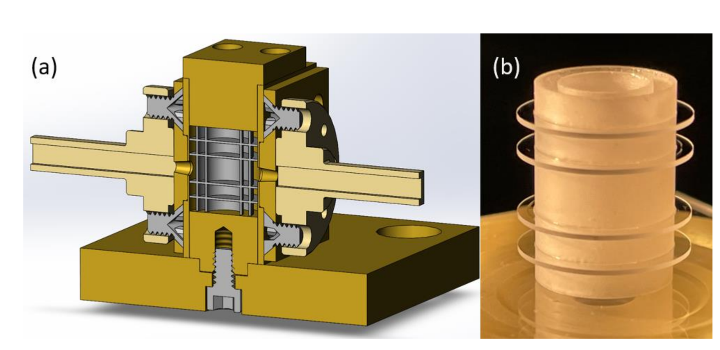
(a) Full-wave simulation of switch in ON-State (b) Simulated and measured performance (a) SPST switch in measurement setup

(a) Full-wave simulation of switch in OFF-State (b) Simulated and measured isolation in OFF-state (b) Micrograph of assembled doubler chips

The G-band switch uses two GaAs Schottky diode frequency-doublers in a waveguide hybrid coupler geometry. Depending on the diode voltage bias, the device either reflects the input signal to the output port, or absorbs/multiplies the signal into loads. Good agreement is realized between measurement and simulation! An unwanted frequency-shift in the high power OFF-state is observed.

Low Phase Noise Oscillator Progress:





Top: Assembly and test of Ka-band sapphire Distributed Bragg Resonator (DBR) oscillator, built as a proof-of-concept. Unloaded Q = 170,000, and SSB phase noise -108 dBc/Hz at 10 kHz.

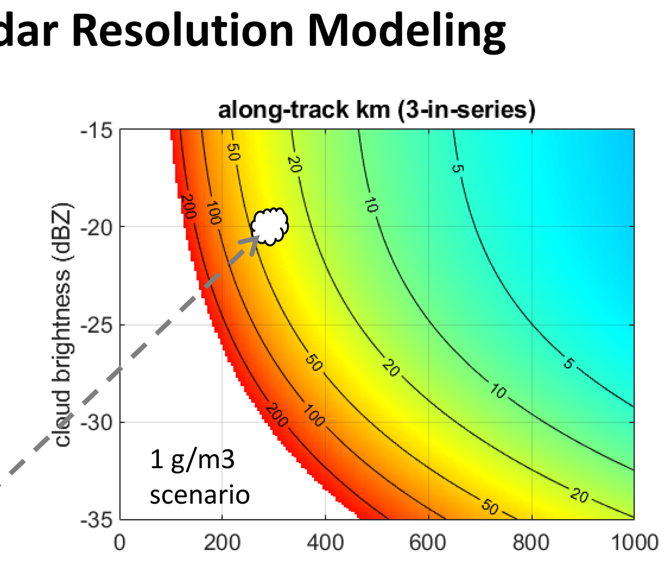
Bottom: Design and start of fabrication of W-band version of the DBR oscillator. Superior quality mm-wave components are expected to yield a phase noise of -120 dBc/Hz at 10 kHz offset.

Spaceborne Differential Absorption Radar Resolution Modeling

Empirical observation for 3-frequency retrieval: $\frac{\Delta\rho}{\rho} \approx \frac{1.5}{\Delta\tau\sqrt{N}}$

Model for 50 W transmitter, 2-m aperture radar @ 400 km

Along-track resolution for -20 dBZ clouds, 300 m vertical humidity profiling retrieval	0.5 g/m3 accuracy	1.0 g/m3 accuracy
number of pulses needed	11,000	2,700
along-track resolution: simultaneous pulses	44 km	11 km
along-track resolution: series pulses	132 km	33 km



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Publications:

- A. Savchenkov, W. Zhang, V. Iltchenko, and A. Matsko, "Robust self-injection locking to a non-confocal monolithic Fabry–Perot cavity," Opt.Lett. 49, 1520 (2024).
- V. Iltchenko, R. Wang, M. Toennies, and A. Matsko, "Compact high-Q Ka-band sapphire distributed Bragg resonator," J. Appl. Phys. 135, 144502 (2024).

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