Progress Towards a 183 GHz Humidity Sounding Radar Transceiver

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ESTO
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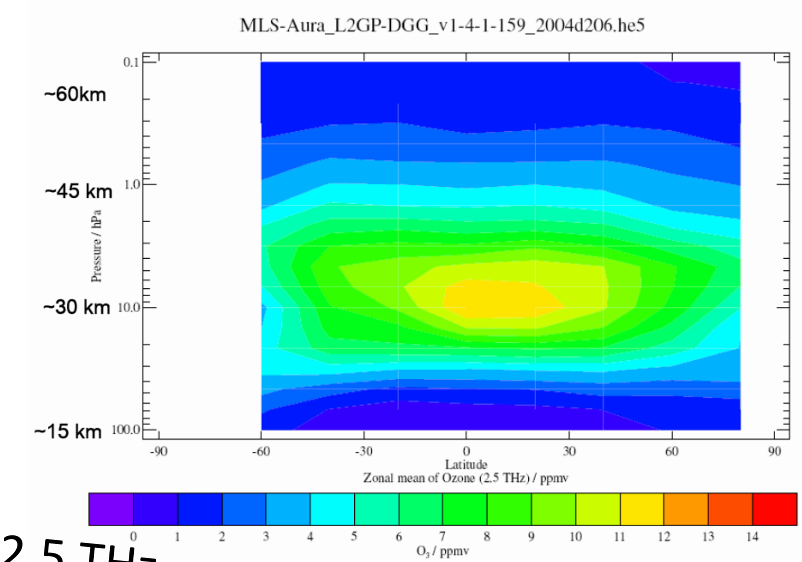
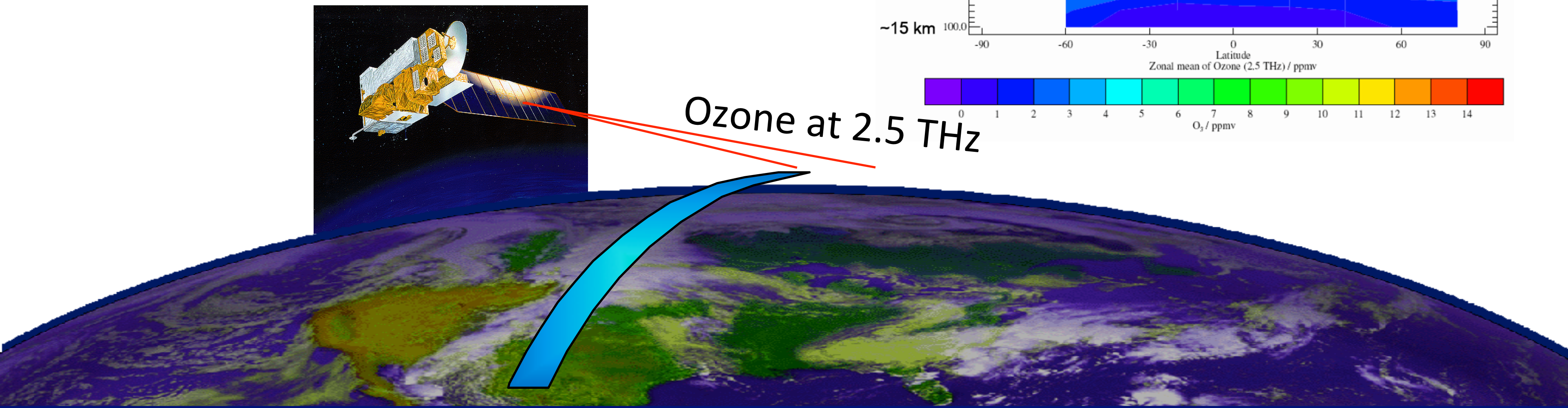
TERAHERTZ EARTH SCIENCE HERITAGE: MLS/AURA-EOS

- Stratospheric and Tropospheric Chemistry
  - ozone layer modeling
  - water distribution/pollutants
- Clouds: Global Warming
  - ice crystal: size & distribution
- Aerosols, Volcanism, Dust

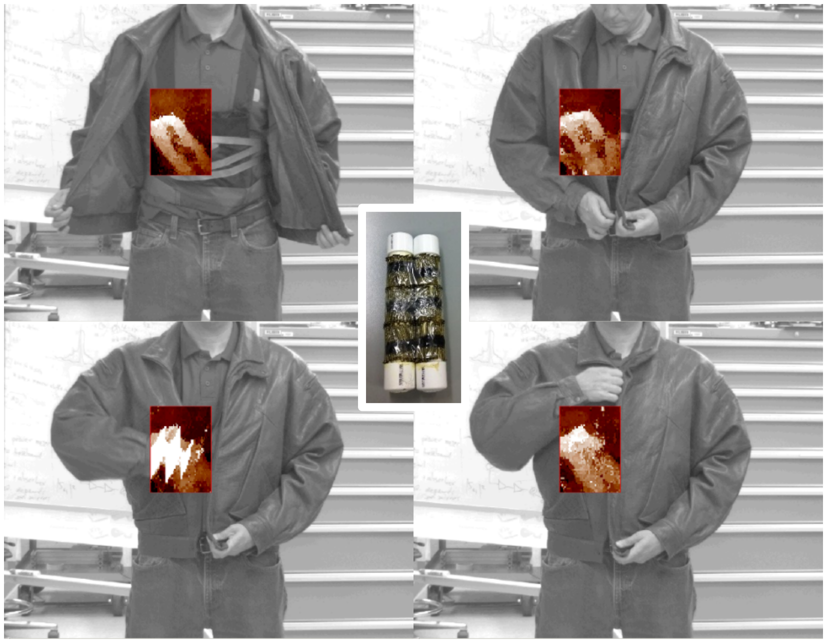
Our first 2.5 THz O_3 retrievals

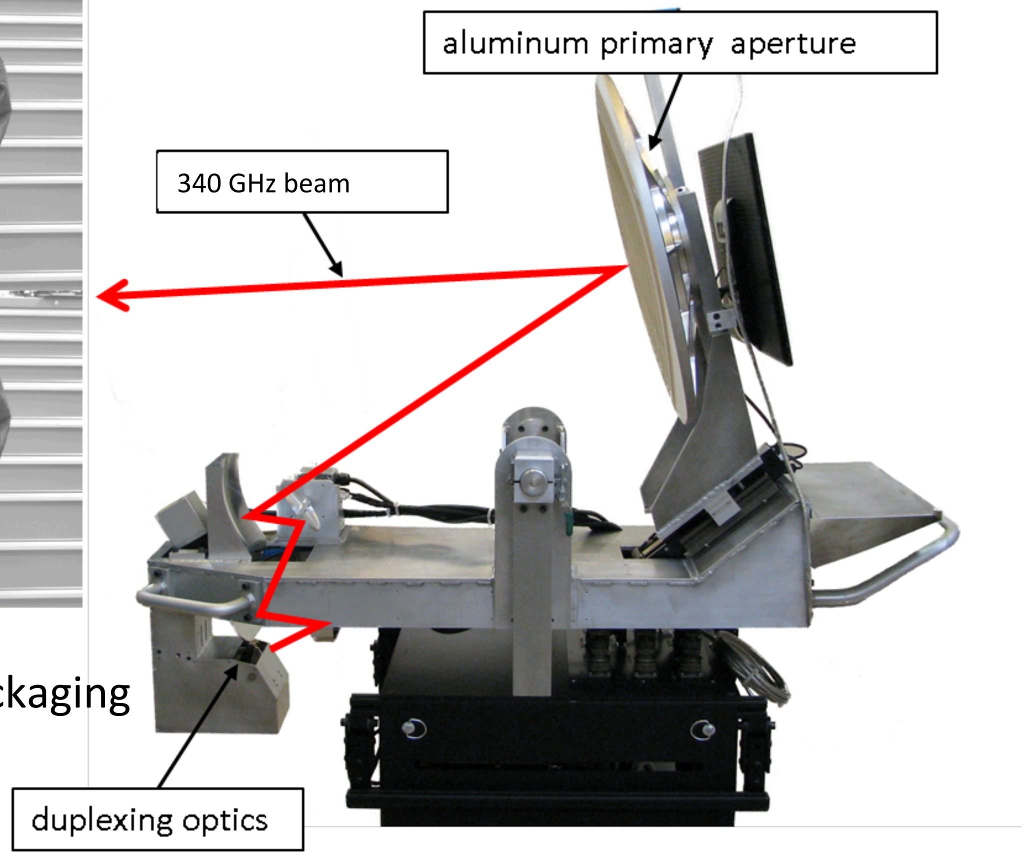




Remote Sensing with Fine Height Resolution (≈ 1 km) via Limb Scanning
heterodyne measurements yield Temp, Pressure, and ppm abundances

TECHNOLOGY HERITAGE: A 8-PIXEL 340 GHz IMAGING RADAR

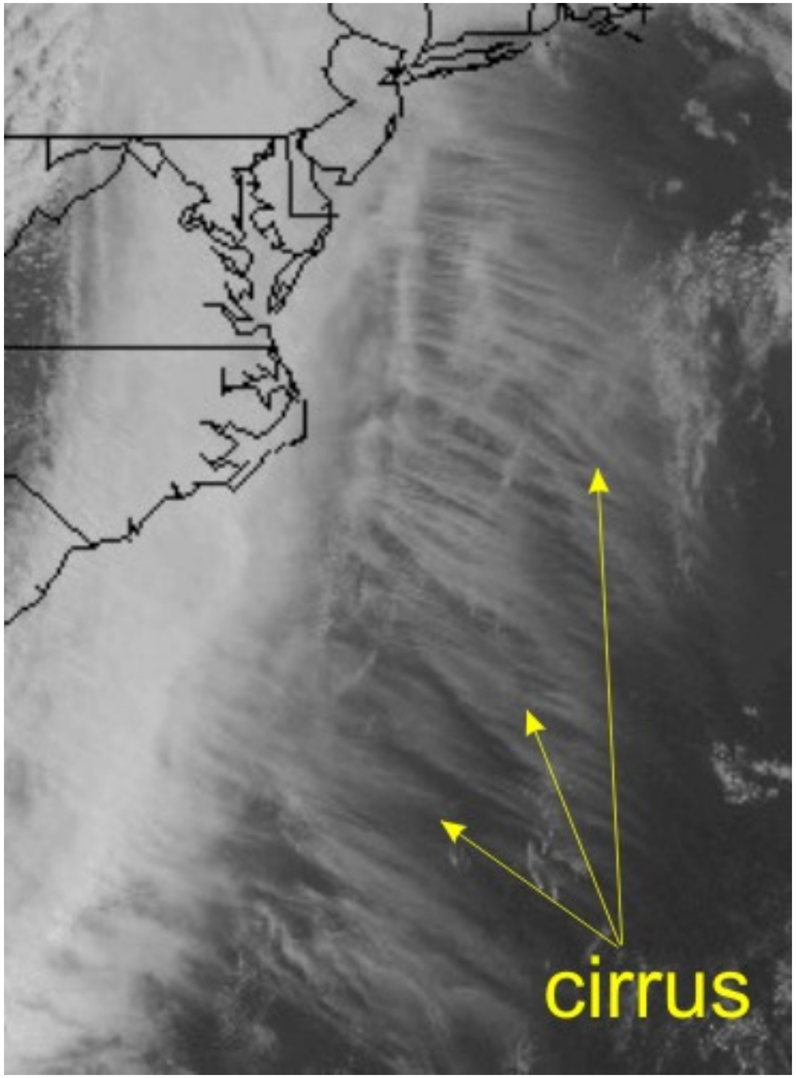




- ✓ Submillimeter-wave components/packaging
- ✓ High isolation quasi-optical duplexing
- ✓ High gain reflector antennas
- ✓ FMCW radar signal processing

183 GHZ RADAR: SCIENCE MOTIVATION

- Clouds are the single most important source of uncertainty in predictions of climate sensitivity.
- Upper-Tropospheric (UT) humidity affects cloud formation and radiative feedback, and therefore accurate measurements are needed for climate modeling.
- Conventional UT humidity measurements rely on passive radiometric sounding using the strong 183 GHz water vapor absorption line, but this technique is unreliable inside clouds.
- Therefore, a remote sensing instrument capable of measuring humidity inside cirrus clouds on a global scale is needed.

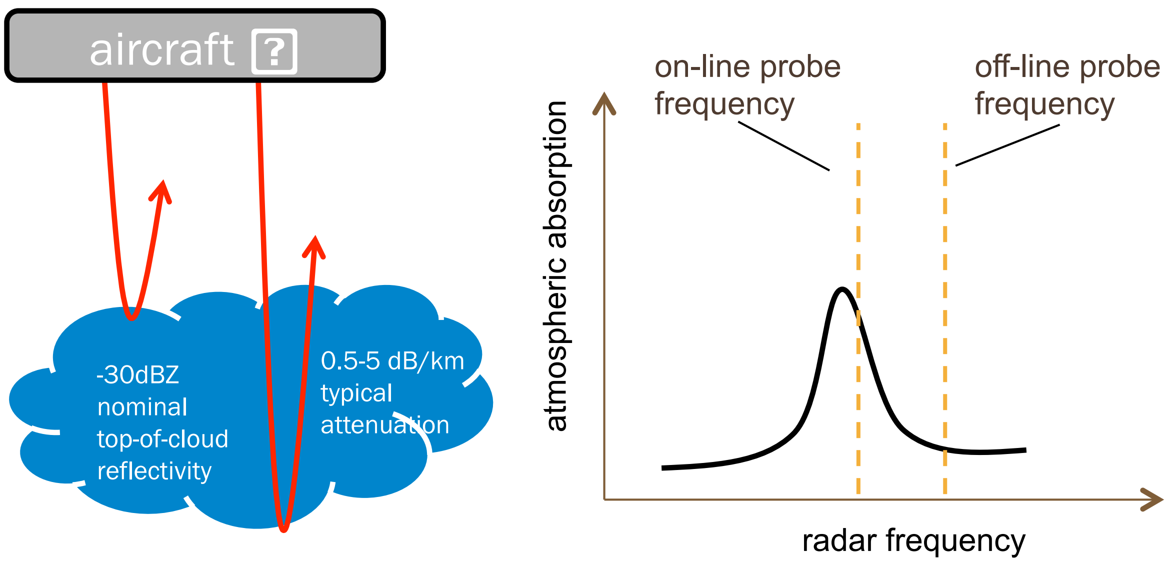


DIFFERENTIAL ABSORPTION RADAR CONCEPT

- *<u>Concept</u>*: use the scattering of ice crystals in cirrus clouds to measure range-resolved **differential absorption radar** signals on and off the 183 GHz water line.

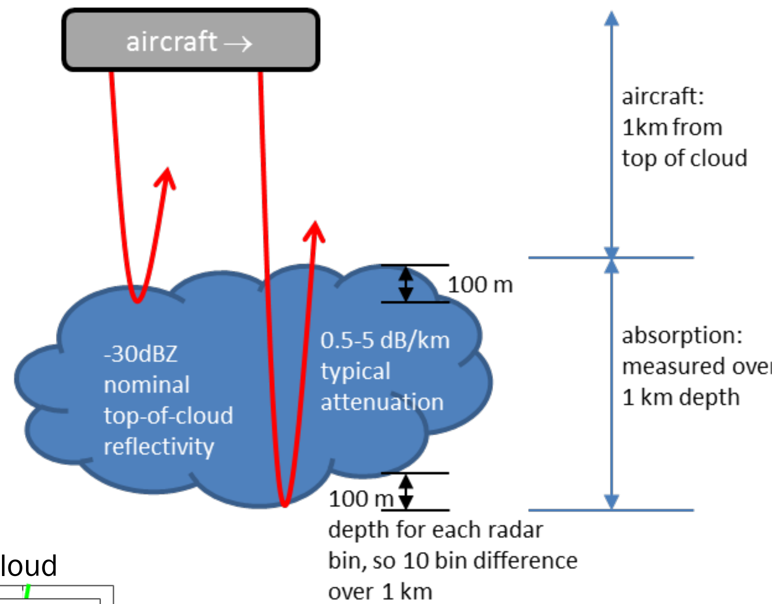
- Shift radar's center frequency between an "on-line" location with significant attenuation from water vapor column, and "off-line" location several GHz away with no significant water attenuation. (<u>Background absorption outside of clouds is minimal in the upper troposphere</u>.)

- Assumption is that the ice crystal's ensemble cross-section does not change much over a few GHz, compared to the water vapor absorption.

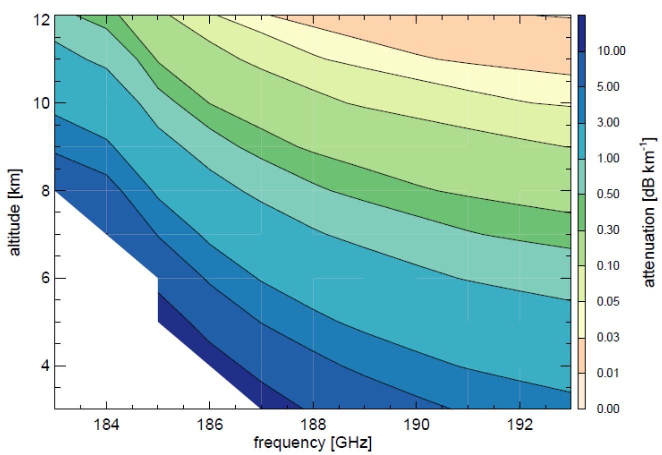


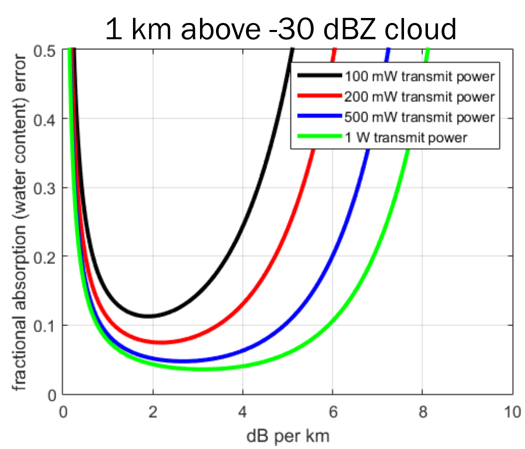
SENSITIVITY ESTIMATES

	Airborne
along-track resolution	1 km
cloud thickness resolution	1 km
platform velocity	200 m/s (dep
receiver noise figure	8 dB
antenna diameter	25 cm
distance from cloud top	0.5-1 km
cloud top reflectivity	-30 dBZ



0.1-1 W power levels give reasonable humidity estimates with 1 km integrated range. What power can we achieve at 183 GHz?



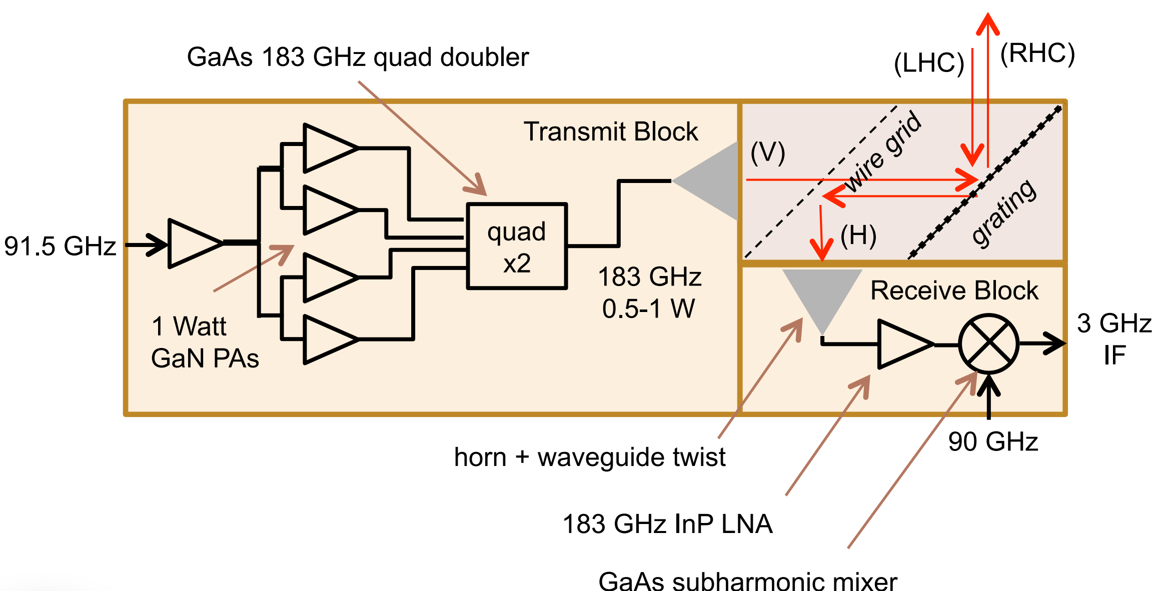


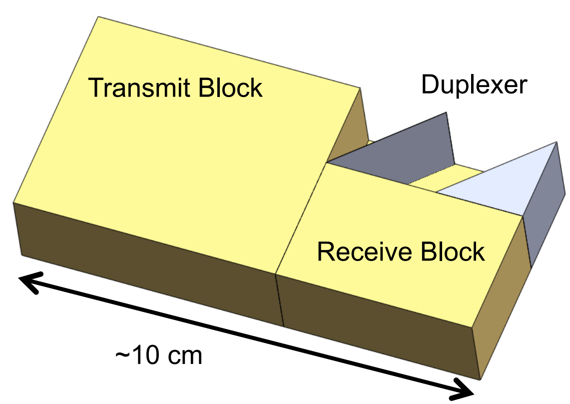
Origin of 1-6 dB/km ‘sweet spot’:

- Attenuation too small: not enough contrast over range swath.
- Attenuation too large: received signal power too small to detect

HIGH-LEVEL INSTRUMENT OVERVIEW

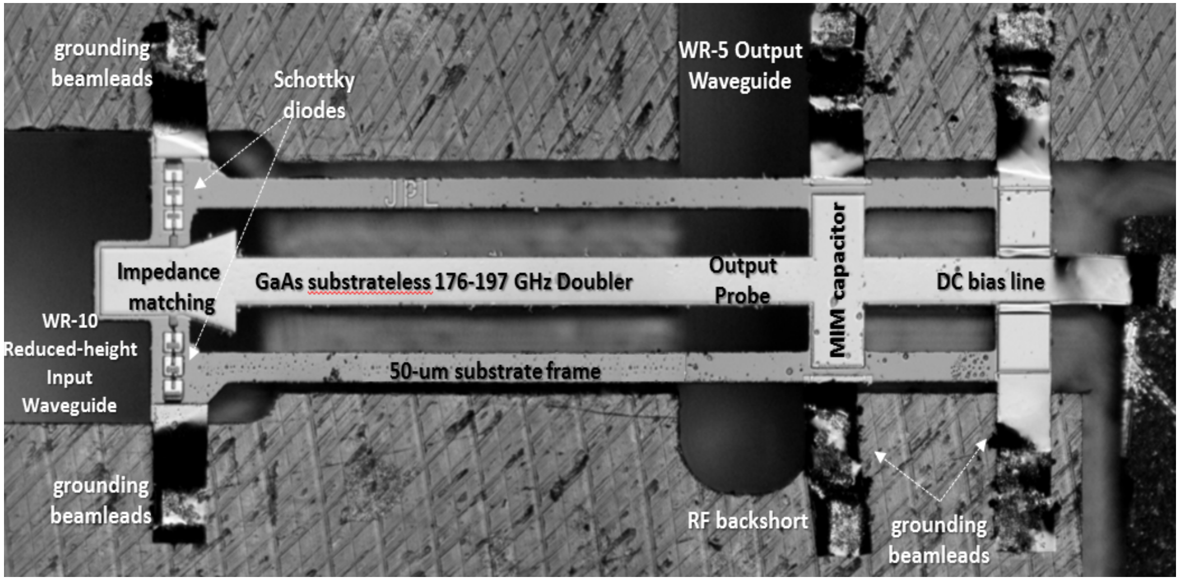
- All-solid-state, room-temperature 183 GHz transmitter & receiver.
- Highest transmit power practical & most sensitive receiver possible, to measure backscattered signals from the weakest clouds.
- Ultra-high transmit/receive isolation for continuous-wave measurements.
- Wide tunability over the 183 GHz water line for probing a variety of cloud densities and depths.
- Expertise and test/measurement equipment for >100 GHz radar measurements.
- Scientific guidance for design and testing phases, and for future proposal collaboration.





TRANSMITTER TECHNOLOGY: SHOTTKY MULTIPLIERS

Operating frequency: Up to 5 THz and beyond.
Operating temperature: Room Temp. to 20K.
Efficiency: 40% @ 100 GHz – 1% @ 2700 GHz.
Output power @ 2700 GHz ≈ 18 uW.
Output power @ 200 GHz ~ 500 mW
Typical Bandwidth ~ 15-20 %



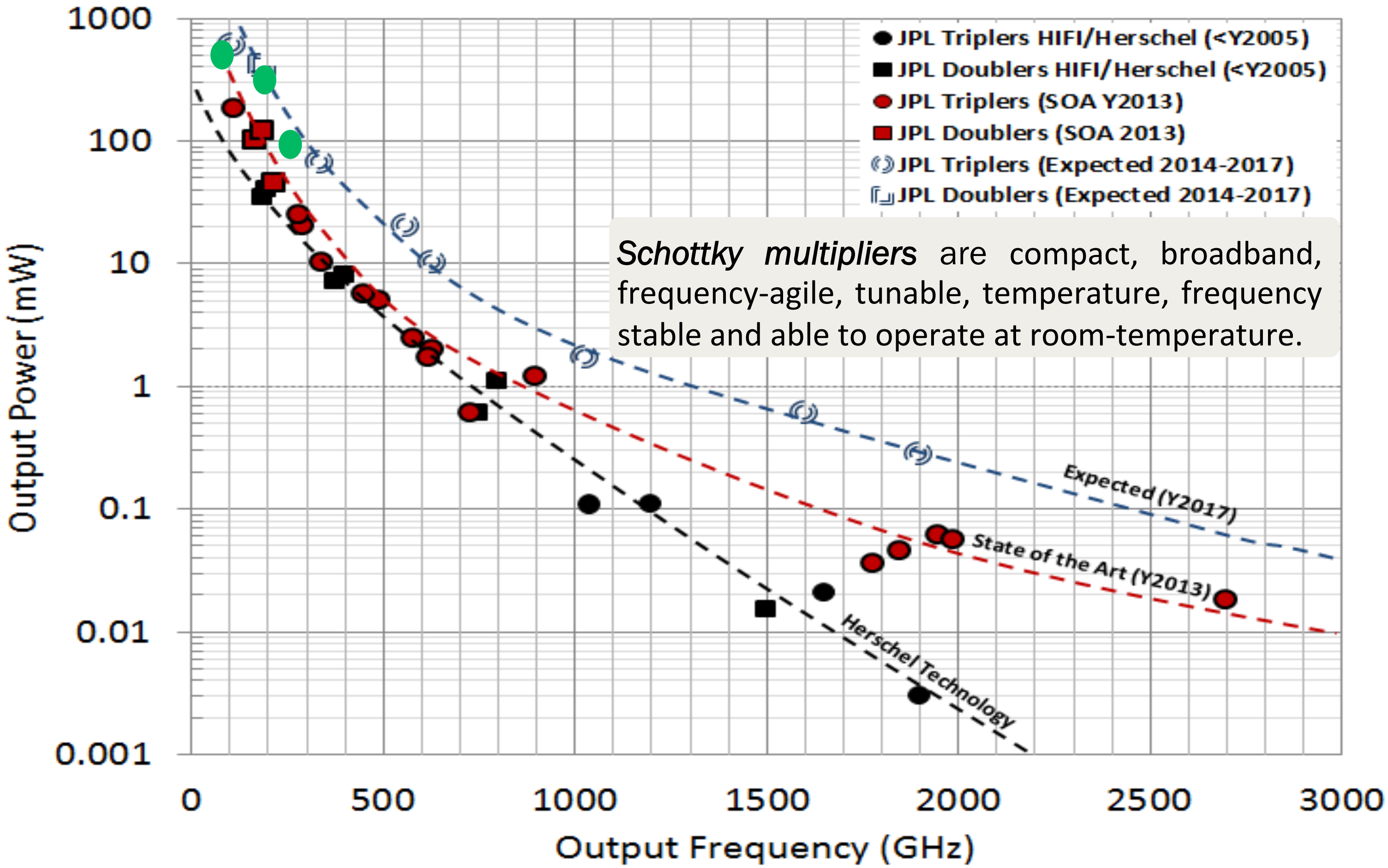
- Planar diode technology
- Robust and mature technology

Schottky Diodes in waveguide.
Human hair diameter: 20-200 um!

Major advantage: can operate at room temp. and lower

GAAS TERAHERTZ MULTIPLIED SOURCES

Room-temperature Schottky diode based multiplied sources

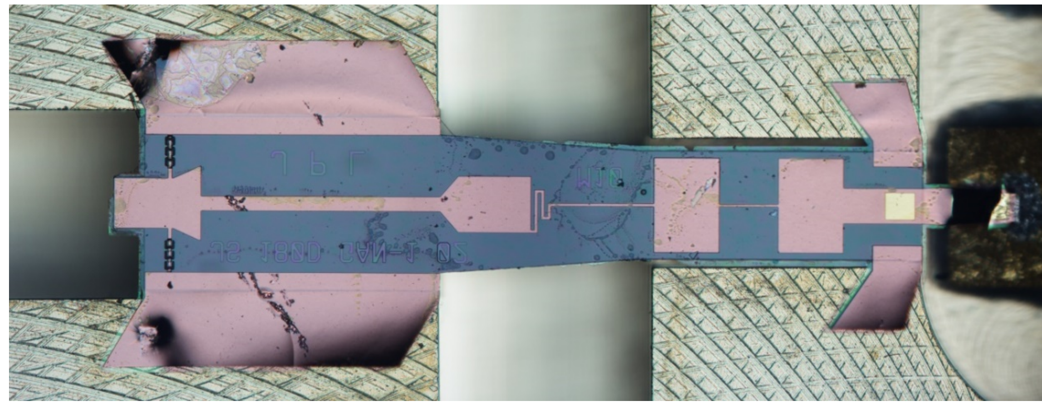


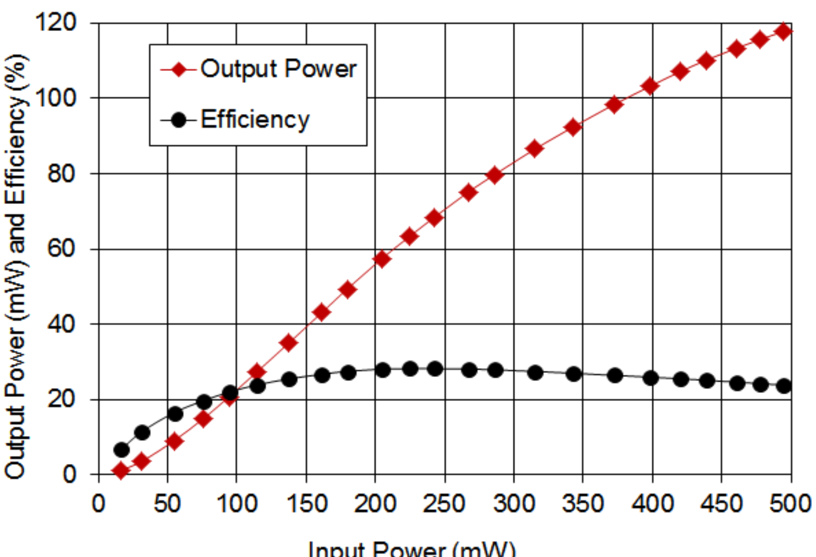
Schottky multipliers are compact, broadband, frequency-agile, tunable, temperature, frequency stable and able to operate at room-temperature.

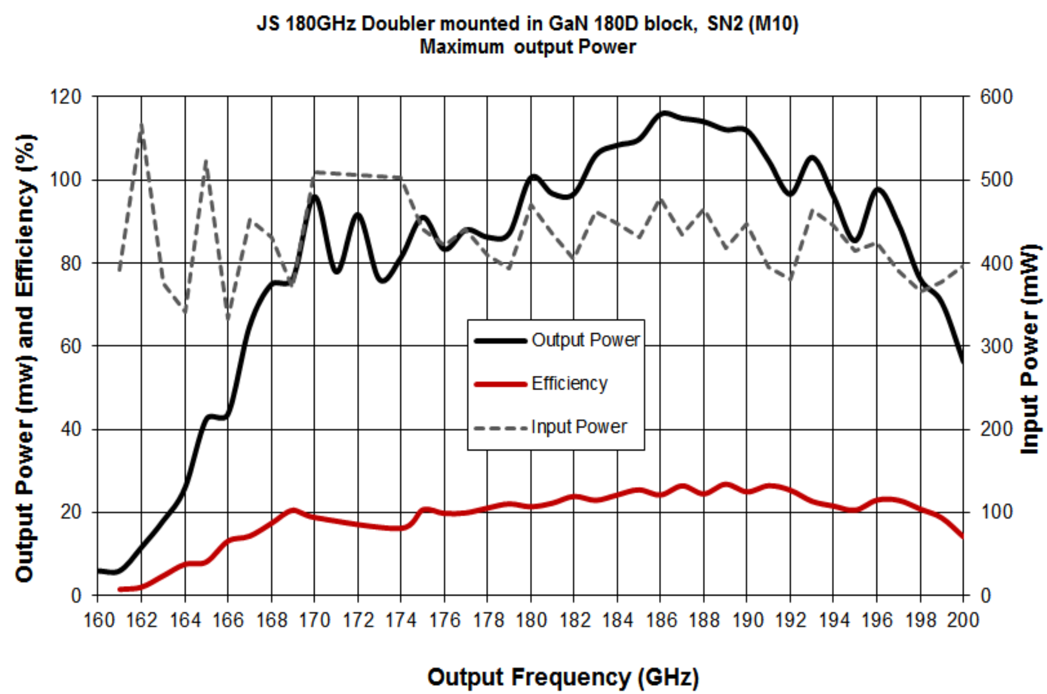
TRANSMITTER ARCHITECTURE:
176 GHz GaAs HIGH-POWER FREQUENCY DOUBLER

Very-high power 180 GHz GaAs Schottky Diode Based Doubler Demonstrated

- **New high power 180 GHz doubler chip design** (handles more than 500 mW input power with no power combining.
- **120 mW output power measured for 500 mW input** (a quad chip version will generate more than the 400 mW required)
- **More than a x3 improvement with regards to HIFI/Herschel doubler** with no penalty in efficiency

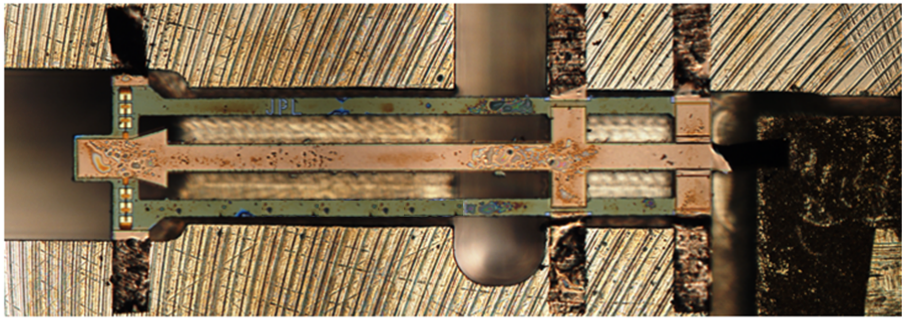


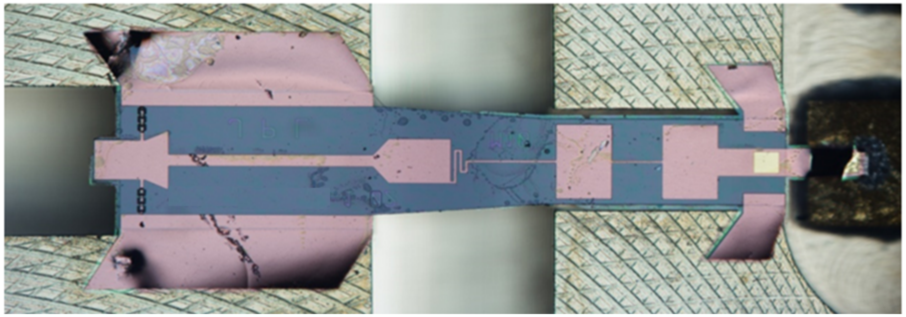




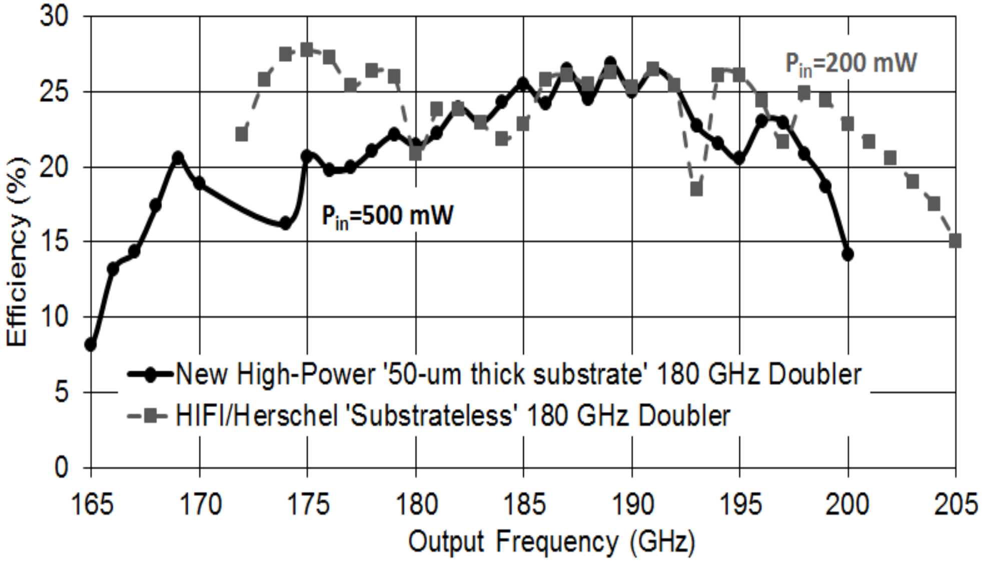
TRANSMITTER ARCHITECTURE:
176 GHz GaAs HIGH-POWER FREQUENCY DOUBLER

HIFI/Herschel Design (Y2000)
Nominal Input=100 mW
Max input =200 mW



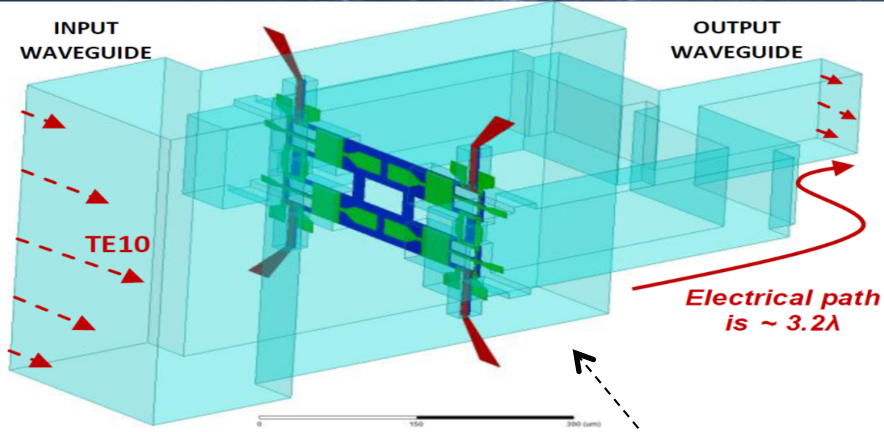


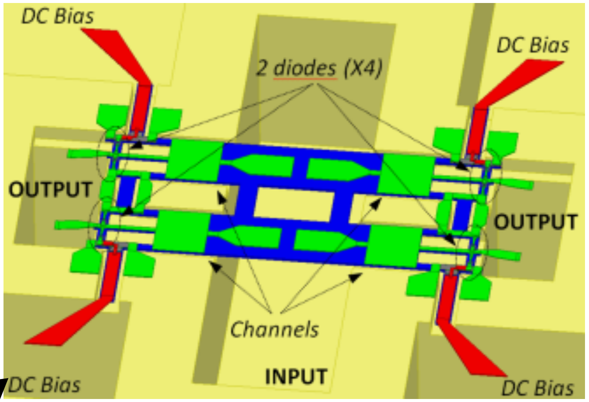
New Design (Y2013)
Nominal Input=250 mW
Max input =600 mW

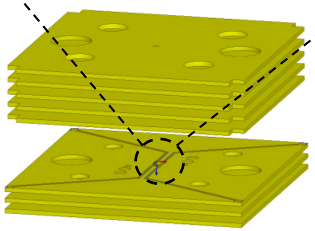


TRANSMITTER ARCHITECTURE: ON-CHIP POWER-COMBINED FREQUENCY MULTIPLIERS

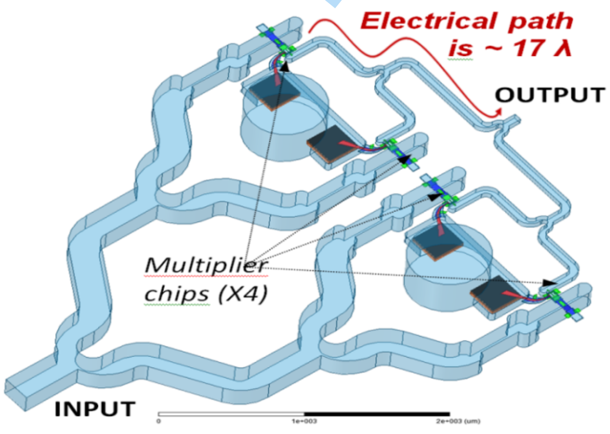
- Power x4
- Size /10
- Losses /5
- Lithographic accuracy x10



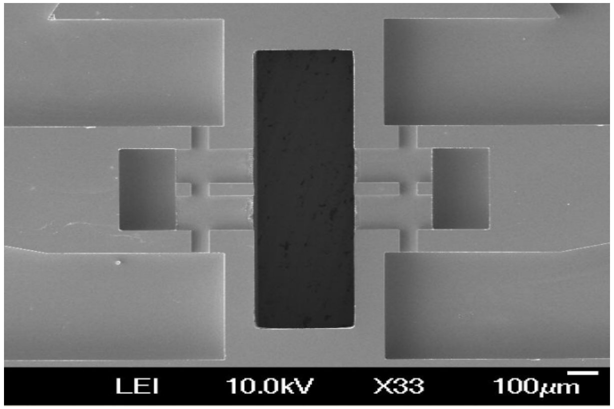


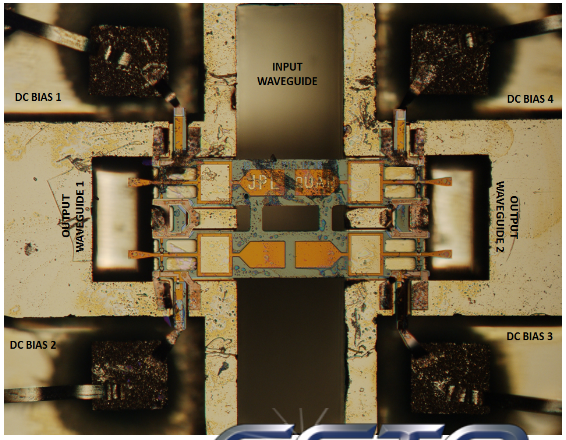


U.S patent (CIT 5953-P), Jet Propulsion Laboratory, California Institute of Technology.



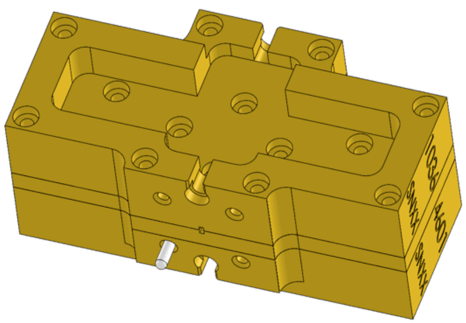
Metal split-block (20mmx20mmx8mm)



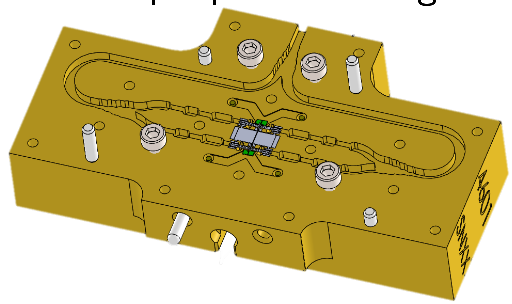


TRANSMITTER ARCHITECTURE:
176 GHz GaAs ULTRA HIGH-POWER FREQUENCY DOUBLER

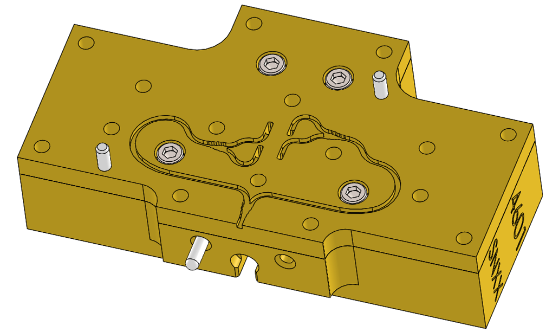
quad-doubler block

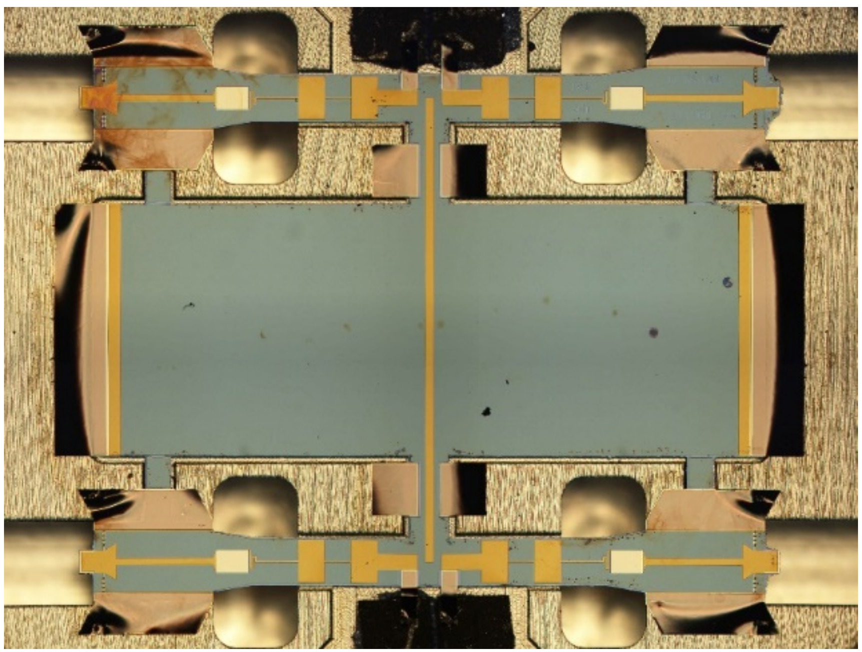


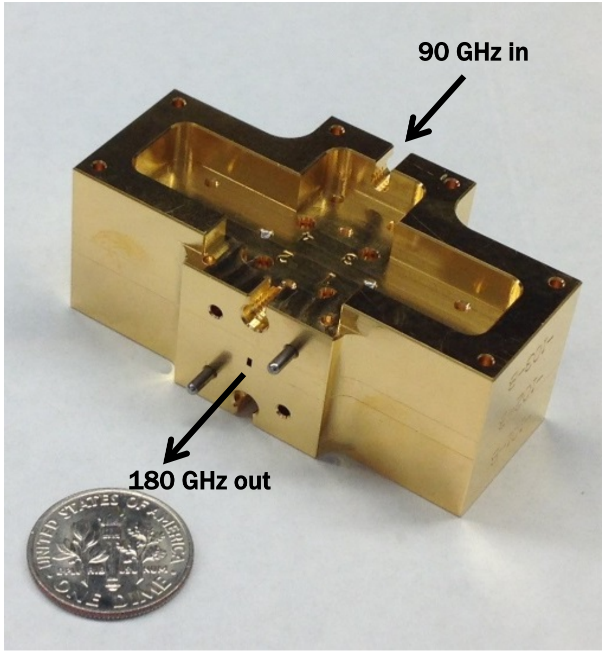
input power dividing



output power combining





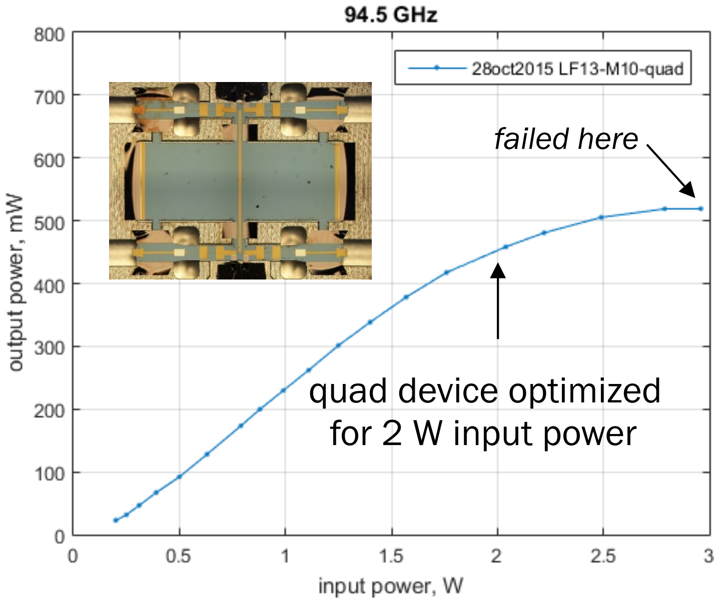


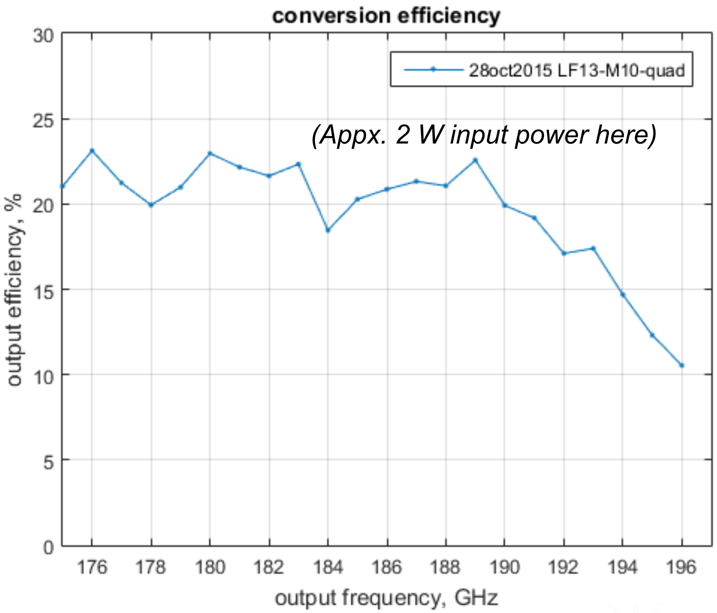
Quad on-chip power-combined GaAs 180 GHz doubler design together with compact housing able to handle more than 2 Watts and produce around 500 mW output

TRANSMITTER ARCHITECTURE: 176 GHz GaAs ULTRA HIGH-POWER FREQUENCY DOUBLER

- World-record output power achieved at 189 GHz (94.5 GHz input): >500 mW output!
- Fairly flat response with ~23% conversion efficiency (2 W input) over >10 GHz bandwidth.
- *This represents a TRL increase from 3 to 4 for demonstrating the concept of high-power quad-chip power combining of a 183 GHz diode doubler.*

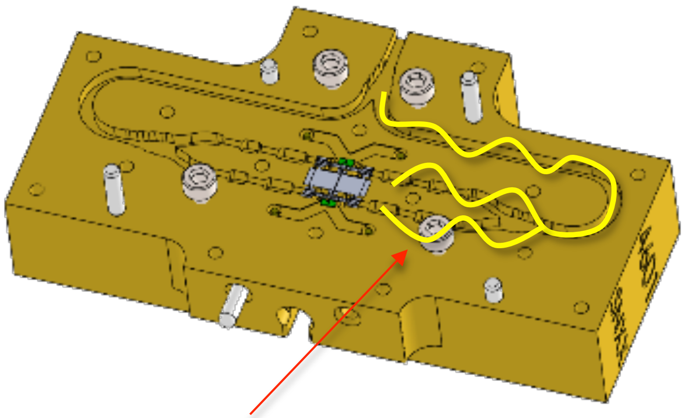
- But a caveat: the device failed after a few minutes of pumping at 3 W input. On the one hand, this is fine because it exceeds the design optimized power of 2 W input. On the other hand, it is surprising because the single-devices should handle 750 mW each without failure.



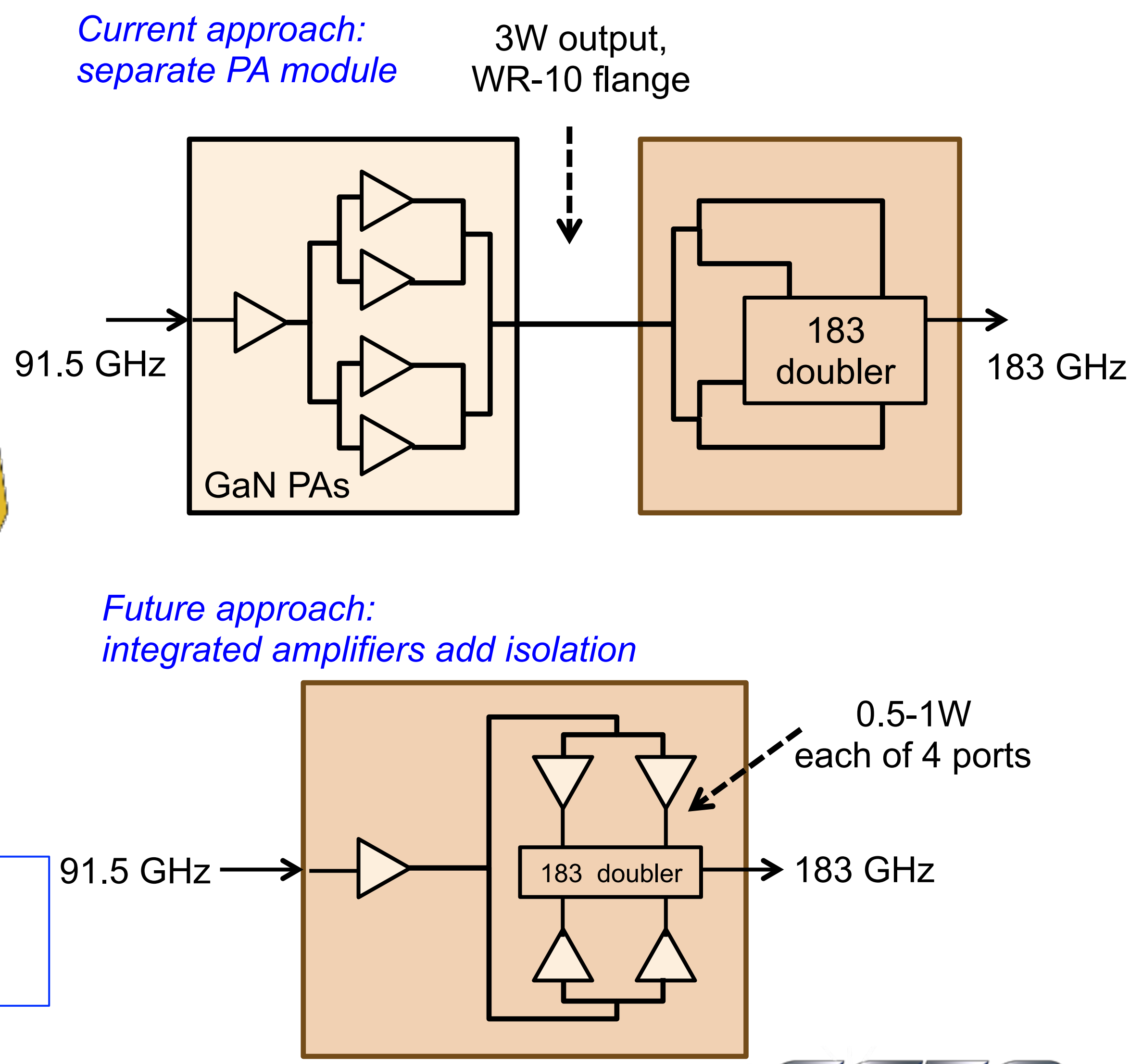


TRANSMITTER ARCHITECTURE: 176 GHz GaAs ULTRA HIGH-POWER FREQUENCY DOUBLER

Imbalances, Standing Waves, and Their *Resolution*

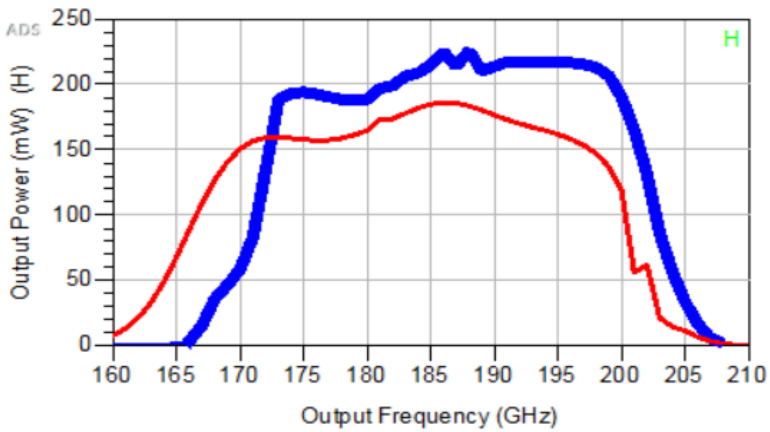


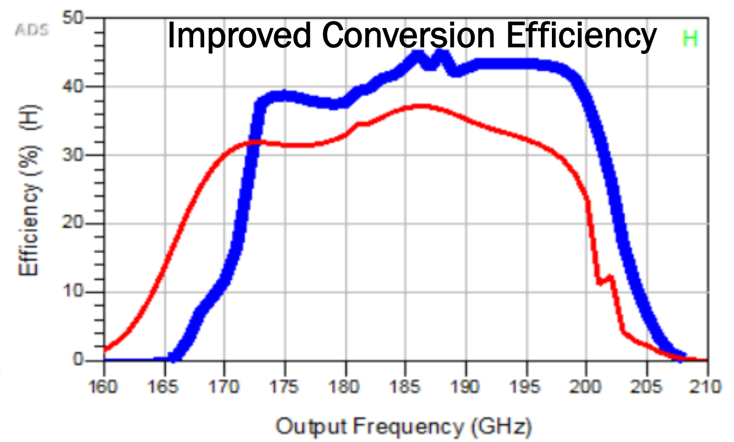
- What about other power dividing structures that have higher isolation? Like magic-T's or hybrid couplers?

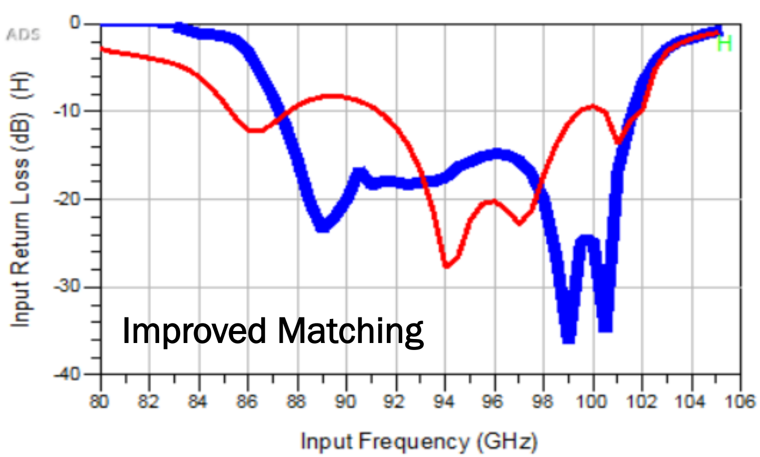


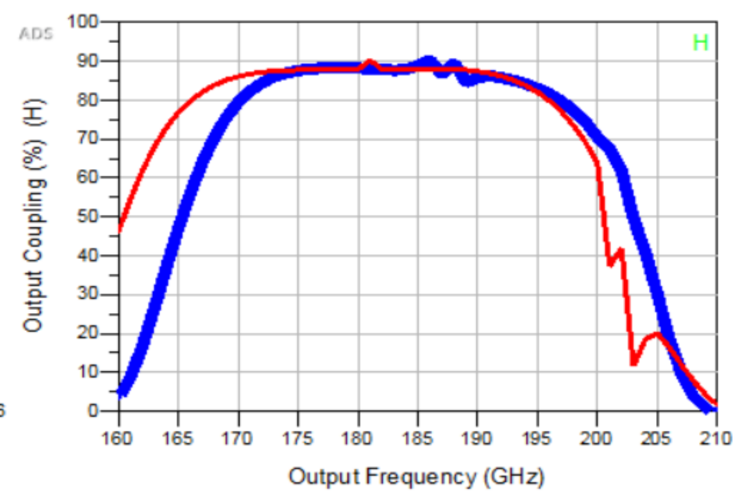
TRANSMITTER ARCHITECTURE:
176 GHz GaAs ULTRA HIGH-POWER FREQUENCY DOUBLER

New PA + Doubler Integrated Design



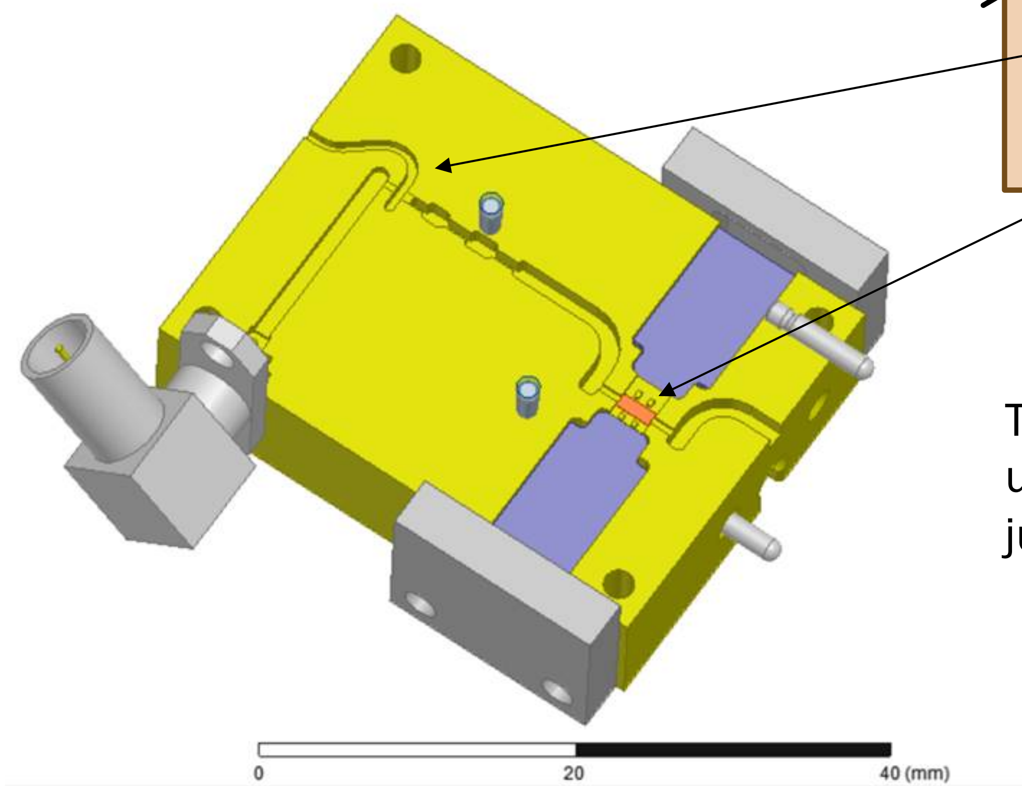


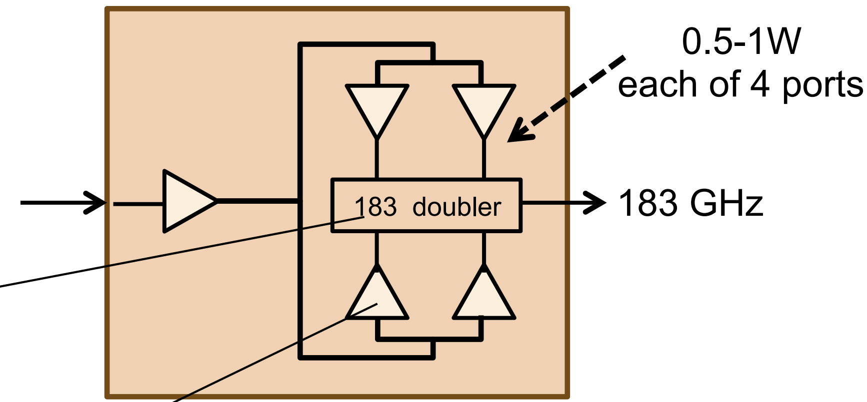




TRANSMITTER ARCHITECTURE:
176 GHz GaAs ULTRA HIGH-POWER FREQUENCY DOUBLER

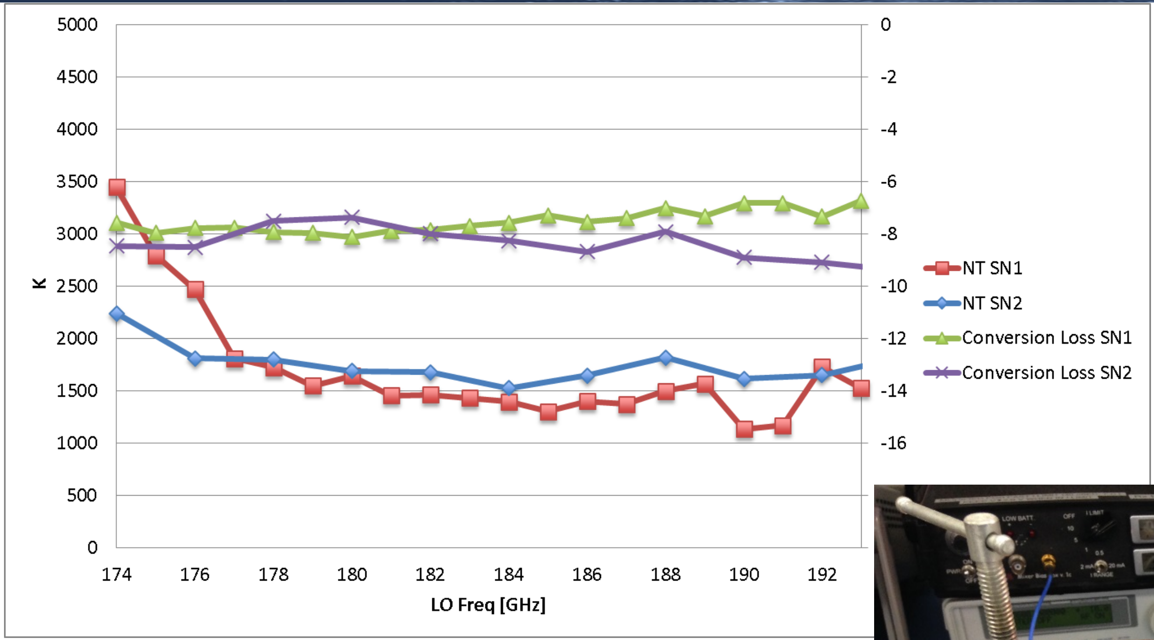
New PA + Doubler Integrated Design



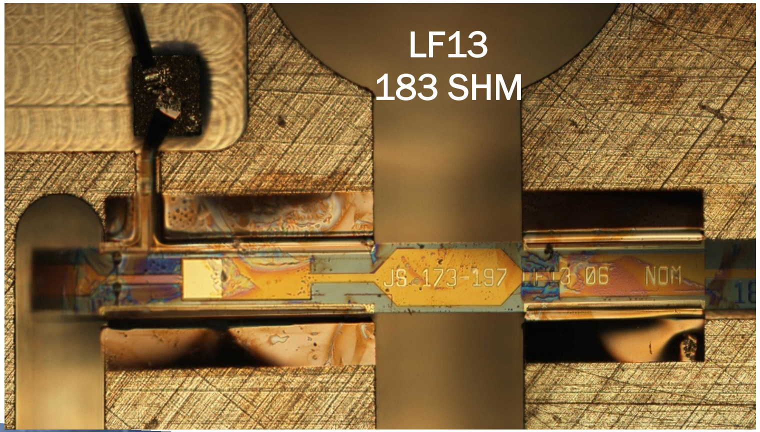


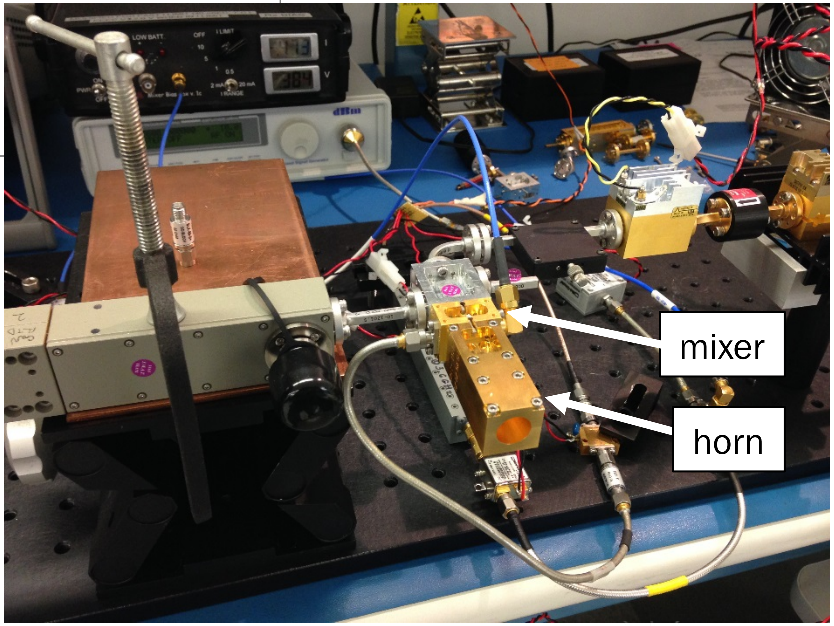
The four outputs will be combined using magic Ts instead of Y-junctions for improved isolation.

RECEIVER ARCHITECTURE:
176 GHz GaAs SCHOTTKY DIODE BASED MIXER



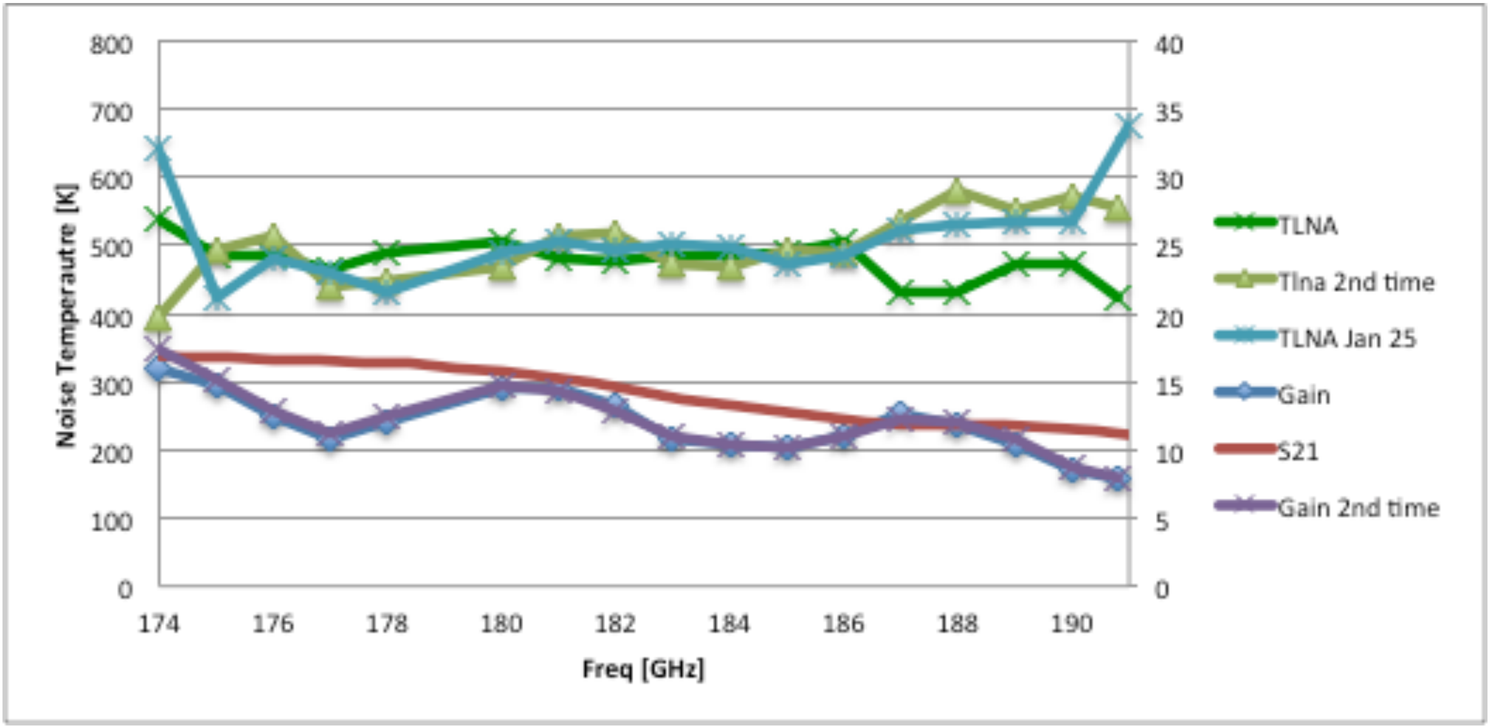
- Good noise and conversion loss performance
- Flat response over 183-193 GHz transceiver bandwidth



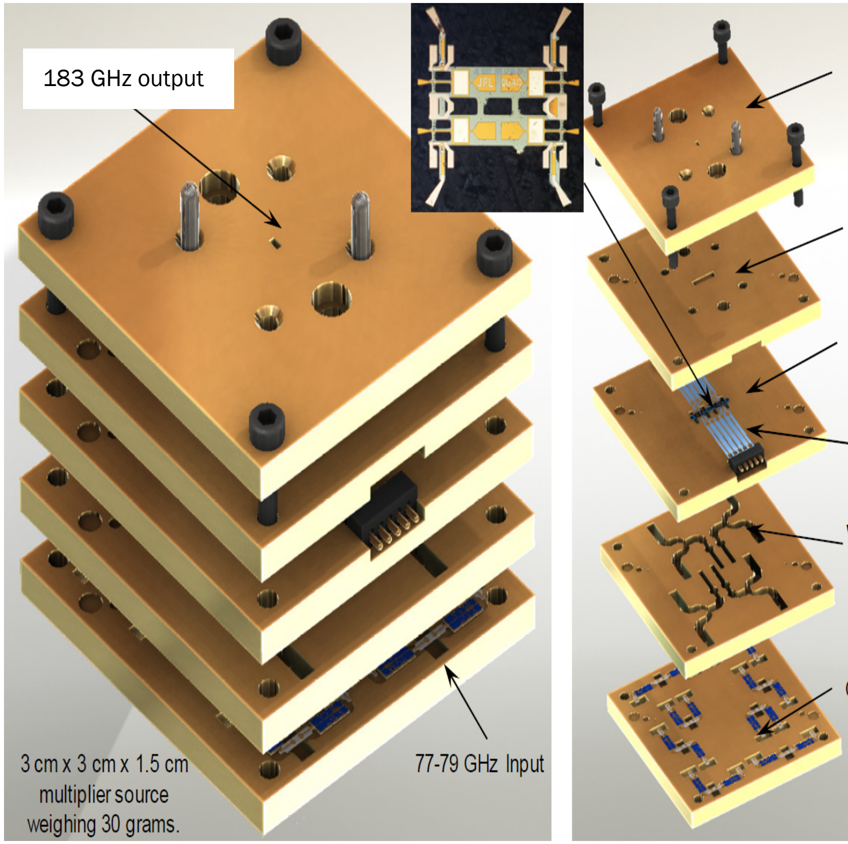


RECEIVER ARCHITECTURE:
176 GHz GaAs SCHOTTKY DIODE BASED MIXER

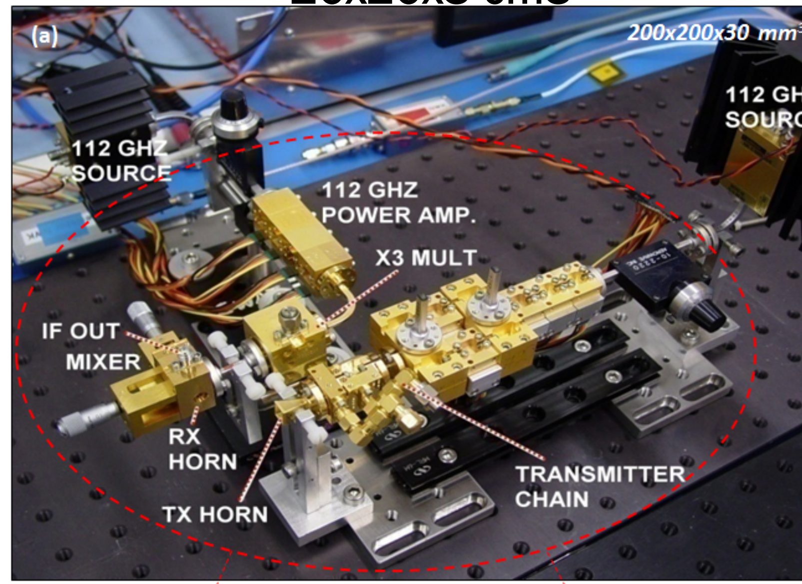
- The 183 GHz InP show good noise temperature (<500 K) over the 173-193 GHz range.
- New 25 nm gate InP chips will be assembled soon that should not have the gain roll-off at high frequencies.

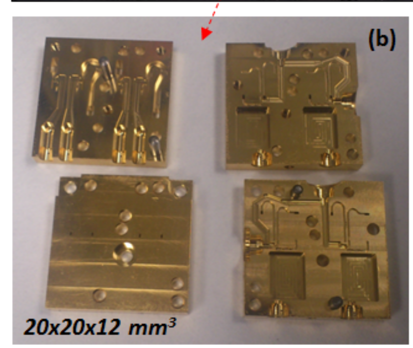


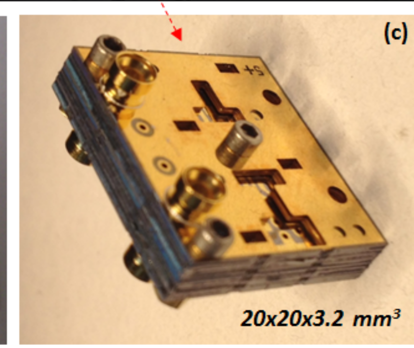
TOWARDS ULTRA-COMPACT TRANCEIVERS



20x20x3 cm3







2x2x1.2 cm3

CNC machining

2x2x0.3 cm3

Silicon machining

CONCLUSIONS

- **Science Focus Area: Climate Variability and Change.**
  - UT humidity disproportionally affects water vapor feedback
  - Ice crystal habit, nucleation, and growth are driven by UT humidity, and they couple to earth's radiative transfer and global energy/water cycles

- **A 183 GHz humidity sounding radar will be complementary to two missions: ACE (cloud/aerosol microphysics) and PATH (temperature and humidity soundings).**

- **The radar will leverage technology developed by several past ACT & IIP investments in extremely high frequency amplifiers using state-of-the-art III-V semiconductor processes.**

- **Compact transceiver is appropriate for UAV and CubeSat platforms (e.g., no vacuum tube sources), and it has potential for measuring accurate cloud heights for moisture retrieval model accuracy.**

- **If re-tuned to 220 GHz atmospheric transmission window, the transceiver enables: measurements of particle size distributions, cloud-penetrating altimetry, low-altitude cloud sensing above arctic ice cracks, and national security applications.**