A 183 GHz Humidity Sounding Radar Transceiver
ACT-13

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Ken Cooper, Matt Lebsock, Jose Siles, Raquel Monje, Luis Millan, Choonsup Lee, Pekka Kangaslahti, Goutam Chattopadhyay, Robert Lin, David Gonzalez, & Simone Tanelli

Jet Propulsion Laboratory, California Institute of Technology

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Clouds are the single most important source of uncertainty in predictions of climate sensitivity.

Problem: passive radiometry is unreliable inside clouds because: (1) broad weighting functions are used that encompass both clouded and cloud-free regions and (2) clouds obscure the relationship between passive brightness temperatures and water vapor.

Therefore, a remote sensing instrument capable of measuring humidity inside cirrus clouds on a global scale is needed.
JPL’s Approach: 183 GHz Differential Absorption Radar

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

- Similar to widely used lidar techniques (DIAL) and microwave differential absorption at 60 GHz to measure integrated $O_2$ absorption from sea surface reflection.
Radar Sensitivity Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>along-track resolution</td>
<td>500 m</td>
</tr>
<tr>
<td>cloud thickness resolution</td>
<td>500 m</td>
</tr>
<tr>
<td>platform velocity</td>
<td>110 m/s</td>
</tr>
<tr>
<td>receiver noise figure</td>
<td>8 dB</td>
</tr>
<tr>
<td>antenna diameter</td>
<td>25 cm</td>
</tr>
<tr>
<td>distance from cloud top</td>
<td>0.5-1 km</td>
</tr>
<tr>
<td>cloud top reflectivity</td>
<td>-30 dBZ</td>
</tr>
</tbody>
</table>

0.1-1 W power levels give reasonable humidity estimates with 1 km integrated range. 1 W clearly probes wider/deeper regime.
What’s Needed to Make It Work

High-level overview:

- All-solid-state transmitter & receiver to achieve smallest SWAP.
- 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.
Power-Combining at 183 GHz

Four-way “on-chip” power combining

quad-chip device

91-97 GHz input

bottom layer

182-194 GHz output

top layer
Quad-Chip 183 GHz Doubler

Raytheon 92 GHz GaN power amplifiers: leveraging security for remote sensing science.

Stacked-Chip Power Combining

- Higher powers likely if we push it
- Stable with 1.2W drive power (210 mW output) for >100 minutes
- 1 W goal is within reach with power-combining

![Diagram with diodes, G-band output waveguide, W-band input waveguide, and graph showing output power versus frequency. The graph indicates up to 24% efficiency with 800 mW input! with a 2 cm scale.]
FMCW radar design based on 340/680 GHz security radar architecture.
183-193 GHz Radar Test-Bench: Hardware

- optics gain: 40 dB
- receiver NF: 7 dB
- detectable rain reflectivity at 300 m, 3 ms integration: -28 dBZ
Tree & Hill Clutter Measurements
Measuring Humidity Using Clutter Targets

averaging 300 MHz, 0.5 ms chirps

183.5:193 GHz spectra

- tree branches
- hillside

it's looking real!

propagation model for very dry conditions
Clutter Target Statistics of Blowing Trees

Frequencies are switched every ~30 seconds here.

Dynamics of target brightness must vary more slowly than ~10 minutes for this approach to work.
Rain (or Clouds): An Excellent Clutter Target

It finally rained at JPL!

- No more problems with blowing corner reflector poles or tree branches
- No radiometer satellites were overhead: transmitting 183-193 GHz is sensitive.
Crucial Technique: Fast Frequency “Switching”

- Perform entire 9.5 GHz chirp at once (in 32 ms) before the clutter target can decorrelate
- Acquire 500 total chirps in a row
- Calculate relative attenuations
Accurate Humidity Measurements Are Possible!

- Received power (arb. dB) vs. range (m)
  - 192.5 GHz
  - 183.5 GHz

- Tx frequency (GHz) vs. range difference: 50 and 175 m
  - Higher absorption
  - 175±5 m avg. pow.

- Relative attenuation to 193 GHz (dB/km)
  - Measurement
  - Model average

Range difference: 50 and 175 m
Conclusions

• New power-combining architectures are being developed for a 183 GHz differential absorption radar transceiver.

• 500 mW has been achieved, but for stable results new isolated-port power combining designs are now being fabricated and tested.

• Radar test-bench experiments show that differential absorption radar can effectively measure humidity inside rain. This is a new measurement technique!

• The measurements require fast frequency-switching when targets have potential for decorrelating.