A 680 GHz Detection Dual-Channel Polarimetric Receiver

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Outline

• Motivation
• Receiver Overview
• 670 GHz Component Design
• Measured Receiver Performance
• 1/f Noise Mitigation Technique
• Sensitivity Improvement from the TWICE receiver
• Conclusion
Motivation - SWIRP Instrument

- SWIRP (Submm-Wave InfraRed Polarimeter) provides measurements of cloud ice, temperature, water vapor content, and precipitation in the upper atmosphere.
- Focused on spectral windows at 220 GHz and 680 GHz, as well as IR 8, 11.4, 12 µm wavelengths.

**THIS WORK:**
- 680 GHz InP HEMT direct detection receiver
25nm InP HEMT Process

- **25 nm gate process**
  - 0.1 µm recess
  - 0.1 µm gate stem and 0.4 µm gate top for minimal gate resistance
  - 25 nm gate fabricated with 100 kV E-beam lithography
  - $f_T = 0.6$ THz, $f_{max} = 1.5$ THz

- **0.5 µm source-drain spacing**
  - Tight alignment of 0.4 µm width gate metal top within 0.5 µm source-drain contacts
  - DC 0.13 Ω-mm source resistance with 0.04 Ω-mm contact resistance

- **Layout scaling for reduced parasitics and losses**
  - Supports transistor sizes from 3 – 25 µm unit gate width
Receiver Architectures for Radiometry

**Superheterodyne**
- Doesn’t necessarily need RF BPF, which can be sensitive to manufacturing tolerances at high frequencies
- Demodulates at IF frequency, RF 1/f noise not present in $V_{out}$

**Direct Detection**
- Fewer components, reduces complexity
- Compact form factor
- Significantly lower DC power consumption - Factor of 10
- No trade off in noise figure with front end RF LNA

Direct Detection: Superior SWaP with No Trade-off in Noise Figure
680 GHz Direct Detection Receiver

**H-plane LNA Module**
- Two 676-688 GHz LNA MMICs
- Separated E/H plane LNAs for compact design = improve sensitivity

**3rd Stage LNA Module**
- One WR-1.5 LNA MMIC

**BPF Module**
- 676-688 GHz Nuvotronics Polystrata

**Detector Module**
- VDI zero bias diode detector
- Accommodates LNA regulator PCB

**Horn/OMT Module**
- WR-1.5 integrated horn, OMT

**E-plane LNA Module**
- Two WR-1.5 LNA MMICs
- Integrated voltage regulator and switching capabilities for 1/f noise reduction

**Video Amplifier**
- DC – 21 kHz video amplifier PCB
- Integrated voltage regulator with +/-12V inputs

**Dimensions:**
- 2.6 x 3.1 x 5.8 cm

**DC power:** 1.0 W

**Gain:**
- H-plane channel: WR-1.5 Horn LNA Gain ~26 dB
- E-plane channel: Waveguide Bend LNA Gain ~14 dB
- BPF 676-688 GHz
- Diode Detector
- Video Amp Gain = ~2000
- Video Amp Fc = ~21 kHz
Horn/OMT Module

- Circular Potter horn with transition to 11 x 11 mil square waveguide
- Orthomode transducer splits incoming signal into two orthogonally linear polarized V/H polarized channels (E-plane/H-plane)
- Back-to-back OMT test structure measured, exhibited > 40 dB isolation across WR-1.5

Radiation Pattern

![Radiation Pattern Diagram]

- **Dimensions:** 0.8 x 1.2 x 2.6 cm
- **18° HPBW**
680 GHz Bandpass Filters - Nuvotronics

- 9 filter variations designed
- Nominal cell length and sidewall angle shifted about 2 GHz down from simulation
- Passband ripple may be from mismatch in filter to waveguide transition design

- **Sidewall angle**: deviation from perfect 90° cell wall in the build direction (88° expected)
- **Cell length**: capacitive cell length increased/ decreased to account for potential frequency shifts
Filter Selection

- Filters chosen to match bandwidth on both channels, keeps NEΔT consistent between channels
- Ideally want to cut off ozone lines below 675 GHz, above 690 GHz
- As long as filter bandwidths match, contributions due to ozone can be accounted for in calibration

Lot Variation

Selected Filters

Spectral Window

Ozone lines

-25 dB down

Spectral Windows Near 680 GHz
680 GHz Component Summary

Horn Pattern

18° HPBW

- Normalized Gain (dB) vs. Angle from Boresight (deg)
- E-plane: 0° to +90°
- H-plane: 0° to +90°
- E-plane: -90° to 0°
- H-plane: -90° to 0°
- E-plane: sim
- H-plane: sim

LNA

32 dB gain

- Receiver RF Gain (dB) vs. Frequency (GHz)
- RX1 Ch. E
- RX1 Ch. H
- RX2 Ch. E
- RX2 Ch. H

Detector

- VDI zero bias detector
- Integrated video amplifier and voltage regulator

H-plane Bend

~4 dB loss

- Highly subject to machining tolerances

Feedthru

WR-1.5 Waveguide

Substrate

Diode

Video Amps

MSSS Outputs

E-Plane Detector

H-Plane Detector
680 GHz Receiver Results

• Configured to output ~2V
• Two units built and characterized
• Noise figure, output voltage, and switching speed characterized
• H-plane channel outputs lower voltage and higher noise figure, extra loss in front-end H-plane waveguide in OMT housing.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RX #1 (E)</th>
<th>RX #1 (H)</th>
<th>RX #2 (E)</th>
<th>RX #2 (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Output Voltage (V)</td>
<td>2.85</td>
<td>1.58</td>
<td>2.81</td>
<td>1.70</td>
</tr>
<tr>
<td>NF (dB)</td>
<td>10.5</td>
<td>10.6</td>
<td>11.4</td>
<td>10.8</td>
</tr>
<tr>
<td>Switching Rise Time (μS)</td>
<td>18.6</td>
<td>19.3</td>
<td>19.6</td>
<td>21.8</td>
</tr>
<tr>
<td>Switching Fall Time (μS)</td>
<td>17.7</td>
<td>19.8</td>
<td>20.2</td>
<td>23.6</td>
</tr>
</tbody>
</table>

Switched Output Voltage
1/f Noise in Direct Detection Receivers

- 1/f “flicker noise” inherent in HEMT transistors
- Direct detection receivers output at DC
- Noise from all RF amplifiers and diode detector present in DC output
- 1/f noise dominates over receiver white noise floor at frequencies of interest, degrading SNR

\[ f_s > f_{knee} \]
1/f Noise in Submillimeter Wave Receivers

- 1/f noise increases with decreasing gate length.
- Gate length must be aggressively scaled to operate at submillimeter wave frequencies (25 nm).
- 1/f noise additive PER TRANSISTOR.
- Number of transistors needed to achieve adequate gain scales with frequency.

Modulated Bias 1/f Noise Mitigation Technique

Pros:
- Avoids noise figure degradation due to lack of front-end switch losses
- No additional RF components, easily integrated into existing radiometer platforms

Cons:
- Concerns for transistor survivability with switching in-rush currents on the bias lines
- No reference load for gain calibration.
- Additional 3 dB loss in receiver sensitivity due to switching
- Only viable at frequencies where single transistor gain is low

- LNAs designed to have 1st transistor bias “chopped”
- 1 kHz 3.3 V control signal
Sensitivity Improvement of the TWICE 670 GHz Receiver

- First demonstration of 1/f noise mitigation technique for submm wave radiometers
- Motivation for further switching development
- Lowered $\Delta T$ by 3.87 K

**NEΔT Results with 50 msec Integration Time**

<table>
<thead>
<tr>
<th>NEΔT Without Switching</th>
<th>NEΔT With Switching</th>
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<tr>
<td>4.75 K</td>
<td>0.88 K</td>
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</tbody>
</table>

Conclusion

• First 680 GHz direct detection polarimeter
  – Enabled by 25 nm InP HEMT TMIC technology
  – 32 dB gain
  – 17 GHz filter bandwidth centered at 680 GHz
  – 10.5/10.6 dB minimum V/H channel integrated noise figure

• Novel 1/f noise mitigation technique
  – Radiometric performance evaluated for TWICE 670 GHz receiver.
  – SWIRP receiver radiometric characterization upcoming
  – Other 1/f mitigation techniques also being investigated
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• Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.
Contact Information for Further Questions

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