Radiometer Testbed Development for SWOT

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Outline

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• LNA Modules
• Direct Detection Radiometers
• Internal Calibration
• Conclusions
Introduction

- Conventional altimeters include nadir looking co-located 18-37 GHz microwave radiometer to measure wet tropospheric path delay
- High-frequency window channels, 90, 130 and 166 GHz are optimum for improving performance in coastal region
- Channels on 183 GHz water vapor line are ideal for over-land retrievals.

*Path Delay derived from 113 and 166 GHz channels over JPL – 2/2/2010*
Introduction

• Window channels (blue boxes) have wide bandwidth and large contrast in water vapor signal
Introduction

- Fixed radiometer field-of-view and no moving parts requires internal calibration
  - Examples:
    - Dicke load and cold sky horn (Topex, ERS-1,2)
    - Dicke load and noise diodes (Jason-1, Jason-2)
- Stability of internal calibration references for frequencies > 90 GHz must be characterized
- Test bed being developed to characterize stability of internal calibration sources between 90-180 GHz
  - RF switches
  - Active Sources (e.g. noise diodes)
  - Inherent stability of Low Noise Amplifiers
LNA Modules

• Development based on a high performance 35 nm gate length InP HEMT (\(f_T > 550\text{GHz}\) and \(f_{\text{max}} > 1\ \text{THz}\))
• LNA MMICs in the 35 nm process were fabricated in previous projects
• LNA module development included housing and microstrip to waveguide transition design
• Transitions included matching networks to compensate for the wirebonds
LNA Modules

• Testing of noise temperature and gain
• Y-factor hot/cold load testing with absorber at room temperature and liquid nitrogen temperature
LNA Modules

- First MMIC LNA type was packaged in WR-05 and WR-08 housings to characterize it over broadband
- Record low noise temperature of 300 K at 150 to 160 GHz frequency range
LNA Modules

- Second MMIC LNA type was packaged in WR-08 and WR-10 housings to characterize it over broadband
- Suitable for the 130 GHz radiometer testbed
Direct Detection Radiometer Testbeds

These LNA modules enabled us to design direct detection radiometer test beds.

• do not require local oscillators
• operate with very low DC power.
• The radiometers are a cascade of two or three LNA modules, band definition filter and detector.
## Direct Detection Radiometer Testbeds

<table>
<thead>
<tr>
<th></th>
<th>92 GHz</th>
<th>130 GHz</th>
<th>166 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gain</strong></td>
<td>40dB</td>
<td>40dB</td>
<td>45dB</td>
</tr>
<tr>
<td><strong>Receiver NT</strong></td>
<td>340 K</td>
<td>340 K</td>
<td>455 K</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td><strong>DC Power</strong></td>
<td>40mW</td>
<td>40mW</td>
<td>60mW</td>
</tr>
</tbody>
</table>

- Direct detection approach minimizes radiometer complexity
Direct Detection Radiometer Testbeds

- Inherent stability of LNA tested to give $\frac{dG}{G}$ at stable temperature
- Receivers exhibit $\frac{dG}{G} \sim 2e^{-4}$ or better to 30s
Direct Detection Radiometer Testbeds

- TEC used to cycle receiver over temperature
- LNAs exhibit low temperature dependency
  - Gain temperature coefficient of 1%/C (0.04dB/C)
  - Receiver noise temperature also stable over temperature
Direct Detection Radiometer Testbeds

- 166 GHz LNAs also exhibit low temperature dependency
  - Gain temperature coefficient of 1.3%/C (0.06dB/C)
  - Receiver noise temperature changes at 2K/C
Internal Calibration

- Measurement noise depends on scene NEDT and noise from calibration
  - Can determine requirements for internal calibration sources

\[ \Delta T_A^2(\tau_A, \tau_{Cal}) = \{NE\Delta T^2(\tau_A) + \Delta T_{Cal\_white}^2(\tau_{Cal}) + \Delta T_{Cal\_Systematic}^2(\tau_{Cal})\} \]

Measurement noise (K) for different calibration source temperature differences based on LNA stability measurements

<table>
<thead>
<tr>
<th>Cal TB difference</th>
<th>90 GHz</th>
<th>130 GHz</th>
<th>166 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.13</td>
<td>0.13</td>
<td>0.16</td>
</tr>
<tr>
<td>50</td>
<td>0.11</td>
<td>0.11</td>
<td>0.093</td>
</tr>
<tr>
<td>150</td>
<td>0.10</td>
<td>0.10</td>
<td>0.083</td>
</tr>
<tr>
<td>300</td>
<td>0.10</td>
<td>0.10</td>
<td>0.082</td>
</tr>
</tbody>
</table>
**Internal Calibration**

- WR-10 packaged AMR noise diode ENR vs frequency and current
- Good ENR at reasonable current up to 120 GHz
- WR-10 package design unmatched
  - 166 GHz WR-05 package will need to be matched to get sufficient ENR
Conclusion

• The developed MMIC LNAs had the lowest reported noise figure at 160 GHz frequency band of receivers operating at ambient temperature.

• The developed 166, 130 and 92 GHz radiometer testbeds have small size, very low power consumption and mass, because of the direct detection mode of operation.

• Demonstrate and test critical technologies for the SWOT radiometer development.

• MMIC LNA modules and radiometer testbeds were developed in ESTO IIP-07 task "Ka-band SAR Interferometry Studies for the SWOT Mission".

• The LNAs were also integrated in the airborne High Altitude MMIC Sounding Radiometer (HAMSR) that was developed under the IIP-98 and currently is funded to be installed onto the Global Hawk UAV for participation in NASA's Genesis and Rapid Intensification Processes (GRIP) hurricane field experiment in the summer of 2010.
Acknowledgement

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