Radiometer-on-a-Chip
End of Fall 2011 Semester Presentation

Thaddeus Johnson and Torie Hadel
Introduction

Thaddeus Johnson
- Pursuing Bachelors in Electrical Engineering
- Worked in Microwave Systems Lab (MSL), ERC EUV, and interned at Micron as a Mobile Product Engineer

Torie Hadel
- Pursuing Bachelors in Electrical Engineering with a minor in Mathematics
- Worked in CSU Semiconductor Processing Cleanroom and interned at Intel as an Analog Circuit Designer
Outline

I. Introduction
II. Background
III. Analysis of Existing Research
IV. Our Project
V. Budget
VI. Future Work

Figure 1: MSL Graduate Students Alex Lee and Darrin Albers Performing Calibration on a 92 GHz Radiometer
Diagram courtesy of Microwave Systems Lab (MSL).
What is a radiometer?

- A radiometer is a passive receiver that is designed to measure a selected frequency range of a scene’s emitted electromagnetic radiation.
- Radiometers can be applied to measure water vapor profiles, wind vectors, sea water salinity, cloud liquid water etc.
- Microwave radiometers have the advantage of taking measurements on a continuous basis as well as nearly all weather operation.
- Our project focuses on improving the performance of a 92 GHz radiometer developed by a joint effort between CSU’s Microwave Systems Laboratory (MSL) and Caltech’s Jet Propulsion Laboratory (JPL).

Figure 2: 92 GHz Radiometer with Front-End Horn Antenna
Diagram courtesy of Microwave Systems Lab (MSL).
Dicke Switched Radiometer

- This type of radiometer uses a single-pole double-throw (SPDT) RF monolithic millimeter-wave integrated circuit (MMIC) switch on the front end of the receiver to eliminate internal gain fluctuations.
- The switch looks at the antenna and the constant noise source, or reference, for equal amounts of time over the integration time $\tau$.

**Figure 3: Single-Pole Double-Throw Switch**

*Diagram provided by Oliver Montes Presentation on High Frequency PIN-Diode Switches for Radiometric Applications*
Figure 4: SPDT Circuit
Diagram provided by Oliver Montes Presentation on High Frequency PIN-Diode Switches for Radiometric Applications

Figure 5: Fabricated SPDT Switch with Asymmetric Symmetry
Diagram provided by Oliver Montes Presentation on High Frequency PIN-Diode Switches for Radiometric Applications
Insertion loss and Isolation are critical in the performance of PIN diode switches. Here the insertion loss is of an acceptable value; however, the isolation was incorrectly modeled and it turned out to be optimized for a much higher frequency.

Figure 6: Simulated and Measured Results on SPDT Switch

Diagrams provided by Oliver Montes Presentation on High Frequency PIN-Diode Switches for Radiometric Applications
Analysis of Existing Research

Post-Fabrication On-Chip Tuning of Isolation

Figure 7: Tuning to SPDT Switch with Asymmetric Symmetry
Diagram provided by Oliver Montes Presentation on High Frequency PIN-Diode Switches for Radiometric Applications

Figure 8: Isolation of tuned vs. Un-tuned PIN-Diode in SPDT Switch
Diagram provided by Oliver Montes Presentation on High Frequency PIN-Diode Switches for Radiometric Applications
Goals of Project

• Learn how to prepare devices and take accurate, reliable, and repeatable measurements using MSL equipment at low and high frequencies
• Measure PIN diodes and SPDT MMIC PIN switch at both low and high frequencies, compare results with JPL results
• Investigate sources of error
• Design a new PIN diode model
• Integrate updated PIN diode model into switch model
• Offer recommendations to JPL
This is the multi-chip module (MCM) for a 92 GHz radiometer developed at CSU’s Microwave Systems Laboratory that utilizes the 80-105 GHz SPDT PIN diode switch that we are improving the model for.

**Figure 8: Cut of 92 GHz Radiometer MCM**
*Diagram courtesy of MSL.*

**Figure 9: Front End of 92 GHz Radiometer**
*Diagram Courtesy of MSL.*
Journal Papers

• K. Lam, et. al., "Wideband Millimeter Wave PIN Diode SPDT Switch Using IBM 0.13µm SiGe Technology,” *Microwave Integrated Circuit Conference*, 8-10 Oct. 2007, Munich, Germany


Books


Figure 10: Epoxied and wire bonded LNA
Diagram provided by Willow Toso Thesis on Development of a Miniaturized Microwave Radiometer for Satellite Remote Sensing of Water Vapor

Gold wire bonds

Silver substance is epoxy

Figure 11: Wire Bonding Station
Courtesy of MSL

Figure 12: Diagram of Wire Bonding and Expoxied GSG Pads
http://www.jmicrotechnology.com/PPPict.gif
SOLT Calibration

- **Short-Open-Load-Thru**
- Commonly used
- Sensitive to probe placement

**Figure 12: PP CMO5LX Used in Our Calibration**

http://www.jmicrotechnology.com/ProductivityNote/PR_RF_MeasWEB.pdf
RF Bandpass Filter

S21 Parameter Measurement Comparison

Figure 14: Previous S-Parameter Measured Response
Diagram provided by Dr. Flavio Iturbide-Sanchez’s Dissertation on Design, Fabrication, and Deployment of a Miniaturized Spectrometer Radiometer Based on MMIC Technology for Tropospheric Water Vapor Profiling

Figure 15: Our Measured S-Parameter Measured Response

8.76 mm
1.89 mm

Figure 13: RF Bandpass Filter
Diagram provided by Dr. Flavio Iturbide-Sanchez’s Dissertation on Design, Fabrication, and Deployment of a Miniaturized Spectrometer Radiometer Based on MMIC Technology for Tropospheric Water Vapor Profiling
Accomplished

- Created website for project
- Researched radiometry, PIN diodes, cascaded noise figure, switches and other relevant topics
- Gave presentation to MSL
- Donations of GSG pads from JMicrotech
- Learned wire bonding and how to epoxy
- Set up probe station and used network analyzer to take S-Parameter measurements from 0-50 GHz on sample passive and active components

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## Radiometer-on-a-Chip Budget

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<tr>
<th>Item</th>
<th>Quantity</th>
<th>Purpose</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>Ground-Signal-Ground Pads</td>
<td>30</td>
<td>Adaption to match MSL probe pitch to JPL pitch on diodes and switches.</td>
<td>Donated by Jmicrotech (Estimated Cost ~ $600)</td>
</tr>
<tr>
<td>0-40 GHz Probes</td>
<td>3</td>
<td>GSG pads were too big to fit on diode test substrates, had to purchase probes to continue measurements.</td>
<td>$750 each</td>
</tr>
<tr>
<td>Trip to JPL</td>
<td>2 x Round-trip Airfare Hotel Accomadations</td>
<td>MSL does not have the necessary pitch of high frequency probe tips. We will go to JPL to take these measurements under their guidance.</td>
<td>(Estimated Cost ~ $1000)</td>
</tr>
<tr>
<td>PIN Diodes and MMIC Switches</td>
<td>9 x PIN Diodes 4 x MMIC Switches</td>
<td>To take measurements on to confirm simulation results.</td>
<td>n/a</td>
</tr>
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<td>Total</td>
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<tr>
<td>Total with Donations</td>
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<tr>
<td>Total Projected Costs</td>
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Table 1: Projected Costs for Radiometer-on-a-Chip Project

Thanks for your generous donation.

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Radiometer-on-a-chip
Future Work

- Start to build initial diode model in Ansoft Design Software (ADS)
- DC and 0-40 GHz AC measurements on PIN diodes
- Build SPDT RF MMIC Switch model in ADS
- Modify switch model to match 0-40 GHz measured S-parameters
- Modify switch model to match JPL W-band measured S-parameters
- If time allows, go to JPL to take W-Band measurements
- Propose recommendations for JPL

Figure 16: Flow Chart for Future Work
We would like to thank Professor Steven C. Reising for helping us arrange this partnership as well as granting us access to his students, his guidance, and his equipment.

We would like to thank Dr. Pekka Kangaslahti and JPL for the opportunity to work on the project, for donating PIN Diodes and MMIC switches for us to use in our measurements, and for his time and technical advice.

We would like to thank Alexander Lee for his time and assisting us this past semester.

We would like to thank Xavi Bosch for taking over our mentoring for the Spring 2012 semester, we look forward to working with you.

We would like to thank Oliver Montes for allowing us to continue his project.

We would like to thank Jmicrotech for their generous donation.
Simple PIN Diode Model

Reverse Biased Small-Signal Model

Forward Bias Small-Signal Model
Comparison of a Dicke Radiometer and a TPR

The advantages of a Dicke radiometer over a TPR can be seen through comparing the equations for radiometric resolution and output voltage.

\[ \Delta T_{DR} = \left[ \frac{2(T_A + T_{REC})^2 + 2(T_{REF} + T_{REC})^2}{B \tau} + \left( \frac{\Delta G_s}{G_s} \right)^2 (T_A - T_{REF})^2 \right]^{\frac{1}{2}} \]

\[ \Delta T = 2 \cdot \frac{T_{REF} + T_{REC}}{\sqrt{B \cdot \tau}} \]

\[ V_{out,Dicke} = kBC_d G(T_A - T_{REF}) + kBC_d \Delta G(T_A - T_{REF}) \]

Total Power Radiometer

\[ \Delta T_{TP} = (T_A + T_{REC}) \left[ \frac{1}{B \tau} + \left( \frac{\Delta G_s}{G_s} \right)^2 \right]^{\frac{1}{2}} \]

\[ \Delta T = \frac{T_{ANT} + T_{REC}}{\sqrt{B \cdot \tau}} \]

\[ V_{out,TP} = kBC_d G(T_A + T_{REC}) + kBC_d \Delta G(T_A + T_{REC}) \]