Calibration of Hurricane Imaging Radiometer C-Band Receivers

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Hurricane Imaging Radiometer

- **Objectives:**
  - Map surface wind speed over wide swath (~50-60 km, for aircraft > FL600) in hurricanes
  - Provide research data for understanding hurricane structure, intensity change
  - Enable improved forecasts, warnings, decision support

- **Technical Approach:**
  - C-band multi-frequency microwave radiometer; retrieval approach similar to operational SFMR
  - Interferometric aperture synthesis in the cross-track direction to image wide swath (SFMR : nadir only measurements).

- **Future Goals:**
  - Upgrade to add wind direction
  - More robust 2nd-generation instrument(s)
HIRAD Wind Speed Retrievals, 2010-2015

2015 Tropical Cyclone Intensity (TCI) Experiment flights with dropsonde comparisons in red

- Ingrid 2013
- Earl 2010
- Erika 2015
- Patricia 2015
- Karl 2010
- Marty 2015
- Joaquin 2015
- Gonzalo 2014

WS (m/s)

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<th>WS (m/s)</th>
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<tr>
<td>10</td>
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HIRAD WS Evaluation during TCI

- Tropical Cyclone Intensity (TCI) Experiment, 2015
  - Sponsored by Office of Naval Research
  - HIRAD and High Density Sounding System (HDSS) on NASA WB-57 in 2015
  - Hurricanes Joaquin, Patricia, Marty, and remnants of TS Erika

- Results (*Cecil & Biswas, 2017)
  - HIRAD surface wind speed retrievals evaluated using HDSS dropsonde intercomparison for 636 sondes, 10 flights during 2015 TCI project
  - Performance looks good across all incidence angles
  - Bias < 2 m s\(^{-1}\); near zero for most flights
  - Estimated RMS Error ~ 4.7 ms\(^{-1}\)
    - SFMR – dropsonde RMS Difference is 3.9 ms\(^{-1}\) (2015 version)

- This presentation details the determination of calibration parameters for 10 HIRAD multi-frequency (4, 5, 6 & 6.6 GHz) receivers. These parameters were used to generate HIRAD TB images during TCI, 2015.

* Cecil D.J. and Biswas S.K., Hurricane Imaging Radiometer Wind Speed Retrievals and Validation Using Dropsondes, *Journal of atmospheric and oceanic technology*, 2017 (submitted)
I1 = Input Isolator  
S1 = Switch assembly generating three switching states (SP3T)  
WL = Warm Load  
CL = Cold Load  
D1 = Directional Coupler (for coupling noise diode)  
G1 = Low Noise Amplifier (LNA)  
DBE = Digital Back End (housed inside C&DH)  

1 through 5 are the location of RTD

-- Antenna Input Reference  
-- Cal Switch Output Reference
Receiver Front End Loss Model

- $L_{fe}$: transmission coefficient of the front-end loss
- $T_{inRx}$: noise temperature referenced at the receiver input
- $T_{inCalSW}$: noise temperature referenced at the switch o/p

The $T_{inCalSW}$ and $T_{inRx}$ are related by:
- $T_{inCalSW} = L_{fe} \cdot T_{inRx} + (1 - L_{fe}) \cdot T_{iso}$ \quad \text{--- (1)}
  - $T_{iso}$ is the physical temperature of $L_{fe}$ (given by RTD#3)

- $T_c$ ($T_w$) is cold (warm) load noise temperature and $T_{nd}$ is the excess noise temperature added by the noise diode

- $L_{fe}$ and $T_c$ or $T_{nd}$ are required to estimate $T_{inRx}$ from measured counts.

- External noise references were used to determine these parameters in laboratory.
Laboratory Calibration Setup

- **External Calibration Reference**
  - **Cold Reference** – 7mm Coaxial Cryogenic termination (MT7118J)
  - **Hot Reference** – 7mm Coaxial Thermal termination (MT7108B)
  - **Ambient reference** – 50 ohm RF termination (DC-20GHz), ~ 30dB return loss.

- Cold reference output noise temperature @ HIRAD freqs: 80.6, 81, 81.5 and 82 K
- Ambient load temp measured using RTD data logger
- Hot load maintained @ 85.3 deg C
Receiver # 01: Counts vs. $T_{in_{Rx}}$

4.0 GHz

$R_{x#01} 4\text{GHz Full Band } T_c(\text{Prosensing}) = 42\text{K}, T_w(\text{Recev}) = 300\text{K}$

5.0 GHz

$R_{x#01} 5\text{GHz Full Band } T_c(\text{Prosensing}) = 70\text{K}, T_w(\text{Recev}) = 300\text{K}$

6.0 GHz

$R_{x#01} 6\text{GHz Full Band } T_c(\text{Prosensing}) = 90\text{K}, T_w(\text{Recev}) = 300\text{K}$

6.6 GHz

$R_{x#01} 7\text{GHz Full Band } T_c(\text{Prosensing}) = 71\text{K}, T_w(\text{Recev}) = 300\text{K}$
Received # 09: Counts vs. $T_{in, Rx}$

4.0 GHz

5.0 GHz

6.0 GHz

6.6 GHz

6.0 GHz Worst Case!
Effect of $L_{fe}$ Adjustment (6 GHz, Rx#09)

$$T_{in\text{CalSW}} = L_{fe} \times T_{in\text{Rx}} + (1 - L_{fe}) \times T_{iso} \quad --- \ (1)$$
Rx#09  Best Fit Residual Error vs $L_{fe}$

$L_{fe}$ solution based on minimum residual error
Estimated Front-end Loss ($L_{fe}$)

$L_{fe}$ vs. Frequency For All Receiver

$L_{fe}$ vs. Receiver For All Frequency

Frequency (GHz)

Receiver #
Final Tin_{CalSW} to Count Transfer Function

4.0 GHz
Rxn#09 4GHz Lfe=0.93 Tc(Prosensing) = 45K, Tnd = 62K

Noise temperature @ CalSwitch O/P (K)

Second Moment Counts

Cold + ND Count
Cold Load Count

6.0 GHz
Rxn#09 6GHz Lfe=0.57 Tc(Prosensing) = 108K, Tnd = 26K

Noise temperature @ CalSwitch O/P (K)

Second Moment Counts

Cold + ND Count
Cold Load Count

Solve Tnd using L_{fe} and Prosensing Tc

5.0 GHz
Rxn#09 5GHz Lfe=0.84 Tc(Prosensing) = 69K, Tnd = 58K

Noise temperature @ CalSwitch O/P (K)

Second Moment Counts

Cold + ND Count
Cold Load Count

6.6 GHz
Rxn#09 7GHz Lfe=0.75 Tc(Prosensing) = 67K, Tnd = 39K

Noise temperature @ CalSwitch O/P (K)

Second Moment Counts

Cold + ND Count
Cold Load Count

Solve Tnd using L_{fe} and Prosensing Tc
Estimated $T_{ND}$

$T_{ND}$ vs. Frequency For All Receiver

$T_{ND}$ vs. Receiver For All Frequency
RMS Uncertainties in Calibrated \( \text{Tin}_{\text{CalSW}} \)

**RMS ERROR vs. Frequency For All Receiver**

- Rx01
- Rx02
- Rx03
- Rx04
- Rx05
- Rx06
- Rx07
- Rx08
- Rx09
- Rx10

**RMS ERROR vs. Receiver For All Frequency**

- 4.0 GHz
- 5.0 GHz
- 6.0 GHz
- 6.6 GHz

Frequency (GHz)

Receiver #
Summary

• Laboratory calibration of HIRAD C-Band receivers is described: front-end loss and injected noise diode temperatures are estimated

• Internal warm load is excluded from current calibration

• RMS uncertainty in absolute calibration varies for receiver/frequency combinations between 0.4-2.3 K at the cal switch output reference.

• Current calibration produces ~ 4.7 ms-1 wind speed error based on estimates from ~600 dropsonde comparison.

Acknowledgement: The authors wish to thank L. Jones (University of Central Florida) whose MT7118J & MT7108B calibration loads were used for the test, C. Ruf (University of Michigan) for the valuable discussions during data analysis, C. Benson (NASA MSFC) and D. Simmons (University of Alabama), who procured the liquid nitrogen for this test and many other members of the HIRAD team who directly or indirectly helped in this work. This work was supported by the NASA Marshall Space Flight Center Earth Science Office and the NASA Hurricane and Severe Storm Sentinel (HS3) mission.
BACK UP CHARTS
## Lfe, Tc and Tnd Used in Final Calibration

<table>
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<th>Receiver#</th>
<th>LFE (ratio)</th>
<th>Tc (K)</th>
<th>Tnd (K)</th>
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<td></td>
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