UWBRAD:
Ultra-Wideband Software-Defined Microwave Radiometer for Ice Sheet Subsurface Temperature Sensing


Year 1 Annual Review Meeting
3rd March 2015
Columbus, OH
Review Goals

The PI must provide a presentation summarizing the work accomplished and results leading up to this Review and must:

1. Describe the primary findings, technology development results, and technical status, e.g., status of design, construction of breadboards or prototype implementations, results of tests and/or proof-of-concept demonstrations, etc.;

2. Describe the work planned for the remainder of the project and critical issues that need to be resolved to successfully complete the remaining planned work;

3. Summarize the cost and schedule status of the project, including any schedule slippage/acceleration. A schedule milestone chart of all major task activities shall be created and maintained and shown at all reviews. A cost data sheet shall be created and maintained, showing total project costs obligated and costed, along with a graphical representation of the project cost profile to completion;

4. Provide a summary of anticipated results at the end of the task; and

5. At subsequent reviews, address the comments and recommendations prepared by the reviewers participating in the most recent review.
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<th>Time</th>
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<td>0900-0920</td>
<td>Overview of project status</td>
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<td>0920-0945</td>
<td>Forward modeling/retrieval investigations</td>
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<td>0945-0955</td>
<td>Radiometer front end design status</td>
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<td>0955-1005</td>
<td>Digital backend and software status</td>
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<td>1005-1030</td>
<td>Antenna design status</td>
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<td>1030-1045</td>
<td>Next 6 months</td>
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<td>1045-1100</td>
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Objectives:
- Design, develop, test & validate an ultra-wide band, 0.5-2.0 GHz software defined microwave radiometer for sensing ice sheet internal temperature at depth
- Develop software defined algorithms for real time RFI mitigation enabling operation outside protected bands
- Design, develop, test & validate a new aircraft 0.5-2 GHz antenna
- Conduct ground based & airborne demonstrations of UWBRAD; flights on DC-3T (Basler) aircraft in Greenland
- Conduct science demonstration/validation of UWBRAD results
- Develop an experiment plan for deployment of UWBRAD to support future science observations of ice sheet temperatures
- Assess adaptation of instrument to other air and space platforms
- Address key NASA climate variability and change issues

Approach:
- UWBRAD is a 0.5-2 GHz nadir observing radiometer having 13 x 100 MHz fully digitized channels for RFI detection and mitigation
- Design, construct and demonstrate four channel system in year 1
- Design, construct, and test prototype antenna in year 1
- After initial tests, expand radiometer to 13 channels and test radiometer performance, software defined algorithms, cognitive radiometry, and full scale antenna in lab environment
- Develop and apply multi-frequency, model based retrieval algorithms to determine internal ice sheet temperatures
- Conduct flight demonstration in 2016 to validate technologies and science capabilities
- Assess science and technical data to develop a plan for integration of UWBRAD into NASA science mission
- Co-Is/Partners: K. Jezek (OSU), C. Chen (OSU), M. Durand (OSU), L. Tsang (University of Michigan)

Key Milestones:
- Complete Detailed System Design 10/2014
- Complete Four Channel Implementation/Test 4/2015
- Complete Antenna Prototype Fabrication/Test 4/2015
- Complete 13 Channel Implementation/Test 10/2015
- Complete Antenna Implementation/Test 10/2015
- Complete Laboratory Tests of Full System 4/2016
- Conduct Airborne Experiments 10/2016
- Complete Data Analysis 4/2017

\[ TRL_{in} = 3 \quad , \quad TRL_{out} = 5 \]
Project Team

**OSU ElectroScience Laboratory, Department of Electrical and Computer Eng.**

- PI: Prof. Joel T. Johnson
- Co-PI: Prof. Chi-Chih Chen (Antenna)
- Research Associate: Mark Andrews (Radiometer Hardware/Software)
- Postdoctoral Researchers: Alexandra Bringer, Hongkun Li (Modeling/Calibration)
- Research Scientists: Dr. Caglar Yardim (Modeling/Retrieval) and Dr. Brian Dupaix (Digital subsystem)
- Graduate Student: Mustafa Aksoy (RFI algorithms)
- Graduate Student: Domenic Belgiovane (Antenna)
- Technician: Jim Moncrief (Radiometer build/test)

**OSU Byrd Polar Research Center, School of Earth Sciences**

- Science PI: Prof. Ken C. Jezek (RT modeling/science/campaign planning)
- Co-PI: Prof. Michael C. Durand (Retrieval algorithms/science)
- Graduate Student: Yuna Duan (Retrieval algorithms/science)

**University of Michigan, Department of Electrical and Computer Eng.**

- Co-PI: Prof. Leung Tsang (Advanced RT modeling)
- Graduate Students: Shurun Tan, Tian-Lin Wang (Advanced RT modeling)
Project Team (cont’d) and Status

Independent Contractor: Dr. Vladimir Leuski (Radiometer Front end design/build)

Collaborators: Drs. Giovanni Macelloni and Marco Brogioni (CNR-IFAC, Italy) (Science/RT modeling/campaign planning)

Collaborators (not official): Drs. Mark Drinkwater, ESA, Ludovic Brucker, GSFC, Willie Thompson, Morgan State

- **Status:**
  - Start date 4/1/14, but project not in place officially at OSU until 5/1/14
  - Spending rate on track with budget now that full team is in place
  - Parts and hardware purchases will “catch back up” in next year
  - Still progressing to milestones on schedule
Milestones and Timeline

T1: Detailed Design
T2: Retrieval/RFI Studies
T3: Four Channel Build/Test
T4: Antenna Prototype Build/Test
T5: Four channel calibration studies
T6: Thirteen channel build/test
T7: Antenna Implement/Test
T8: Ground-based sky/cal tests
T9: Shake down flight: prepare/perform/analyze
T10: Greenland flight: prepare/perform/analyze
T11: Spaceborne Transition Analyses
T12: Other/Science Application Analyses
T13: System refinement/final report
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8/15: Delivery to Italy needed for potential participation in ESA DOME-C measurements
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<tr>
<th>Technology</th>
<th>Heritage</th>
<th>Entry TRL</th>
<th>Current Status</th>
<th>Planned Exit TRL</th>
<th>Success Criteria</th>
</tr>
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<td>Icesheet Subsurface Temperature Sensing</td>
<td>Analyses and SMOS radiometry</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>Successful airborne demonstration</td>
</tr>
<tr>
<td>Multi-frequency 0.5-2 GHz radiometry</td>
<td>MFRAD System (37 channels, 2-18 GHz)</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Subsystems integration and ground test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Successful airborne demonstration</td>
</tr>
<tr>
<td>Software defined radiometry with real-time RFI processing</td>
<td>Previous FPGA-based RFI processors; JPL’s IBOB and GSFC GREX Systems</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Demonstration in ground test</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Successful airborne demonstration</td>
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Motivation

- Understanding dynamics of Earth’s ice sheets important for future prediction of ice coverage and sea level rise
- Extensive past studies have developed a variety of sensing techniques for ice sheet properties, e.g. thickness, topography, velocity, mass, accumulation rate,…
- Limited capabilities for determining ice sheet internal temperatures at present
  - Available from small number of bore holes
- Internal temperature influences stiffness, which influences stress-strain relationship and therefore ice deformation and motion
- Can ice sheet internal temperatures be determined using microwave radiometry?
Ultra-wideband software defined radiometer (UWBRAD)

- UWBRAD = a radiometer operating 0.5 – 2 GHz for internal ice sheet temperature sensing
- Requires operating in unprotected bands, so interference a major concern
- Address by sampling entire bandwidth (in 100 MHz channels) and implement real-time detection/mitigation/use of unoccupied spectrum
- Supported under NASA 2013 Instrument Incubator Program

Goal: deploy in Greenland in 2016

Retrieve internal ice sheet temperatures and compare with in-situ core sites

<table>
<thead>
<tr>
<th>Frequency Channels</th>
<th>0.5-2 GHz, 15 x 100 MHz channels</th>
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<tbody>
<tr>
<td>Polarization</td>
<td>Single (Right-hand circular)</td>
</tr>
<tr>
<td>Observation angle</td>
<td>Nadir</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>1 km x 1 km (1 km platform altitude)</td>
</tr>
<tr>
<td>Integration time</td>
<td>100 msec</td>
</tr>
<tr>
<td>Ant Gain (dB)</td>
<td>11 dB</td>
</tr>
<tr>
<td>/Beamwidth</td>
<td>30°</td>
</tr>
<tr>
<td>Calibration (Internal)</td>
<td>Reference load and Noise diode sources</td>
</tr>
<tr>
<td>Calibration (External)</td>
<td>Sky and Ocean Measurements</td>
</tr>
<tr>
<td>Noise equiv dT</td>
<td>0.4 K in 100 msec (each 100 MHz channel)</td>
</tr>
<tr>
<td>Interference Management</td>
<td>Full sampling of 100 MHz bandwidth in 16 bits resolution in each channel; real time “software defined” RFI detection and mitigation</td>
</tr>
<tr>
<td>Initial Data Rate</td>
<td>700 Megabytes per second (10% duty cycle)</td>
</tr>
<tr>
<td>Data Rate to Disk</td>
<td>&lt;1 Megabyte per second</td>
</tr>
</tbody>
</table>
UWBRAD Science Goals

• Ice sheet temperature at 10 m depth, 1 K accuracy
  – 10 m temperatures approximate the mean annual temperature, an important climate parameter

• Depth-averaged temperature from 200 m to 4 km (max) ice sheet thickness, 1 K accuracy
  – Spatial variations in average temperature can be used as a proxy for improving temperature dependent ice-flow models

• Temperature profile at 100 m depth intervals, 1 K accuracy
  – Remote sensing measurements of temperature-depth profiles can substantially improve ice flow models

• Measurements all at minimum 10 km resolution
  – Timestamped and geolocated by latitude and longitude
MODELING/ RETRIEVAL STUDIES
A simple model of ice sheet internal temperatures is

\[ T(z) = T_s - \frac{G \sqrt{\pi}}{2k_c \sqrt{2k_d H}} \left( \text{erf} \left( z \sqrt{\frac{M}{2k_d H}} \right) - \text{erf} \left( H \sqrt{\frac{M}{2k_d H}} \right) \right) \]

(assumes homogeneous ice driven by geothermal heat flux, no lateral advection)

- Temperature increases with depth; more rapid increase for lower \( M \)

Can reach melting point in some cases

Surface temperature \( T_s \) (K)
Surface accumulation rate \( M \) (cm/yr)
Ice temperature \( T(z) \)
Thermal conductivity \( k_c \)
Thermal diffusivity \( k_d \)
Geothermal Heat Flux \( G \) (mW/m²)
Ice Sheet Properties

- Upper layer of ice sheet comprised of snow: high volume fraction of ice crystals in air
  - "Dense medium" from electromagnetic point of view
  - Mass density of snow determines volume fraction of ice
  - Medium typically represented as air containing spherical ice particles
  - Particle radius typically characterized by the "grain size" parameter

- Density on average increases with depth
  - Volume fraction of ice increases and passes 50% at ~ several m depth
    - Medium is now air inhomogeneities in ice background
    - Inhomogeneity volume fraction on average decreases with depth past this point
  - Grain size increases with depth

- Medium on average approaches homogeneous ice at depths ~ 100 m

- "Random" variations in density and composition with depth on top of the average trends appear as "layering" effects
Emission Physics

- In absence of scattering, thermal emission from ice sheet could be treated as a 0th order radiative transfer process.

- Similar to emission from the atmosphere: temperature profiling possible if strong variations in extinction with frequency (i.e. absorption line resonance).

- Ice sheet has no absorption line but extinction does vary with frequency.
  - Motivates investigating brightness temperatures as function of frequency.

- Inhomogeneities causing scattering or other layering effects are additional complication.

- Need models that can capture effect of scatterers.
Progress

• Continued assessment of forward models
  – Continued intercomparison of “cloud”, DMRT-ML, MEMLS, and coherent codes to understand importance of coherent effects
  – Incorporation of effects of density fluctuations
  – Incorporation of effects of UWBRAD antenna pattern

• Continued use of SMOS/Aquarius 1.4 GHz data to assess model predictions

• Greenland experiment simulations

• Continued expansion of retrieval framework
  – Formulation in terms of desired and nuisance parameters
  – Formulation of CRLB
  – Investigation of ancillary data sources and their impact
DMRT-ML Model

- DMRT-ML model (Picard et al, 2012) widely used to model emission from ice sheets (Brucker et al, 2011a) and snowpacks (Brucker et al, 2011b)
  - Uses QCA/Percus-Yevick pair distribution for sticky or non-sticky spheres
  - RT equation solved using discrete ordinate method
  - Need layer thickness, temperature, density, and grain size for multiple layers
  - Recommended grain size is 3 X in-situ measured grain sizes

- DMRT-ML computed results for DOME-C density/grain size profiles vs. frequency

  ![Graph showing brightness temperature (T_B) vs. frequency for different ice flow rates and layer thicknesses.](image)

  Lower frequencies “see” warmer ice at greater depths.

  ![Graph showing brightness temperature (T_b) vs. frequency for different ice flow rates and layer thicknesses.](image)

  T_B varies with internal T(z).
Forward Model Assessment

- Used “Dome-C”-type physical parameters
  - Including density fluctuations with correlation length parameter
- Results show:
  - Coherent effects can be significant if density correlation length $< \ll$ wavelength; otherwise good agreement between models
  - No significant differences between DMRT/MEMLS
  - Paper accepted by JSTARS

![Graphs showing brightness temperature vs. frequency for different correlation lengths](image-url)
Comparison with SMOS: Antarctica

- DMRT-ML Model predictions compared with SMOS observations of Dome-C
  - Fixed frequency (1.4 GHz), multi-angle and dual polarization

- Ground truth data from Dome-C on density properties incorporated (upper layers only) and temperature profile

- Including density fluctuations important to reproduce data; coherence has only small impact

- Larger errors at H-pol at larger angles possibly due to interface roughness effects

- UWBRAD will emphasize near nadiral observations where match is better
Simulations of Greenland Deployment

- Why Greenland?
  - **PRO:** facilitate logistics
  - **PRO:** opportunity to observe both “cold” ice sheet portions where UWBRAD temperature retrievals are more applicable and other “warm” more complex ice sheet regions
  - **CON:** High accumulation rates make temperature profiles more uniform in depth than in Antarctica. Signals in multi-frequency observations smaller than in Antarctica. 2012 melt event another complication.
  - Nevertheless, comparisons of existing modeled temperature information with core site temperature profiles shows that significant uncertainty is present in knowledge of temperature profiles
  - Temperature information from UWBRAD still of science impact

- Extensive effort this period on assessing temperature information to be obtained from UWBRAD in Greenland
  - Gather existing ground truth, simulate UWBRAD observations, assess retrieval performance…still in progress
Greenland Experiment Planning

- Follow paths of measured ancillary data where possible (e.g. Operation IceBridge ice thickness)
- Tie to the 4 deep ice cores in north and north central Greenland
- April or October deployment to avoid surface melt
- Locate near ice divides to simplify ice dynamics
- Concentrate on dry snow zone to minimize layering effects in melt facies

- **Use available ancillary data to develop model predictions of UWBRAD spectra along the profile line**
Proposed Flight Line

UWBRAD TRANSECT

Surface/Basal Topography (m)

Range from Thule (km)
Greenland Brightness Temp vs. Frequency

- Antarctic geophysical cases: low accumulation rates result in temp profiles that increase with depth
  - Strong changes in TB vs. frequency

- Higher accumulation rates in Greenland (at least for GISP site) result in more uniform temp profile vs. depth

- Smaller changes in TB vs. frequency

- Still observable by UWBRAD
Simulations of Expected TB’s Along Flight Path

- Ancillary Data Sets Used to Generate Estimated Temperature Profile
- OIB Ice thickness
- RAMCO Surface Mass Balance
- MODIS Surface Temperature
- CISM Heat Flux
- Used to generate simulated SMOS TB’s (V-pol, 55 degrees)
Cloud Model Predicted Brightness Temps Along Flight Line

- Cloud model Tb estimate based on temperature profiles derived from ancillary parameters
- 1.4 GHz data forced to align with SMOS data (black) using a constant multiplier. Same multiplier applied to other frequencies.
- Still working to improve match to SMOS data
- Variations are small at 1.4 GHz along flight path because temperature profiles are more uniform in depth
Plans for Improving Models

- Include flags for subglacial water
- Improve layering correction with RACMO density
- Investigate whether RACMO temperature profiles are a better for initializing the inverse calculation
- Investigate other surface regimes (percolation and wet snow facies; near surface aquifer)
Greenland Retrieval Studies

- Generated simulated UWBRAD observations “GISP-like” ice sheets for varying physical properties (500 “truth” cases)
  - Including averaging over density fluctuations
- For each truth case, generate 100 simulated retrievals with UWBRAD expected noise levels (i.e. ~ 1 K measurement noise per ~ 100 MHz bandwidth)
- Select profile “closest” to simulated data as the retrieved profile, and examine temperature retrieval error
- Errors in this simulation meet science requirements
- Additional simulations continuing over Greenland flight path
Expansion of Retrieval Framework

- A variety of approaches are being examined and implemented by the retrieval team to improve retrieval performance
  - Estimating CRLB for given geophysical case
  - Consideration of ancillary information incorporation, e.g. surface temperature, ice sheet thickness, density profiles (couple with RACMO model?)
  - Reformulation of problem in terms of desired science products and nuisance parameters

- Other retrieval methods are under investigation as well

- Work continuing as part of task 2 effort

- Greenland cases emphasize importance of robust retrieval process and careful instrument design
RADIOMETER DESIGN
Radiometer Design

- Three major subsystems: front end, digital backend, antenna
- Front end:
  - Low frequencies of interest enable board-level implementation
  - Traditional Dicke-switch design requires isolators to stabilize amp input impedance
  - Not easily available for 2:1 or more bandwidth
  - Recent “pseudo-correlation” designs eliminate need for isolator

15 channel "pseudo-correlation" design from proposal
Front End Progress

- Review of radiometer frequency plan completed
  - Based on RFI considerations, 15 adjacent channel frequency plan revised to 13 separated channels in 2\textsuperscript{nd} Nyquist of ADC

- Trade study of alternate radiometer front end design based on Dicke Switch architecture also completed
- Baseline “hybrid” radiometer design updated to include RF filtering
- Build of “Hybrid radiometer” LNA/hybrid block in progress to assess performance
Revised Front End Design (13 channels)
Radiometer Front End

• Layout completed for the radiometer front end board
  - Board and components already in-house, build in progress

• IF board layout in progress; components already in house as well
Tests of Front End Hybrid

- Performance of wideband hybrid important in overall pseudo-correlation radiometer
- Developed test board to evaluate hybrid performance
- Meets spec of > 20 dB isolation
- Full front end board also in house
Alternate Dicke Switch Architecture

- To be implemented if hybrid design performance insufficient
- Retains same IF boards; change only to the RF front end
- Still identifying appropriate multiplexer component
Four Channel Test System

• Analog sub-system for the 4 channel unit will consist of the RF front end board and 2 IF boards

• Channels to be used span the 0.5-2 GHz range

• System computer will control calibration state switching
Digital Subsystem

- Digital Subsystem based around the ATS9625 card from AlazarTech, Inc.
  - 2 channel, 250 MSPS, 16 bit/sample data acquisition card
  - Achieves high throughput to host PC
  - Team has past experience with similar AlazarTech board and software interface
  - RFI processing to be performed on host PC

- Each board can handle 2 100 MHz channels

- 7 boards used for 13 channels

- One host PC can accommodate 2 ATS9625 boards
  - Need 4 PC’s

- 2 boards and host PC have been acquired and are being used for code development and throughput studies
Software Status

- Current software approach is one program with two main functions: Acquire and Process
  - Acquire focuses on interacting with the ADC boards and recording the data to hard disk and memory
    - Some processing has been shifted into the Acquire function to optimize the duty cycle of the program (conversion from integer bits to double precision volts for storage to memory).
  - Process focuses on RFI detection and mitigation and extracting brightness temperature information from the data
    - Currently calculates first 4 signal moments, signal power, kurtosis, and 1024 point spectrogram
    - 3 RFI detection algorithms to be used: pulse detection, cross frequency detection, kurtosis detection
- Duty cycle for radiometer measurements currently ranges from 6-20% (final goal of 10%) for 100 ms integration times, depending on whether processing is performed or only raw data is collected
Software Next Steps

- **Main Program**
  - Continue pursuing optimum parallel processing algorithms
  - Incorporate software to hardware interfaces through Alazar card I/O ports
  - Develop internal calibration procedure for radiometer operation
  - Determine necessary information for operator and method of displaying it

- **Acquire Function**
  - Attempt to offload more processing power from Process function into Acquire function

- **Process Function**
  - Finish implementing RFI detection and mitigation algorithms
  - Optimize processing balance with Acquire function
UWBRAD Antenna Development

March 3rd, 2015

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UWBRAD Antenna Development

Objectives:
- Ultra-wide bandwidth (50-2000 MHz) operation
- Stable gain and pattern with 60° Beamwidth
- Platform-independent performance
- Minimal air drag

Approaches:
- Adopt Conical Logarithmic Spiral for Antenna Design
- Utilize Full-Wave Numerical Modeling for Design Optimization
- Deploy and retract antenna mid-air from Aft Camera port accessible from aircraft cabin
- Working with Kenn Borek on Antenna Installation and Flight Testing

Completed Tasks:
- Optimized spiral arm design
- Completed feed circuit design, fabrication, and testing
- Completed antenna mechanical design
- Completed preliminary air drag simulation analysis
- Completed retractable antenna deployment assembly

Future Key Milestones:
- Complete Electrical and Mechanical Tests of Antenna
  - Validate Antenna Performances
  - Test deployment mechanism
  - Improve Antenna and Deployment Design 4/2015
- Complete Antenna Implementation/Test 10/2015
- Conduct Airborne Experiments
  - Finalized Lift system
  - Finalized Antenna 12/2016
Antenna Fabrication and Assembling

- Impedance Matching & Balun Circuit Board
- Spiral arms printed on thin PCB sheets
- Inner foam support
Finalized Spiral Arm Profile

Diameter: 1.1 inches

Cone Angle = 13.2°

H = 37”

Diameter: 10 inches

Realized Gain [dBi]

Frequency [GHz]

56 Turns

Beamwidth [degrees]

Frequency [GHz]
Tapered-Line Balun Design Optimization

Linear Taper

Taper Length: 10 in
Board Length: 12 in

Exponential Taper

Ground Plane Width: 1.30 in
Port 1 Width: 35.5 mil  Z: 180Ω
Port 2 Width: 190 mil  Z: 50Ω
Rogers 5880 Duroid, 62mil thickness, εᵣ: 2.2
Tapered-Line Balun Fab. & Testing

Top View

Bottom View

connect to tips of spiral arms

Insertion Loss [dB]

Frequency [GHz]

Measurement

Simulation

Phase [Deg]

Frequency [GHz]
PCB Substrate and Foam Support Effects

StyroFoam ® (polystyrene)
$\varepsilon_r = 2.6$, $\tan\delta = 0.0003$
Cuming Microwave: RH-10
$\varepsilon_r = 1.14$, $\tan\delta = 0.0009$

Conclusion:
Using low density foam to prevent undesired waveguide mode
Antenna Installation on Lifters

Double Scissor Lift

~19 in Dia. Hole

~36 in

~8 in

Antenna Holder

End Cap

8”

antenna holder
Effect of Antenna Holder
Antenna Installation Plan & Preparation

On-site aircraft inspection took place on Feb 26th to 28th
In-Flight Antenna Deployment System

retracted position during take-off and landing

deployed position during measurement

Existing Port Hole (~19 in Dia.)

https://www.dropbox.com/s/w1c3vdhgeai6ij8/2015-02-25%2022.51.56.mp4?dl=0
Aircraft Update

• Continued discussions with Ken Borek Air, Ltd. for use of Bassler aircraft
  • DC-3T Basler is desired given the extended range and familiarity of Borek Ltd with conducting US science projects in Greenland
  • Project team visit to aircraft 2/26-27, 2015

• Plans compatible with DC-3T (Basler) capabilities
• Budget for 5 days/ 40 flight hours consistent with project plan
• Accommodation of UWBRAD antenna appears straightforward
Milestones and Timeline

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DOME-C Deployment

- IFAC will deploy an L-band radiometer at DOME-C again November 2015-January 2016 (30-45 day campaign)
  - Potential to include UWBRAD tower or ground deployment at DOME-C as part of the proposal
  - ESA project could cover transport costs for UWBRAD to Antarctica if UWBRAD were to arrive at IFAC by August 2015
  - Would be desirable to include full 13 channel system, but a 4 channel system could provide valuable information
  - Costs for project personnel support of this effort likely manageable within baseline budget since “ground based tests of 13 channel unit” are part of baseline project plan

- Developing plan to deploy UWBRAD 4 channel system at DOME-C

- Likely will be supported by IFAC personnel only; project team will train IFAC personnel

- Material won’t return until May 2016; will develop separate 4 channel unit independent from 13 channel unit for this test

- Need to minimize data rate and operator intervention; also ruggedize system for Antarctic environment

- Team will continue to seek opportunities for work in the Antarctic with NSF and NASA
Status Summary

• Project progressing according to schedule
• No major risks identified
• Goals for next 6 months:
  – Four channel unit finished, tested, and underway to Antarctica
  – Thirteen channel unit build underway
  – Differing TB profiles versus frequency in Greenland will continue to be focus of retrieval analyses
    • Finish observation simulation study for Greenland flight path
  – RFI processing algorithms will be focus of software development
  – Design of “backup” Dicke switching architecture will continue
    • No major impact on development schedule since majority of front end design is common to two approaches
Conclusions

- Multi-frequency brightness temperature measurements can provide additional information on internal ice sheet properties
  - Increased penetration depth in pure ice and reduced effect of scatterers as frequency decreases

- SMOS measurements show evidence of subsurface temperature contributions to observed 1.4 GHz measurements

- UWBRAD proposed to allow further investigations
  - Website at: http://bprc.osu.edu/rsl/UWBRAD

- UWBRAD began April 2014, goal for deployment in 2016 to demonstrate performance