The Ultrawideband Software-Defined Microwave Radiometer (UWBRAD)

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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?

Outline

- Ice sheet physical properties
- Emission physics and DMRT-ML
- UWBRAD
- Modeling and Retrieval Studies
- Radiometer, Digital Subsystem and Antenna Design
- Conclusions

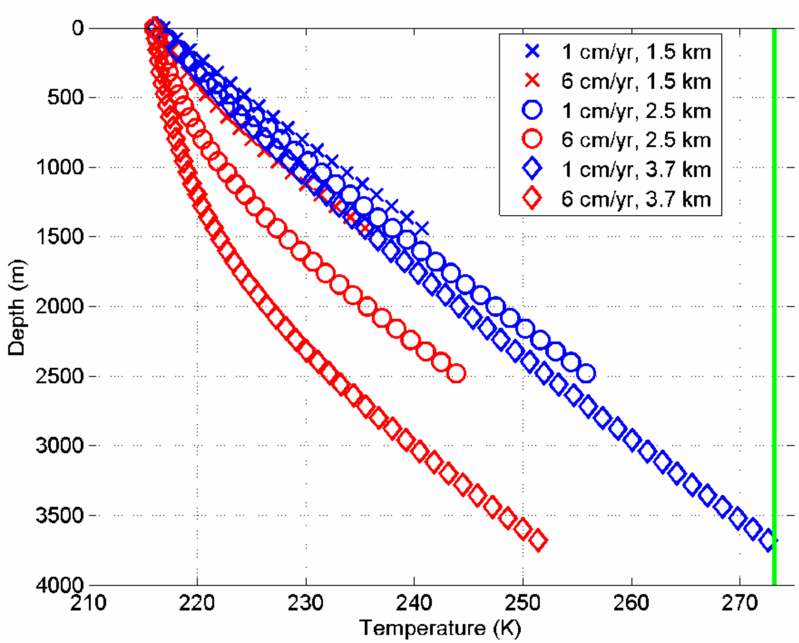
Ice Sheet Temperature Properties

A simple model of ice sheet internal temperatures is

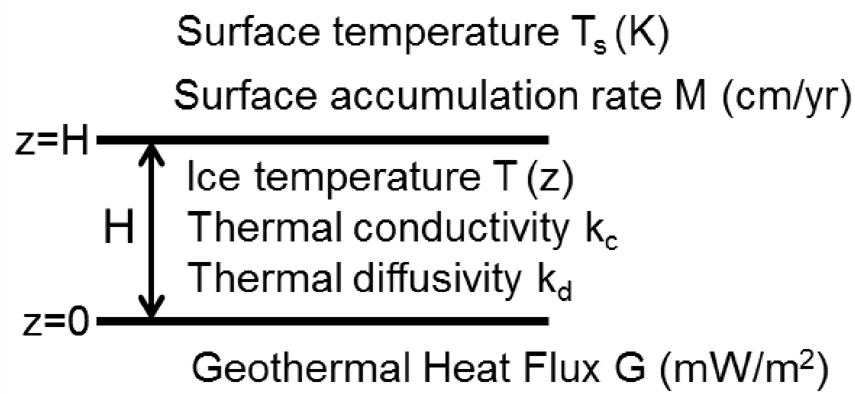
$$T(z) = T_s - \frac{G\sqrt{\pi}}{2k_c\sqrt{\frac{M}{2k_d H}}}\left(\mathrm{erf}\left(z\sqrt{\frac{M}{2k_d H}}\right) - \mathrm{erf}\left(H\sqrt{\frac{M}{2k_d H}}\right)\right)$$

(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



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 can appear as "layering" effects

Emission Physics

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

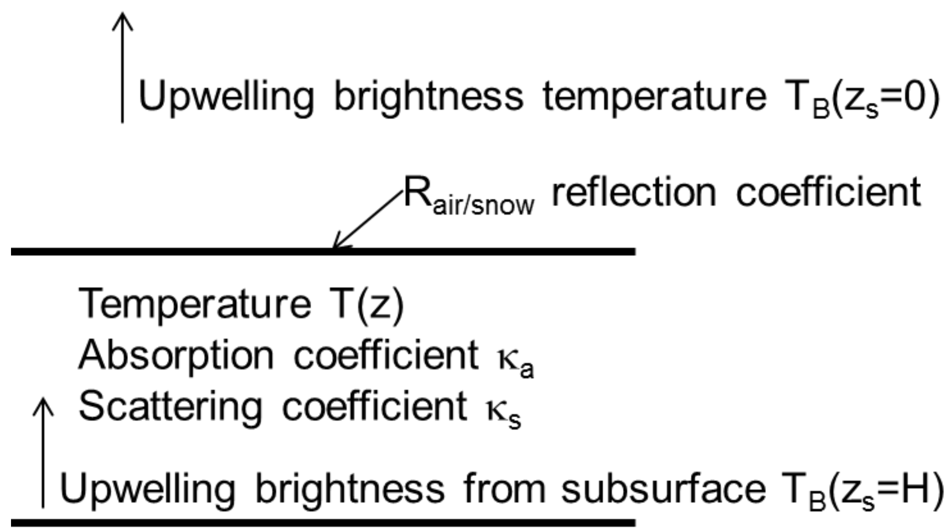
$$T_B(z_s=0) = \left(1 - R_{air/snow)}\right)\left(\int_0^{z_s}(\kappa_a+\kappa_s)Te^{-\int_0^{z_s}(\kappa_a+\kappa_s)dz}\,dz + T_B(z=H)e^{-\int_0^{z_s}(\kappa_a+\kappa_s)dz}\right)$$

- 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

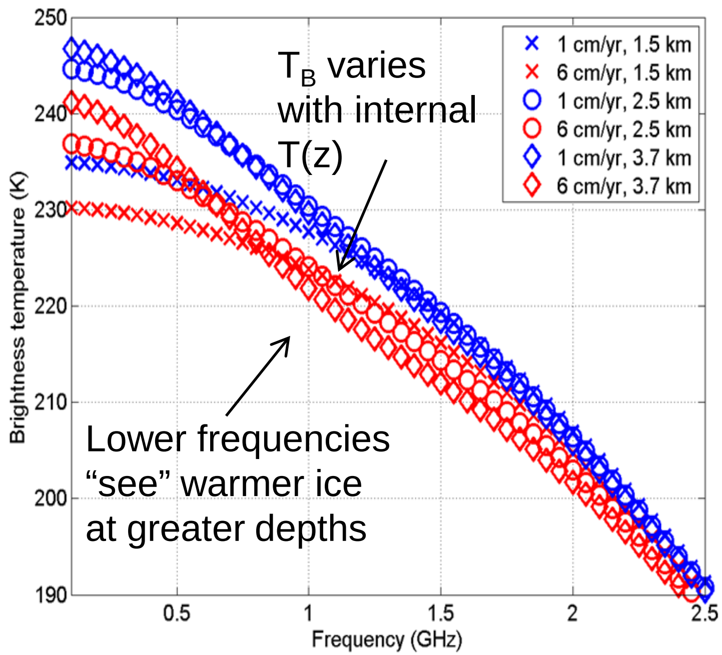
- Inhomogeneities causing scattering or other layering effects are additional complication

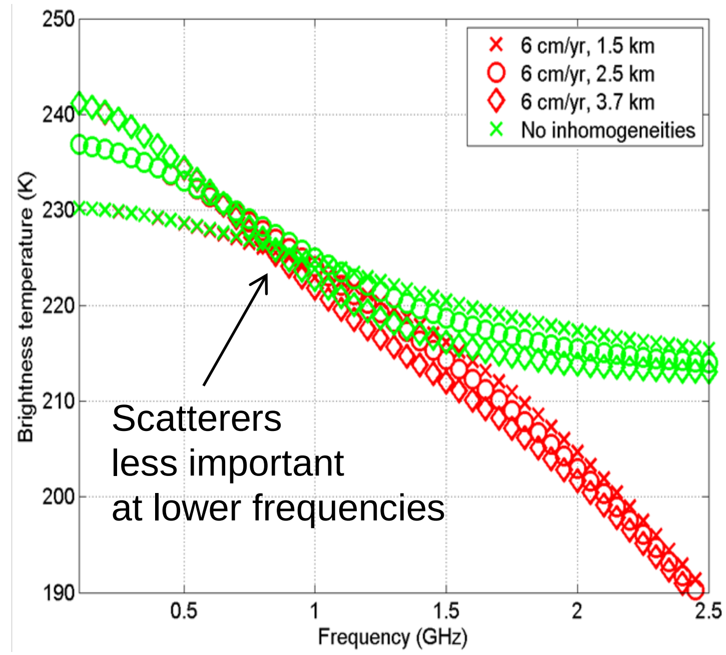
- Need models that can capture effect of scatterers



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





Analysis

- Ice sheet brightness temperatures influenced by a variety of physical effects

- Brightness temperatures at differing frequencies are sensitive to differing portions of the ice sheet and to differing physical effects (e.g. scattering)

- Separating internal temperature information from current radiometer (e.g. L band single frequency or higher single frequency) systems difficult

- Future measurements with multi-frequency radiometers offer potential to extract more information on subsurface temperatures
  - A “model-based” retrieval will be required

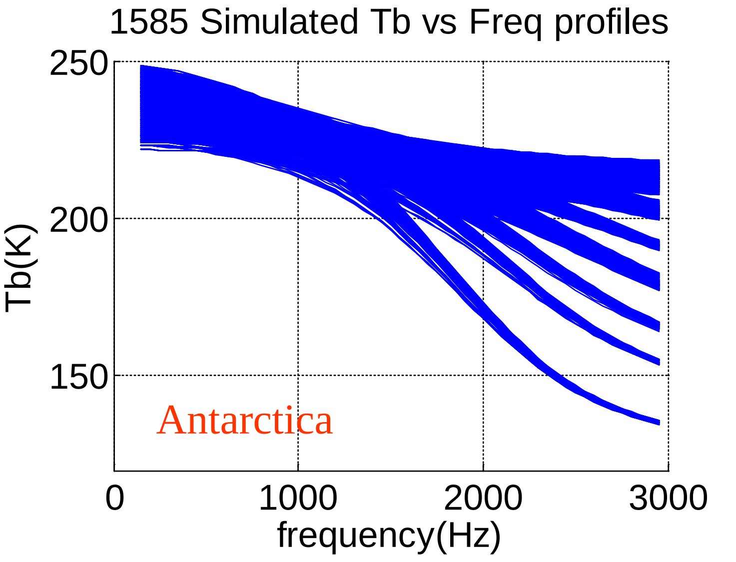
Ultra-wideband software defined radiometer (UWBRAD)

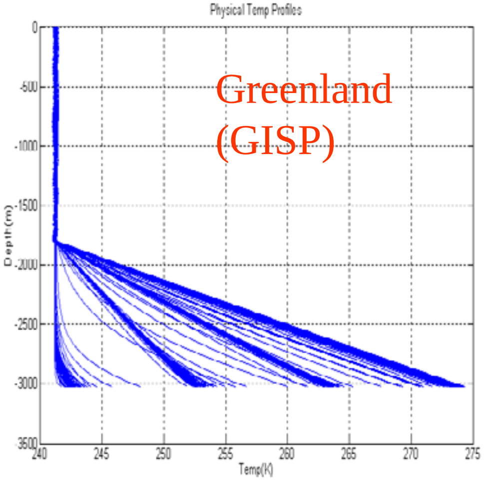
- We propose design of a radiometer operating 0.5 – 2 GHz for internal ice sheet temperature sensing
- Requires operating in unprotected bands, so interference a major concern
- Address by sampling entire bandwidth (in 100 MHz channels) and implement real-time detection/mitigation/use of unoccupied spectrum
- 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

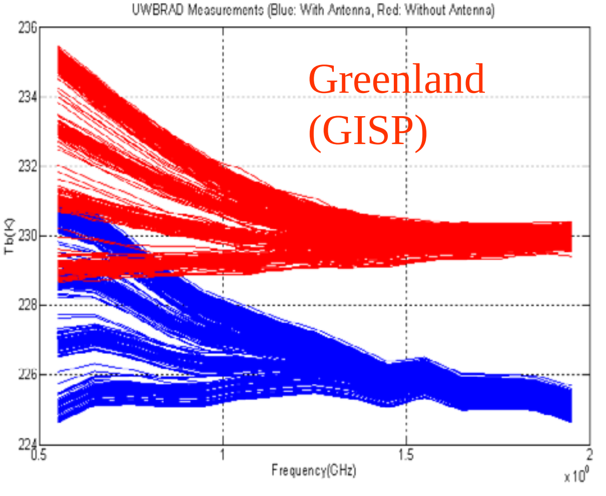
Frequency Channels	0.5-2 GHz, 15 x 100 MHz channels
Polarization	Single (Right-hand circular)
Observation angle	Nadir
Spatial Resolution	1 km x 1 km (1 km platform altitude)
Integration time	100 msec
Ant Gain (dB) /Beamwidth	11 dB 30°
Calibration (Internal)	Reference load and Noise diode sources
Calibration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

Initial Retrieval Studies for Greenland

- Past retrieval study focused on 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

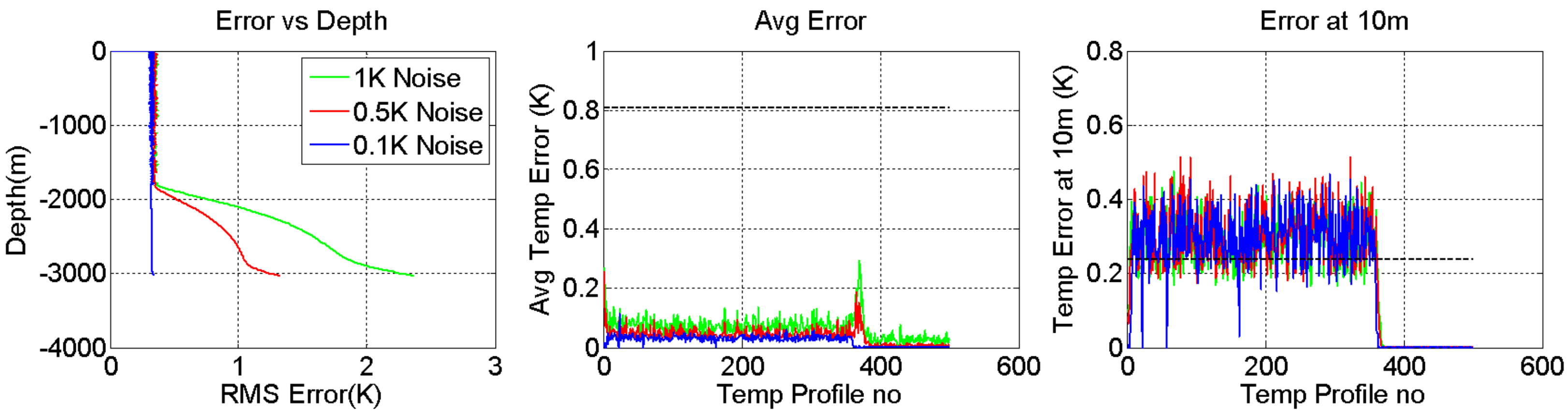






Greenland Retrieval Studies

- 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

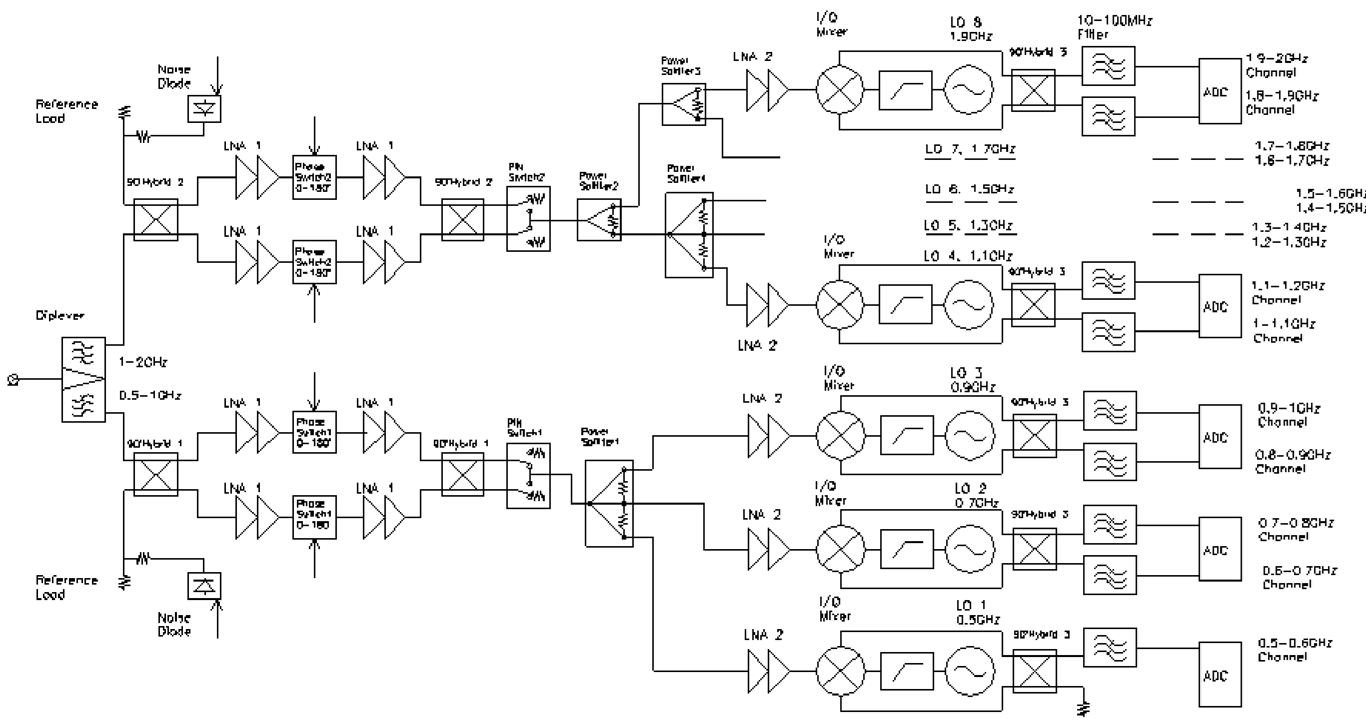


- Additional simulations needed with wider range of Greenland cases
  - Currently examining Operation IceBridge Greenland ground truth data along expected flight path

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

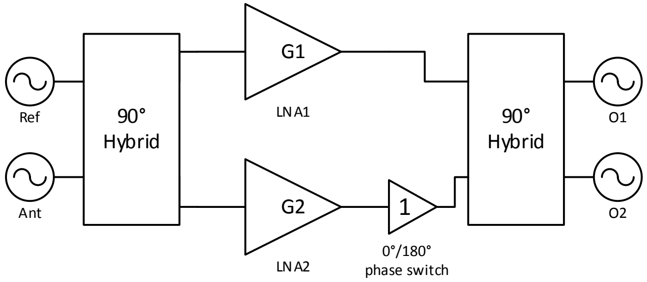
15 channel “pseudo-correlation” design



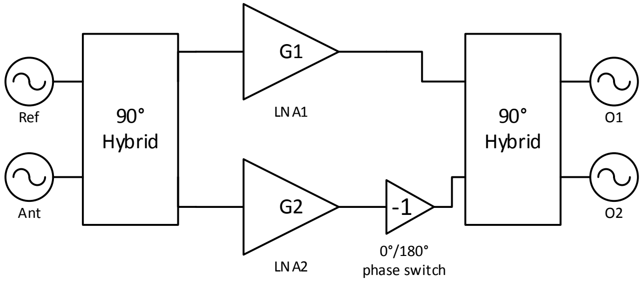
Radiometer Operation Basics

- The pseudo-correlation radiometer proposed for UWBRAD operates by adjusting the phase of the reference and antenna signals and summing them in such a manner as to cancel the contributions from one of the input signals at a time

- Alternating the polarity of one of the 0° /180° phase switches alternates which signal will be observed on the hybrid outputs



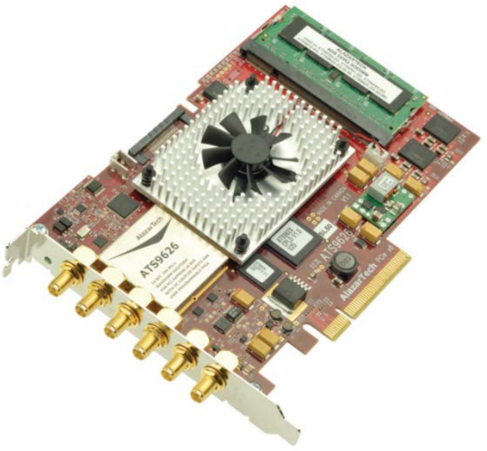
0° position



180° position

Digital Subsystem

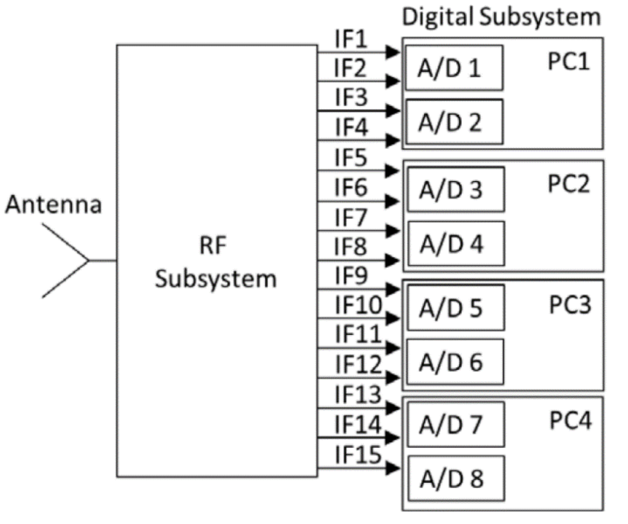
- Digital Subsystem based around the ATS9625 card from AlazarTech, Inc.
  - 2 channel, 250 MSPS by 16 bit data acquisition card
  - Achieves high throughput to host PC
  - Team has past experience with similar AlazarTech board and software interface
  - RFI processing to be performed on host PC



- Each board can handle 2 100 MHz channels; 8 boards used for 15 channels

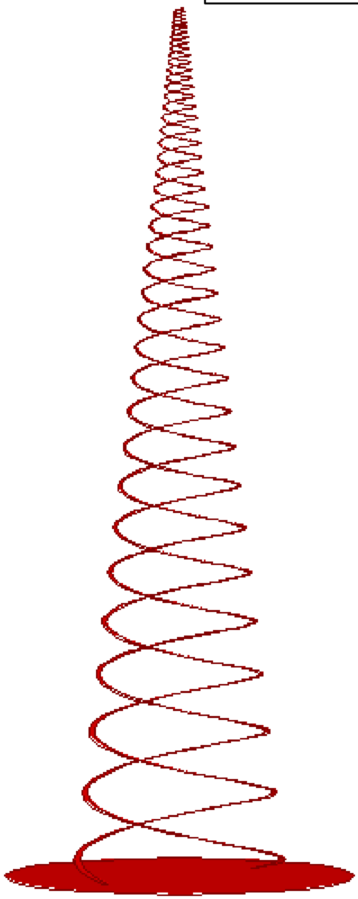
- One host PC can accommodate 2 ATS9625 boards
  - Need 4 PC's

- Early acquisition of 2 boards and host PC will be used for throughput and software studies



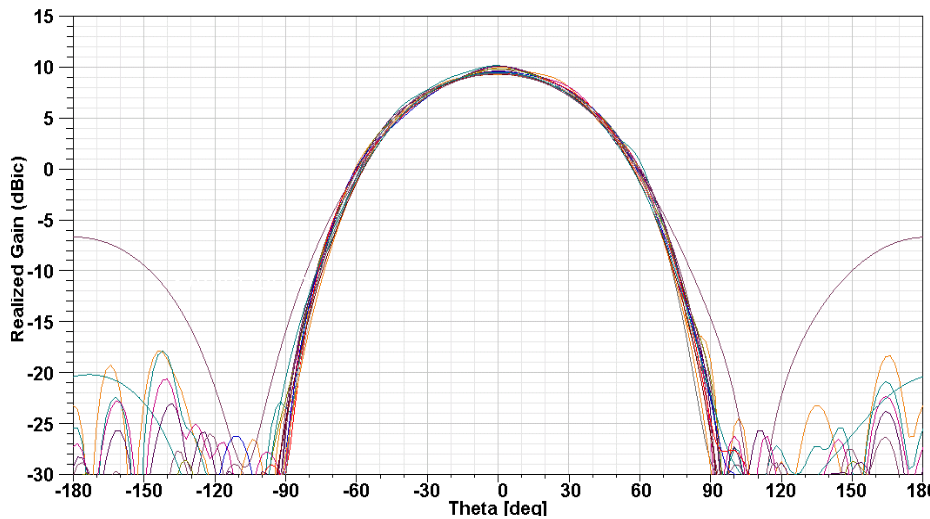
Antenna Design

Base =7.2”
Length=30”
20 turns
GND=12” Dia.



Conical Log Spiral Antenna

High Gain
Symmetric Pattern
Circular Polarization
Ultra-Wide Band
Possible to be Collapsed



Field Program Planning

- Antarctica, Greenland, Russian/Canadian ice caps are desirable sites

- Antarctica pursued in proposal development via potential collaboration with Operation IceBridge
  - Uncertainties with Operation IceBridge McMurdo operations shifted focus instead to Greenland; still interested in Antarctica if possible

- Tentative priority of Greenland sites (based on known surface conditions and availability of ancillary data)
  1) GISP2/GRIP (dry snow zone and substantial ancillary data)
  2) NGRIP (dry snow zone, wet bed in area, some ancillary data)
  3) Camp Century (dry snow zone, some data available- 1966 borehole)
  4) NEEM (most recent site, dry snow zone but ancillary data are difficult to retrieve so far)
  5) Dye 3 (experiences surface melt but substantial ancillary data)

  Canadian Ice Caps as contingency:
  1) Devon Island (ancillary data available, surface conditions need to be investigated, Canadian Cryovex validation site)
  2) Agassiz Ice Cap (ancillary data available, surface conditions need to be investigated)

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

- 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