

Dual-Frequency and Multi-Receiver Radars for Sounding and Imaging Polar Ice Sheets

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Abstract

We developed radars for operation at 150 MHz with a bandwidth of 20 MHz and 450 MHz with a bandwidth of 30 MHz with multiple receivers for sounding and imaging polar ice sheets. The system consists of six receivers used to collect and digitize signals from each element of an antenna array. The antennas consisted of two four-element dipole-arrays mounted under each wing of a NASA P-3 aircraft. We operated the radar both in sounder and imager mode during September 2007, and collected data over several flight lines over the Greenland ice sheet. We also collected data over the smooth ocean surface to calibrate the system and determine antenna pattern. The results show that we can image the ice-bed interface over a ground-swath of about 1 km. Our preliminary analysis shows that we obtained range sidelobes lower than 70 dB at 150 MHz and 60 dB at 450 MHz. Our initial results also show that loss at 450 MHz is much higher than predicted by existing models, and clutter masked weak bed echoes when the radar was flown at high altitudes both at 150 and 450 MHz. In this paper, we discuss the design and performance of the radar system including results from laboratory tests and field experiments. We also present results from data-dependent and data-independent clutter rejection algorithms and provide a comparison of theoretical and experimental attenuation estimates at both frequencies.

1.0 Introduction

Since 1993, the University of Kansas (KU) has been performing radar depth-sounder measurements in polar regions [1, 2]. Most of these measurements were made with a radar operating at 150 MHz. We have recently developed an improved multi-channel radar that operates at 150 MHz and 450 MHz. The system is capable of simultaneous data collection in two different operating modes: depth sounding and interferometric imaging. We have conducted extensive airborne observations during the fall of 2007 in Greenland, where we validated system performance and collected data to test different techniques for clutter suppression.

In this paper we discuss design considerations for the instrument and present results from laboratory tests as well as field experiments. Further, we discuss the implementation of two forms of clutter-rejection algorithms used to enhance the quality of the data. The results from this implementation will be presented and discussed at the conference.

2.0 System Description

2.1 RF Section and Digital System

The radio frequency (RF) section of the system is composed of a two-way high-power transmitter and six independent receiver channels. The transmitter generates a chirp signal of 3- μ s to 10- μ s duration using an arbitrary waveform generator (AWG) in combination with a frequency up-conversion stage. The latter up-converts the baseband signal generated by the AWG to higher frequencies centered at the carrier frequency of interest (either 150 MHz or 450 MHz). The up-converted signal is then amplified by high-power amplifier modules. The peak transmit power at 450 MHz is 1.6 kW over a 30-MHz bandwidth and 800 W over a 20-MHz bandwidth at 150 MHz.

Each-receiver channel has a gain of about 72 dB and a measured noise figure of 3 dB. The receivers are designed such that the gain can be adjusted over a 60-dB range. The amplified signal from each receiver is bandpass filtered and digitized with a 12-bit analog-

to-digital (A/D) converter operating in under-sampling mode. The digitized data are stored on large-capacity hard discs controlled by a dedicated computer running a graphical user interface (GUI). The digitized data from each channel are pulse compressed to provide real-time display of return as a function of range to check data quality.

2.2 Antennas

We use two four-element half-wavelength dipole arrays as radiating structures. Each array is mounted below one wing of the aircraft. The array-element spacing is about 1 m, which is close to $\frac{\lambda}{2}$ at 150 MHz and 1.5λ at 450 MHz, with λ being the free-space wavelength at the frequency under consideration. Figure 2a shows a picture of the antennas as installed on the NASA P-3B aircraft. Figure 2b depicts the radar system installed inside the aircraft.

In the normal operation mode of the radar, one of the four-element antenna arrays is used for transmit and another is used for receive. The transmit-array uses an antenna-feed-network with Dolph-Chebyshev weighting designed to obtain low (<30 dB) sidelobes at 60 to 80 degrees incidence. The feed network is designed to accurately match the amplitude and phase balance between individual elements in the transmit array. The signals from each of the four-receive elements are digitized using four separate channels. Array-processing techniques are then used to reduce surface clutter as will be explained in Section 4.2. In the interferometric mode, we use the inboard elements of the antenna arrays for transmission on alternating pulses (ping-pong mode) and likewise digitize the received signals from the remaining six elements.

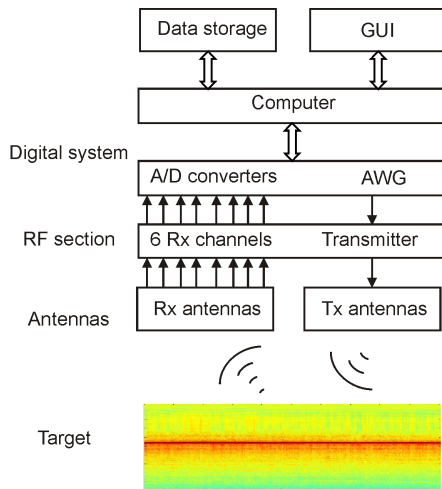


Figure 1. Block diagram of the dual-band multi-channel radar system we have developed. The system can operate sequentially at 150 MHz and 450 MHz.

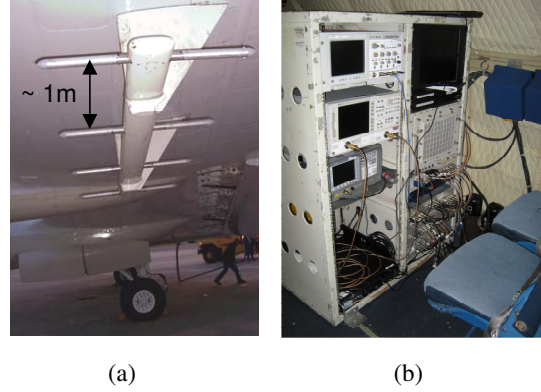


Figure 2: (a) Photograph of a four-element antenna array for 150 MHz operation; (b) Photograph of the main radar components installed inside the NASA P3 aircraft.

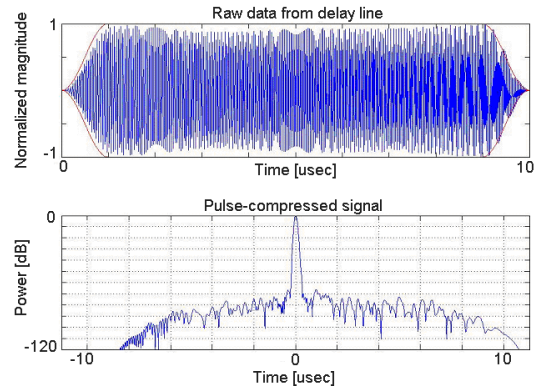


Figure 3. Sample (150 MHz) laboratory results obtained using a waveform pre-distortion technique to reduce range sidelobes.

2.2 Range Sidelobe Reduction

To eliminate Fresnel ripples and obtain low range sidelobes we have implemented a signal pre-distortion scheme for the transmit waveform. This technique allows compensation for the transfer function of the transmitter/receiver system, including non-linearities in the power amplifiers [3]. Figure 2 shows an example of laboratory results obtained using a loop-back configuration at 150 MHz for one receiver channel. The top inset shows the time-domain system response of a 10-us waveform after traveling through a delay line to simulate propagation through 3 km of ice. Next, this waveform is processed to produce the compressed waveform shown on the bottom in a logarithmic (dB) scale. As illustrated in this figure, aside from a couple nearby lobes, all the other compression time sidelobes are below -70 dB. Similar results are obtained at 450 MHz, where the recorded sidelobe level is 60 dB below the main peak.

3.0 Data Collection and Calibration

We collected data over the Greenland ice sheet, flying at altitudes as low as 500 m above the ice surface and as high as 6.7 km above sea level. The system was operated in both interferometric and normal modes at 150 MHz and 450 MHz. Relevant flight lines are discussed in the paper by Jezek, et. al [4]. To calibrate the system and obtain the radiation pattern of the antenna arrays, we collected data over the smooth ocean surface. This test also allowed us to validate the effectiveness of our pre-distortion technique for range sidelobe reduction. Figure 4 shows a sample A-scope collected over the ocean surface with the system operating at 450 MHz. The sidelobe level is 58 dB below the peak, only 2 dB above the level obtained in the laboratory as described above.

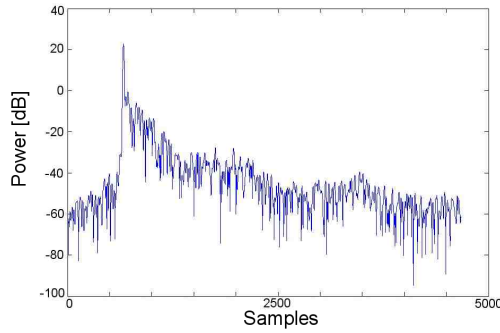


Figure 4. Sample (450 MHz) A-scope obtained over the ocean surface.

4.0 Results

4.1 Sample Results

Figures 5 and 6 show two different sample echograms from data collected during low-altitude missions at 450 MHz and 150 MHz, respectively. A significant portion of the data are currently still under processing and a more extensive set of images will be presented at the conference. Our preliminary analysis indicates that the attenuation at 450 MHz is larger than that predicted by current models. Furthermore, observations from high altitude are severely degraded by the presence of clutter, particularly at 450 MHz.

4.2 Surface Clutter Reduction

Removing surface clutter from the data is a major challenge when trying to image the ice-bed interface, particularly in regions where the surface is heavily crevassed. Off-nadir echoes produced by surface topography and crevassing tend to mask bed echoes at equivalent ranges from the ice-bed interface.

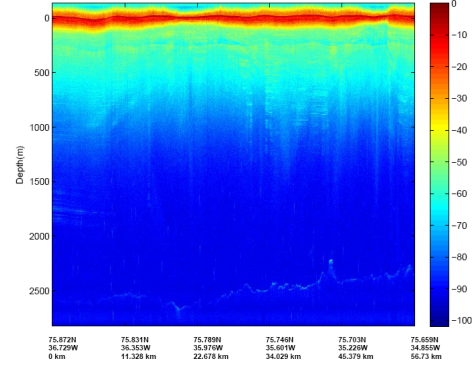


Figure 5. Sample (450 MHz) echogram obtained during a low altitude flight over the east of Thule.

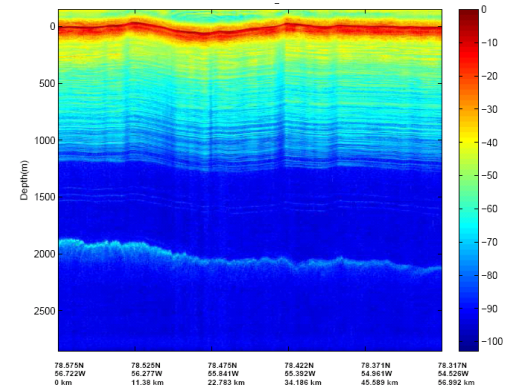


Figure 6. Sample (150 MHz) echogram obtained over the Humbolt glacier during a low altitude flight.

Reducing clutter effects is done with great difficulty when obtaining ice thickness data over fast-flowing glaciers. To address the surface clutter issue in the along-track direction we have used a synthetic-aperture radar (SAR) process. The effect of cross-track clutter is addressed by the implementation of digital-beamforming techniques. In normal operation mode, we collected statistically independent data across the antenna elements distributed in the direction perpendicular to the flight path. Therefore, it is possible to synthesize a specific cross-track antenna pattern by placing nulls at given incident angles, from where surface clutter returns originate [5]. The specific angles of the nulls are estimated based on the surface profile, flight trajectory, and bed topography. The actual pattern is then generated for each range bin by applying a set of weighting factors to the collected data. As a first approximation, we are determining the weighting factors by means of antenna-array theory and mutual coupling data that were obtained in flight using a network analyzer [6]. Our preliminary results show that we can reduce surface clutter, particularly in densely crevassed regions, by about 20 dB. Results from the implementation of the aforesaid clutter-rejection algorithms will be given at the conference.

5.0 Conclusions

We have developed dual-band multi-receiver radars for depth sounding and interferometric imaging of polar ice sheets. Our system was successfully deployed to Greenland in 2007 and used to collect data from high and low elevation flight paths at both 150 MHz and 450 MHz. This is the first time that the ice-bed interface has been mapped consistently at 450 MHz using an airborne instrument, which will be an important precedent for future observations. In contrast to what current models predict, our initial observations give evidence of higher loss at 450 MHz in comparison with its 150 MHz counterpart. We have achieved significant range sidelobe reduction at both frequencies by pre-distorting the transmit waveform. Finally, we are implementing clutter cancellation algorithms to enhance the quality of our SAR images. Clutter suppression of 20 dB or better is expected through the incorporation of SAR techniques in combination with digital beam forming.

4.0 Acknowledgements

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