A Wideband Radar for Mapping Internal Layers in the Polar Icesheets for Estimating Accumulation Rate

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Abstract-**Determination of the mass balance of the polar ice sheets requires information on the accumulation rate. Remote sensing methods to determine the accumulation rate are essential in reducing the uncertainty associated with interpolating in situ measurements that are obtained from ice cores and pits. This is essential to reducing the 20% of uncertainty in current accumulation rate maps. Using data from surface-based radar experiments we determined optimum parameters for an airborne radar. We developed an airborne prototype and successfully demonstrated that we can map internal layers with about 1 m resolution to a depth of about 120 meters over the Greenland ice sheet. We reported the system design, construction and preliminary experimental results at the IGARSS meeting [1]. We have developed an operational radar system for routine measurement. This system operates in FM-CW and stepped-frequency pulse modes and it has 20-dB more sensitivity than the prototype radar. We also developed a radar target simulator for testing and evaluating system performance. The target simulator was constructed using fiber optic cables, microwave delay lines and RF/optical transceivers to simulate reflections from the air/snow interface, internal layers and the antenna reflection, which degrades the system's sensitivity. The simulator serves a dual purpose of optimizing the system performance in the laboratory and for internal calibration in the field. We also used a CAD package to design and simulate overall radar performance. The use of CAD package and target simulator reduced cost and time associated with the radar development. In addition, we are also able to obtain an accurate system model to deconvolve the system effects from the received signal. In this paper we will discuss detailed design, construction and performance of the target simulator and operational radar. We will show a comparison of the simulation results and laboratory measurements of the radar system. Also we will present analysis of the results from measurements made during the 2001 experiments and preliminary results from planned measurements in May 2002.**

I. INTRODUCTION

Over the last century sea level rose by about 15 cm. The sea level has been projected to rise by a further 5mm/year over the next 100 years [2]. About 50% of the current sea level rise has been attributed to the melting of polar ice sheets. However there is a large uncertainty in this estimate. Hence an improved knowledge of the mass balance of these ice sheets is required to determine their role in the sea level rise. The accumulation rate is a key parameter in determining the mass balance of polar ice sheets using the flux approach. It is also an important parameter to help interpret the results in the volumetric approach. Current accumulation rates are determined from ice cores and pits which have uncertainties of about 24% due to the sparse sampling [3]. We have shown in our previous work [4,1] that it is indeed possible to map the isochronous layers and estimate the accumulation rate of the polar ice sheets using our ground based and prototype airborne radar systems. We were able to map the internal layers in the dry, percolation and wet snow zones of the Greenland ice sheet with our prototype airborne radar system. We identified the problems with the prototype airborne system and have improved upon its design and we now have an operational airborne radar system to provide improved spatial and temporal coverage of the polar ice sheets.

During the 2001 field season, we had difficulties testing our radar system outdoors due to due to interference from and to wireless communication devices that operate in the 600-900 MHz frequency range. Due to this problem a target simulator was designed and developed as an undergraduate honors research project [5]. The target simulator was built using fiber optic cables, microwave delay lines and RF/optical transceivers to mimic the antenna feed-through path, reflection from air/firn interface and reflections from the internal layers. The simulator is not only useful for laboratory characterization of the radar system but also serves as a good calibration tool in the field.

Both the new radar system and the target simulator were designed with the aid of the CAD tool EEsof® to reduce the cost and time associated with system development.

II. SYSTEM DESCRIPTION

Fig. 1 shows the result of internal layers observed with our prototype radar system during the 2001 field season. We were able to successfully map the internal layers upto a depth of about 120 m with better than 1 m resolution despite the fact that the system was less than optimum. During the test flight we determined a number of problems with the prototype radar system. The problems with the prototype system and the improvements have been documented in [6]. Fig. 2 shows a block diagram of the improved design. The signal source is the STEL-9949 programmable digital chirp synthesizer (DCS). It can be operated with a maximum clock frequency of 1 GHz to generate a chirp signal between 1 MHz and 400 MHz. We also used the 1 GHz clock to directly upconvert the 100-400 MHz signal to 600-900 MHz. This is accomplished by taking the lower sideband of the upconverted signal. The 1 GHz PLO is referenced to a 50 MHz temperature-compensated crystal oscillator (TCXO). A sample of the 50 MHz signal is used as the input clock for the timing system. This ensures that all the signals are synchronized. A band-pass filter is used to reject the upper sideband and leakage signals from the 100-400 MHz chirp and 1 GHz clock. The signal from the upconverter is then amplified to an appropriate level to drive the power amp. A portion of this signal is coupled to the local oscillator port for the mixer to downconvert the received signal to IF. The power amplifier amplifies the transmit signal to two watts before it is attenuated to one watt by a 3-dB attenuator. The attenuator reduces any mismatch between the amplifier output, the band-pass filter and the antenna. The signal is then propagated to free space via a band-pass filter and a TEM horn antenna. The band-pass filter serves to reject all out-of-band components before transmission.

The receive signal is filtered to ensure that no out-of-band signal is coupled into the receiver since strong signals can saturate the receive amplifier and reduce the sensitivity of the system. A low-gain (10 dB), high-isolation amplifier, which has 50-dB of reverse isolation, is used as the first-stage amplifier. We require a low-gain in this stage since the high feed-through signal from the transmit antenna will saturate the mixer if higher gains are used. The high reverse isolation reduces the local oscillator signal coupled into the RF port of the mixer being transmitted via the receive antenna. The received signal is downconverted to IF. The IF signal is filtered using a 3rd order Gaussian high-pass filter to attenuate the antenna feed-through. During last year's field season we noted that the antenna feed through signal appeared at 500 kHz. The high-pass filter is designed to attenuate this leakage signal by 60 dB with a fast settling time. An amplifier with a medium-high output power (20 dBm) is used to amplify the IF signal. We require a fairly high output to avoid saturation by the upper sideband signal that is generated during the mixing process. The signal is then low-pass filtered to reject the upper sideband signal and the LO leakage signal. The IF signal is further amplified to utilize the full A/D dynamic range. The signal is finally filtered with an anti-aliasing filter to keep the input noise from folding over into the desired IF range. This system was simulated using the CAD tool EEsof®. A comparison between the simulation and measured response is shown in Fig. 3. There is an excellent agreement between the measured and simulated data for the main lobe, but there is slight disagreement between the two for sidelobes. These mismatches can be attributed to the fact that not all the adapters and cables that were used in the actual system were characterized on EEsof®.

III. Target Simulator

We developed a target simulator to mimic the antenna feed-through path, reflection from air/firn interface and reflections from the internal layers. The simulator was first designed using ideal components in EEsof®. We used a semi-rigid microwave delay line of 167 ns to match the actual path length of the antenna feed-through path. The 1000 m two way path length between the aircraft and the air/firn interface were simulated using a fiber-optic delay line with optical/RF transceivers to interface the RF and optical sections. Fiber-optic cables are ideal for simulating large path lengths due to its low loss, small size and light weight. The 0.5 m spacing between the internal layers were simulated using a feedback loop with a short cable to simulate the multiple reflections from the layers within the ice. Fig. 4 shows the excellent match between the measured response and the EEsof® simulation. The top figure shows the reflection profile for the entire path. The first signal represents the antenna feed-through signal which is at about 40 dB above the air/firn interface. The signals following the antenna feed-through are the reflections from the air/firn interface and from the internal layers. These reflections have been zoomed in the second figure. The 20 dB mismatch in the noise floor is due to the quantization noise of the network analyzer which was unaccounted for in the simulation.

IV. Summary

We developed a high-resolution airborne radar system to map the internal layers in the polar ice sheets for estimating the accumulation rate. Our radar measurements coupled with in situ measurements from ice cores will help reduce the errors in the current accumulation rate maps which are in the order of 24%. We also developed a radar target simulator to help characterize the system and also serve as a calibration tool in the field. We used the aid of a CAD tool to optimize the system performance before construction.

References

[1] Kanagaratnam, P., R. Eakin and S. Gogineni, "An Airborne Radar System for High-Resolution Mapping of Internal Layers," IGARSS '01, Sydney, Australia, pp. 940-942.

[2] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2001: Impacts, Adaptation, and Vulnerability (Summary for Policy Makers), Geneva, Switzerland, February 13-16, 2001.

[3] Bales, R. C., J. R. McConnell, E. Mosley-Thompson, and G. Lamorey, Accumulation Map for the Greenland Ice

Sheet: 1971-1990, *Geophysical Research Letters*, vol. 28, no. 15, pp. 2,967-2,970, 2001.

[4] Kanagaratnam, P., S. Gogineni, N. Gundestrup and L. Larsen, High-resolution radar mapping of internal layers at the North Greenland Ice Core Project, *Journal of Geophysical Research*, vol. 106, no. D24, pp. 33,799-33,812, 2001.

[5] Plummer, T. and B. Pharatasarathy, Target simulation for internal layers of Greenland ice sheet, IEEE student paper contest, Electrical Engineering and Computer Science, The University of Kansas, Lawrence, Kansas, 2002.

[6] Kanagaratnam, P., Airborne Radar for High Resolution Mapping of Internal Layers in Glacial Ice to Estimate Accumulation Rate. PhD. Dissertation, Electrical Engineering and Computer Science, The University of Kansas, Lawrence, Kansas, 2002.

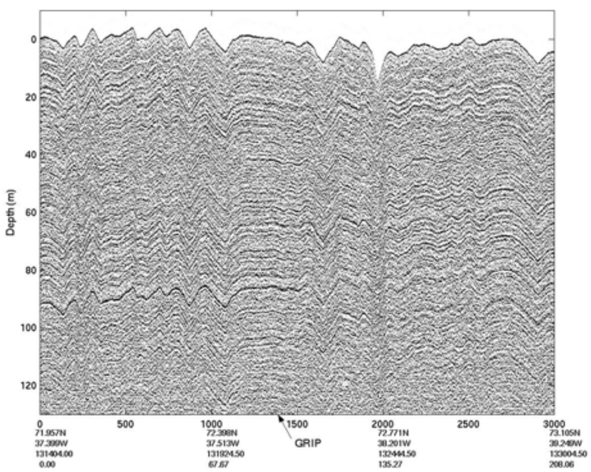

Fig. 1. Internal layers observed at the GRIP camp which is located in the dry snow region of the Greenland ice sheet.

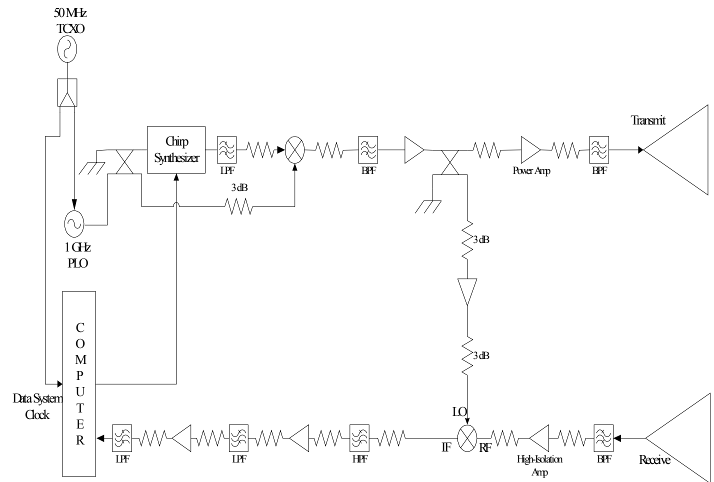

Fig. 2. Block diagram of the wideband FMCW radar system for airborne mapping of internal layers.

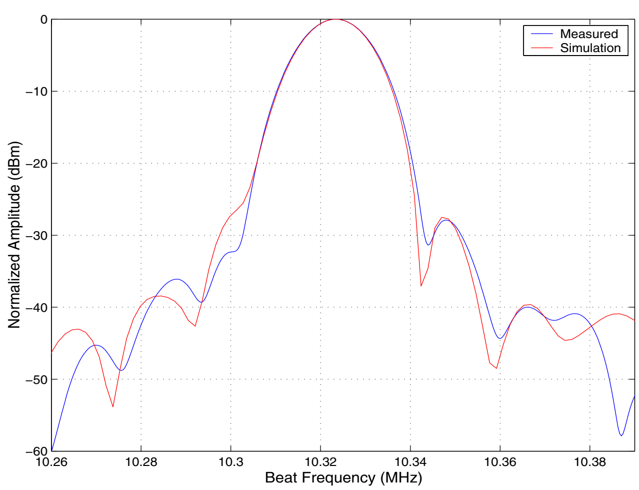

Fig. 3. Comparison between measured and simulated delay line response.

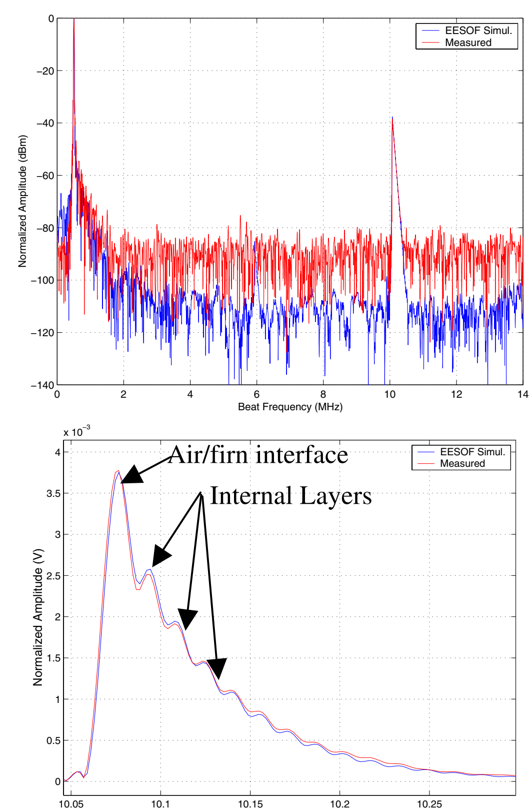

Fig. 4. Comparison between simulated and measured response of target simulator.