GROUND-BASED ULTRA WIDEBAND DUAL-POLARIZED RADAR SOUNDING OF GREENLAND ICE SHEETS

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ABSTRACT

Ice sounding and mapping internal layers with radars over large areas is an effective way to obtain data to understand and model ice dynamics. To map the bottom most layers and determine the ice-bed topography of more than 3-km Greenland ice with fine resolution, we developed a 180 – 340 MHz ultrawide band (UWB) dual-polarized ice sounding radar. The radar was deployed as a part of the East Greenland Ice-core Project (EGRIP) in summer 2019. It is configured as a 12-channel multiple-input-multiple-output (MIMO) system. We designed and built a dual-polarized tightly coupled antenna-array. This paper presents the radar design, antenna performance and sample results from the data collected in the field.

Index Terms— UWB, Radar, Ice, Sounding, Greenland

1. INTRODUCTION

The Greenland ice sheet is losing more mass every year. Data from NASA's GRACE satellites and GPS stations around Greenland's coast showed an ice loss of 280 billion tons of ice per year between 2002 and 2016 [1]. Also, the annual ice loss rate by 2012 is about -393 Gt/year, which is reported to be nearly 4 times the rate in 2003 [2]. This rate is much faster than model predictions. Greenland ice sheet behavior is strongly influenced by processes at its margin and base [3]. Therefore, detailed ice-bed topography and well-defined basal boundary conditions can help ice-flow modelers to have better predictions on the influence of climate change on the future ice sheet.

To assist the ice drilling and study of ice-flow dynamics at the EGRIP site [4], we developed and deployed a high sensitivity surface-based UWB dual-polarized radar, operating from 180 to 340 MHz. This radar system has a total transmit power of 1500 W and an antenna-array aperture of around 8 m^2. The large power-aperture product along with the 160 MHz bandwidth can provide fine-resolution ice-sheet echogram down to the bottom of ice. Compared to the radar systems we deployed before [5], the dual-polarized configuration can provide more information of ice crystal orientation and helps scientists to have better understanding of ice stream dynamics.

2. RADAR SYSTEM DESIGN

2.1. Link Budget

To demonstrate the radar's capability of sounding the deepest ice in Greenland, the signal-to-noise ratios (SNR) of ice bed returned signals at the lowest frequency and the highest frequency are computed and the radar parameters used for the link budget calculation are shown in Table I. At this frequency range, both air-ice and ice-bed boundaries can be treated as large planar reflectors. We also made assumptions that the one-way ice loss at -10 °C is about 10 dB/km at 180 MHz and 13 dB/km at 340 MHz. In the proposed radar system, the transmit power combining from all 12 channels is 62 dBm (1500 W) and the 2-way antenna gain is 28 – 40 dBi across the operating bandwidth. Therefore, the signal reflected from ice-bed interface has an SNR of 63.1 dB at 180 MHz and 51.5 dB at 340 MHz. This high sensitivity radar system is capable of sounding the 3-km ice sheet with fine resolution.

TABLE I
UWB RADAR LINK BUDGET

Frequency	180 MHz	340 MHz
Pulse length	10 us	10 us
Bandwidth	160 MHz	160 MHz
Transmit Power	62 dBm	62 dBm
Antenna Gain (2-way)	28 dBi	40 dBi
Air-ice power trans. coeff. (2-way)	-0.7 dB	-0.7 dB
Total ice loss	60 dB	78 dB
Ice-rock reflection coeff.	-20 dB	-20 dB
Pulse compression gain	29 dB	29 dB
Integration gain (hardware)	21.1 dB	21.1 dB
Spreading loss term 1	22 dB	22 dB
Spreading loss term 2	80 dB	80.5 dB
Noise figure	3.5 dB	3.5 dB
Noise power	-88.7 dBm	-88.7 dBm
Received signal power	-46.7 dBm	-70.3 dBm
Post processing integration gain	10 dB	10 dB
SNR	**63.1 dB**	**51.5 dB**

2.2. Radar Hardware Configuration

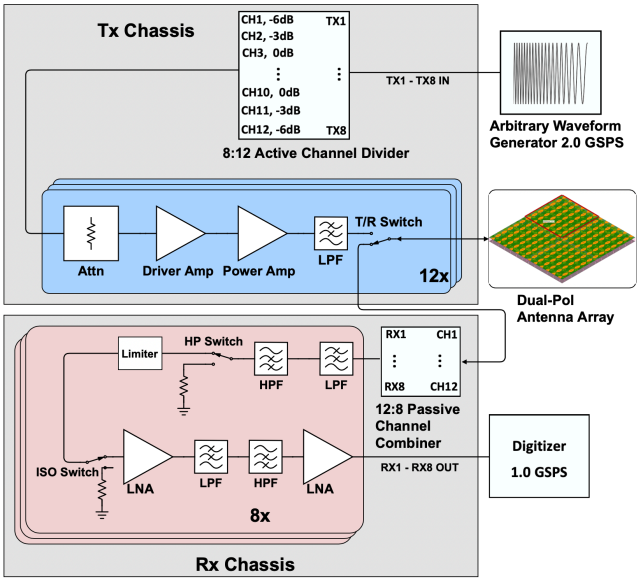

Fig. 1 Radar System Block Diagram

The UWB dual-polarized radar is a pulsed linear frequency modulated (LFM) radar, which has a pulse width of 10 us and a duty cycle of 5%. The radar system consists of 5 major parts including digital system, radio frequency (RF) transmitter (TX), RF receiver (RX), dual-polarized antenna array and computer server. The radar block diagram is shown in Fig.1. The digital system has a 14-bit, 2 giga samples per second (GSPS) 8-channel arbitrary waveform generator (AWG) and a 14 bit, 1 GSPS 8-channel digitizer. Each channel of AWG can directly synthesize a 180 – 340 MHz chirp with amplitude and phase modulation. The digitizer supports real-time data streaming, coherent integration and pulse compression.

The RF transmitter is configured as a 12-channel subsystem to ensure the optimal antenna-array performance. This is done by expanding the 8-channel digital system outputs to 12 TX channels. An 8:12 active channel divider with power level tapering has been developed for the channel expansion. Each of the 12 outputs from channel divider is amplified and filtered through a driver amplifier, a power amplifier and a low pass filer (LPF) as shown in Fig. 1, TX Chassis. A high-power T/R switch is then added to achieve the half-duplex configuration. In TX mode, the tapered high-power RF signals from 12 channels pass through the switch and feed the antenna array. The power level is 150 W for the middle 8 channels and 75 W for the edge 4 channels. The power level tapering helps to reduce the edge effect of the tightly coupled antenna array and suppress antenna side lobes.

After 10 us TX window, the T/R switch is set to RX mode. The same antenna array captures the echo reflected from different ice layers and ice bed then sends it to a passive 12:8 channel combiner. The combined signal is being received by an 8-channel receiver. Each receiver channel consists of low pass filters (LPF), high pass filters (HPS), high power (HP) switch, isolation (ISO) switch and low noise amplifiers (LPF). The cascade of an HP switch and an ISO switch can further protect the receiver from being damaged by the high-power transmitted signal.

2.3. Antenna Array Design

The antenna array design for ground-based ice sounding radars has to meet certain requirements such as lightweight, low-profile and should be easy to transport and ship. At the same time, the antenna array has to have the maximum available bandwidth to be compatible with future deployments. Based on these requirements, we designed a closely coupled dipole-array with 12 × 12 dual-polarized antenna elements and 288 feeding ports. The size of the array is 2.8 m × 2.8 m and the height is only 12.7 cm. The antenna array can operate from 180 to 620 MHz with a gain of 14 – 23 dBi. The antenna array structure and performance are shown in Fig. 2. The array voltage standing wave ratio (VSWR) is less than 2.3 over the entire 180 - 620 MHz range.

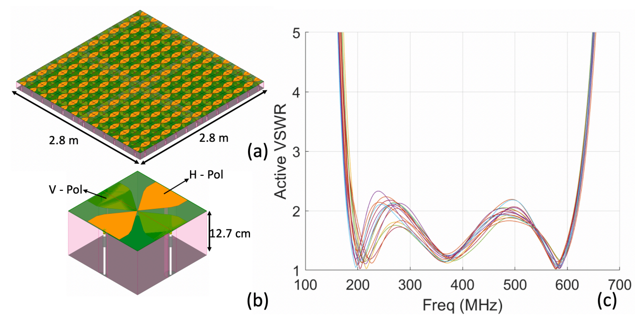

Fig. 2 UWB dual-polarized antenna array. (a) Structure of the full array (b) Structure of a single dual-polarized antenna element (c) Simulated Active VSWR of the full array

3. RADAR LOOPBACK TEST

Before the deployment, we characterized the radar loop sensitivity and impulse response in the lab. We attenuated the high-power output signals from all 12 channels by 100 dB and combined to one channel. The combined signal is then sent through a 7.4 km optical delay-line. The output of the delay-line is divided to 8 channels again and sent to the 8-channel receiver. The measured single-target pulse compression result with hamming window function shows a sidelobe level of less than -25 dB and a range resolution of 1.3 m. The sidelobe performance degradation is caused by the feed network used to combine 8 channels into 1 channel for using a single optical delay line available in the Lab. From loopback test and link budget calculation, the loop sensitivity is about 200 dB, which can be further improved by unfocused SAR processing.

4. DEPLOYMENT RESULTS

The UWB dual-polarized radar system was deployed at the EGRIP camp, Greenland, in Summer 2019. The system was set-up and operated as shown in Fig. 3. Two quick look radar echograms from a single channel are shown in Fig. 4. Echogram (a) shows transmitting and receiving signal using vertical polarization (VV-Pol). Echogram (b) shows transmitting and receiving signal using horizontal polarization (HH-Pol). The ice layers can be easily seen from both echograms, but they have some differences when comparing closely. The most interesting difference is that a layer between 2.6 – 2.7 km is detected when using HH-Pol, which is hard to see in the VV-Pol echogram. By looking at the quick-look results, different polarizations can definitely provide more information about ice layers.

Fig. 3 The snow vehicle carries the UWB radar system was towing the dual-polarized antenna-array on the snow and taking measurements

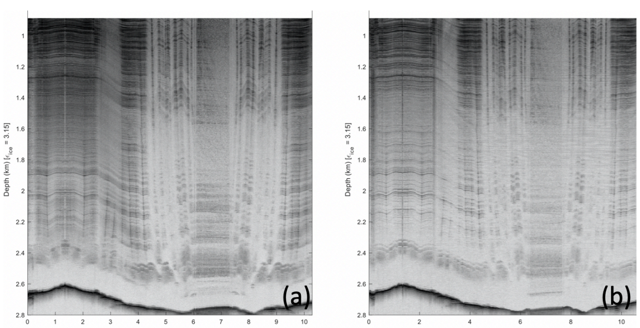

Fig. 4 Radar quick-look echograms of data collected in Northeast Greenland. (a) VV-Polarization (b) HH-Polarization

5. NEXT GENERATION RADAR DEVELOPMENT

For the upcoming 2020 Greenland summer deployment, the radar system will be upgraded to a quad-polarized radar operating from 180 to 480 MHz. With improved bandwidth, the new system will have a vertical resolution of 0.5 m. A preliminary multi-target loopback simulation is done in Advanced Design System (ADS) and the impulse response result is shown in Fig. 5. Target 2 and 3 with similar reflected power level are closely placed with a distance of 0.55 m, which can still be detected as two targets by the new radar system.

6. CONCLUSIONS

A ground based UWB dual-polarized radar system for Greenland ice sounding is proposed. The radar system design,

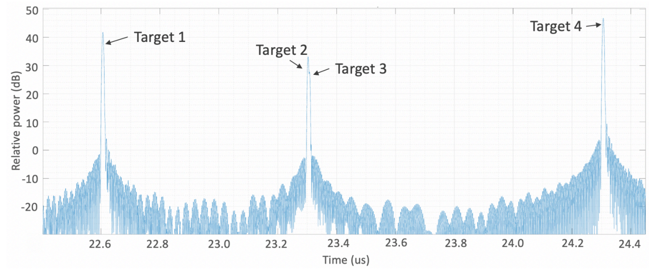

Fig. 5 Pulse compression simulation result of multiple point targets with different attenuations at different distance

UWB dual-polarized antenna array performance, radar loopback test and field deployment results were described in this paper. The quick look results show the benefit of using different polarizations. More processed data will be presented in the conference.

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