SNOW AND ICE THICKNESS RADAR SYSTEM

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ABSTRACT

A real-time snow and fresh water ice thickness radar system under-went airborne testing in March 1998. This system is designed to be an additional sensor for the Canadian Coast Guard's *Ice Probe* real-time ice thickness sensor. The system has been developed around a GSSI 500 MHz ground penetrating radar system. The GSSI antenna unit has been extensively modified to build-in to the radar package the following items: the power supply, radar control electronics, and a DSP board (which has an on-board stereo CODEC chip). Real-time DSP code processes the radar data to determine flying height and snow or ice thickness. The snow thickness radar results are outputted via a RS-232 serial link. The snow thickness processing is based on the conditions expected when flying over sea ice. The processing results shown are for fresh water ice thickness measurements using the original processing algorithm design for snow thickness measurement.

INTRODUCTION

A commercial ground penetrating radar system was flight tested for use as a snow thickness sensor in 1991 at Tuktoyaktuk, N.W.T. as part of the Transport Development Corporation's (TDC) electro-magnetic (EM) ice thickness measurement system (Holladay et al., 1992). For the 1992 trial near St. Anthony, NFLD, new electronics were developed so that all the radar electronics could be contained in a small package mounted in the TDC EM bird (Prinsenberg et al., 1993). Each of these systems required data to be logged on analog tape or on a laptop computer with an analog-to-digital converter board. All processing of data was performed after the flight.

New work on the radar system takes advantage of new DSP-based micro-controllers and stereo analog-to-digital and digital-to-analog converters in the implementation of the control electronics and real-time signal processing for the measurement of snow thickness and flying height. The snow thickness radar system is packaged in a small 30 cm by 35 cm by 15 cm package, with measurement results outputted over an RS-232 serial link.

Test flying of the new snow thickness radar sensor was performed in March 1998. Test flights were flown with the real-time system and with an analog control unit so that a good raw-waveform data set could be collected.

HARDWARE DEVELOPMENT

The snow thickness radar system has been developed around a GSSI model 3102DP ground penetrating radar (GPR) system. This system originally contained the radar antennas and the transmitter and receiver electronics. This unit was designed for use with an external control unit which an operator would use to operate the system and view the data on an oscilloscope. Data were typically recorded on analog tape. This prototype was built upon the original factory unit which was purchased in 1990.

There are seven subsystems in the snow thickness radar system. They are:
1. the antenna elements;
2. the sampling receiver;
3. the transmitter;
4. the sampler control board;
5. the power supply, digital logic and signal conditioning board,;
6. the calibration unit;
7. the Analog Devices EZkit-Lite board.

The antenna elements are mounted on the inside of the bottom of the radar package. The Analog Devices EZkit-Lite board is mounted on the lid of the box. The remaining components are mounted inside the upper section of the radar unit (see Figure 1).

The first three subsystems listed above came with the radar unit. The forth unit, the sampler control board (made by GSSI), was a spare part for an old GSSI System-7 radar control unit. The fifth subsystem was a new component built for this radar.

The sixth module, the calibration unit, was assembled for the 1992 St. Anthony field work. It contains a GSSI sampling receiver board and a circuit which passes the transmitter trigger to a delay line to create a signal with a series of pulses 25 ns apart.

The last module, an Analog Devices EZkit-Lite board has the following functions:

- provides the base clock for the overall system;
- generates the slow ramp required by the sampler control board;
- digitizes the analog input from the radar receiver and the calibration unit;
- processes the incoming data for flying height and snow thickness;
- outputs the result over an RS-232 serial interface.

Figure 2 shows how the various sub-systems are interconnected.

Two VICOR DC-DC converters were used to supply +/- 12 VDC from 28 V helicopter power (available in the *Ice Probe* bird). An Endicot Research 12 VDC to 150 VDC converter modules was used to generate the high voltage required for the radar transmitter and receiver electronics. An Endicot Research 12 VDC to 75 VDC converter module was used to generate the high voltage required for the receiver electronics. The +5 V supply is generated from a 7805 voltage regulator chip.

EZkit-Lite Board

Several modifications on the EZkit-Lite board were required along with the creation of several small ancillary electronic circuits.

The analog output from the digital-to-analog converter (DAC) chip is AC coupled. Modifications were required to tap off a reference voltage and the DAC output signal to a circuit which would provide a DC coupled output. The DAC produces a ‘slow ramp’ at the rate of 15.64 Hz (16 kHz / 1023 points per ramp). The ramp varies from 0 to -6 V each sweep. The rate and slope of the ramp sets the output scan rate and is one of the controls used to set the radar range window length. Potentiometers are mounted inside the radar to scale the ramp for fine adjustment of the range window and to set the time within the radar range window when the transmitter fires. (A capacitor on the sampler control board is used to set the slope of the fast ramp. Together, the fast ramp and slow ramp set the radar range window and scan rate.)

The signal level from the radar receiver and calibration unit is too high for the EZKit-Lite board’s analog-to-digital converter (ADC). These signals are passed through an attenuator circuit to reduce the signal level so it is within the ADC’s input range.

The 12.288 MHz clock used with the on-board analog-to-digital converter chip was tapped off and divided down to 48 kHz for use as the radar system clock.

SOFTWARE DEVELOPMENT

The DSP on the EZKit board interfaces to an analog-to-digital converter (ADC) and a digital-to-analog converter (DAC) chip. This chip provides two channels for each of the ADC and DAC sides of the chip. The ADC is used to digitize the analog signal from the radar receiver and calibration unit. One channel of the DAC is used to generate a slow ramp, which is used by the radar's control electronics to set the output scan rate. The other DAC channel is used to generate a start-of-scan pulse. The start-of-scan pulse is used with external devices such as an oscilloscope (to view the analog waveforms) or to log data with an external analog-to-digital converter (such as a PCMCIA ADC card used with a laptop).

The fact that the DSP generates the slow ramp means that there is now software control over several radar parameters. The software can be changed to select a different scan rate and change the window length.

Snow Thickness Processing

As part of the 1991 and 1992 field trials with the earlier radar systems, a model was established as a basis for classifying radar echoes as ice echoes or snow echoes. A software algorithm was implemented following the model to automatically estimate snow thickness.

The model used the following assumptions:

- the radar footprint diameter is approximately equal to antenna height (about 15 m);
- over a smooth, flat reflector most of the energy is returned from a region with a radius of less than one tenth antenna height (first Fresnel zone);
- small radar targets in a rubble field return echoes with much smaller amplitudes than large flat targets (flat ice);
- the echo from the ice surface (whether covered by snow or not) has the largest amplitude in the trace; and
- the echo from the air/snow interface is the largest signal greater than random noise levels that arrives before the ice echo.

Before peak location begins, the raw radar data is filtered to remove high frequency random noise, low frequency noise and background system noise. For every trace the maximum peak value is found and its value and location are stored. This peak might correspond to an echo from the top of the ice. The data is searched for the first peak that has a value greater than a given threshold. The threshold is chosen to be well above the RMS noise level. If a peak is found, its location and value are also recorded. This peak might correspond to an echo from the air/snow interface.

The peak locations are processed for snow thickness by subtracting the snow peak position from the ice peak position, dividing by the sampling frequency and multiplying by the radar velocity in the snow (0.15 m/ns). No snow thickness determination is made if:

- the ice echo is too small;
- no snow echo is found; or
- the ice peak amplitude is smaller than the snow peak amplitude.

In preparation for the coding of a real-time snow thickness processing system, the radar data archive from the 1991 Tuktoyaktuk field work was restored. The Matlab version of the snow thickness processing algorithm was also restored from an archive and made to work again with the data from Tuktoyaktuk.

The algorithm was coded in 'C' and tested on a DOS-based computer. Once the 'C' code was working, it was recoded in assembler to run on the Analog Devices 2181 DSP chip, where further debugging was required.

Functions implemented in the DSP are as follows:

1. A/D conversion of data and calibration channel;
2. Acquire background - stacking and band-pass filtering;
3. Band-pass filter radar scans;
4. Subtract background;
5. Peak detection;
6. Peak extraction - apply model;
7. Choose dielectric constant;
8. Output snow thickness and flying height.

At present the cal channel is processed off-line to determine the RF sampling interval and the transmitter start time. Figure 3 shows a block diagram of the software implemented for the DSP.

Data Output

By default, the DSP outputs a string with the detected flying height and the snow thickness measurement. Other output strings are available for debugging the system or to get additional information to assist with modifications to the processing algorithm.

Commands can be sent to the radar to output the raw radar waveform, the calibration waveform and the radar waveform after background subtraction. This waveform dump is very slow and has limited use, but it does enable the acquisition of raw radar waveforms without extra cables being added to the tow cable or having a VCR or laptop to record analog data.

FIELD WORK

The snow thickness radar system was field tested in March 1998 using a small test bird. An analog control unit was used to collect raw radar waveforms over a variety of surfaces. Due to the unusually warm winter, most test flights were over fresh water lakes so that there would be a layered surface medium to test the signal processing and radar performance.

Raw Data Collection

Analog data were collected using a Panasonic laptop computer and a Computer Boards Inc. PC-Card A/D converter. The control unit was set to 12.8 scans per second. The A/D conversion rate was 14 kHz. The control unit used was a GSSI model SIR 7. The extra boards installed in the antenna unit were bypassed when it was used with the analog control unit.

Figure 4 shows a plot of raw data collected over a lake near Tracadie Bay, PEI on March 14, 1998. Figure 5 shows a close up view of the analog data as a gray-scale plot and variable area plot. Figure 6 shows a plot of the analog data after background subtraction processing. Figure 7 shows the analog data after aligning the radar returns using the air/ice interface echo. Figure 8 shows a plot of fresh water ice thickness measurement after applying the processing algorithm to the raw data.

Real-time Data Collection

RS-232 serial data from the real-time system was recorded using a data acquisition program originally designed to record data collected with the Bedford Institute of Oceanography's Video Sensor System.

The Video Sensor System acquisition software can record digital video frames, GPS positions from the helicopter's on-board GPS receiver, RS-232 serial laser altimeter readings and digitize the helicopter's flying height from the on-board radar altimeter. This laptop-based logging software was modified to record the output from the snow thickness radar.

A flight was performed with the real-time system on March 13, 1998. Line 45 followed a similar path to the analog data example show in Figures 4 to 8. Figure 9 shows the plot of the GPS positions collected along a survey line. Also in Figure 9 are sample plots of digital images collected along the line. Frame 1 shows the shore line approximately 170 seconds from the start of data collection. Frame 2 shows the ice surface in the middle of the lake approximately 210 seconds from the start of data collection. Frame 3 shows some open water in a smaller lake to the east of the main lake. Figure 10 show a plot of the fresh water ice thickness measurement obtained with real-time system.

ACKNOWLEDGEMENTS

The support of Dr. Simon Prinsenberg of the Bedford Institute of Oceanography, Dartmouth, Nova Scotia has been vital for the continued development of snow and ice thickness sensors.

REFERENCES

Holladay, J.S., I. St. John, V. Schoeggl, J. Lee, J.R. Rossiter and L.A. Lalumiere, TDC Airborne EM Ice Measurement Sensor, Phases 1-2: Final Report, Submitted to Transportation Development Centre, Report No. TP11282E, 1992

Prinsenberg, S.J., J.S. Holladay and L.A. Lalumiere, Electromagnetic/Radar Ice and Snow Sounding Project over the Newfoundland Shelf in 1992, Can. Tech. Rep. Hydrogr. Ocean Sci. No. 144, vii + 57 pp, 1993

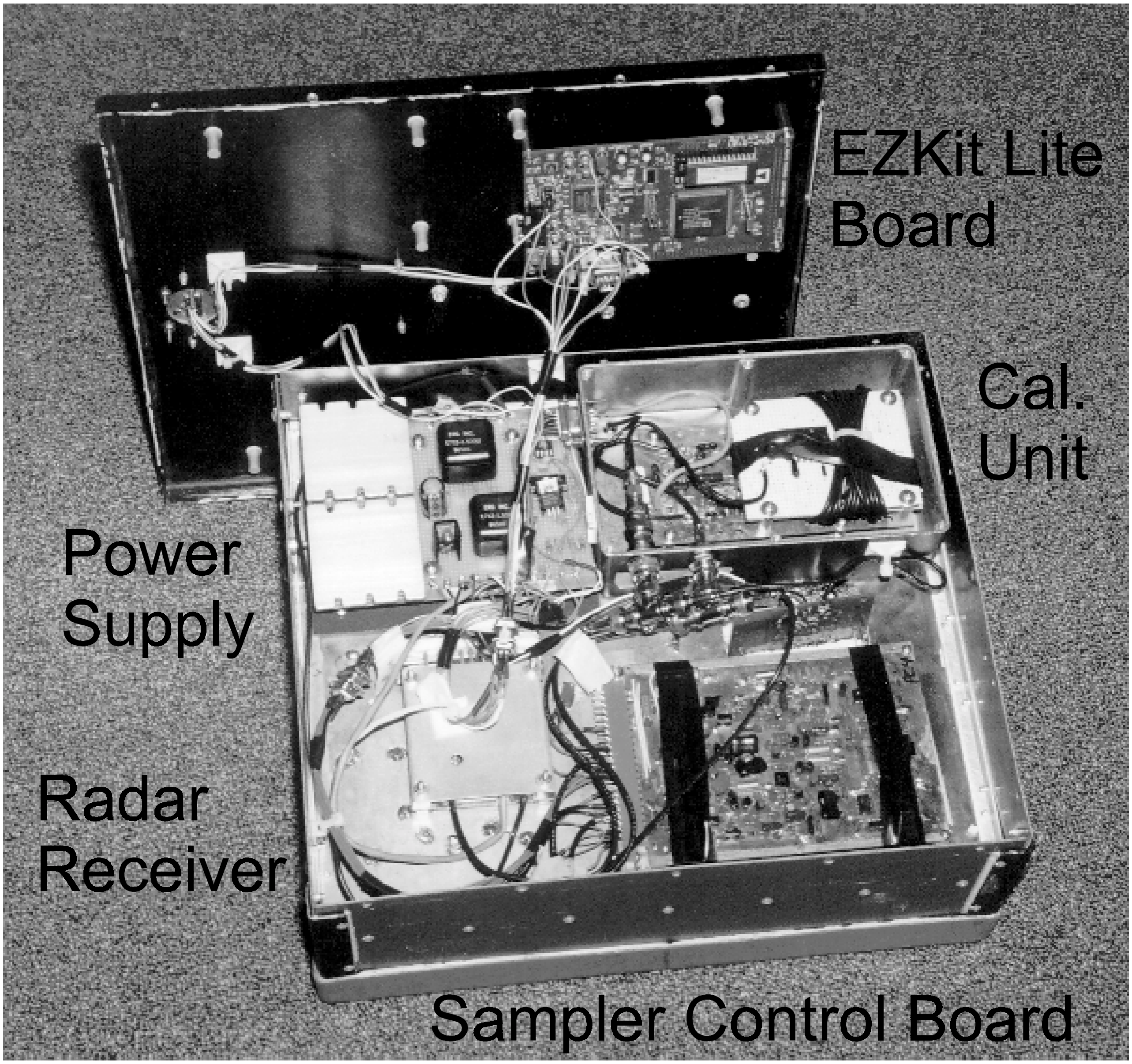

Figure 1. Photograph of the inside components of the ice thickness radar system.

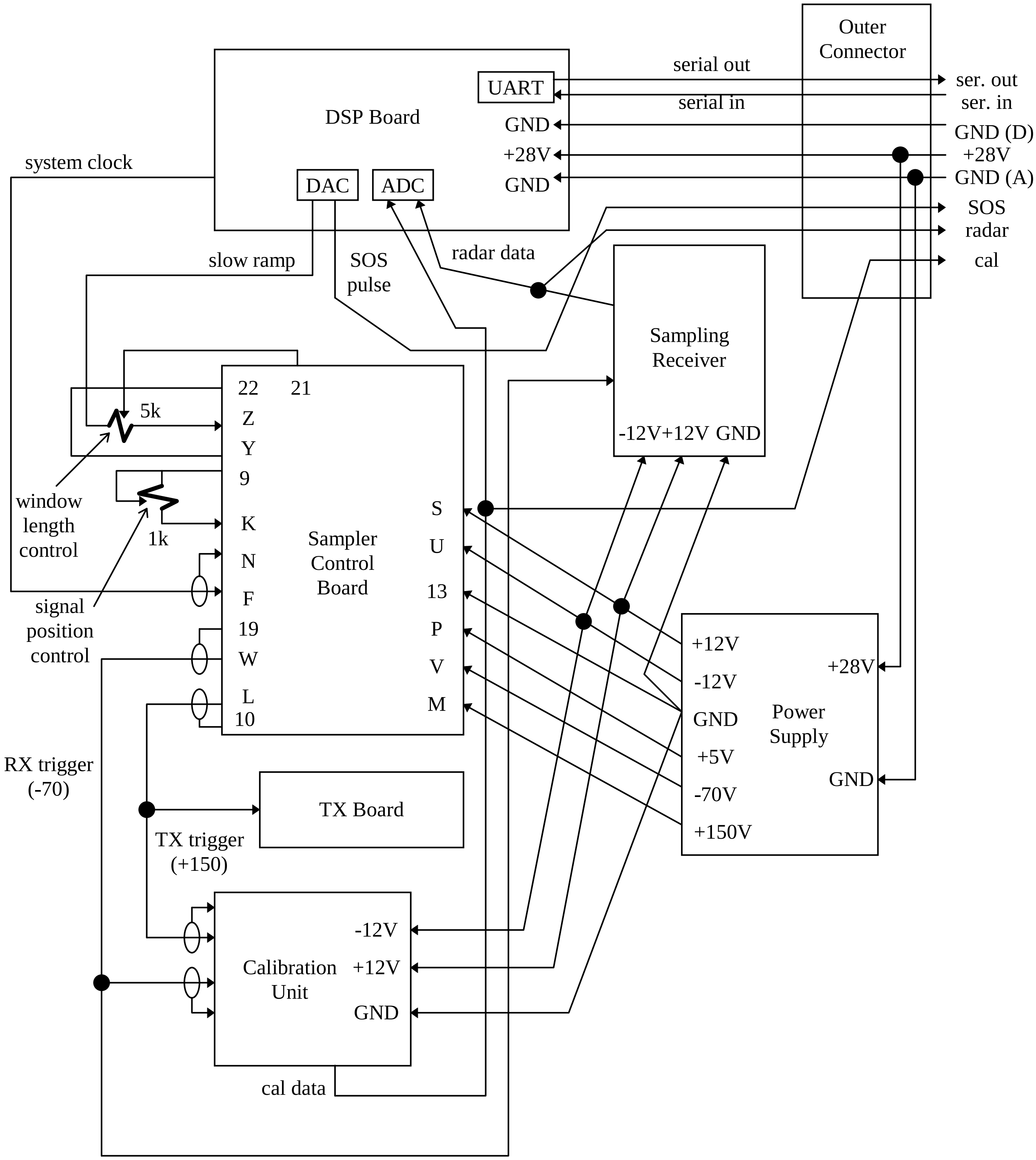

Figure 2. Wiring diagram of major components

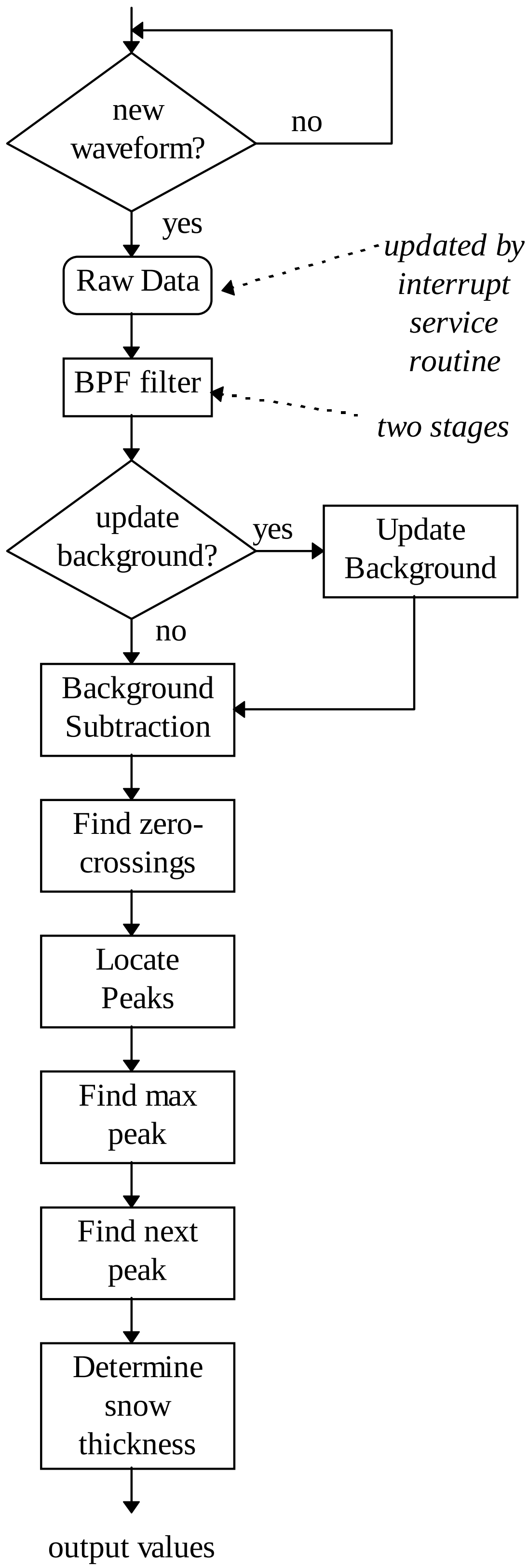

Figure 3. Block diagrams of the DSP software.

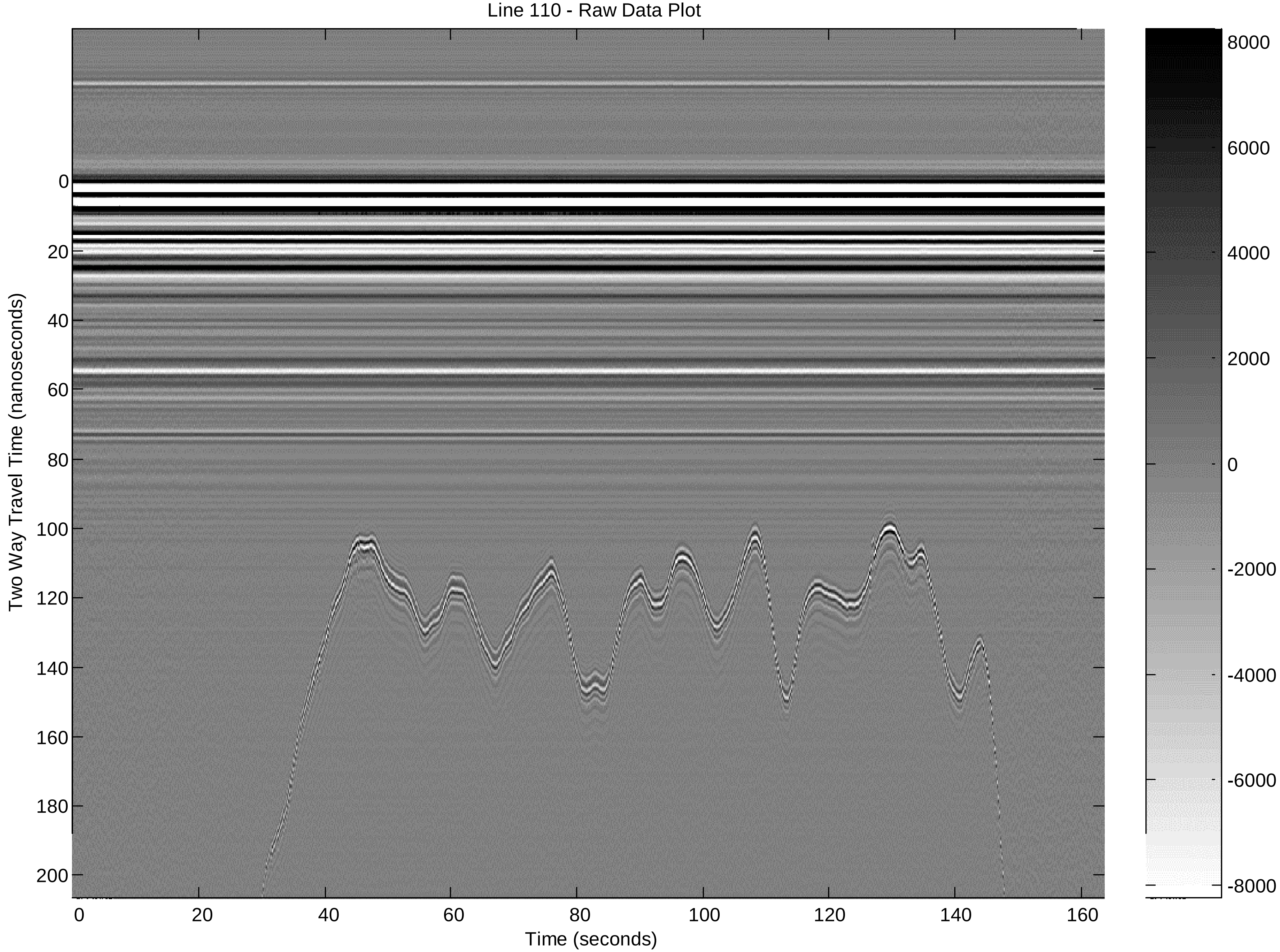

Figure 4. Plot of raw data collected with analog

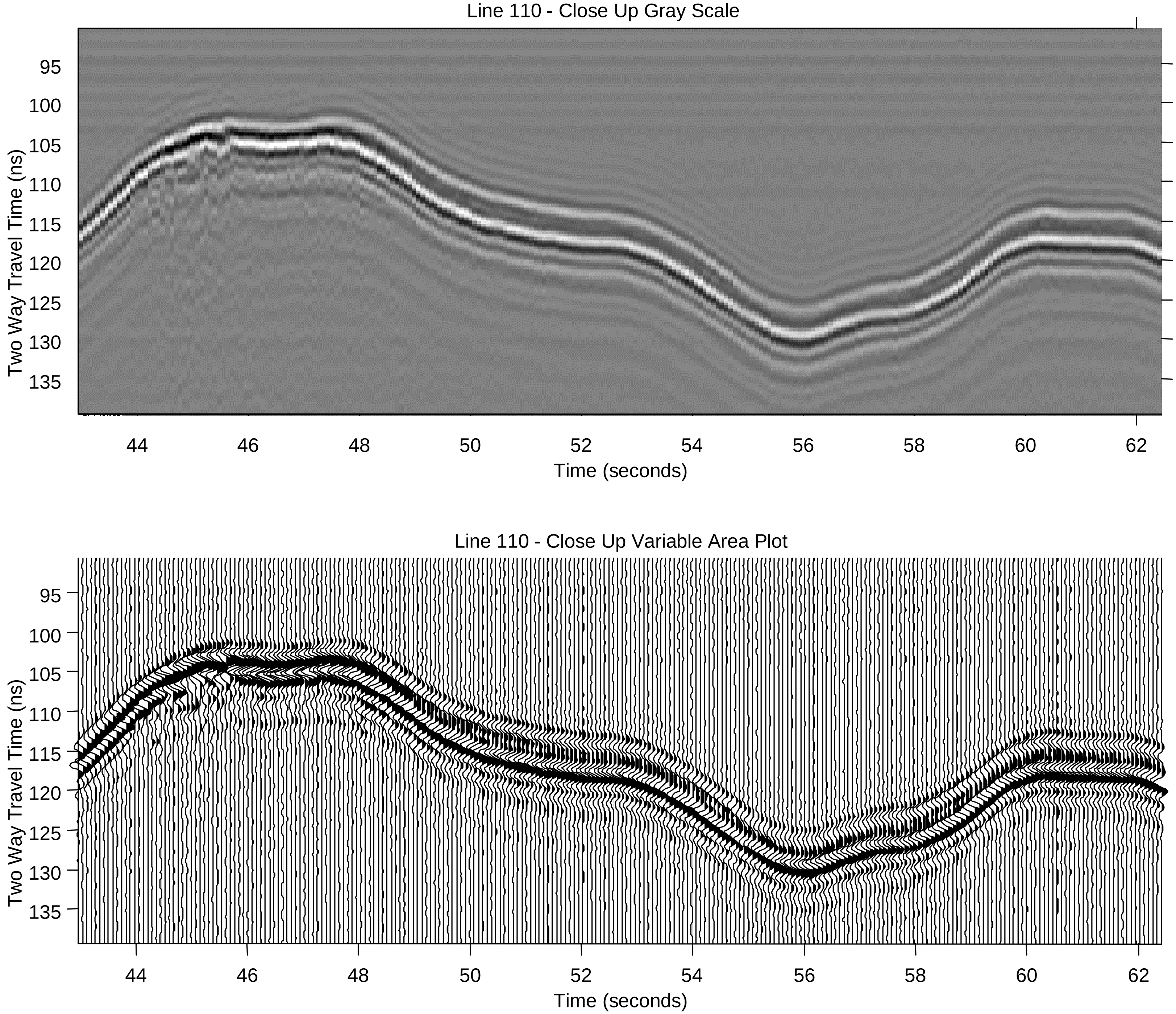

Figure 5. Close up view of analog data as a gray-scale plot and

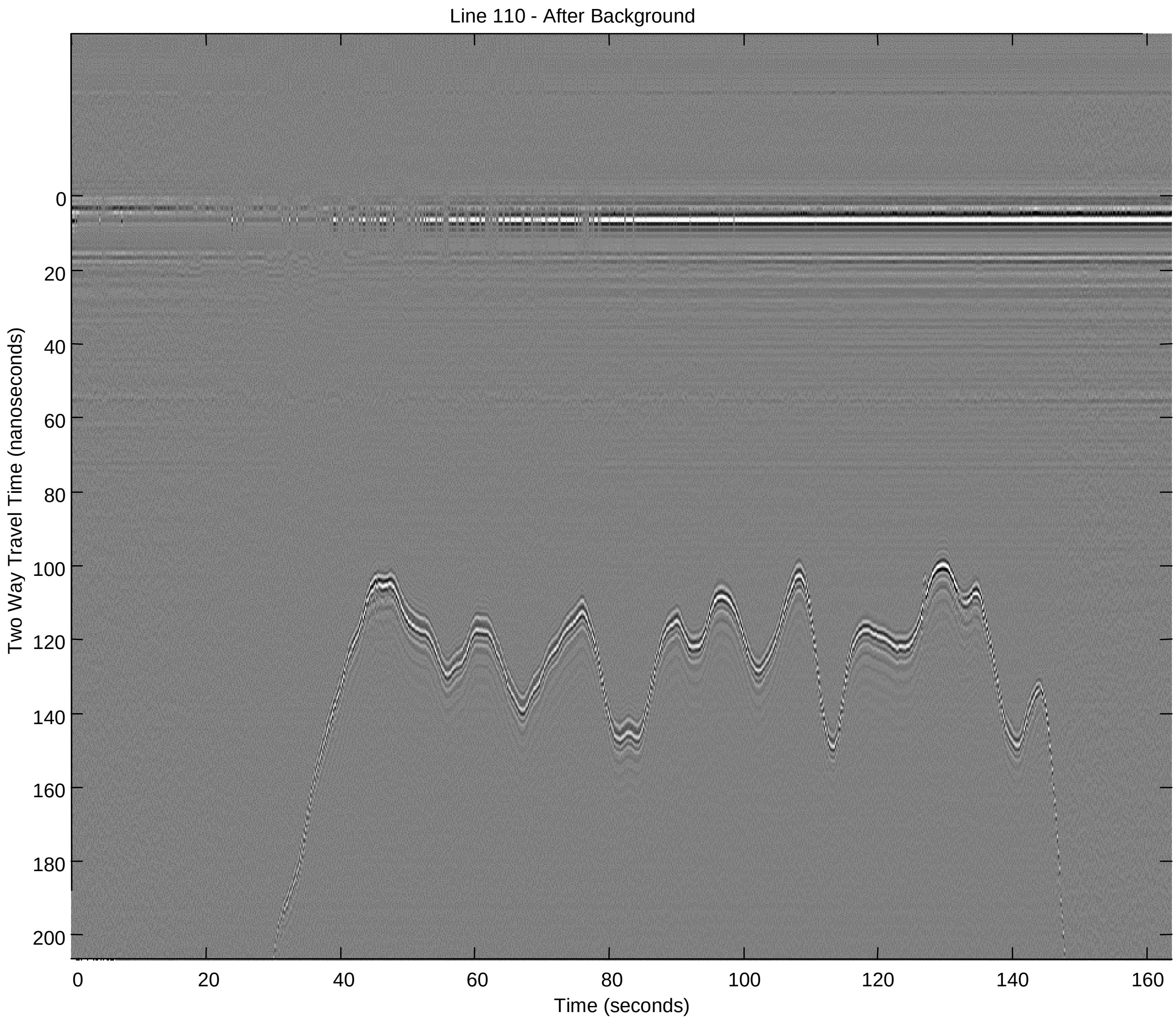

Figure 6. Plot of analog data after background

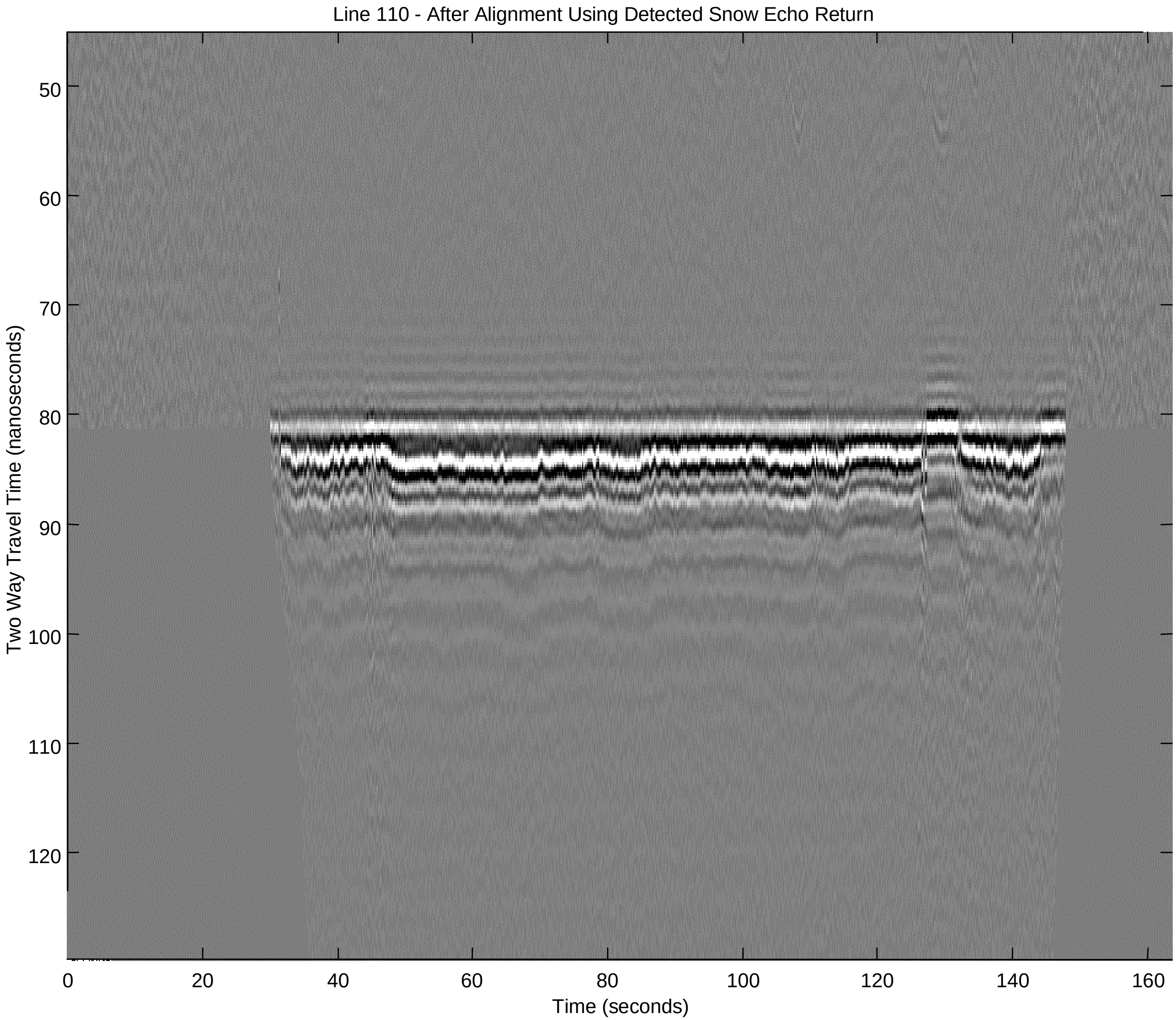

Figure 7. Analog data after aligning the radar returns using the air/ice interface echo.

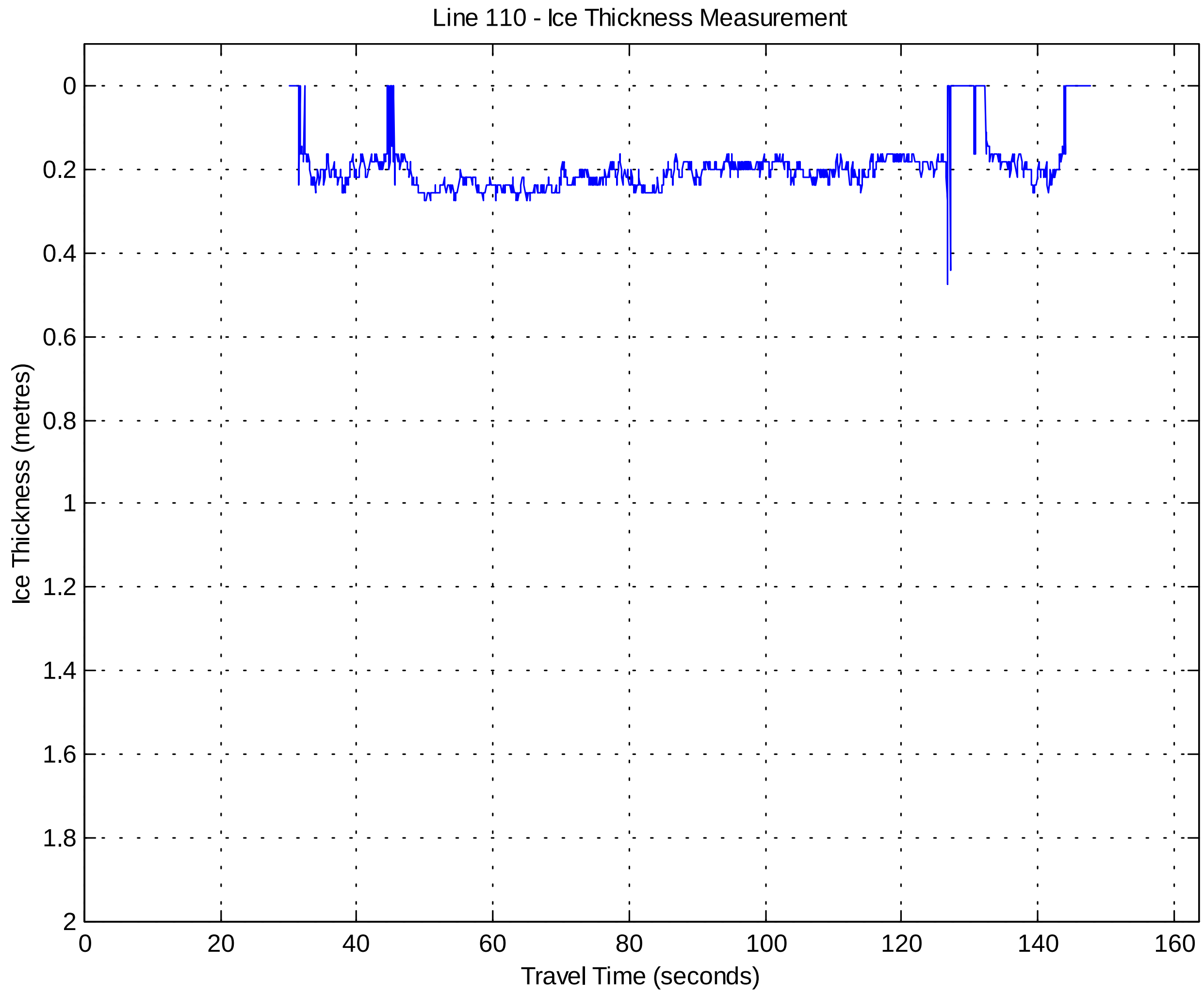

Figure 8 . Plot of fresh water ice thickness measurement using analog data.

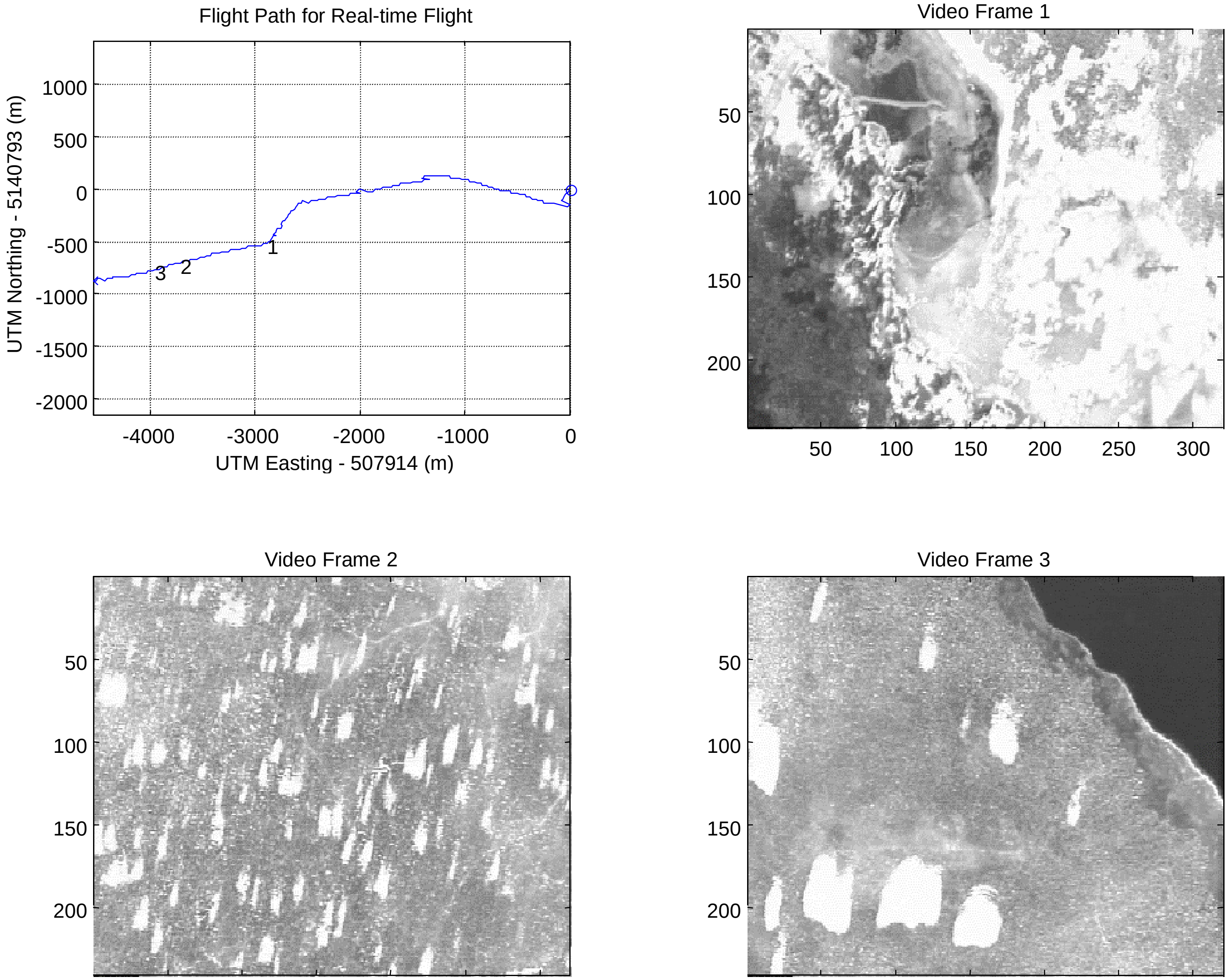

Figure 9. Flight path and video frames from real-time system.

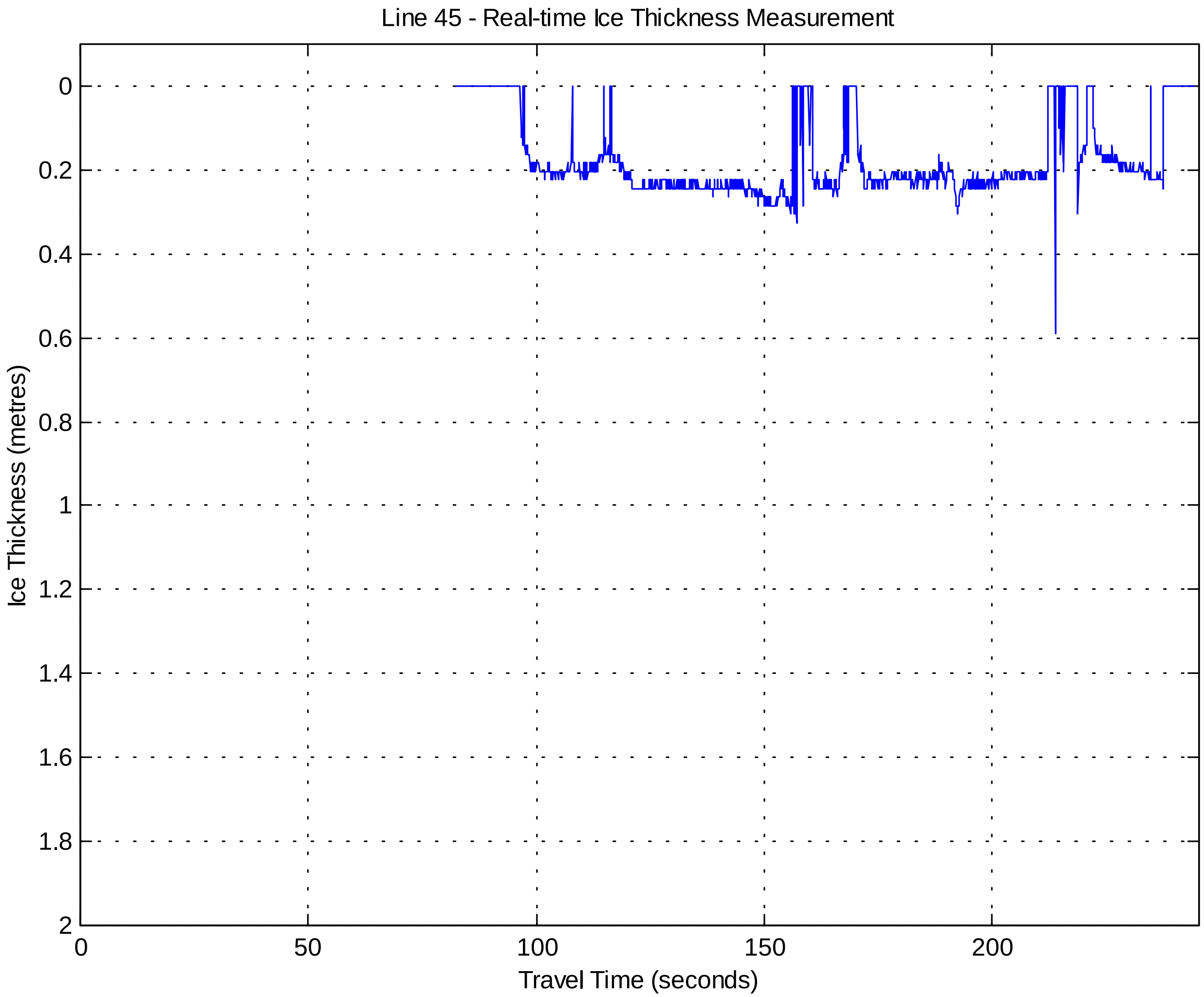

Figure 10. Plot of fresh water ice thickness measured with real-time system.

Photographs to accompany the paper:

Snow and Ice Thickness Radar System

Photo of lake by Tracadie Bay, PEI

Laptop computer used to log data

Video pod mounted on Coast Guard helicopter

Video pod, logging computer and signal/power distribution box

Radar bird ready for takeoff

Radar bird in flight under helicopter