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IMPLEMENTATION OF A PROTOTYPE REAL-TIME SNOW THICKNESS RADAR

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by

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ABSTRACT

Results are described of development work and field test for the integration of a Digital Signal Processing (DSP) board with a ground penetrating radar system for real-time snow thickness measurement of a helicopter-borne sensor package. This is the first airborne ground penetrating radar system to provide real-time processed results.

Ground penetrating radar systems have been flight tested in Canada for use as snow thickness sensors in 1991 at Tuktoyaktuk, N.W.T. and in 1992 near St. Anthony, NFLD. Radar electronics were contained in a small package mounted in a helicopter-towed bird containing, in addition, an electro-magnetic (EM) sensor to measure ice thickness. Data was logged on analog tape or laptop computer with an analog-to-digital converter board and processing was performed after the flights. Results showed that the ground penetrating radar could measure minimum snow depths of approximately 25 cm with a resolution of 5 cm.

The present work 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 ground penetrating 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.

Tests of the new snow thickness radar sensor in March 1997 showed that (1) the addition of the on-board digitization and signal processing to the radar worked well; (2) the software developed to process the incoming data provided real-time output data over a standard serial interface; and (3) the radar was able to return real-time results for flying height, with noisy returns for snow thickness.

Overall noise levels were higher than with the radar electronics used in 1992. Further work should compare the 1997 and 1992 radar electronics to establish reasons for the higher 1997 noise levels. Although for the 1997 flight tests, the radar was mounted inside the *Ice Probe* bird, it can be flown in its own bird or hard-mounted to the helicopter. In addition to sampling real-time snow depths, this system lends itself to the measurement of level fresh water ice thicknesses.

RÉSUMÉ

Présentation des résultats des travaux de développement et d'essais sur le terrain en vue de l'intégration d'une carte de traitement numérique des signaux (DSP) à un géoradar embarqué à bord d'un hélicoptère en vue de la mesure en temps réel de l'épaisseur de neige. Il s'agit du premier géoradar aéroporté fournissant des données en temps réel.

Les systèmes de géoradar ont fait l'objet d'essais en vol au Canada en vue de mesurer l'épaisseur de la neige en 1991 à Tuktoyaktuk, aux T.N.-O., et en 1992 près de St. Anthony, T.-N. Les circuits électroniques du radar étaient contenus dans un petit boîtier monté à bord d'un «oiseau» remorqué, qui contenait en outre un capteur électromagnétique (EM) afin de mesurer l'épaisseur de la glace. Les données étaient enregistrées sur bande analogique ou sur un ordinateur portatif par l'intermédiaire d'une carte à convertisseur analogique-numérique, et le traitement était effectué après les vols. Les résultats ont démontré que ce radar pouvait mesurer des épaisseurs minimales de neige de près de 25 cm avec une résolution de 5 cm.

Les présents travaux tirent parti de nouveaux microcontrôleurs à base de processeurs numériques de signaux (DSP) et de convertisseurs stéréo analogique-numérique/numérique-analogique mis en oeuvre dans l'électronique de commande et le traitement numérique des signaux pour la mesure de l'épaisseur de neige et de la hauteur de vol. Le système de géoradar est intégré à un petit boîtier de 30 cm x 35 cm x 15 cm et les résultats des mesures sont transmis par une liaison série RS-232.

Les essais du nouveau capteur radar de mesure d'épaisseur de neige qui ont eu lieu en mars 1997 ont démontré : (1) que l'ajout de fonctions embarquées de numérisation et de traitement des signaux au radar donnait un fonctionnement correct; (2) que le logiciel élaboré pour traiter les données d'entrée fournissait des données de sortie en temps réel au moyen d'une interface série standard; et (3) que le radar était capable de fournir des résultats en temps réel au sujet de la hauteur de vol, l'épaisseur de neige étant représentée par des échos bruyants.

Les niveaux de bruit d'ensemble étaient supérieurs à ceux obtenus avec les circuits électroniques radar utilisés en 1992. Des travaux ultérieurs devraient comparer les circuits radar électroniques de 1997 et de 1992 afin de déterminer les raisons pour lesquelles les niveaux de bruit sont supérieurs en 1997.

Bien que, pour les essais de 1997, le radar ait été monté à l'intérieur de l'«oiseau» *Ice Probe*, il peut être installé à bord de son propre «oiseau» ou fixé directement à un hélicoptère. Outre la mesure d'échantillons de profondeur de neige en temps réel, ce système se prête à la mesure de l'épaisseur de glace d'eau douce plane.

1. Introduction

This final report documents the work performed on the development of a real-time snow thickness radar system. This system was designed to be an additional sensor in CCG's *Ice Probe* system.

A commercial ground penetrating radar system was flight tested for use as a snow thickness sensor in 1991 at Tuktoyaytuk, N.W.T. as part of the Transport Development Corporation's (TDC) electro-magnetic (EM) ice thickness measurement system. 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. 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 were performed after the flight.

This new work 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 measurements results outputted over an RS-232 serial link.

Test flying of the new snow thickness radar sensor was performed during March 1997. The testing showed that the real-time processing software worked as expected and but there is a problem with the radar electronics. Overall noise levels were higher than with the previous radar electronics (last flown in 1992). Further work with the electronics will be required before further flight testing can occur. To facilitate testing, the 1992 radar electronics should be re-assembled and tested for use in evaluating the new radar's performance prior to more flight testing.

2. Project Tasks

This project had three main tasks, hardware development, software development and testing.

2.1 Hardware Development

2.1.1 System description

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 set system settings 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 7 subsystems in the new snow thickness radar system. They are:

i. the antenna elements;
ii. the sampling receiver;
iii. the transmitter;
iv. the sampler control board;
v. the power supply, digital logic and signal conditioning board,;
vi. the calibration unit;
vii. the Analog Devices EZkit-Lite board.

A photograph of the inside of the radar unit is shown in Figure 1. The antenna elements are mounted on the inside of the bottom of the radar package. A dimensional drawing of the main components mounted inside the radar is shown in Figure 2. The Analog Devices EZkit-Lite board is mounted on the lid of the box.

The first 3 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 is 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 provides the following:
- 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 3 shows a how the various sub-systems are interconnected.

2.1.2 Power supply

The power supply was redesigned from scratch. Some of the components from the old power supply were obsolete and spares could no longer be obtained.

Two VICOR DC-DC converters were used to supply +/- 12 VDC from 28 V helicopter power (available in the *Ice Probe* bird). Two Endicot Research 12 VDC to 150 VDC converter modules were used to generate the high voltage required for the radar transmitter and receiver electronics. The receiver requires -70 volts. This was generated using a 5 V input and reversing the output of the Endicot supply. There are two +5 V supplies, one of them was for the Endicot that produces -70 V, the other was for the new digital logic elements and for the sampler control board. A schematic of the power supply is shown in Figure 4.

2.1.3 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 (shown in Figure 5) which would provided 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. This circuit is shown in Figure 6.

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. The circuit that performs this clock division is shown in Figure 7.

These ancillary circuits for the radar system are mounted on the same board as the power supply components.

2.1.4 Installation

The calibration unit was mounted in an aluminum box and secured inside the radar unit. The transmitter and receiver triggers are fed into the box using coaxial bulkhead connectors. It is important that noise from the calibration unit not be picked up be the radar receiver.

The low power transmitter was removed from the radar and the high power transmitter was installed. The high power transmitter was found (after 5 years of storage) with its wiring attached incorrectly, and some work was required to determine the problem and get it going.

The sampler control board connector was rebuilt. Stand-offs were epoxied to the inside of the box so that this board could be bolted securely.

The EZKit-Lite board was mounted to the lid of the radar box. A new connector was built to bring various radar signals outside the radar box. For debugging purposes, a start of scan pulse and the radar and cal. unit signal can be viewed on an oscilloscope. For normal use in the *Ice Probe* bird, the only connection is the 28 V input and the RS-232 serial connection.

2.2 Software Development

Software development was centred around radar control and data acquisition tasks, processing the radar data into an interpreted result and output of the real-time results to a data logging system.

2.2.1 Radar Control and Data Acquisition

The DSP on the EZKit board interfaces to a 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 wave forms) 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.

2.2.2 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 were 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.

2.2.3 Functions implemented in the DSP.

1. A/D conversion of data and calibration channel.
2. Process cal channel for RF sampling interval and first rising edge of the cal. signal.*

3. Acquire background - stacking and band-pass filtering.
4. Band-pass filter radar scans.
5. Subtract background.
6. Peak detection.
7. Peak extraction - apply model.
8. Choose dielectric constant.
9. Output snow thickness and flying height*.

Note: *indicates that this function is requires further development.

Figure 8 shows a block diagram of the software implemented for the DSP.

2.2.4 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.

A command can be sent to the radar to get it 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 used, but it does enable the acquisition of raw radar waveforms without extra cables added to the tow cable or having a VCR or laptop to record analog data.

2.2.5 Lab Testing

The radar unit, a laptop computer and a power supply were taken outside to the rear of Aerodat's office. A tape measure was laid out from the wall of the building so that the distance of the radar from the wall would be known. Raw radar and calibration waveforms were collected at half metre intervals from 9 metres out to 17 metres. Figure 9 shows a plot of the radar data at the various ranges from the wall. The difference of the time of arrival of the echo from the wall at the different distances is used to confirm the sampling interval of the system.

This sampling interval measured with the test radar data was compared with the sampling interval determined from the cal. signal. Figure 10 shows a plot of the calibration signal. The number of samples between the 25 ns pulses in the calibration signal is used to measure the sampling interval. This measurement will be performed by the DSP in the radar when the system initializes.

The time of arrival of the radar pulse, and the known distance from the wall is used to find the time the transmitter fired. The location of the first rising edge of the calibration unit is located. The offset between this starting point in the cal. data and the time the transmitter fired in the radar return is recorded for later use. With this offset, the transmitter firing position can be located by processing the cal. unit signal by the DSP when the system is initialized. This procedure is necessary due to possible drift in the analog electronics. The drift leads to uncertainty in the radar range window length (changing the sample interval) and the start time of the transmitter. The transmitter start time is not required for snow thickness measurement, but is it required for the measurement of flying height.

2.2.6 *Ice Probe* Software Modifications.

The Bird computer software was modified to use an ACL multi-port serial card as all of the on-board serial ports were already in use. The bird computer packages the snow thickness results in a special *embedded-packet* for logging by the Data-Server. When the Bird receives a command to have the EM system do a Q-coil, a message is be passed to the radar system for it to collect a new background average.

The data server logs the radar data (as embedded packets) but it does not provide a real-time display or chart record. After a flight, the radar results were extracted from the file created by the data server for analysis and plotting. The embedded packets are time-stamped for synchronization with the rest of the data logged with *Ice Probe*.

Several other features were added during the field work. The changes were to allow the recording of raw radar waveforms and the upload of the DSP program when the system initializes.

These Bird computer software modifications have not yet been fully debugged.

2.3 Field Work

A log of field activities is shown in Appendix A.

The radar field trial began while the newly rebuilt *Ice Probe* system was still being debugged. *Ice Probe* software that was to log the real-time snow thickness radar results was not working properly. To view raw radar waveforms during flight, extra cables were added to *Ice Probe's* tow cable to bring analog data from the Radar up to an analog-to-digital converter card in a laptop computer. When flight tested, the analog data was too noisy to see any radar echoes from the ground of ice surface. At this time it was thought that the noise was due to problems with the interface to the ADC card.

New software was added to radar to have it upload raw radar waveforms for storage with the *Ice Probe* logging system. Problems continued with the logging of radar data with the *Ice Probe* logging system. To get around this problem, the cables that where added to bring analog signals up to the helicopter were modified to bring the serial data directly up to the helicopter cabin. The EZKit DSP EPROM with the radar program was replaced with Analog Devices 'Monitor' program. The Monitor program allows uploading of the DSP program over the serial port, allowing quick program updates (even while flying) as a new EPROM did not have to be programmed each time the program was changed.

The serial data rate was increased to 115 kbaud from 9600 baud. This enabled the download of single raw waveforms in about one second. During the next test flight raw waveforms could be acquired over specific areas of interest.

On the afternoon of Saturday March 22, a test flight was made logging real-time and raw waveforms on a laptop computer. Figure 11 shows a plot of Bird height versus time for the real-time radar processing output and the laser altimeter output. This data was collected over the airport runway at Charlottetown. The laser and radar return follow quite closely, but the radar return can be seen to alternate between two heights.

Analysis of the real-time results and the raw waveform showed that the polarity of the radar signal was opposite of what was expected and the DSP code was changed accordingly. Also, the DSP code was modified to provide a continuous download of the digitized raw radar waveforms at a rate of about 1 Hz.

Flights were made over ice and open water on March 24 and 25. Flight notes and fid synchronization information is shown in Appendix B. For the March 25 data, an additional modifications to the DSP code allowed the upload of stacked raw waveforms. This modification was made to check whether or not stacking would make a noticeable improvement in the noise levels. It appeared that the stacking did not make an improvement, indicating that the noise problem was not with random noise but with the radar control circuitry.

3. Conclusions and Recommendations

Three main conclusions can be stated:

1. The small radar package has been modified to add on-board digitization and signal processing capability.
2. Software was developed to process the incoming data in real-time and provide an output over a standard serial interface.
3. Test flying the system showed that the radar was able to return real-time results for flying height, with noisy returns for snow thickness.

The first two were successes, the third was partially successful. The achievement of the first two represent overall success as these points were the technically risky items of the new development. The third represents the first time an airborne ground penetrating radar has an provided a real-time output of a processed result. The real-time implementation of the snow thickness processing algorithm appears to work. Though the input to the processing was noisy, the surface echo was detected and the correct flying height was returned. Further work with the radar hardware is required to improve the snow thickness results.

The noise source may be in the power supply or perhaps in the DSP generated timing ramps. The EZKit board had to be modified to work around its AC coupling of the DAC output signal. There may be a problem with a floating ground in this circuit.

To date, data analysis has been limited to the work performed in the field. Conclusions about the noise levels were made in the field and it does not appear to be worthwhile to spend more time analyzing the March '97 data set at this time.

The performance of the radar in the presence of the EM system *(Ice Probe)* has not been fully tested. Extra analog or digital filtering may be required for accurate snow thickness measurements when operated with the EM system.

For the 1997 flight tests, the radar was mounted inside the *Ice Probe* bird. In the future, the radar could be mounted in the *Ice Probe* bird, in its own bird or hard-mounted to the helicopter. It is likely that the packaging can be made to be in the format that is most useful for Coast Guard's helicopter operations.

The capability of this system to do real-time processing lends itself to other uses. A complimentary application of this radar, either alone or with *Ice Probe*, would be the measurement of fresh water ice thickness in the St. Lawrence River.

The following items are recommended for future work:

1. Re-assemble the 1992 St. Anthony configuration to provide a comparison benchmark.
2. Debug the power supply.
3. Debug the DSP output conditioning circuitry.
4. Replace EZKit-Lite DSP board with newly released board.
5. Finish debugging the logging of radar data with *Ice Probe*.
6. Field test if the system performs as well as the St. Anthony system.
7. Evaluate the system for fresh water ice thickness measurement.

The configuration used in St. Anthony in 1992 should be re-assembled. Data should be collected from a building wall as was done with the current system (results shown in Figure 9). This will provide a bench mark noise level that the new system must meet before further field testing is performed.

The new power supply needs to be debugged and its noise level should be compared with the one used in St. Anthony in 1992.

The ground level of the DSP output conditioning circuitry appear to float. This circuits needs further work. Filtering may be required for the DSP generated slow ramp as (at present) the only filtering is within the DAC chip. The ramp stability should be checked.

Analog Devices has recently release a floating point version of their EZKIT DSP board with the 21061 DSP chip, stereo ADC, stereo DAC and serial output. This board replicates many of the features of the EZKit-Lite board but the implementation is better for this application. The floating point DSP would be better suited for the implementation of digital filters that are probably necessary to filter out noise from the EM equipment in *Ice Probe*. The serial interface is implemented using hardware components (a UART chip) instead of software.

Re-integration of the Radar back into *Ice Probe* may require a small amount of further debugging. Thought the cost for this activity would be small, having the access to the Bird for debugging may be difficult.

Field testing would only be performed if the system performs as well as the St. Anthony system. It is estimated that field work be for a one week period for two people plus travel.

Table 2 lists the tasks and the estimated costs involved for the recommended work.

Table 1. Pin out for various connectors inside the radar unit.

Connector for	Pin	Signal	Description
Calibration Box DE-9P	1	+12	+12V power for calibration receiver board
	2	GND	ground for calibration receiver board
	3	-12	-12V power for calibration receiver board
	4	cal scan	Calibration scan from calibration receiver
	5	GND	(not used at present)
Receiver	1	+12	+12V power for receiver board
	2	GND	ground for receiver board
	3	-12	-12V power for receiver board
	6	radar scan	Radar scan from receiver board
EZ-KIT	1	+5	+5V power for EZ-KIT board
	2	GND	analog ground for EZ-KIT board
	3	cal (att)	attenuated calibration scan for EZ-KIT ADC
	4	radar (att)	attenuated radar scan for EZ-KIT ADC
	6	ref	reference voltage from EZ-KIT board
	7	ramp	ramp from EZ-KIT DAC
	8	SOS	start of scan pulse from EZ-KIT DAC
	9	clock	~12 MHz clock from EZ-KIT board
Fast Ramp Board DE-9S	1	+150	+150V power for board
	2	+5	+5V power for board
	3	+12	+12V power for board
	4	GND	ground for board
	5	-12	-12V power for board
	6	-70	-70V power for board
	7	clock	clock for triggering transmitter
	8	ramp (amp)	amplified slow ramp signal from EZ-KIT
Output Connector	1	+28V	+28 V power for power supply
	2	GND	ground input for power supply
	3	TX	serial port transmit
	4	RX	serial port receive
	5	GND (digital)	ground for serial port
	6	radar analog	radar signal from receiver
	7	cal analog	calibration signal from calibration box
	8	SOS pulse	start of scan pulse
	9	GND (analog)	ground for radar and cal signals

Table 2 - List of the tasks and cost estimates.

		Days	Cost ($)
Labour		Days	Cost ($)
	Put St. Anthony system together and test	2	$1,350.00
	Debug power supply	2	$1,350.00
	Rebuild power supply from scratch	5	$3,375.00
	Debug DSP output conditioning circuit	5	$3,375.00
	Replace fixed point DSP board with floating point DSP	5	$3,375.00
	Ground test system	6	$4,050.00
	Field work 2 weeks	10	$6,750.00
	Write report	3	$2,025.00
	Labour Subtotal:	38	$25,650.00
Direct Costs			
	Floating point DSP board, with spare and one for devlopment		$1,000.00
	Travel and Living to Charlottetown 2 weeks		$3,000.00
	Direct Costs Subtotal:		$4,000.00
	Total:		**$29,650.00**

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

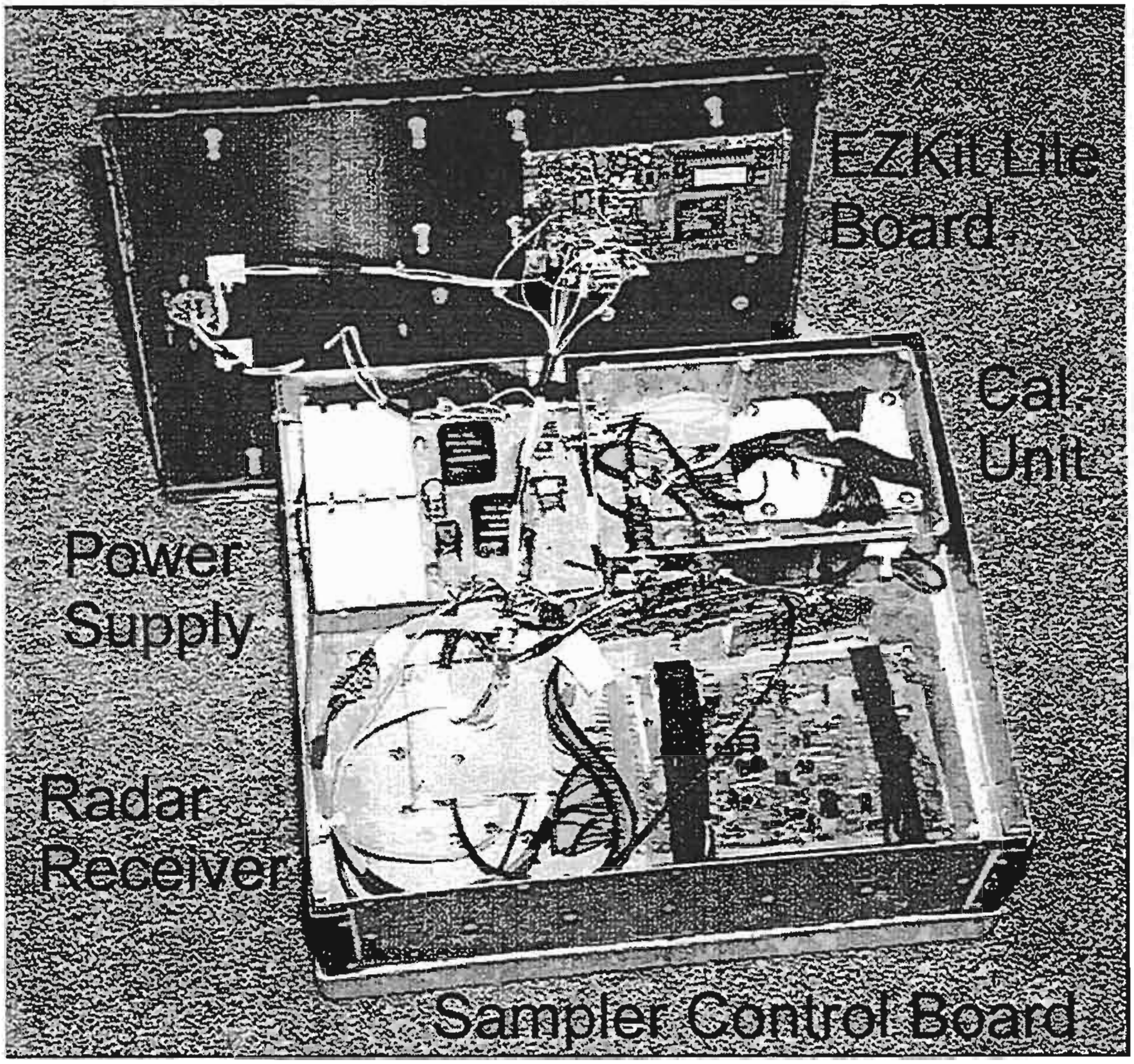


Figure 2. Block diagram of electronic components in the ice thickness radar system. The Analog Devices EZkit-Lite board (not shown) is mounted on the lid of the box.

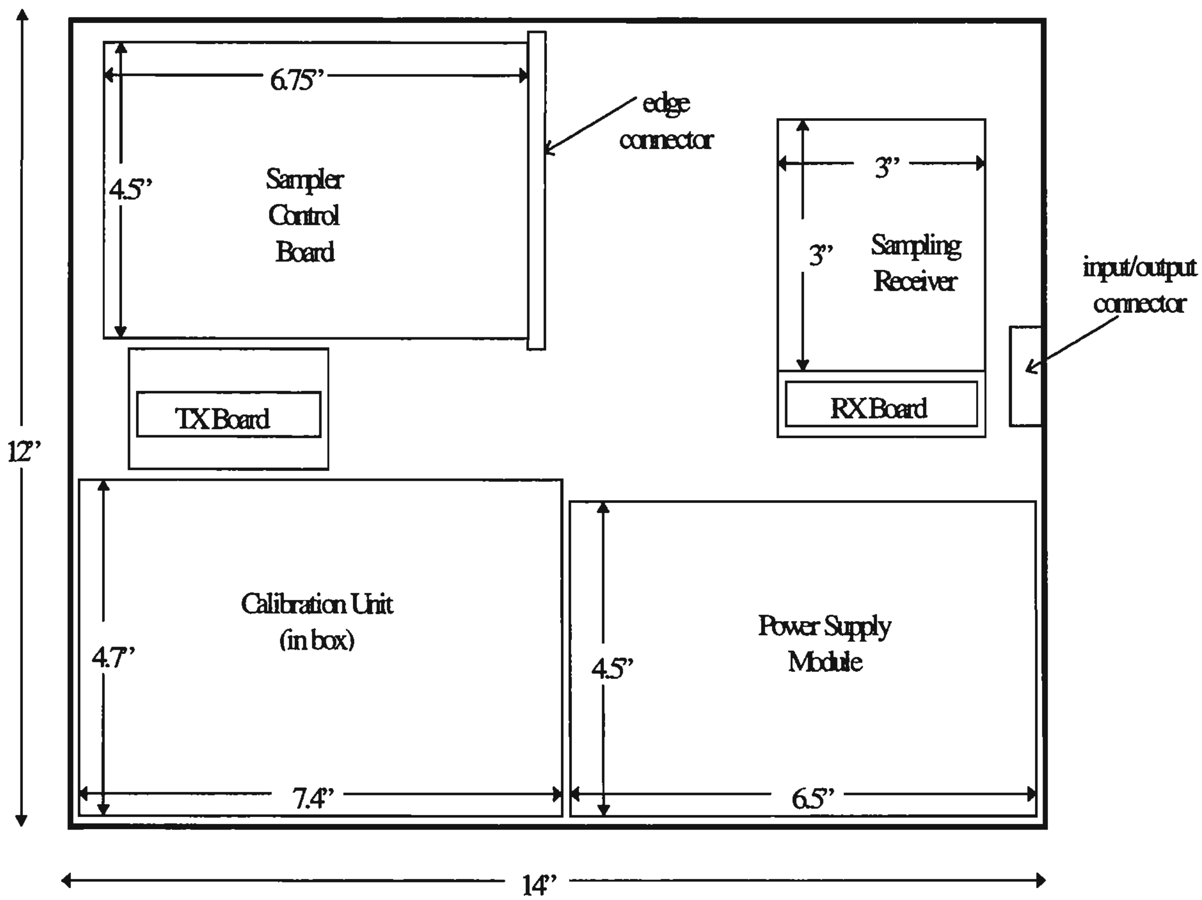


Figure 3. Wiring diagram of major components

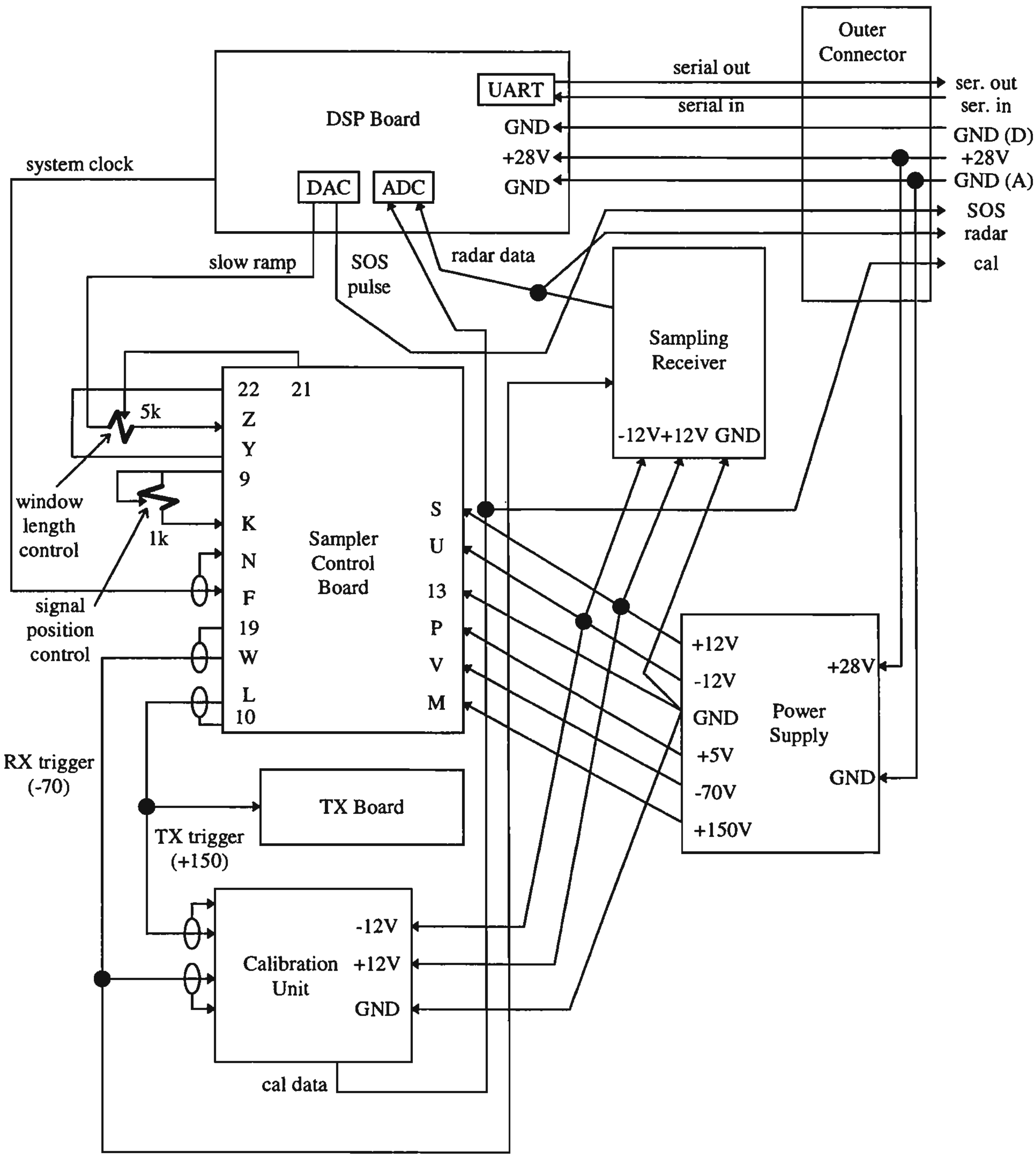


Figure 4. Schematic diagram of power supply

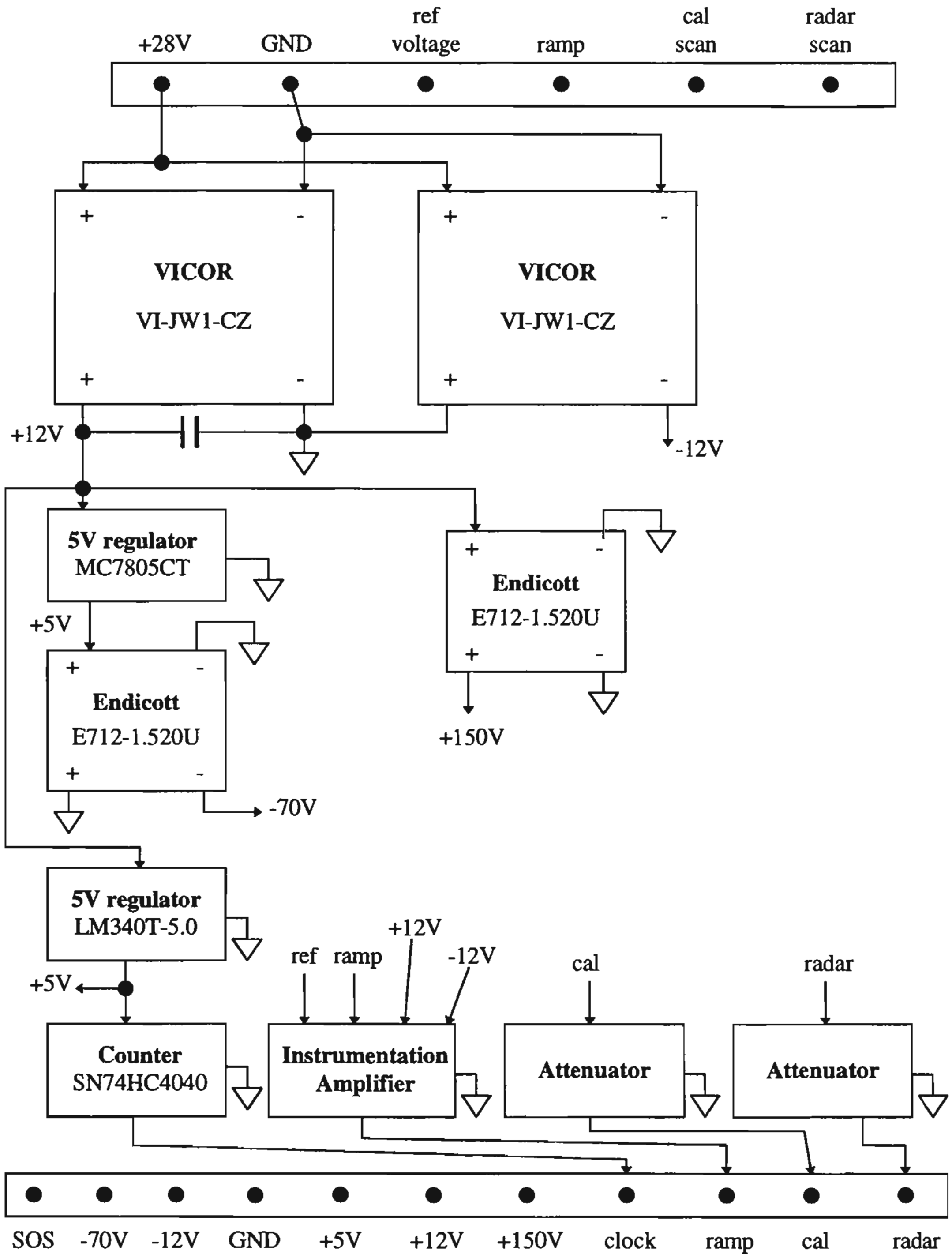


Figure 5. Schematic diagram of D/A converter DC coupled output circuit for slow ramp.

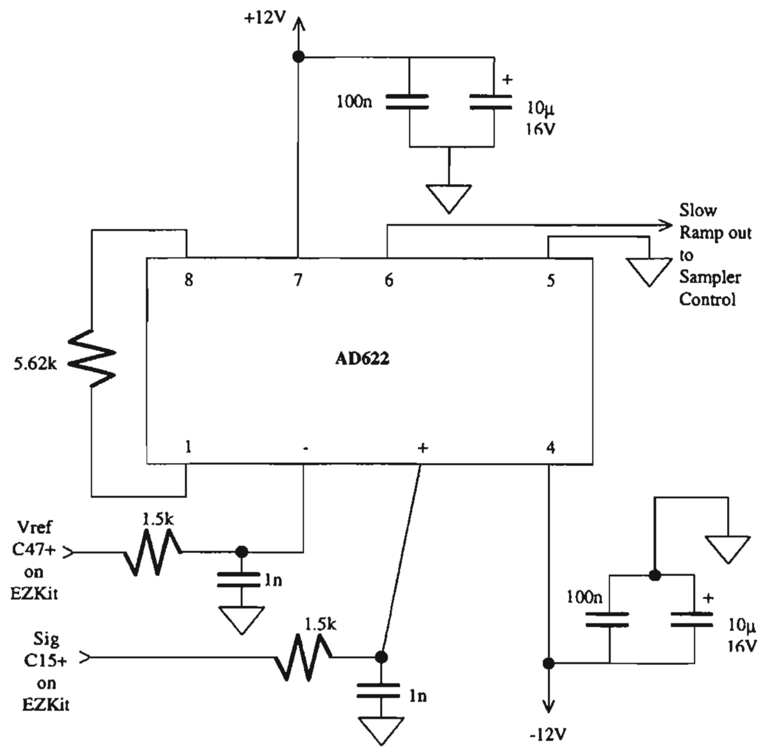


Figure 6. Schematic diagram of attenutator circuit to reduce radar signal levels for into A/D converter.

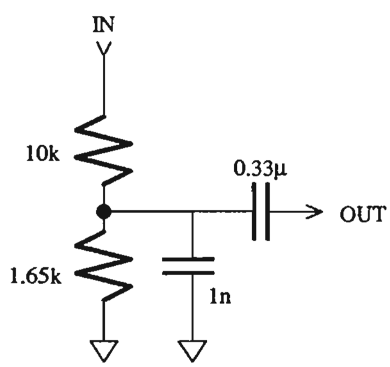


Figure 7. Schematic diagram of clock divider circuit to convert the 1847 XTAL 1 output of 12.288 MHz. When divided by 256 the output clock rate is 48 kHz. The output clock from this device goes to the sample control board, setting the receiver sampler rate and the p.r.f. (pulse repetition frequency) of the radar transmitter.

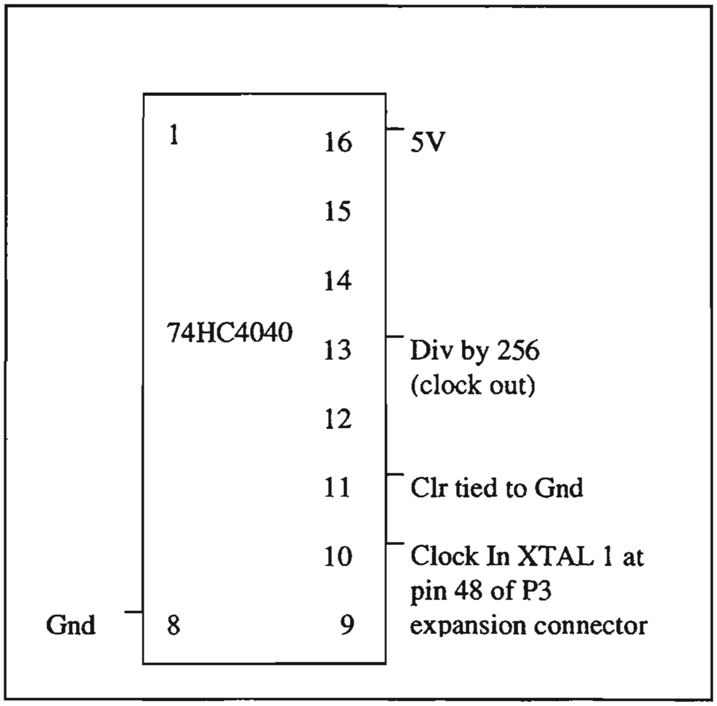


Figure 8. Block diagrams of the DSP software.

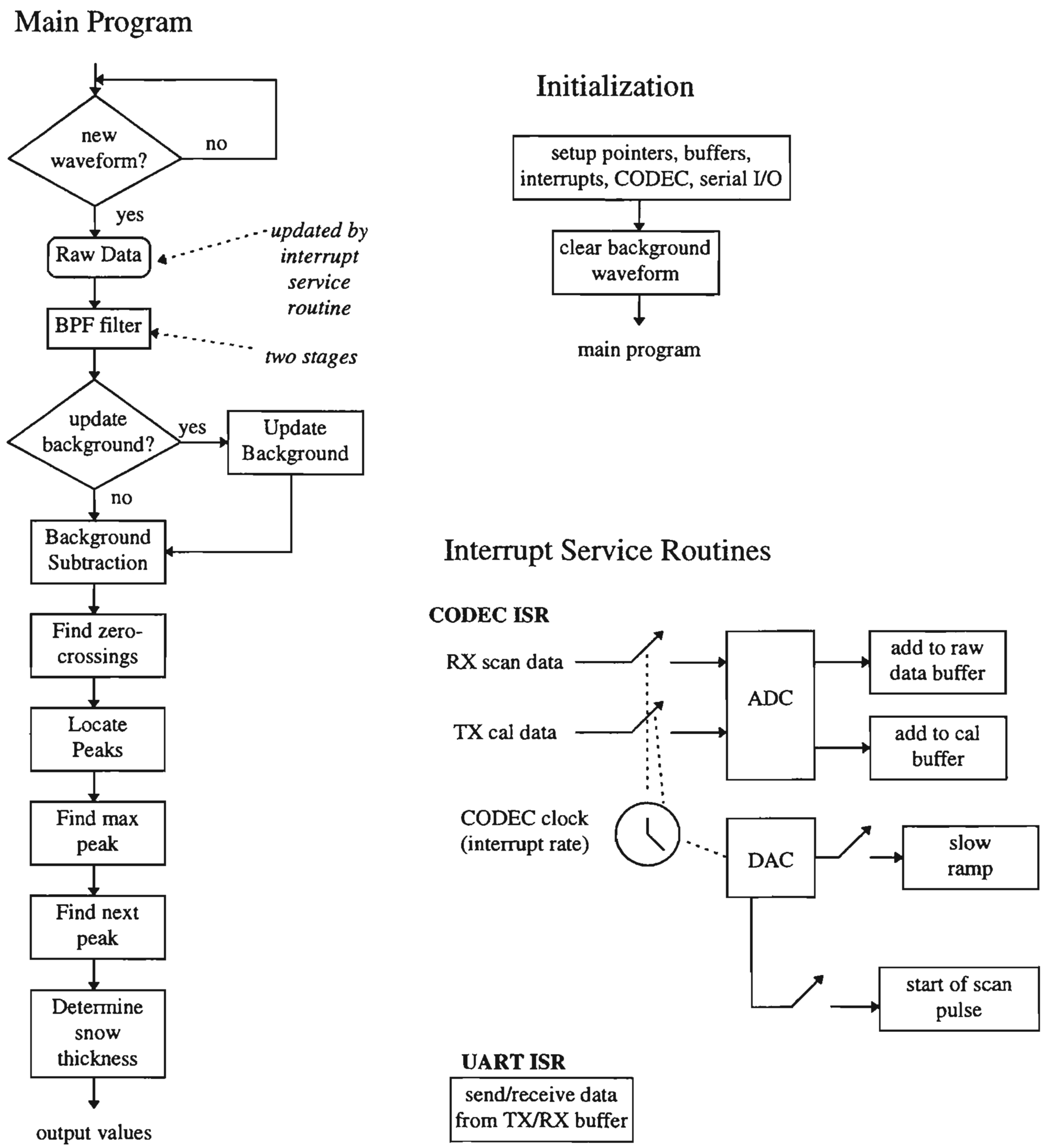


Figure 9. A plot of Radar waveform at several distances from a building wall

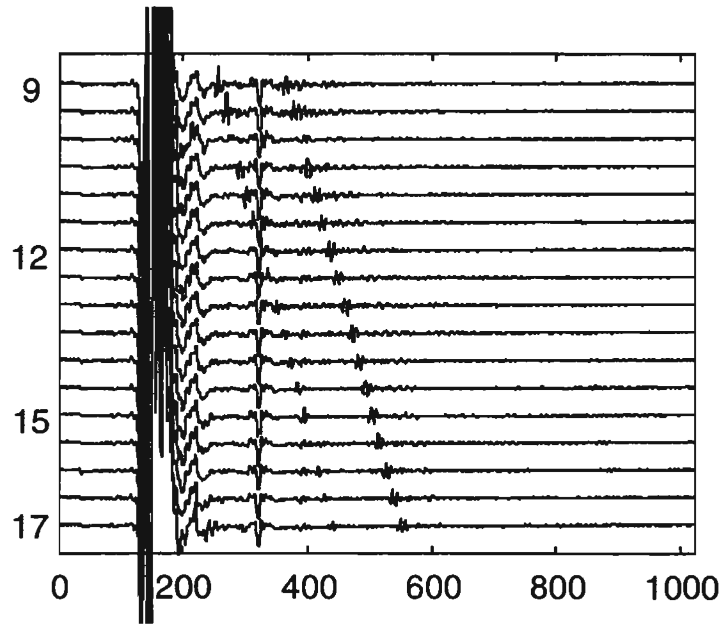


Figure 10. A plot of the calibration waveform.

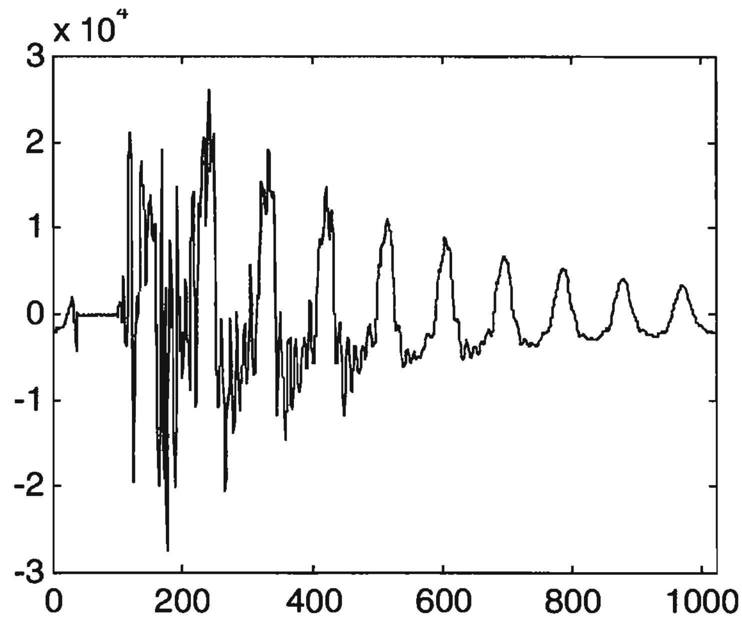
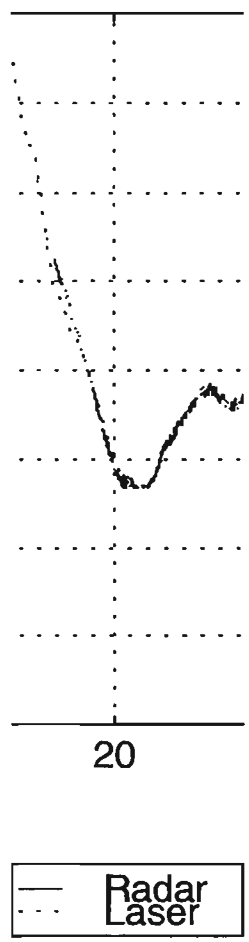


Figure 11. A comparison of the real-time radar bird height and the laser altimeter.



Appendix A - Log of Field Activities

The personnel involved with the snow thickness radar work were Louis Lalumiere and Santanu Paul, both of Aerodat Inc.

Monday, March 17

Travel from Toronto to Charlottetown

SP sets up computer in hotel room.

Tuesday, March 18

Ice Probe being debugged. Working on latest mods to Radar DSP program. Do video flight.

Wednesday, March 19

Ice Probe being debugged. Debugging latest mods to Radar DSP program. Do video flight. PM - finish debugging A/D logging program on laptop.

Thursday, March 20

Fly *Ice Probe* with radar in moming. Radar data not coming up through Bird link. In aftemoon add extra wires to tow cable to bring analog signals to helicopter. Fly *Ice Probe* (with radar) in aftemoon and log analog radar data. The analog radar data is too noisy.

Friday, March 21

Weather down in moming. Work on serial port waveform downloading. Work briefly on analog noise problem with radar. Work on compiling and running *Ice Probe* post-flight inversion routines. Do video over fixed link and out to pancake ice north of PEI.

Saturday, March 22

Rebuild radar after damage cause by Friday aftemoon *Ice Probe* flight. Change wiring to bring serial data directly from the radar up to laptop in helicopter. Do a radar flight. Look at radar data - change DSP processing and increase serial data rate to 115 kbaud. Do test flight over airport runway in snowy weather. Work on binary logging of 115 kbaud serial data using terminal program.

Sunday, March 23

Continue debug of binary logging of 115k baud serial data using terminal program while *Ice Probe* is being repaired. Andy Maillet operates *Ice Probe* with radar logging performed separately - Radar data seems noisy with EM on. Second flight radar only - no markers indicating where they were or what they were flying over - problem with waveform logging part of DSP program, still looking at positive peak - real-time processing alternating between the 2 lower amplitude positive peaks - should look at single negative peak.

Do video flight over the Northumberland Strait.

Monday, March 24

Change radar DSP code to pick negative peak. Debug continuous raw waveform logging. Morning flight with EM and radar - had string to turn on EM transmitter when radar logging was complete. EM debugged all afternoon - new laser rejection code added to bird program. Look at radar data. Spend two hours on VideoGPS playback program.

Tuesday, March 25

Stacked radar output debugged. Fly radar over harbour over ice and open water. Fly EM over cal lines and over ridge line on the north side of PEI. Set up Video/GPS laptop for Simon Prinsenberg to use that afternoon on a video flight. Depart for Toronto.

Appendix B - Tables of Radar Flight Information

Date	*Ice Probe* Filename	Radar Filename	*Ice Probe* Fid Number	Radar Hex Number	Comment
March 24	FLT008				Use *Ice Probe* logging system to record GPS positions and laser altimeter data. EM transmitter off.
		AAA1.txt			Free run raw waveforms
			1		(test fids)
			2	FDB0	Along East River
			3 and 4		(test fids)
			5	1279	go up to 250 feet
			6	13FF	Beyond power lines East River
			7	1535	Head back up to alt.
			8	18C5	At alt. before going back down
			9		False fid
				19C4	Free run waveforms ends
		AAA3.txt			Real-time processing. Start point set to 400
			10	0FD0	Run over landfast ice north of PEI
			11	0AE0	" (photo 27)
			12	0FFF	"
			13	1300	300 feet
		AAA4.txt			Change processing start point to 430. In Tracadie Bay
			14	29D0	On snow line heading west
			15	2C20	over line
			16	2E10	background done
			17	3160	
			18		Near shore
			19	3300	snow line heading east
			20		near men and trucks on ice
			21	3540	end logging real-time results
		AAA5.txt			Log raw waveforms
			22	3870	
			23	3965	Snow line E-W
			24	3A10	at alt.
			25	3AF0	low alt
			26	3B43	on line W-E
			27	3B71	over trucks
		AAA6.txt			Radar waveforms with EM on.

Date	*Ice Probe* Filename	Radar Filename	*Ice Probe* Fid Number	Radar Hex Number	Comment
March 25	FLT011				Use *Ice Probe* logging system to record GPS positions and laser altimeter data. EM transmitter off.
		BBB1.txt			Logging stacked raw waveforms
			1	1D11	
			2	1D42	Low over east river
			3	2062	up over bridge heading to outer harbour
			4	2502	low again
			5	2682	grey ice
			6	2712	open water with small ice floes
			7	2972	just at end of open water - lots of small floes
			8	2AC2	solid ice then go up
		BBB2.txt			real-time output
			9	3229	low over ice
			10	3430	onto grey ice
			11	3600	open water with some traces of ice
			12	3910	swing left towards ice - still over open water
			13	D3B5?	Solid ice
			14	3CE0	open water with some solid ice floes
			15	3E40	solid ice
				41B0	flat floe
				4320	small open water
				44B0	Flat floe then go up

Appendix C - Radar Processing Implemented in 'C' for DOS.

```
// snowth.c - Snow thickness radar processing

#include <stdio.h>
#include <stdlib.h>

/****************************************************************
 *  Structure used for passing parameters                       *
 ****************************************************************/
typedef struct {
    int   wave_size;
    int   skip;
    int   threshold;
    short *bgnd_ptr;
    short *fil_bpf;
    short bpf_len;
    short *fil_bpf2;
    short bpf2_len;
    short *fil_bpf3;
    short bpf3_len;
    short *fil_lp1;
    short lp1_len;
    short *fil_lp2;
    short lp2_len;
    FILE  *ifp;
    FILE  *ofp;
        FILE  *bfp;
} param;


/****************************************************************
 *  Function Declarations                                       *
 ****************************************************************/
int get_parameters(char *par_filename, param *info);
long get_file_size(FILE *fp);
int snowth(char *par_file);
int load_filt(char *file_name, short **filter, short *fil_len);
void sub_background(param *info, short *input, short *output);
void diff4(param *info, short *input, short *output);
void loc_peaks(param *info, short *input, short *data, short *output);
void thresh_peak(param *info, short *input, short *thresh_value, short
*thresh_index);
void find_max(param *info, short *input, short *max_value, short
*max_index);
void fir_filter(param *info, short *filter, short filt_len, short
*input, short *output);
short cont_fir_filter(short *filter, short filt_len, short data, short
*buffer);
void cleanup(param *info);


/****************************************************************
 *  Main Program                                                *
 ****************************************************************/
int main(int argc, char *argv[])
{   int err_val;

    err_val = 1;
    if (argc != 2)
```

```
        printf("Usage: snowth <parameter_file>");
    else
    {   printf("\nSnow Thickness Radar Processing\n");
        err_val = snowth( argv[1] );
        printf("\nDone.\n");
    }

    return err_val;
}


/**************************************************************
 *  Main processing routine                                   *
 **************************************************************/
int snowth(char *par_file)
{   int err_val;
    long file_size, data_read;
    float percent, prev_percent;
#if (0)
    short *raw_data, *background, *bgnd_out, *bpf_out;
    short *bpf2_out, *bpf3_out, *diff_out, *peak_out;
#else
    short raw_data[1024], background[1024], bgnd_out[1024],
bpf_out[1024];
    short bpf2_out[1024], bpf3_out[1024], diff_out[1024],
peak_out[1024];
#endif
    short max_val, max_index, thresh_val, thresh_index;
    short max_index_filt, thresh_index_filt, thickness;
    static short lp1_buff[200], lp2_buff[200];
    param par;


    err_val = get_parameters(par_file, &par);

    if (err_val == 0)
    {
#if (0)
        if ( (raw_data=calloc(par.wave_size, sizeof(short))) == NULL )
        {   printf("Error: Unable to allocate memory for raw data.\n");
            err_val = 5;
        }
        else if ( (background=calloc(par.wave_size, sizeof(short))) ==
NULL )
        {   printf("Error: Unable to allocate memory for background
waveform.\n");
            err_val = 5;
        }
        else if ( (bgnd_out=calloc(par.wave_size, sizeof(short))) == NULL
)
        {   printf("Error: Unable to allocate memory for background
subtraction output buffer.\n");
            err_val = 5;
        }
        else if ( (bpf_out=calloc(par.wave_size, sizeof(short))) == NULL
)
        {   printf("Error: Unable to allocate memory for band-pass filter
output buffer.\n");
            err_val = 5;
        }
```

```
        else if ( (bpf2_out=calloc(par.wave_size, sizeof(short))) == NULL
)
        {   printf("Error: Unable to allocate memory for band-pass filter
2 output buffer.\n");
            err_val = 5;
        }
        else if ( (bpf3_out=calloc(par.wave_size, sizeof(short))) == NULL
)
        {   printf("Error: Unable to allocate memory for band-pass filter
3 output buffer.\n");
            err_val = 5;
        }
        else if ( (diff_out=calloc(par.wave_size, sizeof(short))) == NULL
)
        {   printf("Error: Unable to allocate memory for difference
filter output buffer.\n");
            err_val = 5;
        }
        else if ( (peak_out=calloc(par.wave_size, sizeof(short))) == NULL
)
        {   printf("Error: Unable to allocate memory for peak value
output buffer.\n");
            err_val = 5;
        }
        else
#else
        if (1)
#endif
        {
            fread(background, sizeof(short), par.wave_size, par.bfp);
            if (feof(par.bfp))
               printf("Warning:  background waveform file doesn't contain
enough data.\n");
            fread(background, sizeof(short), 1, par.bfp);
            if (!feof(par.bfp))
               printf("Warning:  background waveform file contains too
much data.\n");
            fclose(par.bfp);
            par.bgnd_ptr = background;

            file_size = get_file_size(par.ifp);
            percent = prev_percent = 0.0f;
            data_read = 0;
            fread(raw_data, sizeof(short), par.wave_size, par.ifp);
            do
            {
                data_read += par.wave_size * sizeof(short);
                percent = 100.0f * (float) data_read / (float) file_size;
                if ( percent >= prev_percent + 10.0 )
                {    prev_percent = percent;
                     printf("%3.0f%% ",percent);
                }
                sub_background(&par, raw_data, bgnd_out);
                fir_filter(&par, par.fil_bpf, par.bpf_len, bgnd_out,
bpf_out);
                fir_filter(&par, par.fil_bpf2, par.bpf2_len, bpf_out,
bpf2_out);
//              fir_filter(&par, par.fil_bpf3, par.bpf3_len, bpf2_out,
bpf3_out);
                diff4(&par, bpf2_out, diff_out);
                loc_peaks(&par, diff_out, bgnd_out, peak_out);
```

```
                find_max(&par, peak_out, &max_val, &max_index);
                thresh_peak(&par, peak_out, &thresh_val, &thresh_index);
//                fwrite(peak_out, sizeof(short), par.wave_size,
par.ofp);
                max_index_filt = cont_fir_filter(par.fil_lp1,
par.lp1_len, max_index, lp1_buff);
                thresh_index_filt = cont_fir_filter(par.fil_lp2,
par.lp2_len, thresh_index, lp2_buff);

                thickness = max_index_filt - thresh_index_filt;
//                thickness = max_index - thresh_index;
                if (thickness<0)  thickness = 0;
#if (0)
//                fwrite(&thickness, sizeof(short), 1, par.ofp);
                fwrite(raw_data, sizeof(short), par.wave_size, par.ofp);
                fwrite(bgnd_out, sizeof(short), par.wave_size, par.ofp);
                fwrite(bpf_out,  sizeof(short), par.wave_size, par.ofp);
                fwrite(bpf2_out, sizeof(short), par.wave_size, par.ofp);
                fwrite(diff_out, sizeof(short), par.wave_size, par.ofp);
                fwrite(peak_out, sizeof(short), par.wave_size, par.ofp);
#else
                fwrite(&max_val, sizeof(short), 1, par.ofp);
                fwrite(&max_index, sizeof(short), 1, par.ofp);
                fwrite(&thresh_val, sizeof(short), 1, par.ofp);
                fwrite(&thresh_index, sizeof(short), 1, par.ofp);
                fwrite(&thickness, sizeof(short), 1, par.ofp);
#endif
                fread(raw_data, sizeof(short), par.wave_size, par.ifp);
            } while (!feof(par.ifp));
        }
    }

    cleanup(&par);
    return err_val;
}


/****************************************************************
 *  Figure out how large a file is                              *
 ****************************************************************/
long get_file_size(FILE *fp)
{   long file_size;
    fpos_t file_pos;

    rewind(fp);
    fseek(fp, 0, SEEK_END);
    fgetpos(fp, &file_pos);
    rewind(fp);
    file_size = (long) file_pos;

    return file_size;
}


/****************************************************************
 *  Parameters for snow thickness processing                    *
 ****************************************************************/
int get_parameters(char *par_file, param *info)
{   FILE *pfp;
    char cbuff[200], in_file[80], out_file[80], back_file[80];
```

```
    char bpf_file[80], bpf2_file[80], bpf3_file[80], lp1_file[80],
lp2_file[80];

    if ( (pfp=fopen(par_file,"r")) == NULL) {
                printf("\nError:  Unable to open parameter file.\n");
return 1;  }
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", in_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", out_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", back_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", bpf_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", bpf2_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", bpf3_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", lp1_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%s", lp2_file);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%d", &info->wave_size);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%d", &info->skip);
    fgets(cbuff, 200, pfp);  sscanf(cbuff, "%d", &info->threshold);
    fclose(pfp);

    if ( (info->ifp=fopen(in_file,"rb")) == NULL) {
                printf("\nError:  Unable to open input file.\n");
return 2;  }

    if ( (info->ofp=fopen(out_file,"wb")) == NULL) {
                printf("\nError:  Unable to open output file.\n");
return 2;  }

    if ( (info->bfp=fopen(back_file,"rb")) == NULL) {
                printf("\nError:  Unable to open background waveform
file.\n");    return 2;  }

    if ( load_filt(bpf_file, &info->fil_bpf, &info->bpf_len) != 0 )
return 3;
    if ( load_filt(bpf2_file, &info->fil_bpf2, &info->bpf2_len) != 0 )
return 3;
        if ( load_filt(bpf3_file, &info->fil_bpf3, &info->bpf3_len) != 0
)  return 3;
    if ( load_filt(lp1_file, &info->fil_lp1, &info->lp1_len) != 0 )
return 3;
    if ( load_filt(lp2_file, &info->fil_lp2, &info->lp2_len) != 0 )
return 3;

    return 0;
}


/*****************************************************************
 *  Load filter from file                                        *
 *****************************************************************/
int load_filt(char *file_name, short **filter, short *fil_len)
{   short *filt_buff, filt_buff_len, err;
    FILE *fp;

    if ( (fp=fopen(file_name,"rb")) == NULL)
    {
                printf("\nError:  Unable to open filter file: %s\n",
file_name);
        filt_buff = NULL;
        filt_buff_len = 0;
        err = 1;
    }
```

```
    else
    {   filt_buff_len = get_file_size(fp) / sizeof(short);
        if ( (filt_buff=calloc(filt_buff_len, sizeof(short))) == NULL )
        {   filt_buff_len = 0;
            err = 2;
        }
        else
        {   fread(filt_buff, filt_buff_len, sizeof(short), fp);
            err = 0;
        }
        fclose(fp);
    }

    *filter = filt_buff;
    *fil_len = filt_buff_len;
    return err;
}


/***************************************************************
 *  Subtract background waveform                               *
 ***************************************************************/
void sub_background(param *info, short *input, short *output)
{   int i;

    for (i=0; i<info->wave_size; i++)
        output[i]=input[i]-info->bgnd_ptr[i];

}


/***************************************************************
 *  Difference Filter                                          *
 ***************************************************************/
void diff4(param *info, short *input, short *output)
{   int i;

    output[0] = 0;
    output[1] = 0;
    output[info->wave_size-1] = 0;
    output[info->wave_size-2] = 0;

    for (i=2; i<info->wave_size-2; i++)
        output[i] = -input[i-2]  - input[i-1] + input[i+1] + input[i+2];
}


/***************************************************************
 *  Apply FIR filter to waveform                               *
 ***************************************************************/
void fir_filter(param *info, short *filter, short filt_len, short
*input, short *output)
{   int grp_delay, i, j;
    long filt_sum;

    grp_delay = (filt_len - 1)/2;

    for (i=0; i<grp_delay; i++)
    {   output[i] = 0;
        output[info->wave_size-i-1] = 0;
    }
```

```
    for (i=grp_delay; i<info->wave_size-grp_delay; i++)
    {   filt_sum = 0;
        for (j=0; j<filt_len; j++)
        {   filt_sum += (long)input[i-grp_delay+j] *
(long)filter[filt_len-j-1];
        }
        filt_sum = filt_sum >> 15;
        if ( (filt_sum >= 32768) || (filt_sum < -32768) )
           printf("*");
        output[i] = (short) ((float)filt_sum + 0.5);
    }

}


/*************************************************************
 *  Apply FIR filter to continuous data, for one data value     *
 *************************************************************/
short cont_fir_filter(short *filter, short filt_len, short data, short
*buffer)
{   short i;
        long filt_sum;

    /* move data back */
    for (i=0; i<filt_len-1; i++)
    {   buffer[i] = buffer[i+1];
    }

    buffer[filt_len-1]=data;    /* load new data value */

    /* apply filter */
    filt_sum = 0;
    for (i=0; i<filt_len; i++)
    {   filt_sum += (long)buffer[i] * (long)filter[filt_len-i-1];
    }
    filt_sum = filt_sum >> 15;
    if ( (filt_sum >= 32768) || (filt_sum < -32768) )
       printf("*");

    return (short) ((float)filt_sum + 0.5);
}


/*************************************************************
 *  Locate Peaks                                                *
 *************************************************************/
void loc_peaks(param *info, short *input, short *data, short *output)
{   int i;

    for (i=0; i<=info->skip; i++)
        output[i] = 0;

    for (i=1+info->skip; i<info->wave_size; i++)
    {   if ( input[i-1] > 0 )
        {   if ( input[i] <= 0 )
               output[i] = data[i];
            else
               output[i] = 0;
        }
        else
```

```
        {   if ( input[i] >= 0 )
               output[i] = data[i];
            else
               output[i] = 0;
        }
    }
}


/**************************************************************
 *  Find maximum value and position in vector                 *
 **************************************************************/
void find_max(param *info, short *input, short *max_value, short
*max_index)
{   int i;

    *max_value = input[0];
    *max_index = 0;
    for (i=0; i<info->wave_size; i++)
    {   if ( abs(input[i]) > *max_value )
        {   *max_value = input[i];
            *max_index = i;
        }
    }
}


/**************************************************************
 *  Find first value over threshold in vector                 *
 **************************************************************/
void thresh_peak(param *info, short *input, short *thresh_value, short
*thresh_index)
{   int i;

    *thresh_value = 0;
    *thresh_index = 0;
    for (i=0; i<info->wave_size; i++)
    {   if ( abs(input[i]) >= info->threshold )
        {   *thresh_value = input[i];
            *thresh_index = i;
            i=info->wave_size;
        }
    }
}


/**************************************************************
 *  Exit routine                                              *
 **************************************************************/
void cleanup(param *info)
{
    free(info->fil_bpf);
    free(info->fil_lp1);
    free(info->fil_lp2);
    fclose(info->ifp);
    fclose(info->ofp);
}
```

Appendix D - Radar Processing Implemented for the 2181 DSP

```
.module/RAM/ABS=0       snow_thickness_radar;

.include     <system.k>;
#include     "ezk_vars.ini";
.external    init_uart;          { UART initialize baudrate etc. }
.external    out_char_ax1;       { UART output a character }
.external    turn_rx_on;         { UART enable the rx section }
.external    process_a_bit;      { timer ISR for UART }
.external    flag_rx_no_word;
.external    get_char_ax1_to;
.external    get_char_ax1;

.external    out_int_ar;
.external    get_int_ar_to;

.external    dndsp;
.external    sendLine;
.external    stop_uart;
#if (0)
.external    irq1isr;
.external    next_cmd;
.external    irqeisr;
.external    sport_rx;

.entry  int_to_ascii_hex;
.global num_string;
#endif


{*********************************************************************
*******
  Defines for conditionaly assembly:
   SIMULATOR - call sport_rx in main loop for faster simulations in
sim2181.exe
   DEBUG - show waveform values as incrementing numbers when in binary
mode
   DEBUG_MEM - log binary mode values in program memory buffer
   FAKE_DATA - use data from fake_data1 buffer as the DAC input
   SKIP_ONE - skip point in waveform
  Defines for constants:
   WAVE_SIZE - size of radar scan
   OUT_BUFF - size filter buffers for ice thickness and altitude (not
used)
   BUFF_HEADER - size of header for buffer structures
   NULL_HEADER - size of header for nulling buffer structure
   ACK_SIZE - size of acknowledge packet string

*********************************************************************
******}

#define SIMULATOR 0
#define DEBUG 0
#define DEBUG_MEM 0
#define KLUDGE 0
#define FAKE_DATA 0
#define WAVE_SIZE 1023
#define SKIP_ONE 1
#define OUT_BUFF 10
```

```
#define BUFF_HEADER 4
#define NULL_HEADER 3
#define ACK_SIZE 20


{**********************************************************************
*******
 *
 *  Variables
 *

**********************************************************************
******}

#if (DEBUG_MEM == 1)
{*****************************************************************
 *  Debug Variables                                              *
 *****************************************************************}
.var/pm/ram/circ debug_mem[3000];
.var/dm/ram debug_ptr;
.var/dm/ram debug_count;
#endif

{*****************************************************************
 *  Paramters                                                    *
 *****************************************************************}
.var/dm/ram codec_delay;                { delay between DAC/ADC }
.init       codec_delay: 0;
.var/dm/ram stack_size;                 { size of stack for raw radar
scans }
.init       stack_size: 1;
.var/dm/ram stack_shift;                { stack is scaled by shifting }
.init       stack_shift: 0;
.var/dm/ram null_stack;                 { size of nulling stack }
.init       null_stack: 32;
.var/dm/ram null_shift;
.init       null_shift: -5;
.var/dm/ram cal_thresh;                 { calibration peack detection
threshold - not used, calibration not implemented }
.init       cal_thresh: 5000;
.var/dm/ram rad_thresh;                 { snow peak threshold }
.init       rad_thresh: 350; {50/600}
.var/dm/ram cal_tol;                    { calibration tolaration - not
used, calibration not implemented }
.init       cal_tol: 10;
.var/dm/ram tx_offset;                  { offset between TX fires and
receiver detects it - not used }
.init       tx_offset: 10;
.var/dm/ram rad_transient;              { transient period for TX to die
down }
.init       rad_transient: 430; {500/360}
.var/dm/ram sos_on_time;                { Start of scan duty cycle in
samples per waveform }
.init       sos_on_time: 5;
.var/dm/ram ramp_start;                 { Start value for ramp }
.init       ramp_start: 0;
.var/dm/ram ramp_inc;                   { Increment/Decrement value for
ramp }
.init       ramp_inc: -16;
.var/dm/ram ramp_val;                   { Current ramp value }
```

```
{****************************************************************
 *  Counters for waveform output                               *
 ****************************************************************}
.var/dm/ram line_count;                { line/packet counter for
waveform output }
.var/dm/ram col_count;                 { column count for waveform
output }
.var/dm/ram temp_count;                { temporary counter }

{****************************************************************
 *  CODEC Rate Parameter                                       *
 ****************************************************************}
.var/dm/ram codec_param;
.init       codec_param: 2;            { used to set CODEC rate }

{****************************************************************
 *  Command Paramters                                          *
 ****************************************************************}
.var/dm/ram  command_string[50];       { command input buffer }
.var/dm/ram  command_flag;             { says whether in the process of
receiving a packet command }
.var/dm/ram  command_letter;
.var/dm/ram  poll_cnt[2];              { command poll counter }
.var/dm/ram  wave_cnt[2];              { wave counter }
.var/dm/ram  stack_cnt;                { stacked waveform counter }
.init        stack_cnt: 0;

{****************************************************************
 *  Initialization string                                      *
 ****************************************************************}
.var/dm/ram  init_string[100];         { initialization string }
.init        init_string: '$','A','D','-',
                          's','n','o','w','
','t','h','i','c','k','n','e','s','s',
                          ' ','s','o','f','t','w','a','r','e',' ',
                          '-','
','m','a','r','c','h','/','9','7',13,10,0;

.var/dm/ram  invalid_string[9];        { invalid command response }
.init        invalid_string: '$','A','D','i','n','v',13,10,0;
.var/dm/ram  not_ready_string[20];     { not ready to output waveform
because still outputting current waveform }
.init        not_ready_string: '$','A','D','e','r','r','-
','n','o','t','_','r','e','a','d','y',13,10,0;
{****************************************************************
 *  Acknowledge strings                                        *
 ****************************************************************}
.var/dm/ram  ack_strings[400];         { acknowledge that command was
received }
.init        ack_strings: '$','A','D','0','0','a','-
','a','u','t','o',13,10,0,'0','0','0','0','0','0',
                          '$','A','D','0','0','a','-
','b','a','c','k','g','r','o','u','n','d',13,10,0,
                          '$','A','D','0','0','a','-','s','h','o','w','-
','r',13,10,0,'0','0','0','0',
                          '$','A','D','0','0','a','-
','d','e','b','u','g',13,10,0,'0','0','0','0','0',
                          '$','A','D','0','0','a','-
','n','o','r','m','a','l',13,10,0,'0','0','0','0',
                          '$','A','D','0','0','a','-
','p','r','o','m','p','t',13,10,0,'0','0','0','0',
```

```
                              '$','A','D','0','0','a','-
','r','e','s','e','t',13,10,0,'0','0','0','0','0',
                              '$','A','D','0','0','a','-
','s','t','a','t','u','s',13,10,0,'0','0','0','0',
                              '$','A','D','0','0','a','-
','s','t','o','p',13,10,0,'0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','b','c','k','/','c','a','l',13,10,0,'0','0','0',
                              '$','A','D','0','0','a','-
','s','1',13,10,0,'0','0','0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','s','2',13,10,0,'0','0','0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','s','4',13,10,0,'0','0','0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','f','8','k',13,10,0,'0','0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','f','9','.','6','k',13,10,0,'0','0','0','0','0',
                              '$','A','D','0','0','a','-
','f','1','6','k',13,10,0,'0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','f','2','7','.','4','k',13,10,0,'0','0','0','0',
                              '$','A','D','0','0','a','-
','f','3','2','k',13,10,0,'0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','f','4','8','k',13,10,0,'0','0','0','0','0','0',
                              '$','A','D','0','0','a','-
','b','c','k',',','b','/','c',13,10;

{***************************************************************
 *  Command strings                                            *
 ***************************************************************}
.var/dm/ram  comm_help[9];      { help }
.init        comm_help:      '$','A','D','0','0','h',13,10,0;
.var/dm/ram  comm_auto[9];      { auto output }
.init        comm_auto:      '$','A','D','0','0','a',13,10,0;
.var/dm/ram  comm_back[9];      { update background waveform }
.init        comm_back:      '$','A','D','0','0','b',13,10,0;
.var/dm/ram  comm_back2[9];     { update background waveform, display
background/calibration waveforms }
.init        comm_back2:     '$','A','D','0','0','B',13,10,0;
.var/dm/ram  comm_back_wave[9]; { show background waveform }
.init        comm_back_wave: '$','A','D','0','0','s',13,10,0;
.var/dm/ram  comm_debug[9];     { switch to debug output }
.init        comm_debug:     '$','A','D','0','0','d',13,10,0;
.var/dm/ram  comm_normal[9];    { switch to normal output }
.init        comm_normal:    '$','A','D','0','0','n',13,10,0;
.var/dm/ram  comm_toggle[9];    { toggle auto/prompted output }
.init        comm_toggle:    '$','A','D','0','0','t',13,10,0;
.var/dm/ram  comm_prompt[9];    { switch to prompted output }
.init        comm_prompt:    '$','A','D','0','0','p',13,10,0;
.var/dm/ram  comm_reset[9];     { reset software }
.init        comm_reset:     '$','A','D','0','0','r',13,10,0;
.var/dm/ram  comm_status[9];    { show status message }
.init        comm_status:    '$','A','D','0','0','i',13,10,0;
.var/dm/ram  comm_stop[9];      { exit software to monitor }
.init        comm_stop:      '$','A','D','0','0','x',13,10,0;
.var/dm/ram  comm_cb_wave[9];   { show cal and background waveforms }
.init        comm_cb_wave:   '$','A','D','0','0','c',13,10,0;
.var/dm/ram  comm_menu1[9];     { set stack size to 1 }
.init        comm_menu1:     '$','A','D','0','0','1',13,10,0;
```

```
.var/dm/ram  comm_menu2[9];     { set stack size to 8 }
.init        comm_menu2:      '$','A','D','0','0','2',13,10,0;
.var/dm/ram  comm_menu3[9];     { set stack size to 16 }
.init        comm_menu3:      '$','A','D','0','0','3',13,10,0;
.var/dm/ram  comm_menu4[9];     { set CODEC rate to 8.0 kHz  }
.init        comm_menu4:      '$','A','D','0','0','4',13,10,0;
.var/dm/ram  comm_menu5[9];     { set CODEC rate to 9.6 kHz  }
.init        comm_menu5:      '$','A','D','0','0','5',13,10,0;
.var/dm/ram  comm_menu6[9];     { set CODEC rate to 16.0 kHz  }
.init        comm_menu6:      '$','A','D','0','0','6',13,10,0;
.var/dm/ram  comm_menu7[9];     { set CODEC rate to 27.4 kHz  }
.init        comm_menu7:      '$','A','D','0','0','7',13,10,0;
.var/dm/ram  comm_menu8[9];     { set CODEC rate to 32.0 kHz  }
.init        comm_menu8:      '$','A','D','0','0','8',13,10,0;
.var/dm/ram  comm_menu9[9];     { set CODEC rate to 48.0 kHz  }
.init        comm_menu9:      '$','A','D','0','0','9',13,10,0;
.var/dm/ram  comm_dndsp[9];     { download dsp program }
.init        comm_dndsp:      '$','A','D','0','0','~',13,10,0;
.var/dm/ram  comm_param[7];     { set parameter }
.init        comm_param:      '$','A','D','0','0','z',0;

{*****************************************************************
 *  Help Screen                                                  *
 *****************************************************************}
.var/dm/ram  help_string[500];  { help screen - some new commands are
missing from this list }
.init        help_string: '$','A','D','0','0','a','-
','h','e','l','p',13,10,
                          '$','A','D','0','0','h','-','a','-
','a','u','t','o',' ','o','u','t','p','u','t',13,10,
                          '$','A','D','0','0','h','-','p','-
','p','r','o','m','p','t','e','d',' ','o','u','t','p','u','t',13,10,
                          '$','A','D','0','0','h','-','t','-
','a','u','t','o','/','p','r','o','m','p','t','
','t','o','g','g','l','e',13,10,
                          '$','A','D','0','0','h','-','n','-
','n','o','r','m','a','l',' ','o','u','t','p','u','t',13,10,
                          '$','A','D','0','0','h','-','d','-
','d','e','b','u','g',' ','o','u','t','p','u','t',13,10,
                          '$','A','D','0','0','h','-','c','-
','s','h','o','w','
','c','a','l','/','b','a','c','k','g','r','o','u','n','d','
','w','a','v','e','f','o','r','m',13,10,
                          '$','A','D','0','0','h','-','s','-
','s','h','o','w',' ','b','a','c','k','g','r','o','u','n','d','
','w','a','v','e','f','o','r','m',13,10,
                          '$','A','D','0','0','h','-','b','-
','u','p','d','a','t','e','
','b','a','c','k','g','r','o','u','n','d',13,10,
{                          '$','A','D','0','0','h','-','B','-
','u','p','d','a','t','e',' ','b','k','g',',','s','h','o','w','-
','b','/','c',13,10, }
                          '$','A','D','0','0','h','-','h','-
','h','e','l','p',13,10,
                          '$','A','D','0','0','h','-','r','-
','r','e','s','e','t',13,10,
                          '$','A','D','0','0','h','-','1','-
','s','t','a','c','k','=','1',13,10,
                          '$','A','D','0','0','h','-','2','-
','s','t','a','c','k','=','2',13,10,
```

```
                            '$','A','D','0','0','h','-','3','-
','s','t','a','c','k','=','4',13,10,
                            '$','A','D','0','0','h','-','4','-','8','
','k','H','z',13,10,
                            '$','A','D','0','0','h','-','5','-
','9','.','6',' ','k','H','z',13,10,
                            '$','A','D','0','0','h','-','6','-','1','6','
','k','H','z',13,10,
                            '$','A','D','0','0','h','-','7','-
','2','7','.','4',' ','k','H','z',13,10,
                            '$','A','D','0','0','h','-','8','-','3','2','
','k','H','z',13,10,
                            '$','A','D','0','0','h','-','9','-','4','8','
','k','H','z',13,10,
                            '$','A','D','0','0','h','-','i','-
','s','t','a','t','u','s',' ','i','n','f','o',13,10,
                            '$','A','D','0','0','h','-','x','-
','e','x','i','t',13,10,
                            '$','A','D','0','0','h','-','z','-
','p','a','r','a','m','e','t','e','r',13,10,0;


{**************************************************************
 *  Filter coefficients                                       *
 **************************************************************}
.var/pm/ram  fil_bpf[25], fil_lpf[25], fil_diff4[10];
.init        fil_bpf: { header: length=21, dec_fac=1, grp_del=10 }
                  h#1500, h#100, h#A00,
                  h#FFC700, h#000E00, h#007E00, h#FE4300, h#FB7800,
                  h#FEC600, h#FD4600, h#ECD000, h#EE7F00, h#19B900,
                  h#380E00, h#19B900, h#EE7F00, h#ECD000, h#FD4600,
                  h#FEC600, h#FB7800, h#FE4300, h#007E00, h#000E00,
                  h#FFC700;
.init        fil_lpf: { same as above }
                  h#1500, h#100, h#A00,
                  h#FFC700, h#000E00, h#007E00, h#FE4300, h#FB7800,
                  h#FEC600, h#FD4600, h#ECD000, h#EE7F00, h#19B900,
                  h#380E00, h#19B900, h#EE7F00, h#ECD000, h#FD4600,
                  h#FEC600, h#FB7800, h#FE4300, h#007E00, h#000E00,
                  h#FFC700;
.init        fil_diff4: { header: length=5, dec_fac=1, grp_del=2 }
                  h#500, h#100, h#200,
                  h#400000, h#400000, h#000000, h#C00000, h#C00000;

{**************************************************************
 *  Command/UART input buffer                                 *
 **************************************************************}
.var/pm/ram/circ    command_buff[1024];          { command input buffer }
.var/dm/ram         command_ptr;                 { command buffer pointer
}
.init               command_ptr: ^command_buff;
.var/dm/ram         command_count;               { unprocessed command
buffer counter }
.init               command_count: 0;
.var/dm/ram         command_total;               { total character count
for command buffer }
.init               command_total: 0;

{**************************************************************
 *  Flags                                                     *
 **************************************************************}
```

```
.var/dm/ram  init_flag;                         { run initialization
code from main loop? }
.init        init_flag: 0;
.var/dm/ram  stop_flag;                         { exit software to
monitor? }
.init        stop_flag: 0;
.var/dm/ram  null_flag;                         { update nulling
waveform? }
.init        null_flag: 0;
.var/dm/ram  cont_flag;                         { auto (continuous)
output? }
.init        cont_flag: 1;
.var/dm/ram  data_off_flag;                     { in the process of
showing waveform? }
.init        data_off_flag: 0;
.var/dm/ram  debug_flag;                        { debug mode output? }
.init        debug_flag: 0;
.var/dm/ram  show_back_flag;                    { in the process of
updating background waveform? }
.init        show_back_flag: 0;
.var/dm/ram  show_rad_flag;                     { in the process of
showing radar waveform? }
.init        show_rad_flag: 0;
.var/dm/ram  cont_wave_flag;                    { continuous radar
waveform output? }
.init        cont_wave_flag: 0;
.var/dm/ram  bin_flag;                          { binary format for
radar waveform? }
.init        bin_flag: 0;
.var/dm/ram  data_bank;                         { which data bank to use
for radar/cal waveform? (double buffering is used) }
.init        data_bank: 1;

{****************************************************************
 *  Waveform stacking parameters                               *
 ****************************************************************}
{.var/dm/ram  stack_size;
.var/dm/ram  stack_shift;}
.var/dm/ram  stack_counter;                     { how many waveforms
have been stacked so far? }
.var/dm/ram  stack_done;                        { finished stacking
waveforms }

{****************************************************************
 *  Data bank pointers                                         *
 ****************************************************************}
.var/dm/ram data_bank_ptr;                      { pointer to current raw
data buffer }
.var/dm/ram cal_bank_ptr;                       { pointer to current
calibration buffer }

{****************************************************************
 *  Counters                                                   *
 ****************************************************************}
.var/dm/ram  counter;                           { line/waveform counter
}
.init        counter: 0;
.var/dm/ram  sample_count;                      { waveform sample count,
reset after each waveform }
.init        sample_count: 0;
```

```
{*****************************************************************
 *  I/O Buffers                                                  *
 *****************************************************************}
.var/dm/ram  num_string[300];                  { string output buffer }

.var/dm/ram  raw_data1[BUFF_HEADER];           { raw data buffer header
}
.var/dm/ram  raw_data2[BUFF_HEADER];
.var/dm/ram  cal_data1[BUFF_HEADER];           { cal data buffer header
}
.var/dm/ram  cal_data2[BUFF_HEADER];
.var/dm/ram  raw_copy[BUFF_HEADER];            { copy of raw data
(header) }
.var/dm/ram  bgnd_out[BUFF_HEADER];            { output after
background subtraction (header) }
.var/dm/ram  bpf_out[BUFF_HEADER];             { output from first FIR
filter (header) }
.var/dm/ram  bpf2_out[BUFF_HEADER];            { output from second FIR
filter (header) }
.var/dm/ram  diff_out[BUFF_HEADER];            { differentation FIR
filter output (header) }
.var/dm/ram  peak_out[BUFF_HEADER];            { peak detection output
(header) }
.var/dm/ram  max_out[BUFF_HEADER];             { maximum detected
(header) }
.var/dm/ram  thresh_out[BUFF_HEADER];          { threshold detected
(header) }

.var/dm/ram/circ  buff0[WAVE_SIZE];
.var/dm/ram/circ  buff1[WAVE_SIZE];
.var/dm/ram/circ  buff2[WAVE_SIZE];
.var/dm/ram/circ  buff3[WAVE_SIZE];
.var/dm/ram/circ  buff4[WAVE_SIZE];
.var/dm/ram/circ  buff5[WAVE_SIZE];
.var/dm/ram/circ  buff6[WAVE_SIZE];
.var/dm/ram/circ  buff7[WAVE_SIZE];
.var/dm/ram/circ  buff8[WAVE_SIZE];
.var/dm/ram/circ  buff9[WAVE_SIZE];

.var/dm/ram/circ  out_buff1[OUT_BUFF];
.var/dm/ram/circ  out_buff2[OUT_BUFF];

.var/dm/ram  null_data[NULL_HEADER+WAVE_SIZE+1];
#if (0)
.init null_data: <null.dat>;
#endif

#if (FAKE_DATA == 1)
.global  fake_data1;
.global  fake_data2;
.global  fake_dptr1;
.global  fake_dptr2;
.var/dm/ram/circ  fake_data1[1024];            { buffer to hold
simulated ADC data }
.var/dm/ram  fake_dptr1;
.init fake_data1: <scan2.dat>;

.var/dm/ram/circ  fake_data2[10];
.var/dm/ram  fake_dptr2;
{.init fake_data2: <scan_new.dat>;}
#endif
```

```
{***********************************************************************
*******
 *
*
 *  Interrupt vector table
*
 *
*

***********************************************************************
******}
int_vec_table:
#if (SIMULATOR == 1)
        jump again;  rti; rti; rti;      {00: reset }
#else
        jump start;  rti; rti; rti;      {00: reset }
#endif
        rti; rti; rti; rti;
        rti;         rti; rti; rti;      {08: IRQL1 }
        rti;         rti; rti; rti;      {0c: IRQL0 }
        ar = dm(stat_flag);              {10: SPORT0 tx }
        ar = pass ar;
        if eq rti;
        jump next_cmd;
        jump sport_rx;
                     rti; rti; rti;      {14: SPORT1 rx }
        jump irqeisr; rti; rti; rti;     {18: IRQE }
        rti;         rti; rti; rti;      {1c: BDMA }
        jump irq1isr;
                     rti; rti; rti;      {20: SPORT1 tx or IRQ1 }
        rti;         rti; rti; rti;      {24: SPORT1 rx or IRQ0 }
        jump process_a_bit;
                     rti; rti; rti;      {28: timer }
        rti;         rti; rti; rti;      {2c: power down }


#include   "start.dsp"

{-----------------------------------------------------------------------
-------
 -  command loop.
-
 ----------------------------------------------------------------------
-------}

again:  { any thing from host ?}
        ar = dm(init_flag);              { do initialization ? }
        ar = pass ar;
        if ne jump stop_check;
        ar=1;  dm(init_flag)=ar;
#if (SIMULATOR == 0)
        call init_uart;
        call turn_rx_on;
#endif
        dis ints;
        ax0=dm(0x3FFE);                  { Wait state control register }
        ay0=0xFFF8;
        ay1=0x2;
        ar=ax0 and ay0;
        ar=ar or ay1;
```

```
        dm(0x3FFE)=ar;

        call do_init;
        ena ints;
        i7=^init_string;
        call sendLine;                    { done initialization }

stop_check:                               { exit to monitor? }
        ar=dm(stop_flag);  ar=pass ar;  if eq jump data_ready_check;
        i7=^ack_strings+ACK_SIZE*8;
        call sendLine;
        rts;

{------------------------------------------------------------------------
-------
 -  process data
-
 -----------------------------------------------------------------------
-------}

data_ready_check:
#if (SIMULATOR == 1)
        call sport_rx;                    { call CODEC interrupt in
simulator to make things easier to follow and faster }
#endif

check_bank1:                              { which of two buffer choices to
use? }
        ar=dm(raw_data1+1);  ay0=WAVE_SIZE;  ar=ar-ay0;  if lt jump
check_bank2;
        ar=^raw_data1;
        dm(data_bank_ptr)=ar;
        ar=^cal_data1;
        dm(cal_bank_ptr)=ar;
        jump proc_data;
check_bank2:
        ar=dm(raw_data2+1);  ay0=WAVE_SIZE;  ar=ar-ay0;  if lt jump
menu_check;
{        ar=dm(sample_count);  ar=pass ar;  if ne jump menu_check; }
        ar=^raw_data2;
        dm(data_bank_ptr)=ar;
        ar=^cal_data2;
        dm(cal_bank_ptr)=ar;

proc_data:
        ar=dm(counter);  ar=ar+1;  dm(counter)=ar;      { increment
line/waveform counter }

        { make copy of raw data }
        i0=dm(data_bank_ptr);
        i1=^raw_copy;
        call buff_stack;
        ar=dm(stack_done);
        ar=pass ar;
        if eq jump menu_check;
#if (1)
        ar=dm(stack_cnt);  ar=ar+1;  dm(stack_cnt)=ar;
#endif

        { band-pass filter stage 1 }
        i0=^raw_copy;
```

```
        i1=^bpf_out;
        i4=^fil_bpf;
        call fir_dec;

        { band-pass filter stage 2 }
        i0=^bpf_out;
        i1=^bpf2_out;
        i4=^fil_lpf;
        call fir_dec;

        { update background nulling waveform }
        i0=^bpf2_out;
        i1=^null_data;
        call update_null;

        { waveform nulling }
        i0=^bpf2_out;
        i1=^bgnd_out;
        call buff_copy;
        i0=^bgnd_out;
        i1=^null_data;
        call sub_background;

        { difference filter }
        i0=^bgnd_out;
        i1=^diff_out;
        i4=^fil_diff4;
        call fir_dec;

        { find peaks }
        i0=^diff_out;
        i1=^peak_out;
        i2=^bgnd_out;
        call loc_peaks;

        { find maximum and first peak above threshold }
        i0=^peak_out;
        i1=^max_out;
        ax0=dm(rad_thresh);     { threshold value }
        ax1=dm(rad_transient); { values to skip }
        call find_max_and_thresh;

        ar=dm(cont_flag);  ar=pass ar;
        if eq jump menu_check;
        call show_results;

{-----------------------------------------------------------------
-------
 -  command menu
-
 ----------------------------------------------------------------
-------}
menu_check:
        ax0=dm(poll_cnt);
        ax1=dm(poll_cnt+1);
        ay1=0;
        ar=ax0+1;
        sr0=ar, ar=ax1+ay1+C;
        dm(poll_cnt)=sr0;
        dm(poll_cnt+1)=ar;
cont_wave_check:
```

```
        ar=dm(cont_wave_flag);  ar=pass ar;  if eq jump showback_check;
        ar=1;  dm(show_rad_flag)=ar;
showback_check:
        ar=dm(show_back_flag);
        ar=pass ar;
        if eq jump showback_skip;
        ar=dm(null_flag);               { background in progress? }
        ar=pass ar;
        if ne jump showback_skip;
        ax0=dm(wave_cnt);  ax1=dm(wave_cnt+1);  ay1=0; ay0=2;
        ar=ax0-ay0;  ar=ax1-ay1+c-1;  if lt jump showback_skip;   { wait
for waveform to accumulate }
        call show_cb_waveform;
        ar=0;  dm(show_back_flag)=ar;
        dis ints;
        call do_init;                   { re-initialize after doing
waveform output }
        ena ints;
showback_skip:
showrad_check:
        ar=dm(show_rad_flag);
        ar=pass ar;
        if eq jump showrad_skip;
#if (0)
        ax0=dm(wave_cnt);  ax1=dm(wave_cnt+1);  ay1=0; ay0=2;
        ar=ax0-ay0;  ar=ax1-ay1+c-1;  if lt jump showrad_skip;
#else
        ar=dm(stack_cnt);  ar=ar-1;
        if lt jump showrad_skip;        { wait for waveform to
accumulate }
        ar=0;  dm(stack_cnt)=ar;
#endif
        call show_rad_waveform;
        ar=0;  dm(show_rad_flag)=ar;
        dis ints;
        call do_init;
        ena ints;
showrad_skip:
#if (SIMULATOR == 1)
        ax1 = 0;
#else
 #if (0)
        ar = dm(flag_rx_no_word);
        none = pass ar;
        if ne jump again;
        call get_char_ax1_to;
        if lt jump again; { time out }
 #else
        ar=dm(command_count);           { at least one character in
command buffer? }
        none = pass ar;
        if eq jump again;
        call get_command_buff;
 #endif
#endif
        ar=dm(command_flag);            { in the process of getting
command packet? }
        ar=pass ar;
        if ne jump get_command;
menu_command:
        ay0 = 36;    { $ }
```

```
        none = ax1 - ay0;               { command packets begin with '$'
}
        if ne jump menu_enter;
        ar=1;  dm(command_flag)=ar;
        ar=1;  dm(command_letter)=ar;
        i0=^command_string;
        l0=0;
        m0=1;
        dm(i0,m0)=36;
        jump again;
menu_enter:
        ay0 = 13;    { <Enter> }
        none = ax1 - ay0;               { <Enter> is prompt command }
        if ne jump menu_a;
        call show_results;
        jump again;
menu_a:
        ay0 = 97;    { 'a' - auto output mode}
        none = ax1 - ay0;
        if ne jump menu_b;
        ar=1;  dm(cont_flag)=ar;
        i7=^ack_strings+0;
        call sendLine;
        jump again;
menu_b:
        ay0 = 98;    { 'b' - update background }
        none = ax1 - ay0;
        if ne jump menu_big_b;
        ar=dm(null_flag);
        ar=pass ar;                     { background already in
progress? }
        if eq jump do_menu_b;
        i7=^ack_strings+ACK_SIZE;
        call sendLine;
        i7=^not_ready_string;
        call sendLine;
        jump again;
 do_menu_b:
        i7=^ack_strings+ACK_SIZE;
        ar=1;  dm(null_flag)=ar;
        call sendLine;
        jump again;
menu_big_b:
        ay0 = 66;    { 'B' - 'b' and 'c' commands together }
        none = ax1 - ay0;
        if ne jump menu_c;
        ax0=dm(null_flag);
        ay0=dm(show_back_flag);
        ar=ax0+ay0;           { background or show waveform already in
progress? }
        if eq jump do_menu_big_b;
        i7=^ack_strings+ACK_SIZE*19;
        call sendLine;
        i7=^not_ready_string;
        call sendLine;
        jump again;
 do_menu_big_b:
        ar=1;  dm(null_flag)=ar;
        ar=1;  dm(show_back_flag)=ar;
        i7=^ack_strings+ACK_SIZE*19;
        call sendLine;
```

```
        jump again;
menu_c:
        ay0 = 99;     { 'c' - cal/background waveform }
        none = ax1 - ay0;
        if ne jump menu_d;
        ar=dm(show_back_flag);
        ar=pass ar;                         { show waveform already in
progress? }
        if eq jump do_menu_c;
        i7=^ack_strings+ACK_SIZE*9;
        call sendLine;
        i7=^not_ready_string;
        call sendLine;
        jump again;
 do_menu_c:
        i7=^ack_strings+ACK_SIZE*9;
        call sendLine;
        ar=1;  dm(show_back_flag)=ar;
        jump again;
menu_d:
        ay0 = 100;    { 'd' - debug output }
        none = ax1 - ay0;
        if ne jump menu_h;
        ar=1;  dm(debug_flag)=ar;
        i7=^ack_strings+ACK_SIZE*3;
        call sendLine;
        jump again;
menu_h:
        ay0 = 104;    { 'h' - help }
        none = ax1 - ay0;
        if ne jump menu_i;
        i7=^help_string;   call sendLine;
        dis ints;
        call do_init;
        ena ints;
        jump again;
menu_i:
        ay0 = 105;    { 'i' - status info }
        none = ax1 - ay0;
        if ne jump menu_n;
        call show_status;
        dis ints;
        call do_init;
        ena ints;
        jump again;
menu_n:
        ay0 = 110;   { 'n' - normal output }
        none = ax1 - ay0;
        if ne jump menu_p;
        ar=0;  dm(debug_flag)=ar;
        i7=^ack_strings+ACK_SIZE*4;
        call sendLine;
        jump again;
menu_p:
        ay0 = 112;   { 'p' - prompted output }
        none = ax1 - ay0;
        if ne jump menu_r;
        ar=0;  dm(cont_flag)=ar;
        i7=^ack_strings+ACK_SIZE*5;
        call sendLine;
        jump again;
```

```
menu_r:
        ay0 = 114;    { 'r' - reset }
        none = ax1 - ay0;
        if ne jump menu_s;
        ar=0;  dm(init_flag)=ar;
        i7=^ack_strings+ACK_SIZE*6;
        call sendLine;
        jump again;
menu_s:
        ay0 = 115;  { 's' - show raw data waveform }
        none = ax1 - ay0;
        if ne jump menu_t;
        ar=dm(show_rad_flag);
        ar=pass ar;                       { show waveform already in
progress? }
        if eq jump do_menu_s;
        i7=^ack_strings+ACK_SIZE*2;
        call sendLine;
        i7=^not_ready_string;
        call sendLine;
        jump again;
 do_menu_s:
        i7=^ack_strings+ACK_SIZE*2;
        call sendLine;
        ar=1;  dm(show_rad_flag)=ar;
        jump again;
menu_t:
        ay0 = 116;    { 't' - toggle auto/prompted output }
        none = ax1 - ay0;
        if ne jump menu_u;
        ar=dm(cont_flag);  ar=pass ar;
        if ne jump cont_off;
 cont_on:   ar=1;  dm(cont_flag)=ar;
            i7=^ack_strings+0;
            call sendLine;
            jump again;
 cont_off:  ar=0;  dm(cont_flag)=ar;
            i7=^ack_strings+ACK_SIZE*5;
            call sendLine;
            jump again;
menu_u:
        ay0 = 117;    { 'u' - turn on binary mode }
        none = ax1 - ay0;
        if ne jump menu_v;
        ar=1;  dm(bin_flag)=ar;
        jump again;
menu_v:
        ay0 = 118;    { 'v' - turn on binary mode }
        none = ax1 - ay0;
        if ne jump menu_w;
        ar=0;  dm(bin_flag)=ar;
        jump again;
menu_w:
        ay0 = 119;    { 'w' - turn off continuous waveform mode }
        none = ax1 - ay0;
        if ne jump menu_y;
        ar=1;  dm(cont_wave_flag)=ar;
        jump again;
menu_y:
        ay0 = 121;    { 'y' - turn off continuous waveform mode }
        none = ax1 - ay0;
```

```
        if ne jump menu_1;
        ar=0;  dm(cont_wave_flag)=ar;
        jump again;
menu_1:
        ay0 = 49;    { '1' - no waveform stacking }
        none = ax1 - ay0;
        if ne jump menu_2;
        ar=1;  dm(stack_size)=ar;
        ar=0;  dm(stack_shift)=ar;
        i7=^ack_strings+ACK_SIZE*10;
        call sendLine;
        jump again;
menu_2:
        ay0 = 50;    { '2' - stack 8 waveforms }
        none = ax1 - ay0;
        if ne jump menu_3;
        ar=8;  dm(stack_size)=ar;
        ar=-3; dm(stack_shift)=ar;
        i7=^ack_strings+ACK_SIZE*11;
        call sendLine;
        jump again;
menu_3:
        ay0 = 51;    { '3' - stack 16 waveforms }
        none = ax1 - ay0;
        if ne jump menu_4;
        ar=16;  dm(stack_size)=ar;
        ar=-4; dm(stack_shift)=ar;
        i7=^ack_strings+ACK_SIZE*12;
        call sendLine;
        jump again;
menu_4:
        ay0 = 52;    { '4' - 8 kHz }
        none = ax1 - ay0;
        if ne jump menu_5;
        ax0=0x0;  dm(codec_param)=ax0;
        call reset_codec;
        i7=^ack_strings+ACK_SIZE*13;
        call sendLine;
        ar=0;  dm(init_flag)=ar;
        jump start;
menu_5:
        ay0 = 53;    { '5' - 9.6 kHz }
        none = ax1 - ay0;
        if ne jump menu_6;
        ax0=0xE;  dm(codec_param)=ax0;
        call reset_codec;
        i7=^ack_strings+ACK_SIZE*14;
        call sendLine;
        ar=0;  dm(init_flag)=ar;
        jump start;
menu_6:
        ay0 = 54;    { '6' - 16 kHz }
        none = ax1 - ay0;
        if ne jump menu_7;
        ax0=0x2;  dm(codec_param)=ax0;
        call reset_codec;
        i7=^ack_strings+ACK_SIZE*15;
        call sendLine;
        ar=0;  dm(init_flag)=ar;
        jump start;
menu_7:
```

```
        ay0 = 55;    { '7' - 27.4 kHz }
        none = ax1 - ay0;
        if ne jump menu_8;
        ax0=0x4;  dm(codec_param)=ax0;
        call reset_codec;
        i7=^ack_strings+ACK_SIZE*16;
        call sendLine;
        ar=0;  dm(init_flag)=ar;
        jump start;
menu_8:
        ay0 = 56;    { '8' - 32 kHz }
        none = ax1 - ay0;
        if ne jump menu_9;
        ax0=0x6;  dm(codec_param)=ax0;
        call reset_codec;
        i7=^ack_strings+ACK_SIZE*17;
        call sendLine;
        ar=0;  dm(init_flag)=ar;
        jump start;
menu_9:
        ay0 = 57;    { '9' - 48 kHz }
        none = ax1 - ay0;
        if ne jump menu_x;
        ax0=0xC;  dm(codec_param)=ax0;
        call reset_codec;
        i7=^ack_strings+ACK_SIZE*18;
        call sendLine;
        ar=0;  dm(init_flag)=ar;
        jump start;
menu_x:
        ay0 = 120;    { 'x' - exit software }
        none = ax1 - ay0;
        if ne jump menu_invalid;
        i7=^ack_strings+ACK_SIZE*8;
        call sendLine;
        rts;                                  { go back to monitor. }
menu_invalid:
        i7=^invalid_string;
        call sendLine;
        jump again;


{************************************************************************
*******
  Get command one character at a time

************************************************************************
******}
get_command_buff:
        ax0=dm(command_count);  ar=-ax0;  m7=ar;
        ar=ax0-1;  dm(command_count)=ar;
        i7=dm(command_ptr);  l7=%command_buff;
        modify(i7,m7);  ax1=pm(i7,m7);
        rts;

{************************************************************************
*******
  Get command one character at a time

************************************************************************
******}
```

```
get_command:
        i0=^command_string;
        l0=0;
        ar=dm(command_letter);
        m0=ar;
        modify(i0,m0);
        m0=1;
        dm(i0,m0)=ax1;
        ar=ar+1;
        dm(command_letter)=ar;
        ay0=10;
#if (KLUDGE == 1)
        ay0=13;
#endif
        ar=ax1-ay0;
        if ne jump again;
        ar=0;  dm(command_flag)=ar;
{        dm(i0,m0)=10; }
        dm(i0,m0)=0;

        { compare command string with available commands
                - set to one character command if possible
                - paramter entry is a special case }
        i0=^command_string;
c_help:
        i1=^comm_help;  call strcmp;  ar=pass ar;
        if eq jump c_auto;
        ax1=104;  jump getcomm_done;
c_auto:
        i1=^comm_auto;  call strcmp;  ar=pass ar;
        if eq jump c_back;
        ax1=97;  jump getcomm_done;
c_back:
        i1=^comm_back;  call strcmp;  ar=pass ar;
        if eq jump c_back2;
        ax1=98;  jump getcomm_done;
c_back2:
        i1=^comm_back2;  call strcmp;  ar=pass ar;
        if eq jump c_back_wave;
        ax1=66;  jump getcomm_done;
c_back_wave:
        i1=^comm_back_wave;  call strcmp;  ar=pass ar;
        if eq jump c_debug;
        ax1=115;  jump getcomm_done;
c_debug:
        i1=^comm_debug;  call strcmp;  ar=pass ar;
        if eq jump c_normal;
        ax1=100;  jump getcomm_done;
c_normal:
        i1=^comm_normal;  call strcmp;  ar=pass ar;
        if eq jump c_toggle;
        ax1=110;  jump getcomm_done;
c_toggle:
        i1=^comm_toggle;  call strcmp;  ar=pass ar;
        if eq jump c_prompt;
        ax1=116;  jump getcomm_done;
c_prompt:
        i1=^comm_prompt;  call strcmp;  ar=pass ar;
        if eq jump c_reset;
        ax1=112;  jump getcomm_done;
c_reset:
```

```
        i1=^comm_reset;
        call strcmp;
        ar=pass ar;
        if eq jump c_status;
        ax1=114;  jump getcomm_done;
c_status:
        i1=^comm_status;  call strcmp;  ar=pass ar;
        if eq jump c_stop;
        ax1=105;  jump getcomm_done;
c_stop:
        i1=^comm_stop;  call strcmp;  ar=pass ar;
        if eq jump c_cb_wave;
        ax1=120;  jump getcomm_done;
c_cb_wave:
        i1=^comm_cb_wave;  call strcmp;  ar=pass ar;
        if eq jump c_menu1;
        ax1=99;  jump getcomm_done;
c_menu1:
        i1=^comm_menu1;  call strcmp;  ar=pass ar;
        if eq jump c_menu2;
        ax1=49;  jump getcomm_done;
c_menu2:
        i1=^comm_menu2;  call strcmp;  ar=pass ar;
        if eq jump c_menu3;
        ax1=50;  jump getcomm_done;
c_menu3:
        i1=^comm_menu3;  call strcmp;  ar=pass ar;
        if eq jump c_menu4;
        ax1=51;  jump getcomm_done;
c_menu4:
        i1=^comm_menu4;  call strcmp;  ar=pass ar;
        if eq jump c_menu5;
        ax1=52;  jump getcomm_done;
c_menu5:
        i1=^comm_menu5;  call strcmp;  ar=pass ar;
        if eq jump c_menu6;
        ax1=53;  jump getcomm_done;
c_menu6:
        i1=^comm_menu6;  call strcmp;  ar=pass ar;
        if eq jump c_menu7;
        ax1=54;  jump getcomm_done;
c_menu7:
        i1=^comm_menu7;  call strcmp;  ar=pass ar;
        if eq jump c_menu8;
        ax1=55;  jump getcomm_done;
c_menu8:
        i1=^comm_menu8;  call strcmp;  ar=pass ar;
        if eq jump c_menu9;
        ax1=56;  jump getcomm_done;
c_menu9:
        i1=^comm_menu9;
        call strcmp;
        ar=pass ar;
        if eq jump c_dndsp;
        ax1=57;  jump getcomm_done;
c_dndsp:
        i1=^comm_dndsp;
        call strcmp;
        ar=pass ar;
        if eq jump c_param;
        { make sure only interrupts for UART occur }
```

```
        ifc = b#00000011111111;      { clear pending interrupt }
        nop;                         { wait for ifc latency }
        imask=b#0000000101;
        jump dndsp;
        jump start;
c_param:                             { this has to be the last command
being checked because of the special code below }
        i0=^command_string;
        ar=0;  dm(command_string+6)=ar;   { add null for string compare
}
        i1=^comm_param;
        call strcmp;
        ar=pass ar;
        if eq jump c_invalid;
        call decode_param_string;       { update selected parameter with
value in packet }
        dis ints;
        call do_init;
        ena ints;
        jump again;
c_invalid:
        i7=^invalid_string;
        call sendLine;
        jump again;

getcomm_done:
        jump menu_command;

{************************************************************************
*******
  Show status information
    Info:
       stack: XXXX\n (1,2,4)
       null_stack: XXXX\n
       cal_tol: XXXX\n
       rate: XX.X\n (08.0,09.6,16.0,27.4,32.0,48.0)
       delay: XXXX\n
       rad_thresh: XXXX\n
       cal_thresh: XXXX\n
       tx_offset: XXXX\n
       rad_trans: XXXX\n
       sos_on_time: XXXX\n
       ramp_start: XXXX\n
       ramp_inc: XXXX\n

************************************************************************
******}
.var/dm/ram status_info[250];
.init       status_info: '$','A','D','s','-','s','t','a','c','k',':','
',' ',' ',' ',13,10,          { 17 }
                         '$','A','D','s','-
','n','s','t','a','c','k',':',' ',' ',' ',' ',13,10,      { 18 }
                         '$','A','D','s','-
','c','a','l','_','t','o','l',':',' ',' ',' ',' ',13,10,  { 19 }
                         '$','A','D','s','-','r','a','t','e',':',' ','
','.',' ',13,10,              { 16 }
                         '$','A','D','s','-','d','e','l','a','y',':','
',' ',' ',' ',13,10,          { 17 }
                         '$','A','D','s','-
','r','a','d','_','t','h','r','e','s','h',':',' ',' ',' ',' ',13,10, {
22 }
```

```
                        '$','A','D','s','-
','c','a','l','_','t','h','r','e','s','h',':',' ',' ',' ',' ',13,10, {
22 }
                        '$','A','D','s','-
','t','x','_','o','f','f','s','e','t',':',' ',' ',' ',' ',13,10, { 21 }
                        '$','A','D','s','-
','r','a','d','_','t','r','a','n','s',':',' ',' ',' ',' ',13,10, { 21 }
                        '$','A','D','s','-
','s','o','s','_','o','n','_','t','i','m','e',':',' ',' ',' ',' ',13,10,
{ 23 }
                        '$','A','D','s','-
','r','a','m','p','_','s','t','a','r','t',':',' ',' ',' ',' ',13,10, {
22 }
                        '$','A','D','s','-
','r','a','m','p','_','i','n','c',':',' ',' ',' ',' ',13,10, { 20 }
                        0,0,0,0;

show_status:
        i7=^ack_strings+ACK_SIZE*7;
        call sendLine;
        l0=0; m0=1;
       { stack size info }
        i0=^status_info+11;  ax0=dm(stack_size);  call int_to_ascii_hex;
       { null stack size }
        i0=^status_info+29;  ax0=dm(null_stack);  call int_to_ascii_hex;
       { cal tolerance }
        i0=^status_info+48;  ax0=dm(cal_tol);  call int_to_ascii_hex;
       { delay }
        i0=^status_info+81; ax0=dm(codec_delay);  call int_to_ascii_hex;
       { rad_thresh }
        i0=^status_info+103; ax0=dm(rad_thresh);  call int_to_ascii_hex;
       { cal_thresh }
        i0=^status_info+125; ax0=dm(cal_thresh);  call int_to_ascii_hex;
       { tx_offset }
        i0=^status_info+146; ax0=dm(tx_offset);  call int_to_ascii_hex;
       { rad_trans }
        i0=^status_info+167; ax0=dm(rad_transient);  call
int_to_ascii_hex;
       { sos_on_time }
        i0=^status_info+190; ax0=dm(sos_on_time);  call
int_to_ascii_hex;
       { ramp_start }
        i0=^status_info+212; ax0=dm(ramp_start);  call int_to_ascii_hex;
       { ramp_inc }
        i0=^status_info+232; ax0=dm(ramp_inc);  call int_to_ascii_hex;
       { CODE rate info }
        i0=^status_info+64;  l0=0;  m0=1;  m1=2;
        ax0=dm(codec_param);
        ay0=0;  none=ax0-ay0;  if ne jump s096k;
s080k:  dm(i0,m0)=48;  dm(i0,m1)=56;  dm(i0,m0)=48;
        jump sdone;
s096k:  ay0=14;  none=ax0-ay0;  if ne jump s160k;
        dm(i0,m0)=48;  dm(i0,m1)=57;  dm(i0,m0)=54;
        jump sdone;
s160k:  ay0=2;  none=ax0-ay0;  if ne jump s274k;
        dm(i0,m0)=49;  dm(i0,m1)=54;  dm(i0,m0)=48;
        jump sdone;
s274k:  ay0=4;  none=ax0-ay0;  if ne jump s320k;
        dm(i0,m0)=50;  dm(i0,m1)=52;  dm(i0,m0)=55;
        jump sdone;
s320k:  ay0=6;  none=ax0-ay0;  if ne jump s480k;
```

```
        dm(i0,m0)=51;  dm(i0,m1)=50;  dm(i0,m0)=48;
        jump sdone;
s480k:  ay0=12;  none=ax0-ay0;  if ne jump sxxxk;
        dm(i0,m0)=52;  dm(i0,m1)=56;  dm(i0,m0)=48;
        jump sdone;
sxxxk:  dm(i0,m0)=120;  dm(i0,m1)=120;  dm(i0,m0)=120;
sdone:
        i7=^status_info;
        call sendLine;
        rts;


{***********************************************************************
*******
  Retrieve Paramater from command string and update appropriate variable

***********************************************************************
******}
.var/dm/ram  param_strings[33];
.init        param_strings:
                'd','e',0,   { codec delay }
                's','s',0,   { stack size }
                'n','s',0,   { null stack }
                'c','t',0,   { cal thresh }
                'r','t',0,   { rad thresh }
                'c','a',0,   { cal tolerance }
                't','o',0,   { tx offset }
                'r','a',0,   { rad transient }
                's','o',0,   { sos on time }
                'r','s',0,   { ramp start }
                'r','i',0;   { ramp increment }
.var/dm/ram  param_invalid[17];
.init        param_invalid: '$','A','D','0','a','p','-
','i','n','v','a','l','i','d',13,10,0;
.var/dm/ram  param_ack_string[12];
.init        param_ack_string: '$','A','D','0','a','p','-',' ','
',13,10,0;
.var/dm/ram  param_val;

decode_param_string:
        ar=0;  dm(command_string+9)=ar;
        l0=0;  m0=1;
        i0=^command_string+10;
        call get_hex;                  { extract parameter value }
        dm(param_val)=ar;
        i0=^command_string+7;
       { codec delay }
pcodec:
        i1=^param_strings+0;  call strcmp;  ar=pass ar; if eq jump
pstack;
        ar=dm(param_val);  dm(codec_delay)=ar;
        jump param_ack;
       { stack size }
pstack:
        i1=^param_strings+3;  call strcmp;  ar=pass ar; if eq jump
pnull;
        ar=dm(param_val);  ar=-ar;  dm(stack_shift)=ar;
        jump param_ack;
       { null stack }
pnull:
```

```
        i1=^param_strings+6;  call strcmp;  ar=pass ar; if eq jump
pcthresh;
        ar=dm(param_val);  ar=-ar;  dm(null_shift)=ar;
        jump param_ack;
       { cal thresh }
pcthresh:
        i1=^param_strings+9;  call strcmp;  ar=pass ar; if eq jump
prthresh;
        ar=dm(param_val);  dm(cal_thresh)=ar;
        jump param_ack;
       { rad thresh }
prthresh:
        i1=^param_strings+12;  call strcmp;  ar=pass ar; if eq jump
pctol;
        ar=dm(param_val);  dm(rad_thresh)=ar;
        jump param_ack;
       { cal tolerance }
pctol:
        i1=^param_strings+15;  call strcmp;  ar=pass ar; if eq jump
ptxoffset;
        ar=dm(param_val);  dm(cal_tol)=ar;
        jump param_ack;
       { tx offset }
ptxoffset:
        i1=^param_strings+18;  call strcmp;  ar=pass ar; if eq jump
prtrans;
        ar=dm(param_val);  dm(tx_offset)=ar;
        jump param_ack;
       { rad transient }
prtrans:
        i1=^param_strings+21;  call strcmp;  ar=pass ar; if eq jump
psos;
        ar=dm(param_val);  dm(rad_transient)=ar;
        jump param_ack;
       { sos on time }
psos:
        i1=^param_strings+24;  call strcmp;  ar=pass ar; if eq jump
prstart;
        ar=dm(param_val);  dm(sos_on_time)=ar;
        jump param_ack;
       { ramp start }
prstart:
        i1=^param_strings+27;  call strcmp;  ar=pass ar; if eq jump
princ;
        ar=dm(param_val);  dm(ramp_start)=ar;
        jump param_ack;
       { ramp increment }
princ:
        i1=^param_strings+30;  call strcmp;  ar=pass ar; if eq jump
pinvalid;
        ar=dm(param_val);  dm(ramp_inc)=ar;
        jump param_ack;
pinvalid:
        i7=^param_invalid;
        call sendLine;
        rts;
param_ack:
        i0=^command_string;
        ar=dm(command_string+7);  dm(param_ack_string+7)=ar;
        ar=dm(command_string+8);  dm(param_ack_string+8)=ar;
        i7=^param_ack_string;
```

```
        call sendLine;
        rts;

{*********************************************************************
*******
  Decode 4 digit hex string
   - i0 = pointer to string
   - ar = return value

*********************************************************************
******}
get_hex:
        ar=0;                           { clear accumulator }
        ax0=dm(i0,m0);  my0=h#1000;  call get_hex_digit;
        ax0=dm(i0,m0);  my0=h#100;  call get_hex_digit;
        ax0=dm(i0,m0);  my0=h#10;  call get_hex_digit;
        ax0=dm(i0,m0);  my0=h#1;  call get_hex_digit;
        rts;
get_hex_digit:
        si=ar;                          { save accumulator }
        ay1=97;  ar=ax0-ay1;  if lt jump not_lowercase;
        ay1=10;  ar=ar+ay1;             { lowercase hex digit }
        jump digit_comp;
not_lowercase:
        ay1=65;  ar=ax0-ay1;  if lt jump not_big_letter;
        ay1=10;  ar=ar+ay1;             { uppercase hex digit }
        jump digit_comp;
not_big_letter:
        ay1=48;  ar=ax0-ay1;            { digit between 0 and 9 }
digit_comp:
        mr=ar*my0 (uu);
        sr=lshift mr1 by -1 (hi);
        sr=sr or lshift mr0 by -1 (lo);
        ay1=si;                         { restore accumulator }
        ar=sr0+ay1;
        rts;



{*********************************************************************
*******
  Compare two strings
   - return ar=1 if strings are the the same

*********************************************************************
******}
.var/dm/ram start_i0;
.var/dm/ram start_i1;
strcmp: ar=0;
        l0=0;  l1=0;  m0=1;  m1=1;
        dm(start_i0)=i0;
        dm(start_i1)=i1;
scmploop:
        ax0=dm(i0,m0);  ay0=dm(i1,m1);
        none=pass ax0;
        if eq jump strcmp_done;     { check for terminator on first
string }
        none=ax0-ay0;
        if ne ar=ar+1;
        if eq jump scmploop;
strcmp_done:
```

```
        none=pass ay0;
        if ne ar=ar+1;              { check for terminator for second
string }
        ay0=ar;
        ar=pass ar;
        if eq jump strcmp_match;
        ar=0;
        jump strcmp_return;
strcmp_match:
        ar=1;
strcmp_return:
        i0=dm(start_i0);
        i1=dm(start_i1);
        rts;


{**********************************************************************
*******
  Show some results at output

**********************************************************************
******}
show_results:
        toggle fl1;
        i0=^num_string;  l0=0;  m0=1;
        dm(i0,m0)=36;    { '$' }
        dm(i0,m0)=65;    { 'A' }
        dm(i0,m0)=68;    { 'D' }
        dm(i0,m0)=48;    { '0' }
        dm(i0,m0)=48;    { '0' }

        ar=dm(debug_flag);
        ar=pass ar;
        if ne jump debug_out;
normal_out:
        dm(i0,m0)=110;   { 'n' }
        call show_normal;
        jump show_line;
debug_out:
        dm(i0,m0)=100;   { 'd' }
        call show_debug;
show_line:
        dm(i0,m0)=13;
        dm(i0,m0)=10;
        dm(i0,m0)=0;
        i7=^num_string;
        call sendLine;
        rts;

{**********************************************************************
*******
  Reset CODEC
    Parameter: AX0 = sample rate choice parameter

**********************************************************************
******}
reset_codec:
        ar=dm(init_cmds+8);
        ay0=0xFFF0;
        ar=ar and ay0;
        ay0=ax0;
```

```
        ar=ar or ay0;
        dm(init_cmds+8)=ar;
        rts;

{***********************************************************************
*******
  Show normal info

***********************************************************************
******}
show_normal:
        { height above ground }
        mx0=dm(fm_max_index);
        my0=84;               {h#100}
        mr=mx0*my0 (ss);
        ax1=mr1;
        ax0=mr0;
        call num_to_ascii;
{        dm(i0,m0)=32;}

        { snow thickness }
        ax0=dm(fm_max_index);
        ay0=dm(fm_thresh_index);
        ar=ax0-ay0;
        my0=168;              {h#200}
        mr=ar*my0 (ss);
        ax1=mr1;
        ax0=mr0;
        call num_to_ascii;

        rts;

{***********************************************************************
*******
  Show debug info

***********************************************************************
******}
show_debug:
        ax0 = dm(counter);  ax1=0;
        call int_to_ascii_hex;
#if (0)
        dm(i0,m0)=32;

        ax0 = dm(sample_count);  ax1=0;
        call int_to_ascii_hex;
        dm(i0,m0)=32;
#endif

        ax0=dm(fm_thresh_val);  ax1=0;
        call int_to_ascii_hex;
{        dm(i0,m0)=32;}

        ax0=dm(fm_thresh_index);  ax1=0;
        call int_to_ascii_hex;
{        dm(i0,m0)=32;}

        ax0=dm(fm_max_val);  ax1=0;
        call int_to_ascii_hex;
{        dm(i0,m0)=32;}
```

```
        ax0=dm(fm_max_index);  ax1=0;
        call int_to_ascii_hex;
        rts;

{*********************************************************************
*******
  Show cal/background waveforms

*********************************************************************
******}
.var/dm/ram cb_pointer;
show_cb_waveform:
        l1=0;  m1=1;
        l2=0;  m2=1;

        ar=1;  dm(data_off_flag)=ar;
        ar=0;  dm(line_count)=ar;  dm(col_count)=ar;

        ar=dm(data_bank);
        ar=ar-1;
        if eq jump cb_bank2;
cb_bank1:
{        i1=^raw_data1;}
        i1=^null_data+3;
        i2=^cal_data1;
        jump cb_header;
cb_bank2:
{        i1=^raw_data2;}
        i1=^null_data+3;
        i2=^cal_data2;

cb_header:
        ax1=dm(i2,m2);  { pointer }
        modify(i2,m2);  { skip count }
        modify(i2,m2);  { skip total }
        ax0=dm(i2,m2);  { length }

        ax0=WAVE_SIZE;
        i2=ax1;
        dm(cb_pointer)=ax0;

        jump cb_newline;

cb_loop:
            ar=dm(cb_pointer);  ar=ar-1;
            if lt jump cb_done;
            dm(cb_pointer)=ar;

            ax0 = dm(i1,m1);
            call int_to_ascii_hex;
            ax0 = dm(i2,m2);
            call int_to_ascii_hex;
{            dm(i0,m0)=32;}
            ay0=20;  ar=dm(col_count);  ar=ar+1;  dm(col_count)=ar;
            ar=ar-ay0;  if lt jump cb_loop;
            dm(i0,m0)=13;  dm(i0,m0)=10;  dm(i0,m0)=0;
            i7=^num_string;
            call sendLine;
cb_newline:
            i0=^num_string;  l0=0;  m0=1;
            dm(i0,m0)=36;   { '$' }
```

```
            dm(i0,m0)=65;    { 'A' }
            dm(i0,m0)=68;    { 'D' }
            dm(i0,m0)=48;    { '0' }
            dm(i0,m0)=119;   { 'w' }
            dm(i0,m0)=99;    { 'c' }
            ar=dm(line_count);  ar=ar+1;  dm(line_count)=ar;
  ar=dm(counter);
            ax0=ar;  call int_to_ascii_hex;
{            dm(i0,m0)=32;}
            ar=0;  dm(col_count)=ar;
            jump cb_loop;
cb_done:
            ar=dm(col_count);  ar=pass ar;  if eq jump cb_term;
            dm(i0,m0)=13;  dm(i0,m0)=10;  dm(i0,m0)=0;
            i7=^num_string;
            call sendLine;
cb_term:
        ar=0;  dm(data_off_flag)=ar;
        rts;

{************************************************************************
*******
  Show background waveform

************************************************************************
******}
.var/dm/ram rad_pointer;
show_rad_waveform:
        ar=1;  dm(data_off_flag)=ar;
        ar=0;  dm(line_count)=ar;  dm(col_count)=ar;

#if (DEBUG == 1)
 ar=0;  dm(temp_count)=ar;
#endif
#if (DEBUG_MEM == 1)
 i4=^debug_mem;
 dm(debug_ptr)=i4;
 l4=%debug_mem;
 m4=1;
#endif
        ar=dm(data_bank);
        ar=ar-1;
        if eq jump rad_bank2;
rad_bank1:
{         i1=^raw_data1;}
 i1=^raw_copy;
        jump rad_header;
rad_bank2:
        i1=^raw_data2;
 i1=^raw_copy;

rad_header:
        ay0=dm(i1,m1);                     { pointer }
        modify(i1,m1);                     { skip wave_count }
        modify(i1,m1);                     { skip stack_size }
        ay1=dm(i1,m1);                     { length }

        ay1=WAVE_SIZE;
        i1=ay0;
        dm(rad_pointer)=ay1;
        l1=0;  m1=1;
```

```
        jump rad_newline;

rad_loop:
            ar=dm(rad_pointer);  ar=ar-1;
            if lt jump sr_done;
            dm(rad_pointer)=ar;

            ax0 = dm(i1,m1);
            ar = dm(bin_flag);
            ar = pass ar;
            if eq jump text_show;
bin_show:
            ay0 = h#00FF;
            ar = ax0 and ay0;
#if (DEBUG == 1)
 ar=dm(temp_count);
{ ar=3;}
#endif
            dm(i0,m0)=ar;
            ay0 = h#FF00;
            ar = ax0 and ay0;
            sr = lshift ar by -8 (lo);
#if (DEBUG == 1)
{ sr0=3;}
 sr0=dm(temp_count);
#endif
            dm(i0,m0)=sr0;
#if (DEBUG == 1)
 ar=sr0+1;  dm(temp_count)=ar;
#endif
            jump text_show_done;
text_show:
            call int_to_ascii_hex;
text_show_done:
{            dm(i0,m0)=32;}
            ay0=50;  ar=dm(col_count);  ar=ar+1;  dm(col_count)=ar;
            ar=ar-ay0;  if lt jump rad_loop;
            dm(i0,m0)=13;  dm(i0,m0)=10;  dm(i0,m0)=0;
            i7=^num_string;
            call sendLine;
#if (DEBUG_MEM == 1)
        i0=^num_string;  l0=0;  m0=1;
        i4=dm(debug_ptr);
        ax0=112;
        cntr=ax0;
        do debug_pm_transfer until ce;
                    ar=dm(i0,m0);
debug_pm_transfer:  pm(i4,m4)=ar;
        dm(debug_ptr)=i4;
#endif
rad_newline:
            i0=^num_string;  l0=0;  m0=1;
            dm(i0,m0)=36;   { '$' }
            dm(i0,m0)=65;   { 'A' }
            dm(i0,m0)=68;   { 'D' }
            dm(i0,m0)=48;   { '0' }
            dm(i0,m0)=119;  { 'w' }
            ar=114;  ay0=14;
            ax0=dm(bin_flag);  none=pass ax0;  if ne ar=ar-ay0;
            dm(i0,m0)=ar;   { 'r' (hex) or 'b' (binary) }
```

```
            ar=dm(line_count);  ar=ar+1;  dm(line_count)=ar;
  ar=dm(counter);
            ax0=ar;  call int_to_ascii_hex;
{            dm(i0,m0)=32;}
            ar=0;  dm(col_count)=ar;
            jump rad_loop;
sr_done:
            ar=dm(col_count);  ar=pass ar;  if eq jump rad_term;
            dm(i0,m0)=13;  dm(i0,m0)=10;  dm(i0,m0)=0;
            i7=^num_string;
            call sendLine;
rad_term:
        ar=0;  dm(data_off_flag)=ar;
        rts;


{ ****  Some Interrupt Service Routines }
{-----------------------------------------------------------------------
-------
 -
 -  SPORT interrupt handler
 -
 ----------------------------------------------------------------------
-------}
.var/dm/ram is_mem[10];
.var/ram/dm context[9];

sport_rx:
        ena sec_reg;
        dm(context)=   i0;
        dm(context+1)= m0;
        dm(context+2)= l0;
        dm(context+3)= i1;
        dm(context+4)= m1;
        dm(context+5)= l1;
#if (0)
        dm(is_mem)=ar;
        dm(is_mem+1)=ax0;
        dm(is_mem+2)=ax1;
        dm(is_mem+3)=ay0;
#endif
        ar = dm(flag_rx_no_word);
        none = pass ar;                 { check UART receive buffer by
polling in this interrupt }
        if ne jump skip_getchar;
        call get_char_ax1;
#if (0)
        none=pass ax1;  if le jump skip_getchar;
#endif
        dm(context+6)= i7;
        dm(context+7)= m7;
        dm(context+8)= l7;
        ar=dm(command_count);  ar=ar+1;  dm(command_count)=ar;
        ar=dm(command_total);  ar=ar+1;  dm(command_total)=ar;
        i7=dm(command_ptr);  l7=%command_buff;  m7=1;
        pm(i7,m7)=ax1;  dm(command_ptr)=i7;
        i7=dm(context+6);
        m7=dm(context+7);
        l7=dm(context+8);

skip_getchar:
```

```
#if (0)
 { moved down below }
        ar=dm(data_off_flag);
        ar=pass ar;
        if ne jump done_read;
#endif

        m0=0;  m1=1;
#if (FAKE_DATA == 1)
        i0=dm(fake_dptr1);  l0=%fake_data1;
        i1=dm(fake_dptr2);  l1=%fake_data2;
        ax0=dm(i0,m1);  ax1=dm(i1,m1);
        ar=-ax0;  ax1=ar;
        dm(fake_dptr1)=i0;
        dm(fake_dptr2)=i1;
#else
        ax0=dm(rx_buf+2);        /* R channel */
        ax1=dm(rx_buf+1);        /* L channel */
#endif
#if (0)
        { display ramp by multilying sample count by -16 }
        ar=dm(sample_count);
        ar=-ar;
        ay0=ar;  ar=ar+ay0;
        ay0=ar;  ar=ar+ay0;
        ay0=ar;  ar=ar+ay0;
        ay0=ar;  ar=ar+ay0;
        dm(tx_buf+1)=ar;         /* L channel */
#else
        ar=dm(ramp_val);
        dm(tx_buf+1)=ar;         /* L channel */
        ay0=dm(ramp_inc);
        ar=ar+ay0;
        dm(ramp_val)=ar;
#endif
        ar=dm(sample_count);  ay0=1;  ar=ar-ay0;
        if le jump pos_sos;
zero_sos:
        ar=0;
        dm(tx_buf+2)=ar;         /* R channel */
        jump inc_sample;
pos_sos:
        ar=32000;
        dm(tx_buf+2)=ar;         /* R channel */

inc_sample:
        ar=dm(sample_count);  ar=ar+1;  dm(sample_count)=ar;   {
increment counter }
#if (SKIP_ONE == 1)
        ay0=WAVE_SIZE+1;
#else
        ay0=WAVE_SIZE;
#endif
        ar=ar-ay0;  if lt jump read_data;
        ar=0;  dm(sample_count)=ar;
        ar=dm(ramp_start);  dm(ramp_val)=ar;

        { increment wave count }
        ax0=dm(wave_cnt);  ax1=dm(wave_cnt+1);  ay1=0;  ar=ax0+1;
        sr0=ar, ar=ax1+ay1+C;  dm(wave_cnt)=sr0;  dm(wave_cnt+1)=ar;
```

```
#if (1)
    ar=dm(data_off_flag);
    ar=pass ar;
    if ne jump skip_switch;
#endif
        { switch data banks }
        ar=dm(data_bank);
        ar=ar-1;
        if eq jump bank2;
        ar=1;
        jump set_bank;
bank2:  ar=2;
set_bank:
        dm(data_bank)=ar;
skip_switch:
#if (SKIP_ONE == 1)
        jump done_read;
#endif

read_data:
        ar=dm(data_bank);
        ar=ar-1;
        if ne jump read_bank2;

read_bank1:
        i0=dm(raw_data1);  l0=dm(raw_data1+3);
        ar=dm(raw_data1+1);  ar=ar+1;  dm(raw_data1+1)=ar;  { increment
counter }
{        ar=dm(raw_data1+2);  ar=ar+1;  dm(raw_data1+2)=ar;   increment
total }
        dm(i0,m1)=ax0;
        dm(raw_data1)=i0;               { update pointer }
        i0=dm(cal_data1);  l0=dm(cal_data1+3);
        ar=dm(cal_data1+1);  ar=ar+1;  dm(cal_data1+1)=ar;  { increment
counter }
{        ar=dm(cal_data1+2);  ar=ar+1;  dm(cal_data1+2)=ar;   increment
total }
        dm(i0,m1)=ax1;
        dm(cal_data1)=i0;               { update pointer }
        jump done_read;

read_bank2:
        i0=dm(raw_data2);  l0=dm(raw_data2+3);
        ar=dm(raw_data2+1);  ar=ar+1;  dm(raw_data2+1)=ar;  { increment
counter }
{        ar=dm(raw_data2+2);  ar=ar+1;  dm(raw_data2+2)=ar;   increment
total }
        dm(i0,m1)=ax0;
        dm(raw_data2)=i0;               { update pointer }
        i0=dm(cal_data2);  l0=dm(cal_data2+3);
        ar=dm(cal_data2+1);  ar=ar+1;  dm(cal_data2+1)=ar;  { increment
counter }
{        ar=dm(cal_data2+2);  ar=ar+1;  dm(cal_data2+2)=ar;   increment
total }
        dm(i0,m1)=ax1;
        dm(cal_data2)=i0;               { update pointer }

done_read:
#if (0)
        ar=dm(is_mem);
        ax0=dm(is_mem+1);
```

```
        ax1=dm(is_mem+2);
        ay0=dm(is_mem+3);
#endif
        i0=dm(context);
        m0=dm(context+1);
        l0=dm(context+2);
        i1=dm(context+3);
        m1=dm(context+4);
        l1=dm(context+5);
#if (SIMULATOR == 1)
        dis sec_reg;
        rts;
#else
        rti;
#endif

{**********************************************************************
*******
 IRQE ISR - Push Button Interrupt Service Routine

**********************************************************************
******}
.var/dm/ram irq_mem;

irqeisr: dm(irq_mem)=ar;
         ar=1;  dm(stop_flag)=ar;
         ar=dm(irq_mem);
         rti;

{----------------------------------------------------------------------
-------
 -
 -  transmit interrupt used for Codec initialization
 -
 ---------------------------------------------------------------------
-------}
.var/dm/ram nc_mem[3];
next_cmd:
        dm(nc_mem)=ax0;
        dm(nc_mem+1)=ay0;
        dm(nc_mem+2)=ar;

        ax0 = dm (i3, m1);           { fetch next control word and }
        dm (tx_buf) = ax0;           { place in transmit slot 0    }
        ax0 = i3;
        ay0 = ^init_cmds;
        ar = ax0 - ay0;
        if gt rti;                   { rti if more control words still
waiting }
        ax0 = 0xaf00;                { else set done flag and }
        dm (tx_buf) = ax0;           { remove MCE if done initialization
}
        ax0 = 0;
        dm (stat_flag) = ax0;        { reset status flag }

        ax0=dm(nc_mem);
        ay0=dm(nc_mem+1);
        ar=dm(nc_mem+2);
        rti;
```

```
{*************************************************************************
*******
 *  A high to low transition on flag_in signifies the start bit; it also
 *  triggers IRQ1 ISR which then turn on timer if the timer is off.
This is
 *  at to most 1/3 bit period too late but we should still catch the
byte.

*************************************************************************
******}
irq1isr:
        pop sts;
        ena timer;              { start timer now }
        rts;                    { note rts }

{-------------------------------------------------------------------------
-------
 ------------------------------------------------------------------------
-------
 ------------------------------------------------------------------------
-------
 ------------------------------------------------------------------------
-------
 ------------------------------------------------------------------------
-------}

{****************************************************************
 *  Initialize Variables                                        *
 ****************************************************************}
do_init:
        { initialize buffers }
        m0=1;  l0=0;
        m1=1;  l1=0;
        i0=^raw_data1; i1=^buff0;  ax0=WAVE_SIZE;  call buff_init;
        i0=^raw_data2; i1=^buff1;  ax0=WAVE_SIZE;  call buff_init;
        i0=^cal_data1; i1=^buff2;  ax0=WAVE_SIZE;  call buff_init;
        i0=^cal_data2; i1=^buff3;  ax0=WAVE_SIZE;  call buff_init;
        i0=^raw_copy;  i1=^buff4;  ax0=WAVE_SIZE;  call buff_init;
        i0=^bgnd_out;  i1=^buff5;  ax0=WAVE_SIZE;  call buff_init;
        i0=^bpf_out;   i1=^buff6;  ax0=WAVE_SIZE;  call buff_init;
        i0=^bpf2_out;  i1=^buff7;  ax0=WAVE_SIZE;  call buff_init;
        i0=^diff_out;  i1=^buff8;  ax0=WAVE_SIZE;  call buff_init;
        i0=^peak_out;  i1=^buff9;  ax0=WAVE_SIZE;  call buff_init;
        i0=^max_out;   i1=^out_buff1;  ax0=OUT_BUFF;  call buff_init;
        i0=^thresh_out;  i1=^out_buff2;  ax0=OUT_BUFF;  call buff_init;

        { initialize counters }
{        ar = 0;  dm(counter) = ar;}
        ar = 0;  dm(sample_count) = ar;
        dm(poll_cnt)=ar;  dm(poll_cnt+1)=ar;
        dm(wave_cnt)=ar;  dm(wave_cnt+1)=ar;

        { initialize waveform nulling structure }
        i0=^null_data; ax0=WAVE_SIZE;  ax1=dm(null_stack);  call
null_init;

        { initialize flags }
        ar=0;
        dm(stop_flag)=ar;
        dm(null_flag)=ar;
{        dm(cont_flag)=ar;}
```

```
{        dm(debug_flag)=ar;}
        dm(data_off_flag)=ar;
        dm(show_back_flag)=ar;
        dm(show_rad_flag)=ar;
        dm(command_flag)=ar;
        dm(command_letter)=ar;

        { set stack parameters }
{        ar=1;  dm(stack_size)=ar;}
        ar=dm(stack_shift);  ar=-ar;  se=ar;  si=1;  sr=lshift si (lo);
dm(stack_size)=sr0;
        ar=dm(null_shift);  ar=-ar;  se=ar;  si=1;  sr=lshift si (lo);
dm(null_stack)=sr0;
        ar=0;  dm(stack_counter)=ar;
        ar=0;  dm(stack_done)=ar;

        { set data bank pointers }
        ar=1;  dm(data_bank)=ar;
        ar=^raw_data1;
        dm(data_bank_ptr)=ar;
        ar=^cal_data1;
        dm(cal_bank_ptr)=ar;


#if (FAKE_DATA == 1)
        i0=^fake_data1;  dm(fake_dptr1)=i0;
        i0=^fake_data2;  dm(fake_dptr2)=i0;
#endif
        rts;

{****************************************************************
 *  Initialize Buffer                                            *
 * i0,m0,l0 - header to initialize                               *
 * i1,m1,l1 - buffer to initialize                               *
 * ax0 - buffer length                                           *
 * Destroys: ar,i0                                               *
 *  Structure Format: 0) pointer                                 *
 *                    1) count                                   *
 *                    2) total                                   *
 *                    3) length                                  *
 *                    (data not adjacent to header in memory)    *
 ****************************************************************}
buff_init:
        ar=i1;  dm(i0,m0)=ar;           { pointer }
        dm(i0,m0)=0;                    { count }
        dm(i0,m0)=0;                    { total }
        dm(i0,m0)=ax0;                  { length }
        ar=0;
        cntr=ax0;
        do binit_lp until ce;
binit_lp:   dm(i1,m1)=ar;
        rts;

{****************************************************************
 *  Copy Buffer                                                  *
 * i0 - input header                                             *
 * i1 - output header                                            *
 * Destroys: ax0,ay1,ar,m0,m1,l0,l1                              *
 *  Structure Format: 0) pointer                                 *
 *                    1) count                                   *
 *                    2) total                                   *
```

```
 *                  3) length                                  *
 *                  (data not adjacent to header in memory)    *
 ***************************************************************}
.var/dm/ram  bc_input_count;
.var/dm/ram  bc_input_hptr;
.var/dm/ram  bc_output_hptr;
buff_copy:
        m0=0;  m1=1;  l0=0;  l1=0;

        dm(bc_input_hptr)=i0;
        dm(bc_output_hptr)=i1;

        ax0=dm(i0,m1);                  { input pointer }
        ar=dm(i0,m0);                   { input count }
        none = pass ar;  if le rts;     { return if there is no new data
}

        dm(bc_input_count)=ar;
        dm(i0,m1)=0;                    { set input count to zero }
        modify(i0,m1);                  { skip input total }
        ar=dm(i0,m1);
        l0=ar;  i0=ax0;                 { set input buffer length,
pointer }
        ar=dm(bc_input_count);
        ar=-ar;  m1=ar;  modify(i0,m1); { rewind pointer to beginning of
data }
        m1=1;
        ar=i0;  i0=dm(bc_input_hptr);  ay1=l0;  l0=0;
        dm(i0,m0)=ar;                   { update pointer }
        i0=ar;  l0=ay1;

        ax0=dm(i1,m1);                  { output pointer }
        ar=dm(i1,m0);                   { output count }
        ay1=dm(bc_input_count);
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output count }
        ar=dm(i1,m0);                   { output total }
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output total }
        ar=dm(i1,m1);
        l1=ar;  i1=ax0;                 { set output buffer length,
pointer }

        cntr=dm(bc_input_count);
        do bcpy_lp until ce;
            ar=dm(i0,m1);
bcpy_lp:    dm(i1,m1)=ar;
        ax0=i1;
        i1=dm(bc_output_hptr);  l1=0;
        dm(i1,m1)=ax0;                  { update output pointer }
        rts;

{***************************************************************
 *  Copy into Stacking buffer                                  *
 * i0 - input header                                           *
 * i1 - output header                                          *
 * Destroys: ax0,ay1,ar,m0,m1,l0,l1                            *
 *  Structure Format: 0) pointer                               *
 *                    1) count                                 *
 *                    2) total                                 *
 *                    3) length                                *
```

```
 *                     (data not adjacent to header in memory)   *
 *****************************************************************}
.var/dm/ram  st_input_count;
.var/dm/ram  st_input_hptr;
.var/dm/ram  st_output_hptr;
buff_stack:
        m0=0;  m1=1;  l0=0;  l1=0;

        dm(st_input_hptr)=i0;
        dm(st_output_hptr)=i1;

        ax0=dm(i0,m1);                  { input pointer }
        ar=dm(i0,m0);                   { input count }
        none = pass ar;  if le rts;     { return if there is no new data
}

        dm(st_input_count)=ar;
        dm(i0,m1)=0;                    { set input count to zero }
        modify(i0,m1);                  { skip input total }
        ar=dm(i0,m1);
        l0=ar;  i0=ax0;                 { set input buffer length,
pointer }
        ar=dm(st_input_count);
        ar=-ar;  m1=ar;  modify(i0,m1); { rewind pointer to beginning of
data }
        m1=1;
        ar=i0;  i0=dm(st_input_hptr);  ay1=l0;  l0=0;
        dm(i0,m0)=ar;                   { update pointer }
        i0=ar;  l0=ay1;

        ax0=dm(i1,m1);                  { output pointer }
        modify(i1,m1);                  { skip output count }
        modify(i1,m1);                  { output total }
        ar=dm(i1,m1);                   { length }
        l1=ar;  i1=ax0;                 { set output buffer length,
pointer }

        ar=dm(stack_counter);
        ar=pass ar;
        if ne jump do_stack;
do_first:
        se=dm(stack_shift);
        cntr=dm(st_input_count);
        do stcpy_lp until ce;
            si=dm(i0,m1);
            sr=ashift si (lo);
stcpy_lp:   dm(i1,m1)=sr0;
        jump stack_cleanup;
do_stack:
        se=dm(stack_shift);
        cntr=dm(st_input_count);
        do stadd_lp until ce;
            ay0=dm(i1,m0);
            si=dm(i0,m1);
            sr=ashift si (lo);
            ar=sr0+ay0;
stadd_lp:   dm(i1,m1)=ar;
stack_cleanup:
        ax0=i1;
        i1=dm(st_output_hptr);  l1=0;
        dm(i1,m1)=ax0;                  { update output pointer }
```

```
        ar=0;  dm(stack_done)=ar;
        ar=dm(stack_counter);  ar=ar+1;  dm(stack_counter)=ar;
        ay0=dm(stack_size);
        ar=ar-ay0;
        if lt rts;
        ar=1;  dm(stack_done)=ar;
        ar=0;  dm(stack_counter)=ar;
        i1=dm(st_output_hptr);
        ax0=dm(i1,m1);                  { output pointer }
        ar=dm(i1,m0);                   { output count }
        ay1=dm(st_input_count);
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output count }
        ar=dm(i1,m0);                   { output total }
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output total }
        rts;

{****************************************************************
 *  Initialize Nulling Structure                                *
 * i0,m0,l0 - waveform structure to initialize                  *
 * ax0 - waveform size                                          *
 * ax1 - stack size                                             *
 * Destroys: ar,i0                                              *
 *  Structure Format: 0) wave_size                              *
 *                    1) wave_count                             *
 *                    2) stack_size                             *
 *                    3) waveform vector                        *
 ****************************************************************}
null_init:
        dm(i0,m0)=ax0;                  { waveform size }
        dm(i0,m0)=-1;                   { waveform count }
        dm(i0,m0)=ax1;                  { stack_size }
#if (SIMULATOR == 1)
        cntr=ax0;
        do nclr_lp until ce;
nclr_lp:    dm(i0,m0)=0;
#endif
        rts;

{****************************************************************
 *  Update background nulling waveform                          *
 * i0 - input data                                              *
 * i1 - waveform nulling structure                              *
 * Destroys: ax0,ay1,ar,m0,m1,l0,l1                             *
 *  Data structure format:                                      *
 *                    0) pointer                                *
 *                    1) count                                  *
 *                    2) total                                  *
 *                    3) length                                 *
 *                    (data not adjacent to header in memory)   *
 *  Nulling structure format:                                   *
 *                    0) wave_size                              *
 *                    1) wave_count                             *
 *                    2) stack_size                             *
 *                    3) waveform vector                        *
 ****************************************************************}
.var/dm/ram n_input_hptr;       { input header pointer }
.var/dm/ram n_wave_size;
.var/dm/ram n_count;
```

```
.var/dm/ram n_stack_size;
.var/dm/ram n_wave_ptr;
.var/dm/ram n_null_hptr;

update_null:
        ar=dm(null_flag);  ar=pass ar;
        if eq rts;

        m0=0;  m1=1;  l0=0;  l1=0;

        dm(n_input_hptr)=i0;
        dm(n_null_hptr)=i1;
        ay1=dm(i1,m1);                    { wave_size }
        ax0=dm(i0,m1);                    { input pointer }
        ar=dm(i0,m1);                     { input count }
        ar=ar-ay1;
        if lt rts;

        modify(i0,m1);                    { skip input total }
        ar=dm(i0,m1);
        l0=ar;  i0=ax0;                   { set input buffer length,
pointer }
        ar=-ay1;  m1=ar;  modify(i0,m1); { rewind pointer to beginning
of data }
        m1=1;

        { save waveform structure header }
        dm(n_wave_size)=ay1;
        ar=dm(i1,m1);  dm(n_count)=ar;
        ar=dm(i1,m1);  dm(n_stack_size)=ar;
        dm(n_wave_ptr)=i1;

        { clear waveform if n_count is negative }
        ar=dm(n_count);  ar=pass ar;
        if ge jump n_dosum;
        ax0=0;
        cntr=dm(n_wave_size);
        do nz_lp until ce;
nz_lp:      dm(i1,m1)=ax0;
        ar=0;  dm(n_count)=ar;

n_dosum:
        ar=dm(n_count);  ar=ar+1;  dm(n_count)=ar;

        { sum current waveform with data in waveform structure }
        i1=dm(n_wave_ptr);
        se=dm(null_shift);
        cntr=dm(n_wave_size);
        do ns_lp until ce;
            ay0=dm(i1,m0);
            si=dm(i0,m1);
            sr=ashift si (lo);
            ar=sr0+ay0;
ns_lp:      dm(i1,m1)=ar;
        i1=dm(n_null_hptr);  ay1=l1;  l1=0;
        modify(i1,m1);                    { skip wave_size }
        ar=dm(n_count);  dm(i1,m1)=ar;  { update wave_count }
        ay1=dm(n_stack_size);
        ar=ar-ay1;  if lt rts;

#if (0)
```

```
        { check if it is time to divide summed waveform }
        ar=dm(n_count);  ay1=dm(n_stack_size);
        ar=ar-ay1;  if lt rts;
        i1=dm(n_wave_ptr);
        se=dm(null_shift);
        cntr=dm(n_wave_size);
        do nd_lp until ce;
            si=dm(i1,m0);
            sr = ashift si (lo);
nd_lp:      dm(i1,m1)=sr0;
#endif
        ar=0;  dm(null_flag)=ar;
        i1=dm(n_null_hptr);  l1=0;
        modify(i1,m1);                  { skip wave_size }
        dm(i1,m1)=-1;                   { set wave_count to -1 }
        rts;

{*****************************************************************
 *  Subtract background (nulling) waveform                      *
 * i0 - data to be nulled                                       *
 * i1 - waveform nulling structure                              *
 * Destroys: ax0,ay1,ar,m0,m1,l0,l1                             *
 *  Data structure format:                                      *
 *                  0) pointer                                  *
 *                  1) count                                    *
 *                  2) total                                    *
 *                  3) length                                   *
 *                  (data not adjacent to header in memory)     *
 *  Nulling structure format:                                   *
 *                  0) wave_size                                *
 *                  1) wave_count                               *
 *                  2) stack_size                               *
 *                  3) waveform vector                          *
 *****************************************************************}
sub_background:
        m0=0;  m1=1;  l0=0;  l1=0;

        { make sure that data count is greater than or equal to wave
size }
        ay1=dm(i1,m1);                  { wave_size }
        ax0=dm(i0,m1);                  { skip pointer }
        ar=dm(i0,m1);                   { data count }
        ar=ar-ay1;
        if lt rts;
        modify(i1,m1);                  { skip wave_count }
        modify(i1,m1);                  { skip stack_size }

        modify(i0,m1);                  { skip total }
        ar=dm(i0,m1);                   { buffer length }
        l0=ar;  i0=ax0;

        cntr=ay1;
        do sb_lp until ce;
            ax0=dm(i0,m0);
            ay1=dm(i1,m1);
            ar=ax0-ay1;
sb_lp:      dm(i0,m1)=ar;
        rts;

{*****************************************************************
 *  Decimation FIR filter                                       *
```

```
 * i0 - data to be filtered                                           *
 * i1 - output buffer                                                 *
 * i4 - filter structure                                              *
 * Destroys: ax0,ay0,ar,m0,m1,m3,m4,l0,l1,l4                          *
 *           mr,mx1,my1,i7,l7,m7                                      *
 *  Data structure format:                                            *
 *                    0) pointer                                      *
 *                    1) count                                        *
 *                    2) total                                        *
 *                    3) length                                       *
 *                    (data not adjacent to header in memory)         *
 *  Nulling structure format:                                         *
 *                    0) length                                       *
 *                    1) dec_factor                                   *
 *                    2) group_delay                                  *
 *                    3) coefficient vector                           *
 ****************************************************************}
{ ** --------------------- FIR Decimation Filter }
{ Paramters:
        Filter Length:          AX0
        Decimation Factor:      AX1
        New Inputs:             AY0
        Input Buffer:           I0,L0
        Filter Coefficients:    I4
  Returns:
        i1                      new output buffer pointer
}
.var/dm/ram  f_fil_start;
.var/dm/ram  f_input_count;
.var/dm/ram  f_input_hptr;
.var/dm/ram  f_output_hptr;
.var/dm/ram  f_group_delay;
fir_dec:
        m0=0;  m1=1;  l0=0;  l1=0;

        dm(f_input_hptr)=i0;
        ax0=dm(i0,m1);                  { input pointer }
        ar=dm(i0,m0);                   { input count }
        none = pass ar;  if le rts;     { return if there is no new data
}
        dm(f_input_count)=ar;
        dm(i0,m1)=0;                    { set input count to zero }
        modify(i0,m1);                  { skip input total }
        ar=dm(i0,m1);
        l0=ar;  i0=ax0;                 { set input buffer length,
pointer }
        ar=dm(f_input_count);
        ar=-ar;  m1=ar;  modify(i0,m1); { rewind pointer to beginning of
data }
        m1=1;
        ar=i0;  i0=dm(f_input_hptr);  ay0=l0;  l0=0;
        dm(i0,m0)=ar;                   { update pointer }
        i0=ar;  l0=ay0;

        dm(f_output_hptr)=i1;
        ax0=dm(i1,m1);                  { output pointer }
        ar=dm(i1,m0);                   { output count }
        ay1=dm(f_input_count);
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output count }
        ar=dm(i1,m0);                   { output total }
```

```
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output total }
        ar=dm(i1,m1);
        l1=ar;  i1=ax0;                 { set output buffer length,
pointer }

        l4=0;  m4=1;
        ax0=pm(i4,m4);                  { filter length }
        ax1=pm(i4,m4);                  { dec_factor }
        ar=pm(i4,m4);                   { group_delay }
        dm(f_group_delay)=ar;
        m4=ax0;
        modify(i4,m4);  m4=-1;  modify(i4,m4);
        dm(f_fil_start)=i4;

        AR = ax0-1;
        AR = -AR;
        ay0 = dm(f_group_delay);
        ar = ar + ay0;
        M3 = AR;
        MODIFY(I0,M3);
        I7 = I0;                { store starting position }
        L7 = L0;
        M7 = ax1;
        CNTR = dm(f_input_count);
        DO dat_dlp UNTIL CE;
          I0 = I7;              { start of data }
          I4 = dm(f_fil_start); { start of filter coefficients }
          MR = 0;
          MX1=DM(I0,M1), MY1=PM(I4,M4);
          CNTR = AX0;
          DO fir_dlp UNTIL CE;
fir_dlp:    MR = MR + MX1*MY1 (ss), MX1=DM(I0,M1), MY1=PM(I4,M4);
          MR = MR (RND);
          DM(I1,M1)=MR1;
dat_dlp:  MODIFY(I7,M7);
        ar=i1;  i1=dm(f_output_hptr);  l1=0;
        dm(i1,m1)=ar;                   { update output pointer }
        RTS;

{*****************************************************************
 *  Locate peaks in zero-crossing data                            *
 * i0 - input header                                              *
 * i1 - output header                                             *
 * i2 - data header                                               *
 * Destroys: ax0,ay1,ar,mr0,m0,m1,l0,l1                           *
 *  Structure Format: 0) pointer                                  *
 *                    1) count                                    *
 *                    2) total                                    *
 *                    3) length                                   *
 *                    (data not adjacent to header in memory)     *
 *****************************************************************}
.var/dm/ram  lp_input_count;
.var/dm/ram  lp_input_hptr;
.var/dm/ram  lp_output_hptr;
loc_peaks:
        m0=0;  m1=1;  l0=0;  l1=0;  l2=0;

        dm(lp_input_hptr)=i0;
        dm(lp_output_hptr)=i1;
```

```
        ax0=dm(i0,m1);                  { input pointer }
        ar=dm(i0,m0);                   { input count }
        dm(lp_input_count)=ar;
        dm(i0,m1)=0;                    { set input count to zero }
        modify(i0,m1);                  { skip input total }
        ar=dm(i0,m1);
        l0=ar;  i0=ax0;                 { set input buffer length,
pointer }
        ar=dm(lp_input_count);
        ar=-ar;  m1=ar;  modify(i0,m1); { rewind pointer to beginning of
data }
        m1=1;
        ar=i0;  i0=dm(lp_input_hptr);  ay1=l0;  l0=0;
        dm(i0,m0)=ar;                   { update pointer }
        i0=ar;  l0=ay1;

        ax0=dm(i1,m1);                  { output pointer }
        ar=dm(i1,m0);                   { output count }
        ay1=dm(lp_input_count);
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output count }
        ar=dm(i1,m0);                   { output total }
        ar=ar+ay1;
        dm(i1,m1)=ar;                   { increment output total }
        ar=dm(i1,m1);
        l1=ar;  i1=ax0;                 { set output buffer length,
pointer }

        ax0=dm(i2,m1);                  { data pointer }
        modify(i2,m1);                  { skip count }
        modify(i2,m1);                  { skip total }
        ar=dm(i2,m1);  l2=ar;  i2=ax0;  { set data buffer length,
pointer }

        ar=dm(lp_input_count);  ar=ar-1;
        ay1=dm(i0,m1);  modify(i2,m1);  dm(i1,m1)=0;
loc_lp:     mr0=dm(i2,m1);              { get data value }
            ax0=dm(i0,m1);              { get current difference
filtered value }
            none=pass ay1;
            if gt jump pos_check;
 neg_check:                             { case: check for -ve/0 to +ve }
                none=pass ax0;
                if gt jump store_lp;
                mr0=0;
                jump store_lp;
 pos_check:                             { case: check for +ve to -ve/0 }
                none=pass ax0;
                if le jump store_lp;
                mr0=0;
 store_lp:
            dm(i1,m1)=mr0;
            ay1=ax0;                    { current value is used in next
iteration }
            ar=ar-1;
        if gt jump loc_lp;
        ax0=i1;
        i1=dm(lp_output_hptr);  l1=0;
        dm(i1,m1)=ax0;                  { update output pointer }
        rts;
```

```
{*****************************************************************
 *  Find max and threshold values in buffer                      *
 * i0 - input header                                             *
 * i1 - output header                                            *
 * ax0 - threshold                                               *
 * Destroys: ax0,ax1,ay0,ay1,ar,m0,m1,l0,l1                      *
 *  Structure Format: 0) pointer                                 *
 *                    1) count                                   *
 *                    2) total                                   *
 *                    3) length                                  *
 *                    (data not adjacent to header in memory)    *
 *****************************************************************}
.var/dm/ram  fm_input_count;
.var/dm/ram  fm_input_hptr;
.var/dm/ram  fm_output_hptr;
.var/dm/ram  fm_threshold;
.var/dm/ram  fm_skip;
.var/dm/ram  fm_max_val;
.var/dm/ram  fm_max_index;
.var/dm/ram  fm_thresh_val;
.var/dm/ram  fm_thresh_index;
find_max_and_thresh:
        m0=0;  m1=1;  l0=0;  l1=0;

        dm(fm_threshold)=ax0;
        dm(fm_skip)=ax1;
        dm(fm_input_hptr)=i0;
        dm(fm_output_hptr)=i1;

        ax0=dm(i0,m1);                  { input pointer }
        ar=dm(i0,m0);                   { input count }
        none = pass ar;  if le rts;     { return if there is no new data
}

        dm(fm_input_count)=ar;
        ay0=dm(fm_skip);  ar=ar-ay0;  dm(fm_input_count)=ar;

        dm(i0,m1)=0;                    { set input count to zero }
        modify(i0,m1);                  { skip input total }
        ar=dm(i0,m1);
        l0=ar;  i0=ax0;                 { set input buffer length,
pointer }
        ar=dm(fm_input_count);
        ar=-ar;  m1=ar;  modify(i0,m1); { rewind pointer to beginning of
data }
        m1=1;
        ar=i0;  i0=dm(fm_input_hptr);  ay1=l0;  l0=0;
        i0=ar;  l0=ay1;

        ax0=dm(i1,m1);                  { output pointer }
        ar=dm(i1,m0);                   { output count }
        ay1=dm(fm_input_count);
        ar=ar+1;
        dm(i1,m1)=ar;                   { increment output count }
        ar=dm(i1,m0);                   { output total }
        ar=ar+1;
        dm(i1,m1)=ar;                   { increment output total }
        ar=dm(i1,m1);
        l1=ar;  i1=ax0;                 { set output buffer length,
pointer }
```

```
        ay0=dm(fm_threshold);
#if (1)
        ar=0;  dm(fm_max_index)=ar;  dm(fm_max_val)=ar;  ay1=ar;
        dm(fm_thresh_val)=ar;  dm(fm_thresh_index)=ar;
        ax1=dm(fm_input_count);
#else
        ay0=dm(fm_threshold);
        ax0=dm(i0,m1);  ar=abs ax0;  ay1=ar;
        dm(fm_max_index)=ar;
        ax0=0;  dm(fm_thresh_val)=ax0;
        dm(fm_thresh_index)=ar;
        ar=dm(fm_input_count);
        ar=ar-1;
        ax1=ar;
        dm(fm_max_val)=ay1;
#endif
fm_lp:
            ax0=dm(i0,m1);
{            ar=abs ax0;}
            ar=-ax0;
            if le jump fm_next;
            none=ar-ay1;
            if le jump thresh_check;
                dm(fm_max_index)=ax1;    { save biased index }
                dm(fm_max_val) = ax0;    { save max value }
                ay1=ar;
 thresh_check:
            ar=dm(fm_thresh_val);
            none=pass ar;
            if ne jump fm_next;          { skip threshold check if peak
already found }
{            ar=abs ax0;}
            ar=-ax0;
            if le jump fm_next;
            none=ar-ay0;
            if lt jump fm_next;
                dm(fm_thresh_index)=ax1; { save biased index }
                dm(fm_thresh_val)=ax0;    { save threshold peak value }
 fm_next:
            ar=ax1-1;
            ax1=ar;
        if gt jump fm_lp;
        ay1=dm(fm_max_index);  ar=dm(fm_input_count);
        ar=ar-ay1;                       { unbias max index }
        ay0=dm(fm_skip);  ar=ar+ay0;
        dm(fm_max_index)=ar;
        ay1=dm(fm_thresh_index);  ar=dm(fm_input_count);
        ar=ar-ay1;                       { unbias thresh index }
        ay0=dm(fm_skip);  ar=ar+ay0;
        dm(fm_thresh_index)=ar;

        ax0=i1;
        i1=dm(fm_output_hptr);  l1=0;
        dm(i1,m1)=ax0;                   { update output pointer }
        rts;


{*****************************************************************
 *  Integer to ASCII hex string conversion                       *
 * i0,m0,l0 - output buffer                                      *
```

```
 * ax1,ax0 - number to convert                                  *
 ****************************************************************}
.var/dm/ram input[2];
num_to_hex:
        dm(input)=ax1;
        dm(input+1)=ax0;
{        ar=48;  dm(i0,m0)=ar;  dm(i0,m0)=ar; }
        ax0=dm(input);
        call int_to_ascii_hex;
{        ar=dm(digit);    dm(i0,m0)=ar;
        ar=dm(digit+1);  dm(i0,m0)=ar;
        ar=dm(digit+2);  dm(i0,m0)=ar;
        ar=dm(digit+3);  dm(i0,m0)=ar;}
        ax0=dm(input+1);
        call int_to_ascii_hex;
{        ar=dm(digit);    dm(i0,m0)=ar;
        ar=dm(digit+1);  dm(i0,m0)=ar;
        ar=dm(digit+2);  dm(i0,m0)=ar;
        ar=dm(digit+3);  dm(i0,m0)=ar; }
        rts;

.var/dm/ram digit[4];
int_to_ascii_hex:
        mr0=ax0;
        sr=lshift mr0 by -12 (lo);
        call digit_to_hex;
        dm(i0,m0)=ar;                           { hex digit 3 }
        ay0=0x0F00;  ar=ax0 and ay0;
        sr=lshift ar by -8 (lo);
        call digit_to_hex;
        dm(i0,m0)=ar;                           { hex digit 2 }
        ay0=0x00F0;  ar=ax0 and ay0;
        sr=lshift ar by -4 (lo);
        call digit_to_hex;
        dm(i0,m0)=ar;                           { hex digit 1 }
        ay0=0x000F;  ar=ax0 and ay0;
        sr0=ar;
        call digit_to_hex;
        dm(i0,m0)=ar;                           { hex digit 0 }
        rts;

{ Input: sr0,  Output: ar }
digit_to_hex:
        ay0=0xA;  ar=sr0-ay0;  if ge jump letter_digit;
        ay0=48;  ar=sr0+ay0;  rts;
letter_digit:
        ay0=55;  ar=sr0+ay0;  rts;

{****************************************************************
 *  Fixed-Point number to ASCII string conversion               *
 *   - assumes the input is 32 bits with 20 bits for integer    *
 *     and 12 bits for the fractional component                 *
 *   - the output is 999999.999 if there's an overflow          *
 * i0,m0,l0 - output buffer                                     *
 * ax1,ax0 - MSW,LSW of number to convert                       *
 * ay0 - round off factor to add to number                      *
 ****************************************************************}
.var/dm/ram  round_fac;
.var/dm/ram  start_n2a;
.var/dm/ram  fac_n2a[2];
.init fac_n2a: 0x006, 0x4000;
```

```
.var/dm/ram digit_n2a;
.var/dm/ram dig_index_n2a;
num_to_ascii:
        ay1=0;
 ay0=0;
        ar=ax0+ay0;
        mr0=ar, ar=ax1+ay1+c;
        ax1=ar;  ax0=mr0;
        ar=-1; dm(digit_n2a)=ar;
        ar=0;  dm(dig_index_n2a)=ar;
        dm(start_n2a)=i0;                { save start - used by n2a_bad
}

        { Subtract y (ay1,ay0) from x (ax1,ax0) }
n2a_s:  ar=0;
        af=pass ax1;
        if lt ar=ar+1;
        mr0=ar;                          { mr0 is used to flag MS bit }
        ay1=dm(fac_n2a);  ay0=dm(fac_n2a+1);
        ar=ax0-ay0;
        ax0=ar, ar=ax1-ay1+c-1;
        ax1=ar;
        ar=dm(digit_n2a);  ar=ar+1;  dm(digit_n2a)=ar;

        ar=pass ax1;
        if ge jump n2a_s;
        ar=pass mr0;  if ne jump n2a_s;  { flag check }

        { Got digit in digit_n2a now, increment digit index }
        ar=dm(dig_index_n2a);  ar=ar+1;  dm(dig_index_n2a)=ar;

        { Check to see if digit > 9 }
        ar=dm(digit_n2a);  ay0=9;  ar=ar-ay0;  if gt jump n2a_bad;

        { Save digit}
        ar=dm(digit_n2a);  ay0=48;  ar=ar+ay0;  dm(i0,m0)=ar;

        ar=dm(dig_index_n2a);  ay0=6;  ar=ar-ay0;
        if ge jump n2a_done;        { Done last digit? }
        ar=dm(dig_index_n2a);  ay0=3;  ar=ar-ay0;
        if ne jump n2a_no_dec;      { Reached decimal point? }
        ar=46;  dm(i0,m0)=ar;       { Insert decimal point }
        jump n2a_no_dec;
n2a_no_dec:
        { Reset digit }
        ar=-1; dm(digit_n2a)=ar;

        { Update ax1, ax0 for next digit by finding remainder and
          multiplying by 10 }
        ay1=dm(fac_n2a);  ay0=dm(fac_n2a+1);
        ar=ax0+ay0;
        mx0=ar, ar=ax1+ay1+c;
        mx1=ar;                     { remainder is in mx1,mx0 now }
        my0=5;
        { Do multiply }
        mr=mx0*my0 (uu);
        ax0=mr0;
        mr0=mr1;  mr1=mr2;
        mr=mr+mx1*my0 (uu);
        ax1=mr0;
```

```
        jump n2a_s;
n2a_done:
        rts;

        { set to 999.999 for overflow }
n2a_bad:i0=dm(start_n2a);
        ar=9+48;
        dm(i0,m0)=ar; dm(i0,m0)=ar; dm(i0,m0)=ar;
        ar=46;  dm(i0,m0)=ar;  ar=9+48;
        dm(i0,m0)=ar; dm(i0,m0)=ar; dm(i0,m0)=ar;
        rts;
.endmod;
```