UNITED STATES DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY

Benthic Acoustic Stress Sensor (BASS): **Electronics Check-Out Procedures**

December 9, 1994

by
Marinna A. Martini, U.S. Geological Survey, Woods Hole, MA 02543
Albert Williams III, Woods Hole Oceanographic Institution, Woods Hole, MA 02543

U.S. Geological Survey Open File Report OF-93-722

Use of trade names is for the purposes of identification only and does not constitute any endorsement by the USGS.

Contents

Forward

The following is a series of test and calibration procedures for the Oceanographic Instrument Systems (OIS) Benthic Acoustic Stress Sensor (BASS). Although these procedures were written for a BASS system with a Tattletale 4 microcomputer, they should generally apply to those BASS systems with Tattletale Model 5 microcomputers.

Please send any comments or corrections to Marinna Martini at the U.S. Geological Survey, mmartini@usgs.gov, or to the address on the cover of this report.

List of Abbreviations

CCW	counter clockwise
div	division
DT-V	differential time-voltage (circuit board)
m	meters
ma, mA	milliamps
MHz	megahertz
ms	milliseconds
mv, mV	millivolts
ns	nanoseconds
pf	picofarads
p-p	peak to peak
s	seconds
V, v	volts
VDC	volts, direct current
μs	microseconds

I. Summary

The procedures described here are presented so that a technician with limited experience with BASS can perform basic tests which, when executed properly, should be a thorough evaluation of the health of the system. This is not intended as an in depth explanation of how BASS works. Should any significant problems be found, it is suggested that you contact the manufacturer, Oceanographic Instrument Systems, North Falmouth, MA. The Tattletale controller is manufactured by the Onset Computer Corporation, Cataumet, MA.

II. Recommended Test Equipment

The following equipment was used to perform the electronics evaluations described in this report. Models used at USGS test facility are given as examples other equipment with the same specifications may be substituted:

1. Hewlett Packard Model 54601A 100MHz Oscilloscope:
   Featuring four channel inputs, delay time and memory for trace storage and recall. This scope does not have a separate, external trigger input.
2. Tektronix Model 7613 Oscilloscope:
   Featuring two channel inputs, delay time, store and external trigger input.
3. BASS sensor pod, submerged in water
4. Extender board
5. 21 VDC, 1.5 amp Power supply
6. Computer with one RS232 serial port free
7. Onset's TattleTools or other terminal emulation software.
8. BASS Schematics
9. Data Precision Model 3500 4 1/2 digit volt-ohmmeter
10. Onset TC-4 RS232 communications cable
11. Tektronix AM503 Current Probe amplifier with model P6302 probe
12. Oceanographic Instrumentation Systems (OIS) nanosecond delay test unit
13. Capacitance meter

The author has used a number of terminal emulation software packages to communicate with Tattletales rather than the TattleTools software provided by Onset. These procedures, therefore, have been written for use with any terminal emulation software.

III. Procedures

1. **Set up the hardware**: Place the BASS on a test bench so that the front and back of the electronics are accessible. Supply +21 VDC to pin 3 of the microcomputer board of the BASS. Connecting an ammeter in series with the power supply is recommended to make later measurements more convenient. Settings for a current probe are also provided.

   Plug a BASS pod which has been submerged in water into the end cap. It is recommended that these tests be done with the actual pods to be used in an upcoming deployment. The voltage and current drain levels indicated are only a guide. A record of typical behavior should be maintained for each BASS system.

2. **Set up communications with the BASS system's Tattletale 4**: Connect the TC-4 RS232 cable to the Tattletale 4 on the microcomputer board. Communications should be set to 9600 BAUD, 1 stop bit, no parity and 8 data bits. Verify that the correct port has been selected. Turn on the power supply. If no program is loaded, the BASS should respond with something similar to:

```
TATTLETALE MODEL #4

S/N 0
(C) 1989 ONSET COMPUTER CORP.

TTBASIC 2.23

OK
>
```

   Appendix C on page 32 is a listing of an example BASS program (in Onset's TTBASIC) which will display data and sample at 1 second intervals. Follow the procedures in your communications software for clearing the Tattletale's memory and uploading the ASCII text program code.

   If a BASS program exists in the Tattletale's memory when the power is turned on, the output will look like the following:

```
000000000000000000000000000000000000000000000000
007351007354007355A007371007389007 3E30073BA0073770073E9
```

   Using the example program in Appendix C, data output will look similar to the following:

00:02	FFE8 FFDA 000E FFEE	8000 8000 8000 8000
00:03	FFE3 FFDA 0006 FFEE	8000 8000 8000 8000
00:03	FFE6 FFD8 0007 FFEC	8000 8000 8000 8000
00:03	FFE6 FFDC 0010 FFE9	8000 8000 8000 8000

If none of the above sample output occurs on power up, check connections and terminal emulator set up.

3. **Check 21 v battery power**: Pin 3 on the microcomputer board should be at the setting for the power supply being used, between +12 and +21 v.

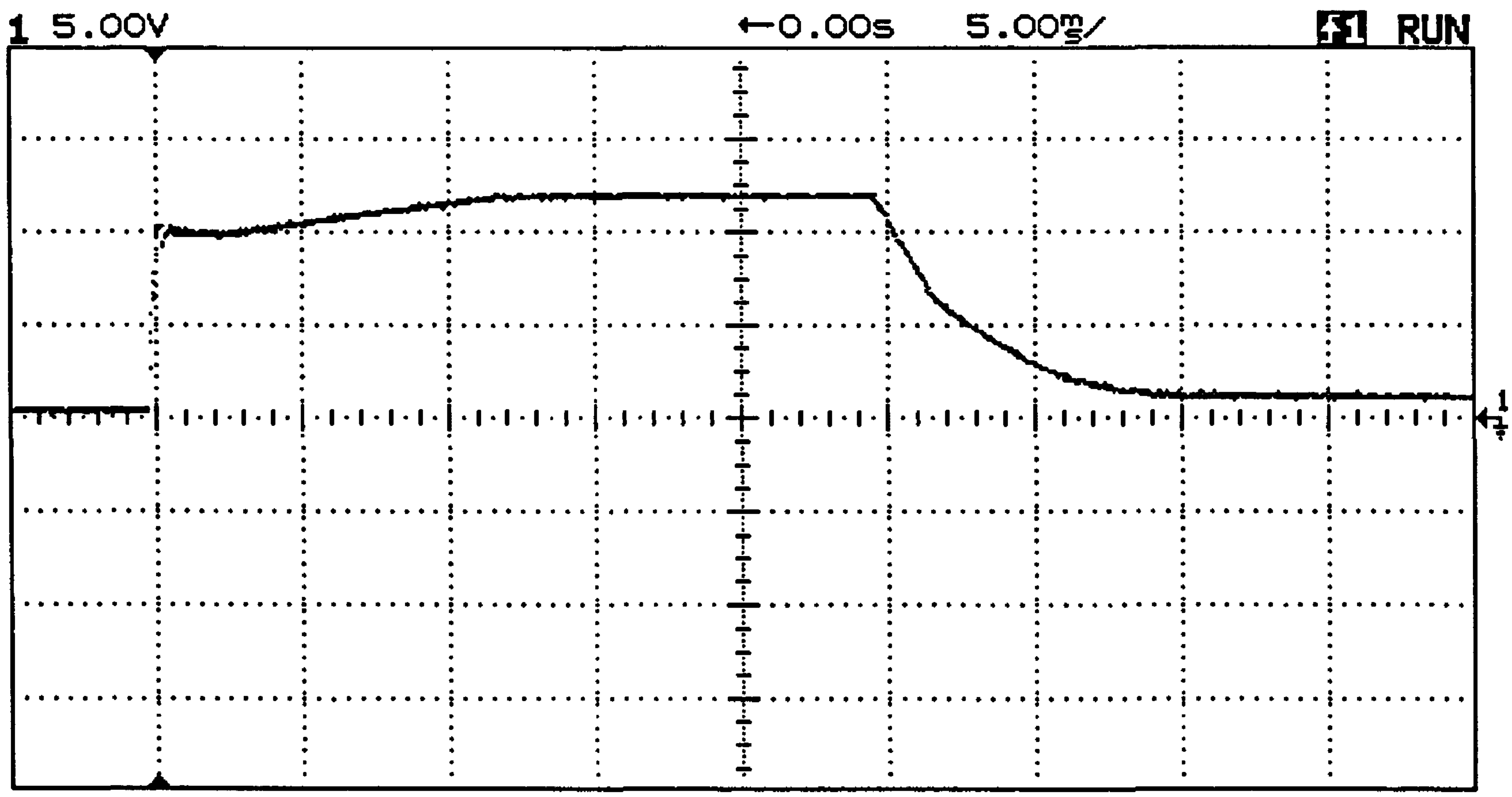
4. **Quiescent current**: This check should be made without any software programs running in the BASS. Type ^C to stop any programs. The BASS should respond with **OK >**. Connect an ammeter in series with the power supplied to pin 3 on the microcomputer board. The current drain is typically 6.4 ma.

5. **Start BASS sampling**: The rest of the checks will be made while the instrument is sampling. Type **RUN** to start the BASS program. One second BASS sample output should scroll by on the screen.

6. **Check 5 v regulated power**: With the power supply on, pin 2 on the microcomputer board should be +5.0 volts.

7. 12 V Switched Power

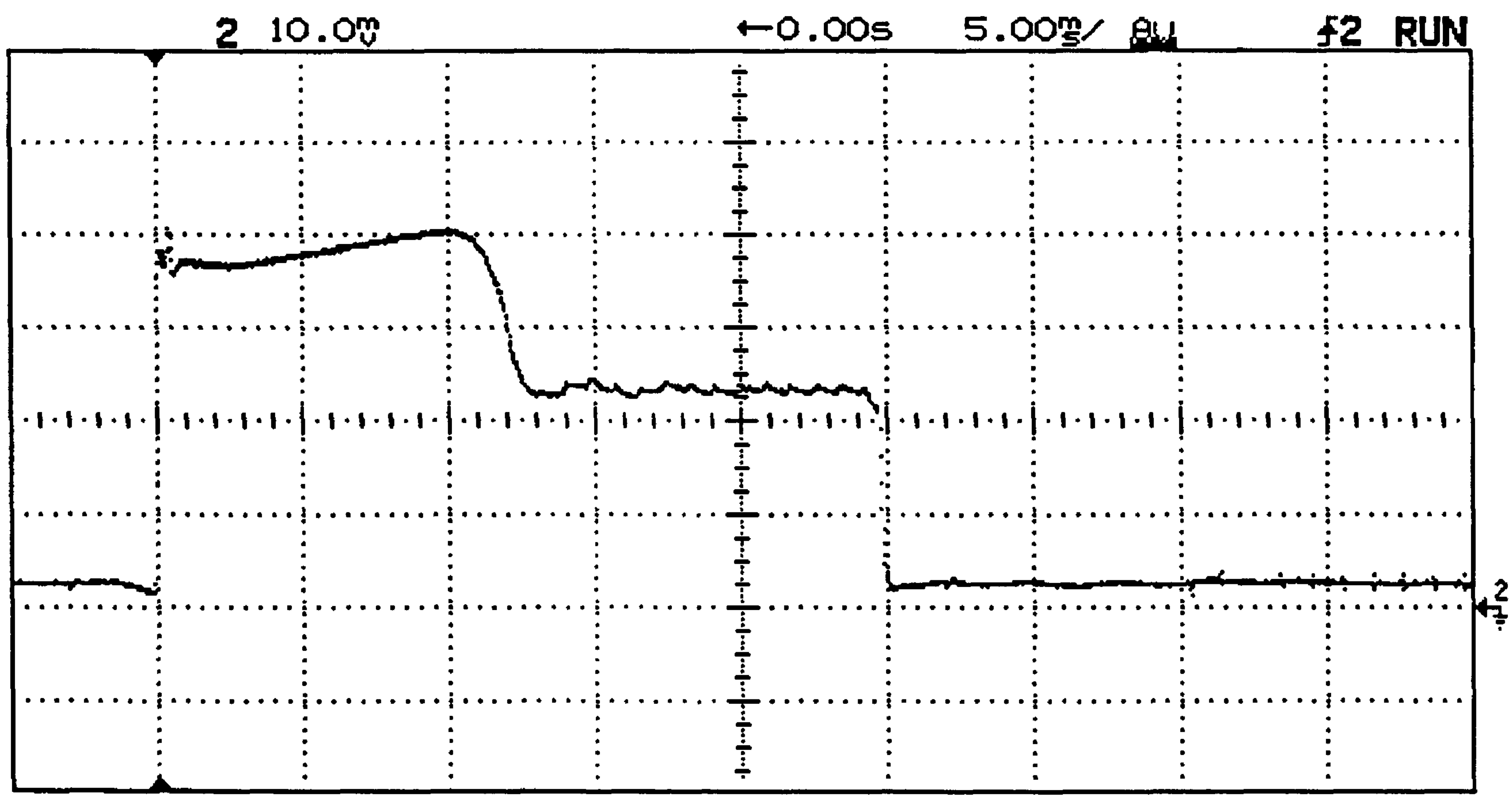
Input to CH1: 12 v switched power line, pin 34 on the microcomputer board
Input to CH2: none
Current probe: none
Sweep: 5 ms/div
CH1 setting: 5 v/div
CH2 setting: n/a
Trigger: CH1, normal
Trigger slope: positive
Trigger level: 8.5 v recommended
Current probe setting: n/a



Voltage should peak at 12 v and last for 25 ms. The 2 v, 10 ms droop is a result of charging the -12 v reference. This regulator is switched on each time BASS makes a measurement. The frequency of this signal should therefore correspond to the BASS sampling frequency.

8. BASS Sampling Current Drain

Input to CH1:	none
Input to CH2:	current probe output
Current probe:	BASS system power lead, pin 3 of microcomputer board
Sweep:	5 ms/div
CH1 setting:	n/a
CH2 setting:	10 mv/div or appropriate for current probe
Trigger:	CH2, normal
Trigger slope:	positive
Trigger level:	as required
Current Probe setting:	50 ma/div
Averaging or store:	on



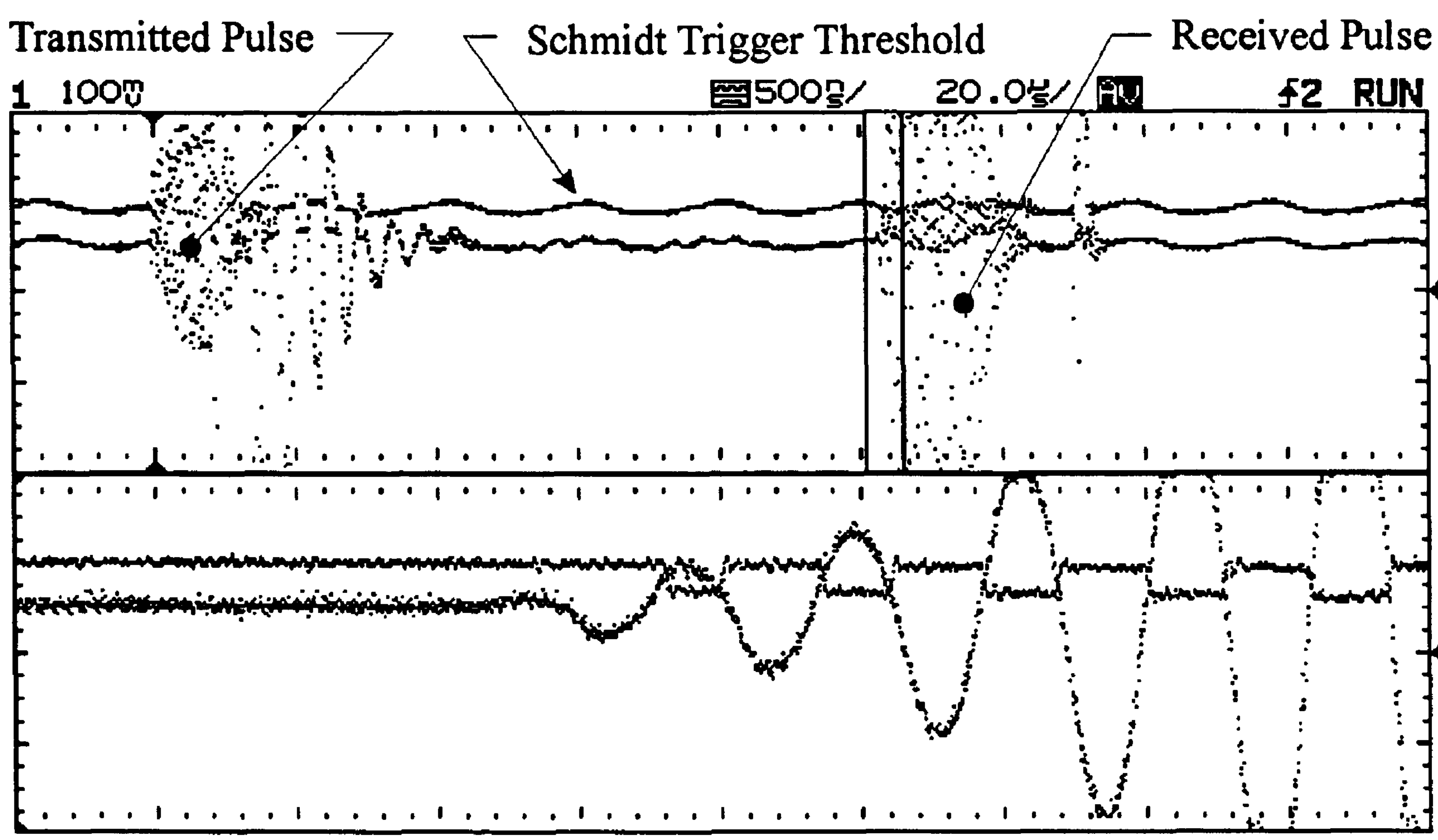
The figure shows the current drawn by the BASS at the beginning of a sampling cycle. The base current drain is 12.5 ma with a primary peak of 200 ma for 12 ms and a secondary peak of 115 ma for 13 ms. Note that the DC offset was removed from the current probe before making these measurements.

9. Received Signal & Schmidt Trigger

Input to CH1: Received signal: pin 1 on either LM161 op-amp on the DT-V board
Schmidt trigger: pin 2 on either LM161 op-amp on the DT-V board
The LM161's are near the 35 pin connector at the edge of the receiver DT-V board. Pin 1 is the first pin in the CCW direction from the metal tab (which marks pin 10), looking at the top of the board.

Input to CH2: output from xmit/rec board for respective axes
A: pins 22 or 25, B: pins 18 or 21, C: pins 14 or 17, D: pins 10 or 13

Current probe: n/a
Sweep: 20 µs/div
CH1 setting: 100 mv/div
CH2 setting: 2 v/div
Trigger: CH2, normal
Trigger slope: positive
Trigger level: 2 v
Current Probe setting: n/a
Averaging or store: on
Delay: ≈100 µs at 500 ns/div sweep



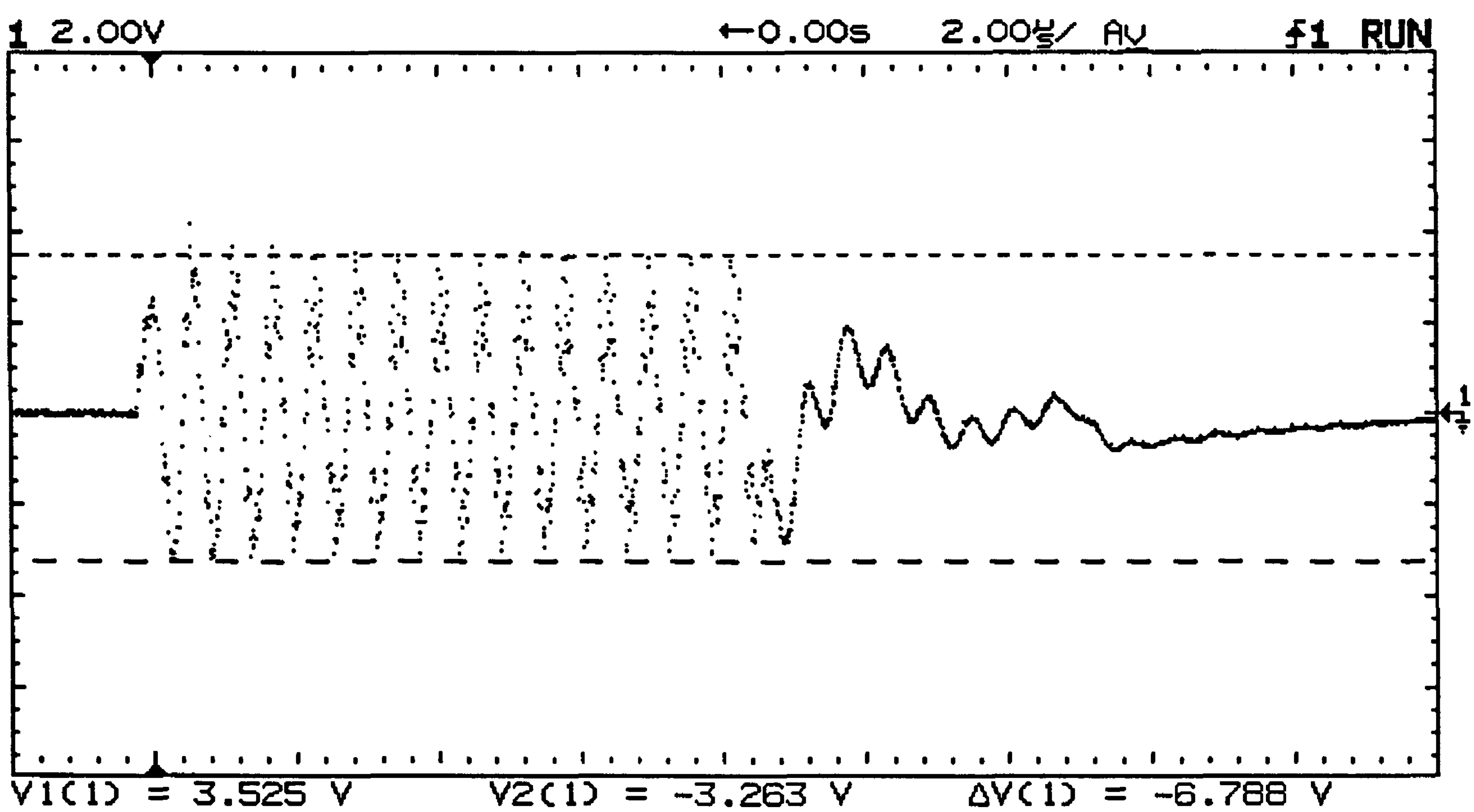
The upper half of the figure shows the complete signal with transmit and received pulses. The lower half shows the portion of the received pulse which crosses the Schmidt trigger threshold. The trigger should drop when crossed by the first rising edge of the received signal. The threshold is fixed at approximately 77 mV by R10 and R3 on the receiver DT-V board. This trigger level is designed to be high enough to avoid the 20 mv p-p noise in the received signal and still capture that first rising edge. It is the time from the transmission of the transmitted pulse to the first rising edge of the received signal that BASS is measuring to determine the speed of the water passing through its measurement volume.

Note: this measurement is tricky. It is easy to display the signals above, however, delays in an oscilloscope's circuitry can cause the scope to trigger and display the received signal from one axis, but the Schmidt trigger from another. The BASS may then appear to be missing the first rising edge of the received signal, when in fact the wrong signals are being compared. If the schmidt trigger does not to match the received signal, check the scope settings to make sure that the signals displayed are really those for the axis providing the trigger signal for the scope. Or, display the signals separately and measure the time of occurrence for the first rising edge, then compare that with the time for first descending edge of the schmidt trigger. The series of 8 transmit pulses generated per BASS sample (one for each transducer) are only about 850 μsec apart.

The example scope display image for this step was made by utilizing our digital scope's memory feature. Using CH2 at 2 v/div as the trigger, the received signal was displayed at 100 mv scale on CH1 (expanding CH2 to 100 mv would stop triggering on our particular scope). When a good image was obtained, it was saved to memory. Then the schmidt trigger was displayed, with the memorized received signal image in the background. The same effect was achieved on an analog Tektronix 7613 scope using its store feature. The CH1 input was switched between the received and schmidt trigger signals while store was on. The delay was set on 1 μs and the delay time multiplier was set to approx. 4.8.

10. Transducer Transmit Pulse

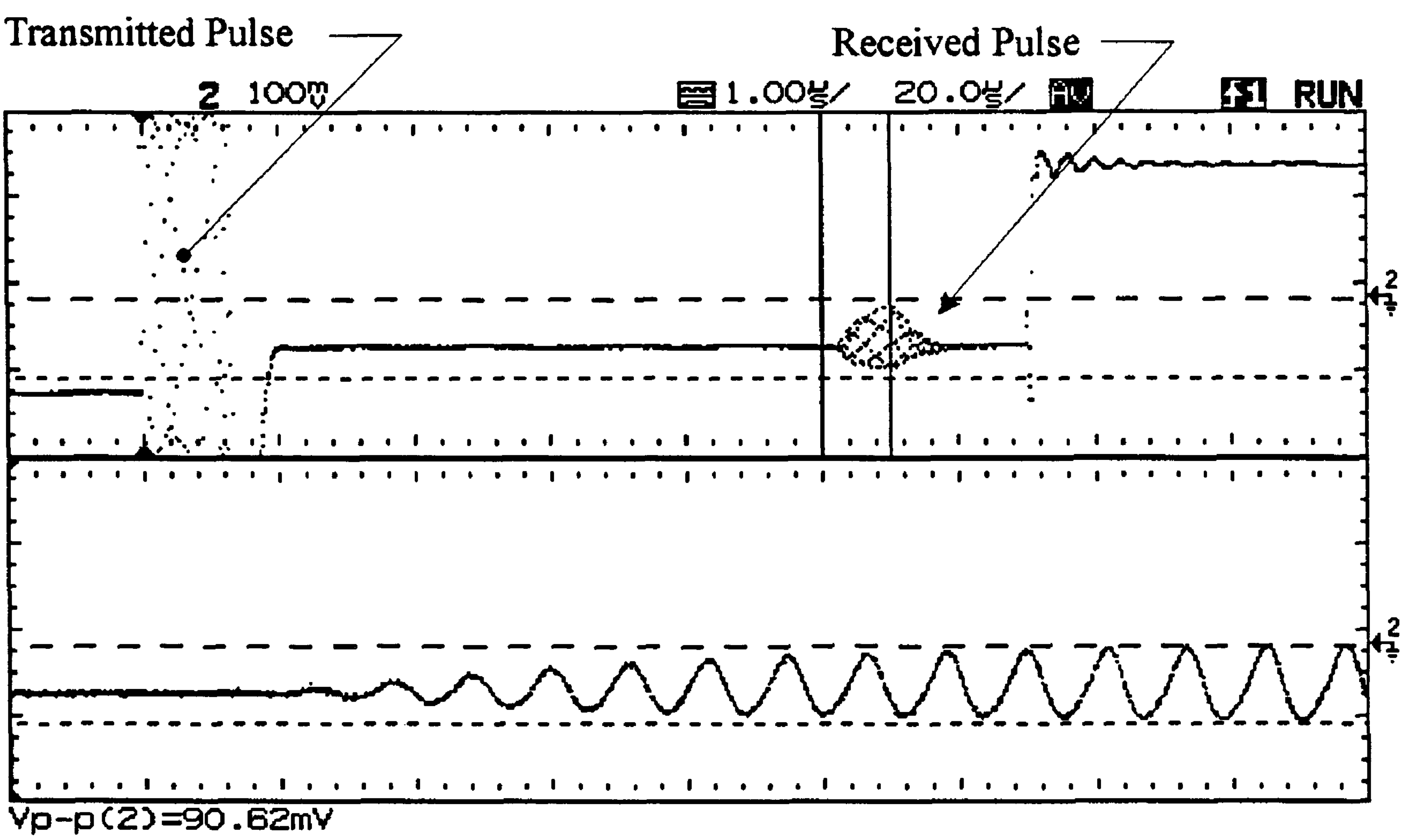
Input to CH1:	output from xmit/rec board for respective axes A: pins 22 or 25, B: pins 18 or 21, C: pins 14 or 17, D: pins 10 or 13
Input to CH2:	none
Current probe:	n/a
Sweep:	2 μs/div
CH1 setting:	2 v/div
CH2 setting:	n/a
Trigger:	CH1, normal
Trigger slope:	positive
Trigger level:	2 v
Current Probe setting:	n/a
Averaging or store:	on
Delay:	none



A typical transmit pulse is shown. The amplitude should be as large as possible (6.8 v p-p in this case) to maximize dv/dt at the zero crossing without introducing distortion at the output of the cascode transistor or conduction at the transmit/receive diodes. The amplitude is adjusted using potentiometer R11 on the microcomputer board.

11. Transducer Received Signal

Input to CH1:	output from xmit/rec board for respective axes A: pins 22 or 25, B: pins 18 or 21, C: pins 14 or 17, D: pins 10 or 13
Input to CH2:	Received signal: same source as for CH1
Current probe:	n/a
Sweep:	20 μs/div
CH1 setting:	2 v/div
CH2 setting:	40-100 mv/div
Trigger:	CH1, normal
Trigger slope:	positive
Trigger level:	2 v
Current Probe setting:	n/a
Averaging or store:	on
Delay:	100 μs at 1 μs/div



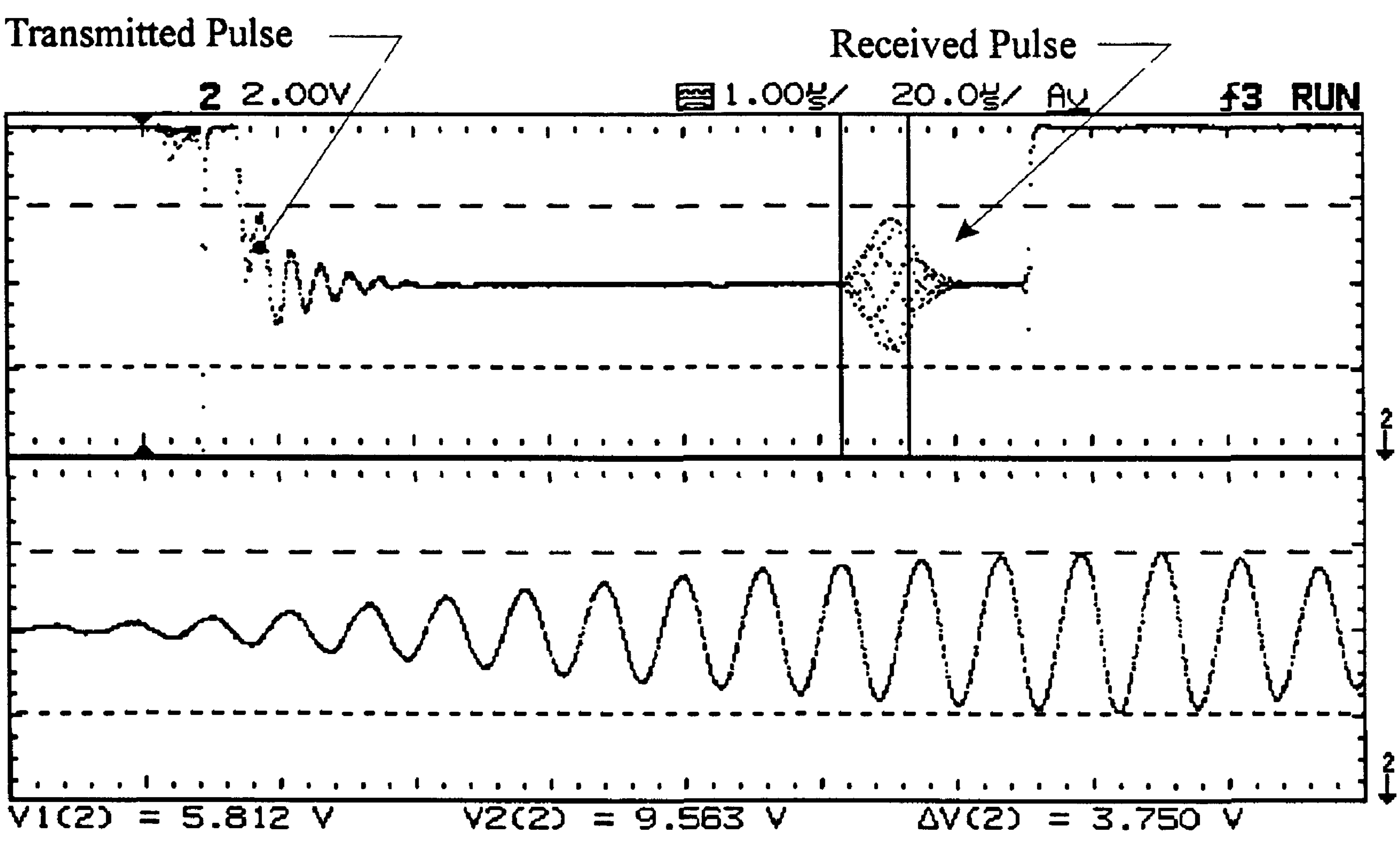
The upper half of the figure shows the complete signal with the transmit and received pulses visible. The lower half is delayed to show the detail of the part of the received signal with the greatest amplitude. The received signal should not exceed ±0.3 v, -0.02 to -0.09 v is typical (the signal is always negative). If the amplitude is too large, the signal will be clipped (the schottkey diodes will conduct at the wrong time). Other failure modes include a bad transducer, bad transducer alignment, a bubble or other blockage of the transducer, and schottkey diode failure (the signal will be below -0.3 v).

The signals should be checked and recorded for all axes. The results are pod-dependent and a good indicator of each sensor pod's health.

Both scope channels are used to view the same signal because in the case of the tendency of our digital scope to lose trigger lock on the signal if the v/div scale is expanded to 100 mv. If a scope with more than two display channels or external triggering is used, this step can be combined with the cascode output check (next step) by displaying the received signal on one channel and the cascode output on another.

12. Cascode Output Signal

Input to CH1: output from xmit/rec board for respective axes
A: pins 22 or 25, B: pins 18 or 21, C: pins 14 or 17, D: pins 10 or 13
Input to CH2: pin 10 or 28 of the DT-V board.
Current probe: n/a
Sweep: 20 µs/div
Trigger: CH1, normal
Trigger slope: positive
Trigger level: 2 v
CH1 setting: 2 v/div
CH2 setting: 2 v/div
Current Probe setting: n/a
Averaging or store: on
Delay: 100 µs at 1 µs/div



The upper half of the figure shows the complete signal with transmit and received pulses. The lower half is delayed by approx. 100 µs to display the part of the received pulse with the greatest amplitude. The cascode signal for each axis should fall between 10 v and 5 v or a range of 5 v. The signal amplitude should be as large as possible without causing distortion. The amplitude is recorded. The amplitude is controlled by potentiometer R11 on the microcomputer board.

13. **Tattletale 4 A/D reference voltages:** BASS switches the positive and negative reference voltage supplies on and off as it samples, so that these are best measured with an oscilloscope. The positive reference is pin 13 on the 32 pin connector on the TT4. Pin 32 is nearest the RS232 connector, and it should read +5.0 v. The negative reference is at pin 2, and it should read -5.0 v.

14. **Differential time to voltage circuit calibration:** A simulated input signal to a single axis is used to check the current meter for time to voltage conversion linearity. The OIS nanosecond delay test unit simulates the precise time of travel delays similar to those detected by the sensors when submerged in moving water.

    Disconnect a pod from the BASS and plug in the delay unit's connector in its place. Figure 7 shows the connections to set up the nanosecond delay unit. To switch between forward and reversed readings (positive and negative BASS output), swap the connections at the input to the 10 db attenuators. If not already running, start the display program to watch the BASS output. At this point you should be able to change the delay settings in the delay unit and see one of the axis values change. Use the small delay switches (8 through 0.25) to bring the output as close to zero as possible.

Signal Out	o——o	Delay In		o——o	= one 48" Coax cable		
Trigger	o——o	Undelay Out	o——o	10 db Attenuator	38 Ohms	BASS	
	Delay Out	o——o	o——o	10 db Attenuator	38 Ohms	BASS	

Figure 7: Guide to connections for the OIS BASS nanosecond delay test box.

A quick and dirty way to check the BASS' calibration is to compare the current operation with the last calibration provided by OIS, which lists BASS hex count output corresponding to three or four delay input values, typically 160, 80, 40,0 and -40, -80, -160 ns. To check against this curve, set all the calibrator's delay switches off. Then increase the delay by turning switches on until the output count is zero. This eliminates any residual offset from the capacitance in the wires. Set the delay to the ns values used in the previous calibration (160, 80 or 40 ns) and observe the BASS output. The output count should represent quarter, half and full scale magnitudes. Table I shows representative readings. The BASS output should be within 10 counts of these values.

Differences from the target values in Table I can be corrected by adjusting the integrators on the DT-V board. As before, turn on enough of the delay switches to bring the BASS output as close to zero as possible to eliminate any residual offset from capacitance in the wires. Adjust the BASS to the half scale reading. Use the test box to supply a 80 nanosecond (60 cm/s) input signal for a BASS set to measure a full range scale of 160 nanoseconds. Adjust both potentiometers on the DT-V board evenly until an output count of 07FF hex (assuming this is the forward, or positive direction, see Table I) is achieved. Repeat and check for the reverse direction. It helps to use the oscilloscope to display the A/D input while making this adjustment so that you can see the effect of the potentiometer setting on the forward and reverse measurement voltage levels.

Table I: Target values for BASS DT-V circuit calibration. †Positive values indicate the forward direction along an axis towards the upper ring.

Delay Input		BASS Output Count		
ns†	cm/s†	Hex	Dec	
160	120	0FFF	4095	full scale
80	60	07FF	2047	half scale
40	30	03FF	1023	quater scale
0	0	0	0	
-40	-30	FC01	-1023	quarter scale
-80	-60	F801	-2047	half scale
-160	-120	F001	-4095	full scale

To perform a more thorough check of the BASS for linear behavior, starting from 0 delay, increase delay by 10 ns intervals until full range is attained (the instrument output will show full scale count value). Reverse the delayed and undelayed outputs and repeat. Record the BASS output count for each delay input. ? and Figure 9 show the results from a calibration. The lower plots show calibration results compared with a least squares fit of the same data and the input of the calibrator expressed in cm/s. The upper plots show the conversion factor from counts to cm/s derived from each data point in the calibration. Note that the BASS' response is not perfectly linear, and this step is a means of tracking how well an individual system behaves over time and over the operating range of the instrument. The plots were generated using MATLAB by the Mathworks, Inc. of Natick, MA. The 'm-file' used to perform the computations is listed in Appendix D on page 36.

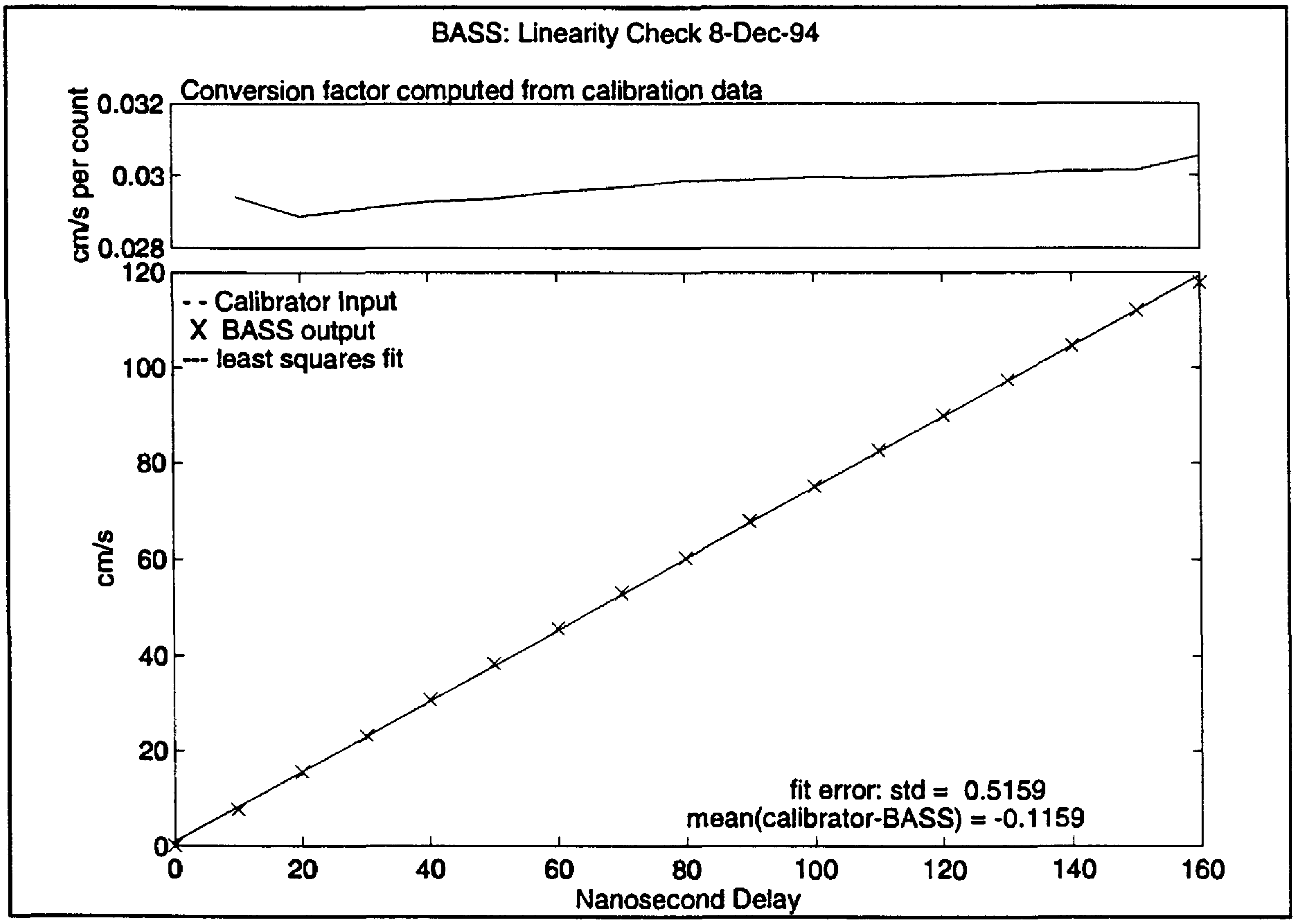


Figure 8: Plot of forward direction output from a BASS calibration.

Delay	Input	Out: BASS,	Fit	Error	Factor
ns	cm/s	cm/s	cm/s	cm/s	cm/s per count
00.0	00.0	0.021	0.868	0.847	0.0000
10.0	07.5	7.650	8.274	0.623	0.0294
20.0	15.0	15.588	15.680	0.092	0.0289
30.0	22.5	23.204	23.086	-0.118	0.0291
40.0	30.0	30.731	30.492	-0.239	0.0293
50.0	37.5	38.311	37.898	-0.413	0.0294
60.0	45.0	45.688	45.304	-0.384	0.0295
70.0	52.5	53.079	52.710	-0.370	0.0297
80.0	60.0	60.296	60.116	-0.181	0.0299
90.0	67.5	67.795	67.522	-0.274	0.0299
100.0	75.0	75.128	74.928	-0.200	0.0299
110.0	82.5	82.658	82.334	-0.324	0.0299
120.0	90.0	90.028	89.740	-0.289	0.0300
130.0	97.5	97.364	97.146	-0.218	0.0300
140.0	105.0	104.596	104.552	-0.044	0.0301
150.0	112.5	111.963	111.958	-0.005	0.0301
160.0	120.0	117.869	119.364	1.494	0.0305

Offset applied to zero BASS output: 5.25 ns

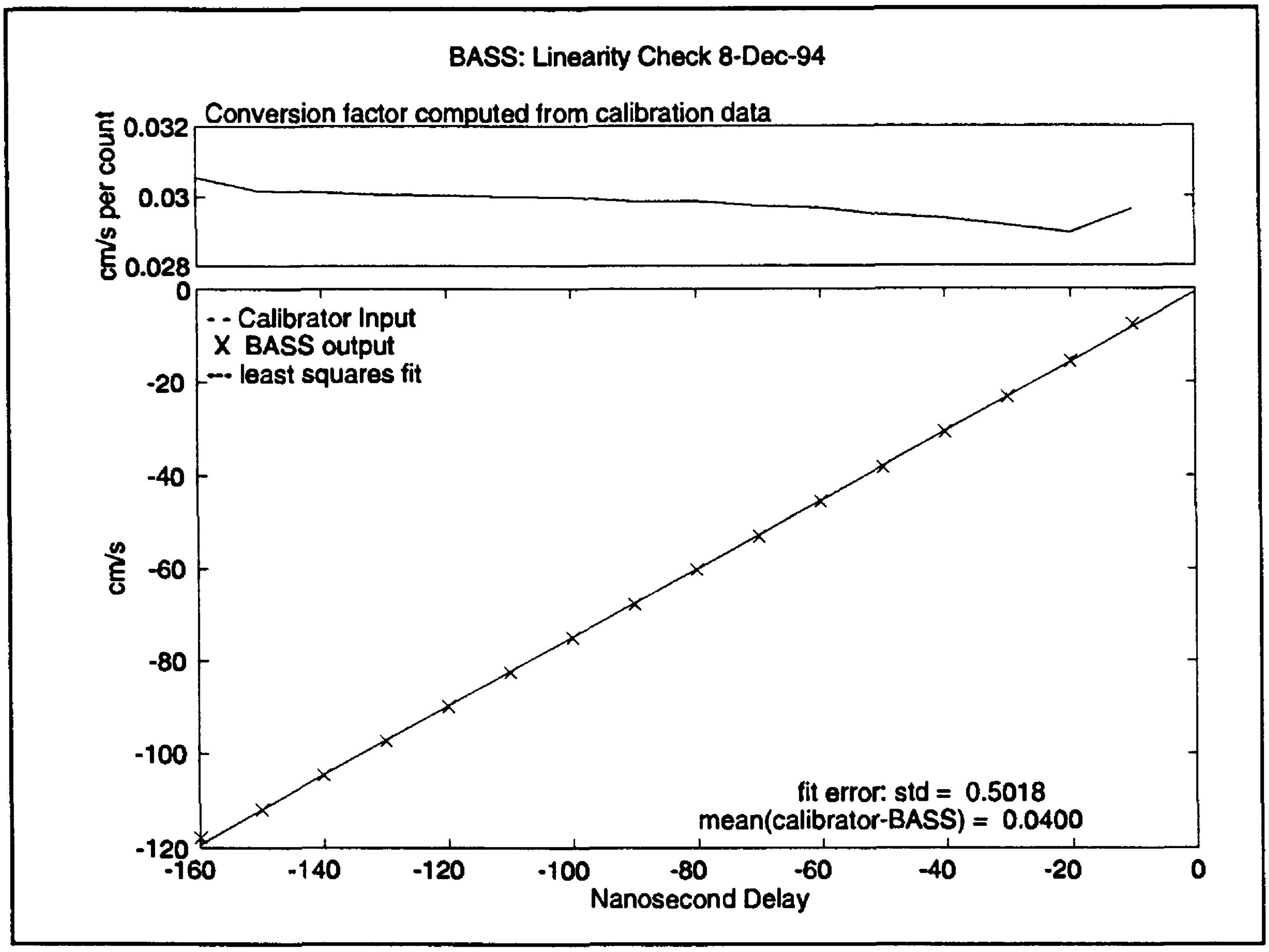


Figure 9: Plot of reverse direction output from a BASS calibration.

Delay	Input	Out: BASS,	Fit	Error	Factor
ns	cm/s	cm/s	cm/s	cm/s	cm/s per count
00.0	00.0	0.099	-0.777	-0.876	0.0000
-10.0	-7.5	-7.598	-8.184	-0.586	0.0296
-20.0	-15.0	-15.545	-15.592	-0.047	0.0289
-30.0	-22.5	-23.144	-23.000	0.144	0.0292
-40.0	-30.0	-30.638	-30.408	0.229	0.0294
-50.0	-37.5	-38.188	-37.816	0.372	0.0295
-60.0	-45.0	-45.509	-45.224	0.285	0.0297
-70.0	-52.5	-52.986	-52.632	0.354	0.0297
-80.0	-60.0	-60.280	-60.040	0.241	0.0299
-90.0	-67.5	-67.832	-67.448	0.384	0.0299
-100.0	-75.0	-75.044	-74.856	0.188	0.0300
-110.0	-82.5	-82.539	-82.264	0.276	0.0300
-120.0	-90.0	-89.869	-89.672	0.197	0.0300
-130.0	-97.5	-97.302	-97.080	0.222	0.0301
-140.0	-105.0	-104.542	-104.488	0.055	0.0301
-150.0	-112.5	-111.901	-111.895	0.006	0.0302
-160.0	-120.0	-117.858	-119.303	-1.445	0.0305

Offset applied to zero BASS output: 5.75 ns

IV. BASS Transducer and Cable Check

Each sensor pod which makes a three axis current measurement uses a total of eight acoustic transducers to do so. These are generally rugged parts, however their capacitance should be checked periodically and whenever there is any suspicion of damage. To insure that no moisture can penetrate the sealed housing, capacitance should be measured after the transducer has been soaked in water for several days. The capacitance is typically 1000 pf ± 30 %. Note that the true capacitance will be the capacitance measured with the test leads connected to the transducer minus the capacitance of the test leads by themselves.

The electrical condition of the cables can also be checked by measuring capacitance. Once the capacitance for each transducer has been recorded, the measurement is repeated through the cable. A cable in good condition should not significantly differ from the capacitance reading at the transducer.

V. References

1. Morrison III, A.T., Williams 3rd, A.J., and Martini, M., 1993, Calibration of the BASS Acoustic Current Meter with Carrageenan Agar: Institute of Electrical and Electronics Engineers, Oceanic Engineering Society, OCEANS '93 Conference Proceedings, vol. 3, pp. 143-148.

2. Trivett, D.A., Terray, E.A. and Williams 3rd, A.J., Error Analysis of an Acoustic Current Meter, J. of Oceanic Engineering, vol. 16, pp. 329-337.

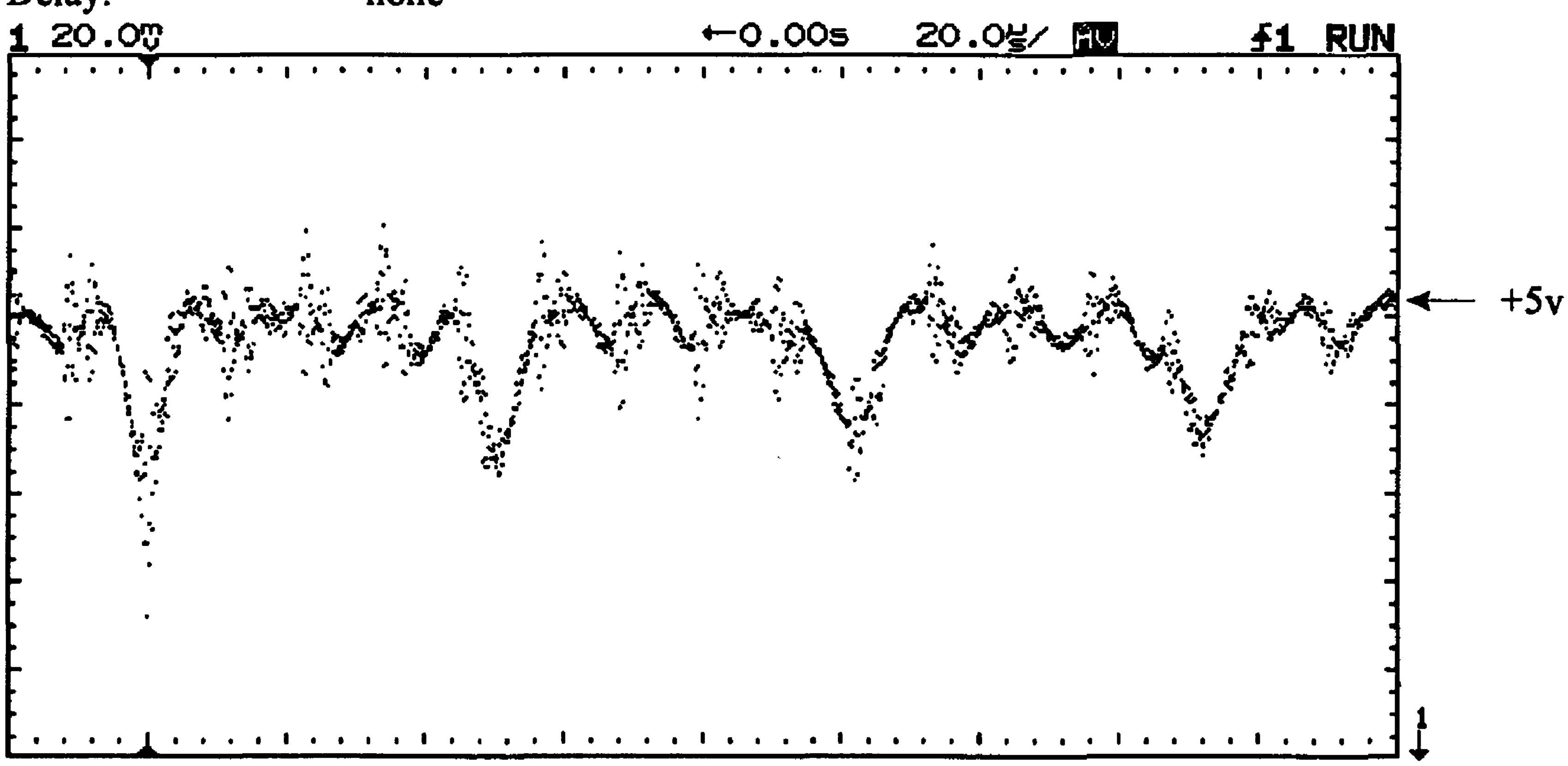
3. Williams 3rd, A.J., 1984, An Acoustic Current Meter Array for Benthic Flow-Field Measurements, Marine Geology, vol. 66, pp. 345-355.

Appendix A. Other Signals of Interest

The figures on the following pages show details of different BASS signals which may be of interest to the user but are not considered necessary to check every time a BASS is to be deployed.

5 Volt Regulated Power

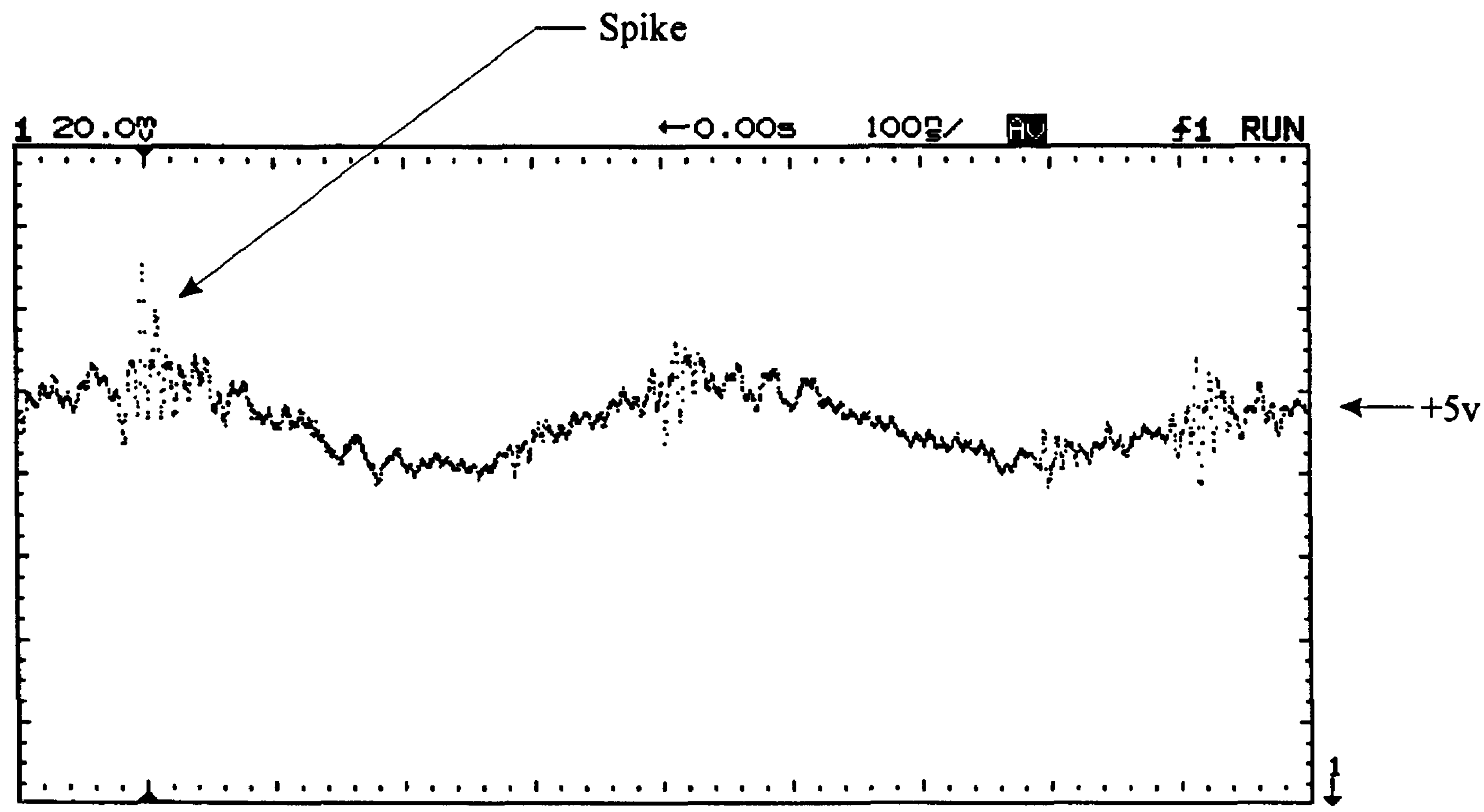
Input to CH1:	5 v regulated line, pin 2 on the microcomputer board
Input to CH2:	none
Current probe:	n/a
Sweep:	20 μs/div
Trigger:	CH1, normal
Trigger slope:	positive
Trigger level:	automatic (or as required)
CH1 setting:	20 mv/div
CH2 setting:	n/a
Current Probe setting:	n/a
Averaging or store:	on
Delay:	none



The switching power regulator produces a 50 kHz, 20 mv ripple on the regulated line. The maximun expacted drop is 7 mv due to charging. The regulated power level is changed by adjusting potentiometer R7 on the right side of the microcomputer board (looking down on the top of the board).

A/D Reference Voltage

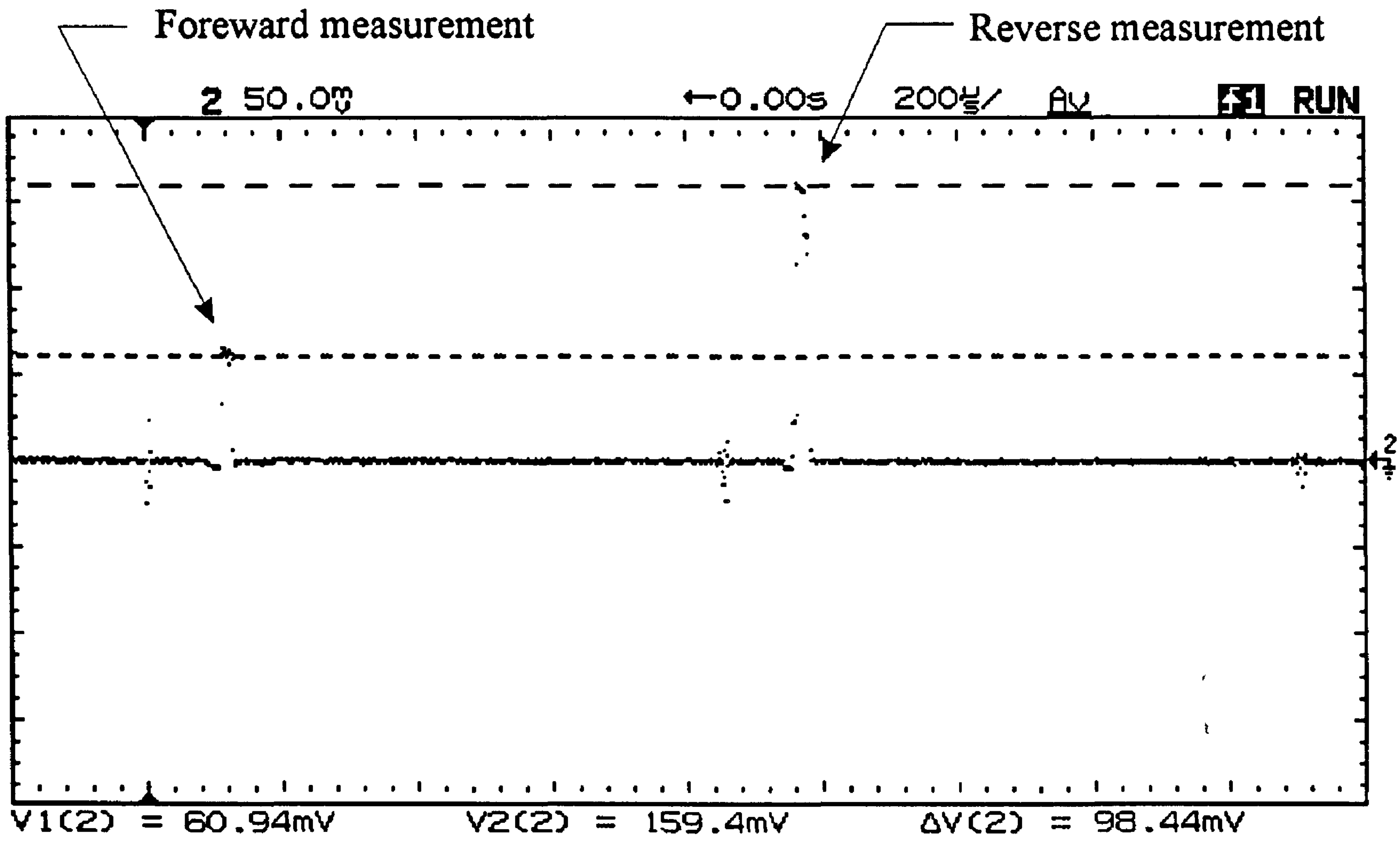
Input to CH1:	5 v reference voltage for the A/D, (pin 13 on the 32 pin connector to the Tattletale 4, pin 32 is nearest the backplane) on the microcomputer board.
Input to CH2:	none
Current probe:	n/a
Sweep:	100 ns/div
Trigger:	CH1, normal
Trigger slope:	positive
Trigger level:	4.79 v
CH1 setting:	20 mv/div
CH2 setting:	n/a
Current Probe setting:	n/a
Averaging or store:	on
Delay:	none



Expect a 20 mv ripple and 20 mv spikes 400 ns apart.

A/D Input (CH0)

Input to CH1:	output from xmit/rec board for respective axes A: pins 22 or 25, B: pins 18 or 21, C: pins 14 or 17, D: pins 10 or 13
Input to CH2:	A/D input signal, pin 17 of the microcomputer board
Current probe:	n/a
Sweep:	200 µs/div
Trigger:	CH1, normal
Trigger slope:	positive
Trigger level:	2 v
CH1 setting:	2 v/div
CH2 setting:	50 mv/div
Current Probe setting:	n/a
Averaging or store:	on
Delay:	none



The two peaks are the foreward and reverse measurement for the axis, the difference between them is the final current measurement value recorded or output by the BASS system. These peaks will be very mall and hard to see for a BASS pod sitting in a bucket of still water. This image was made using the BASS delay input test set, simulating a large current velocity signal.

Appendix B. Suggested Form for Recording Observations

System Power: Input voltage ______________________

Quiescent current ___________________

Sample rate used during checks ______________

+5 v Regulated Power ____________________

+12 v Switched Power ____________________

Operating Current Peak _____________________

Intermediate _______________

Base _____________________

Schmidt Trigger: Threshold _________________

Triggers on first rising edge? YES/NO

Transmit Pulse v p-p ______________________

Analog to digital converter reference voltages: + _____________

\- _____________

Serial #'s: MIDAS _______ TT4 ________ BASS ___________ Date: _______________

Data File Name: __________ Pod ________ and Axis _________ used for calibration.

Received Signals (mv)		
Pin - Axis	Pod 1: _______ Cable 1: _______	Pod 2: _______ Cable 2: ________
25 - A		
22 - A		
21 - B		
18 - B		
17 - C		
14 - C		
13 - D		
10 - D		

Cascode Output (v p-p)		
Pin - Axis	Pod 1: _______ Cable 1: _______	Pod 2: _______ Cable 2: ________
25 - A		
22 - A		
21 - B		
18 - B		
17 - C		
14 - C		
13 - D		
10 - D		

Serial #'s: MIDAS _______ TT4 ________ BASS ___________ Date: _______________

Data File Name: __________ Pod ________ and Axis _________ used for calibration.

Foreward calibration settings:
Offset applied to achieve zero output __________ ns

Int.	Delay	Switches on	Actual delay	BASS Output	BASS Output
#	ns		ns	count	ns or cm/s
	0.0				
	10.00				
	20.00				
	30.00				
	40.00				
	50.00				
	60.00				
	70.00				
	80.00				
	90.00				
	100.00				
	110.00				
	120.00				
	130.00				
	140.00				
	150.00				
	160.00				
	170.00				
	180.00				
	190.00				
	200.00				

Serial #'s: MIDAS _______ TT4 ________ BASS ___________ Date: _______________

Data File Name: __________ Pod _________ and Axis _________ used for calibration.

Reverse calibration settings:
Offset applied to achieve zero output _________ ns

Int.	Delay	Switches on	Actual delay	BASS Output	BASS Output
#	ns		ns	count	ns or cm/s
	0.0				
	10.00				
	20.00				
	30.00				
	40.00				
	50.00				
	60.00				
	70.00				
	80.00				
	90.00				
	100.00				
	110.00				
	120.00				
	130.00				
	140.00				
	150.00				
	160.00				
	170.00				
	180.00				
	190.00				
	200.00				

Appendix C. A Tattletale 4 BASS Program

```
1000 REM TT4 BASS PROGRAM FOR MONITORING BASS
1005 REM --- S1_LIT4.TTB
1010 X=0:A=0:B=0:C=0:D=0:E=0:F=0:G=0:H=0:REM ASSEMBLY ROUTINES
1015 PRINT #06H,A,B,C,D,E,F,G,H,X
1020 GOSUB 8000            :REM FIRST PASS
1025 PRINT #06H,A,B,C,D,E,F,G,H,X
1030 GOSUB 8000            :REM SECOND PASS
1031 PRINT #06H,A,B,C,D,E,F,G,H,X
1032 GOSUB 8000            :REM THIRD PASS
1035 PRINT #06H,A,B,C,D,E,F,G,H,X
1040 PCLR 7,8,9,10,11,12,13,14,15   :REM ESTABLISH DDRs
1050 ASM &HBB,DB &H02      :REM A/D BIPOLAR,TURNS OFF,12 BIT
1060 SLEEP 0               :REM START TIMER
1064 REM
1065 REM *******************MAIN LOOP**********************************
1066 REM
1075 REM IF PIN(0) = 1 GOTO 1080          :REM WAIT FOR START PULSE FROM BIG 6
1076 REM GOTO 1075
1080 RTIME                          :REM READ RTC
1090 X=0                            :REM INITIALIZE DATAFILE
1100 STORE X,#2,?(1)                  :REM MINUTES
1110 STORE X,#2,?(0)                  :REM SECONDS
1120 CALL &H7300,0                     :REM CALL A/D ROUTINE
1130 CALL &H73C0,0                     :REM CALL SUBTRACT AND TRANSFER
1140 X=0
1150 SLEEP 25              :REM WAIT
1220 REM PRINT {4,20}
1225 PRINT #02,GET(X,#2),":",GET(X,#2),"    ";  :REM MM:SS
1230 FOR M=1 TO 2: FOR L=1 TO 4:REM PRINT IN READABLE ASCII
1240 PRINT #04,GET(X,#2)," ";
1250 NEXT L:PRINT "    ";
1255 NEXT M:PRINT
1260 GOTO 1075               :REM LOOP TO DO IT ALL AGAIN
1270 REM ****************** ASSEMBLER CODE ******************************
8000 X=&H7460            :REM MULTIPLEXOR LIST, NORMAL ORDER
8010 ASM X,DW &H0000;DW &H8000;DW &H4000;DW &HC000
8015 ASM X,DW &H2000;DW &HA000;DW &H6000;DW &HE000
8020 ASM X,DW &H0400;DW &H8400;DW &H4400;DW &HC400
8025 ASM X,DW &H2400;DW &HA400;DW &H6400;DW &HE400
8050 ASM X,DW &HFFFF;DW &HFFFF  :REM END OF LIST
8100 X=&H7300            :REM BASS ROUTINE
8110 ASM X,SLP             :REM START TIMING AT END OF SLP
8120 ASM X,LDAA &H17
8130 ASM X,ANDA #&H47
8140 ASM X,ORAA #&H40
8150 ASM X,STAA &H17       :REM PORT 6,0100 0XXX,PWR ON,/CS=1
8160 ASM X,LDX #&H7400     :REM INDEX TO MUX LIST AND OUTPUT
8170 ASM X,LDAB &H60,X
```

```
8180 ASM X,STAB &H03       :REM PORT 2
8190 ASM X,TAB
8200 ASM X,ORAB #&H08
8210 ASM X,STAB &H17       :REM CLOCK HIGH,0100 1XXX
8220 ASM X,STAA &H17       :REM 1st FALLING EDGE
8230 ASM X,STAB &H17
8240 ASM X,STAA &H17       :REM 2nd FALLING EDGE,ACCEPTS /CS=1
8250 ASM X,ANDA #&HBF       :REM 0000 0XXX ACCA
8260 ASM X,ANDB #&HBF       :REM 0000 1XXX ACCB
8270 ASM X,STAB &H17       :REM /CS=0
8280 ASM X,STAA &H17       :REM 1st FALLING EDGE
8290 ASM X,STAB &H17
8300 ASM X,STAA &H17       :REM 2nd FALLING EDGE,ACCEPTS /CS=0
8310 ASM X,SLP            :REM 42us USED OF 10ms
8320 ASM X,LDAA #&HE4       :REM RESET BURST GENERATOR
8330 ASM X,STAA &H03       :REM ADDRESS LAST AXIS
8340 ASM X,OIM &H01,&H15;OIM &H01,&H15 :REM P50=1, LONG PULSE
8350 ASM X,AIM &HFE,&H15   :REM P50=0
8360 ASM X,LDAB #&H02
8370 T=X              :REM TEST LOOP
8380 ASM X,BITB &H15       :REM TEST STROBE
8390 ASM X,BEQ T
8395 L=X            :REM A/D LOOP
8400 ASM X,LDAA &H60,X  :REM LOAD MUX,START OF A/D LOOP
8410 ASM X,STAA &H03       :REM MUX WORD
8420 ASM X,LDAA #&H86      :REM 1000 0110 BYTE INTO A/D
8430 ASM X,CLRB
8440 ASM X,PSHX
8450 ASM X,LDX #&H000C     :REM 12 BITS
8460 T=X              :REM A/D SERIAL I/O LOOP
8470 ASM X,AIM &HF7,&H17   :REM CLOCK LOW,BIT LOOP
8480 ASM X,ASLD           :REM BIT TO CARRY
8490 ASM X,BCC A
8500 ASM X,OIM &H10,&H17   :REM "1"
8510 ASM X,BRA B
8520 A=X
8530 ASM X,AIM &HEF,&H17   :REM "0"
8540 B=X
8550 ASM X,TIM &H20,&H17   :REM READ Dout
8560 ASM X,BEQ C           :REM IF "0",WRITE NOTHING,
8570 ASM X,INCB           :REM ELSE STORE "1"
8580 C=X
8590 ASM X,OIM &H08,&H17   :REM CLOCK HIGH
8600 ASM X,DEX
8610 ASM X,BNE T           :REM LOOP
8620 ASM X,SEI           :REM SET INTERRUPT MASK
8630 ASM X,OIM &H01,&H15   :REM START TIMING
8640 ASM X,OIM &H01,&H15   :REM P50=1,LENGTHEN PULSE
8650 ASM X,AIM &HFE,&H15   :REM P50=0
8660 ASM X,TIM &H04,&H15   :REM READ "BOTH REC" LAST VALUE
8670 ASM X,BEQ D
8680 ASM X,ORAA #&H80      :REM NOT REC,FLAG WITH SIGN BIT
```

```
8682 D=X
8684 ASM X,BITA #&H08      :REM CHECK FOR NEGATIVE
8686 ASM X,BEQ H
8688 ASM X,ORAA #&H70      :REM FILL OUT NEGATIVE
8690 H=X
8700 ASM X,PULX            :REM CONTINUE,IF"BOTH",DON'T FLAG
8710 ASM X,STD &H00,X      :REM STORE AT DATA,FIRST BOGUS
8720 ASM X,INX:ASM X,INX   :REM INCREMENT TWICE
8730 ASM X,TIM &H01,&H5E,X :REM CHECK FOR END OF LIST
8740 ASM X,BEQ E
8750 ASM X,CLI             :REM CLEAR INTERRUPT MASK
8760 ASM X,CLRA
8770 ASM X,STAA &H03       :REM PUT MULTIPLEXORS ON PARK
8780 ASM X,JSR &HFFD0      :REM CONOFF TURN POWER OFF
8790 ASM X,RTS             :REM EXIT FROM DIGITIZE ROUTINE
8800 E=X
8810 ASM X,LDAA &H17       :REM PREPARE TO RESPOND FAST
8820 ASM X,ANDA #&HE7
8830 ASM X,LDAB #&H02
8840 T=X                   :REM TEST LOOP
8850 ASM X,BITB &H15       :REM TEST A/D STROBE
8860 ASM X,BEQ T
8870 ASM X,STAA &H17       :REM HOLD WITH FALLING EDGE
8880 ASM X,CLI             :REM CLEAR INTERRUPT MASK
8890 ASM X,PSHX            :REM CONVERSION PART
8900 ASM X,LDX #&H0019     :REM 25,1st 2 FOR DEGLITCH
8910 ASM X,ORAA #&H40      :REM /CS=1
8920 ASM X,TAB
8930 ASM X,ORAB #&H08      :REM 0100 1XXX
8940 T=X                   :REM LOOP
8950 ASM X,STAB &H17       :REM 0100 1XXX
8960 ASM X,STAA &H17       :REM 0100 0XXX
8970 ASM X,STAB &H17
8980 ASM X,STAA &H17
8990 ASM X,DEX
9000 ASM X,BNE T           :REM 50 CYCLES,12x4+2
9010 ASM X,ANDA #&HBF      :REM 0000 0XXX
9020 ASM X,ANDB #&HBF      :REM 0000 1XXX
9030 ASM X,STAB &H17       :REM /CS=0
9040 ASM X,STAA &H17       :REM 1st FALLING EDGE
9050 ASM X,STAB &H17
9060 ASM X,STAA &H17       :REM 2nd FALLING EDGE
9070 ASM X,PULX
9080 ASM X,JMP L           :REM RETURN TO START
9090 G=X
9100 X=&H73C0              :REM SUBTRACT AND TRANSFER SUBROUTINE
9110 ASM X,LDX #&H7400
9120 L=X
9130 ASM X,LDD &H02,X      :REM GET WORD
9140 ASM X,INX:ASM X,INX
9150 ASM X,BMI F           :REM TEST FLAG ON NORMAL MEAS
9160 ASM X,SUBD &H02,X     :REM DOUBLE SUBTRACT
```

```
9170 ASM X,TST &H02,X      :REM TEST FLAG ON REVERSED MEAS
9180 ASM X,BMI F
9200 ASM X,STAB &H02,X     :REM SAVE LOW BYTE
9202 ASM X,ASLA            :REM TEST FOR NEGATIVE
9204 ASM X,ASRA            :REM FILL WITH WHATEVER IT IS
9206 T=X
9210 ASM X,JSR &HFFD3      :REM STRMEM HIGH BYTE
9220 ASM X,LDAA &H02,X     :REM RECOVER LOW BYTE
9230 ASM X,JSR &HFFD3      :REM STRMEM LOW BYTE
9240 ASM X,INX:ASM X,INX
9250 ASM X,TIM &H01,&H60,X :REM CHECK END OF LIST
9260 ASM X,BEQ L
9270 ASM X,RTS             :REM EXIT
9280 F=X
9290 ASM X,LDAA #&H80      :REM FLAG MISSED RETURN
9300 ASM X,CLR &H02,X      :REM CLEAR LOW BYTE
9310 ASM X,BRA T
9900 RETURN
9999 END
```

Appendix D. MATLAB Script File for BASS Calibration

```
% based on
%function [fit, err] = basscal(data, delay, avgint);
%
%       display the results from a bass
%       calibration with least squares fit
%       data = bass raw data in counts
%       delay = ns delay input to BASS
%       avgint = average interval if data contains cumulative sums
%               from MIDAS average intervals.  If avgint is not
%               provided, data is assumed not to be a cumulative sum
%       fit = coefficients for the fit
%       err = deviation from linearity
%
%   this file edited for open file report
%

function [fit, err] = ofbcal(data, delay, avgint);
clg
if exist('avgint') ~= 1,
       avgint = 1;     % no averages
end

% ---- convert to real units
Factor = 0.03;          % 0.03 cm/s per count
bnorm=(data./avgint).*Factor;
cms=delay./1.333;

% ---- liner fit
l=length(data);
c = polyfit(delay, bnorm,1);
fit = polyval(c, delay);

% ********************** upper plot *************************

% ---- display fit and data points
subplot(2,1,1)
plot(delay,bnorm,'x',delay,fit,'-');
%grid
title('BASS Calibration Linearity Check')
xlabel('Nanosecond Delay')
ylabel('cm/s')

% ---- calculate difference between fit and data points & plot
%err=fit-bnorm;
%hold on
%plot(delay,err+mean(fit),'-.')
%plot(delay,ones(length(fit),1).*mean(fit),'--')
%txt=sprintf('.-.- error: std = %7.4f',std(err));
```

```
%text('units','normalized','position',[0.2 0.05],'string',txt)
%text('units','normalized','position',[0.1 0.7],'string','--- zero error')
text('units','normalized','position',[0.1 0.8],'string','___ least squares fit')
text('units','normalized','position',[0.1 0.9],'string','X    BASS output')
hold off

% ********************** lower plot ***********************
% ---- plot different in cm/s
subplot(2,1,2)
dif=cms-bnorm;
plot(delay,cms,'-',delay,bnorm,'*');
%grid
title('BASS Calibration Input vs Output')
ylabel('cm/s')
xlabel('Nanosecond Delay')
hold on
%plot(delay,dif+mean(cms),'-.')
%plot(delay,ones(length(dif),1).*mean(cms),'--')
%txt=sprintf('.-.- error: mean = %7.4f, std = %7.4f',mean(dif),std(dif));
%text('units','normalized','position',[0.2 0.05],'string',txt)
%text('units','normalized','position',[0.1 0.7],'string','--- zero error')
text('units','normalized','position',[0.1 0.8],'string','___ calibrator')
text('units','normalized','position',[0.1 0.9],'string','X    BASS output')
hold off


if nargout ~= 2,
	clear fit
	clear err
end
```