CSM SmartDam Sensor Mote

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Date	Modified By	Change
12-04-2010	C. Oden	New document
09-28-11	C. Oden	Introduction, test procedure, tables, MODBUS, errata

Table of Contents

1 Overview

The CSM SmartDam sensor mote is a user specific model of Earth Science System's GP-Mote. The device is designed for *in-situ* monitoring applications. The CSM SmartDam version measures spontaneous potential, 3-component acceleration for seismic and tilt, and interfaces with external 4-20 mA sensors. Other versions are configured to make galvanic resistivity and induced polarization. There are versions available that incorporate solar recharging circuits (see Figure 1).

Figure 1. GP-Mote with solar charging cells. The unit on the left has solar recharging cells.

2 Electrical Interface

The electrical interface to the unit provides connections for external power, external serial communications, external sensors (4-20 mA), and electrodes for galvanic measurements. The GP-Mote circuit board is shown below, where connectors and the SD card can be located.

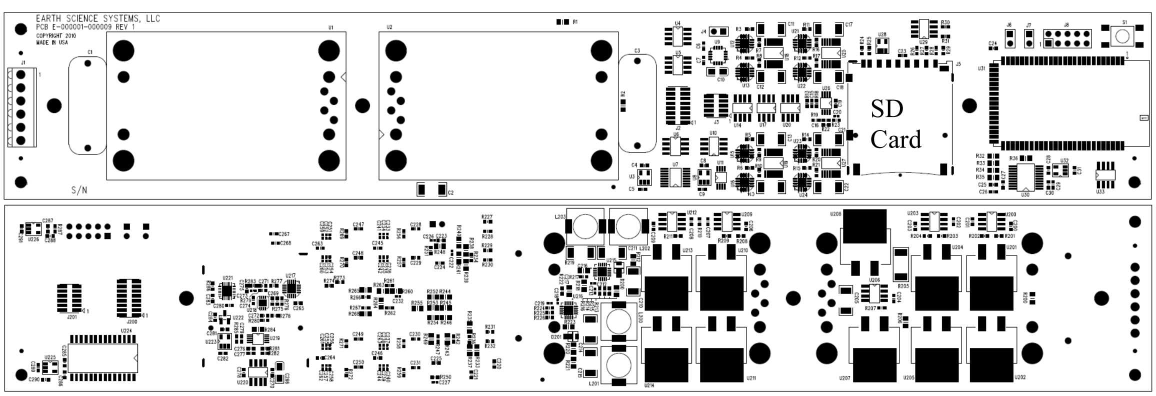


Figure 2. Top panel shows component locations for the top side of the circuit board, and the bottom panel shows component locations for the bottom side of the board. Connectors J1 (located on the left side of the top side of the board) and J3 (located in the center of the top side of the board) are used to interface with the external world.

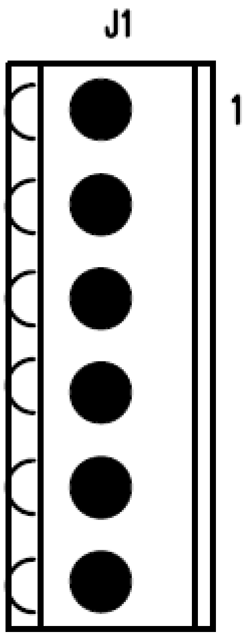


Figure 3. Electrical Connector (Power)

Table 1: Pinouts for J1

Pin	Name	Function
1	VBatt	Battery
2	GND	Ground
3	ELEC1	Electrode 1
4	ELEC2	Electrode 2
5	ELEC3	Electrode 3
6	ELEC4	Electrode 4

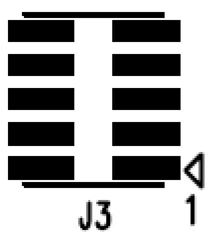


Figure 4. External Connector

Table 2: Pinouts for J3

Pin	Name	Function
1	VBatt	Battery
2	GND	Ground
3	PWR_1	+3.3 VDC
4	PWR_2	+13.8 VDC
5	VIN4+	4-20mA Sensor return 1
6	VIN5+	4-20mA Sensor return 2
7	VIN6+	NC
8	VIN7+	NC
9	TX	RS232
10	RX	RS232

Table 3: Pinouts for Housing Connector

Pin	Goes To Pin	Name/Function
1	J1-1	VBatt/Battery
2	J3-4	PWR_2/+13.8 VDC
3	J1- 2	GND/Ground
4	J1- 3	ELEC1/Electrode1
5	J1- 4	ELEC2/Electrode2
6	J1- 5	ELEC3/Electrode3
7	J1- 6	ELEC4/Electrode4
8	J3- 5	VIN4+/4-20mA Sensor return 1
9	J3- 6	VIN5+/4-20mA Sensor return 2

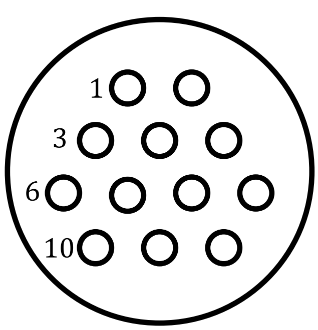


Figure 5. Cabling to Housing Connector – Hirose HR30 Male

3 Firmware Interface

The GP-Mote firmware provides (will provide when completed) a rich set of functions for controlling sensors, analog signal flow, data storage, and communications as listed below.

1. Mote status and diagnostics.
2. Sensor measurements including: temperature, battery voltage, spontaneous potential, resistivity, induced polarization, seismic, external 4-20 mA sensors.
3. Radio protocol supporting redundant multi-hop communications, time synchronization, and firmware updates. Provided by the SiFlex MAC library.
4. Wired and wireless Modbus communications. The Master node will connect to an external controller (possibly remote) via a wired connection, and all node will connect wirelessly. Provided by the FreeModbus library.
5. Data storage on FRAM and an SD card.

The low-level firmware routines encapsulate the hardware functions and simplify higher level programming. There are low-level routines for controlling power supplies, configuring analog signal processing circuitry, the analog-to-digital converter, FRAM memory access, and SD memory access. The firmware makes use of the FreeModbus and the SiFlex MAC libraries to support communications. A checkout program has been written using the low-level routines that can be used together with the test procedures located in this manual. The Atmel JTAG ICE MkII debugger is needed for the checkout procedures.

4 Test Procedure

The test procedure for the sensor board can be performed with common external test equipment including an adjustable power supply, a digital multi-meter, the Atmel AVR firmware development system (JTAG ICE mkII), a set of ear buds or head phones, and the test jig. The test jig contains a few simple circuits for providing known signals. Once radio communications have been established, the AVR development system will not be needed.

Each step in the test procedure is accomplished by connecting an external component, executing some test code, and verifying some ADC readings. Currently this is accomplished by running the test program to a breakpoint, and examining some values in memory. After setting up for the test as directed in each step, the test program is run to the indicated breakpoint. For each step listed below, the firmware will take 1024 ADC readings and tally the minimum, maximum, and average readings.

1. Connect 4.5 VDC battery or power supply to J1 pin1 (+) and J1 pin 2 (-). When using a power supply, limit the current to 500 mA if possible to prevent catastrophic damage if a fault occurs. Connect the JTAG ICE debugger connector to J8. Power up the supply and verify that the supply current is less than 250 mA. When using a battery or a power supply without an ammeter, place a milli-ammeter in series with the supply or battery to measure the current.
2. The onboard temperature sensor output is measured directly by the Atmel ATXMEGA256A3 12-bit ADC. At room temperature (23 C) the sensor will produce about 830 mVDC, and the ADC should produce an average value of 830 mV +/- 25%, with minimum and maximum values within 1% of average. Run the test program to `Breakpoint 1a`, to collect the room temperature, and verify an appropriate reading. Hold your finger on U222, located on the backside of the PCB board, for a few moments and repeat the experiment running the test program to `Breakpoint 1b`. Verify an increase in the temperature reading. [FW functions: power ADC on, Atmel ADC reading of processor pin AD1]

3. The battery voltage is also measured directly by the Atmel ATXMEGA256A3 12-bit ADC. For a 4.5 volt battery, the circuitry will input a voltage of about 400 mVDC to the ADC, and the ADC should produce an average value of 400 mV +/- 25%, with minimum and maximum values within 1% of average. Run the test program to `Breakpoint 2` and verify an appropriate reading. [FW functions: power ADC on, Atmel ADC reading of processor pin AD2]
4. Test the measuring circuit for SP electrodes 1 and 2.
    a. Connect J1-3 to the evaluation board node A, and connect J1-4 to the evaluation board node B. This will produce 300 mV at the input of the measure circuit when the test program powers up the input circuit. Run the test program to `Breakpoint 3a` where it will collect a sample from channel 1. This DC couples the signal to the 24-bit ADC with a gain of 2, and produces a 600 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 2, HP cutoff=0 Hz, LP cutoff=600 Hz]
    b. Run the test program to `Breakpoint 3b` where it will collect another sample from channel 1. This DC couples the signal to the 24-bit ADC with a gain of 1, and produces 300 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]
    c. Connect both J1-3 and J1-4 to the evaluation board node A, and connect J1-4 to the evaluation board node B. This will produce 0 mV at the input of the measure circuit when the test program powers up the input circuit. Run the test program to `Breakpoint 3c` where it will collect a sample from channel 1. This DC couples the signal to the 24-bit ADC with a gain of 1, and produces a 0 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]
    d. Connect J1-3 to the evaluation board, node B and connect J1-4 to the evaluation board node A. This reverses the polarity of the input voltage. Run the test program to `Breakpoint 3d`, where it will collect a sample from channel 1 with a reverse polarity. This DC couples the signal to the 24-bit ADC with a gain of 1, and provides a -300 mV signal at the ADC. Record the average value and verify that the minimum and maximum values within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]
    e. Run the test program to `Breakpoint 3e`, where it will collect another sample from channel 1 with a reverse polarity. This DC couples the signal to the 24-bit ADC with a gain of 2, and provides a -600 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. Remove all connections from the evaluation board. [FW functions: power EXT on, analog input channel 1, preamp gain = 2, HP cutoff=0 Hz, LP cutoff=600 Hz]
    f. Enter the average ADC readings for the 600, 300, 0, -300, and -600 mV ADC inputs into a spreadsheet and make a scatter plot of the ADC inputs versus the ADC readings. Fit a line to the data and determine the best-fit equation. Verify the R-value is greater than 0.98.
5. Test the measuring circuit for SP electrodes 3 and 4.
    a. Connect J1-5 to the evaluation board node A, and connect J1-6 to the evaluation board node B. This will produce 300 mV at the input of the measure circuit when the test program powers up the input circuit. Run the test program to `Breakpoint 4a` where it will collect a sample from channel 1. This DC couples the signal to the 24-bit ADC with a gain of 2, and produces a 600 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 2, HP cutoff=0 Hz, LP cutoff=600 Hz]
    b. Run the test program to `Breakpoint 4b` where it will collect another sample from channel 1. This DC couples the signal to the 24-bit ADC with a gain of 1, and produces

300 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]

c. Connect both J1-5 and J1-6 to the evaluation board node A, and connect J1-4 to the evaluation board node B. This will produce 0 mV at the input of the measure circuit when the test program powers up the input circuit. Run the test program to `Breakpoint 4c` where it will collect a sample from channel 1. This DC couples the signal to the 24-bit ADC with a gain of 1, and produces a 0 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]

d. Connect J1-5 to the evaluation board node B, and connect J1-6 to the evaluation board node A. This reverses the polarity of the input voltage. Run the test program to `Breakpoint 4d`, where it will collect a sample from channel 1 with a reverse polarity. This DC couples the signal to the 24-bit ADC with a gain of 1, and provides a -300 mV signal at the ADC. Record the average value and verify that the minimum and maximum values within 1% of average. [FW functions: power EXT on, analog input channel 1, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]

e. Run the test program to `Breakpoint 4e`, where it will collect another sample from channel 1 with a reverse polarity. This DC couples the signal to the 24-bit ADC with a gain of 2, and provides a -600 mV signal at the ADC. Record the average value and verify that the minimum and maximum values are within 1% of average. Remove all connections from the evaluation board. [FW functions: power EXT on, analog input channel 1, preamp gain = 2, HP cutoff=0 Hz, LP cutoff=600 Hz]

f. Enter the average ADC readings for the 600, 300, 0, -300, and -600 mV ADC inputs into a spreadsheet and make a scatter plot of the ADC inputs versus the ADC readings. Fit a line to the data and determine the best-fit equation. Verify the R-value is greater than 0.98.

6. Test the 4-20 mA sensor interface circuit 1. Connect a 2K resistor (available on the test jig) between J3-4 to J3-5. This should produce 293 mV at the input of the measure circuit. Run the test program to `Breakpoint 5a` and record the average value. Use the linear best-fit equation from step 4 to calculate the input voltage. Verify that this voltage is 293 mV +/-10%, and that the minimum and maximum values are within 1% of average. Now replace the 2k resistor with a 1k resistor (available on the test jig). This should produce 571 mV at the input of the measure circuit. Run the test program to `Breakpoint 5b` and record the average value. Use the linear best-fit equation from step 4 to calculate the input voltage. Verify that this voltage is 571 mV +/-10%, and that the minimum and maximum values are within 1% of average. Remove the 1k resistor. [FW functions: power ADC-HV on, analog input channel 4, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]

7. Test the 4-20 mA sensor interface circuit 2. Connect a 2K resistor (available on the test jig) between J3-4 to J3-6. This should produce 293 mV at the input of the measure circuit. Run the test program to `Breakpoint 6a` and record the average value. Use the linear best-fit equation from step 4 to calculate the input voltage. Verify that this voltage is 293 mV +/-10%, and that the minimum and maximum values are within 1% of average. Now replace the 2k resistor with a 1k resistor (available on the test jig). This should produce 571 mV at the input of the measure circuit. Run the test program to `Breakpoint 6b` and record the average value. Use the linear best-fit equation from step 4 to calculate the input voltage. Verify that this voltage is 571 mV +/-10%, and that the minimum and maximum values are within 1% of average. Remove the 1k resistor. [FW functions: power ADC-HV on, analog input channel 4, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]

8. Test the x-axis accelerometer. Accelerometer produces 2.31VDC at 1g, 1.65 VDC at 0g, and 0.99 VDC at -1g. Place the PCB on edge so that it is resting on its long edge and J1 pin one is facing up. Run the test program to `Breakpoint 8a` and record the average value. Verify that the minimum and maximum values within 5% of average. Rotate the board so that it is lying flat and J1 is horizontal. Run the test program to `Breakpoint 8b` and record the average value.

Verify that the minimum and maximum values within 5% of average. Flip the board so that it is resting on its long edge and J1 pin one is facing down, then run the test program to `Breakpoint 8c` and record the average value. Verify that the minimum and maximum values within 5% of average. Enter the average ADC readings for the -1, 0, and 1 g accelerometer inputs into a spreadsheet and make a scatter plot of the accelerometer inputs versus the ADC readings. Fit a line to the data and determine the best-fit equation. Verify the R-value is greater than 0.95. [FW functions: power ADC on, analog input channel 6, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]

9. Test the y-axis accelerometer. Accelerometer produces 2.31VDC at 1g, 1.65 VDC at 0g, and 0.99 VDC at -1g. Place the PCB on edge so that it is resting vertically on its narrow edge and J1 is facing up. Run the test program to `Breakpoint 9a` and record the average value. Verify that the minimum and maximum values within 5% of average. Rotate the board so that it is lying flat and J1 is horizontal. Run the test program to `Breakpoint 9b` and record the average value. Verify that the minimum and maximum values within 5% of average. Flip the board so that it is resting vertically on its narrow edge and J1 is facing down, then run the test program to `Breakpoint 9c` and record the average value. Verify that the minimum and maximum values within 5% of average. Enter the average ADC readings for the -1, 0, and 1 g accelerometer inputs into a spreadsheet and make a scatter plot of the accelerometer inputs versus the ADC readings. Fit a line to the data and determine the best-fit equation. Verify the R-value is greater than 0.95. [FW functions: power ADC on, analog input channel 6, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]
10. Test the z-axis accelerometer. Accelerometer produces 2.31VDC at 1g, 1.65 VDC at 0g, and 0.99 VDC at -1g. Place the PCB on a level surface so that it lies flat and J1 facing up. Run the test program to `Breakpoint 10a` and record the average value. Verify that the minimum and maximum values within 5% of average. Rotate the board so that it is resting on its long edge and J1 pin one is facing up. Run the test program to `Breakpoint 10b` and record the average value. Verify that the minimum and maximum values within 5% of average. Flip the board so that it lies flat and the J1 facing down, then run the test program to `Breakpoint 10c` and record the average value. Verify that the minimum and maximum values within 5% of average. Enter the average ADC readings for the -1, 0, and 1 g accelerometer inputs into a spreadsheet and make a scatter plot of the accelerometer inputs versus the ADC readings. Fit a line to the data and determine the best-fit equation. Verify the R-value is greater than 0.95. [FW functions: power ADC on, analog input channel 6, preamp gain = 1, HP cutoff=0 Hz, LP cutoff=600 Hz]
11. Test the x-axis accelerometer frequency response. Strap a speaker from a set of headphones or ear buds to the PCB with a rubber band. Connect the speaker to the audio output jack on a PC. Run a program to generate a sine wave using the PC's audio adapter (such as http://www.marchandelec.com/ftp/fg_lite.exe), and set the output frequency to 100 Hz. Run the test program to `Breakpoint 11a`. Note the delta value. Increase the sine wave generator output by 50%, then reset the test program and run to `Breakpoint 11a`. Repeat until the delta value begins to increase. Next, increase the signal generator output by 100% and run to `Breakpoint 10b`. Record the delta value. Again, Increase the signal generator output by 100% and run to `Breakpoint 10c`, and record the delta value. Enter the average ADC readings for the relative accelerometer input levels (1, 2, 4) into a spreadsheet and make a scatter plot of the accelerometer inputs versus the ADC readings. Fit a line to the data and determine the best-fit equation. Verify the R-value is greater than 0.95. [FW functions: power ADC on, analog input channel 6, preamp gain = 16, HP cutoff=2 Hz, LP cutoff=600 Hz]
12. Repeat step 11 for the y-axis and z-axis accelerometers, using `Breakpoint 12a & 12b` and `Breakpoint 13a & 13b` respectively.
13. Power down power supply (if used) and disconnect the battery or power supply from J1.

5 Housing and Assembly

This section contains the assembly instructions for the CSM SmartDam mote. Each fully assembled mote consists of the following parts:

1. 1x PCB
2. 1x plywood mounting board
3. 3x 1" nylon screw, 3x 0.65" nylon spacers, and 3x nylon hex nuts (PCB)
4. 1x battery case
5. 2x 0.5" nylon screw, 2x nylon hex nuts (battery case)
6. 1x 3" diameter PVC unthreaded end cap
7. 1x 3" diameter PVC threaded end connector and accompanying screw cap
8. 1x 3" diameter, 14.5" length PVC tube with tapped hole (using M11 x 1 tap)
9. 1x 2.5" diameter, 1" length wedge tubing (with milled wedge)
10. 1x 2.5" diameter, 3" length spacer tubing
11. 1x 0.64 mm-spacing flat cable
12. 1x HFCS connector/cable assembly (board connector to J3)
13. 1x Hirose HR30-7R-12P male connector (housing connector)

Required tools:

1. Drill and drill bit: #6-32
2. Channel Locks or Pliers (needle nose)
3. Pipe primer and glue

Housing Assembly Procedure (refer to Figure 6):

1. Verify lengths are satisfactory to ensure a tight fit. If the fit is too tight, the 3" length spacer tubing may be cut or sanded. If the fit is too loose, the 14.5" tube may be cut or sanded. Note: Glue may add negligible length-spacing to the apparatus.
2. Wedge a mounting board into a wedge piece to verify fit; if the board does not fit, the wedge should be widened. Place mounting board into wedge so that the power-end of the PCB is located nearest the wedge.
3. Slide the wedge/mounting board apparatus into the 14.5" length tube so that the wedge end is located nearest the tapped hole.
4. Clean and glue the base of the wedge to the unthreaded end-cap, then place the end-cap on the 14.5" length tube as tightly as possible. Turn the apparatus around and place the now capped-end on a level surface. Press down firmly on the mounting board from the open-end to ensure it seated all the way down. Allow the glue to dry for 5 minutes.
5. When the glue is dry, remove the mounting board from the apparatus. The wedge and end cap should now be firmly glued together. Clean and glue the threaded-end connector and firmly press into place on the opposite (non-capped) end of the 14.5" length tube. Allow the glue to dry another 5 minutes.
6. Determine placement of battery case and drill #6-32 holes into the two mounting locations.
7. Mount PCB onto mounting board using (3x) nylon screws, spacers, and nuts at pre-drilled locations.
8. Mount battery case onto mounting board using (2x) nylon screws.
9. Place mounting board apparatus into the pipe apparatus, making sure it is seated in the wedge. Screw on end-cap.

Wiring Assembly:

1. Cut three lengths of 26 gauge stranded insulated wire to the same length as the HFCS connector/cable assembly (~ 2 feet).
2. Use the 26 gauge wires and the HFCS connector/cable assembly to wire the housing connector to J1 and J3 as specified in Table 3.
3. Connect the positive terminal of the battery holder to J1 pin 1, and the negative battery holder terminal to J1 pin 2. Use 26 gauge stranded wire as needed.

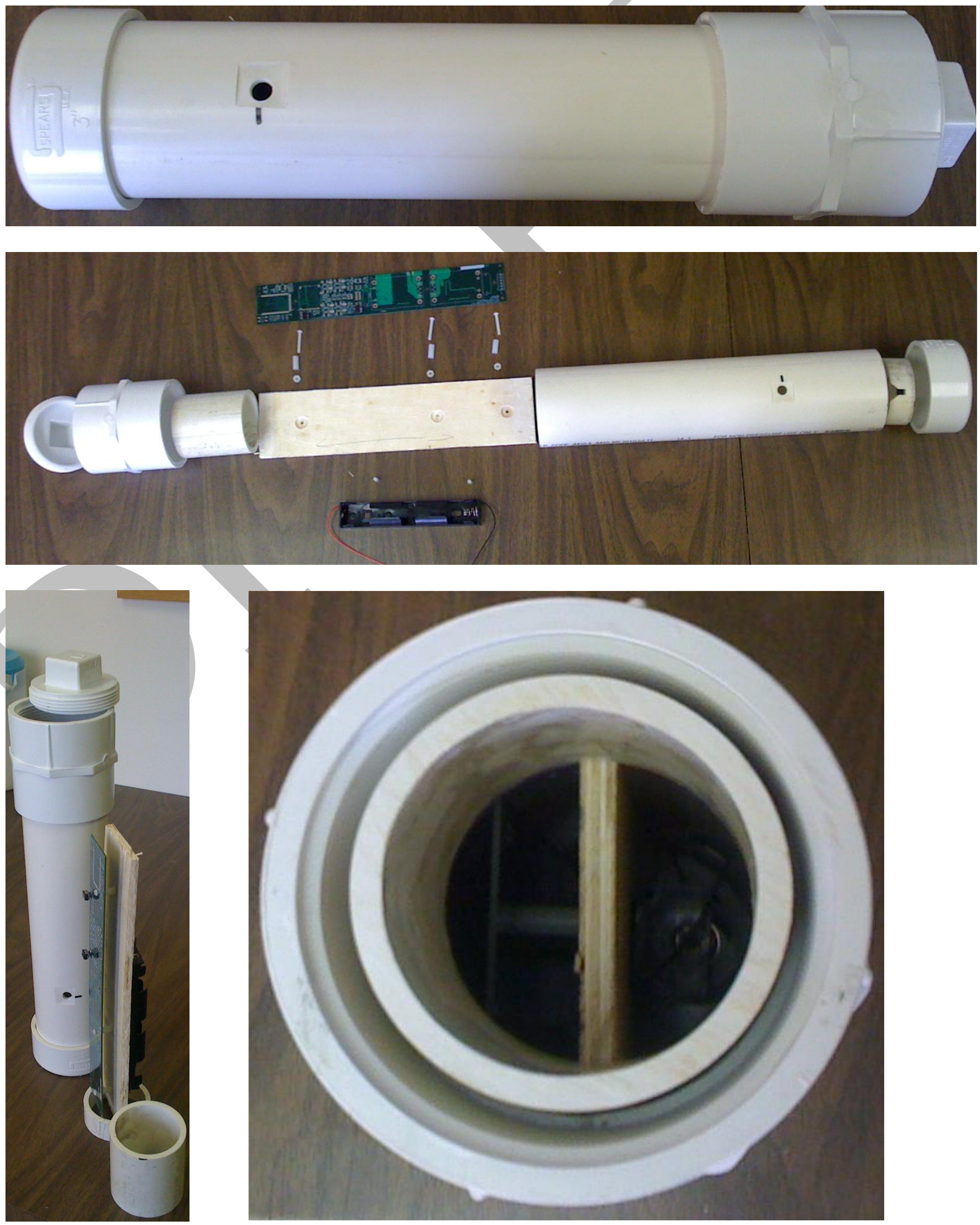


Figure 6. Photos illustrating housing assembly procedure.

6 Software and Firmware Interfaces

6.1 Firmware I/O Interface

The ATXMEGA256A3 processor in the LSR module is connected to the circuitry as outlined in the following table.

Atmel Pin	LSR Module Pin	PCB Signal	Connection	Description
PA2	17	IO1	Current generator for electrodes 1 and 2: right side H bridge	0=low side on, 1=high side on
PA1	18	IO2	Current generator for electrodes 1 and 2: left side H bridge	0=low side on, 1=high side on
PA7	19	IO3	Current generator for electrodes 3 and 4: right side H bridge	0=low side on, 1=high side on
PA4	20	IO4	Current generator for electrodes 3 and 4: left side H bridge	0=low side on, 1=high side on
PA5	21	IO5	EN: ADG758 (mux)	Enable pin for ADC input selection multiplexer
PA6	22	IO6	A0: ADG758 (mux) and AD8231 (amp)	ADC input selection multiplexer, input amplifier gain
PB1	23	IO7	A1: ADG758 (mux) and AD8231 (amp)	ADC input selection multiplexer, input amplifier gain
PB2	24	IO8	A2: ADG758 (mux) and AD8231 (amp)	ADC input selection multiplexer, input amplifier gain
PB3	25	IO9	CS: FM25V05-G (FRAM)	CS for FRAM memory chip (SPI)
PF3	27	IO10	CS: DAC8881	CS for DAC (SPI)
PF2	28	IO11	LDAC: DAC8881	
PF1	29	IO12	CS: AD7684 and AD7767	CS for ADCs (only one ADC installed)
PF0	30	IO13	DRDY: AD7767	ADC data ready
PE5	31	IO14	MCLK: AD7767	ADC clock input
PE4	32	IO15	SYNC: ADG739 (mux)	SYNC pin for filter configuration mux, channels 1,2,5,6
PC1	37	IO16	SYNC: ADG739 (mux)	SYNC pin for filter configuration mux, channels 1,2,5,6
PC0	38	IO17	EN: AP122AUJZ	Enable for 3.3VDC-2 and 3.3VDCA power supplies
PF5	39	IO18	EN: AP122AUJZ	Enable for 3.3VDC-3 power supply
PF6	40	IO19	EN: AP122AUJZ	Enable for 3.3VDC-2 power supply

PF7	41	IO20	SHDN: LT3477	Enable 13.8 VDC power supply
PA3	42	IO21	CS: MCP23S17	CS for SPI bus on I/O expander chip
PA0	15	AN1	VO: LM61	Analog temperature signal
PB0	16	AN2		Analog battery voltage signal
PE3	33	INT-TX	MAX3160 (transceiver)	Asynch serial to internal devices
PE2	34	INT-RX	MAX3160 (transceiver)	Asynch serial to internal devices
PC3	35	EXT-TX	MAX3160 (transceiver)	Asynch serial to external controller
PC2	36	EXT-RX	MAX3160 (transceiver)	Asynch serial to external controller
PE1	56	IIC-SCL	IIC bus	
PE0	57	IIC-SDA	IIC bus	
PC4	58	SPI-SS	SPI bus	IO expander, FRAM, SD Card, ADC, DAC, filter config muxes
PC7	59	SPI-CK	SPI bus	
PC6	60	SPI-MISO	SPI bus	
PC5	61	SPI-MOSI	SPI bus	

MCP23S17 Pin	PCB Signal	Connection	Description
1	PIO22	MOS switch	High voltage power supply for current generator (on/off)
2	PIO23	PhotoMOS switch	Switch to indicate if SD Card is present
3	PIO24	PhotoMOS switch	Switch battery voltage monitor circuit to battery
4	PIO25	CS: SD Card	CS for SPI bus interface to SD Card
5	PIO26		SPARE
6	PIO27	PhotoMOS switch	AC/DC Accelerometer coupling
7	PIO28	PhotoMOS switch	Connect Electrodes 3 and 4 to measure circuits. Make sure to disconnect when current generator is on.
8	PIO29	PhotoMOS switch	Connect Electrodes 1 and 2 to measure circuits. Make sure to disconnect when current generator is on.
21	PIO30	CS: AD8231	Input amplifier 1
22	PIO31	CS: AD8231	Input amplifier 2
23	PIO32	CS: AD8231	Input amplifier 3
34	PIO33	CS: AD8231	Input amplifier 4
35	PIO34	CS: AD8231	Input amplifier 5
36	PIO35	CS: AD8231	Input amplifier 6
37	PIO36	CS: AD8231	Input amplifier 7
38	PIO37	CS: AD8231	Input amplifier 8

System Power Modes	
ADC Power	On: PCB I/O17 = 1, Off: PCB I/O17 = 0
Ext1 Power	On: PCB I/O18 = 1, Off: PCB I/O18 = 0

Ext2 Power	On: PCB I/O19 = 1, Off: PCB I/O19 = 0
HV Power	On: PCB I/O20 = 1, Off: PCB I/O20 = 0

Analog Input Selection Table	
Input channel selection coding	1: *abc*=000, 2: *abc*=001, 4: *abc*=010, 8: *abc*=011, 16: *abc*=100, 32: *abc*=101, 64: *abc*=110, 128: *abc*=111
Programming	PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O5=1
Note	Set chip select PCB I/O5=0 when using {I/O8, I/O7, I/O6} to communicate with other peripherals

Preamp Gain Settings Table	
Channel 1	chip select PCB I/O30=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O30=0
Channel 2	chip select PCB I/O31=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O31=0
Channel 3	chip select PCB I/O32=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O32=0
Channel 4	chip select PCB I/O33=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O33=0
Channel 5	chip select PCB I/O34=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O34=0
Channel 6	chip select PCB I/O35=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O35=0
Channel 7	chip select PCB I/O36=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O36=0
Channel 8	chip select PCB I/O37=0, PCB {I/O8, I/O7, I/O6}=0b*abc* chip select PCB I/O37=0
Gain coding	1: *abc*=000, 2: *abc*=001, 4: *abc*=010, 8: *abc*=011, 16: *abc*=100, 32: *abc*=101, 64: *abc*=110, 128: *abc*=111

Analog Filter Settings Table	
Channel 1	chip select PCB I/O15=0, shift data in on SPI port MSB first, data=0b*PPPPabcd*, chip select PCB I/O15=1
Channel 2	chip select PCB I/O15=0, shift data in on SPI port MSB first, data=0b*abcdPPPP*, chip select PCB I/O15=1
Channel 3	chip select PCB I/O16=0, shift data in on SPI port MSB first, data=0b*PPPPabcd*, chip select PCB I/O16=1
Channel 4	chip select PCB I/O16=0, shift data in on SPI port MSB first,

	data=0b*abcdPPPP*, chip select PCB I/O16=1
Channel 5	chip select PCB I/O15=0, shift data in on SPI port MSB first, data=0b*PPPPabcd*, chip select PCB I/O15=1
Channel 6	chip select PCB I/O15=0, shift data in on SPI port MSB first, data=0b*abcdPPPP*, chip select PCB I/O15=1
Channel 7	chip select PCB I/O16=0, shift data in on SPI port MSB first, data=0b*PPPPabcd*, chip select PCB I/O16=1
Channel 8	chip select PCB I/O16=0, shift data in on SPI port MSB first, data=0b*abcdPPPP*, chip select PCB I/O16=1
High pass cutoff frequency	2 Hz: *a*=0; 0 Hz: *a*=1
Low pass cutoff frequency	infinite: *bcd*=000; 32 kHz: *bcd*=001; 6 kHz: *bcd*=010; 600 Hz: *bcd*=100
Note	Notation 0b*PPPPabcd* means to leave the most significant nibble at its original value, and change the least significant nibble for the required filter settings. This requires that the microprocessor keeps a copy of the contents of these ports in local registers.

6.2 MODBUS Register I/O Table

Modbus is a fanility of serial communications protocols that has become one of the *de facto* standards in the industry, and it is now amongst the most commonly available means of connecting industrial electronic devices. Each device intended to communicate using Modbus is given a unique address. In serial port networks the Modbus RTU protocol (provided by the FreeModbus library) is used (consider using Modbus TCP), where only the node assigned as the Master may initiate a command. In an GP-Mote network, the Master node receives commands over the serial port and relays them to the wireless network. The Master's serial port may connect to a local computer that controls the wireless network, or to a remote computer via a modem and the internet. Each Modbus command contains the Modbus address of the device it is intended for, and only the intended device will act on the command even though other devices might receive it (an exception is specific broadcastable commands sent to node 0 which are acted on but not acknowledged). All Modbus commands contain checksum information, ensuring that a command arrives undamaged. The basic Modbus commands can instruct a node to read or write a value in one of its I/O ports or registers. Registers can by 8 , control or read an I/O port, as well as commanding the device to send back one or more values contained in its registers.

Modbus RTU is used in serial communication & makes use of a compact, binary representation of the data for protocol communication. The RTU format follows the commands/data with a cyclic redundancy check checksum as an error check mechanism to ensure the reliability of data. Modbus RTU is the most common implementation available for Modbus. A Modbus RTU message must be transmitted continuously without inter-character hesitations. Modbus messages are framed (separated) by idle (silent) periods. Refer to the Modbus RTU specification for more details.

A transmitted or received frame contain (in order): a slave address (1 byte), function code (1 byte), data (0-252 bytes), and CRC (2 bytes). Both data and control values are mapped as 16 bit file registers with addresses ranging from 0 to 65535. A record is a group of registers (0 to 65535), and a file is a group of records with addresses ranging from 0 to 9999. The file addresses range from 0 to 65535. The length of the registers is limited by the packet length limitations (253 bytes). The GP-Mote addressing is arranged such that within a given file, the record and register addressing is contiguous, so multiple records can be read or written with a single command as long as they are adjacent and will fit in a single packet. File 0 is reserved for configuration and the remaining files are reserved for acquired data. A different register in each data file for each mote sensor. If N digitize sequences have been performed, there will be N+1 data file records that can be read.

File 0 – Mote Configuration		
Register Address	Function	Description
Record 0 – Clock Configuration		
0	Slow Clock Ticks	32.768 Hz increment
1	Fast Clock Ticks	32 MHz increment
2	Date	Days since Jan 1, 1970
3	Hours	
4	Seconds	
5	Enable Alarm	
6	Awaken Alarm Day	
7	Awaken Alarm Hour	
8	Awaken Alarm Seconds	
9	Enable Awaken Interval	
10	Awaken Interval Days	
11	Awaken Interval Hours	
12	Awaken Interval Seconds	
Record 1 – ADC Configuration		
0	ADC Sample Interval for channel 1	In milliseconds
5	ADC Sample Interval for channel 6	
6	Number of samples per acquisition cycle for channel 1	The number of samples recorded each time an acquisition cycle occurs. A cycle can initial from a command, an alarm, or an awaken interval.
11	Number of samples per acquisition cycle for channel 6	
12	Number of samples to average for channel 1	Number of ADC samples that will be averaged and stored as a single value.
17	Number of samples to average for channel 6	
18	Recording hold-off in number of samples for channel 1	
23	Recording hold-off in number of samples for channel 6	
24	Seismic channel interleave mode	0=no interleaving 1=X,Z interleaving 2=Y,Zinterleaving 3=X,Y,Z interleaving
Record 2 – Radio Configuration		
0	Preamble length	In bytes
1	Receiver on time	This register and the next specify the receiver power duty cycle (in ms)
2	Receiver off time	(in ms)
3	Transmitter power	
4	Receiver sync interrupt enable	

Record 3 – Current Generator Configuration		
0	Peak Amplitude	In mA for values greater than 0, in volts for value less than 0
1	Waveform mode	0=square, 1=triangle, 2=sine
2	Duty cycle	In percent
3	Number of frequencies	
4	First frequency	In Hz for values greater than 0, In mHz for values less than 0
5	Last frequency	
6	Number of frequencies per decade	
7	Sweep type	0=linear, 1=logarithmic

File N – Data		
Register Address	Function	Description
Record 0 – Clock Data		
0	Slow Clock Ticks	32.768 Hz increment
1	Fast Clock Ticks	32 MHz increment
2	Date	Days since Jan 1, 1970
3	Hours	
4	Seconds	
5	Battery Voltage	
6	Temperature	
Record N – Channel Data		
0		Accelerometer coupling
1	Analog Channel 1 ADC [15:0]	
2	Analog Channel 1 ADC [gain bits][filter bits] [23:16]	
11	Analog Channel 6 ADC [15:0]	
12	Analog Channel 6 ADC [gain bits][filter bits] [23:16]	

7 Specifications

Inputs
8 channels
Input gain: 1-128
Input impedance: 10^9 ohms
ADC resolution: 24 bits, 115 dB, 128 kSPS

Sensor Excitation
Programmable with 16 bit 1 MSPS DAC
Arbitrary waveform generation
Current servo mode
Output: up to 200V, 500 mA

Standard Geophysical Measurements
Spontaneous (self) potential
Resistivity
Induced polarization
Non-linear complex resistivity
Three component seismometer
Ambient temperature

Optional Geophysical Measurements
Ground penetrating radar
Time domain reflectometer
Time domain EM induction
Broadband tensor magnetometer

General Purpose External Measurements
4-20 mA sensors

Bridge sensors
Strain, moisture, pressure, pH, etc.

Radio Transceiver
Frequency: 900 MHz ISM band
Modulation: DSSS, O-QPSK, BPSK
Data rate: 1 MBps
Antenna: internal 3 dBi, optional external antenna
Wireless time synchronization: 1 µs
RF output power: 250 mW
RF receive sensitivity: -102 dBm
Range: up to 2 miles

External Sensor Connector
Hirose: HR30 or RM15TRD

Dimensions
Diameter: 2.25 inches
Length: 16.5"

CPU
256 K Flash
Data storage: SD Card (up to 4 GB)
Program storage: 32 kB
Peripheral interface: RS232, RS422, RS485, MODBUS

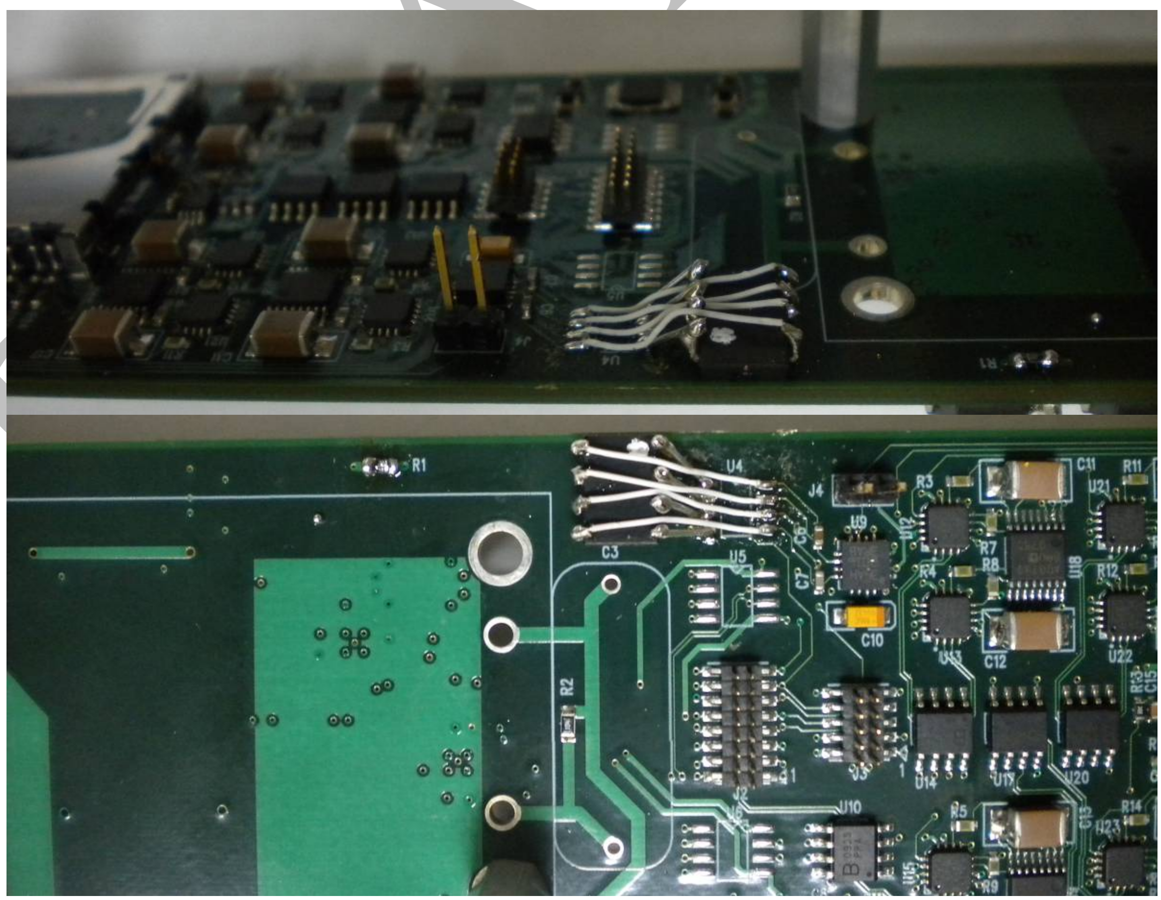
Power
Internal 3.7 V LiPo or Li ion (14.8 V when configured for galvanic geophysical measurements)
Optional integrated PV charger
Current draw 5 µA sleep
100 mA typical in operation
Connector for external power supplies

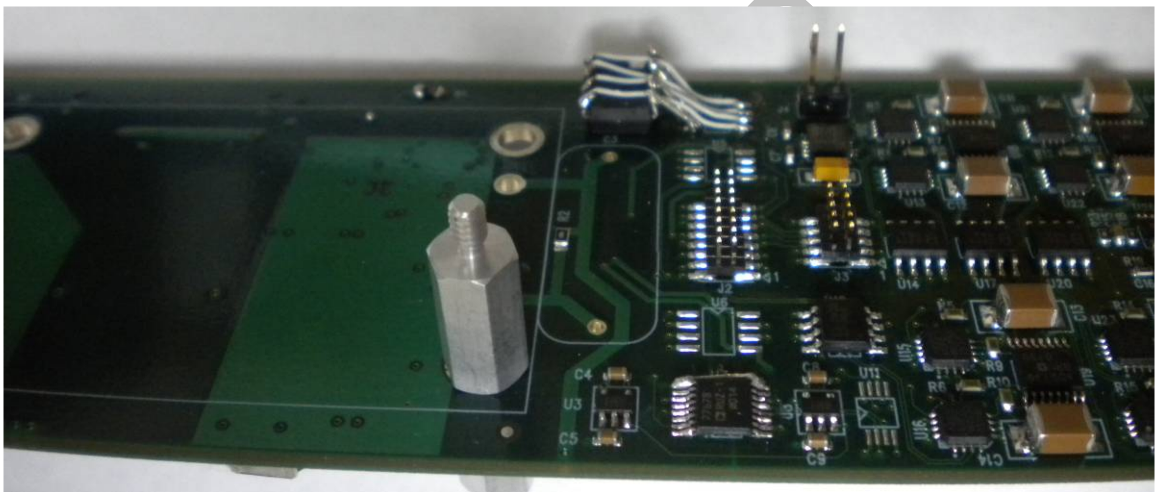
8 Errata

This section describes the errata in present revision of the sensor mote.

8.1 Modifications to top of PCB board:

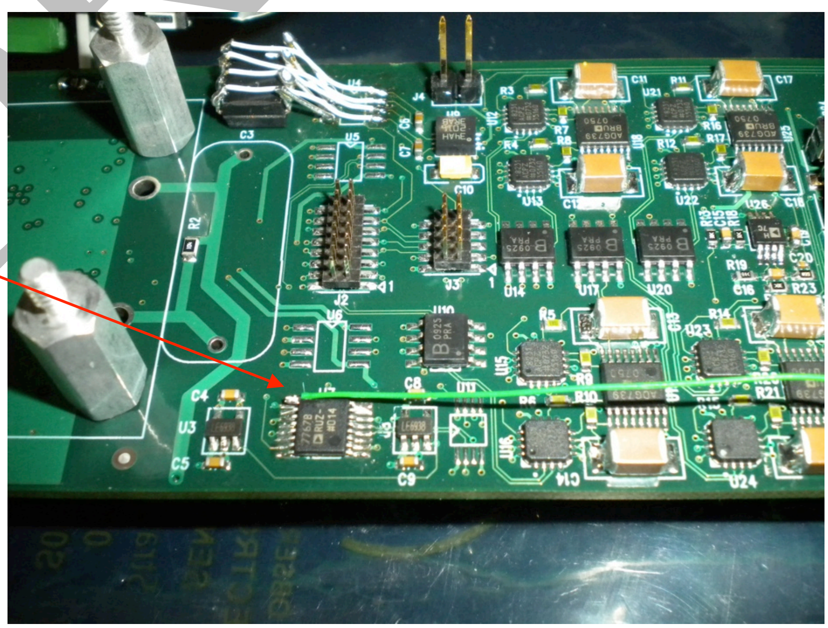
1. U4 and U29 need to be glued to the PCB board upside-down next to where their respective pads are located. Below is an example of how we would like this to be done. The I.C. pins have been shortened and soldered with 30 AWG wire. The white dot on the bottom of the I.C. designates pin 1.





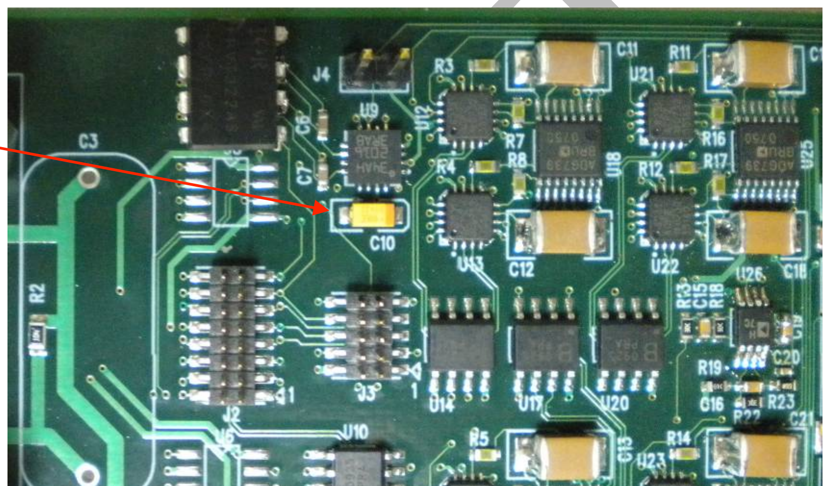
2. Connect U7 pin 7 to U7 pin 8. Lift U7 pin 9 and connect to U33 pin 8.

U7



3. The polarity of the polarized caps is not clearly marked on the silk screen of the PCB. The following picture indicates how these capacitors are to be mounted.

C10

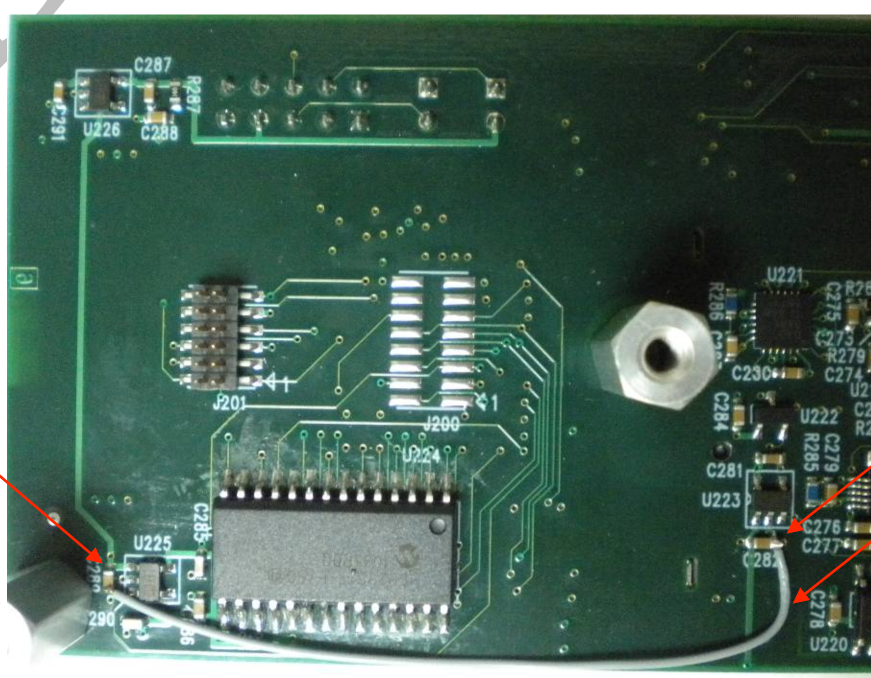


C10: The polarity marking for this capacitor should be to the right of the capacitor on the PCB board. The photo shows the top of PCB board near the center.

8.2 Modifications to bottom of PCB board:

1. Connect analog ground to digital ground by adding a jumper between C282 and C289. The photo shows the bottom of PCB board near the lower left.s

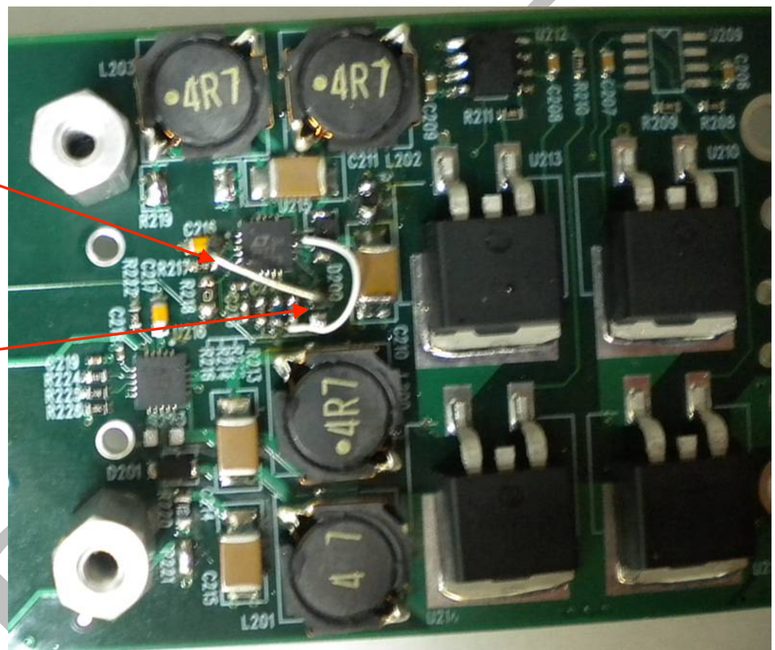
C289



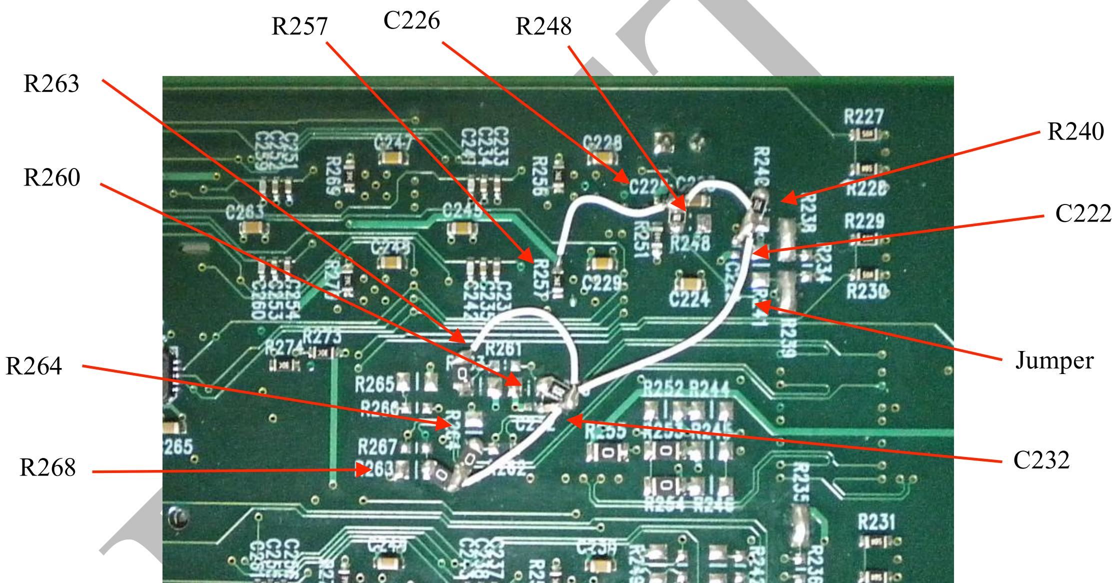
C282

Jumper

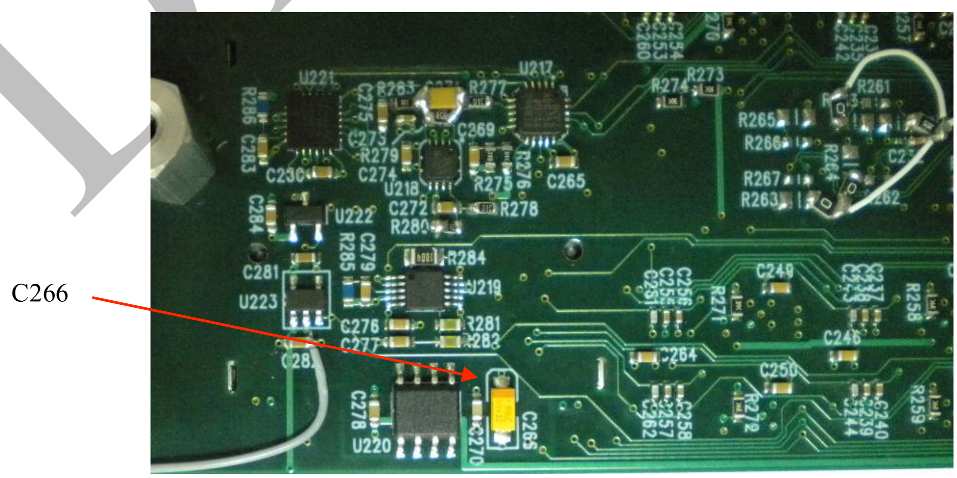
2. Connect the top pad of R213 to the right pad of C216 with a jumper wire. The photo shows the bottom of PCB board near the center.



3. Perform the flowing circuit modification.
    a. Add resistor R240 by soldering on end to the top pad of R240, letting the other end float above the PCB board 1/16th to 1/8th inch.
    b. Add capacitor C222 by soldering on end to the top pad of C222, letting the other end float above the PCB board 1/16th to 1/8th inch. Because the capacitor is so small, it could also be mounted vertically.
    c. Add resistor R268 by soldering on end to the top pad of R268, letting the other end float above the PCB board 1/16th to 1/8th inch.
    d. Add resistor R260 by soldering on end to the top pad of R260, letting the other end float above the PCB board 1/16th to 1/8th inch.
    e. Add capacitor C232 by soldering on end to the top pad of C232, letting the other end float above the PCB board 1/16th to 1/8th inch. Because the capacitor is so small, it could also be mounted vertically.
    f. Add resistor R263 by soldering on end to the top pad of R263, letting the other end float above the PCB board 1/16th to 1/8th inch.
    g. Add resistor R248 by soldering on end to the top pad of R248, letting the other end float above the PCB board 1/16th to 1/8th inch.
    h. Add capacitor C226 by soldering on end to the top pad of C226, letting the other end float above the PCB board 1/16th to 1/8th inch. Because the capacitor is so small, it could also be mounted vertically.
    i. Add resistor R264 by soldering on end to the top pad of R264, letting the other end float above the PCB board 1/16th to 1/8th inch.
    j. After all of the resistors and capacitors have been installed according to the instructions above, all of the floating leads can be connected together as shown in the picture below. Some of the components are so close that all that is needed for a connection is some solder. Once this is done, a jumper from the floating end of R248 needs to be connected to the top side of R257.



4. The Polarity of the polarized caps is not marked on the silk screen of the PCB. Therefore the following picture with description will tell how the capacitor is to be mounted.



C266: The polarity marking for this capacitor should be on the top of the capacitor on the PCB board. The photo shows the bottom of PCB board in the lower left.

9 Customer License Agreement

This is a legal agreement between Earth Science Systems, LLC (ESS) and you, the Customer. If you use this equipment, you willingly accept all the terms and conditions of this agreement. Specifically, you agree to the following.

1. All of the Intellectual Property of the equipment designed and produced by ESS remains the sole property of ESS.
2. The Customer will not attempt to reverse engineer this product or involve others in such acts.
3. The Customer acknowledges that it has no rights to distribute or produce hardware.
4. The Customer hereby agrees to hold harmless and indemnify ESS to the fullest extent authorized or permitted by the provisions of the Bylaws and the Code.
5. There is no warranty expressed or implied offered by ESS.
6. This agreement will be governed by the laws of the United States of America. If any part of this Agreement is found void and unenforceable, it will not affect the validity of the balance of the Agreement, which shall remain valid and enforceable according to its terms.

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