SAM Construction Manual

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I. Description

The Simple Aurora Monitor (SAM) magnetometer system was designed by Dirk Langenbach (hardware) and Karsten Hansky (software). A schematic is provided at the end of this document.

The basis for the SAM is a fluxgate magnetometer sensor manufactured by Speake & Co Llanfapley. The sensor signals are processed by a Microchip PIC16F877 microcontroller, which provides serial data, analog and alarm outputs. The basic specifications for the magnetometer system are

- Range: Approximately ± 50000 nT
- Resolution: 1 – 2 nT
- Connection of 2 sensors
- Microprocessor controlled, 16 MHz clock
- Data displayed on backlit 4x20 LCD (STN yellow/green standard)
- Measured data transmitted over EIA-232 serial interface as ASCII text
- Measurements available on two analog outputs (adjustable 0 ...+5 V or -2.5 ...+2.5 V)
- Real-time clock with backup battery
- Form A relay output for K-index alarm (maximum contact rating 200 V dc or V ac-peak, 1.0 a dc or a ac-peak, in a combination not exceeding 20 w)
- Opto-isolated input for detection of external voltage condition to deactivate measurements
- Software setup and measurement logging via EIA-232 serial interface
- Power: 12 V dc at 60-80 mA
- Dimensions (optional enclosure): 200 mm x 112 mm x64 mm
- Temperature sensing capability (not yet supported in North American version)
- Connectors:
  - I/O DIN 8-pin
  - Sensor DIN 6-pin
  - EIA-232 DB-9M
  - dc power coaxial 2.1 mm x 5.5 mm, center +
- Keyboard controls:
  - Command mode (F1)
  - Calibration mode (F2)
  - Software reset (F3)
  - Display backlight (F4)
- Application software:
  - SAM_VIEW
  - SAM_INI
  - SAM_BROWSER
  - SAM_STAT

II. General Building Tips:

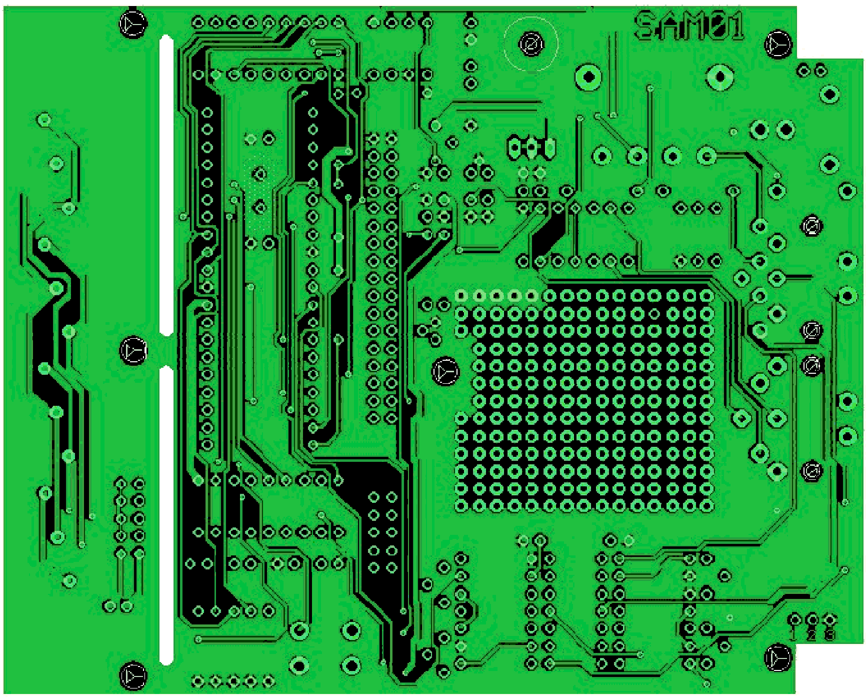
- The SAM kit is built using conventional electronic construction techniques. All components are through-hole types
- Before starting assembly, perform an inventory of all components – see the file *SAM Kit Parts List.xls* on the CD
- Some parts are very small and easy to lose or may become tangled with other parts (for example, connector contacts), so be careful emptying the reclosable plastic bags and keeping track of the parts during inventory and during assembly
- Resistors supplied with the kit may or may not have color coded stripes to indicate their value. The colors, if used, may have little contrast and be difficult to read. It is best to confirm resistor values with an ohmmeter
- Review online sources for soldering techniques if necessary (for example, www.elecraft.com/TechNotes/N0SS_SolderNotes/N0SS_SolderNotesV6.pdf)
- The parts required for construction are listed in a table at the beginning of each section. As each component or group of components is soldered and trimmed, place a checkmark in the boxes provided
- READ ALL NOTES AND COMMENTS that follow the parts list in each section before assembling or soldering any components
- After soldering a small group of components, trim the extra lead lengths with a flush wire cutter
- After completing each section, use a magnifying glass and bright work light to examine each and every solder joint for inadvertent bridges or cold solder. Do not proceed with the next section until repairs are made
- The leads of some components are taped together. Do not pull the leads out of the tape and then insert into the PCB. The tape gum may scrape off and make soldering difficult. There is plenty of extra lead so simply clip the part of the lead contacting the tape
- Dual-inline integrated circuits will have a dimple or notch on one end and it must be oriented as indicated on the PCB silkscreen
- Diodes have a bar or stripe on one end and it must be oriented with the bar indicated on the PCB silkscreen
- Electrolytic capacitors are marked with a bar on one side, indicating the negative lead, and one of the leads is longer, indicating the positive lead. The positive (longer) lead must be inserted in the hole with a + symbol indicated on the PCB silkscreen
- Leave all integrated circuits and other semiconductor devices in their anti-static carriers (aluminum foil) until they are to be installed
- Use anti-static protection whenever installing integrated circuits and other semiconductor devices
- After integrated circuits and other semiconductor devices are installed on the PCB, use static protection whenever handling the PCB
- Use solder with a diameter $\leq$ 0.031 in. diameter
- Soldering component leads to the ground plane may require a 60 w soldering iron; do not use this size iron for general soldering unless it has a very fine tip

III. Separate the Controller PCB and Keyboard PCB

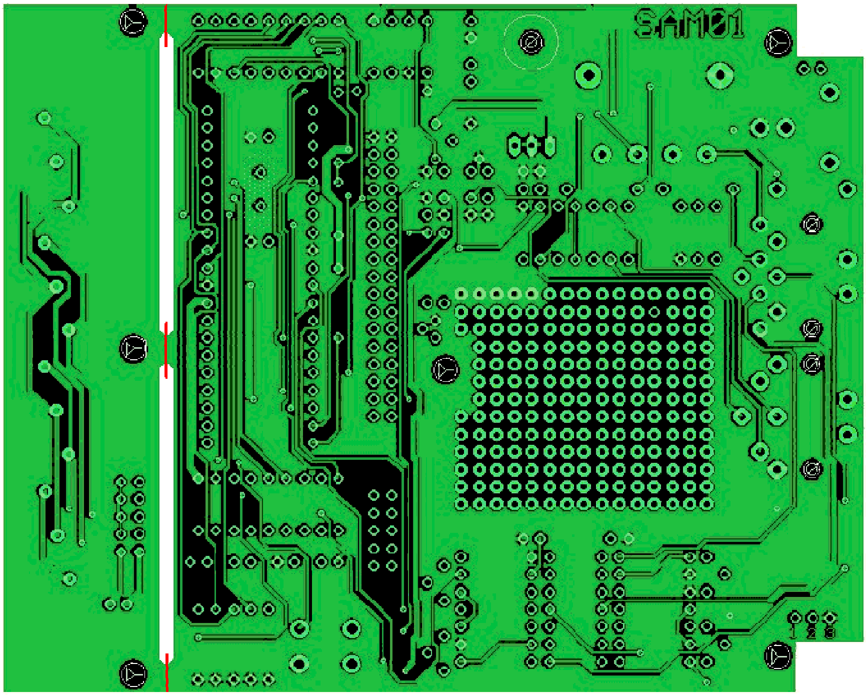
Required parts:

Parts list ID	**Qty**	**Description**
☐	1	Printed circuit board

As packaged in the kit, the printed circuit board (PCB) appears as shown in the illustration below. It actually consists of two PCBs joined by three small bridges. The left portion is for the keyboard and the right portion is for the main controller.



Before placing any components, carefully cut the three small bridges between the controller PCB and keyboard PCB with a fine saw such as a modeler's saw. See red cutting line on the illustration below. Do not attempt to break the two boards apart without cutting because the likelihood is very high the boards will be damaged.

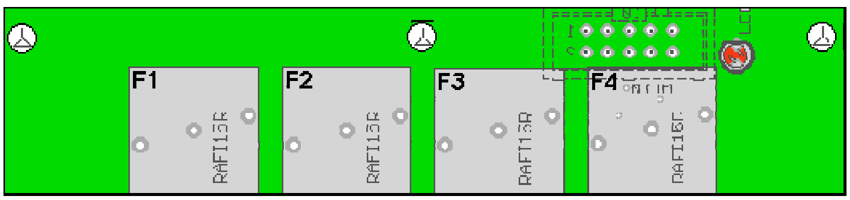


After separating the two PCBs, the sharp edges can be removed with some fine sandpaper or a file. It may be helpful to sandwich the PCB between two pieces of soft wood and clamp in a vise while cutting; do not clamp the PCB directly in the vise jaws.

IV. Install the Keyboard Components

Required parts:

Parts list ID	Qty	Description
D4 ☐	1	LED, 3 mm, red
SV3 ☐	1	10-pins ribbon cable socket
TA1 ☐, TA2 ☐, TA3 ☐, TA4 ☐	4	Pushbutton RAFI RF 15R



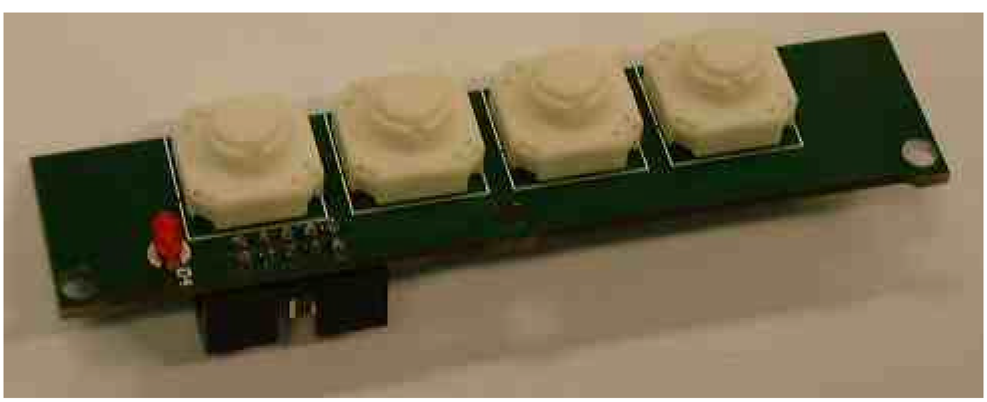
Install the four pushbuttons and red LED on the top (silkscreen side) and the ribbon cable socket on the bottom:

- Solder the four pushbuttons (they will fit only one way on the silkscreen side of the PCB)
- Solder the LED with shortest lead (cathode) in the hole nearest to the edge of the board. If the keyboard will be mounted in the optional enclosure, the body of the LED will have to be raised slightly. In this case, raise the LED enough so the flange at the bottom of the LED body is flush with the pushbutton body
- Turn the board upside down and place the 10-pin ribbon cable socket with the aperture (center polarization slot) nearest to the edge of the board

☐ Double-check all components for location and check polarity sensitive components (LED)

☐ Double-check all soldering

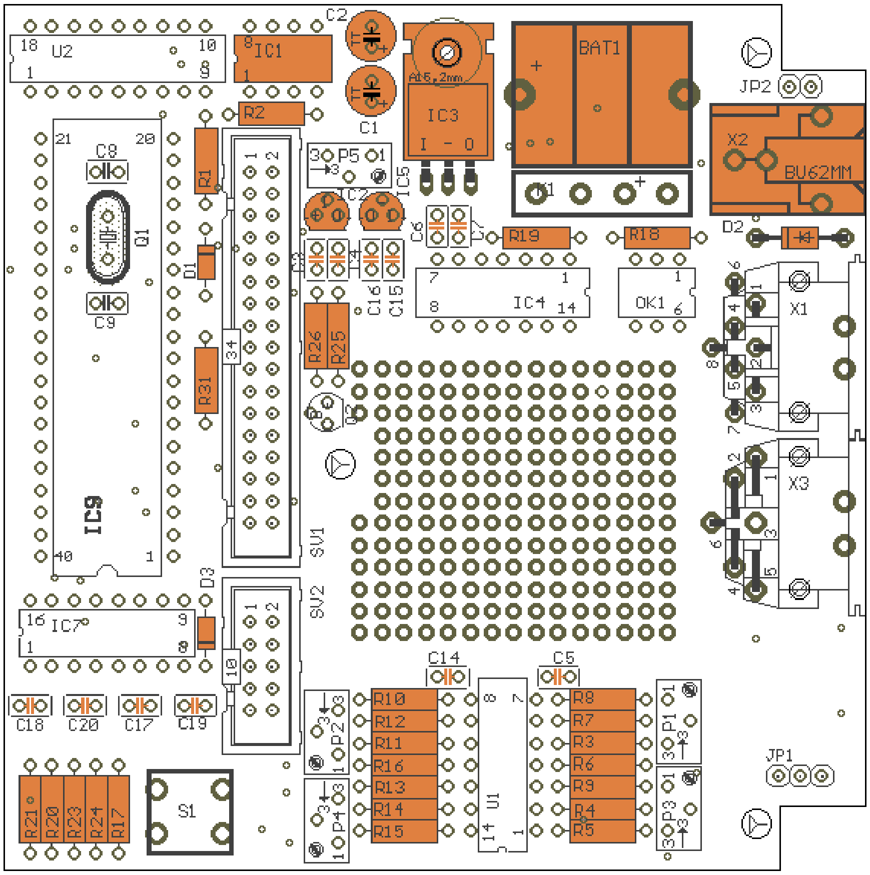
When the keyboard PCB is finished it should look like the illustration below. Set the keyboard PCB aside.



V. Install the Power Supply Components

Required parts:

Parts list ID	Qty	Description
R25 ☐	1	Resistor, 68R1 1/4 w
R17 ☐, R18 ☐, R31 ☐	3	Resistor, 1k, 1/8 w
R26 ☐	1	Resistor, 2k2, 1/8 w
R3 ☐, R10 ☐, R19 ☐	3	Resistor, 10k, 1/8 w
R22 ☐, R27 ☐	2	Resistor, 10k, 1/8 w
R4 ☐, R11 ☐	2	Resistor, 39k, 1/8 w, see Note 3
R2 ☐, R6 ☐, R7 ☐	3	Resistor, 100k, 1/8 w
R8 ☐, R9 ☐, R13 ☐	3	Resistor, 100k, 1/8 w
R14 ☐, R15 ☐, R16 ☐	3	Resistor, 100k, 1/8 w
R20 ☐, R21 ☐, R23 ☐	3	Resistor, 100k, 1/8 w
R24 ☐	1	Resistor, 100k, 1/8 w
R5 ☐, R12 ☐	2	Resistor , 470k, 1/8 w
D1 ☐, D3 ☐	2	Diode, 1N4148
D2 ☐	1	Diode, 1N4007
D5 ☐	1	Diode, 1N5819 Schottky
C5 ☐, C6 ☐	2	Capacitor, ceramic, 100 nF
C7 ☐, C14 ☐	2	Capacitor, ceramic, 100 nF
C15 ☐, C16 ☐	2	Capacitor, ceramic, 100 nF
C17 ☐, C18 ☐	2	Capacitor, ceramic, 100 nF
C19 ☐, C20 ☐	2	Capacitor, ceramic, 100 nF
C1 ☐, C2 ☐	2	Capacitor, electrolytic, 10 μF/25 V
IC1 ☐	1	Voltage converter, ICL7660, –5 V out
IC3 ☐	1	Voltage Regulator 7805, TO-220, +5 V/1 A
IC5 ☐	1	Voltage Regulator 78L05, TO-92, +5 V/100 ma
☐	1	4-40 x 5/16 in. screw, washers & nut
X2 ☐	1	dc power socket BU62MM
G1 ☐	1	Lithium battery, 3 V, 3-pin, see Note 4
ac power adapter	1	12VDC/200 mA (not supplied except as accessory)



Notes:

1. IC2, C3, and C4 are not used in this version; D5 replaces R1 in this version
2. Install all components from the top (silkscreen) side of the PCB
3. Early versions used 10k resistors
4. If necessary, bend the negative pin slightly so battery has at least 2 mm clearance from the dc power socket X2
5. R22 and R27 are not shown in illustration above; they are located just below X3. On the schematic, they are the two 10k resistors connected to IC4 pins 2 and 13

- Solder all resistors
- Solder all 100 nF ceramic capacitors (these capacitors are not polarity sensitive and may be placed either direction)
- Solder both electrolytic capacitors; these capacitors are polarity sensitive and must be installed with the proper orientation. The bar marked on the side of the capacitor indicates the negative lead, and the longest lead is the positive lead. Be sure to put the long lead in the hole marked with the + polarity
- Solder the dc power connector. Use enough solder to make a rigid mechanical connection
- Solder the diodes. Diodes are polarity sensitive and must be installed with the proper orientation. The bar or stripe on one end of the diode indicates the cathode and it must correspond with the bar on the PCB silkscreen
- Solder the integrated circuit voltage regulators IC1 and IC5, observing their proper orientation.

- Solder the voltage regulator IC3. The leads on IC3 should be bent so the TO-220 tab can lie flat on the PCB. Use 4-40 hardware (supplied) to mechanically secure the tab; insert the screw from the bottom of the PCB
- Solder the battery. The battery fits only one way. The battery terminals are VERY thin and fragile. Be VERY careful handling the battery. DO NOT short it out. Note: The + terminal of the battery has two pins on the edge and the – terminal has one pin. Your SAM Kit includes one of two battery types, with slightly different spacing between the + and – terminals. The PCB may be equipped with one or two holes for the – terminal. If the PCB has one hole, it may be necessary to slightly bend the battery – terminal so that it fits the PCB. The battery must be installed with at least 2 mm clearance from the dc power socket X2

☐ Double-check all components for location and check polarity sensitive components (electrolytic capacitors, diodes, battery), voltage regulators and integrated circuits for proper orientation.
☐ Double-check all soldering
☐ If you installed IC sockets, be sure that only IC1 (ICL7660) is plugged in at this time

VI. Test the Power Supply

The power supply components are now ready to test.

AC power adapters are a huge source of problems because they generally are very cheap and many are poorly designed. If you purchased your SAM with an ac adapter (North America customers only), you received a quality brand with sufficient capacity.

If you supply your own ac adapter its output must be rated at least 9 to 12 Vdc, 200 mA. DO NOT attempt to power the SAM with an under-rated ac adapter. DO NOT use an ac adapter with an output higher than approximately 17 Vdc. The 7805 regulators used in the SAM have a maximum input voltage rating of 35 Vdc but you should allow for a margin of 1/2. Similarly, the SAM input current draw is approximately 60-80 mA (fully built with sensors connected) but you should allow for a margin of at least 2. DO check your ac adapter for proper polarity, center +.

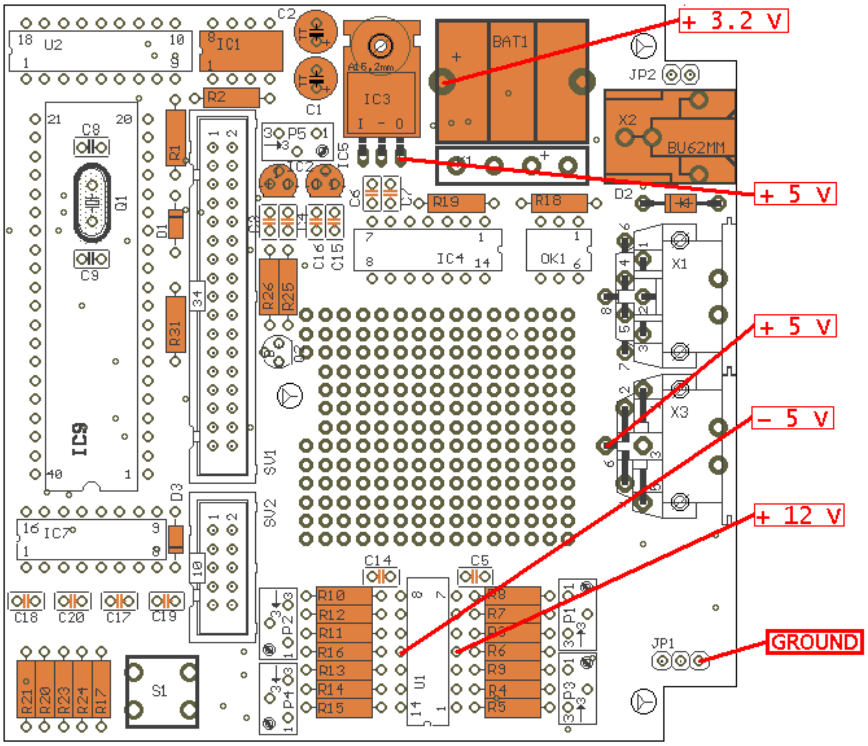
Insert the 12 V dc power plug in X2 and then plug the power supply or ac adapter into an ac receptacle.

Note: The power supply or ac adapter should have the following characteristics

- Output voltage within the range of: 9 to 12 V dc
- Output current: ≥ 200 ma
- Coaxial power connector with
    - Center pin positive
    - 2.1 mm x 5.5 mm pin and body diameters

With a multimeter set to the 20VDC range, check the following voltages with respect to ground (refer to illustration below):

Nominal voltage	**Measured range**	**Remarks**
-5 V dc	-4.75 to -5.25 V	Determined by ICL7660
+5 V dc	+4.75 to +5.25 V	Determined by 7805 or 78L05
+3.2 V dc	+3.2 to +3.4 V	New battery, no load
+12 V dc	+11 to +19 V	Actual input voltage less ~0.7 V
Input current		
~9 mA dc		Nominal

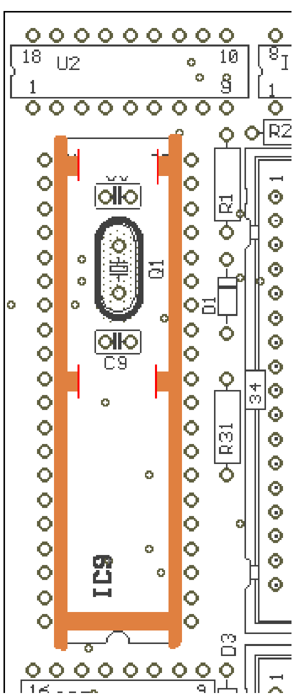


If all voltages are within the specified ranges, the power supply components are working properly. Remove the dc power plug before continuing!

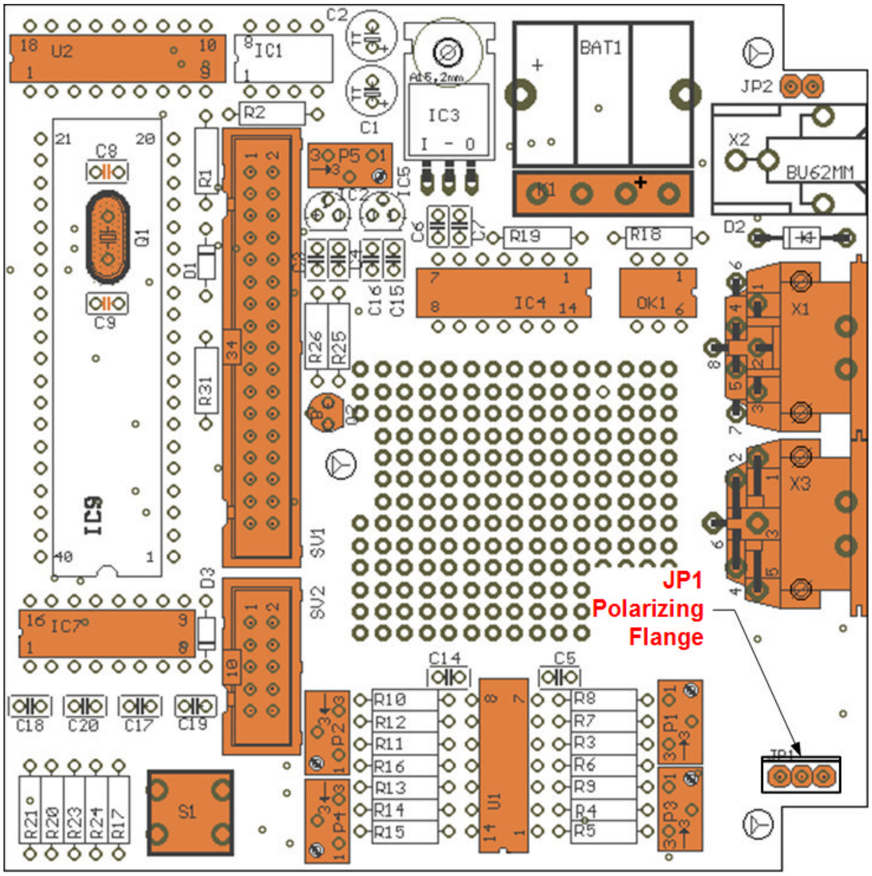
VII. Install the Logic Circuits

Required parts:

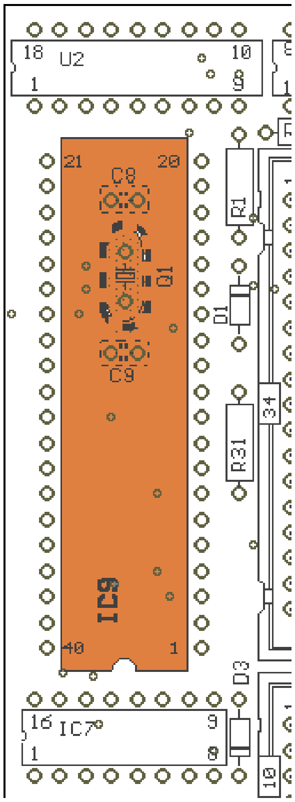
Parts list ID	Qty	Description
C8 ☐, C9 ☐	1	Capacitor, 22pF
IC4 ☐	1	NAND-Gate 74HCT00 logic IC
IC7 ☐	1	MAX232 transceiver IC
IC9 ☐	1	Microprocessor PIC16F877 IC
JP1 ☐	1	3-pin polarized header block
JP2 ☐	1	2-pin header block
K1 ☐	1	Reed relay, 5 V
OK1 ☐	1	Opto-coupler CNY17F
P1 ☐, P2 ☐	2	Variable resistor 47k or 50k
P3 ☐, P4 ☐, P5 ☐	3	Variable resistor 10k
Q1 ☐	1	Crystal, 16MHz / HC49U-V
Q2 ☐	1	Transistor, BC337
S1 ☐	1	Reset pushbutton
SV1 ☐	1	34-pins ribbon cable socket
SV2 ☐	1	10-pins ribbon cable socket
U1 ☐	1	Opamp, LM324
U2 ☐	1	Real time clock, RTC72421
X1 ☐	1	DIN PCB socket, 8 pins
X3 ☐	1	DIN PCB socket, 6 pins
☐	1	DIL 40-pin IC socket, see below



- Carefully cut two bridges out of the 40-pin IC socket (see red lines in the illustration above); use a thin hobby saw and be very careful not to damage the pins or break the plastic structure. Solder the IC socket in position.



- Solder the two headers JP1 and JP2. JP1 has a polarizing flange on one side and it must be installed with the flange toward the DIN connector as shown in the illustration above. JP2 is a simple 2-pin header and must be installed with the shorter pins soldered to the PCB
- Solder the DIN connector sockets X1 and X3. Be sure they are firmly soldered onto the PCB
- Solder the ribbon cable sockets SV1 and SV2. The apertures (center polarizing slot) must be on the side toward the 40 pin IC socket
- Solder the variable resistors P1, P2 (47k)
- Solder the variable resistors P3, P4, and P5 (10k)
- Solder the reset pushbutton S1 (either way)
- Solder the reed relay K1. The relay has an internal diode across the coil winding to prevent inductive kickback, so it is polarity sensitive. Be sure the + mark on the relay corresponds with the + on the illustration above; the text on the relay must be on the side toward the battery
- Solder ICs U1, U2, IC4, IC7, Q2 and OK1; some builders prefer to install DIL sockets (not supplied) rather than solder the ICs directly to the PCB
- Solder the ceramic capacitors C8 and C9. Bend them flat on the PCB away from the crystal location and then solder
- Solder crystal Q1. Do not let the crystal touch the PCB and short out the traces; raise it a little above the PCB (say, the thickness of a piece of paper). DO NOT overheat the crystal as it could be damaged



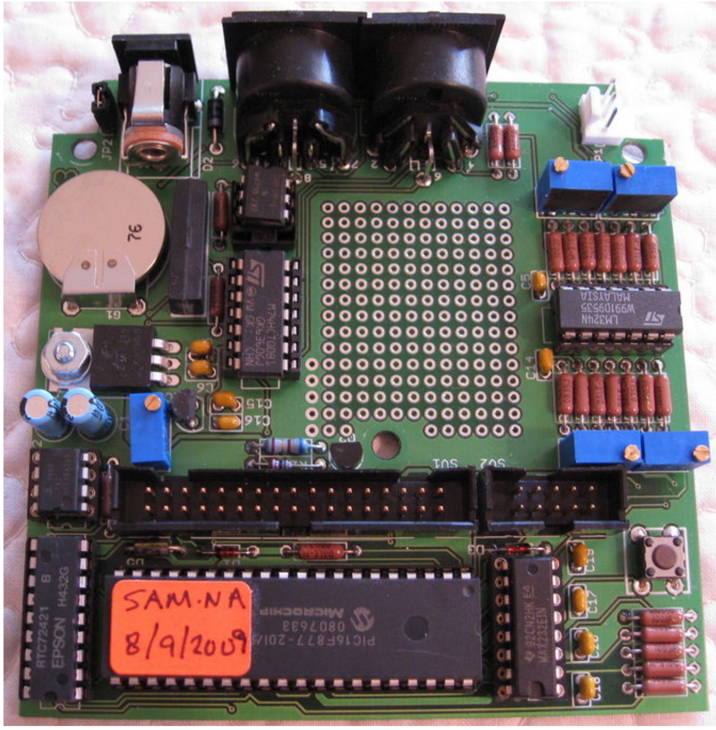
All controller PCB soldering is done.

Install the 40-pin microprocessor (and other ICs if you used sockets). Be very careful to not bend the pins when inserting in the socket (it is quite easy to bend a pin underneath the IC body). Use static protection when handling ICs and observe proper orientation of the notch or dimple in the IC.

Note: Most ICs are shipped with the leads at a slight angle away from the body. It is much easier inserting them into a socket by first carefully bending the leads so they are at right-angles to the body. To do this, lay one side of the IC with the pins on a flat, smooth surface and carefully rotate the body toward the pins a few degrees so the pins are uniformly bent at a right angle. Flip the IC over and repeat on the other side.

- ☐ Double-check all components for location and check polarity sensitive components (electrolytic capacitors, diodes, battery), voltage regulators and integrated circuits for proper orientation.
- ☐ Double-check all soldering

The controller board should now look similar to the illustration below (some components may look slightly different). Note: All ICs in this illustration are installed in sockets.

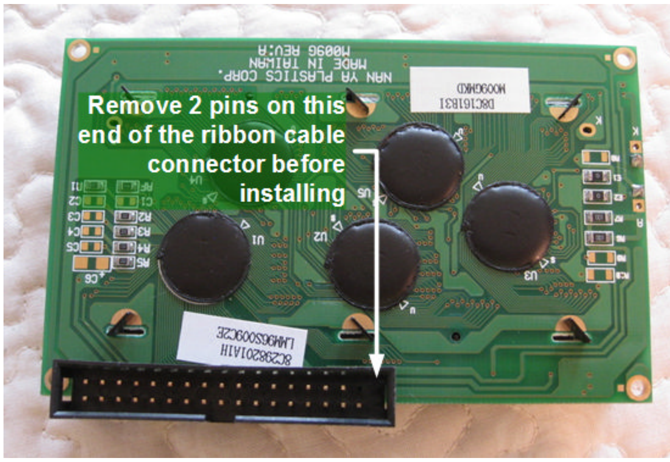


Set the controller PCB aside.

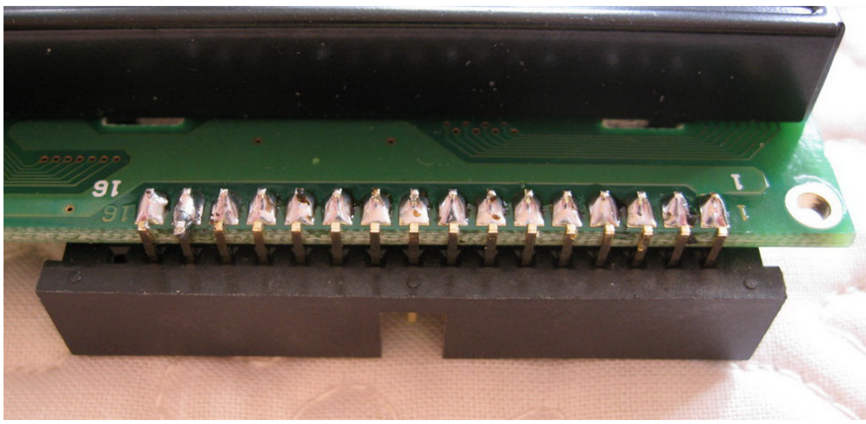
VIII. Install the Display Components

Required parts:

Parts list ID	Qty	Description
☐	1	Display module (LCD)
☐	1	34-pin ribbon cable socket



- Some LCD modules are shipped with the ribbon cable connector already installed. If not, remove the two end pins of the 34-pin ribbon cable socket so that it will fit the 16 holes in the PCB. See illustration above
- Place the LCD module on a soft cloth with the display facing down
- Insert the ribbon cable socket from the bottom so that the center polarizing slot is facing out. When properly oriented, the cut off pins will be in the middle of the LCD module, and the row of pins closest to the polarizing slot will rest against the board edge. See illustration below
- Carefully solder the 16 pins

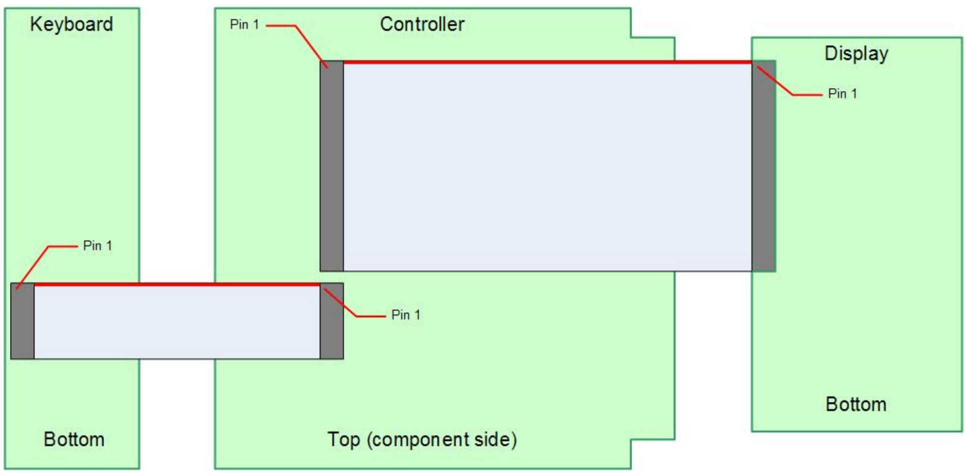


All printed circuit boards are now done.

IX. Install the Ribbon Cables

Required parts:

Parts list ID	Qty	Description
☐	1	10-15 cm 34C ribbon cable
☐	1	10-15 cm 10C ribbon cable
FBK1 ☐	2	34-pin ribbon cable connector with strain relief
FBK2 ☐	2	10-pin ribbon cable connector with strain relief



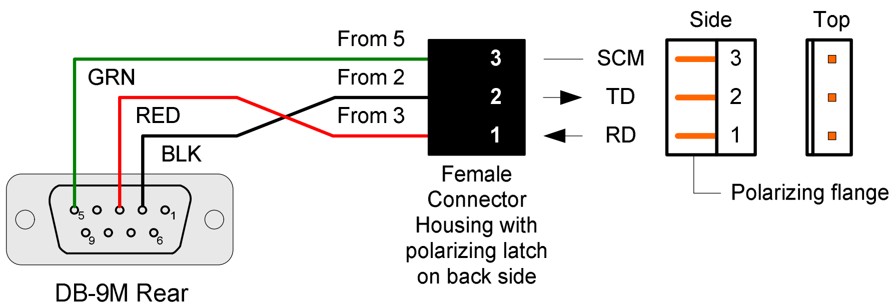
- The two ribbon cables, one with 10 conductors and one with 34 conductors, already may have the connectors installed. If not, install the connectors, being sure to align the colored wire with pin 1 on both connectors. Fold the cable over the top of the connector and snap the strain relief into place
- Lay the boards as shown in the illustration above with the ribbon cable sockets facing up
- Carefully insert the connectors in the sockets. They will fit only one way
- Turn the three boards over

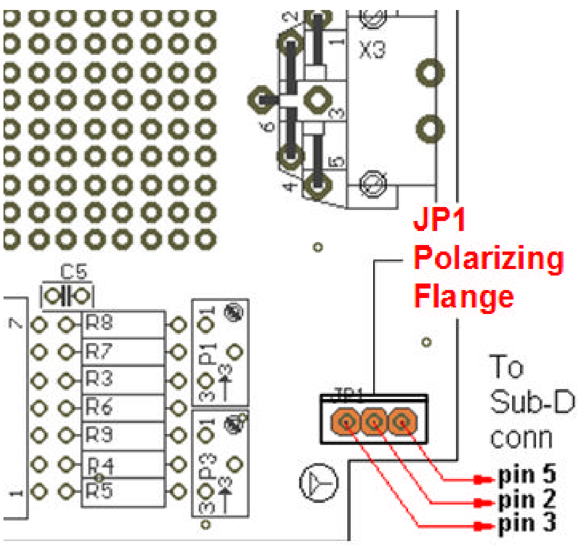
X. Wire the EIA-232 Serial Port Cable

Required parts:

Parts list ID	Qty	Description
JP4 ☐	1	DB-9M plug
JS1 ☐	1	Female connector housing
☐	3	Terminal contact
☐	1	24 AWG wire, 15 cm long wire, red
☐	1	24 AWG wire, 15 cm long wire, black
☐	1	24 AWG wire, 15 cm long wire, green

Solder a wire to pins 2, 3 and 5 on the DB-9M connector JP4 using the color code shown in the schematic below. Twist the three wires together and trim the leads to the same length. The supplied wires can be shortened if the DB-9M connector is mounted close to the PCB.





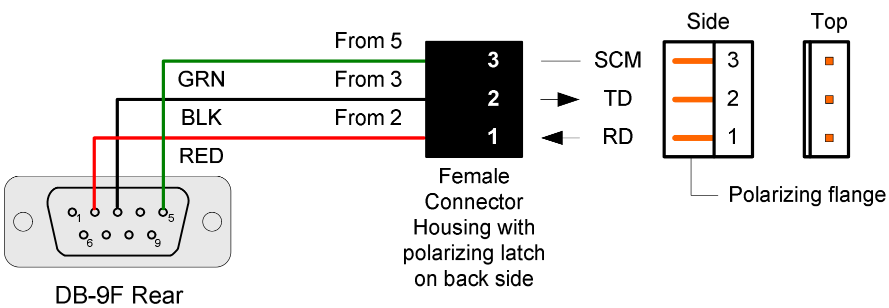
Crimp (if you have the proper tool) or solder each wire from the DB-9M connector to a contact. Use the wire color to identify the pin on the DB-9M connector and insert into the female connector housing JS1 in the proper order. The PCB header JP1 has a polarizing flange and the female connector housing JS1 has a corresponding latch; be sure the contacts are inserted in the proper order.

Install the serial port cable JS1 on the controller PCB JP1. It will fit only one way.

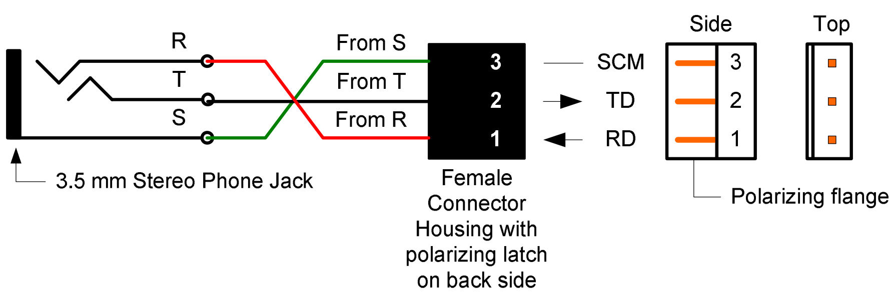
<u>Alternate Arrangements for Serial Port Connector</u>:

The following paragraphs describe two alternate arrangements for the serial port connector.

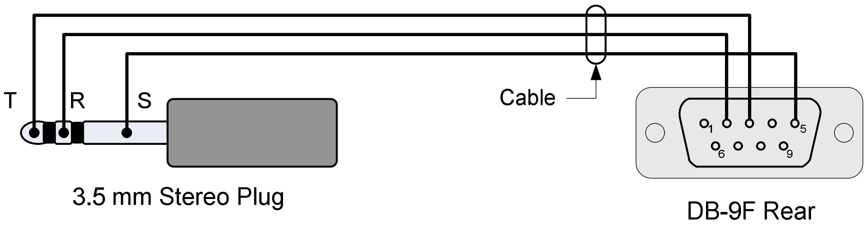
Alternate arrangement 1: This arrangement replaces the supplied DB-9M connector with a DB-9F and wires it in a DCE configuration. The advantage is that the SAM can be connected directly to a PC serial port (or USB/EIA-232 adapter) without a null modem cable. Instead, a straight-through cable may be used that has a DB-9M plug at one end (SAM) and DB-9F plug at the other end (PC). Even though a null modem cable is supplied with the SAM Kit, some users may prefer using this more common arrangement. The drawing below shows the alternate wiring arrangement.



Alternate arrangement 2: This arrangement saves a little panel space and does not require cutting an odd-shaped hole for a DB-9 connector. Use a regular 3.5 mm stereo phone jack for the connector on the SAM enclosure as shown in the drawing below.



Of course, a null modem cable with DB-9 connectors at each end will not work with this arrangement for connecting the SAM to a PC, but an existing cable with at least one DB-9F connector can be easily modified. Cut off one of the connectors (retain one DB-9F on the cable) and wire the cable blunt end to a 3.5 mm stereo plug as shown in the drawing below.



Some data loggers (for example, the Onset Computer HOBO and Omega Engineering data loggers) use the same configuration, so users with these data loggers already have a cable and do not need to make one.

XI. Testing and Adjusting

Required parts:

Parts list ID	Qty	Description
☐	1	EIA-232 null modem cable, DB-9F/DB-9F
☐	1	AC power adapter, 12 Vdc, 200 mA, 2.1 x 5.5 mm coaxial plug, center positive (user supplied or optionally provided for North American customers)

The microcontroller has testing software (IB_ENG.HEX) preinstalled that allows display and interface testing and adjustment. The following sections test all functions and interfaces except the magnetometer sensors. The operating system software (SAM_ENG.HEX) and sensors will be installed later.

☐ Install the shorting block on JP2 to activate the internal real time clock battery

☐ Connect the null modem cable (supplied) between the SAM controller DB-9M connector and the serial COM port on the computer. Note: The null modem cable uses only pins 2, 3 and 5 on the DB-9F connectors, and the conductors for pins 2 and 3 are reversed on one of the connectors

A USB-serial interface adapter is required if your PC does not have a built-in serial port. In order to use the PIC loader program supplied with the SAM kit, the USB adapter must support COM1, COM2, COM3, COM4, COM5 or COM6. The drivers supplied with most USB adapters allow the COM Port to be set in this range. It may be necessary to use Advanced settings in Windows Device Manager (Port Settings tab) to set the port within this range.

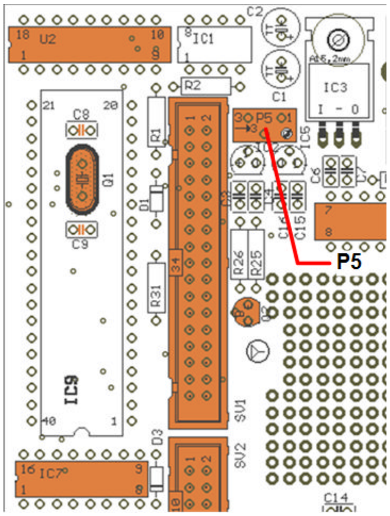
Initial Power Up

Insert the power adapter plug into the dc power connector on the SAM controller board and plug the ac adapter into an outlet receptacle. The LCD probably will not show very much at this time. With no sensor connected, the current draw will be around 50 ma with the LCD backlight on and around 30 ma with it off. Each sensor will add around 15 mA; however, at this time the sensor should not be connected.

With the test firmware (IB_ENG.HEX) installed and power applied to the PCB, the LED on the keyboard will flash at ~2 Hz rate.

Adjust the LCD Contrast

Slowly adjust variable resistor P5 until the display letters turn dark. Continue turning slowly until the display background just changes (background pixels start to show) and then back-off the adjustment just enough so the background disappears. This setting provides good contrast for the present lighting conditions. It may be necessary to readjust the contrast when you move the SAM to a new location.



The display should now read:

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SAM - Simple Aurora
Monitor
by DG3DA & DL3HRT
Initial tests
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or, more likely, if the initial screen timer expired during display adjustment:

```
Keyboard:
Subsequently press
F1-F4...
```

If you wish to view the initial screen, press the reset pushbutton (S1) on the controller PCB. This will reboot the SAM controller and start over. In the following tests, you may press S1 anytime you would like to return to the initial screen and start over.

Go to the next test.

Test the Keyboard

Press the keys F1 to F4 in order.

```
Keyboard:
Successively press
F1-F4
F1 F2 F3 F4
```

The text F1 F2 F3 F4 appear on the screen as you press each key.

Shortly after F1 through F4 have been pressed the display should show:

```
Test okay...
```

If the keyboard test was successful, the next text appears:

```
RS-232:
Connect PC and
Press F1 if data
is readable
```

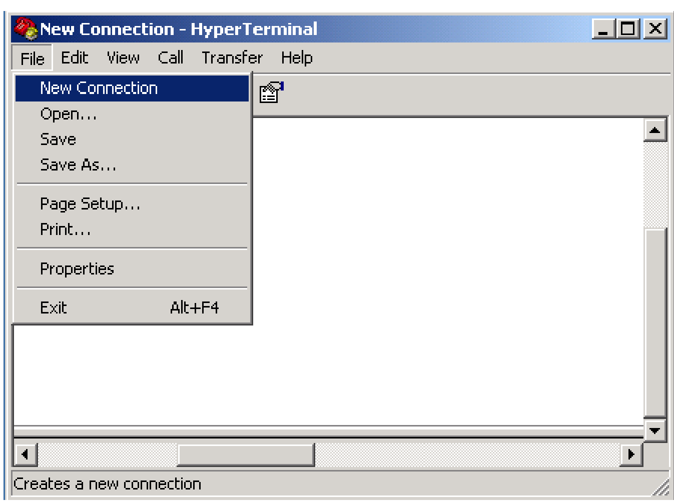
DO NOT press F1. The preliminary tests are done. Go to the next test.

Test the EIA-232 Serial Interface:

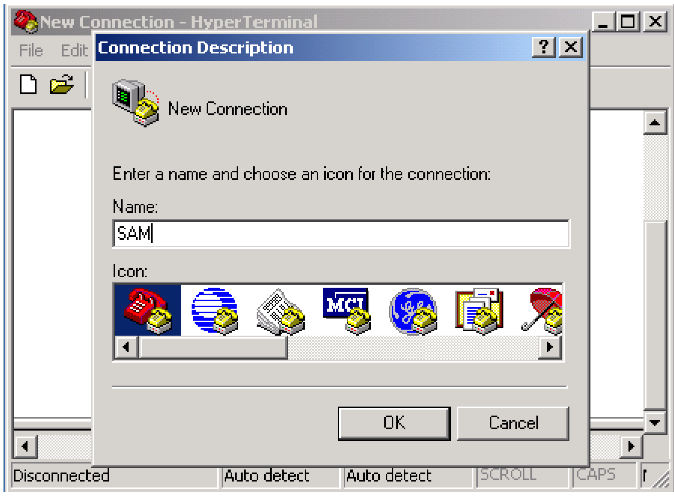
To test the EIA-232 serial port, it will be necessary to use a terminal emulator program such as HyperTerminal. Go to the next step to setup HyperTerminal

Setup HyperTerminal

Start the HyperTerminal program (Start – All Programs – Accessories – Communications) and create a new connection.

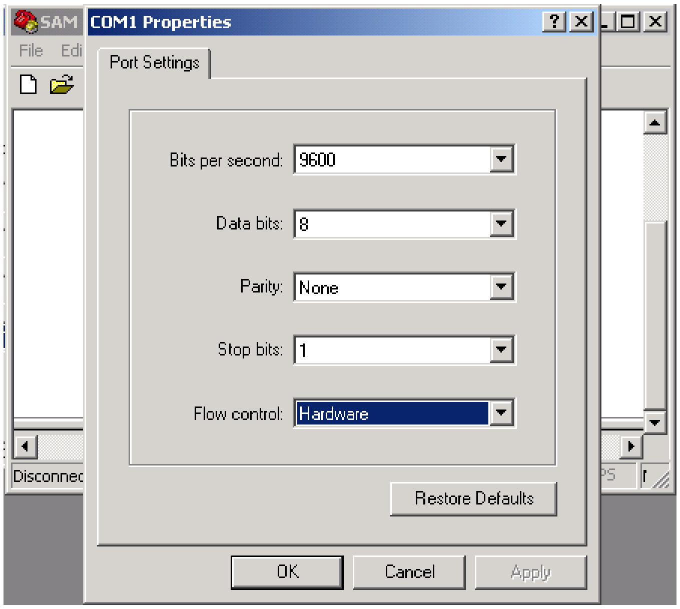


Select File – New Connection.



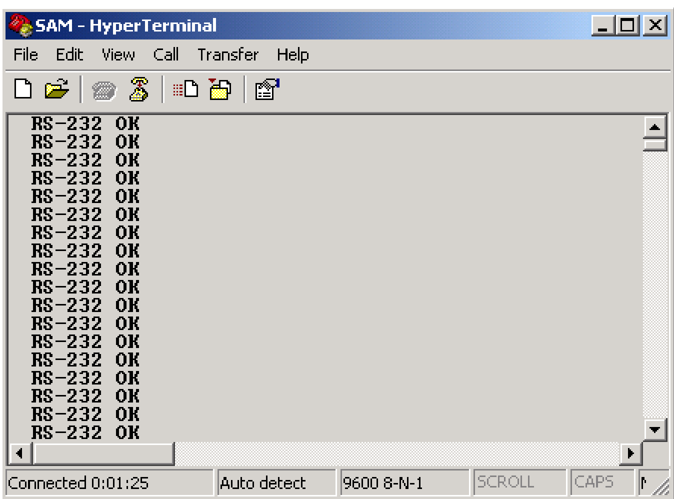
Type the name SAM.

Choose the appropriate COM Port from the dropdown list. If you are using a USB-serial adapter, this is the COM Port used by the adapter. Be sure the USB-serial adapter drivers are installed and then plug the adapter into a USB port. Do not connect the USB-serial adapter to a USB hub; connect it directly to the PC. To find the COM Port assigned to the adapter, go to Start – Control Panel – System – Hardware Tab – Device Manager and click the + next to Ports (COM & LPT).



Adjust the settings in the drop-down boxes as follows: 9600 Bits per second – 8 Data bits – Parity None – Stop bits 1. Click OK

The text "RS232-OK" should appear in the HyperTerminal window as shown below. It may be necessary to press the Call icon button on the menu bar.



If nothing happens, it is possible that pins 2 and 3 on JS1 need to be swapped. Use a digital multimeter set to the 20 vdc voltage range to measure the voltages on the DB-9M connector. Measure the voltage from

- pin 5 (negative multimeter lead) to pin 2 (positive multimeter lead)
- pin 5 (negative multimeter lead) to pin 3 (positive multimeter lead)

In both cases, the voltage must be in the range –6V to –12V. If not, remove power from the SAM and try swapping pins 2 and 3 on the DB-9M connector or the 3-pin header connector. A good software tool for troubleshooting serial ports is *PortMon for Windows*. It is free and available from http://technet.microsoft.com/en-us/sysinternals/bb896644.aspx .

If the terminal emulator program is configured properly and the serial port is wired correctly, the HyperTerminal window should show "RS-232 OK". The LCD shows

```
RS-232:
Connect PC and
Press F1 if data
is readable
```

When the serial port tests okay, press F1 and the following will flash on the LCD:

```
RS-232:
Test okay...
```

In HyperTerminal, press the DISCONNECT icon and close the program.

Go to the next test.

Test and Set the Real Time Clock

The real time clock should be set to Universal Coordinated Time (UTC) so that it operates on the same time scale as other geomagnetometers throughout the world. In the United States, first go to http://nist.time.gov/ to set your PC clock or watch, and then set the SAM time as described below. For other areas of the world, go to http://www.timeanddate.com/worldclock/ to set your PC or watch.

When setting the SAM real time clock, the first line displays the Date and Time. The display format is `DD.MM.YY HR:MM:SS`. In operation, the SAM clock display format is `DD.MM. HR.MM.SS` (the year is not shown). The day, month, year, hour, and minutes can be set; the seconds cannot be set. In the procedures below, the field being adjusted is highlighted in green. The highlight does not show on the LCD; however, by pressing the F2 and F3 keys, it will be obvious which field is changed.

After successfully completing the serial port tests, the LCD will look something like this

```
00.01.00 00:05:56
Clock:
Press F1 if clock
is running
```

If the clock is running, the seconds field (1st line, last field on right) will be counting. If it is counting, press F1. The display will flash

```
Test okay...
```

Now the day can be set

```
00.01.00 00:29:32
Set date: day
F1=OK
F2=+ F3=-
```

Use the F2 or F3 function keys to scroll the day field up or down. When set to the correct day, press F1.

The screen to set the month appears

```
25.01.00 00:29:49
Set date: month
F1=OK
F2=+ F3=-
```

Use the F2 or F3 function keys to scroll the month field. When set to the correct month, press F1.

The screen to set the year appears

```
25.07.00 00:30:02
Set date: year
F1=OK
F2=+ F3=-
```

Use the F2 or F3 function keys to scroll the year field. When set to the correct year, press F1.

The screen to set the hour appears

```
25.07.09 00:31:10
Set time: hour
F1=OK
F2=+ F3=-
```

Use the F2 or F3 function keys to scroll the hour field. Set the hour to UTC so that your magnetograms use the same time scale as other geomagnetometers. When set to the correct hour, press F1.

The screen to set the minute appears

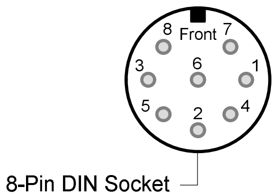
```
25.07.09 00:31:21
Set time: minute
F1=OK
F2=+ F3=-
```

Use the F2 or F3 function keys to scroll the minute field. When set to the correct minute, press F1. Note that the seconds cannot be set, but the seconds are reset to zero each time you scroll the minute field. With a little practice, you can set the minutes and seconds exactly to correspond to your watch or PC clock. The clock is now adjusted. It will keep time with power removed from the SAM controller PCB (the real time clock IC is battery powered).

Go to the next test.

Test Inputs and Outputs

The SAM input and outputs appear on DIN connector X1. The wiring of the 8-pin DIN socket as viewed from the front is shown below.



8-Pin DIN I/O Assignments

Pin	Function
1	Voltage detector -
2	Analog channel 2 output
3	Ground
4	Voltage detector +
5	Analog Channel 1 output
6	Alarm relay contact A
7	Alarm relay contact B
8	+12 v dc

Test the Alarm Relay

After the clock has been adjusted, the following text should show on the LCD:

```
Alarm switch:
Relais switches in
1s-interval. Press
F1 to confirm.
```

Put your ear near the board and listen for a clicking sound at a rate of 1 click/second. The relay is a reed relay and the clicking is very faint. If you do not hear anything, set a digital multimeter to measure resistance and connect one lead to pin 6 of X1 (8-pin DIN socket) and the other to pin 7.

The measured resistance should alternate between an open and short circuit. Note: Some digital multimeters do not respond fast enough to provide a meaningful display, but the display should not show a steady open (infinite resistance) or steady short (zero resistance). A low-inertia (small and light) analog multimeter is best for this test but a digital multimeter can be used.

Press F1 if the test is successful and to move to the next test.

Test the Input

The input circuit is decoupled from the rest of the circuits by an opto-coupler (opto-isolator). An external 12 V dc voltage source is required for this test. When F1 was pressed in the previous test, the LCD should show

```
Digital input:
Apply voltage to
digital input.
Press F1 to abort.
```

To proceed with the test, refer to the DIN connector pinout shown above. Connect the +12 V dc lead from the power supply to pin 4 of X1 (8-pin DIN socket) and the – lead to Pin 1. Note: 12 V dc is available between pin 8 (+) and pin 3 (-) of the DIN connector X1. It may be used to test the input but this voltage is not isolated from the PCB ground, and it will not be a true test of the isolated input circuit.

As soon as the SAM processor detects 12 V the following text will appear on the display:

```
Digital input:
Test ok...
```

The SAM automatically will go to the next test.

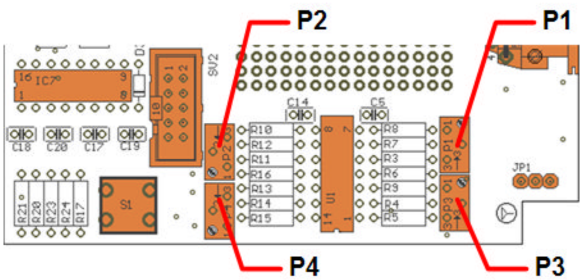
This test can be skipped by pressing F1. If you press F1, you should see

```
Digital input:
Test aborted
```

The SAM automatically will go to the next test.

Test the Analog Outputs

The SAM has two analog output channels that provide a voltage proportional to the magnetic induction measured by the SAM sensor. The analog outputs are adjusted by potentiometers P1 and P3 (channel 1) and P2 and P4 (channel 2). The locations of P1, P2, P3 and P4 are shown below.

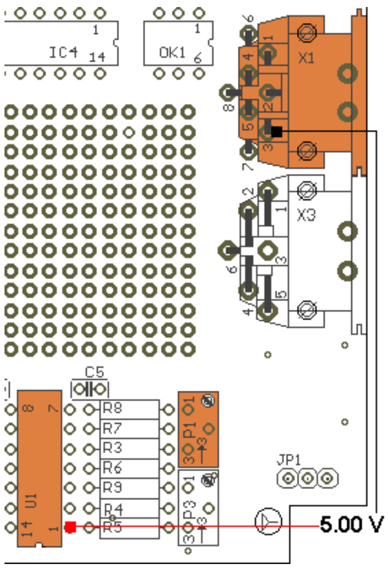


The two analog outputs are designated AA1 and AA2. Each output can be calibrated to provide a range of 0 to +5 V or –2.5 to +2.5 V.

After the previous tests were done, the SAM starts with output channel 1 (AA1) and displays the following text:

```
1st analog output
P1: gain P3: offset
F1 = OK F2 = 1/2Umax
F3 = Umax F4 = Umin
```

To set the output of AA1 to a range of 0 to 5 V, press F3 (Umax)



Set the multimeter to the 20 vdc range, and connect the meter negative lead to pin 3 (ground) of X1. Connect the meter positive lead to pin 1 of U1 (LM324). See illustration above. Adjust P1 until the meter shows +5.00 V. Press F4 (Umin).

Connect the meter positive lead to pin 5 (AA1) of X1. Adjust P3 until the meter shows 0.00 V. Repeat the previous two steps until the voltages do not change.

For a range of –2.5 V to +2.5 V, press F2 (1/2Umax).

Connect the meter negative lead to pin 3 (ground) of X1. Connect the meter positive lead to pin 5 (AA1) of X1. Adjust P3 until the meter shows 0.00 V. Repeat the previous adjustments until the voltages do not change.

Press F1 when you are done adjusting analog output channel 1. The following text appears:

```
2nd analog output
P2: gain P4: offset
F1 = OK F2 = 1/2Umax
F3 = Umax F4 = Umin
```

To adjust analog output channel 2 (AA2) for a range of 0 to 5 V, press F3 (Umax).

Connect the meter negative lead to pin 3 (ground) of X1. Connect the meter positive lead to pin 8 of U1 (LM324). Adjust P2 until the meter shows +5.00 V. Press F4 (Umin).

Connect the meter negative lead to pin 3 (ground) of X1. Connect the meter positive lead to pin 2 (AA2) of X1. Adjust P4 until the meter shows 0.00 V. Repeat the previous two steps until the voltages do not change.

For a range of –2.5 V to +2.5 V, press F2 (1/2Umax).

Connect the meter negative lead to pin 3 (ground) of X1. Connect the meter positive lead to pin 2 (AA2) of X1. Adjust P4 until the meter shows 0.00 V. Repeat the previous adjustments until the voltages do not change.

Press F1 when you are done adjusting analog output channel 2. The following will briefly flash on the LCD:

```
Test completed
```

The LCD will then show

```
Initialize EEPROM
with default parame-
ters?
F1 = yes F2 = no
```

All tests are now done!

The above tests and adjustment can be repeated by pressing the reset button on the SAM controller PCB. You have to cycle through the entire set of tests but you can skip a particular test or adjustment by pressing F1. You can press the reset button any time and it will not change anything.

If you are finished with testing and adjusting, you can initialize the SAM EEPROM with default parameters by pressing F1. If you press F1, the LCD should briefly show

```
EEPROM initialized
successfully.
```

The LCD should then show

```
Congratulations! SAM
is ready for opera-
tion. Load SAM.HEX
now...
```

You are ready to load the operating system software onto the SAM microprocessor as described in the next section. Nothing will be harmed if you remove power from the SAM.

If you pressed F2 instead of F1, the EEPROM will not be initialized with default parameters, but it otherwise will be ready for installation of the operating system software. When you press F2, the LCD should briefly show

```
EEPROM not
initialized.
```

The LCD should then show

```
Congratulations! SAM
is ready for opera-
tion. Load SAM.HEX
now...
```

If you just finished construction of the SAM PCBs, you normally would press F1 to load the default parameters. You would press F2 if you had been using the SAM for some time and wanted to readjust the analog outputs or retest a function but wanted to retain the parameter settings from previous use. In this case, you would load the initialization and test software, make the adjustments and tests, but press F2 at the end. Whatever parameters were in EEPROM will be retained.

Trouble Shooting

If problems occur during testing, double-check the following:

- Current drawn by the SAM. With no sensors connected the current draw is approximately 30 mA with the LCD backlight off and 50 mA with the backlight on. Each sensor adds about 5-10 mA to the load current
- Resistors are correct values and in the correct location
- Diodes correctly oriented and in the correct location
- Capacitors in the correct location and electrolytic capacitors oriented correctly
- ICs soldered properly and oriented correctly
- No cold solder joints
- All pins soldered
- No solder bridges
- Power supply input voltage and the voltage at the voltage regulator outputs

If no problems are found but the SAM still does not test okay, contact us by email (SAMinfo@reeve.com).

XII. Load the Microcontroller Operating System Firmware

The supplied microprocessor has bootloader and test/initialization firmware (IB_ENG.HEX) preloaded. The test/initialization firmware is used only for testing purposes. It is now necessary to replace the test/initialization firmware with the operating system firmware (SAM_ENG.HEX) so that the SAM can be used with the application programs (the applications programs are described in the SAM Software Setup Manual).

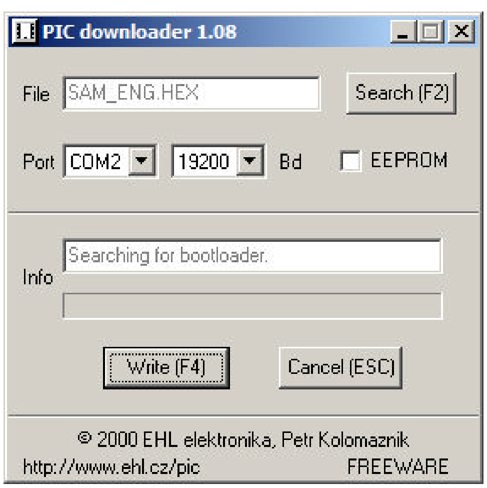
Note that either IB_ENG.HEX or SAM_ENG.EXE can be loaded onto the microcontroller but not both at the same time. In general, IB_ENG.HEX is loaded when it is necessary to test and adjust the SAM, and SAM_ENG.EXE is loaded when the SAM is to be placed in service.

The operating system program is loaded through the EIA-232 serial port from a Windows PC running a PIC loader program. The PIC loader supplied on the SAM CD is freeware called PIC_downloader.exe and it is compatible with the bootloader firmware already installed on the PIC. Remember this loader only supports COM1 through COM6. If you have a USB-serial interface adapter, it must be configured for one of these ports.

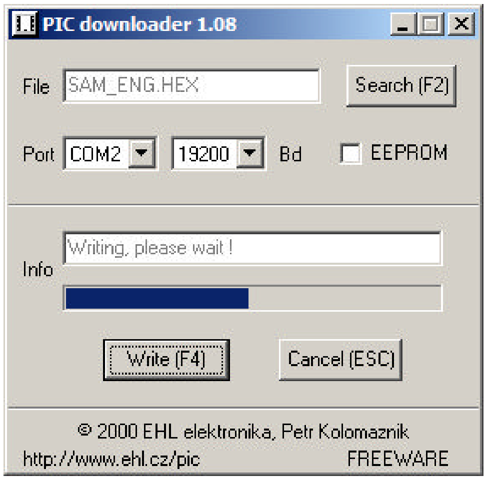
To load the operating system software

- Create a new folder such as C:\SAM\PICLoader
- Unzip the picloader.zip file into the new folder
- Run PIC_downloader.exe
- Set the parameters as follows:
  - File: SAM_ENG.EXE [use SEARCH (F2) to find the file]
  - Port: Set to the PC serial COM Port that is connected to the SAM
  - Speed: 19200 Bd
  - ☐ EEPROM [DO NOT check]

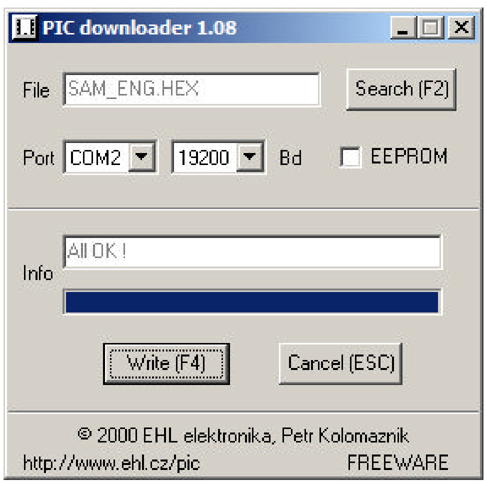
When all parameters are set (refer to the screenshot below), press F4 – Write. The PIC downloader should show “Searching for bootloader” and look like this



Press the reset button on the SAM controller PCB. The PIC downloader should immediately start writing the file as shown below



When done, the PIC downloader should look like this, and the SAM should automatically reboot.



After the SAM has rebooted, press the RESET (F3) button on the SAM keyboard. The SAM should reset and the LCD should look like this (line 4 initially will be blank but will appear after a moment)

```
25.07. 22:07:12  0.0
■: -82000/0nT

K: 0(-)  D: 0nT
```

The next section describes the display layout. Default magnetic induction values will be displayed until the sensor is connected.

The ***SAM Software Setup Guide*** describes how to install and use the application software.

At this point, you can install the PCBs in an enclosure as described in the section following the display layout and keyboard description. The section following the enclosure installation describes how to hook up and install the sensor.

XIII. SAM Display and Keyboard Reference Information

SAM Display:

The SAM display is a 4x20 (4 lines x 20 characters per line) LCD with the following layout:

Line	Example
1	04.05. 14:33:56 0.0
2	Y: -18206 / -3nT ->
3	X: -12345 / 4nT <-
4	K: 4 (5) D: 61nT

Line 1: Date, Time and Temperature DD.MM. HR:MM:SS TT.T.

The date and time are self-explanatory. Note that the date is in the European format with day followed by the month. The last parameter on Line 1 is the temperature in celsius. If the SAM is not equipped with a temperature sensor, this field always shows 0.0.

Line 2 & 3: Measured value of magnetic induction in nT for axis Indicated / Relative value compared to the value at 00:00 UTC or first value after reset/power on and Trend indicator.

The Trend indicator shows the trend of the magnetic field over the last 20 minutes. It also is used to trigger the K-Index alarm relay. The SAM calculates the variations over the last 20 minutes and compares the amplitude of the variations with the K-Index triggers. If the variation is such that K4 would be reached within 20 minutes, the alarm is triggered.

The trend indicator symbols are:
Quiet magnetic field: "->" (20 minute variation ≤ K2
Moderate field variations: "/" or "\" for falling or rising (20 minute variations ≤ K4)
Strong variations: "|" – ALARM (20 minute variations > K4)

If an alarm is triggered, it will reset after 20 minutes unless the condition that caused the alarm still is in effect.

Line 4:
Normal operation: Current period K-index (previous period K-index) and magnetic field variation within the current K-index period. The K-indices are determined for the prescribed three hourly intervals (0000-0300, 0300-0600, . . . , 2100-2400). The K-index displayed first is measured from the beginning of the current 3-hour period with K0 assigned at the beginning of the interval. The K-index displayed in parentheses is for the previous 3-hour period. In the example shown, the current K-index is K4 as measured from the beginning of the current 3-hour period (1200), the K-index was K5 at the end of the previous K-index interval (1200), and the current amplitude variation is 61 nT.

The maximum positive and negative deviations during the 3-hour period are added together to determine the total maximum fluctuation. These maximum deviations may occur anytime during the 3-hour period.

The K-index varies by location (latitude and longitude). The default values are typical for approximately 40-50 deg. north latitude. The actual K-index limits for a given location normally are determined over a period of time, typically at least one year corresponding to one solar cycle. Professional geomagnetometer systems typically go through a 22 year (complete positive and negative sunspot cycles) calibration period. For SAM purposes, starting values may be obtained from a nearby magnetic field observatory. For additional information on the K-index and how to set it for your installation, refer to *Geomagnetometry for Amateur Radio Astronomers* available from the following web address: www.reeve.com/Documents/SAM/GeomagAmRadioAstron.pdf

The K-index triggers can be changed for the SAM processor in standalone mode using the SAM_INI program. The charting program, SAM_VIEW, has its own triggers for computing the K-index so the values have to be set twice - in the microcontroller EEPROM for standalone operation and again in SAM_VIEW for logging operation with a PC. See the SAM Software Setup Guide for details on using SAM_INI and SAM_VIEW.

Calibration mode: When a sensor is connected and function key F2 is pressed, the 4th line of the LCD changes to show the sensor frequency counter as in the upper example below. If no sensor is installed, the frequency shown on the display will be `0Hz` as in the lower example below. Press F2 again to exit sensor Calibration mode.

`F:  70617Hz`	Sensor installed, frequency will vary
`F:  0Hz`	No sensor installed

SAM Keyboard:

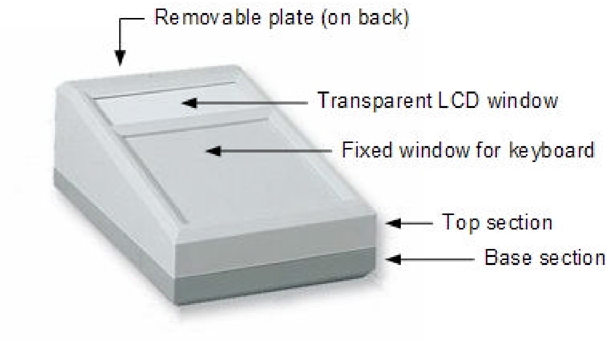
With the SAM_ENG.HEX operating system installed, the SAM keyboard function keys F1 – F4 operate as follows:

F1: Command Mode (places the SAM in command mode for uploading or downloading setup information, LED flashes at ~2 Hz rate)
F2: Calibration Mode (displays the sensor counter frequency, LED flashes at ~2 Hz rate)
F3: Software Reset (restarts the SAM microcontroller but retains EEPROM parameters)
F4: Display Backlight (Turns on the backlight)

XIV. Install the Controller, Keyboard and LCD in the Enclosure

If the optional enclosure is to be used, the three boards should be installed now. The builder is required to use a certain amount of resourcefulness and planning to install the boards in the optional enclosure.

The optional enclosure is a slightly sloped and consists of several parts as shown below.



It will be necessary to cut holes for the two DIN connectors, EIA-232 serial port connector, dc power connector and keyboard pushbuttons and LED. The enclosure top section has screw landings already installed for mounting the LCD and keyboard, but additional spacers are required (spacers are supplied with the optional enclosure). When viewing the enclosure from the front, the open window for the LCD is at the top. The keyboard is mounted on the fixed window section just below the display.

Before cutting any holes, double-check the dimensions shown on the drawings to make sure they correspond to your parts. There will be some minor variations because of manufacturing and shop tolerances and substitutions. The datasheets for some components are in mm and for other components are in inches. To provide some consistency, the drawing dimensions below are in inches to the nearest 1/32nd inch (with apologies to our shop, which prefers metric dimensions).

The drawings in this section are not to scale but a PDF file is provided on the supplied CD that has full-size drawings. In some cases, the printer will not print the file at the correct scale. If so, use the scaling properties available in most printer drivers or, alternately, open the included Word.doc file and adjust the size of the images as required. Print the PDF or images and then cut out the templates for use in marking the drill center-points. Tape the template in place and use a sharp awl to mark the center-point of all holes.

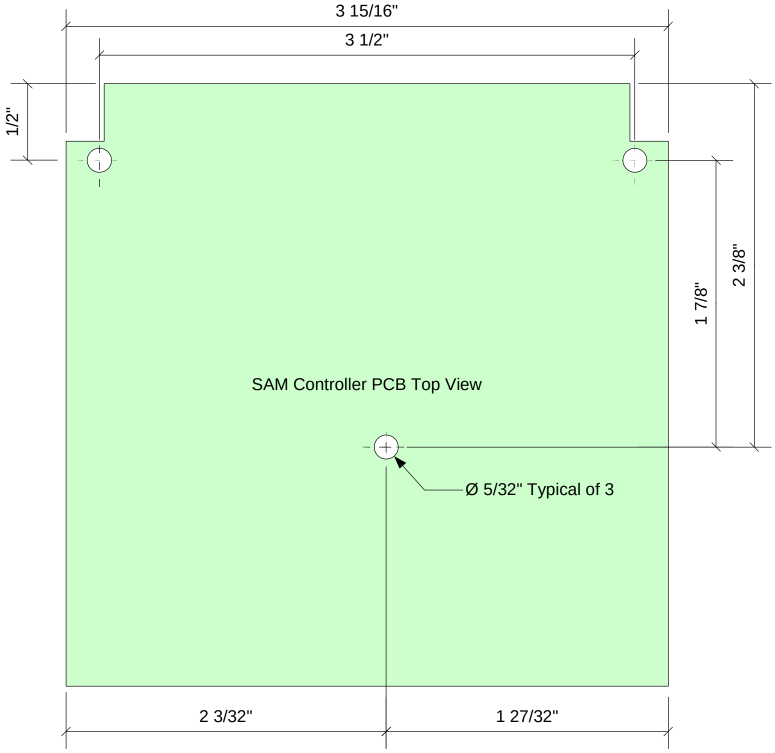
Always start with a small drill to cut a pilot hole, 1/16 in. – 3/32 in. (1.5 mm – 2.4 mm) diameter, make a test fit and then enlarge the hole as required. The plastic material is soft plastic and easy to cut. Brad-point drills and step drills work well.

<u>Controller:</u>

The controller PCB is mounted in the base section with the connectors facing the back (away from you as you look at the enclosure). The controller PCB requires three spacers and three sets of fasteners. The spacers are 3/8 in. nylon and have 4-40 threaded studs at one end. The studs are inserted through the holes in the PCB and nylon 4-40 hex nuts are screwed on. Carefully tighten the nuts; do not tighten them beyond snug or you will break the studs. Regular steel 4-40 hardware is used to mount the spacers to the enclosure base section.

The 3/8 in. spacers supplied with the PCB raise it about even with the edge of the base section. The drawing below can be used as a template for mounting the controller PCB. Cut the template out and tape it in the base section, mark the holes with an awl and then cut the three holes with a brad-point drill. The PCB should be centered left-right in the base with the back edge (the edge with connectors) flush with the base flange.

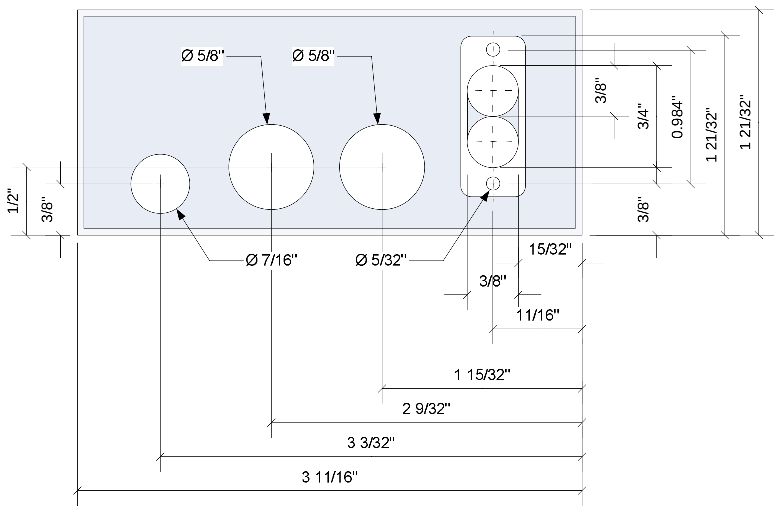
Controller PCB, viewed from top (component side); NOT full size. The controller PCB is mounted to the base section with three 3/8 in. spacers.



Backplate:

The openings in the removable back-plate for the DIN connectors, dc power connector and EIA-232 serial port connector are shown in the drawing below. Two holes are cut for the serial port connector housing as shown and then trimmed with a sharp hobby knife to an oblong shape. Mount the serial port connector with the supplied 4-40 hex jackscrew hardware.

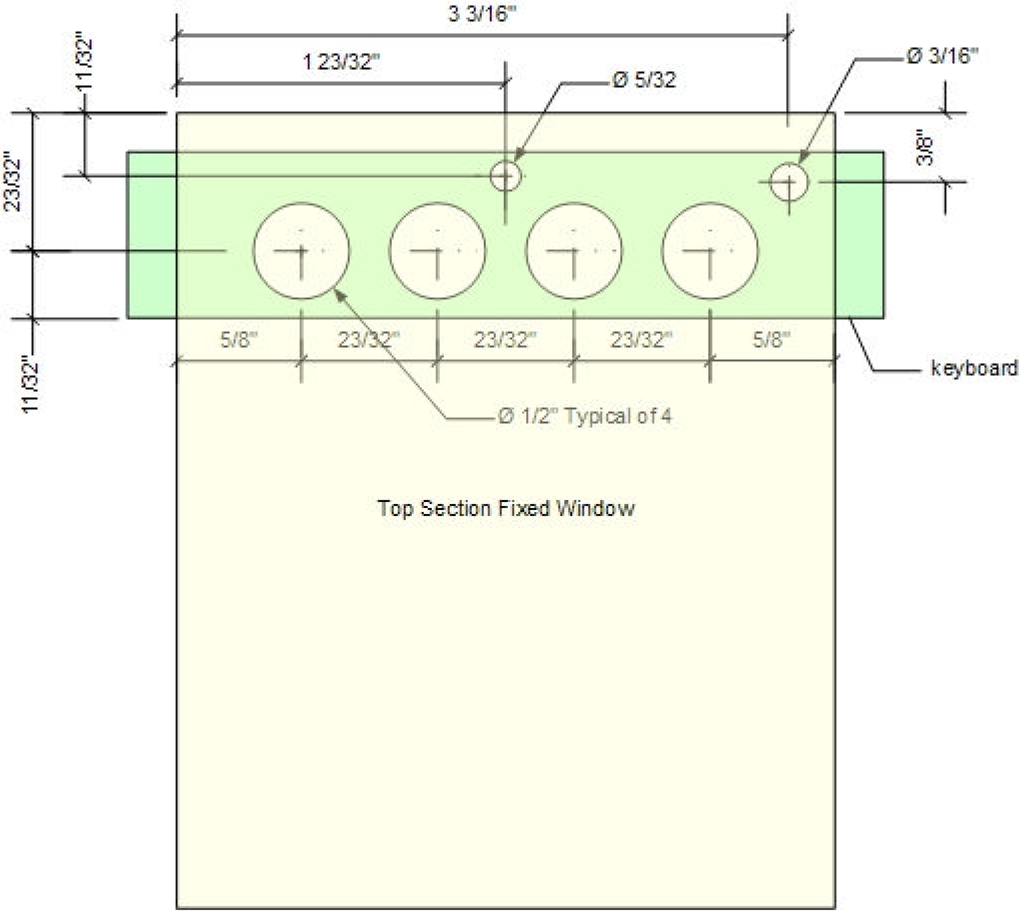
Removable back-plate, viewed from inside; NOT full size. Use a step-drill to cut the larger holes after pilot-drilling.



Keyboard:

The enclosure top section has two molded standoffs for the keyboard just below the display window on the inside. These line up with the two outer holes in the keyboard PCB and provide sufficient support for most applications. If additional support is needed, use a 1/4 in. spacer (not supplied) at the middle hole in the keyboard. Use the supplied No. 3 or 4 x 1/2 in. self-threading screws and 3/16 in. spacers to mount the keyboard. Before mounting the keyboard, pre-thread the standoffs with the supplied screws; turn very slowly so you do not split the openings. Test fit the keyboard to make sure there is clearance.

Keyboard; NOT full size. The keyboard is mounted in the top section fixed window area below the display cutout. The drawing below is viewed from outside of the enclosure. Use a step drill to cut the larger holes after pilot drilling. Not shown are the two mounting holes at the ends of the keyboard, which correspond to the molded standoffs in the enclosure top section. If these are the only mounting holes used, you do not need to drill the 5/32 in. hole in the middle. The template is designed to be placed in the top section fixed window from the outside after trimming.

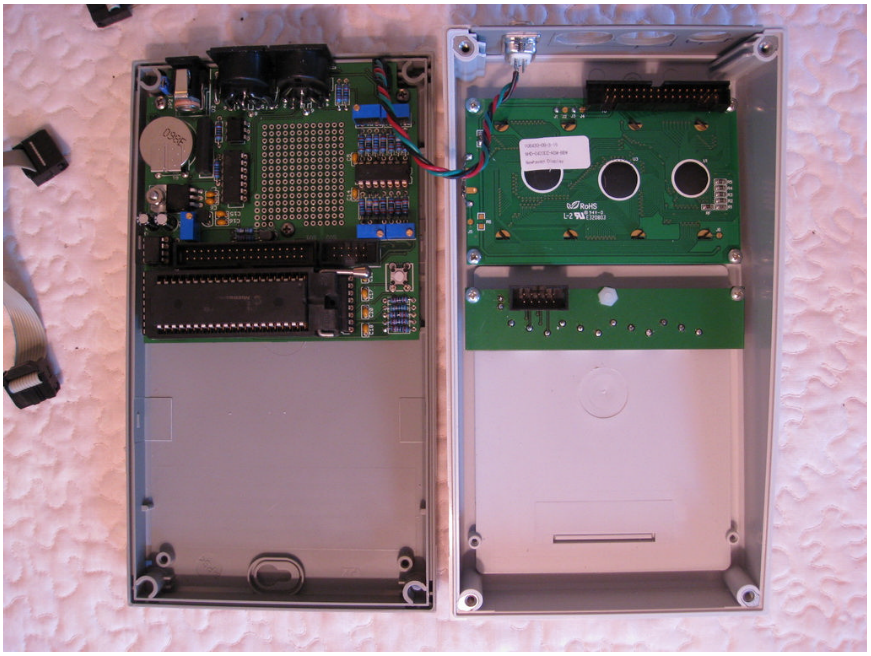


Display:

The LCD is installed on molded standoffs in the enclosure top section. Use the supplied 3/16 in. spacers and No. 3 or 4 x 1/2 in. self-threading screws. Before mounting the LCD, pre-thread the standoffs with the supplied screws; turn very slowly so you do not split the openings.

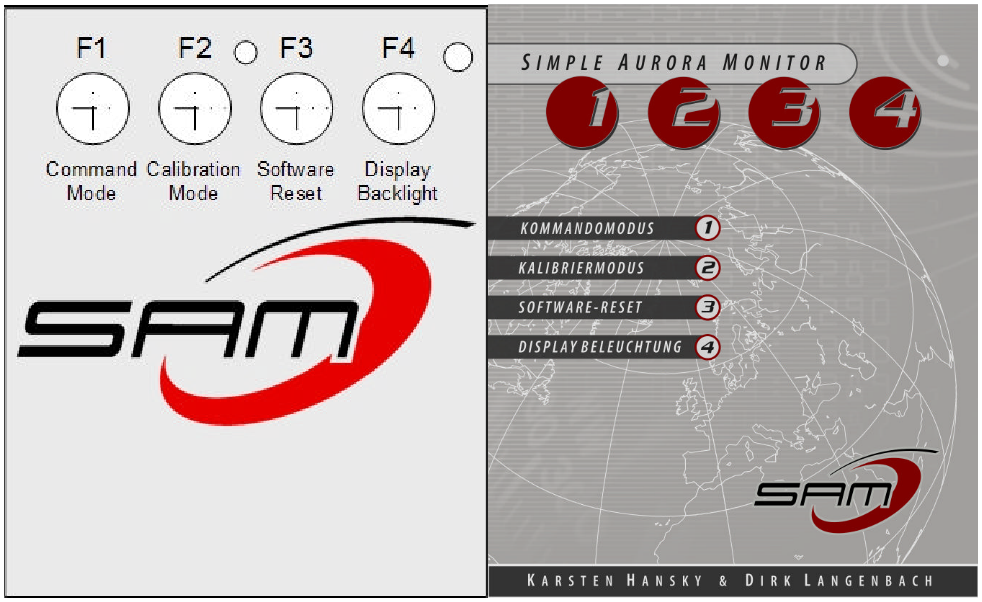
Before mounting the LCD, remove the protective cover from the glass display. Also, peel the protective cover from the transparent window supplied with the enclosure and snap it into position in the window opening.

After the PCBs and display are mounted, the inside of the enclosure bottom (left) and top (right) sections should look like the picture below. Note: The microcontroller in this picture is mounted in a ZIF socket for testing purposes.



Two keyboard label images (one in German) are provided on the supplied CD. Print them and trim the holes with a sharp hobby knife.

Not full size. Keyboard labels for use with the SAM



XV. Sensor Hookup

Description

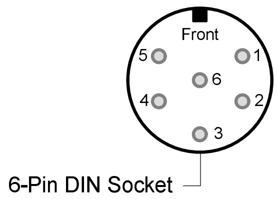
The SAM uses the Speake & Co Llanfapley FGM-3 magnetometer sensors (see picture below). The sensors have four pins and the label on the sensor indicates pin designations.

Required parts:

Parts list ID	Qty	Description
☐	1	Magnetometer sensor
☐	1	4-pin header connector
☐	3	Contact for header connector
☐	1	10 μF, 25 V tantalum capacitor
☐	1	100 nF, 25 V ceramic capacitor
☐	1	6-pin DIN cable plug
☐	1	Sensor cable (not supplied)

Sensor connections

The sensors connect to the SAM controller through the 6-pin DIN connector X3 and a supplied 6-pin DIN cable connector. The builder must supply the cable (discussed later in this section). The DIN connector pinouts are shown below. The drawing shows the pin numbering from the front of the DIN socket on the controller PCB; the pin numbering on the rear of the DIN plug is identical.



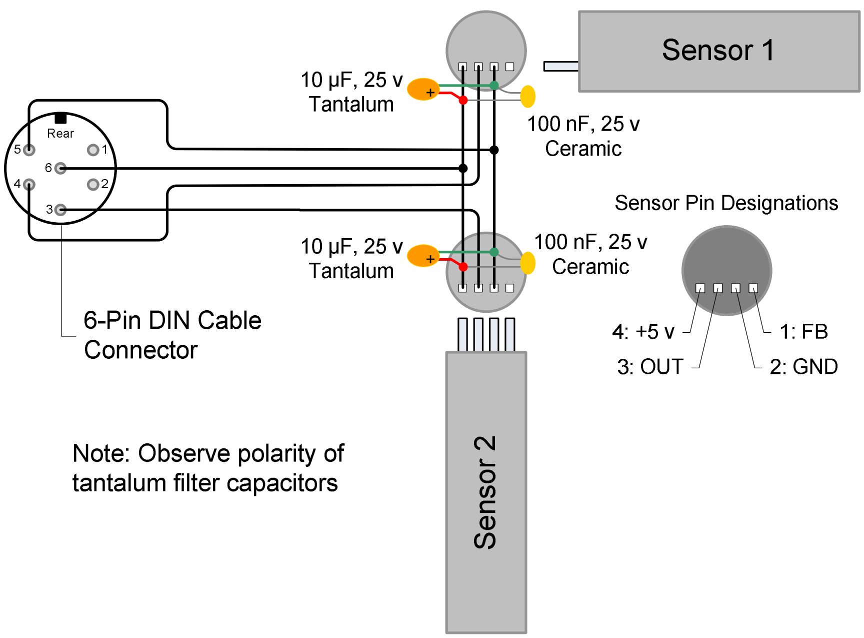
Sensor 6-Pin DIN Assignments

Pin	Function
1	Sensor 2 field winding (N/C)
2	Sensor 1 field winding (N/C)
3	Sensor 2 signal output
4	Sensor 1 signal output
5	Ground
6	Sensor power +

A 4-pin single inline header connector and contacts are supplied for connecting the cable to the sensor. Do not solder wires directly to the sensor. The header has no built-in polarity indicator so it should be marked with nail polish, paint or tape to indicate proper alignment.

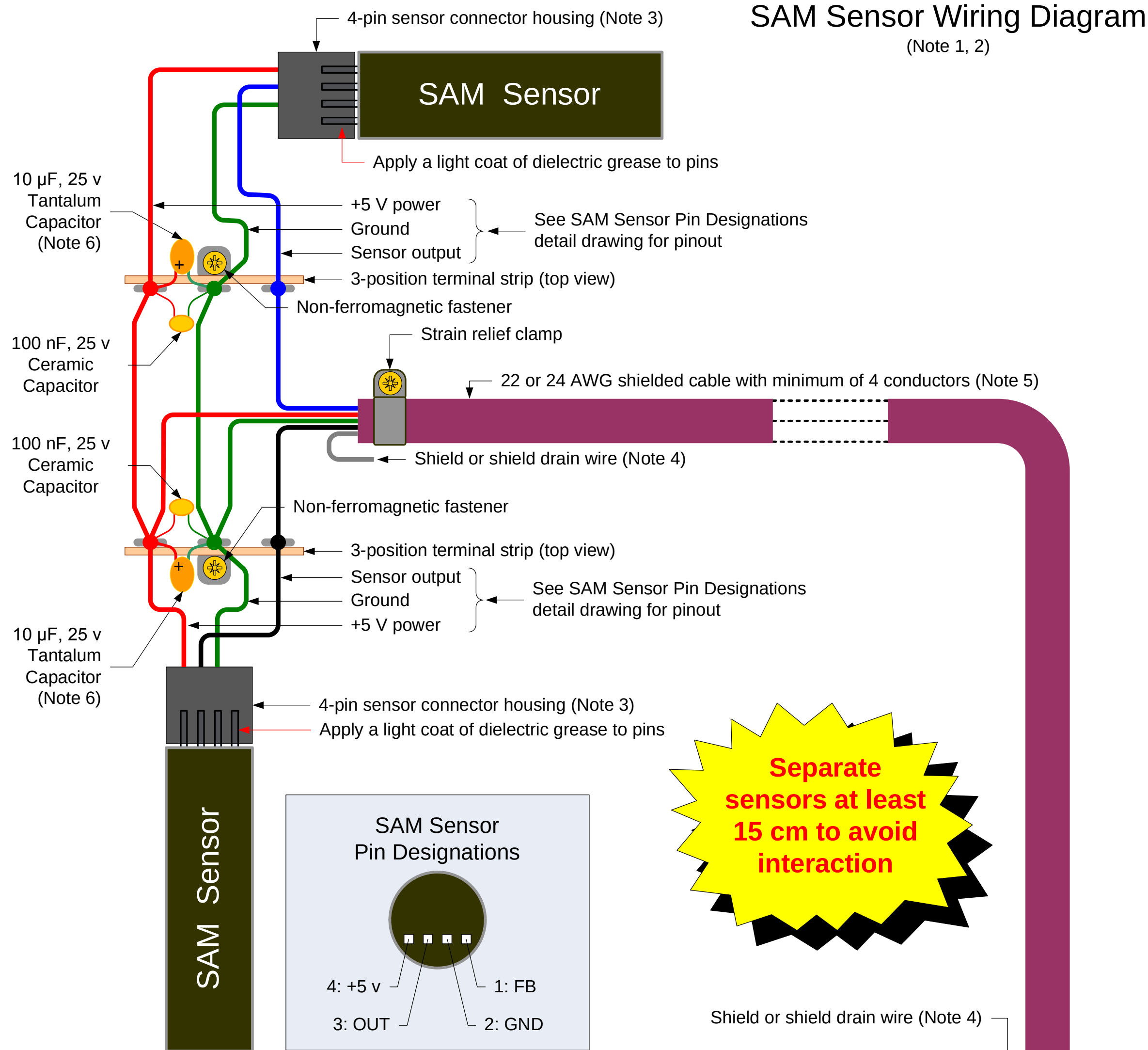
The sensor pinout is indicated on the sensor label and in the drawings below. Before inserting the single inline (SIL) header onto the sensor pins, put a small amount of dielectric grease (for example, Permatex 81150 available at most automotive parts stores) on the sensor pins. This will help prevent corrosion if the sensor is used in outdoor applications.

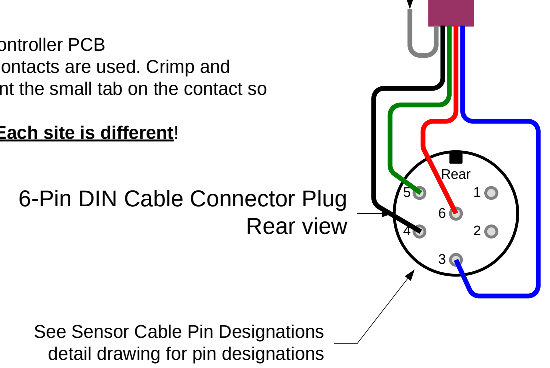
Either one or two sensors can be connected to the SAM. The schematic diagram below shows two sensors. This drawing assumes that the 78L05 voltage regulator IC5 is installed on the controller PCB and that the sensors are fed with 5 V power from the controller. If only one sensor is installed, it is connected as Sensor1. Two filter capacitors are used for each sensor, a fairly large value tantalum type for low frequency filtering and a small value ceramic type for high frequency filtering. Be sure to observe the polarity of the tantalum capacitor. A more detailed functional wiring diagram also is provided below.



SAM Sensor Wiring Diagram

(Note 1, 2)



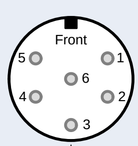


Notes:
1. Use only non-ferromagnetic materials
2. Use this configuration only if 78L05 voltage regular IC5 is installed on controller PCB
3. Each 4-pin sensor connector is supplied with 4 contacts. Only 3 of the contacts are used. Crimp and solder wire to contact and then insert contact into connector housing. Orient the small tab on the contact so it slides into the slot on one side of the housing
4. Refer to SAM Construction Manual for bonding/grounding information. **Each site is different**!
5. Other types of cable may be suitable. See SAM Construction Manual
6. Observe polarity of tantalum capacitors

Sensor Cable Pin Designations

Sensor 6-Pin DIN Assignments

Pin	Function
1	Sensor 2 field winding (N/C)
2	Sensor 1 field winding (N/C)
3	Sensor 2 signal output
4	Sensor 1 signal output
5	Ground
6	Sensor power +

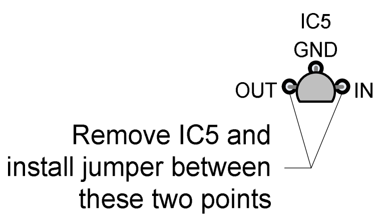


6-Pin DIN Socket
Front View

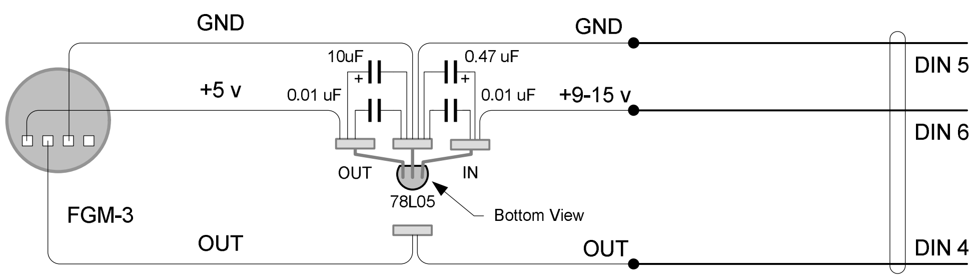
Sensor power

The sensors are powered by a dedicated +5 V voltage regulator (78L05, IC5) on the SAM controller. The sensor power ground and signal ground are shared. Each sensor draws around 15 ma.

In some applications, it may be desirable to move the sensor voltage regulator from the SAM controller PCB to the sensor location to improve voltage regulation at the sensor. Only a minor change is required on the SAM controller PCB to accommodate a remote voltage regulator (typically a 78L05). Remove IC5 from the controller PCB and install a jumper between the in and out pin locations (these are the two outer pins as shown below). This modification applies +12 V dc to pin 6 of the DIN connector X3. With this modification, it is imperative that a voltage regulator be installed with the sensor to provide +5 V dc for its operation (applying more than 5 V to the sensor will damage it).



The wiring diagram for a remote voltage regulator at the sensor location is shown below for sensor No. 1. Duplicate the wiring for sensor No. 2 except the output signal from sensor No. 2 is connected to DIN connector pin 3. Note that filter capacitors are used at both the input and output of the voltage regulator. A small terminal block provides rigid terminations as shown in the accompanying photograph (the photograph shows a shop-built fixture, or "monkey cage", for the sensor). Do not use any ferromagnetic components near the sensor.



Sensor cable

The cable between the SAM and the sensors should be shielded, either coaxial cable or shielded twisted pair. Cat5 or better unshielded twisted pair cable is a suitable alternate cable and works well for indoor installations.

The conductor gauge for short runs should be 24 AWG (0.5 mm) or larger. Longer runs should use 22 AWG (0.64 mm) or larger.

Where cabling is exposed to the weather, it should be waterproof cable suitable for direct-buried applications (for example, waterproof shielded twisted pair telecommunications drop wire, type DBW). For indoor testing and use, CAT5 cable is suitable and easy to obtain.

Mutual interference

Sensors can interact with each other if mounted too close together. Therefore, in a 2-sensor application, the sensors should be physically separated by at least 15 cm (6 in.). Some experimentation may be required to find the best separation. In geomagnetometer applications, the two sensors are installed a right-angles to each other.

The photograph below shows a 2-sensor fixture made from nonmetallic conduit fittings. Each sensor is mounted in its own round junction box. The two boxes are glued to a piece of conduit at right angles with sufficient separation. The third junction box at the bottom-right was used for test purposes and has a short DIN cable for connection to the SAM.

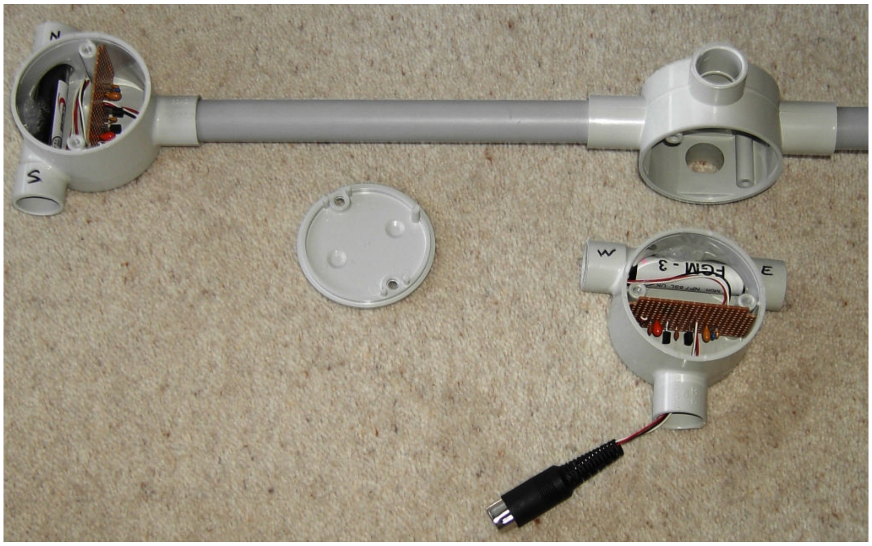


Photo courtesy of Ray Schmidt.

Electromagnetic Interference (EMI)

The SAM is susceptible to EMI from nearby amateur radio transmitters. The interference generally is picked up by the sensor cable. The sensor output is a PWM waveform with a maximum frequency of about 130 kHz. The SAM processor operates at 16 MHz and the sensor multiplexer (SN7400 quad NAND gate) operates at several megahertz. The interference usually manifests itself in the SAM as a geomagnetic storm because the SAM detects and counts the transmitter frequency or intermodulation products and not the sensor frequency. Here are a few mitigation techniques that may help reduce faulty operation due to interference:

- Different configurations of sensor cable shield bonding and grounding (bond to Earth at one or both ends, mid-point bond to Earth)
- Burial of sensor cable
- Low pass filter on the signal lead. (the low pass filter should have a cutoff frequency of 1 ~ 2 MHz)
- Single-ended to differential transceiver on sensor signal lead (information available at: http://www.marsport.org.uk/observatory/magmod.htm)
- Use the radio transmitter PTT to activate the input voltage detector. When +12 V dc is applied to pin 4 (with respect to ground at pin 3), the SAM stops measuring the sensor output. In this way, the SAM will ignore the interference during transmission. When the PTT is released, and +12 V dc removed from pin 4, the SAM resumes sensor measurements

XVI. Sensor installation

Orientation

Field components
It is first necessary to decide what component or components of the magnetic field are to be measured. The SAM supports one or two sensors, so it may be setup to measure the following combinations:

1-sensor installation, one of the following	**2-sensor installation, one of the following**
X (east-west)	X and Y
Y (north-south)	X and Z
Z (vertical)	Y and Z

A 1-sensor installation often is setup to measure the Y-component and a 2-sensor installation is setup to measure the X-component and Y-component, but it is a matter of personal choice which components are to be measured. It is best to stay with the three components and not use arbitrary orientations. Each sensor is configured in the SAM software for one of the three magnetic field components and arbitrary orientations are not specifically supported.

Generally, it is the Y-component that is affected most by geomagnetic storms and, in fact, the K-index is based on that component. For aurora watchers and amateur radio operators that take advantage of propagation opportunities caused by geomagnetic disturbances, variations in the Y-component are of the most value. However, the other components also show interesting variations, especially at higher latitudes, so they should not be discounted from consideration when you are contemplating your sensor installation. The Z-component (vertical) normally is influenced most by induced electric currents in the Earth's crust. These currents could be from local sources (for example, currents due to nearby powerlines), the anomalous field component and remnant magnetism or local ore bodies.

Transient magnetic variations (as opposed to secular, or long-term, variations) are of interest to SAM users. These usually are broken into three basic categories: Solar daily variations (S), lunar daily variations (L) and magnetic disturbances (D). How each magnetic component is affected by these variations is beyond the scope of this manual. For additional information, the SAM user is referred to online sources. Also, SAM users should download *Geomagnetometry for Amateur Radio Astronomers* from this internet address:

http://www.reeve.com/Documents/SAM/GeomagAmRadioAstron.pdf .

Finally, probably one of the best references on the Earth's magnetic field ever written is *Geomagnetism*, Vol. I and II, by S. Chapman and J. Bartels. This 2-volume set was published in 1940 and is available from online used-book sellers.

Body direction

For correct measurement of the magnetic field components, the sensor body and pins must be oriented as shown in the table below.

Magnetic field component	Sensor body orientation	Pins direction
X	**Magnetic North – South**	**SOUTH**
Y	**Magnetic East – West**	**WEST**
Z	**Vertical**	**UP**

When sensors are setup to measure the X- and Y-components, the sensors are installed perfectly horizontal. When a sensor is setup to measure the Z component, it is installed perfectly vertical. Where two sensors are used, they are rigidly and accurately mounted at right-angles to each other. However, the sensors must be physically separated as discussed in the previous section.

The rotational orientation of an individual sensor does not matter. Once its long axis is pointed properly, the body can be rotated and it will not change the measurements.

Reference direction
It is important to orient the sensors with reference to geomagnetic north and not geographic north. The two references differ by the magnetic declination at the site. The magnetic declination for any location on Earth can be estimated by using the calculator at this website: www.ngdc.noaa.gov/geomagmodels/Declination.jsp .

<u>Environment</u>

Temperature
The FGM-3 sensor is very sensitive to temperature variations, so it must be shielded from temperature changes. This usually entails insulating the sensor from the environment. However, the sensor has been reported to overheat if insulation is applied directly to it. Therefore, when an insulated enclosure is used, there should be space around the sensor to allow convection and radiation cooling.

Placing the sensor in a watertight enclosure and burying it 0.5 – 1.0 m (or more) below the surface is a viable method to eliminate diurnal temperature variations. The watertight sensor enclosure can be placed in a small foam picnic cooler with additional thermal insulating foam fitted around the fixture and the entire assembly then buried in the earth.

Burial in earth
When the sensor is buried in the earth, it must be sealed to prevent moisture intrusion. A sensor enclosure buried 1 m below the surface will be subjected to a pressure of 1 m head of water during rain. This pressure is equivalent to 1.4 pounds/sq. inch. or about 10 kilopascal, a nominally small amount but enough to force water through even the smallest pinholes or defects in the enclosure seals. A drawing of a sensor enclosure using commonly available materials (in the United States) is shown at the end of this section.

Location
Place the sensor in a magnetically quiet location where it will experience as little magnetic disturbance as possible, usually in an open field or yard away from any building and automobile traffic. Ferromagnetic objects within the vicinity of the sensor generally do not cause problems if their location is permanent and they do not become magnetized.

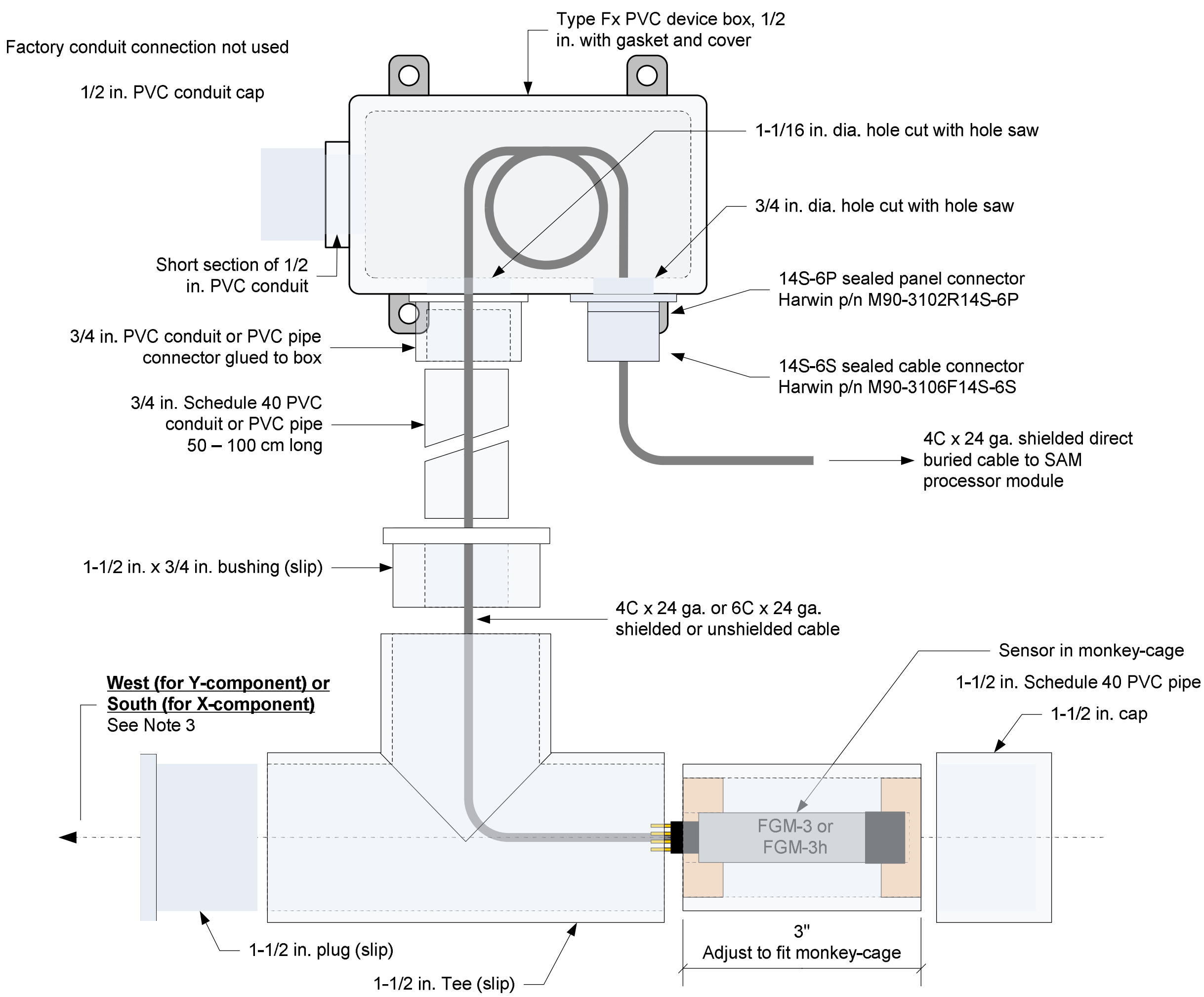
It is important to remember that the magnetic sensor will pick up any variation in the local magnetic field including automobiles moving in the area, ferromagnetic tools brought nearby and other manmade magnetic disturbances.

Any movement of the sensor or movement of ferromagnetic materials in its vicinity will cause a variation in the magnetic field measurements. Therefore, after any movement it usually is necessary to re-zero the SAM processor by pressing the F3 function key (Reset). Alternately, let the magnetometer run and it will re-zero itself within 24 hours.

Field Use

The FGM-3 sensors have proven to be very robust in the field and have survived incorrect signal and power connections and shock from being dropped. However, they should never be routinely treated that way. The sensor is encapsulated in an epoxy-like compound, which can be cracked and broken. Also, the pins are fairly fragile and if bent back and forth will break. Broken pins are not repairable.

Buried Sensor Fixture – Single-sensor installation, Typical

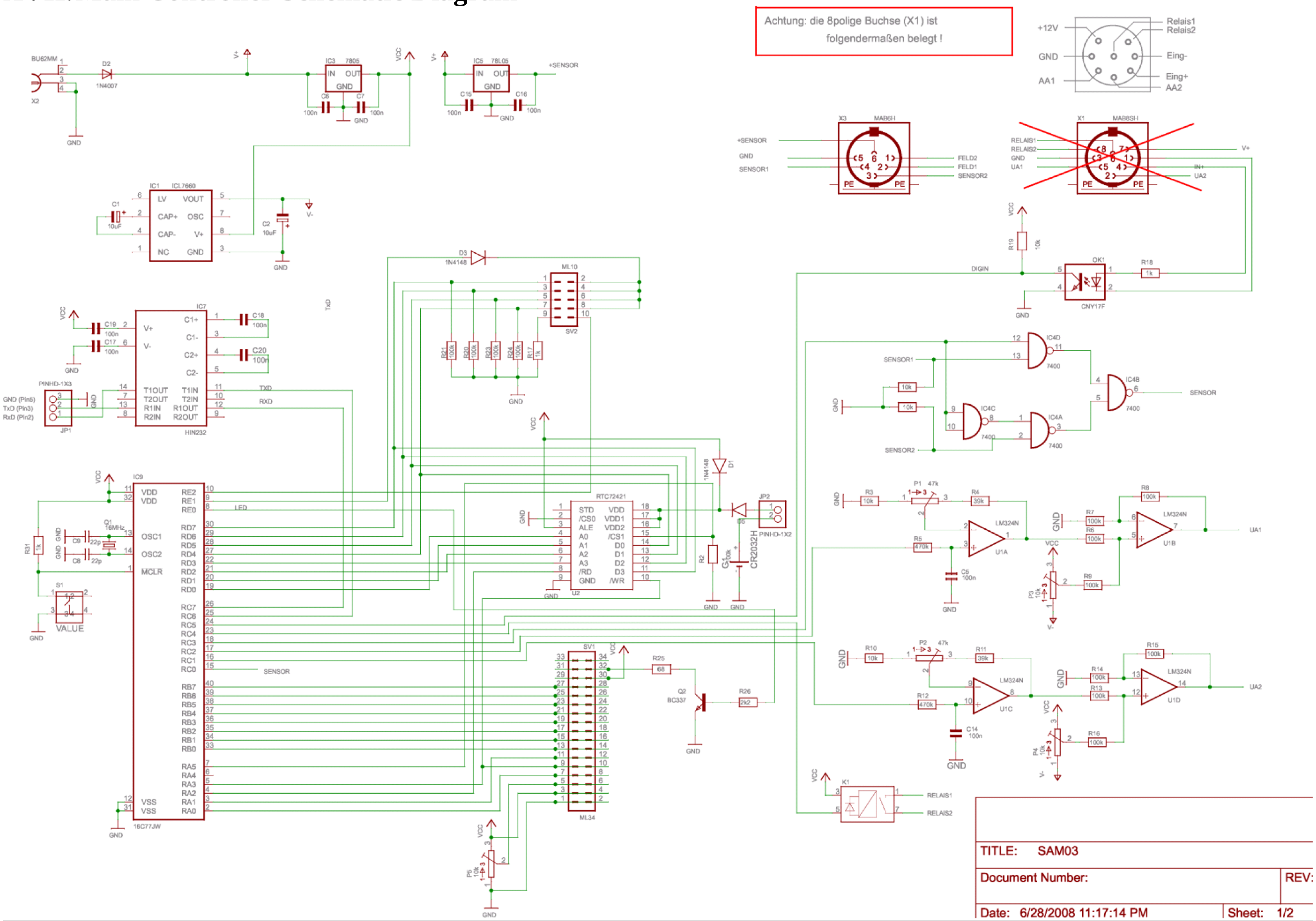


Notes:
1. All pipe and conduit sizes are non-metric trade sizes
2. All joints double-glued, once to assemble and again to provide additional seal
3. This fixture for horizontal sensing (E-W or N-S) only; orient as shown

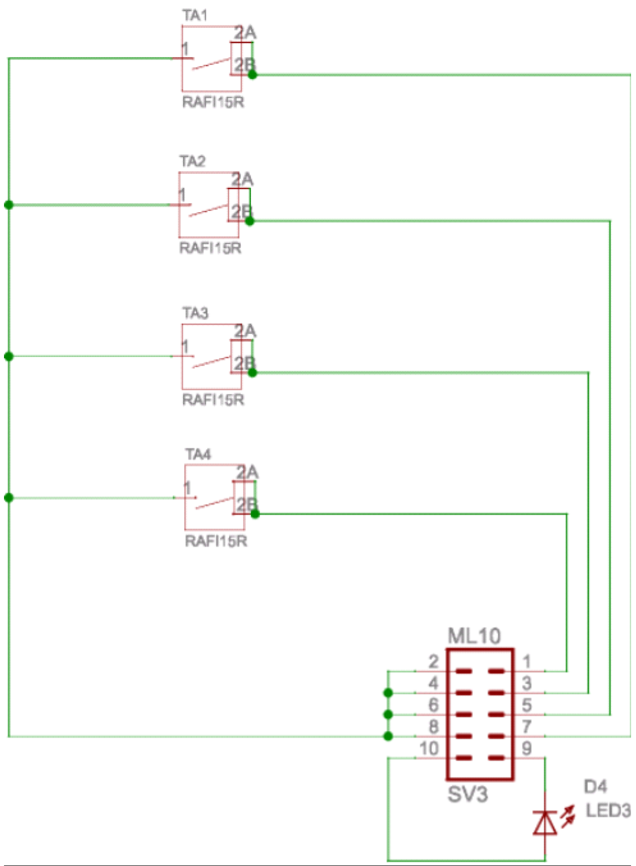
Bill of Material

Qty	Description
1 ea.	Fx PVC device box, 1/2 in.
1 ea.	Device box cover, gasket
1 ea.	1/2 in. PVC conduit cap
1 ea.	3/4 in. PVC conduit connector
1 ea.	3/4 in. Sch. 40 PVC pipe, 40 in. long
1 ea.	1-1/2 in. x 3/4 in. PVC slip bushing
1 ea.	1-1/2 in. PVC slip Tee
1 ea.	1-1/2 in. PVC slip plug
1 ea.	1-1/2 in. PVC pipe cap
1 ea.	14S-6P sealed panel connector
1 ea.	14S-6S sealed cable connector
1 ea.	4C x 24 AWG or 6C x 24 AWG unshielded cable, 60 in. long
1 ea.	4C x 24 AWG shielded direct buired cable, as req'd

XVII. Main Controller Schematic Diagram



XVIII. Keyboard Schematic Diagram



XIX. Document History

Author: Whitham D. Reeve, Anchorage, AK USA
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Revision history: Iss. 0.0 (Initial draft started, July 1, 2009)
Iss. 0.1 (Edited to reflect current configuration, July 24, 2009)
Iss. 0.2 (Edited test section, July 25, 2009)
Iss. 0.3 (Edited enclosure section, July 27, 2009)
Iss. 0.4 (Edited to include Hansky comments, July 31, 2009)
Iss. 1.0 (Issued for distribution as DRAFT, July 31, 2009)
Iss. 1.1 (Edited sensor sections, August 1, 2009)
Iss. 1.2 (Reissued as Preliminary, August 13, 2009)
Iss. 1.3 (Final cleanup, August 16, 2009)
Iss. 1.4 (Minor edits, August 22, 2009)
Iss. 1.5 (Added power supply info, schematics, September 5, 2009)
Iss. 1.6 (Replaced photo of controller PCB, September 30, 2009)
Iss. 1.7 (Additional edits, October 2, 2009)
Iss. 1.8 (Added function key description, December 8, 2009)
Iss. 1.9 (Removed PCB layout drawing, January 24, 2010)
Iss. 2.0 (Added LED, power adapter information, TOC, April 16, 2010)
Iss. 2.1 (Added sensor information, April 21, 2010)
Iss. 2.2 (Corrected sensor wiring diagram, May 15, 2010)
Iss. 2.3 (Minor edits, June 11, 2010)

Note: The basic contents of this construction manual, including SAM logos, were taken from the original designer's website with their permission. The manual was then revised to reflect the current PCB configuration and components and to translate some of the details that originally were in German. Please let us know if you find errors – send an email to SAMinfo@reeve.com with "SAM Kit" in the subject line (or else your email may be caught by our spam filters).