Mitigating SAM-III Magnetometer Sensor Cable Crosstalk

Whitham D. Reeve

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1. Introduction

The SAM-III, or *Simple Aurora Monitor - 3-Axis*, is an upgrade of the original 1- or 2-axis SAM and has been available since 2009. The SAM-III is used for geomagnetic observations and as a geomagnetic disturbance monitor for aurora photography and amateur radio VHF communications.

When the signal outputs from two or three sensors are carried in the same cable to the SAM-III Controller, crosstalk interference can occur depending on the length and type of cable. The sensor outputs are unbalanced and their signals easily couple into adjacent conductors and become part of the signals from other sensors. Crosstalk has been observed on cable lengths as short as 10 m.

The input circuits in the SAM-III Controller cannot distinguish between the interfering and actual signals. As a result, crosstalk manifests as noisy and inaccurate data and magnetogram traces. Unbalanced sensor signaling circuits also are susceptible to noise from other sources such as powerlines and radio transmission systems.

A robust crosstalk mitigation method is described in this paper including design, construction and field installation. It uses interface circuitry at the ends of the sensor cable that converts the unbalanced sensor outputs to balanced circuits for transmission over inexpensive *twisted pair* cable. This method is based on the TIA-422 interface, which not only ensures sensor signal integrity but also allows the sensors to be installed much farther from the SAM-III Controller than possible with unbalanced circuits.

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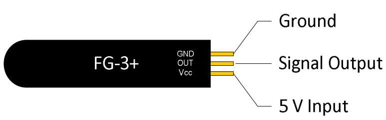
2. Signal crosstalk and mitigation

The SAM-III magnetic flux sensor has power, ground and signal pins (figure 1). The ground pin is common to both the signal and power. As such, the signal output is unbalanced (*single ended*) and can couple into adjacent circuits in the interconnecting cable and become part of the signal from other sensors. The unbalanced circuit also allows noise from powerlines or other sources to couple into the cable conductors, where it can interfere with the desired signals.



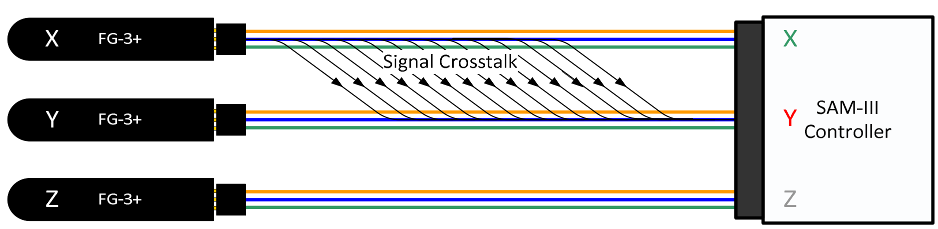


Figure 1 ~ Left: Magnetic flux sensor used with the SAM-III magnetometer. The signal output and 5 V input pin use the common ground pin. Sensor dimensions are approximately 60 x 12 mm. A label on the sensor identifies the three pins. Right: Crosstalk between sensor circuits can corrupt the signals and cause noisy and inaccurate data. This illustration shows crosstalk, or signal leakage, from the signal output wiring from the X-axis sensor at top to the Y-axis sensor wiring in the middle. Consequently, the input signal at the SAM-III Controller for the Y-axis is a mixture of both X and Y signals. This illustration shows crosstalk only from X to Y but it may exist in any combination between X, Y and Z. Image © 2022 W. Reeve

Various methods have been used to mitigate crosstalk interference, including running a separate cable for each sensor and installing a lowpass filter in each sensor signal lead. Signal distortion limits the cable lengths that may be used with these methods. A more effective method is to use circuitry external to the SAM-III Controller and sensors that converts the sensor unbalanced signal output to a balanced interface (*double ended*) for transmission.

Balanced circuits have inherent common mode noise rejection capability especially when used with twisted cable pairs. If the circuit is balanced, the common mode noise currents from crosstalk and other noise sources have equal amplitudes and flow in the same direction on the two conductors (figure 2). The common mode currents cancel each other at the termination, while the differential mode signal currents are unaffected. Twisting the two conductors, as in twisted pairs, improves the overall circuit balance.

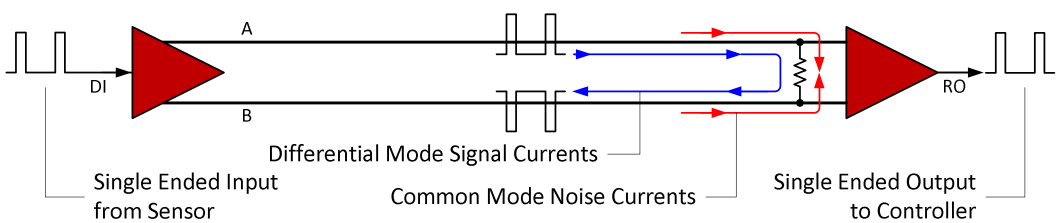


Figure 2 ~ Balanced interface circuits and twisted cable pairs mitigate common mode crosstalk currents and ensure signal integrity over long distances. The Receive Out (RO) signal is a reconstructed version of the Data In (DI) signal. Image © 2022 W. Reeve

The balanced interface described here is based on the TIA-422 standard [TIA-422] (originally known as RS-422, then EIA-422 and TIA/EIA-422 and currently TIA-422) and uses integrated circuits specifically designed for it. The TIA-422 interface is electrically similar to the TIA-485 interface, the latter providing additional multipoint connection and receiver termination methods that are not needed in this application [TIA-485].

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3. Description

The complete interface system consists of Local and Remote Interfaces and a multipair cable that interconnects them. The three SAM-III sensors connect to a collocated Remote Interface, which conditions the unbalanced signals for balanced transmission to the Local Interface. The Local Interface converts the signals back to the unbalanced mode for connection to the collocated SAM-III Controller (figure 3).

Ordinary 4-pair, 24 AWG, CAT5 UTP or STP (Unshielded Twisted Pair or Shielded Twisted Pair, respectively) cable can be used as a convenient and inexpensive transmission medium. Three cable pairs in the interconnecting cable carry the signals from the sensors back to the Local Interface, and one pair carries power from the Local Interface to the Remote Interface electronics and sensors.

The TIA-422 interface is based on balanced *line drivers* and *line receivers*. Because the balanced circuits are transmission lines, they need to be properly terminated. Generally, an impedance of 100 to 150 ohms is compatible with the TIA-422 interface and CAT5 cable.

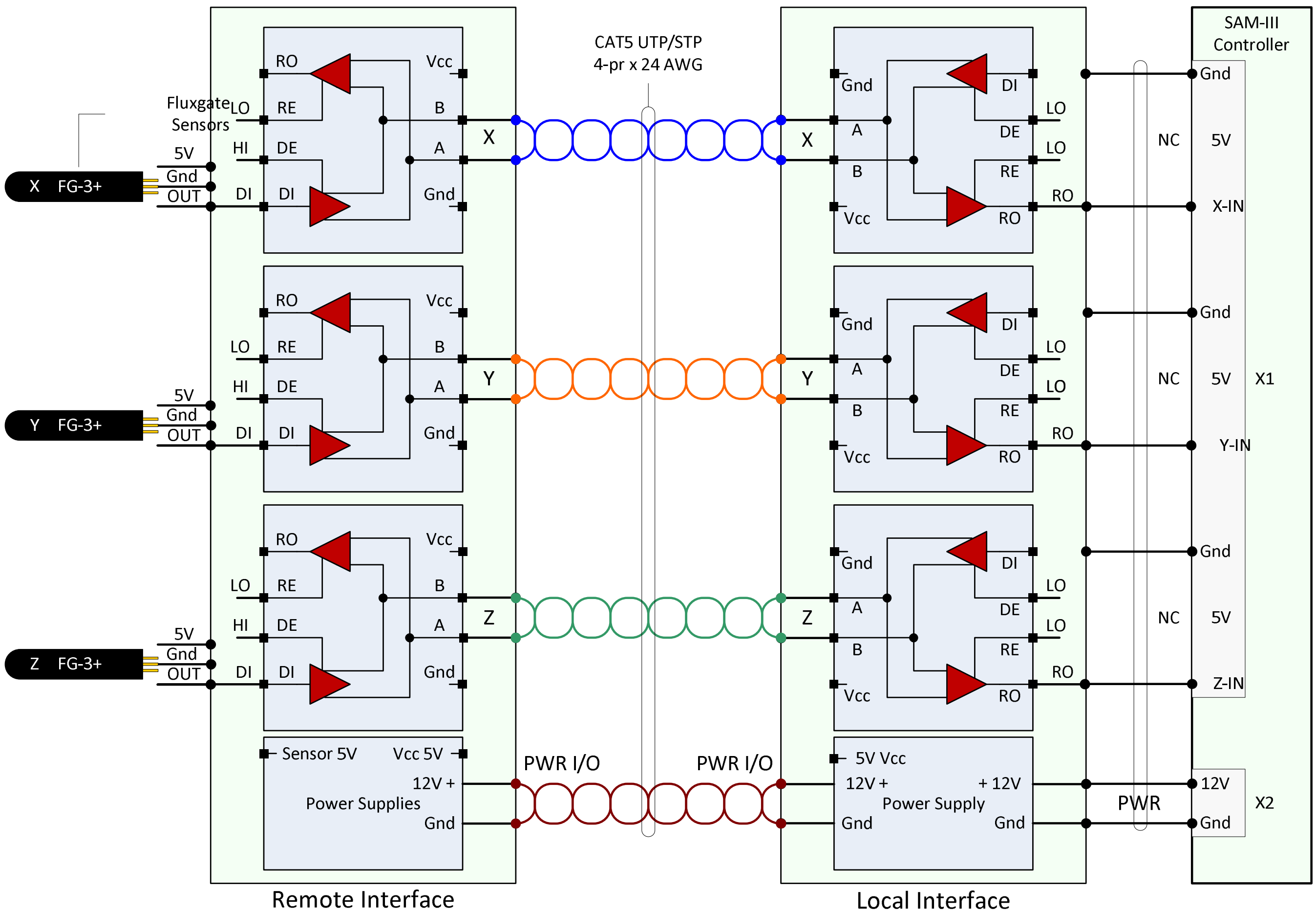

figure 3 ~ System block diagram. The integrated circuits have bi-directional capability but are setup for uni-directional operation through the enable pin (RE and DE) selections as shown. The sensor output signal is connected to the Data In (DI) pin at the Remote Interface. The Receive Out (RO) pin at the Local Interface outputs the signal to the SAM-III Controller. Image © 2022 W. Reeve

As previously mentioned, the sensors may be located much farther from the controller than the original unbalanced connection scheme. The estimated maximum distance is 500 m of 24 AWG cable but this has not been field verified. The tradeoffs for the improved circuit operation compared to the original unbalanced transmission method are the added cost and power consumption of the interfaces.

The MAX485 integrated circuit (IC) by Maxim forms the basis for the system [Maxim]. Equivalent ICs are made by other manufacturers. The MAX485 IC has bidirectional capability but is used in simplex mode for transmission in one direction only. The drop-in compatible MAX487 also may be used. It has reduced slew-rate line drivers that minimize electromagnetic interference (EMI) and reduce reflections caused by improperly terminated cables.

The Local and Remote Interfaces use identical printed circuit boards (PCB) but they are populated with components according to the requirements of each end. Both interfaces include the three MAX485 ICs, one for each sensor, and a 5 Vdc voltage regulator for powering the MAX485 ICs. The field-side connections of the interfaces are protected against overcurrent by current limiting resistors and against overvoltage by transient voltage surge suppressors (TVSS). Figure 4 shows block diagrams of the Remote and Local Interfaces.

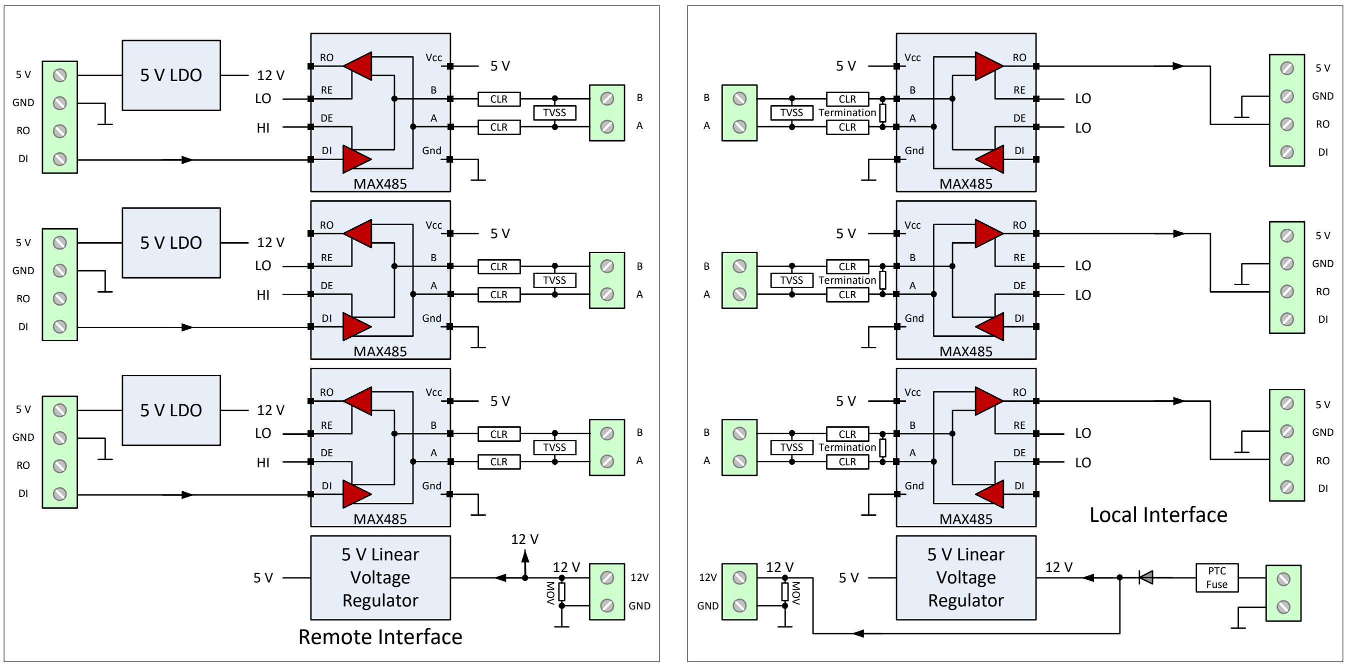

figure 4 ~ Remote (left) and Local (right) interface block diagrams. The sensors connect to the screw terminal blocks on the far left and the SAM-III Controller connects to the screw terminal blocks on the far right. The field-side cable connects to the screw terminal blocks in the middle. The Remote Interface includes three 5 V low dropout (LDO) voltage regulators, one for each sensor. These are not required at the Local Interface. The power feed circuitry at the Local Interface has overcurrent protection and a polarity guard diode that protects both interfaces. The field-side connections of the power feed circuit are protected from overvoltages by metal oxide varistors (MOV). Overcurrent and overvoltage protection is provided on the field side of the balanced circuits (CLR – current limiting resistor – and TVSS – transient voltage surge suppressor). Only the Local Interface has termination resistors for the balanced unidirectional circuits. Image © 2022 W. Reeve

The Local Interface has a 12 Vdc power input circuit with overcurrent protection and polarity guard for the Local circuits as well as for the power feed to the Remote circuits. The power feed circuit includes a metal oxide varistor (MOV) at each end to limit induced voltages. The Remote Interface also includes three individual 5 Vdc high performance, low dropout (LDO) voltage regulators, one for each sensor.

The sensor signals are a PWM (pulse width modulation) waveform whose period varies from approximately 5 to 30 µs (corresponding to frequencies of 200 to 33 kHz), depending on the magnetic induction along the sensor axis. The nominal output amplitude of the PWM signal is either 0 or 5 V with respect to the ground reference voltage of 0 V. The signals are converted by the MAX485 ICs to differential waveforms that have the same PWM characteristics but are balanced with respect to ground and suitable for transmission on a twisted pair.

The MAX485 line driver differential output signal has an amplitude up to 5 V across the two conductors of the twisted pair. The signal is attenuated by the cable, so the signal voltage at the line receiver depends on cable length. The MAX485 ICs receivers will properly detect and regenerate the signal for a differential input voltage of 0.2 V or greater. Only the receiving ends of the transmission circuits (Local Interface) have a 120 ohm termination resistor. The line driver in each MAX485 IC properly terminates the sending end.

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4. Construction

The interface printed circuit boards (PCB) use through-hole and surface mount components. Most are through-hole types, and they all are installed on the PCB top. The current limiting resistors and TVSS are surface mounted devices (SMD) and installed on the PCB bottom. Two versions of the printed circuit board have been made, one with small screw terminal blocks (2.54 mm pitch and requiring a jeweler's screwdriver) and several movable jumper options (figure 5) and another with larger pluggable screw terminal blocks (3.96 mm pitch) and fewer jumper options. DIP-8 sockets were used in the development system for the three MAX485 ICs on each PCB.

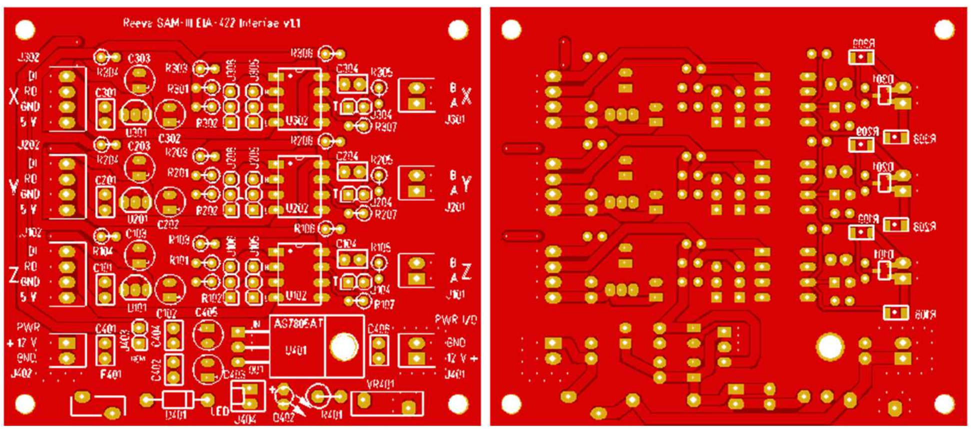


figure 5 ~ Version 1.1 prototype printed circuit boards, top (left) and bottom (right). As mentioned in the text, the Remote and Local Interface boards are identical, and the interfaces are differentiated by the components placed on them. All resistors are mounted vertically to save space, and all external connections are through screw terminal blocks. Silkscreen labels identify all terminals and components. The PCBs used in the prototype include many option jumpers and pull-up/pull-down resistors used during development. The version 2.0 PCBs use pluggable screw terminal blocks and have fewer optional components. The PCBs were designed with Target 3001 PCB CAD software and manufactured by JLCPCB.

To lower component count, cost and assembly time, the screw terminal blocks may be eliminated if it is desired to permanently solder the external wire connections. On the other hand, screw terminal blocks aid troubleshooting and replacement and are worth the small extra cost.

The PCBs are designed to accommodate headers and removable jumper links to select the component configurations needed for the Local and Remote Interfaces. However, in a typical permanent installation, soldered jumpers may be used instead. The prototype PCBs have pads for additional pull-up and pull-down resistors that were used during PCB development, but these normally are not needed in a permanent installation.

The Remote Interface board receives power from the Local Interface board over the field interconnection cable. Therefore, the Local Interface board was tested first and then connected to the Remote Interface board for further testing. Initial tests were made without any external connections except power and the interconnection cable. During all tests, the power supply current was continuously monitored. It was found that the normal operating current was 103 mA with no sensors connected. Additional measurements are described in section 6.

The final assembly step was installation of the interfaces in enclosures for protection of the electronics. The Local Interface was mounted in an extruded aluminum enclosure (figure 6), but it also may be mounted in the new part number BEN-1 polycarbonate enclosure (figure 7) now supplied with all SAM-III kits or in a separate plastic enclosure. The Remote Interface must be installed near the sensor fixture, so it was installed in a weatherproof enclosure that was made part of the buried sensor fixture described in the next section.

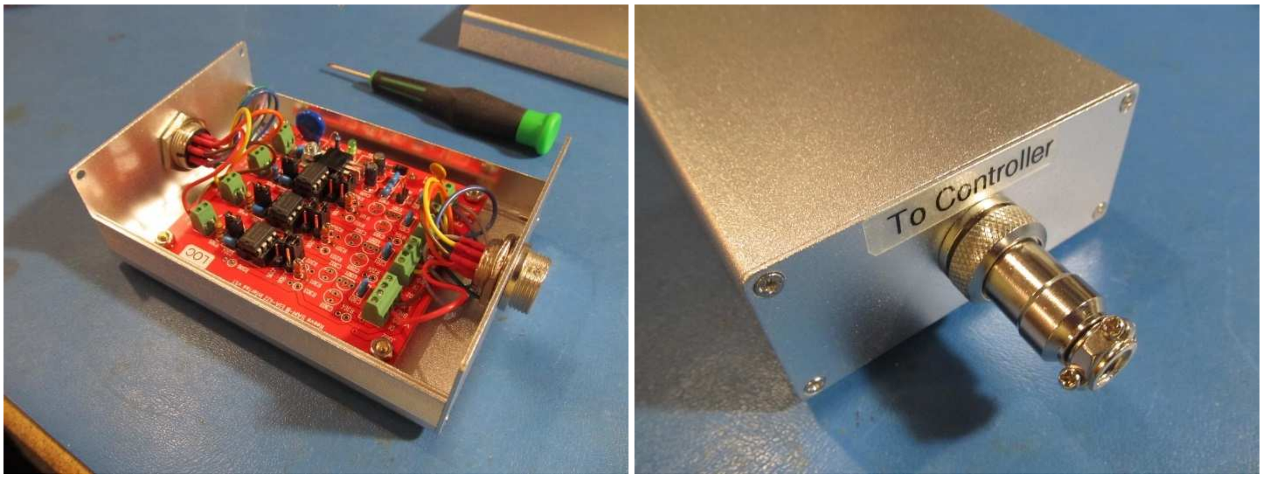


figure 6 ~ Example of a Local Interface enclosure. The PCB is mounted on M3x6 mm brass standoffs. Field-side interconnection cable and SAM-III Controller connections are through 8-pin and 10-pin connectors, respectively, with one connector on each end panel. The Local Interface board receives its power from the SAM-III Controller and relays it to the Remote Interface through the interconnection cable. No other controls or connectors are needed. Image © 2022 W. Reeve

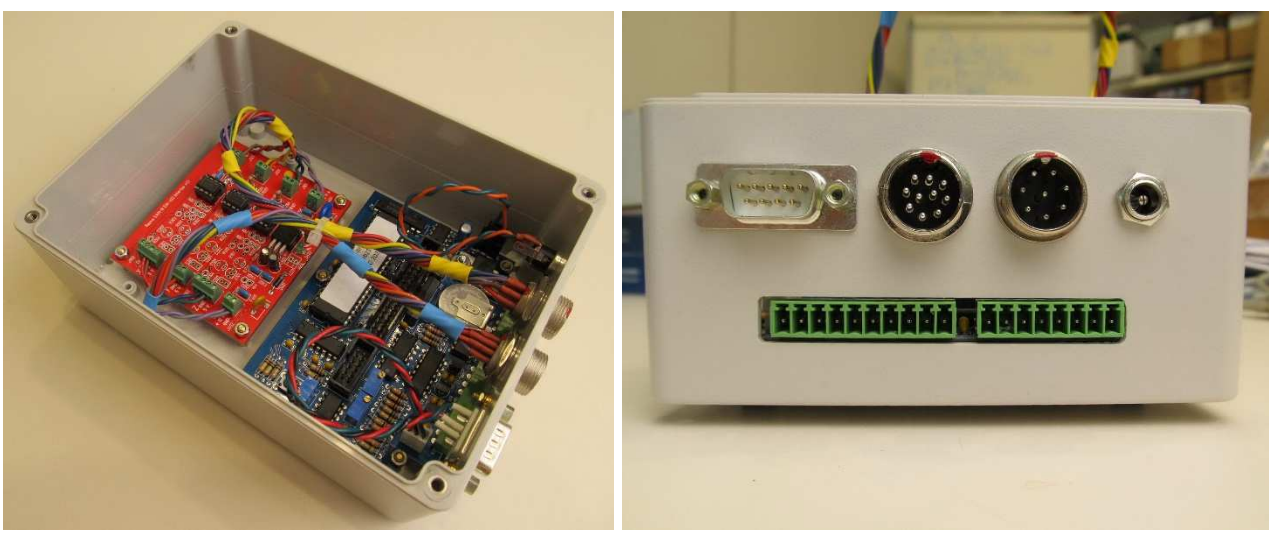
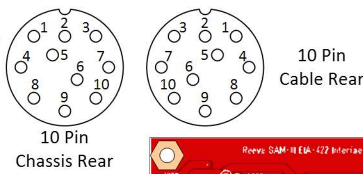


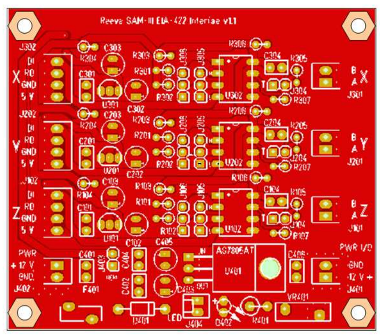
figure 7 ~ Local Interface PCB installed in the SAM-III Controller enclosure on M3x6 mm brass standoffs. In the image above-left, the interface PCB is to the left of the main controller PCB and is wired to the two connectors on the end panel shown above-right. Also seen on the end panel are the X1 and X2 pluggable terminal blocks, DB-9M serial port connector and 2.1 x 5.5 mm coaxial dc power jack. The two interface connectors, identical to those used in the standalone aluminum enclosure in the previous figure, are used for connections to X1 and X2 and the field cable. This way, the SAM-III Controller does not require any modifications except cutting the four 1/8 in (3 mm) diameter mounting holes for the PCB and the two 5/8 in (16 mm diameter) openings for the connectors. Image © 2022 W. Reeve

The Local Interface enclosure requires 8 pins on the field side and 8 pins on the SAM-III Controller side. To prevent accidentally reversing the connections and damaging the electronics, the development system used connectors with different pin counts. The Local Interface enclosure used an 8-pin connector for the field side connections and a 10-pin connector for the SAM-III Controller connections (figure 8). If preconnectorized CAT5 Ethernet cable is used for interconnection, 8-pin, 8-contact modular panel connectors (often, but incorrectly, called RJ-45) may be installed on the enclosures in place of the circular connectors that were used in the development system.

10 Pin Chassis to Controller

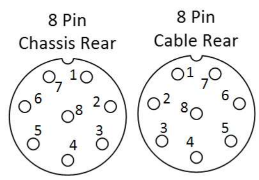
Pin	PCB	Color	Contrllr
1	X-GND	BRN	X2-1
2	X-RO	RED	X2-2
3	Y-GND	ORG	X2-4
4	Y-RO	YEL	X2-5
5	Z-GND	GRN	X2-7
6	Z-RO	BLU	X2-8
7	+12 V	VIO	X1-7
8	GND	GRY	X1-8
9	NC		
10	NC		





8 Pin Chassis to Field

Pin	PCB	Colorr	Field
1	X-A	BRN	Blu
2	X-B	RED	Wht
3	Y-A	ORG	Org
4	Y-B	YEL	Wht
5	Z-A	GRN	Grn
6	Z-B	BLU	Wht
7	+12 V	VIO	Brn
8	GND	GRY	Wht



9 Pin Chassis to Sensors

Pin	PCB	Color	Sensor
1	X-DI	BRN	OUT
2	X-GND	RED	GND
3	X-5 V	ORG	5 V
4	Y-DI	YEL	OUT
5	Y-GND	GRN	GND
6	Y-5 V	BLU	5 V
7	Z-DI	VIO	OUT
8	Z-GND	GRY	GND
9	Z-5 V	WHT	5 V

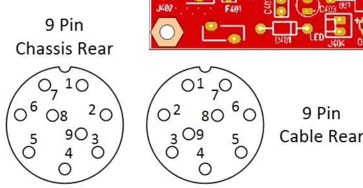


figure 8 ~ Panel-mount connectors used in the development system are GX16 style (16 mm diameter). The pinouts are shown from the rear of the connectors. The tables show connector pin numbers, silkscreen labels on the interface PCB, wire colors used in the development system and terminal numbers on the SAM-III Controller terminal blocks X1 and X2 (upper-left), sensors (lower-left) (not used in the development system) and field side cabling (upper-right). Image © 2022 W. Reeve

The development system Remote Interface used an 8-pin connector for field side connections (same connector as the Local Interface). The three sensors require a total of 9 pins. However, in the development system, the Remote Interface enclosure was made part of the buried sensor fixture and a separate connector for the sensors was not required (the sensors wiring was connected directly to the interface PCB screw terminal blocks after applying a small amount of dielectric grease to prevent corrosion).

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5. Field installation

<u>Sensor fixture</u>: For the development system, the sensors were glued to disks cut from 7/32 in hobby plywood and wired with a 3-conductor cable (figure 9). The disks easily could be printed on a 3D printer. The sensors were installed in a waterproof fixture for burial underground to reduce temperature effects (figure 10). in this type of fixture, the sensor wiring is fed up through the standpipe to a weatherproof enclosure above the surface that holds the Remote Interface (figure 11). All wires and cables are color-coded for easy identification.

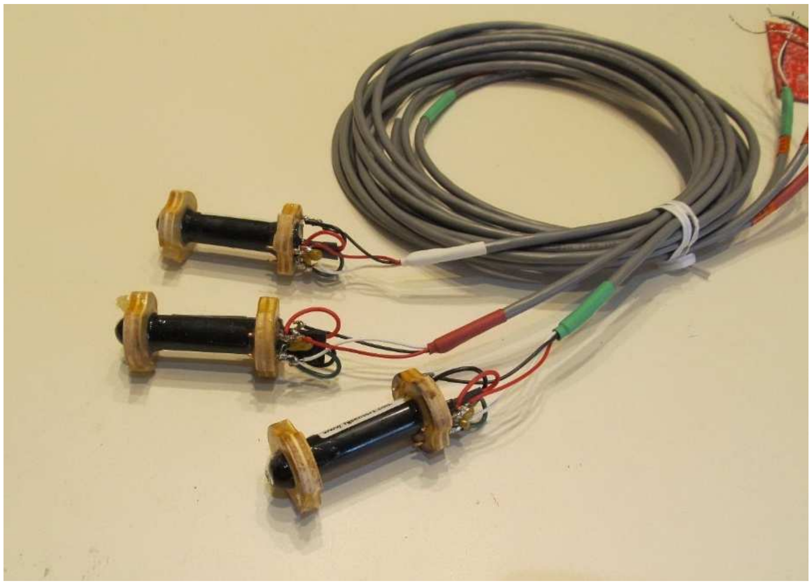

figure 9 ~ Sensors. The sensor pins connect through a pluggable wire mount housing whose terminal contacts have been moisture- and corrosion-proofed with dielectric grease. Each sensor was wired to a 3-conductor cable. Wood disks were cut with a hole saw and glued to the sensor to keep it centered when placed in the sensor fixture tubes. The outside diameter of the disks matches the inside diameter of the fixture tubes. The plywood pieces were notched to provide three gaps to allow air convection within the fixture and then coated with epoxy resin. The sensors cabling is color-coded for easy identification. Image © 2022 W. Reeve

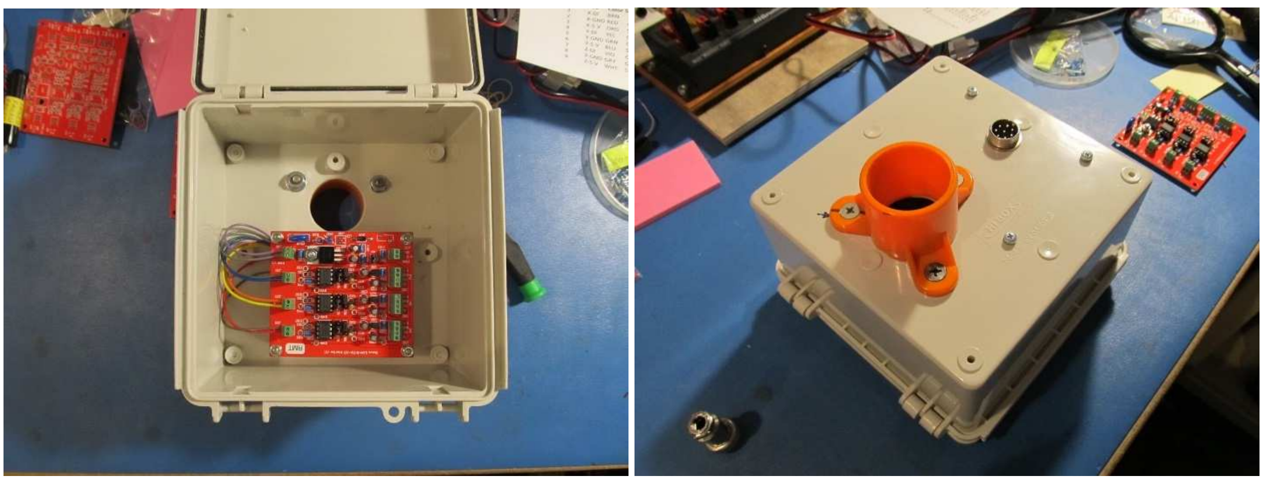

figure 10 ~ Example of Remote Interface enclosure. Left: Enclosure with the hatch opened to show the Remote Interface PCB. It is mounted on 25 mm brass standoffs. The dimensions of this enclosure are 150 L x 150 W x 90 D mm. The enclosure has a rubber gasket to provide a weatherproof seal when the hatch is closed. Right: Outside-bottom of the enclosure. The orange object on the enclosure is a *Table Screw Cap*. It will be glued to the standpipe from the sensor fixture. A 1 in diameter hole has been cut through the screw cap and enclosure to feed through the sensor cables to the interface PCB terminal blocks. The hole will be sealed with electrician's duct seal after installation. The 8-pin, chassis mount, cable entry connector is seen above and to the right of the screw cap (the connector is hidden by the PCB in the left image). The connector and associated wire mount housing and all hardware are non-magnetic. Image © 2022 W. Reeve

The sensor fixture is easy to fabricate from Inexpensive and readily available PVC pipe and associated fittings. Schedule 40 *furniture grade* PVC (figure 12) was used in the development system deployed at the HAARP facility, but PVC plumbing pipe used in potable water applications has the same dimensions and may be used as well.

SAM-III Controller: The SAM-III Controller connects to the Local Interface by eight individual conductors (figure 13) or a short 4-pair cable of the same type used in the field side interconnection. The development system used

8 individual color-coded wires that are 12 in long and twisted together. All connections between the SAM-III Controller and Local Interface should be as short as possible to ensure signal integrity of the unbalanced circuits.

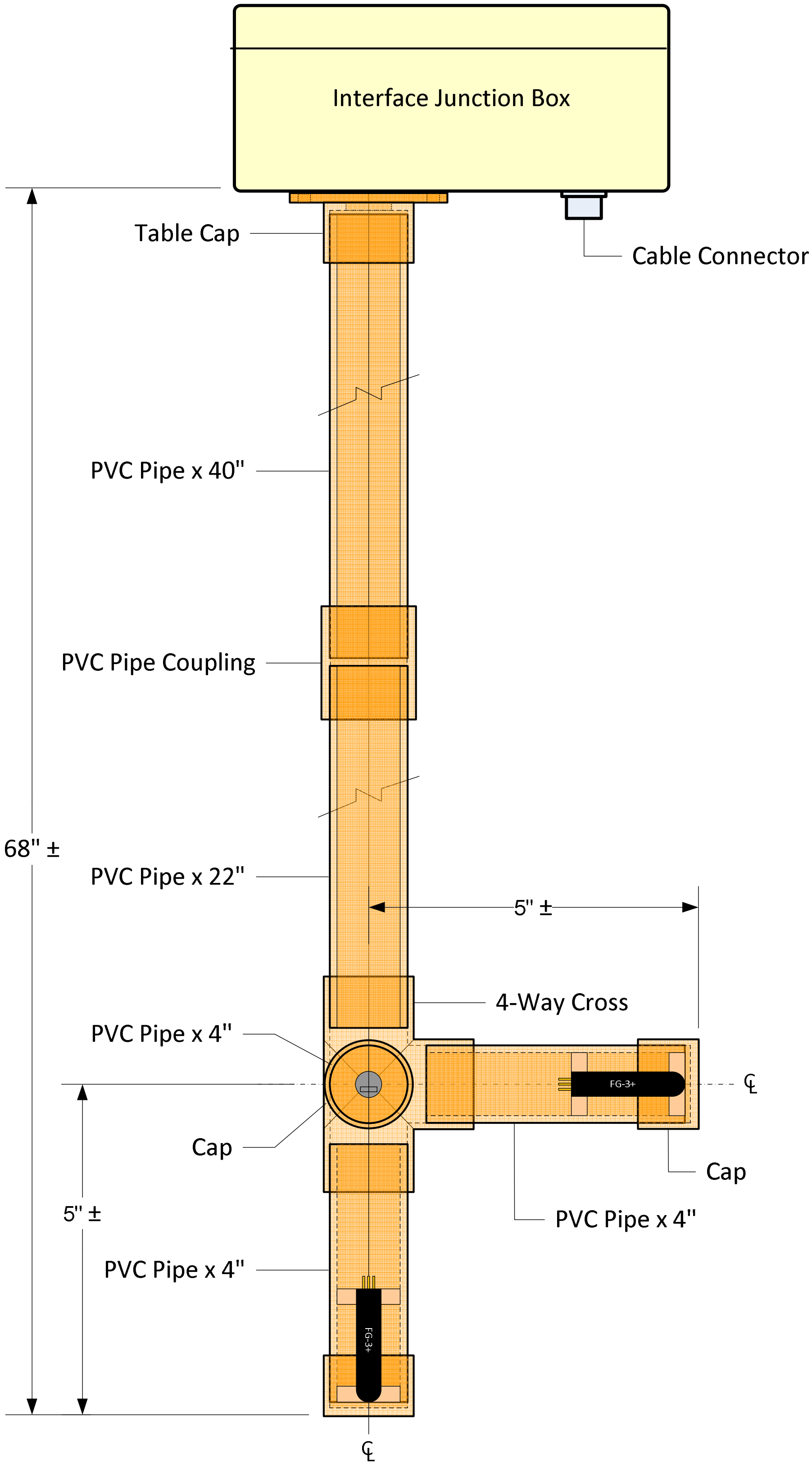

Figure 11 ~ 3-axis sensor fixture. The lengths shown are for the development system. All pipe and fittings are 1 in trade size PVC that are double-glued to ensure waterproof joints. The Remote Interface PCB is mounted inside the Interface Junction Box above the ground surface. The sensors are buried at a minimum depth of 1 m. In this illustration, the x-axis points right, the y-axis points out of page, and the z-axis points down. Image © 2022 W. Reeve

Figure 12 ~ Lower portion of sensor fixture. The sensor fixture for the development system was made from 1 in trade size PVC pipe and a 4-way crossed-tee, the latter providing the correct 90° orientation of each of the three sensors. The sensors, pictured above with wood disks, are held in position with hot-glue. Colored tape, which matched the sensor cables, was used for identification of the sensor tubes. The sensor fixture includes a standpipe (toward upper-left of image) that carries the sensor cabling to the above-ground Remote Interface Junction Box. Image © 2022 W. Reeve

The X1 and X2 pluggable screw terminal blocks on the SAM-III Controller allow easy connection to the Local Interface (figure 14). X2 connects the three sensor signals and associated ground, and X1 supplies 12 Vdc power and ground to the Local Interface.

<u>Remote Interface</u>: A PVC Table Cap is mounted on the Remote Interface enclosure and glued to the sensor fixture standpipe (figure 15). The sensors are wired up through the standpipe and terminated on the screw terminal blocks on the Remote Interface PCB. The field-side interconnection cable terminates in an 8-pin connector (same as the Local Interface).. The ends of all wires connected to the screw terminals in the Remote Interface enclosure were lightly coated with dielectric grease before installation on the screw terminal blocks.

Figure 13 ~ SAM-III Controller connections to the Local Interface. A short free-hanging cable was made from individual color-coded wires and connected to the pluggable screw terminal blocks on the controller (left). The other end was terminated in a 10-pin connector for connection to the Local Interface enclosure (upper-right). Image © 2022 W. Reeve

<u>Field-side interconnection cable</u>: Although CAT5 UTP and STP cables are mentioned above for field interconnection, other cable types may be used. Generally, any multipair cable used for telecommunications applications is suitable, but it must have at least 4 pairs (8 conductors). Cables used in control applications that

do not have twisted pairs also may be used but are more susceptible to interference from common mode noise. Outdoor cable should be a waterproof and designed for direct burial. Information on the cable used in the development system is provide in section 6.

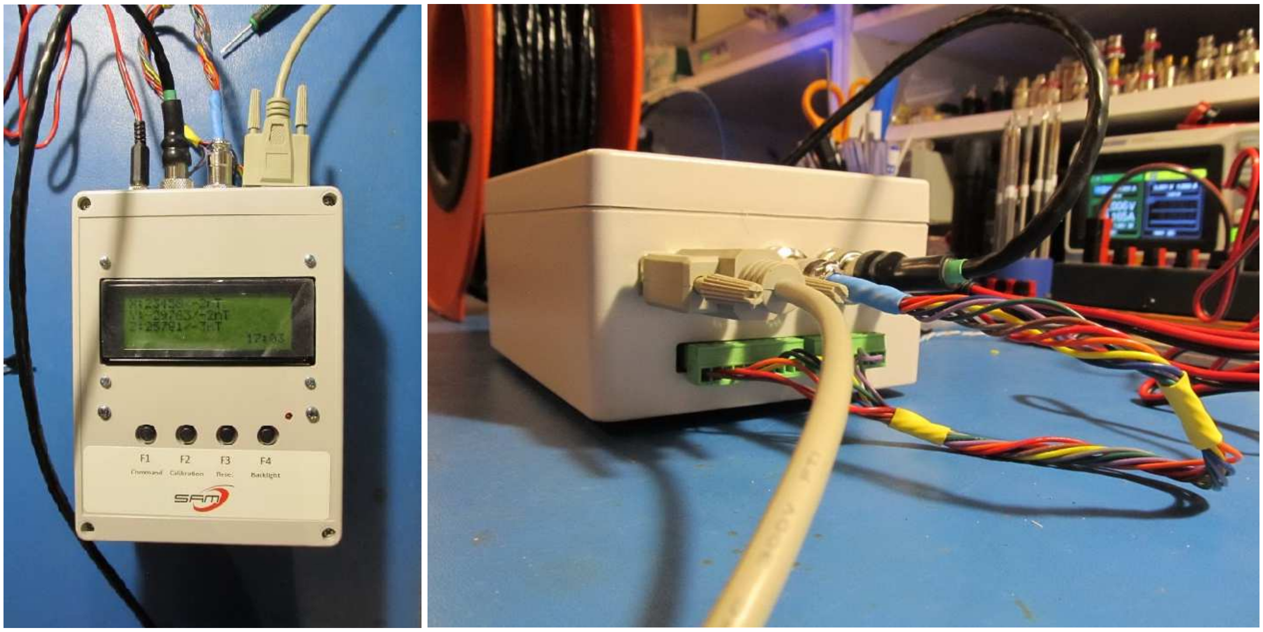

Figure 14 ~ SAM-III Controller X1 and X2 connections to a Local Interface that has been integrated with the controller enclosure. Image © 2022 W. Reeve

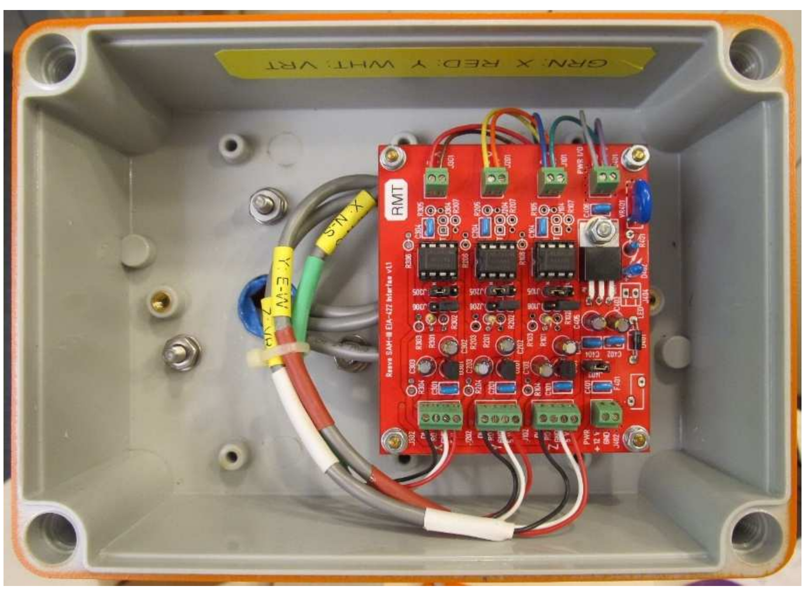

Figure 15 ~ Another example of the Remote Interface enclosure with 3-conductor sensor cables terminated on screw terminal blocks on the lower end of the Remote Interface PCB. The field-side interconnection cable connector is underneath the PCB and has been wired to the upper screw terminal blocks with individual wires. The opening to the Table Cap and standpipe is barely visible under the sensor cables at middle-left. A 1 mm diameter weep hole was drilled in the enclosure bottom to prevent pressurization during hot summer days and collapse during cold winter days. Image © 2022 W. Reeve

Additional materials: The field-side interconnection cable that was used in the development system is suitable for direct burial but to reduce the labor it was ground-laid instead. To prevent the cable from being chewed up by foxes and porcupines, the cable was installed in ordinary 1 in polyethylene water pipe purchased at a hardware store. Also, because the gravel pad at the site is full of rocks of all sizes and sharpness, the pit for the sensor fixture was backfilled with traction sand purchased at an aggregate supplier in 60 lb (27 kg) sacks. The sand was necessary because the rocks could damage the PVC sensor fixture through movement and crushing forces during repeated freeze/thaw cycles. Coax sealing tape was used to seal the Remote Interface connector.

Tools: Installation of the sensor fixture requires digging tools to open a pit about 4 to 5 ft (1.2 to 1.5 m) deep. We attempted to use an 8 in power auger at the HAARP site but the ground was too rocky. We ended up using the site's forklift, with which the forks were rammed into the ground and then rotated to open a short trench (figure 16).

Figure 16 ~ The ground was too rocky for a power auger, so a fully articulating forklift was used to open a short trench for the sensors. The forks were rotated to a vertical position, rammed into the ground and then rotated to scoop out the soil. No water was encountered to a depth of about 1.5 m (5 ft) but wood residue from the original site clearing was found.

The sensor fixture was oriented according to the Geographic Reference System, which is based on True North reference. The declination (figure 17) was determined from the online geomagnetic calculator at {NOAA}. A compass was adjusted for the required declination and then used to align the sensor fixture. A post/pipe level was used to ensure the standpipe was vertical during installation. The completed sensor installation (figure 18) was then connected to the SAM-III controller and the system placed into service on 1 July 2022 (figure 19).

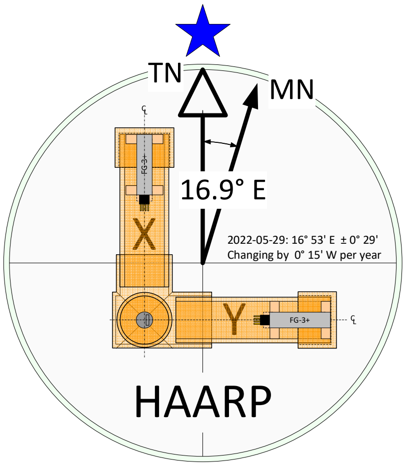

Figure 17 ~ Sensor fixture orientation according to the Geographic Reference System with the sensor x-axis aligned to True North (TN). The declination was set to 16.9° East on a transit/compass used for alignment. Image © 2022 W. Reeve

Figure 18 ~ The area around the sensors in the trench was backfilled with a layer of pea gravel followed by six 60 lb bags of traction sand. After backfilling, the connectorized cable was connected to the sensor junction box and the system placed into service.

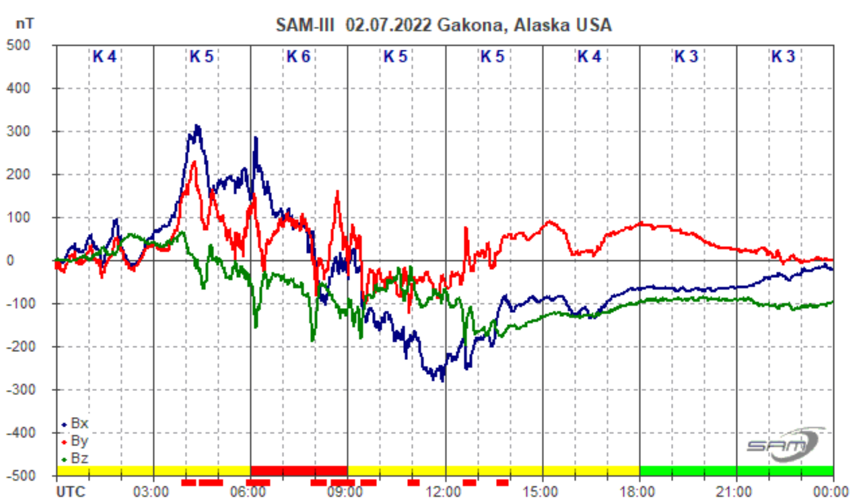

Figure 19 ~ Magnetogram from 2 July 2022, one day after the SAM-III system was commissioned. The day before was magnetically very quiet, but magnetic storm conditions were recorded the next day. The system software was configured with initial K-index settings, which will be adjusted in about one year if necessary.

6. Operating parameters

Initial tests of the development system included the SAM-III Controller, three sensors and two TIA-422 interface boards interconnected by 15 m of CAT5 UTP cable. The total load current for that configuration including an active serial port connection to a PC serial port, was 163 mA at 12 Vdc input when the Controller alarm LED was not lit and 176 mA when it was lit. The total load current was 152 mA when the Controller alarm LED was not lit and the serial port was disconnected.

The load current of the interface boards, interconnected by cable but without any connections to the SAM-III Controller or sensors, was 103 mA, of which 20 mA was used by the power indicating LEDs on the interface boards (removing the two LEDs will reduce the load current by 20 mA). The Local Interface used the most current because of the 120 ohm termination resistor at the receiving end of each TIA-422 circuit.

The final complete development system consisted of the SAM-III Controller, three sensors, and Remote and Local Interface boards interconnected by 63 m of CAT5E UTP cable (5.15 to 5.45 ohms resistance per conductor). The cable was Vertical Cable p/n 059-485/CMXF, CAT5E CMXF, Direct Burial, Gel Flooded Core, LLDPE Jacket, 8-Conductor, 24AWG, Solid Bare Copper, Shielded Twisted Pair.

Some test data from the complete development system was recorded before it was deployed. All measurements were made with sensors at arbitrary orientations, so period and frequency varied due to movements. The voltage drop in the power feed circuit across the 63 m interconnection cable was 1.1 V (12.7 V at Local Interface, 11.6 V at Remote Interface). The loop resistance was approximately 10.6 ohms, so the Remote Interface load current was about 104 mA. The measured signal output from one of the sensors is shown below along with that same signal measured at the Remote and Local Interface field-side connection terminals A and B and the connection to the SAM-III Controller (figure 17).

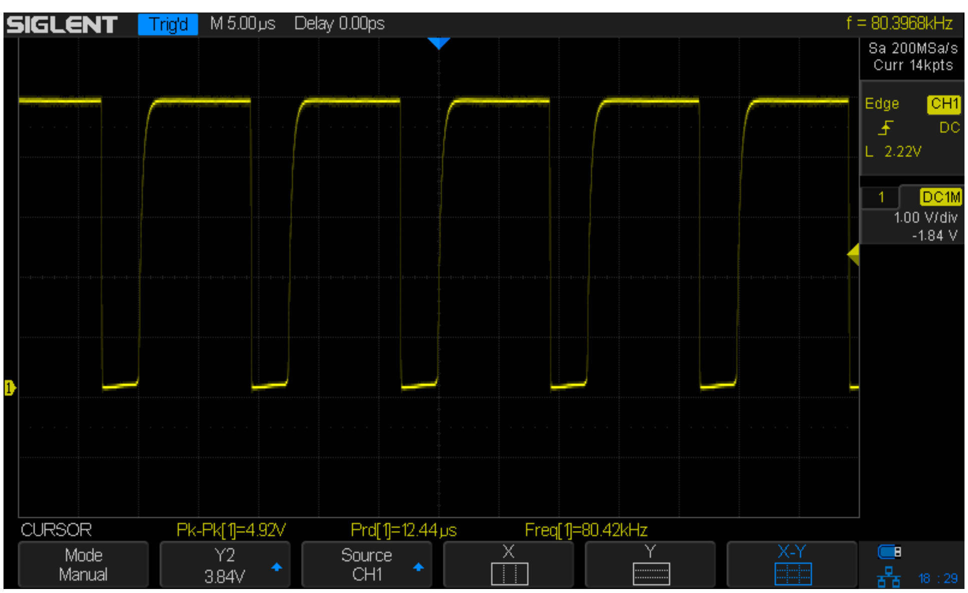

Figure 17.a ~ Y-sensor output signal measured at the Remote Interface Data In connection terminal.

Pk-Pk Amplitude = 4.92 V
Period = 12.44 µs
Frequency = 80.42 kHz

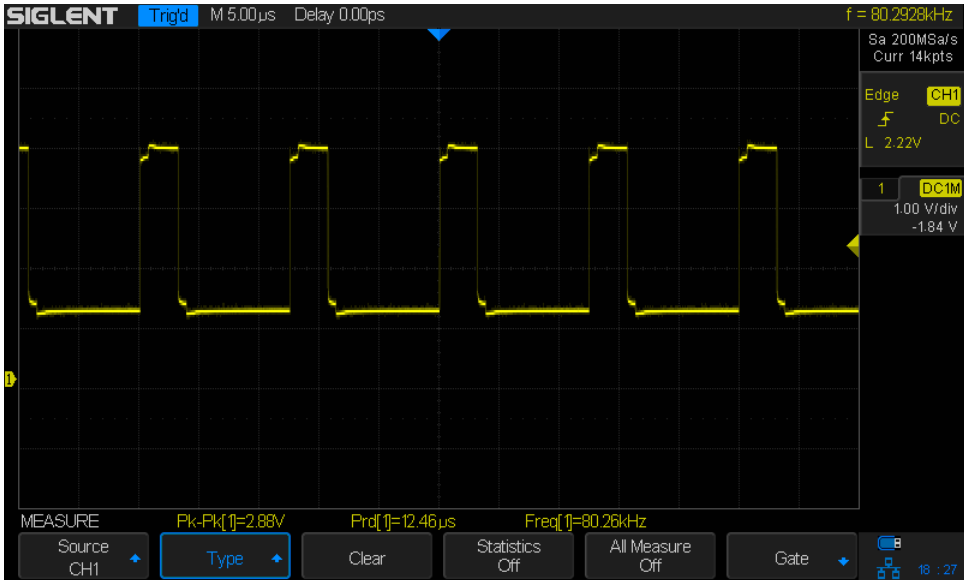

Figure 17.b ~ Y-sensor output signal measured at the Remote Interface field-side cable connection terminal A.

Pk-Pk Amplitude = 2.88 V
Period = 12.46 µs
Frequency = 80.26 kHz

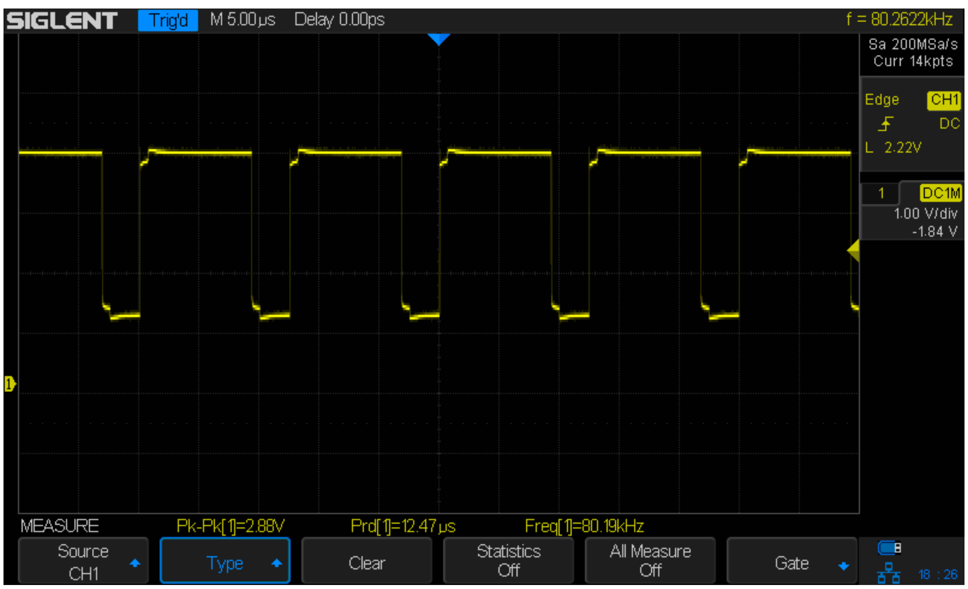

Figure 17.c ~ Y-sensor output signal measured at the Remote Interface field-side cable connection terminal B.

Pk-Pk Amplitude = 2.88 V
Period = 12.47 µs
Frequency = 80.19 kHz

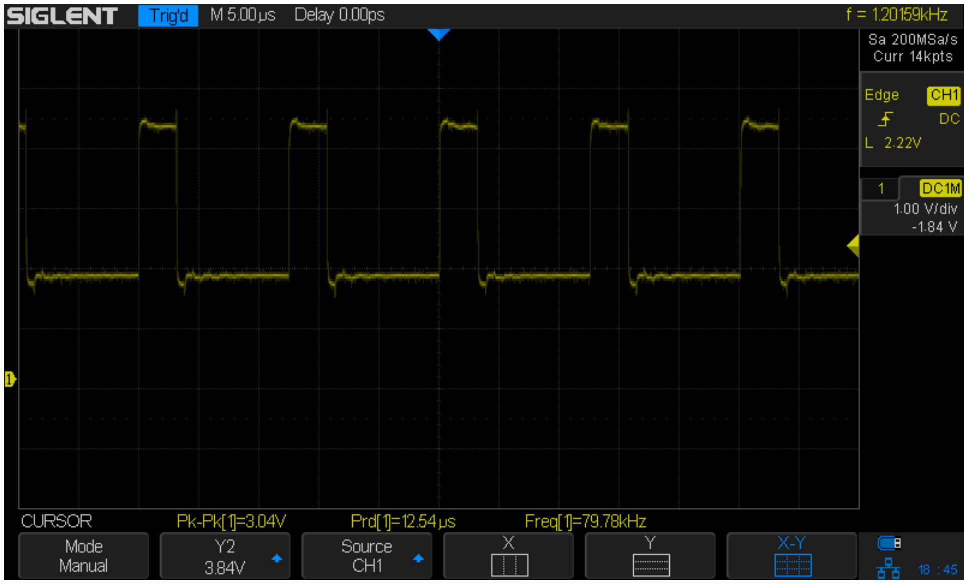

Figure 17.d ~ Y-sensor output signal measured at the Local Interface field-side cable connection terminal A.

Pk-Pk Amplitude = 3.04 V
Period = 12.54 µs
Frequency = 79.78 kHz

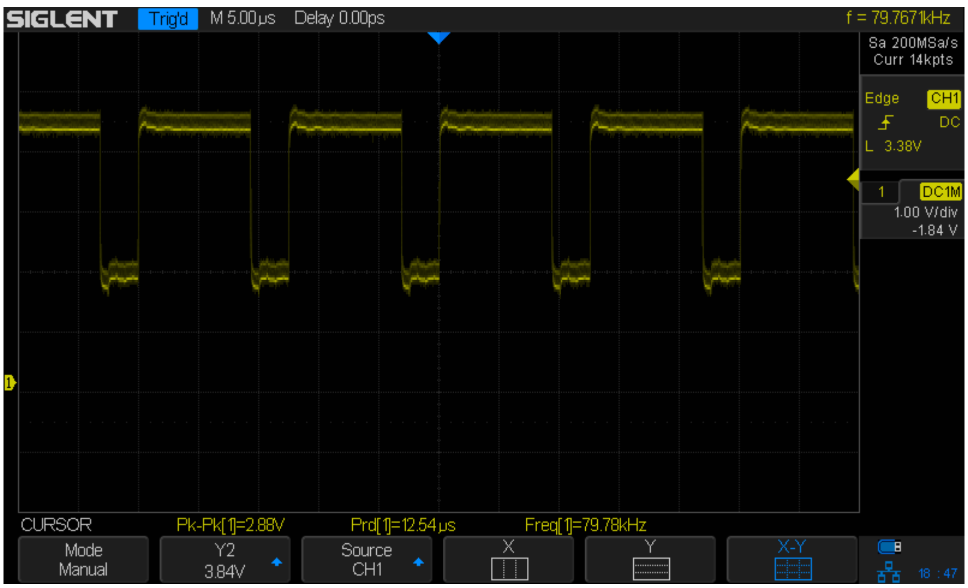

Figure 17.e ~ Y-sensor output signal measured at the Local Interface field-side cable connection terminal B.

Pk-Pk Amplitude = 2.88 V
Period = 12.54 µs
Frequency = 79.78 kHz

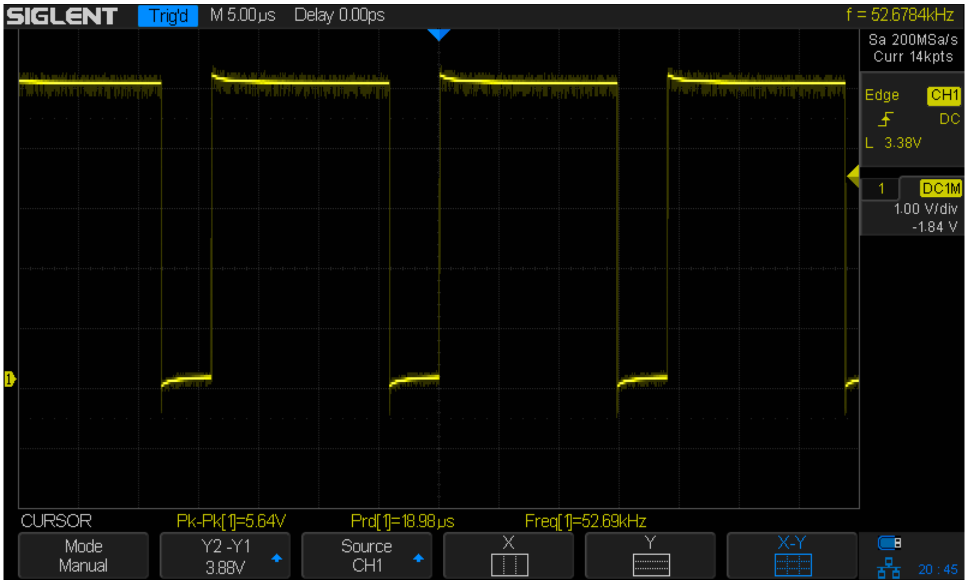

Figure 17.f ~ Y-sensor output signal measured at the Local Interface Receive Out connection terminal. Note that the sensor was moved just prior to the measurements, and its period and frequency changed accordingly.

Pk-Pk Amplitude = 5.64 V
Period = 18.98 μs
Frequency = 52.69 kHz

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7. References

[Maxim] MAX485, Low-Power, Slew-Rate-Limited RS-485/RS-422 Transceivers, datasheet Rev. 10, 9/14

{NOAA} https://ngdc.noaa.gov/geomag/magfield.shtml

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[TIA-485] TIA-485, Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems, Rev. A, March 1998, amended through December 2012

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