

Antenna Rotator Controller

A stand-alone or PC-controlled rotator controller with true azimuth indication & control

During the last VHF contest I came to the realization that my portable station was in dire need of an antenna rotator. As a single operator I found myself caught in the frantic pace of manually aiming antennas, working contacts, and logging duties.

After the contest, I resurrected my old TV antenna rotator from the garage and did a quick check to assure that it was still working. While it was hooked up, I taped a GPS on top of the rotator and compared the controller and GPS readings for several rotations. I was surprised to discover that not only were the controller indicator lines off by as much as 25° , but the controller also had poor repeatability. This discovery led me to think about building a new controller with better accuracy. While searching the internet I came across a compass sensor that senses the earth's local magnetic field and outputs a $0-359^\circ$ signal. If the sensor was mounted on the mast I could read the rotator's magnetic position. A simple math routine could then add my local declination to the magnetic reading and display true azimuth. Intrigued, I decided to build a prototype to test the idea.

The Antenna Rotator Controller (ARC) was successfully built and debugged over the next several months and has proven to be a valuable asset to my station. It features a back-lit LCD displaying the current azimuth, target azimuth, rotator status, and control input. It uses software defined limits to restrict the rotation to $0-359^\circ$ and features motor overload protection. The ARC is not an add-on unit as it replaces the existing controller and supplies power for the rotator motor, microcontroller circuitry, and compass sensor. The microcontroller program is easily customized to the builder's magnetic declination using free software.

The ARC is unique in that it senses, displays, and controls to the earth's true magnetic field. The compass sensor, mounted in a waterproof enclosure, is attached to the mast and sends its signal to a microcontroller. The ARC can receive azimuth commands from its internal keypad, MixW¹, or ARC VB (a custom grid square program) and will control many low cost 24V rotators to a level of precision not found in the original controller.

Rotator (Magnavox M61415)

The antenna rotator used in this project is representative of the light duty single-axis rotators that employ a 24VAC motor. These rotators are usually north-centered and feature a mechanical stop between 359° and 0° . Comparable models from Channel Master, Gemini, Philips, Radio Shack, and Zenith work well for small VHF antenna arrays with at least one company selling the rotator alone for \$45².

Microcontroller, U1 (Cubloc CB220)

A new type of microcontroller is available that combines Basic programming with PLC (Programmable Logic Controller) ladder logic. The chip features two serial ports, 16 I/O ports, 80K flash memory, eight 10-bit A/D analog inputs, I2C bus, and three 16-bit PWM analog outputs in a 24 pin DIP that is pin compatible with the Basic Stamp BS2. Serial port-1 is dedicated to the LCD display and serial port-2 is shared between program downloading and computer control. The power requirement at 5VDC is 40mA. The chip has a built-in 5V regulator that allows it to run from 5.5 to 12VDC power sources.

Keypad and Controller, M1 & M2 (Cubloc P02007 & U07008)

A 16-button keypad and controller provides operator input to U1. U1 has a dedicated port for keypad inputs and can create interrupts when a key is pressed, simplifying the programming. The keys are labeled using dry transfer lettering or labeling machine by removing the clear key covers and applying the labels.

Compass sensor, M3 (Devantech CMPS03)

This 2-axis compass sensor was designed for use in robots as an aid to navigation. The module uses two Philips KMZ51 magnetic field sensors, which are sensitive enough to detect the earth's magnetic field. The output from two sensors mounted at right angles to each other are used to compute the direction of the horizontal component of the earth's magnetic field. The outputs are pulse width modulation or I2C bus, and the power requirement is 5VDC@15mA. The I2C bus is used in this application.

I2C Bus Extender, U2-U3 (82B715)

Due to cable loading capacitance the I2C bus is restricted to a maximum distance of 12 feet. In this application the compass sensor will be mounted up to 100 feet away on the antenna mast. By adding a bus extender chip at each end of the cable, distances up to 4000 feet are possible. A 100-foot length of twisted-shielded 2-pair cable connects the compass sensor to the ARC.

LCD Display Module, DS1 (Cubloc CLCD420-B)

This module features a blue 20x4 digit back-lit LCD display with communications via RS-232 or I2C bus. The Cubloc I2C bus normally supports multiple devices, but when used for displays only one device is permitted. Therefore, the display uses channel-1 of the microcontroller's two RS-232 ports. Set the module's baud rate to 115200 on the rear by setting DIP switches 1, 2 and 3 to ON. The power requirement with the backlight on is 5VDC@100mA.

Power Supply

Transformer T1 provides 24VAC to the rotator motor and 12VAC from one side to the center tap to full wave bridge rectifier D1. Capacitor C1 provides filtering and feeds voltage regulator U4 to provide 12VDC to U1 and the two relays. The output of U4 feeds voltage regulator U5 which provides 5VDC to the rest of the circuitry. Both voltage regulators are mounted on heat sinks to dissipate the heat.

Rotator Motor Drive & Protection

Digital outputs on U1 ports P8 and P9 turn on transistors Q1 and Q2 to drive relay coils RLY1 and RLY2, respectively. The relay contacts then switch one side of a non-polarized capacitor (C4) to each of the two motor windings to obtain CW and CCW rotation. Diodes D2 and D3 serve as spike suppressors when the coil is turned off, protecting Q1 and Q2.

Current transformer T2 monitors the motor current and outputs a proportional AC voltage. A one-turn loop of #18AWG insulated wire through the coil serves as the transformer's primary winding. The secondary is sent to a full wave rectifier formed by D4-D7. Filter capacitor C11 and load resistor R10 converts the AC voltage to DC. An A/D converter in U1 then translates this voltage to a value of 0-1023. Whenever the current exceeds a preset amount in software (750) the ARC removes power from the rotator motor and displays "Stalled" in the status line. This feature protects the motor from damage in the event that the rotator attempts to rotate past its stops or is otherwise unable to turn.

Construction

The circuit layout is not critical and can be built on perf-board with point-to-point wiring using component leads and small gauge wire-wrap wire. Terminal strips serve as a convenient transition point between perf board wiring and external components.

Transformer T1 and capacitor C4 are mounted on top of the enclosure's internal chassis. To minimize the amount of metal around the compass sensor, nylon hardware is used for the standoffs and the compass sensor perf board is mounted in a plastic enclosure. A cable grip clamp is used on the compass sensor enclosure to reduce the risk of water leakage. SW1 turns power on and off, SW2 selects keypad or computer input, and SW3 is used to calibrate the compass sensor.

Programming

To program the microcontroller, download Cubloc Studio⁴ from the manufacturer's website. Install this free software on your PC and practice opening, editing, and saving programs while connected to U1 (CB220). If your PC doesn't have a serial port, use a USB to serial adapter such as the IOGear GUC232A, and set up the communication port in Cubloc Studio to match your port number. When you first connect your PC to the CB220 the software may prompt you to do a firmware download from their website. This is a good idea as it will install the latest firmware and bug fixes to the microcontroller. The firmware version used for this project is version 2.2.f.

Next, download the ARC.zip⁵ file which contains two Cubloc files. Look up the desired magnetic declination and direction (E or W), and inclination from a Magnetic Field Calculator⁶ and jot these down. To customize the program for your declination follow the instructions in program lines 286-288 and then edit line 290 using Cubloc Studio. Save the program and then load it into the CB220 by typing Ctrl R. Unplug the serial cable and the microcontroller is ready to run on its own.

Software Features & Operation

Upon power up, the display will show the title, author, software version, and initialize program parameters. During initialization, the target azimuth is set equal to the current azimuth. All values are updated every 200mS or less and displayed during rotation. The displayed values are:

- Azimuth: 0-359° (current true azimuth)
- Target: 0-359° (desired true azimuth)
- Status: Idle, Turning CW, Turning CCW, Jog CW, Jog CCW, and Stalled
- Control: Keypad or PC

The output of the compass sensor is 0-3599, with the last number representing tenths of a degree. True azimuth is calculated by adding the user's local declination value to the magnetic reading as sensed by the compass sensor. Based on whether the declination is positive or negative, math routines then add or subtract 3600 to prevent the true azimuth from reading greater than 359 or less than zero. After the declination math has been performed only the first three digits are displayed.

When SW2 is switched to KEYPAD the controller operates in stand-alone mode and receives all commands from the built-in keypad. When CLR is pressed the Target value clears and the user enters a three digit azimuth. Azimuth values are restricted to values from 000° to 359°, and values less than three digits (i.e. 8°) must be preceded by zeros (008°). Pressing CLR at any time clears the entered value and waits for a new value. If an invalid azimuth has been entered and GO is pressed, the target azimuth will clear and the display backlight will flash several times and wait for a new target. When a valid Target azimuth has been entered and GO is pressed, the rotator will begin turning to the desired azimuth. Pressing STOP at any time during rotation cuts power to the rotator. Pressing GO continues turning to the Target. Pressing JOG CW or JOG CCW will move the rotator approximately 2° in each respective direction. The RST button resets the microcontroller and reinitializes the software. If the rotator is unable to travel in the desired direction the motor current will increase. Power is then removed from the motor and the status line will indicate STALLED for several seconds.

When SW2 is switched to PC, the controller receives azimuth target values from MixW via J1, and rotator movement is controlled from the program. MixW sends the target azimuth to the ARC, starts rotation, and then simulates rotator movement with on-screen graphics (see Figure 1). Rotator status can then be monitored on the ARC display which displays the same information as it does in KEYPAD mode except the keypad is nonfunctional.

To set up the ARC in MixW (Figure 1), first ensure that your latitude and longitude have been entered (Configure/Personal Data). Then, turn on the World Map display (View/World Map), select Yaesu rotator (Configure/Rotor/Yaesu), and serial port number (Configure/Rotor/Settings). Set the baud rate to 38400, 8 data bits, no parity, 1 stop bit, and the azimuth offset to 0. When a call sign is entered the short path azimuth is displayed on the world map. Click on the World Map Up Arrow (lower left) to move to the short path azimuth and the Down Arrow (lower right) to move to the long path azimuth. There is also

a command to turn to a user specified azimuth (Configure/Rotor/Turn To). Clicking on the CCW and CW arrows at the top left and top right will jog the rotator 2° in its respective direction. A black line emanating from the center of the globe simulates the rotator turning by moving approximately 1° per second. This speed is very close to the rotator's actual turning speed.

This rotator does not have braking, so to prevent the rotator from exceeding the target azimuth, rotation stops when the azimuth is within 2° of the target. The microcontroller programming port and the MixW port are shared, so if the MixW cable is connected when starting MixW the ARC will reset.



Figure 1

ARC VB (Figure 2)

A custom grid square program was written to control the ARC from a computer serial port. It supports Yaesu and Orion rotator formats, com ports 1 through 12, and communicates at 38400 baud, 8 data bits, no parity, and 1 stop bit. Enter your grid square, the target grid square, and click the “Calculate” button to see the azimuth and distance to target. Then, click on “Rotate” to rotate to the target heading. Once there, click on “Jog CW” or “Jog CCW” to fine-tune the azimuth in 2° increments.

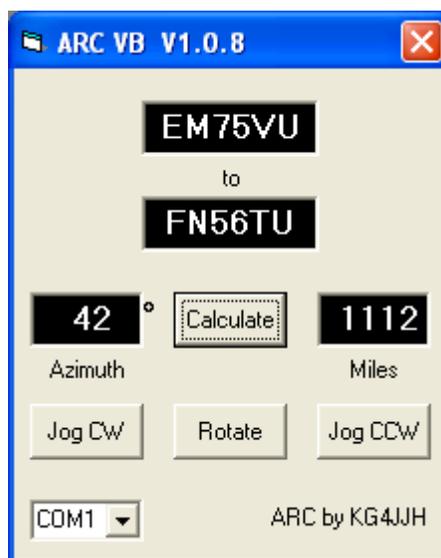


Figure 2

Accuracy and Calibration

Like a compass or GPS, the compass sensor must be level to get accurate readings. Similarly, keep the unit away from magnets, motors and large metallic objects to reduce interference. The resolution of the compass sensor is listed as 0.1° , but due to calibration accuracy and local interference the accuracy is $\pm 2^\circ$.

Calibration of the CMPS03 compass sensor only needs to be done once - the calibration data is stored in EEPROM on the compass module. The module has been factory calibrated to an inclination of 67° , and if your location is close to this you may want to try the compass without re-calibrating⁷. The inclination at my QTH is 65° , so I chose to re-calibrate. You will need a flat level surface free of motors, magnets, and metal and a decent compass to perform the calibration. I found it helpful to place the sensor and reference compass on a rotatable board and align them along parallel drawn lines. The compass points can be set in any order, but all four points must be calibrated to *magnetic* compass points. With the compass sensor level, press SW3 and hold it down for one to two seconds at each compass point, N, E, S, and W. To aid in calibration, I added an LED from pin 5 to +5VDC through a 390Ω resistor. The LED will light when calibration is in progress.

Setup and Operation

Connect all cables between the ARC, rotator, and compass sensor. Turn the ARC on and set the rotator to 0° by moving CCW until the rotator will not turn. Secure the rotator to a stationary pipe and make every effort to ensure that it is plumb. Mount the mast on the rotator loose enough so that it can be manually turned. Mount the compass sensor on the mast in an area away from large metallic objects or motors. (For installation on the side of an RV or camper, mount the compass sensor 2-3 feet above the vehicle.) Next mount the antenna(s) and align the antenna beam direction and compass sensor so they are aligned to true north. Tighten the rotator's U-bolts on the mast and confirm that the displayed azimuth is 0° . Finally, perform a trial run to ensure that the mast is turning unobstructed.

A newly constructed 222 MHz transverter and Yagi provided an opportunity to test the ARC in the upcoming 2008 ARRL January VHF Sweepstakes. With the rotator mounted on a length of galvanized pipe driven into the ground, the compass sensor and antenna were mounted on a painter pole and extended to 16 feet. Although conditions were less than optimum, the ARC performed well.

Subsequent testing was performed with the arrival of warm weather. The compass sensor, 3 VHF/UHF Yagi's, and a 6m Moxon were mounted on a fiberglass mast (Max-Gain Systems MK-6). The rotator had no problems turning this 35 pound load and the ARC repeatedly rotated to the target azimuth within 2° from either direction. Additional testing with 10 through 17m wire Moxon antennas worked equally well. No RFI problems were observed using power levels up to 100 watts.

One problem was observed during clockwise rotation to azimuths near 359° . If the compass sensor indicates 0° or higher due to high winds or mast slippage, the ARC will misinterpret the next command. It will attempt to rotate clockwise and the mechanical stop between 359° and 0° will prevent this. However, no damage will result because the motor overload

protection removes power. The easiest solution is to jog counter-clockwise until the azimuth is 359° and then move to the next target. When time permits, re-align the compass sensor and rotator to 0°.

Summary

The ARC has a level of accuracy and repeatability not available from the rotator's original controller. It is unique among all commercial controllers in that it continually senses the earth's magnetic field instead of relying on a potentiometer, and when connected to one of the light duty rotators it presents an economical package that works well for small beams. So, if you have an unused rotator lying around or just want to update the controls, the ARC is ideal as it will free the busy contest operator to do other tasks. I am looking forward to the next VHF contest as well as general HF use with this new setup. Good luck and happy building!

73,
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Notes

1. *MixW*, Digital Mode Software, N. Fedoseev (UT2UZ), D. Nechitailov (UU9JDR); <http://mixw.net>
2. Magnavox M61415 Replacement Rotor Motor, Part # M-61415, Summit Source; <http://www.summitsource.com/antenna-rotor-motor-rotator-antennacraft-universal-3-wire-replacement-for-philips-magnavox-m61415-steren-automatic-signal-locator-outdoor-offair-tv-antenna-rotator-replacement-rotor-motor-part-m61415-p-9152.html>
3. ExpressPCB; <http://www.expresspcb.com/>
4. *Cubloc Studio*, Comfile Technology.; <http://www.comfiletech.com/>
5. KG4JJH website; <http://kg4jjh.com/program/ARC.zip>
6. *Magnetic Field Calculator*, National Geophysical Data Center; <http://www.ngdc.noaa.gov/seg/geomag/jsp/IGRFWMM.jsp>
7. *Calibrating the CMPS01, CMPS03 Robot Compass sensors*; http://www.robot-electronics.co.uk/htm/cmeps_cal.shtml

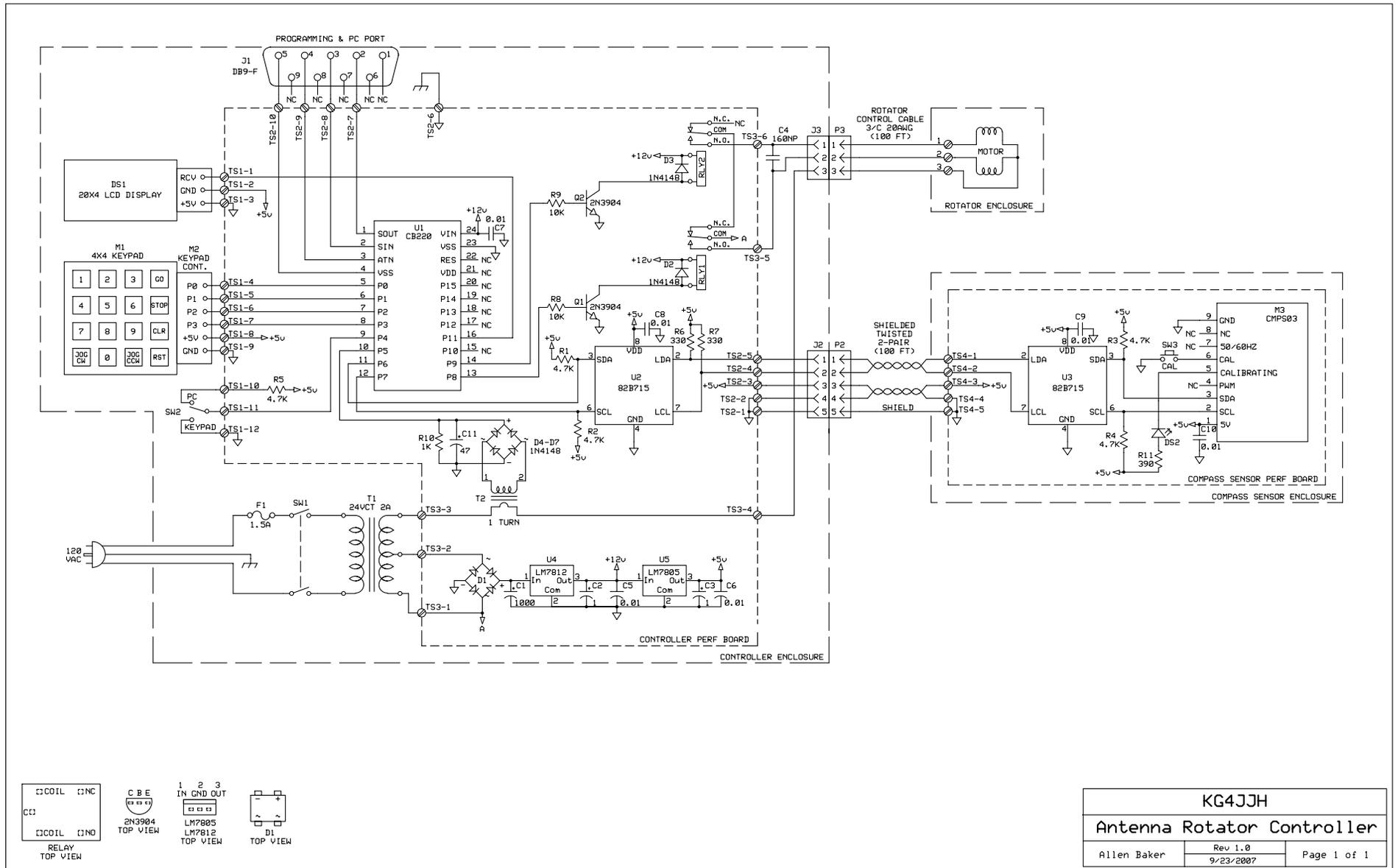


Figure 3

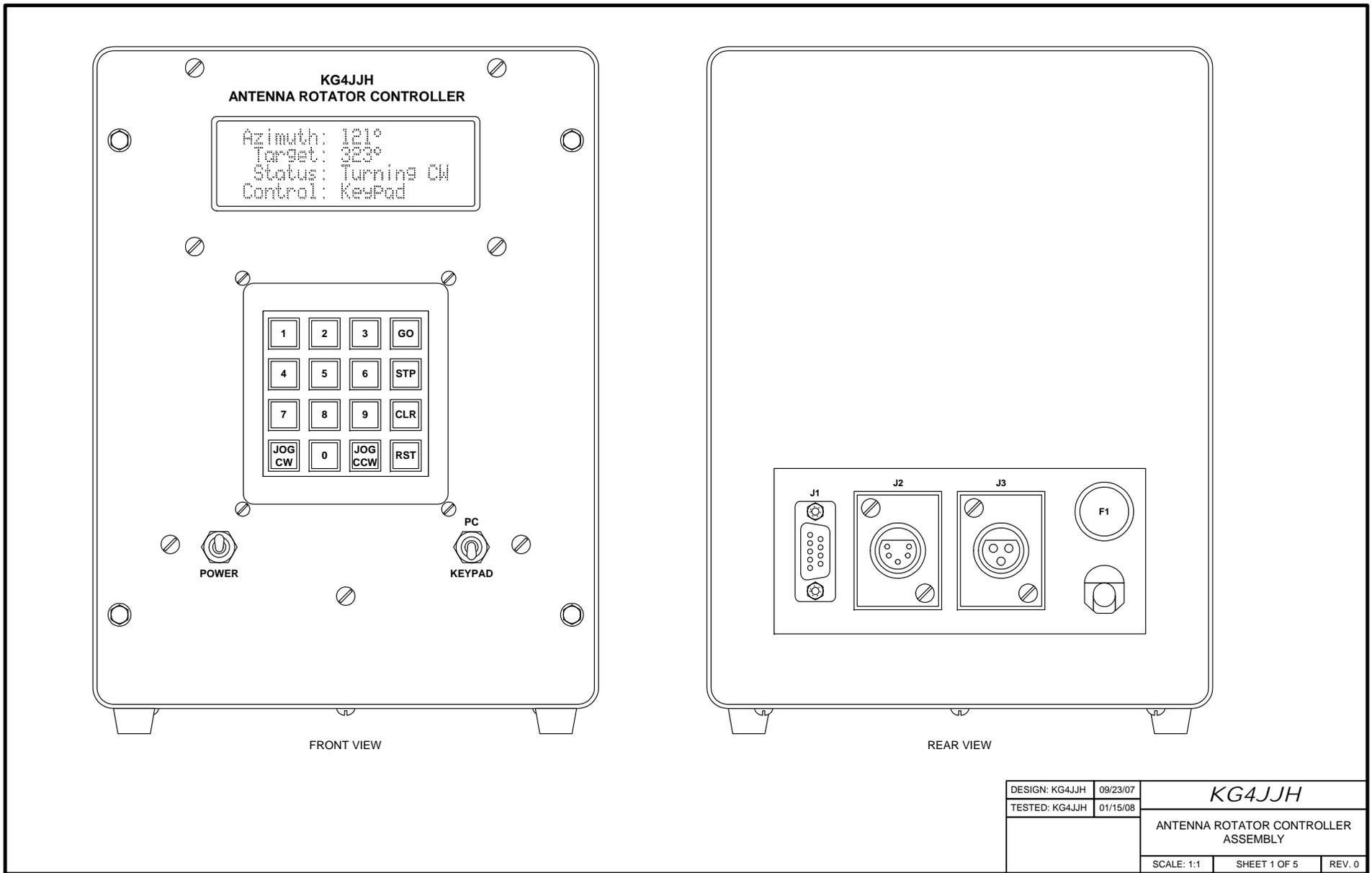


Figure 4

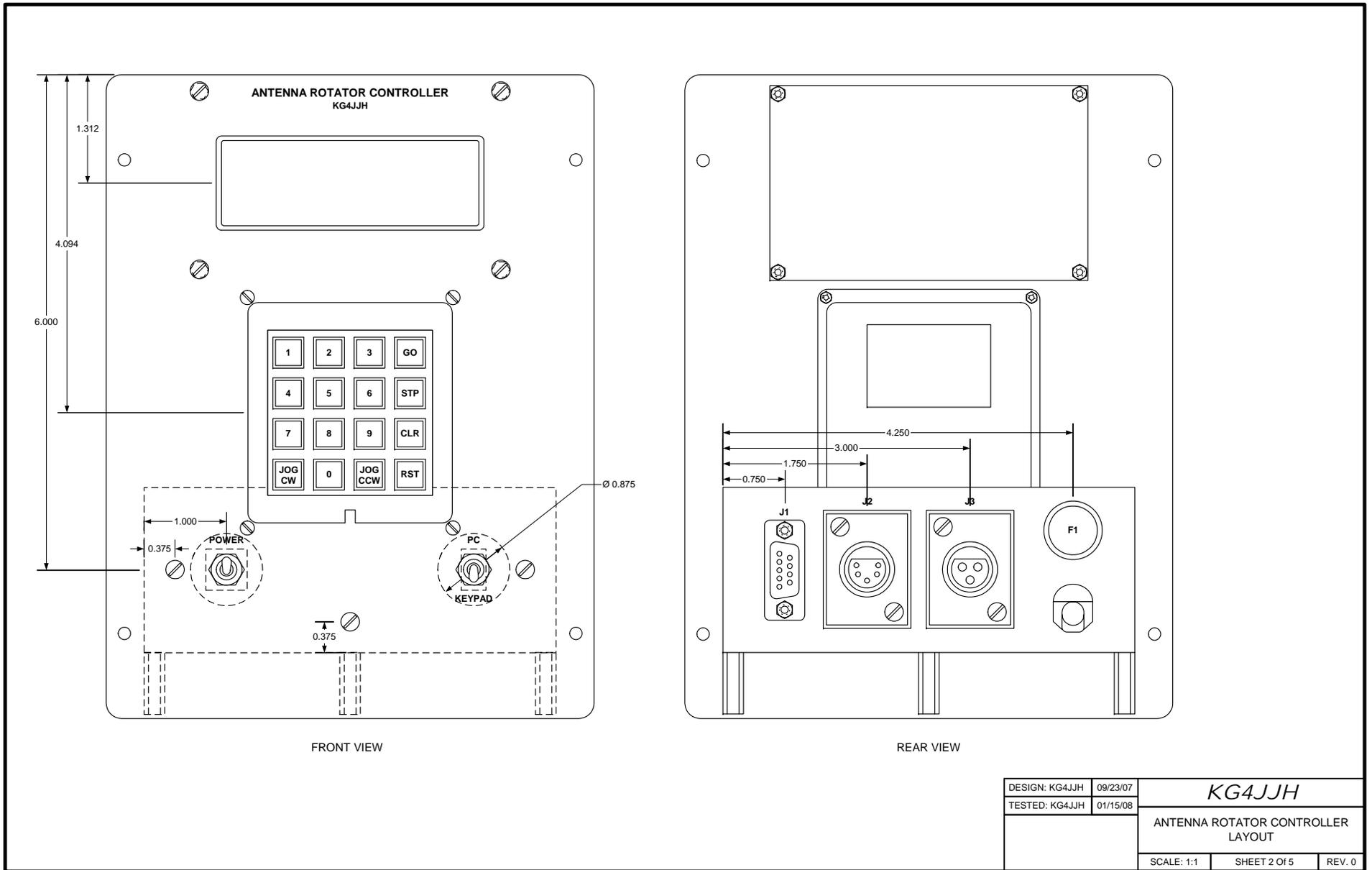


Figure 5

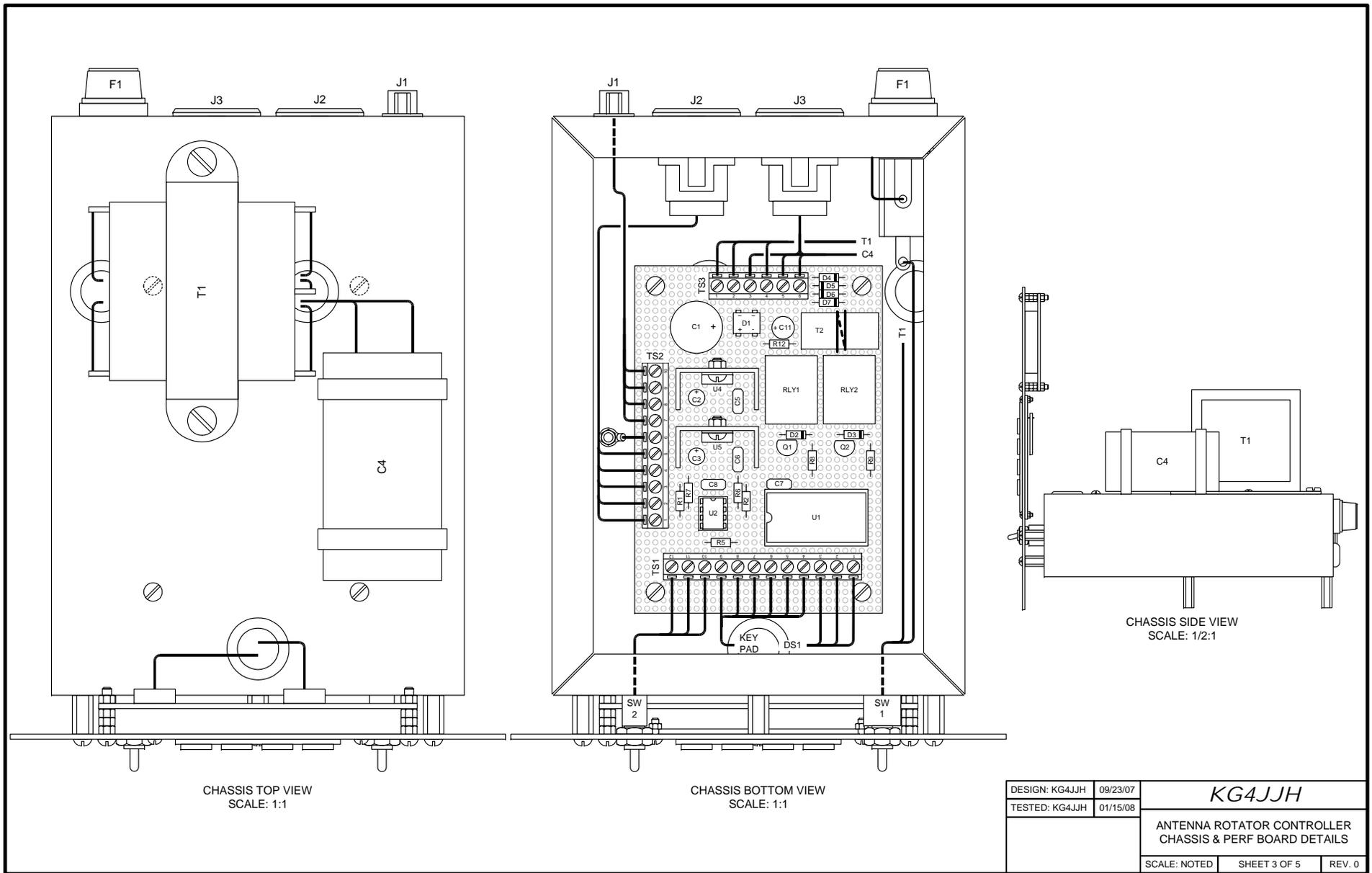


Figure 6

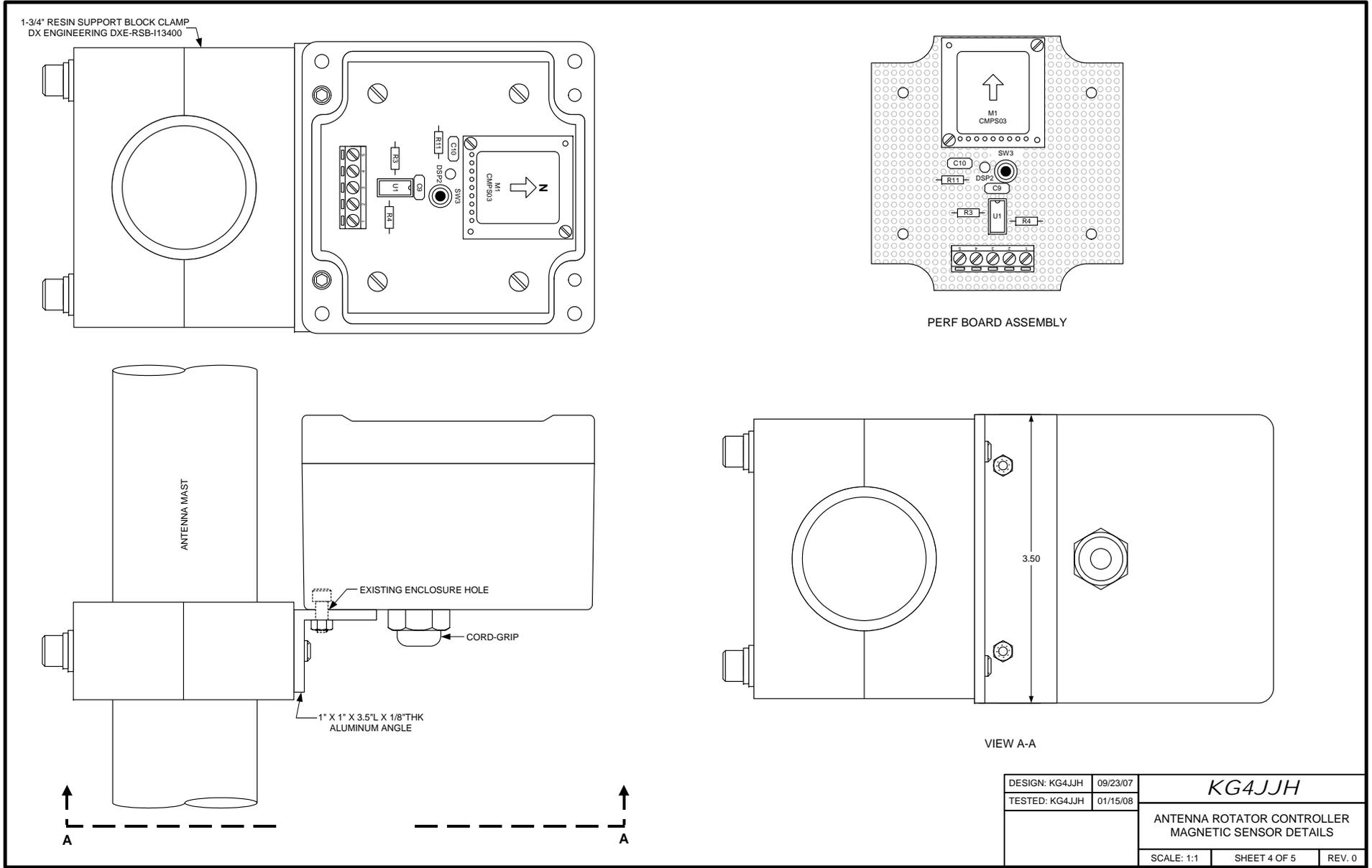


Figure 7

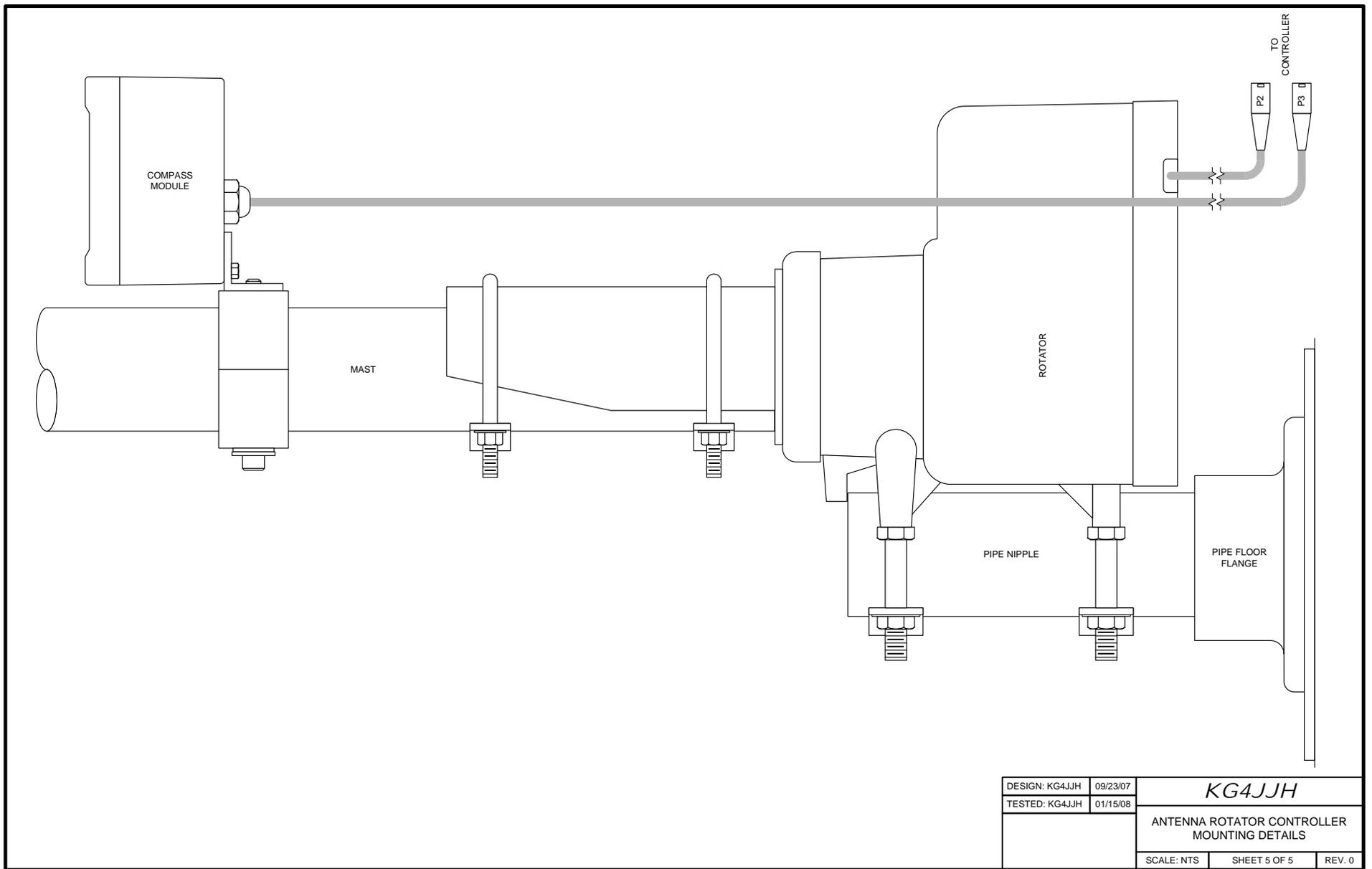


Figure 8

Antenna Rotator Controller Materials List				
Part	Qty	Description	Part Number	Source
U1	1	Microcontroller, 24-Pin DIP, Cubloc CB220	U01002	comfiletech.com
U2-U3	2	IC, I2C Bus Extender, 8-Pin DIP, Philips P82B715	C7-P82B715	comfiletech.com
U4	1	Voltage Regulator, TO-220, 12V@1A	511-L7812ACV	mouser.com
U5	1	Voltage Regulator, TO-220, 5V@1A	511-L7805ACV	mouser.com
M1	1	Keypad Module, 4x4, Cubloc (Note-2)	P02007	comfiletech.com
M2	1	Keypad Controller Module, Cubloc (Note-2)	U07008	comfiletech.com
M3	1	Compass Module, Daventech	CMPS03	snailinstruments.com
DS1	1	Display, LCD, 20x4, Cubloc CLCD420-B (Note-2)	D08001	comfiletech.com
T1	1	Transformer, Primary 120VAC, Secondary 24VAC CT@2A	553-F192X	mouser.com
RLY1-RLY2	2	Relay, 12VDC, SPDT, 10A Contacts	893-812H1CS12VDC	mouser.com
Q1-Q2	2	Transistor, NPN, 2N3904	512-2N3904_D10Z	mouser.com
D1	1	Diode Bridge,	583-DB107	mouser.com
D10-D11	2	Diode, 1N4148	512-1N4148	mouser.com
SW1	1	Switch, Toggle, DPDT	108-1MD1T2B3M1QE-EVX	mouser.com
SW2	1	Switch, Toggle, SPDT (Note-2)	108-1MS1T2B3M1QE-EVX	mouser.com
SW3	1	Switch, Pushbutton, Momentary	10PA018	mouser.com
F1	1	Fuse Holder & 1A Fuse	441-R3-13-GRX	mouser.com
-	2	Heatsink, TO-220	707-821902B00	mouser.com
C1	1	Capacitor, Electrolytic, 1000uF@50V	140-XRL50V1000-RC	mouser.com
C2-C3	2	Capacitor, Electrolytic, 1uF@50V	140-XRL50V1.0-RC	mouser.com
C4	1	Capacitor, Electrolytic, Non-Polarized, 160uF@125VAC	87F1264	newark.com
C5-C10	6	Capacitor, Ceramic, 0.01@50V	581-SR215C103JAR	mouser.com
R1-R5	5	Resistor, Metal Film, 1/4W, 4.7K	271-4.7K-RC	mouser.com
R6-R7	2	Resistor, Metal Film, 1/4W, 330	271-330-RC	mouser.com
R8-R9	2	Resistor, Metal Film, 1/4W, 10K	271-10K-RC	mouser.com
R10	1	Resistor, Metal Film, 1/4W, 1K	271-1K-RC	mouser.com
R11	1	Resistor, Metal Film, 1/4W, 390	271-390-RC	mouser.com
J1	1	Connector, DB-9, Female, Chassis Mount	152-5109	mouser.com
J2	1	Connector, XLR, 3-Pin, Female, Chassis Mount	565-5113A	mouser.com
J3	1	Connector, XLR, 5-Pin, Female, Chassis Mount	565-6854	mouser.com
P2	1	Connector, XLR, 3-Pin, Male Plug	565-6851	mouser.com
P3	1	Connector, XLR, 5-Pin, Male Plug	565-5126A	mouser.com
TS1-TS2	2	Terminal Strip, 12 Contact, PCB Mount	158-P02ELK508V12-E	mouser.com
TS3-TS4	2	Terminal Strip, 5 Contact, PCB Mount	158-P02ELK508V5-E	mouser.com
-	1	Enclosure, Controller, Bud PortaCab WA-1540	WA-1540	adproductsco.com
-	1	Chassis, Controller, Bud AC-402	AC-402	adproductsco.com
-	1	Enclosure, Azimuth Sensor, Hammond 1555EGY	546-1555EGY	mouser.com
-	1	Power Cord, 6 ft.	173-53101-E	mouser.com
-	AR	Perf Board, 0.1-inch hole spacing		mouser.com
-	1	Socket, 24-Pin DIP	575-11044624	mouser.com
-	2	Socket, 8-Pin DIP	575-893308	mouser.com
-	50	Cable, Rotator, 3-Conductor, 20 AWG, Radio Shack	15-1150	radioshack.com
-	50	Cable, Twisted-Shielded 2-Pair, Alpha 5472C	602-5472C-100	mouser.com
-	1	Strain Relief, Controller Enclosure, Heyco	836-3210	mouser.com
-	1	Strain Relief, Sensor Enclosure, Heyco	836-3207	mouser.com
-	4	Standoff, Hex, 0.25x0.50, Aluminum	534-2203	mouser.com
-	16	Screw, 4-40NCx0.25	5721-440-1/4SS	mouser.com
-	1	Clamp, Resin Support Block, 1-3/4"	DXE-RSB-I13400	dxengineering.com

Table 1