ETP CubeSat Simulator (Part 1, the technical part)

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During my interaction with classroom teachers involved in the ARRL's Education and Technology Program (ETP), I encourage the teachers to develop a portfolio of space related activities for use in their classrooms. These activity suggests include, for example, the use of Amateur Radio satellites, NOAA weather satellites, an ARISS contact, Radio JOVE, INSPIRE, and radio astronomy. During the Teachers Institute (http://www.arrl.org/FandES/tbp/ti.html), one afternoon of the 4-day institute is dedicated to bring space into the classroom with hands-on demonstrations of these suggested portfolio activities. Details of many of these activities have been highlighted in *The AMSAT Journal*, *QST* and *CQ VHF* magazines and there have been positive responses to these articles among the non-teacher ham population. This year I had the fortunate opportunity to pilot a Teachers Institute-2 (TI-2) course that focused entirely on using Amateur Radio satellites, particularly satellite telemetry, in the classroom (Figure 2). This initiative proved very successful and it will serve as a model program that is being developed to provide a training course and resources for teachers that are preparing for a scheduled ARISS contact so that the teachers are better prepared to use the ARISS contact, and other space borne resources, in their classrooms long after the ISS has gone LOS.

Figure 1: CubeSat Simulator satellite.

In preparation for the TI-2, I wanted to develop an affordable classroom resource that teachers could add to their portfolio of space related activities to demonstrate satellite fundamentals in a controlled and predictable way so that the more tenuous live on-the-air satellite activity would be more effective as an instructional tool. The result of this effort, the CubeSat Simulator, is described here. This article, part one of the description of the simulator, will focus on the technical side. . In part two of this article, I will list a growing list of possible CubeSat Simulator activities that can be used in the classroom.

This effort really isn't re-inventing the wheel. Professor Bob Bruninga, WB4APR, of the Naval Academy has develop some exceptional hardware for teaching satellite fundamentals, and his work was (and is) inspirational. However, Bob's target audience is the Naval Academy Cadet, a uniquely talented audience. Another readily available satellite simulator resource, EyasSat, is a frequent advertiser in the *Journal*. This simulator is a very comprehensive and capable resource, unfortunately for my program, it has a price tag to match and again the target audience is the university and working professional level.

The target audiences for the ETP are primary, middle, and high school teachers and students. The instructional materials and associated instructional resources for this audience need to be scaled appropriately (appropriate level of rigor, depth, detail, scope, and in today's economic environment, it must be affordable). Also based on my experience with developing other instructional resources, many of the resources developed for schools also have found a place of interest among the general ham population. I anticipate that the CubeSat Simulator will also peak the interest of some readers of the Journal.

The criteria upon which the CubeSat Simulator was developed include:

1. A resource that simulates a satellite operating in orbit as closely as possible in a classroom environment.
2. A resource that can be used to demonstrate the most basic fundamentals of satellite operations.
3. A resource with an open architecture that is easily constructed, modified, adapted, expanded, contracted, explored and used by students and teachers in the typical public school classroom.
4. A resource that is flexible enough to be used at some level by all students.
5. A resource that is rugged and easy to pull off the shelf and get working with minimum preparation time.
6. A resource that will not break the bank.

The CubeSat Simulator is made up of four basic component parts or blocks, each block will be described separately (Figure 3). These component blocks include the CubeSat itself, a 70 cm transceiver used for

Figure 2: TI-2 participants in the antenna farm.

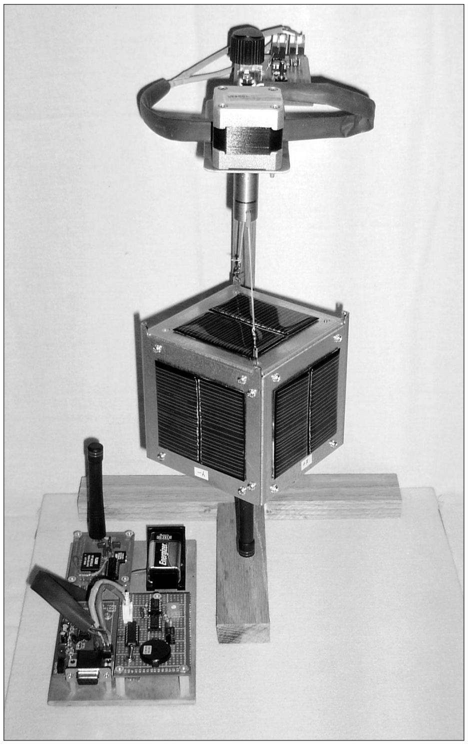

Figure 3: CubeSat Simulator.

the data link pair, the ground station receiver with associated computer display software for receiving, displaying and interpreting the telemetry data sent from the satellite, and a rotator harness that holds and rotates the satellite.

The CubeSat

The simulated satellite (Figure 1) is the actual size of a CubeSat, a 10 cm sided cube. The original prototype was constructed out of circuit board material, but that proved a very mechanically delicate and also very difficult to duplicate. The current version of the CubeSat that is depicted here was made possible with the assistance of Kurt Spencer, N6SMD, who designed a professional case, and Edge Technology, Inc. (http://www.edgetechnology.com/) that donated the materials and equipment to manufacture a couple of the prototyping enclosures (Figure 4). The satellite is populated with 12-6.7 volt, 30mA solar panels glued to the sides of the satellite structure with epoxy and wired in parallel on each of the 6 each faces. This panel arrangement provides enough power to run the satellite under normal room lighting conditions, but it works even better when in direct sunlight through a room window opening.

There is ample room within the satellite enclosure to add boards and components, for instance a servo with fly wheel could be added to simulate a torque motor rotational control feature (Figures 5 and 6). The basic circuit of the CubeSat is based on a 16F676 PIC microcontroller (Figure 7). The solar panels on the cube faces are multiplexed together through isolation diodes, in parallel with a pair of 3.6 volt NiCad batteries (in series) to provide the power source for the PIC micro. Seven PIC microcontroller ADC channels are connected to the seven current sources (six sets of solar panels and the battery). The PIC micro is programmed to read the voltage on each source and send the ADC values either in ASCII format at 2400 baud or in Morse code at 10 WPM. The data transmission mode used is toggled each time the CubeSat is turned on by the user.

The 70 cm Transceiver Modules

The data link for the CubeSat Simulator is based on Linx Part 15, 70 cm receiver/transmitter devices (Figure 8). These surface mount RF modules use On-Off Keying (OOK) for the modulation scheme (basically CW, either carrier present for logic state "1" or carrier absent for logic state "0"). The receiver and transmitter modules are combined in a circuit that also includes an antenna T/R switch and some controlling digital logic (NAND gates).

The input to the transmitter is simply a logic level "1" to switch on the carrier, and logic level "0" to turn off the carrier. There is also a transmitter enable line that allows the transmitter to transmit, and a power level line that allows the user to set the transmitter output power level with the appropriate added resistance value (to keep the TX output within Part 15 requirements and also to reduce power consumption for power limitation considerations within the simulated satellite).

The output of the receiver is a bit more complicated, with a data line and an RSSI line (received signal strength line). When there is no signal present, there is a substantial random data bit noise that is present on the receiver data line. This characteristic of the receiver is either good or bad. The random data bit noise can be used in the simulator to simulate the background noise that is ever present in the typical receive situation … this makes the reception of Morse code a bit more realistic. However, the random data bit noise must be dealt with either electronically with an external squelch circuitry or through software to prevent the noise from corrupting digital data stream. This is where the RSSI line becomes useful. When a signal is present, the voltage on the RSSI line increases proportionally with the strength of

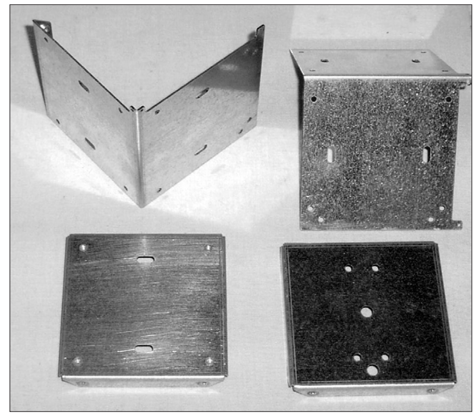

Figure 4: CubeSat enclosure.

the received signal. By comparing the RSSI line voltage to some reference voltage, and combining the outcome of that comparison with the received data bit state, the attached PIC micro (or op-amp circuitry) can provide a squelch function to clean up the random noise issue by muting the receiver when no signal is present. The PIC microcontrollers in the CubeSat Simulator satellite and the receiver (to be described next) are both configured to use the on-board comparator circuitry and programmed to squelch the random data bit noise of the receivers.

Because the RF modules and the T/R switch IC are surface mount packages, the data link transceivers are constructed on circuit boards designed specifically for that purpose (upper left corner of the ground station in Figure 9).

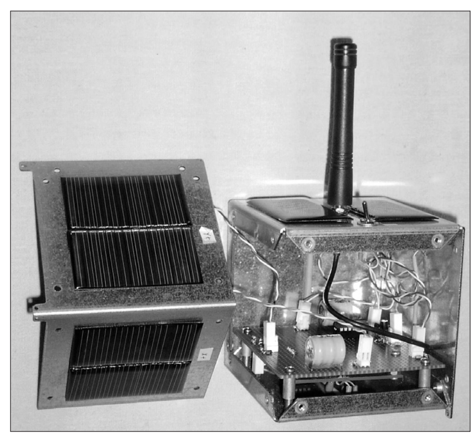

Figure 5: CubeSat interior.

The CubeSat Simulator Ground Station

The receiver of the CubeSat Simulator includes three component blocks, the data link transceiver described above, a TTL to RS232 interface, and a tone generator to facilitate hearing the Morse code telemetry (Figures 10 and 11).

The receiver PIC-micro is programmed to monitor the receiver RSSI and data lines as

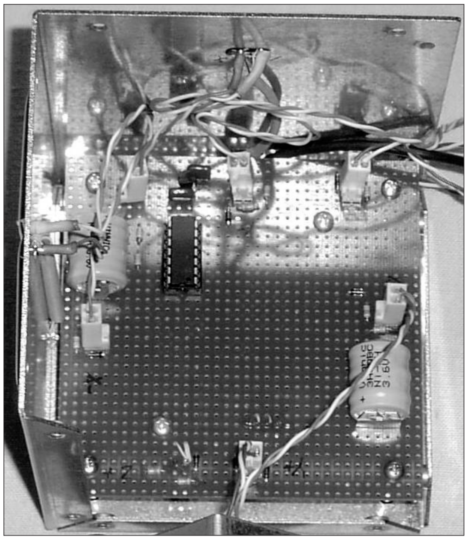

Figure 6: Hand-wired circuit board.

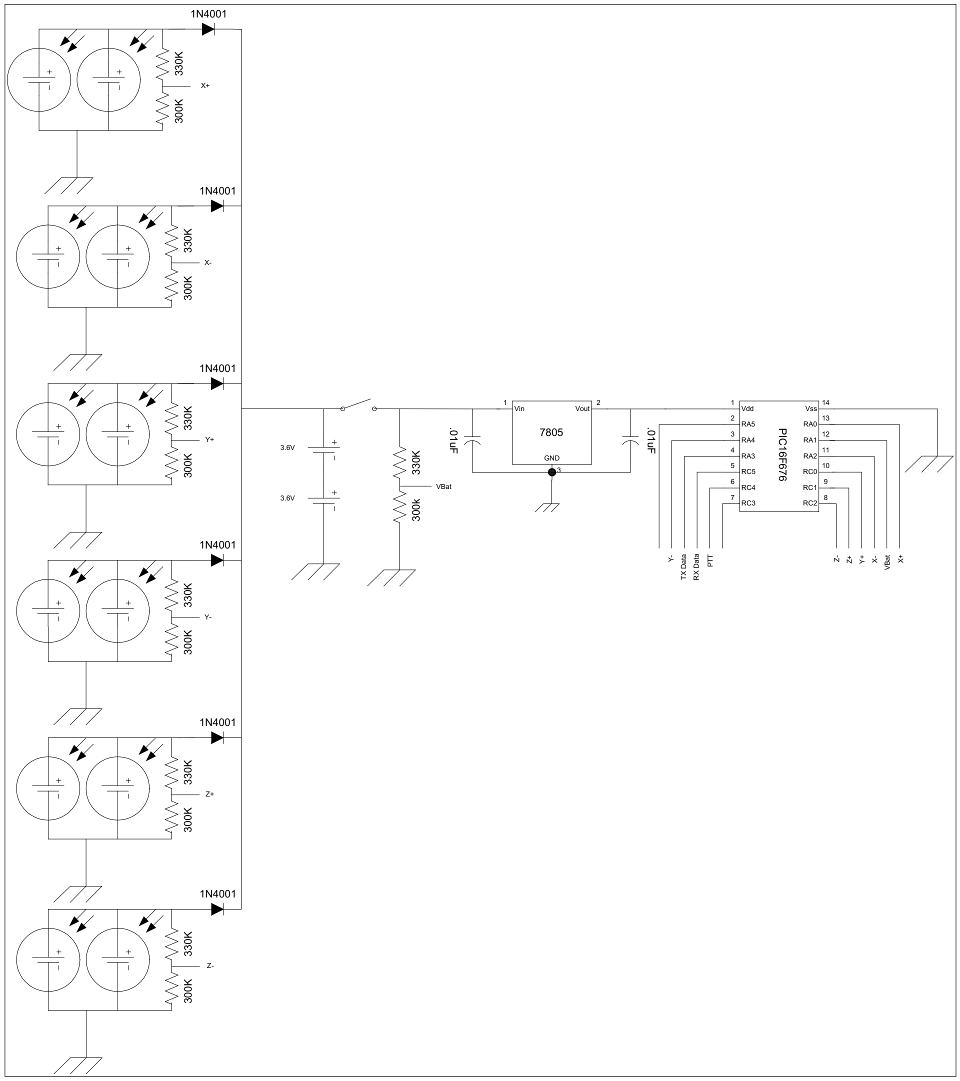

Figure 7: CubeSat satellite circuit.

described above to squelch out the random received noise. A manually adjusted variable resistor is set to the squelch level. When a signal is present, the 1000 Hz tone generating subroutine is switched on to generate the tone for Morse code reception. The received bits alternatively are passed through the TTL to RS232 converter and presented to the serial port of the computer.

Microsoft Excel is used as the main display software of the ground station. A Visual Basic macro serves as the interface between the ground station receiver and Excel (Figure 12). VB allows the students to easily modify the macro to meet their specific simulator application. Clicking on the appropriate macro control button opens and closes the Excel application for a simulation; opens, closes, and sets the port baud rate for the serial port connection; and can be used to send commands to the satellite if programmed (the basic simulation does not use this capability, the programming to upload commands would have to be added by the students). Once the telemetry data is received into Excel, the students can manipulate the data and display the results using the math and graphing capabilities of the application.

The CubeSat Rotator Harness

The CubeSat is mounted upside down in a simple harness made of common fishing line and tackle (Figure 13). This arrangement allows the satellite to be tilted in relation to the nadir position in its orbit during various simulation activities. The harness is connected to the shaft of a stepper motor that is driven at pre-determined rotation rates. The PIC micro of the rotator is programmed to sense the position of an attached variable resistor using one of the ADC channels and translate this resistor position into the pulse widths and sequence to rotate the harness with the suspended satellite at fixed rates from 4 RPM down to .5 RPM in .5 RPM steps. The power source for the rotator is a common 1 amp, 12 volt power cube. The direction of rotation (CW or CCW) is switch selectable (Figure 14).

Conclusion, Part 1

You might consider the CubeSat Simulator as an addition to your satellite demonstration bag of tricks. Having a CubeSat model on display at your hamfest booth or demonstration area will draw passers-by to stop and look. This will give you the opportunity to strike up a conversation about satellites, satellite operations and give the audience a live (though simulated) look at satellite operations. Then invite the audience to come back to witness and participate in a live satellite pass. If you want additional information about the CubeSat Simulator project including readable circuit diagrams, PIC-micro software, and the VB macro software, contact Mark Spencer, WA8SME, mspencer@arrl.org, or 530-495-9150 (expect a CD-ROM of the associated materials upon request).

***Editor's Note: Part 2 of Mark's article will appear in the next issue of* The AMSAT Journal.**

Figures continue through page 8 ...

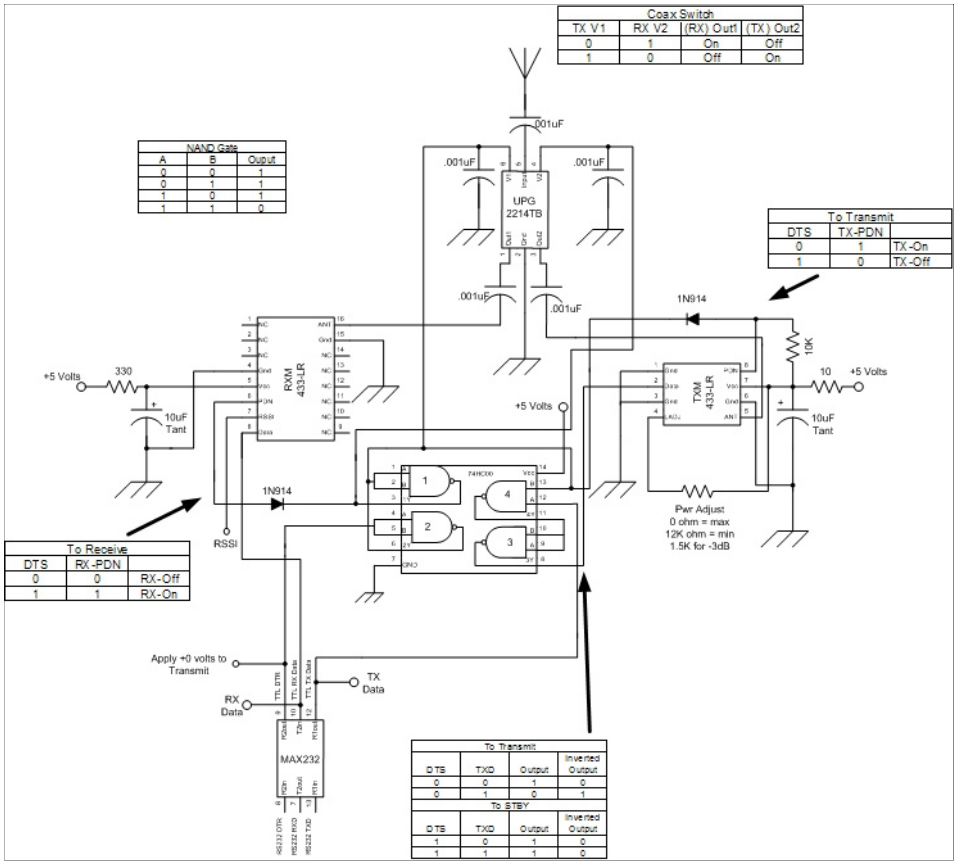

Figure 8: 70 cm transceiver module circuit.

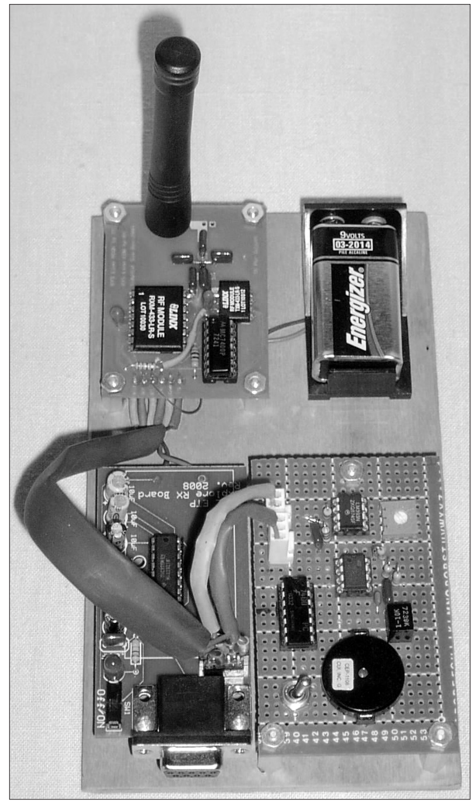

Figure 9: CubeSat ground station.

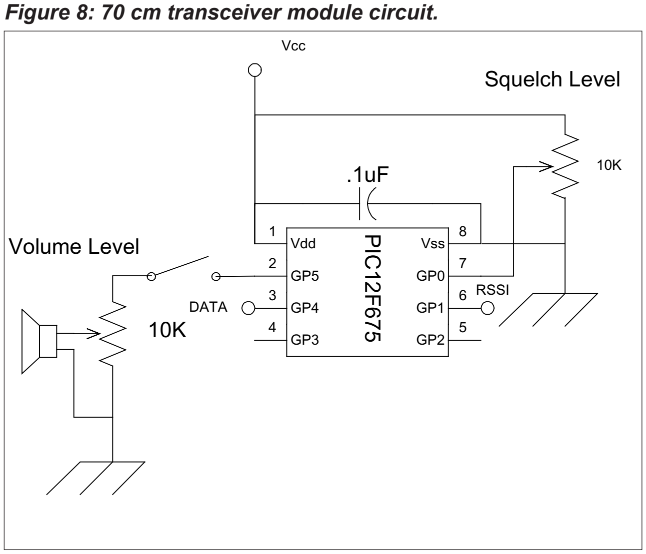

Figure 10: CubeSat ground station circuit.

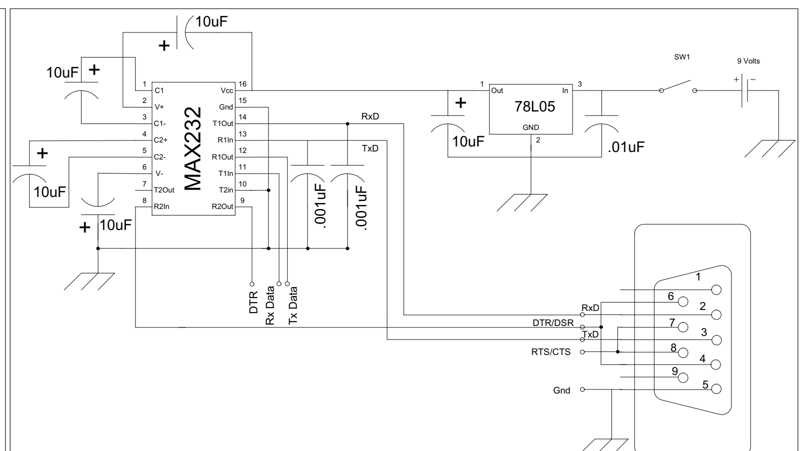

Figure 11: TTL to RS232 circuit.

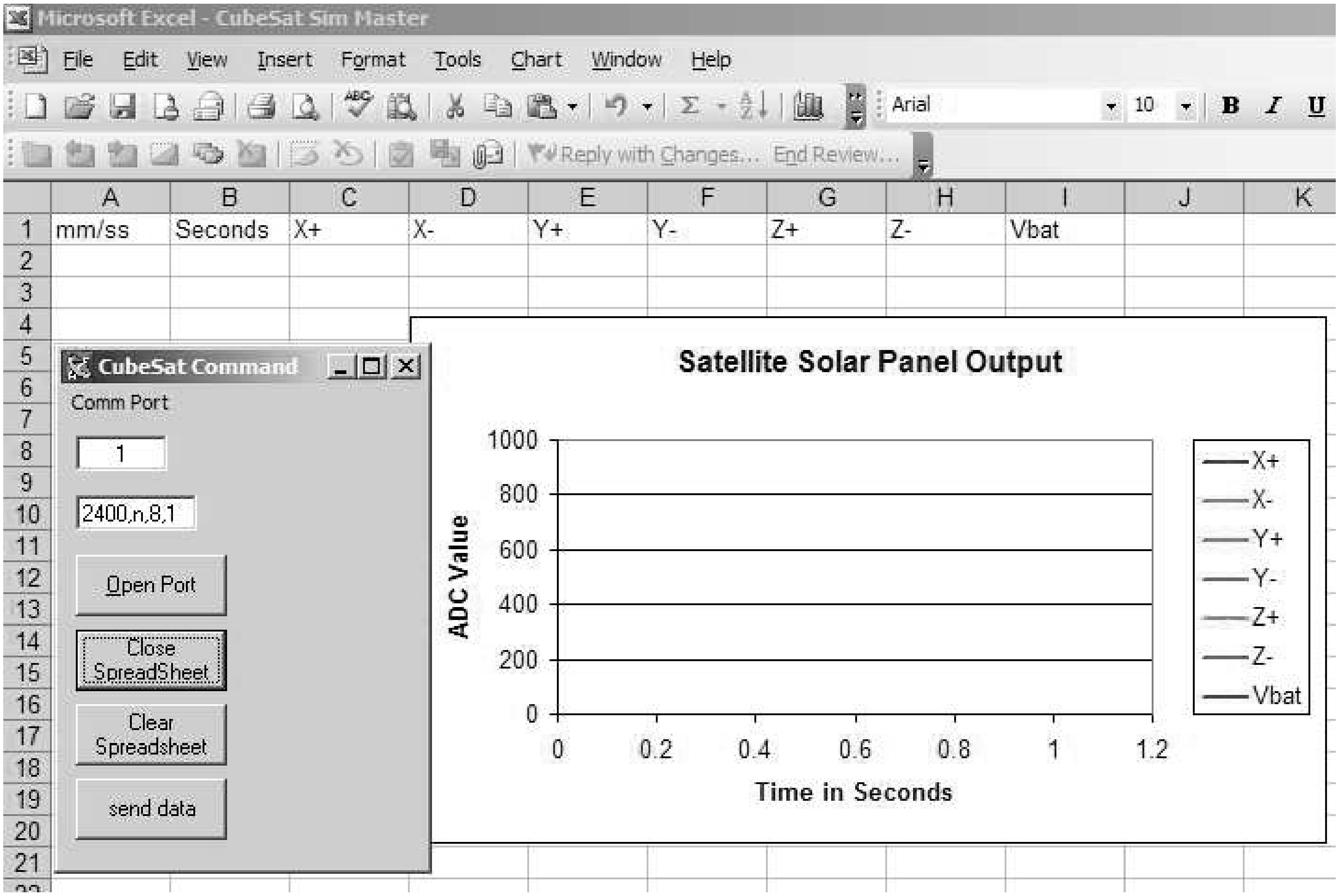

Figure 12: CubeSat Excel macro.

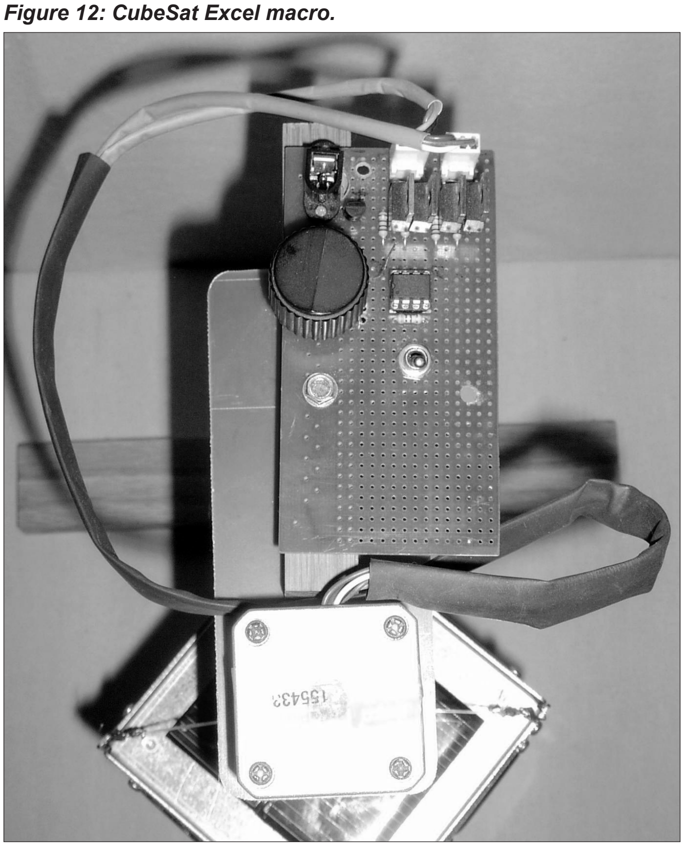

Figure 13: Rotator control board and stepper motor.

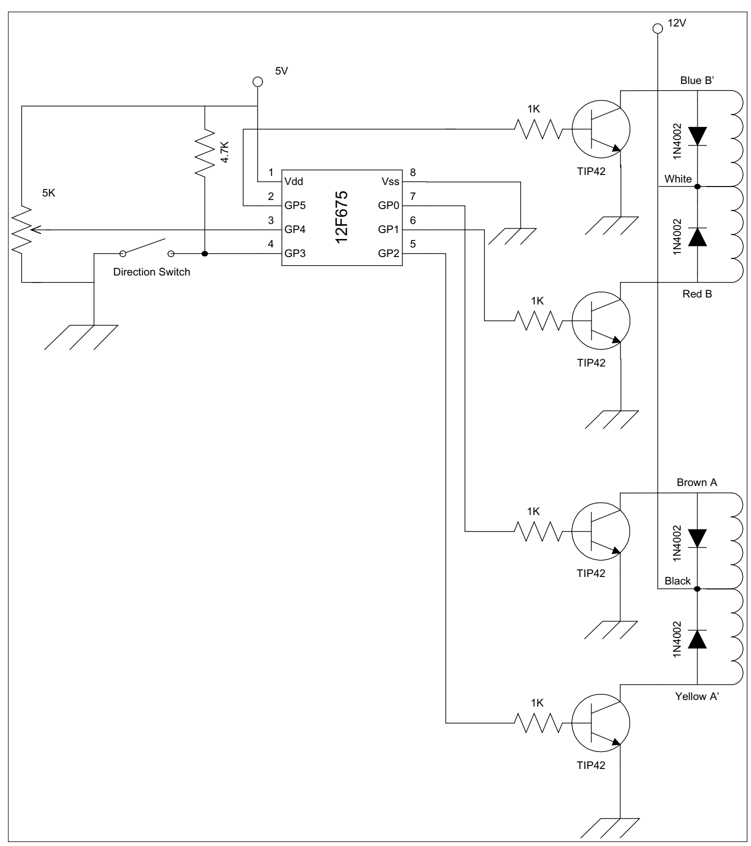

Figure 14: Stepper rotator control circuit.