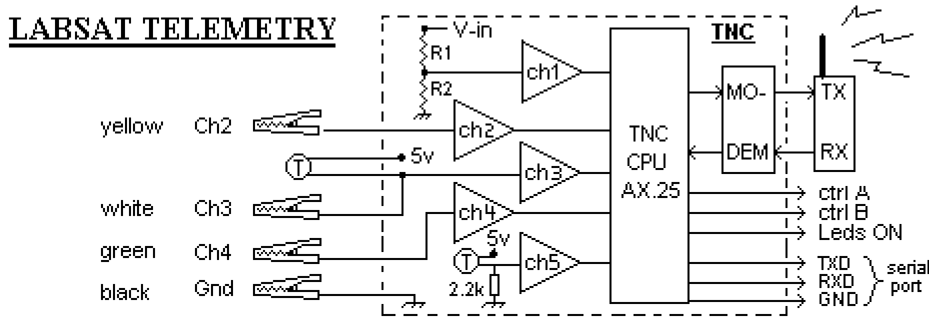
EA-467 Telemetry and Analog Sensors (rev-c) Fall 2008

Elements:

- Analog-to-digital conversion
- Analog data encoding
- Scaling with a voltage divider
- Current sensors
- Temperature sensors
- TDMA Multiplexing
- Data parsing
- Engineering unit conversion
- Data display



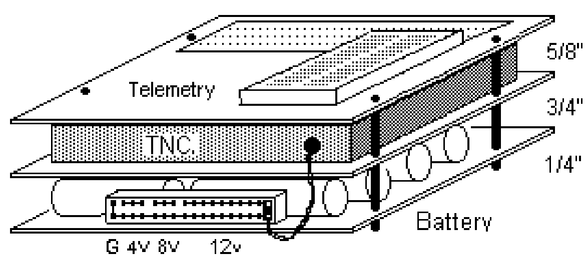
Introduction: This lab introduces the LABsat telemetry system and will show how telemetry values are sampled, converted to digital form, and multiplexed into a telemetry stream for transmission on a TDMA AFSK channel. On the ground, the telemetry packets are converted back into digital values, which are then entered into the "telemetry equations" so that the end result is a display of the original analog values and units. The format of each telemetry packet is shown below. The first three fields are the satellite callsign, beacon address and path, followed by the actual data consisting of a T#002 serial number, then the 5 analog channels, and then 8 discrete bit values. Each ADC channel is encoded to 8 bit resolution giving a resolution count from 0 to 255.

Telemetry Format: W3ADO-1>BEACON:SGATE:T#002,132,138,159,131,213,11111111

Software Setup: Run the serial port comm software called 4800COM1 (Hyperterm) on your desktop.

LABsat Setup: There are 5 LABsat workstations for teams of two students each. Each LABsat has a 5 channel telemetry system as shown above, connected to a radio transceiver to transmit the data to the central ground station on the shared TDMA channel. To simplify reception of just your own LABsat's telemetry you will connect your PC's serial port directly to your LABsat's serial port as in the last lab. A direct connection to a satellite is called a GSE or Ground Service Equipment connection.

LABsat Prototype Stack

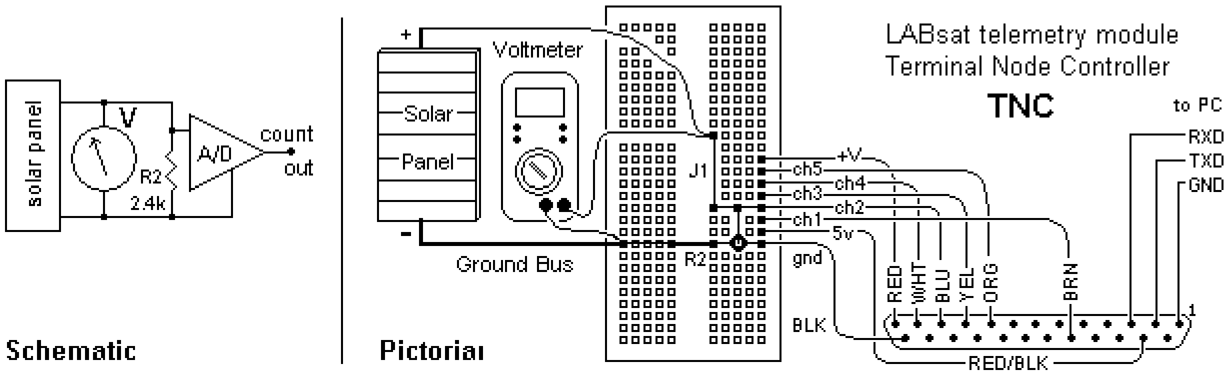


1. Stack the Battery, TNC and telemetry boards as shown above but with double the size spacers.
2. Carefully plug the power connector of the TNC into the 12v end of the battery board connector keeping the connector vertical as shown to the right above.
3. Plug in the TXD, RXD and GND wires from the serial port into pins 1,2 & 3 of the TNC as shown in the diagram in Part A.
4. Toggle on the TNC button and verify the TNC start up data on the PC ending with the "cmd:" prompt.

Part A: Analog-to-Digital Converter (ADC) Input Range

This first portion of the lab demonstrates how the Analog to Digital Converter (ADC) 0-5v input range is converted into a corresponding 0-255 telemetry count. This count is then multiplexed together with four other telemetry channels into a single data packet for transmission. On receipt, the telemetry count, X, is converted back to original engineering units for display using a telemetry equation. A linear equation for example would yield a voltage measurement V from count X using the equation $V = A*X + B$.

1. Connect the 8 wire twisted cable from the Telemetry board to the TNC's DB-25 connector as shown in the figure below using the color guide.
2. Connect the solar panel black lead to the TNC ground and the positive solar panel lead to the unused row on the proto board (below) and install a jumper J1 down to the channel 2 input of the TNC. Add a 2.4K resistor R2 as a load and connect the voltmeter to read the solar panel volts across this resistor as shown. Set the voltmeter to the 20 volt scale.



3. Position the light source about 12" from the LABsat solar array and cover the solar array with a piece of cardboard so you can control the amount of light hitting the cells beneath it. Energize the light as needed and allow at least 10 seconds for the LABsat to transmit its telemetry to your PC. Record the voltmeter and telemetry channel 2 readings of a dark solar panel with minimal output.
4. Adjust the opaque material to allow some light to yield a voltmeter reading of about 1 V making sure to allow at least 10 seconds for the LABsat to transmit the data to the ground station. Then record the voltmeter and telemetry channel 2 count. Turn off the lamp during long pauses in taking data.
5. Repeat step 4 while adjusting the solar light levels for approximately 2, 3, 4, 5, 6, 7, 8 and 9 V output. You will observe and note the saturation voltage where the count reaches its maximum.

Post Lab: Plot the output count versus input voltage of the ADC and notice how the channel 2 ADC circuit saturates with a 255 count with an input of 5 volts and cannot count any higher voltage. For the linear portion of the plot, below 5 volts, derive a telemetry equation that will convert the count value X into the original voltage value, V_{AD}.

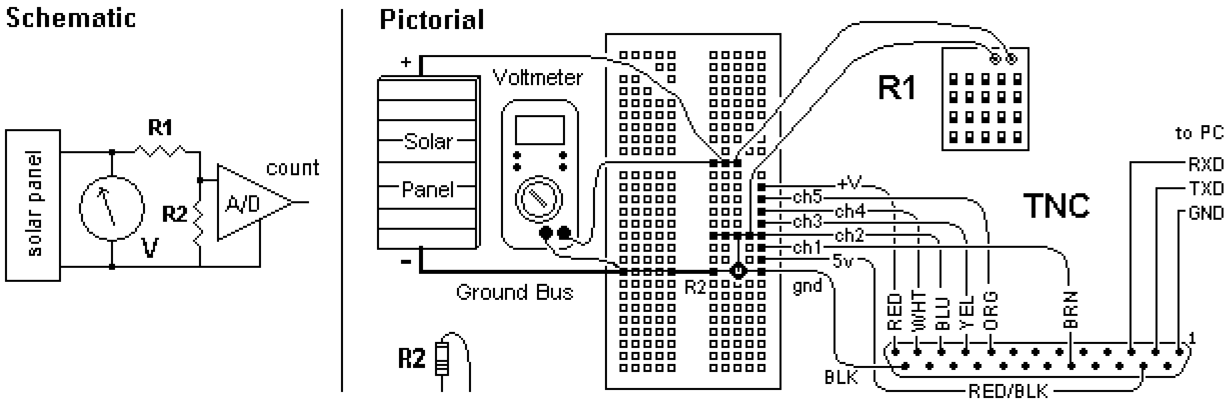
Part B: Sensor Circuitry Design (Voltage Divider)

This part demonstrates ADC operation in conjunction with a voltage divider to scale or "condition" the input voltage down to a range suitable for the 0-5V input. The voltage divider is a pair of resistors that gives an output voltage V_{AD} to the ADC that is less than the input voltage Vin by a ratio determined by the two resistors.

V_{AD}=Vin (R2 /(R1+R2)   and for the ADC, the relationship   Count/255 = V_{AD} /5v

You will design a voltage divider to give a convenient telemetry range of 0.0 to 25.5 volts with a precision of 0.1 volt fully using the ADC count range of 0 to 255. For example, this will give a count of 90 for a voltage input of 9.0 volts.

1. Assemble a Voltage Divider consisting of R_1/R_2 by removing the J1 jumper and connecting a resistor box R_1 in its place as shown while keeping the 2.4 k Ω resistor at R2 between the telemetry channel 2 input to the TNC and ground. Start with the R1 box set to 0 Ω on all switches (down) and adjust R1 by flipping switches up to the desired value.

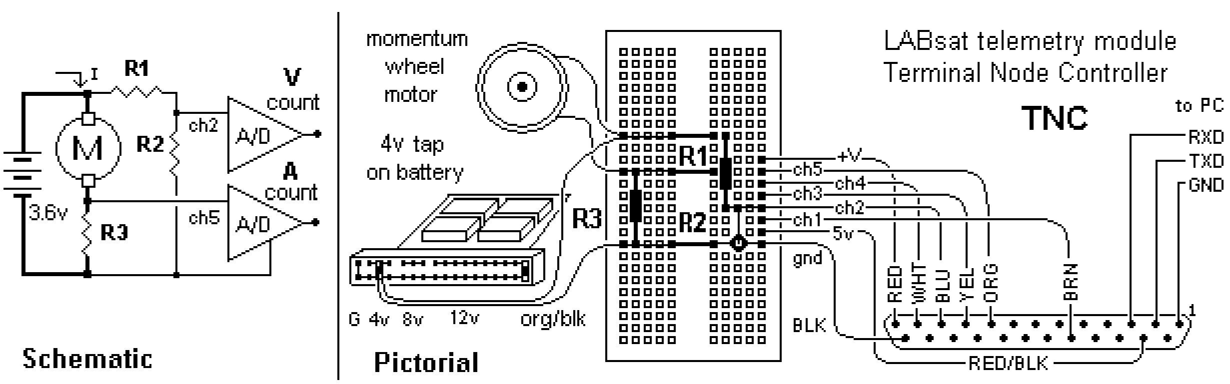


2. Given that 0-5v into the ADC results in a 0-255 count at the output, your objective is to calculate the V_{AD} voltage that is necessary to give a telemetry count of 90. Then use the voltage divider equation to solve for R_1 that produces that necessary V_{AD} voltage with a 9 V input. This makes a 9.0V input yield a convenient count of 90 such that each count equals 0.1 volt.
3. Verify your design by setting the resistor box to the calculated value for R_1 and turn on the lamp and adjust its position and the opaque cover so the panel voltage is each of approximately 1, 2 , 3 , 4 , 5 , 6 , 7 , 8 , and 9V and compare with the telemetry counts at each. Allow adequate time (at least 10 seconds) for the LABsat to transmit the data and record the input voltage and the telemetry counts.
4. In later parts, you will need this voltage divider, but without the cumbersome R1 resistor box. Replace it with a standard 10k resistor (where J1 was originally). Now set the input to 9.0 volts and record your count which may no longer be exactly 90. You will correct for this in your telemetry engineering unit conversion equation.

Post Lab: Plot the telemetry count versus the voltage input. Derive the A and B coefficients of a linear telemetry equation to represent the relationship V = A * X + B where X is the telemetry count and B is any constant offset. How much error results from using the 10K standard resistor instead of your actual R1 value? Discuss the maximum input voltage that this voltage divider can measure before the ADC saturates. Annotate the telemetry packets you saved. Generally, only include the ones that are significant.

Part C: Measuring Current with an ADC Channel

This portion of the lab demonstrates how the ADC can measure current. You will measure the current to your momentum wheel on ADC channel 5 by observing the voltage across a low value shunt resistor (R3) in series with the load current. In this experiment, we desire to have a current range from 0 to 255 mA to result in a telemetry count of 0 to 255.



1. Since we want an ADC input value of 5 volts when 255 mA is flowing through R3, calculate the needed value of R3 using Ohm's law V = I * R.
2. Connect an org/blk power jumper from the 4 volt tap on the LABsat battery to the momentum wheel motor and connect a standard 20 ohm current sensing resistor for R3 to the ADC channel 5 as shown above. Observe the motor telemetry counts reported on channel 5 and the voltage reported on channel 2. Notice how they seem to vary quite a bit. **Lesson:** As a class, use an O'scope on Ch2 and you will see that the motor current varies at the RPM rate and so our telemetry sampling gets various values. This is a perfect example of the need to FILTER the CH2 input with a capacitor to get the average value.
3. Now move the battery tap to the 8 and then 12 volt taps, observing the current and voltage telemetry in each case.

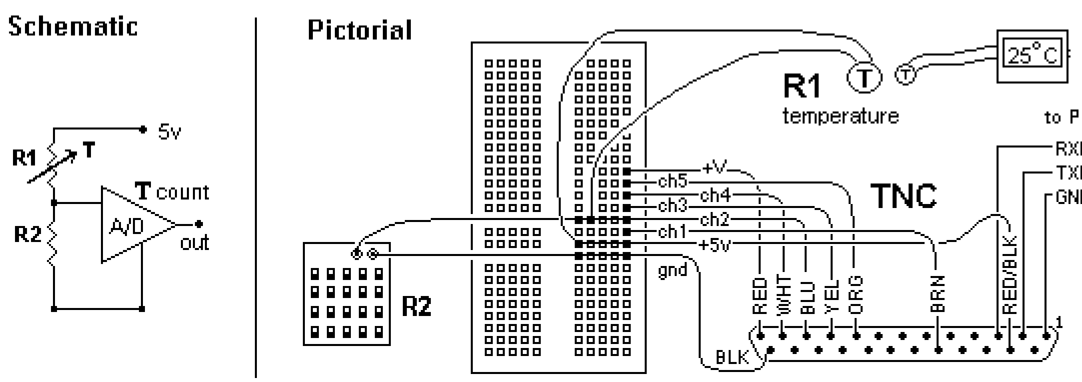
Post Lab: Now that you have three sets of telemetry for three conditions of the wheel, compute the voltage, current and power delivered to the wheel system for each case (use an average value for the count). Since the standard value shunt resistor (R3) was used instead of your calculated value, what should the final telemetry equation for current be, instead of the desired I = 1.0*X mA?

Notice that there is another issue with this circuit. The R3 shunt resistor has a voltage drop needed to give the ADC an input voltage to represent current. This reduces the voltage available to the motor. Thus the measured telemetry voltage is not all across the motor. How much voltage is lost across R3 in each case?

The conflicting requirements between adequate sensing voltage (across R3) and circuit voltage losses in the shunt are why this simple approach is not often used. To solve this problem a much lower shunt resistor (fractions of an ohm) is used to get the much smaller voltage drop and then an amplifier is used to raise it to the 0-to-5 volt range of the ADC while minimizing circuit losses.

Part D: Temperature Measurements:

To measure temperature we simply use a similar R1/R2 voltage divider but replace R1 with a resistor that varies according to temperature. The resistance of a thermistor has a high negative temperature coefficient meaning that as the temperature goes up, the resistance goes down. By inserting the Thermistor as R_1, an increasing temperature causing a lower resistance conveniently results in an increasing voltage to the ADC and therefore an increasing telemetry count.



1. Remove R1, R2, R3, the motor leads and the org/blk power jumper from the previous part and connect the Thermistor between the channel 2 input of the ADC and the regulated internal 5 volts of the Telemetry Unit as shown above. Connect the resistor box as a new R_2 using gold pins if needed.

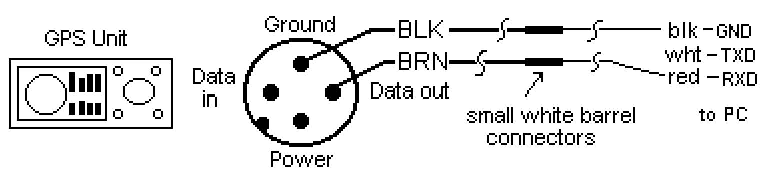
2. With the thermistor as the R1 in the voltage divider and 5 volts as the Vin, you can select a value for R2 that will establish room temperature at the mid point count of 128 for optimum measurements colder and warmer than room temperature from 0 to 255. To do this, adjust the R2 resistance box so the telemetry channel 2 reading is approximately 128 (half of 255), allowing adequate time (at least 10 seconds) for the LABsat to transmit the data. *Do not touch the thermistor until Step 4, otherwise you will warm it up and get a bad reading for the room temperature.*
3. Record the temperature as shown on the commercial digital thermometer and the telemetry channel 2 count reading at nominal room temperature.
4. Next, Hold the thermistor and the thermometer probe in your hands for a minute or so to register human body temperature and allow the thermometer reading to stabilize (at least 10 seconds) for the LABsat to transmit the data. Record this telemetry channel 2 body temperature reading (37 deg C).
5. Following the same procedures, put the sensors in the rubber glove finger and measure also the temperature of ice, two cold waters, and two hot waters and any other temperatures in between. Use the microwave to keep the water hot and ice to keep some cool. Allow a minute or two for the thermister and thermometer to stabilize at each termperature.

Post Lab:

1. Plot the recorded temperatures versus the reported telemetry counts. Notice the plot is non linear and probably a cubic. This plot then can be used to manually observe the conversion from counts to original temperatures.
2. You should also be able to derive two engineering unit conversion telemetry equations to convert the A/D converter's counts back to temperature:

   - manually derive a simple linear equation for the range where the plot is reasonably linear (0 to 40 C).
   - let matlab generate a 3^{rd} order polynomial for temperatures over the full range of the curve.
3. Estimate (based on the plot) the temperature represented if you were to receive a count of 190. What does your equation give you? How close are they?

Part E: Serial Telemetry with GPS Data



This experiment adds a GPS unit to the LABsat to demonstrate the ability to not only send analog telemetry values from an ADC in a multiplexed telemetry packet, but also to packetize or bundle serial data from any other kind of sensor into the downlink stream. The GPS (similar to what we used on PCSAT) outputs repetitive NMEA-0183 serial data that is formatted into several "sentences" that each contain numerous data fields. Connecting this data to the serial port of the TNC can then transmit the data to the ground on demand or on a schedule.

1. With your PC serial port still connected to the TNC, send the TNC commands to set up parsing of the GPS data as follows. Hit ENTER on your PC to get the "cmd: " prompt, then type these commands:

LT 1 CLEAR	- clears any previous GPS information in the LABsat's position buffer
GPSH $GPRMC	- Tells the TNC to only parse the $GPRMC sentence
BLT 1 E 00:01:00	- sets GPS update rate to Every 1 minute
INT GPS	- sets TNC's serial port mode to GPS parsing and to ignore all other data
CD S	- sets channel detect to software to make the collision detect work properly

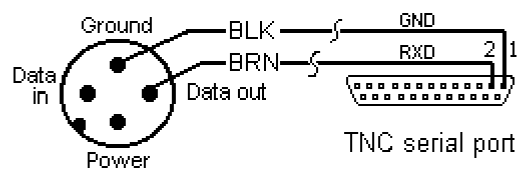
2. When you are sure the commands are correct, then power cycle the TNC. The serial port can now only be used for GPS. No TNC commands are possible. Now, connect your PC serial port RXD and GND wires to the BRN & BLK wires of the GPS and its connector as shown above so you can see the

GPS data on the PC.

3. Next configure the TNC to operate indoors in SIMULATE mode.
    a) Turn GPS on with the red ON button
    b) Hit PAGE key several times to get to the MENU
    c) Hit down joystick to SYSTEM SETUP and then hit ENTER key
    d) Hit down joystick to MODE and select it with ENTER key
    e) Hit down joystick to cycle to SIMULATOR and hit ENTER key
    f) hit QUIT key several times to return to the navigation screen that shows LAT/LONG

4. Observe the repetitive GPS serial data on your PC. How many different "sentences" of data do you notice in each update? How often is the data updated? You can disconnect a wire to pause operation so you can closely observe the data. Copy a complete set for your report. Look for the $GPRMC sentence which your TNC will use to send your position LAT, LONG, SPD and CSE data.

5. To enable your GPS data into the downlink of the LABsat, connect the GPS to the LABsat serial port as shown to the right on the DB-25 pin connector. Your TNC has been configured for GPS mode and set up with a one minute position data rate. The TNC parses the data looking for the $GPRMC sentence and transmits it only once every 60 seconds (to save power and bandwidth).



6. To see this data transmitted on RF into our ground station and then from there into the worldwide APRS system, connect the LABsat RX/TX tray consisting of a UHF transceiver on 437.925 MHz. Turn on the radio, and plug its audio connections into the DB-9 radio port of the TNC. Be sure that any previous data received from your LABsat has been cleared from the ground station receiver and map displays. The ground station APRS plot has been zoomed in on Annapolis to the 0.5 mile scale.

7. After a minute, the data from your LABsat should appear on the USNA Ground station position plot. Go to the APRS console and use the arrow and pgup/pgdn keys to zoom into your GPS's reported position. Note its LAT/LONG on the bottom line by clicking on it with the cursor.

8. See if this data got to the global APRS system by using a browser to check the position of your LABsat (using its correct –N number on this URL: http://map.findu.com/LABsat-N). When the map comes up, click on satellite view to see what the area looks like. Click on the link to the left for "Nearby APRS activity" to get a table of other nearby stations sorted by distance. At the bottom of that list. "Click to see a map of all stations" to see where they are.

Post Lab: Identify the GPS reported LAT/LONG fields. Annotate the different fields in the GPS serial data. Some of the fields should be obvious, while others may need you to look them up on the web. Search for NMEA $GPRMC and the other sentences. See what you get…

Laboratory Report: Write your report in the same formal format as we have used for the other labs this semester. Remember to include these features:

- Briefly describe the laboratory setup, including a block diagram, for each section.
- Complete all tasks in the "Post-Lab" sections and answer any questions. Complete the analysis and discuss the results by making comparisons between measurements and theory. Use computer generated figures and plots to support your conclusions.
- Summarize your conclusions and learning points regarding telemetry. Show us what you learned about telemetry.