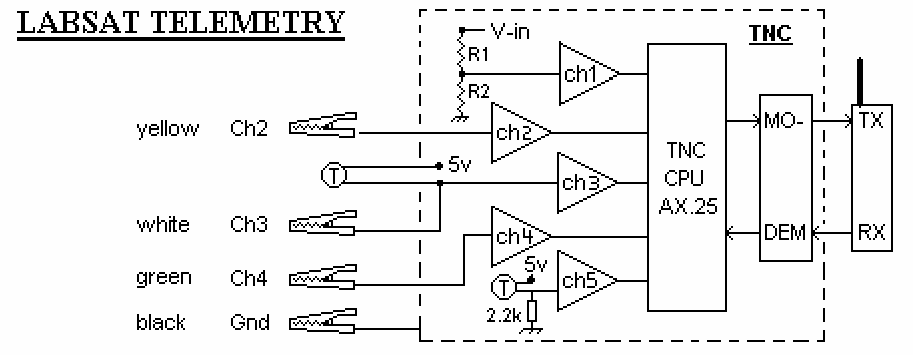
Communications III: Sensors and Telemetry (rev 2) Fall 2006

Elements:

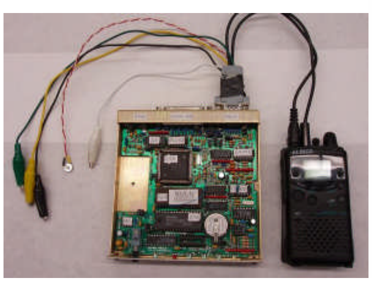
- Analog-to-digital conversion
- Analog data encoding
- Scaling with a voltage divider
- Current sensors
- Temperature sensors
- TDMA Multiplexing
- Data parsing
- Engineering unit conversion
- Data display

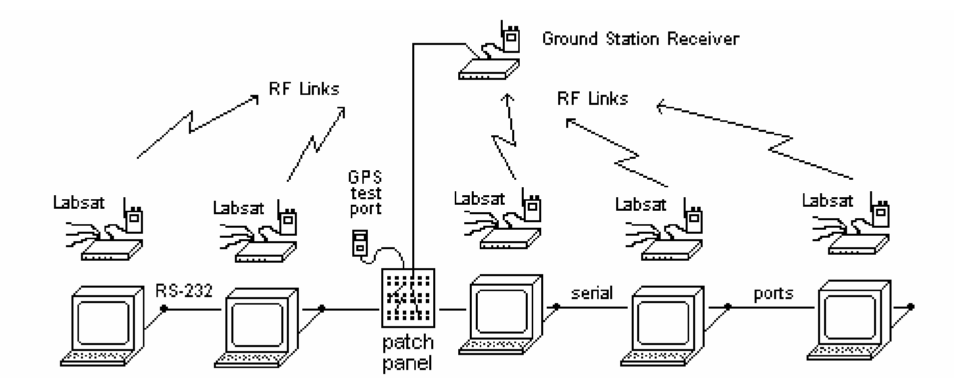


Introduction: This lab introduces you to the LABsat telemetry system which you will use for capturing data in a number of other of our LABsat labs. This lab will show you how telemetry values are sampled, converted to digital form, and multiplexed into a telemetry stream for transmission. On the ground, then, the telemetry stream is 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 measured. This final step of conversion from digital counts to displayable original values is called "Engineering Unit Conversion". These aspects of digital communications will be demonstrated:

Laboratory Setup:

There are 8 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 (Time Division Multiple Access) channel. The Ground Station's serial port RS-232 data is then patched through the patch panel and distributed back to the individual workstations for display. This way, each workstation can see the telemetry from all other LABsats on the channel and see how a TDMA channel can carry multiple sources of data by time division multiplexing. Notice that Channel 1 is connected to monitor the TNC input voltage (LABsat Battery). Do not let it go below 10 volts. The format of each telemetry packet is shown in the figure below:





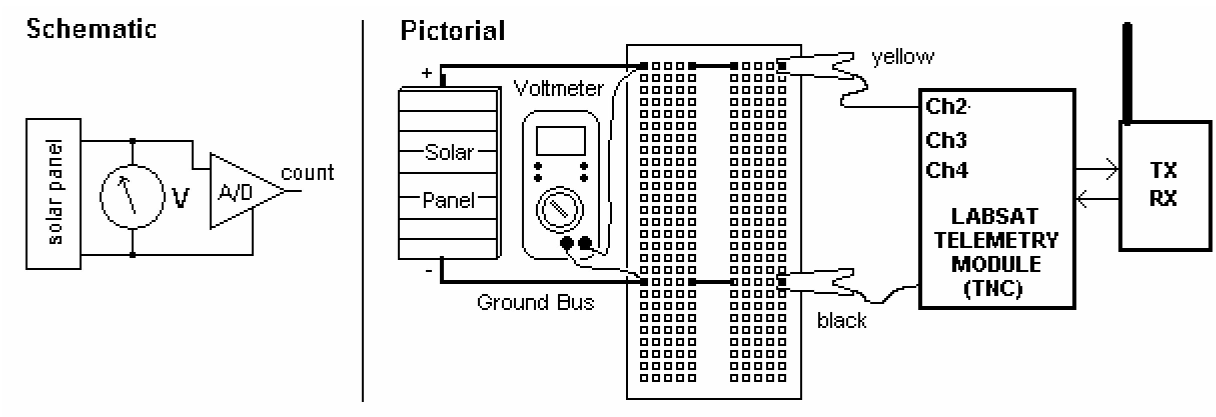
Telemetry Format: **W3ADO-1>BEACON:SGATE:T#002,132,138,159,131,213,11111111**

Where the first three fields are the satellite Callsign, Beacon address and SatGate callsigns, followed by the actual data consisting of a T#002 serial number, then the 5 analog channels, and then 8 discrete bit values.

Part A: Analog-to-Digital Converter Input Range

This portion of the lab demonstrates how the Analog to Digital Converter (ADC) 0-5v input range and 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 using the equation V = A*X + B.

1. Connect the telemetry unit ground lead (black) to the solar panel black lead and the channel 2 lead (yellow) to the solar array red lead as shown below. Also connect the voltmeter.



2. Position the light source about 18" 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 and allow at least 10 seconds for the LabSat to transmit the data to your ground station. Record the voltmeter and telemetry channel 2 readings of a dark solar panel with minimal output.
3. 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 readings.
4. Repeat step 3 while adjusting the solar light levels for 2, 3, 4, 5, 6, 7, 8 and 9 V output.
5. Observe and note the saturation voltage V_{sa} where the count reaches its maximum.

Post Lab:

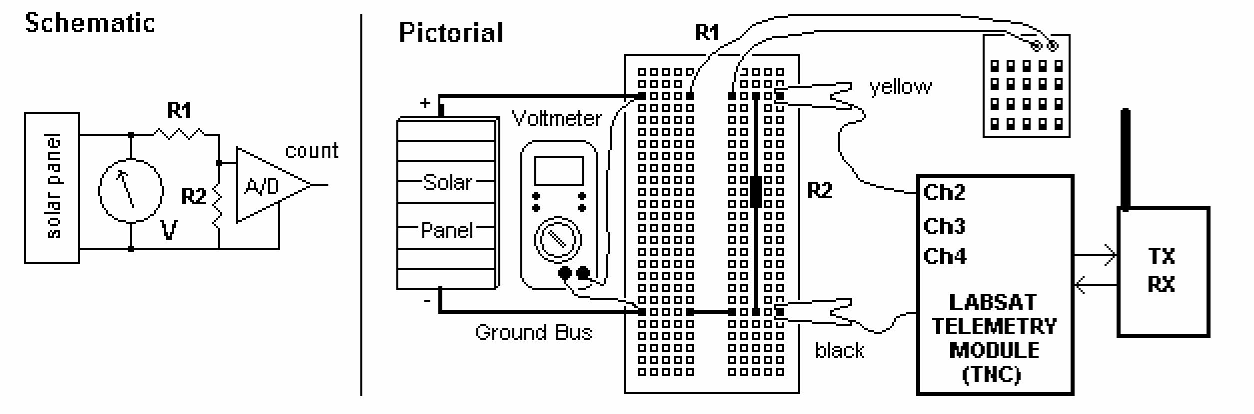
Plot the count output versus the voltage input to the A/D converter and notice how the channel 2 A/D circuit saturates at 5 volts and cannot read any higher voltage. For the linear portion of the plot, below 5 volts, derive a telemetry equation that will convert the count value X into the original voltage value, V.

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 ADC. The voltage divider is a pair of resistors that gives an output voltage to the ADC less than the input voltage by a ratio determined by the two resistors.

V_{AD}=Vin (R2 / R1+R2)

You will design a voltage divider to give a convenient telemetry range of 0 to over 25 volts with a precision of 0.1 volt.



Lab Period:

1. Connect the resistor box at R_1 and insert a 2.4 kΩ resistor at R2 as shown above. Connect the telemetry channel two (yellow) clip lead to the voltage divider of R_1/R_2. Start with the resistance box set to 0 Ω on all switches (down). Adjust resistance by flipping switches up to the desired value.
2. Given that a 0-5v input results in a 0-255 decimal count at the output, calculate the voltage input (across R2) that is necessary to give a telemetry decimal count of 90. Use the voltage divider equation to solve for R_1 that produces that necessary V_{R2} voltage with a 9 V input. This causes a 9.0 V input to 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 1, 2 , 3 , 4 , 5 , 6 , 7 , 8 , and 9V and compare with the telemetry counts. Allow adequate time (at least 10 seconds) for the LabSat to transmit the data to the ground station 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. 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:

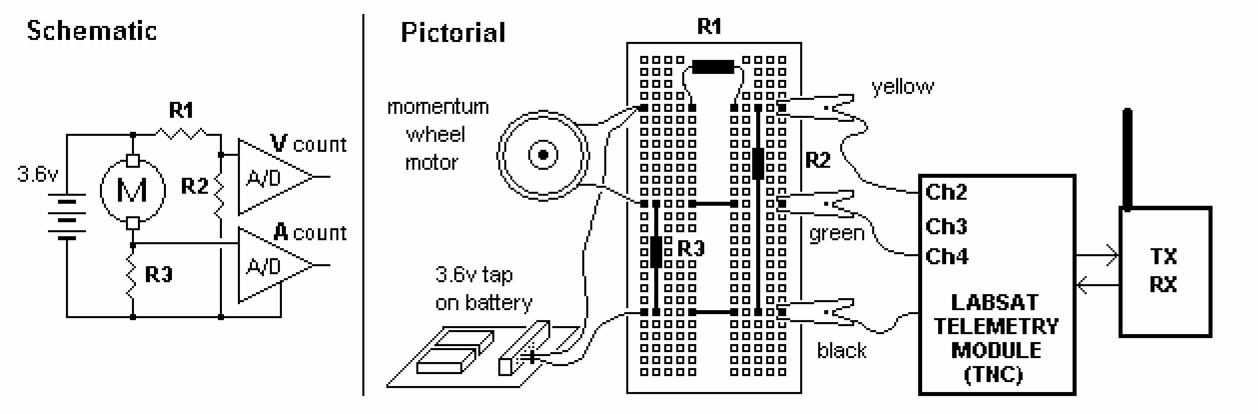
Plot the telemetry count versus the voltage input. Derive the coefficients of a linear telemetry equation to represent the relationship. V = A * X + B for both your calculated R1, and then for the actual one with the 10K resistor. Discuss the maximum input voltage that this voltage divider can measure before the ADC saturates. Annotate the telemetry packets you saved.

<u>Part C: Momentum Wheel Current Telemetry Channel</u>

This portion of the lab demonstrates how the ADC is used to measure load current. Current is measured by placing a low value shunt resistor in series with the load current and measuring the voltage drop across it. In this experiment, we desire to have a current range from 0 up to 255 mA. Choose a resistor value with Ohm's law to give this range scale for the A/D converter.

$V = I * R$ where R is the value of the shunt resistor and I is the current

1. Connect a power jumper from the 3.6v tap on the LABsat battery to the momentum wheel motor and connect a 20 ohm current sensing resistor to ADC channel 4 (green) as shown below. Observe the motor current reported on channel 4 and the voltage reported on channel 2.



2. Now move the battery tap to the 7.2 and then 10.8 volt taps, observing the current and voltage telemetry in each case..

Post Lab:

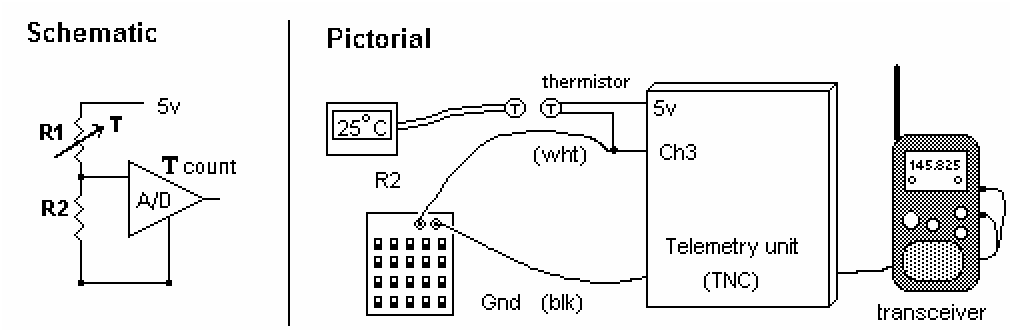
Now that you have three sets of telemetry for three conditions of the wheel, compute the power delivered to the wheel system for each case. Since the standard value shunt resistor was used instead of your calculated value, what should the final telemetry equation for current be, instead of the desired I = 1.0*X mA?

Notice, however, that the R3 shunt resistor is dropping the available voltage from the battery by the amount needed to give the ADC its needed input voltage (to read current). Thus the measured telemetry voltage is not all across the wheel. How much voltage is lost across R3 in each case?

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

<u>Part D: Temperature Measurements:</u>

To measure temperature we simply use a voltage divider and replace either R1 or R2 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. Although a thermistor can be inserted as either R_1 or R_2 in the voltage divider circuit, by inserting it as R_1, an increasing temperature conveniently results in an increasing telemetry count.



Lab Period:

1. The thermistor is already connected to channel 3 of the ADC and also the regulated internal 5 volts of the Telemetry Unit. Disconnect the Ch2 and Ch 3 leads from the previous part and connect the Thermistor and white and black leads as shown above to the resistor box as a new R_2. This makes the thermistor appear as the R1 in the voltage divider equation with 5 volts as the Vin and by selecting R2, you can establish a convenient calibration point..
2. To calibrate the thermistor reporting scale to about mid-range, adjust the R2 resistance box so the telemetry channel 3 reading is approximately 128 (half of 255), allowing adequate time (at least 10 seconds) for the LabSat to transmit the data to the ground station. This calibrates the mid-range temperature to room temperature. 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 3 count reading at room temperature.
4. 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 to the ground station. Record this telemetry channel 3 body temperature reading.
5. Following the same procedures, measure also the temperature of ice, cold water, and hot water.

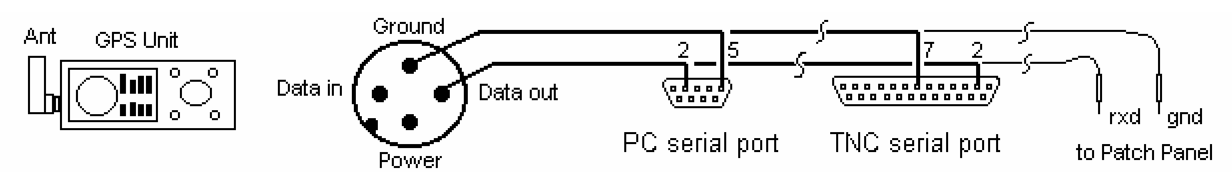
Post Lab:

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 ADC count back to temperature:

   - a simple linear equation for the range where the plot is reasonably linear
   - 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 (using GPS Data)

This experiment adds a GPS unit to the LABsat to demonstrate the ability to not only send down analog telemetry values 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. The GPS data is output once every 2 seconds into the RS-232 serial port of the TNC which then transmits it to the ground on demand or on a schedule.



Lab Period:

1. Since we will be indoors, you will first have to set your GPS to 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

2. First, take your GPS to the Test PC at the back of the class and connect the ground and data pins to it's serial port (the 9 pin connector shown above, though we will have a pigtail already connected to make this more convenient. Observe the repetitive GPS serial data on the screen using Hyperterm. How many different "sentences" of data do you notice in each update? How often is the data updated? Capture a complete set for your report.

3. Observe that your LABsat has not yet appeared on the PCSAT ground station APRS plot of stations heard. This plot has been zoomed in on Annapolis to the 0.5 mile scale.

4. Connect your GPS to your LABsat system serial port as shown above (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). The $GPRMC sentence contains time, position information, speed, course and date. Capture one of your GPS data packets for your report.

5. The data from your LABsat should begin to appear on the USNA Ground station position plot

6. Go to the APRS console and see if your station has appeared on the map. Use the arrow and pgup/pgdn keys to zoom into your GPS's reported position. Note its LAT/LONG

Post Lab:

1. 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 see what you get…

2. See some GPS position reports from users of our USNA satellites. See if your LABsat packets got picked up on the global network of APRS satellite Ground stations. See your own station by entering its LABSAT-N number into the following URL:

    - http://map.findu.com/labsat-N

3. Also, as a follow-up to previous labs check on activity on PCSAT-1 and see if you can tell when it went back power negative and could no longer support as many users per day.

    - http://pcsat.aprs.org

<u>Laboratory Report:</u> 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.