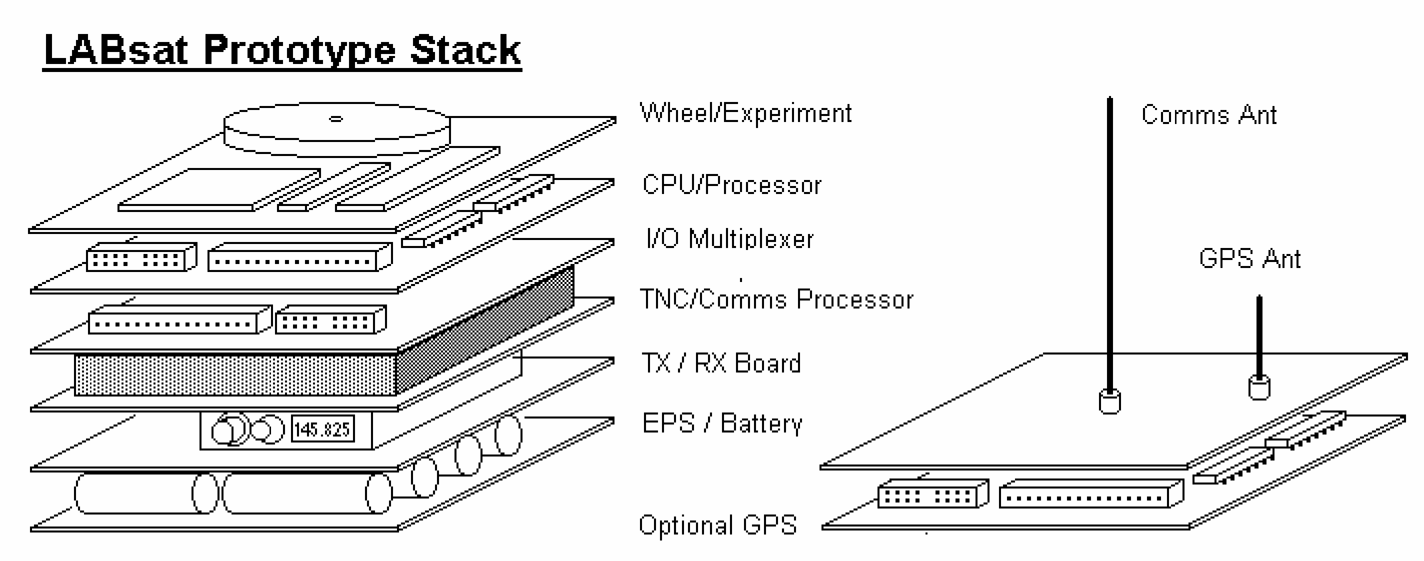
LABsat Manual

Fall 2005

This manual describes the USNA Laboratory Satellite System which has been designed to provide a realistic combination of all the aspects of satellite design including the Electrical Power system (EPS), Communications system including antennas, Command and Data Handling (C&DH), Attitude Determination and Control (ADCS) with momentum wheels, magentorquing, Thermal system, Telemetry, and extensible interfaces for further experiments. Individual labs have been written incorporating all of these subsystems into a continuum of experience for students leading to a fully integrated spacecraft at the end of the semester. The satellite system may be stacked to an approximate 6" cube design or laid out on a pair of one foot square flat-sat trays for easy access and handling during the design phase.



The LABsat consists of 8 modules and two one foot square experimental trays. :

- Transmitter / Receiver Module
- Battery / Regulator module, EPS system
- Command and Data Handling module (Terminal Node Controller)
- Telemetry multiplexing and conditioning Module
- Temperature / thermal module
- Antenna panel
- Optional Programmable CPU board
- Optional GPS Board
- Optional Voice synthesizer

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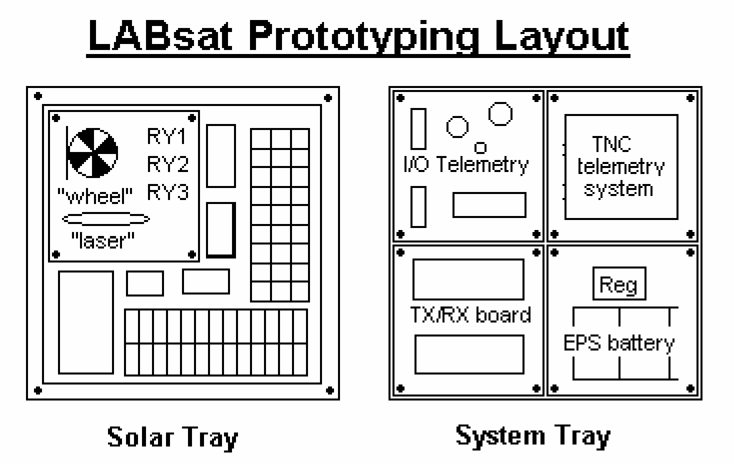
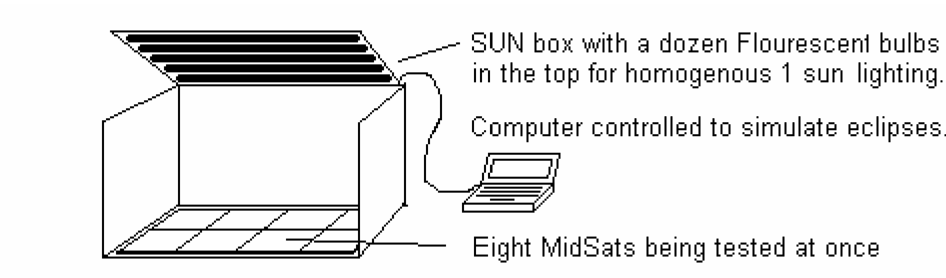


To give realistic operational scenarios to the LABsats, we have constructed a large Sun Box consisting of enough lights to equal about one sun. Students may assemble the spacecraft model and set it in the solar simulator running any given operations and orbit scenario for 48 hours as shown in figure 2. Eventually, students will be able to monitor their system remotely on the WEB or via an umbilical to their laptop.



The EPS system for the LABsats is not pre-determined. The students have at least 8 different solar cell systems of various voltages, currents, size and cost that they must balance with a variety of batteries to get a power-positive design. The following paragraphs provide some basic design basis for each of the components of the design:

Solar panels: The surface area available for solar panels for this experiment is the one square foot flat-sat carrying panel as shown above. A number of solar panel modules from Solarworld.com are available that come in multiple sizes, voltages and currents and price: (http://www.solarworld.com/SolarMini-Panels&Motors.htm)

Size	1 x 1.75	1 x 1.75	1.75 x 3	1.75 x 3	2.5 x 3.75	2.5 x 3.75	2.5 x 3.75	5.3 x 4.5	5.3 x 4.5
Current	20 mA	50 mA	500 mA	100 mA	200 mA	100 mA	50 mA	120 mA	60 mA
Voltage	3 Volts	1.5 Volts	0.5 Volts	1.5 Volts	1.5 Volts	4.0 Volts	6 Volts	9 Volts	18 Volts
Cost $	$11	$9	$8	$10	$13.50	$17	$18	$32	$32
Mass									

Batteries: There are several sizes and styles of battery cells available. Typical selections are:

	AAA	AA	C	D	9 Volt	Lithium AA	AA NiMH
SIZE							
CAPACITY	300 mAh	600 mAh	1200 mAh	4 Ah	120 mAh	Tbd	1800 mAH
VOLTS	1.2 Volts	1.2 Volts	1.2 Volts	1.2 Volts	7.2 Volts	3 Volts	
MASS							

Charge and Bus regulators: Students may select any type of regulator, series, shunt, or switching. These normally come in standard voltages of 3, 5, 6 8, 9 and 12 volts.

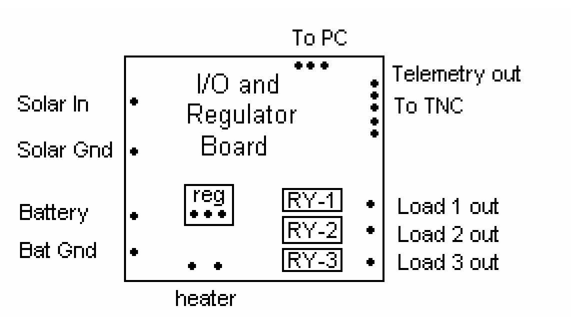
Heater: To maintain a certain spacecraft temperature a heater is provided for thermal experiments

Receiver/Transmitter: The Transmitter/receiver system used is actually capable of closing the link to LEO with simple ground stations. This makes their experience directly related to our on-orbit birds. Students measure TX power and EMI emissions, Antenna Tuning and SWR, RX sensitivity and Noise floor, 6 dB bandwidth and SNR.

Telemetry System: The telemetry system is similar to our PCSAT design with a minimum of 5 analog channels or using the I/O multiplexer board, this can be extended to four banks of 5 for a total of 20 analog channels and four 1 bit on/off channels.

Sensor System: Voltage dividers, current sensors, Sun sensors, and thermister circuits are provided for driving the telemetry system. Students determine the engineering unit conversions and design the fundamental scaling circuits.

Experimental I/O board: This board contains three relay control circuits suitable for controlling the heater, GPS board, Momentum wheel, Laser and other ON/OFF payloads.



Command and Data Formats: The telemetry system is capable of the following transmissions:

5 or 20 values every N seconds (Voltage, Temp, Solar/Battery/Load Currents)

One to 5 selected TEXT strings every N seconds

CW beacon every N minutes.

GPS data every N seconds (using optional GPS device)

Voice Synthesizer (using optional text-to-speech module)

Optional Programmable CPU serial port data

Optional Voice Synthesizer serial interface

Plus you can command on or off 3 or 4 of your loads.

Laser: This is a payload with a given power requirement and Ops cycle. TBD

Momentum Wheel: This is a payload with a given power requirement and pulse requirement. There can be a variety of wheel-mass also. There are two motors available as shown in the following table:

Motor	Volts	Current	Starting Current	RPM	Mass
MC-05/07	3	20 mA	100 mA	300	
MRE-260	3	80 mA	200 mA	???	

Magnetorquing Experiment: Attitude control via magnetorquing can be demonstrated with the set of orthogonal coils which can be commanded via the LABsat C&DH. The coils are 6 inches square and contain 205 turns of number 30 wire. They are commanded ON or OFF by the CTRL A and CTRL B commands. The power bus for this experiment is a 6 cell 1000 mAH nicad battery pack rated at 7.2 volts.

Optional GPS Data:

One of your spacecraft payloads may be a GPS. The serial data output from the GPS data can be routed to the TNC serial port for parsing of position data. The TNC can select how often to transmit this data to the ground station. The sketch below shows the GPS to TNC serial input port:

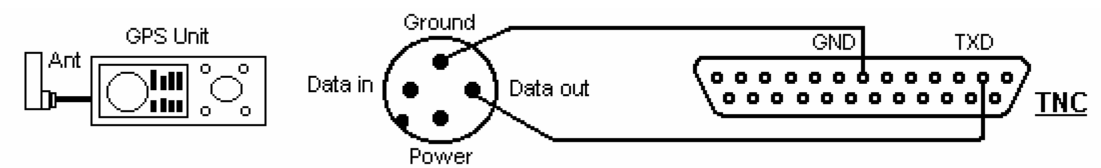


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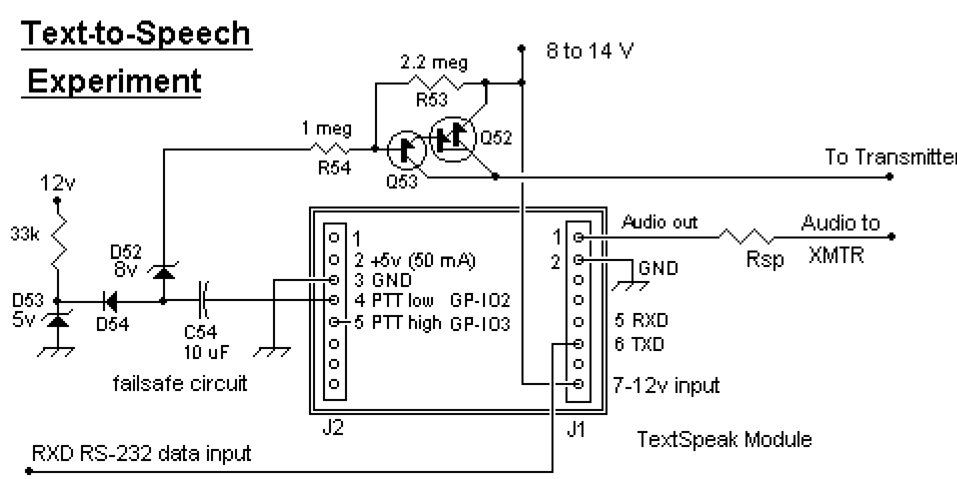
Figure 1 GPS Port Connection

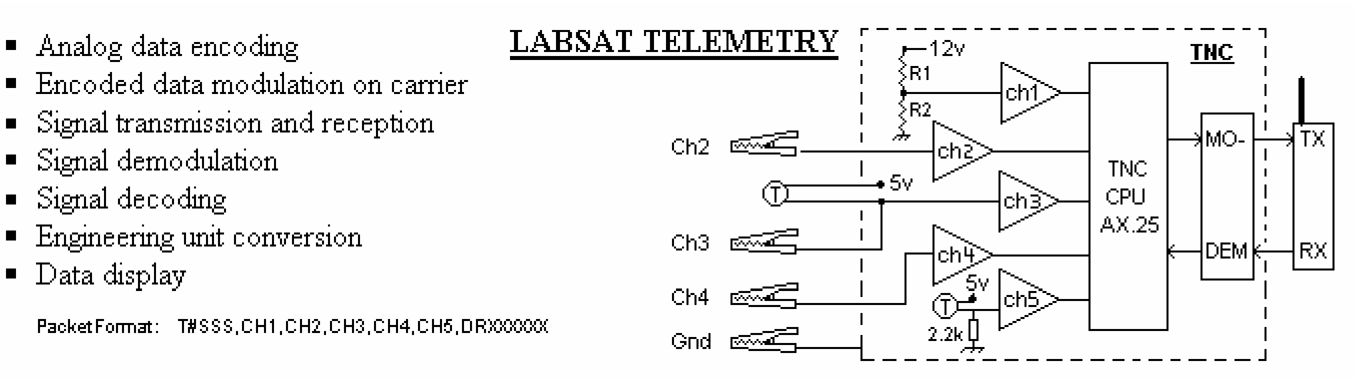
Speech Synthesizer:

An optional text-to-speech voice synthesizer is available for letting the LABsat speak its telemetry for low technology ground stations at other schools to monitor. The module will speak any text that is sent to it from the TNC, from the ground, or from the optional CPU:



TELEMETRY SYSTEM:

The block diagram of the basic 5 channel telemetry system is shown below: It may be connected to a bus for voltage, three current sensors for solar, battery and load currents and to a temperature sensor on the heater system as shown below: (this is not the final figure)



GROUND STATION:

Each of the LABsats can transmit on its own C&DH RF channel to individual command stations or all satellites can operate on the same shared TDMA channel. A typical application will use one ground station for the constellation of LABsats with the data stream being distributed to all student terminals. Alternatively, this data can then be fed into the internet so that students can monitor their systems remotely as shown below. This way, each design team can see the telemetry from their LABsat and see how a Time-Division-Multiplex channel can carry multiple sources of data. (this is not the final drawing)

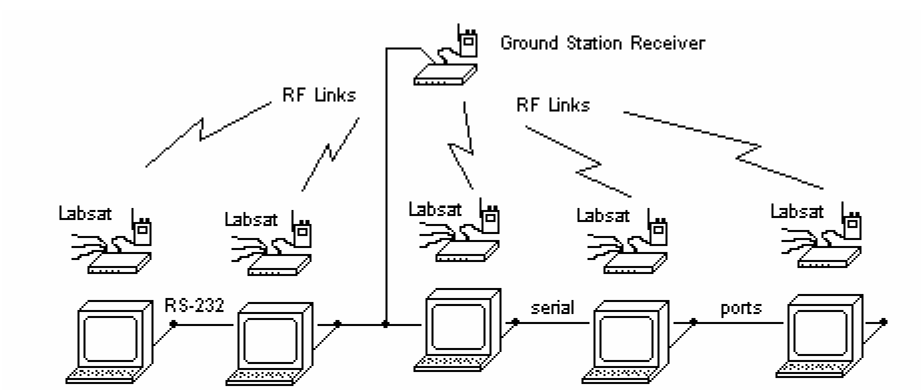


Figure 2 LabSat Network

TELEMETRY APPLICATIONS:

The following several sections contain detail set-up suggestions on how to use the basic LABsat telemetry system in a variety of not only just LABsat applications, but other practical data collection projects as well.

Part A: ADC Input Range

First designers must scale whatever they need to measure into the range of 0 to 5 volts input range of the Analog to Digital Converter (ADC). The result is an 8 bit telemetry value corresponding to a 0-255 telemetry count. This count is then multiplexed together with four other telemetry channels into a single data packet for transmission of the format MYCALL>TLM:T#SSS,111,222,333,444,555.

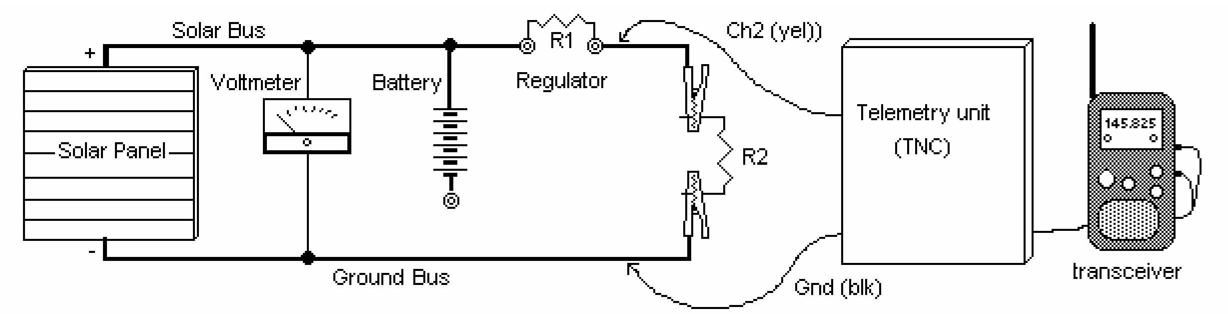
Part B: Voltage Scaling (Voltage Divider)

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

Vout=Vin (R2 / R1+R2)

A simple 10k/2.4k voltage divider will give a convenient telemetry conversion range of 0 to 25.5 volts with a precision of 0.1 volt (actually 9.8k/2.4k). Or to lessen the load on the circuit you can use a 42k/10k divider to give the same convenient ratio. Any voltage divider can be used and just converted to volts later in a spreadsheet. **Caution: Never let any voltage greater than 5 volts get to the input of the A/D or you will burn it out. That is why we condition signals first using a voltage divider**

Telemetry Lab arrangement of the voltage divider:



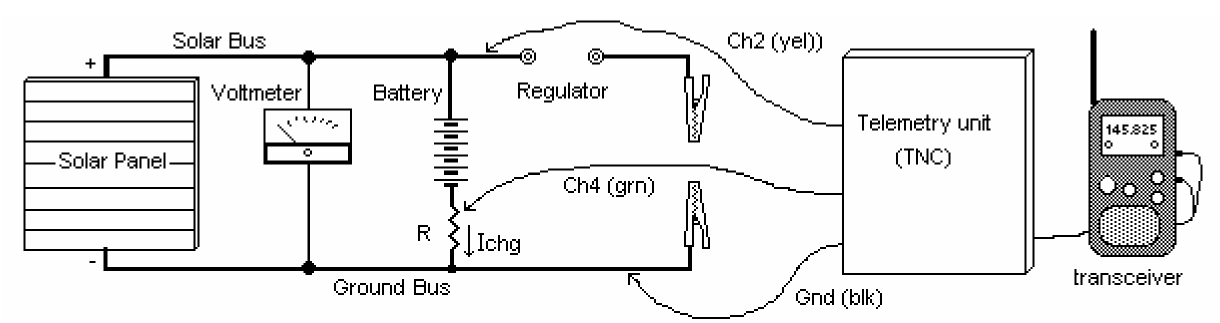
Part C: Battery Charge Current Telemetry

Current is measured by placing a low value shunt resistor in series with the current and using one of the Telemetry systems A/D inputs to read the voltage drop across the resistor. Then using Ohm's law to convert this voltage to the actual current in the circuit. The voltage drop across the shunt resistor is:

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

Lab Model:

In this diagram the voltage on the Solar bus is read by the Ch2 input (and its internal 25.5 volt voltage divider) and the Ch4 input is reading the voltage across a low value shunt resistance. Designers want to choose a shunt resistor to give at least 1 volt of drop for the current you want to measure. This will give a resolution of 1/5th of the 255 range or about a 0 to 50 reading… Choosing a value of 1.96 ohms will result in a count of 255 = 2.55 amps.

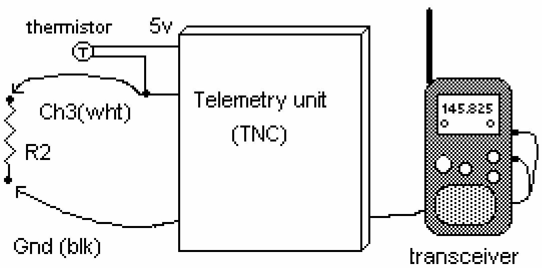


Part D: Temperature Readings:

Designers may also use one of the A/D inputs to read temperature by using a similar "voltage divider", but with one of the resistors as a Thermister and the voltage being the regulated 5v bus of the TNC. The thermister has a high negative temperature coefficient meaning that as the temperature goes up, the resistance goes down. By placing the thermister as R_1 in the voltage divider circuit, then an increasing temperature conveniently results in an increasing telemetry count.

Lab Example:

By using the prefabricated clip-lead cables used in the EA-467 lab, notice how the thermister is already connected internally to the 5v reference in the TNC and to the channel 3 input. Thus, the designer only has to choose the R2 value to scale the nominal temperature she wants to measure to the center of the A/D range. Different thermisters are specified by their nominal resistance at 25C. In the lab and on PCsat, we used 3k thermisters. On ANDE and RAFT and MARScom we are using 10k thermisters for reduced power loss.



If using other R2's or thermisters, designers should run a calibration first to get a conversion relationship between actual temperature and the telemetry readings. Convenient points are ice from the refrigerator (after letting it reach steady-state melting), room termperature, and body temperature.

TNC Setup:

Connect the TNC to the serial port of the PC. Run HYPERTERM (or Special Edition) which should be under the Programs/Accessory/Communications menu. Set it for 9600 baud no Parity, 1 stop bit and no handshaking. (sometimes the TNC's were last used at 4800 baud and you may need to run 4800 baud). Power the TNC from a small wall transformer. Turn on the TNC and you should see its boot-up sequence and a cmd: prompt. If you don't see the prompt, then pause 2 seconds, hit three ^C's in rapid sequence and wait another 2 seconds. This will get it out of "transparent mode".

The TNC has two useful commands for using it in this manner. Just typing the command with no parameters will show you the current setting for that parameter. Entering the command with a parameter will change it. For the other hundred or so parameters, see the Kantronics Manual.

1) Set the MYCALL callsign of the LABsat system to match your experiment. It must be a 6 character callsign. Use the MYCALL XXXXXX command to set this paramter.

2) Set the telemetry rate as desired using the TE(lemetry) X command where X is the value in TENS of seconds that you want the samples to be taken. The fastest rate is TE 1 which is once every 10 seconds.

DATA Capture:

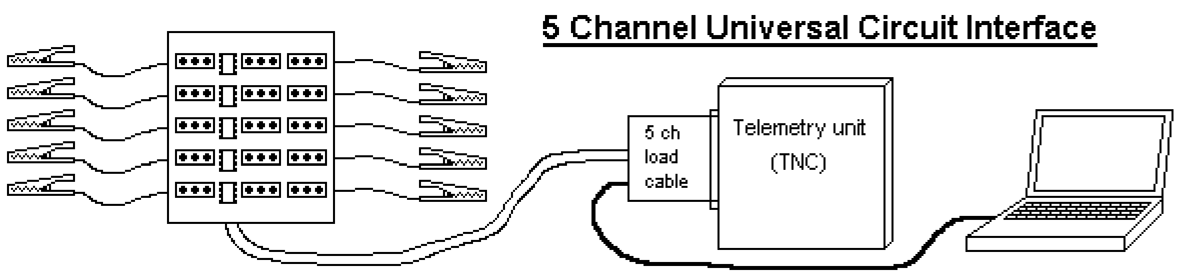
Once the TE X command is given the TNC will begin transmitting telemetry data packets as follows:

MYCALL>APRS:T#SSS,111,222,333,444,555

Where SSS is a serial number incremented with every count
111,222,333,444,555 are five three digit values for each of the 5 telemetry channels.

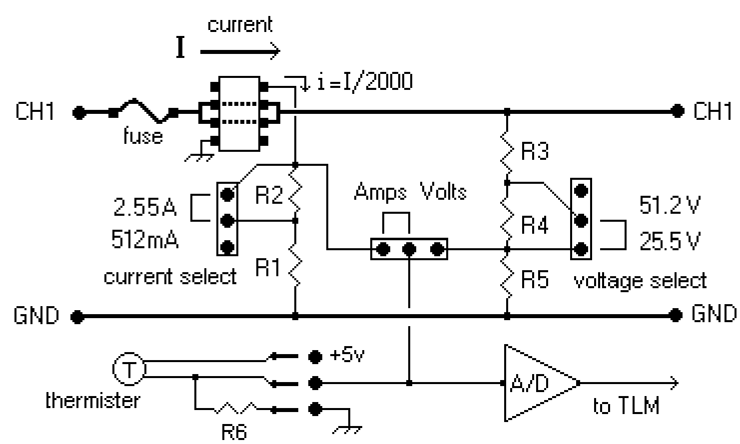
To capture data, use the TRANSFER pull down menu in Hyperterm to capture this data to a file for later use in a spreadsheet for analysis. Or scroll back to view off-screen data.

UNIVERSAL TELEMETRY CIRCUIT INTERFACE:



Jumpers select Voltage or Current and high or low range. Temperature probles are available.

A special cable has been prepared for interfacing the 5 telemetry channels to circuitry for measuring voltages, currents or temperatures with simple jumper selection. The end of the cable contains a paddle board with 5 input circuits for each of the 5 channels. Jumpers are used to select Voltage, Current or Temperature. For current, a MAX471 current sensor chips identical to that used on PCSAT2 and our other satellites are used. Two current ranges are selected by another jumper. Voltage is sensed with a simple voltage divider., again with a high/low jumper selection. Temperature is selected by plugging a thermister onto the proper pins. The figure below shows the circuitry associated with each of the 5 channels.



Current Sensor:
R1 = 3.92K 255 = 2.55 Amps
R2 = 15.7K
R1+R2 = 19.6K 255 = 510 mA

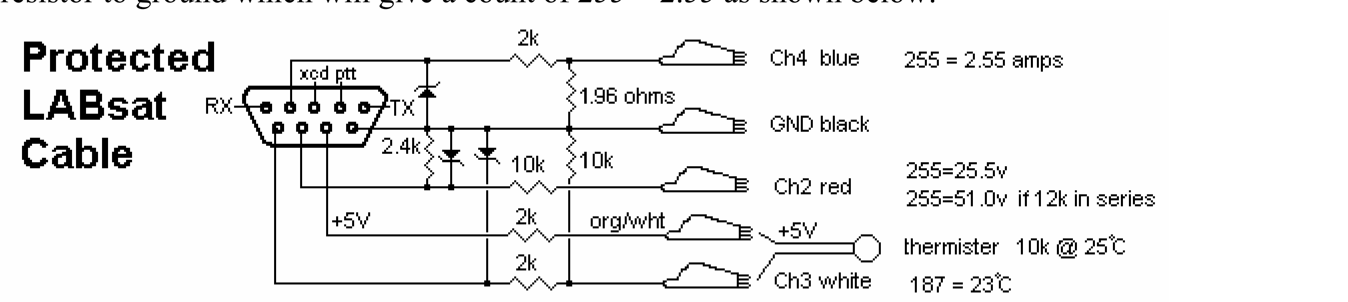
Voltage Divider:
R3 = 102 k 255 = 25.5 Volts
R4 = 127 k
R4+R5 = 229 k 255 = 51.0 Volts
R5 = 24.8 k

Actual Values:
R1/R2 actually in parallel with R5 so
R1 = 4.65k (4641), R2 = 87.3k (8872),
R4 = (1243)
R6 = 18.7 k parallel R5 = 10.7k

The engineering units conversion has been designed so that 255 = 25.5 volts on low range and 255 = 51.0 volts on the high range. Current is converted as 255 = 2.55 Amps on the high range and 255= 510 mA on the low range. The temperature curve is attached as appendix A.

SPECIAL PROTECTED CABLE for Volts, Temperature anc Current:

A special Protected cable has been prepared for voltages as high as 50 volts and it has protection diodes for temporary inadvertent connections. The Red Channel 2 Voltage probe is designed to give a count of 25.5 volts max for a count of 255. This has been extended with an external 12k series resistor to give a peak voltage of 255 = 51 volts (a 2:1 conversion equation). It also has a built in 1.96 ohm current shunt resistor to ground which will give a count of 255 = 2.55 as shown below:

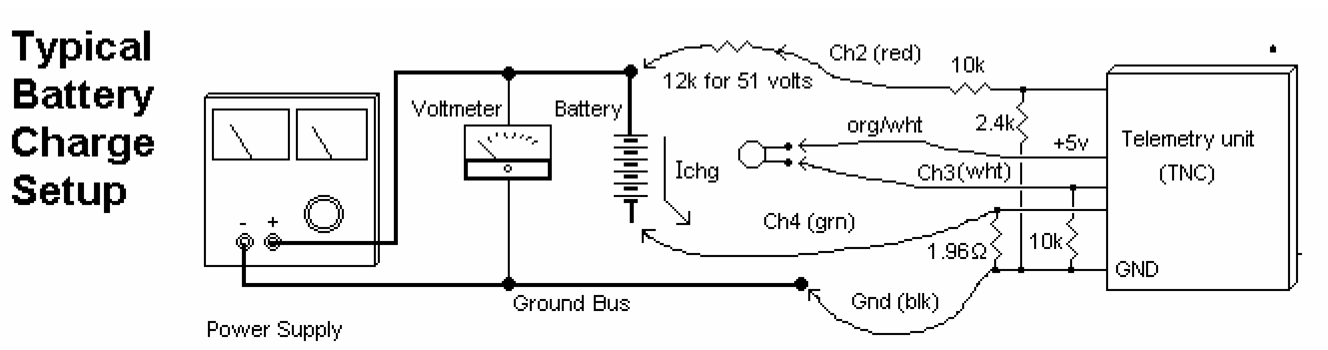


The Zener protection diodes do provide a slight loading on the circuit as the A/D voltage approaches 5 volts according to the following table. This test cable uses relatively low resistance voltage dividers and low shunt resistance to swamp out the effect of these zeners.

5.0v	4.5v	4.0v	3.5v	3.0v	2.5v	2.0v
1k	5k	14k	50k	175k	625k	2.2m

Typical Battery Charge Telemetry Arrangement:

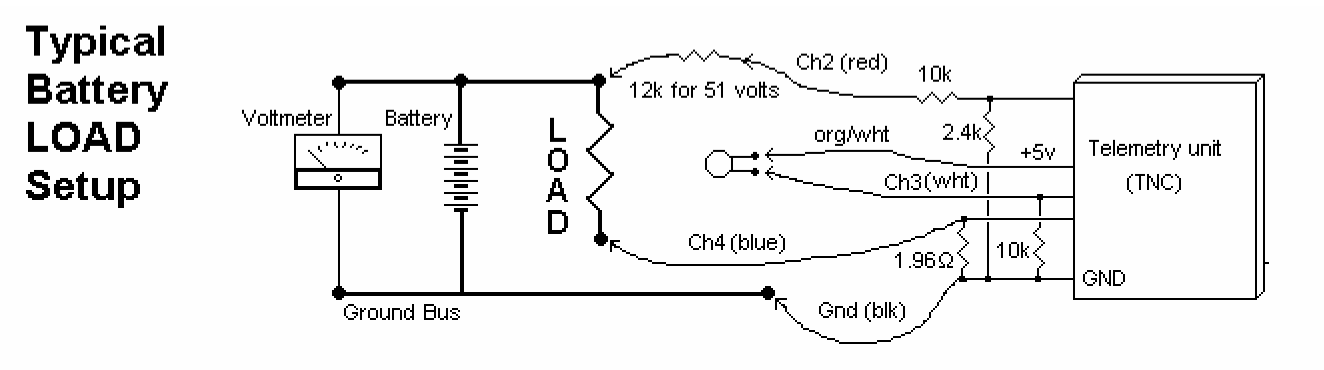
The special Protected LABsat cable has built in voltage divider for up to 25.5 volts and with an external series 12k resistor, will read to 51 volts for a telemetry count of 255.   It also has a built-in 1.96 Ohm shunt resistor for the negative lead of a battery to read charge currents to 2.55 amps. For temperature it has two clip leads for an external 10k thermister. Using this cable, the test set-up should be arranged as shown below:



Typical telemetry readings for this configuration are: 162,202,186,040,161.   Where:

- 162 means the TNC is running on 16.2 volts
- 202 means the voltage is 40.4 volts
- 186 means about 23 deg C (a calibration curve is needed for other temps)
- 040 means 400 mA
- 161 is not used

To use the LABsat Telemetry system to measure the load on a battery, the current is in the opposite direction and so the shunt resistor connected to the Channel 4 input has to be moved to the ground leg of the LOAD as shown in the following diagram:



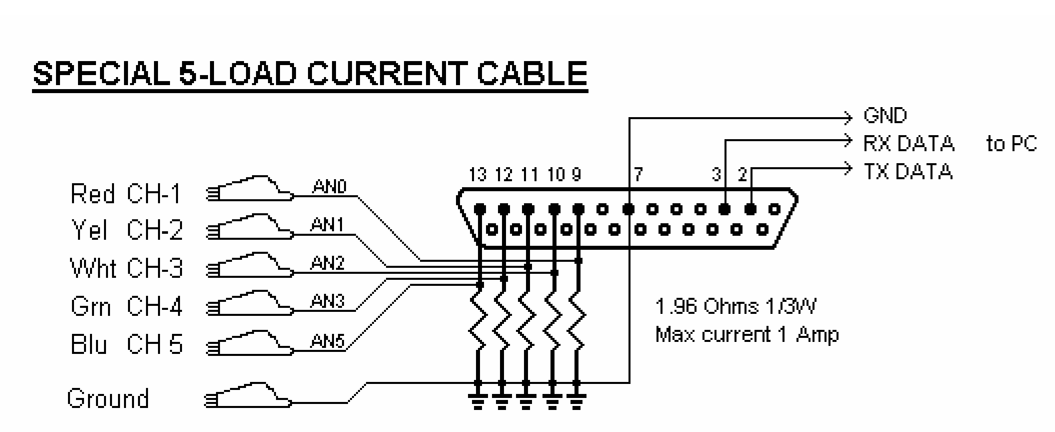
Again, using the internal 1.96 Ohm shunt resistor, care must be taken not to exceed the 2.55 Amps limit of this circuit. And as before, for voltages higher than 25.5 volts, the additional 12k series resistor is required in the Channel 2 lead.

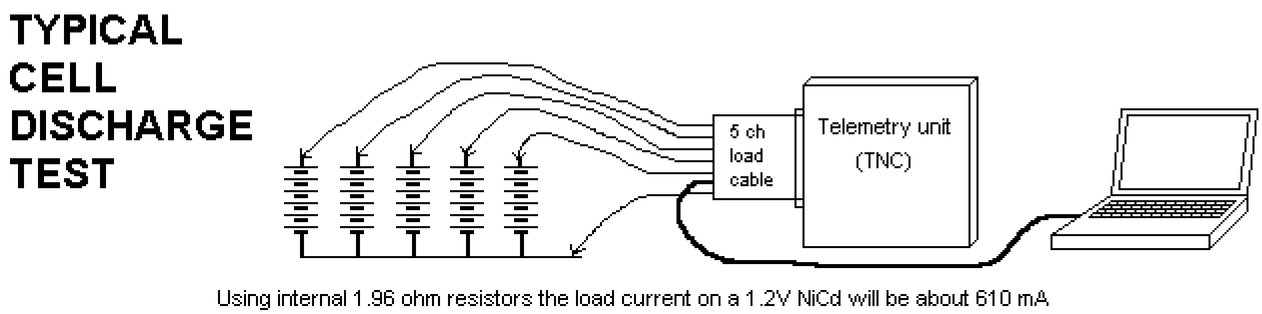
SPECIAL DISCHARGE TELEMETRY CABLE (5 currents):

This special cable is designed for measuring 5 currents at once such as during the measured discharge of a battery cell test. The cable contains a 1.96 ohm 1/3W load resistor on each of the 5 input channels. This equates the telemetry count 0 to 255 to be 0 to 2.55 amps. However, the load resistors are only rated for 1 amp continuous so do not overload them. Internally channel 1 is still connected to a 2.4k Ohm voltage divider and channel 5 is still connected to an internal 10k thermister. But clearly these are totally swamped by the 1.96 Ohm shunts and do not load down the circuit.

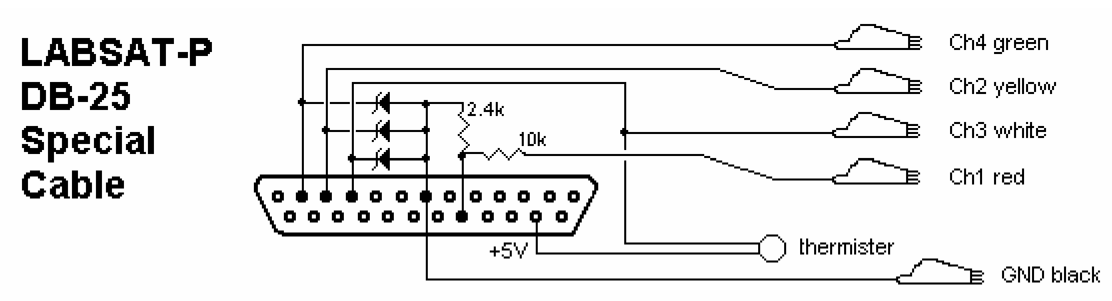
TYPICAL CONNECTION OF THE LOAD CABLE FOR CELL TESTING:

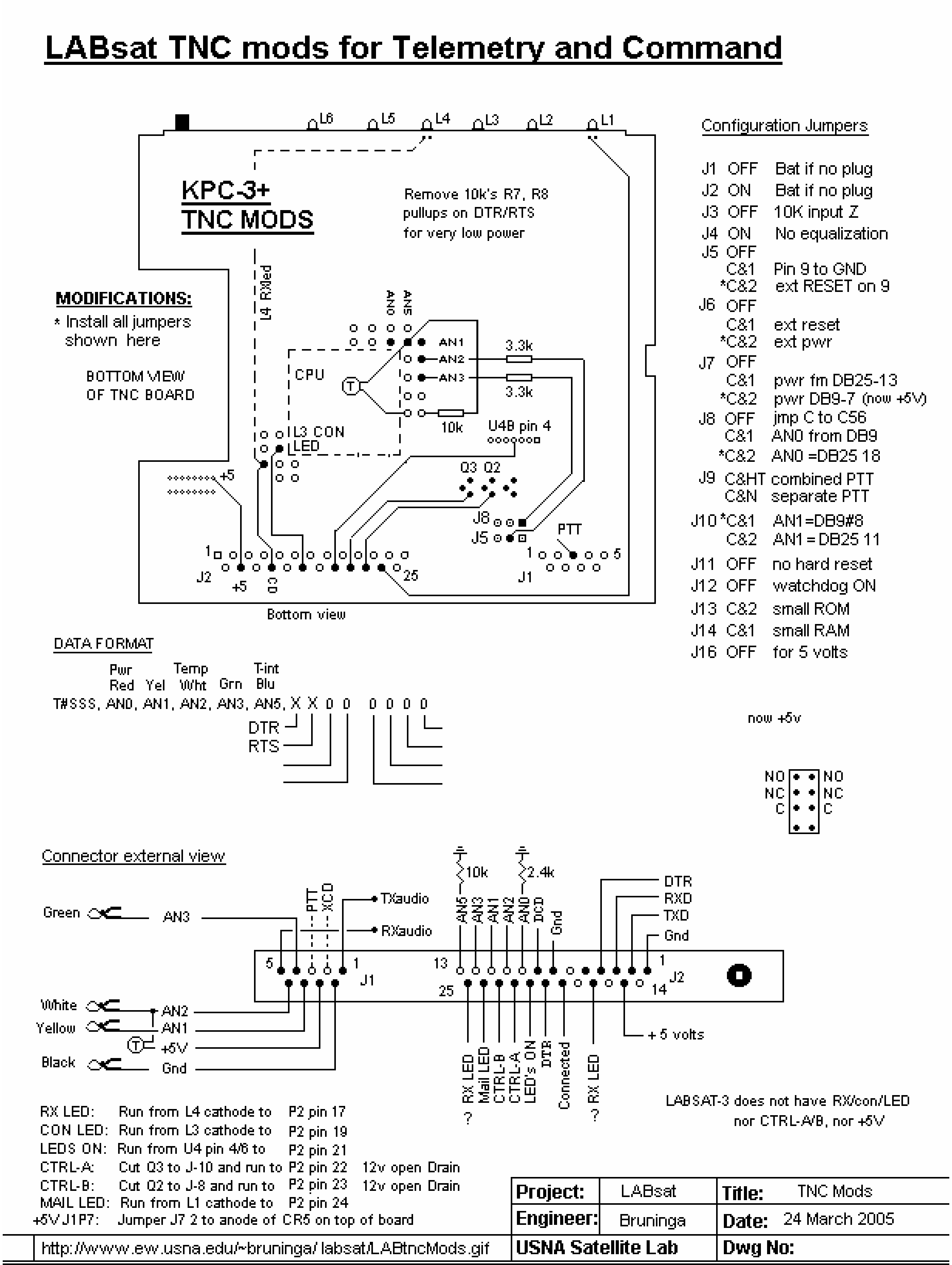
Five cells can be tested at a time in this configuration:





SPECIAL TELEMETRY CABLE FOR LABSAT-P: This LABsat is half modified and so it has only the 4 channels of telemetry on the DB-25 connector. This connector is not interchangeable with any other LABsat. It includes protection zeners and should only be used with this LABsat:





Configuration control:

LABSAT-3 does not have RX/con/LED nor CTRL A/B nor 5V on DB-25

LABSAT-4 is now identical to LABSAT-2 and both have 5 channels on the DB25