# EA-467 Spacecraft Electrical Power Subsystem (EPS) Lab **(part 2)** (rev b) **Fall 2008**

**Elements**: PV cells, IV curves, Shadowing, Series/Shunt Regulators

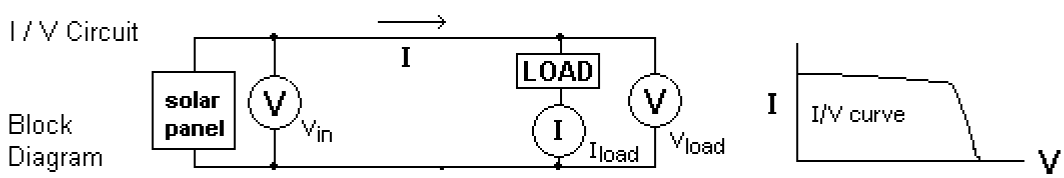

**LABsat Configuration:** Last period you learned in parts A and B about the charging and discharging of your spacecraft battery. This period you will add a solar panel and a circuit prototyping area for connecting loads (a resistor box) and regulators to your telemetry system. As in the telemetry labs, your LABsat will output its telemetry via its serial port to your PC running Hyperterm. You will use this configuration to observe the following experiments:

1. Solar panel current-voltage (I-V) and power curves.
2. Temperature and shadow effects on solar panels.
3. Voltage regulator performance for Series, Shunt and Switching regulators.

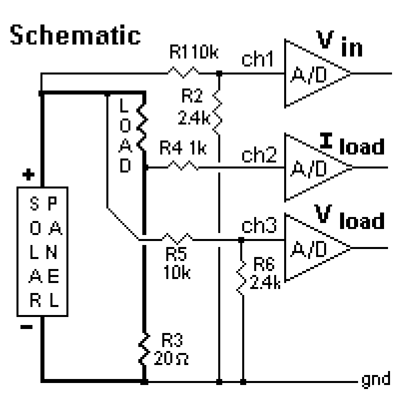
Form groups of two for each LABsat. Although you will use the LABSat telemetry for most plots, you should also sketch your data during the lab to ensure its validity while you still have time to fix it.

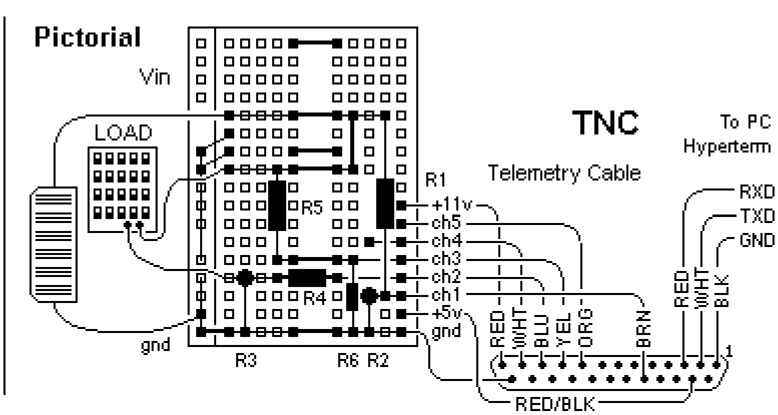
**Part C. Temperature effects:** The temperature of solar panels has a negative effect on the voltage output of the cells. Spacecraft design should include thermal design of the panels to keep them as cool as possible. During this lab, the LABsat we used for the thermal demo will be placed in the thermal chamber and operated under a variety of temperatures so we can track the output voltage with temperature. You will go adjust the chamber from -20 to +60 in 10 degree steps every 10 minutes. The file will be recorded with Hyperterm and sent to you after class.

## Part D. Solar Panel I-V Characteristics:




You are familiar with common power sources that have a relatively fixed voltage (12v, 115v, etc) under various loads. Solar panels, however, have a limited current and an output voltage that is not constant but is dependent on the load and internal impedance (and temperature) of the panel. The resulting changes in source voltage that occur due to changing loads are usually described by an I-V curve shown above. This experiment will derive the I-V curve for your LABsat solar panel similar to that shown above.



1. Begin a new Hyperterm capture file for this experiment.
2. Using the same prototyping area, connect the load box and solar panel to Channel-1 via R1/R2
3. Keep Channel-2 connected to the R3 shunt resistor via R4 as before.
4. Add another 10k/2.4k voltage divider R5 and R6 to read the Load Voltage on channel 3.
5. Place your LABsat in the Sun spot provided by one of the four lab spot lamps.
6. Waiting at least 10 seconds and confirming each data sample, successively set the resistor to each of these loads: 0, 10, 20, 30, 40, 60, 80, 100, 120, 140, 170, 200, 230,270, 300, 340, 400, 500, 700, 1000, 1400, 2000, 2400, 3000 Ω and confirm that the channel-1 and channel-3 voltages and channel 2 current telemetry are changing.

**Post-Lab:** Load your capture file into Excel importing only the Ch1, Ch2 and Ch3 data. The serial number T#nnn is not needed. Notice that Ch1 and Ch3 should be the same since the input voltage and load voltage are the same (we have no regulator in the circuit yet). Now add a new column in Excel for power/10 computed from Vin and Iload. Do an XY plot of current, and power versus voltage (current in mA, power in ten's of milliwatts on the same vertical scale. Identify the peak power point for your panel. Discuss the curves.

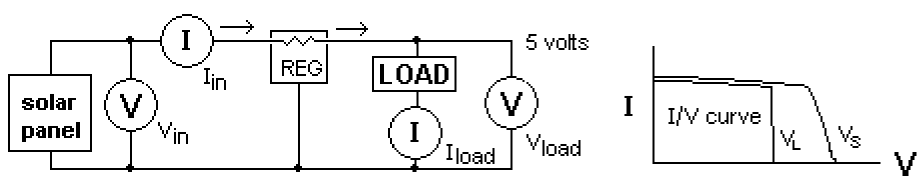
## Part E. Shadow Affects:

A single small shadow can reduce a PV panel's output drastically. Even though the shadow may only cover a small percentage of the panel area (one cell), it can reduce the panel's power output by a significant factor because all the cells are in series. Also, the shadowed cell will be driven in reverse by the other cells still in sun and could cause damage in high voltage strings. (a simple reverse diode across each cell eliminates this hazard). Use the connections you still have from part B.

1. Adjust the load near the peak power point (200 ohms) and note the telemetry voltage and current.
2. Place a shadow obstruction on one cell (3% of panel), wait 10 seconds and observe the telemetry.
3. In your report, discuss your observations (power lost) and the importance of shadows in spacecraft design (hint, compare the power lost as a percentage).

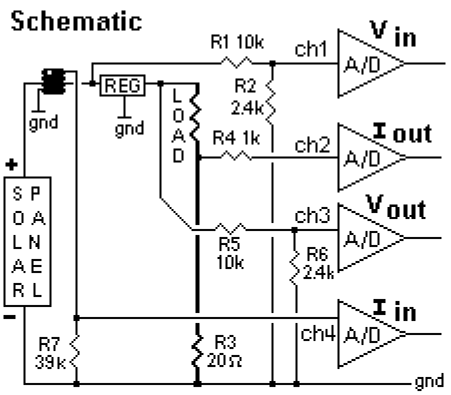
## Part F. Series Voltage Regulation:

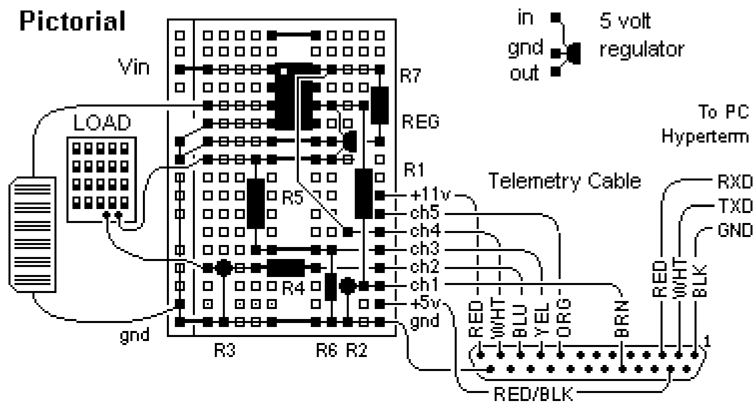
Series Regulator Block Diagram




Since electronics generally require fixed voltages, while the solar array voltage output (I-V curve) varies according to the load, voltage regulators are used to maintain constant voltages for the electronics and charge regulators ensure proper currents for battery charging. The most common terrestrial *series regulator* provides a constant output voltage by dropping excess voltage across an internal series resistance. However, the series regulator's internal resistance consumes power proportional to the current. Although this is inefficient at high current loads, its primary advantage is that it dissipates little wasted power under small loads. The block diagram above represents the series regulation circuit diagram. The figure below shows the schematic and layout for connection of a 5v series regulator to our TNC Telemetry system.

1. Start a new capture file for this part D.

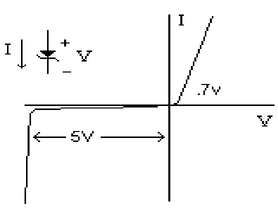


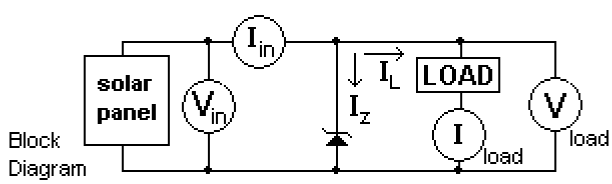



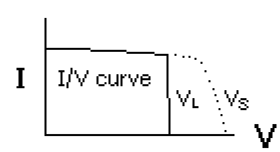

2. Remove jumper and add an input current sensor chip as shown. The output of this chip is a current proportional to .0005 of the input current. Add a 39K resistor for R7 which will result in a voltage (0-5v) for a count of 0-255 representing a current of 0-255 mA. Jumper this output to channel-4.
3. Add a series regulator to your circuit as shown above so that channel 1 continues to read the input voltage from R1/R2 and channel 2 reads the load current (voltage across the 20 ohm resistor R3)
4. Channel 3 continues to read the Load voltage using R5 (10k) and R6 (2.4k).
5. Reset your TNC to re-start your telemetry serial number at the start of this experiment.
6. As before, vary the load resistance for: 0, 10, 20, 30, 40, 60, 80, 100, 120, 140, 170, 200, 230,270, 300, 340, 400, 500, 700, 1000, 1400, 2000, 2400, 3000 Ω., making sure to get at least one 10 second telemetry value for each setting.

**Post-Lab:** Load your data file into Excel taking in Ch1 through Ch4. The serial number T#nnn is not needed. Generate three new columns for input power (Vin * Iin), load power (Vload * Iload), and efficiency (Pload/Pin). Also generate a column for Regulator Power (Vin - Vload) * Iload. Plot the load voltage, load current, input power, load power and efficiency against input voltage. Note the peak power points. Comment on the differences in the I-V curve for the series regulated load and the unregulated I-V curve. What is the efficiency of this series regulator then at the load's peak power point compared to the original I-V solar panel's peak power point?

## Part G. Shunt Regulation:

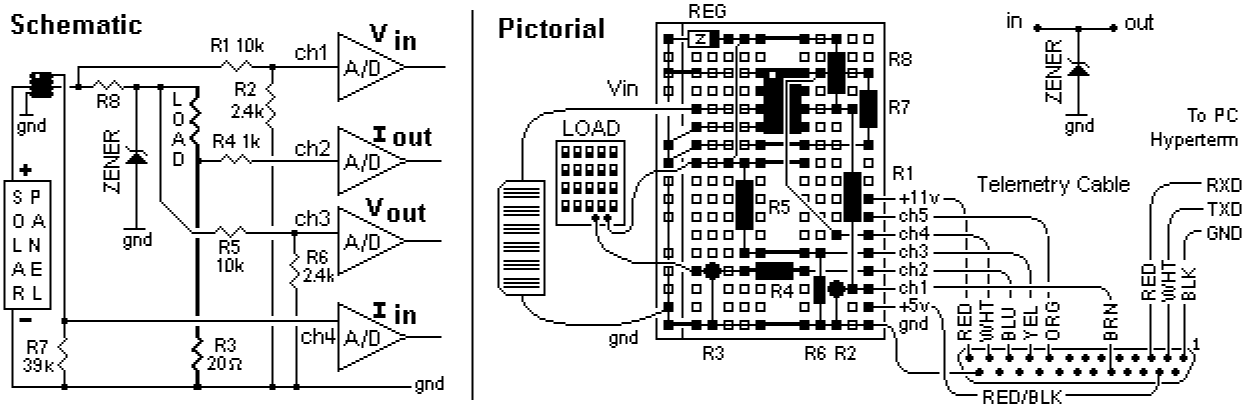



Shunt regulators limit voltage by dumping (shunting) excess current into a resistive load. A simple Shunt Regulator is simply a Zener diode which has an I-V characteristic as shown above. In the forward direction, it passes current like any diode above its turn-on threshold (about 0.6 volts). In the reverse direction, it passes almost no current (like an open circuit) below its "Zener" threshold. Once that Zener voltage threshold is exceeded, it begins to conduct heavily, clamping the circuit at that voltage.

The primary advantage of a shunt regulator is its simplicity and the absence of any series voltage drop. Thus, it can provide regulation under peak current loads down to a lower input threshold than a similar series regulator. Its chief disadvantage is that at all power levels below that peak, it has to dissipate all excess power. Thus it is never used terrestrially. But in space, the power is already paid for. This heat dissipation of the shunt regulator must be accounted for by the thermal control subsystem.




1. Start a new capture file and replace the series regulator with the Zener diode regulator shown with a tiny “Z” in the above layout. The anode (black band) should be to the right as shown above.
2. Insert a 20 Ohm series resistor, R8 to simulate distribution losses in the spacecraft.
3. Channel 1 will read the input voltage, Channel 2 the load current, Channel 3 the Load voltage and channel 4 the input current
4. Use the load resistor box to cycle through the resistances of 0, 10, 20, 30, 40, 60, 80, 100, 120, 140, 170, 200, 230,270, 300, 340, 400, 500, 700, 1000, 1400, 2000, 2400, 3000 Ω making sure to pause for more than 10 seconds to get a good telemetry value at each one. Save your capture file.

**Post-Lab:** Load your capture file into Excel taking in the first 4 channels. The serial number T#nnn is not needed. Plot the same parameters as for the serial regulator but instead of the series regulator power, calculate the Zener power Vload * (Iin - Iload). Plot all the parameters against input voltage, scaling the power values (divide by 10) to stay on a good scale resolution. Choose appropriate scaling factors to get reasonable resolutions of the various curves on your plot. (If you know how to have different “Y” scales on the left and right, please do). Note the peak power points. Comment on the differences in the I-V curve for the regulated load and the unregulated I-V curve. What is the efficiency of this shunt regulator then at the load’s peak power point compared to the original I-V solar panel’s peak power point? Also compare to the series regulator’s efficiency.

Include comments on the heat from the zener regulator when it is dissipating excess current. What would happen if the Shunt regulator failed Open? Shorted?

## Laboratory Report:

This section of the EPS lab will be combined with the EPS Battery lab and next weeks Design Exercise into a laboratory report similar to what you have done on previous labs and the following guidelines.

- For each part, describe the laboratory’s purpose, apparatus, procedures, results and conclusions.
- Include block diagrams and answer all “Post-Lab” and other questions.
- Compare measurements and theory/expectations. Discuss observations, results and conclusions.
- Include all figures, data tables, and graphs within the section where it applies.