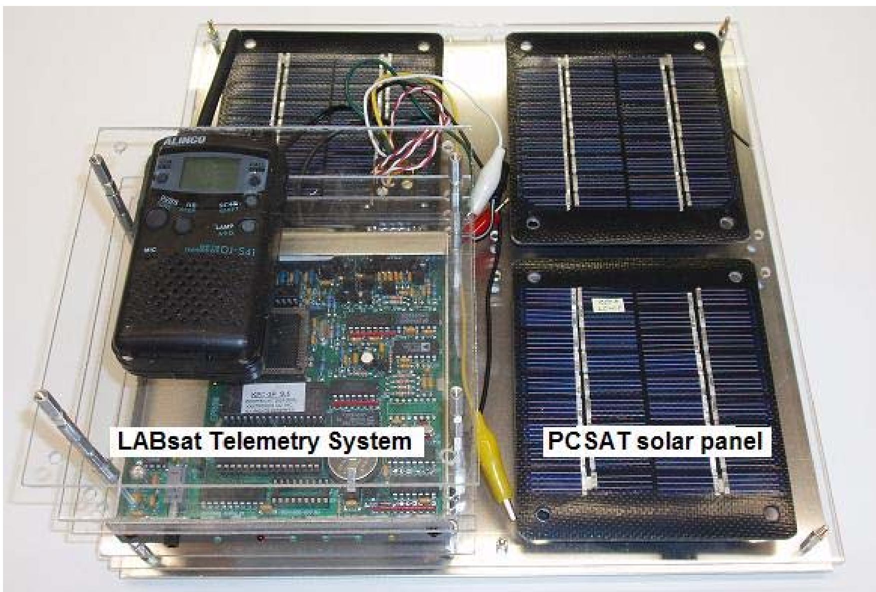
EA-467 Spacecraft Electrical Power Subsystem (EPS) Lab **(part 1)** (draft) **Fall 2006**

Introduction: This lab will use the LABsat system to explore typical spacecraft electrical power systems (EPS) concepts. The EPS "provides, stores, distributes, and controls spacecraft electrical power"[1] and consists of a power source (usually panels of photovoltaic cells), an energy storage device (usually batteries), a means of power distribution, and a means of power regulation and control.[2] Photovoltaic cells convert solar energy to electric power. Rechargeable batteries provide power (discharge) when the panels are not in view of the sun and recharge when the panels are providing the power.[3] Power regulation and distribution provides power at the right voltages to all components according to their specific needs.[4] Power control electronics ensure the EPS is operating optimally for the given condition.[5]

Previously covered in EA-204: The following topics were previously covered in EA-204 using the EPS power system board:

IV curve, glass/silicon efficiency, incidence angle, $1/r^2$ distance, thermoelectric generator



LABsat Power System: The LABsat EPS includes a "solar panel" (photovoltaic cell), a power bus with variable loads provided by a resistor box, and the telemetry system of the LABsat for recording data directly to file. This configuration can be used to measure the solar panel characteristics as well as the charge and discharge characteristics of the batteries and the performance of various types of power regulators. The laboratory examines four elements:

1. The temperature effects on solar panel voltage output.
2. Battery charge and discharge characteristics
3. The solar panel current-voltage (I-V) and power-voltage (P-V) characteristic curves.
4. The voltage regulator performance for series and shunt regulators.
5. Solar panel efficiency and shadow effects.

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[1] Larson, Wiley J., and Wertz, James R., *Space Mission Analysis and Design*, 3rd Edition, Microcosm Inc., 1999, p. 407
[2] Larson, Wiley J., and Wertz, James R., *Space Mission Analysis and Design*, 3rd Edition, Microcosm Inc., 1999, p. 407
[3] Agrawal, Brij N., *Design of Geosynchronous Spacecraft*, Prentice-Hall, 1986, p. 323
[4] Larson, Wiley J., and Wertz, James R., *Space Mission Analysis and Design*, 3rd Edition, Microcosm Inc., 1999, p. 423
[5] Agrawal, Brij N., *Design of Geosynchronous Spacecraft*, Prentice-Hall, 1986, pp. 359-360

Equipment:

1. LABsat with solar panel
2. LABsat telemetry system
3. Zener diode, series Regulator, and short regulator jumper (in envelope)
4. Decade resistor box and two clip-lead jumpers
5. Lamp with 200 W bulb
6. PCSAT style solar panel
7. Peltier junction thermoelectric generator, candles, thermometers, volt and amp meters.

Laboratory Procedure:

Form small groups. The procedures must be followed to obtain acceptable laboratory results. Immediately sketch the data plots (power and current on separate scales) to ensure its validity. Show sketches to the instructor before leaving class. All distances are from the glass surface of the light bulb to the solar panel; the filament is approximately 1" from the bulb's glass surface.

CAUTION

Do not leave the lamp on the solar cell for more than a few 10's of seconds or it will overheat and even shatter. High temperatures significantly degraded solar cell performance. Prevent the cell from overheating by blocking the light radiation between readings.

Part A. Battery Discharge :

This portion of the lab will be performed on your LABsat battery using the LABsat telemetry system. The purpose of this experiment is to record the discharge characteristic of the battery composed of multiple NiCd cells in series. You will use the LABsat momentum wheel as the electrical load for this experiment.

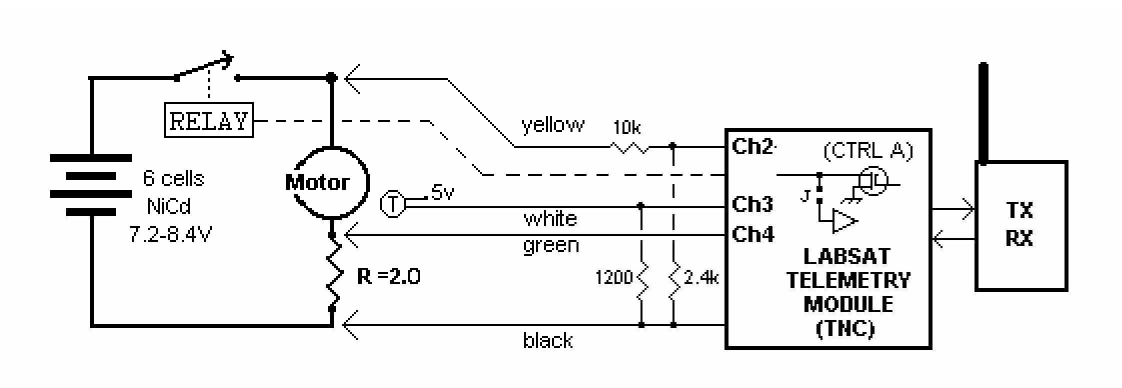


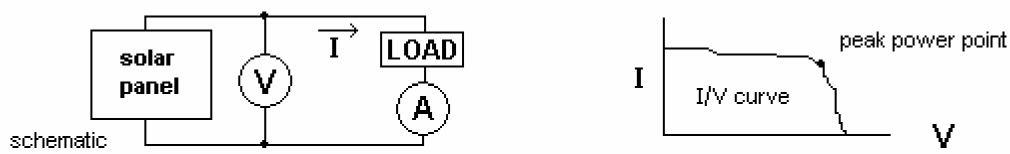
Figure 1. Battery Discharge Circuit

Lab Period:

Battery Discharge: The momentum wheel motor is connected to the 6 cell NiCd battery pack via a relay that can be commanded on or off by the LABsat telemetry and command system as shown above. The telemetry channel 2 (yellow) is connected to read the battery voltage, and channel 4 (green) is connected to read current (as the voltage drop across the 2.0 ohm resistor). The thermister (channel 3, white) is attached to the motor housing so we can see any temperature rise as the motor warms up. The LABsat will transmit the telemetry data every 10 seconds to the ground station for capture to file while the battery fully discharges.

Post-Lab: Using the telemetry file, plot the voltage, current and power versus time of the battery discharge. Discuss the curves. Did you notice any stair-step drops in the battery voltage as individual cells ran out? Estimate the area under the I (current) curve to give you the total milliamp-hours (mA-h) extracted from the battery.

Part B. Solar Panel I-V Characteristics:



Although we think of power sources as usually being of fixed voltage (12v, 115v, etc) on which we place a variety of loads to draw current, the voltage is not actually constant but is dependent on the load and a number of internal factors. The resulting changes in voltage that occur due to changing loads is usually described by an I-V curve. This experiment will derive the I-V curve for two of our solar panels.

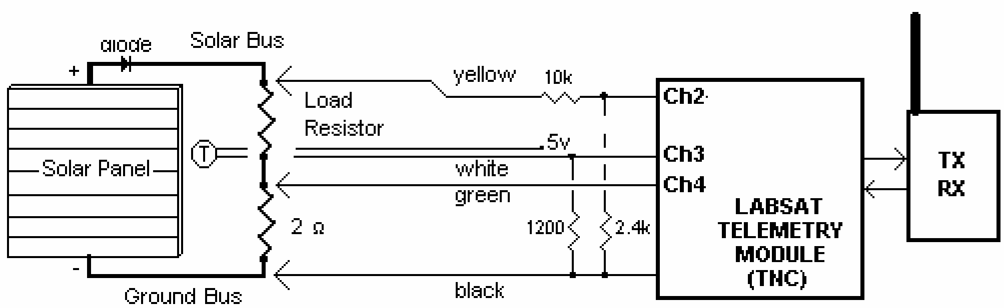


Figure 2. Solar Cell I-V Characteristic Circuit

Lab Period:

1. Using Hyperterm, begin a new telemetry capture file for this experiment.
2. Connect the load (resistor box) to the Solar Panel and 2 ohm shunt resistor as shown above. The voltage drop across this 2 ohm resistor allows us to read current on channel 4.
3. Tape the thermister to the middle of the solar panel
4. Place the light source 2” from the solar panel on the test power board.
5. Waiting at least 10 seconds for a data sample, set the resistor to each of these loads: 0, 20, 40, 60, 100, 120, 150, 200, 300, 500, 700, and 900 Ω.
6. Confirm that the channel 2 voltage and channel 4 current telemetry are changing.
7. Connect the PCsat panel over the glass one and repeat steps 2-6. Add 10 and 2000 Ω test points.

Post-Lab: Run the capture file through the data conversion program TLM2XLS.exe program to make the file directly readable by EXCEL and Plot current versus voltage, power vs voltage and identify the peak power point for each panel. Discuss the curves. Compute the efficiency of the solar panels at the peak power point.

Part C. Shadow Affects:

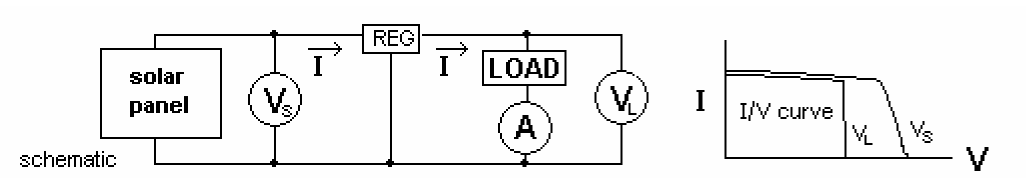
A single shadow only large enough to knock out a single cell is enough to reduce the panel output drastically. Even though the shadow may only cover a small percentage of the panel area (one cell), it can reduce the panel's power output by a significant factor. To achieve the maximum shadow effect the shadow must cross at least one cell in the string. Use the connections you still have from part B.

Lab Period:

1. Adjust the load to achieve approximately peak power from the PCSAT panel and note the telemetry voltage and current.
2. Place the "tape-measure" obstruction on the panel along the long axis of the cells so that it obstructs four cells fully. Wait 10 seconds and again observe and write down the telemetry.
3. Re-orient the obstruction so that is blocks most of the illumination for a column of cells (9 cells) and observe and write down the telemetry.
4. Re-orient the end of the tape measure so that it only blocks one cell and again observe and write down the telemetry.

Post-Lab: Discuss the worse case shadow orientation and importance of shadows in spacecraft design.

Part D. Series Regulation:



Electronics generally require fixed voltage supplies, while the solar array voltage output (I-V curve) varies according to the load it experiences. Power regulators ensure constant voltages for the electronics and also variable currents to charge the batteries based on their state. The series regulator provides a constant output voltage by dropping excess voltage across a series resistance as necessary. However, the series regulator's internal resistance consumes power proportional to the current. The series regulator's primary advantage is that it dissipates little power under small loads. Its disadvantage is the loss incurred under high loads. Figure 3 represents the series regulation circuit diagram.

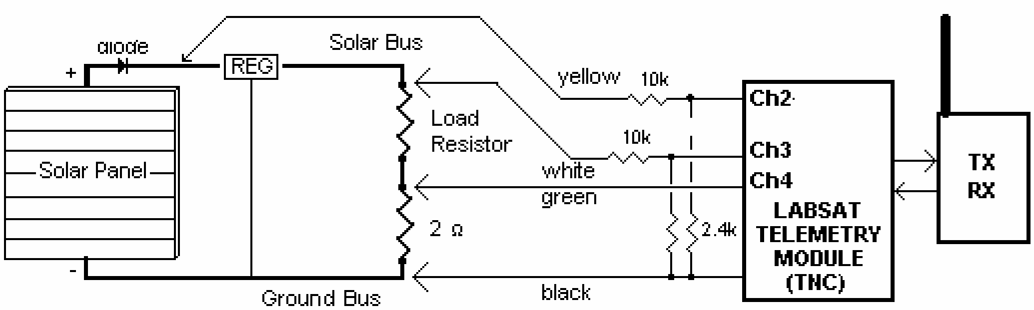


Figure 3. Series Regulation Circuit

Lab Period:

1. Connect the PCSAT solar panel to the LABsat telemetry system as shown above so that channel2 reads input voltage, channel 3 reads the regulator output voltage and channel 4 reads the load current.
2. Start a new Hyperterm capture file.
3. As before, vary the load resistance for: 0, 20, 40, 60, 100, 120, 150, 200, 300, 500, 700 and 900 Ω.
4. Be sure to get at least one 10 second telemetry value for each setting.

Post-Lab:

Run the capture file through TLM2XLS.exe program and then load into EXCEL. Generate a new column for input power (Vin x Iload) and load power (Vload x Iload). Plot the load voltage, load current, input power and load power against input voltage. Note the peak power point. 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 series regulator then at the load's peak power point compared to the original I-V solar panel's peak power point.

Part E. Shunt Regulation:

Shunt regulators limit voltage by dumping (shunting) excess current into a resistive load. A simple Shunt Regulator is easy to construct using a Zener diode. The zener diode I-V characteristic is shown in figure 4. In the forward direction, it passes current like any diode once its turn-on threshold is reached (usually about 0.6 volts). In the reverse direction, it passes almost no current (like an open circuit) below its "Zener" threshold. Once that Zener threshold is exceeded, it begins to conduct heavily. Thus a Zener diode makes an excellent low power shunt regulator. The zener diode conducts current at all voltages above its threshold, thus, limiting the load voltage to a constant value.

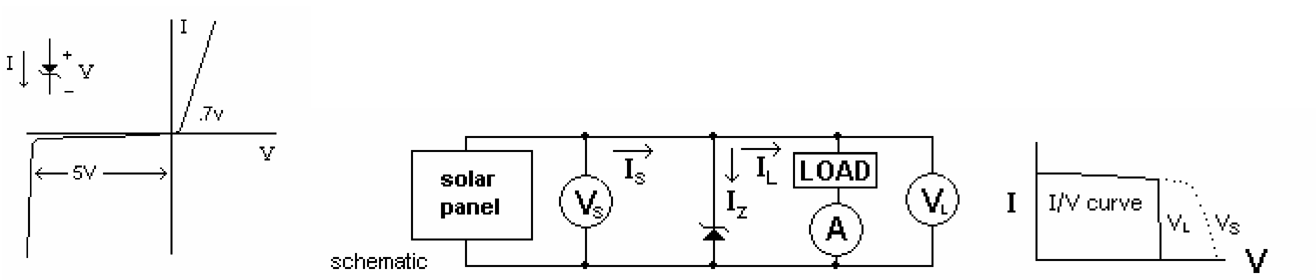


Figure 4. Zener Diode Performance

The primary advantage of a shunt regulator is that there is no series voltage drop necessary for it to provide its regulation function. Thus, it can provide regulation down to a lower input threshold than a similar series regulator. Its chief disadvantage is that at all power levels where it is conducting to provide regulation, it is dissipating power. The power dissipated by the shunt regulator takes the form of heat, which must be accounted for by the thermal control subsystem. Figure 5 shows a shunt regulation circuit.

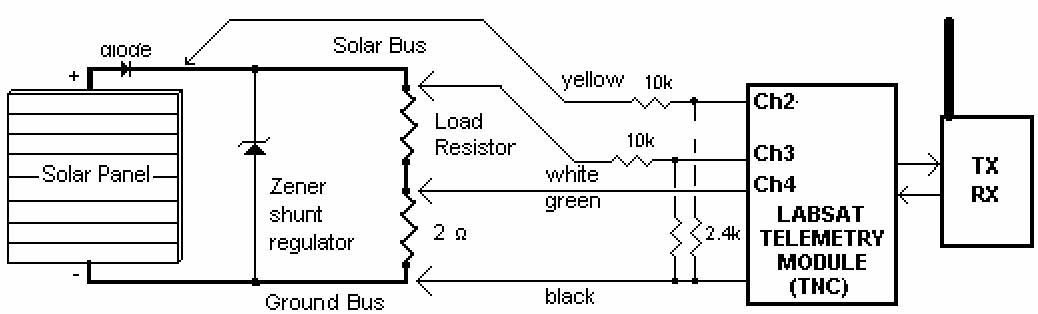


Figure 5. Shunt Regulation Circuit

Lab Period:

1. Connect the PCSAT panel and load resistor box to the LABsat power system as shown above.
2. Open a new capture file in Hyperterm and wait at least 10 seconds between each load adjustment
3. Set the load to resistances of: 0, 20, 40, 60, 100, 120, 150, 200, 300, 500, 700 and 900 Ω.
4. Be sure to get at least one 10 second telemetry value for each setting.

Post-Lab: Run the capture file through TLM2XLS.exe and then load into EXCEL. Generate a new column for input power (Vin x Iload) and load power (Vload x Iload). Plot the load voltage, load current, input power and load power as functions of input voltage. Note the peak power point. 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 series regulator then at the load's peak power point compared to the original I-V solar panel's peak power point.

Discuss ways of dealing with the heat from the zener regulator when it is dissipating excess current. Discuss the differences and why shunt regulators are not used in commercial electronics but are used in spacecraft. Discuss the impact of disconnecting the zener diode regulator.

Part F. Battery Charge Characteristics:

This procedure examines the solar array's capability to charge the 120 mA-h, "9 V" battery. The battery consists of a number of NiCd cells that require 1.4 V to charge and which discharge at 1.2 V per cell. For typical consumer applications NiCd's are charged at the 0.1C current rating (for 14 hours) to allow for 40% inefficiency in the charging process to yield a 10 hour at 0.1C capacity or 1C. Charging at higher rates can overheat, and/or destroy the battery.

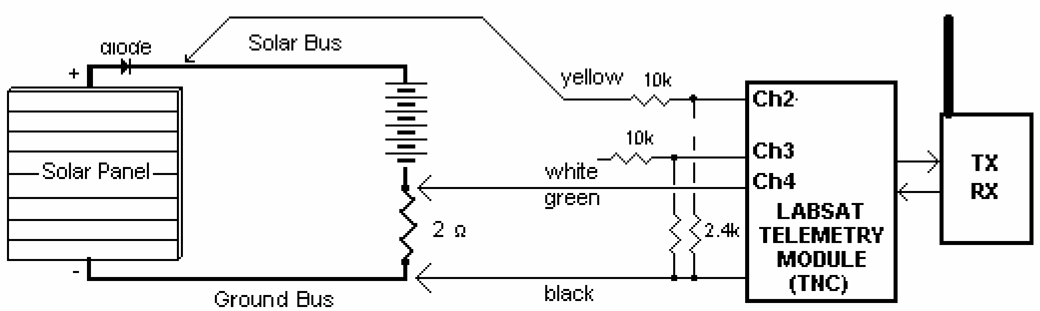


Figure 6. Battery Charge Current

Lab Period:

1. Insert the 6 cell NiCd battery in place of the load resistor box in the above diagram and connect the telemetry channels as shown.
2. Begin a new Hyperterm telemetry capture file.
3. Since we are charging at a 0.1C rate, it will take 10 hours to record this data, so the instructor will email you your file at the end of this period.
4. Note the battery capacity printed on the battery. All NiCd's will have the capacity noted on the cell.

Post-Lab: Run the data file through TLM2XLS.exe and load into Excel. Plot the cell voltage and charge current with time. See if your data detected the peak voltage rise at the point where the cells reached full charge.

<u>Laboratory Report:</u>

Prepare a laboratory report similar to what you have done on previous labs and the following guidelines.

- Use a standard report cover page.
- For each lab section, describe the laboratory's purpose, apparatus, procedures, results and conclusions.
- Include a block diagram. Discuss circuit elements relevant to the learning objectives and EPS design.
- Answer the "Post-Lab" questions. Compare measurements and theory/expectations.
- Include all figures, data tables, and graphs within the section where it applies.
- Summarize your conclusions and discuss how well the theory supports the observations.
- Make specific comments concerning knowledge gained, the knowledge's suitability for naval officers in space operations, and the laboratory's value as a learning tool. Recommend any improvements to the laboratory.

References:

1. Larson, W. J. and Wertz, J. R. *Space Mission Analysis and Design*, 3rd Ed., Microcosm Inc., 1999
2. Agrawal, Brij N., *Design of Geosynchronous Spacecraft*, Prentice-Hall, Inc., 1986
3. Bailey, S., Landis, G., Flood, D., *Photovoltaic Space Power: Status and Future*, AIAA 98-1053