XACT Rocket Low Voltage Power Supply

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July 30, 2010

Abstract

As part of the NASA-Olin Summer Research Program, our team developed a low voltage power supply design for an unregulated 28V supply to fit the electrical and mechanical requirements of the XACT rocket system. Subsets of our system include supporting circuitry to measure and output voltage, current, and temperature housekeeping readings from the power board and a graphical user interface through which users can set adjustable voltages. Our design implemented a 6-inch by 12-inch printed circuit board (PCB) that accounted for 15 DC-DC voltage converters, 6 adjustable voltages, and housekeeping subsystems for these components and the rocket battery. The adjustable voltages are controlled with a digital-analog converter that receives user-specified voltages using I²C communication. Four analog multiplexers read the housekeeping functions of the DC-DC converters, and operational amplifiers are used for the adjustable voltage setting. The housekeeping functions require supporting circuitry to attenuate values to a measurable value, with 2.2V corresponding to the expected values. Furthermore, a USB communication line was established using a programmable PIC 18F2455 microcontroller on a secondary PCB to connect the digital-analog converter and multiplexers with the graphical user interface.
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I. BACKGROUND

The NASA Goddard Space Flight Center is developing the X-Ray Advanced Concepts Testbed Project (XACT) as a means to provide cost-effective, low-resolution X-ray telescopes. The program utilizes low-cost, reusable rockets to conduct short scientific experiments in space. These research rockets, more commonly called sounding rockets, have several advantages over standard space satellites. Most notable are cost-effectiveness, low turnaround time, compact size, and the ability to achieve sub-orbital flight.

![XACT Sounding Rocket and Payload](image)

The XACT Sounding Rocket is one of the research rockets under development as part of the XACT Project. The Goddard Space Flight Center is in the initial phases of designing the payload for this rocket to perform astrophysics research.

The XACT rocket houses one battery that must power the various detectors as well as command and data handling units located in the payload. Because the multiple units require various amounts of power, our task is fundamental to the successful operation of the XACT rocket. Our mission was to design and build a prototype for a low voltage power supply that fits the electrical and mechanical requirements of the XACT rocket system. We also provide basic housekeeping readings (voltage, current, and temperature) displayed on a graphical user interface. The requirements for our system can be seen in the following section.

II. OUR SYSTEM

A. Specifications

Due to the fluctuating voltage of the rocket battery and physical contraints of the payload, there are multiple electrical and mechanical requirements for the low voltage power supply (LVPS) board design. This main circuit board is called the XACT Main Electronics Node (XMEN) power board, while our small housekeeping board is known as the XMEN data card.

B. Electrical Requirements

The XMEN power board provides secondary power to three polarimetry electronics boards (PEBs), three high voltage electron multipliers (HVEMs), three modulated X-ray source 10kV supplies, and the XMEN data card. The input voltage from the rocket battery is an unregulated 28V that ranges from 20V to 33V. The electrical specifications are summarized in the table below. The components used in the XMEN power board meet requirements for output voltage, output current, and ripple. Because we used DC-DC converters for their high efficiency, filling these requirements involved a rigorous parts search. Additionally, we designed for six adjustable voltages that the user can set from a graphical user interface connected to the circuitry via USB. These adjustable voltages range from 2.5V to 5V.
<table>
<thead>
<tr>
<th>Voltage</th>
<th>Ripple&amp; Noise</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+3.3 to digital</td>
<td>&lt;35mV p-p</td>
<td>500</td>
</tr>
<tr>
<td>+5.0 to digital</td>
<td>&lt;35mV p-p</td>
<td>500</td>
</tr>
<tr>
<td>+2.5-5.0 variable</td>
<td>&lt;35mV p-p</td>
<td>250</td>
</tr>
<tr>
<td>+6 to analog</td>
<td>&lt;100mV p-p</td>
<td>200</td>
</tr>
<tr>
<td>-6 to analog</td>
<td>&lt;100mV p-p</td>
<td>200</td>
</tr>
<tr>
<td>+12 to digital</td>
<td>&lt;100mV p-p</td>
<td>1000</td>
</tr>
</tbody>
</table>

Fig. 2. This chart displays the output voltages and associated electrical requirements from the power board.

C. Mechanical Requirements

The dimensions of the XACT payload define mechanical limitations for the XMEN power board. The payload has a diameter of .52m and a length of 3.26m. The space for the XMEN power board has dimensions of 6 inches x 12 inches with a 1.25 inch clearance above the board and .75 inches below for the components. We aimed to make our system easy to use, which required equipping the XMEN power board with appropriate connectors for everything it will power. In addition, the DC-DC converters we used get to high temperatures during operation, especially under load. Because their performance starts to degrade at 50°C, we designed the power board with copper pads to facilitate heat sinking the PCBs that comprise the underside of the converters. The metal casings of the converters can also be heat sunk to improve performance, though they don’t get as hot as the undersides of the converters.

D. Housekeeping Requirements

The housekeeping functions we provide include voltage, current, and temperature measurements for each converter. Each of these measurements is fed to a sixteen input analog multiplexer (MUX). Each housekeeping MUX is then read out using a separate 4-bit address supplied by the XMEN data card. Our version of the XMEN data card uses a PIC microcontroller to communicate with a computer via USB.

Additionally, each type of housekeeping function has individual specifications. The voltage measurements must be attenuated before being read into the housekeeping system such that the rated voltage is equal to 2.2V. For the current measurements, the voltages transferred to the housekeeping system must be linearly proportional to the currents. In this conversion ratio, 0V must correspond to 0A and the shut-off currents to 2.2V. For the temperature measurements 0V must correspond to approximately 0°C and 2.5V to 150°C.

III. System Diagram

Fig. 3. This is a diagram for the communication between the low voltage power supply board (XMEN power board) and the PIC microcontroller board (XMEN data card). HK stands for housekeeping, which includes voltage, current, and temperature readings.
IV. HARDWARE

Fig. 4. This image shows the second draft of the PCB layout for the low voltage power supply board.

A. Overview

For each voltage output from the low voltage power supply board, a DC-DC converter is accompanied by a voltage divider to attenuate the voltage reading to the MUX, a current sense amplifier to output a voltage proportional to current output to the MUX, and a temperature sensor that outputs a voltage proportional to temperature to the MUX. Because there are 14 measured voltage converters, 6 adjustable voltages, and the rocket battery, there are 21 of these subsystems. This repetition can be seen in the printed circuit board (PCB) design shown in Figure 4. The large rectangles near the edges of the board are DC-DC converters, and each converter has supporting housekeeping circuitry in its vicinity.

The four large dual-inline package (DIP) parts in the center of the board in Figure 4 are the analog multiplexers (MUXes) that read in all the housekeeping data: the voltages, current outputs, and temperatures of each voltage converter.

The clusters of small components directly below the MUXes form the adjustable voltage outputs. The digital-analog converter outputs the user-specified voltages, which go through operational amplifiers (op amp) buffers that are monitored for housekeeping. The connectors on the edges of the board link the voltage outputs from the power board to the parts of the payload that they power.

B. Design Decisions

The TDK-Lambda CC-E series DC-DC converters were selected because of their listed current ratings, output voltage ripples, isolated output lines, and metal casings. Op amps were chosen based on function and current rating; BUF634s were used to buffer the I²C-controlled DAC outputs for the six adjustable voltages and LT1097s were employed in the inversion and attenuation of the -6V converters’ outputs for the purpose of housekeeping.

In order to measure the outputs of the DC-DC converters and their current and temperature monitors, the output voltages were passed across voltage dividers. The resistances were chosen such that the output voltage of the divider would be 2.2V when the converters output the desired voltages. For the adjustable voltages, a voltage divider output of 2.2V corresponds to a set voltage of 5V. The resistances that make up these voltage dividers need to be relatively small so that the resistance of the PIC’s internal analog-digital converter does not put a measurable load on the XMEN power board circuitry. An op amp buffer would also prevent this impedance problem. Although sensor placements and tolerances vary, approximately 2.2V also corresponds to the maximum rated current and a temperature of approximately 134°C for the ADM4073 current monitors and AD22100 temperature sensors with a 1:2 voltage divider, respectively.

Reading in the output voltages of the -6V converters requires additional support circuitry. The three converters employ a shared 12V converter that powers one op amp per -6V supply. The virtual grounds of each of these op amps are held at the system’s overall ground, which is a voltage of +8V with respect to the dedicated 12V converter return line. This setup effectively powers the op amps with +4V and -8V rails and allows them to invert and attenuate the voltage from the -6V output to +2.2V with respect to system ground. Although each op amp uses its own zener diode to maintain the +4/-8 split of the 12V, these zeners are effectively in parallel when the entire system is in place and all grounds are connected.

V. SOFTWARE

A graphical user interface allows the user to set adjustable voltages at specified rates through a digital-analog converter and to read in voltages, currents, and temperatures via analog multiplexers. Communication with both the multiplexers and digital-analog converter occurs through a USB connection with a programmed PIC18F2455 microcontroller.
A. Graphical User Interface (GUI)

Written in PyQt, a subset of Python, the GUI allows users to set adjustable voltages by typing in a value and pressing the enter key. When the enter key is pressed, Python communicates with the PIC microcontroller to ramp the voltages at a user-specified rate from 0-1 V/s. The adjustable voltages increase by increments of 50 mV. Both adjustable voltage and ramp rate settings are saved from the last session and can be put into effect by pressing the enter key.

The other main functionality of the GUI is a table of housekeeping values, which reads in all relevant voltages, currents, and temperatures. The table can update several times a second (at a user-selectable rate determined in the code) and save the values to a text file.

![GUI screenshot](image)

**Fig. 5.** This is our final GUI, complete with adjustable voltages, ramping rates, housekeeping values, and details on our component labeling scheme.

B. Multiplexers (MUXes)

The multiplexing of the low voltage power supply’s housekeeping data is handled by four 16-input analog multiplexers (ADG406). The outputs from the voltage regulators, current sensors, and temperature sensors are fed into the multiplexers, which all share common address lines. In order to update the system’s housekeeping information, the PIC increments the multiplexers’ address lines and reads in their values sequentially to its onboard analog-digital converter. The PIC code maps these values to their respective variables, which the microcontroller passes to the host computer. Although the GUI requests housekeeping data converter by converter, the PIC updates all of its stored values every time a request is made in order to ensure that all of its local variables remain up to date.

C. Digital-Analog Converter (DAC)

In order to output user-specified variable voltages, I^2^C communication was used. I^2^C is a communication protocol that uses two pins, one for the clock and one for data, and a standardized protocol to transmit data between devices. Because spooling of commands is not supported, a procedure is used in which the device clears an interrupt, sends a byte, and waits for the interrupt to be set so that the process can begin again. The LTC2637 DAC requires a 3-byte sequence of information to change its output voltages. The first byte determines which of its 8 outputs will change and what command type is to follow. The last two bytes are a combination of a number corresponding to the voltage the DAC should output and a series of bits the DAC does not use. The DAC used in this system has ten-bit accuracy, so the first ten of the final sixteen bits are regulated and the last six are left blank. Figure 6 is a diagram of the byte transfer.
The \( \text{I}^2\text{C} \) protocol is a fairly simple procedure. When a start condition is initiated by the master, in this case the PIC microcontroller, the software clears the SSPIF (an interrupt flag). Then the master sends an address out corresponding to the slave it wants to answer, in this case the DAC. The slave responds with an Acknowledge (Ack) bit and the SSPIF is set. The software waits for the SSPIF to be set, then clears it and sends the first byte of information. The slave receives and sends another Ack bit, the SSPIF is set, and the cycle occurs once more for the final byte. The final step is a stop condition sent by the master. A visual representation of this is shown in Figure 7.

VI. DISCUSSION

Our version of the XMEN data card can be used to test any revision of the XMEN power board as long as the files listed in Appendix A are downloaded and the analog MUXes are connected to converters as detailed in the MUXpinouts.xlsx file on the LVPS website. Simple changes that can be made to the Python code to increase usability can be found in Appendix B.

The schematic on the LVPS website has been tested as a system, albeit with some converters missing. The main uncertainties lie in current measurement for the rocket battery and -6V converters. For the rocket battery, we suggest replacing the ADM4073 with an LTC6102 current sense amplifier for its wide supply range, though we did not have a chance to test it. We conjecture that current-draw housekeeping information could be measured on the -6V converters either with a current sense resistor and rail-to-rail instrumentation amplifier or with low-side current sensor integrated circuit (IC).

Care should be taken to ensure that voltages from the DC-DC converters are not floating when the power is turned on as floating voltages may cause damage to the electronic components on the LVPS board. This may have been the problem that burnt out many of the DC-DC converters on our first draft of the XMEN power board. A common board logic, analog, battery,
and chassis ground would help mitigate the risk of such damages, but has the possibility of creating grounding loops within the system.

It should be noted that the latest schematic has all of the -6V converters using one 12V regulator and one set of zener diode circuitry for housekeeping, a feature which connects all of the -6V return lines. This decision was made not only to reduce the chip count (isolation would have forced each converter to use its own 12V regulator and zener circuitry), but also to ensure that small differences in the clamping voltages of the different zeners did not fight to establish where the zeners’ cathodes rest with respect to ground. If it is decided that board space is not a problem, then we suggest that each -6V converter be paired with its own 12V source and zener circuitry.

More important than the details surrounding the monitoring of the converters is the nature of the converters themselves. Although the datasheets suggest that the TDK-Lambda parts we used would meet the minimum electrical requirements of the LVPS, it was discovered in practice that this was not the case.

Most if not all converters exhibited a large amount of high frequency noise that was difficult if not impossible to eliminate with capacitors and inductors. This noise was periodic, proportional to the voltage, and appeared to coincide with the switching frequency of the converters; for example, the ripple on the 12V converters took the form of underdamped oscillations with an amplitude of 400mV and recurred at a frequency of roughly 50MHz. Although our parts search was exhaustive, we believe that it may be wise to investigate using different converters. Better converters than the ones we bought will probably need to be specially ordered and may have weeks of lead time.

In addition to rippling, many of the converters reached high temperatures at an alarming rate. This was especially true of the 5V converters that were used as 6V and -6V supplies. Although the output of the converters was adjustable and raising the output of the 5V converters to 6V was within the ratings listed on the datasheet, it was found that converters that had been “trimmed” heated much faster than their counterparts in standard configurations. While much of the heat could probably be transported away from the converters by proper heat sinking, we believe that it might be more efficient to find (or perhaps specially order) dedicated, isolated 6V converters with high current capacity.

VII. Appendices

A. Appendix A: System Manual

In the documentation section of the LVPS website, available at nasa.olin.edu, the Python file for the graphical user interface is called LVPSGUIWindows.py for Windows and LVPSGUIMac.py for Macintosh. Download the version that corresponds to your operating system as well as the file SavedAdjustableVoltages.txt, and save them in the same folder on your computer. The USB driver file for Windows is called libusb0.dll for Windows and usb.bundle for Macintosh. Windows will also require the inf file located on the website. These are the files needed to run the graphical user interface (GUI) that monitors housekeeping and sets adjustable voltages on the low voltage power supply board. After following the instructions in this section and plugging in the Olin XMEN data card (PIC board), the GUI should be functional.

1) Installing a USB driver:
   a) To install a USB driver for a Windows computer, follow these instructions:
      • Download the libusb-win32 device driver at Source Forge or a similar site.
      • Place the inf file and USB file from the website in the bin folder of the download.
      • Using a USB cable, plug the PIC board into your computer. A new hardware wizard should pop up. Select the option “No, not this time” in the first panel, and check the option that allows you to browse for a driver on the second panel. Browse for the bin folder in the libusb folder. If the wizard warns you that the driver is not digitally signed, proceed with the installation. Once this driver is linked to the PIC board, the GUI should be functional.
   b) To install a USB driver for a Mac computer, follow these instructions:
      • Go to Softpedia or run a search of “download libusb mac” to find a similar site.
      • If you use Softpedia, click the link to External Mirror 1, and the download should begin.
      • Double click the tar file that shows up when you save the download and the files will be unarchived into a new folder.
      • Navigate to the folder in the command line.
      • Run these three commands: “./configure”; “make”; “make install”. These three commands are also documented in the INSTALL plain text file in the libusb folder from the tar file. If “make install” does not work you may need to run “sudo make install” and type in the password for the root user.
      • The commands “make clean” and “make distclean” will remove the unnecessary files created during the install process. These commands along with others are also documented in the INSTALL text file.

This section of the manual was written by the Olin MXS team.

2) Installing Python and PyQt:
   a) In order to use the GUI with a Windows computer, you will need the following:
      • Python version 2.6 If you have a more recent version of Python on your computer, make sure that you run the GUI in version 2.6.
      • PyQt4
b) In order to use the graphical user interface (GUI) with a Mac computer, you will need the following:

- **Python version 2.6** If you have a more recent version of Python on your computer, make sure that you run the GUI in version 2.6. If you already have Python 2.5 or 2.6 (OSX often comes with it), you don’t need to install Python again. Our code works with both versions 2.5 and 2.6.
- Download [Xcode](https://developer.apple.com/xcode/) from Apple
- Download QT for C++ development on Mac (Cocoa package)
- Download SIP source
- Install SIP source by extracting, and running: “python configure.py”, “make”, “sudo make install”
- Download PyQt4 Mac source
- Install PyQt4 by extracting, and running: “python configure.py”, “make”, “sudo make install”

After installation of Python, PyQt, and the usb driver, the GUI should run on your computer. If you’re having trouble, make sure that the versions of PyQt4 and Python match. If you have multiple versions of Python on your machine, you may need to run the program from the command line with the version of python you want before the name (e.g. “python2.5 LVPSGUIMac.py”).

B. Appendix B: Complete Code

Complete, well-commented Python code for the graphical user interface and communication with the PIC C can be found in the file called LVPSGUIWindows.py and LVPSGUIMac.py, which are the same except for a few lines of code (regarding which driver to use and the window size). Complete, commented PIC C code can be found in the file LVPSPIC.c. If any PIC code is ambiguous, we recommend reading over the PIC18F2455 datasheet.

There are certain adjustments that can be made when using the GUI. Simply open the script in Idle to edit it and at the top is a section called “Values that can be user adjusted.” UpdatesPerSec is exactly what the name suggests, however a really high number may impair other functionality in the GUI. The system should work fine up to at least 100 updates per second.

The other user adjustable values are calibration parameters that were implemented to make the GUI display the actual voltages on the board. VxCalibrate is the calibration parameter corresponding to the converter of output x volts (3 means 3.3), and the equation is: actual measured voltage over uncalibrated GUI displayed voltage. If no calibration is necessary simply make this number 1. The AdjCalibrate is in place to offset the +.05V the adjustable outputs were giving. This is a guess and check scenario, though approximately 8 corresponds to .05V. If the output is higher than the set value, increase the drop, and if the actual voltage is less than the desired voltage decrease the drop. Be aware that decreasing the drop (i.e. making AdjCalibrate > 0) may give unexpected voltages at or around 5V since this may increase the number sent to the DAC above 1023, which is the maximum number the DAC understands. If no calibration is necessary, make this number 0.

VIII. ACKNOWLEDGEMENTS

Many thanks to Olin College professors Steve Holt, Brad Minch, and Gill Pratt for their help throughout this project, as well as our Goddard Space Flight Center sponsors Keith Gendreau, Fred Huegel, and Bob Baker.