Power Analysis System Test Apparatus

(PASTA)

with

Student Application Ubiquitous Control Environment

(SAUCE)

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Version History

Date	Description
03/07/2022	Original Release
04/26/2022	Updated Release
05/02/2022	Final Release

Document Purpose

This document describes the functional requirements for Rowan University's Electrical and Computer Engineering Department's Power Analysis System Test Apparatus (PASTA). The apparatus is home-made as opposed to an off-the-shelf boxed version. We strived for the highest-quality and functionality not found in COTS (Commercial Off The Shelf) units. The apparatus was designed to provide students with a platform to test their power supplies and battery chargers, their final projects for Electronic. The system provides students with the appropriate conditions to test whether their power supply follows the technical specifications provided by the customer. The tests are conducted with the Student Application Ubiquitous Control Environment (SAUCE), which is also homemade. The SAUCE is the application running on an embedded processor (Microchip microcontroller) which sits on top of the PASTA.

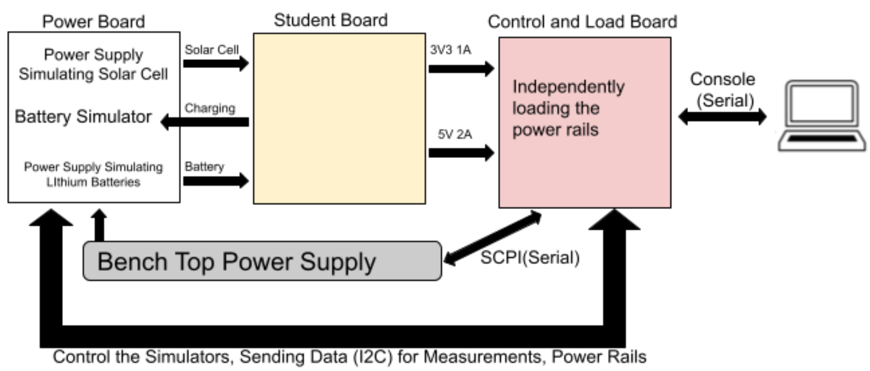
Glossary

SCPI - (Standard Commands for Programmable Instruments) a standard for syntax and commands to use in controlling programmable test and measurement devices, in this case a external power supply

Initial Apparatus Proposal

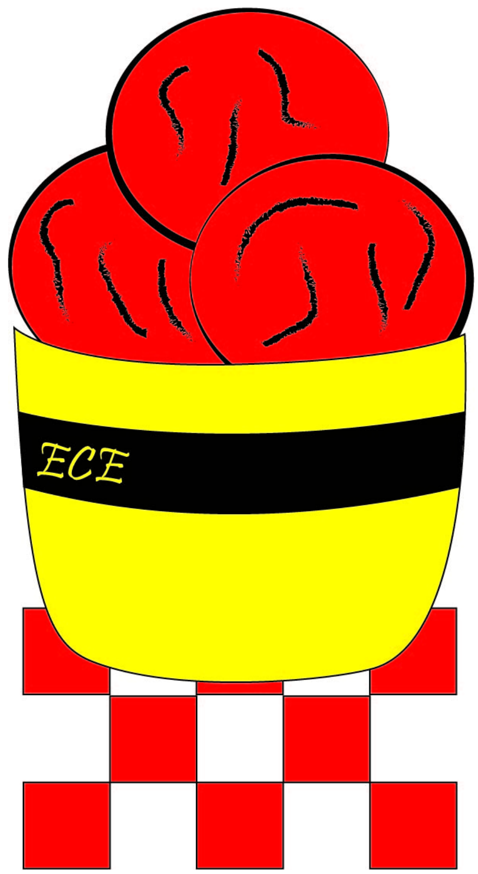
Below is the one-page, high-level system originally proposed. The apparatus will contain two boards, the power board and the control/load board. This apparatus will be used to test the student designed board which has a charging circuit for Lithium Ion batteries and produces 2 power rails, 5V current limited at 2A and 3V3 current limited at 1A. The power board will monitor the charging circuit output from the student board and supply power for the solar cell and battery. The solar cell will be simulated for 8.92V at 165.3 mA for the charging circuit. Students will not put any connectors for batteries or solar cells outside of the ones designated in the schematic and PCB layout provided.

The control/load board will send SCPI to the bench top power supply (HP E3632A) to simulate being either the Solar Cell or batteries. The control/load board is powered independently from the power supply and controlled over serial communication from a faculty laptop. The control/load board also controls the resistive load which can also be configured independently for each of the power rails.



Artistic Proposal

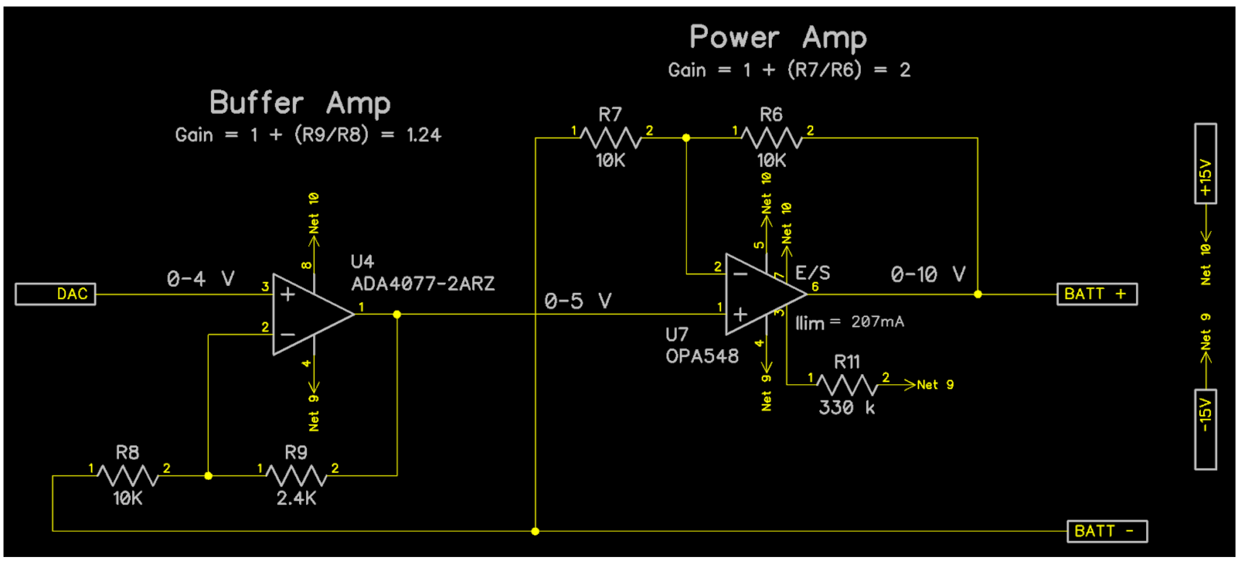
Below is the initial artistic proposal for how the boards would be connected to look like a bowl of pasta on a table. The red and white checkerboard is the power board which will be a red solder mask with white silk screen. The middle bowl is the students power supply which has a yellow solder mask with a white silk screen which will connect to the power board. The student designed power supply then connects to the spaghetti and meatballs which is the control/load board. The power board and control/load board will before be underneath the student designed power supply and have the female connectors but the student designed power supply will have the male connectors.



Circuit Descriptions

Battery Simulator

Below is the battery simulator circuit diagram that will be used in stress testing the student designed charging circuits. The Lithium Ion batteries that would normally be used in conjunction with the charging and power supply circuits can take multiple hours to fully charge and discharge. This circuit is designed to simulate the entire voltage range of the charging process within seconds, greatly decreasing the required testing time for each charging circuit. The charging process of a Li+ battery involves a constant current phase from the minimum discharge voltage of ~2.75V up to 4.2V (per cell, we are using 2 cells in series, so the voltage will range from ~5.5 V to 8.4 V), at which the battery charger switches to a constant voltage mode.



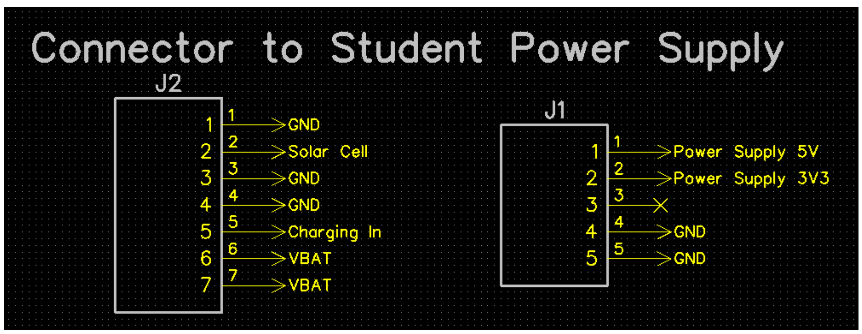
For more information on how some of the values were calculated see the equations below:
Current Limiting Resistor R11 was calculated using the equation below from the datasheet

$$I_{LIM} = (15000)(4.75) / (13750\ \Omega + R_{CL})$$

Rcl = R11 = 330 kΩ
Ilim = (15000)(4.75)/(13750 + 330000) = 207 mA

Student Board Connections

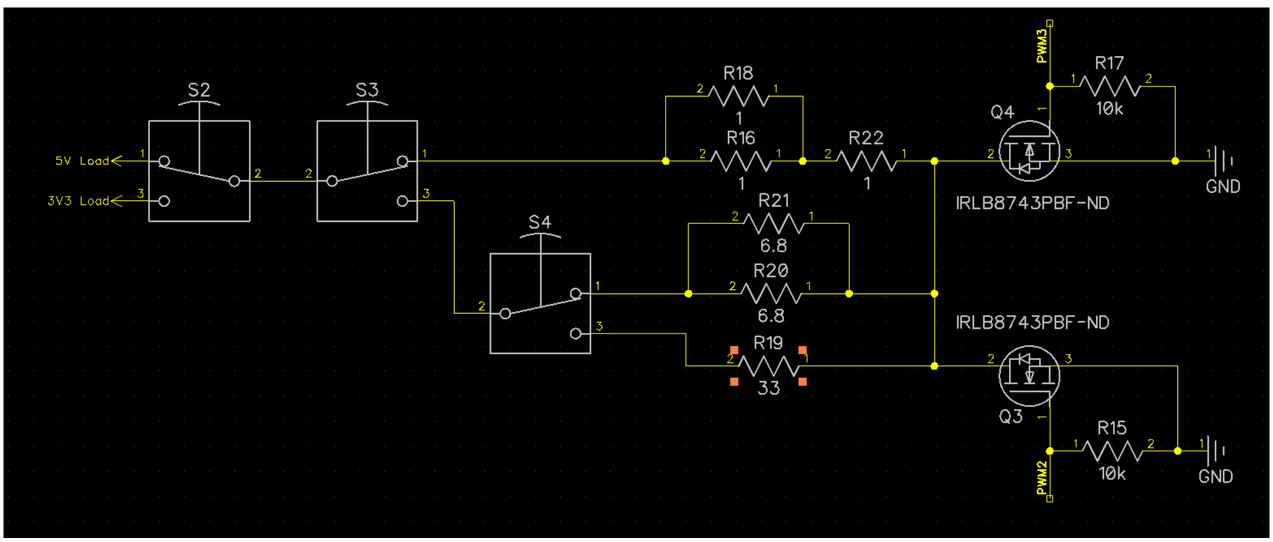
Below is the circuitry that was given to the students for their Power Supply. The students put the male end of the Molex Connector into their board and the female end goes into the power board or the control/load board. The female and male connectors are rated for the same voltage but the female connector is only rated for 5A per pin and since VBAT may be up to 6A these pins we doubled up. J2 plugs into the Power Board, GND is ground, Solar Cell is connected to the a power supply which simulate the solar cell, the Charging In and VBAT are disconnected because in order to monitor and analysis the current going into the battery we need to break the circuit and then VBAT is the the simulated 2 cell Lithium Ion Battery which is also utilizing a power supply. J1 is plugged into the Main, Power Supply 5V and Power Supply 3V3 are the two power rails that the students are expected to make.



Resistive Loads

Below is the circuit diagram for the resistive loads for each of the power rails. The loads will be controlled by the IRLB8743PbF MOSFET which is controlled by the microcontroller. The next are labeled as PWM2 and PWM3 which is not PWM control because of changes in the circuitry on April 28th. This MOSFET was chosen because of its low Rds of 3.2 mΩ. These mosfets are not heat sinked because of this low Rds.

S2 is the switch that is used to select whether the 5V or 3V3 power is connected to a load. S3 and S4 control what resistor network it is connected to. The S3 switch controls whether or not the power rail chosen is connected to the high current. If high current testing is not connected to the loads then the users can decide whether or not the load is for medium current testing or high current testing. To start, none of these loads are electronically connected to ground so the switch is something to prepare the circuit for testing.



For the different resistor networks they are classified into low current test, medium current test, and high current test. The math for the equivalent resistance equations are below:

High Current Resistor Network:

$$R_{equivalent} = (1^{-1} + 1^{-1})^{-1} + 1 = 1.5\Omega$$

Medium Current Resistor Network:

$$R_{equivalent} = (6.8^{-1} + 6.8^{-1})^{-1} = 3.4\Omega$$

Low Current Resistor Network:

$$R_{equivalent} = 33\ \Omega$$

Below I have the math for the specific current outputs from the power rails that I expect. They are broken up into the outputs I expect from the 5V rail and the 3V3 rail. These calculations are based on ohm's law, V = IR.

5V Rail:

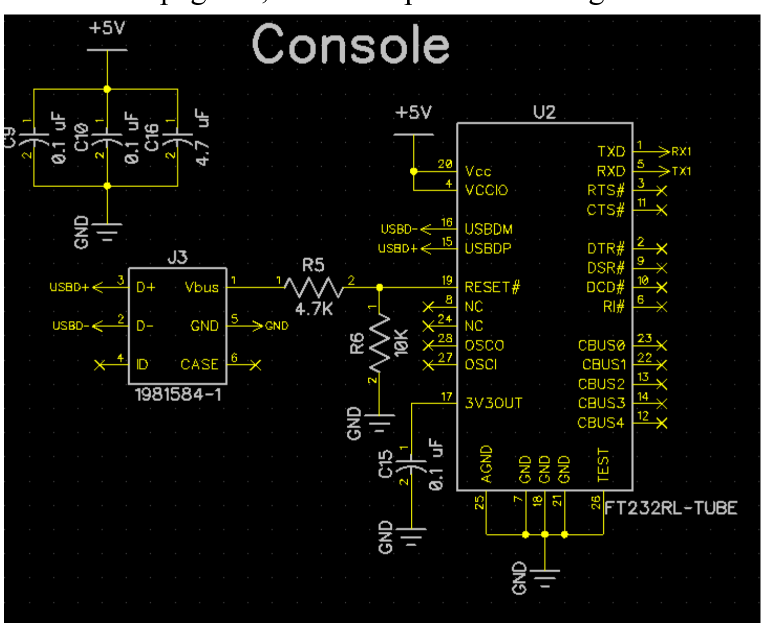
$$5V\ /\ 33\Omega\ = 0.16A$$
$$5V\ /\ 3.4\Omega\ = 1.47A$$
$$5V\ /\ 1.5\Omega\ = 3.33A$$

3V3 Rail:

$$3.3V\ /\ 33\Omega\ = 0.1A$$
$$3.3V\ /\ 3.4\Omega\ = 0.97A$$
$$3.3V\ /\ 1.5\Omega\ = 2.2A$$

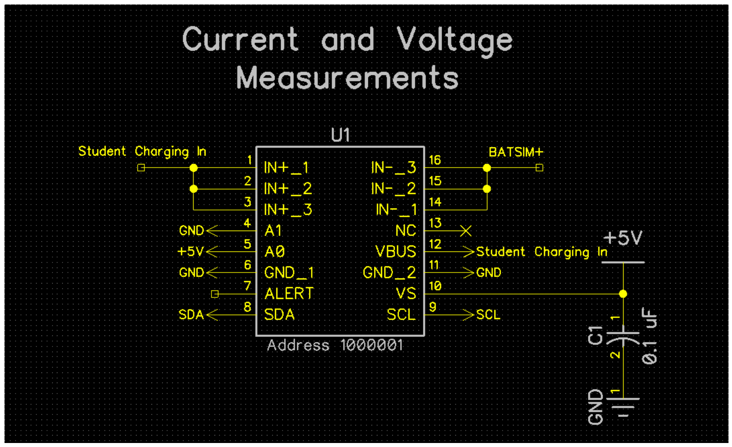
Console

The console serves as the serial user interface allowing the user to gather data and test their board. Below is the circuitry required to take a USB from a laptop to the Serial port on the microcontroller. The user plugs a micro usb into the board, and the data is sorted to go to UART1 through the FTDI Chip FT23RL. The values for some of the resistors (R5, R6) were chosen from the FT23RL datasheet on page 24, titled self powered configuration.

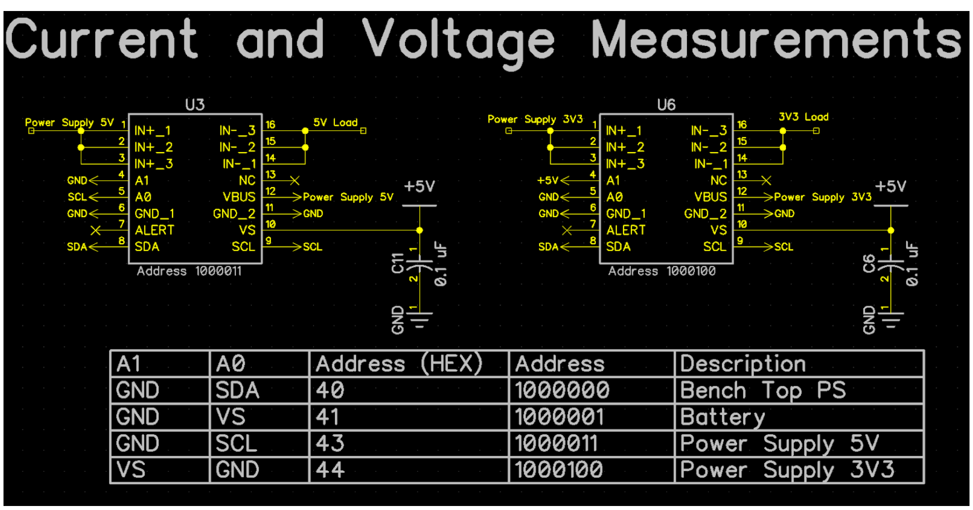


Power Analysis

Voltage and Current is measured at the source for the solar cell and battery which is the the power supply but the voltage and current in other places are measured with the INA260AIPW which uses a precision ADC conversion to spit out the voltage in volts and current in amps over I2C. Below are the circuit diagrams for each other and their addresses. The chip measuring the voltage and current going into the battery sink simulator is located on the power board and the address is 1000001.



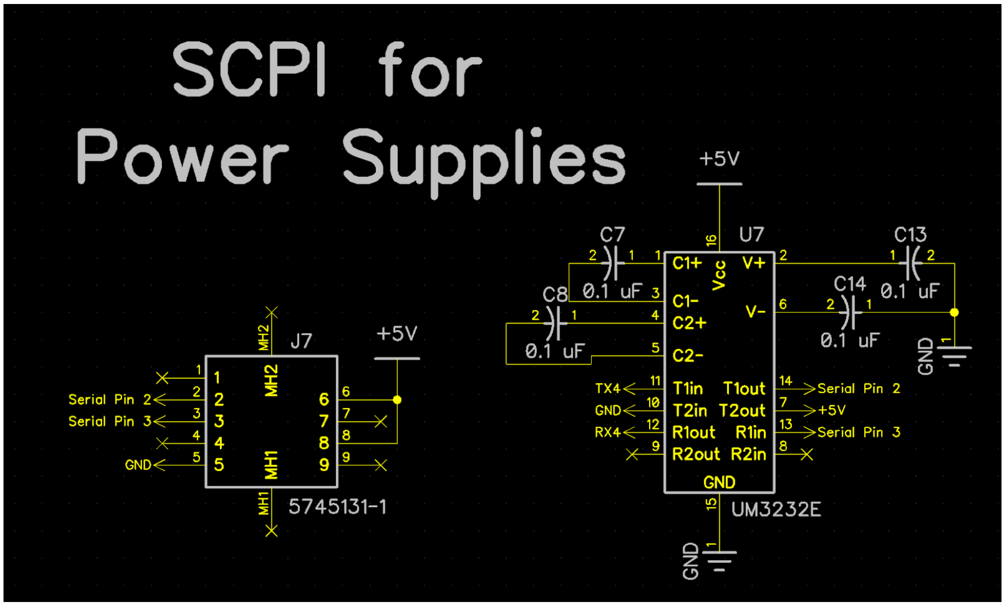
The current and voltage measurements going from the students power supply to the resistive load are measured on the control/load board. The address for the chips measuring values for the 5V rail is 1000011 and the 3V3 rail 1000100.



A1	A0	Address (HEX)	Address	Description
GND	SDA	40	1000000	Bench Top PS
GND	VS	41	1000001	Battery
GND	SCL	43	1000011	Power Supply 5V
VS	GND	44	1000100	Power Supply 3V3

Serial for SCPI

To simulate the battery and the solar cells an external power supply will be used and controlled with SCPI. SCPI is sent over serial from the microcontroller to the UM3232E chip which handles sending and receiving for the data from the serial port complying with the EIA/TIA-232 standard. Below is the circuitry required to do that and from the microcontroller via TX4 and RX4.



In datasheets for the E3632A the SCPI is formatted in ways at a high level to show what the command does. For SCPI found in data sheets the capitalized letters are the ascii characters that are sent to the power supply and anything enclosed in square brackets ([]) is optional. A colon (:) separates a command keyword from a lower-level keyword like output on or off which is sent to the power supply. Braces ({}) enclose the parameter choices for a given command string like setting the current. The braces are not sent with the command string. A vertical bar (|) separates multiple parameter choices for a given command string like off and on.

The SCPI I am using are listed below:

SYSTem
    :LOCal
    :REMote
OUTPut
    [:STATe] {OFF|ON}
[SOURce:]
    CURRent[:LEVel][:IMMediate][:AMPLitude]{<current>|MIN|MAX|UP|DOWN}
    VOLTage[:LEVel][:IMMediate][:AMPLitude]{<voltage>|MIN|MAX|UP|DOWN}

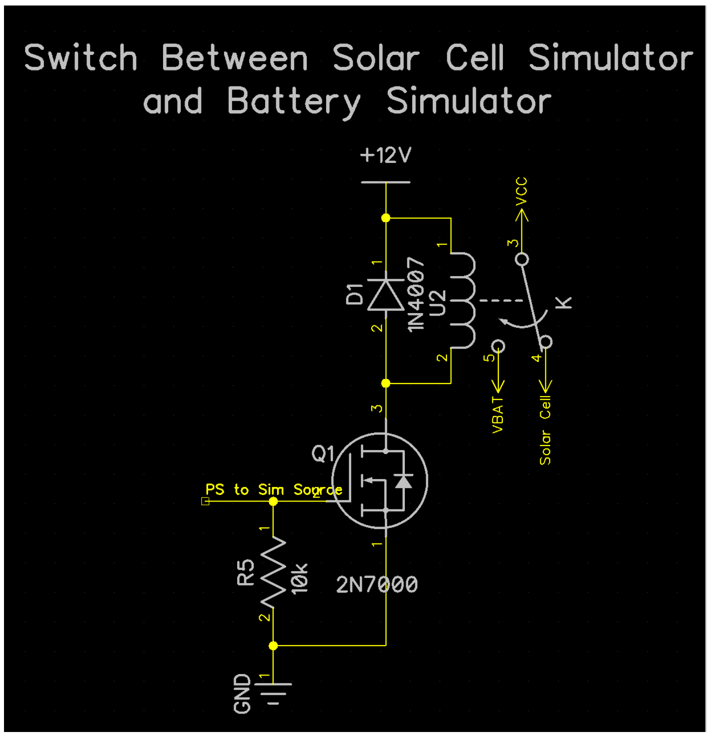
System local and remote are used for RS-232 protocol to allow the power supply to be controlled. You must send a remote command which disables the front panel of the power supply and to enable the front panel of the power supply you sent it in local control. Output is turned on and off with OUTP: ON and OUTP: OFF.

Figure 2-3 RS-232 data frame format

The figure above is a useful diagram for the data frame format I used for RS-232. Each ascii chart is transmitted one at a time over UART 4. The UM3232E handles the RS-232 protocol.

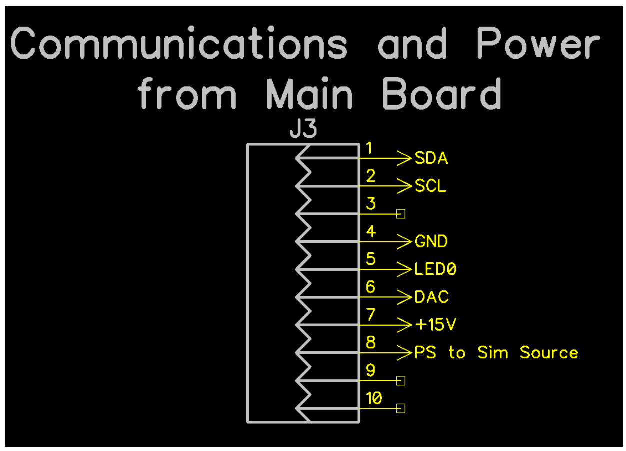
Power Supply to Solar Cell or Battery Voltage

Since the power supply only has one channel it needs to be able to switch between simulating the battery source or the solar cell. The battery source will be variable time, voltage, and current depending on the specifications from the console. The solar cell simulator (external power supply) will output 8.92V at 165.3 mA. Below is the circuit located on the power board to connect VCC (External Power Supply Voltage) to either VBAT (Simulated Battery Voltage) and Solar Cell (Simulated Solar Cell). VBAT and Solar cell connect directly to the student board. PS to Sim Source is driven from the microcontroller. D1 is a 1N4007 flyback used to suppress sudden voltage spikes across a relay when its supply current is suddenly reduced or interrupted.



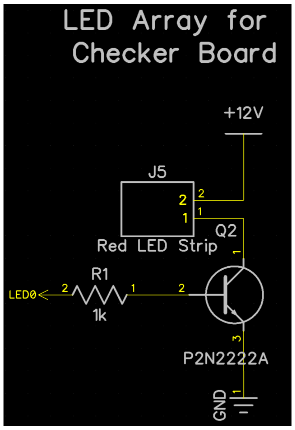
Connector Between Power Board and Control/Load Board

The Power Board for the apparatus will get power from an external power supply. There will be a ribbon cable that will go between the Power boards for communication and power to the Control/Load Board. SDA and SCL are for the data and clock for I2C. +15V is the main power for the Control/Load Board and is stepped down to +12V and +5V for the power on that board. LED0 is for the array of decorative red LEDs which will be controlled by the microcontroller. Reset is for the reset from the microcontroller to the battery simulator. PS to Sim Source controls whether the external power supply is connected to the solar cell or the battery simulator. The connector below is located on both the power board and the control/load board. DAC is the digital to analog converter outputs of the microcontroller and is used to set the battery source/sink circuitry to be 0V to 12.5V.



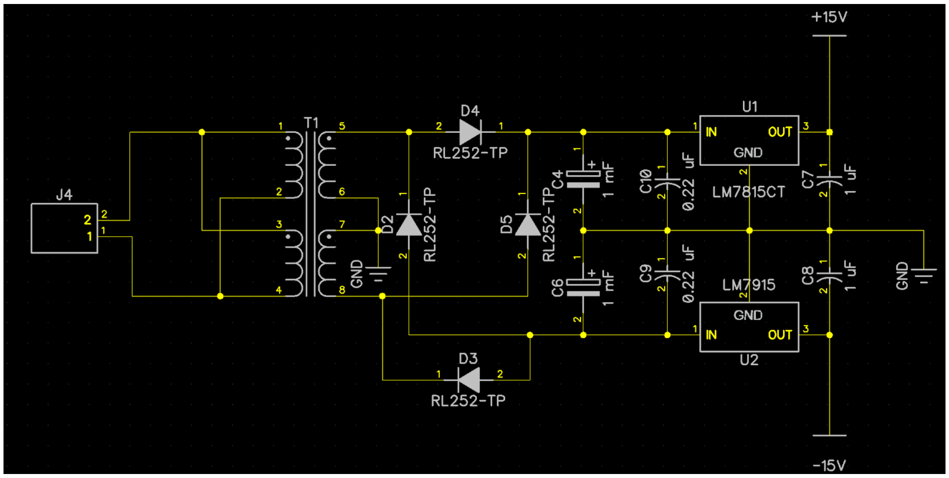
Decorative LEDs

Below is the circuit diagram for the 12V red LED strip that will be located around the acrylic for the Power Board. These are decorative, designed to be embedded into acrylic to give the appearance of a checkerboard table cloth. Q2 is a P2N2222A and used to either complete the circuit for the LED strip or cut it to turn it off. This LED strip is controlled by the microcontroller.



Power Supply

Below is the circuit diagram for the AC to DC power supply that was designed for this apparatus. The input is 120VAC and the output is +/- 15VDC. The power supply was designed because the operational amplifiers on the board require +/-15VDC for their power rails and the +15V is stepped down to +12V for the LED strip and the OLED display, and relay. That +12V is then taken down to +5V for a large portion of the power on the board. The final power rail is +2.85 V for the logic on the OLED display. Below is the schematic for the AC to DC power supply. Missing from this schematic are the 500mA fuses on the case of the apparatus and on/off switches.



Serial Interfaces – Console

The PASTA uses one serial link to communicate with the faculty computers. It utilizes a TTL to USB serial translation interface based on the FTDI FT232RL USB to serial IC, Windows recognizes this USB device and will install the necessary drivers automatically.

The links are configured as follows:

- Connector: micro-USB
- COM port settings:
    - Baud: 19200
    - Data bits: 8
    - Parity: None
    - Stop bits: 1
    - Flow control: None
- ACK/NAK: None
- All bytes are printable ASCII characters, case insensitive
- There is no end of packet terminator

Console

The Console link provides the system administrator (faculty) with the ability to control and set system operations via a terminal emulator program such as puTTY. The interface is a simple text-based menu system.

Console Interface

There is an administrative console to provide system level control, typically used by the authors for diagnostic purposes, or by the faculty to set testing parameters. The console is accessed by connecting the "Console" cable to a computer USB port and launching a terminal emulation program (e.g. puTTY) as mentioned in the section on Serial Interfaces. A screenshot of the current menu is below:

```
SAUCE Menu

           Time since last reset dd:hh:mm:ss = 00:00:00:00

           Relay Switching
        F: Set Power Rail ON. Set Charging Circuit OFF.
        N: Set Power Rail OFF. Set Charging Circuit ON.

           LED Control
        M: LED ON
        P: LED OFF

           Battery Simulator
        D: Set DAC. Current DAC Value: 170 Voltage: 8.353333
        O: Calibration: DAC @255 = 12.530000 V

           SCPI
        E: Set Voltage to #.##V
        C: Set Voltage to 4.56V
        G: Set the Current Limit to #.##A
        L: Power Supply Front Panel is fully functional
        R: Power Supply Front Panel is disabled

          CURRENT AND VOLTAGE MEASUREMENTS
        W: Display Data at Location

         CHARGING CIRCUIT TESTING
        X: Charging Circuit Testing
        A: Test Charging Circuit Below 5.5V
        Y: Test Charging Circuit Above 8.4V

         POWER RAIL TESTING
        H: Power Rail Testing (Battery = 8.4V)
        B: Power Rail Testing (8.4V >= Battery >= 5.5V)
        I: Power Rail LONG DURATION TESTING (Battery = 8.4V)

        Z: RESET SCA

Enter a menu choice:
```

There are two commands controlling the relay. This relay controls whether the output of the E3632A Benchtop Power Supply is connected to the solar cell simulation source or the battery simulated source

F = set Power Rail on. Set the Charging Circuit off.

N =set Power Rail off. Set the Charging Circuit on.

The LED control section selects LEDs to be on or off

M = turns the LEDs on

P = turns the LEDs off

The battery simulator section corresponds to the power amplifier that is used as a substitute for batteries while charging.

D = manually sets the DAC to be from 000 to 255 which roughly corresponds to 0V-12.5V on the output of the power amplifier

O = calibration setting to see what the voltage on the output of the power amplifier is when the DAC is set to 255. This value is stored non-volatile so the value is not lost when powered off and on.

The SCPI section are parameters and values you can set on the benchtop power supply.

E = sets the voltage on the power supply form some value entered by the user from 0.00V to 9.99V

C = sets the voltage on the power supply to 4.56V

G = sets the current limit on the power supply form some value entered by the user from 0.00A to 7.00A

L = command is the equivalent of pressing local on the power supply, during the remote interface for SCPI over RS-232 the power supply must be in remote operating mode

R = opposite of ‘L’, put the power supply into the remote interface for SCPI over RS-232

The Current and Voltage Measurements section selects the I2C address for the INA chip you wish to measure

W = displays the data in the voltage, current, and power register of the INA chip you wish to measure

The charging circuit testing routines are set to test the charging circuit portion of the student designed power supply. For all of these commands the solar cells (benchtop power supply) is set to 8.92V at 165.3mA. Voltage and current are measured on the input and output of the charging circuit and displayed for all of the commands below.

X = test the charging circuit, battery source goes from 5.5V to 8.4V

A = test the charging circuit as if the batteries 5.5V to 0V

Y = test charging circuit as if the batteries were over 8.4V

The power rail testing routines are set to test the two power rails separately of the student designed power supply. This combines many of the commands and configuration from the previous section but erases values that were previously set. Voltage and current are measured on the input and output of the charging circuit and displayed for all of the commands below. All the commands below ask the user which power rail to test before proceeding with the test routine.

H = measures constant voltage once and then constant current once, battery source set to 8.4V

B = measures constant voltage and then constant current once, battery source sweeps from 5.5V to 8.4V in 0.1V increments

I = power rail shown is loaded on constantly for a set amount of time from 1 minute to 99 minutes, battery source set to 8.4V.

The Z command will perform a reset of the SAUCE controller, reverting back to a power up state.