



University of
South Australia



In association with

The School of Engineering Systems

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and

The Australian Power Institute (API)

Power & Sustainability Project

Technical Manual

API Solar Cell Project

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The API solar cell project consists of three major components.

1. The solar cell: Specified as a 5 watt “12 Volt” solar cell
2. The regulator: A electronic circuit to regulate the voltage to the voltage needed to drive the pump
3. The pump: A submersible water pump

This document is about the design and functions of the “Regulator” and its purpose in the project.

The Need for a Regulator

The voltage regulator purpose is to provide a stable voltage output from a changing voltage input. This is especially critical in a solar project, as the input voltage changes greatly depending on the amount of sun striking the cell, the temperature of the cell, and even the time of the year as the intensity of the sun changes depending on the time of year.

The voltage out of the solar cell in full sunlight is normally about 20V. As I apply load to the cell, this load will draw current, and the voltage will drop. The cell supplies 5W of power, and $P=VI$. So, at 20V the current available will be $5/20=0.25A$ or 250mA. This is the maximum voltage (and therefore minimum current, $I=P/V$) that could be available, during ideal conditions. The voltage is almost always less, different by an unknown factor that depends on the available sun, clouds, angle of the cell, etc.

The voltage regulator takes these changing voltages and regulates them to a known output. For instance, if I set the regulator to output 5 volts, the input voltage to the regulator might change between 20 volts and 8 volts, the regulator would output 5 volts irrespective of the input voltage.

Most electronic equipment requires a stable input voltage to work. The above pump might well be destroyed if 20 volts is supplied to it, or the load on the solar cell could cause the cell to be destroyed or have degraded output. The purpose of the regulator is to control this and give a known stable voltage output. Note here that a voltage regulator is not the only type, it is also possible to make a current regulator (to produce a constant current output) and this is often used in solar systems.

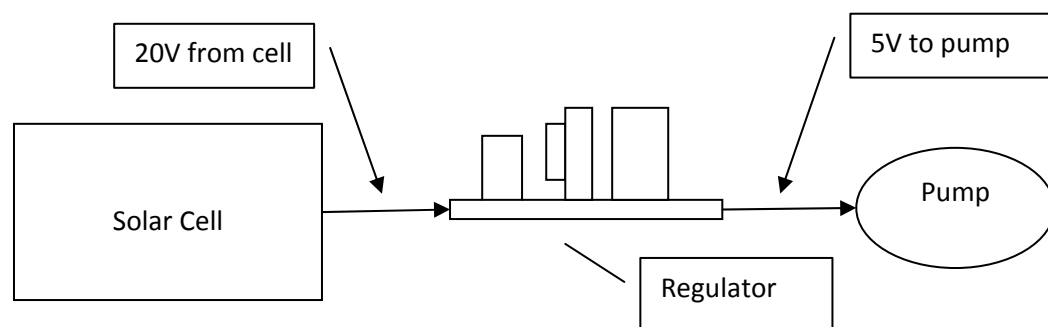


Figure 1 Solar API Project

Types of Regulators

There are several types of regulators; they normally fall into the following two areas: Analogue and Switch Mode.

Analogue Regulators

Analogue regulators control the output voltage by limiting the input voltage, normally using a transistor or MFET output drive. Like most regulators, the output voltage (or current if a current regulator) is monitored and the level is used to control the input voltage.

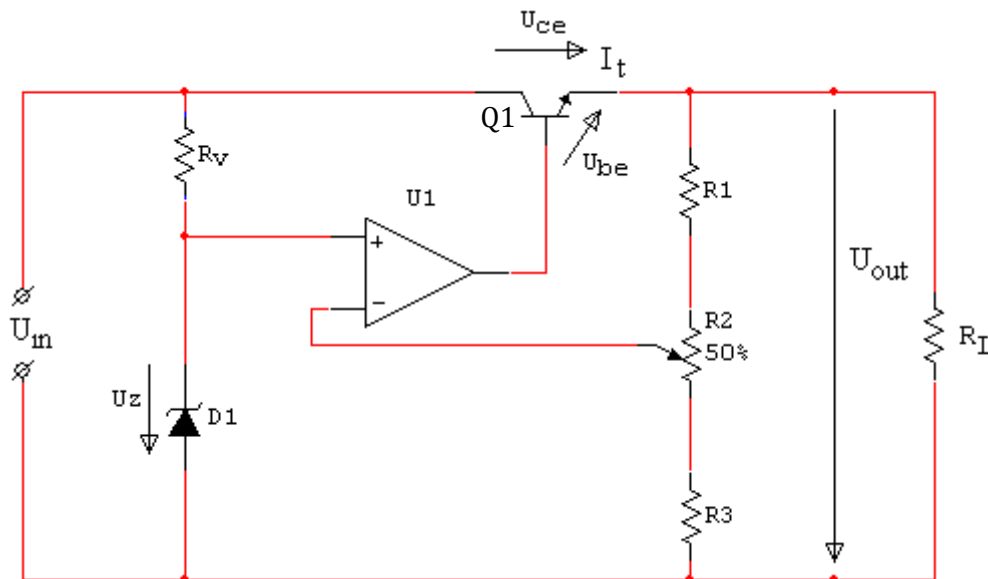


Figure 2: Analogue Regulator

Analogue Regulator (http://en.wikipedia.org/wiki/Voltage_regulator)

In the above case, D1 and R_v form a reference voltage. This is used to compare the output voltage across R_1 , R_2 and R_3 , to the desired (reference) voltage. The transistor Q1 is turned on to allow current to flow to the load R_L , however when the output voltage (divided by R_1 , R_2 and R_3) exceeds the reference, the transistor turns off. This feedback method is used to control the output to the required voltage.

The major issue with this type of regulator is the extra power is dispersed as heat by the transistor and, although useful in a large range of systems, is wasteful of power in a solar system. Normally analogue regulators are not used in solar systems.

Switch Mode Regulators

Switch Mode regulators come in a range of different types the type talked about here is a "BUCK" regulator. Like the analogue regulator above, the switch mode type monitors the output voltage and feeds this back to control the output voltage. The transistor, however, is switched on and off at a high rate, normally with a type of waveform called Pulse Width Modulation (PWM). This waveform is a constant frequency (as the time between the beginnings of each cycle is constant) but ratio of the amount of time it is on for to the amount of time it is off is changed to allow different amounts of

power through. This power is stored normally in an inductor, and when turned off the power may still be drawn from this inductor.

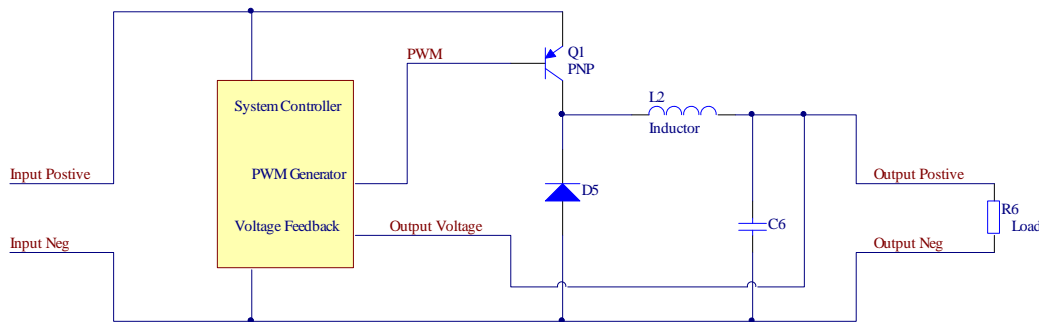


Figure 3: Switch Mode "BUK" regulator

The Inductor (L2) stores the power from the PWM output. Diode D5 allows current to flow when the transistor Q1 is off. The transistor switches the power on and off to the inductor (L2). The output voltage is returned to the System Controller to control the PWM levels sent to the transistor (Q1).



Figure 4: PWM Waveform

The PWM waveform shown in figure 4 is how the transistor is controlled. Waveform 1 shows an example in which the transistor is mostly off, while waveform 2 shows when the transistor is mostly on. The ratio of time on to the time off is changed to regulate the power applied to the inductor (L2). The inductor stores electrical energy that can be used as needed. The voltage out of L2 is what is supplied to the output stage (load). As the voltage drops on the output of L2, the system controller increases the time the PWM waveform is on, allowing more power to move into the inductor. The system regulates by allowing more power when needed and less power when not.

The BUCK regulator transistor is either on or off with power stored in the inductor/capacitor. It therefore works with greater efficiency, wasting less power. The power is regulated with considerably less loss than analogue systems; less power is converted to heat. This system is used in this project to make efficient use of the available power from the solar cell.

The API Buck regulator PCB

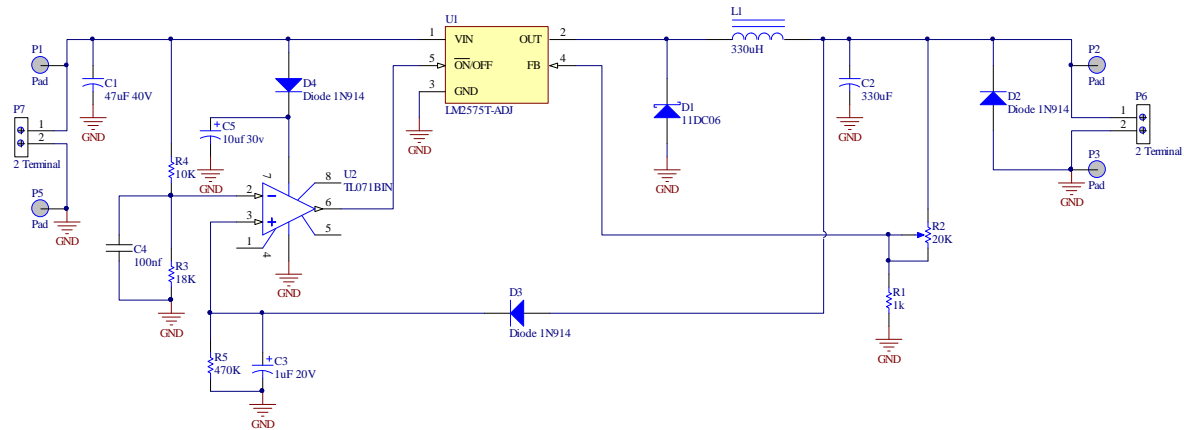


Figure 5: API Buck Regulator

LM2575 Regulator

The API regulator board is based in a National Semiconductor LM2575 adjustable regulator chip. This chip is described as a simple switcher. It includes the following parts all integrated into a single chip.

- Voltage BAND-GAP reference (Voltage reference)
- Fixed gain voltage amplifier
- Voltage Comparator for PWM generation
- 52Khz PWM waveform generator
- Reset NOR gate
- Thermal Shutdown control
- Current Limit control
- Driver and 1A switch transistor
- Internal Regulator and Power Control

This chip forms the heart of the project and provides all of the PWM control, voltage feedback reference and power monitoring. Information on this chip is available from National Semiconductors <http://www.national.com/ds/LM/LM1575.pdf>. The chip requires an input capacitor (C1), Inductor (L1), fast diode (D1) and output capacitor (C2). These parts form the design of the “BUCK” regulator. R1 and R2 form a voltage divider that provides the voltage reference feedback to the regulator, by changing the voltage returned the regulator will change the output voltage, this is how the output voltage becomes adjustable.

Comparator

A TL071 operational-amplifier is also used to control the regulator. The op-amp is in comparator mode for this usage, a rail to rail op-amp is needed but the selection is not critical. A comparator can work as a voltage switch. If the voltage at the positive terminal is greater than the voltage at the negative terminal, then the output is positive (swings to the op-amp supply voltage). If the voltage at the positive terminal is less than the voltage at the negative terminal, then the output is negative (swings to the op-amp negative voltage). In this way a voltage switch can be made comparing two voltages.

The resistors R4 and R5 form a voltage divider to measure the input voltage supplied to the negative terminal of the comparator. The positive terminal is connected to the supply output with a diode. If

the supply voltage is greater than the output voltage by a small amount the comparator will be negative output allowing the regulator to work. However if the input supply voltage drops below the output voltage then the comparator goes high and closes down the regulator. This action is to stop floating regulator voltages around the critical regulation voltage area. The comparator will quickly recover when input voltage rises.

PCB Specifications

The LM2575 chip is specified in a TO220 package (this is the physical package the chip is mounted in) This package allows for a Heat Sink (a piece of metal to help disperse the chip heat) to be attached, this project it is unlikely to be needed as the wattage is unlikely to be used fully, in testing the device remained cool in operation. The input capacitor and LM2575 limit the input voltage to a maximum of 40 Volts, however the solar cell output is unlikely to reach this level. The system can work to 1 Amp regulation, again the more likely current is less than 0.5A (500mA). The device has automatic shutdown in the event that too much heat is generated in the LM2575 or excess current is drawn from the board.

Parts List

Table 1: Parts List

Designator	Comment	Description
C1	47uF 40V	Capacitor
C2	330uF	Capacitor
C3	1uF 40V	Polarized Capacitor (Radial)
C4	100nf	Radial 0.1 spacing
C5	10uf 30v	Polarized Capacitor (Radial)
D1	11DC06	Schottky Diode 60V
D2, D3, D4	Diode 1N914	High Conductance Fast Diode
D5	Diode	Default Diode
L1	330uH (500ma min)	Magnetic-Core Inductor
R1	1k	Resistor
R2	20K	Potentiometer 10 Turn type
R3	18K	Resistor
R4	10K	Resistor
R5	470K	Resistor
U1	LM2575T-ADJ	SIMPLE SWITCHER 1A Step-Down Voltage Regulator
U2	TL071BIN	Low-Noise J-FET Single Operational Amplifier
PCB	API PCB	

Points about parts list

- D1 is a fast acting diode used to allow the inductor to release current when the power transistor in the LM2575 is off critical part for operation.
- L1 current minimum should be 500ma but 1A or grater is better
- U1 must be this part other regulators will not easily fit the pinning
- Resistors are 0.6w 10% types

API Printed Circuit Board

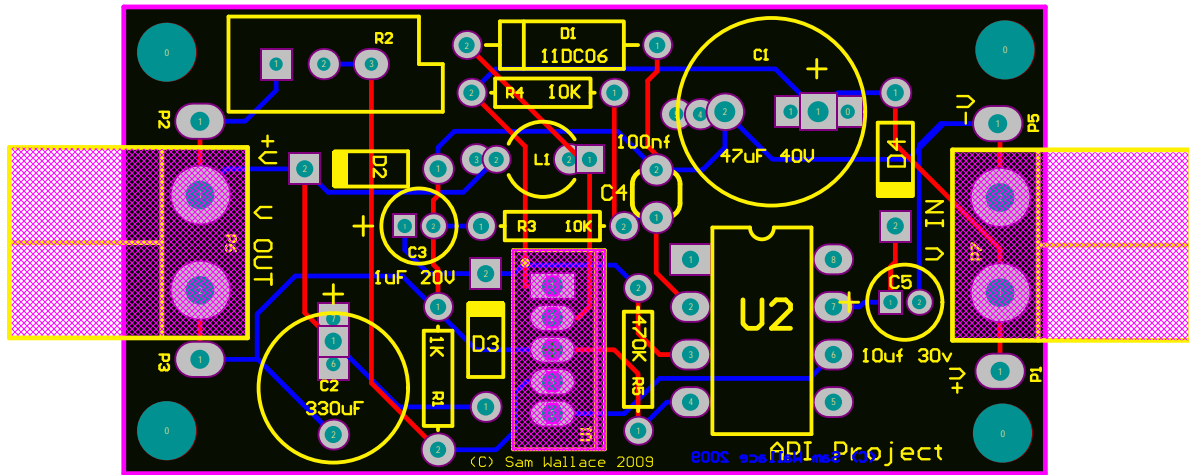


Figure 6: PCB Layout

The above figure 6 shows the PCB layout with the red lines being copper connections on the top layer and the blue lines being connections on the bottom layer. Plugs P6 and P7 are normally not used but can be added if required.

To make the PCB the first parts that should be fitted in the order shown below

Resistors

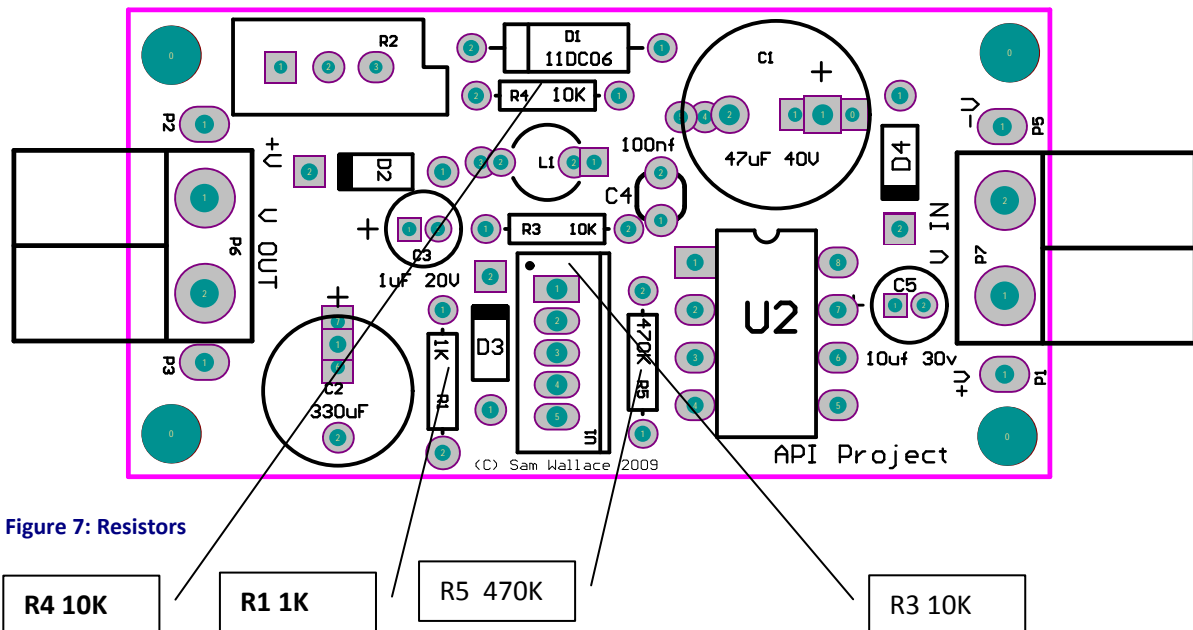
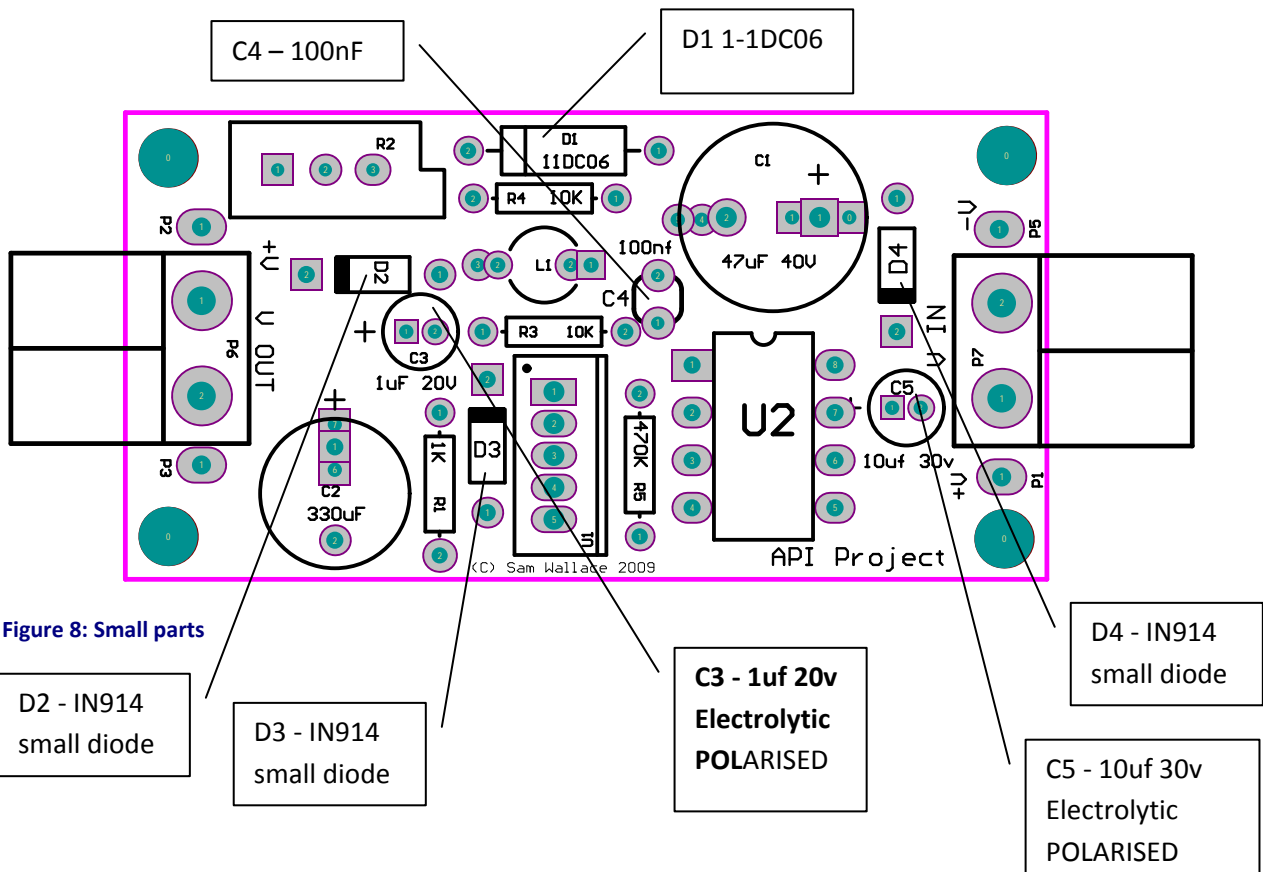
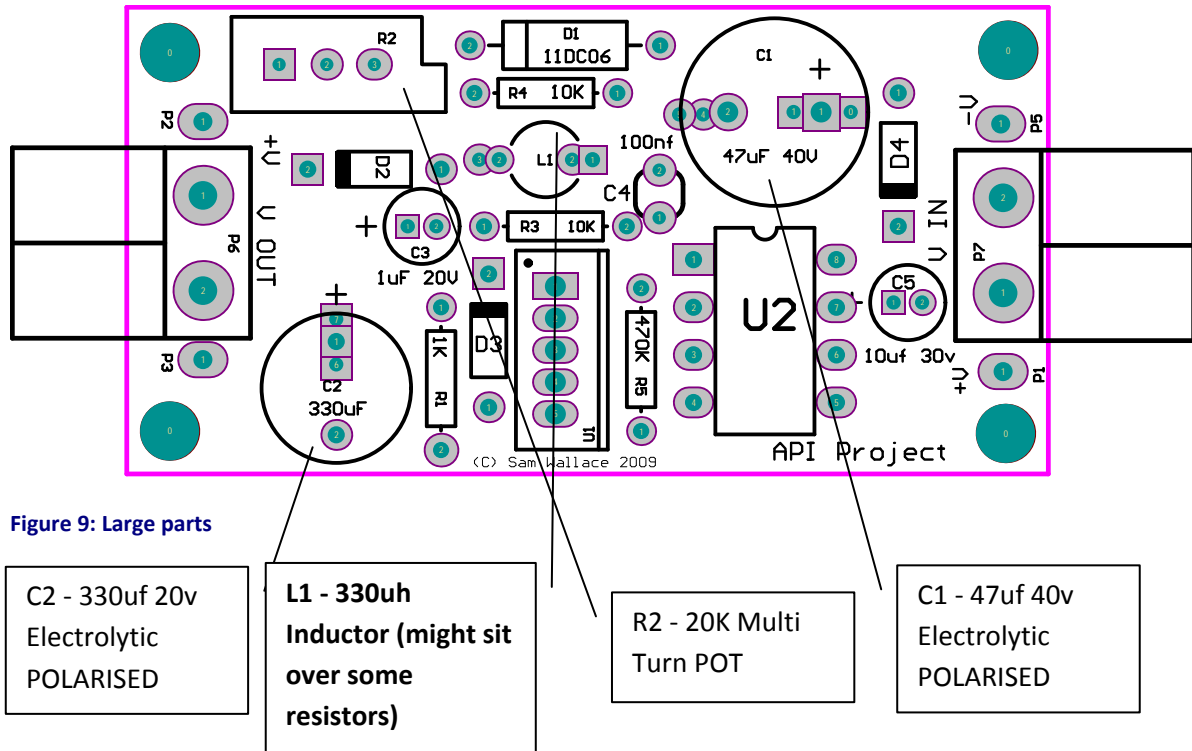


Figure 7: Resistors

Fitting Small Parts



Large Parts



Large Components Placement

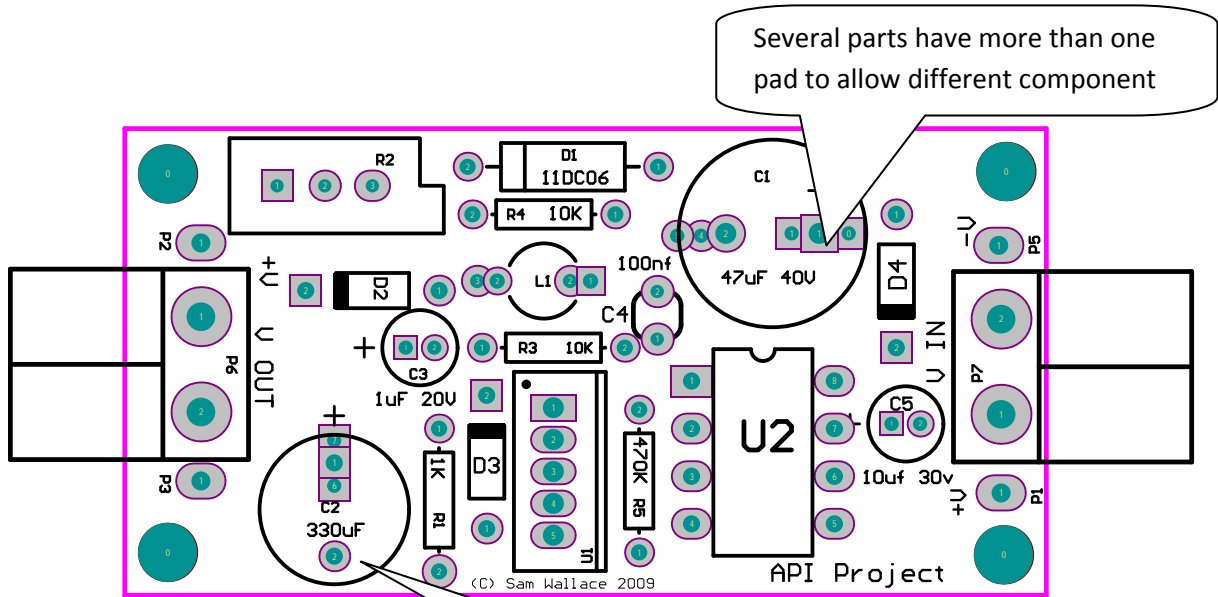


Figure 10: Pads for Larger parts

Several parts have more than one pad to allow different component sizes

Semiconductors

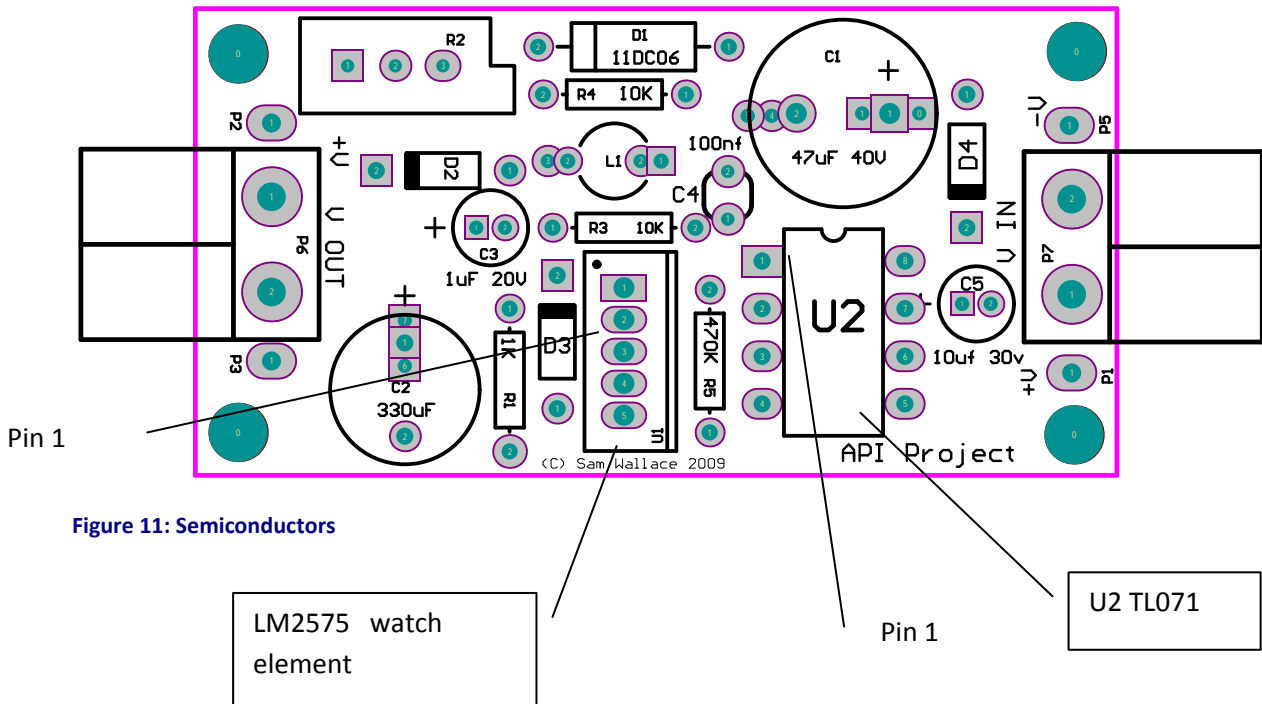


Figure 11: Semiconductors

Testing

Once the PCB is assembled the board should be inspected for dry soldering joints and that all parts are soldered correctly.

Voltage can be applied to the input terminals the potentiometer adjusted and output voltage checked. Once completed the system is working and can be mounted as needed.

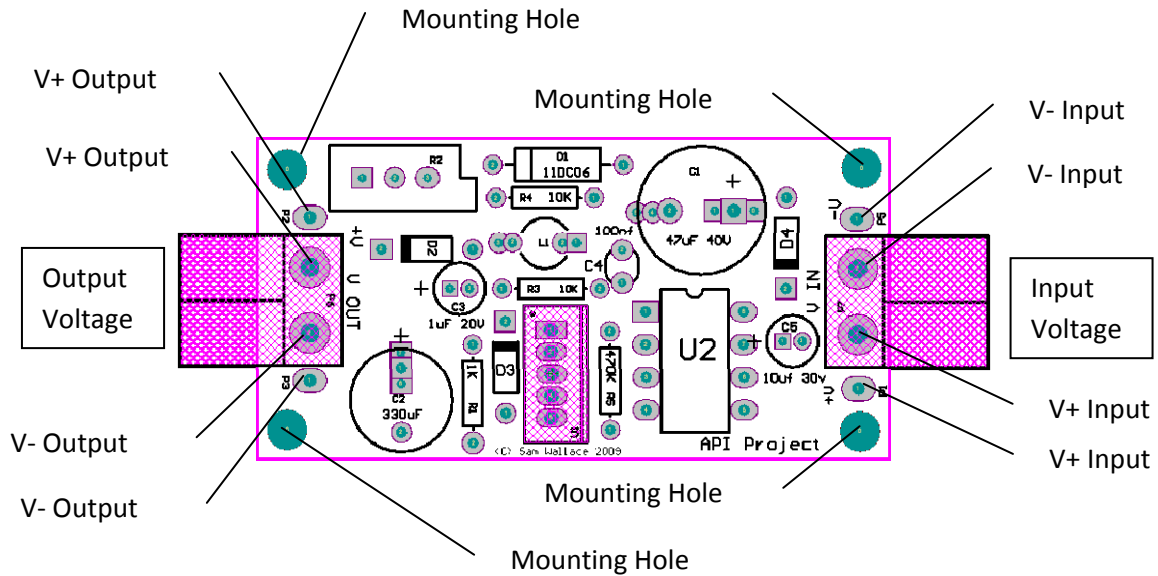


Figure 12: Inputs and Outputs

The Designers

We hope you like this API kit and have fun making and testing the systems. Our aim is to introduce the use of POWER and the technology surrounding and supporting power generation and usage. This is critical to our lives in the 21st century. We hope you find the learning experience useful and informative.

Sam Wallace

Hilary Beck