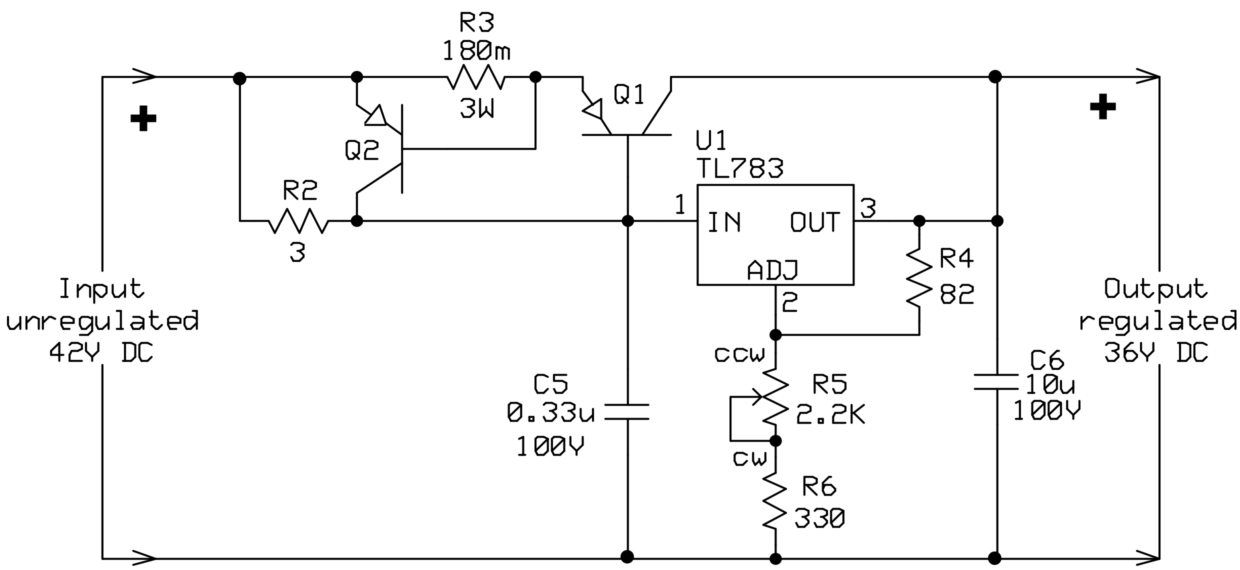
Dual adjustable 36V 3A regulated DC power supply

I am beginning work on an ultrasonic speaker project which is going to need three amperes of current at +36V and −36V. I have decided to construct the power supply as a separate project.

For low-voltage DC power supplies, one can make good use of three-terminal regulators like the LM7805 and LM7812. That series does not extend up to 36V. Although there are ways to use the lower-voltage devices to regulate higher voltages, I decided to build the circuit around the TL783 high-voltage regulator. The TL783 can handle input voltages up to 125V. The resulting circuit is more robust than one cobbled together from low-voltage regulators.

The following partial schematic shows the heart of the circuit. U1 is the TL783. It has the same three terminals − input, output and adjust/ground − as do the low-voltage regulators. But it is limited to 700mA of output current. What I have done is introduce pnp transistor Q1 to carry most of the current. U1 uses the chain of resistors R4, R5 and R6 to monitor the output voltage. By controlling the current flowing into the base of Q1, U1 allows Q1 to pass whatever current is needed to keep the voltage over the load (not shown) at the monitored level. A second pnp transistor Q2 shuts down the circuit in the event that the output terminals are short-circuited. For convenience, I used the same kind of transistor for both Q1 and Q2. They are BD244CG transistors, which are rated to handle 6A at 100V.



Let's assume for the moment that we have a source of unregulated 42V DC for this circuit. I will describe that source in a later section.

U1's principal function is to maintain a reference voltage between its output and adjustment terminals (leads 3 and 2, respectively) which is fixed at 1.27V. The current flowing down through 82Ω resistor R4 will therefore be fixed at I = V/R = 1.27V ÷ 82Ω = 15.5mA. (The value of resistor R4 was chosen, in part, to ensure that the output current from U1 is always greater than 15mA, which the datasheet says is the minimum required for successful operation.)

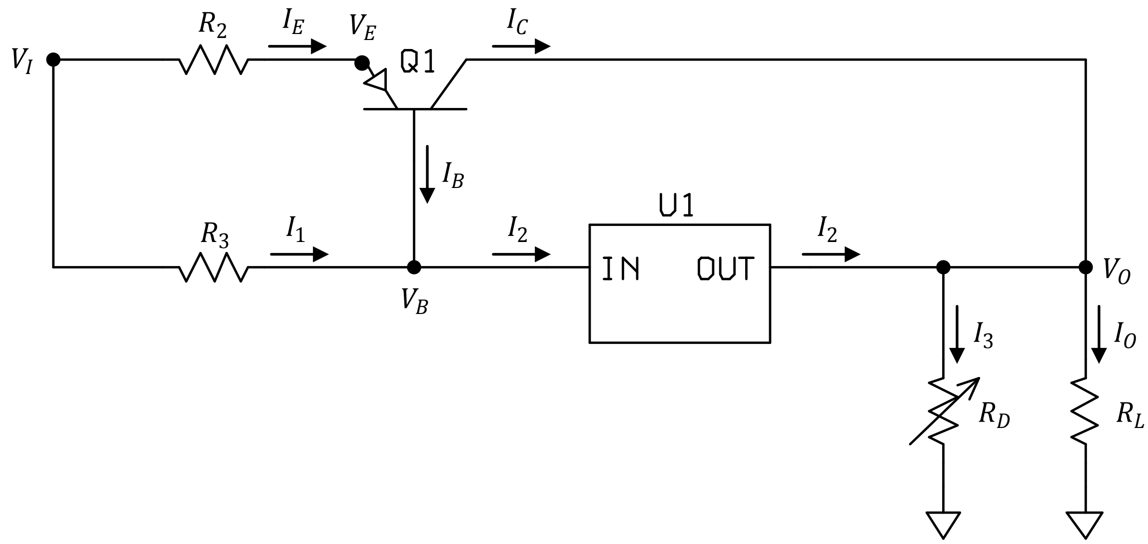
The current flowing into or out of U1's adjustment terminal is negligible. The datasheet says it is typically 83µA, with a maximum of 110µA. That means that the current flowing down through the combined series resistance of R5 and R6 will also be 15.5mA. R5 is a panel-mounted potentiometer the user can turn to vary the output voltage from the circuit.

When R5 is turned to the furthest clockwise position, the R5+R6 series resistance will be 2,530Ω. 15.5mA flowing down through this resistance will cause a voltage drop of V = IR = 15.5mA × 2.53K = 39.2V. That will be the voltage at the adjustment terminal. The voltage at the output terminal will be 1.27V higher, giving the circuit an output voltage of 40.5V.

When potentiometer R5 is turned to the furthest counter-clockwise position, the R5+R6 series resistance will be 330Ω. 155mA flowing down through this resistance will cause a voltage drop of 5.1V. The output voltage of the power supply will therefore be 5.1V + 1.27V = 6.4V.

Now let's look at how the current flow through Q1 is managed. First, observe that most of the current will flow from left-to-right across the top path of the circuit, from the +ve side of the unregulated input voltage, through resistor R3, into the emitter terminal of Q1, out of the collector terminal of Q1 and into the +ve side of the load. Some current will flow down through resistor R2, but it will be a minor amount compared with the current flowing through R3 and the emitter-collector pathway of Q1.

The following diagram shows the circuit I will analyze. There are four voltages of interest: V_I and V_O at the input and output, respectively, and V_E and V_B at Q1's emitter and base, respectively. Transistor Q2 plays no role in normal operations and has been ignored. Four resistors are involved. R_2 and R_3 set the bias. R_L is the load resistance, which will likely be between 3Ω and 12Ω. I have combined the chain of three resistors at U1's output into a single variable resistance R_D (subscript "D" stands for divider). The resistors used permit R_D to be varied between 412Ω and 2.612K. I have labelled seven currents, showing the assumed positive direction of each. Note that the current flowing through U1's adjustment terminal is ignored, so the current I_2 flows into and out of U1.



Circuit analysis

Applying Ohm's Law to the four resistors gives:

$$V_I = R_2 I_E + V_E \quad (1)$$
$$V_I = R_3 I_1 + V_B \quad (2)$$
$$V_O = R_D I_3 \quad (3)$$
$$V_O = R_L I_O \quad (4)$$

During normal operation, transistor Q1 will operate in its "linear" region. This has two consequences. Firstly, its emitter-to-base junction will be forward-biased, and the voltage drop from the emitter to the base will be the standard voltage drop (0.7V, say) across a silicon p-n junction. Secondly, the collector current will be some multiple of the base current. This multiple is called the "DC current gain" and is usually represented either by the symbol β or by the symbol h_{FE}. For high performance transistors, β will be large, several hundred or even a thousand. For power transistors, β will be less, but if the transistor is to be of any use as a current amplifier, β must be large compared to one. For the BD244CG transistor used, β can be as low as 15. β will vary as the operating point of the transistor changes, but it can be considered to be a constant for small variations from any particular operating point. These two characteristics can be expressed mathematically as follows.

$$V_E = V_B + 0.7 \quad (5)$$
$$I_C = \beta I_B \quad (6)$$

Now, the current flowing into the transistor must be equal to the current flowing out of it, so that:

$$I_E = I_C + I_B \quad (7)$$

We have two nodes through which the net flow of current must be zero.

$$I_2 = I_1 + I_B \quad (8)$$
$$I_2 + I_C = I_3 + I_O \quad (9)$$

So, we have ten circuit equations, which will allow us to solve for ten unknown values. Since we have used a lot more than ten variable names, we need to be more precise about which are truly unknown and which are being used for algebraic convenience. The following table does this.

Variable name	**Status**
Input voltage V_I	Fixed at 45V, say
Node voltages V_E, V_B and V_O	Unknown
Seven currents I_E, I_B, I_C, I_1, I_2, I_3 and I_O	Unknown
Bias resistors R_2 and R_3	Fixed at 3Ω and 0.18Ω, respectively
Load resistance R_L	Parameter, chosen by user
Divider resistance R_D	Independent variable

Note that I have chosen to approach matters by leaving the output voltage as a dependent (unknown) value. The user may have a target output voltage in mind, but what actually comes out of the power supply is determined by his setting of the potentiometer. Therefore, it is the resistance of the voltage divider that is the independent variable.

The table tells us that there are ten unknowns, being three voltages and seven currents. Actually, there is one more thing we know. U1 will keep the current flowing down through the resistor divider (current I_3) virtually constant at 15.5mA. I_3 is not really an unknown at all. We can use the nine circuit equations to solve for the remaining nine unknowns.

In the usual case, the user attaches a load resistance R_L to the power supply and then adjusts the potentiometer's resistance (in effect, R_D) so that the output voltage settles at some target output voltage V_O. We don't need to solve the circuit equations to figure out how R_D and V_O are related; Equation (3) gives us that directly. Instead, we need to know how U1 causes the circuit to deliver V_O. U1 does that by controlling the amount of current I_2 which flows out of its output terminal. Our first goal, therefore, is to derive an expression for current I_2 in terms of a given load resistance R_L and potentiometer setting R_D. We need to eliminate all unknown variables other than I_2.

Let's start by using Equations (5), (6) and (9) to eliminate V_E, I_C and I_O, respectively. Substitution into the other equations gives us the following six equations in six unknowns.

$$V_I = R_2 I_E + V_B + 0.7 \quad (10)$$
$$V_I = R_3 I_1 + V_B \quad (11)$$
$$V_O = R_D I_3 \quad (12)$$
$$V_O = R_L(I_2 + \beta I_B - I_3) \quad (13)$$
$$I_E = (1+\beta) I_B \quad (14)$$
$$I_2 = I_1 + I_B \quad (15)$$

Next, let's use Equations (11) and (14) to eliminate V_I and I_E, respectively. After substitution, we have the following four equations in four unknowns.

$$R_3 I_1 = (1+\beta) R_2 I_B + 0.7 \quad (16)$$
$$V_O = R_D I_3 \quad (17)$$
$$V_O = R_L(I_2 + \beta I_B - I_3) \quad (18)$$
$$I_2 = I_1 + I_B \quad (19)$$

Note that voltage V_B dropped out. Next, let's use Equations (17) and (19) to eliminate V_O and I_1, respectively, which leaves:

$$R_3 I_2 = [(1+\beta) R_2 + R_3] I_B + 0.7 \quad (20)$$
$$(R_L + R_D) I_3 = R_L I_2 + \beta R_L I_B \quad (21)$$

Lastly, let's rearrange Equation (21) to isolate I_B, which can be substituted into Equation (20) to give:

$$R_3 I_2 = [(1+\beta) R_2 + R_3] \left[\frac{(R_L + R_D) I_3 - R_L I_2}{\beta R_L}\right] + 0.7 \quad (22)$$

This can be reduced to:

$$I_2 = \frac{[(1+\beta) R_2 + R_3](R_L + R_D) I_3 + 0.7\beta R_L}{(1+\beta)(R_2 + R_3) R_L} \quad (23)$$

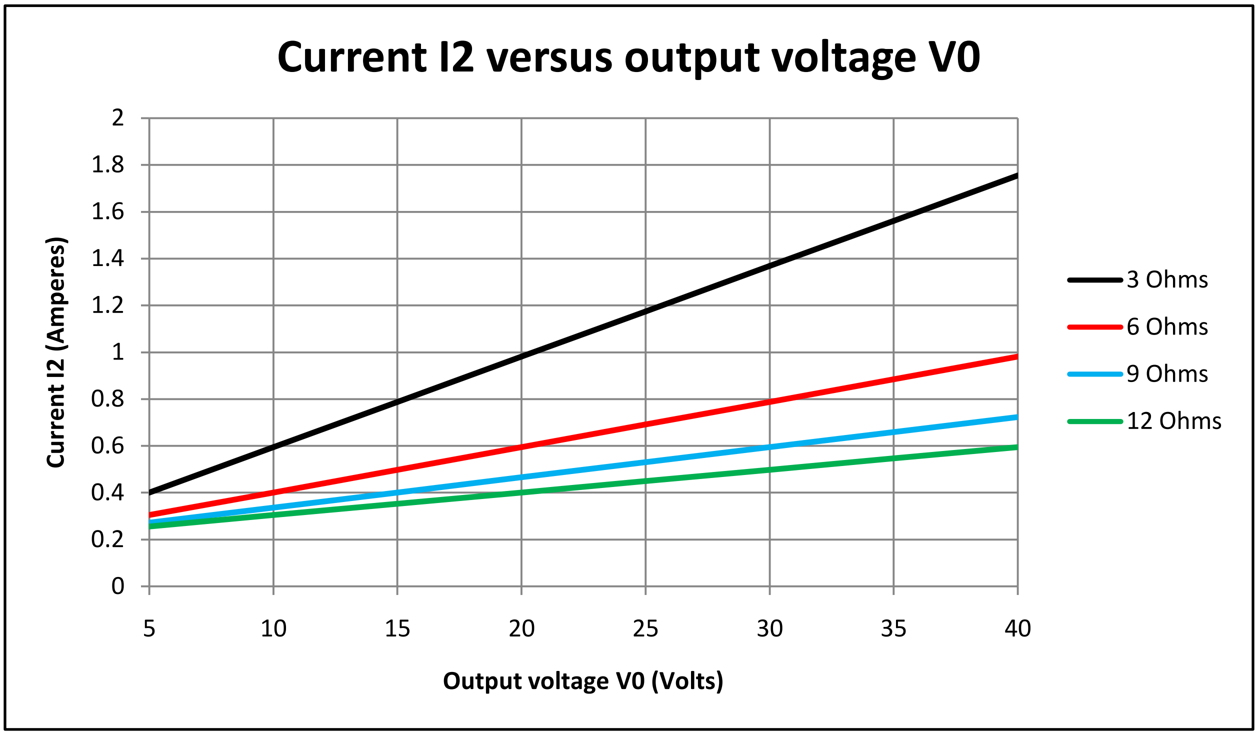
This is the expression I sought. It gives current I_2 in terms of a given load resistance R_L and potentiometer setting R_D. It happens, however, that this can be made more useful if we go one step further. Let's use Equation (3) to replace the potentiometer setting R_D with the target output voltage V_O. We get, after some re-arranging:

$$I_2 = \frac{[(1+\beta) R_2 + R_3] V_O + \{[(1+\beta) R_2 + R_3] I_3 + 0.7\beta\} R_L}{(1+\beta)(R_2 + R_3) R_L} \quad (24)$$

Substituting numerical values, 0.18Ω for R_2, 3Ω for R_3, 0.0155A for I_3 and 15 (the very minimum value) for β, gives:

$$I_2 = \frac{0.116}{R_L} V_O + 0.208 \quad (25)$$

The following Excel plot is a graph of I_2 versus output voltage V_O for four values of load resistance R_L.



Under some circumstances, current I_2 exceeds 700mA, the maximum current at which U1 is guaranteed to regulate. I will describe in a following section the short-circuit protection which guards against this occurrence. On the other hand, current I_2 has a minimum of 256mA, well above the 15mA minimum required for successful regulation.

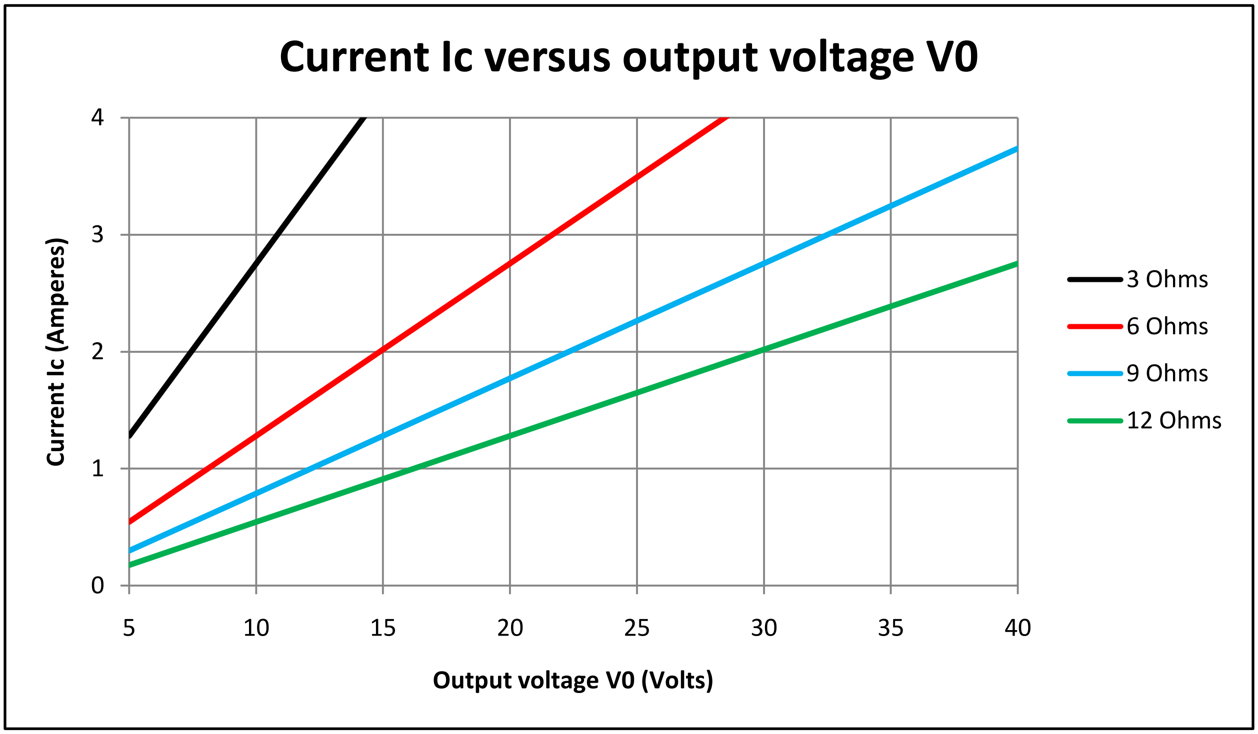
The other current of interest to us is I_C, which is the current flowing out of the collector of transistor Q1. Roughly speaking, the sum of currents I_C and I_2 flows into the load. (More precisely, 15.5mA is drawn off through the voltage divider across the output of U1.) If we re-solve the circuit equations to obtain I_C in terms of V_O and R_L, we get:

$$I_C = \frac{\beta R_3 V_O + \beta(R_3 I_3 - 0.7)R_L}{(1+\beta)(R_2 + R_3)R_L} \quad (26)$$

Substituting the same numerical values as before gives:

$$I_C = \frac{45V_O - 9.8025R_L}{50.88R_L} = 0.884\frac{V_O}{R_L} - 0.193 \quad (27)$$

The following Excel plot is a graph of I_C versus output voltage V_O for the same four values of load resistance R_L used in the preceding graph.



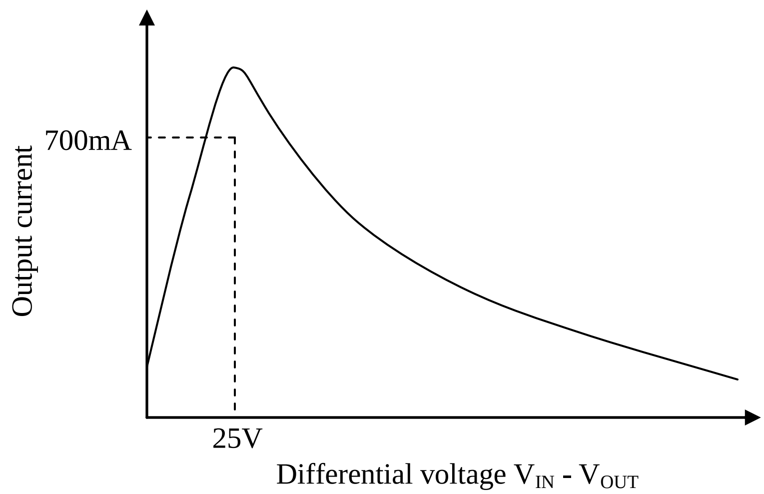
When the circuit is loaded, it is clear that transistor Q1 carries a lot more of the current than does regulator U1. Note that I have truncated the vertical scale to a maximum of four Amperes. The BD244CG can handle six amperes, but I added the protection described in the following section to ensure that it never gets to that extreme.

Short circuit protection

Transistor Q2 shuts the circuit down if the current flowing through Q1 becomes excessive. It will be activated if the output terminals are short circuited. But it will also be activated if the load resistance is too low for the output voltage demanded. Let's look at how and when Q2 kicks in.

If the voltage drop from Q2's emitter to its base is less than about 0.7V, it will be cut off and negligible current will flow into or out of any of its terminals. Resistor R3 happens to be wired between the emitter and base, so the current flowing through R3 will determine the E-B voltage drop. The value of R3 (180m**Ω**) has been chosen so that the voltage drop will rise to 0.7V when the current flowing through is equal to (using Ohm's Law once again) I = V/R = 0.7 ÷ 0.18 = 3.9A.

Once the current flowing through R2 exceeds 3.9A, transistor Q2 will become active. Current will begin to flow through its main emitter-to-collector pathway. The current which takes this path will be diverted from pass transistor Q1 and will flow instead into the input terminal of regulator U1. This diversion protects Q1 from being overloaded. If nothing else happened, though, the increasing flow of current into U1 would destroy it. But something else does happen. U1 "drops out", which is to say that it stops holding the output voltage at the design value and allows it to fall. This phenomenon is shown graphically in Figure 2 of the TL783's datasheet. I have shown the main features of Figure 2 below. The actual position and shape of the curve depend on the junction temperature, the length of time the over-current situation persists, and so forth. What happens is that, if too much current is demanded from the device, it will roll over onto the tail on the right-hand side. As the output voltage falls, the current



flowing through the load resistance will fall and all will be well. Interestingly, it is possible that the regulator can become trapped on the right-hand tail and will not revert to its normal regulating function after a short-circuit condition is fixed. In that event, it will be necessary to power down the circuit and start over.

It is not possible to do a rigorous analysis of the short-circuit condition because the "drop out" curve is not well-defined.

Power dissipation

Three components are going to burn off a lot of heat: R2, Q1 and U1. In this section, I will try to estimate the worst-case conditions.

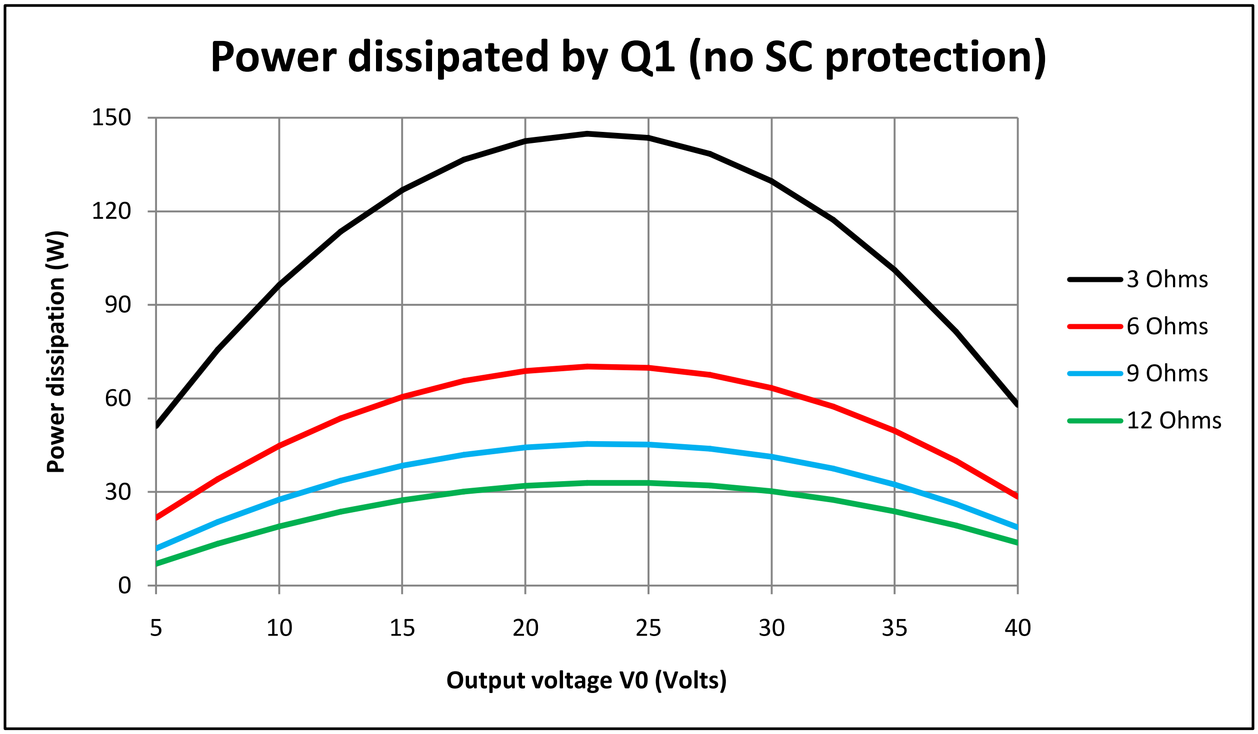
Although R2 is small (180mΩ), it will pass substantial current. As I described, I chose R2's value so that transistor Q2 would kick in at a current of 3.9A. When the current is 4A , the power dissipated by R2 will be $P = I^2R = 4^2 \times 0.18 = 2.9W$. A 3W resistor will do.

The worst case for Q1 will occur during a short-circuit condition, when 4A, say, flows through its emitter-to-collector pathway. The voltage at Q1's emitter will be the input voltage (45V, say) less a small voltage drop over R2 ($V = IR = 4 \times 0.18 = 0.72V$), or 44.3V. If U1 has completely dropped out, then the voltage at Q2's collector will be zero. The voltage drop over Q1's main pathway will be 44.3V and, when passing current of 4A, Q1 must dissipate power of $P = IV = 4 \times 44.3 = 177W$. This is an extreme case, of course, and one which should not be allowed to persist for very long.

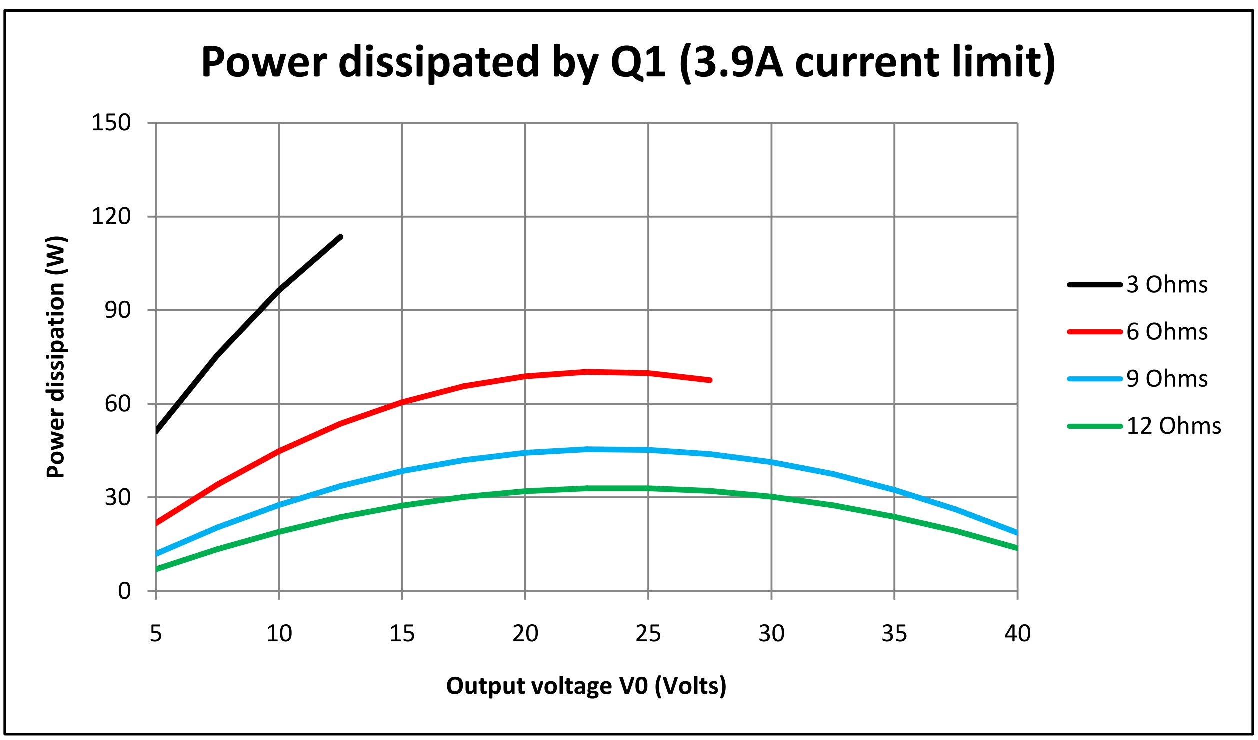
The worst case for Q1 during normal operations will not occur at either voltage extreme, but at some intermediate voltage. It is easiest to understand what happens by plotting the power dissipated as a function of the output voltage. The graph above titled "Current Ic versus output voltage V0" is the place to start. If the input DC voltage is 45V, say, then the voltage drop over Q1 will be 45 – V0 (neglecting the small drop over resistor R2) and the power dissipated will be $P = (45 - V0) \times Ic$. The following graph shows this curve for the same four load resistances used before.

The graph shows that the maximum power dissipation occurs at an output voltage of about 22.5V. The smaller the load resistance, the more power Q1 must dissipate.

One cannot draw too many conclusions from this graph because it is not the complete picture; it does not take into account the short-circuit protection afforded by transistor Q2. I will account for that next.



The following graph is my simplified attempt to take into account the short-circuit protection. I have simply removed from the previous graph all points where the current flowing through Q1 exceeds 3.9A, at which limit Q2 comes into play.

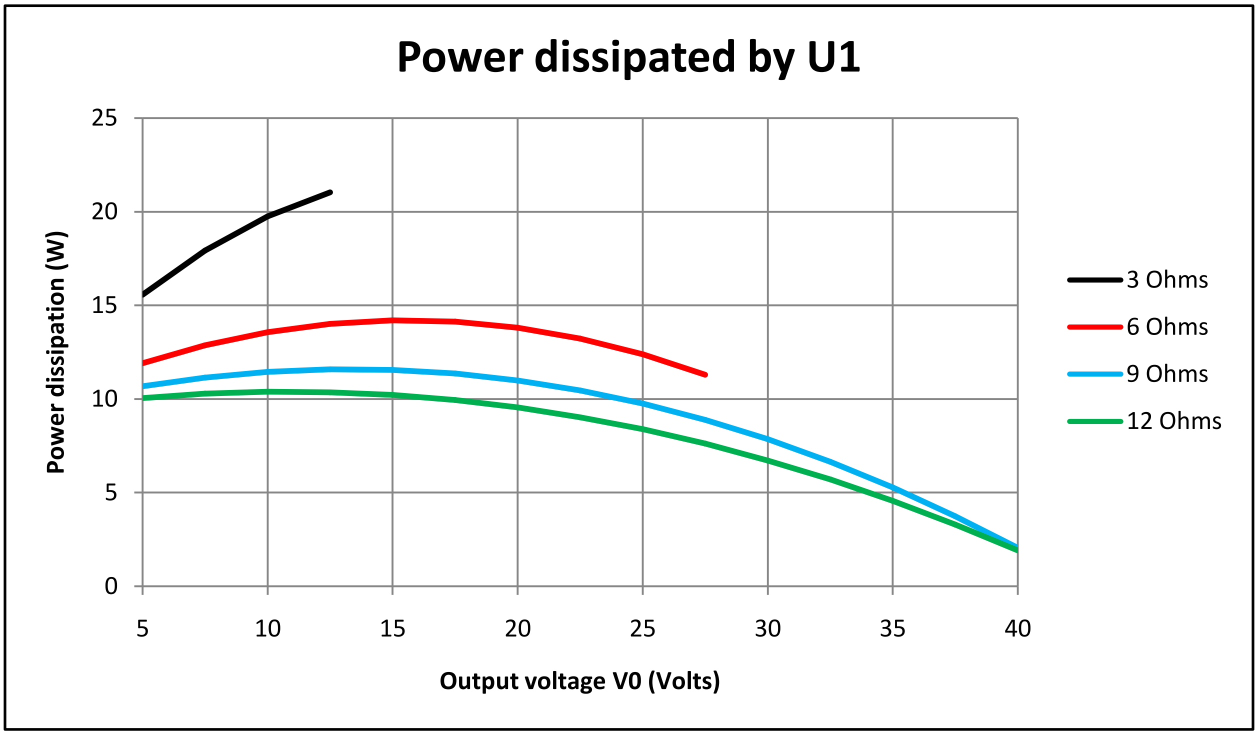


Two lessons can be learned:

1. The user should exercise care when the load resistance is very low, and
2. Q1 is going to burn off a lot of heat – up to 100W or so.

Before describing my solution to the heat problem, I will repeat the power analysis for regulator U1. As before, I will assume that the input DC voltage is 45V. I will assume that the current flowing through resistor R3 is the same as the current flowing into the regulator. (This assumption is tantamount to neglecting the current flowing through Q2 and the current flowing into Q1's base terminal.) Then, the voltage at U1's input terminal is equal to 45 − (R3 × I2), where I2 has the same meaning it did during the circuit analysis, namely, the current flowing into the regulator. Since V0 (the output voltage) is the voltage at U1's output terminal, the voltage drop between U1's input and output terminals is given by 45 − (R3 × I2) – V0. The power dissipated by U1 is the product of this voltage drop and current I2 flowing through the regulator, being P = [45 − (R3 × I2) – V0] × I2. One of the graphs above gives I2 as a function of V0 and can be used to calculate the values.

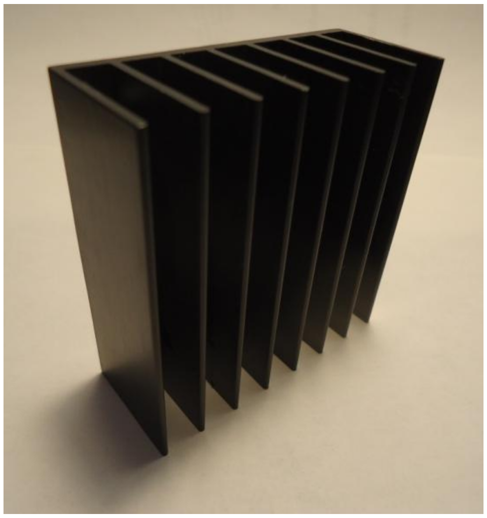
The following graph shows this power dissipation for the same four load resistances used before. This graph takes into account the short-circuit protection. It does so by excluding the same operating points as were excluded in the foregoing graph.



Two lessons can be learned:

1. The user should exercise care when the load resistance is very low, and
2. U1 will not be stressed as much as Q1, but is still going to need to dissipate 20W or so.

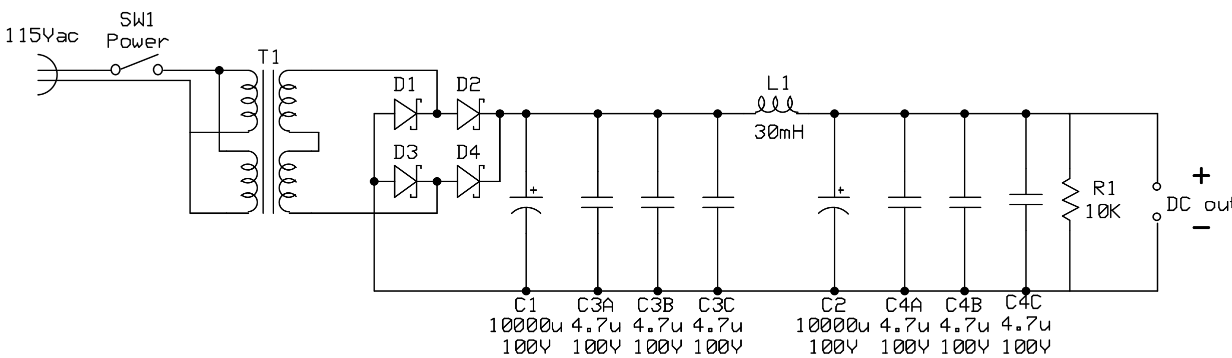
I used four heat sinks from my spare parts box for Q1 and U1. (Don't forget that there are two identical channels in a dual power supply.) These heat sinks have a footprint of 2-1/4 inches by one inch and a height of 2-3/8 inches. Q1 and U1 come in TO-220 packages and I bolted them in the vertical position on the far face.



I also used a fan. Mouser part number 670-OA80AP112TB is a fan driven directly by 115VAC. It is 80mm square and has a depth of 35mm. It has a sound rating of 22dB, which I found to be delightfully quiet.

The input DC voltage

Up to this point, I have assumed that the regulator draws its power from a DC source of 42V or so. I used the following circuit to provide that source. It is a traditional power supply, and uses inductors (chokes) as well as capacitors to filter the rectified AC. Some may argue that the use of chokes is overkill.



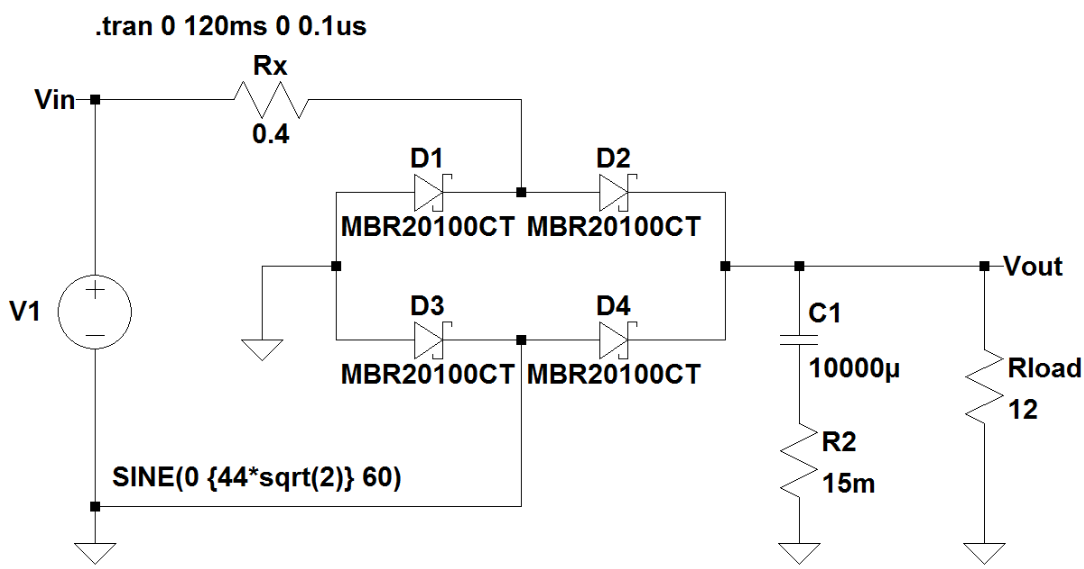
Transformer T1 is a Hammond #1182N22 transformer. It has two primary coils and two secondary coils. When the primaries are wired in parallel and the secondaries are wired in series, it provides 44Vrms at 3.64A. What is interesting is that it is a toroidal transformer. I had never used toroidal power transformers before and was impressed. They are truly beautiful to look at. They are compact and can be mounted on the walls of the enclosure.

Note the following caution about the use of toroidal power transformers. "Due to the superior magnetic properties of toroidal transformers, they will be susceptible to high magnetizing current when initially energized, only limited by the low DC resistance of the primary winding. Where you are in the AC cycle when the transformer is energized dictates the chances of overloading the supply circuit. This is why the transformer may sometimes energize without a problem and other times will blow the fuse or trip the circuit breaker. The duration of this overload is rarely longer than half a cycle. Therefore, you should consider using a slow-blow fuse, time delayed circuit breaker or other form of soft start circuitry for the supply line when using these high efficiency toroidal transformers." I did not take any precautions and did not experience any problems.

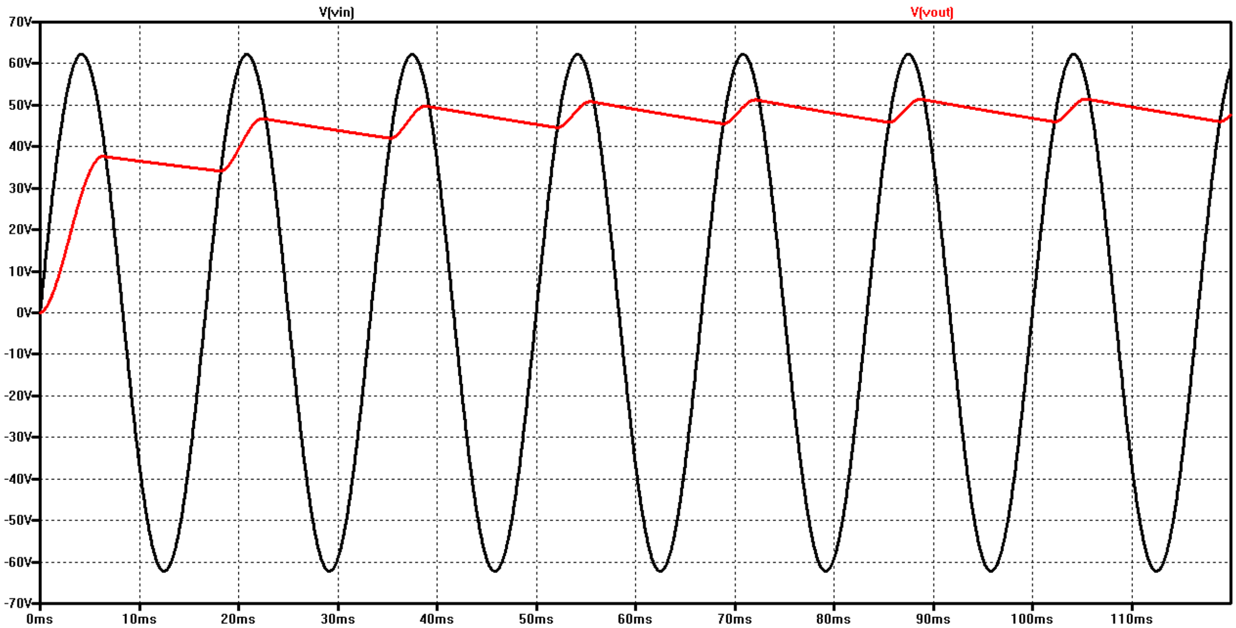
I used four Schottky diodes to configure a bridge rectifier. I used Mouser part #863-MBR20H10CTG diodes, which can handle 20A continuous, 180A surge and withstand 150V. I used Schottky diodes for their very low forward voltage drop. These diodes drop only 870mV, which means that the first filter capacitor will have an AC input of $44 - (2 \times 0.87) = 42.24$Vrms.

The first filter capacitor is a 10,000μF aluminum electrolytic. It, and the three small ceramic capacitors wired in parallel, are rated to withstand 100V. I chose this value of capacitance on the following basis. The time between peaks in the incoming rectified 60Hz waveform is 1/120 = 8.3 milliseconds. Under heavy load, the capacitor will recharge during short intervals near the peaks, and the stored charge will be drawn down during the interval until the next peak. If the load resistance is such that the load is drawing a steady current of 3A, the capacitor will have to supply this 3A for the 8.3ms between peaks without suffering too great a decrease in its voltage. A 3A current from a 42V source represents the expenditure of power equal to $P = IV = 3A \times 42V = 126W$. Over an interval of 8.3ms, this power level represents the transfer of energy equal to $E = Pt = 126W \times 0.0083s = 1.05$ Joules. Now, the energy stored in capacitance C when it is charged to voltage V is given by $E = \frac{1}{2}CV^2$. Rearranging gives $C = 2E/V^2$. Suppose we want the first filter capacitor to hold ten times as much energy as is required during one peak-to-peak interval. The capacitor must therefore hold 10.5J of energy, which requires a capacitance of $C = 2 \times 10.5 \div 42^2 = 0.0119F$, or 11,900μF. My choice of 10,000μF means the input capacitor holds about nine times as much energy as is used between peaks.

It would be possible to use the filter capacitor as the only stage of filtering. I looked at that possibility using the following LTSpice model.



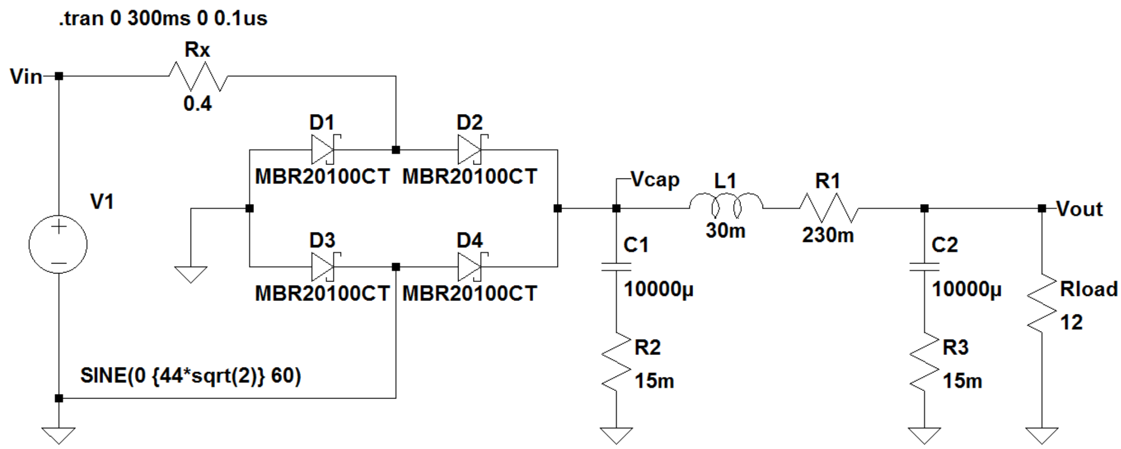
I have represented the transformer as a sinusoidal waveform with a peak voltage of $44\sqrt{2}$ Volts at 60Hz. The internal resistance of the transformer secondary is taken from Hammond's dimensional drawing for the 1182N22 (the internal resistance is not mentioned in the datasheet), which quotes 200mV ± 20% for each secondary coil. The capacitor I used is Mouser part #661-E36D101HPN103MC7. Its datasheet quotes a maximum equivalent series resistance (ESR) of 14.8mΩ. I have used a load resistance of 12Ω, which will draw current of 3A or a little more. The following graph shows the input and output voltages of this circuit for the first 125ms after power-on.



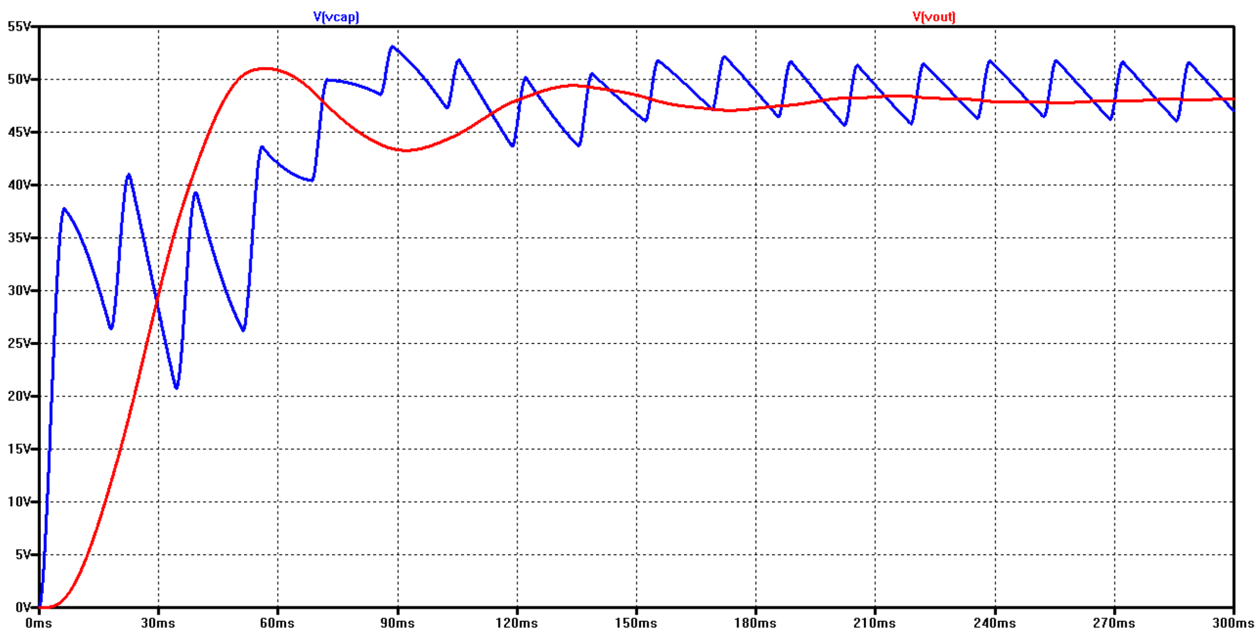
The ripple is about five Volts. I do not want to say that the TL783 could not manage with this much ripple, but I have chosen to add an inductive filter stage.

I chose the value of the choke using the same kind of energy-based reasoning as for the capacitor. The energy stored in inductance L when conducting current I is given by $E = ½LI^2$. Rearranging gives $L = 2E/I^2$. Suppose we set the same goal as for the capacitor, that the inductor should hold ten times as much energy as is required between peaks. The inductor would have to hold 10.5J of energy, which would require an inductance of $L = 2 \times 10.5 \div 3^2 = 2.3$ Henries. That is an enormous choke, much larger than is practical for this application. The limiting factor is the resistance of the wire from which the choke is wound. This resistance is in series with the pathway of the main current. There is a trade off between the regulation provided by the inductance (a good thing) and the voltage drop across the resistance (a bad thing). It is instructive to note that the biggest choke which Mouser sells that is rated for 3A or more has an inductance of only 150mH. This brings us to the second limiting factor: cost. Mouser's 150mH choke costs C$126.00. (Mouser has a 50mH choke that can handle 20A, but it costs C$998.00!) I settled on Mouser part # 546-195P5, which is 30mH ± 15% and rated is to 5A. It has a series resistance of 230mΩ.

The following LTSpice model shows the input power source with this inductor in place. The choke is followed by a second filter capacitor, with the same 10,000μF capacitance as the first filter capacitor.



The following graph is a plot of the important voltages during the first 300ms after power-up. I have not shown the input voltage, which is the same sinusoid as before. I have shown the voltage over the first filter capacitor (in blue) and the output voltage (in red). It takes this circuit longer to stabilize than the capacitor-only circuit. Adding the choke increases the ripple over the first capacitor, which now has to provide the current to build up the choke's magnetic field as well as sending current into the load. But the magnetic field decays during the second half of each cycle, when the choke adds to the current delivered by the capacitor. After about one second of operation, the output voltage swings between 47.97V and 48.07V, a ripple of only 100mV.



Other items in the final circuit

I make reference to Appendix "A", which is the schematic diagram for the final circuit.

As a visual indicator that the circuit is operating, I used a panel-mounted neon lamp which is powered directly off the 115Vac supply.

The fan is controlled by its own toggle switch, which I mounted on the rear face of the enclosure.

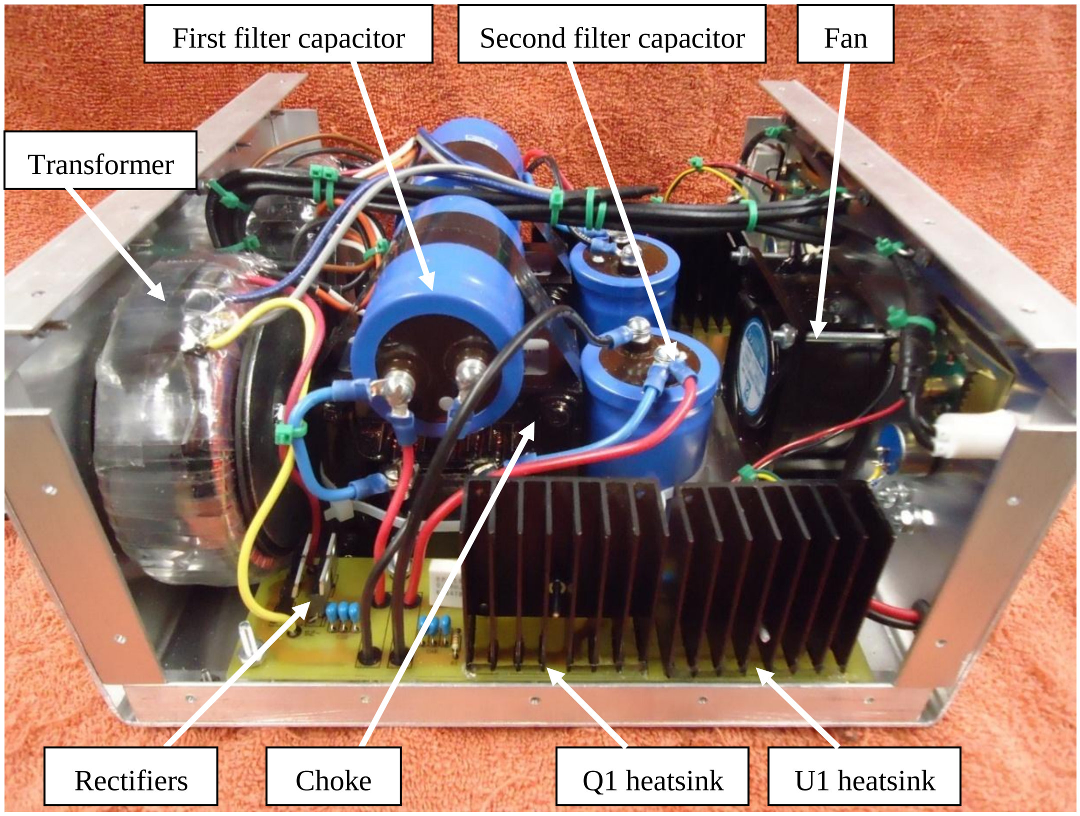
The 10K resistors wired across each second-stage filter capacitor are used to bleed the energy out of the capacitors after the power is turned off. For this purpose, the chokes can be thought of as jumpers which connect the first- and second-stage capacitors. The combined parallel capacitance of 20,000μF will discharge through the 10K bleed resistors with a time constant of τ = RC = 10K × 0.02 = 200 seconds. It will take several minutes for the energy to bleed out of the capacitors. At a nominal input voltage of 45V, these resistors will draw current of I = V/R = 45 ÷ 10K = 4.5mA, which will have negligible impact on the main current.

Because the output voltages are adjustable, it is handy to build-in voltmeters to allow the voltage of each channel to be monitored continuously. For this purpose, I used Mouser part # 580-20LCD-1-DCM-C. These are interesting little voltmeters, but they are not cheap. They are two-terminal voltmeters and can be wired into a circuit at the same points at which the probes of a hand-held voltmeter would be applied. However, they have a digital display and draw the power required to run the display from the voltage drop they are measuring. It follows that they will not work at voltages that are too low. The voltmeters I used have a range from 8V to 50V, and display one decimal digit. They are nearly perfect for this application.

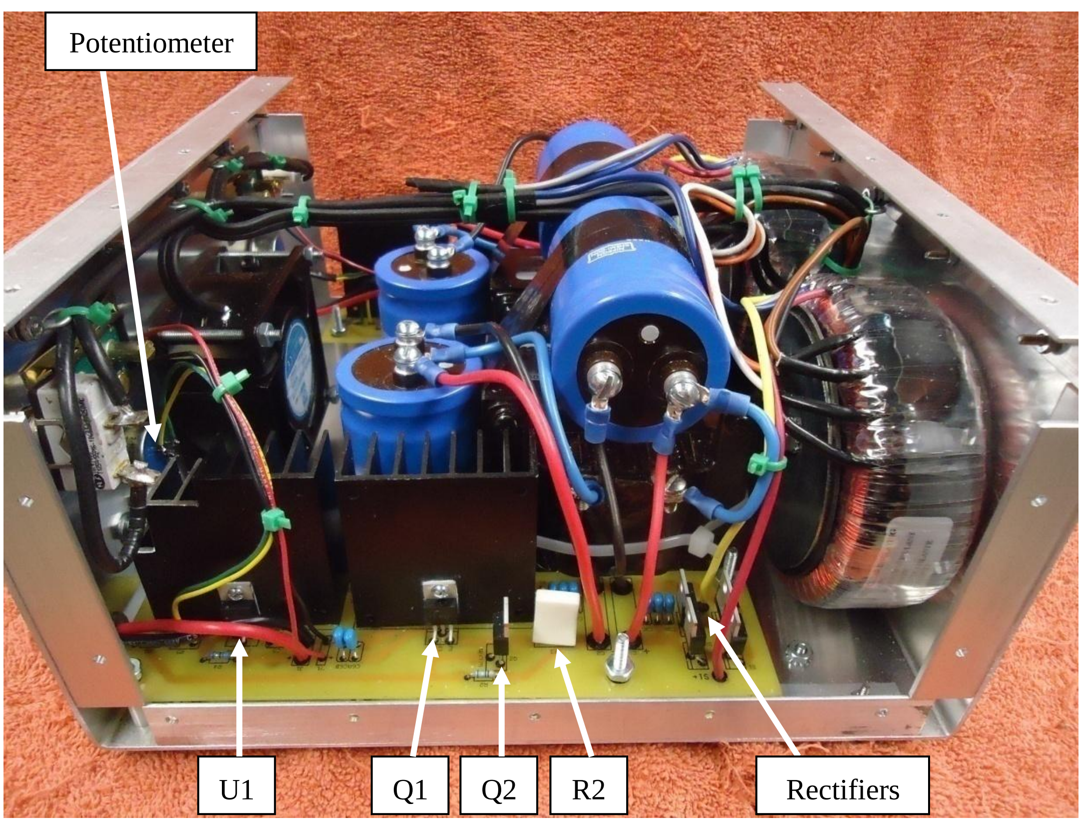
Photographs of the finished device

The following is the front panel. The fan is mounted in the center. It is oriented to blow air into the unit, from which it is exhausted through vents on either side. The power-on toggle switch is at the upper right and the neon lamp is at the corresponding position at the upper left. The voltmeters have rectangular displays and are mounted immediately below the “Channel A” and “Channel B” labels. The voltage-control potentiometers are below the voltmeters. I used big knobs (33mm diameter) to make fine adjustments easier. Output power is taken from barrier blocks mounted below the potentiometers.

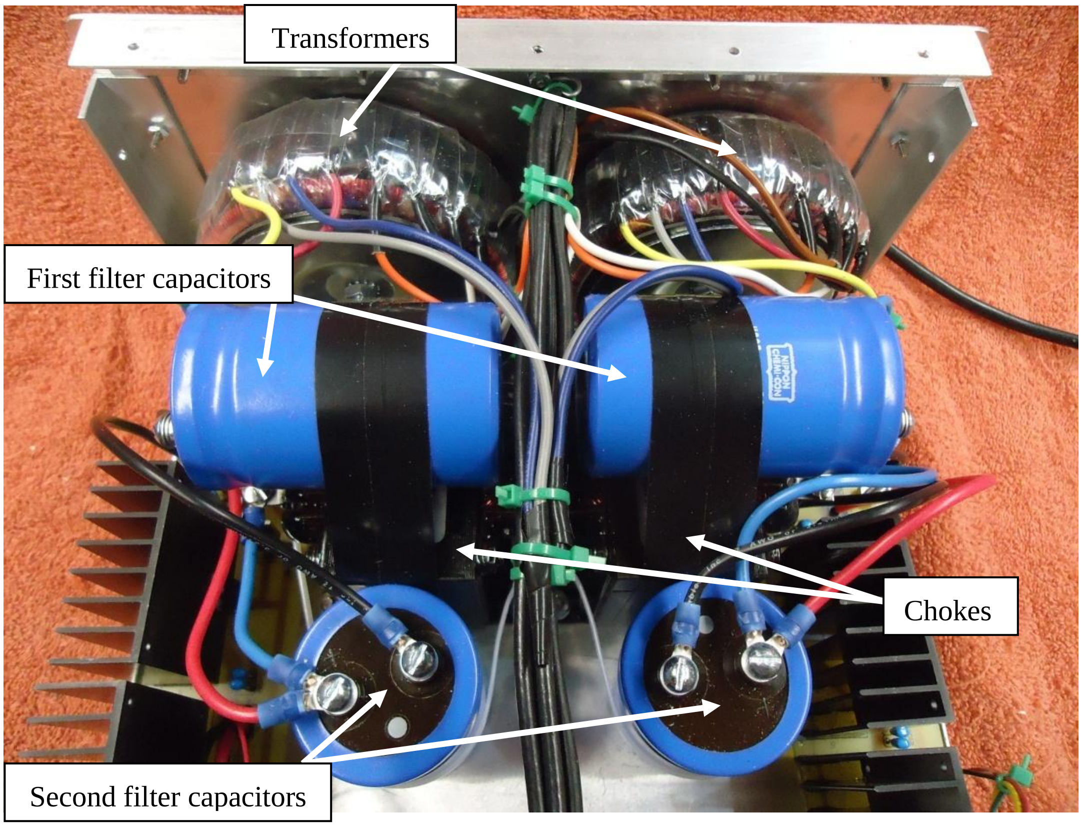
The following photograph is a view into the enclosure from the left side. I have labelled some of the "Channel A" components. The first filter capacitor is mounted crosswise on top of the choke. The second filter capacitor is mounted upright in front of the choke.



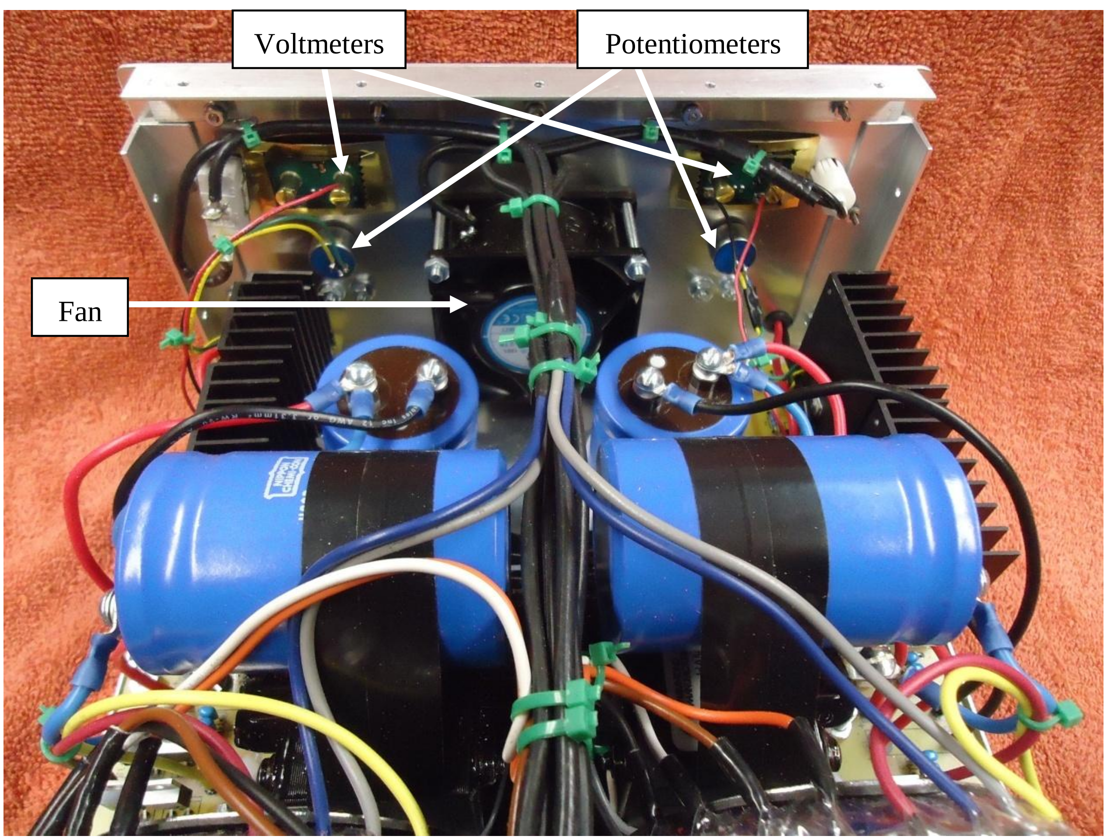
The following photograph is the corresponding view from the right side of the enclosure. The "Channel B" components are now in the foreground.



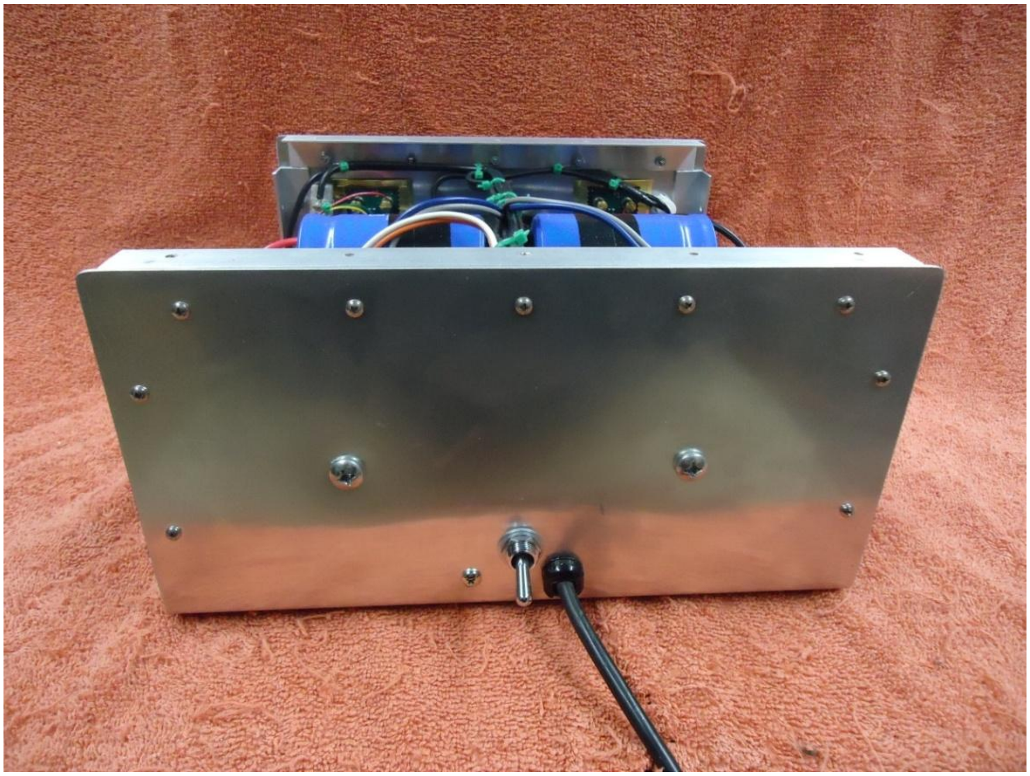
This is a view down into the enclosure from above the front panel. For convenience, I used the same printed circuit boards for both channels.



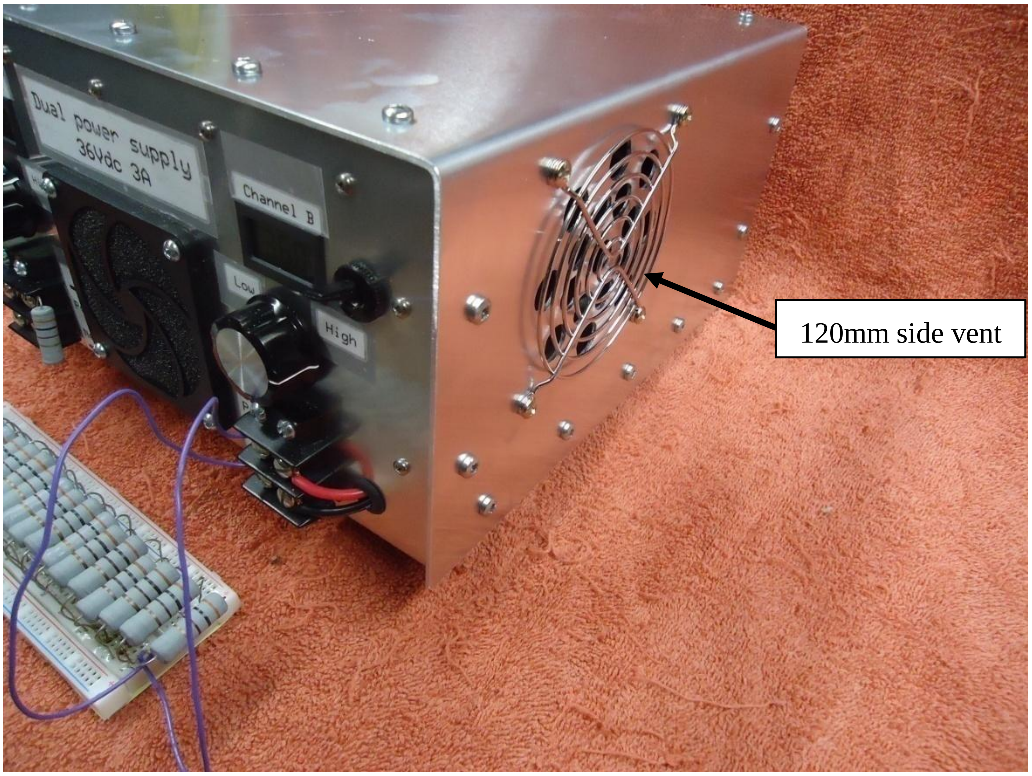
This is the view of the interior from above the rear panel.



The following photograph shows the rear panel. The toggle switch which controls the fan is located beside the point where the power cord enters the enclosure.



The following photograph shows the side of the power supply after the top has been screwed into place. The enclosure is made from 12-gauge aluminum sheet (0.0808 inches thick). The bottom and top are both bent into U-shapes using a bending brake. An L-shaped aluminum channel with 3/4-inch sides was bolted along the eight free edges of the bottom piece. To close up the unit, the top piece was screwed into these channels using sheet metal screws.



Lastly, the following photograph shows the power supply in operation. Channel A is holding 30.0V over a single 300Ω resistor. It is a 5W resistor which can easily dissipate the 3W to which it is being subjected.

Channel B is holding 36.0V over a resistance made up of 25 300Ω resistors connected in parallel on a small breadboard. The combined parallel resistance is 12Ω so the current flowing through the assembly is 3A. The resistors are dissipating a total of 108W and one can feel it.

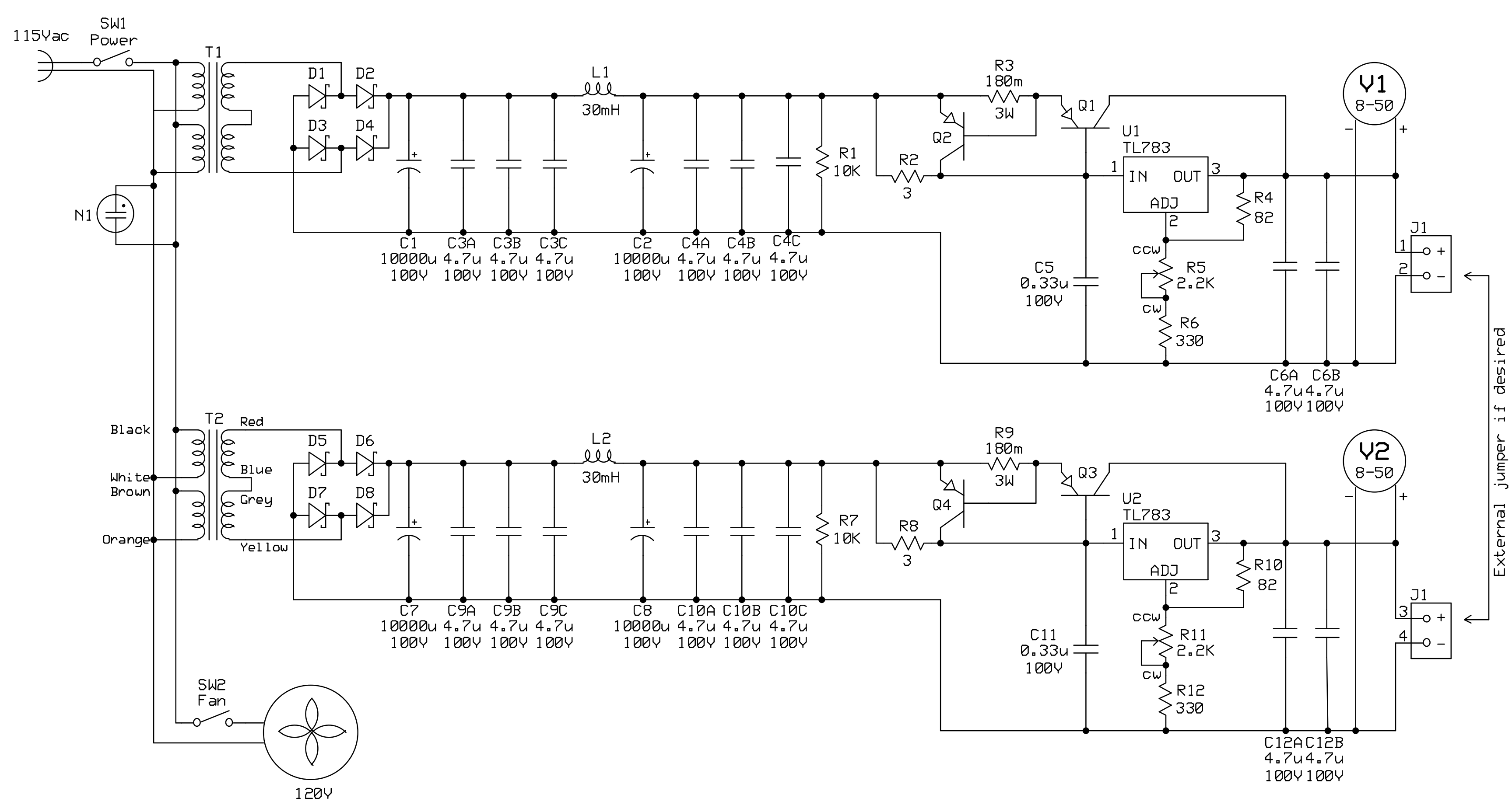
The following appendices are attached.

Appendix "A" – schematic diagram
Appendix "B" – printed circuit board layout
Appendix "C" – parts list

June 2017

Jim Hawley

(As always, I would appreciate an e-mail describing any errors or omissions.)



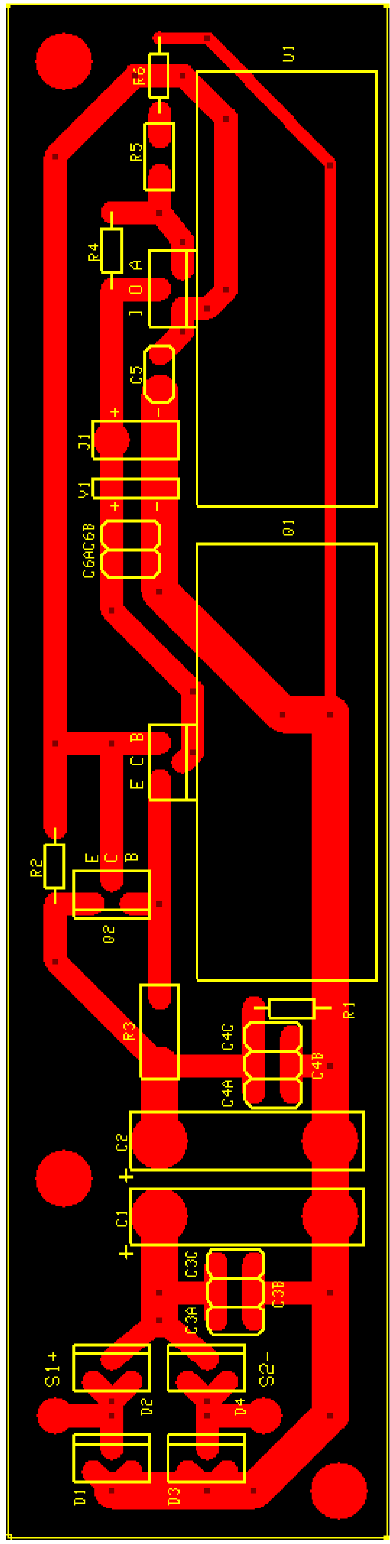
N1 = 120Vac neon indicator lamp
V1,V2 = 8V-50V voltmeter (I used Mouser #580-20LCD-1-DCM-C)
R3,R9 = 180mOhm 5% 3W (I used Mouser #660-BPR58CR18J)
R5,R11 = 2.2K 10% linear single-turn (I used Mouser #279-MCU2K210)
U1,U2 = TL783CKC3SE
Q1-Q4 = BD244CG 100V 6A pnp
L1,L2 = Hammond 195P5 30mH 5A 230mOhm
C3,C4,C9,C10 = Murata RCEC72A475MWK1H03B 4.7uF 20% 100V X7S ceramic
C1,C2,C7,C8 = United Chemi-Con 10,000uF 20% 100V 14.8mOhm aluminum
D1-D8 = MBR20H150CTG 0.87Vfwd 20A 180Asurge 150Vpiv
T1,T2 = Hammond 1182N22 toroid 44VCT 3.64A

Dual 36V 3A power supply

Jim Hawley

Appendix “B”

Printed circuit board layout (8.1 inches × 2 inches)



Appendix "C"

Parts list

T1,T2 - Power transformer (2)
Mouser #546-1182N22
Hammond #1182N22
Torioidal transformer 44VCT @ 3.64A
$85.44 (minimum two)

D1-D8 - Rectifier diodes (8)
Mouser #863-MBR20H150CTG
Diodes Inc. #MBR20H150CTG
Schottky rectifier 0.87Vfwd 20A 150PIV 180Asurge Ir=50uA
$1.32 (minimum 10)

L1,L2 - Filter choke (2)
Mouser #546-195P5
Hammond #195P5
Wirewound 30mH 5A 230mOhm
$103.33 (minimum two)

C1,C2,C7,C8 - Filter capacitors (4)
Mouser #661-E36D101HPN103MC7
United Chemi-Con #E36D101HPN103MC79M
Electrolytic 10,000uF 20% 100V 14.8mOhm
$24.55 (each)

SW1 - Power switch (1)
Mouser #642-631NH2
Apem #631NH/2
SPST toggle switch 250VAC paddle actuator
$5.03 (each)

U1,U2 - High-voltage Voltage regulator (2)
Mouser #595-TL783CKCSE3
TI #TL783CKCSE3
125V 700mA three-terminal voltage regulator TO220-3
$2.81 (each)

Q1-Q4 - pnp power transistor (4)
Mouser #863-BD244CG
ON Semi #BD244CG
pnp 100V 6A TO220-3
$1.41 (each)

V1,V2 - Voltmeter (2)
Mouser #580-20LCD-1-DCM-C
Murata #DMS-20LCD-1-DCM-C
8V-50V 3.5 digit LCD 2-terminal digital voltmeter panel-mount
$44.10 (each)

R5,R11 - Potentiometer (2)
Mouser #279-MCU2K210
TE Connectivity #MCU2K210
2.2K 10% linear cermet single-turn 2W
$26.95 (each)

R3,R9 - Short-circuit protection resistor (2)
Mouser #660-BPR58CR18J
KOA Speer #BPR58CR18J
0.18Ohms 5% 5W
$0.985 (each)

N1 - Power indicator light (1)
Mouser #607-1050A1
VCC #1050A1
120VAC neon lamp panel-mount
$5.10 (each)

C3,C4,C9,C10 - Ceramic capacitors (12)
Mouser #81-RCEC72A475MWK1H3B
Murata #RCEC72A475MWK1H03B
4.7uF 20% 100V X7S 5mm-spacing
$1.94 (minimum 10)

C5,C11 - Ceramic capacitors (2)
Mouser #80-C320C334K1R5TA
KEMET #C320C334K1R5TA
0.33uF 10% 100V X7R 2.54mm-spacing
$0.662 (each)

C6,C12 - Ceramic capacitors (2)
Mouser #81-RDEC71H106K3K1H3B
Murata #RDEC71H106K3K1H03B
10uF 10% 50V X7S 5mm-spacing
$0.864 (minimum 10)

R2,R8 - Resistors (2)
Mouser #660-MF1/4DCT52R3R00F
KOA Speer #MF1/4DCT52R3R00F
3Ohm 1% 1/4W
$0.147 (each)

R4,R10 - Resistors (2)
Mouser #660-MF1/4DCT52R82R0F
KOA Speer #MF1/4DCT52R82R0F
82Ohm 1% 1/4W
$0.081 (minimum 10)

R6,R12 - Resistors (2)
Mouser #660-MF1/4DCT52R3300F
KOA Speer #MF1/4DCT52R3300F
330Ohm 1 1/4W
$0.081 (minimum 10)

Fan guards (2)
Mouser #978-KM92
Sanyo Denki #KM92
92mm finger guard
$1.18 (each)

AC fan (1)
Mouser #670-OA80AP112TB
Orion #OA80AP-11-2TB
80mm x 35mm 115Vac 23CFM 22dB
$22.51 (each)

Fan screen (1)
Mouser #562-09325F30
Qualtek #09325-F/30
80mm fan PPI filter assembly
$2.91 (each)

Cabinet feet (4)
Mouser #563-F-7264-A
Budd #F-7264-A
3/4-inch diameter plastic feet with bolt
$0.882 (each)

Knobs for potentiometers (4)
Mouser #45KN016-GRX
Eagle Plastics #45KN016-GRX
33mm-diameter knob with skirt for 1/4-inch shaft
$2.43 (each)