WeiKedz 0-30V 2mA-3A Adjustable DC Regulated Power Supply DIY Kit
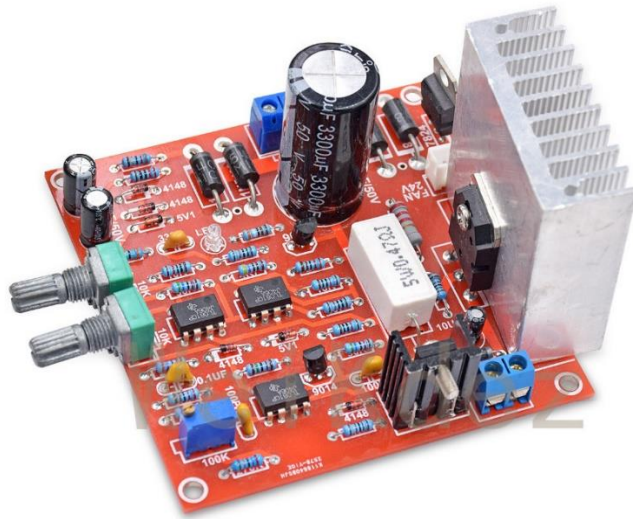
Operation and Maintenance Manual

The WeiKedz Adjustable DC Regulated Power Supply provides continuously variable output voltage between 0 and 30V and continuously variable output current between 2mA and 3A. This power supply is an indispensable tool for circuit design, experimenting, and testing work. The current limiting feature is especially important when used properly as it can prevent simple wiring mistakes from destroying circuit components, which saves time and money.

Technical specifications:

Input voltage:	24VAC
Input current:	3A DC (max)
Output voltage:	0 to 30VDC (adjustable)
Output current:	2mA to 3A DC (adjustable)
output voltage ripple:	0.01% (max)

Power Supply Features:

- All through-hole components. Assembly, troubleshooting, and repair is easy.
- Easily adjustable output voltage and current.
- LED indicates when current limit is triggered.

The WeiKedz variable power supply is a standard analog regulator design with 5 functional blocks as described below:

Bridge Rectifier and Capacitor Filter

Converts the 24 VAC power from the transformer into +32.5 VDC and -5 VDC power for use by other function blocks.

Voltage Reference

Provides a fixed known reference voltage that other function blocks use to control the power supply output voltage and limit the power supply output current.

Error Amplifier

Compares the voltage set-point to the actual output voltage and signals the Current Pass function to raise or lower the output voltage to match.

Current Limiter

Senses the output current and signals the Error Amplifier to reduce the output voltage when the current limit is exceeded.

Current Pass Regulator

Maintains the voltage set by the Error Amplifier independent of the current drawn by the circuit attached to the power supply.
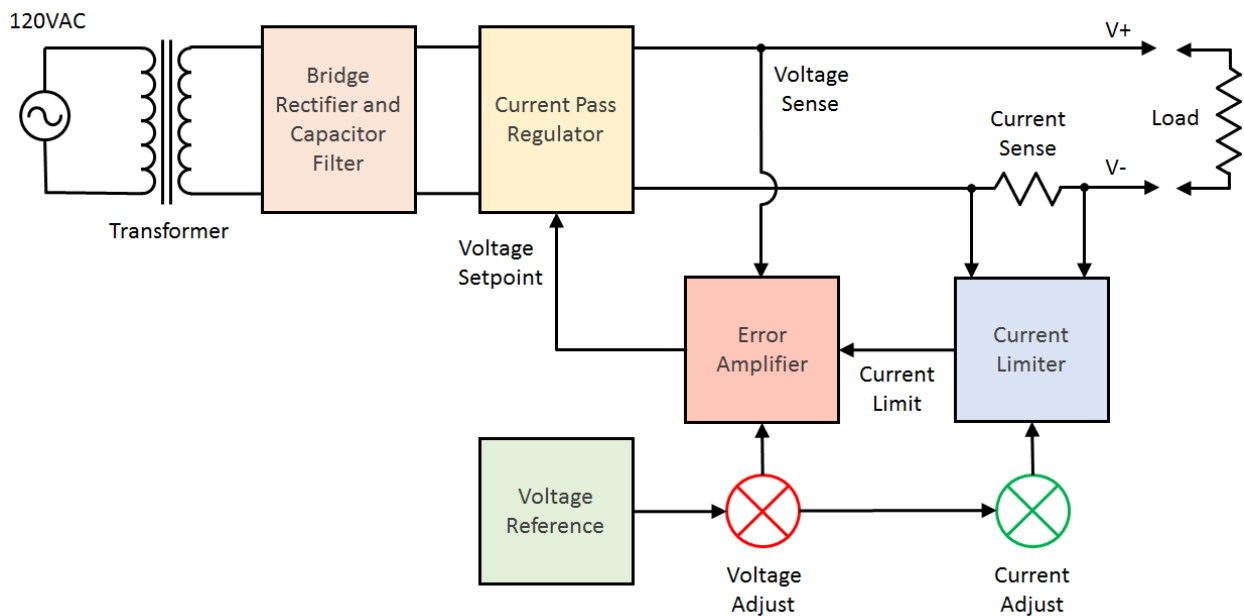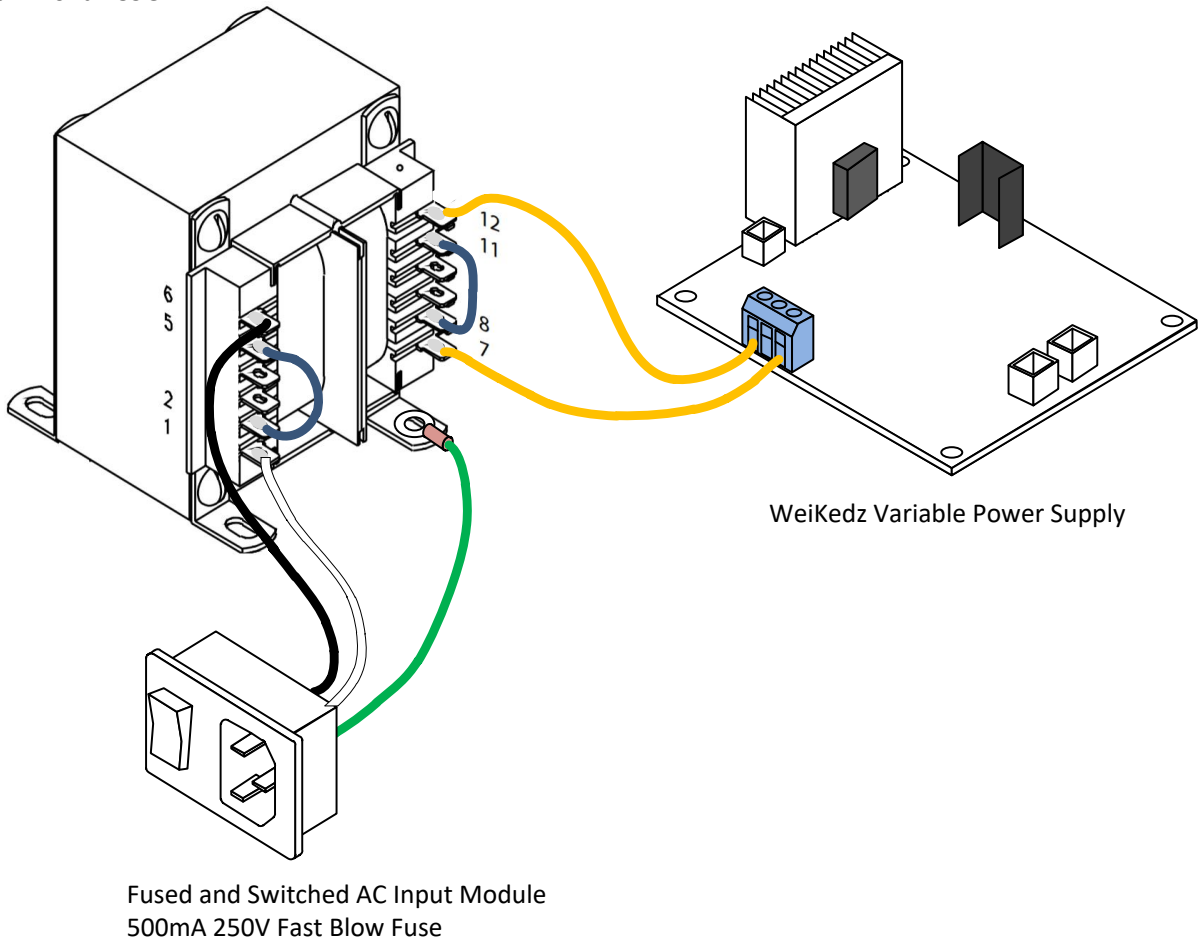
Attaching a Transformer

WeiKedz product documentation recommends the use of a 24VAC transformer with power rating greater than or equal to 90VA. Based on product lab testing, however, it is highly recommended that a 20VAC transformer of approximately 80VA be used instead. This will keep all components well below their maximum operating limits. The recommended transformer is a Hammond Manufacturing model number 185E20. However, if the user prefers to keep to the WeiKedz recommendation, a Hammond Manufacturing model number 185G24 can be used. Both transformers can be purchased for around $35 from several retailers. The connection diagram for the Hammond transformers is shown below for US 60Hz 115VAC.

Hammond 185E20 (Recommended) or
Hammond 185G24

WeiKedz Variable Power Supply

Fused and Switched AC Input Module
1A 250V Fast Blow Fuse
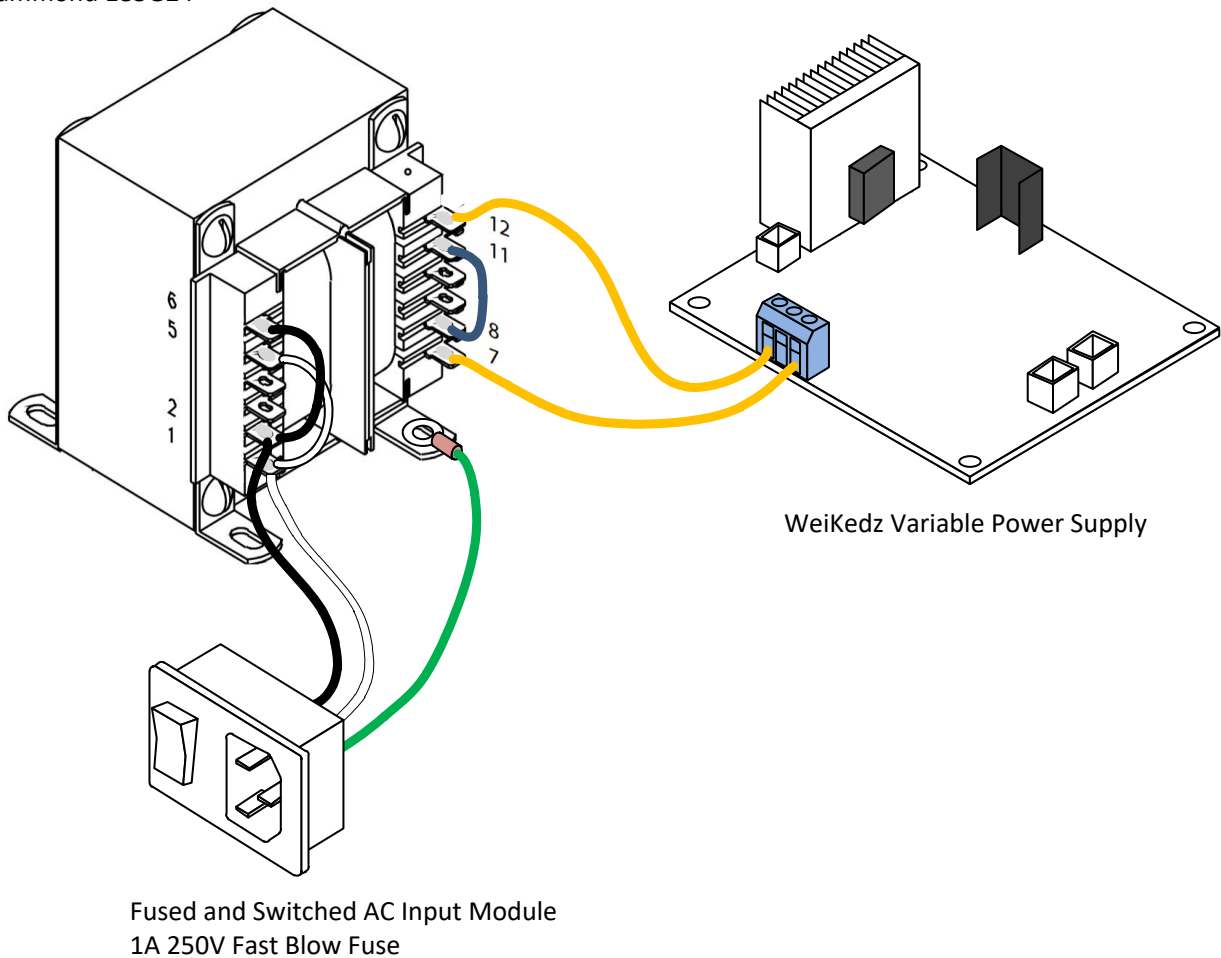
The connection diagram for the Hammond transformers is shown below for International 50Hz/60Hz 230VAC.

Hammond 185E20 (Recommended) or
Hammond 185G24

WeiKedz Variable Power Supply

Fused and Switched AC Input Module
500mA 250V Fast Blow Fuse

It is highly recommended that all power supply components be enclosed in a suitable case. If the case is plastic, be sure to attach the ground pin of the AC Input Module to the transformer mounting bracket. If the case is metal, attach the ground pin of the AC Input Module to a bare metal mounting point.

Power Supply Setup

1. Turn the voltage potentiometer P1 fully counter-clockwise.
2. Turn the current potentiometer P2 fully counter-clockwise.
3. Attach a digital voltmeter to the poser supply output terminals.
4. Adjust trimmer resistor RV1 until the output voltage is exactly 0V.

The power supply is now ready for use.

Theory of Operation – Rectifier/Filter Circuit

The Rectifier/Filter circuit is composed of three separate power supplies: The V+ Supply, the V- Supply, and the Fan Supply. A short description of each is provided below.

The V+ Supply

The rectifier and filter section is a very basic full-wave bridge bridge circuit (D1 through D4) with a large filter capacitor attached (C1). Resistor R1 will safely discharge C1 when AC power is disconnected from the transformer. The transformer attached to the power supply provides an alternating current (AC) voltage with frequency of 50Hz or 60Hz depending on country. On the positive half of the AC cycle, diodes D1 and D4 conduct which charges capacitor C1 for that portion of the cycle. On the negative half of the AC cycle, diodes D2 and D3 conduct which also charges capacitor C1 for that portion of the cycle. See Illustration 1. The peak voltage on C1 is determined by the following formula: $V_p = V_{rms} * 1.414$ where Vrms is the transformer secondary coltage.

The V- Supply

The remainder of the circuit is a -5V power supply for use by the Current Limit, Error Amplifier, and Current Pass function blocks. During the negative half of the AC cycle, C2 is charged through R2 and D3/D5. The time constant of R2/C2 allows C2 to reach an average charge of about +21.5V. R2 also serves to limit the ripple current in C2 to around 60mA which is important as the manufacturers datasheet recommends no more than about 112mA ripple current or reliability will be affected. During the positive half of the AC cycle, C2 discharges into C3 via R2 and D1/D6 until C3 reaches an average charge around -10V. Zener diode D7 then regulates the voltage from C3 down to -5.6V which is then sent to other power supply function blocks. For this supply to work correctly, the transformer must have a secondary voltage of at least 18V RMS.

The Fan Supply

The fan included with the WeiKedz power supply is a standard DC brushless fan requiring 24V at 100mA. A three-terminal regulator IC U4 (7824) is used to provide a constant 24V output to the fan. Power dissipation for U4 is almost 1W so this part will get very warm during operation. There is no heat sink provided for this part so some convection or forced air flow will be required to keep it from going into thermal shutdown.
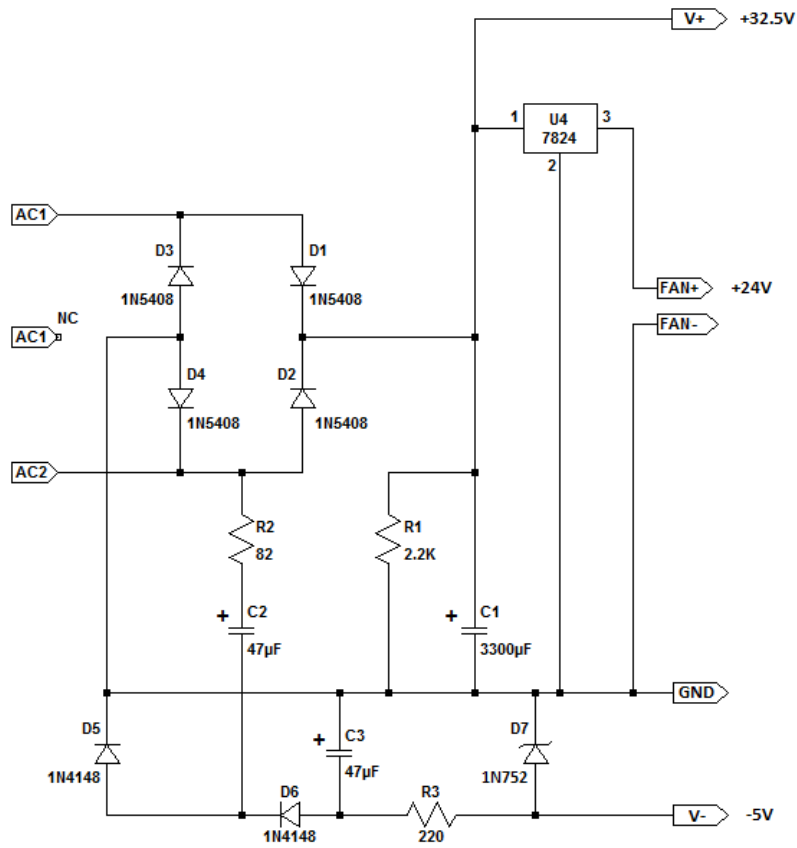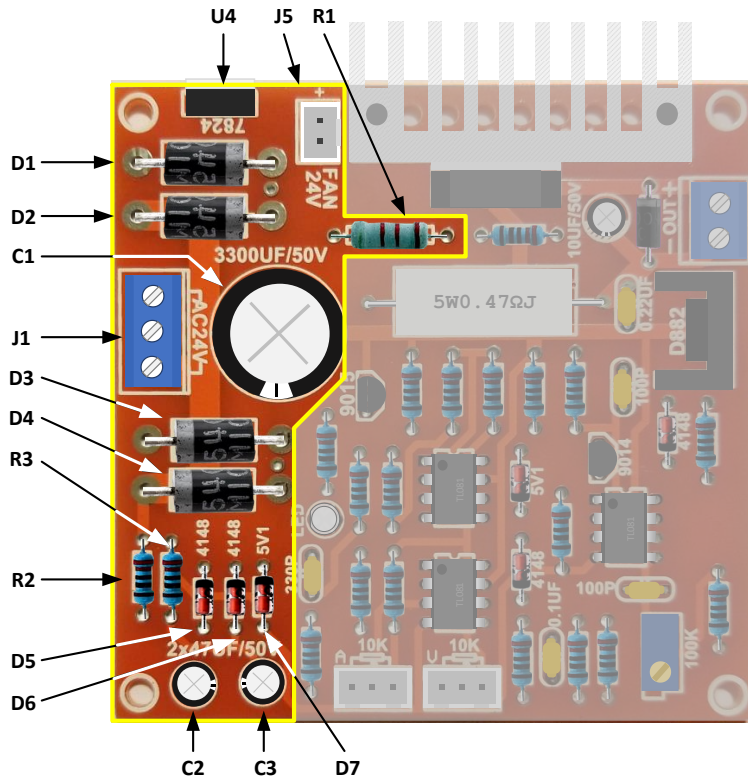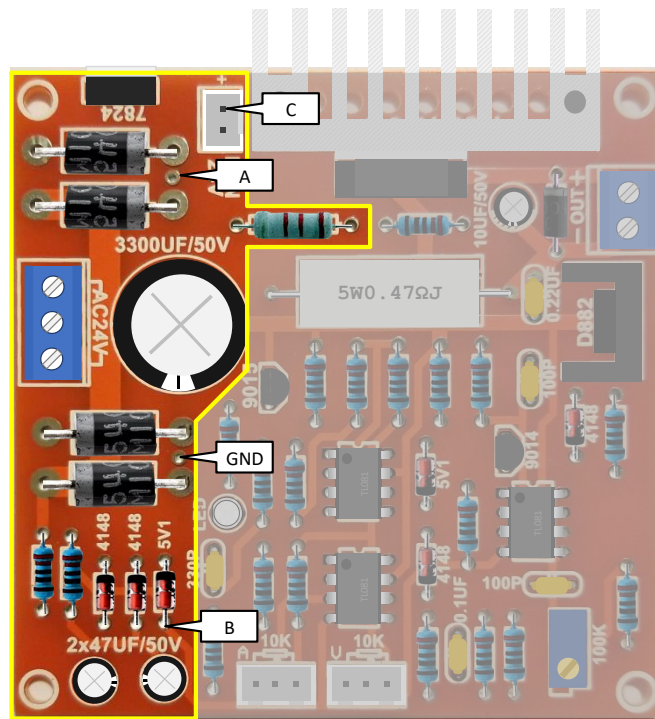
Illustration 1 - Rectifier Section Schematic and Component Placement

Illustration 2 - Rectifier Section Test Point Voltages

All voltages measured with respect to GND. No load attached. All voltages +/- 10% of indicated value.

Reference Point	20V Transformer	24V Transformer
A	+26.9V	+32.5V
B	-5.6V	-5.6V
C	+24V	+24V

Theory of Operation – Voltage Reference Circuit

The voltage reference circuit generates a constant voltage for controlling the power supply output voltage and current. Operational amplifier U1 (TL081) doubles the 5.6V Zener voltage of D8 to 11.2V which is then scaled into output voltage and current set-points via potentiometers P1 and P2. The VREFout can be adjusted between 0 and 11.2V. The IREFout voltage can be adjusted between 0.006V and 1.7V.

The output voltage of U1 is described by the following equations:

Va = Vo * R6 / (R5 + R6)   where Va is the voltage on the non-inverting (+) pin of U1

Vb = Vo - Vz   where Vz is the zener diode voltage and Vb is the voltage on the inverting (-) pin of U1

Vo = Va - Vb   where Vo is the voltage on the output pin of U1

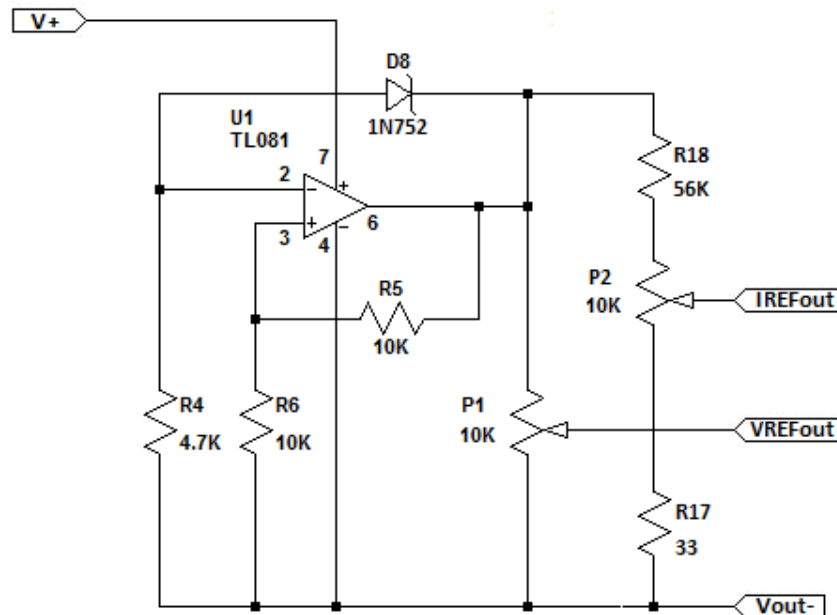The above equations simplify to:

Vo = Vz * 2

Illustration 3 - Reference Section Schematic
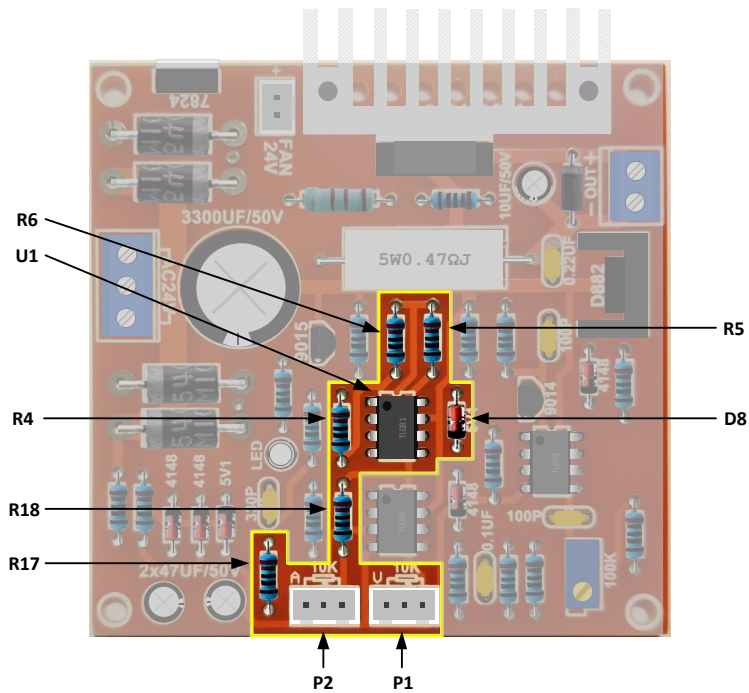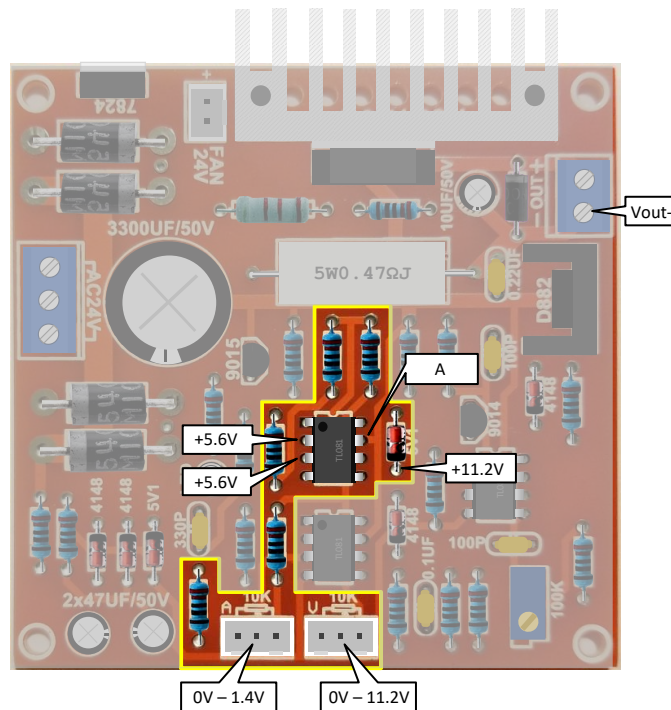
Illustration 4 – Component Placement and Test Point Voltages

All voltages measured with respect to Vout-. No load attached. Test Point A is 32.5V for 24VAC Transformer, 26.9V with 20VAC Transformer. Potentiometer's must be attached for P1 and P2 test points to be valid (check from center pin of potentiometer). All voltages +/- 10% of indicated value.

Theory of Operation – Error Amplifier Circuit

The Error Amplifier measures the power supply output voltage, compares it to the set-point voltage selected by the user, and tells the Current Pass function to raise or lower the output voltage until it matches the set-point voltage. The Error Amplifier circuit provides a number of features that enhance the control of the output voltage:

1. Low pass filter for P1/P2

R8 and C4 form a low pass filter with cutoff frequency of:

$Fc = 1 / (2 * pi * R * C)$
$Fc = 1 / (2 * pi * 27000 * .0000001) = 59$ Hz

This prevents AC and RF noise pickup on the potentiometer wiring from affecting the power supply output.

2. Regulator Soft Start

To avoid power supply output ringing and possible oscillation during startup and after a current limit event, the time constant of R8 and C4 smoothly raises the output voltage over a time period of 14ms as defined by the following equation:

$t = 5 * R * C$
$t = 5 * 27000 * .0000001 = .014$ seconds

3. Error Amplifier Offset Null

Operational Amplifiers aren't perfect and sometimes the IC output doesn't reach the exact voltage expected due to IC variation, temperature, and external component tolerances. The difference between the expected output voltage and the actual output voltage is called the "offset voltage". Normally this voltage is very small and doesn't affect the operation of a typical OpAmp circuit. But in precision control circuits it can be critical that offset be removed or "nulled out". The TL081 provides an optional set of pins to do this. Trimmer resistor RV1 and fixed resistor R10 comprise the external null adjustment for IC U2.

4. Current Limit Signal

The Error Amplifier input is connected to the Current Limiter output through diode D9 (See Current Limiter circuit description) which provides a fold-back current limit feature that reduces the set-point voltage at the Error Amplifier until the output current falls below the current limit set-point. To completely turn off the power supply voltage output, the current limiter output must be able to go negative by at least -0.7 volts due to the voltage drop on diode D9. This is facilitated by the negative 5.6V power supply.

5. Feedback Low Pass Filter

The addition of C6 to feedback resistors R11 and R12 form a low pass filter with cutoff frequency approximately 32Khz. This feature is included to prevent high frequency noise at the output being amplified by the power supply.

6. Slew Rate Limiter

The TL081 OpAmp has a maximum slew rate of 13V/uS which is exceptionally fast for a simple low-cost IC. The addition of C9 between the U2 output and inverting input (-) pin limit the OpAmp slew rate to around 50uS. Without C9 the output of U2 tends to overshoot and ring with sudden changes in the power supply output voltage. In combination with capacitor C6, capacitor C9 further reduces the feedback filter cutoff frequency to 16Khz. Frequency response rolls off to unity gain around 100Khz which helps prevent the power supply from becoming an oscillator.

7. Voltage Error Amplifier

The Error Amplifier is a simple non-inverting amplifier described by the following standard equation:

Vout = Vref * (1 + R12 / R11)

The feedback loop is not connected to the output of U4 per standard OpAmp design. Instead it is connected after the Current Pass function which has a DC voltage drop of 1.4V which results in the modification of the standard equation:

Vout = Vref * (1 + R12 / R11) + 1.4

The closed-loop DC gain of the amplifier is:

Acl = 1 + R12 / R11 = 1 + 56K / 27K = 3

The Voltage Reference includes a set-point potentiometer P1 which provides a voltage to the Error Amplifier between 0 and 11.2V. The Error Amplifier output to the Current Pass section is therefore between:

Vout = (Vref * Acl) + 1.4 = (0 * 3) + 1.4 = 0V

and

Vout = (Vref * Acl) + 1.4= (11.2 * 3) + 1.4 = 35V

When the set-point reference voltage is set with P1, the error amplifier will continuously compare the power supply voltage to the set-point and adjust its output voltage up or down so that the power supply output voltage does not change regardless of load current.
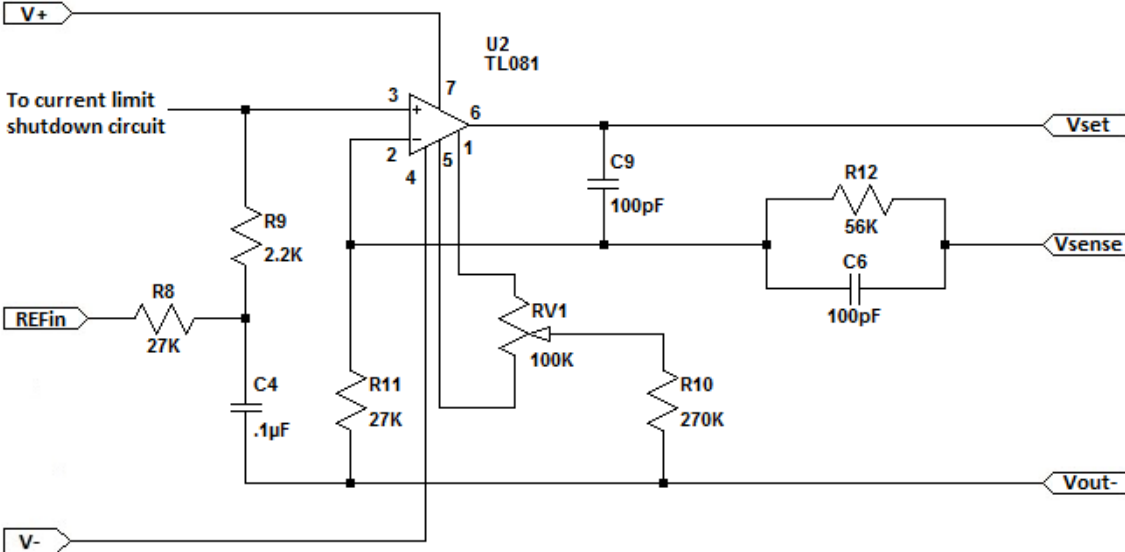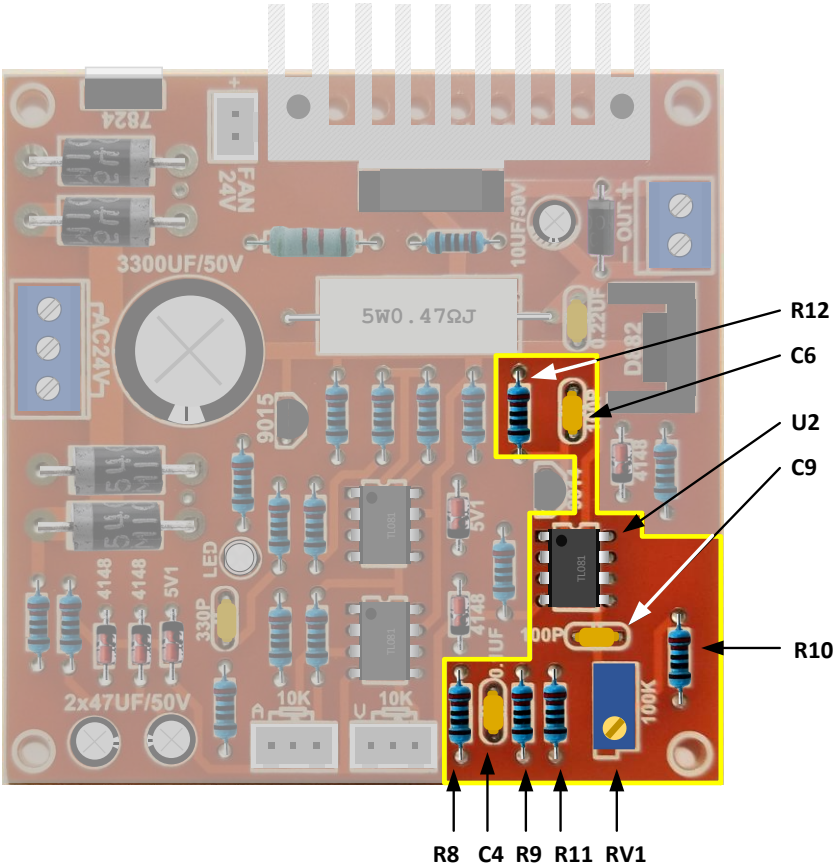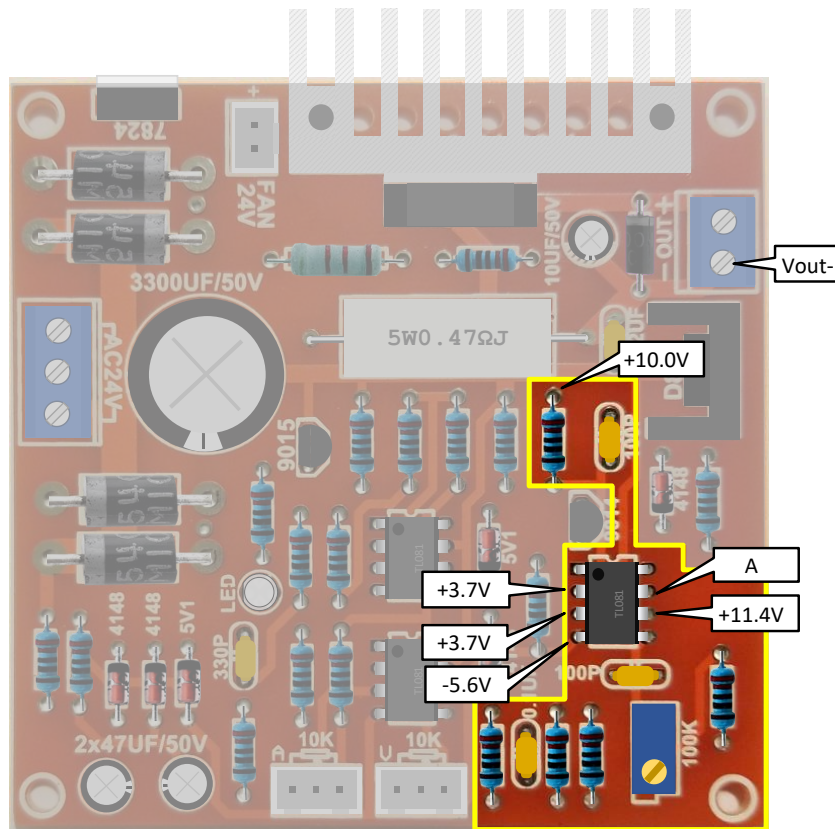
Illustration 5 – Schematic and Component Placement

Illustration 6 – Error Amplifier Section Test Point Voltages

All voltages measured with respect to Vout-. No load attached. Test Point A is 32.5V for 24VAC Transformer, 26.9V with 20VAC Transformer. Potentiometer's must be attached for test points to be valid. Adjust Current potentiometer P2 to 1/2 rotation. Adjust Voltage potentiometer P1 to power supply output of 10V between Vout+ and Vout-. All voltages +/- 10% of indicated value.

Theory of Operation – Current Limit Circuit

The current limiter circuit measures the voltage on the current sense resistor and compares it to the current set-point voltage. Initially the output of the limiter is near the V+ power rail, but switches toward the V- power rail when the current set-point is exceeded. This reduces the reference voltage at the Error Amplifier and keeps the regulator output current near the current set-point.

1. Current Sensing

The current sense resistor R7 is a small value power resistor (sometimes referred to as a "shunt") that works as a current-to-voltage transducer. Its value must be small so that only a minimal amount of energy is lost, but it also must be large enough to produce a measurable voltage for U3. The relationship between the current through R7 and the voltage on R7 is:

Vr = I * R where I is the power supply output current and R is the value of R7. For various output currents the voltage on R7 is:

Vr = 0 * 0.47 = 0V when I is 0 Amps.

Vr = 1 * 0.47 = 0.47V when I is 1 Amp.

Vr = 2 * 0.47 = 0.94V when I is 2 Amps.

Vr = 3 * 0.47 = 1.41V when I is 3 Amps.

2. Voltage Comparator

IC U3 compares the voltage on the current sense resistor with the current set-point voltage on potentiometer P3 and generates an output voltage proportional to the equation:

Vo = A * (Va - Vb) where Va is the voltage on the non-inverting (+) input pin and Vb is the voltage on the inverting (-) input pin.

When there is no feedback network attached to U3, gain A is a very large number so the output of U3 can be described as follows:

Vo = 0, when (Va - Vb) = 0

Vo = V+ (V+ is the positive power supply voltage), when (Va - Vb) > 0

Vo = V- (V- is the negative power supply voltage), when (Va - Vb) < 0

The current sense voltage can vary between 0V and 1.41V when output current varies between 0A and 3A. This is the voltage range that will be compared to the current limit set-point voltage.

3. Current Limit Set-Point

Potentiometer P2 is used to provide the set-point current limit voltage. It's a simple voltage divider composed of P2, R17, and R18. The set-point voltages that can be obtained from P2 are described by:

Vccw = Vref * (R17 / (R17 + P2 + R18)) where Vref is the reference voltage of 11.2V and Vccw is the voltage on U3 Pin3 when P2 is fully counter-clockwise.

Vcw = Vref * ((R17 + P2) / (R17 + P2 * R18)) where Vref is the reference voltage of 11.2V and Vcw is the voltage on U3 Pin3 when P2 is fully clockwise.

Because OpAmp U3 is acting as a voltage comparator its output will shift from V+ to V- only when the current sense voltage is greater than the current set-point voltage. So the minimum and maximum power supply output currents can be calculated as:

Iccw = Vccw / R7 = 0.0056 / 0.47 = 12mA

Icw = Vcw / R7 = 1.70 / 0.47 = 3.62A

4. Slew Rate Limiting

The TL081 OpAmp has a maximum slew rate of 13V/uS which allows it to traverse the recommended +V/-V power rails in about 2uS. This is fast enough for parasitic inductance and capacitance to induce ringing and oscillation in the power supply. To prevent that, C8 limits the slew rate from 13V/uS to around 0.3V/uS.

5. Current Limit Indicator

The current limiter includes an indicator feature that lights an LED when current limiting is engaged. When U3 output falls to around 28V, PNP transistor Q3 is forward biased through resistors R19 and R20 as described in the formula:

Vo = (V+) - (VBEsat * (R19 + R20)) / R19 where V+ is the voltage on C1 and VBEsat is the forward biased base-emitter saturation voltage for the SS9015 PNP transistor (see data sheet below).

When Q3 turns on, almost the full V+ voltage is applied to R22/D12 and the LED current is limited to approximately 7.8mA:

ILED = (V+ - VLED) / R22 = (32.5 - 2.2) / 3900 = 7.8mA

Power dissipated in R22 is:
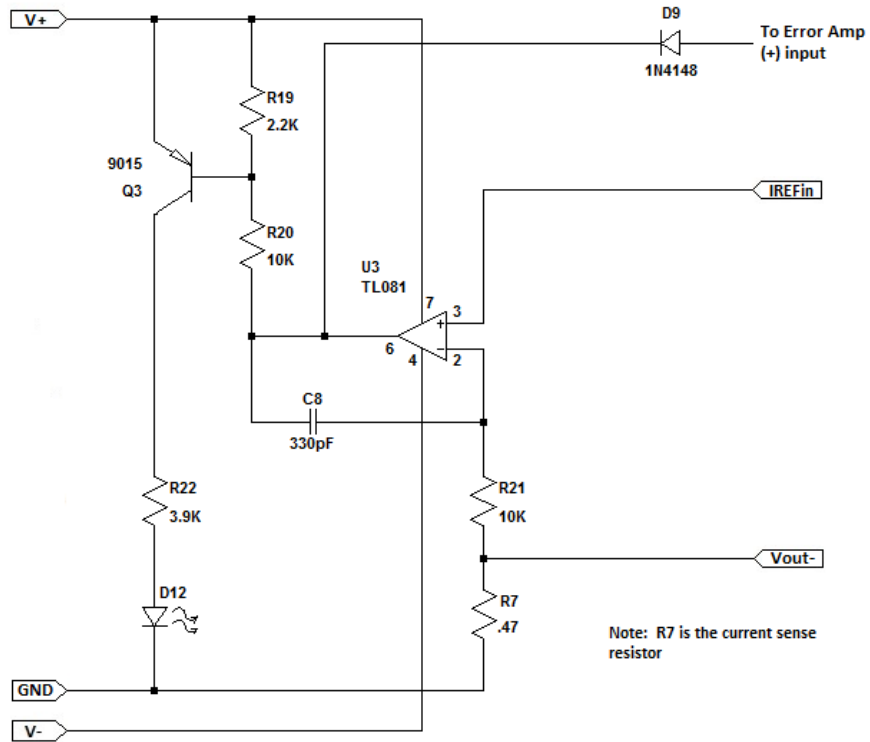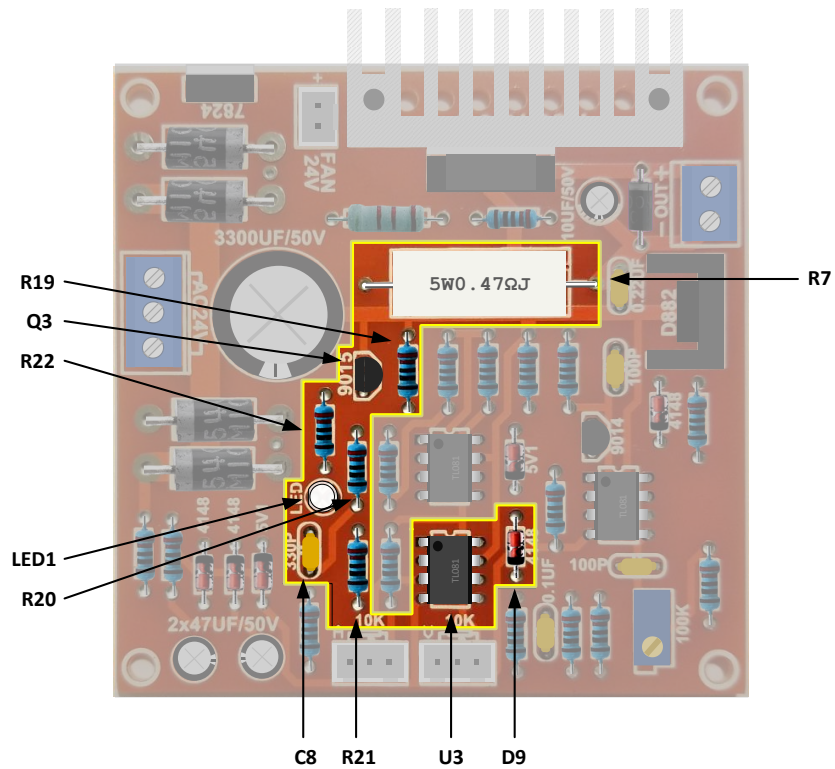
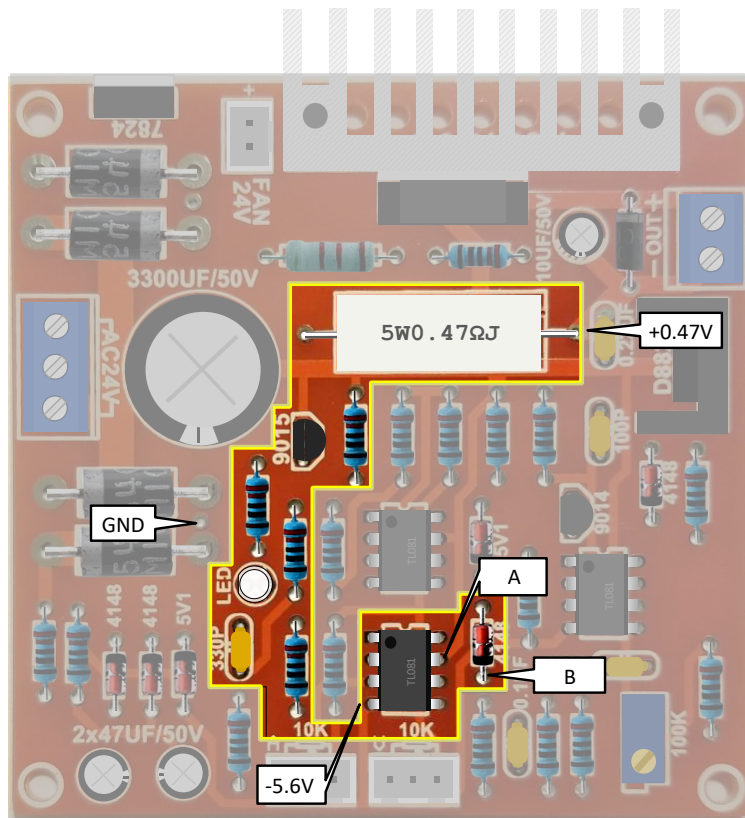P = ILED^2 * R22 = .0078^2 * 3900 = 237mW

Illustration 7 – Current Limit Schematic and Component Placement

Illustration 8 – Current Limit Test Point Voltages

All voltages measured with respect to GND. Test Point A is 32.5V for 24VAC Transformer, 26.9V with 20VAC Transformer. No load attached. Potentiometer's must be attached for test points to be valid. The voltage at test point B should be approximately 1.5V below test point A.

Attach a 100 Ohm 2W resistor to Vout+ and Vout-. Adjust current potentiometer P2 to full clockwise rotation. Turn voltage potentiometer P1 until the voltage on R7 is +0.47V as indicated. Slowly turn current potentiometer P2 counter-clockwise until LED1 starts to light. The voltage at test point B will decrease as P2 is rotated counter-clockwise and LED1 will brighten.

All voltages +/- 10% of indicated value.

Theory of Operation – Current Pass Circuit

The Current Pass circuit provides a fixed output voltage regardless of the load attached to the power supply (depending on the current limit set-point or the maximum current rating of the supply).

The active elements are Q2 (2SD1047) and Q4 (2SD882). These two transistors are wired in a Darlington configuration which provides an extremely high input impedance (>50K Ohms) to the Error Amplifier and a very low output impedance (<0.1 Ohms) to the load and very high DC current gain (>10,000).

The output voltage is described by the following equation:

Vout+ = Vset - 1.4 where Vset is the set-point voltage from potentiometer P1

The current pass circuit also provides a few ancillary functions described below:

1. -5V Failure Shutdown

The -5V supply is required for the variable power supply to operate properly. Without it, the Error Amplifier and Current Limit functions become unstable. R13, R14, and Q1 form a shutdown circuit for the Current Pass function if the -5V power supply falls below approximately -3.8V. Q1 will be saturated by R13 which shorts the output of Error Amplifier U2 to ground. This turns off Q2 and Q4 and drops the power supply output to 0 volts. U2 is internally protected from short circuit to ground or to either of the power supply pins.

2. C7 Discharge

C7 improves output voltage stability when powering circuits with small but rapid changes in load current. However, C7 doesn't have a low impedance discharge path if no load (or very light load) is attached to the power supply. The only path available is the large value resistors R11/R12 (83K Total) in the Error Amplifier. If the power supply output voltage is set to maximum, and then quickly set to zero, Q4 Base-Emitter junction will be reverse biased and no current will flow through the Current Pass function. It will then take over 4 seconds for C7 to discharge through R11/R12 according to the following:

Discharge Time = R * C * 5 = (56000 + 27000) * .00001 * 5 = 4.15 seconds

This will be visible if a volt meter is used to measure the power supply output, and can make adjusting the power supply difficult without a load attached.

To prevent this, D10 and R15 were included to provide a low impedance discharge path for C7. If the reference voltage falls below the output voltage, D10 will be forward biased which results in R15 being connected across C7. The discharge rate for C7 will then be:

Discharge Time = R * C * 5 = 1000 * .00001 * 5 = .05 seconds

R11/R12 were not included in the above equation because their combined value is so large that R15 dominates.

3. Reverse Output Voltage Protection

To protect the power supply from reverse voltages attached to the output (charged capacitors, batteries, another power supply, etc.) diode D11 is attached across C7. If a voltage greater than -0.7 volts is attached to the power supply output, D11 will conduct preventing the voltage from rising further until the offending voltage is removed or D11 is destroyed.
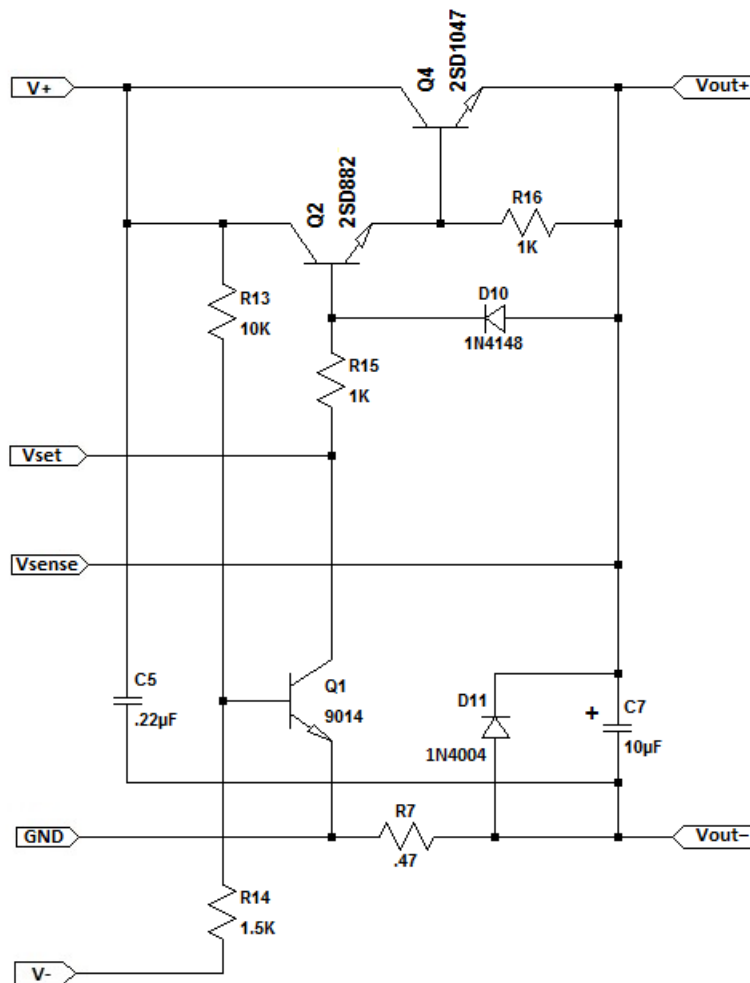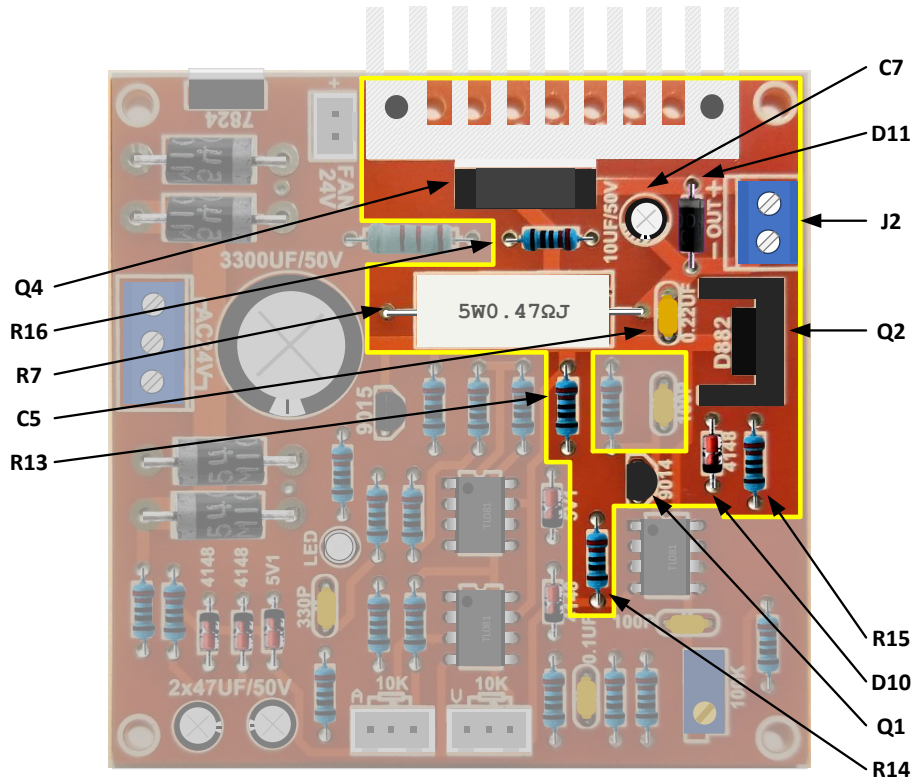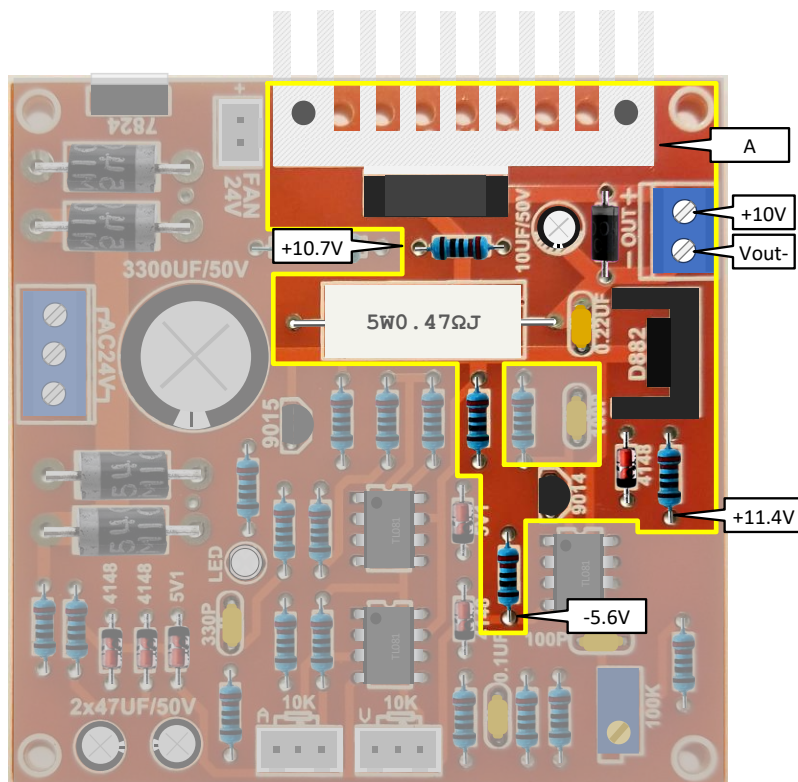
Illustration 9 – Current Pass Circuit Schematic

Illustration 10 – Current Pass Component Placement and Test Point Voltages

All voltages measured with respect to Vout-. Test Point A is 32.5V for 24VAC Transformer, 26.9V with 20VAC Transformer. No load attached. Potentiometer's must be attached for test points to be valid.

Adjust current potentiometer P2 to full clockwise rotation. Turn voltage potentiometer P1 until the voltage between Vout+ and Vout- is +10V as shown.

All voltages +/- 10% of indicated value.