Constant Current Electronic Power Supply Load
By Jeff K. Steinkamp N7YG April 3, 2012

Power supplies, especially external units, have become an ever increasing necessity in today's world of electronic gadgets. This is especially true for Amateur Radio Operators. Most radios require a 13.8 volt power source, which can normally be obtained from a vehicle, but to make these radios function elsewhere, some sort of device is required to provide that 13.8 voltage from a local mains supply.

Sometime in the course of our everyday life it will become necessary to test one of these power supply devices for various reasons. Most of the tests that you can preformed on a power supply will require you to place some type of load on the output of the supply so that it draws a specified amount of current. Figuring out how to do that can be the challenging part.

Before we go any further, lets have a quick review of ohms law. Mr. Ohm states that the current, or the rate at which electrons flow in a circuit is directly proportional to it electromotive force (the applied voltage) and inversely proportional to its opposition (resistance or load). We can take this theorem and express it into a mathematical formula:

$$I=\frac{E}{R} \quad \textbf{or} \quad R=\frac{E}{I} \quad \textbf{or} \quad E=I*R$$

Using these formulas, we can determine how much resistance or load we need to apply to a power supply to achieve a set amount of current. So, let's assume we have a 13.8 volt power supply and we want to introduce a constant 1 amp load. Using the middle formula as resistance is the unknown and we are given the voltage and current, simple division tells us that we will need to apply a load resistance of 13.8 Ω to the supply.

When current flows in a circuit, work is being accomplished and is referred to as power. The amount of power that is produced in a circuit is the product of the applied voltage and the circuit current. We get similar formulas as we did with Ohms Law:

$$P=E*I \quad \textbf{or} \quad I=\frac{P}{E} \quad \textbf{or} \quad E=\frac{P}{I} \quad \textbf{or} \quad P=I^2*R$$

using the example above the 1 amp of current on our 13.8 volts power supply will result in a power dissipation, in the load resistor, of 13.8 watts. With all of this

abundant knowledge in our hands, we can run down to the local electronics parts house and pick up a 13.8 Ω resistor, rated at 13.8 watts. Let me know how that works out for you!!!

The likelihood of locating such a resistor is probably nil. The closest you could get would be a 10 or 15 Ohm resistor at 20 watts. The last time I was in the local part house, one of these was close to $25.00 – just to provide 1 amp of current.

In our testing we will want to vary the load resistance to vary the actual load we place on the power supply. If we wanted to induce a 10 amp load on the device, then we'd need a 1.38 Ohm resistor rated at 138 watts. That is going to be one huge sucker. Make for a nice foot warmer in the winter time!!

If we need something that is constant current and variable, we will need to come up with a method that can apply a resistance between infinite resistance and down to as little as 0.69 ohms for a maximum load of 20 amps that will also dissipate up to 276 watts.

Enter the transistor, more precisely the power MOSFET. Recalling our transistor theory, we know that bi-polar transistor are current controlled devices whereas FET's are voltage controlled device. For this particular application, the FET is a lot easier to work with than the normal Bipolar device.

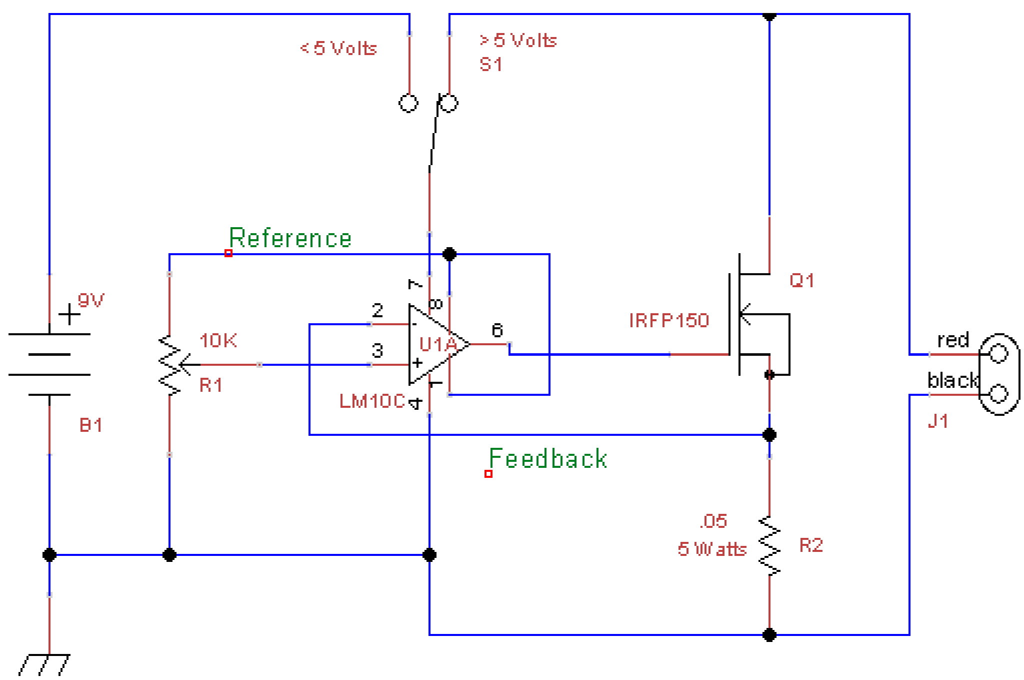
As an approximation, we can think of the transistor as a variable resistor. In a FET device, if we apply no control voltage to the gate, the drain to source resistance is on the order of 10^{12} ohms (think along the lines of our national debt in dollars). On the other hand, if we apply the maximum control voltage to the gate, then the transistor is completely on and it's drain to source resistance can be as low as 0.005 ohms, depending on the MOSFET used. In essence, we can control the resistance between the drain and source of the transistor using a small voltage on the gate and cause a change in the currant flow in the circuit were the MOSFET is attached.

The MOSFET is our variable resistor that we can use as the load for our power supply. In the next few paragraphs, I will describe the use a standard IRFP150 N-Channel MOSFET to make a simple variable 0 – 4 amp constant current load.

Before we get into the meat of this discussion, we need to talk about the MOSFET's ratings. A simple Google Search will bring you the data sheet for this device. From there we discover that the absolute maximums this device can operate at are 100

volts between the Drain and Source, 42 amp of current, and 180 watts of power dissipation. All of this is predicated on the temperature of the device being less than 25 degrees Celsius. A quick look at the temperature verses drain current curve tells us that the device will function up to 175 degree, but is severely de-rated. At 150 degrees, the maximum current you can draw would be around 17 amps. And with a power de-rating of 1.1 watts/Cº, we could only dissipate 22.5 watts.

For this exercise I've elected to use one MOSFET device that will draw a maximum of 4 amps through the device. At 13.8 volts and 4 amps, we'll have about 55 watts of power and heat to dissipate. Mounting the MOSFET on a heat sink and blowing some air across it will make it happy as a clam.



This circuit is a very simple variable, constant current load. The heart of the circuit is U1, a LM10C operational amplifier. This particular opamp includes a very stable 200 mV voltage reference. The opamp portion of the circuit is setup in a basic servo loop. A servo loop is a circuit where the output of the opamp will drive in one direction or the other so that it causes the feedback loop to equal the reference loop.

If we apply that 200 mV reference to a potentiometer, R1, we can vary that voltage over the entire range from 0 – 200 mV, thereby allowing us to drive the servo loop in either direction. By varying the gate voltage on the MOSFET, we vary the current through the device. The servo loop gives us the constant current properties.

In order to make this happen we need to construct the feedback loop. Before we do that, we need to recall some more basic electronics – Kirchoffs Law. Kirchoff came up with two basic rules used in all electrical circuits that deal with how current flows in a series and parallel circuit. In a circuit where all of the elements are in series, the current through each element is equal to the total circuit current, and the sum of the voltage drops across each element will equal the applied voltage. However, in a parallel circuit, the voltage drops across each element will be equal to the applied voltage and the sum of the individual branch currents will equal the total circuit current. We'll revisit the parallel law latter in this discussion.

The feedback is generated by the voltage drop across resistor R2. Kirchoff said that if we draw 4 amps through the series combination of Q1 and R2, the voltage developed across R2 and the voltage developed across Q1 will equal whatever the applied voltage we have that represent our Device Under Test (DUT). At this stage of the game we really don't care what the voltage is, but what we do want is to be able to drop 200 mV across R2 when we have a current of 4 amp flowing though that series element of Q1/R2. Using Ohms Law where R = E/I – 0.2/4 = 0.05 ohms. R2 does two things; it develops the feedback for the servo loop and it limits the maximum amount of current you can develop. If you wanted to increase the amount of current that you can draw, then we need to change the resistor so that it will develop 200 mV when 10 amps flows. In this case 200mV/10A = 0.02 ohms.

Now that we know the value of the resistor that will develop our feedback voltage, we still have to deal with the power dissipation in the resistor.

Recalling from our previous discussion about power, we concluded that power is determined by the product of the current and voltage through a device. In this case the maximum voltage that will be dropped across resistor R2 is 0.2 volts at 4 amps. Therefore this will result in 0.8 watts, and for all practical purposes 1 watt. The schematic diagram indicates a 0.05 ohm resistor at 5 watts, but this just happen to be what we had on hand. These types of very small resistance power resistor can sometime be difficult to locate at the local electronic supply house. However they can be ordered from various supply houses online. Two well manufactured items can be had from either Dale Manufacturing (P/N LVR05R) or Ohmite (P/N 15FR050E). You can also manufacture one yourself using a high value 2 Watt composition resistor as a form and winding some #22 hookup wire around it. I will explain how to do this at the end of this discussion.

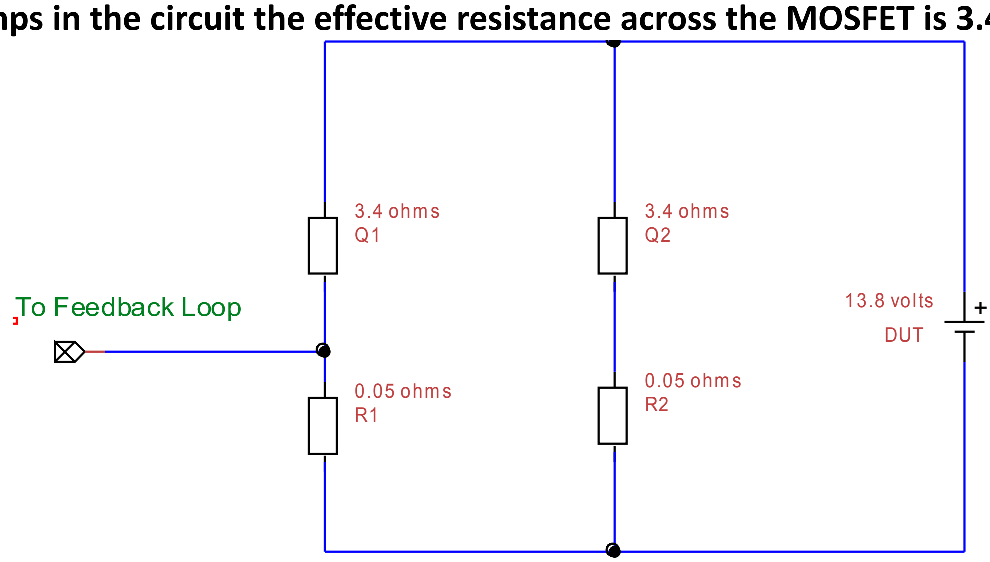
While we are on the power discussion, it should be obvious by now that the

remainder of the 55 watts that will be generated with a 4 amp load on a 13.8 volts power supply will be sourced in the MOSFET. Earlier we determined that this particular MOSFET was capable of 180 watts. The 180 watt value is assuming we can keep the device cool enough. You should mount the device on a large heat sink with forced air cooling. In the real world, you would probably have to put the device and heat sink into the freeze section of your refrigerator to achieve 180 watts for a good period of time. De-rating the MOSFET down to about 120 – 125 watts would be more reasonable with the heat sinks that are available along with some force air cooling. The maximum voltage that you could apply to this load using the 125 watt rating for the MOSFET would be 31.25 volts.

In the amateur world, this would probably be reasonable, but if you need to apply a higher voltage, then you will need to either recalculate the resistance of R2 to provide less current at the higher voltage, or manually limit the current using R1.

Breadboard this up and you will have a workable variable, constant current load for power supply testing. But, you say you need more current. No problem!! If you add another Q1/R2 combination in parallel with Q1/R2, then you will double the current. Remember when I said earlier that we would discuss the effect of Kirchoff's law in parallel circuit? Now is that time.

The figure below represents a parallel combination of the resistance of each MOSFET and its associated source resistance. Instead of drawing the MOSFET symbol, we use the resistor symbol to represent the drain to source resistance when the device is pulling 4 amps. In our 13.8 volts scenario, with 0.2 volts dropped across the feedback (source) resistance, the drop between the MOSFET drain and source will be 13.6 volts. With 4 amps in the circuit the effective resistance across the MOSFET is 3.4 ohms.



Knowing what we have learned about series and parallel circuits, we determine that the series resistance in each branch of the parallel circuit is 3.45 Ohms. We can now combine the parallel resistance to achieve one effective resistance using the parallel resistor formulas where we get a total effective resistance of 1.725 ohms and a total current draw of 8 amps. 4 amps flow through one branch, and another 4 amps will flow through the other branch. Therefore, if we need to increase the current capability even more, we can add additional parallel elements and increase the current another 4 amps. For 20 amps, you'll need 5 elements and 10 elements will give you 40 amps. NOTE: you only need one feedback element, and that can be taken off any one of the resistors.

At this stage you should be able to fabricate you own load for whatever current requirements you might have. Just make sure that you use the proper gauge wire in the current carrying paths of the circuit. The control part of the load requires very minimal current, approximately 300 microamps. I have included S1 to allow the opamp to be self powered by the load itself, or from a separate 9 volt battery. The LM10C will function properly down to about 1.5 volts in a single ended configuration such as we are using. But, the gate voltage required for the MOSFET to conduct could be as high as 4.5 to 4.8 volts. If you need to load a power supply that is less than 5 volts, then you will need to switch the power source for the opamp to the internal 9 volt battery to allow the load to sink 4 amps through each MOSFET.

If you have trouble locating the 0.05 ohm resistors, you can "roll your own" using a high value resistor as a form and wind some hookup wire around it and solder these ends of the wire to the leads of the resistor.

In most terms we think of wire as having no resistance which is why we use it to make connections between different elements of an electrical circuit. But in reality, all wire will have some resistance, although minute. The resistance of a wire is calculated by its cross-sectional area (wire size) and its length. For American Standard Wire, the published wire tables will give you the resistance of any size wire. A good source for this, which includes a resistance calculator, is:

http://www.cirris.com/testing/resistance/wire.html

This website will give you the diameter of the wire, along with the resistance of the wire in 1, 10 and 100 foot increments. It will also allow you to calculate the resistance of a specific length of wire.

To make our feedback resistor of 0.05 ohms we are actually placing two resistances in

parallel. Using the parallel resistance formula for two resistors in parallel as shown below

$$RT = \frac{(R1 * R2)}{(R1 + R2)}$$

we can deduce that for any two resistors in parallel, the total resistance will always be less than the lowest value resistor. We can also theorize from the formula that as the value of one resistor increases, the total resistance gets closer to the lowest value resistor. Using a 1000 ohm resistor and with enough wire around it that works out to be 0.05 ohms of wire, the resultant resistance will be 0.0499975. Close enough to 0.05 ohms for our purposes.

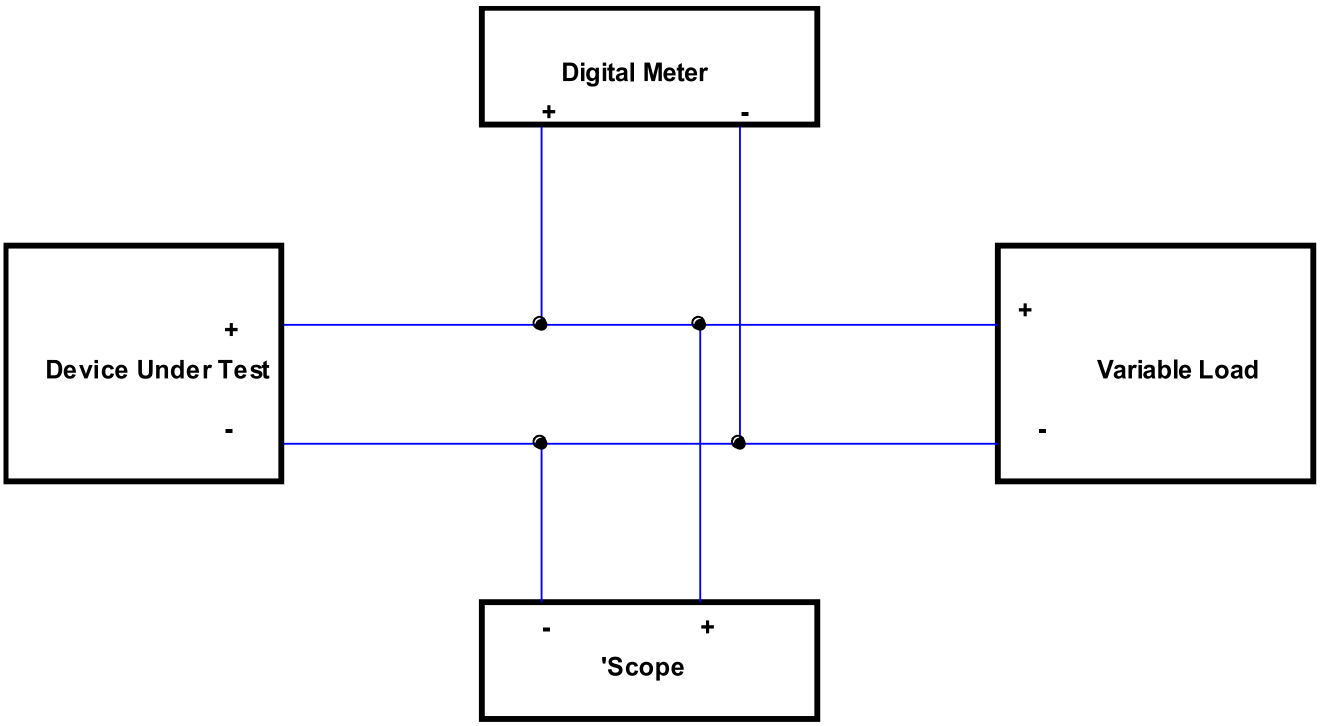
So, how much wire and what size do we need? As you can see from the wire tables, as the wire gauge increases, so does the resistance. The smaller the diameter of the wire, the greater the resistance per foot and the less wire you will need. But, there is a practical limit to the wire size if you are going to run 4 amps through that wire. From experience, I know that 4 – 5 amps through a piece of #30 wire will cause that wire to light up like the filament of a 60 watt light bulb and eventually go up in smoke. If you have a need to "smoke test" something, this would be a good start. If you design a load bank that is capable of 40 amps, then make sure that the current carrying paths use wire that will handle 40 amps of current. Doubled up #10 or #8 would be suggested for lengths of less than 5 feet.

In practicality, #22 or #24 gauge wire would be suitable for our 0.05 ohm resistor. From the wire tables the resistance for 1 foot of #22 is 0.01614 ohms and #24 is 0.02567 ohms. For #22 wires you will need 37 inches of wire. (0.05/0.01614) *12 = 37.174 inches. For #24 -- 23.373 inches. Enamel covered solid wire works best, but if all you have is plastic covered solid or stranded wire it will also work. Cut the wire to length, plus a little extra to compensate for the wire used to make the connections at each end of the resistor. Solder one end of the wire to one of the resistor leads, close to the body. Wrap the rest around the body of the resistor, attaching the free end to the opposite end of the resistor and soldering close to the body.

You now have all the tools you need to develop you own power supply load fixture. R1 should be a multi-turn potentiometer to allow for fine tuning of the current. Remember that this device will generate a lot of heat. Use large area heat sinks for the transistors and a good fan to force air across the heat sink. Forced air cooling, at room temperature, across any heat sink will increase the heat sinks dissipation by a factor of 10.

Power Supply Testing

We are ham operators so we don't have an arsenal of test equipment like most manufactures and test facilities, but if we have the basics tools such as a Digital Multimeter, an Oscilloscope, and our variable load, we can pretty much test and diagnose the majority of power supply issues.



Test Setup

The diagram shows how you would setup a test station for power supply testing. For a scope, any 5 MHz scope that will allow the vertical channel to get down to 10 mv/div using a 10:1 probe will suffice.

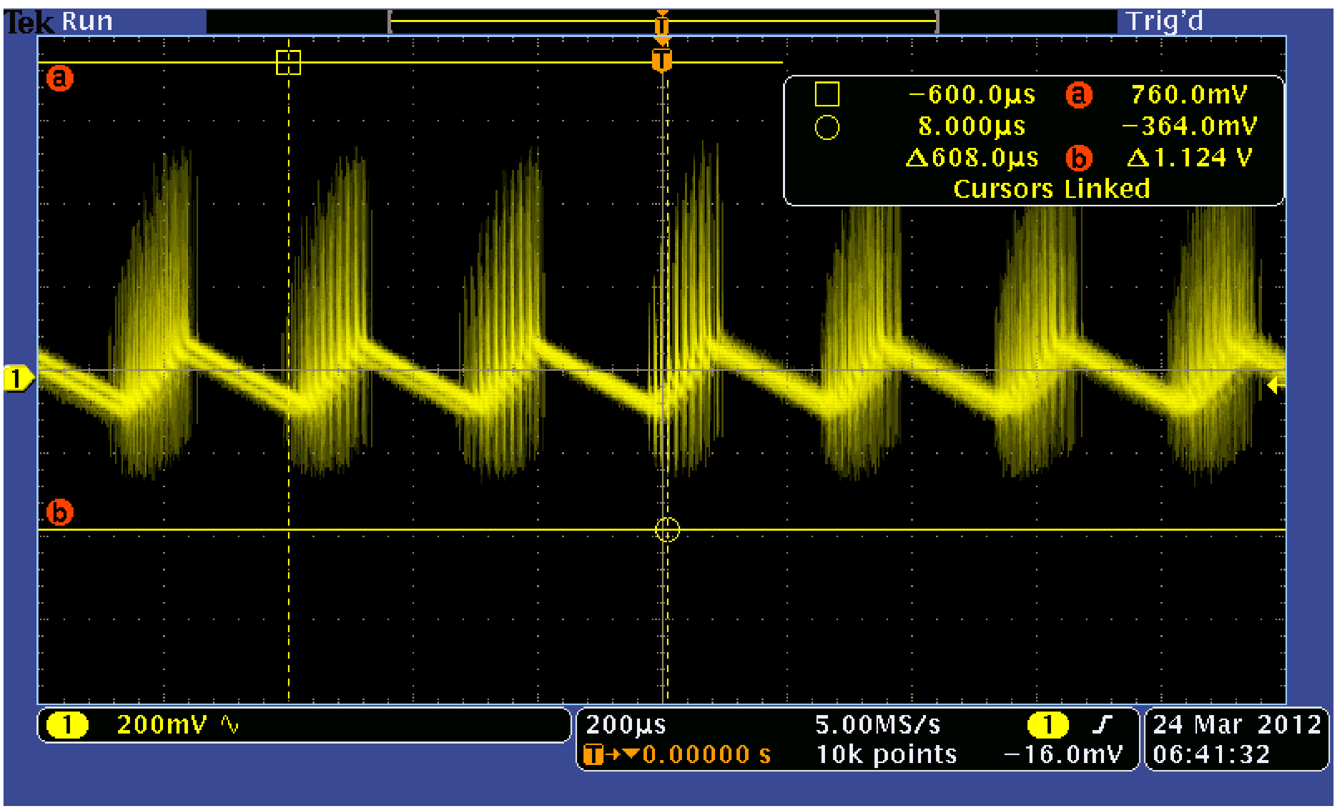
Start by setting the load bank for minimum load, the pot should be in the full CCW position. Turn on the digital meter and set it for DC volts. Turn on the scope and set the vertical channel for AC coupling at 10 mV/Div. Set the horizontal time base for 10 us/div. This is not really important at this time as we'll need to adjust that later.

Turn on the power supply and record the no load voltage and analyze the scope presentation. With no load it is hoped that you have a solid line across the scope with no indications of any type of AC waveform. Other than maybe some very small noise spikes that may be coming from nearby equipment, you should have a very clean signal on the scope. If you do not, then it's time to start troubleshooting.

Start incrementing the load bank in 10% increments of output current. If your power supply is rated for a maximum current of 10 amps, then 1 amp increments. If the power supply does not have an internal amp meter, then you will need to add one of those to your test setup if you have something suitable. But, if you constructed this loading using a 10 turn pot for R1, then 1 turn of the pot will be 10% of the maximum load you based the load bank on.

Continue loading the power supply in 10% increments until you reach the maximum load the power supply is rated for, recording the voltage and ripple you see on the scope. Once you start seeing some ripple on the scope, you may have to adjust the horizontal time base and trigger to get a stable display.

The rule of thumb for linear supplies is no more than 5 mV of ripple per amp of load. If you have a Switching Power Supply (SMPS), then this figure could be as high as 20 mV/amp of load. What you do not want to see, is something like the picture below.



This is a 1 amp switching power supply that is loaded to 930 ma. This is a perfect example of a poorly designed supply and something that you would not want to see on the output of a power supply used in the amateur radio service!!! This is also a constant load. I'd hate to see what this would look like with a dynamic load such at what would be present on a power supply during heavy SSB or QSK CW.

Increase the load past the maximum rated to see where the power supply start to go into either current limiting or into a fold back state depending on how the supply is designed. This figure should be 110% of the maximum rated current and for most power supplies, it is an adjustment inside of the unit. Make sure this feature of the supply is working correctly as it is this feature that will protect your supply in the case of an accidental short. If the supply is designed with a fold back circuit, then once you reach that trip point, you will need to turn the supply off, reduce the load then turn it back on again for it to recover properly.

I have no pictures of the device we are building, but once we finish it, and I receive permission from my employer to publish this design, I'll update this paper.