Regulated Linear Power Supply Construction

What's inside your Astron®?

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This article first appeared in the November 1996 issue of the SEITS on-line magazine. It has been one of the most requested articles by amateur radio operators and electronics hobbyists for the past 10 years. It is now provided here, as its own standalone document.

Introduction

I get my best ideas for articles from on-the-air conversations. One night N0RXD and I were discussing 13.8 volt DC linear power supplies. This is one piece of ham gear that all of us own and use every day. Most of us either use the ultra common Astron® power supplies or some other manufacturer or variation of this same basic design.

The Guts

If you look inside any of the popular 13.8 VDC linear power supplies and you'll find the same stuff in about all of them. There will be a large transformer, a 'bean can' sized filter capacitor, a small PC board and several large transistors (TO-3 case) on a big heat sink. Regardless of size (amperage) of these supplies, the basic design is the same. If you understand one, you understand them all and better yet, can home brew them!

Mark and I were both working on power supplies that day. Mine was a real classic hamfest bargain. I found it under the table for $ 2.00. A twenty amp 13.8 volt power supply with 6 burned out pass transistors and a big black hole burned through the regulator board. *This was a lightning strike special*. Not too bad for 2 bucks!

Now the important thing is that the 'hard to find', expensive parts were all in good shape. That is the power transformer, rectifiers, heat sinks and a nice big steel chassis.
Oh yes, I forgot to mention that the power switch was welded shut. It must have been one hell of a lightning bolt that hit it!

Poor Design

The first thing I did was to remove the damaged parts and check out the rest of the supply, after tracing out the circuit. After examining the design, I rapidly came to the conclusion that the designer had to have been on drugs. Deciding that the design was not worthy of a simple repair, I ripped out the remaining burned components of the original goofy regulator board and built my own using our friend LM723 integrated circuit (IC). The LM723 is an old Signetics IC originally designed and marketed in the 1970s to be a universal voltage regulator. Being cheap and well understood it was quickly adopted by a wide variety of bench supply manufacturers and is the core regulator of the popular Astron series. The schematic shows the design that I have used several times in my own homebrew supplies. There are many variations to this basic design and none of the parts values are critical.

How it works

Any bench supply consists of a transformer with a secondary of about 18 volts AC, a rectifier block and a filter capacitor. With no load, the DC voltage across the terminals of the filter is going to be 18 to 30 volts. Under load the voltage will sag due to the impedance of the secondary of the power transformer. If it sags too far, the supply will loose regulation and it will pass 120 Hertz ripple (hum) to whatever you are powering with it. Since the voltage across the filter capacitor can vary wildly as the load changes we need a method of regulating the voltage.

The work of regulation is done by the pass transistors (Q2 to Q5). They in turn are controlled by the 723 regulator. Let's look at the 723 in a little more detail now. Note that it has its own filter power supply made up from diodes D1 - D4 and filter capacitor C2. The 723 has an internal highly regulated voltage reference supply (pin 6). Internally, the 723 compares this reference voltage to the output of the power supply. Voltage adjustment pot RV1 sets the ratio of the reference voltage to the output of the supply. This sets the output voltage.

The output of the 723 is pin 10. This voltage drives the base of Q1. Q1 acts as a simple amplifier to increase the current available to drive the current hungry bases of the pass transistors. As the load increases on our power supply, the voltage from the wiper of RV1 drops as well. When this occurs, the 723 increases the voltage from pin 10 driving the pass transistors harder through Q1. So, the more base current that flows through the pass transistors, the higher the output voltage will be. Thus we have regulation, the 723 continuously changing its output voltage to meet the minute changes in load on the supply. Remember, the 723 does the thinking, the pass transistors do the work!

The Passing Lane

Lets look a bit at what the pass transistors do. The key thing here is current carrying capacity and heat dissipation. In our example, lets say or power supply uses the common 2N3055 NPN power transistor. This transistor can pass up to 15 amps of collector current. Note that it is not wise to run any device at its maximum rating. Thus for a 25 amp power supply you would want to have more than two 2N3055's in parallel. For the last supply I built, I used four. If you used higher current rated transistors, you could get by with less of them. If you simply placed the multiple pass transistors in parallel, slight differences in gain between them would cause unbalanced current flow. The highest gain transistors would hog most of the current flow and most likely fail. To balance the current small value resistors called "Emitter Ballast Resistors" are added in series with the emitter lead of each transistor. These can be between .01 to .1 ohms and should be of at least 5 watt dissipation.

How hot is Hot?

The next and most serious issue is heat dissipation. Or just where does all the energy go? In this example think of the pass transistors as simply big variable resistors, for this is what they are really doing. A little simple math shows the problem. For our example, we have an unregulated voltage of 20 volts and the load is 15 amps.
Ohm's Law shows us that: 20 volts minus 13.8 volts = 6.2 volts drop across the pass transistors. 6.2 volts X 15 amps = 93 watts of heat to be dissipated!
This means you need a LARGE heat sink to dissipate this amount of heat. A quick look at some data sheets shows that the heat sink would be around 5" wide, 3" high with eight fins and 12" long!

The size alone of the heat sink has a great deal to do with the rating of a power supply. Our popular Astron supplies, for example, are rated being able to supply only half of the current continuously that their specified for! That is, a twenty amp Astron can in reality supply only ten amps continuously.

The trick is that in normal amateur operation the draw of current from the supply is intermittent. Astron assumes that you will be drawing current no more than 50% of the time an then for not over a few minutes. This gives time for the heat sink (and pass transistors) to cool down.

When using any power supply for continuous operation it pays to derate it from its specified output current by 50% and than place a cooling fan on it! Don't forget that the power transformer and rectifier block need additional cooling to. On my Astron I arranged the fan so some air is blown into the case to cool the internal components as well.

Now the really Good News

There are two kinds of power supplies, those that have blown up, and those that will. There are some things you can do to extend the life of your Astron or other power supply. First and most important, KEEP IT COOL! Reread what I just said about heat dissipation, duty cycle and adding a cooling fan. Heat causes the majority of power supply failures! Next be sure there is a MOV (Metal Oxide Varistor) across the 120VAC power coming into the supply. Adding two additional ones from each side of the power line to ground is not such a bad idea either. This will help protect the supply from voltage spikes (lightning) coming in on the power line. Keep in mind that lighting damage can come from induction as well. Good grounding and lead dress is your best protection.
If your power supply uses a 723 IC, add a 1K resistor in series with the voltage adjustment pot wiper (R2 on the schematic). For some reason this simple modification prevents certain failures of the 723. At the same time place a .1 mF capacitor across the positive and negative terminals of the rectifier block.

Parts

Luckily parts values are not critical in this type of power supply. You can always go bigger. For example if the schematic calls for a 35,000 mfd filter cap, anything larger will work even better. The same principal applies with the voltage rating. If the schematic calls for a 25 VDC capacitor, you can't go smaller, but larger is just fine.
Almost any high current power transistor will work for the pass transistors. Years ago the old 2N3055 was the industry standard. Today the 2N3771 (ECG181 replacement) used by Astron and the Darlington like the TIP120 (5 amp collector current in an easy to mount TO-220 case) are popular.

At most hamfests I have been able to find large heat sinks with the power transistors and ballast resistors already attached for a couple of dollars each. These if you can find them save you a lot of work and expense! Filter caps and full wave rectifier blocks are also common and cheap. If you see them buy a few as spares. The same for 2N3771 transistors if you own an Astron power supply. Someday you will need a set for your power supply!

Emitter Ballast resistors can be homebrewed if need be. I've made my own by winding copper magnet wire on large value resistor bodies. The wire acts as the resistor and the body of the large resistor simply acts as a form to hold the wire. You can also make ammeter shunts this same way

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Wind that wire

To design one get out your ARRL handbook and look up the Copper Wire Specifications chart. This chart gives the current carrying capacity and resistance per one thousand feet for each size of wire. For my last supply I needed .1 ohm at ten amps. The smaller the wire diameter, the greater its resistance. Going down the column for wire in bundles, the smallest wire I could use for ten amps was #18. #18 is rated at 6.38 ohms per 1,000'. That's .00638 ohms per foot (6.38 divided by 1,000). .1 / .00638 = 15.6 feet of #18 wire to give .1 ohm resistance. That's makes for a sort of ugly resistor, but they did work as planned, I had them when I need them and they are damned hard to burn out!

Metering

I love meters and I meter all of my power supplies. Many times I've learned of trouble before it got serious by checking the current that amps and transmitter draw. Same for the power supplies, drooping voltage is a sure sign that one or more pass transistors have failed or other problems have developed. The meters that come on Astron supplies are junk and all that I have owned have failed and had to have been replaced. Lucky for us old meters are cheap at hamfests. Look for easy to mount clean meters with ranges of 0 to 100 microamps to 1 milliamp. These are easy to recalibrate to use as power supply amp and volt meters.

For my last power supply I dug through the junk box till I found two meters (one will work just as well with a switch) that I liked. They're 0-1 mA with scales that read 0-50 something. OK, the scales are useless, but that is not a problem. By CAREFULLY taking the meter out of the case, you can remove the scale. Using a stiff ink eraser careful and slowly rub out the unwanted numbers on the scale. Than using transfer lettering (available at office supply stores) you can place your own scale on the meter. In this case I numbered the main divisions 0 to 25. A little work with ohms law told me that an 18K resistor in series with the meter and a 10K pot for fine calibration gave me my voltmeter.

Check the schematic for details and read up in the hand book for more information on calibrating your own meters. For the amp meter I wound my own shunt using copper wire again. A small ten turn pot in series makes fine calibration easier. I wanted my meter to read full scale (1MA) with 25 amps of current coming from the supply. To calculate the shunt resistance I needed to know the resistance of the meter and the center resistance of the calibration pot.

Math Time

The formula is:
SHUNT RESISTANCE = Meter Resistance / (Multiplication factor - 1)
My meter resistance is 50 ohms. I'm going to place a 100 ohm pot in series for fine calibration. Setting the pot to mid scale gives me a total meter resistance of 100 ohm. The full scale reading of the meter is .001 Amps. I want it to read 25 amps. Multiplication factor = 25 amps / .001 amps = 25,000 - 1 = 24,999.

Checking the copper wire specifications, we see that common #14 runs 2.52 ohms per 1,000'. Therefore, 2.52/1,000 = .00252 ohms per foot. .004 ohms (our shunt) divided by .00252 (ohms per foot) = 1.6 feet of wire for our shunt. Using the formulas and charts in the ARRL handbook and some transfer lettering, you can make up your own calibrated meters for your power supplies. If you need felt with any of this contact me.

Summary

To sum things up in this article, armed with a little information you can repair, modify or build your own 13.8 volt linear power supplies. If you can find the right junk, building is certainly cheaper than buying a new Astron supply!

Just remember, as long as the power transformer is good, any junk burned out 13.8 volt power supply is a bargain.

Schematic

The schematic referenced in this article can be found on the last page of this document. I also have the schematic for this project available for the ISIS Cadpak software package. If you would like that version, please contact me directly.

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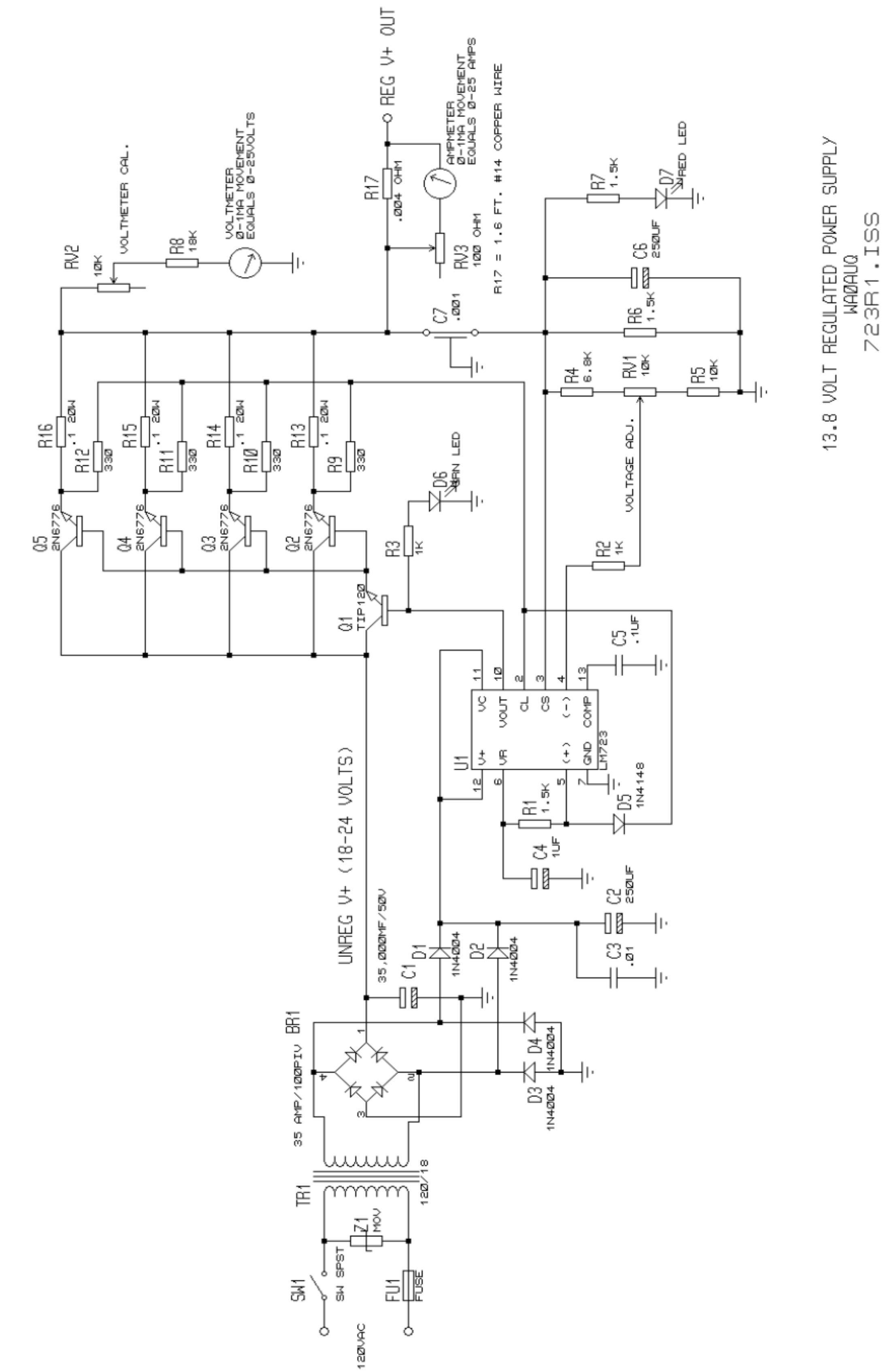
Schematic


13.8 VOLT REGULATED POWER SUPPLY
WA0AUQ
723R1.ISS
REG V+ OUT
UNREG V+ (18-24 VOLTS)
VOLTMETER CAL.
VOLTMETER
0-1MA MOVEMENT
EQUALS 0-25VOLTS
AMPMETER
0-1MA MOVEMENT
EQUALS 0-25 AMPS
R17 = 1.6 FT. #14 COPPER WIRE
VOLTAGE ADJ.
120VAC
35 AMP/100PIV
35,000MF/50V
120/18
LM723

