

## Experiment #35—Power Supply Analysis

The past 34 experiments have tackled individual circuits in splendid isolation. Most electronic equipment consists of several circuits working together. This month, we'll take a common piece of equipment—the linear power supply—and find out why the whole is greater than the sum of the parts.

### Introduction

When equipment needs troubleshooting, the schematic diagram for the equipment is opened up and the head scratching begins. While some schematics are a lot easier to read than others, you can tame even the most obtuse by breaking the overall circuit into its various subcircuits, each with a separate job to do.

Before we get started, I'd like to thank the Astron Corporation ([www.astroncorp.com](http://www.astroncorp.com)) for granting permission to reproduce a popular radio supply's schematic diagram, found at [www.repeater-builder.com/astron/astron-rs35m.pdf](http://www.repeater-builder.com/astron/astron-rs35m.pdf). You should also review Experiments #6 (Rectifiers), #8 (Linear Regulator), and #10 (SCRs), all of which are available on the Hands-On Radio Web site, [www.arrrl.org/tis/info/HTML/Hands-On-Radio](http://www.arrrl.org/tis/info/HTML/Hands-On-Radio). A copy of the LM723 voltage regulator's data sheet can be had at [www.national.com/pf/LM/LM723.html#Datasheet](http://www.national.com/pf/LM/LM723.html#Datasheet). Ready? Let's go!

### Divide and Conquer

The first order of business is to understand the *big picture* by finding out where all of the inputs, outputs, power and con-

trols are located. Most schematics have a flow of signals or power from left to right. A good schematic will also keep components that work together near each other and perhaps even labeled with their function. Before starting to trace a signal or troubleshoot a symptom, take a few minutes to understand how the schematic is organized. Remember the need for clarity the next time you draw a schematic yourself!

Figure 1 shows a schematic of one version of the popular Astron RS-35 power supply capable of supplying 12 V dc at 35 A. (If you have a linear Astron power supply, you might want to open up your unit and "follow along" as we go.) On the left you can see the ac input circuit, and on the right, the dc output terminals. As the power moves from input to output, it goes through a rectifier circuit and then pass transistors that are controlled by a regulator. There is also a mysterious circuit called a *crowbar* that protects equipment against excessive output voltage. I've drawn lines around some of the circuits, while the larger regulator circuit occupies everything in the middle. The numbers in hexagons are connections to the printed-circuit board. The two components labeled RX are only used for power supply testing at Astron.

### Input and Rectifier

There's nothing fancy about the input circuit. The hot side of the ac line passes through an 8 A fuse—heavy enough to withstand the current surge at turn-on as the filter capacitors

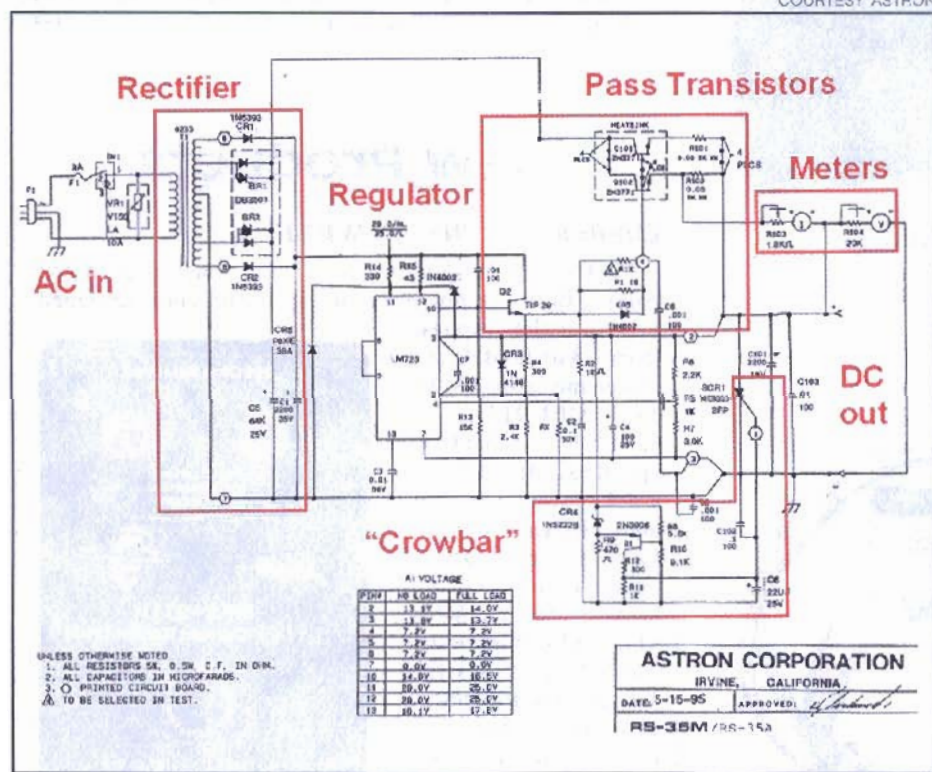


Figure 1—Power supply schematics are best understood with each "subcircuit" analyzed individually. The red lines show the subcircuits.

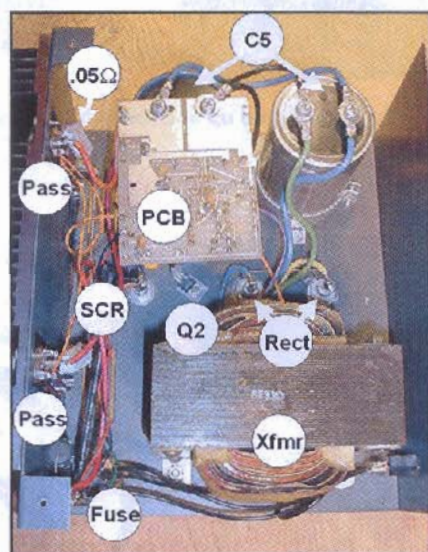


Figure 2—The major components of the power supply. Be careful to avoid contacting the ac line components when measuring voltages!

charge up. VR1 is a V150LA varistor that conducts at voltages above 150 V, protecting the supply against input voltage surges. (Note—you can usually find detailed information on components by entering their part number and “data sheet” with the quotes into an Internet search engine.)

The rectifier circuits look a little strange until you realize that there are two full-wave, center-tapped circuits nested one inside the other. The inner circuit supplies the high current output power. It uses a DB3501 full-wave bridge rectifier ([www.diotec-usa.com/35dbm.pdf](http://www.diotec-usa.com/35dbm.pdf)) with the diodes connected in parallel to share the current load. The dashed line around the diodes indicates that they’re all in a single package. My model of the power supply in Figure 2 uses two separate diodes. The filter capacitor, C5, is a large 64,000  $\mu\text{F}$ , 25 V electrolytic. My supply has two 32,000  $\mu\text{F}$  caps in parallel. The outer circuit supplies power for the regulator circuitry at higher voltage and much lower current with 1N5393 rectifiers (CR1 and CR2) and C1, a 2200  $\mu\text{F}$ , 35 V electrolytic.

## Pass Transistors and Metering

Now follow the output of the high-current rectifier to the pass transistors. Here again, you encounter a dashed line as well as a cryptic notation, 4 PLCS, which means “four places” or “there are four of these.” If you look at an actual supply, you’ll see four 2N3771 transistor circuits all connected in parallel—that’s what the dots mean on the connections between Q101 and Q102.

In order for the transistors to share current equally, 0.05  $\Omega$ , 5 W, wire-wound (WW) resistors are in series with the emitter of each transistor. If one transistor begins to hog all the current, the voltage across this resistor increases and lowers its base to emitter voltage, reducing drive and also emitter current. One resistor is used as a shunt, providing a voltage proportional to overall current so that a meter can display total current without having to pass all of it through the meter movement. The current meter, labeled I, conducts a few mA at full scale, as calibrated by R103. A voltage meter is connected directly across the output terminals.

## Regulator

Look at the LM723 data sheet and find the equivalent circuit on page 2. This shows how the regulator works without including every transistor. Try to correlate the equivalent circuit with the linear regulator circuit of Experiment #8. In the LM723, the Zener diode is buffered by the voltage reference amplifier (output at pin 6) to improve the stability of the regulator’s reference voltage. A “Current Limit” transistor (pins 10 and 11) works by diverting some of the output drive if the output current gets too high.

The LM723 uses a 29 V supply at pin 12, protected by a 1N4002 and CR6, a P6KE39A transient absorber. These protect the regulator IC and clamp any voltage spikes at 39 V. R15 acts to limit the current when a spike occurs, but is small enough not to upset regulator function.

The LM723 compares a fraction the output voltage of the supply (obtained through the voltage divider of R5, R6 and R7) at pin 4 to that of the voltage reference, which is connected to pin 5. If the output is too low the regulator supplies more output drive, and vice versa. Even with high-gain pass transistors, the LM723 can’t drive them hard enough to get full output, so Q2, an intermediate driver transistor, is needed—a TIP129. The LM723’s internal drive transistor with its collector connected to input power at pin 11 through R14, supplies base current to Q2 from pin 10. So, the LM723 drives Q2, which drives the 2N3771. Q2’s output current passes through R1 (18  $\Omega$ ) and CR5 (1N4002) that limit base drive current to the 2N3771’s.

The current limiting transistor inside the LM723 (base connected to pin 2 and emitter to pin 3) is off unless the voltage at pin 2 rises to 0.7 V above the output voltage at pin 3, turning on the internal transistor and diverting drive current from Q2. The values of R3 and R4 set  $V_{\text{PIN2}}$  to  $0.9 \times V_{\text{Q2}}$ .

Working toward the output from Q2, there is a 0.7 V drop across CR5, another 0.7 V drop from the 2N3771’s base to emitter, then  $1/4$  of the output current times 0.05 W. So  $V_{\text{PIN2}}$  equals  $0.9 \times (V_{\text{OUT}} + 0.7 + 0.7 + 0.05 I_{\text{OUT}}/4)$ . If the supply is set to the usual output voltage of 13.8 V, the current limiting transistor will turn on when the output current reaches about twice the rated steady state output current, or 70 A. (This is probably high because I assumed a low value of 0.7 V across the power transistors.) CR3 protects the current limit transistor from voltage spikes. There are a number of 0.1, 0.01 and 0.001  $\mu\text{F}$  capacitors in the circuit—they filter out any RF that might upset regulator operation. C4 and C101 filter any sags or spikes at the output due to sudden changes in load.

## Overvoltage Protection—The Crowbar

This leaves the odd circuit at the lower right, combining a Zener diode, a transistor and an SCR directly across the output of the supply. The function of this circuit is to protect external equipment against excessive voltage due to a supply failure. The remedy is a little extreme—the SCR is turned on, shorting out the supply (and hopefully blowing the input fuse)! It’s just like dropping a crowbar across the output terminals and hence the name.

Q1 turns on whenever its emitter is 0.7 V above the base voltage, which is equal to  $V_{\text{OUT}} \times R10 / (R8 + R10) = 0.62 V_{\text{OUT}}$ . Since Zener diode CR4 has a 5.6 V drop from  $V_{\text{OUT}}$ , Q1 will turn on when  $V_{\text{OUT}} - 5.6$  V equals  $0.62 V_{\text{OUT}} + 0.7$  V, or when  $V_{\text{OUT}}$  equals 16.6 V. When Q1 turns on, C6 charges up through R12 and triggers the SCR, which dumps current to ground until the supply fuse blows or the filter caps are discharged. R9 keeps Q1 off until CR4 conducts and R11 keeps the SCR off until Q1 turns on.

We’ve covered the job done by every single component in this power supply! This won’t make you a power supply designer, but it should make you a much better power supply troubleshooter! Using the table of voltages at the bottom of the schematic, you can rapidly isolate a problem and get the supply back on the job. Use these same techniques of carving the *big problem* into *little problems* and soon schematics will become much clearer.

## Suggested Reading

To follow up on and reinforce what we’ve learned in this experiment, take a look at other power supply circuits in the *ARRL Handbook*,<sup>1</sup> magazine articles or schematics of other commercial equipment. See if you can break the circuit down into sections. For other regulator ICs, use a search engine to download their data sheets and see how they are used in the circuit.

## Next Month

We’re going to stick our toes in the deep waters of digital electronics next month by experimenting with an amazingly versatile counter/divider chip that can just about do it all. If you’re not familiar with digital electronics, I suggest that you bone up on bit basics by reading the appropriate sections of the *ARRL Handbook*.<sup>2</sup>

<sup>1</sup>Available from your local ARRL dealer, or from the ARRL Bookstore, ARRL order number 9845, Telephone 860-594-0355 or, toll-free in the US 888-277-5289, fax 860-594-0303; [www.arrl.org/shop/](http://www.arrl.org/shop/); [pubsales@arrl.org](mailto:pubsales@arrl.org). 