BASIC ELECTRONICS #2A

by Ron C. Johnson

Hello again, and welcome back to our series on Basic Electronics. This month, as promised, we get down to some practical aspects of electronics and build a power supply, which we can use in future experiments and projects. Elsewhere in this issue we will discuss some more on semiconductors, (especially transistors), which will prime us up for next month's project.

Last month we plunged into the area of PN junctions and how their characteristics applied to real devices such as diodes, rectifiers, light emitting diodes and zeners. In our power supply project we will use some of those devices (plus a couple you haven't seen yet). The power supply is a single supply which will provide adjustable output voltage from 1.2 volts DC to about 28 volts DC and has pretty good regulation (a term we'll discuss later). It can source up to 1.5 amps with minimal ripple. If you are following this series and want to do some of the activities we are suggesting this one is relatively easy to build and not too expensive (especially if you can scrounge a few of the parts).

My goal in this project was to keep it simple but useful and buildable without a lot of specialized equipment, so in my version I did not use a custom printed circuit board. I also left out some features which you might want to add later. For example, although I included a simple analog voltmeter and the components necessary to drive and calibrate it, I did not include circuitry to switch the meter to indicate current. Also, a current control adjustment was not included, either. I considered doubling the size and making it a dual tracking supply with digital readouts and a fixed 5 volt supply . . . but you can see what happens. These things tend to get out of control.

I made sure that all of the parts, including the box, meter, etc., can be obtained from your local Radio Shack, or other electronics part supply houses. (Not to give Radio Shack a plug, but because they may be the most accessible for the beginner.) If you were to buy all the parts it might cost about fifty dollars. If you can scrounge some of the hardware and basic parts you could reduce that figure significantly. There is no need to build the supply in such a relatively small box. In fact, if you anticipate adding a few other features or doubling the circuit to make a dual supply, a larger box would be desirable.

Enough! Let's look at this critter. Let's start with the schematic to see how it works. Later we can consider some of the practical aspects of how it was built and why.

Figure 1 shows a schematic of the supply. You will note that the first part of it looks like the example I showed you in last month's article. There are three main sections to the circuit: the unregulated supply which steps down the line voltage, rectifies and filters the DC; the adjustable regulator which keeps the output voltage constant; a light emitting diode used as an 'ON' indicator; and an analogue meter circuit which displays the output voltage.

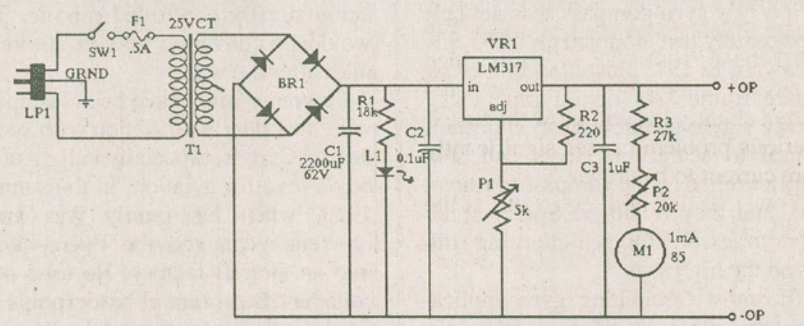


Figure 1. A Variable Regulated Power Supply

How It Works

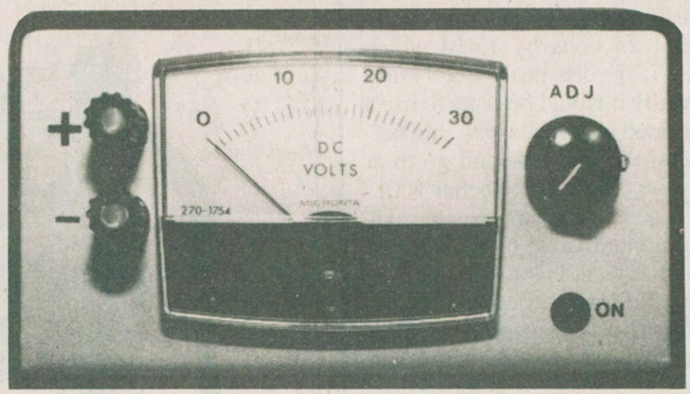
One hundred and ten volt AC line power is obtained by plugging a three prong plug into your standard home power outlet. From the plug, power is supplied via the line power cord to the on/off toggle switch. The 'hot' side of the AC line voltage is connected to the on/off switch of the power supply to ensure that, when the switch is off, no exposed parts are 'live' and constitute a safety hazard. Even so, caution should be taken when power is on as the fuse holder has exposed contacts which are hazardous.

Referring to the schematic again, the next part in line is the fuse just mentioned. Have you ever wondered how to determine the correct current rating for a fuse on the primary side of a power transformer? It's quite simple really. We know from magnetics theory that the turns ratio (ratio of the number of turns of wire on the primary side to the number on the secondary side) determines the factor that the voltage is stepped up or down. In this case we are using a step down transformer to go from 110 volts AC to 25 volts AC so the ratio is roughly 4 to 1. We also know that if a given current is being drawn from the secondary then the current being draw from the power line will be *less* by the same factor of 4. (This also means that the same power (I x V) is supplied to the primary as is dissipated by the load on the output of the secondary.)

So, if the maximum current that this power supply will put out is going to be about 1.5 Amps, (at 25 volts AC from the transformer), then the maximum input current will be about 1/4 as much. That means our fuse should be slightly higher than 1.5/4 which is about 375 mA. I chose to use a 500 mA fuse which allows the supply to exceed its rated current slightly but will blow the fuse if a serious problem causes significantly more current to be drawn.

Wow! All that and we're still at the fuse! Let's push on.

As I said, the power transformer output is 25 volt. In this case we are using a 25 volt *centre tap transformer*, rated at a maximum of 2 amps. If you are new to this, a centre tapped transformer is



Build this D.C. Power Supply

one in which the output coil has a connection brought out from its centre. This allows you to use the voltage output from the top half, bottom half, or the whole coil. If the transformer is rated at 25 volts (RMS by the way) then 12.5 volts will be available across each half. In this case we will not use the centre lead but centre tapped transformers are often used to obtain dual (plus and minus) supply voltages. See Figure 2 for an example of how this is done.

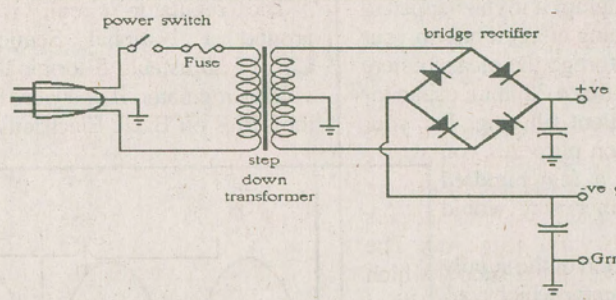


Figure 2. Basic Schematic of a Dual Supply

The output of the transformer is applied to BR1, a bridge rectifier. It is shown here as four discrete rectifier diodes but is physically a single device with four leads exiting it. (See Figure 3) As we discussed last month, the bridge rectifier 'steers' the current so that it always flows out of the bridge with the same polarity, regardless of the polarity of the alternating voltage from the transformer. It is called a rectifier because it is the device which changes AC voltage to DC voltage. Even though we have a form of DC at the output of the bridge it is still *pulsating* DC. This must be smoothed or filtered to obtain the stable DC voltage that we require. This is done by the filter capacitor, C1.

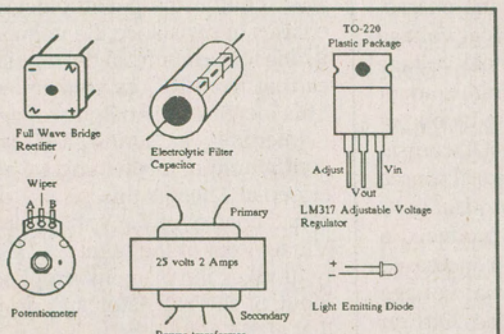
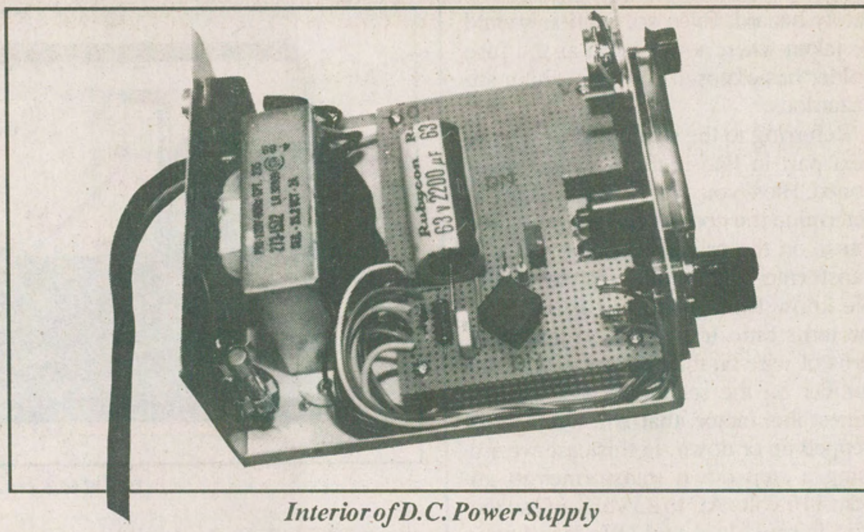


Figure 3. Some of the parts used in the power supply

The filter cap is a fairly large electrolytic capacitor (2200 uF) which should have a voltage rating which exceeds the highest voltage which may be impressed across it. (If you exceed that voltage, or if you connect this capacitor in the wrong polarity, the results can be spectacular — it tends to physically explode.) In my power supply I used a cap with a 63 volt rating just because I had that particular one lying around. Sixty-three volts is more than enough. In fact the minimum voltage rating is about 36 volts. This is determined by calculating the maximum voltage possible across it. We said that the output of the transformer was 25 volts and that the bridge converted that to pulsating DC but we must remember that the 25 volts we are referring to is given in RMS volts. The actual peak voltage is determined by multiplying 25 volts by 1.414 which gives us 35.35 volts peak. See Figure 4A. Normally it would be risky to use a capacitor rated at 36 volts here. It's better to be on the safe side and go to at least 40 volts (50 might be better yet).

There is actually a way of determining the minimum value of capacitance for this part as well. I won't go into it in depth here but I will describe the principle. The whole concept of a filter capacitor is based on the charge and discharge times involved in the circuit. The capacitor smooths out the ripple from the output of the bridge by charging up very quickly when the bridge output goes positive and discharging more slowly into the load (the rest of the supply and its output) when the bridge output is lower than the voltage on the cap. The value of capacitance must be chosen large enough so that sufficient charge can be stored to supply the output current required without its voltage dropping an objectionable amount. See Figure 4B. This can all be calculated, (and you can attempt it if you happen to enjoy the numbing effect it has on your brain), but I'll forego the pleasure here and assure you that a 2200 uF capacitor will give excellent filtering. For your own construction purposes you may find that a few hundred microfarads either way would be acceptable.

The next section of the supply is the 'ON' indicator which consists of a resistor, R1, and light emitting diode, L1. These are connected in series across the 'unregulated' supply. At this point in the circuit the voltage, rectified and filtered, will be about 30 volts. The LED is connected here rather than at the output because the output will vary between 1.2 and 28 volts, depending how we have set the front panel potentiometer, and this would change the current through the LED. The resistor serves to limit the current through the LED to somewhere in the vicinity of 20 mA (which is the general range of current an LED usually draws). If the DC voltage is about 30 volts, and the forward voltage drop across the LED is about 2 volts, the voltage across the resistor is about 28 volts. In order to limit the current through the resistor and LED to about 20 mA the resistor should be 28 volts/20 mA = 14 kohms. Standard EIA resistor values are 15 k and 18 k. I chose 18 k, (which gives a current of about 15 mA) to keep the current well below the maximum. At this current the brightness of the LED is still acceptable.



Interior of D.C. Power Supply

The regulator circuit is centred around a National Semiconductor LM317 adjustable 3 terminal positive voltage regulator. If you were following the series on Basic Electricity, several months ago we discussed the characteristics of ideal and non-ideal voltage sources. We said that an ideal voltage source would supply an infinite amount of current while maintaining its output voltage perfectly constant. Of course, there is no such thing as an ideal source and we discussed how a non-ideal voltage source, like a battery, produced a nominal voltage but as you increased the current drawn the terminal voltage decreased. The source acted like an ideal source with a low value of resistance in series with it.

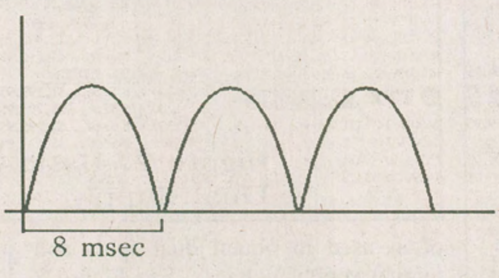


Figure 4A. Full Wave Rectified Waveform

The unregulated part of our supply (which feeds the regulator) would act like a non-ideal voltage source. Characteristics of the transformer and bridge rectifier would simulate the internal resistance mentioned and as the current drawn increased the output would decrease. Furthermore, if the AC line voltage level were to fluctuate, (and it does), the output voltage would also change.

The job of the voltage regulator here is twofold: First, it compares the output voltage to an internal reference and controls the output voltage so that it remains constant, and, second, it provides a method for adjusting the output voltage to the level we want by using a potentiometer. Internally the regulator uses a zener diode to provide a fixed reference voltage of 1.2 volts across the external resistor R2. Because of this the voltage at the output can never decrease below 1.2 volts, but as the potentiometer, P1 increases in resistance the voltage across it, due to current from the regulator plus current from R2, its voltage increases. This increases the output voltage.

Internally a "series-pass" transistor configuration, (something we may look closer at later in this series) does the actual control of the voltage drop from Vin to Vout of the regulator. Essentially, it takes the 30 volts supplied to the input of the regulator and drops it so that at the output the voltage is proportional to the voltage of the potentiometer plus the 1.2 volt reference voltage. If the input voltage decreases the regulator senses a tendency to decrease the output and immediately changes the voltage drop across the device to maintain the output where it was before. Also, if additional current is drawn from the output of the regulator, this will tend to decrease the output voltage due to the inherent internal resistance of the supply. As soon as a decrease in output voltage is sensed, again the regulator adjusts the voltage drop across itself to maintain the same voltage as before. Of course, all this happens so quickly and the sensing is sensitive to very minor changes so virtually no change in the output is perceptible.

There are two capacitors, C2 and C3 added on either side of the regulator. C2 is a .1 uF capacitor which is used to decouple transient noise which can be induced into the supply by stray magnetic fields. Usually it is only required if the regulator is far from the filter cap. I added it anyway, although it may not be necessary. C3 improves transient response. This means that while the regulator may perform perfectly at DC and at low frequencies, (regulating the voltage regardless of the load current), at higher frequencies it may be less effective. Adding this 1 uF capacitor should improve the response at those frequencies.

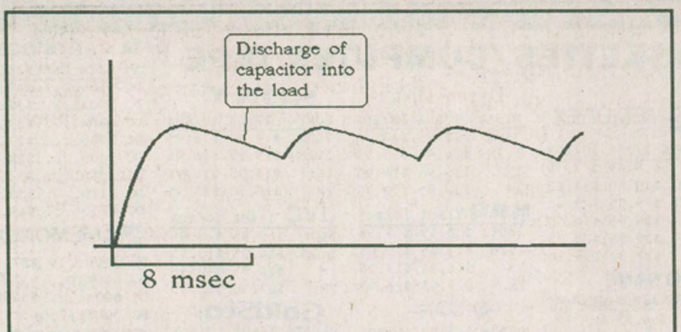


Figure 4B. Filtered Full Wave with Ripple

Finally, in order to see what the output voltage of the supply is, we add an analogue meter circuit. The meter movement I obtained had scale markings indicating zero to 15 volts DC full scale reading. On the package it said that the internal resistance of the meter movement was 85 ohms and that with a 15 k resistor in series with the meter, it would indicate 15 volts full scale. If there were 15 volts applied to a circuit with 15 k plus 85 ohms in series the full scale current would be approximately 1 mA. If we want it to indicate 30 volts full scale, (the maximum this supply will put out) we have to limit the current to 1 mA and then change the markings on the scale to read appropriately. At 30 volts we would require about 30 k in series with the meter. In order to calibrate the meter as closely as possible I used a 27 k resistor and a 20 k ten turn potentiometer. (A 5 k pot might have been better but I scrounged this one and it worked fine.)

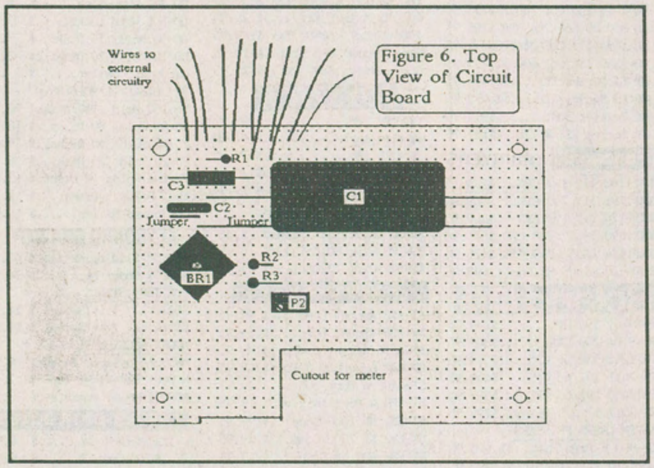


Figure 6. Top View of Circuit Board

When connected across the output of the power supply and calibrated using a known accurate meter the meter gives a fairly close indication of the voltage output. Unfortunately this meter movement was slightly non-linear and the specs said it was only accurate to about 2.5% of full scale. This would mean that it could be out as much as .025 x 30 = .75 volts. This is pretty high so the meter on the power supply should only be used as a guideline. For accurate voltage setting you should use a better quality voltmeter.

Construction

In the construction of my power supply I elected to use a relatively small box as the number of discrete components was low. In your case you may want to use something you have available, or you may want a larger box to accommodate more circuitry to implement a negative supply as well. If you can obtain a box made of soft aluminum it makes construction a lot easier. Not only is drilling holes simplified but if you need to enlarge or shape them, (as you do with mounting grommets, potentiometers, banana jacks and the meter movement), this can be done much more easily.

I scavenged a power cord with a three prong plug from another project and found a grommet which would provide some strain relief for the cord. It is important that you do connect the green ground wire from the cord (which is connected to the plug's third prong) to the chassis of the supply. This is a safety measure in case the chassis accidentally comes in contact with the 110 volts AC. The current will flow to ground through the cord instead of through you. I also scrounged a toggle switch which happened to have leads instead of terminals which was good because I could connect to the line cord using small Marr connectors and not have an exposed hot wire inside the chassis. I mounted the switch on the rear panel of the box so

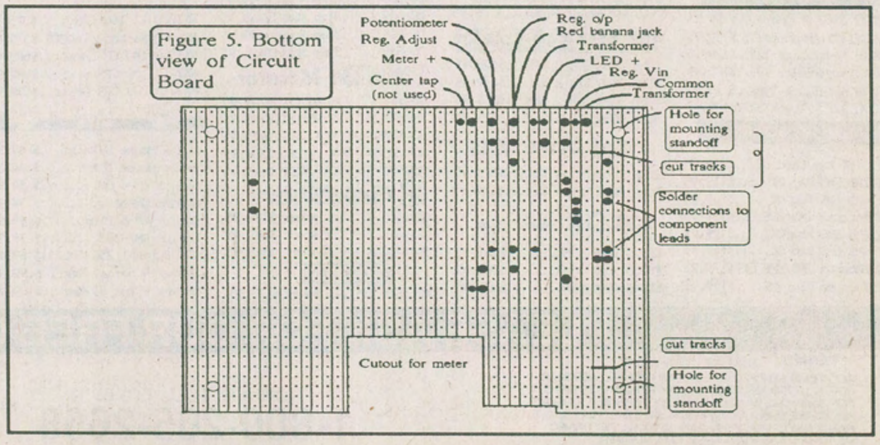


Figure 5. Bottom view of Circuit Board

the cord instead of through you. I also scrounged a toggle switch which happened to have leads instead of terminals which was good because I could connect to the line cord using small Marr connectors and not have an exposed hot wire inside the chassis. I mounted the switch on the rear panel of the box so that AC would not have to be run to the front and back to the transformer. Remember, if you build this project: **BE CAREFUL**. Always unplug the AC line cord when working inside the chassis. If you are troubleshooting the power supply use one hand only whenever possible to minimize the possibility of getting a shock.

The fuse holder I used was a small clip type which was also mounted on the rear panel. This type of fuse holder is not as safe as I would have liked it to be as the contacts are exposed and voltage is present if the on/off switch is on. The alternative is to use a cylindrical fuse holder which allows external access from the rear panel and can be more easily insulated with heat shrinkable tubing. The one I used just happened to be available. (I was also concerned that the other kind might take up an objectionable amount of room.)

After mounting the power transformer in the rear of the box using pop rivets I proceed to drill all the holes for the adjustment pot, LED and banana jacks. The banana jacks should be 2 cm apart.

The circuit board is made out of a product called Veroboard. Generic versions are available at parts supply houses. This is a phenolic printed circuit board with copper strips on one side. It is predrilled on .25 cm centres so that you can insert component leads through the board, solder them and have them connected to any other component soldered to that strip. See Figure 5. If you want to isolate one part of a strip from another it is a simple procedure to cut the copper using a knife or to use a drill bit to cut the track around the holes. In my version I mounted the components on one side of the board so that I could add circuitry later if I wished. See Figure 6. All the wiring from the board to other parts of the circuit were connected near the same end so that I could fold out the board for access to its underside and other components in the box. The 3 terminal regulator was mounted on the bottom of the box to make use of the metal box as a heatsink. Leads were run from it back to the circuit board. It is important to know that the metal tab on the regulator is connected to the output pin of the device so it had to be isolated from the metal box using a mica insulator and a special isolating washer for the machine screw which fastened it to the box. White heat sink compound was used to maximize the heat transfer from the device to the box.

Because the meter movement was something of an afterthought I had to cut a notch out of the circuit board to accommodate the rear of the meter movement. I used a nibbler tool for this as well as to cut out the hole in the front panel for the meter movement. To mount the circuit board I used 2 cm standoff hardware making sure that the metal standoffs did not short out any of the copper strips which were being used.

Well, there it is. When you are just starting out on a project like this you may not have some of the tools and possibly you are not aware of a few of the tricks. Hopefully, some of the details here will have been helpful. In future segments we'll use this unit to check out some other interesting circuits. ❐

Sperry, *cont'd from page 11*

guidance systems, long-range aircraft and submarines. Instead of mounting two stabilizers separately, as he had earlier, he nested four gyros on a single platform. The gyros established a stable reference and servos aligned the airplane with the reference.

Sperry used a combination of electrical, mechanical and pneumatic components to align the airplane automatically with the horizontal stable platform. When the airplane went into an error state — when it deviated from the horizon —the relative movement between the stabilized platform and the airplane initiated a command signal that operated the servomotors, which moved the airplane's control surfaces.

The stabilizer also had control surfaces so that the airplane would not pass beyond the horizontal in its response.

"Sperrys have made aeroplanes safe," the New York Times reported in June, 1914, after a public demonstration of the stabilizer in Paris. And although needing refinement, his stabilizer had, indeed, made the skies more friendly.

Increased research and the production of dozens of inventions made Sperry a corporate head. But one suspects most of Sperry's dress shirts still carried the odd drop of grease or smell of solder. Like most hobbyists, Sperry's mind never ceased to whir with innovation. New Yorker Magazine profiled Sperry shortly before his death in 1930. Ill and ordered by his doctor to stay away from machine shops for health reasons, he nevertheless penned gizmos which he sent to his engineers. He also added, whenever inspiration hit him, to an "ever-present notebook" — No. 78 by the time of the article. Hours before he died after complications from an operation on June 16, he was still inventing. Sperry placed ice before an electric fan to create a cooler breeze beside his hospital bed. ❐