Designing Dc Power Supplies

Step-by-step procedure describes how to design the fixed power and adjusted power supplies you need for solid-state applications

By Joseph J. Carr

The dc power supply is one of the most important parts of any electronic circuit, yet it is often also the least-considered portion of the design. Dc supplies used by designers and experimenters include both integral power supplies mounted inside a cabinet, and "universal" bench power supplies used for testing, adjusting, troubleshooting, or otherwise experimenting with an electronic circuit. Examined here are methods for "designing" simple dc regulated power supplies, both fixed- and variable-voltage types.

Fixed-Voltage Types

The task of designing a fixed-output voltage regulator is made much simpler nowadays by three-terminal integrated circuit voltage regulators. There are quite a few of these devices on the market, but they all share certain characteristics. For one thing, their output voltages are fixed at some standard value. The actual value is usually identified from the type number. For example, a 7805 is a 5-volt regulator, while the 7812 is a 12-volt device. There are, of course, exceptions to the numbering rule, but in general there are summarized as follows:

1) LM-309 series are 5-volt, 100-mA or 1-ampere (depending on case style) regulators;
2) LM-323 is a 5-volt, 3-ampere regulator in a "K" package (same as TO3);
3) LM-340n-xx are positive-output voltage regulators. The *n* in the type number denotes package type, the *xx* is the voltage rating. For example, LM-340K-12 is a 12-volt regulator in a "K" package (it passes 1 ampere);
4) 74xx is a family of regulators similar to the LM-340n-xx series. The xx denote output voltage (7812 is a 12-volt regulator). Package style determines output current;
5) LM-320n-xx is a negative-output version of the LM-340n-xx, while 79xx is a negative-output version of the 78xx. (Note: input and ground terminals on the LM-320 and 79xx are reversed from the pinouts of the LM-340 and 78xx. Failure to observe this convention will result in destruction of the regulator!);
6) The package designations are: *H* indicates a TO-5 case, or its

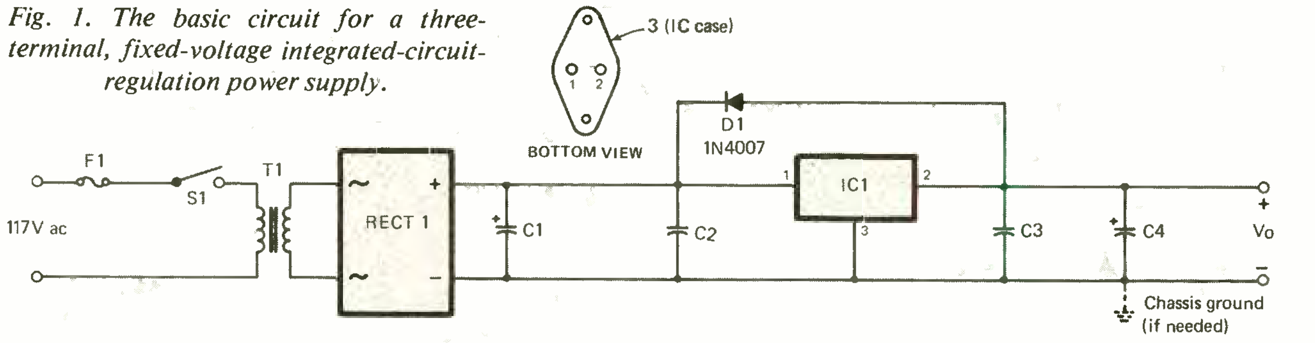

Fig. 1. The basic circuit for a three-terminal, fixed-voltage integrated-circuit-regulation power supply.

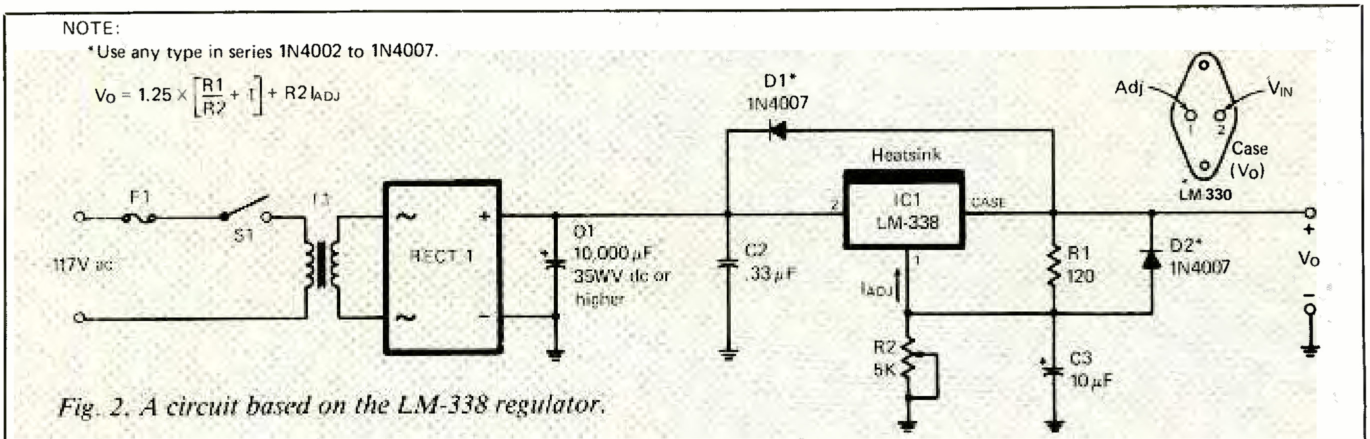

Fig. 2. A circuit based on the LM-338 regulator.

plastic equivalent, and a current of 100 mA; *K* indicates a TO-3 case and a current of 1 ampere (1.5 amperes if properly heatsinked); *T* indicates a TO-220 plastic power transistor type case and a current rating of 750 mA in free air or 1 ampere if properly heat sinked.

With regard to current ratings, heat and high currents are the twins that destroy electronic circuits. If these devices are routinely operated at or near maximums, you can expect to experience a higher-than-usual failure rate.

Shown in Fig. 1 is the basic circuit for a three-terminal, fixed-voltage IC regulator. Transformer *T1*, bridge rectifier *RECT1* and filter capacitor *C1* are selected according to the usual rules for any dc power supply. The transformer steps the 117-volt ac line potential down to the level required for the input of the regulator. As a rule, there should be a minimum 2.5-volt difference between the rated regulator output and the minimum allowable input voltage. For a +5-volt regulator, a minimum of +7.5 volts is needed.

With the foregoing in mind, when selecting a transformer, choose one that provides at least the minimum differential. Also, remember that the voltage across the regulartor's input, which is also the voltage across filter capacitor *C1*, will be approximately 0.9 times the peak ac voltage across the transformer secondary. Since the secondary voltage is specified in rms values, you must multiply the rate value by 1.414 to determine the peak voltage. If all terms are accounted for, the output voltage will be approximately $0.9 \times 1.414 \times V_{rms}$, or $1.27 \times V_{rms}$.

The minimum rms value of the secondary voltage should be the minimum value of dc requried to feed the regulator divided by 1.26. For the +7.5 volts required for a +5-volt regulator, then, you need an rms rating of 7.5/1.26, or 5.95 volts. Since 6.3-volts rms is the next highest standard value, you would select a 6.3 volt ac transformer.

Transformer current rating should be no less than the highest expected dc value you expect the load to draw, plus a margin for safety. In addition, keep in mind that most transformers with center-tapped secondaries are rated for regular full-wave rectification, not full-wave bridge rectification. When the bridge circuit is used the current available is one-half the rated value because of the voltage doubling and the fact that you don't want to exceed the volts × amperes rating of the transformer.

Some transformers will bear up when a greater than rated current is drawn, but it isn't good practice to make them work so hard. Transformer current rating, then, must be at least the current rating of the regulator—and preferably more. There's a general design rule that requires us to use only about 75% of capacity on the average.

There are two rectifier ratings that require particular attention. These are forward current and peak inverse voltage (PIV). Forward current is simply the amount of current that the bridge rectifier will normally pass in the forward direction without suffering a heart attack. In most cases, the forward-current rating of the rectifier should be equal to or greater than the regulator's forward current rating. Again, good design practice dictates that you should allow some excess capacity, so that the rectifier is never made to operate for long at its maximum rating. If you observe this simple rule of thumb, your circuit will operate with almost failsafe reliability.

The peak-inverse-voltage rating is the maximum reverse-bias voltage that the rectifier will withstand without breaking down. Exceeding the device's PIV is almost certain to result in destruction of the rectifier. The normal rule of thumb here is to use a minimum PIV of 2.83 times the applied rms. The reason for this is that the normal PIV seen by the rectifier is 1.414 × rms plus the voltage on the capacitor (*C1* in Fig. 1), which is also 1.414×rms. Thus 2×1.414×rms is 2.83×rms.

This rule doesn't mean much when dealing with 6.3-volt ac transformers, because the minimum available PIV is 25 volts, which is above the maximum reverse voltage generated. But the rule becomes increasingly more important when the voltage increases.

Filter capacitor *C1* in Fig. 1 is selected to provide enough ripple reduction to make the regulator happy. It isn't necessary for *C1* to provide *all* of the ripple reduction needed by the external circuitry powered by the regulator. (The regulator itself adds considerable ripple reduction.) Most authorities recommend a capacitance value of between 1000 and 2000 μF/ampere of current drawn. If you use the 2000-μF/ampere figure, a 1-ampere regulator (the most common type) requries a 2000-μF capacitor. At least 500-μF must be in the circuit, even when the forward current is less than 500 mA.

The working voltage rating (WVDC) of the filter capacitor must be somewhat greater than the maximum expected voltage. Keep in mind that most electrolytic capacitors have a 20% tolerance and that voltages normally vary 15%. Therefore, you require a 35% margin of error on the WVDC rating. For example, if you have 18 volts coming from *RECT1* to regulator *IC1*, this is what will be applied across *C1*. Using the 35% rule, you would specify 18 volts×1.35, or 24.3 volts (or more). Since 25 WVDC is a standard value, you can use this as the minimum WVDC of *C1*. But to be on the safe side, at only a very small additional cost, you would be much better off using a 35- or 50-WVDC if practical.

Capacitors *C2* and *C3* in Fig. 1 are used for noise immunity/protection. Their values aren't critical. Typically, you would use any value between 0.1 and 1.0-μF. These capacitors are best mounted as close as possible to

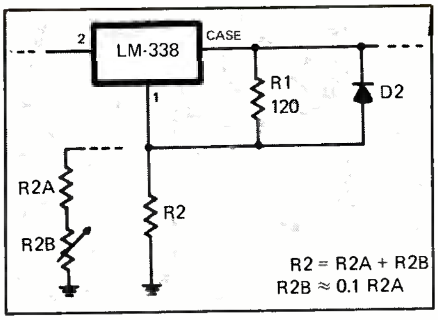

Fig. 3. Fixed output voltage is initially set with R2A/R2B, which are replaced by same-value resistor.

the regulator device. In fact, many designers mount them right on the regulator itself.

Output capacitor *C4* is optional. It's included in the circuit to improve the transient response of regulator *IC1*. When external current demand increases very rapidly, it will take a certain amount of time (in microseconds) for the regulator to catch up. During this period, the external circuit will draw current from *C4*, thus preventing a "glitch" in the power supply voltage. The value of *C4* should be determined by assuming that 100 μF/ampere is needed. The WVDC rating shouldn't be less than 1.35 times the rated output voltage of the regulator.

If you do use *C4*, it's a good idea to also use diode *D1* to dump the charge on the capacitor when power is removed from the circuit. Otherwise, the charge can be dumped back into the circuit through and cause damage to the regulator. Any rectifier diode in the 1N4002 through 1N4007 series will suffice here.

Adjustable-Voltage Types

Adjustable-voltage regulators used to be somewhat more difficult to design than fixed types. Today, however, there are several three- and four-terminal devices on the market that greatly simplify the design procedure. To keep this article brief, we'll limit our discussion to the LM-317 and LM-338 devices, since these are readily available to experimenters through mail-order and walk-in retail outlets that sell parts.

The LM-317 and LM-338 are similar to each other in function. They differ in that the LM-317 handles 1.5 amperes, while the LM-338 is rated at 5 amperes. Information given below for the LM-338 is generally usable for the LM-317 as well.

A circuit based on the LM-338K is shown in Fig. 2. Note that the output terminal of this regulator is the case, whereas the case of the fixed-voltage three-terminal regulator in Fig. 1 is the reference terminal for the input

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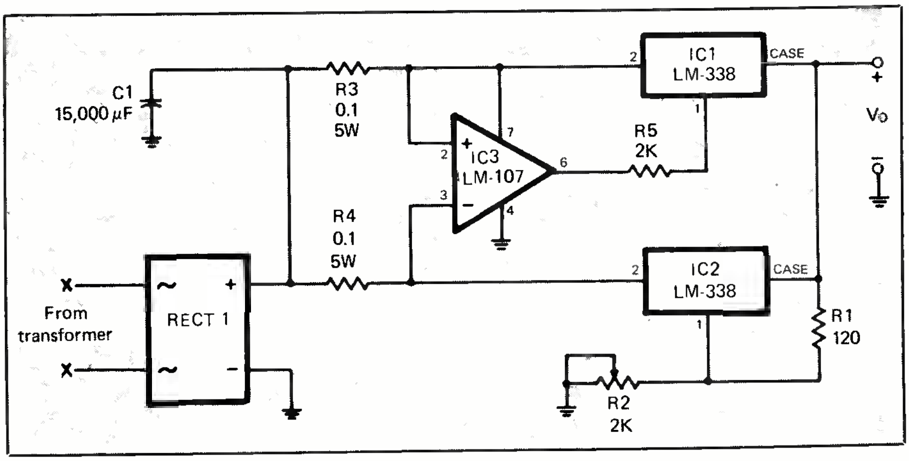

Fig. 4. In this variable-output-voltage circuit, two LM338K IC voltage regulators are used to provide a 1.2-to-16-volt regulated output with a current-delivery capability of 10 amperes.

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and output. Don't forget this important difference! Because of the pinout arrangement of the LM-338K, you'll have to insultate the case and/or the heat sink it rests on from the chassis, especially if the chassis is used as the common/ground!

The transformer, rectifier and filter capacitor are selected for the Fig. 2 circuit using the same criteria spelled out for Fig. 1.

The LM-338K can accept an input of up to 35 volts. It will produce a maximum output of several volts less than the 35-volt input. The exact output voltage is set by the ratio of *R1* and *R2*. In Fig. 2, *R2* is a variable potentiometer. With the circuit arranged as shown, output voltage V_o will be approximately $1.25V[(R1/R2 + 1 + (R2 \times I_{adj})]$. Normally, the term $(R2 \times I_{adj})$ is so small as to be ignored.

With the values given in Fig. 2, the output can be varied from 1.25 to more than 35 volts (assuming the input would allow it). In some cases, where the voltage is set and then forgotten, *R2* will be a trimmer pot mounted on the power supply board. In other cases, it will be an operator-adjustable front panel control.

Diodes *D1* and *D2* serve the same protection function in this circuit as in Fig. 1. Once again, any 1N4002 through 1N4007 diode will suffice.

If you want to make the LM-338K (or the LM-317) into a fixed-voltage regulator, you can with one of the two modifications shown in Fig. 3. In one case, two fixed resistors are used for *R1* and *R2*. Normally, *R1*'s value will be 120 ohms and *R2* will have a value selected to set the output voltage at the required level. In the other case, *R2* becomes *R2A* and *R2B*, with the value of *R2B* being roughly 10% to 15% of the value of *R2A* and set to trim the output to a precise value. This latter arrangement has the advantages of fixed operation, while allowing trimming of the output to the exact voltage required.

Our final circuit, shown in Fig. 4, has two LM-338K regulators connected together to form a 1.2- to-16-volt dc regulated power supply capable of delivering 10 amperes. Since the cases of the LM-338K devices are connected together, you can use the same heat sink for both. Potentiometer *R2* sets the output voltage and is adjustable to just over 16-volts dc.

The input voltage for the Fig. 4 circuit can be acquired from rectifying a 12.6-volt ac (rms) transformer's output and filtering it with 15,000 μF, or more, of capacitance.

Conclusion

The dc power supply is very important to the success of any electronic project. Dc supplies are also very important to have on your workbench. With the information presented, you should now be able to design and build most of the elementary supplies needed by hobbyists and experimenters in solid-state electronics. **ME**