Experiment 283: DC Power Supplies

Aim

To demonstrate the actions of rectification, ripple reduction and regulation in low-voltage power supplies.

References

1. Gary E.J. Bold, "Transistor Electronics", Chapters 2 and 3.
2. Horowitz and Hill, "The Art of Electronics", pp 44 – 48, 326 – 335.

Introduction

All electronic equipment requires one or more stable *dc* voltage supplies. Here we examine the operation of low-voltage (less than 30V) supplies normally needed for transistorised equipment.

The basic requirements of such a power supply are:

- A steady *dc* voltage should be produced.
- Any superimposed ripple (50 Hz or 100 Hz from the mains) should be acceptably small.
- Variation in the *mains* supply voltage should not produce significant changes in the *dc* output voltage.
- Variations in the current drawn from the supply should not produce significant changes in the output voltage.

The term "significant" means different things in different contexts. A precision oscillator or low-level *dc* amplifier requires a more precise supply than a high-level audio-amplifier.

Diodes

The rectifying diodes supplied are silicon types. If these become very hot at any stage (uncomfortable to touch), your circuit is faulty. **Turn it off** immediately, rectify the fault, or call a demonstrator.

The absolute maximum ratings for these diodes are:

- Continuous forward current of 1 A (in free air).
- Peak reverse voltage of 1000 V. This is the maximum voltage that can be applied in the *non-conducting* direction before the diode fails.

Electrolytic Capacitors

Capacitors having values greater than about 1 μF are usually electrolytic. They are *polarised* and must *always* be connected with their negative terminal (marked "-") connected to the more negative voltage. Alternating voltages should *never* be applied across them.

All such capacitors have a maximum voltage rating (the maximum continuous *dc* voltage the component can withstand). If this is exceeded, or if the capacitor is wired backwards, it is liable to explode!

Zener Diodes

These are used as *voltage regulating* elements, and are always connected in the *reverse* direction.[1] The nominal zener voltage and maximum power ratings of those supplied are 6.2 V and 1 W respectively.

Question 1. Calculate and record the maximum *current* rating of the zener diode.

This current should never be exceeded. In particular, be careful *not* to connect the zener diode directly across the power supply. This will destroy it within a few milliseconds!

Transformer

This supplies 7.5 V *rms* at a maximum current of 500 mA between output terminals labelled A and B.

Oscilloscope

The dual-trace oscilloscope provided provides either *ac* or *dc* coupling to the input terminals of the two y-amplifiers. To observe a *complete* voltage waveform the *dc* setting should be used with the zero voltage level set on a known horizontal graticule calibration mark. To observe small variations superimposed upon a much larger *dc* voltage, the *ac* connection is more suitable.

Important! Remember that the shield (ground) connections to the oscilloscope inputs *must* be connected only to the *bottom rails* of the circuits!

Circuit Board

The circuit board contains all the components needed to construct the various power supply circuits. The board is constructed in two sections, as in Figure 1.

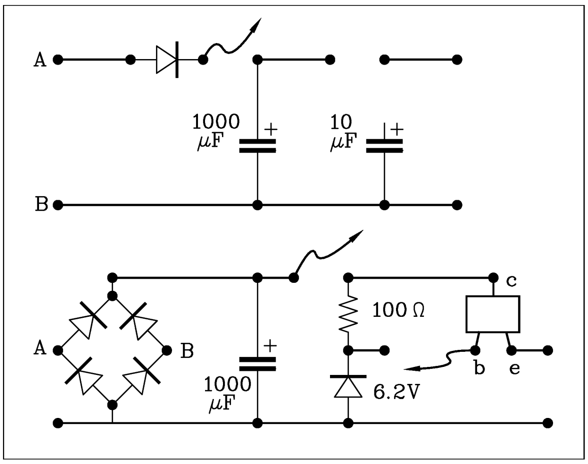

Figure 1: Circuit board layout

- The upper section is used for the half-wave rectifier experiment only. The transformer outputs labelled A and B are connected to the corresponding points on the circuit board.
- The lower section is used for the fullwave and regulated supply circuits.

[1] *Transistor Electronics*, pages 22 – 24

Caution! Be careful wiring up each circuit! *Check it again* before switching on the power. If you are at all doubtful, ask a demonstrator for help. In particular, remember that the shield (ground) connections to the oscilloscope inputs *must* be connected only to the *bottom rails* of the circuits!

Load R_L

To determine the *regulation characteristics* of a power supply, we need to vary the load current. An additional board is supplied having a number of fixed resistors ranging in value from 3300Ω to 33Ω which can be switched across the supply output, either singly or in various combinations. An ammeter and a voltmeter are connected to the resistor board as shown in Figure 2 and the *entire combination* constitutes the resistive load R_L used in all the following experiments.

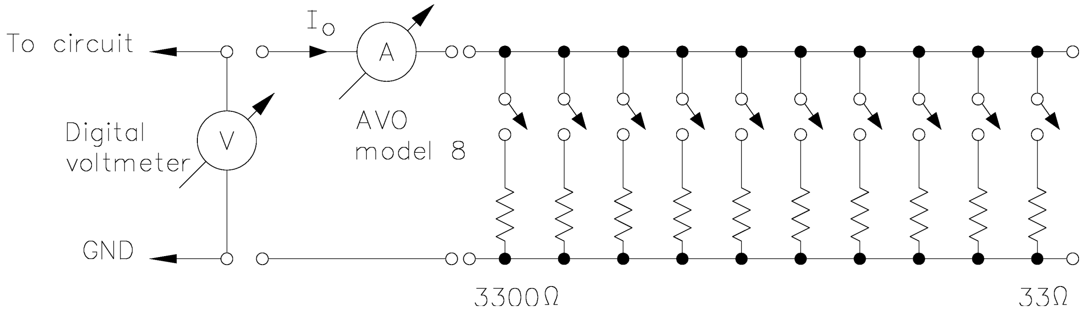

Figure 2: Schematic of resistive load

The AVO 8 meter shown connected as an *ammeter* measures the load *current* and the DVM (Digital Volt-Meter) the power supply output *voltage*. Hence, these two instruments will tell us the mean *dc* output current I_0 and the mean *dc* output voltage V_0, respectively.

Graphing the Results

In the experiments that follow, you will be asked to measure the mean *dc* output voltage V_0 and, for some of the circuits, the peak-to-peak ripple voltage V_{pp} as the load current I_0 is increased. *All these graphs* must *be plotted on lin-lin graph paper using the same axes.*

I_0 is plotted on the x-axis since it is the independent variable. A suitable scale is 10 mA per cm. The range for I_0 is 0 to 100 mA.

V_0 and V_{pp} are plotted on the y-axis and a suitable scale is 2 cm per volt. The range for V_0 is 0 to 11 or 12 volts.

Part 1: The Half-wave Rectifier

This is the simplest circuit, and is illustrated in Figure 3. Note that it requires only one diode. We will investigate the regulation characteristics of this circuit for values of smoothing capacitor $C_s = 0\mu$F, 100μF and 1000μF. Initially, we will set $C_s = 0\mu$F. The load R_L is supplied by the circuit of Figure 2.

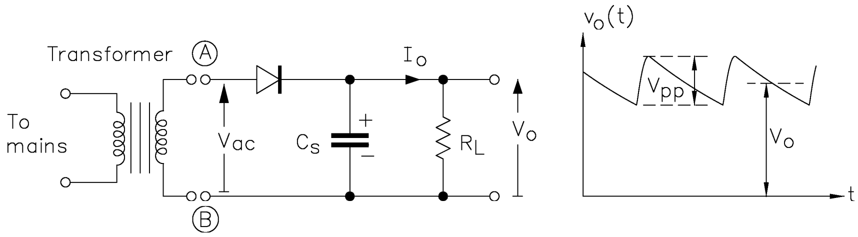

Figure 3: Circuit for the half-wave rectifier.

(1) For each of the following procedures (2), (3) and (4), observe $v_{\mathrm{ac}}(t)$ and $v_o(t)$ simultaneously using the oscilloscope. Both oscilloscope inputs should be

- *dc* coupled,
- set to the same sensitivity (volts per division).
- adjusted so that both zero voltage levels are the same.

In your Lab Book, tabulate and display the oscilloscope pictures that you observe using the format of Table 1. Sketch both the *ac* input voltage, $v_{ac}(t)$ and output voltage, $v_o(t)$ in the table spaces. Use the *same* vertical and horizontal axis scales throughout the table.

For each procedure, also tabulate separately for each capacitor and load resistor

- the mean *dc* output voltage, V_o, read from the digital voltmeter,
- the mean *dc* output current, I_o, read from the AVO 8.

R_L $\rightarrow$	Sketch, 1 kΩ load.	Sketch, 220 Ω load.
No capacitor	$V_0 =$ $I_0 =$	$V_0 =$ $I_0 =$
$C_s = 100\mu$F	$V_0 =$ $I_0 =$	$V_0 =$ $I_0 =$
$C_s = 1000\mu$F	$V_0 =$ $I_0 =$	$V_0 =$ $I_0 =$

Table 1:

(2) Construct the circuit of Figure 3 with $R_L = 1$ kΩ but leave the capacitor C_s *disconnected.* On the same, labelled axes, sketch the form of both $v_{ac}(t)$ and $v_0(t)$ in the top, leftmost box of the table. Record the mean *dc* output voltage V_o from the digital voltmeter and the mean *dc* output current I_o from the AVO 8.

(3) Repeat procedure (2) with the load resistor R_L set at 220Ω. Sketch in the next box in the table.

(4) Repeat procedures (2) and (3) for both values of smoothing capacitance provided C_s (100 μF and 1000 μF). Don't forget to record V_o and I_o as well.

Question 2. For a given value of load current I_o, what effect does increasing the value of the smoothing capacitor have on the output voltage? For a "good" power supply, should we make the value of C_s large or small?

We now examine the *regulation characteristics* of this power supply circuit by observing the output voltage V_o and the peak-to-peak ripple voltage V_{pp} as functions of the load current I_o.

(5) Select the smoothing capacitor C_s to be 1000 μF. Use one channel of the oscilloscope, set to *ac* coupling, to measure the *peak-to-peak ripple voltage*, V_{pp}, superimposed on the mean output voltage V_o. Change the sensistivity scale on the oscilloscope as necessary to obtain accurate estimates of V_{pp}. Make measurements of the *dc* output voltage V_o and the ripple voltage V_{pp} for a range of values of I_o from 0 to 100 mA.

(6) Using the same axes, plot graphs of V_o and V_{pp} against I_o.

Note: Plot I_o on the x-axis since it is the independent variable. You may plot these graphs as the readings are taken, to avoid tabulating the data.

Question 3. Summarise how V_{pp} and V_0 change as the load current I_0 increases.

Question 4. Using the diode data provided, calculate the maximum *rms* voltage which could be used (i.e. the secondary transformer voltage) in a half-wave rectifier circuit without damaging this diode. Assume that R_L is very large so that negligible current is drawn.

Part 2: Bridge Rectifier

Note: For the rest of this experiment, use the *lower section* of the board.

The circuit shown in Figure 4 is almost universally used in power supply circuits, since it provides *full-wave* rectification, which utilises *both* halves of the *ac* waveform cycle. This reduces the size of smoothing capacitor required to provide a given, maximum ripple voltage at the rated load current.

The bridge circuit is so commonly used that the bridge itself may be purchased as a single integrated device.

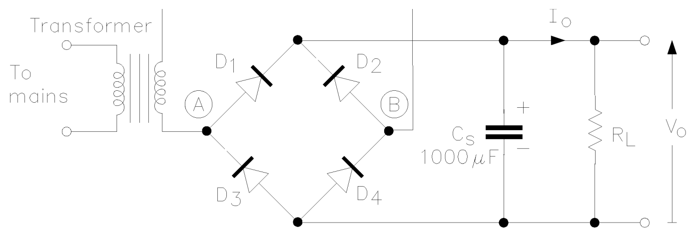

Figure 4: Bridge rectifier circuit.

Assume ideal diodes. During the half cycle when the upper end of the transformer secondary winding is positive, diodes D_2 and D_3 conduct, while diodes D_1 and D_4 are open circuits. Hence the positive and negative ends of the transformer are connected to the positive and negative ends of the capacitor, respectively. When the transformer secondary voltage polarity reverses, diodes D_1 and D_4 conduct, while diodes D_2 and D_3 are open circuits. Again, the capacitor is connected to the transformer end having the correct polarity.

One minor disadvantage compared to the half-wave rectifier is that *two* diode voltage drops are now in series with the capacitor, reducing the output voltage.

(7) Construct the circuit of Figure 4. For a range of values of I_o from 0 to 80 mA, plot graphs of

- V_o against I_o,
- V_{pp} against I_o.

(8) Add a plot of the theoretical value of V_{pp}, given by simple theory[2] as

$$\begin{aligned} V_{pp} &= \frac{I_o}{2C_s f} \\ \text{where } f &= \text{mains frequency in Hz.} \end{aligned}$$

(9) Determine and record the effective *dc* output resistance of the *dc* supply, when $I_o = 50$ mA. Compare this with the theoretical value.

$$\begin{aligned} R_o &= -\frac{dV_o}{dI_o} && \text{From your graph} \\ R_o &= \frac{1}{4C_s f} && \text{From simple theory} \end{aligned}$$

Question 5. For a "good" power supply, should this internal resistance R_o be large or small?

Part 3: Zener Diode Regulator

This produces much better regulation characteristics than either supply above. A zener diode has a very stable and reproducible *breakdown voltage* in the reverse-biased direction[3]. This is called the *zener voltage*, and is almost constant over a wide current range.

Figure 5 shows the zener diode reverse biased from the unregulated power supply in series with a resistor, R_z, to limit the current I_z flowing through it. The unregulated supply voltage must be greater than the zener voltage.

The load, represented by R_L, is connected *across* the zener diode. The current flowing through R_z is thus shared between the zener diode and the load. As long as the zener diode conducts, the load voltage will equal the zener voltage. If the load current, I_o, *decreases*, the zener current, I_z *increases* to compensate and vice versa. Regulation ceases when the load draws *all* of the current flowing through R_z, reducing I_z to zero. At this point zener turns off, becoming an open circuit, and the output resistance of the power supply is that of the unregulated supply in series with R_z.

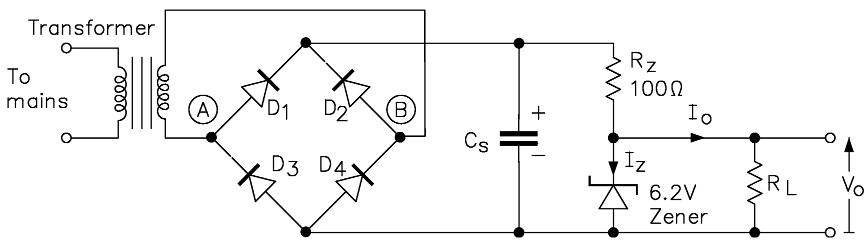

Figure 5: Zener diode regulating circuit.

(10) Set up the zener diode regulator circuit circuit as shown in Figure 5.

(11) Plot V_o against I_o. While doing this, note and record the ripple voltage V_{pp} at around 20 mA and 60 mA. You should observe that this is an order of magnitude smaller than for the unregulated full-wave circuit. You should also find that when the load current exceeds a critical value, the output voltage drops steeply as the load current increases further.

[2] *Transistor Electronics*, p. 15
[3] *Transistor Electronics*, pp 8, 11, 20

(12) From your graph, estimate the output resistance of the zener diode supply when $I_o = 20$ mA and $I_o = 60$ mA. Record this, with that of the unregulated fullwave supply for comparison.

Question 6: *Why* did the output voltage decrease steeply when the load current exceeded the critical value?

Question 7: For what load current is the power dissipation of the zener diode *maximum*? What is the approximate value of this maximum power dissipation? (**Hints:** What is V_z? When is I_z maximum? Estimate I_z by measuring appropriate voltages and using the value of R_z.)

You should have observed that the zener circuit has *much* better regulation characteristics than the simple full-wave circuit. However, it has two disadvantages:

- All power dissipated in the zener diode is wasted.
- The maximum load current is limited by the maximum current that can be safely passed through the zener diode. This is typically 100 mA to 1 A.

If *higher* load currents are required, the circuit of the next section is often used.

Part 4: Series Transistor Regulator

In Figure 6, a forward biased *npn* power transistor is used as a *current amplifier*[4].

As before, a zener regulator supplies a constant voltage as a reference. However, this now supplies only the *base* current, I_b, of the transistor, and the output current, I_o, is the transistor *emitter* current, I_e. These currents obey the relationship

$$I_e = (\beta + 1) I_b$$

where $\beta \approx 25 - 50$ for a power transistor, and is nearly independent of the voltage developed across the transistor. Thus, the output current is about β times that which the zener diode has to supply. In this way, output currents of 2 - 10 A are readily obtainable. Technically, this is an *emitter follower* circuit[5].

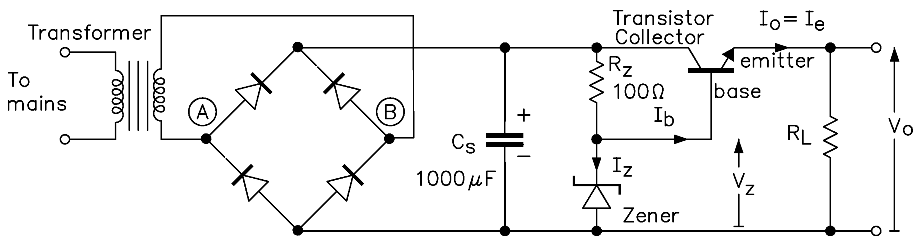

Figure 6: Series-pass transistor regulating circuit.

However, there is one catch. The base-emitter voltage, V_{be}, of a forward biased silicon transistor is about 0.7 - 1 V. Hence the *output* voltage will be *lower* than the zener voltage by this amount.

(13) Construct the circuit of the series transistor regulator as shown in Figure 6.

(14) On the same graph as before, plot V_o against I_o. Again, note and record the order of magnitude of V_{pp}.

[4] *Transistor Electronics*, pp 38 – 39
[5] *Transistor Electronics*, pp 64 – 65

(15) You should find that your graph of V_0 against I_0 has a very small slope and as a consequence, it will be difficult to estimate the output resistance of the regulated supply from the graph. However, because the graph is nearly linear, we can use the following method to estimate the output resistance when $I_o =$ 40 mA. Set the load current I_0 to approximately 30 mA and carefully record V_0. Now do the same with I_0 set to approximately 50 mA. From these pairs of readings, estimate the output resistance of the power supply when $I_o =$ 40 mA.

(16) Calculate the power dissipated in the series transistor when $I_o = 40$ mA. (**Hint:** The power dissipated in any component is the product of the voltage across it and the current through it.)

Question 8: What factors would limit the maximum current that could be supplied by this transistor-regulated supply?

(17) From measurements in Part 2 and Part 4, determine the value of R_z which will result in the output voltage of the power supply being approximately constant over the range 0 to 100 mA (assume the power transistor has $\beta = 25$).

Question 9: In Figure 2, why is the DVM connected across the series combination of ammeter and load resistor? Why was it not connected just across the load resistors?

Conclusion

We have examined several different *dc* power supply circuits having increasingly desirable levels of performance. Even better supplies are readily constructed, and obtainable in integrated packages as *three-terminal regulators*[6]

The most modern, smallest and lightest power supplies are constructed using *switching regulators*[7]. These are an order of magnitude more complex. The schematic of a typical PC power supply is shown in the reference.[8] These are almost invariably purchased as complete units.

Write-up

Your write-up should cover the following points:

1. Circuit diagrams, where appropriate.
2. Graphs or tables of experimental data as requested.
3. Answers to all the questions

List of Equipment

1. 1 x Hitachi Oscilloscope Type V212 or V552
2. 2 x X1-X10 Oscilloscope Probes
3. 1 x Fluke Model 77 Digital Multimeter
4. 1 x Circuit Board Housing
5. 1 x Circuit Board

[6] *Transistor Electronics*, pp 23 – 25, 36 – 40.
[7] *Transistor Electronics*, pp 43 – 44
[8] *The Art of Electronics*, pp 362 – 363.

6. 1 x Alligator-to-alligator connecting leads
7. 3 x Banana-to-alligator connecting leads

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