PHYSICS 536

Experiment 4: DC Power Supply

I. Introduction

The process of changing AC to DC is investigated in this experiment. An integrated circuit regulator makes it easy to construct a high-performance voltage source using only four parts: a transformer, full-wave bridge rectifier, capacitor filter, and regulator. A zener diode regulator is also included as a simple illustration of regulator properties.

1. **Transformer** A transformer is used to obtain the approximate output voltage of the power supply. The output of the transformer is still AC.

2. **Rectification** A rectifier converts AC to DC. The *peak* voltage, V_p, from the rectifier is slightly less than the peak transformer voltage, V_T.
$$V_p = V_T - 2V_d \tag{1.1}$$
V_d is the voltage drop across the diode, typically ~ 0.8 V, and in a typical bridge rectifier the current flows through two diodes. Since the voltage of the transformer secondary is always specified as an effective or RMS voltage, V_e, and is related through the peak voltage by the following relation
$$V_T = 1.4V_e . \tag{1.2}$$

3. **Capacitor filter** The filter capacitor stores charge so that it can smooth the deep valley in the rectified waveform. The drop in capacitor voltage, *i.e.* the ripple, can be estimated using the relations
$$\begin{aligned} i &= C\frac{dV}{dt} \\ dv &= \frac{i}{C}dt \end{aligned} \tag{1.3}$$
Changing from differential to delta notation
$$\Delta V = \frac{i}{C}\Delta t \tag{1.4}$$
Δt is the reciprocal of frequency, f, so
$$\Delta V = \frac{I_C}{fC} \text{ (half wave)} \tag{1.5}$$
where I_C is the current flowing out of the capacitor. For a full wave rectifier
$$\Delta V = \frac{I_C}{2fC} \text{ (full wave)} . \tag{1.6}$$
In practice, a better approximation to ripple is slightly less and is given by
$$\Delta V = \frac{0.7I_C}{fC} \tag{1.7}$$

for a full wave rectifier. By choosing a large capacitance the ripple can be reduced to any desired level, however this brute-force approach has several drawbacks. First of all, the capacitors may be prohibitively large and/or expensive. Another drawback is that even though the ripple may be negligible line voltage variations are transferred to the output voltage. A better approach is to regulate the output voltage.

The current drawn from the capacitor depends on the type of the regulator used. We will consider two types of regulators: IC and zeners. V_o is the output voltage of the regulator and R_L is the external load resistor connected to the regulator, i.e. it is the resistance of the device or load to which power is being transferred. For an IC regulator

$$I_c = V_o / R_L. \tag{1.8}$$

For a Zener regulator

$$I_c = (\overline{V}_C - V_Z) / R_2 \approx (V_A - V_Z) / R_2. \tag{1.9}$$

$\overline{V}_C$ is the average voltage on the capacitor; the peak rectified voltage, V_A, can be used as an estimate for $\overline{V}_C$. V_z is the voltage of the zener diode and R_2 is the resistor between the filter capacitor and the zener diode.

When the load resistor is attached directly to the capacitor without a regulator the current is given by the relation

$$I_c = \overline{V}_C / R_L \approx V_A / R_L \tag{1.10}$$

4. **Zener regulator** The voltage from a zener regulator is given by the following expression

$$V_o = V_z \frac{R_2}{R_2 + r_z} + V_C \frac{r_z}{R_2 + r_z} - I_o (r_z, R_2) \tag{1.11}$$

R_2 is the resistor that supplies current to the zener, and r_z is the zener equivalent resistance. The zener can be visualized as a voltage generator in series with a small equivalent resistance, r_z, (*c.f.* Fig. 3). Each of the terms in (1.11) has a physical meaning. In particular, the second term represents input regulation; changes in the capacitor voltage, V_c, have an effect on V_o. Specifically, a change in the output voltage, V_0, is related to a change in V_c by the equation

$$dV_o = dV_C \frac{r_z}{R_2 + r_z}. \tag{1.12}$$

The third term represents the output regulation, specifically how changes in the output current, I_0, impact V_0. Changes in V_0 are related to changes in I_0 by the equation

$$dV_o = -dI_o(r_z, R_2). \tag{1.13}$$

The maximum current that can be delivered to the external load is

$$I_o(\max) = \frac{V_C(\min) - V_o}{R_2} - I_z(\min) \tag{1.14}$$

$V_c(\min)$ is the lowest voltage on the capacitor and I_z (min) is the minimum current needed to maintain low resistance in the zener diode. If R_L draws more current than specified by the preceding equation, the zener is pulled out of conduction and acts like an open circuit.

5. **IC Regulator** The peak voltage, V_T, from the transformer must be larger than the voltage needed for the rectifier, $2V_d$, ripple, ΔV, regulator, V_R, and output voltage, V_0.

$$V_T \geq 2V_d + \Delta V + V_R + V_o \tag{1.15}$$

6. **Regulator Specifications** The input regulation is specified as a change in V_0 for a permanent change of the input voltage, V_i.

    Input regulation: ΔV_o when V_i changes from V_1 to V_2.

    The effect of input ripple on V_o is stated separately as attenuation in db.

    Ripple rejection: $RR(db) = -20Log(\Delta V_o / \Delta V_i)$

    $$\Delta V_o = \Delta V_i 10^{-(RR/20)}$$

    Output regulation: ΔV_o for I_o change from I_1 to I_2.

    The temperature coefficient specifies the change in V_o caused by a change in internal temperature.

    Temperature coefficient: $TC - V_o = \Delta V_o / ^\circ C$

6. **Power Dissipation** The heat that must be transferred from the regulator to surrounding air is

$$P = (\overline{V}_C - V_o)I_o = (V_p - \Delta V/2 - V_o)I_o \tag{1.16}$$

The average capacitor voltage, $\overline{V}_C$, is estimated as the peak rectified voltage, V_p, minus half the ripple. The internal temperature, T_j, is

$$T_j = T_A + \Theta_{JA} \mathrm{P} \tag{1.17}$$

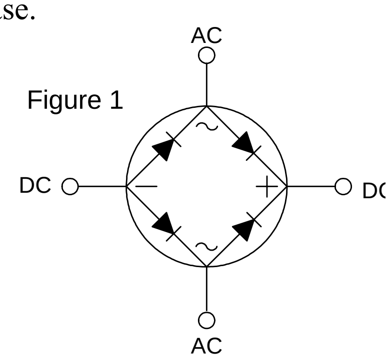
T_A is the air temperature around the regulator and Θ_{JA} is the thermal resistance in $^\circ C$/watt. When a heat sink is used to improve heat transfer, the resistance has three components; from inside to the device case, from case to sink, and from sink to air

$$\Theta_{JA} = \Theta_{JC} + \Theta_{CS} + \Theta_{SA} \qquad (1.18)$$

B. <u>Rectifier</u>

The arrangement of the diodes in the bridge rectifier is shown in the following sketch. (The drawing is rearranged, but the connections are the same as shown in the lecture notes.) The rectifier case is round, and the pins are arranged as shown. Only the positive pin is labeled on the case.

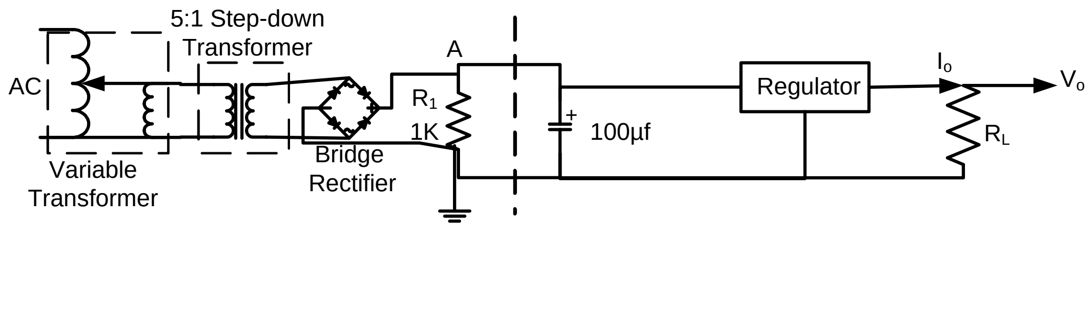
Figure 1



1) Refer to GIL section 9 and test a 914 diode for practice. Then check all the diodes in your bridge rectifier to be sure that it is working correctly.

The complete circuit of a basic power supply is shown below. You will assemble and test the rectifier portion first (the part on the left side of the dashed line). Later you will add the filter capacitor and then the regulator. The variable transformer is used to adjust the AC voltage applied to the rectifier.

Figure 2



(This is a convenient arrangement in our teaching lab, but in a normal power supply the transformer would be selected to match the requirements of the supply.) Connect the secondary of the transformer to the *red* and *green* terminals of the circuit box, *not the black terminal.*

2) During the lab use the transformer secondary voltage specified on the component sheet and calculate the peak rectified voltage, V_A, at point A. Draw a sketch of $v_A(t)$ covering a full cycle. How much time is required for a half cycle?

On the oscilloscope use DC input coupling with zero volts as a reference (refer to GIL section 5.3). Switch the input to ground and adjust the vertical position until the trace is along a convenient horizontal line. In this case, a line near the bottom of the display is appropriate since the observed voltage is only positive. Do not change the scope settings until you have observed the rectified waveform with and without the filter capacitor in step 5.

3) Observe $v_A(t)$. Adjust the variable transformer until V_A has the value calculated in step 2. Is this the waveform you expect?

C. <u>Filter Capacitor</u>

4) During the lab or before calculate the ripple voltage for the capacitor specified. Use the peak voltage (V_A)calculated in step 2. Add a sketch of $v_A(t)$ with C present to the sketch begun in step 2.

Be sure that you use the correct polarity when the filter capacitor is added to the circuit. The negative side of the 100µf capacitor is marked with a minus sign and arrows on a blue band running down the side of the capacitor. Normally you should turn off the voltage to the circuit when components are changed. However, in the next step a clearer image is obtained by putting the capacitor in and out of the circuit with the voltage on to see the effect on the waveform. Arrange the components so that this can be done without the danger of accidental connections. The scope settings should be the same used in step 3.

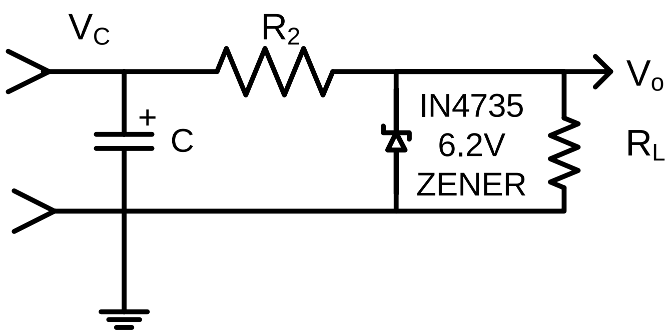
5) Touch and remove the capacitor several times. Compare the change in waveform to the sketch you drew in step 4. (An additional sketch is not required for the lab report). After you have observed the effect of the capacitor, turn off the voltage and connect C for the remainder of the experiment. Switch the scope back to AC coupling and change the gain so that it is convenient to measure the amplitude of the ripple.

The capacitance of electrolytic capacitors can be twice the normal value printed on the case; hence the observed ripple may be smaller than expected.

D. <u>Zener Regulator</u>

Remove R_1 and add R_2 and the zener diode in the following sketch. The zener diode operates with reverse voltage polarity, i.e. the band-end should be positive. R_L is not used initially. Assume $r_z = 10\Omega$

Figure 3



6) Calculate the ripple voltage on the capacitor (ΔV) and the change in $V_o, \Delta V_o$, caused by ΔV. (The peak value of the capacitor voltage (V_c) is given on the component sheet. Since the ripple will be small, V_c can be used as the average value of $v_c(t)$).

7) Measure the ripple ΔV and ΔV_o. Use AC coupling and a cable to measure ΔV_o because it is small. Calculate r_z from the measured ΔV and ΔV_o.

8) Calculate the change in V_o that would be produced by the specified change in I_o.

9) Use the digital volt-meter to measure V_o. Insert R_L to draw output current. Calculate I_o, Observe the change in V_o. Calculate r_z using I_o and the measured ΔV_o.

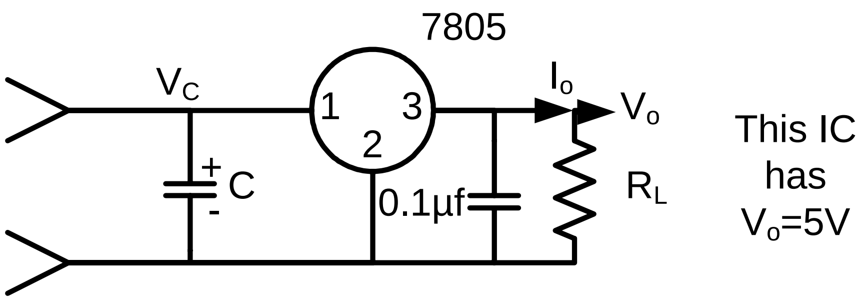
10) Calculate the maximum I_o that will leave a minimum of 2 ma flowing through the zener diode. The specified R_L draws too much current and causes the zener to come out of conduction. Calculate V_o with this R_L in the circuit.

11) Insert R_L and measure V_o

E. <u>IC Regulator</u>

Remove R_2 and the zener diode. Add the 7805 IC regulator. Specifications and pin arrangement are given at the back of these instructions.

Figure 4



Use care, the pins on the regulator can break if they are bent excessively. The capacitor at the output reduces the danger that the regulator will oscillate. (the regulator uses negative feedback, which can cause oscillation, as discussed in Chapter 13 of the notes).

12) Calculate the minimum capacitor voltage that is acceptable for this regulator? Calculate the capacitor ripple ΔV for the specified R_L. What is the smallest acceptable value of the capacitor voltage at its peak [V_c(peak)]?

13) Adjust the variable transformer so that V_c(peak) is approximately 2V larger than the minimum calculated in step 12. Measure the ripple voltage ΔV.
The following procedure should be used to observe failure of the IC regulator when the capacitor voltage gets too low. The voltage across the capacitor (V_c) and V_o will be observed on the dual trace, not the differential mode. Set the vertical gain on both channels at 2V/div. Use DC coupling with zero volts as the reference. Use the same reference line for both traces near the bottom of the display. The difference between the two traces should be the voltage across the regulator.

14) Adjust the variable transformer to lower v_C below the normal value. You should see that V_o drops at the low point on the capacitor discharge, which demonstrates that the regulator fails when the capacitor ripple goes too low. Increase V_c until its minimum is slightly larger than that needed for the regulator to work correctly. Compare the observed minimum voltage needed across the regulator to its specifications.

15) Estimate the change in V_o caused by changing V_c from 7 to 25 volts.
The current flowing through the regulator should be small to minimize heating effects when V_c is changed. However, some current is required for the regulator to work correctly. Use R_L=1K. Measure V_o as soon as V_c has been increased because there will be a slow drift due to heating in the regulator.

16) Use the variable transformer to change the minimum value of v_C from 7 to 25 volts. (Observe v_C with the scope.) Use the digital meter to measure V_o before and after the change.

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Experiment 5 (A)

2-3. $V_e = 15V$ AC, $R_1 = 1K$

4-5. $C=100\mu f$, $R_1 = 1K$

6-7. $R_2=1K, V_c=17V$, $V_Z=6.2V$

8-9. $\Delta I_o=5.2ma$, $R_L=1.2K$

10-11. $R_L=470\Omega, V_P=17V$, $R_2=1K$

12-14. $R_L = 100\Omega$

15-16. $R_L=1K$

17-18. $R_L=100\Omega$

21. $\overline{V}_c=12V, T_A=40^oC$

22. $\Theta_{JC}=5^oC/W, \Theta_{CS}=0.3^oC/W, \Theta_{SA}=22^oC/W$

For example, see T 6107 heat sink on text page 179

Components

Transformers: variable and step-down

Semiconductors: 1N914 diode, 1N4635A zener diode, bridge rectifier, 7805 IC-regulator.

Capacitors: 100μf, 0.1 μf

Resistors: 100Ω, 470Ω, 1K, 1.2K