Experiment No. 3. Pre-Lab

Power Supplies and Linear Regulators

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Introduction:

All electronic systems which operate on DC voltages (+5 V, ±12 V, etc.) and are plugged to the AC (120 V, 60 Hz) system require a power supply. This includes all audio components (CD player, tape player, receiver, etc.) and most home/office electronic units (computers, printers, alarm clocks, microwave ovens, and dishwashers/fridges/washing machines if they have microprocessor controls). A power supply schematic is shown in Figure 1. The 120 V AC voltage is first stepped down to ~12 V AC using a transformer, then passes by a diode bridge rectifier and a low-pass "filtering" capacitor. The resulting DC voltage has a ripple of around ±10% V_p (for example 12V ± 1 V).

The main focus of Experiment No. 3 is on the input section of the power supply, mainly the transformer, diode rectifier and the low-pass capacitor. The relevant equations for a full-wave or half-wave bridge rectifier are given in the course notes. Notice that these equations are accurate to ±25% since they are derived from very simple assumptions. They are intended to give a conservative estimate of the output voltage ripple, the peak diode current and the peak inverse voltage.

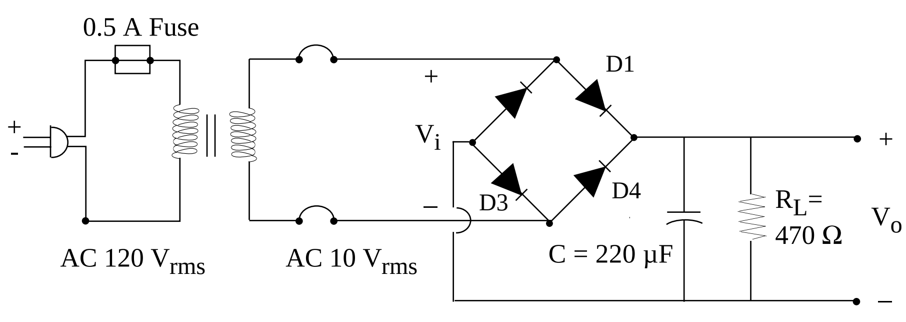
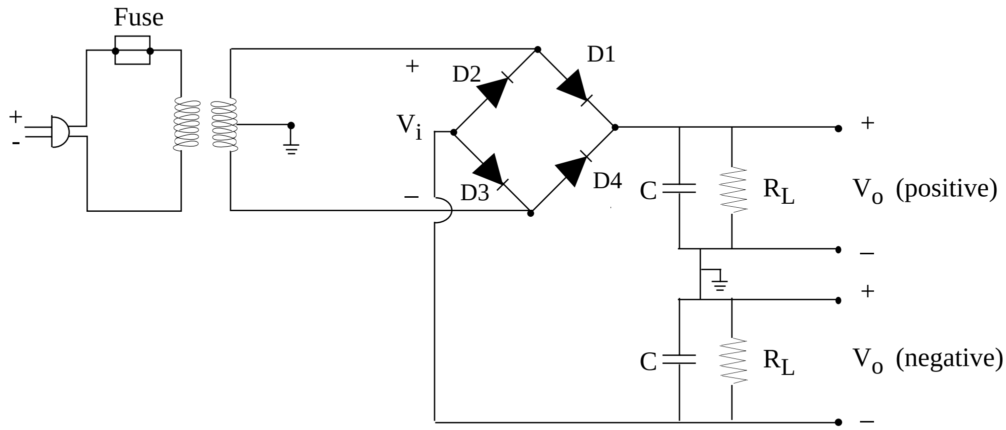


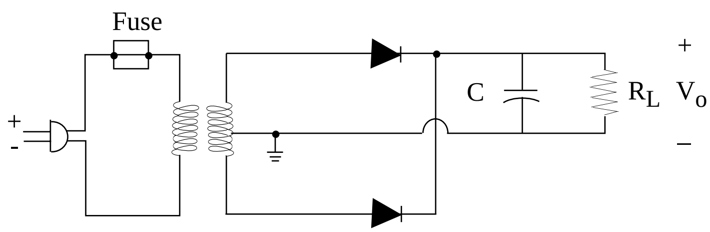
Figure 1: A full-wave bridge rectifier.

Dual (Positive and Negative) Output Power Supplies:

In order to get a dual output power supply, a center-tap transformer must be used. The center tap is usually connected to ground. Relative to the center tap, one of the output transformer lines is at a positive voltage and the other is at a negative voltage. A full-wave rectifier delivering dual-output voltages is shown below:



A full-wave single-output rectifier can also be obtained using a center-tap transformer as indicated below:



There is basically no difference in Vpk, V_R, and Id between this topology and the four-diode bridge, except that this topology requires a center-tap transformer and results in a peak-inverse voltage across the diodes of (2 Vpk – V_D).

Linear Regulators:

The full-wave bridge rectifier has terrible voltage regulation! This means that if R_L decreases by a factor of 2 (thus the output current is doubled), the output voltage ripple doubles! Also, if the input voltage (called line voltage) changes by $\pm$10% (which is quite typical in 120 V AC systems), then the output DC voltage also changes by $\pm$10%! Therefore, a power supply composed of only a transformer, a bridge rectifier and a capacitor is quite bad for high performance applications, and linear regulators must be used to ensure very low voltage ripple and excellent load and line voltage regulation.

Linear (or series) regulated power supplies were introduced many years ago and are still used extensively today. The basic design technique consists of placing a control element in series with the rectifier and load device. Figure 2 shows a simplified schematic of a series regulated supply with the series element depicted as a variable resistor. Feedback control circuits continuously monitor the output and adjust the series resistance to maintain a constant output voltage. Because the variable resistance (series element) of Fig. 2 is actually one or more power transistor operating in the linear (class A) mode, supplies with this type of regulator are often called *linear* power supplies.

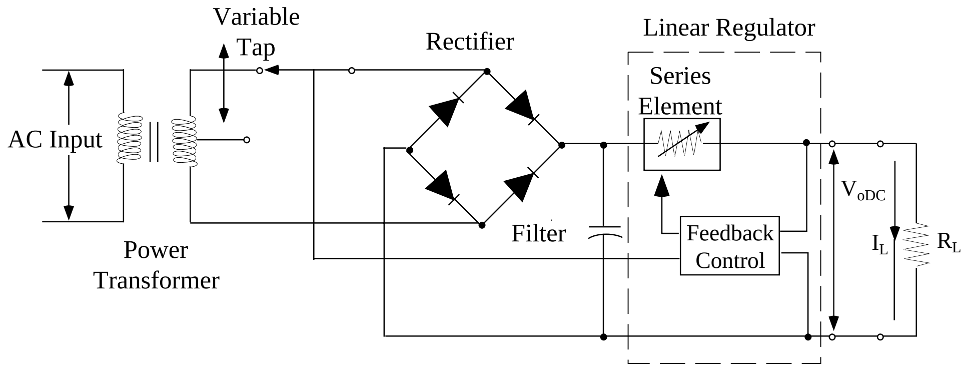


Figure 2: The Agilent E3631A power supply.

In terms of performance, linear regulated supplies have a very precise regulating properties and respond quickly to variations of the line and load. Hence, their line and load regulation and transient recovery time are superior to supplies using other regulation techniques (such as switching mode power supplies). These supplies also exhibit low ripple and noise, are tolerant of ambient temperature changes, and with their circuit simplicity, have a high reliability.

Series regulated power supply are not efficient and in some cases dissipate a lot of power. Let us take the example of a bridge rectifier designed to give 15 V $\pm$ 1 V DC and connected to a (series) linear regulator with an output regulated voltage between 5 and 12 V. If the output voltage is 12 V, then the voltage drop across the series regulator is 3 V. For an output current of 1 A, the output power is 12 W (P_o), the power consumed by the regulator is 3 W and the bridge rectifier therefore delivers 15 W (P_{in}). Thus the regulator efficiency (P_o/P_{in}) is 12 W/15 W = 80% which is quite good. However, if the output voltage is 5 V, the series regulator voltage drop is 10 V and the power consumed by the regulator is 10 W. This results in a poor regular efficiency (P_o/P_{in}) of 5 W/15 W = 33%! For high output currents/powers a poor efficiency means that a huge amount of power is consumed in the linear regulator!

One way to solve this problem is to always make sure that the rectified bridge voltage is only a few volts (1-2 V) above the required output voltage, thereby resulting in a low power dissipation in the regulator (and high efficiency).

For a high-power variable voltage power supply such as the Agilent E3631A, the feedback controls the transformer tap so as to change the input DC voltage to the regulator. This is expensive and requires a DC motor or SCR switches to move the tap, but results in a very efficient power supply.

Multiple Output Power Supplies:

If several output voltages are needed such as +5, +12 and +24 V, then it is best to use a multiple-tapped transformer with 3 different rectifiers and regulators as shown in Fig. 3a.

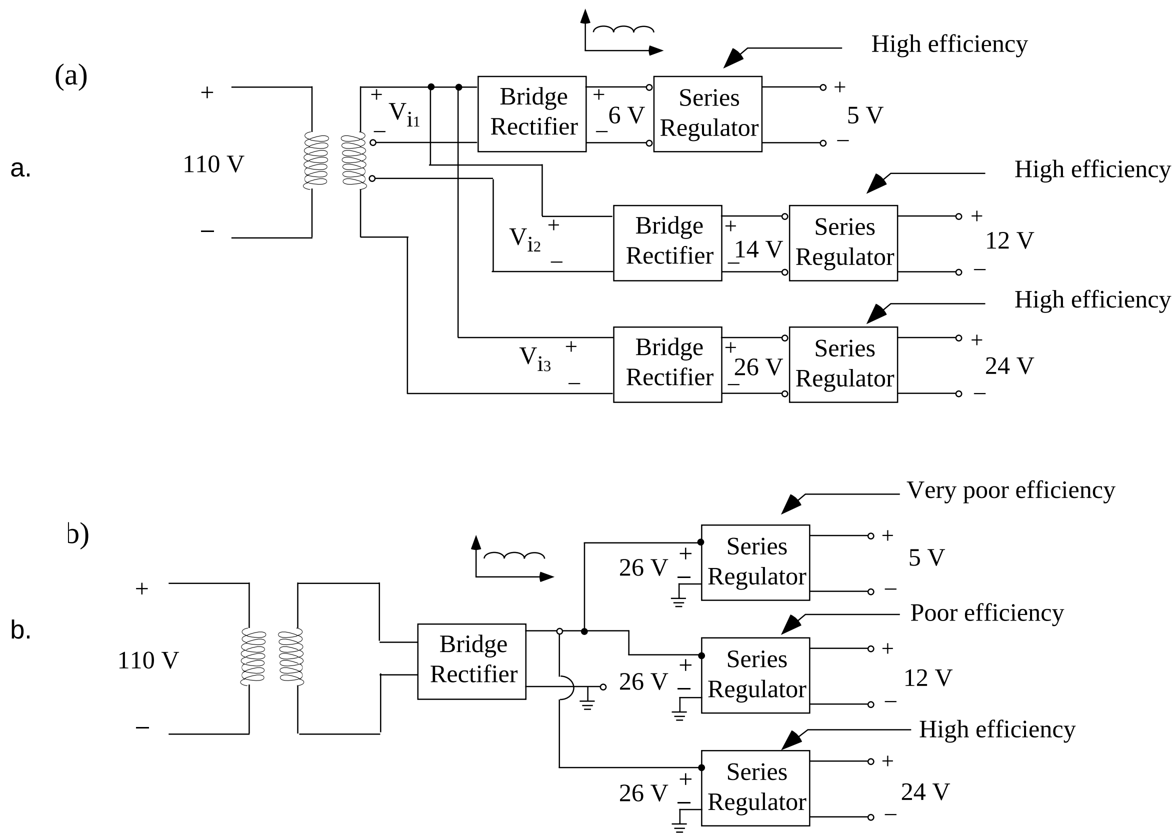


Figure 3: An efficient multiple output power supply with multiple-tapped transformer (a) and a simple but very inefficient implementation (b).

This is much more power efficient than using a simple transformer/rectifier and three regulators (Fig. 3b).

Linear Regulator Specs:

Linear regulators specifications are easy to understand and their performance is summarized in a few specifications:

Regulated Output Voltage $\equiv V_O$ (~1 V to V_{line} - 2 V)

Output Voltage Ripple $\equiv V_R$ (mV levels)

Line Regulation $\equiv \dfrac{\Delta V_o}{\Delta Vin}$ $\dfrac{\text{Change in output voltage}}{\text{Change in input voltage}}$ (<mV/V)

Load Regulation $\equiv \dfrac{\Delta V_o}{\Delta I_L}$ $\dfrac{\text{Change in output voltage}}{\text{Change in output current}}$ (~mV/A)

Short Circuit Current $\equiv I_{SC}$ (10 mA to 10 A)

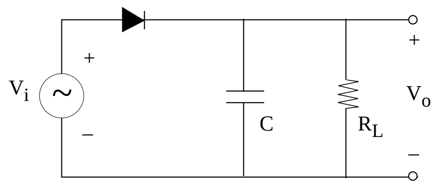
The data sheet of the LM 105/205/305/376 linear regulator family is in the Appendix.

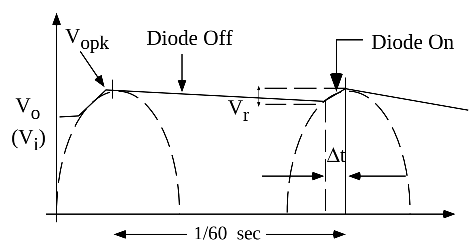
Switching Power Supplies:

As seen above, linear regulators are not efficient especially if a large range of output voltages are needed. For high power systems a switching power supply is used. The theory of these supplies are beyond this course but it suffices to say that they are very efficient (85-95%) and can deliver large amounts of power (50-1000 W). However, they do *not* offer excellent line and load regulation, low ripple and low noise as linear power supplies. For this reason, all analog/instrumentation/audio systems use linear regulators and all digital/computer/printer systems use switching power supplies.

Diodes & Bridge Rectifiers

Half-Wave Rectifier





$$V_{opk} = V_{ipk} - V_D \qquad (V_D \approx 0.7\,V)$$

$$V_{oav} = V_{opk} - \frac{V_r}{2}$$

$$V_r = \frac{V_{opk}}{f R_L C} \qquad (f = 60\,Hz)$$

$$\omega \Delta t = \sqrt{\frac{2V_r}{V_{opk}}} \qquad (\omega = 2\pi f)$$

$$I_L = V_{opk}/R_L$$

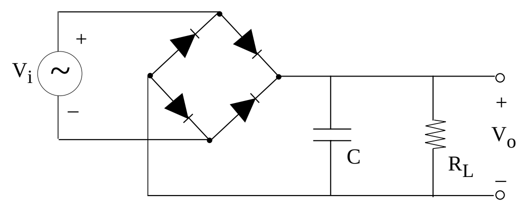
$$I_{D(av)} = (I_L)\left(1+\pi\sqrt{\frac{2V_{opk}}{V_r}}\right)$$

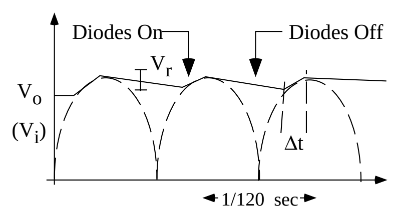
$$I_{D(pk)} = (I_L)\left(1+2\pi\sqrt{\frac{2V_{opk}}{V_r}}\right)$$

$$I_{C(av)} = (I_L)\left(\pi\sqrt{\frac{2V_{opk}}{V_r}}\right)$$

$$I_{C(pk)} = (I_L)\left(2\pi\sqrt{\frac{2V_{opk}}{V_r}}\right)$$

Full-Wave Rectifier





$$V_{opk} = V_{ipk} - 2V_D \qquad (V_D \approx 0.7\,V)$$

$$V_{oav} = V_{opk} - \frac{V_r}{2}$$

$$V_r = \frac{V_{opk}}{2 f R_L C} \qquad (f = 60\,Hz)$$

$$\omega \Delta t = \sqrt{\frac{2V_r}{V_{opk}}} \qquad (\omega = 2\pi f)$$

$$I_L = V_{opk}/R_L$$

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$$I_{C(av)} = (I_L)\left(\pi\sqrt{\frac{V_{opk}}{2V_r}}\right)$$

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