EE283 Lab 12
Transformers, Diodes and Filter Circuits

Objectives:
- To become familiar with the I-V characteristics of rectifying diodes.
- To understand and construct a linear DC power supply.

Equipment:
- Digital Multimeter (DMM Keysight 34461A)
- Tektronix TBS 1064 Oscilloscope
- Variac
- Diodes
- 10µF, 100µF and 1000µF capacitors
- Resistor

Theory:

Diodes

Diodes are two terminal electrical components that exhibit directional, nonlinear, current versus voltage (I-V) characteristics. The circuit symbol and a typical I-V curve are illustrated in Figures 1 and 2. Forward biased diodes allow current to flow with only a small effective (but nonlinear) resistance, while reverse biased diodes have only a very small leakage current up to the diode's peak inverse voltage (PIV). A PIV of hundreds of volts is common. The diode's we will use have a rating of PIV=400V. (That's high enough to be useful directly rectifying 120V AC to DC.) Diodes in the KV range, such as those used in microwave ovens, are usually physically smaller diodes connected in series. (Don't do that with discrete diodes without special precautions to distribute the voltage evenly.) Going beyond the PIV rating can cause enormous heat dissipation in the diode (P=VI) and usually destruction of the diode as well as, perhaps, other components.

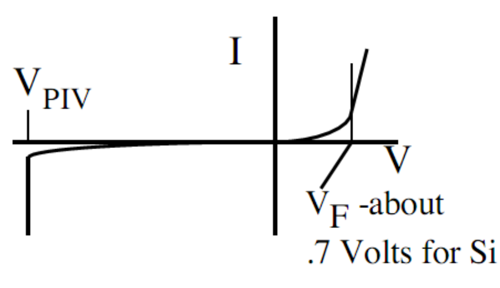


Figure 1
Diode Current – Voltage Characteristics

A band on the diode identifies the cathode, the terminal towards which current flows if forward biased (see Figure 2).

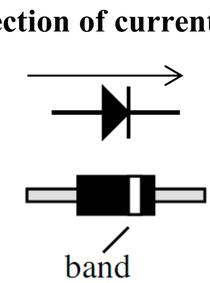


Figure 2
Diode Symbol and Appearance

Transformers

A transformer can be thought of as an inductor with two windings. In a tightly coupled transformer of the type used for power handling, the voltage across the two (or more) coils is proportional to the number of turns on each winding, neglecting resistance losses in the copper wires and a small loss of power in the transformer's iron core connecting the windings magnetically. The symbol for a transformer is shown in Figure 3 below. For power supply use on a small scale, the primary voltage is controlled by the voltage source, typically 120 Volts (rms) at 60 Hz drawn from utility outlets. The turns ratio then determines the secondary voltage. If a transformer has 300 turns for the primary winding, and 30 turns for the secondary winding, then if used normally with 120 Volt AC it would be called a 12 Volt power transformer. The black dots at the ends of the windings indicate which terminals go positive together at the same time, that is, they are in phase. The secondary often has a "Center Tap" that divides the secondary into two equal Voltages, 6 Volts and 6 Volts in this case. (Other types of taps are sometimes seen.)

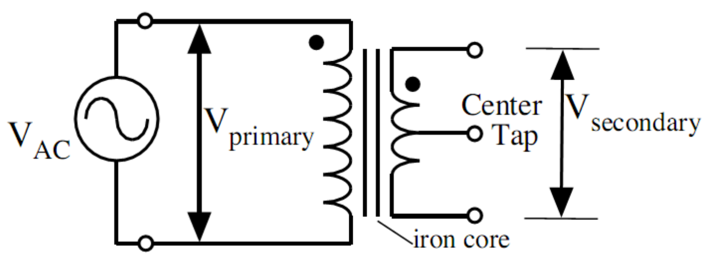


Figure 3
A Transformer Schematic

Rectifier Circuits

A "half-wave" rectifier circuit (shown in Figure 4) allows current to flow in one direction and not the other, so that only the positive (or negative, depending on diode orientation) can appear on the other side of the diode. A "load" that is being supplied by the diode is represented by a resistor.

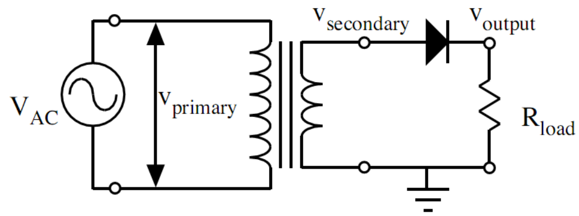


Figure 4
A Half Wave Rectifier Circuit

Figure 5 shows the secondary and output voltage waveforms.

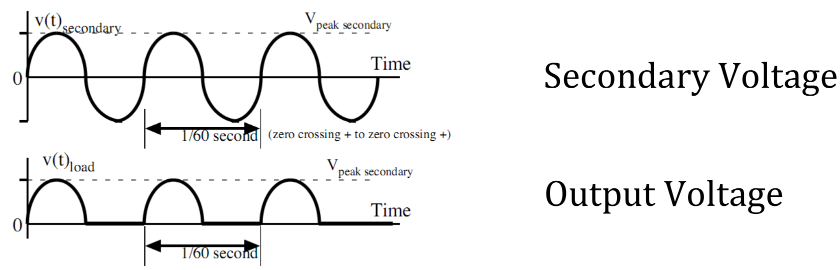


Figure 5
Secondary and Output Voltage Waveforms

Note that the half wave gives a pulse once per cycle, and is actually zero half of the time, the part of the cycle where the diode anode voltage swings negative. While this would register as a DC voltage on a meter, an AC meter would register considerable AC voltage as well. If you want pure DC, this is NOT a good circuit as it is. (The peak output voltage is a bit lower than the secondary voltage peak due to the forward voltage drop in the diode, often about .7 volts or a bit more.)

A "full wave" rectifier circuit (shown in Figure 6) can be contrived using a center tapped transformer. The center tap is grounded, and both ends of the winding are connected to the load through a diode. Whichever way the waveform swings, one diode or the other will conduct. The catch is, the peak voltage out is a bit less than ½ of the AC peak, because for each phase only half of the transformer is being used. So, if you wanted about 17 volts peak out, you'd use a 24V VAC secondary transformer, because ½ of 24 Volts is 12 Volts, and that's multiplied by 1.414 ($\sqrt{2}$) to get 17 Volts. With the diode drop, you'd get a peak voltage output of about 16.2 Volts. Note that neither end of the secondary is grounded! The load goes back to ground, the center tap.

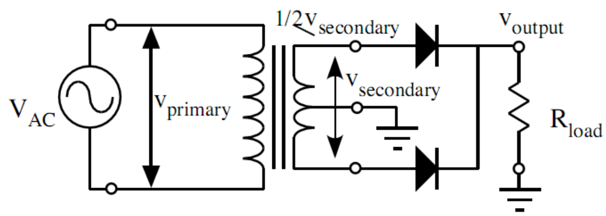


Figure 6
A Full Wave Rectifier Circuit

Figure 7 shows the output voltage waveform.

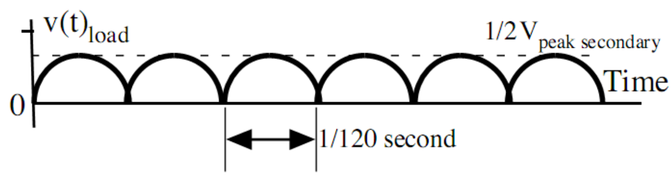


Figure 7
Full Wave Rectifier Output Voltage Waveform

A second "full wave" rectifying circuit (shown in Figure 8) can be used if there is no center tap. In this case, the peak of the load Voltage is a bit less than the full secondary AC peak, but the circuit suffers from two diode losses instead of one.

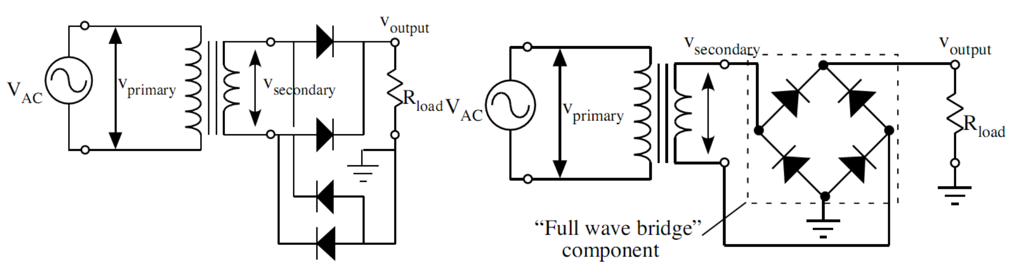
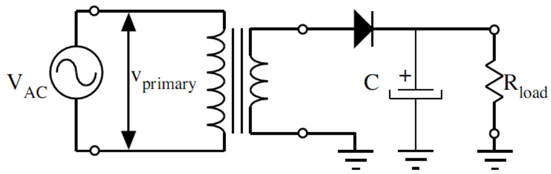


Figure 8
A Full Wave Rectifier Circuit Using a Bridge Rectifier
(the above circuits are identical – just drawn differently)

Filtering Circuits

Both the half wave rectifier and the full wave rectifier produce less than full, smooth DC. Both have a "ripple" voltage that is easily detectable with a meter or the oscilloscope. Usually it is desirable for a DC power supply to have very little AC ripple. What is needed is a filter circuit. Specifically, we need an AC low pass filter which has a cutoff well below the ripple frequency, which is 60 Hz for a half wave rectifier, and 120 Hz for full wave. The simplest form of filtering is to put a capacitor across the rectifier output, as seen in Figure 9a. The capacitor charges rapidly when an AC peak comes along. Then, after the peak, the capacitor supplies all of the current to the load until the next peak comes along. This results in a waveform that is approximately a "sawtooth" form, as seen in Figure 9b. We want the filter capacitor to be "big," so we usually use a polarized electrolytic capacitor, as seen by the symbol.



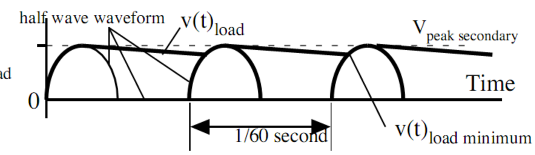


Figure 9a Figure 9b

Capacitor Filter and Half Wave Rectifier Waveform

The question is, "How big?" That depends on how much ripple you can tolerate. In this case, let us suppose that the output voltage averages 16 Volts. The ripple voltage is small, let's suppose just 0.5 Volts would be tolerable. (Usually you'd want it smaller.) It is 1/60 seconds between peak pulses. We assume output current, which all comes from the capacitor during the downward ramp, is about constant. Suppose the load is 16 Ohms. Then the average current is 1 ampere. A capacitor has the characteristic $i(t) = C\, dv(t)/dt$. If we assume current is constant over 1/60 second, then 1A=C(.5V)/(1/60 sec). Solving for C, we get C = .0333 F, or, 33,300 µF. We would use the next commercially available value up from that, 50,000 µF. If this was a full wave rectifier circuit instead of half wave, the period of the ripple would be 1/120 sec, and the needed capacitor would be only half as large. Diodes are usually cheap. Capacitors are relatively expensive. So, using a full wave rectifier instead of half wave rectifier is what you'll usually see. Only in applications where the diodes are expensive or ripple doesn't matter much will you see half wave rectifiers. Those include battery chargers and microwave ovens.

Procedure:

Note: **Be sure the Variac is disconnected from the AC power before touching any part of your circuit.**

- Using the supplied transformer, diode and resistor, construct the half wave rectifier circuit shown in Figure 10.

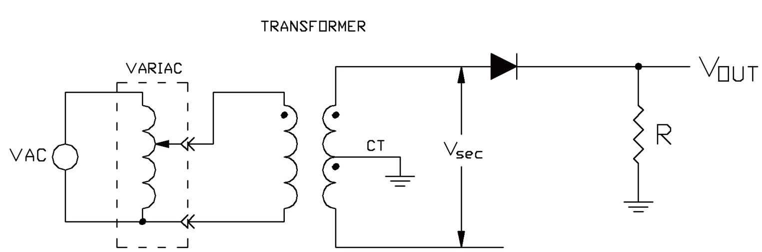


Figure 10

Half Wave Rectifier Using a Variac

- Plug the primary side of the transformer into the variac output receptacle. Before turning the variac on be sure the variac knob is turned fully **counterclockwise**. Use the DMM to measure the secondary voltage, V_{SEC}. Be sure to measure the voltage across the entire secondary winding. Adjust the variac knob until the DMM voltage reads 15.0 V_{RMS}. Record this reading on the form provided.

- Use the oscilloscope connected across the resistor to observe the output voltage, V_{OUT}. Measure the peak output voltage, $V_{OUT\ PEAK}$, using the oscilloscope voltage cursor. Measure V_{OUT} DC and AC voltage components using the DMM. Record these reading on the form provided.

- Build a "full wave" unfiltered DC rectifier using your transformer, diodes and resistor as shown in Figure 11. The "full wave" rectifier only requires the addition of one diode to the "half wave" rectifier circuit.

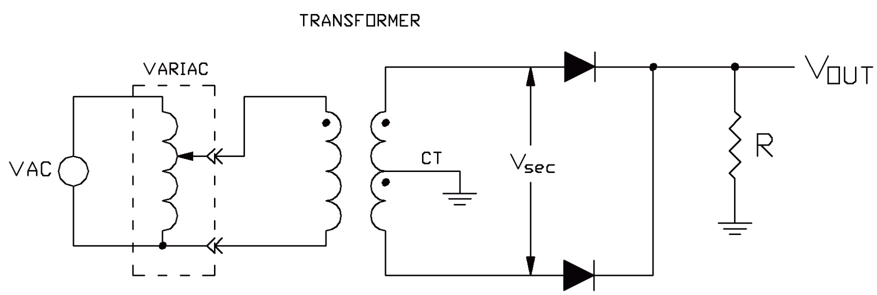


Figure 11
Full Wave Rectifier Circuit Using a Variac

Use the DMM to verify the secondary voltage, V_{SEC} is still set to 15 V_{RMS}.

- Use the oscilloscope connected across the resistor to observe the output voltage, V_{OUT}. Measure the peak output voltage, $V_{OUT\ PEAK}$, using the oscilloscope voltage cursor. Measure V_{OUT} DC and AC voltage components using the DMM. Record these reading on the form provided.

- Add a filter capacitor to your full wave rectifier circuit as shown in Figure 12. **Be sure to observe the correct polarity when inserting the capacitor.**

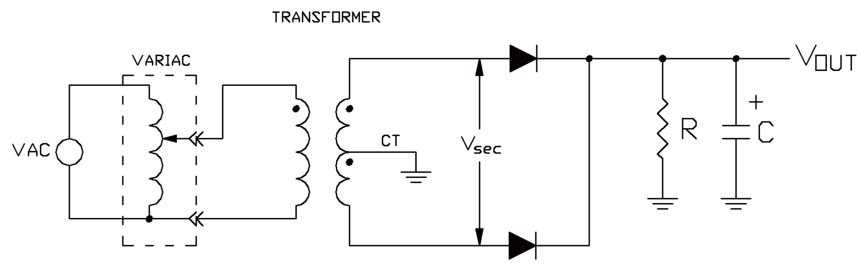


Figure 12
Full Wave Rectifier With Capacitor Filter

Start with a 10uF capacitor, and see how it changes the waveform. Then substitute 100µF, and 1000 µF capacitors. For each case, use the oscilloscope connected across the resistor to observe the output voltage, V_{OUT}. Measure the peak output voltage, $V_{OUT\ PEAK}$, and the peak to peak output voltage, $V_{OUT\ PEAK\ TO\ PEAK}$, using the oscilloscope. Use the voltage cursors on the oscilloscope to measure these voltages. Measure $V_{OUT\ DC}$ using the DMM. Record these reading on the form provided.

Extra Credit (+10%)

I will add up to 10% to your grade if you submit a report to determine the peak to peak ripple voltage of the full wave rectifier with the 100µF capacitor and compare it to your measured ripple voltage for this value of capacitor. You can determine the ripple voltage in any one of three ways:

- Use the equation shown in the Filter Circuits paragraph of this exercise. You must show your calculations in your report.

or

- Use Excel and the discharge equation for an RC circuit. You must show the Excel data in your report.

or

- Use LTspice or PSpice to simulate the circuit.

If you choose to simulate the circuit you don't have to use a transformer (which can be a little tricky to model) just use two voltage sources set to the peak voltage of $V_{SEC}/2$. Be sure you have the voltage sources out of phase. You must show the simulation circuit and the results in your report. The simulation results must have cursors showing the peak to peak ripple voltage.

I do not want a formal report. Just a sheet with your name and the calculations, or Excel data or spice figures. It must be readable and clearly show the value of the peak to peak output ripple voltage and your comparsion to your measured data. This extra credit report is due at the time of the AC practical exam. No reports will be accepted after the exam.

If you need help just ask.

EE283 Laboratory Exercise 12 Form Report

Name:______________________ Section:_____ Station:_____ Date:___________

Lab 12 Reporting Form
(To be turned in at the end of the lab)

$V_{SEC\ RMS}$ ______________

Half Wave Rectifier:

$V_{OUT\ PEAK}$ ______________
$V_{OUT\ DC}$ ______________
$V_{OUT\ AC\ RMS}$ ______________

Full Wave Rectifier:

$V_{OUT\ PEAK}$ ______________
$V_{OUT\ DC}$ ______________
$V_{OUT\ AC\ RMS}$ ______________

Full Wave Rectifier (with 10µF capacitor):

$V_{OUT\ PEAK}$ ______________
$V_{OUT\ PEAK\ TO\ PEAK}$ ______________
$V_{OUT\ DC}$ ______________

Full Wave Rectifier (with 100µF capacitor):

$V_{OUT\ PEAK}$ ______________
$V_{OUT\ PEAK\ TO\ PEAK}$ ______________
$V_{OUT\ DC}$ ______________

Full Wave Rectifier (with 1000µF capacitor):

$V_{OUT\ PEAK}$ ______________
$V_{OUT\ PEAK\ TO\ PEAK}$ ______________
$V_{OUT\ DC}$ ______________