PRINCETON UNIVERSITY **PHYSICS 104 LAB**
Physics Department **Week #11**

EXPERIMENT X
DIODE RECTIFIER AND TRANSISTOR AC VOLTAGE AMPLIFIER

Introduction.

The devices you have studied in the Ph104 circuit labs thus far, resistors, capacitors, inductors (and even transformers), either conserve energy or dissipate it. There is, however, considerable practical interest in devices that can redistribute energy and power such that an output signal is an amplified copy of the input signal. Such devices cannot be built with components all of which obey Ohm's law, even in its generalized form $V = I Z$, where V is a voltage, I is a current and Z is an impedance. However, *nonlinear* electronic components, for which a plot of V vs. I does not follow a straight line, can be used to built amplifiers and many other sophisticated electronic devices.

The final two Ph104 Labs will explore the basic of nonlinear circuit elements. In this Lab, you will explore the behavior of the two most basic nonlinear devices, the diode rectifier and the transistor. In the following and final Lab, you will combine these circuit elements to construct an AM radio.

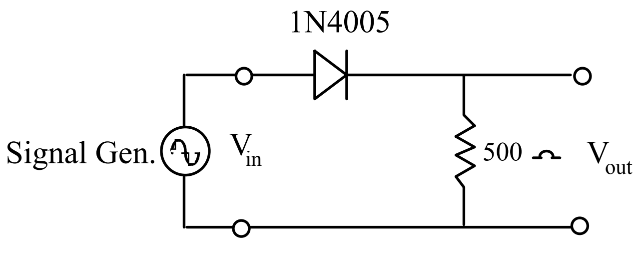
Nonlinear devices can be understood on at least two levels. You can think of the diode and transistor as "black boxes" whose input-output characteristics you look up in a book or measure in the laboratory; or you can try to understand how the device works at the atomic level. You will be using your lab time to do the former, *i.e.,* to learn about the input-output characteristics by measuring them in a circuit; on the other hand, as a steptowards understanding what's going on at a deeper level, read section 38-7 of Tipler/Mosca. It is worth your time to have some sense of how a p-n junction works, as this is the basis of both diode and transistor.

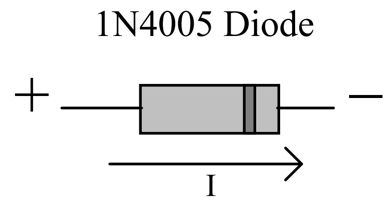
1. Diode Rectifier

The most common diode is made from a p-n junction in a semiconductor (Section 38-6 of Tipler). It forms a one-way valve for electric current. That is, current flows when the applied voltage is has one sign (when the diode is "forward-biased"), but (almost) no current flows when the sign of the voltage is reversed (when the diode is "back-biased") (See Fig. 38-21 of Tipler.) *A plumbing analog is called a check valve, as used in wells to keep the water from going back down when you stop pumping.* Diodes are commonly used in rectifier circuits to convert AC voltage (from the wall sockets) into DC voltage, needed in most electronic circuits.

Wire the circuit shown below on a "breadboard", and apply a sinusoidal input from the signal generator of about 10 $V_{p\text{-}p}$ and a frequency of about 60 Hz.

Display both the input voltage V_{in} and the output (rectified) voltage V_{out} on your oscilloscope. The DC levels of the input and output voltages, which are important, should also be recorded in your notebook.





The rectified output voltage V_{out}, is essentially all of the same sign, but is too bumpy to be very useful. As you can see on the oscilloscope, the diode has rectified the sinusoidal input voltage from the signal generator by "chopping off" the bottom half. This happens when the current will try to flow through the diode in the reverse bias and it is not permitted to flow that way by the diode.

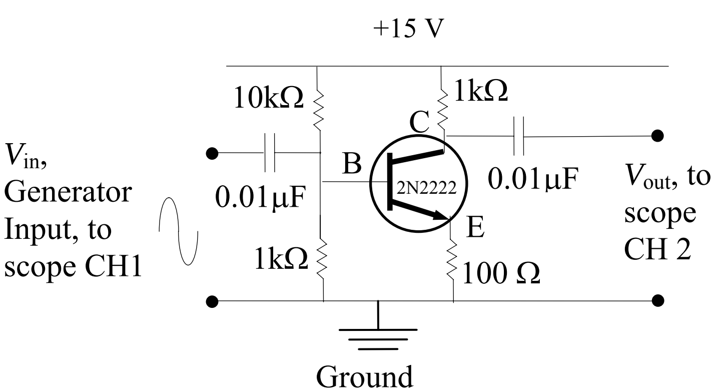
What happens if you reverse the diode?

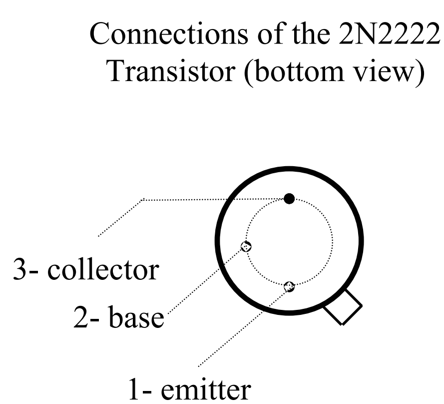
Next, try to smooth out the bumps with a low-pass filter (see Exp. VII). Design a filter using a 2.2 μF capacitor from your tray. Careful! The capacitor is polarized; the lead closest to the dark band on the capacitor is the – lead.

Describe/plot the new output wave form in your notebook; the DC level is important. How might you decrease the ripple even further? Try it if you have time after doing the transistor amplifier on the next page.

2. Transistor Amplifier.

The transistor is one of the most influential devices invented in the 20th century because of the property illustrated in the circuit shown below — voltage amplification. Its ability to amplify tiny signals, picked up on antennas, strain gauges, microphones, temperature sensors, magnetic card readers, CD scanners, phonograph needles, *etc*,. to drive speakers, video monitors, recorders, TV tubes, *etc.*, is the basis of modern electronics. A small signal applied to the input of the circuit, the Base (B), causes a large signal of a similar shape to appear at the output. The source of the large current is the 15 VDC power supply.





A plumbing analogy is as follows: imagine a valve which controls the amount of flow in a large pipe. A small force on the valve causes a large change in the amount of water flowing in the pipe, which can be converted into a large force varying in proportion to the small input force exerted at the valve—thus amplification.)

Wire the circuit. Each element in the circuit diagram has a specific function. The 10 kΩ and 1 kΩ resistors connected to the Base form a voltage divider which applies the correct bias voltage to the Base-Emitter junction. The 0.01 μF capacitor on the input prevents the 50 Ω impedance of the generator from dragging down the DC voltage on the Base. The 0.01 μF capacitor on the output blocks the DC and couples the AC part of the output to the next circuit with the voltage varying around zero volts.

First, make some observations with no input signal connected. Predict and measure the Base to ground DC voltage, $V_{\mathrm{B},0}$. It is important to mention that any measurement of voltage here should be done with respect to ground, thus you should always have one end of the 10X probe at ground when making measurements. Also, measure the current I_{B} flowing into the Base, using a digital multimeter.

Next, measure the voltage $V_{\mathrm{E},0}$ at the Emitter (again with respect to ground), as well as the current I_{E} flowing out of the Emitter. The Base-to-Emitter junction of the transistor is a diode, so that you should find that $\Delta V = V_{\mathrm{B},0} - V_{\mathrm{E},0}$ has the same value as the voltage drop across the diode that you observed in part 1 of this Lab. Since $V_{\mathrm{E},0}$ is also the voltage drop across the $100\,\Omega$ resistor R_{E}, your measurements of V_{E} and I_{E} should be related by Ohm's law.

With the input signal still disconnected, measure the voltage $V_{\mathrm{C},0}$ at the Collector, and the current I_{C} into the Collector. Since the total current into the transitor must be the same as the current out of it, you can expect that $I_{\mathrm{B}} + I_{\mathrm{C}} = I_{\mathrm{E}}$. A purpose of the transistor is that a small current in the Base can control large currents in the Collector and Emitter. Do you confirm the expectation that $I_{\mathrm{C}} \approx I_{\mathrm{E}}$ and $I_{\mathrm{B}} \ll I_{\mathrm{E}}$? Use Ohm's law applied to the $1\,\mathrm{k}\Omega$ "load" resistor R_{C} that is connected to the Collector to predict $V_{\mathrm{C},0}$ in terms of your measurement of I_{C} and the voltage of the DC power supply.

Now connect the signal generator to the circuit input (and to Ch1 of your oscilloscope). Set V_{in} to about 1 $V_{\mathrm{p\text{-}p}}$ with a frequency f of about 1 MHz, and observe the voltage V_{B} on the Base (using the scope probe on Ch2 of the scope). It should have the same AC amplitude as V_{in}, but be offset from ground by the DC level of $V_{\mathrm{B},0}$ that you found above. That is, $V_{\mathrm{B}} = V_{\mathrm{B},0} + V_{\mathrm{in}}$.

Measure the Emitter voltage on the scope. The expectation is that $V_{\mathrm{E}} = V_{\mathrm{B}} - \Delta V = V_{\mathrm{in}} + V_{\mathrm{B},0} - \Delta V$. The AC current out of the Emitter is, of course, $I_{\mathrm{E}} = V_{\mathrm{E}} / R_{\mathrm{E}} = \left(V_{\mathrm{in}} + V_{\mathrm{B},0} - \Delta V\right) / R_{\mathrm{E}}$.

Next, observe the Collector voltage V_{C}. Since the Base current is small, we expect that $I_{\mathrm{C}} \approx I_{\mathrm{E}}$. Hence, the voltage at the Collector is expected to be

$$V_{\mathrm{C}} = 15 - I_{\mathrm{C}} R_{\mathrm{C}} \approx 15 - I_{\mathrm{E}} R_{\mathrm{C}} = 15 - \left(V_{\mathrm{in}} + V_{\mathrm{B,0}} - \Delta V\right)\frac{R_{\mathrm{C}}}{R_{\mathrm{E}}} = 15 - \left(V_{\mathrm{B,0}} - \Delta V\right)\frac{R_{\mathrm{C}}}{R_{\mathrm{E}}} - V_{\mathrm{in}}\frac{R_{\mathrm{C}}}{R_{\mathrm{E}}}.$$

The AC part of V_{out} is therefore expected to be $V_{\mathrm{C,AC}} = -V_{\mathrm{in}} R_{\mathrm{C}} / R_{\mathrm{E}}$. That is, the effect of the transistor is to multiply the input voltage V_{in} by the **voltage gain** factor $R_{\mathrm{C}} / R_{\mathrm{E}}$.

Finally, observe the output voltage V_{out} on the far side of the 0.01 μF capacitor. The expectation is that $V_{\mathrm{out}} = V_{\mathrm{C,AC}}$.

An important property of any amplifier circuit is its frequency response. Measure and plot the **voltage gain,** $|V_{out}/V_{in}|$, *vs.* log *f*. Take 6 to 8 measurements, between 1khz and 1Mhz. This transistor should have have useful response up to a few MHz.

Now explore the effects of various circuit elements (one at a time) on the frequency response of the circuit, as follows:

(1) Put a 0.01 μF capacitor across the 1 kΩ load resistor.

(2) Put a 0.01 μF capacitor across the 100 Ω resistor in the Emitter circuit.

From your knowledge of RC filters explain the changes that you see in the frequency response. As usual, write out your ideas, results and observations (in words) in your notebook.

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EXPERIMENT X PRELAB PROBLEM SET

1. What size resistor would you use with a 2.2 μF capacitor to design a low pass filter with characteristic frequency of 60 Hz?

2. The amplifier (schematic on p. 2) has an input capacitor primarily to "block" the DC (average) voltage of the signal coming in from the signal generator, making this an AC amplifier. Another way to look at the input cap is as part of a filter; the other part is the pair of resistors connected to the transistor base. Treat the two resistors as being in parallel (although they are in fact connected to different parts of the power supply). What is the effective resistance of the two? Is this filter a low or a high-pass filter on the input? Find its characteristic frequency f_0.

Continued on reverse.

3a. In the amplifier circuit on p. 2 the 10 kΩ and 1 kΩ resistors are connected to the base of the transistor (B) to form a voltage divider that divides the +15 volts. What is the DC level between the base of the transistor and ground? Pretend that the base draws no current.

3b. In reality, some current does flow into the base of the transistor. The amount varies depending on the signal into the amplifier, but a typical value would be 50 μA. Compare this with the current flowing in the 1 kΩ resistor. Does the base current have a large effect on the voltage divider?