# Physics 364, Fall 2014, Lab #10    **Name:** _____

*(AM radio receiver)*

Wednesday, October 1 (section 401); Thursday, October 2 (section 402)

Course materials and schedule are at   `positron.hep.upenn.edu/p364`

We intended for you to build a simple AM radio receiver just after learning about filters and diodes, but in our new DRL lab space, the signal from our ad-hoc antenna is too weak to use without amplification. Now that you know how to build opamp-based amplifier circuits, you can apply what you've learned in the past several weeks about filters, diodes, and amplifiers to build a circuit that lets you listen to an AM radio station. This should be fun, so there's very little if anything for you to write down today.

Our intent is for this lab to use less than the full 3 hours, so that you can go back to finishing up Lab 9 (opamp imperfections) once you're done with the radio. We'll aim to do the same with next Monday's/Tuesday's lab, so that there will be plenty of time to finish Lab 9.

**Part 1**                                              **Start Time:** _____

**what is amplitude modulation?**                        (time estimate: 20 minutes)

First, to get a sense for what Amplitude Modulation means, we'll turn on the AM feature of your function generator. Start by generating a 4 $V_{pp}$ sine at 440 Hz. Now use the "mod" button to enable modulation: type=AM, shape=sine, depth=100%, AMfreq=10 Hz. Look at the resulting waveform on the scope and see if it looks like a 440 Hz sine whose amplitude varies sinusoidally at 10 Hz.

Try varying the modulation depth to see what this does. Try changing the modulation shape from sine to square to triangle, etc. Try varying the modulation frequency.

Also try varying these parameters while **listening** to the effect, by connecting a speaker to the function generator's output. The speaker's input resistance is only 8 $\Omega$, while the FG's output resistance is 50 $\Omega$, so plugging in the speaker should reduce the FG's output amplitude by about a factor of 7. You should be able to see this by looking with the scope before and after connecting the speaker.

Finally, try using the scope's FFT mode to look at the Fourier transform of the AM signal. This is inside the Math menu. Use a vertical cursor to figure out what frequency the peak corresponds to.

**Part 2**
**extracting envelope from modulated waveform**          (time estimate: 20 minutes)

A couple of weeks ago, you tried both a half-wave rectifier and full-wave rectifier to turn an AC input signal into a strictly positive output signal. You later added a capacitor to turn the output into a relatively flat DC value. With a relatively small capacitor value, you saw the output ripple between peaks, as the capacitor charged then partially discharged.
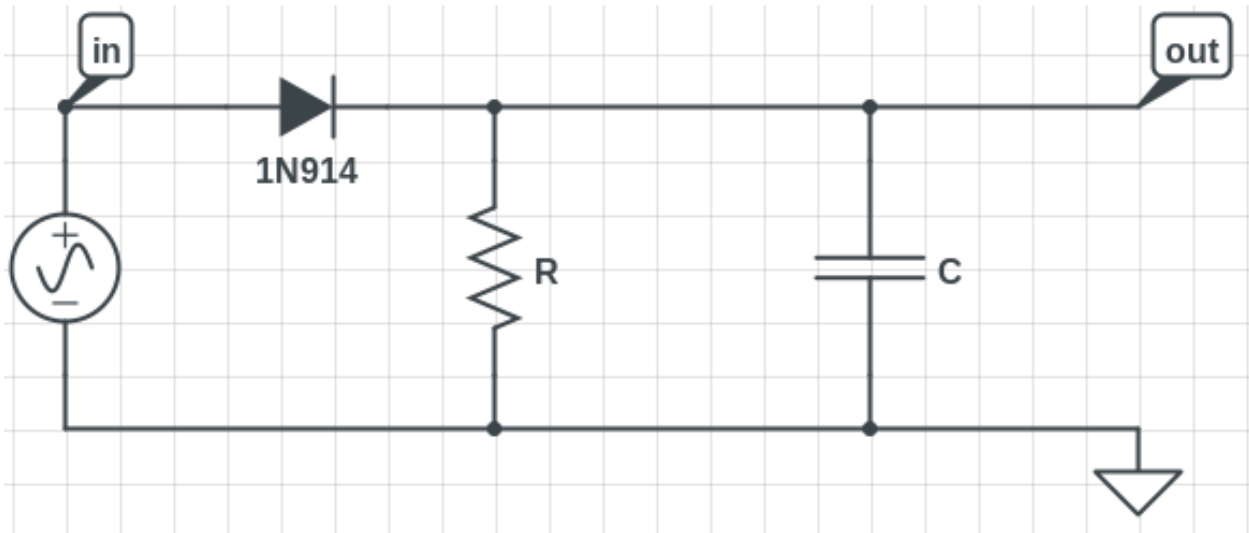


Use the above half-wave rectifier, with capacitor included, to extract the envelope from the FG's amplitude-modulated waveform. Use $R = 10$ k$\Omega$ and $C = 1$ $\mu$F, to get $RC = 10$ ms, which is several times the 2.3 ms period of the 440 Hz tone that the FG is modulating.

Unplug the speaker and send the FG output (still amplitude-modulated) into your rectifier.

If you remove the capacitor and look at $V_{\text{out}}$, you should see just the positive half of the incoming waveform, minus a diode drop. Check that if the amplitude of the incoming signal is smaller than about 0.6 V (the diode drop), the output disappears. This fact will be important later for our radio receiver.

Bring the amplitude back up to about 4 V$_{\text{pp}}$ and install the capacitor. You should see the modulation function (the "envelope"), with the 440 Hz "carrier" frequency removed. Be sure that you understand how this circuit manages to extract just the envelop from the AM signal, and check in with us to explain if necessary.

**building up your radio receiver**                                              (time estimate: 75 minutes)

**3.1** The figure below shows a "block diagram" overview of what you're going to put together. The incoming antenna signal contains many different frequency components (e.g. many different radio stations, plus whatever other electromagnetic waves the antenna picks up), so you'll first use an LC bandpass filter to pick out the radio station of interest (initially 900 kHz).[1] The output of this filter will be a fraction of a volt — too small for a diode rectifier. So you'll next use an opamp circuit (using a pair of special high-frequency opamps,[2] the AD847) to amplify this signal (increasing the voltage amplitude) by about a factor of 20 (adjustable up to a factor of 100). At this stage, the signal should conceptually resemble what you saw from your function generator in Part 1, but with a carrier frequency of 900 kHz and a complicated envelope function. If the radio announcer were singing a perfect rendition of the A note above middle C, the envelope function would resemble a 440 Hz sine. For AM broadcast radio, the envelope function will have frequency content up to about 5 kHz.
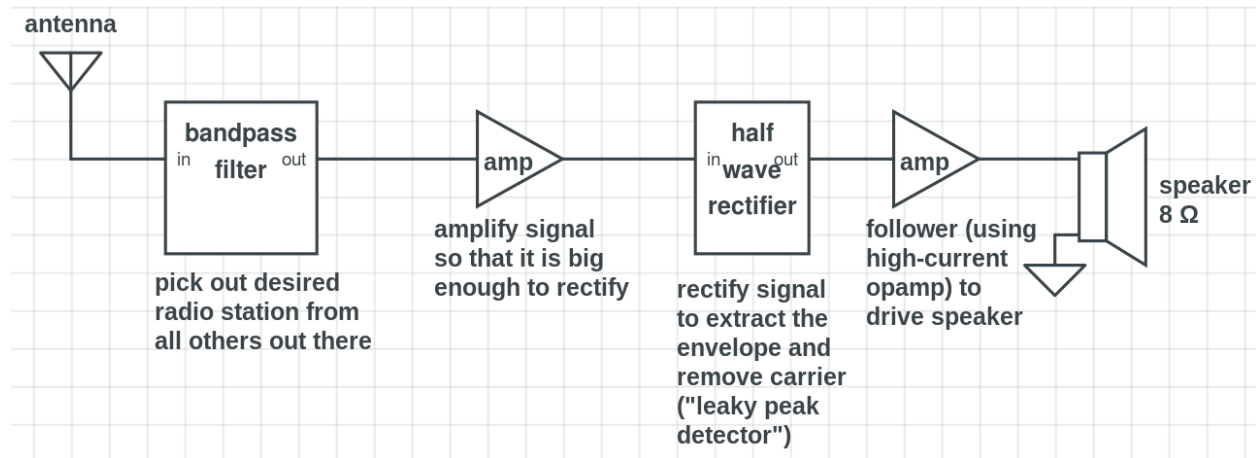


Next, you'll use the half-wave rectifier circuit (which Tom Hayes's notes called the "leaky peak detector") from Part 2, but with different $R$ and $C$ values, to extract the envelope function from this waveform, thereby removing the 900 kHz carrier frequency. This is the audio signal you want to hear! But if you send it directly into a speaker (whose input resistance is 8 $\Omega$), the sound will be much too quiet — barely audible — and badly distorted, because the high-speed AD847 opamp has a maximum current output of 32 mA (similar to the 25 mA limit of the familiar 741 opamp). So you'll add an opamp follower (using a special high-current opamp) to boost the current supplied to the speaker, thereby sending enough power to the speaker to produce an audible signal.

We only have one antenna signal for everyone to share, so you'll build and debug your circuit initially using the function generator in place of the antenna. Once your circuit is working, we'll bring over the antenna cable to plug in instead.

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[1] 900 AM is WURD, whose 1 kilowatt transmitter is about 2 miles south of us, in southwest Philly. Depending on the bandwidth of your LC filter, you may hear interference from 950 AM (WKDN "family radio"), whose 43 kilowatt transmitter is just a few miles west of us.

[2] `www.analog.com/static/imported-files/data_sheets/AD847.pdf`

**3.2** Let's start by setting up your function generator to create a good test signal for your circuit. Select a sine wave at 900 kHz and about 2 $V_{pp}$ amplitude. Enable modulation: type=AM, shape=sine, depth=100%, AMfreq=440 Hz. That corresponds to

$$V(t) = (1.0 \text{ V})(1 - D\sin(2\pi f_{\text{mod}}t))\sin(2\pi f_{\text{carrier}}t)$$

where $f_{\text{carrier}} = 900$ kHz and $f_{\text{mod}} = 440$ Hz (the A above middle C), and the modulation depth is $D = 1.0$. Look at this waveform on the oscilloscope and make sure that its key features make sense to you.

**3.3** Now use your function generator's amplitude-modulated waveform as the input to an LC resonant circuit, as shown below. This time we're using the LC series configuration. We don't include any resistor in this circuit, because the inductor's internal series resistance is large enough for the desired bandwidth (ideally about 20 kHz, but in reality somewhat higher). To get a combined $L = 94$ $\mu$H, we'll use two 47 $\mu$H inductors in series. To get $C \approx 333$ pF, use (in parallel) one 220 pF capacitor, one 100 pF capacitor, and one screw-adjustable $(6.8 - 45)$ pF capacitor. Measure the inductors and the (non-adjustable) capacitors, so that you can be pretty sure that the adjustable capacitor will get you close to the desired $\frac{1}{2\pi\sqrt{LC}} = 900$ kHz.
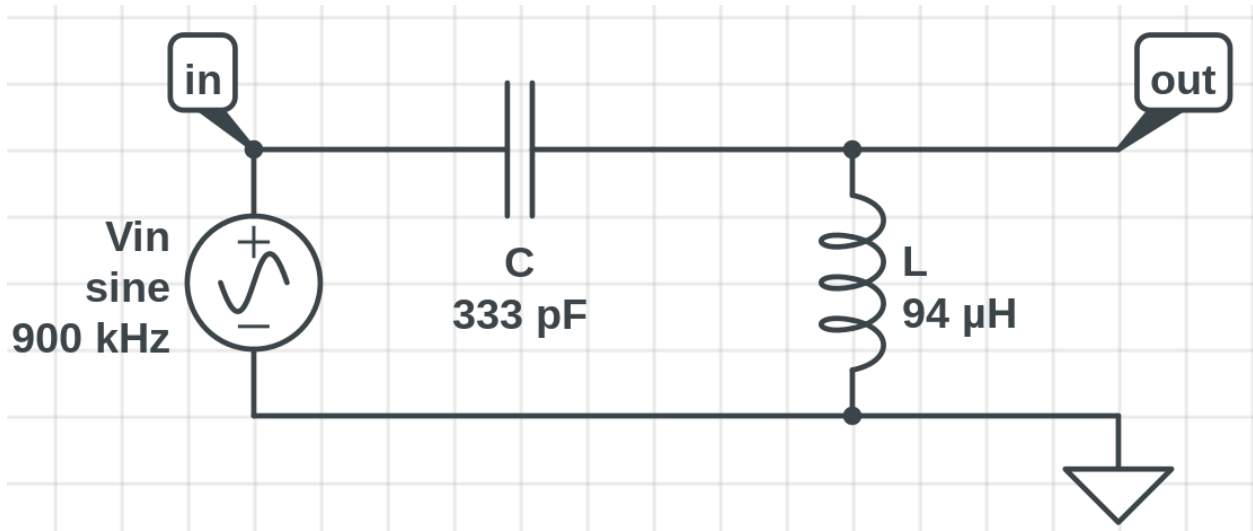


Take the voltage across the two inductors (which are in series) to be $V_{\text{out}}$. Adjust the tunable capacitor with the screwdriver to maximize $V_{\text{out}}$ — hopefully the optimal setting is not all the way at one end or the other.

Now move the FG's 900 kHz carrier frequency up and down to see whether the peak response is indeed at 900 kHz. (You'd like it to be within a few kHz if possible.) **Optionally**, continue moving the carrier frequency to measure the LC filter's 3dB bandwidth, which ideally should be on the order of 20 kHz, but in practice may be a bit bigger.

Finally, reduce the amplitude of the FG's output waveform until the $V_{\text{out}}(t)$ waveform that you measure across the capacitor is about 0.5 $V_{\text{pp}}$. This will be more representative of the small signal from the antenna, which we need to amplify next.

**3.4** Now let's use our recently acquired knowledge of opamps to boost the output of your LC filter. Because of the rectifier circuit's diode drop (about 0.6 V), we need the input to the rectifier to be at least one or two volts in amplitude, as you saw in Part 2. The dozen or so nearby AM radio stations (in the 540–1610 kHz AM broadcast band) detectable with our antenna vary widely in measured amplitude (at our antenna). The strongest stations need an amplification of about ×10, while others need ×50 or so.

The gain×bandwidth product for a 741 opamp[3] is only 1.5 MHz, which is not sufficient to get a gain of 10–50 for a 1 MHz signal. (We need at least 10 MHz gain×bandwidth for ×10 and at least 50 MHz for ×50.) So we'll use the much faster AD847 opamp, whose gain×bandwidth is 50 MHz.

For ×50 gain, even the AD947 is marginal, and we might like the option of as much as ×100 gain. So we will use two AD847 opamps, one after the other. The first will be a ×21 non-inverting amplifier, which has the advantage of very large input resistance (so it will draw negligible current from the LC filter, thus preserving the incoming amplitude). The second will be an inverting amplifier with an adjustable resistor (a potentiometer) in the feedback loop, so that the second amplifier gain $-R_2/R_1$ can be adjusted from ×0 to ×5, for a combined gain of ×0–×105. The advantage of the inverting configuration here is that its gain can be smaller than 1, if that is convenient.

The AD847 has the same familiar pinout as the LM741. Use ±15 V power-supply voltages, as usual. Connect the middle ("wiper") pin of the 1 kΩ potentiometer to one of the other two pins, to turn the potentiometer into a 0–1 kΩ variable resistor.
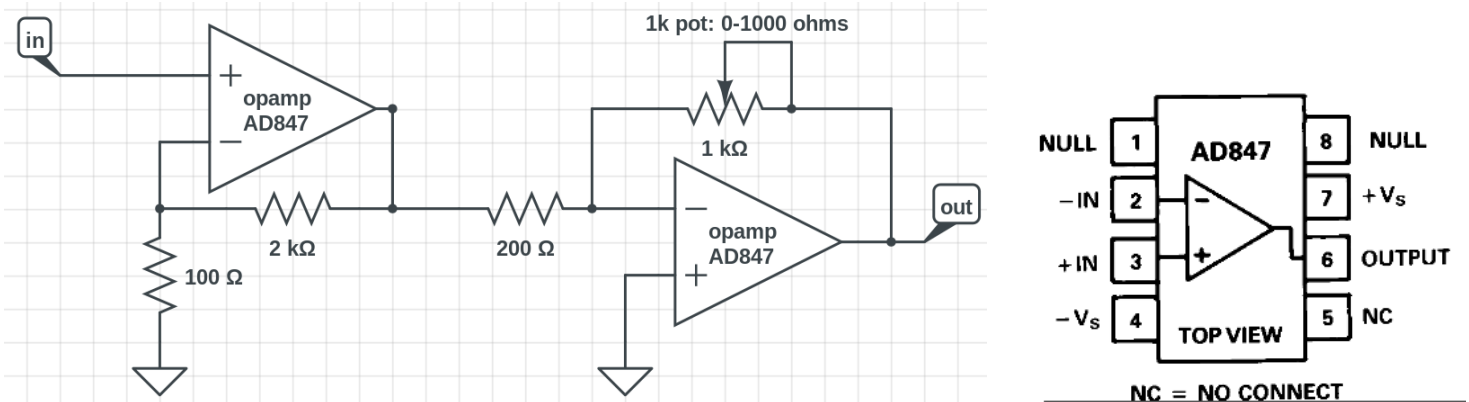


After double-checking that the output of your LC filter is less than about 1 $V_{pp}$, connect the output of the filter to the input of the amplifier, and see if the opamp's $V_{out}(t)$ is a faithfully amplified copy of your amplitude-modulated signal. If not, ask for help. Check that you're able to adjust the amplitude of $V_{out}$ by dialing the gain via the potentiometer.

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[3]http://www.ti.com/lit/ds/symlink/lm741.pdf

**3.5** Add a half-wave rectifier to the output of your amplifier. This is the same design we used in Part 2, but with a shorter $RC$ time constant. We need to keep $RC$ much longer than the 1 $\mu$s period of the carrier wave but much shorter than the $\mathcal{O}(1 \text{ ms})$ period of audio signals, so we choose $RC = 10\ \mu$s.
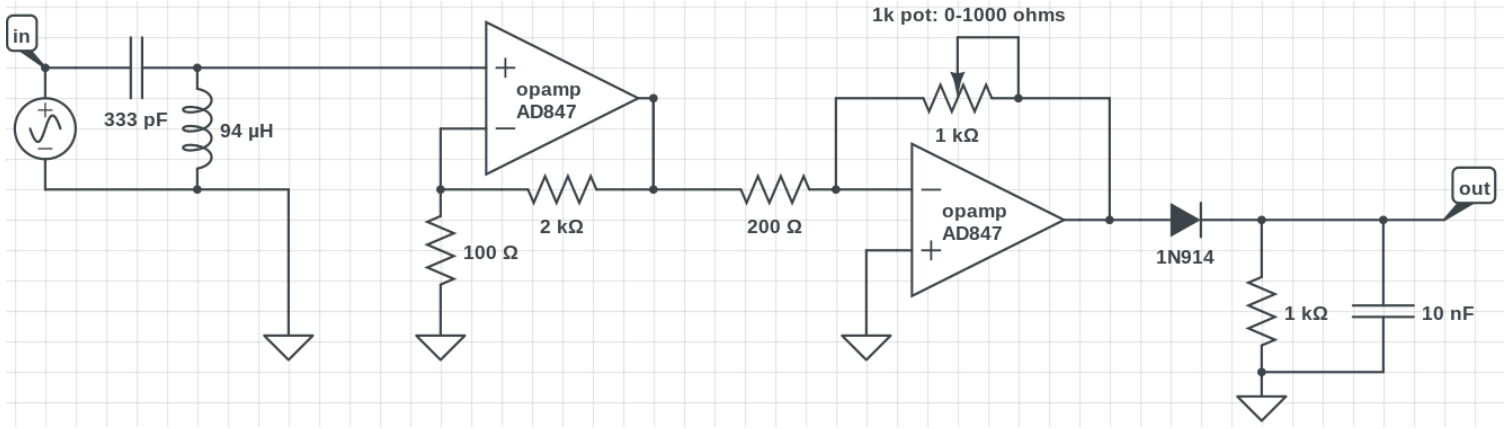


Look at the output of this circuit both with and without the capacitor present. (Remove the capacitor momentarily and see if the waveform makes sense to you, given your earlier experience with rectifying sinusoidal signals.) The diode permits only the positive half of the waveform to get through, and the capacitor "remembers" the most recent peak voltage for several microseconds. The result is that we get the envelope of the AM waveform.

**3.6** Try directly plugging in a speaker, with one lead connected to the output of your rectifier and the other lead connected to ground. Look at the rectifier output with the oscilloscope before and after you connect the speaker. You should see that the upstream opamp is unable to drive the 8 Ω speaker beyond about ±0.25 V, because the AD847 opamp's maximum output current is about 32 mA.

To solve this problem, we need to make a **follower** circuit (which amplifies current but preserves voltage) using an opamp capable of delivering a larger output current. We happen to have on-hand a supply of L272M opamps,[4] whose maximum output current is 1 ampere (!). It's gain×bandwidth is only 350 kHz, however, so it would have been even worse than a 741 opamp for the first stages of amplification.

Notice that in taking on this practical problem of receiving a radio signal, we have had to consider the pros and cons of various opamps — their gain×bandwidth, their maximum output current, etc. These practical considerations are the reason why it is helpful to know the meaning of the various specifications listed on an opamp's data sheet. That's why you've gone through the tedious task of observing these opamp limitations in contrived circuits.

**WARNING!** The L272M has a **totally different pinout** from the LM741 and AD847.
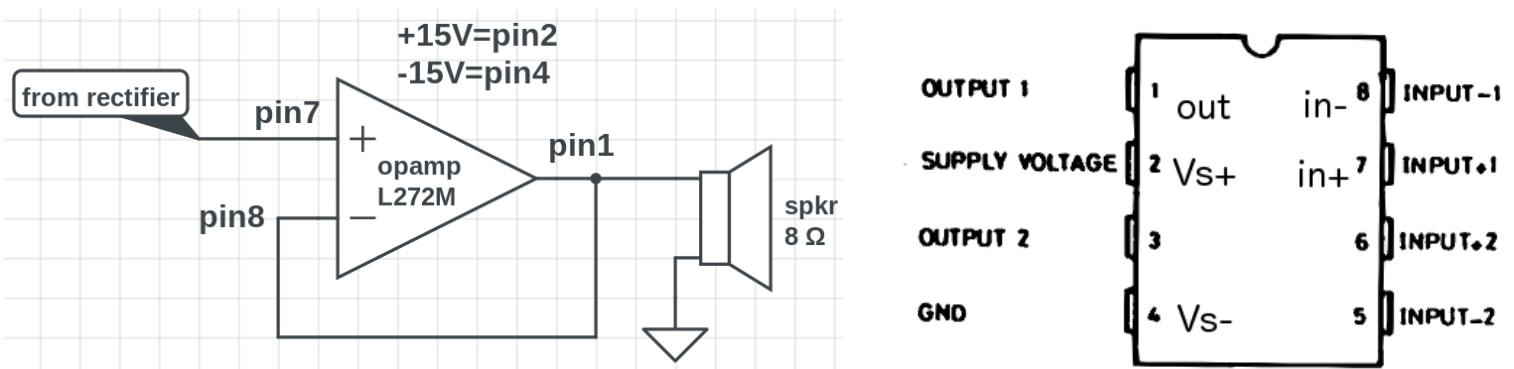


Look with the oscilloscope at the follower input and output, both before and after connecting the speaker. If all goes well, the signal reaching the speaker should be a pleasant 440 Hz sine. If not, ask us for help!

Next: ask us to bring over the antenna cable. Then, if time allows, you can go back to working on Lab 9.

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[4]www.st.com/web/en/resource/technical/document/datasheet/CD00000054.pdf