4. AM Detector

Chapter 4 Goals

- Understand a simple diode detector circuit and analyze it with LTspice
- Understand a biased diode detector circuit and analyze it with LTspice
- Analyze a complementary feedback pair (CFP) detector with LTspice
- Breadboard and test simple diode detector, biased diode detector, and CFP detector circuits
- Add your chosen detector circuit to your radio's audio amplifier and test

The AM detector's job is to extract the audio signal, or *envelope*, from the AM signal. This audio signal is then amplified and passed to the speaker. We will investigate a very simple diode detector followed by a biased diode detector for better performance. Both of these will be studied in LTspice. Then, we will simulate a complementary feedback pair (CFP) detector circuit which has clear advantages over the diode detector circuits.

4.1 Simple Diode Detector

A very simple detector circuit consists of a diode rectifier circuit, with an ***RC time constant*** chosen fast enough to follow the audio signal, but too slow to follow the carrier. This concept should become clear as you work through this lab.

A simple diode circuit is shown in Figure 4.1. Notice that current passes through the resistor only during the positive half cycle. Now a capacitor has been added to the circuit (Figure 4.2). This capacitor charges during the positive half cycle, and then it discharges through the resistor during the negative half cycle. The RC time constant is a measure of how long it takes the capacitor to discharge. The larger the RC product, the longer is the discharge time. Notice the voltage across the resistor in Figure 4.3 when the RC time constant is made 10 times larger. It is straightforward to show the voltage *v(t)* across the resistor is

$$v(t) = V_o e^{-t/RC}$$

where V_o is the initial voltage. When time t is equal to the time constant (RC), then the voltage has dropped to e^{-1} (~37%) of its initial value.

Exercise 4.1: Calculate the RC time constant for the circuits in Figure 4.2 and 4.3.

(Figure 4.2) t_{RC} = ___________

(Figure 4.3) t_{RC} = ___________

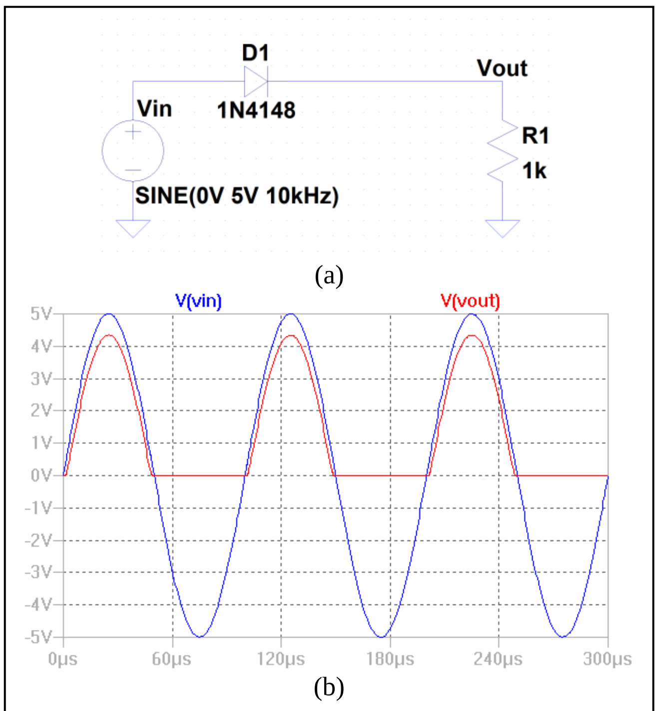


Figure 4.1: Simple diode circuit

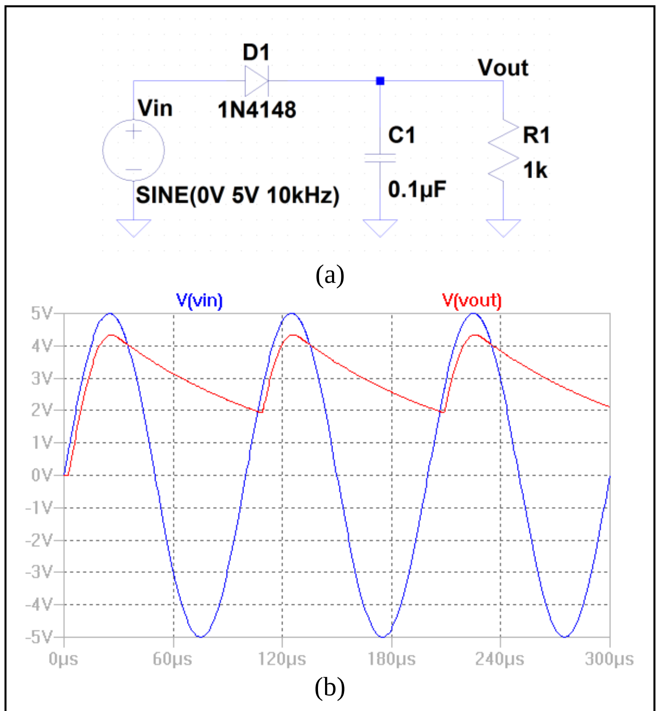


Figure 4.2: Rectifier with moderate time constant

4.1a LTspice Simulation

(note: bold indicates items for your report)

1. For an LTspice warm-up, begin by constructing the simple rectifier circuit **schematic** of Figure 4.2(a). Run a **transient simulation** to duplicate the output of Figure 4.2(b). Change R1 to 10 kΩ and re-run a transient simulation. Does this duplicate the result of Figure 4.3(b)?

2. Construct the LTspice **schematic** shown in Figure 4.4. Run a **transient simulation** to duplicate Figure 4.5.

- We want to extract an audio signal from an amplitude modulated signal. In LTspice, an AM signal will require 3 series-connected SINE sources as shown in Figure 4.4. These correspond to the spectral peaks we saw in Chapter 1, Figure 1.5. For a 200 kHz carrier and a 1 kHz modulation, the three sources will be 199 kHz, 200 kHz, and 201 kHz. The respective amplitudes to achieve ~66% modulation can be 0.25V, 0.75V, and 0.25V.
- Initially the Vout signal lies on top of the input signal. We can right-click on the "V(vout)" text in the plot and then add a suitable constant to shift the output to just above the input level, as shown in Figure 4.5.

3. Experiment with your detector circuit by changing resistor R1, re-running and turning in the **transient simulation**. **Comment** on the results.

- Change R1 to 100 Ω
  Comments:

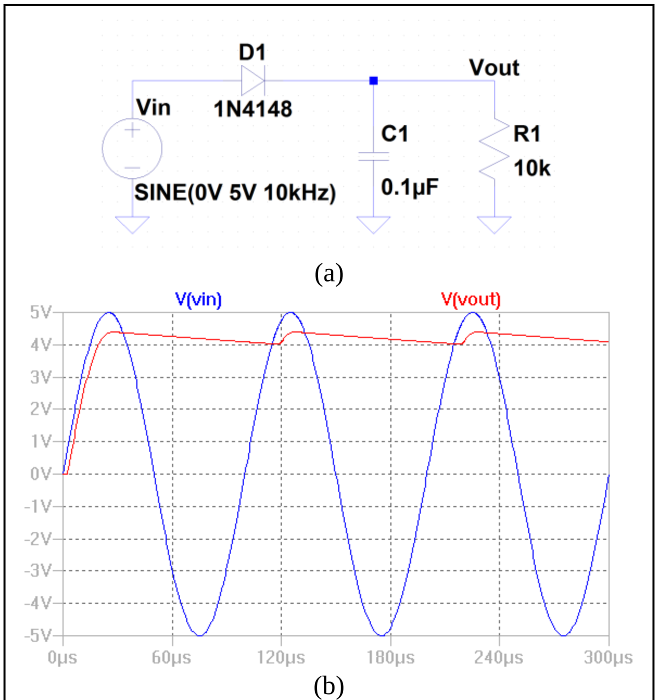


Figure 4.3: Rectifier with longer time constant

- Change R1 to 10 kΩ
  Comments:

4. Decrease the signal level in the circuit of Figure 4.4 by dividing all signal voltages by 2. **Comment** on what happens to the output signal.

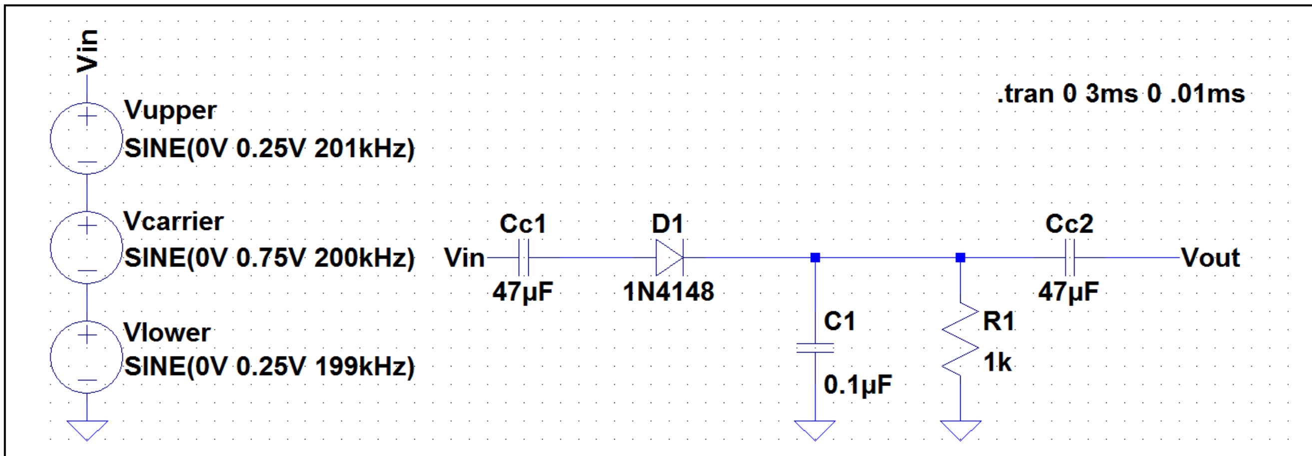


Figure 4.4: LTspice schematic of an AM detector.

4.2 Biased Diode Detector

The simple detector circuit works fairly well (can extract audio signal from AM input) as long as the signal is strong enough to turn on the diode. However, if the signal is strong enough to turn on the diode, it then tends to be too strong for the audio amplifier, so the output is distorted. But usually the signal coming in to the detector is rather weak, and the output suffers because the diode doesn't turn on. A remedy for this is to bias the diode detector.

<u>4.2a LTspice Simulation</u>

1. Construct the LTspice **schematic** of the circuit shown in Figure 4.6. Notice that this is still a fairly strong input signal. Run a **transient simulation** on this circuit. You should get the results shown in Figure 4.7.

2. Now divide the input signal levels by 2 and **re-simulate**. **Comment** on how these results differ from that of step 4 in the previous section where the same signal level was applied to an unbiased diode.

3. Now divide the signal levels of Figure 4.6 by 10 and **re-simulate**. **Comment** on the results.

4. (optional) <u>Germanium diode detector circuit</u> One way to improve the output signal level for relatively weak signals is to use a Ge ("Germanium") diode. If one if available, replace the D1N4148 with a germanium diode (perhaps the D1N270). While the D1N4148 diode has a turn-on voltage of approximately 0.6V – 0.7V, the germanium diode's turn-on voltage is only about 0.1V. How is the detector performance changed, if at all? *(note: If simulating in LTspice, a model for the diode must be imported.)*

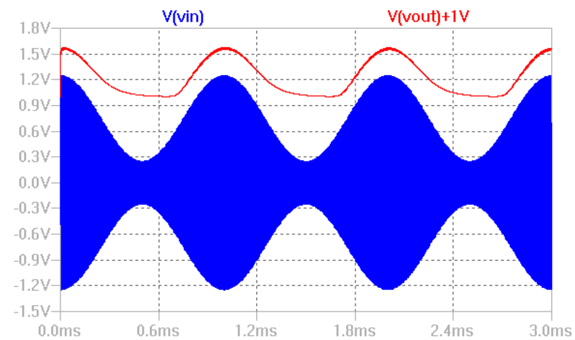


Figure 4.5: LTspice simulation of the AM detector of Figure 4.4

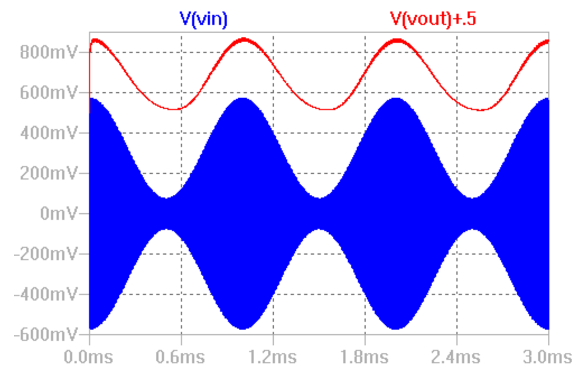


Figure 4.7: LTspice simulation of the biased detector circuit of Figure 4.6

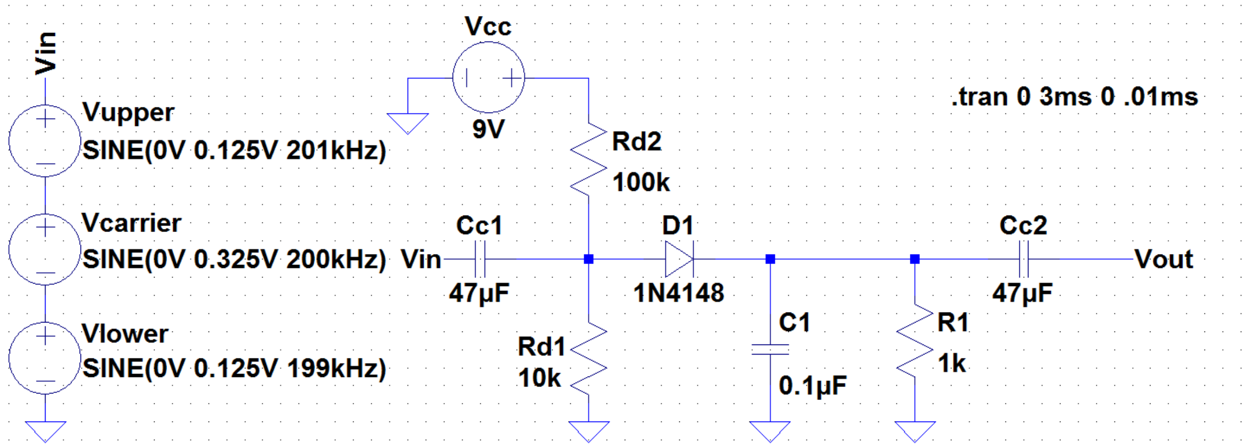


Figure 4.6: biased diode detector circuit

4.3 Complementary Feedback Pair (CFP) Detector

The common-collector amplifier configuration can be modified to function as an AM detector. Figure 4.8 shows such a configuration, which has the advantage of achieving better detection for weaker AM signals. The simulation yields Figure 4.9a. The operation is just like that of a detector diode. When the input signal is high, the transistor is on and capacitor Ce1 charges. When the input signal is low, the voltage level of the charged Ce1 prevents the emitter voltage from dropping low enough to turn the transistor on. Ce1 therefore discharges through Re1, with a time constant too slow to follow the carrier but fast enough to follow the envelope.

With a weaker AM signal, the circuit doesn't perform as well, as indicated in Figure 4.9b.

A clever alternative configuration is the so-called *complementary feedback pair* (CFP) detector shown in Figure 4.10. Here we have simply added a pnp transistor, and a collector resistor to the npn. When the input signal is high, both transistors are on and the Ce1 capacitor charges. When the input signal is low, both transistors cut off and Ce1 again discharges through Re1. But now, the pnp transistor provides additional current for more rapidly charging Ce1. Figure 4.11 indicates how well the CFP detector can extract a very weak AM signal.

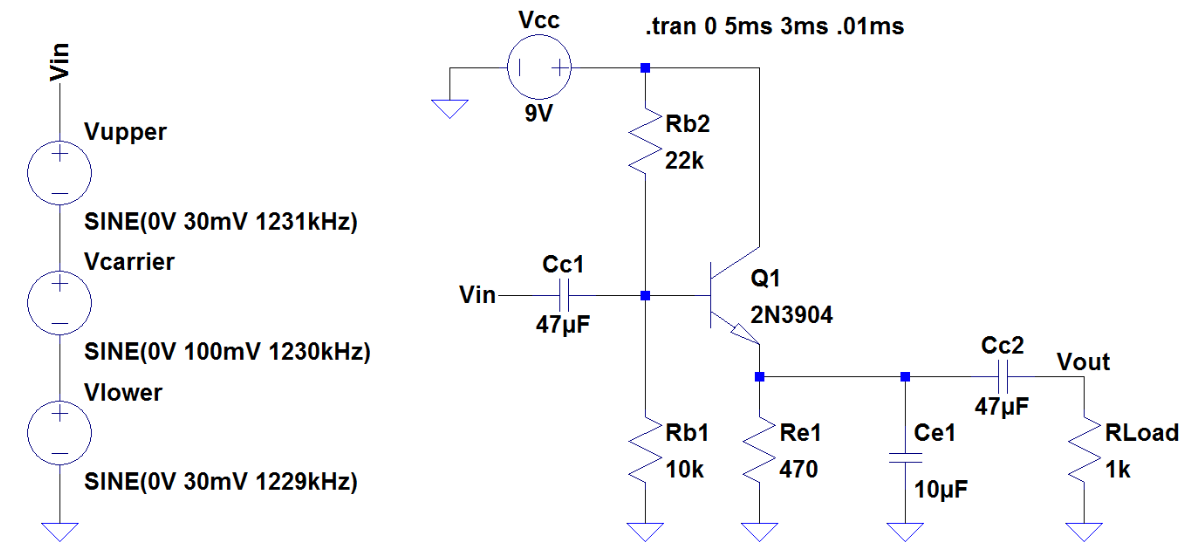
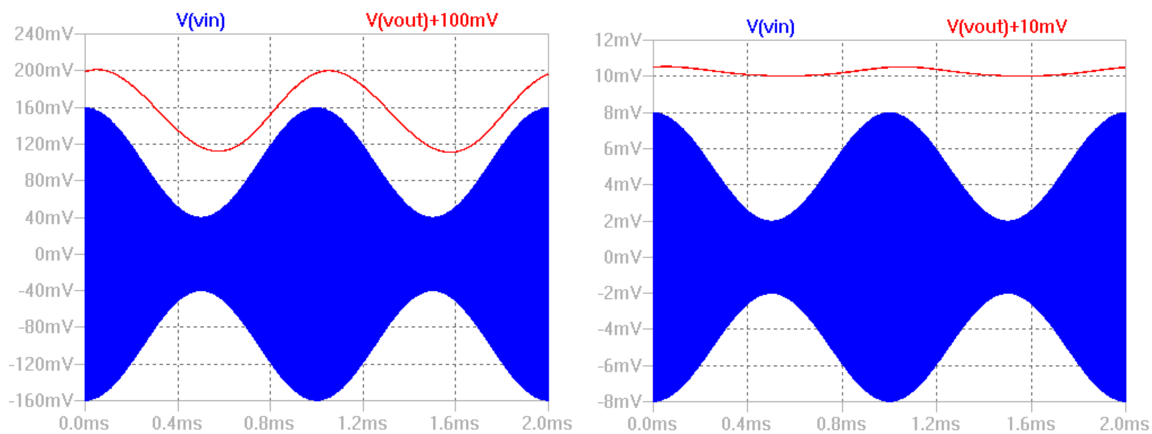


Figure 4.8: A common-collector based AM detector.



(a) (b)

Figure 4.9: Output for common-collector AM detector for (a) the default case of Figure 4.8, and (b) the case where the input signal has been reduced to a 5mV amplitude carrier, and 1.5mV amplitudes for the upper and lower sidebands.

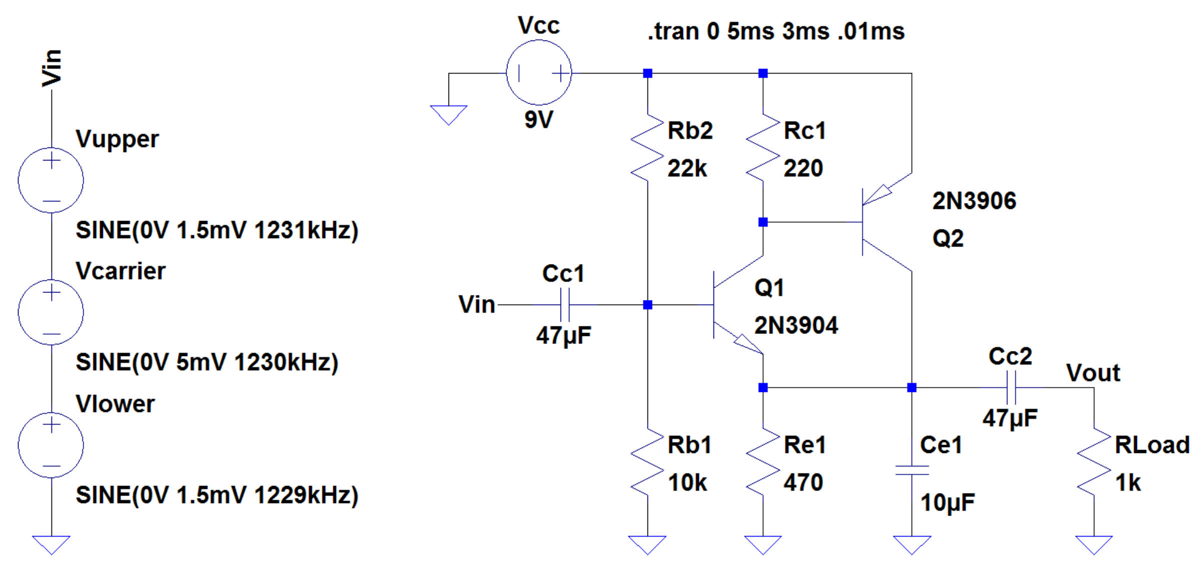


Figure 4.10: Complementary Feedback Pair (CFP) Detector

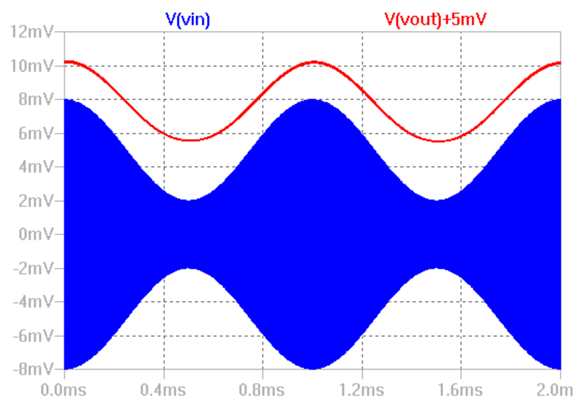


Figure 4.11: Output for CFP Detector for a weak input signal.

4.3a LTspice Simulation

1. The common-collector based detector of Figure 4.8 features a very strong input signal (100 mV carrier amplitude). **Simulate** this circuit to duplicate the output shown in Figure 4.9a.

2. Now reduce the signal level to a 5 mV carrier amplitude with 1.5mV amplitude side-bands. **Re-simulate** to duplicate the output shown in Figure 4.9b.

3. Now **construct and simulate** the CFP detector of Figure 4.10 to achieve the output shown in Figure 4.11. **Why is the resistor Rc1 required?**

4.4 (optional-advanced/bonus on prelab) Guided Design:

Maximum Detector Range

It is suggested that you work with your project partner on this portion of pre-lab.

At this point it is uncertain how strong the audio signal will be that finds its way to the detector circuit. It is desirable to have a detector stage which can extract audio signals over a wide range of AM signal levels. What might be a good range for AM signal levels (in terms of carrier frequency amplitude)?

You have studied several detector circuits in pre-lab. What are the apparent advantages and disadvantages of these circuits? How can they be compared over your chosen range? While the choice may at first appear obvious, sometimes other considerations may results in a different circuit choice.

For your chosen circuit, can you modify it to improve the detector range? How can you compare the improvement over the initial design? What simulation results can you use to verify the improved performance? Your pre-lab preparation should include your thoughts on these questions, along with the proposed circuit and things to look for in the measurements.

4.5 Constructing AM Detectors

1. Construct a simple detector circuit. This will appear similar to the circuit shown in Figure 4.4, except that the voltage source will be your generator (set for an AM signal in step 2). To begin, let D_1 be a D1N4148, R_1 = 1 kΩ, and C_1 = 0.1 μF (labeled 104M).

2. Feed an AM signal to your detector circuit ***(You may wish to revisit chapter 1 to see how to generate an AM signal)***. Select a carrier frequency f_c = 200 kHz, internal modulation for intelligence frequency f_i = 1 kHz, and set 50% modulation.

- A weak signal will best represent the signal entering the input from your antenna. For the amplifiers, start with a low carrier amplitude (~100 mVpp). For the diode detector, you will probably not see any intelligence signal being detected at this time as you have probably exceeded your diodes turn on voltage.

3. Use the dual channel feature of your scope to observe the generator signal input and the rectifier output signal at the same time. **Do not use both channels of your FGEN, instead directly measure the input and output of your circuit.**

4. Examine the output signal as the input signal amplitude is increased. **Comment** on results and include information on which input voltage levels your detector works best at.

5. Adjust the signal amplitude so that you have an easy to read, steady input and output signal. Now, change R_1 to 10 kΩ and observe the signal. **Comment** on the results.

6. Repeat step 5 for R_1 = 100 kΩ and **comment** on results.

7. Construct the biased diode detector circuit shown in Figure 4.6.

- Feed a suitable AM signal to this detector circuit and examine the results using the dual channel feature of your scope as before. Vary the AM signal level. **Comment on your results. Include information on which input voltage levels your detector works best at.**

8. Construct the CFP detector circuit of Figure 4.10. (Do not disassemble the biased diode detector)

- Feed a suitable amplitude (refer to your prelab simulations) AM signal to this detector circuit and examine the results using the dual channel feature of your scope as before. Vary the AM signal level. **Comment on your results. Include information on which input voltage levels your detector works best at.**

4.6 Bonus Section: Spectrum Analyzer

Now you may choose to complete this section for *bonus points and glory!*

This is our first time offering this, so please provide us feedback on how it goes and any issues!

You may remember using the spectrum analyzer from Lab 1, and now you will get to see some more practical applications of the frequency domain.

You will test both the CFP and Biased Diode detectors, so hopefully you have not brashly disassembled them already.

1. Connect your biased diode detector and provide it a 1230 kHz carrier with a 50% modulation and input amplitude of 200 mVpp. Connect it to the o-scope and verify that it is operating correctly.

2. Now, press the *RF* button to turn on the spectrum analyzer
3. Using the buttons in the lower right hand corner, let us set up the measurement: set the *Center Frequency* to 1230 kHz and the *span* to 20 kHz. Set the *Ref Level* to 0 dBm. Then set the *RBW* to 300 Hz.
4. Connect the output of the spectrum analyzer to the AC input of the biased diode to measure the input of the circuit using the *Manual Markers* (here the **dBm** not dBm/Hz is the power level of interest). Record the amplitude of the carrier and sideband in Table 1.
5. Now, measure the output spectrum of the biased diode detector and put it in Table 1. **Comment on the difference between the output and input. Note, this is for bonus, so actually think about the comment!**

Now let's measure the CFP detector!

6. FIRST, reduce the AM wave amplitude to 20 mVpp. Connect up the CFP and verify it is still working on the o-scope (back in the old time domain version now, not frequency domain)
7. Now, let's leave the time domain behind and jump Back to the Frequency domain (Weak movie reference, I know). By jumping back to the frequency domain, I mean back to the spectrum analyzer.
8. First, measure the input of the waveform like you did in step 4, then measure the output like you did in step 5 and put the results into Table 1. **Again, make a good comment on differences**.

Table 1: Power levels of AM Waveforms

	Carrier	Sideband
Biased Diode		
Input		
Output		
CFP		
Input		
Output		

9. Now you might smartly ask, "Why am I measuring the carrier? Shouldn't I be more interested in the intelligence actually being detected by my detector?" To this, your wise TA should say yes then give you a sticker.
10. So, since you care about intelligence, let's check it out. Leave your CFP detector connected as it is currently, and lets adjust the spectrum analyzer to measure the intelligence.
11. Set the *Span* to 1 kHz and the *Center Frequency* to 1 kHz (note this is your intelligence frequency). Finally, set the *RBW* to 30 Hz. **Another note, the spectrum analyzer is a bit slow at measuring low frequencies due to the very low RBW so give it a few seconds to sweep and provide a measurement.**
12. Now measure the peak level of the carrier at the output (first) and input (second) then write it in Table 2. You may need to decrease the *Ref Level* under the *Ampl* menu to find the power level for the input.

Table 2: Power Levels at 1 kHz

	Power Level
Output	
Input	

13. Why is the input level so low compared to the output? **Comment on these results**. Again, this is for bonus, so we expect some extra work and thought on this section for the extra credit. If you don't know why, think about what signal you are inputting and what signal is being output from the circuit. Also, what does it mean that so much of the carrier is bleeding through? How will that effect overall radio performance? Is the input even above the spectrum analyzer's noise floor? Why? (Hint, these are guiding questions!)

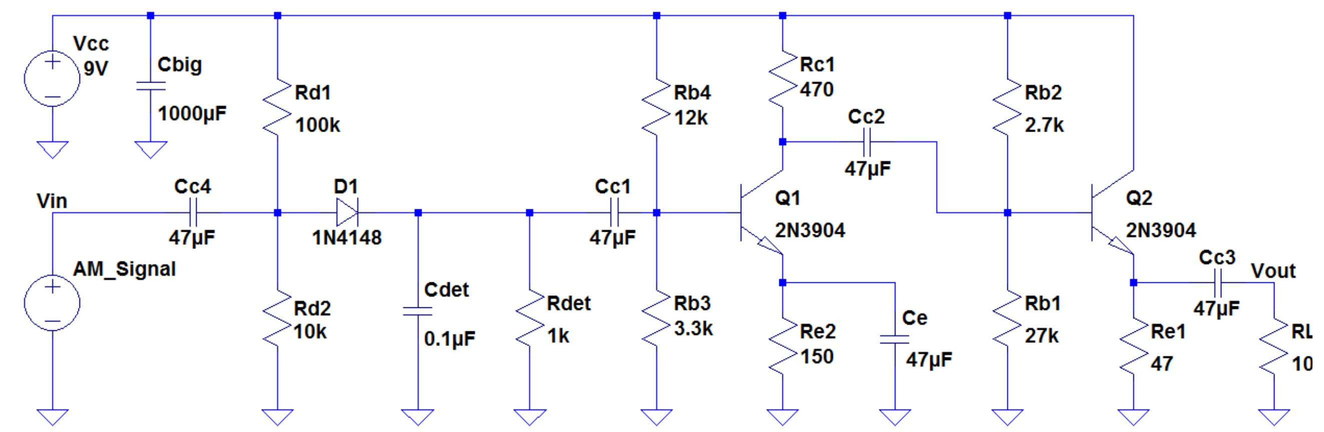


Fig 4.12: Biased diode detector circuit added to the CE-CC version of the audio amplifier.

4.7 Add AM Detector to Your Radio (AKA you are not done yet!)

Now it is time to select the detector circuit for your radio, based on the above measurements (and on the Guided Design considerations, if you did that option). You should breadboard and test your proposed circuit.

4.8 Adding the AM Detector to the Audio Amplifier

1. Add your chosen detector circuit to your chosen audio amplifier. Figure 4.12 displays a possible scenario.
   a. Note the presence of the big capacitor across the power supply. This is a good way to cut down on noise. Use your largest electrolytic capacitor, with **proper polarity**, placed from the +9V line to the ground line on your breadboard.

2. Create an AM signal to feed your circuit. Set the carrier to 1230 kHz. Use a second generator for your intelligence frequency. Initially set this to 1 kHz. Adjust for approximately 50% modulation.

3. Replace Rload in the circuit with your speaker. Adjust the intelligence frequency. **Comment** on the sound quality coming from your speaker.