

A.M. RADIO DESIGN LAB

BEFORE YOU BEGIN

PREREQUISITE LABS

- ▶ Passive and Active Filters Lab
- ▶ Fourier Transforms Lab
- ▶ Introduction to Oscilloscope
- ▶ Introduction to Arbitrary/Function Generator

EXPECTED KNOWLEDGE

- ▶ Laplace transform circuit analysis
- ▶ Analog filters
- ▶ Op-Amp applications

EQUIPMENT

- ▶ TDS3034B Series Digital Phosphor Oscilloscope
- ▶ AFG3000 Series Arbitrary/Function Generator
- ▶ Programmable Power Supply
- ▶ Speaker Switch Box
- ▶ Computer Speakers

MATERIALS

- ▶ Inductor Bobbin and Wire
- ▶ Variable Capacitor (8.5 – 120 pF)
- ▶ 2 x 741 Op Amps
- ▶ Germanium Diode
- ▶ Condenser Microphone
- ▶ 20 feet of wire
- ▶ Solderless Breadboard

OBJECTIVES

After completing this lab you should know how to:

- ▶ Modulate an A.M. signal
- ▶ Demodulate an A.M. signal
- ▶ Build a simple A.M. receiver

INTRODUCTION

AMPLITUDE MODULATION

Radio stations transmit electromagnetic waves at different frequencies. When you turn the tuning dial on your car radio, you change the frequency that your radio receives. For example, when

your radio receives an FM station at 107.5 MHz, it is tuned to receive only signals with frequency content that is close to 107.5 MHz.

You can not hear electromagnetic waves and, even if you could, you can not hear frequencies as high as 107.5 MHz. You can only hear audible frequencies up to about 20 kHz. Radio transmitters “mix” the sound waves into the 107.5 MHz signal and convert it to an electromagnetic wave. This process of mixing two signals at different frequencies is called modulation. Your car radio receives the electromagnetic waves, converts them to electrical signals, separates the audio and radio signals, and sends the audio signal to your speakers.

Radios use one of two methods to “mix” audio frequency sounds into a radio signal. They are frequency modulation (F.M.) and amplitude modulation (A.M.). The scope of this lab is limited to amplitude modulation.

A.M. modulation changes the amplitude of a high frequency, sinusoidal electromagnetic wave by an amount proportional to the amplitude of the sound wave. Figure 1 shows a radio signal with no modulation.

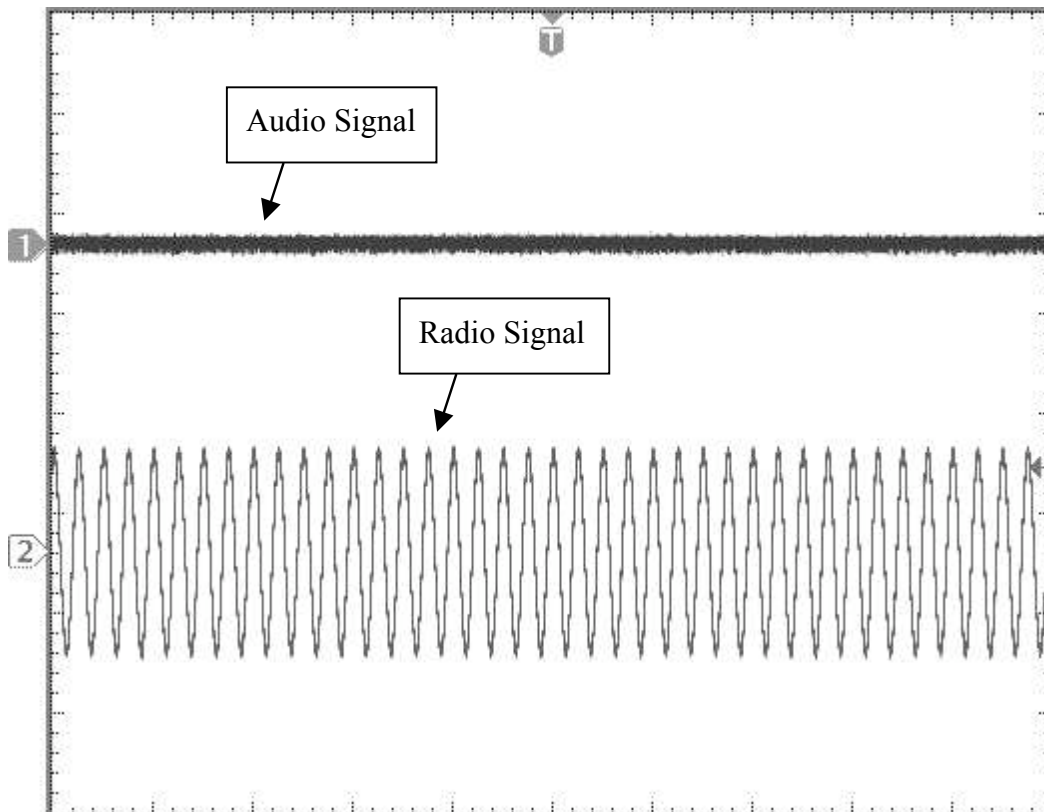


Figure 1: Radio wave with no modulation

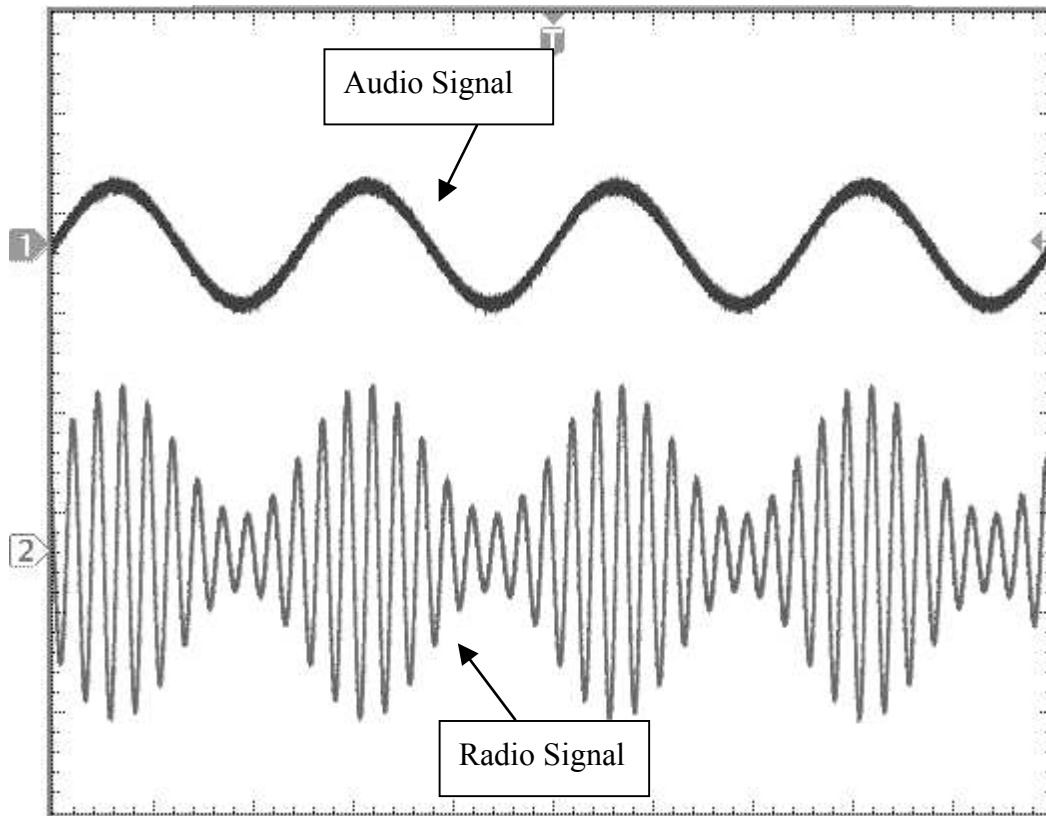


Figure 2: Radio wave with amplitude modulation

Figure 2 shows a radio signal with amplitude modulation. The amplitude of the radio wave follows the amplitude of the sound wave as in Figure 2.

A.M. DEMODULATION

In this lab, we will be using a diode to convert the received signal into an audio signal. This process is called A.M. demodulation.

A diode is a device that only allows current flow in one direction. If we apply an AC signal to one end of a diode, as in Figure 3, we will only see the positive portion of that signal at V_{out} .

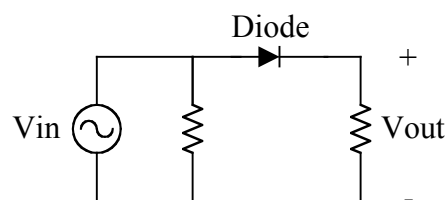


Figure 3: Diode Demonstration Circuit

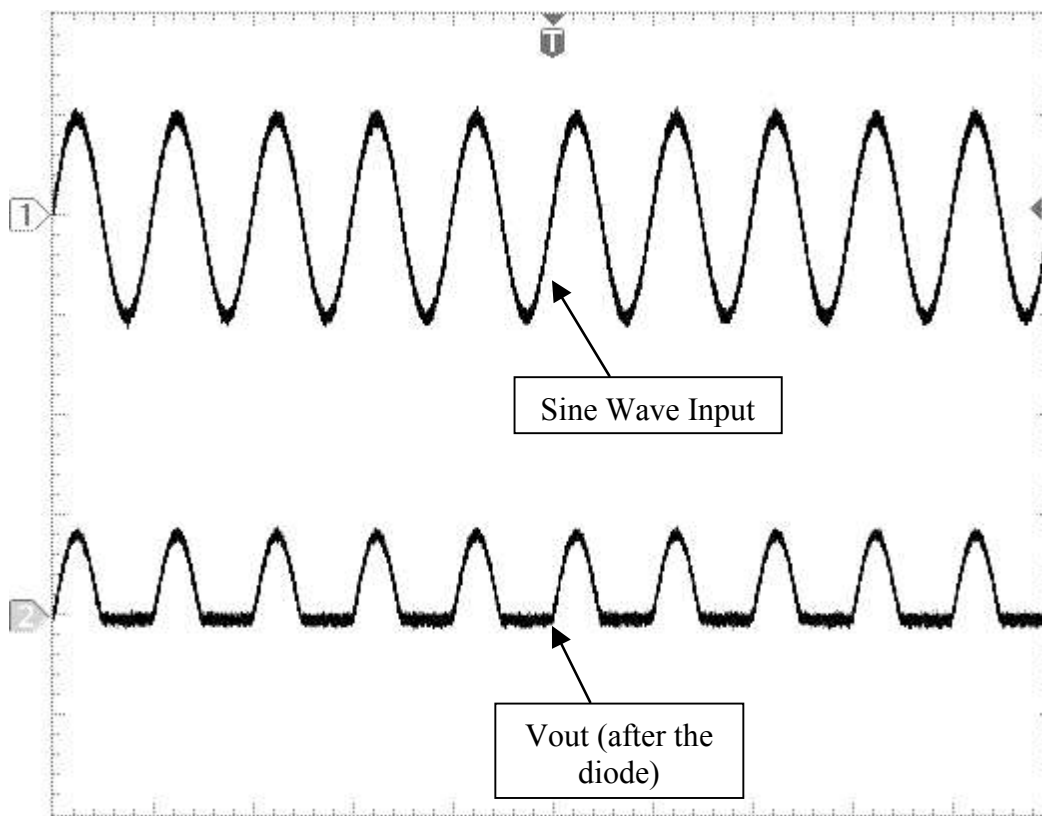


Figure 4: Rectified Sine Wave

As you can see in Figure 4, the diode removes the negative portion of the incoming signal. This is called half wave rectification. The lower waveform in Figure 4 is said to be half wave rectified.

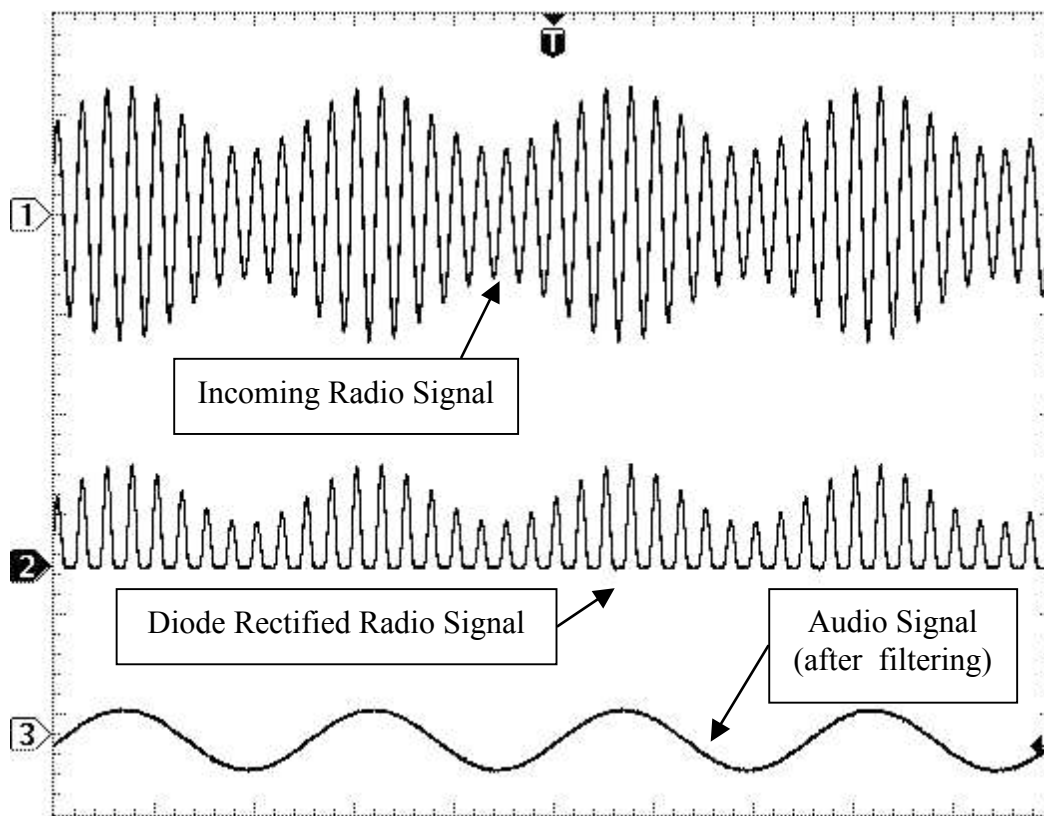


Figure 5: A.M. Radio Wave Rectification

Diode rectification is a simple way to help demodulate an A.M. radio signal. Figure 5 shows how an incoming radio wave is effectively cut in half when it passes through a diode. Since the current can only flow in one direction we will only see positive voltages. The remaining signal is low pass filtered to remove the radio frequency, leaving only the low-frequency audio signal.

PRELAB

AUDIO SIGNAL GENERATION

To generate our audio signal, we will use a condenser microphone and an op-amp as shown in Figure 6. The condenser microphone needs a small DC current to make it operate correctly. This current is controlled by R3.

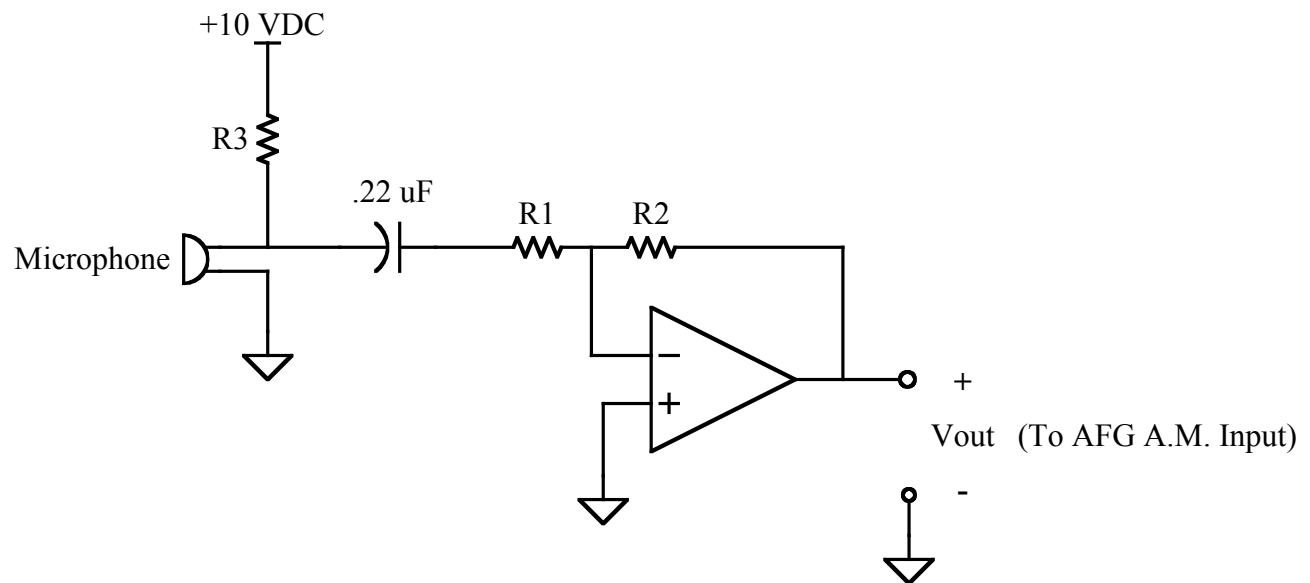


Figure 6: Microphone and Amplifier Circuit

In this configuration, the microphone acts like a sound controlled variable resistor. The sound waves that the microphone picks up control the resistance of the microphone. The changing resistance causes the voltage on the microphone's ungrounded pin to change according to the amplitude of the sound wave on the microphone. This produces an audio frequency AC voltage signal at the microphone's ungrounded pin. The audio AC signal then passes through the large capacitor to block all DC voltages, and is amplified by the inverting amplifier circuit.

Answer Questions 1 – 2.

A.M. RADIO TRANSMISSION

To transmit A.M. signals, we will be using the Arbitrary/Function Generator (AFG). The AFG has a modulation input, and it will amplitude modulate any signal. The only remaining component is the antenna. Radio signals are waves with a specific frequency and wavelength. For an antenna to efficiently broadcast radio waves, it has to be a specific length. According to wave theory, $v = f\lambda$ where v is the velocity of the wave (in our case, 300 M m/s), f is frequency of the wave (in hertz), and λ is the wavelength (in meters). An efficient antenna has a length

equal to half of a wavelength. For a 1 MHz wave ($\lambda = \frac{v}{f}$, $\lambda = \frac{300 * 10^6}{1 * 10^6}$, $\lambda = 300$ meters) an efficient antenna would be 150 meters long.

Answer Question 3.

Other slightly less efficient antennas are $\lambda/4$ and $\lambda/8$ meters long. We are not concerned with making the most efficient antenna, so any antenna length that is 3 meters or longer will work fine. The antenna will be connected to the positive terminal of Channel 1 output of the AFG.

How an Antenna Works

Charged particles emit radiation when they are accelerated and radio waves are one type of radiation. The AC voltage from your AFG forces electrons into and out of the antenna. This AC voltage accelerates the electrons and causes the electrons to emit radio waves that travel perpendicular to the broadcasting antenna. Therefore, it is best to set up your transmitting antenna so it is oriented parallel to your receiving antenna.

IS THIS LEGAL?

In radio talk, a “band” is a group of frequencies that are all used for the same purpose. The A.M. band on your radio starts at 500 kHz and ends at 1800 kHz. Commercial radio stations use these frequencies. Usually, the U.S. Government requires a person or company to obtain a license before they can transmit on any frequency. However, the government does make some exceptions. Anyone can transmit on the A.M. band as long as their transmissions do not cause any harmful interference to existing stations and as long as their transmissions are not too powerful. The small amounts of power that are used in this experiment are within the legal limits.

A.M. RADIO RECEIVER

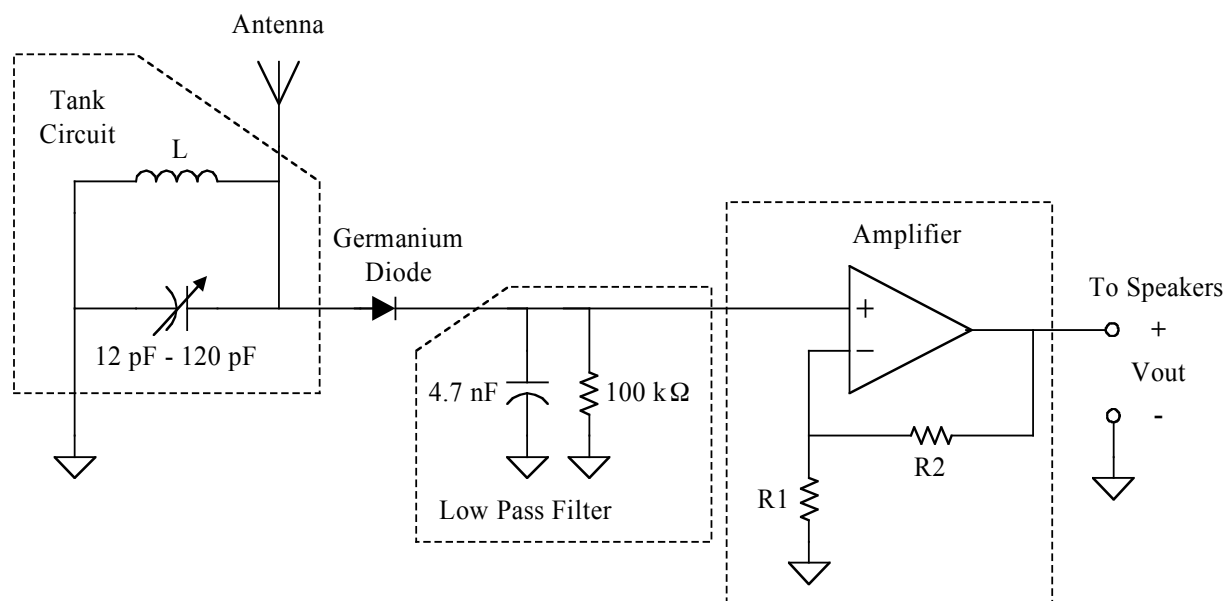


Figure 7: Receiver Circuit

Figure 7 shows the circuit you will build for your radio receiver. This circuit consists of four basic sections: a “tank circuit”, a diode, a low pass filter, and a non-inverting amplifier.

The inductor-capacitor parallel combination is commonly called a tank circuit. The tank circuit is a band pass filter with a fairly high Q value. To analyze the tank circuit, we can model the antenna as a sinusoidal current source, as in Figure 8. For this circuit, $\frac{V_o(s)}{I_s(s)} = H(s)$.

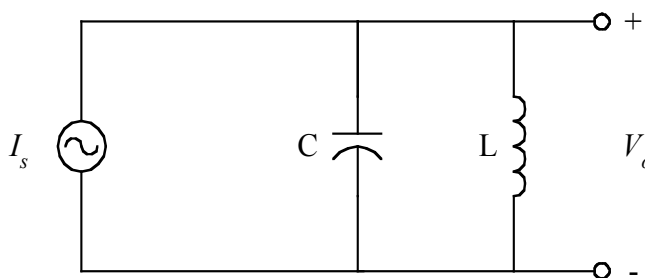


Figure 8: Tank Circuit Analysis

Answer Questions 4 – 5.

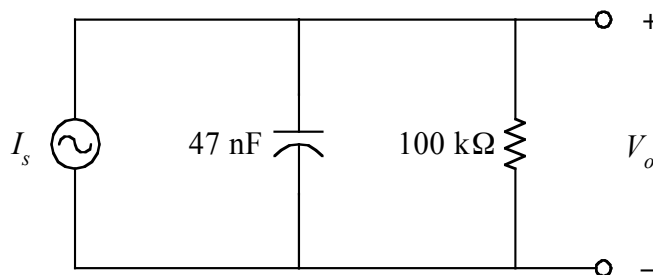


Figure 9: Low Pass Filter Analysis

The capacitor-resistor parallel combination in the receiver circuit is acting as a low pass filter. The current through the diode is acting as the current source in this case.

Answer Question 6.

The op-amp in the receiver circuit is acting as a non-inverting amplifier. We will need a gain greater than 50 to amplify our audio signal enough for us to hear the received signal in the speakers.

Answer Question 7.

BUILDING THE RECIEVER

Your teaching assistant will assign you one of the following frequencies:

1 MHz

1.15 MHz

1.4 MHz

1.8 MHz

2.5 MHz

You will be sharing the frequency with one other group in your lab section.

Answer Question 8.

Unfortunately, factors including parasitic capacitance and resistance change the value you actually need for your inductor. Wrap your inductor bobbin with 150 wraps. **Do not** use the ceramic core to increase the inductance. The ceramic core is intended for use only at low frequencies (<10 kHz). If you use the core, it will greatly decrease the Q value of your tank circuit, making it unsuitable for tuning your radio. You will need to use wire-wrapping wire (AWG 30 or smaller). Connect the inductor and capacitor as in Figure 10.

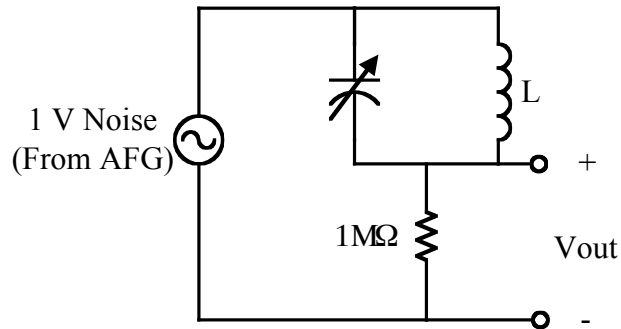


Figure 10: Tank Test Circuit

Change the function on the AFG to Noise and the amplitude to 1 V. At this setting, the AFG will produce white noise that you will feed through your tank circuit. Perform an FFT analysis on the voltage across the 1 MΩ resistor. Set Channel 1 to 100 μs per division and set the FFT to 500 kHz per division. For best results, you will need to have your probe set on 1X and the Channel 1 impedance on the Scope set to 1 MΩ. You should see something like Figure 11 when you have everything set correctly.

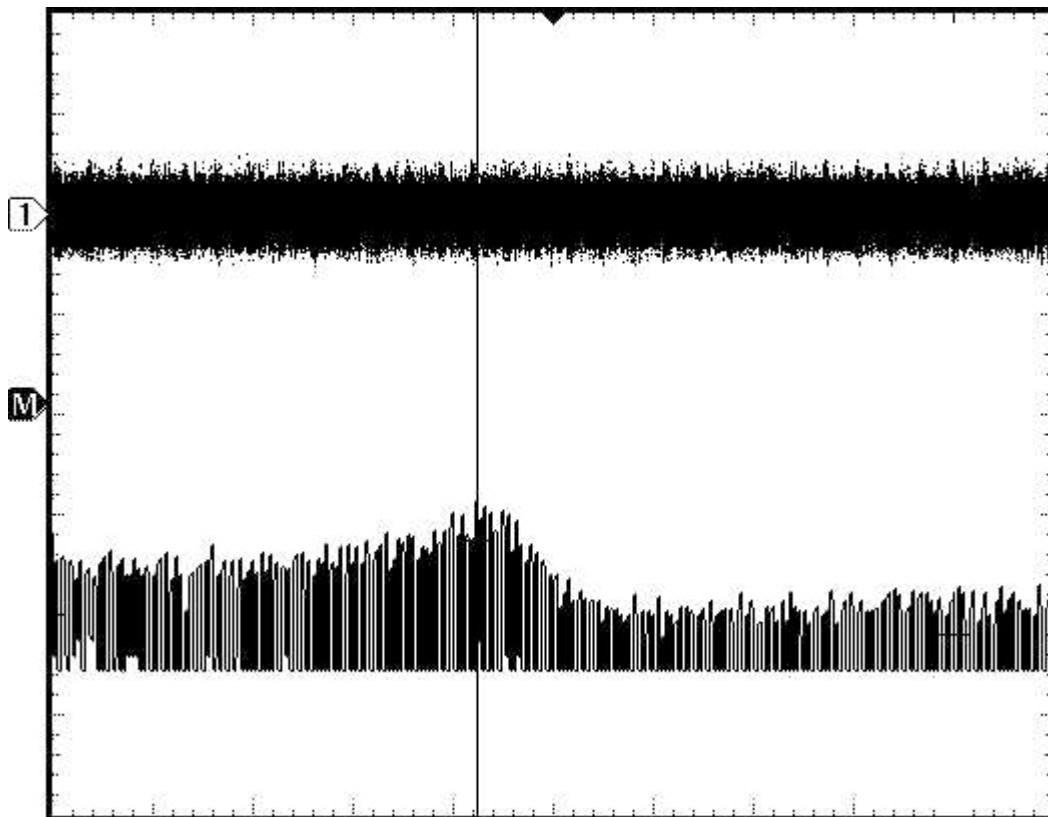


Figure 11: FFT of Noise through Tank Circuit

Figure 11 shows an oscilloscope with Channel 1 activated, and the math plot set to FFT. The bump on the FFT plot corresponds to the resonate frequency of the tank circuit. If you were

using this circuit to tune in a radio station, the station you would be hearing would be the one transmitting on frequency corresponding to the maximum in your FFT plot. As you adjust your capacitor, you will see the bump on your FFT move left and right. If you do not see this, you are looking at the wrong bump on the FFT. The correct bump will probably be between 100 kHz and 5 MHz.

Answer Questions 9 – 10.

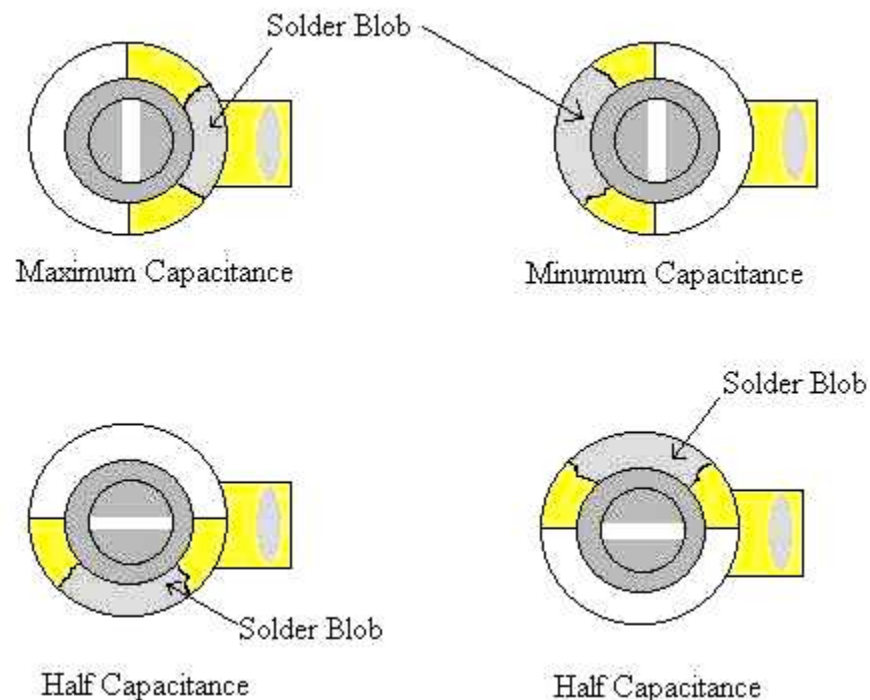


Figure 12: Variable Capacitance Adjustment

Set your capacitor to half capacitance as in Figure 12. You will need to adjust your inductor so that your circuit resonates at the frequency assigned to you when the capacitor is set near its halfway point. If your inductor is too small, the frequency will be too high. You will need to increase the number of wraps on your inductor. If your frequency is too low, you will need to decrease the number of wraps on your inductor.

When you actually combine this tank circuit with the rest of your radio, the tunable frequency range will decrease somewhat due to parasitic capacitance in your solderless breadboard. The frequency assigned to you should still be within your tunable range.

Connect the Receiver Circuit in Figure 7. Use a 10-foot piece of wire for the antenna. Connect the output of the amplifier to the speakers. Use ± 10 V to power the op-amp.

TESTING THE RECEIVER

Follow the following steps to configure the AFG as an AM transmitter.

1. Connect the Channel 2 output to the modulation input for Channel 1 on the back of the AFG.
2. Set Channel 2 to produce a 1 kHz sine wave at 1 volt peak to peak.
3. Turn on the output of Channel 2.
4. Connect a BNC to Banana adapter to Channel 1.
5. Set Channel 1 to produce a 2 V peak-to-peak sine wave at the frequency assigned to you by your teaching assistant.
6. Turn on the output of Channel 1.
7. Connect a banana to alligator lead to the positive side of your BNC to Banana adapter. This will serve as your transmitting antenna while you test your receiver.
8. Press the Modulation button, select Modulation Type AM, and AM Source External.

Keep the Channel 1 amplitude below 2 V to avoid causing interference to other groups. Scan from 700 kHz to 3 MHz with the AFG until you hear a tone from your speakers. You will need to keep the receiver antenna within one foot of your transmitting antenna while you test your receiver.

Answer Questions 11 – 12.

The answers to Questions 11 and 12 give you the tunable band for your radio.

Set Channel 1 of your AFG to the frequency assigned to you by your TA. Adjust your capacitor until the tone in your speakers is loudest. This will tune your receiver to your assigned frequency

BUILDING THE TRANSMITTER

Build the circuit in Figure 6. Use the values you calculated for R3 and R2 in the prelab. Use ± 10 V to power the op-amp. Use the +10 V op-amp supply as the input voltage for your microphone. Test your circuit by connecting the output of the op-amp to the speakers at your bench. You should be able to talk into the microphone and hear it amplified through speakers. If you set the speaker volume too high, the speakers will produce a high pitched squeal. This is called feedback. Turn the speaker volume down to eliminate this problem.

Connect the output of your transmitter circuit to the modulation input for Channel 1 on your AFG. Increase the amplitude of Channel 1 to 10 V. Lengthen your transmitting antenna by connecting 3 more banana to alligator leads to the banana to alligator lead already connected to Channel 1. Your transmitting antenna should be about 12 feet long. DO NOT use any cables with BNC connections for your transmitting antenna. These cables are shielded and will not transmit radio waves.

You should now be able to have a radio conversation with the group sharing your frequency. When you transmit, disconnect the power from your receiver and shut off your speakers. When you receive, disconnect power from transmitter and turn off the Channel 1 output on your AFG.