McGill

Experiment 1: The design of an AM receiver

ECSE 434

N O T E S

- Get your equipment and components from parts-master on the 4th floor parts counter in the Trottier building. Ensure that the components you design for are available from the parts-master. Use the Components & Parts Request Form.
- Make sure to come to the laboratory with the relevant preparation typed and completed for your TAs to review and grade.
- It is suggested to assemble some of the circuit components prior to entering the laboratory to save time. <u>Do not disassemble circuits as they will be required later on, as the experiment progresses.</u>
- Do not rely on the signal generator amplitude readouts, measure your inputs with the oscilloscope.

❖ When writing the report, make sure to include where possible:
  - <u>hand calculations</u>
  - <u>simulation results</u>

  <u>Compare the two.</u> An <u>explanation of your observations, and discussions,</u> will help validate your <u>experimental findings</u>.

Plagiarism will not be tolerated.

INTRODUCTION

Wireless technology is omnipresent. Wireless LANs, cell phones and radios are parts of our every day lives. At the core of this wireless revolution, analog circuits will always be required. The critical component in all wireless systems is the front-end analog transceiver, which consists of a transmitter and a receiver. Signals are transmitted and received through electro-magnetic (EM) emissions.

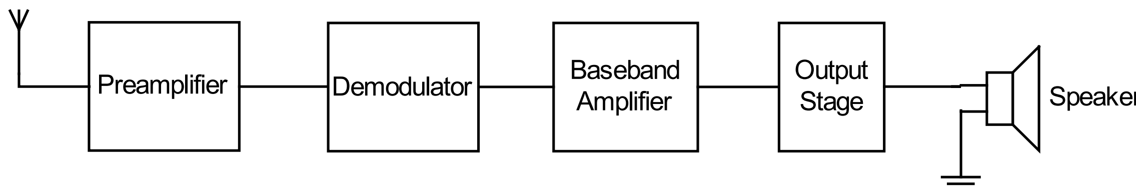

Figure 1- System-level diagram of the AM receiver

The signal information, also called the baseband signal, is usually a low-frequency signal which, in the case of audio systems, is comprised of the audio band (from 0 Hz to 20 kHz). As these signals cannot be transmitted efficiently (they would require very long antennas), they are usually transmitted on top of a high-frequency carrier signal, also known as the RF (Radio Frequency) carrier. The carrier frequency is a high frequency signal which carries the baseband signal containing data. This process is known as signal modulation. There are many types of signal modulations, some of the simplest are: amplitude modulation (AM) and frequency modulation (FM). This experiment will focus on the AM receiver shown in Figure 1.

1 - BASEBAND AMPLIFIER

Once the radio signal has been pre-amplified and demodulated, an amplifier circuit is used to provide gain to the resulting audio signal. To do this, a circuit like the one shown in Figure 2 can be used. The topology is based on a non-inverting amplifier, and allows manual gain control through a potentiometer.

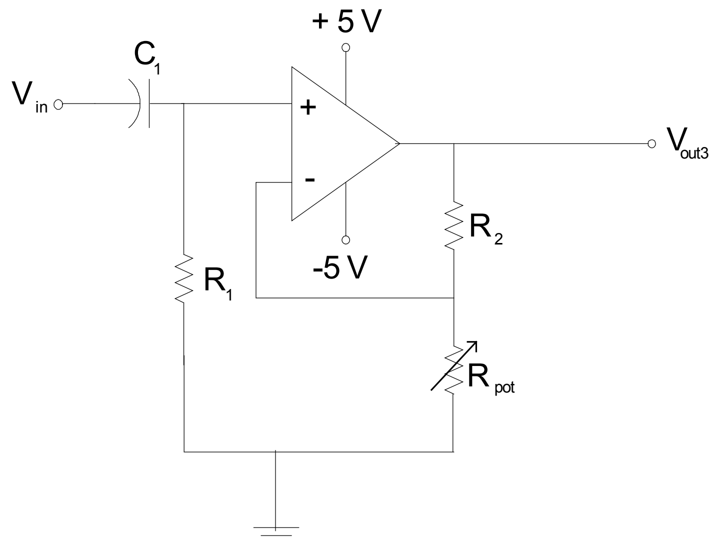

Figure 2- Baseband amplifier schematic

1.1 CIRCUIT PARAMETERS

Op-Amp Model: TL084 (found on the course website)

V_{CC}	=	+5 V
V_{EE}	=	-5 V
C_1	=	1 µF
R_1	=	150 kΩ
R_2	=	____________
R_{pot}	:	0-10kΩ potentiometer

1.2 PREPARATION

Refer to chapter 2 of Microelectronic Circuits by Sedra and Smith, 6th (chapter 2 in 5th Ed.) Ed. if you need additional background material.

1.2.1 Briefly explain the purpose of capacitor C_1.

1.2.2 Briefly explain the purpose of resistor R_1.

1.2.3 Derive the gain equation of the circuit shown in Figure 2. Perform the analysis both for C_1 neglected, then when it is taken into account. How does C_1 affect the gain of the circuit?

1.2.4 Choose values for R_2 and R_{pot} that will achieve an in-band gain of 150 V/V to the nearest 5 % accuracy.

1.2.5 Calculate the input and output resistances, while neglecting C_1.

1.2.6 Determine the 3-dB bandwidth of the circuit using the SPICE simulator. Use the TL084 opamp model found on the course web site.

Note*: For frequency simulation of the op-amp, ensure that each pin is modeled as a 5 pF parasitic capacitor from that pin's node to ground. Also, take into account the parasitic resistor and capacitor values of the oscilloscope (1 MΩ resistor in parallel with a 20 pF capacitor going from the measuring node to ground). If you use a 10X probe, the loading <u>will be different</u>. Check which kind of probe you are using, and take note of its resistance and capacitance.*

1.2.7 Vary the value of the potentiometer resistance, R_{pot}, in order to modify the gain of the circuit, and to ultimately be able to construct a plot of the 3-dB cutoff frequency versus the in-band gain of the amplifier. Comment on the behavior of the curve and on the product of the 3-dB cutoff frequency by the in-band gain.

1.2.8 Considering the function of this circuit as a baseband voltage amplifier, what are the characteristics that this circuit should have regarding input impedance, output impedance and bandwidth?

1.2.9 Suggest a method of intelligently measuring the input resistance, without requiring a current measurement.

1.3 EXPERIMENTATION

Assemble the amplifier circuit shown in Figure 2, and adjust the potentiometer so that its in-band gain be 150 V/V. Ensure that the input amplitude is sufficiently small so that the amplifier operates within its linear region. You may have to use a voltage divider on the input signal to achieve that. Demonstrate the following:

1.3.1 Plot the overall frequency response of the amplifier, highlighting the in-band gain, 3-dB cutoff frequency, and the gain bandwidth product.

1.3.2 What is the gain range that your baseband amplifier covers? Plot the gain versus the corresponding R_{pot} values.

1.3.3 Measure the input resistance of the amplifier using the method you devised in 1.2.9.

2 - DEMODULATOR

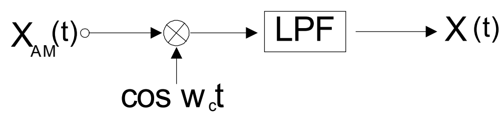

Figure 3- High-level system diagram of an AM demodulator

In general, to downconvert a signal to its baseband frequency, the signal must be multiplied by a carrier wave, then sent through a low pass filter as shown in Figure 3. (this approach will be further discussed in detail in ECSE-304). However, for AM signals, a simpler method involving amplitude detection may be used. To do so, you will use the demodulator circuit shown in Figure 4.

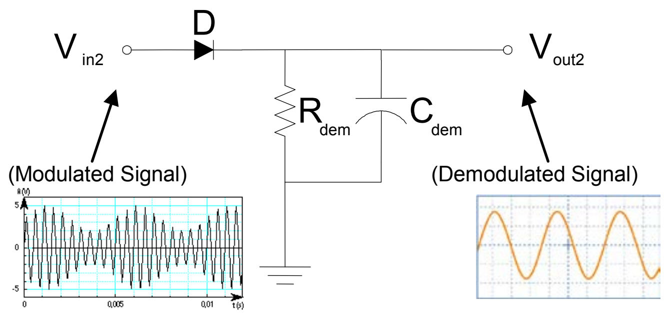

Figure 4- Circuit diagram of a passive demodulator

2.1 CIRUCIT PARAMETERS

Germanium Diode model:1N34A (found on the course website)

R_{dem} = ________

C_{dem} = ________

2.2 PREPARATION

Refer to section 4.5.4 in Sedra and Smith 6th Ed. (3.5.4 in 5th Ed.), if needed.

2.2.1 In your own style, briefly explain the operation of the circuit shown in Figure 4 (do not copy the book!), and indicate the factors to consider when selecting the capacitor and resistor values.

2.2.2 Select appropriate values for C_{dem} and R_{dem}, knowing that the wanted baseband signal is in the 0-20kHz range, and that the unwanted carrier signal is in the 200kHz-1.2 MHz range.

2.2.3 What are the constraints on the DC point at the input of the demodulator for correct operation? How can loading effects impact this circuit?

2.2.4 Simulate your design to ensure correct operation using an appropriately modulated input signal. This signal can be generated using a multiplier which multiplies two sine waves. Refer to the SPICE tutorial on the course's website for more information. Ensure that your signal is correctly modulated so that your demodulator functions properly. *Hint: The demodulator only demodulates the positive portion of the signal envelope.*

2.3 EXPERIMENTATION

Create the circuit shown in Figure 4. Using the signal generator, set the carrier signal to the frequency band assigned to you by your laboratory TA. Second, modulate this signal using the AM modulation function of the generator. The audio signal frequency will then be "carried onto" the carrier frequency through AM modulation.

Note: Keep in mind that the human ear is capable of easily hearing signals between ~200 Hz to ~10 kHz.

2.3.1 Connect the input of the modulator to the signal generator, and plot the input and output signals confirming the demodulation of your signal.

2.3.2 Plot the gain response[1] of the modulator versus the *baseband* signal frequency, while using the same carrier frequency.

2.3.3 Plot the gain response[1] of the modulator versus the *carrier* signal frequency, while using the same baseband signal frequency.

3 - CLASS A OUTPUT STAGE (POWER AMPLIFIER)

[1] *It is assumed here that the amplitude of the input modulated signal is as large as that of the carrier signal (set this up with the function generator). The gain is defined here as the ratio between the amplitude of the output demodulated signal, and that of the input carrier signal amplitude.*

Speakers are made up of a coil, with a magnetic core inside, attached to a diaphragm; therefore, they are low impedance devices, i.e. typically 8-32 Ω. When AC current flows into the coil, it causes a magnetic field that forces the coil to move back and forth. By pulling the diaphragm back and forth, sound waves are generated. To achieve a high enough output power to the speaker, large current amplitudes are required. Hence, a power amplifier is needed between the low current-drive output of the baseband amplifier and the speaker. The circuit used to achieve this can be a simple emitter follower biased at a high current. It reduces the output impedance, and therefore the loading effect of the speaker.

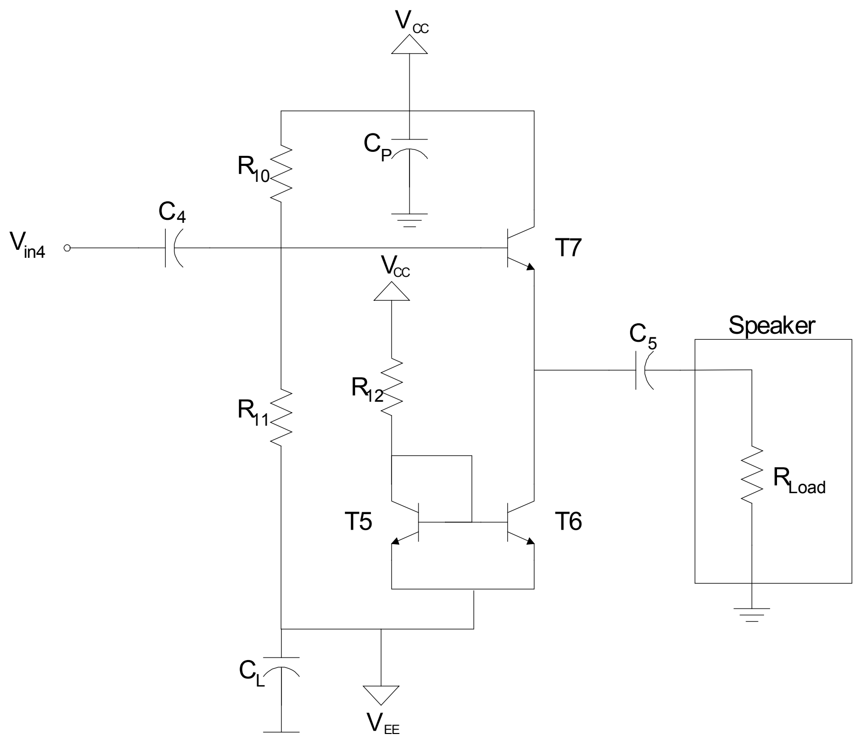

Figure 5- Class A output stage

3.1 CIRUCIT PARAMETERS

NPN Transistor Model: MPS3704

V_{CC}	=	+5 V	C_L	=	22µF
V_{EE}	=	-5 V	R_{10}	=	________
C_4	=	22 µF	R_{11}	=	________
C_5	=	22 µF	R_{12}	=	________
C_P	=	22 µF	R_{Load}	=	8 Ω

3.2 PREARATION

Refer to sections 11.1 and 11.2 of Sedra and Smith 6th Ed. (14.1 and 14.2 in 5th Ed.) for further information, if needed.

3.2.1 Design this circuit such that the biasing current is sufficient to supply a $1V_{p\text{-}p}$ amplitude signal to an 8Ω load. Set the DC points for correct operation.

3.2.2 What is the main limitation of this circuit?

3.3 EXPERIMENTATION

Note 1: Because of the high current at which the transistors will be biased, this circuit may have stability issues (free oscillations that are not input related). To ensure the stability of this circuit, you may need to add an inductor in series with the speaker, or you may equally add a small capacitor to ground in parallel with the collector of T_6.

Note 2: To handle the high power without burning transistors, you will need to use several transistors in parallel. To determine the number of transistors you need, first estimate the maximum power the circuit will be providing to the speaker. Then, using the power ratings provided in the transistor's datasheet, figure out the number of transistors needed to handle this amount of power safely. Make sure to have a safety margin.

Note 3: Ensure that the transistors are not too close to each other in order for air to act as a heat sink and allow for heat dissipation, in order to prevent thermal runaway.

3.3.1 Build the circuit shown in Figure 5. Measure the overall frequency response (create a plot) noting the in-band gain, 3-dB cutoff frequency. Verify that the frequency response is the same for large and small signal inputs, in order to ascertain the circuit is correctly designed to drive the speaker.

3.3.2 What is the maximum possible output voltage amplitude of this circuit? Show a plot of the output signal when it is limited due to insufficient current biasing.

4 - PREAMPLIFIER

The preamplifier shown in Figure 6 is used to amplify the weak radio signal received, and to tune to the required band, and to filter out interfering radio signals. It is composed of a cascode common emitter amplifier loaded with an LC resonating circuit (also called LC tank). The function of the tank in Figure 6 is to act as a tuned load (or bandpass filter). Remember (from ECSE 210) that the impedance of an LC parallel pair, and consequently the circuit's gain, is maximized at the resonant frequency. The resonant frequency in this case is selected so that it matches the frequency of the *carrier signal*.

A cascode amplifier is used here to improve the speed of the circuit and to ensure high output impedance for T_2. An output buffer using a Darlington pair is used to maintain a high impedance node at the collector of T_2 for small output loads. This high impedance node ensures a narrow bandwidth of the LC tank. This can be understood through the concept of quality factor. Any energy stored in the LC tank has the potential of leaking from the collector of T_2 to ground (think of a small resistor going to ground). From ECSE 210, you know that energy lost translates into a lower quality factor:

$$Q = \left[\frac{E_{stored}}{E_{lost}}\right] = \frac{f_{res}}{BW}. \qquad \text{Equation 1}$$

Effectively, this means that the bandwidth of the tank gets wider as more energy is lost. If one designs the circuit so that the critical node had very high impedance, then energy loss to ground is minimized, and the tank will have a high quality factor providing a narrow bandwidth. Refer to section 16.5 & 16.11 in Sedra and Smith 6th Ed. (12.5 & 12.11 in 5th Ed.) for more details.

It can be shown that the impedance of the LCR combination is maximal at the resonant frequency. That frequency can be shown to be given by:

$$f_{res} = \frac{1}{2\pi\sqrt{L_T C_T}} \qquad \text{Equation 2}$$

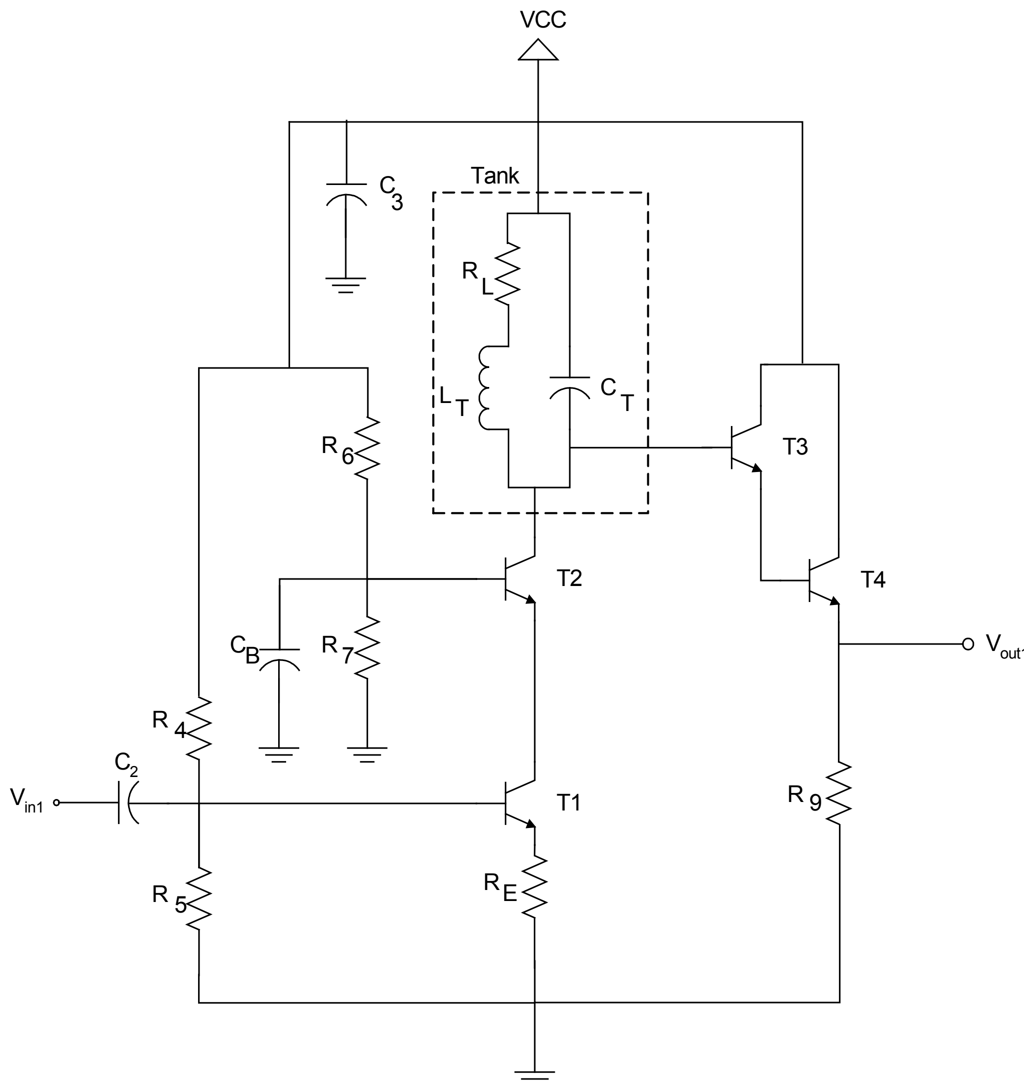

Figure 6- Preamplifier circuit

4.1 CIRCUIT PARAMETERS

TA assigned f_{res} =

NPN Transistor Model: MPS3704
V_{CC} = +5 V
C_2 = 1 µF
C_3 = 1 µF
C_B = 1 µF
R_L = 10-20 Ω
↳**parasitic** resistance of inductor to be used in SPICE simulations.

R_E = ____________
R_4 = ____________
R_5 = ____________
R_6 = ____________
R_7 = ____________
R_9 = ____________
Gain bigger than 50 V/V at f_{res}.
Bandwidth smaller than 100 kHz.

4.2 PREPARATION

Refer to section 16.5 & 16.11 in Sedra and Smith 6th Ed. (12.5 & 12.11 in 5th Ed.)*, if needed.*

4.2.1 Using Equation 2, choose an inductor, L_T, and a capacitor, C_T, to obtain the desired resonant frequency, f_{res}. Why do you need to readjust these values in SPICE to get the correct f_{res}? Suggest an improvement to Equation 2 in order to make it more faithful to SPICE simulations.

4.2.2 Briefly explain what is the purpose of R_4, R_5, R_6 and R_7?

4.2.3 Briefly explain what is the purpose of R_E?

4.2.4 Capacitors have many roles in electronic circuits; can you guess what the purpose of C_3 and the purpose of C_B are?

4.2.5 Design the resistor values so that the output swing is maximized.

4.2.6 What are the disadvantages of your preamplifier having a very wide bandwidth? What about if it has a very narrow bandwidth?

4.2.7 Derive the gain expression of this circuit assuming that R_L=infinity, and that the Darlington buffer stage yields a gain of unity. Lump all ***small signal resistances*** at the collector of T2 into one resistance named R_T to ground. Plot the gain function versus frequency for different values of R_T. Comment on the dependency of the bandwidth and the gain on R_T.

Hint: use the frequency domain analysis you learned in ECSE 210 and combine them with the inspection techniques you learned in ECSE 330.

4.2.8 What frequency related reason can you think of for the need for a buffer in this circuit?

4.3 EXPERIMENTATION

4.3.1 Construct your designed circuit, and plot its frequency response. Determine the 3-dB bandwidth and midband gain.

4.3.2 Make sure that your resonant frequency is close to what you have been assigned. If it does not match, make the necessary adjustments to your tank.

5 - AM RECEIVER

The AM receiver is built by connecting the different components together in a straightforward manner as shown in Figure 7.

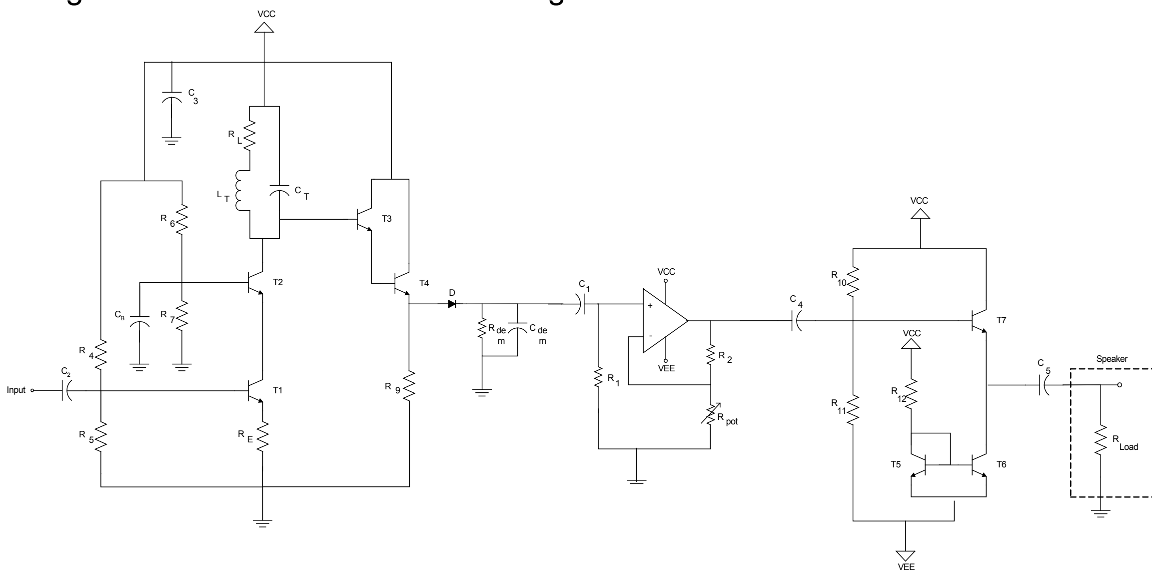

Figure 7- AM Receiver schematic

5.1 PREPARATION

5.1.1 Simulate the whole system in SPICE using a multiplier to create your AM modulated input. Provide a plot of the output signal and of the input signal, so that the modulation and demodulation are apparent.

5.1.2 Discuss the effect of loading between each sub-system in the receiver path on performance.

5.2 EXPERIMENTATION

5.2.1 Connect the circuits including the speaker as shown in Figure 7. Input an AM modulated signal corresponding to your carrier frequency from the generator. Listen to the output and confirm that you can hear different musical notes depending on the baseband signal's frequency. Table 1 below gives a reference of the different tones you should subject your system to. *Note that you can use the potentiometer for volume control and then you may have to use a resistor in series with the signal generator to reduce the input amplitude to levels which are comparable to antenna received radio signals (few mV).*

Table 1- Musical tones frequencies

Note	C	D	E	F
Frequency (Hz.)	1046.502	1174.659	1318.510	1396.913
Note	G	A	B	C
Frequency (Hz.)	1567.982	1760.000	1975.533	2093.005

5.2.2 Disconnect your generator and the series resistor that might have been required with it, and connect a long stripped wire in to act as an antenna. Now fix a stripped wire to the signal generator to act as a transmitter antenna and tune to the same frequencies you did before. You may need to increase the amplitude of the generator to a few volts to achieve adequate transmission/reception. Ensure that the volume is maximized. Listen to the output and confirm that you can hear different musical notes depending on the baseband signal's frequency.

5.2.3 Either wirelessly or wired, plot the input to your system and the corresponding output.

5.2.4 Plot the frequency response of the overall system with respect to the baseband signal **and** the carrier frequency.

Tip: If you have reception problems, you can hold on to your antenna (the human body can act as an antenna). Do not simultaneously hold both antennas, use one person for each!

6 - WIRELESS RADIO SIGNALS

AM commercial (not military) radio signals range from 200-1200 kHz. It is possible with the AM receiver you have constructed to listen to these radio signals, provided that the resonant frequency of the preamplifier's tank is tuned to an existing radio station. Usually, to tune to radio signals by ear, it is required to have a variable capacitor to dynamically change the resonating frequency of the tank. This can be accomplished and, with the proper gain and reception apparatus, one can listen.

6.1 PREPARATION

6.1.1 Through research, find a few local AM radio stations that you can listen to. Calculate the required capacitance values required for a constant inductor value to tune to these stations. Make sure the inductor is not too big as you might get very small values for C_T (and vice-versa).

6.2 EXPERIMENTATION

6.2.1 Disconnect the circuit from the antenna. Connect the antenna to the oscilloscope and plot the spectrum (FFT function in oscilloscope) of radio frequencies you receive. Catalog the overall amplitudes in dB and the frequency of each channel you observe. Ensure that you catalog all received channels from 200 kHz to 1.2 MHz. This information can help you selecting the easiest channel to pick up.

6.2.2 Replace the input to the preamplifier with your wire antenna. Replace capacitor C_T by a variable capacitor and attempt to tune to AM radio stations. Make sure that the inductor value you are using is appropriate.