Design of an AM Radio Receiver

ECSE 434

Micro Electronics Lab

Final Report

Group # 08

Sharhad Bashar, *260519664*

Chrouk Kassem, *260512917*

Zixuan Yin, *260502051*

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1. INTRODUCTION

Wireless technology has become intertwined with our daily activities. An important component of a wireless system is front-end analog receiver, made of a transmitter and receiver. Signals are transmitted and received through electro magnetic (EM) emissions. The baseband signal has a low frequency range (0 – 20 KHz). To efficiently transmit them, a carrier signal with high frequency is often used. This process is known as signal modulation.

In this lab, we will build an AM radio receiver to receive these signals. The receiver is made of six main components, as shown in the diagram below:

1. Antenna
2. Preamplifier
3. Demodulator
4. Baseband Amplifier
5. Output Stage
6. Speaker

Due to the fact that most information-carrying signals are modulated so it is more efficient to transmit, the resulting waves are typically very low in amplitude. Thus, the wireless AM receiver should be able to do a couple of things:

- Filter out unwanted signals
- Amplify the low amplitude signal
- Demodulate the signal to recover the baseband envelope
- Drive a large current through

The four stages along with the antenna and speaker work together to receive these modulated signal and process it and outputs the information inform of radio signals which we can hear through the speaker.

We will go into further detail outlining the design theory, experimental results and relevant discussion for each of the four stages.

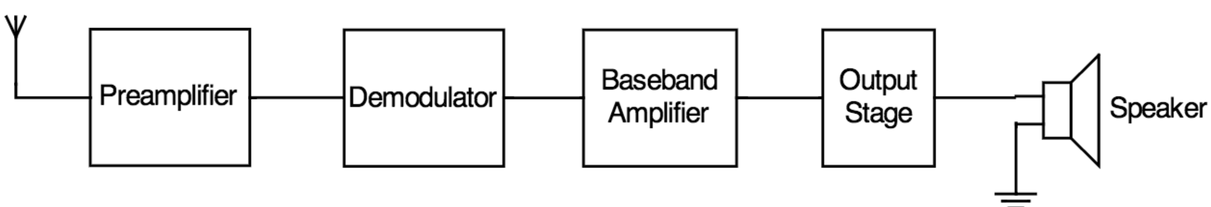


Figure 1.1: System-level diagram of AM receiver [1]

2. BASEBAND AMPLIFIER

i. Theory

The experiment begins by designing the third stage of the circuit, which is the baseband amplifier. The incoming signal has been pre-amplified and demodulated. Since the demodulator has a gain of less than one, then it will have reduced amplitude. This stage is used to achieve an in-band gain of 150V/V of the incoming signal. Op-Amp model TL084 is used. The topology is based on a non-inverting amplifier. This stage also includes a variable resistor that manually varies the gain. The potentiometer is used as volume control in the final circuit of the AM radio receiver.

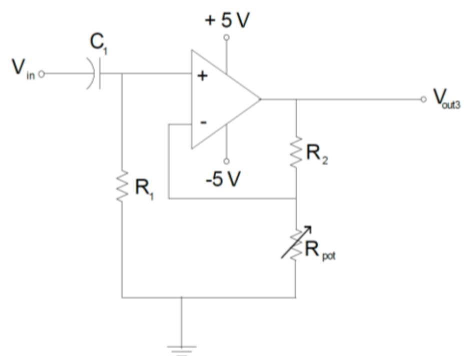


Figure 2.1: Baseband amplifier circuit [1]

Capacitor, C_1, is used to remove the DC component from the incoming demodulated signal. Capacitors act as an open circuit at DC frequencies, thus blocking the DC components of incoming signal. The resistor, R_1, serves as a path for the input bias current to flow to ground. Resistors, R_2 and R_{pot}, are used to control the gain. The gain, A_v, of this circuit not including capacitor C_1 is given by the following equation

$$A_{v1} = \frac{Vout}{Vin} = 1 + \frac{R2}{Rpot} \tag{2.1}$$

Including the capacitor, C_1, changes the gain to

$$A_{v2} = \frac{jwC1}{jwC1 + {}^{1}/_{R1}}\left(1 + \frac{R2}{Rpot}\right) \tag{2.2}$$

This shows that the gain with capacitor reduces by a factor of $\frac{jwC1}{jwC1 + {}^{1}/_{R1}}$.

Assuming an ideal op-amp with an infinite input resistance and zero output resistance, the input resistance of this stage is given by

$$R_{in|baseband} = R_1 \,||\, R_{in|opamp} = R_1 = 150k\Omega \tag{2.3}$$

The output resistance of this stage is given by

$$R_{out|baseband} = (R_2 + R_{pot}) \,||\, R_{out|opamp} = 0\Omega \tag{2.4}$$

ii. EXPERIMENT

a. Frequency Response

Using the TL084 op-amp model, the baseband circuit shown in Figure 2.1 must be built. The following parameters are given:

V_{CC} = +5V R_1 = 150k

V_{EE} = -5V R_{pot} = 0 – 10kΩ

C_1 = 1μF

The circuit is assembled on breadboard with value of R_2 equal to 180kΩ. The signals are observed using the oscilloscope. The overall frequency response of the amplifier is plotted. The frequency was varied from 1Hz to 100 kHz. The input voltage fed into the circuit was 36mV using a voltage divider. The gain is 153.33V/V. The upper 3dB cutoff frequency is 30 kHz and lower 3dB cutoff is 2Hz. Table 9.1 in appendix shows the points taken to plot graphs. The frequency response plots are shown below in Figures 2.2 and 2.3:

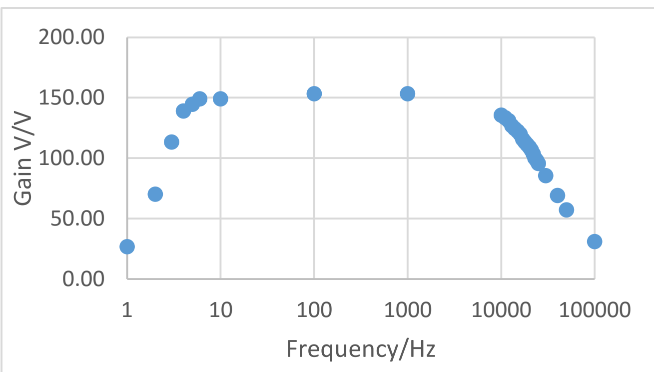


Figure 2.2: Frequency response for gain in V/V

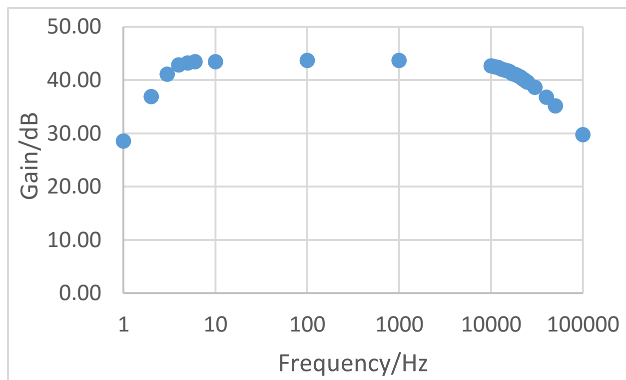


Figure 2.3: Frequency response for gain in dB

b. Variable Resistance versus Gain

The relation between R_{pot} and gain is plotted for the circuit. Table 9.2 in appendix shows points for both plots. The potentiometer is varied from 470Ω to 10 kΩ. The plot of gain in V/V and dB versus R_{pot} can be seen in Figures 2.4 and 2.5 respectively:

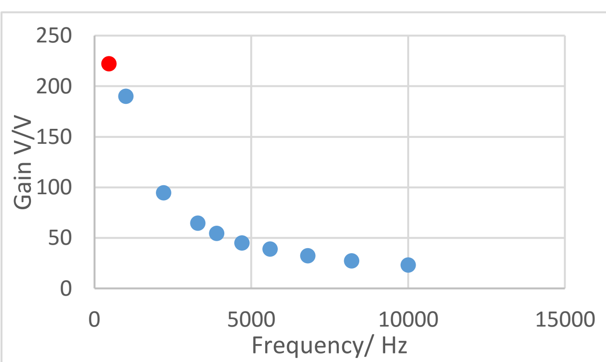


Figure 2.4: Plot of gain in dB versus variable resistance

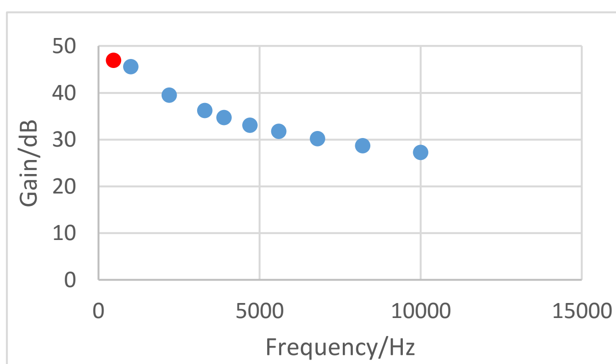


Figure 2.5: Plot of gain in dB versus variable resistance

These plots clearly prove that relation between R_{pot} and gain is inversely proportional.

c. Input Resistance

The input resistance of circuit must be measured. In order to measure the input resistance, another known resistor, R_{known}, is added in series to the amplifier stage. The input voltage of the circuit is known, V_{known}. The voltage, V_+, is measured using a voltmeter/oscilloscope. Using voltage divider rule, the input resistance can be calculated by:

$$V_+ = \frac{Rin}{Rin + Rknown} V_{known} \qquad (2.5)$$

Finding for R_{in}:

$$R_{in} = \frac{Rknown}{Vknown - V+} V_+ \qquad (2.6)$$

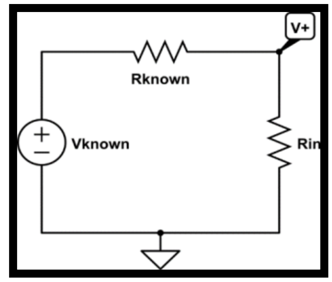


Figure 2.6: Equivalent circuit for measuring input resistance [2]

An input voltage, V_{known}, of 372mV was fed into the circuit. A known resistance, R_{known}, of 100kΩ was connected to the circuit in series. V_+ measured 226mV. Putting these values back into equation 2.4 gives a value of $R_{in|baseband}$ equal to 155kΩ.

iii. Discussion

The value of R_2 was found using the theoretical gain equation, with R_{pot} at 1kΩ for an in-band gain of 150V/V. Selecting R_{pot} to be 1kΩ, using the gain equation 2.1, R_2 theoretical is calculated to be 141.55-156.45kΩ to the nearest 5% accuracy. This range was used in SPICE simulation to find R_2 that gives the desired results. Table 2.1 shows the different values used in SPICE simulation and experimentally:

Table 2.1: Comparison of simulated and experimental results of baseband amplifier

	SPICE Simulation	Experimental
R_2	156 kΩ	180 kΩ
$R_{in\|baseband}$	150 Ω	155Ω
Mid-Band Gain	149.333V/V	153.33V/V
Low 3-dB frequency	1.07532 Hz	2 Hz
High 3-dB frequency	35.96785 kHz	30 kHz
Bandwidth	35.96678 kHz	28 kHz

There is discrepancy between the simulated and experimental values. Difference in bandwidth can be a result of the parasitic capacitance in the op-amp that may not be taken into account in simulation. The probes of the oscilloscope and generator can load the circuit affecting gain of the circuit. The op-amp model in SPICE may not have exact gain in experiment, this can also affect the gain of the circuit. This is a 10% discrepancy, which is acceptable.

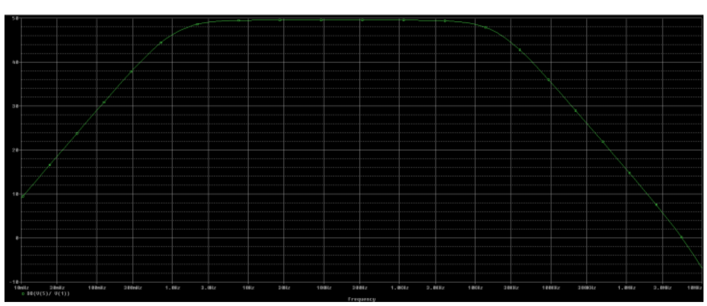


Figure 2.7: SPICE simulation of baseband amplifier

3. DEMODULATOR

i. Theory

Demodulator is the second stage of the AM Receiver. Demodulator reconstructs the original baseband signal by detecting the positive envelope of input signal (received AM signal). The diode-resistor configuration represents a half-wave rectifier that filters the upper half of the circuit. By using a capacitor, the envelope of the circuit can be detected.

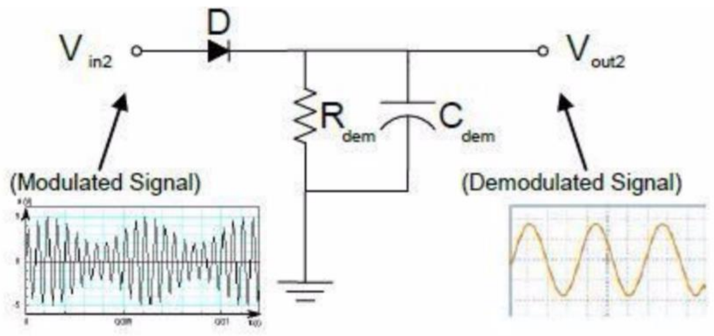


Figure 3.1:High-level system diagram of AM demodulator [1]

The discharge and charge of capacitor, C_{dem}, through the resistor, R_{dem}, detects the envelope of the output signal. However, the discharge rate must be limited. The time constant, $\tau = C_{dem}*R_{dem}$, must be:

- Greater than period of carrier signal to minimize the ripple in output signal. It must also be
- Less than period of baseband signal to ensure that the rate of voltage drop is not too low and it follows envelope of input signal.

This gives the following inequality:

$$\tau_{carrier} < \tau_{RC} < \tau_{baseband} \tag{3.1}$$

In term of frequencies, it can be expressed as:

$$f_{baseband} < f_{RC} < f_{carrier} \tag{3.2}$$

Knowing that the wanted baseband signal is in the 0-20kHz range, and the unwanted carrier signal is in the 200 kHz – 1.2 MHz range. Knowing f_{RC} can be expressed as $\frac{1}{\sqrt{2\Pi RdemCdem}}$.

$$20 \text{ kHz} < \frac{1}{\sqrt{2\Pi RdemCdem}} < 200 \text{ kHz} \tag{3.3}$$

The DC point at the inputs of the demodulator need to be high enough such that the diode is on at all peaks, it should satisfy the following inequality:

$$V_{DC} > -(V_{carrier} - V_{baseband} - 0.3v) \tag{3.4}$$

ii. Experiment

The circuit was simulated in Pspice and the resulting plot was produced, as shown in figure 3.5. The circuit was assembled with an input voltage of 3.6V. The values used experimentally for C_{dem} was 103nF. The value of R_{dem} used was using two resistors in parallel to give a resistance of 1.364 kΩ.

The waveform of the input signal and demodulated output signal can be seen in Figure 3.2. The gain of the demodulator versus the baseband frequency was taken by varying the baseband frequency from 1 kHz to 20 kHz. The table showing points taken can be found in Table 9.3 in appendix. The plot of the gain is shown in Figure 3.3. The gain is 0.367V/V.

The gain of demodulator versus the carrier frequency was also taken by varying the carrier frequency from 200 kHz to 1200 kHz. . The table showing points taken can be found in Table 9.4 in appendix. The plot of the gain is shown in Figure 3.4. The gain is 0.344V/V.

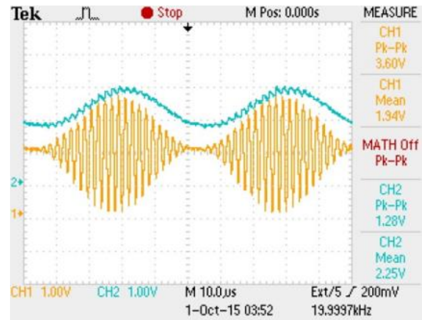


Figure 3.2: Waveform of input signal versus the output signal

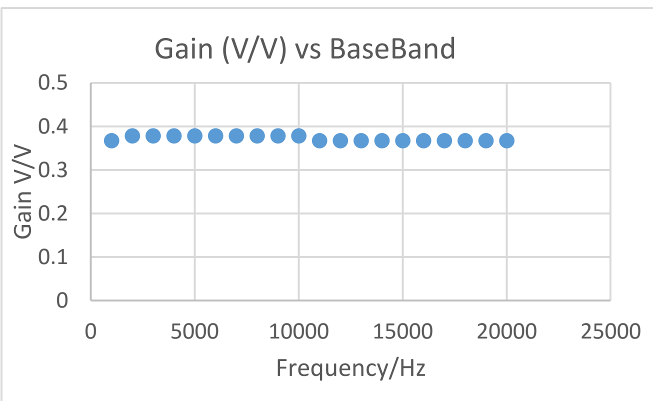


Figure 3.2: Gain versus baseband frequency plot

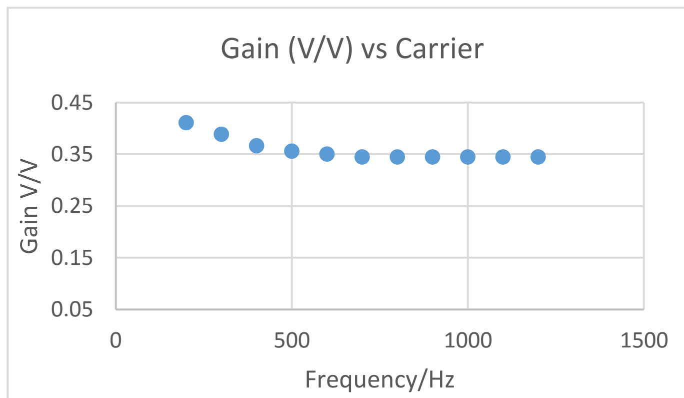


Figure 3.4: Gain versus carrier frequency plot

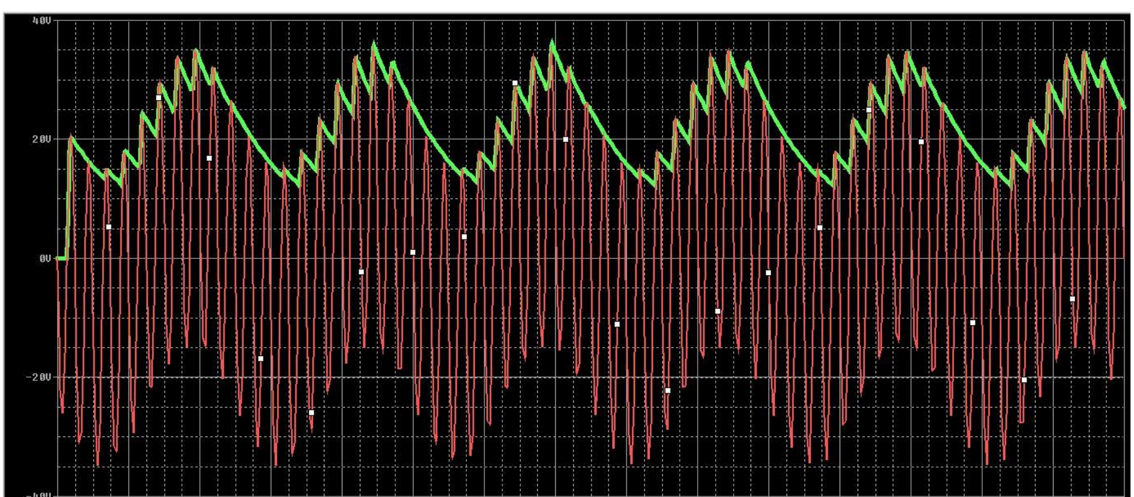


Figure 3.3: Pspice simulation for Demodulator

iii. Discussion

The table below compares simulated and experimental data for the demodulator.

Table 3.1: Comparison of simulated and experimented values of demodulator

	SPICE Simulation	Experimental
R_{dem}	10 kΩ	1.367 kΩ
C_{dem}	0.934 nF	103 nF
Gain(baseband frequency)	0.984 V/V	0.367 V/V
Gain(carrier frequency)	0.896 V/V	0.344 V/V

There are clear differences between the values for R_{dem} and C_{dem} used in SPICE simulations and experimentally. The value of R_{dem} was assumed theoretically, and then C_{dem} was found accordingly. However, experimentally there was no 0.934nF capacitor and least value of capacitance available is 10nF. Thus the value of capacitance was first chosen and R_{dem} was found accordingly.

The gain for both responses must be less than one. The diode is ideally considered as a short circuit in small signal analysis. However, in real life the diode has a small resistance. This acts as voltage divider with R_{dem}. Changing the voltage charged and discharged by C_{dem}. This can be the result of the differences seen in gain between simulations and experimentally. It must also be noted that the R_{dem} value experimentally is much smaller than one used in SPICE simulation, thus it will be more affected by voltage divider of small resistance of diode. This can be reason is smaller gain experimentally.

The experimental data for the varied baseband signal frequency and the carrier signal frequency supports the fact that the gain response is approximately constant, having wide bandwidth. It is highly desirable to have a wide bandwidth when hearing a certain channel, to pass all the frequencies at the same gain. The varying baseband signal ensures that the output is stable at the range of human hearing (0 - 20 kHz). The varying carrier signal ensures that the output is stable for all the channels in the range of 200 - 1200 kHz.

4. CLASS A OUTPUT STAGE

i. Theory

Power amplifier is the final stage of the AM receiver. This stage serves to amplify the low current from baseband amplifier, in order to power the speaker and make sound. It is an emitter follower biased at a high current. T5 and T6 can be seen as a current source.

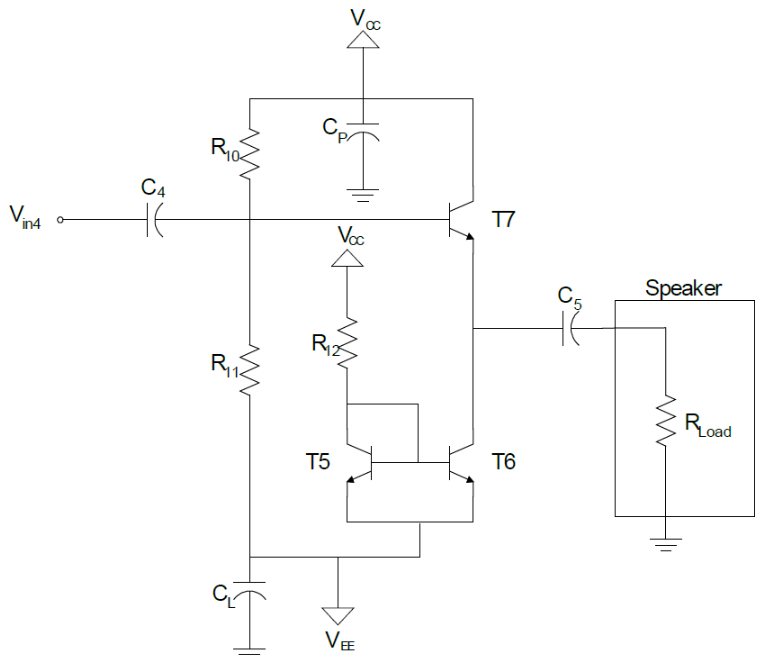


Figure 4.1: Circuit schematic of Class A output [1]

Maximum output current at the load is determined by ${}^{Vcc}/_{R12}$. The circuit should be biased such that DC point at the load is 0V, so maximum voltage swing can be achieved. The boundaries of the voltage swing are shown below. Input resistance of this stage should be high as possible in order to decrease the loading effect from previous stage. It has a voltage gain of unity theoretically, within the output swing.

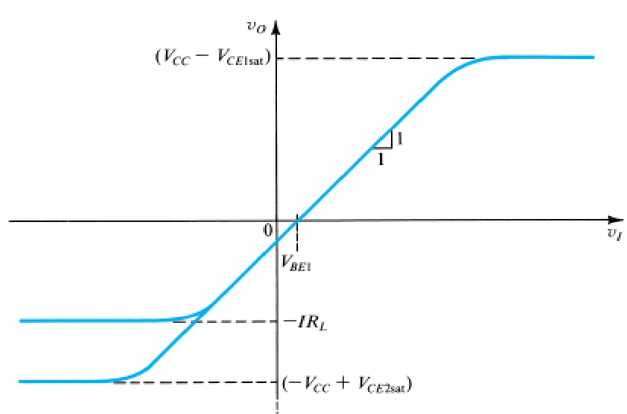
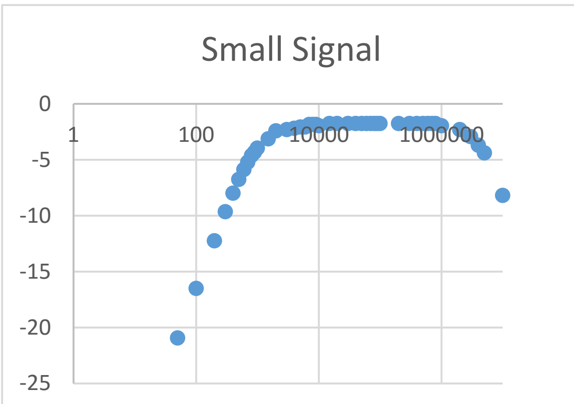


Figure 4.2: Graph showing cutoff voltages of a transistor [2]

ii. Experiment

Once the power amplifier starts working, transistors will start to heat up, which will further increase the current until the transistors burn. To avoid this, we put R_E of same value at the emitters of T5 and T6, decreasing the V_{be} across transistors. Another thing we did is that we put two transistors in parallel with space between as use the pair as one transistor. They will share the current flow and thus, avoid transistors getting burnt.

Here are the resistor values in our final circuit: R_{10}=15kΩ, R_{11}=100kΩ, R_{12}=82Ω, R_E= 10Ω, R_L=10Ω. The frequency analysis of small signal model (200mV peak to peak) and large signal model (1V peak to peak) was measured. Plots are shown below in Figure 4.3. Tables 9.5 and 9.6 in appendix show points taken. There is consistency in the results.



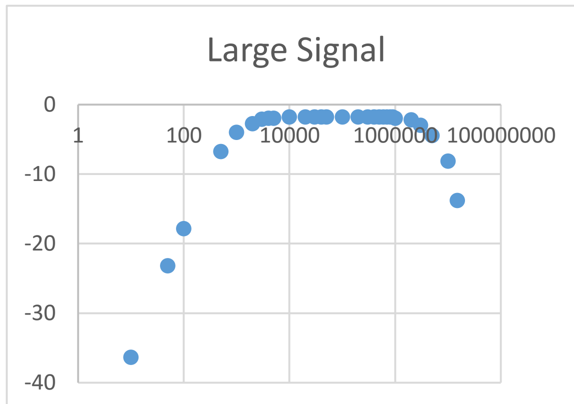


Figure 4.3: Small versus Large signal gain (dB)

Table 4.1: Small versus Large signal cutoff and gain

	3-db cutoff frequency	In-band gain
Small Signal	750Hz-5MHz	0.82
Large Signal	800Hz-5MHz	0.8

Maximum voltage output is at 2.2V pk-pk, measured is 10 KHz, beyond that, the output starts to get clipped.

iii. Discussion

Table 4.2: Spice versus Experimental values for class A output stage

	SPICE Simulation	Experiment
R10	4.3KΩ	15KΩ
R11	5.7KΩ	100KΩ
R12	48Ω	82Ω
RE	47Ω	10Ω

When doing spice stimulation, we didn't take loading effect from previous stage into consideration, the final values been used gives us a DC biasing the closest to 0.7 V. The difference mainly comes from loading effect.

Overall, we were able to build an output stage with a voltage gain of about 0.8 and swing of 2.2V for a 10 Ω load resistor. That's good enough to power the speaker and make audio sound. One drawback of the circuit is the low power efficiency. Class A output stage can only achieve a maximum 25% power efficiency. Also the transistors still heat up after minutes of operation.

5. PREAMPLIFIER

i. Theory

The preamplifier is the first stage of the receiver. The input, connected to the antenna is sending in modulated signals. These signals are very weak and require amplification. The circuit below shows the baseband amplifier used for the receiver. The circuit consists of an LC tank, a Darlington pair and a cascaded common emitter amplifier. The inductor and capacitor are placed in a parallel configuration, acting as a band pass filter to filter out signals from unwanted frequencies. The cascaded amplifier amplifies the signal, while improving the speed of the circuit. It also works with the Darlington pair to ensure high impedance seen from the tank.

The impedance of the tank is maximal at resonant frequency, which was provided. The values for L and C were arbitrarily selected to satisfy the following equation:

$$f_{res} = \frac{1}{2\pi\sqrt{L_T C_T}} \qquad (5.1)$$

We choose C_T to be 100nF, and calculated L_T to be 1.099 µH, for the given frequency of 480 KHz.

There are several resisters used in the design of the circuit. R_4 and R_5 are used to bias the input, and R_6 and R_7 are used to bias T_2. R_E is emitter degeneration resistor. Its main purposes are to increase the output resistance of the amplifier, control the gain and to stabilize the amplifier.

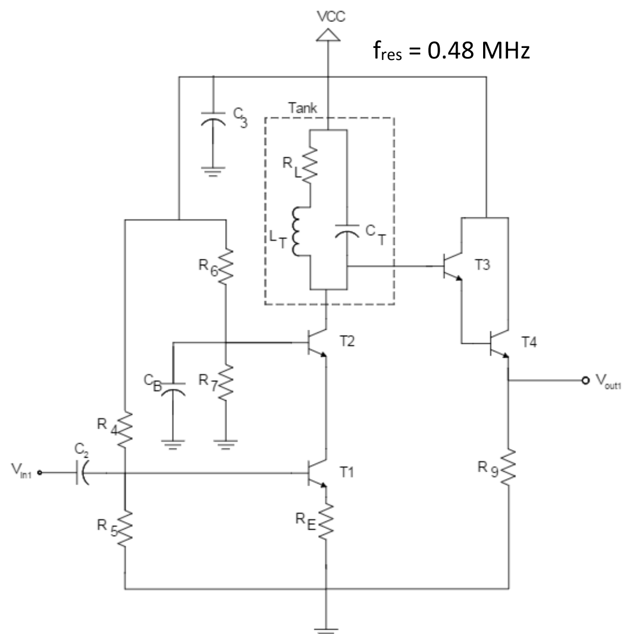


Figure 5.1: Preamplifier circuit [1]

The capacitors in the circuit are used as decoupling capacitors for isolating and cancelling out the noise.

The size of the bandwidth produced by the preamplifier is inversely proportional to its efficiency and quality factor. Wide bandwidth decreases the frequency selectivity of the amplifier and gain of the amplifier. Therefore we could pick up signals in other bands. Narrow bandwidth makes the amplifier more selective with greater quality factor (Q), thus larger output resistance of tank. This in hindsight may cut off desired signal.

The gain of the circuit was set to be 50 V/V. The small signal gain can be calculated as the collector impedance divided by the emitter resistance of T_1. The equation was derived as follows:

$$A_v = \frac{R_T || (\beta^2 (r_e + R_e))}{r_e + R_e} \qquad (5.2)$$

A buffer might also be used in this circuit. Buffer increases the base resistance of the output transistor. Higher base resistance minimizes the energy loss of the LC circuit, therefore giving the circuit a high Q-factor and low bandwidth.

ii. Experiment

Resistor values were calculated to ensure maximum voltage swing. The voltages at each node were selected to ensure all transistors were operational. The resistor values calculated are as follows:

Table 5.1: Values used in Pspice versus experiment

Spice	Experiment
$R_E = 10\Omega$	$R_E = 90\Omega$
$R_4 = 2.8K\Omega$	$R_4 = 8.5K\Omega$
$R_5 = 2.2K\Omega$	$R_5 = 0.5K\Omega$
$R_6 = 2.5K\Omega$	$R_6 = 22K\Omega$
$R_7 = 2.5K\Omega$	$R_7 = 22K\Omega$
$L_T = 1.099$ uH	$L_T = 820$ uH
$C_T = 100$ nF	$C_T = 0.01$ uF

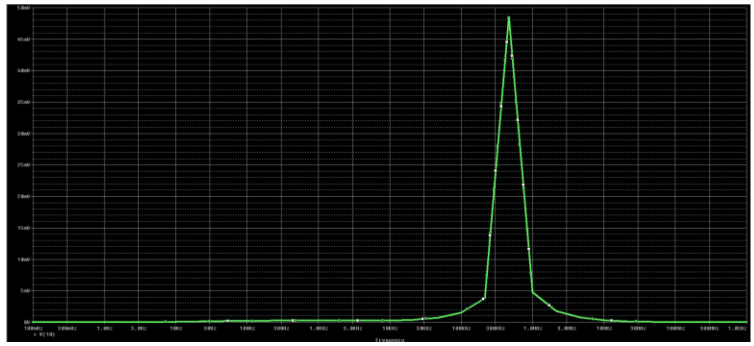


Figure 5.2: Spice simulation of Preamplifier

These values were used in a spice simulation of the circuit and a gain of approximately 50 V/V was achieved.

The circuit was assembled and simulated with a modulated signal as the input. A modulated signal was produced to match the given frequency, with a peak-to-peak value of 2 mV. The output voltages were measured, and used to calculate the gain. The graph below shows the result. Table 9.7 in the Appendix lists the measured V_{out} values.

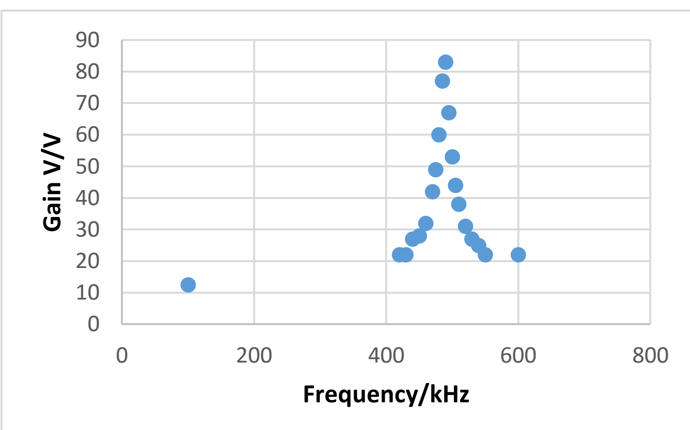


Figure 5.3: Frequency response of preamplifier

From the graph we can see that the preamplifier has a gain of 88 V/V.
The peak occurs close to the resonant frequency, at a value of 483 kHz.
The circuit produced a low 3dB cutoff of 470 kHz and a high 3dB cutoff of 510 kHz
This gave a bandwidth of 40kHz.

iii. Discussion

Comparing the simulation and experimental data, we can see similarities in the shape of the gain. The theoretical design of the preamplifier is to achieve high gain with a relatively narrow bandwidth. As seen from the plot, both the desired features were attained. The frequencies did not match exactly, due to the fact that the capacitors and inductors are not ideal elements, and can affect the gain, bandwidth and quality factor of the circuit.

6. AM RECEIVER

i. Theory

In this section of the lab all the four stages are connected together with an antenna and speaker. The diagram below shows the circuit model of the AM receiver.

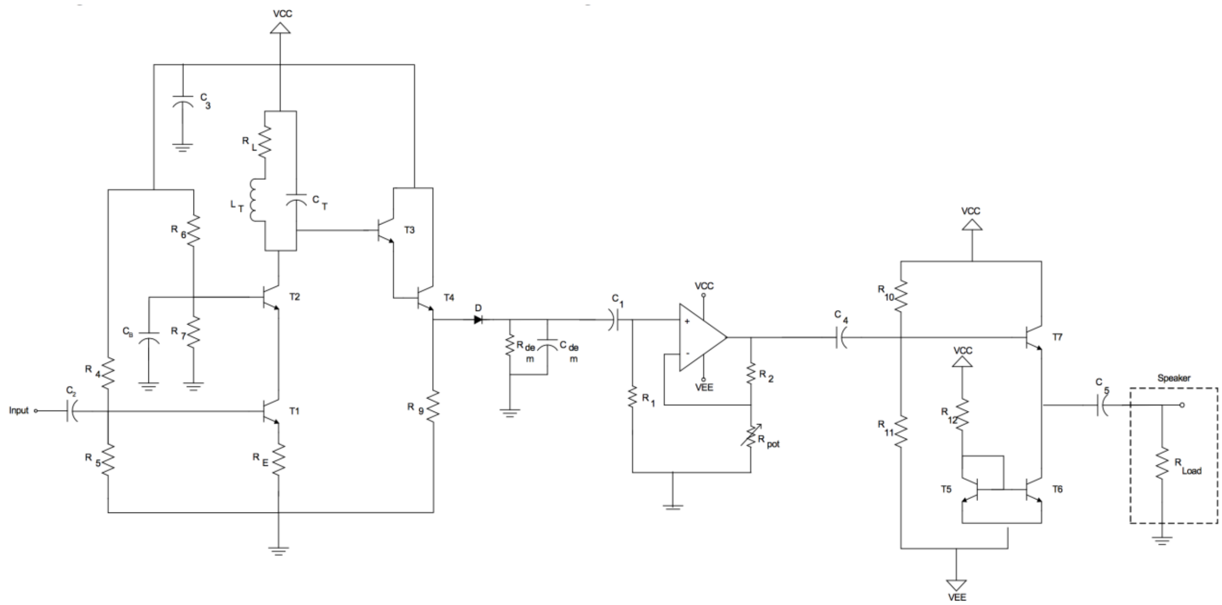


Figure 6.1: AM Receiver schematic [1]

When connecting all circuits, the loading effect of each individual circuit must be considered. The loading effect is the input impedance of the subsequent stage, which acts as a load for the current stage. Theoretically, it would be ideal to have high input impedance and low output impedance for each of the different systems.

Loading effect at first stage:

If the input resistance of the next stage, $R_{in|stage2}$, isn't large enough then the output resistance, $R_{out|stage1}$, will have an added resistance. The output voltage will decrease which in turn decreases the gain of the stage:

$$v_{out} = i_{out} \times (R_{in|stage2} \; || \; R_{out|stage1}) \tag{6.1}$$

However, if the input resistance of the next stage is much larger than output resistance, then its effect on the gain should be minimal.

Loading effect at the second stage:

The input resistance of the baseband amplifier is: $R_{in|baseband} = R1 = 150k\Omega$

This changes output resistance of second stage to:

$$R_{out|stage2} = R_{out|demod} \; || \; R_{in|baseband} \tag{6.2}$$

The gain at the second stage is 1V/V. The added resistance at the output resistance will decrease the gain minimally.

The added impedance at the output will affect the time constant, τ. Initially, time constant was:

$$\tau = R_{dem} \times C_{dem} \text{ to } \tau = C_{dem} \times (R_{dem} \,||\, R_{in|baseband}) \qquad (6.3)$$

This decreases the time constant of the demodulator, thus resistance at the demodulator, R_{dem}, must be increased to compensate for this decrease. R_{dem} was changed from 1.367 kΩ to 5 k Ω.

Loading effect at the third stage:

The input resistance of Class A output stage is very high, and output resistance of the baseband amplifier is 0Ω. Thus, there will be no significant loading effect.

Loading effect at the fourth stage:

The load of this stage is an 8Ω speaker. This was taken into account when designing the output stage.

ii. Experiment

The circuit was assembled in Pspice and simulated. The following diagram shows the input and output.

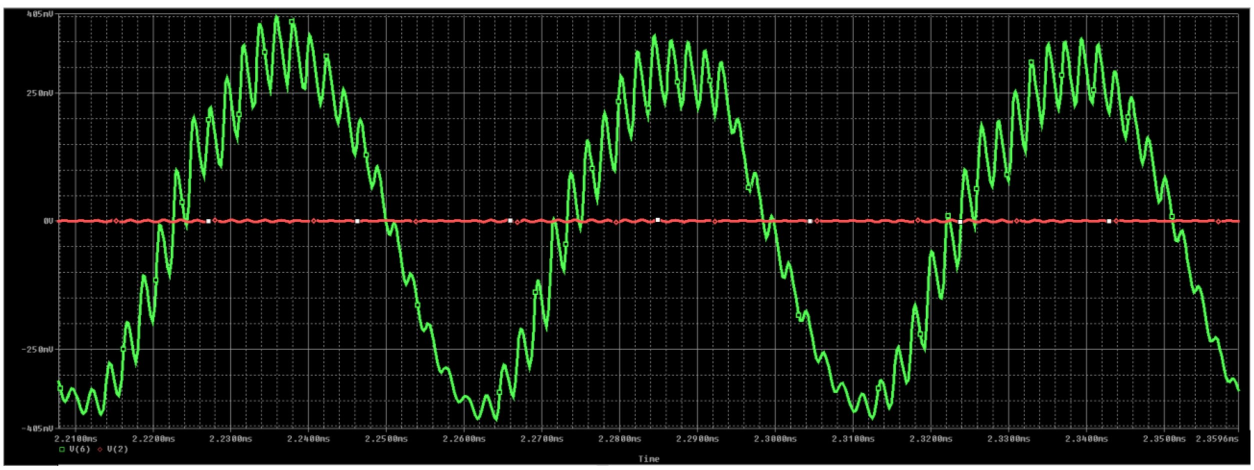


Figure 6.2: Psipce simulation of AM Receiver

The red line is the input, a modulated signal, with amplitude of 500uV.

The green curve is the output, with amplitude of 500mV

The simulated gain of the circuit is therefore 500mV/500µV = 1000 V/V

The circuit was assembled, and tested. Different baseband frequencies provided the different notes as per the table chart below:

Table 6.1: Musical tone 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

The gain for the receiver was measured for 2 frequency values: Baseband and Carrier. Tables 9.8 and 9.9 in appendix show the measured values. The yellow cells highlight the bandwidth of the circuit. The output for the baseband was calculated by setting the carrier frequency 1MHz and varying the baseband frequency from 0 – 20 kHz, the frequency range for hearing. The gain for the carrier frequency was measured in a similar fashion, by setting the baseband frequency to 1 kHz. The figure 6.3 below shows the output of the Receiver once it has stabilized for a baseband frequency of 5kHz. Figure 6.4 shows the output at resonant frequency of 480kHz. The two charts below compare the gain of the receiver for baseband and carrier frequencies.

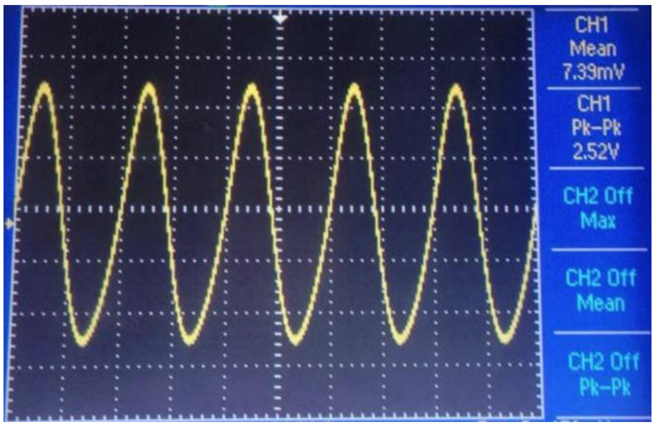


Figure 6.3: Output for baseband frequency: 5kHz

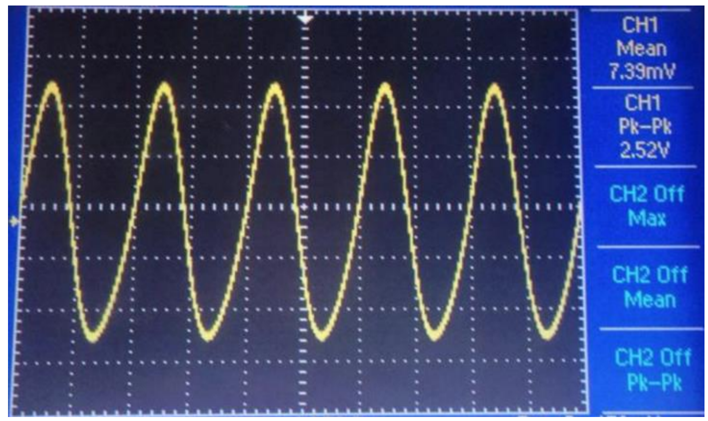


Figure 6.3: Output at resonant frequency: 480 kHz

The outputs were all measured, and used to calculate the gain for both the frequencies. The graphs below show the gain achieved:

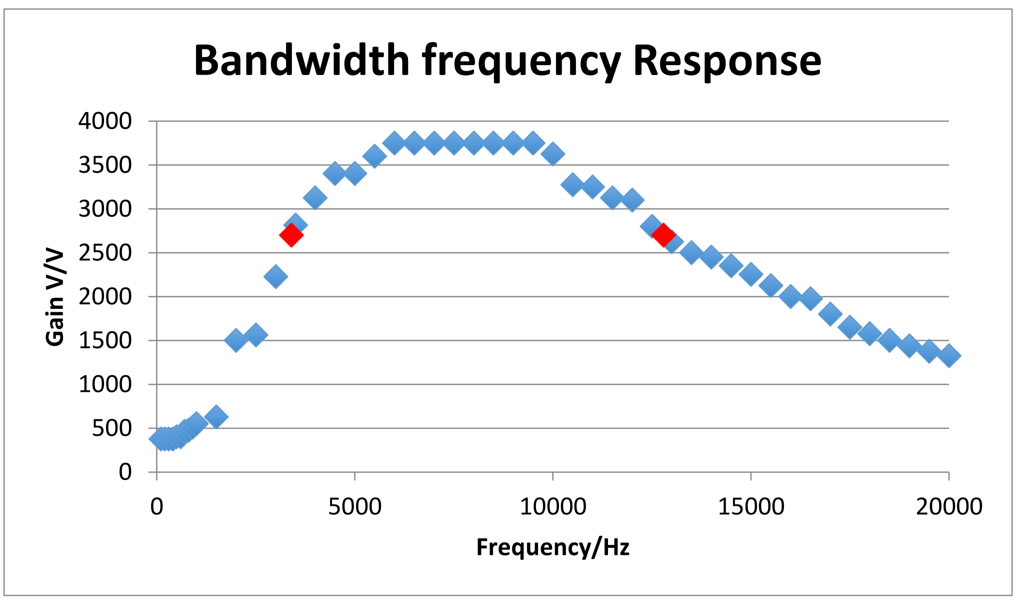


Figure 6.4: Gain(V/V) for the receiver for a selection for baseband frequencies

The red markers on the graph are the high and low 3dB cutoff points. The gain for the circuit using baseband frequencies was calculated to be 3750 V/V. The bandwidth is 9.4 kHz

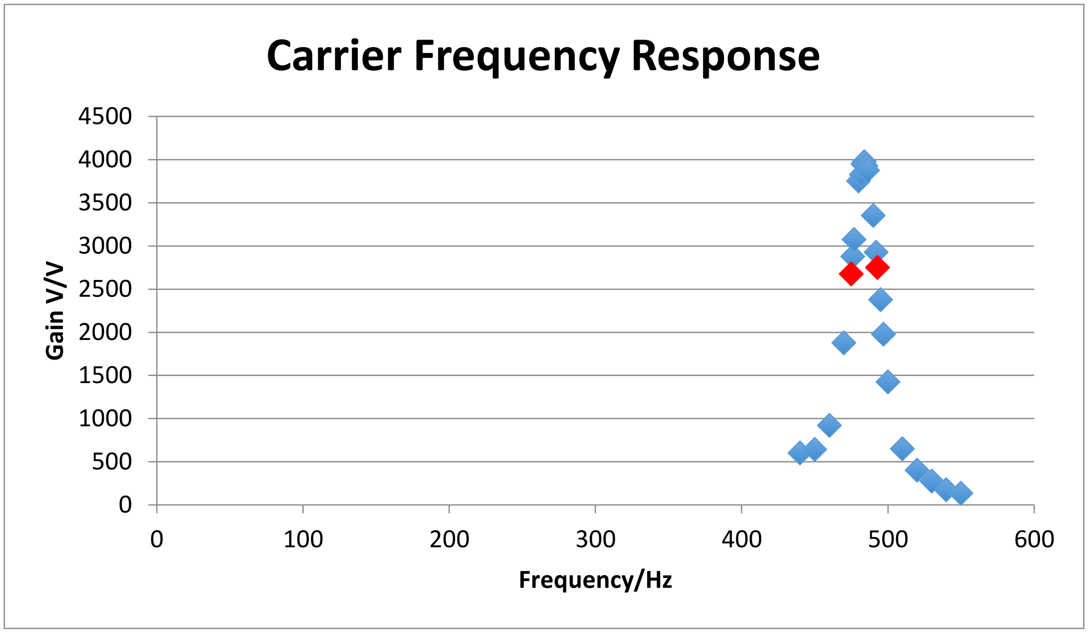


Figure 6.5: Gain(V/V) for the receiver for a selection of carrier frequencies

The gain for the circuit was measured to be 3750 V/V at resonant frequency. The bandwidth was 40 kHz.

iii. Discussion

Because of loading effect of each stage, the components of the demodulator and preamplifier had to be modified. Other than that, the receiver functioned as expected. An antenna was connected to the input and a variable capacitor was used to listen to different radio stations. Since our assigned frequency was not a local AM radio channel, we had to change the tank elements to match the radio frequency of a local French radio station. Figure 6.6 shows the oscilloscope reading of the channel at 690 kHz. The Table 6.2 shows local stations, and the respective capacitor values needed to tune into those stations for a constant inductor value of 100 uH.

Table 6.2: Local stations and respective capacitance

Station	Frequency (KHz)	Language	Capacitor
WVMT	620	English	6.58957E-09
CINF	690	French	5.32037E-09
CKAC	730	French	4.75329E-09
CJAD	800	English	3.95786E-09
CINW	940	English	2.86672E-09
CKGM	990	English	2.58446E-09
CFMB	1280	Polyglot	1.54604E-09
WIRY	1340	English	1.41069E-09
CHOU	1450	Polyglot	1.20477E-09
CFAV	1570	French	1.02764E-09

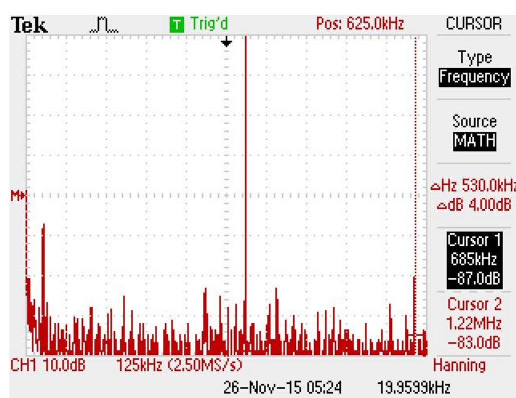


Figure 6.6: Frequency of channel at 690 kHz

7. CONCLUSION

This experiment has taken us through the different modules of an AM receiver, component by component. The figure below is the final product. The functioning of each individual stage in the proper functioning of the radio was explored. Though each stage could be successfully assembled and tested with relative ease, it was a challenge to combine them together and still generate expected signal. This is mainly due to the loading effect of each successive stage. This experiment also showed the importance frequency response of each stage affecting the overall frequency response of the system. In conclusion, this lab was a success, effectively allowing the students to apply the theory learned in previous courses.

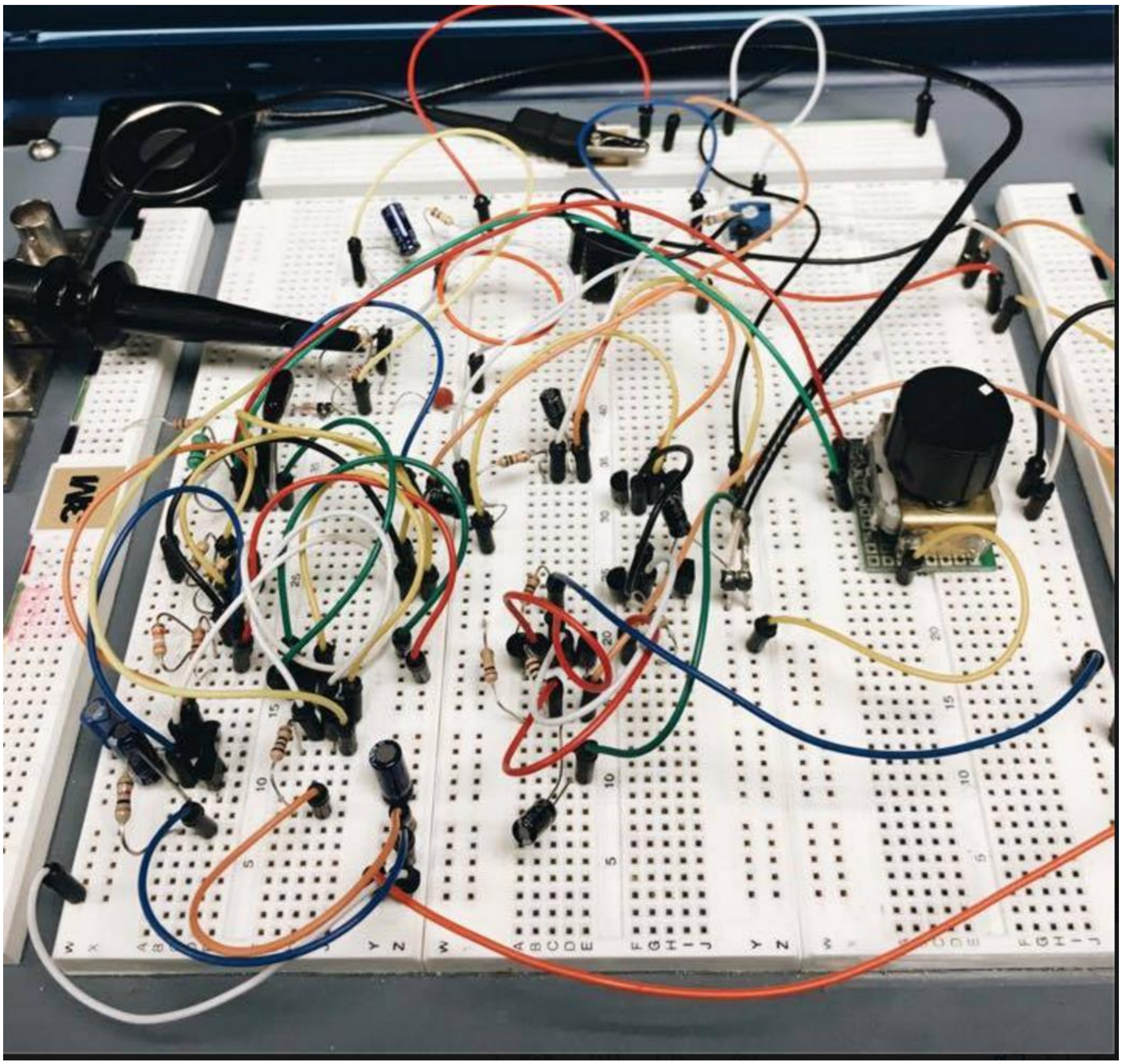


Figure 7.1: The AM Receiver of group 8

8. References

1. McGill University, Lab Handout, *Experiment 1: The design of an AM receiver.* (2015)
2. Sedra/Smith, *Microelectronic Circuits.* (2013)(6th ed.)

9. Appendix

Table 9.1: Values for frequency response of baseband amplifier

Frequency (Hz)	Vin (V)	Vout (V)	Gain (V/V)	Gain (dB)
1	0.036	0.96	26.67	28.52
2	0.036	2.52	70.00	36.90
3	0.036	4.08	113.33	41.09
4	0.036	5	138.89	42.85
5	0.036	5.2	144.44	43.19
6	0.036	5.36	148.89	43.46
10	0.036	5.36	148.89	43.46
100	0.036	5.52	153.33	43.71
1000	0.036	5.52	153.33	43.71
10000	0.036	4.88	135.56	42.64
11000	0.036	4.8	133.33	42.50
12000	0.036	4.72	131.11	42.35
13000	0.036	4.56	126.67	42.05
14000	0.036	4.48	124.44	41.90
15000	0.036	4.4	122.22	41.74
16000	0.036	4.32	120.00	41.58
17000	0.036	4.16	115.56	41.26
18000	0.036	4.08	113.33	41.09
19000	0.036	4	111.11	40.92
20000	0.036	3.92	108.89	40.74
21000	0.036	3.84	106.67	40.56
22000	0.036	3.72	103.33	40.28
23000	0.036	3.6	100.00	40.00
24000	0.036	3.52	97.78	39.80
25000	0.036	3.44	95.56	39.61
30000	0.036	3.08	85.56	38.64
40000	0.036	2.48	68.89	36.76
50000	0.036	2.06	57.22	35.15
100000	0.036	1.11	30.83	29.78

Table 9.2: Variable Resistance versus gain for baseband amplifier

Rpot(Ω)	Vin (V)	Vout (V)	Gain (V/V)	Gain (dB)
470	0.036	8	222.2222	46.93575
1000	0.036	6.84	190	45.57507
2200	0.036	3.4	94.44444	39.50353
3300	0.036	2.32	64.44444	36.18371

3900	0.036	1.96	54.44444	34.71907
4700	0.036	1.62	45	33.06425
5600	0.036	1.4	38.88889	31.79651
6800	0.036	1.16	32.22222	30.16311
8200	0.036	0.98	27.22222	28.69847
10000	0.036	0.832	23.11111	27.27642

Table 9.3: Baseband frequency versus gain for demodulator

Baseband (HZ)	Vin (V)	Vout (V)	Gain (V/V)	Gain(dB)
20000	3.6	1.32	0.366667	-8.71457
19000	3.6	1.32	0.366667	-8.71457
18000	3.6	1.32	0.366667	-8.71457
17000	3.6	1.32	0.366667	-8.71457
16000	3.6	1.32	0.366667	-8.71457
15000	3.6	1.32	0.366667	-8.71457
14000	3.6	1.32	0.366667	-8.71457
13000	3.6	1.32	0.366667	-8.71457
12000	3.6	1.32	0.366667	-8.71457
11000	3.6	1.32	0.366667	-8.71457
10000	3.6	1.36	0.377778	-8.45527
9000	3.6	1.36	0.377778	-8.45527
8000	3.6	1.36	0.377778	-8.45527
7000	3.6	1.36	0.377778	-8.45527
6000	3.6	1.36	0.377778	-8.45527
5000	3.6	1.36	0.377778	-8.45527
4000	3.6	1.36	0.377778	-8.45527
3000	3.6	1.36	0.377778	-8.45527
2000	3.6	1.36	0.377778	-8.45527
1000	3.6	1.32	0.366667	-8.71457

Table 9.4: Carrier frequency response versus gain of demodulator

Carrier (kHz)	Vin (V)	Vout (V)	Gain (V/V)	Gain (dB)
200	3.6	1.48	0.411111	-7.72082
300	3.6	1.4	0.388889	-8.20349
400	3.6	1.32	0.366667	-8.71457
500	3.6	1.28	0.355556	-8.98185
600	3.6	1.26	0.35	-9.11864
700	3.6	1.24	0.344444	-9.25762
800	3.6	1.24	0.344444	-9.25762
900	3.6	1.24	0.344444	-9.25762
1000	3.6	1.24	0.344444	-9.25762

1100	3.6	1.24	0.344444	-9.25762
1200	3.6	1.24	0.344444	-9.25762

Table 9.5: Small signal frequency response for output stage A

Vin(mV)	*Vout (mV)*	*Frequency/Hz*	*Vout/Vin*	*Gain(dB)*
200	18	50	0.09	-20.91514981
200	30	100	0.15	-16.47817482
200	49	200	0.245	-12.21667831
200	66	300	0.33	-9.629721202
200	80	400	0.4	-7.958800173
200	92	500	0.46	-6.744843366
200	102	600	0.51	-5.848596478
200	110	700	0.55	-5.19274621
200	118	800	0.59	-4.582959767
200	122	900	0.61	-4.2934033
200	127	1000	0.635	-3.944525494
200	140	1500	0.7	-3.0980392
200	152	2000	0.76	-2.383728154
200	154	3000	0.77	-2.270185497
200	156	4000	0.78	-2.158107946
200	158	5000	0.79	-2.047458174
200	158	6000	0.79	-2.047458174
200	162	7000	0.81	-1.830299622
200	162	8000	0.81	-1.830299622
200	162	9000	0.81	-1.830299622
200	160	10000	0.8	-1.93820026
200	164	15000	0.82	-1.723722952
200	164	20000	0.82	-1.723722952
200	164	30000	0.82	-1.723722952
200	164	40000	0.82	-1.723722952
200	164	50000	0.82	-1.723722952
200	164	60000	0.82	-1.723722952
200	164	70000	0.82	-1.723722952
200	164	80000	0.82	-1.723722952
200	164	90000	0.82	-1.723722952
200	164	100000	0.82	-1.723722952
200	164	200000	0.82	-1.723722952
200	164	300000	0.82	-1.723722952
200	164	400000	0.82	-1.723722952
200	164	500000	0.82	-1.723722952
200	164	600000	0.82	-1.723722952
200	164	700000	0.82	-1.723722952

200	164	800000	0.82	-1.723722952
200	160	1000000	0.8	-1.93820026
200	154	2000000	0.77	-2.270185497
200	143	3000000	0.715	-2.913879164
200	131	4000000	0.655	-3.675174
200	121	5000000	0.605	-4.364892507
200	78	10000000	0.39	-8.178707859

Table 9.6: Large signal frequency response for output stage A

Vin(pk-pk)/mV	*Vout /mV*	*Frequency/Hz*	*Vout/Vin*	*Gain(dB)*
0.984	0.015	10	0.015244	-36.33807679
0.984	0.068	50	0.069106	-23.20972371
0.984	0.126	100	0.128049	-17.85249107
0.984	0.452	500	0.45935	-6.757133272
0.984	0.62	1000	0.630081	-4.012068179
0.984	0.716	2000	0.727642	-2.761641522
0.984	0.768	3000	0.780488	-2.152677568
0.984	0.784	4000	0.796748	-1.973580715
0.984	0.784	5000	0.796748	-1.973580715
0.984	0.8	10000	0.813008	-1.798102229
0.984	0.8	20000	0.813008	-1.798102229
0.984	0.8	30000	0.813008	-1.798102229
0.984	0.8	40000	0.813008	-1.798102229
0.984	0.8	50000	0.813008	-1.798102229
0.984	0.8	100000	0.813008	-1.798102229
0.984	0.8	200000	0.813008	-1.798102229
0.984	0.8	300000	0.813008	-1.798102229
0.984	0.8	400000	0.813008	-1.798102229
0.984	0.8	500000	0.813008	-1.798102229
0.984	0.8	600000	0.813008	-1.798102229
0.984	0.8	700000	0.813008	-1.798102229
0.984	0.8	800000	0.813008	-1.798102229
0.984	0.8	900000	0.813008	-1.798102229
0.984	0.782	1000000	0.794715	-1.995766907
0.984	0.76	2000000	0.772358	-2.243630123
0.984	0.696	3000000	0.707317	-3.007717176
0.984	0.588	5000000	0.597561	-4.472355447
0.984	0.384	10000000	0.390244	-8.173277481
0.984	0.2	15000000	0.203252	-13.83930206

Table 9.7: Frequency response of preamplifier

Frequency (KHz)	Vin (mV)	Vout (mV)	Gain (V/V)	Gain (dB)
100	2	25	12.5	21.93820026
420	2	44	22	26.84845362
430	2	44	22	26.84845362
440	2	54	27	28.62727528
450	2	56	28	28.94316063
460	2	64	32	30.10299957
470	2	84	42	32.46498581
475	2	98	49	33.8039216
480	2	120	60	35.56302501
485	2	154	77	37.7298145
490	2	166	83	38.38156185
495	2	134	67	36.52149605
500	2	106	53	34.48551739
505	2	88	44	32.86905353
510	2	76	38	31.59567193
520	2	62	31	29.82723388
530	2	54	27	28.62727528
540	2	50	25	27.95880017
550	2	44	22	26.84845362
600	2	44	22	26.84845362

Table 9.8: Baseband frequency response of entire circuit

Frequency (Hz)	Vin (mV)	Vout (mV)	Gain (V/V)	Gain (dB)
100	0.8	300	375	51.48062535
200	0.8	300	375	51.48062535
300	0.8	300	375	51.48062535
400	0.8	300	375	51.48062535
500	0.8	320	400	52.04119983
600	0.8	320	400	52.04119983
700	0.8	370	462.5	53.30223474
800	**0.8**	**380**	**475**	**53.53387219**
900	0.8	408	510	54.15140352
1000	0.8	440	550	54.80725379
1500	0.8	500	625	55.91760035
2000	0.8	1200	1500	63.52182518
2500	0.8	1250	1562.5	63.87640052
3000	0.8	1780	2225	66.94660031
3400	0.8	2160	2700	68.62727528
3500	0.8	2250	2812.5	68.98185062
4000	**0.8**	**2500**	**3125**	**69.89700043**

4500	0.8	2720	3400	70.62957834
5000	0.8	2720	3400	70.62957834
5500	0.8	2880	3600	71.12605002
6000	0.8	3000	3750	71.48062535
6500	0.8	3000	3750	71.48062535
7000	0.8	3000	3750	71.48062535
7500	0.8	3000	3750	71.48062535
8000	**0.8**	**3000**	**3750**	**71.48062535**
8500	0.8	3000	3750	71.48062535
9000	0.8	3000	3750	71.48062535
9500	0.8	3000	3750	71.48062535
10000	**0.8**	**2900**	**3625**	**71.18616022**
10500	0.8	2620	3275	70.30422609
11000	0.8	2600	3250	70.23766722
11500	0.8	2500	3125	69.89700043
12000	0.8	2480	3100	69.82723388
12500	0.8	2240	2800	68.94316063
12800	0.8	2160	2700	68.62727528
13000	0.8	2100	2625	68.38258615
13500	0.8	2000	2500	67.95880017
14000	0.8	1960	2450	67.78332169
14500	0.8	1880	2350	67.42135725
15000	0.8	1800	2250	67.04365036
15500	0.8	1700	2125	66.54717869
16000	0.8	1600	2000	66.02059991
16500	**0.8**	**1580**	**1975**	**65.911342**
17000	0.8	1440	1800	65.1054501
17500	0.8	1320	1650	64.34967888
18000	0.8	1260	1575	63.94561116
18500	0.8	1200	1500	63.52182518
19000	0.8	1150	1437.5	63.15215707
19500	0.8	1100	1375	62.76605396
20000	**0.8**	**1060**	**1325**	**62.44431757**

Table 9.9: Carrier frequency response of entire circuit

Frequency (kHz)	Vin (mV)	Vout (mV)	Gain (V/V)	Gain (dB)
440	**0.8**	**480**	**600**	**55.56302501**
450	0.8	512	640	56.12359948
460	0.8	736	920	59.27575655
470	0.8	1500	1875	65.46002544
475	0.8	2140	2675	68.54647573

476	0.8	2300	2875	69.17275698
477	0.8	2460	3075	69.7569024
480	**0.8**	**3000**	**3750**	**71.48062535**
482	0.8	3060	3825	71.65262879
483	0.8	3160	3950	71.93194191
484	**0.8**	**3180**	**3975**	**71.98674266**
485	0.8	3140	3925	71.87679322
486	0.8	3100	3875	71.76543414
490	0.8	2680	3350	70.50089614
492	0.8	2340	2925	69.32251741
493	0.8	2200	2750	68.78665388
495	0.8	1900	2375	67.51327228
497	0.8	1580	1975	65.911342
500	**0.8**	**1140**	**1425**	**63.07629729**
510	0.8	520	650	56.25826713
520	0.8	320	400	52.04119983
530	0.8	220	275	48.78665388
540	0.8	140	175	44.86076097
550	**0.8**	**106**	**132.5**	**42.44431757**