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ELE 402 – Electronics Lab

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Final Project Report

AM Receiver

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Introduction

Amplitude Modulation (AM) is one of the earliest and most widely used analog communication techniques. It operates by varying the amplitude of a high-frequency carrier wave in response to the amplitude of a lower-frequency baseband signal, typically in the audio range. The modulated waveform carries the information in its upper and lower sidebands while maintaining the carrier frequency unchanged. AM remains popular in radio broadcasting and basic analog systems due to its simplicity and the ease of implementation with low-cost receivers [2].

One of the primary reasons AM is preferred for long-distance communication is its compatibility with high-frequency transmission. Transmitting baseband signals directly would require extremely large antennas, which is impractical. By modulating the signal onto a higher-frequency carrier, the antenna size becomes manageable, and the modulated wave can propagate over long distances, especially through ionospheric reflection. This characteristic makes AM particularly suitable for covering wide geographical areas in broadcasting applications [3].

To recover the transmitted information at the receiver end, a process called demodulation is employed. One of the simplest and most effective methods for AM demodulation is envelope detection. This technique uses a diode to rectify the signal and an RC network to smooth it, allowing the envelope—which represents the original baseband information—to be extracted. This method is widely used due to its low complexity and effectiveness in extracting audio signals from AM waveforms.

In this project, we designed, built, and tested a complete AM receiver system composed of three main stages:

1. **A passive demodulator** was constructed using a germanium diode and a low-pass RC filter to extract the envelope of the incoming modulated signal.
2. **A baseband amplifier** implemented using a non-inverting op-amp topology to boost the recovered signal's amplitude.
3. **A Class A output stage** built using bipolar junction transistors (BJTs) to provide the necessary current to drive an 8 Ω speaker.

Each part was first analyzed and simulated individually. Then, the full system was assembled, tested, and soldered onto a perforated board. The project not only reinforced our understanding of modulation and demodulation techniques but also gave us practical experience in designing and troubleshooting multi-stage analog circuits.

Material and components used

The components used can be summarized in the following table along with their prices

Table 1: Used components values/models, quantity, price

#	Component	Value/Model	Quantity	Price ($)
1	**Resistor**	1 kΩ	5	0.02
2	**Resistor**	510 Ω	1	0.02
3	**Resistor**	130 Ω	1	0.02
4	**Resistor**	150 kΩ	2	0.02
5	**Resistor**	200 Ω	1	0.02
6	**Capacitor**	22 μF	4	0.1
7	**Capacitor**	1 μF	1	0.1
8	**Capacitor**	1 nF	1	0.1
9	**Capacitor**	1.8 nF	1	0.1
10	**Diode**	OA71	1	0.5
11	**Transistor**	BC337	12	0.25
12	**Op-amp**	TL084	1	0.6
13	**Speaker**	8 Ω	1	1.25
14	**Wires**	X	X	2
15	**IC socket**	X	1	
16	**Perforated breadboard**	X	1	

AM Demodulation

I. Demodulator

To recover a baseband signal, the received RF signal is typically multiplied by a carrier wave then passed through a low-pass filter to extract the original low-frequency content. However, for AM signals, a simpler amplitude detection method can be used: a demodulator circuit. This circuit is used to extract the original baseband signal from a modulated carrier wave.

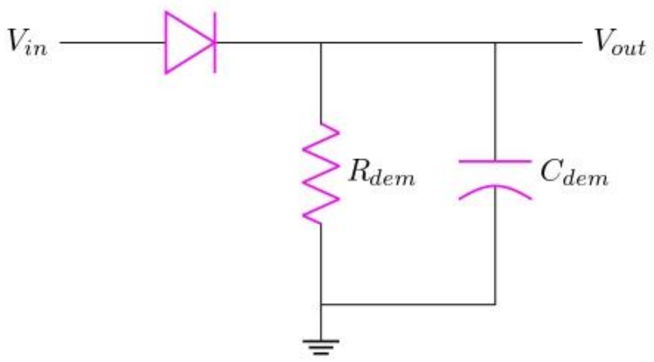

Figure 1: Demodulator circuit configuration

I.1 Background and Theory

1. A demodulator circuit works by extracting the original signal from a modulated carrier. It consists of a diode, a capacitor, and a resistor. The diode rectifies the signal by allowing only the positive half-cycle to pass. The capacitor charges to the peak voltage of the signal, effectively tracing the envelope that represents the original modulation. The resistor then discharges the capacitor slowly between peaks, smooths the waveform, and removes the high-frequency carrier.

When selecting the capacitor and resistor values, the most important thing to consider is the RC time constant ($\tau = RC$). It must be chosen carefully: long enough to filter out the high-frequency carrier, yet short enough to accurately follow the variations in the modulating signal. If the time constant is too long, the circuit will not respond quickly to signal changes. On the other hand, if it is too short, it will not effectively filter out the carrier.

2. Appropriate values of R_{dem} and C_{dem} must be carefully chosen knowing that the wanted baseband signal is in the 0-20 kHz range, and the unwanted carrier signal is in the 200 kHz – 1.2 MHz range (800 kHz in this case).

The cutoff frequency f_c is the point where the capacitive reactance is equal to the resistance.

$$X_C = R \tag{1}$$

$$\frac{1}{2\pi fC} = R \tag{2}$$

Rearranging the terms yields:

$$f_c = \frac{1}{2\pi RC} \tag{3}$$

Keeping in mind that the cutoff frequency of the passive RC low-pass filter should be larger than the bandwidth of the baseband signal and smaller than the frequency of the carrier:

$$f_b \ll f \ll f_c \tag{4}$$

Taking the inverse on all sides

$$f_b \ll \frac{1}{2\pi RC} \ll f_c \tag{5}$$

We can ignore 2π in the denominator since it is negligible. Thus we will be left with:

$$f_b \ll \frac{1}{RC} \ll f_c \tag{6}$$

Plugging our values,

$$20kHz \ll \frac{1}{RC} \ll 800kHz$$

We select $R = 1k\Omega \; and \; C = 2nF$ to satisfy the equation.

$$20kHz \ll 500kHz \ll 800kHz$$

3. For the correct operation of a demodulator, the DC point at the input must be appropriately set to ensure the diode conducts appropriately. The input signal must have a sufficient positive peak voltage to forward bias the diode and make it rectify the signal. In this case, the threshold voltage of the diode is around 0.34 V. On the other hand, an excessive DC bias can cause the diode to conduct continuously which leads to distortion or loss of the envelope shape.

I.2 Simulation

We then used LTspice to simulate the circuit; we plotted the input and output waveforms; the input is given to be a modulated signal resulting from the multiplication of two sine waves. The simulation code is shown in the figure below:

```
V1 1 0 SIN(0 2 800k 0 0)
V2 2 0 SIN(0 2 1k 0 0)
E3 in 0 POLY(2) (1,0) (2,0) 0 0 0 0 1
D  in 4 DX
Rdem 4 0 1k
Cdem 4 0 2n
RLPF 4 out 510
CLPF out 0 1n

.MODEL DX D(IS=800.0E-18)
.tran 0.0001

.model 1N34A D (bv=75 cjo=0.5e-12 eg=0.67 ibv=18e-3 is=2e
    -7 rs=7 n=1.3 vj=0.1 m=0.27)

.end
```

Figure 2: LTspice .net code for simulating the demodulator stage

1. We plotted the input and output signals as shown below for two cases, the first one for a baseband frequency of 1kHz and the second one for 10kHz.

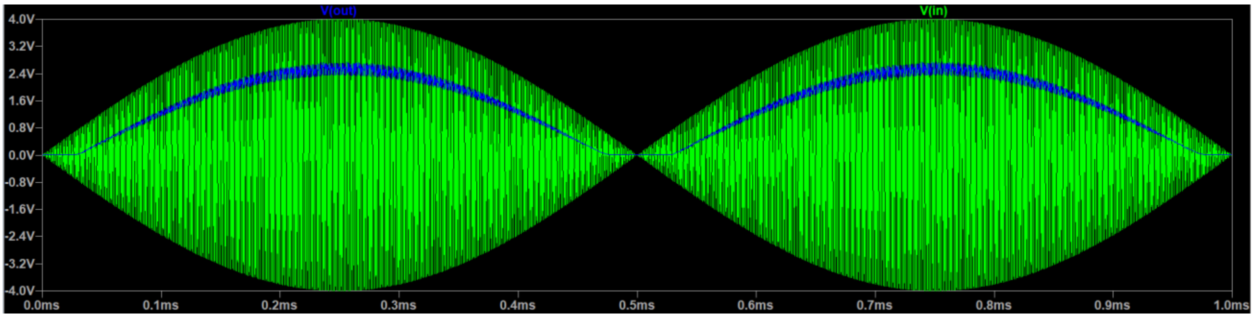

Figure 3: Input and output waveforms of the demodulator with a baseband frequency of 1 kHz

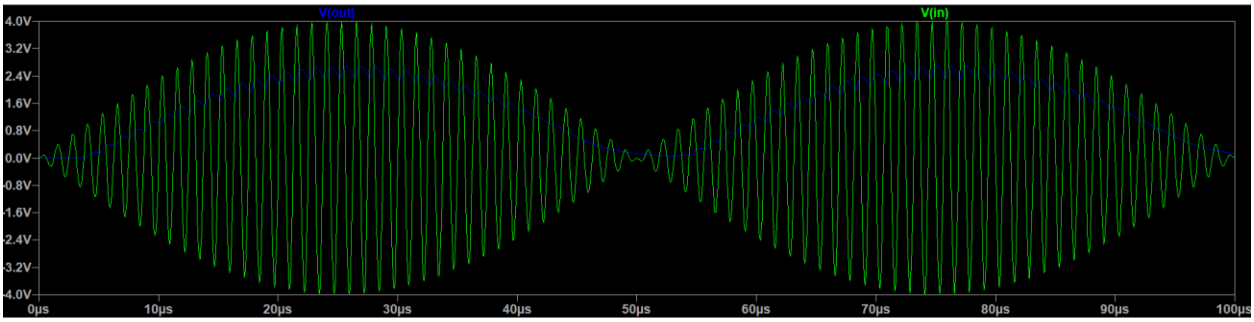

Figure 4: Input and output waveforms of the demodulator with a baseband frequency of 10 kHz

As evident in both cases, the output is a perfectly modulated signal of the input.

1. We plotted the gain response of the demodulator versus the baseband signal frequency using this netlist code.

```
V in 0 DC {Vm} AC 1
D  in 4 DX
Rdem 4 0 1k
Cdem 4 0 2n
RLPF 4 out 510
CLPF out 0 1n

.param Vpp=2 Vm=Vpp/1
.ac dec 10 1k 20k
.MODEL DX D(IS=800.0E-18)
.model 1N34A D (bv=75 cjo=0.5e-12 eg=0.67 ibv=18e-3 is=2e
    -7 rs=7 n=1.3 vj=0.1 m=0.27)

.end
```

Figure 5: LTspice .net code for plotting the gain for demodulator stage

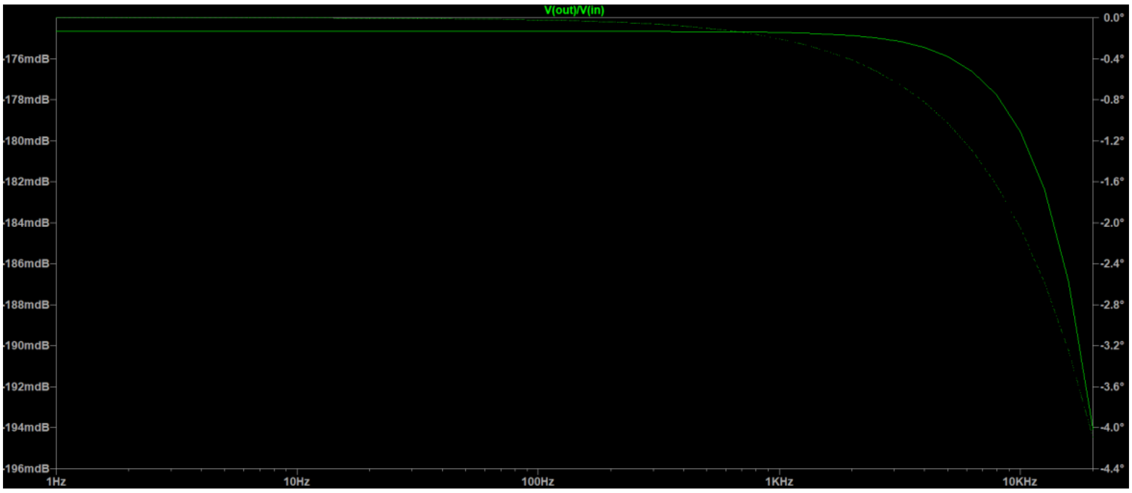

Figure 6: Gain plot for the demodulator stage

I.3 Hardware

Then, we built the circuit on a breadboard. We chose to add a low pass filter to the output of the circuit to provide a smoother output (R_{LPF} = 510 Ω, C_{LPF} = 1nF)

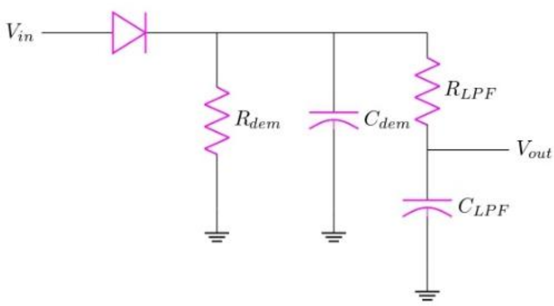

Figure 7: Demodulator circuit configuration with a low pass filter

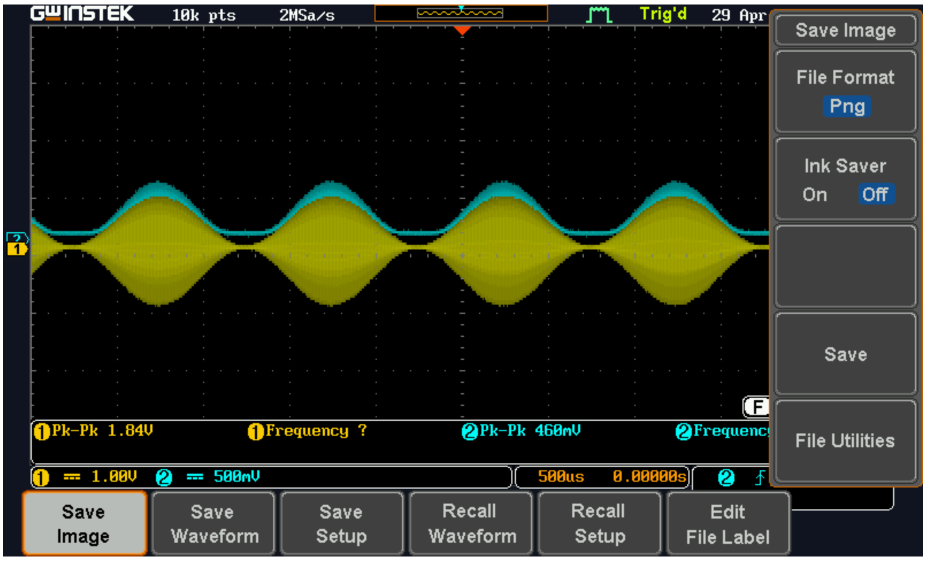

Figure 8: Visualization of the input and output waveforms of the demodulator via the oscilloscope (without LPF)

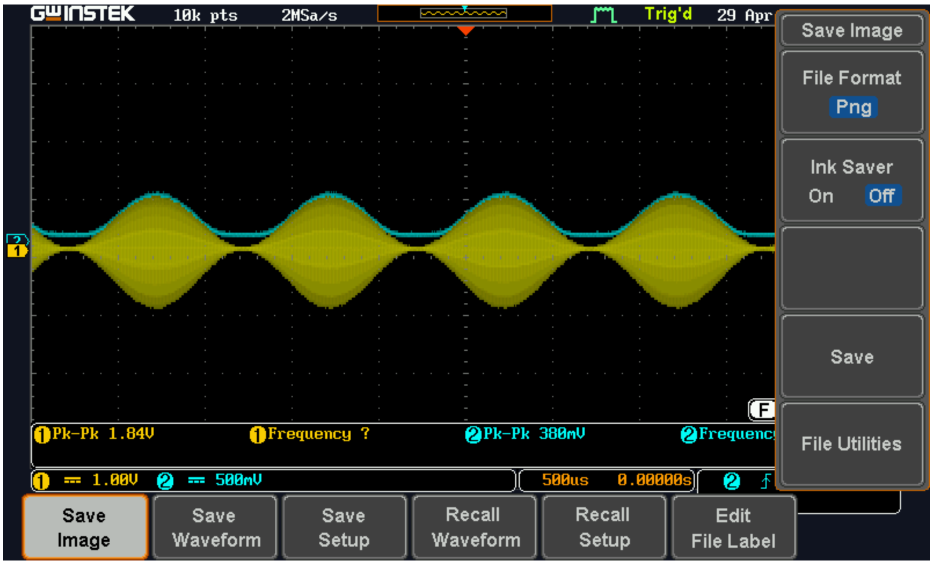

Figure 9: Visualization of the input and output waveforms of the demodulator via the oscilloscope (with LPF)

The output waveform clearly is a clean demodulated version of the input.

II. 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 below can be used. The topology is based on a non-inverting amplifier and allows manual gain control through a potentiometer.

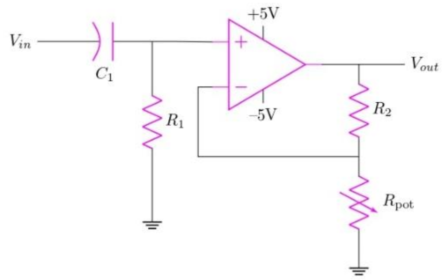

Figure 10: Baseband amplifier circuit configuration

1. The capacitor in the circuit functions as a coupling capacitor, which is needed to block any DC component from the input signal while allowing the AC components to pass through. This is important in amplifier circuits where the goal is to amplify only the AC signal and ignore any unwanted DC offset that might be present in the source. This ensures that the amplifier operates linearly and does not get driven into saturation due to a DC shift in the input.

2. In the circuit, the resistor R_1 serves two important purposes. First, it provides a path to ground for the input bias current of the operational amplifier, which is necessary for the op-amp to operate correctly and maintain a stable input voltage. Second, R_1 works together with the capacitor C_1 to form a high-pass filter. This filter blocks low-frequency and DC components of the input signal allowing only the desired AC signals to pass through to the op-amp for amplification.

3. We need to derive the gain equation of the circuit for C_1 neglected, then when considered.

<u>For C_1 neglected:</u>

$$\frac{V_{in} - V_0}{R_2} + \frac{V_{in}}{R_{pot}} = 0 \tag{7}$$

While grouping,

$$V_{in}\left(\frac{1}{R_2} + \frac{1}{R_{pot}}\right) = \frac{V_0}{R_2} \tag{8}$$

Then finding the ratio explicitly,

$$\frac{V_0}{V_{in}} = 1 + \frac{R_2}{R_{pot}} \tag{9}$$

<u>For C_1 considered:</u>
At the non-inverting input:

$$\frac{V_+ - V_{in}}{X_C} + \frac{V_+}{R_1} = 0 \tag{10}$$

$$V_+\left(\frac{1}{X_C} + \frac{1}{R_1}\right) = \frac{V_{in}}{X_c} \tag{11}$$

$$V_+ = \frac{V_{in}}{X_c\left(\frac{1}{X_c} + \frac{1}{R_1}\right)} \tag{12}$$

At the inverting input, by taking $V_+ = V_-$:

$$\frac{V_+ - V_{out}}{R_2} + \frac{V_+}{R_{pot}} = 0 \tag{13}$$

$$\frac{V_{in}}{X_C\left(\frac{1}{X_C} + \frac{1}{R_1}\right)}\left(\frac{1}{R_2} + \frac{1}{R_{pot}}\right) = \frac{V_{out}}{R_2} \tag{14}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_2}{X_C\left(\frac{1}{X_C} + \frac{1}{R_1}\right)}\left(\frac{1}{R_2} + \frac{1}{R_{pot}}\right) \tag{15}$$

Finally, we substitute X_C into the equation:

$$\frac{V_{out}}{V_{in}} = \frac{1 + \frac{R_2}{R_{pot}}}{\frac{1}{2\pi f C}\left(2\pi f C + \frac{1}{R_1}\right)} = \frac{1 + \frac{R_2}{R_{pot}}}{1 + \frac{1}{2\pi f C R_1}} \tag{16}$$

When C_1 is considered in the gain analysis, it makes the gain frequency dependent. At low frequencies, the capacitive reactance is high which causes the input signal to be largely blocked resulting in a reduced gain. As the frequency increases, the reaction of C_1 decreases, allowing more of the input signal to pass through. This causes the gain to rise and approach the value determined by the gain when C_1 is neglected, which is the maximum gain of the amplifier.

4. The parameter values are given to be: V_{cc}= +5 V, V_{EE}=-5 V, C_1=1 uF, and R_1=150 Ω. The remaining resistor value R_2 can be found using the gain equation. R_2 and R_{pot} must be selected to achieve a gain of 150 V/V.

Using equation (8):

$$1 + \frac{R_2}{R_{pot}} = 150\ V/V$$
$$R_2 = 150R_{pot}$$

We take R_{pot} = 150 kΩ and set R_{pot} = 1 kΩ.

II.2 Simulation

We then used LTspice to simulate the circuit; we plotted the input and output waveforms; the input is given to be a sine wave. The simulation code is shown in the figure below:

```
Vin 1 0 SIN(0 0.02 1k)
C1 1 5 0.001m
R1 5 0 150k
V+ 7 0 5V
V- 0 8 5V
R2 9 6 150k
Rpot 6 0 1k
XU1 5 6 7 8 9 TL084

.SUBCKT TL084 1 2 3 4 5
  C1    11 12 3.498E-12
  C2     6  7 15.00E-12
  DC     5 53 DX
  DE    54  5 DX
  DLP   90 91 DX
  DLN   92 90 DX
  DP     4  3 DX
  EGND  99  0 POLY(2) (3,0) (4,0) 0 .5 .5
  FB     7 99 POLY(5) VB VC VE VLP VLN 0 4.715E6 -5E6 5E6
      5E6 -5E6
  GA     6  0 11 12 282.8E-6
  GCM    0  6 10 99 8.942E-9
  ISS    3 10 DC 195.0E-6
  HLIM  90  0 VLIM 1K
  J1    11  2 10 JX
  J2    12  1 10 JX
  R2     6  9 100.0E3
  RD1    4 11 3.536E3
  RD2    4 12 3.536E3
  RO1    8  5 150
  RO2    7 99 150
  RP     3  4 2.143E3
  RSS   10 99 1.026E6
  VB     9  0 DC 0
  VC     3 53 DC 2.200
  VE    54  4 DC 2.200
  VLIM   7  8 DC 0
  VLP   91  0 DC 25
  VLN    0 92 DC 25
.MODEL DX D(IS=800.0E-18)
.MODEL JX PJF(IS=15.00E-12 BETA=270.1E-6 VTO=-1)
.ENDS

.tran 0.01
.end
```

Figure 11: LTspice .net code for simulating the baseband amplifier stage

1. We plotted the input and output signals.

The input is chosen to have an amplitude of 0.2 V and a frequency of 1 kHz.

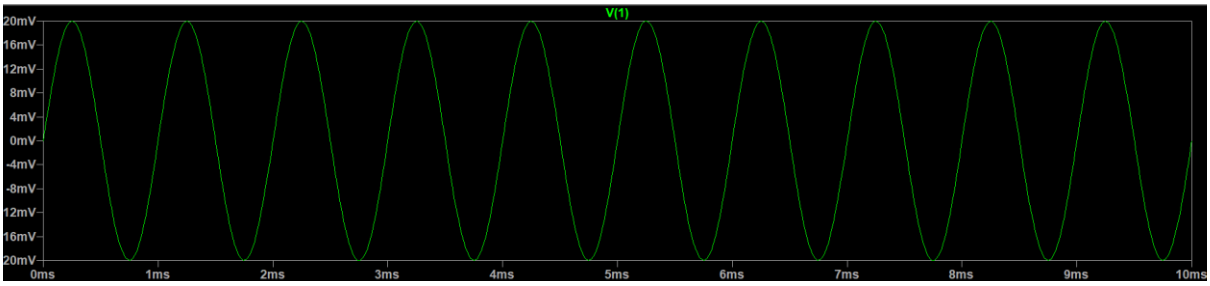

Figure 12: Input waveform of the baseband amplifier with 0.2mV pk

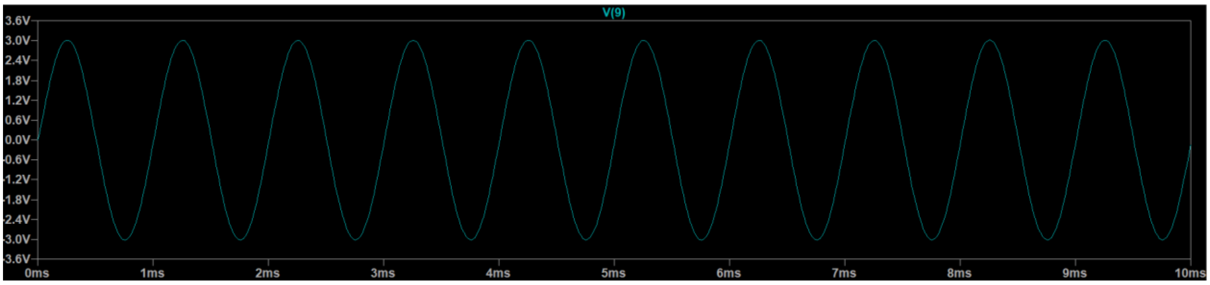

Figure 13: Output waveform of the baseband amplifier with 3V pk

As clear from the waveform, the output is an amplified version of the input.

2. We plotted the gain response of the baseband amplifier in order to determine its 3-dB bandwidth. For frequency simulation of the op-amp, we connect 5pF parasitic capacitors to each pin. Also, we take into account the parasitic resistor and capacitor values of the oscilloscope (1MΩ resistor in parallel with a 20pF capacitor going from the measuring node to ground)

```
Vin 1 0 SIN(0 0.02 1k) AC 1
C1 1 5 0.001m
R1 5 0 150k
V+ 7 0 5V
V- 0 8 5V
R2 9 6 150k
Rpot 6 0 1k
XU1 5 6 7 8 9 TL084

;parasitic capacitors
C5 5 0 5p
C6 6 0 5P
C7 7 0 5p
C8 8 0 5p
C9 9 0 5p

;oscilloscope's parasitic capacitor and resistor
Rscope 9 0 1Meg
Cscope 9 0 20p


.AC DEC 10 100 20k
.end
```

Figure 14: LTspice .net code for plotting the baseband amplifier stage gain

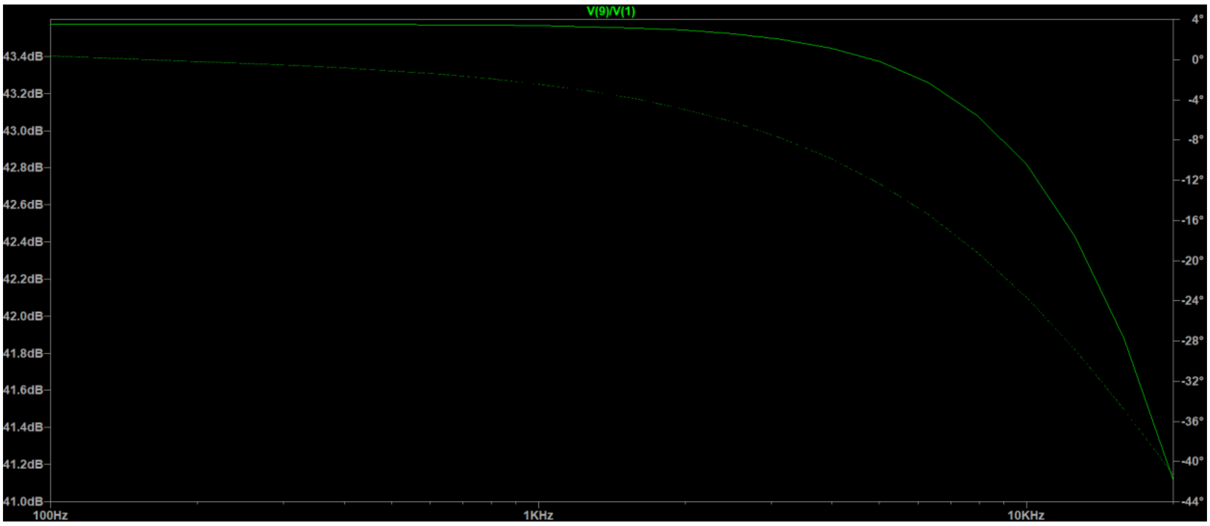

Figure 15: Gain plot for the baseband amplifier stage

We placed the cursor on the peak magnitude of the gain.

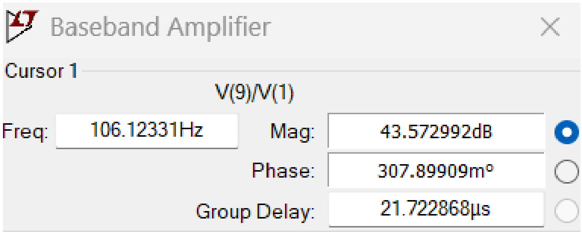

Figure 16: Baseband amplifier peak gain in dB

The frequency where the gain drops 3 dB below the peak is the desired 3-dB bandwidth, which was shown to be around 19kHz.

II.3 Hardware

Then, we built the circuit on a breadboard. We added a voltage divider (R_{D1} = 10 kΩ, R_{D2} = 470 Ω) at the output of the demodulator which is connected to the input of the baseband amplifier in order to maintain a voltage gain of 150 V/V.

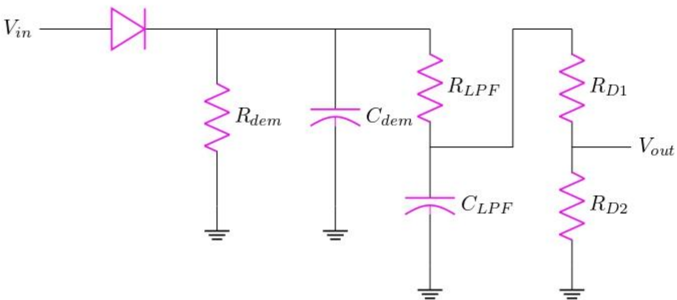

Figure 17: Voltage divider at the output of stage 1

The output voltage of the first stage was around 500mV. This is inefficient since we need to maintain a voltage gain of 150 V/V.

We selected the following values of resistors to create a voltage divider:

$$R_{D1} = 10\ k\Omega$$

$$R_{D2} = 470\ \Omega$$

$$V_{out} = \frac{470}{470 + 10 \times 10^3} \times 0.5 = 0.022\ V$$

By observing the behavior of the output on the oscilloscope, we came to a conclusion that a 0.022V input is efficient and appropriate for the circuit as the output waveform was no longer clipped as it was when the input was as large as 500mV.

To proceed, we first tried the circuit on its own with a sinusoidal input.

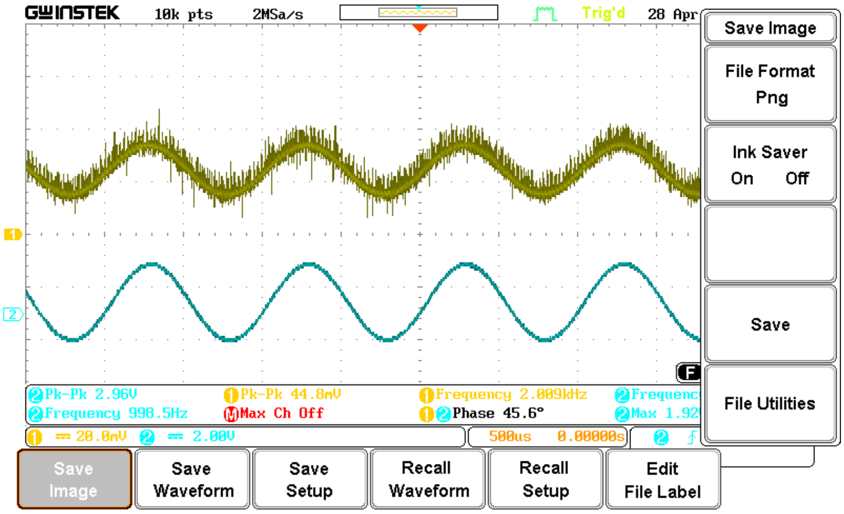

Figure 18: Visualization of the input and output waveforms of the baseband amplifier with a sinusoidal input

Then, we connected it to the output of the previous demodulator stage.

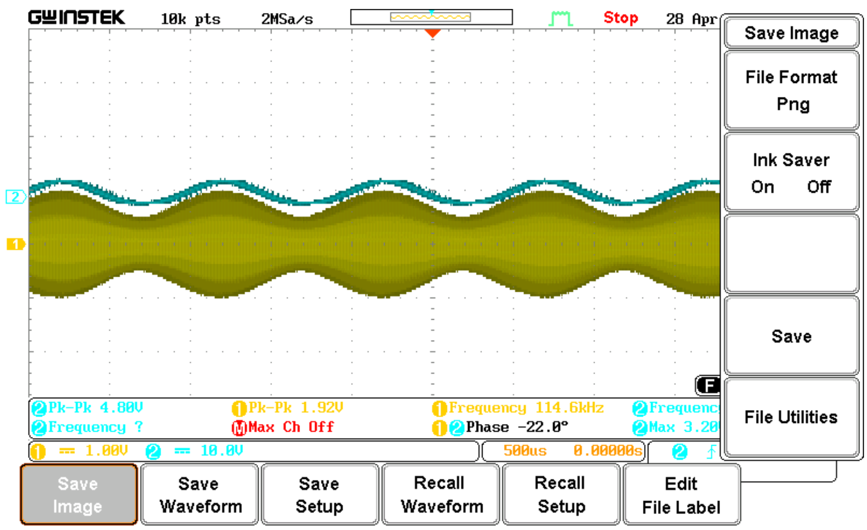

Figure 19: Visualization of the input and output waveforms of the baseband amplifier when connected to stage 1

III. Class A Output Stage

The output stage is a stage that involves taking the output of the previous baseband-amplifier and outputting it to the speaker. However, since speakers require large currents to operate, a power amplifier is used to increase the current and drive the speaker loud. The circuit used will be a class "A" amplifier as shown in the following figure.

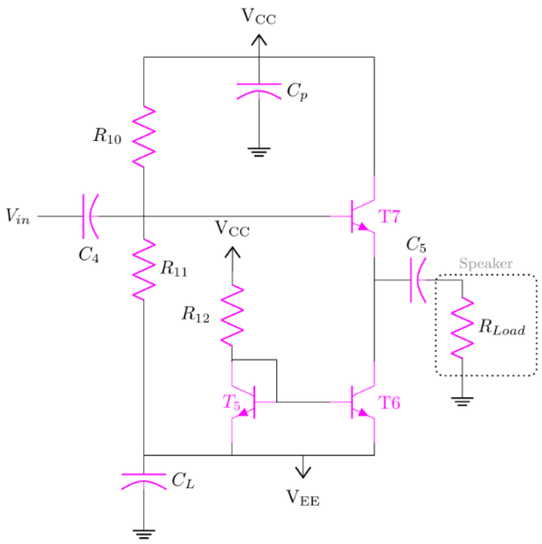

Figure 20: Class "A" output stage amplifier circuit configuration

III.1 Background and Theory

1. The parameter values are given to be: V_{cc}= +5 V, V_{EE}=-5 V, C_4=C_5=C_p=C_L=22 μF, R_{12}=127 Ω, and R_{load}=8 Ω (to model a typical speaker). The remaining resistor values R_{10} and R_{11} can be found by assuming that the bjt transistors should be in active mode, thus we will assume that the voltage across the base V_{B7} of T_7 is 3.2 V. Assuming that very little current passes through the base of the transistors, voltage division can be used to find the ratio of the resistors.

$$V_{B7} = \frac{R_{10}}{R_{10} + R_{11}} \times 10 - 5 \tag{17}$$

Setting V_{B7} to 3.2 V, and rearranging equation (3),

$$R_{11} = 4.56R_{10} \tag{18}$$

Commercially, we found some values that satisfy this condition to a good extent, we went with:

$$R_{11} = 1\ k\Omega$$
$$R_{10} = 200\ \Omega$$

2. This circuit is limited with many constraints, since it is a power amplifier, it will be limited to the power handling of the transistors, also, clipping effect can be experienced for inputs that are above the rated signal inputs, moreover, slew rate could be a concern when the input is high frequency audio signal. Nevertheless, the circuit is equipped with coupling capacitors that may lower the performance at low frequencies. In addition, much

of the output power will be dissipated as heat even if no output is connected, which decreases the efficiency of this amplifier.

III.2 Simulation

1. We then used LTspice to simulate the circuit; we plotted the input and output waveforms; the input is given to be a pure sin wave. The simulation code is shown in the figure below:

```
V1 1 0 SIN(0 0.6 1k)
Vcc vcc 0 5
Vee vee 0 -5

C4 1 2 22u
R10 2 vcc 200
R11 2 vee 1k
Cl vee 0 22u
Cp vcc 0 22u
Q5 3 3 vee npn
Q6 4 3 vee npn
Q7 vcc 2 4 npn
R12 3 vcc 127
C5 4 5 22u
Rl 5 0 8

.model npn NPN(IS=7.809E-14 NF=0.9916 ISE=2.069E-15 NE=1.4
    BF=436.8 IKF=0.8 VAF=103.6 NR=0.991 ISC=6.66E-14 NC=1.2
    BR=44.14 IKR=0.09 VAR=14 RB=70 IRB=2.00E-04 RBM=8 RE=0.12
     RC=0.24 XTB=0 EG=1.11 XTI=3 CJE=3.579E-11 VJE=0.6657 MJE
    =0.3596 TF=5E-10 XTF=2.5 VTF=2 ITF=0.5 PTF=88 CJC=1.306E
    -11 VJC=0.3647 MJC=0.3658 XCJC=0.455 TR=2.50E-08 CJS=0
    VJS=0.75 MJS=0.333 FC=0.843 Vceo=45 Icrating=500m mfg=NXP
    )

.tran 0 5000u
.backanno
.end
```

Figure 21: LTspice .net code for simulating the stage output - class "A" amplifier

The input is chosen to have an amplitude of 0.6 V and a frequency of 1 kHz, then 10 kHz. The output waveforms of both signals are shown below.

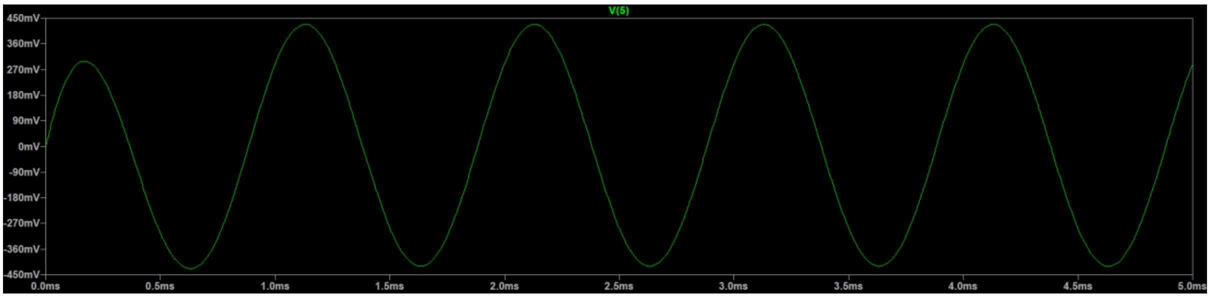

Figure 22: Output waveform of the class "A" amplifier with a sinusoidal input of 1 kHz

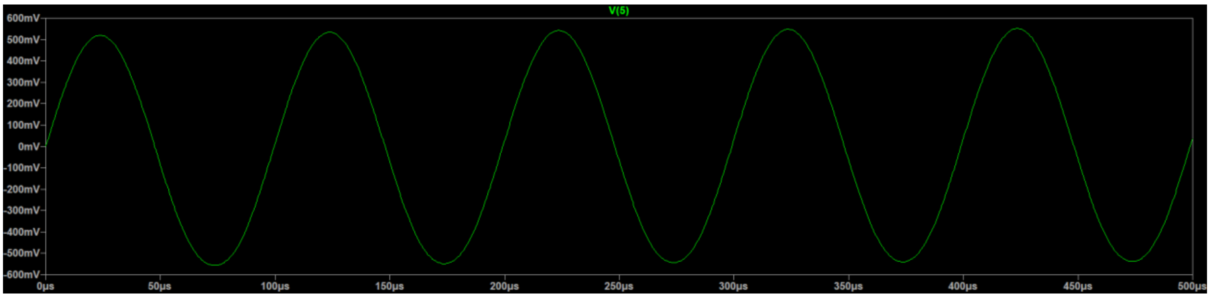

Figure 23: Output waveform of class "A" amplifier with a sinusoidal input of 10 kHz

As clear from the waveform, the output is a replicate of the input with linear amplification, verifying what this amplifier is made for, the output is providing around 1 V_{pp} to the output which is also required. By that, the circuit is ready to be made with real circuitry and tested out.

III.3 Hardware

To implement the circuit physically, we first need to pay attention to some constraints we might have, the circuit provides high current inputs which flow through the transistors, so the transistors may experience high power dissipation through them, thus multiple transistors should be used in parallel. To make a rough estimate of the number of transistors that should be used, we will first determine the total power dissipated in the circuit, by assuming that the current driven from the previous stage is negligible since the main power source will be the 2 power supplies, V_{cc} and V_{EE}, the total power P_{total} in the circuit is

$$P_{total} = P_{Vcc} + P_{VEE} \tag{19}$$

Which means that:

$$P_{total} = V_{CC}I_{CC} + V_{EE}I_{EE} \tag{20}$$

We then simulate the current driven from both sources through LTspice, at DC input. The values came out to be $I_{CC-DC} \approx -160\ mA$ and $I_{EE-DC} \approx 160\ mA$. Thus, the total power is:

$$|P_{total}| = 5 \times 160 + 5 \times 160 = 1600\ mW$$

The used transistor model is the BC337 model, which is rated at maximum power dissipation of 625mW at room temperature according to its datasheet. Taking all of this into consideration while considering a great safety margin, for each transistor T_5, T_6, and T_7, we implemented the circuit with 4 transistors in parallel instead of one.

The circuit is then connected to the function generator with a sinusoidal input, the output waveform was also visualized on the oscilloscope, the input and the output waveforms are shown below.

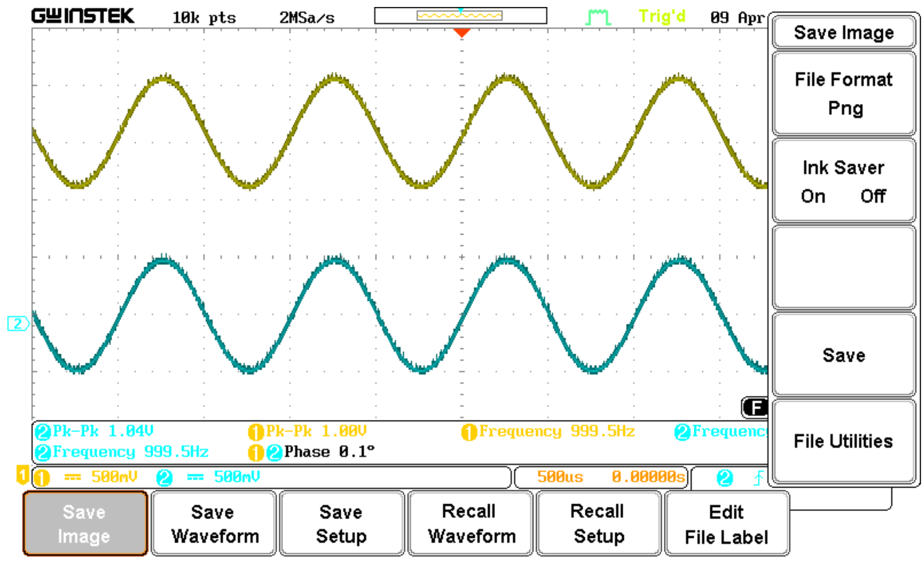

Figure 24: Visualization of the input and output waveforms of the output stage amplifier via the oscilloscope

The output waveform clearly is a clean version of the input, with output peak-to-peak voltage of 1 V which is required to drive the output speaker.

IV. AM Receiver

After discussing, simulating, and building each circuit physicaly and independently, we are now ready to connect the whole circuit together in cascade as shown in the figure below:

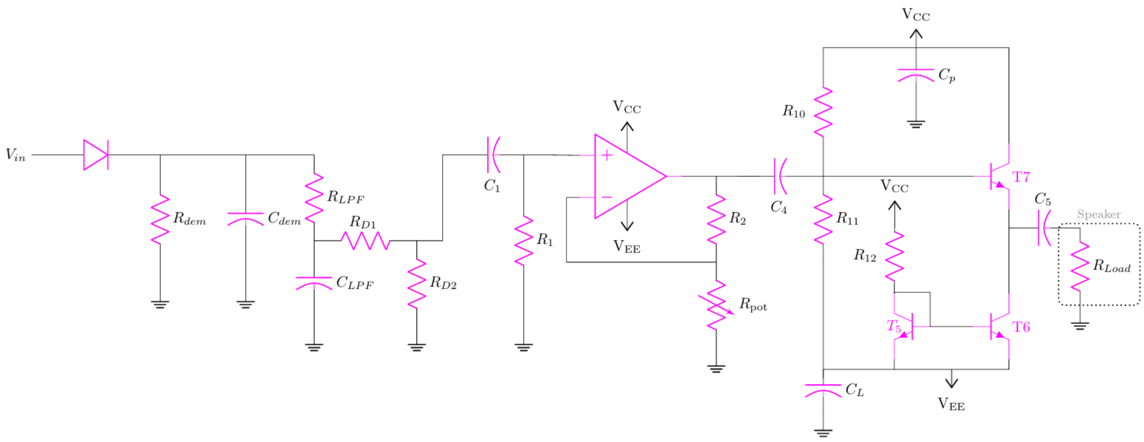

Figure 25: AM receiver circuit configuration

Here we note two major differences between this circuit configuration and the configuration proposed in the manual. First, we added an additional low-pass-filter in the demodulator to smooth out the signal. Second, we added a voltage divider between stages 1 and 2 to reduce the voltage entering the base-band amplifier so that it can have high gain values.

IV.1 Background and Theory

1. We then used LTspice to simulate the circuit; we plotted the input and output waveforms; the input is given to be a modulated signal. The simulation code is shown in the figure below:

```
* Part 1
V1 1 0 SIN(0 2 800k 0 0)
V2 2 0 SIN(0 2 1k 0 0)
E3 in 0 POLY(2) (1,0) (2,0) 0 0 0 0 1
D  in 4 DX
Rdem 4 0 1k
Cdem 4 0 2n
R 4 out 510
C out 0 1n

* Part 2
Rv1 out v 10k
Rv2 v 0 470
C1 v 5 0.001m
R1 5 0 150k
V+ 7 0 5V
V- 0 8 5V
R2 9 6 150k
Rpot 6 0 7k
XU1 5 6 7 8 9 TL084

* Part 3
C4 9 12 22u
R10 12 7 200
R11 12 8 1k
Cl 8 0 22u
Cp 7 0 22u
```

Figure 26: LTspice .net code for simulating the AM receiver

```
Q5 13 13 8 npn
Q6 14 13 8 npn
Q7 7 12 14 npn
R12 13 7 127
C5 14 15 22u
R1 15 0 8

* Models
.SUBCKT TL084 1 2 3 4 5
  C1    11 12 3.498E-12
  C2     6  7 15.00E-12
  DC     5 53 DX
  DE    54  5 DX
  DLP   90 91 DX
  DLN   92 90 DX
  DP     4  3 DX
  EGND  99  0 POLY(2) (3,0) (4,0) 0 .5 .5
  FB     7 99 POLY(5) VB VC VE VLP VLN 0 4.715E6 -5E6 5E6
      5E6 -5E6
  GA     6  0 11 12 282.8E-6
  GCM    0  6 10 99 8.942E-9
  ISS    3 10 DC 195.0E-6
  HLIM  90  0 VLIM 1K
  J1    11  2 10 JX
  J2    12  1 10 JX
  R2     6  9 100.0E3
  RD1    4 11 3.536E3
  RD2    4 12 3.536E3
  RO1    8  5 150
  RO2    7 99 150
  RP     3  4 2.143E3
  RSS   10 99 1.026E6
  VB     9  0 DC 0
  VC     3 53 DC 2.200
  VE    54  4 DC 2.200
  VLIM   7  8 DC 0
  VLP   91  0 DC 25
  VLN    0 92 DC 25
.ENDS

.MODEL DX D(IS=800.0E-18)
.MODEL JX PJF(IS=15.00E-12 BETA=270.1E-6 VTO=-1)
.MODEL 1N34A D(bv=75 cjo=0.5e-12 eg=0.67 ibv=18e-3 is=2e
    -7 rs=7 n=1.3 vj=0.1 m=0.27)
.MODEL BC337-40 npn(IS=7.809E-14 NF=0.9916 ISE=2.069E-15
    NE=1.4 BF=436.8 IKF=0.8 VAF=103.6 NR=0.991 ISC=6.66E
    -14 NC=1.2 BR=44.14 IKR=0.09 VAR=14 RB=70 IRB=2.00E
    -04 RBM=8 RE=0.12 RC=0.24 XTB=0 EG=1.11 XTI=3 CJE
    =3.579E-11 VJE=0.6657 MJE=0.3596 TF=5E-10 XTF=2.5 VTF
    =2 ITF=0.5 PTF=88 CJC=1.306E-11 VJC=0.3647 MJC=0.3658
     XCJC=0.455 TR=2.50E-08)

.tran 0.005
.end
```

Figure 27: LTspice .net code for simulating the AM receiver- continued

The circuit is simulated with inputs being the modulated signal of carrier frequency f_c=800 kHz and baseband signal f_b= 1 kHz and f_b=10 kHz. The input and output waveforms are shown below:

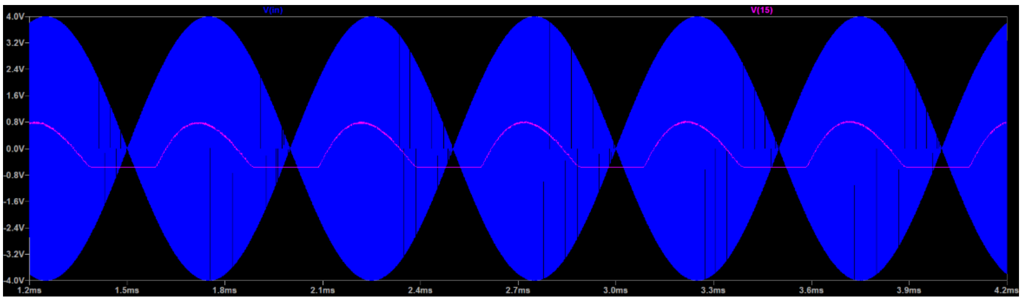

Figure 28: Output waveform of the AM receiver with AM sinusoidal input of baseband signal of 1 kHz

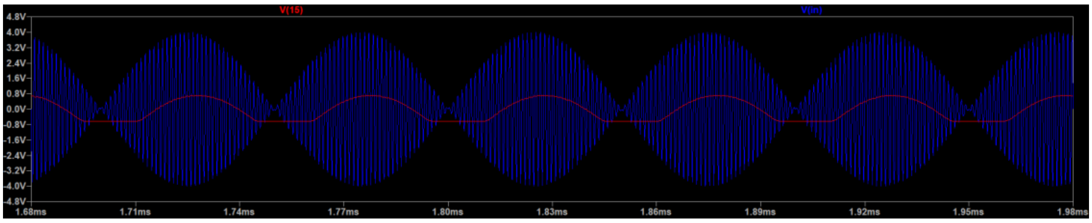

Figure 29: Output waveform of the AM receiver with AM sinusoidal input of baseband signal of 10 kHz

IV.2 Hardware0

Then, the system is connected on breadboard, the function generator is used to generate an AM signal with modulation index of 100%, the input and output waveforms are shown on the oscilloscope, below.

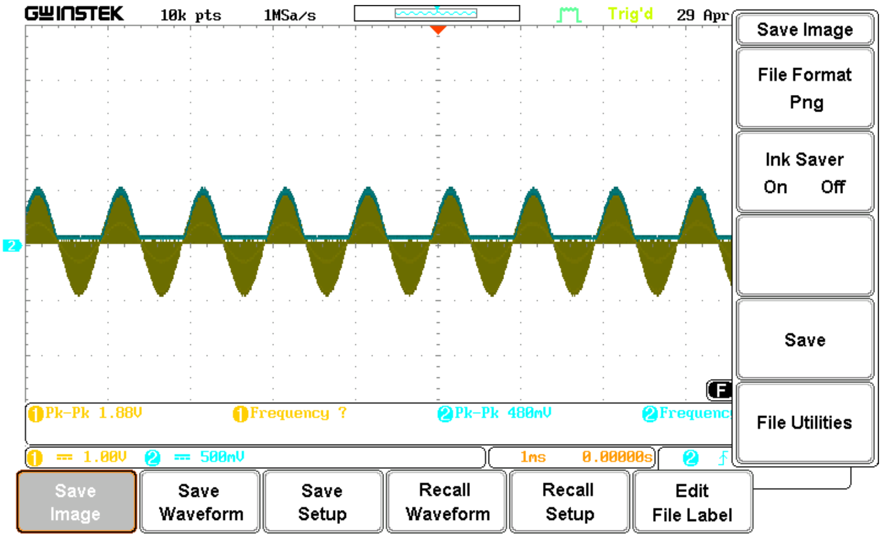

Figure 30: Visualization of the input and output waveforms of the AM receiver via the oscilloscope

The output signal can be adjusted, and we can have higher peak voltages with changing the potentiometer sweep.

We then soldered the whole setup on a perforated breadboard as shown below.

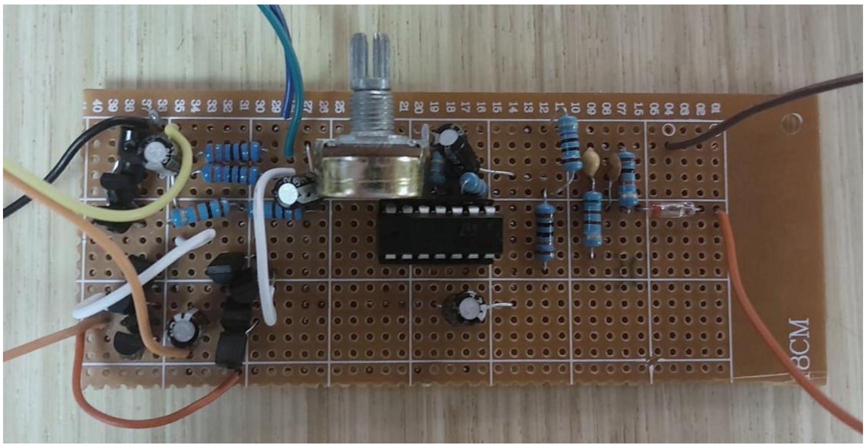

Figure 31: Soldered AM receiver

Here, we encountered a problem which is that the output is disturbed a bit as shown in the figure below.

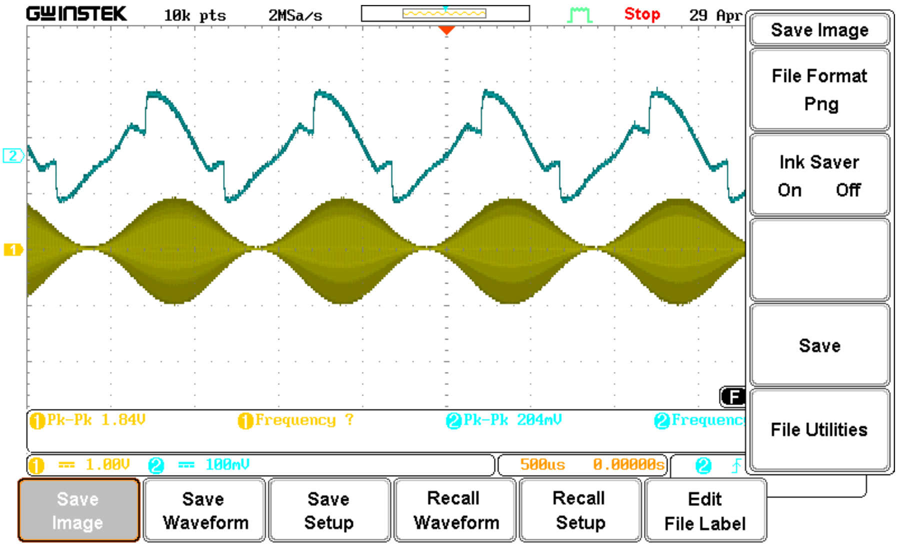

Figure 32: Visualization of the input and output waveforms of the soldered AM receiver via the oscilloscope

We suggest that this wiggling in the output is due to the transistors heating a lot which ruins their amplification capability.

We then connect a speaker to the output, and we set the input baseband signal to some frequencies suggested in the manual, we thus hear a clear sound tone from the speaker, furthermore, we adjusted the value of the potentiometer and got louder sound.

Challenges

During the design and implementation process, we encountered several challenges, these challenges can be summarized in what follows:

A. **Low pass filter**
   The output of stage 1 was not satisfactory enough so a low pass filter was introduced in order to smooth it out.
B. **Diode voltage drop**
   At first, the diode we were using had a forward bias voltage of around 0.8. The voltage drop is considered high, so the input signal was required to be higher in order for it to be demodulated and low voltages were attenuated to zero. To solve this issue, and after many trials to find a better diode, we switched to using the diode model currently present in our design (OA71).
C. **Baseband Amplifier gain**
   It was required to design the baseband amplifier stage to keep a voltage gain of 150V/V. Connecting this circuit to the output of the demodulator stage was not efficient to keep the gain as desired since the output pk-pk voltage was considerably high (500 mV). For that, we were obliged to add a voltage divider at the input of stage 2 in order to regulate the behavior of the circuit.
D. **High 127-ohm resistor current**
   On the first attempt to power the output stage amplifier, we noticed some components were burning, after careful inspection, we noted that the 127 Ω resistor was burning out due to the high current traversing it. The used resistor was not capable of handling the high-power dissipation through it since the used resistor was rated at 500mW maximum power dissipation, and by simulation, the maximum power will exceed this limit to around 700mW, thus we decided to divide the current on 2 parallel resistors, yet, grouping resistors in parallel decreases their resistance, thus we used values to achieve similar total resistance, i.e.

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \tag{21}$$

   Setting this equation to 127, and assuming that both resistors are equal, we need to get a value that is multiple of 127.
E. **Transistor Overload and Heat Dissipation**
   After testing the final circuit, we found out that the transistors were drawing too much current, causing them to heat up and burn some resistors. To fix this, we connected four transistors in parallel so they could share the load and prevent overheating.
F. **Soldering Errors**
   When we soldered the circuit, many of the pin connections turned out to be incorrect. We went back and carefully rechecked each one using the continuity test on the digital multimeter, which helped us find and fix the issues. We also discovered that the op-amp wasn't getting power because its supply connections were missing, so we connected those as well to get the circuit working properly.

Limitations

While the AM receiver circuit functioned as expected overall, we encountered a few limitations during testing:

- **Low Speaker Volume**: The output signal from the amplifier stage was not strong enough to produce high volume through the 8 Ω speaker. The voice output was clear but noticeably low.
- **Frequency Response Drop**: As we increased the input frequency beyond 10 kHz, we observed a significant drop in gain. This limited the receiver's effective range and made it less responsive to higher-frequency audio signals.
- **Power Consumption**: The circuit consumed a relatively high amount of current, especially in the Class A output stage. This affected efficiency and could be improved in future designs.
- **Overheating Resistors**: Some resistors, especially those near the transistors, heated up during extended operation. This required careful monitoring and may call for better thermal design or higher wattage components.
- **Limited Operating Time**: Due to heat and stability concerns, the circuit couldn't stay powered on for long periods without risking performance issues or damage.

Conclusion

Through this project, we successfully designed, simulated, and implemented a complete AM receiver using three key stages: a passive demodulator, a baseband amplifier, and a Class A output stage. Each circuit was first analyzed theoretically and verified through SPICE simulations before being built and tested on the breadboard. The final design was soldered onto a perforated board, allowing us to deliver a fully functioning system capable of demodulating and amplifying AM audio signals.

Beyond circuit design, this project gave us hands-on experience with debugging real hardware issues, such as incorrect soldering, component heating, and gain stability across frequencies. These challenges pushed us to go beyond simulation and develop practical troubleshooting skills, like using continuity testing, voltage dividers, and parallel components to address performance and thermal limitations.

We also deepened our understanding of analog communication concepts, such as envelope detection, gain-bandwidth trade-offs, and power amplification, by applying them to a working system. Collaborating across our team, we divided tasks, documented findings, and worked through multiple iterations to ensure our receiver operated as expected.

Ultimately, hearing a clear audio tone from a signal we generated, demodulated, and amplified ourselves was a rewarding culmination of our learning in analog electronics.

References

[1] *How does AC Coupling and DC Coupling help in Reducing Noise for Signal*

[2] GeeksforGeeks. (2024, May 15). *Amplitude modulation Definition, types, expression*. GeeksforGeeks. https://www.geeksforgeeks.org/amplitude-modulation-definition-types-expression/

[3] *Why is amplitude modulation used for long distance communication?* (n.d.). https://www.vedantu.com/question-answer/amplitude-modulation-used-for-long-distance-class-12-physics-cbse-60e3d7dbf6ffbf22db24e6e6

Appendix A

Our group was made up of two lab teams: Ali Awada and Malak Darwish, Dana Hachem and Mahdi Zein Al Dine; all working together on building and testing the AM receiver.

Awada and Darwish were responsible for the passive demodulator and the baseband amplifier stages. They worked together on solving the theoretical equations, choosing the right component values, and building the two circuits on the breadboard. They tested each stage individually to make sure everything was working as expected, and then we all tested both stages combined.

Hachem and Zein Al Dine worked on the class A output stage and handled the integration of all the stages into one complete system. After assembling the full circuit, we all tested it together as a team to ensure everything worked properly and that the final system produced the expected output.

Zein Al Dine also took the lead on soldering the final circuit onto the perforated board, carefully checking each connection to avoid any errors.

For the report, each member contributed by writing the section related to the part they worked on. Awada and Darwish wrote the sections covering the demodulator and baseband amplifier. They worked together on both parts, performing the SPICE simulations in parallel, writing all the necessary equations, and dividing the theory questions equally from both parts. Darwish also wrote the challenges they faced when implementing their circuits physically. Hachem and Zein Al Dine wrote the parts related to the class A output stage and full system integration. Zein Al Dine focused more on solving the theoretical equations and drawing the circuit diagrams using LaTeX, while Hachem worked on the rest of the theory along with introduction, conclusion, and appendices. We all reviewed the report together to make sure it reflected our teamwork and the effort put into each part.

Appendix B

1. TL084 Operational Amplifier

- **Type**: Quad JFET-input op-amp
- **Supply Voltage Range**: ±3V to ±18V
- **Input Offset Voltage**: Typically 3 mV, max 13 mV
- **Input Bias Current**: Typically 20 pA, max 200 pA
- **Gain Bandwidth Product**: Typically 4 MHz
- **Input Resistance**: ≥ 10^{12} Ω (very high input impedance)
- **Typical Applications**: Used in baseband amplifier for signal gain with high input impedance.

2. BC337 NPN Transistor

- **Type**: NPN Silicon Amplifier Transistor
- **Collector-Emitter Voltage (V_{ce})**: 45V
- **Collector Current (Ic)**: Max 800 mA
- **Power Dissipation**: 625 mW
- **DC Current Gain (hFE)**: 160–400 (BC337-25)
- **Typical Applications**: Used in the Class A output stage for current amplification and low output impedance driving an 8Ω speaker.

3. OA71 Diode (Germanium)

- **Type**: Germanium point-contact diode
- **Forward Voltage Drop**: ~0.2–0.3V
- **Peak Reverse Voltage**: ~90V
- **Max Forward Current**: ~50 mA
- **Typical Applications**: Used in the demodulator for AM signal detection due to its low forward voltage drop.

4. 22 µF and 1 µF Capacitors

- **Types: Electrolytic for µF values, ceramic for nF values (based on typical usage)**
- **Voltage Ratings: Usually 16V–25V for electrolytic, 50V for ceramic**
- **Tolerances: ±20% (electrolytic), ±10% or better (ceramic)**
- **Functions in Circuit:**

1. **22 µF: Used for power supply decoupling and output coupling in amplifier stages**
2. **1 µF: Acts as a DC blocking or bypass capacitor in signal paths**
3. **1 nF & 1.8 nF: Used in filtering (e.g., low-pass or bandpass filters), timing, or stability networks**

- **Typical Applications in Project: Capacitors were used in the demodulator and amplifier stages to pass AC signals while blocking DC, stabilize gain, and smooth signal transitions.**

5. Resistors (Various Values)

- **Type**: Carbon film
- **Tolerance**: ±5%
- **Power Rating**: 0.25W
- **Function**: Used in biasing networks, gain control, filtering, and load stabilization.

6. Speaker (8 Ω)

- **Impedance**: 8 ohms
- **Power Rating**: Typically ~1–2W
- **Function**: Final output stage to convert electrical signal into sound.

7. Wires, IC Socket, Perforated Board

- **Function**: For physical connections, mounting, and soldering of the circuit components.