Lab 1: Audio Amplifier Circuit

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Objectives

In this laboratory session, we will conduct three experiments using the LM386 IC.

- In Experiment 1, we implement an audio amplifier circuit using the LM386 IC given in section 9.2.1 of the datasheet[1] on a breadboard. Our objective was to observe the default lower gain limit of the circuit.
- In Experiment 2, we obtain the frequency response of the audio amplifier circuit built in Experiment 1 by changing the input signal frequency and measuring the resulting output voltage amplitude. We experimentally determined the lower cutoff frequency of the circuit.
- In Experiment 3, we modify the audio amplifier circuit built in Experiment 1 to get a gain of 200. By referring to section 9.2.2 in the datasheet [1], we analyze the impact of increasing the gain of the LM386 IC-based audio amplifier from 20 to 200 for a fixed input magnitude.

Background

An operational amplifier (Op-amp) is an integrated circuit (IC), which comes in different packages including the Dual Inline Package (DIP), and the Small Outline Integrated Circuit (SOIC) package. Op-amps are widely used as signal amplifiers, filters, and oscillators.

The op-amp needs power supply input and a grounded power supply for its operation and the output of an op-amp circuit always stays within the power supply values. An op-amp is usually used with a negative feedback circuit in signal amplification applications. This means the voltage gain of the op-amp is completely dependent on external resistors and capacitors in the circuit. By choosing appropriate values of these external circuit components we can achieve any desired low value of gain. In some application-specific op-amp ICs, such as the LM386, a default value of closed-loop gain is achieved by including some additional resistors inside the IC.

We will be using an application-specific op-amp IC: the LM386, which is a low-voltage audio power amplifier and is commonly used in AM-FM radios and portable music players. In this experiment, by referring to the datasheet of the LM386 IC we will build a simple audio amplification circuit, and then obtain and analyze the frequency response of the circuit over the human audible frequency range (20 Hz to 20 kHz).

Bandwidth is the range of frequencies where the voltage gain of the op-amp is at least 70.7% of the desired maximum output value. A signal will be amplified without distortion if its frequency lies within the bandwidth range. An ideal op-amp has infinite bandwidth, this is only useful theoretically. In reality, commercially available op-amps have very high open-loop gain (~10^5) near 0Hz. Increasing the frequency causes the open-loop gain to decrease drastically (~1) for frequencies in the MHz range. The gain*bandwidth product is a constant for op-amps and the gain of order 10^5 is not necessary for most applications, therefore we will be increasing the bandwidth by reducing the gain.

Pre Lab Questions

1. *What is the maximum value of analog input voltage for LM386?*

-0.4v to 0.4v

2. *What is the minimum value of DC supply voltage for LM386?*

4v Min. to 12v Max.

3. *What is the range of load impedance that LM386 can drive?*

Recommended 4Ω

4. *What is the default voltage gain of LM386?*

20 db
There is an internal 1.35-KΩ resistor that sets the gain of this device to 20.

5. *How can the voltage gain value be modified to 50?*

the addition of an external resistor and capacitor between pins 1 and 8 increases the gain to any value from 20 to 200.

Datasheet ->

"If a capacitor is put from pin 1 to 8, bypassing the 1.35-kΩ resistor, the gain will go up to 200 (46 dB). If a resistor is placed in series with the capacitor, the gain can be set to any value from 20 to 200."

Gain (db) = log representation of the linear voltage gain

Av (unitless) = voltage gain -> ratio of the output voltage to the input voltage in linear terms. A multiplier.

Gain (db) = $20\log_{10}(Av)$ -> $10^{\wedge(gain/20)}$ =Av

$50 = 20\log_{10}(Av)$

$50/20 = \log_{10}(Av)$

$2.5 = \log_{10}(Av)$

$Av = 10^{\wedge 2.5} = 316.23$

Av = 20 + R1/Ri (in datasheet) 20: default gain, r1: external resistor between pin 1 and 8, ri: internal resistance to pin 8 (15 Ω for LM386)

Solving for R1

R1 = (Av -20)*Ri

R1 = (316.23 - 20) * 15 kΩ

R1 = 296.23 * 15 kΩ

R1 = 4443.45kΩ R1 = 4.44 MΩ

6. *What is the typical power output from LM386 when operated with a dc supply voltage of 6v, and a load resistance of 8 Ω?*

a. Datasheet suggests 325mW
b. Potentially calculated by peak output voltage swing 5v
   i. 5v/2 = 2.5v peak from the midpoint
   ii. Rms voltage = Vpeak/root 2 = 1.77V
   iii. Pout = V^2rms/root 2 = 1.77^2/8 Ω = 395mW

7. *If voltage gain of LM386 is 100, what will be its equivalent value when expressed in dB?*

a. log10(100) = 2, Gaindb = 20* 2 = 40 dB

8. *What is the typical supply current taken up by the circuit given in Fig. 12 of the datasheet for a dc supply voltage of 5v?*

a. Looking at the graph in Figure 13 shows about 3.7 mA

9. *What does RoHS mean?*

Restriction of Hazardous Substances

10. *What is the difference between Absolute Maximum Ratings and Recommended Operating Conditions?*

    The Absolute Maximum Ratings are the extreme limits that the device can withstand without being damaged. Beyond this, the device might suffer irreversible damage. Recommended Operating Conditions are the ranges within which the device is intended to operate normally. Recommended conditions (voltages, currents, temperatures, etc.) result in the device functioning as specified with a particular guarantee from the manufacturer.

Integrated Circuit Description

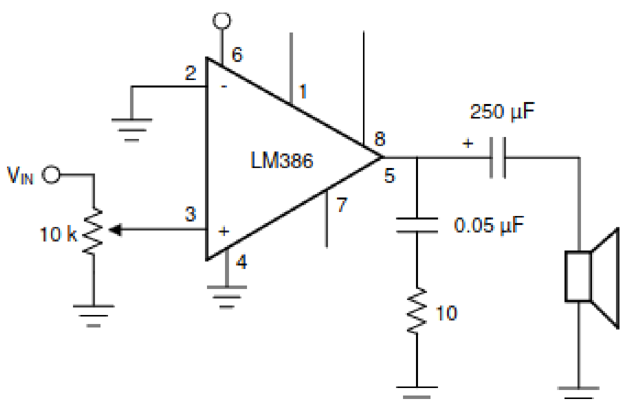

Figure 10. LM386 with Gain = 20

Figure 1: Minimum part count application using the LM386 IC provided by the datasheet that models the actual circuit tested in the lab.

Listed adjustments and default values performed in the actual test circuit (see Figure 2 below for an updated schematic):

- 250 µF capacitor replaced with 470 µF electrolytic capacity.
- 0.05 µF capacitor replaced with 0.047 µF ceramic capacitor.
- There is no 10 kΩ resistor following the 0.047 µF capacitor on the output.
- Analog V_{in} is connected directly to pin 3 with a default value set to 0.1 V amplitude and 3 kHz frequency.
- +5 V to power the IC on pin 6.
- 0.25 W speaker replaced with an 8 Ω dummy load resistor.

- Added a 10 μF capacitor to our analog v+ to block any dc bias coming in.
- Typical bypass capacitor connected to pin 7 (shown in datasheet 9.2.2 [1]) was not used.

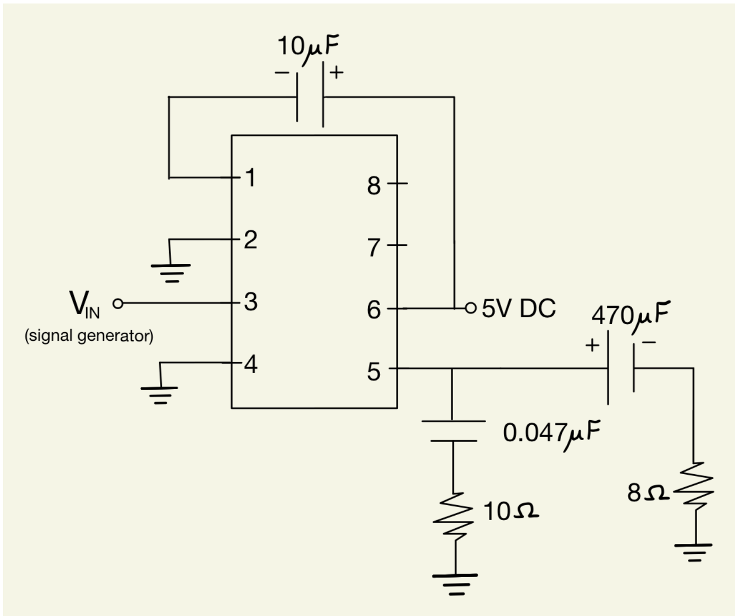

Figure 2: Adjusted Audio Amplifier Circuit Using the LM386 IC used in the experiment

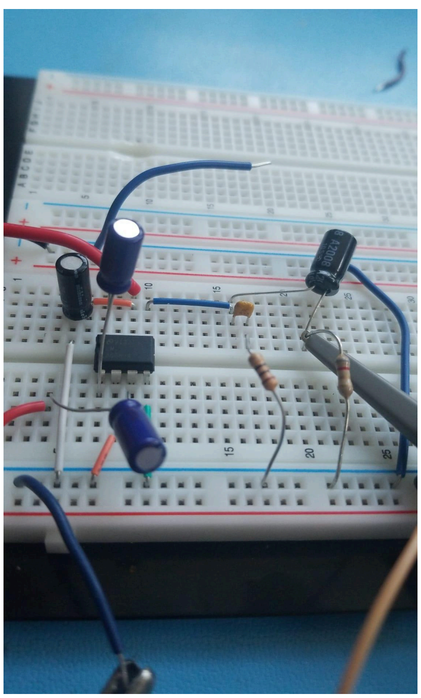

Figure 3: Implemented circuit (rebuilt in IEEE lab)

The 10 μF filtering capacitor between our power supply voltage and pin 1 goes to ground (Figure 3). This is a recommended practice, (see 10 Supply Recommendations [1]) and functions to decouple AC noise (high frequencies) and pass the DC on the power pin. The capacitor provides lower impedance to changing voltage (higher frequencies) and will block lower frequencies (~0 V). As a result, the DC power signal is blocked by the capacitor and appears on the power pin and the higher frequencies will go to ground. This capacitor could also function as a power source “bypass”, when transient voltage drops occur; the capacitor could supply the power lost in the drop further stabilizing the signal. Using the cutoff frequency formula and assuming low line input resistance of 0.1Ω

$F_c = 1/2\Pi RC \Rightarrow 1/2\Pi * 0.1 * 10 * 10^{-6}F = 159{,}155$ Hz or 160 kHz
Frequencies at 160kHz and above will be removed from the power signal.

The 470 μF (figure 2) is functioning as a DC blocking capacitor. We are preventing any DC bias voltage potentially leaving the IC386 from hitting our speaker. DC voltage hitting the speaker (8Ω dummy load) does not add value to the sound quality and would simply heat up the speaker. This capacitor would provide low capacitive reactance to higher frequencies, thereby allowing our audio signal to pass to the speaker.

$C = 470 * 10^{-6}$ F
$R = 8\ \Omega$
F_c = cutoff frequency

$F_c = 1/2\Pi RC \Rightarrow 1/(2\Pi * 8 * 470*10^{-6} F) = 42$ Hz

This cutoff frequency means that the capacitor will attenuate all frequencies below 6.76 Hz greater than 3 dB.

Finally, the 0.047 μF decoupling capacitor is functioning as a high pass filter to ground. It will show a lower reactance to higher frequencies.

$C = 0.047*10^{-6}$ F
$R = 10\ \Omega$ (series resistor)
F_c = cutoff frequency

$F_c = 1/2\Pi RC \Rightarrow 1/2\Pi * 10 * 0.047*10^{-6} F = 338.63$ Hz

The signal will see reduced reactance and will be shunted to ground beyond the cutoff frequency of 338.63Hz.

Also, note that we placed an additional 10 μF capacitor to our analog Vin+ coming into pin 3 from the function generator to block any potential DC bias (not shown in Figure 2).

Results

Experiment 1

In Experiment 1, we tested the circuit shown in Figure 2.

a. +5V power applied to the IC
b. Analog input sine wave with 0.1V amplitude and 3 kHz frequency using a signal generator.
c. Voltage waveform **across the load resistor** measured at $2.05V_{pp}$. Given that our input signal was 0.1 V with a default gain of 20, we expected 20 * 0.1V = 2V
d. The displayed measurement in the oscilloscope shows the voltage at the **output pin of the IC** (see Figure 4).

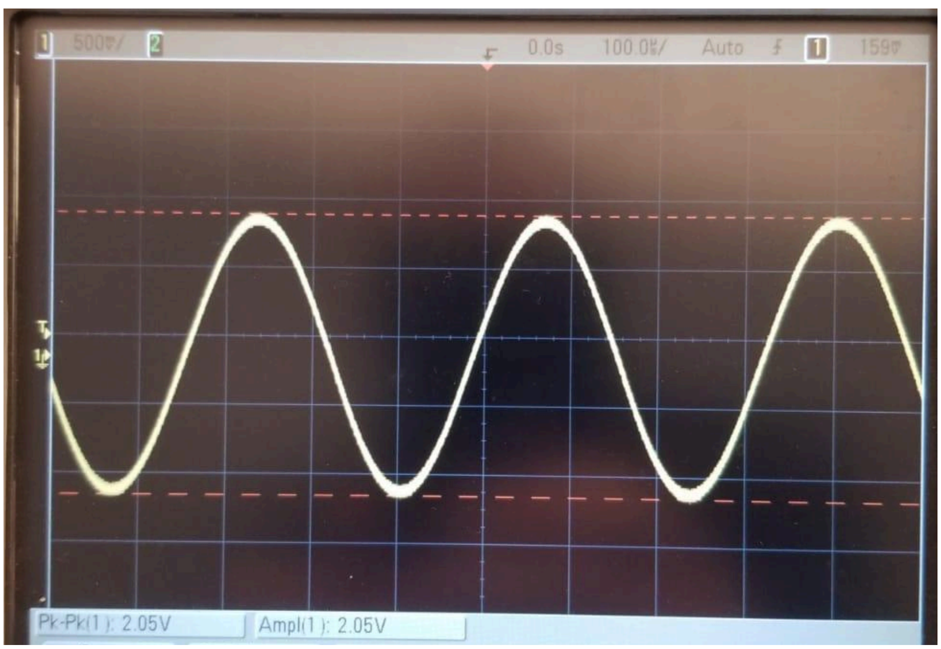

Figure 4: Gain of 20 across internal 1.35kΩ with 0.1V analog input.

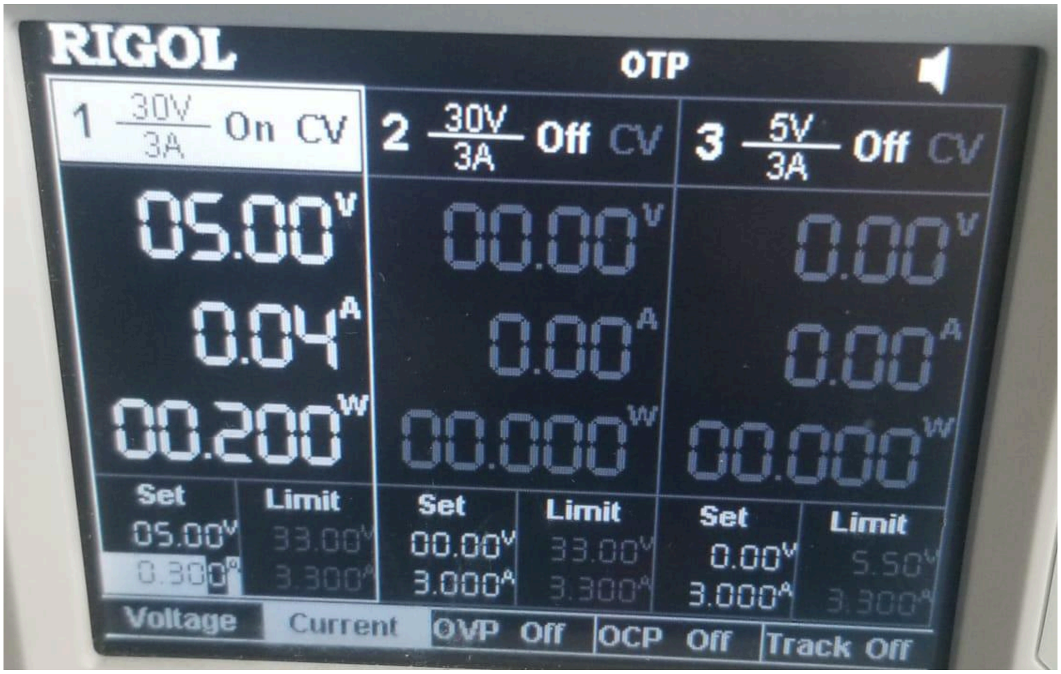

Figure 5: 0.04 A - Low Current Draw (high input impedance)

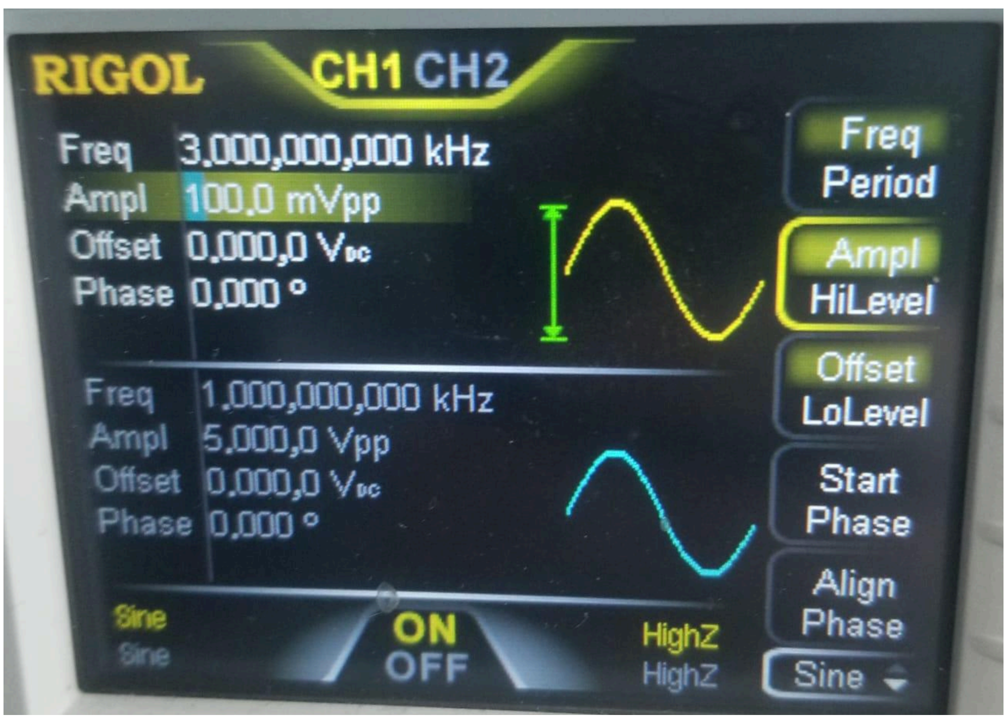

Figure 5: Channel 1 Signal (Yellow) Applied to Analog V+

Experiment 2

In the second experiment, we obtain the frequency response of the circuit used in Experiment 1 by changing the input signal frequency to the following values in Table 1 and measuring the output voltage amplitude under each condition.

- 5V Supply Voltage
- 0.1V Analog V+

Input signal frequency (Hz)	Output voltage peak value as measured in oscilloscope
20	930 mV
40	1.5 V
80	1.8 V
160	2V
200	2 V
400	2 V
800	2 V
2000	2 V
4000	2V
8000	2V
16000	2V
20000	2V

Table 1: Input Signal Frequency Response

Figure 6: Input of 0.1V at 40 Hz resulting in an attenuated output voltage

Experiment 3

In the third experiment, we modified the circuit used in part 1 by adding a 10 μF capacitor across pin 1 and 8 to get a gain of 200 as specified in the datasheet in section 9.2.2[1].

Once the circuit is modified for the new gain value,
(a) Use +5 V to power the IC.
(b) Input a sine wave with 0.1 V amplitude and 3 kHz frequency using a signal generator.
(c) Measure the voltage waveform across the load resistor and display it in an oscilloscope.
(d) Also measure and display in the oscilloscope the voltage at the output pin of the IC.

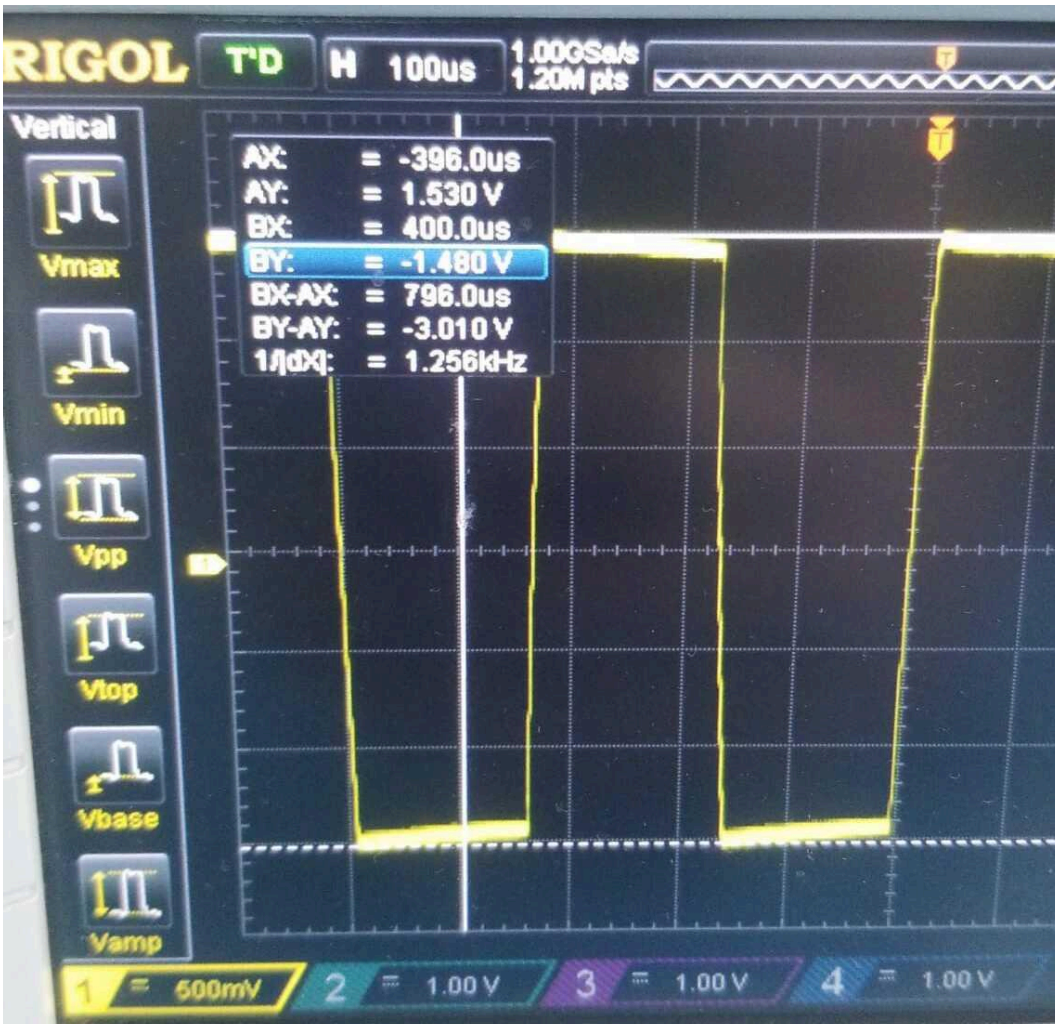

Figure 7: Observed clamping around 3V at 200 gain

Discussion:

1. *What are the advantages and drawbacks of using LM386 IC instead of a generic op-amp for audio amplification?*

Unlike generic op-amps, the LM386 IC includes an internal resistor that provides a closed-loop gain default value of (~20 db). Adding a capacitor in parallel to the internal resistor between the gain control pins 1-8 acts to bypass the internal resistor allowing a maximum gain of up to (~200 db). The internal resistor sets a default closed-loop gain which provides the engineer with a low part count system, thereby reducing footprint size and costs. Despite these advantages we sacrifice precise gain settings that we might see in a generic op-amp.

The LM386 is a low-voltage audio op-amp IC which is capable of receiving AM radio signals, making it ideal for use in audio applications with low power consumption. However, the bandwidth is limited to 300 kHz, this isn't suitable for high frequency applications.

2. *Compare the theoretical values and the experimental results for the (a) First experiment (b) Third experiment*

    a. As we touched on in discussion 1, the internal resistor provides a default closed-loop gain of 20. In an "ideal" op-amp, we would expect to see an infinite open loop gain. In real-world applications such as the lm386, the IC can accept and operate on signals within the voltage levels limit between the two power rails, in this case, +5v and ground. Theoretical value for experiment 1:

    20 (gain) * 0.1 V (analog input) = 2 V

    Because our signal is within the supply voltage limits we expect to see an amplified sine wave. Our experiment accurately shows the amplified signal at 2 volts in figure 4.

    b. In experiment 3, we expect to encounter the upper bounds of output voltage through a higher gain of 200. We can achieve this by bypassing the internal resistor with a 10 μF capacitor in parallel.

    200 (gain) * 0.1 V (analog input) = 20 V

    Due to the output voltage limits set by input supply voltage, we would expect clamping to occur around 5 volts. Looking at figure 7, we do see the clamping drawn on the scope clipping the sine wave resembling a square wave.

3. *Comment on any deviations between the theoretical and experimental results for the (a) first and (b) third experiment*

    a. Looking at figure 4, the gain tracked closely to our expectations:

20 * 0.1V = 2V.

b. Looking at figure 7, the gain is 200 and has not been reduced, but the output voltage range is clamped at 3 volts. We expected clamping at 5 volts minus a few diode voltage drops (4.8 V) that appear within the op-amp shown in the LM386 schematic[1]. The excessive clamping surprised us, however, according to Horwitz, "The op-amp output cannot switch beyond the supply voltages (typically it can swing only to within 2 V of the supplies"[5]. Based on this we can say that 3 V clamping is within 2 V of our 5 V supply. This explanation might be further clarified in future testing at higher supply voltages.

- Comment on the bandwidth of the op-amp circuit using the results obtained in the second experiment.

Bandwidth, as described above in the background section is the range of frequencies where the output voltage is 70.7% of the maximum output. Looking at table 1 and our theoretical gain calculation, we see that the maximum output is 2 V under the default configuration.

2 V * 0.707 = 1.414 V

Our bandwidth constitutes every frequency where the output voltage is above 1.4141 V. We can see from table 1 that 20 Hz has an output of 930 mV (well below 1.4V), but at 40 Hz we see 1.5 V, slightly above 1.4 V. We can conclude that our *experimental* lower cutoff frequency to be around ~38 Hz. In the circuit description section, we determined that the *expected* lower cutoff frequency of the amplifier output across the 470 μF capacitor and 8 ohm resistor to be 42 Hz, restated:

$Fc = 1/2\Pi RC \Rightarrow 1/(2\Pi * 8 * 470*10^{-6} F) = 42$ Hz (close to experimental 38Hz)

The stated bandwidth in the datasheet under this configuration will be approximately 300 kHz. This means that our theoretical upper cutoff frequency would be 300kHz - 42 Hz = 299, 958 Hz. Since we did not actually test this frequency, we cannot conclude with certainty that the output voltage would drop near 1.414 V at this theoretical upper cutoff value.

- Discuss all the challenges you encountered while performing the experiment. Also, mention how you overcame these challenges.

We encountered a combination of noise, distortion, and bias likely introduced by esr/esl through our breadboard connections. With hints from the lab technicians, placing capacitors on our inputs (power and signal) proved to be effective.

Conclusion

In this lab experiment, we successfully improved our understanding of op-amps, capacitive reactance and impedance, bandwidth, voltage, voltage supply, and voltage input and gain. Proper voltage gain through the op-amp allows us to get the needed output with a lower input voltage by way of its low output impedance. We can achieve these gains (up to 10^5) with negligible input current due to its high input impedance. Bandwidth must be considered to avoid compromising voltage output. Additionally, we better understood audio amplifier circuits, specifically using the LM386IC. We constructed and tested an audio amplifier circuit on a breadboard and powered it with 5V and observed its performance by measuring the amplified output across a resistor. By using different input signal frequencies we identified the bandwidth. Also, we examined the impact of increasing gain from 20 to 200 and showed how higher gain settings amplify the output, but also introduce distortion and limit bandwidth.

Overall, this experience with the LM386 IC allowed us to reinforce these theoretical concepts and improve our practical circuit skills. All of this will assist us during the design, development, construction and testing of the clock radio project.

References

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5. Horowitz, P., & Hill, W. (2015). *The art of electronics* (3rd ed.). Cambridge University Press.