## Introductory Comments for VCP members:

The following pages are taking from a workbook I supply students at the beginning of the semester in our circuits 1 course for electrical and computer engineers. The activities I include in this document cover the second “project circuit” students build during the semester. The materials support our study of sinusoidal steady-state analysis. Prior to the first activity described herein, we have spent time in lecture introducing phasor notation and impedance and students have completed a separate in-class activity during which they make basic calculations with impedance in series and in parallel.

Included are three fifty-minute lecture periods worth of collaborative group work (the two in-class activities) and two, 1 hour and 50 minute lab activities.

In the past, I have used informal collaborative groups to work through the in-class prelabs. During these in-class sessions, I introduce the topic of the day and then walk around the room listening in on the group discussions, providing guidance as needed. When I find common questions or misconceptions among the groups, I capture the attention of the entire class and then discuss the concepts with the class as a whole. During lab, students typically work with a partner; lab reports are required from each student. Based on what I have learned in the VCP, I am strongly considering using formal teams assigned via CATME or similar for Fall 2013.

# PROJECT CIRCUIT 2:

# The EELE 201 Audio Amplifier Circuit

Our second project will be an audio circuit designed to convert the stereo output of an mp3 player to mono and allow the user to alter the frequency content of the mp3 player's output prior to driving a speaker. We will break the overall circuit into three sub-circuits: (1) the summing amplifier used to combine (and potentially amplify) the left and right channels into a single signal, (2) a tone control circuit allowing the user to adjust the frequency content of the signals passing through the circuit, and (3) a power amplifier capable of driving a standard 8Ω speaker. A block diagram for the battery-powered audio circuit is shown in Figure 3.

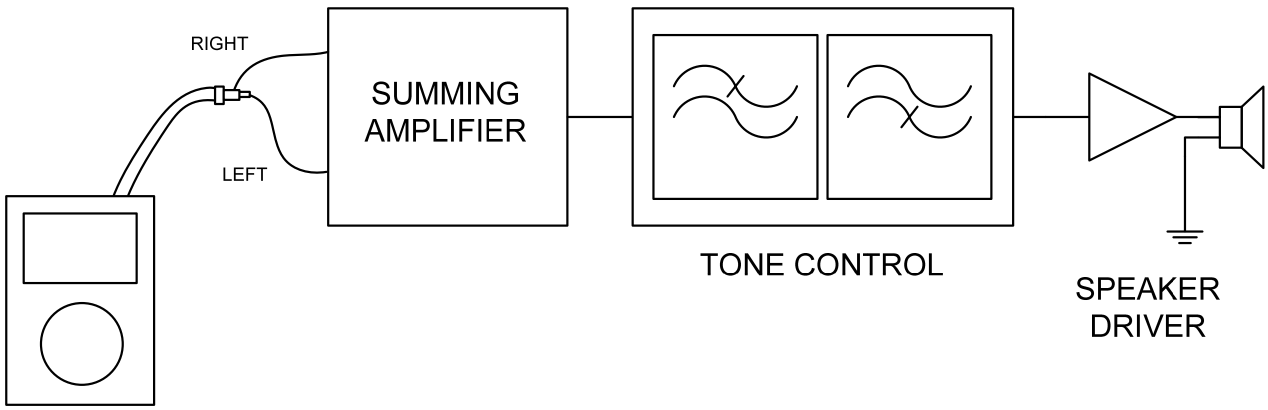


***FIGURE 3: Block diagram of the audio amplifier circuitry.***

We must make clear at the outset that the audio circuit you will explore is a very basic one, meant more to teach you important concepts in circuit analysis and design, rather than to realize a high-performance audio system. One look at the speaker you will use in your circuit will tell you this quite quickly! The fact that audio applications are so commonplace suggests that elegant solutions to the problem at hand already exist. Indeed, there are single-chip solutions to the basic audio concept outlined in Figure 3. While using such commercially available chips would realize a superior end-product, the amount of learning in going that route would be very limited. Hopefully, understanding the project circuit you are about to explore will encourage you to do some investigations on your own.

***Task Sequence:***

- In-Class Activity 1: Summing Amplifier Design and the 3 dB Frequency
- Lab Activity 1: Summing Amplifier Design
- In-Class Activity 2: Tone Control – High Pass and Low Pass Filters
- Lab Activity 2: A Simple Tone Control Circuit

# Audio Lab In-Class Activity 1: Summing Amplifier Design

***Additional Materials Needed:***

• Calculator

***Goals:***

• To gain further practice and confidence in analyzing op amp circuits and in utilizing superposition

• To identify key properties of two op amp circuits that may be used to add two or more inputs together

• To use sinusoidal steady-state analysis to determine the “3 dB frequency” of a summing circuit

***Time Expectation:***

It is expected that your group will be able to work through the first four steps of these in-class activities today. If your group does not make it through this point today, please complete these steps prior to the next lecture period. During the second class period devoted to these activities, the instructor will introduce the use of the decibel scale and allot approximately 40 minutes, which should be sufficient time, to complete these activities.

# Audio Lab In Class Activity 1: Summing Amplifier Design

## Introduction

In these prelab activities you will investigate two potential summing amplifier designs that could be used to combine the left and right channels of an mp3 player. During these exercises and in working through the corresponding lab activities, keep in mind that the audio spectrum spans approximately 20 Hz to 20 kHz.

## Exercises

1. Consider the two potential op amp configurations shown in Figure 1. *Assuming that the capacitor acts like a short circuit at signal frequencies of interest, determine the output voltage in terms of the input voltages and the resistors for each configuration*. The input voltages $_{VOC,LEFT}$ and $_{VOC,RIGHT}$ along with their respective resistances, $R_{TH,LEFT}$ and $R_{TH,RIGHT,}$ represent the Thévenin equivalent circuits of the left and right channels of a typical mp3 player.

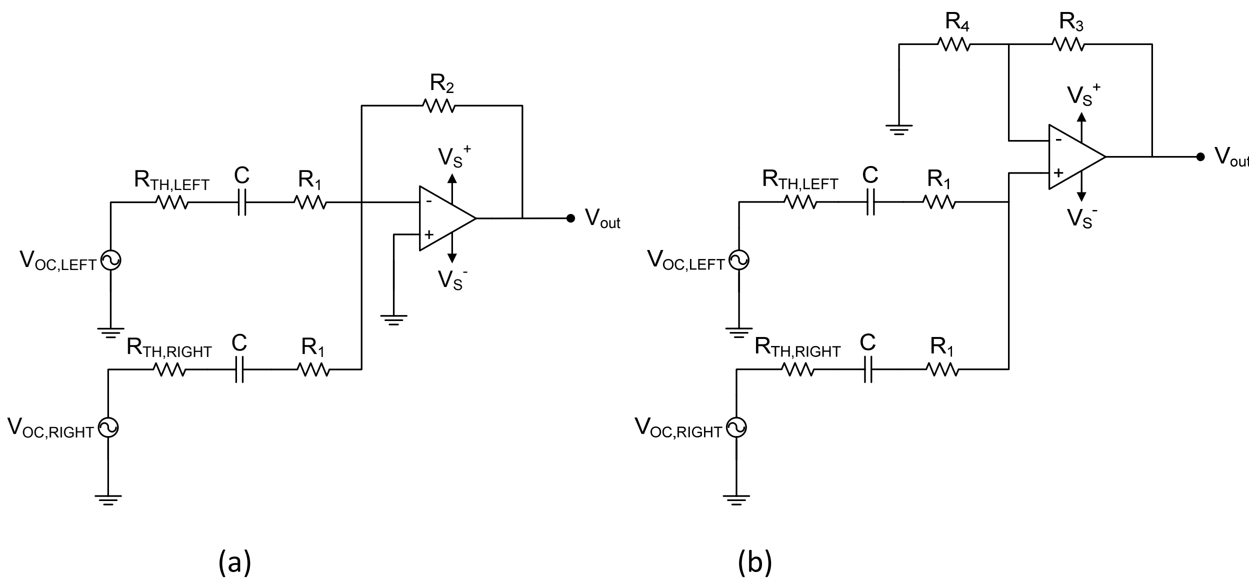


Figure 1: *Two potential summing configurations to combine the left and right channels of the mp3 player.*

2. Based on what we have learned about sinusoidal steady-state analysis and impedance, under what conditions do you feel treating the capacitors as short circuits would be valid in the circuits considered in 1?

3. Assuming it is important that the gain of one channel is independent of the properties of the other channel, which configuration would you choose? Briefly explain how the circuit achieves this independence through negative feedback and the connections at the inverting and noninverting nodes of the op amp.

4. Reintroduce the capacitors in the configuration (a) circuit. Assuming the input is a single-frequency sinusoid of radian frequency $\omega$, find the expression for the steady-state output voltage in terms of $V_{OC,LEFT}$. (An identical expression may be found for $V_{out}$ in terms of $V_{OC,RIGHT}$.)

5. What is the maximum value of the output voltage expression found in 4 and does the circuit realize a lowpass or highpass filtering response? Explain.

6. Solve for the frequency at which the magnitude of the output voltage drops to $1/\sqrt{2}$ of its maximum value – this is the so-called “3dB frequency.” The 3dB represents the frequency at which the power (proportional to voltage squared for a resistor) drops by ½ from its maximum.

7. Based on our audio application, discuss the considerations in placing the 3 dB frequency as found in 5.

8. Given circuit (a), and assuming $V_s^+$ = 9V and $V_s^-$ = - 9V, what is the ideal (i.e. maximum) signal swing of a sinusoidal output voltage?

9. Assume that the output of the op amp is to drive a typical 8Ω speaker. Consider the required current at full voltage swing to determine if a typical op amp could “drive” such a low resistance load.

# Audio Amplifier Lab One: Design of the Summing Amplifier

## Introduction

Based upon what we found in the prelab exercises, we will elect to build the summing stage using an inverting amplifier and utilize an LM358 in doing so. While we could elect to realize signal amplification with this stage, we will use it as a unity summer; in other words, we will set the gain to one.

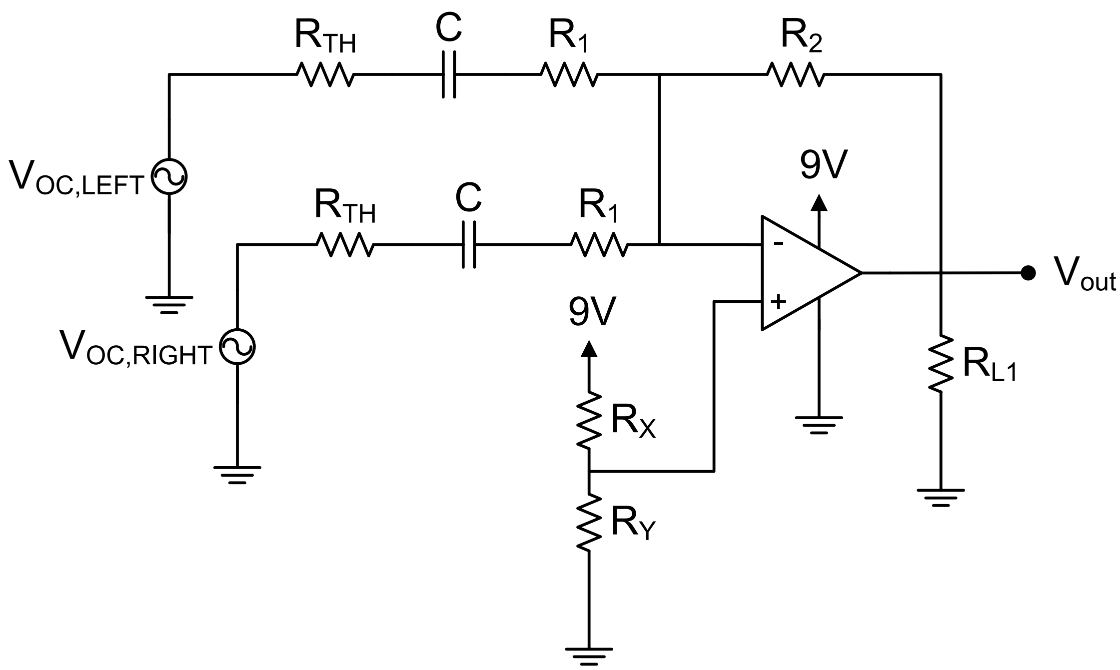


Figure 1: *A single-supply inverting summer to be used to ultimately convert the mp3 player's stereo output to mono.*

## Lab Exercises

### SINGLE – SUPPLY SUMMING AMPLIFIER

1. Using the LM358 build the single-supply inverting summing amplifier shown above in Figure 1 where $R_{th}$ refers to the function generator's (or mp3 player's) Thévenin resistance. *Attempt to realize the circuit with parts in your kit subject to the following design specifications:* ***$R_{L1}$ = 3.3k$\Omega$, unity voltage gain (per channel at max gain), $f_{3dB}$ < 20Hz and current drawn through $R_2$ < 0.5 mA at the maximum output voltage.*** The function generators in our lab have two channels; use one to realize $V_{OC,LEFT}$ and the other $V_{OC,RIGHT}$.

*What are key considerations in choosing $R_X$ and $R_Y$ for our battery-powered audio circuit? Complete table 1 with your selected values (nominal based on available 5% resistors).*

*Show the calculations necessary to establish the 0.5 mA current limit through $R_2$.*

*Show the calculations used to decide on values for $R_1$, $R_2$ and C for your unity gain summer circuit. Complete table 1 with your selected values.*

*Assuming that the mp3 player can be characterized with Thévenin resistance of approximately 5$\Omega$, based on your choice for $R_1$ and $R_2$ how much effect does $R_{TH}$ have on the gain expression when driving the amplifier with the mp3 player? How about the expected effect when driving the amplifier with the function generator?*

**TABLE 1: Component Value Selections**

| $R_1$ | $R_2$ | $R_X$ | $R_Y$ | C |
|---|---|---|---|---|
| | | | | |

2. Set one input to 1 kHz sinusoid with a 1 volt peak-to-peak amplitude and the second input to a 5 kHz input with a 2 volt peak-to-peak amplitude. *In the space below, provide a sketch of the output signal and attempt to explain its general form. Save a screenshot for use in a report.*

3. Ask your instructor for a large coupling capacitor (~220 μF). <u>This capacitor is polarized and so orientation is critically important</u>! Power down your circuit and connect the coupling capacitor between the LM358 and an 8Ω resistor (modeling a simple 8Ωspeaker) as suggested in Figure 2. Set one input to 1 kHz sinusoid with a 1 volt peak-to-peak amplitude and ground the second input.

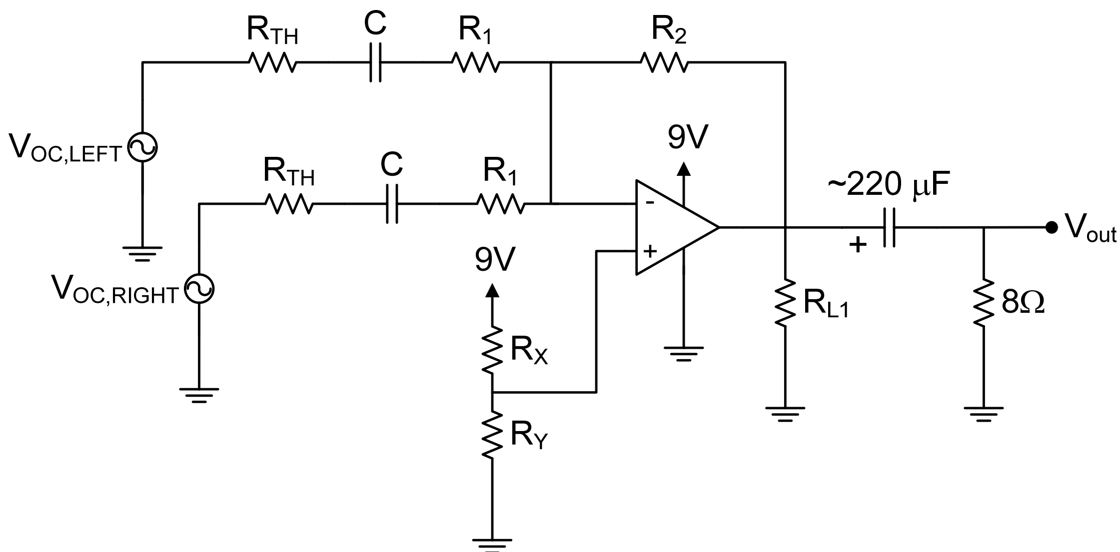


Figure 2: The single-supply inverting summer AC coupled to an 8Ω resistive load.

4. *Can the configuration make use of the entire available output signal swing?* This may require you to fiddle with the input amplitude. **<u>Explain</u>**. (The available output swing is limited by the DC output voltage in comparison to the supply voltage.) Explain.

5. Calculate the maximum current flowing through the 8Ω resistor.

*Demonstrate the "clipping" effect and your maximum current calculation to the instructor.*

**DO NOT DISASSEMBLE YOUR CIRCUIT AS YOU WILL NEED IT DURING THE NEXT LAB SESSION!**

# Audio Lab In-Class Activity 2: A Simple Tone Control Circuit

### *Additional Materials Needed:*

• Calculator

### *Goals:*

• To gain further practice in sinusoidal steady-state analysis and in the manipulation of complex numbers

• To be able to identify the difference between lowpass and highpass filters

• To understand how to place the corner frequency in a first-order circuit

### *Time Expectation:*

It is expected that your group will be able to complete steps 1 through 4 during today's class and will need approximately twenty minutes of additional time to work through and discuss step 5. Please complete the entire set of activities prior to this week's lab – Audio Amplifier Lab 2.

# Audio Lab 2 In-Class Activity: A Simple Tone Control Circuit

## Introduction

In these prelab activities you will investigate a first-order filtering section that you will introduce in your audio amplifier to modify the frequency content of the music reaching the speaker.

## Exercises

1. Consider the circuit shown below:

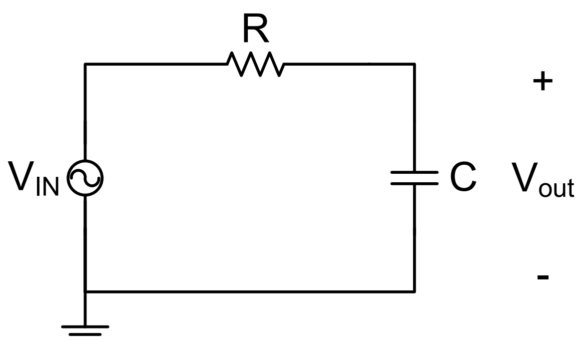


Figure 1: *A Simple First Order RC Circuit*

1. Assuming sinusoidal steady-state, develop an expression for the voltage "gain" as a function of frequency. This function, denoted, H(ω), is often referred to as the *network function* or *transfer function*. That is, find:

$$H(\omega) = \frac{\tilde{V}_{out}}{\tilde{V}_{in}}$$

2. Develop an expression for the magnitude of this network function, $|H(\omega)|$.

3. Based on the expression for the magnitude of the network function, do you think this is a lowpass or highpass filter? In a lowpass (highpass) filter, the magnitude is large (small) at low frequencies and decreases (increases) as frequency increases. *Explain*.

4. A filter's *corner frequency* (or 3dB frequency) is defined as the frequency at which the magnitude of the network function is 1/√2 of its maximum value, recall that this corresponds to the half-power frequency.

a) At what frequency is the magnitude of the network function a maximum and what is its maximum value?

b) Assuming that C = 1nF, find the value of R to place the circuit's corner frequency at $f_c$ = 20 kHz. That is, what value of R is necessary such that:

$$\left|H\left(2\pi f_c\right)\right| = \frac{1}{\sqrt{2}}\left|H\left(\omega\right)\right|_{MAX}$$

5. Now consider the following circuit in which we introduce a simple op amp circuit between our filter and the input circuit to the LM386.

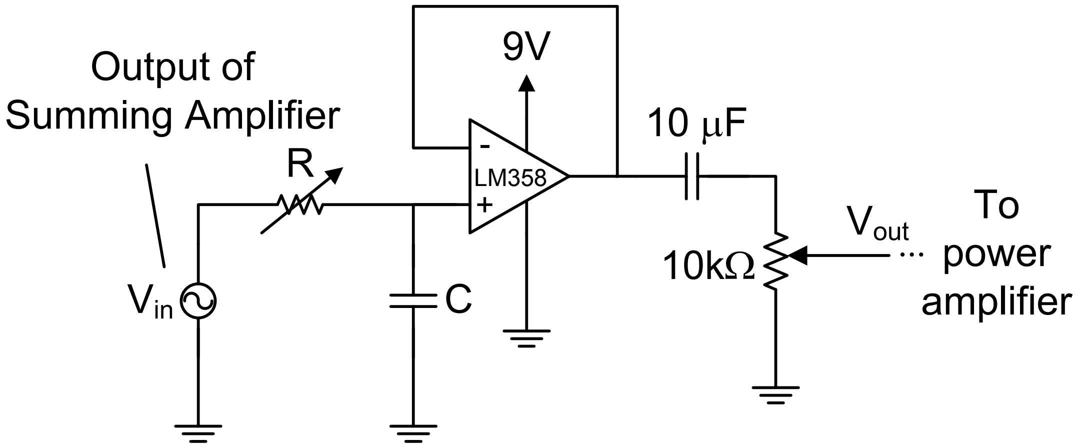


Figure 2: *The First Order RC Circuit with a coupling circuit.*

a) What is the purpose of the op amp portion of the circuit?

b) Assuming that $V_{in}$ is a sinusoidal input with peak amplitude of 1V and variable frequency, C = 1 nF, R is the value you found in 4b), and that the potentiometer's wiper is at the top of the 10kΩ potentiometer, provide a sketch of the output voltage as a function of the input frequency between 0 Hz and 20 kHz. HINT: Think about the impedance values of the capacitors at the extremes of the frequency range.

c) Why might we consider the overall response of the circuit of Figure 2 to be bandpass?

# Audio Amplifier Lab Two: Implementing A Simple Tone Control Circuit

## Introduction

In this lab you will implement and characterize a simple RC filter in between the summing amplifier and the power amplifier of the EELE 201 Audio Amplifier. This filter will be used to “clean up” an audio file with added noise. Since the filter you will implement is the most basic of such filters, we must expect that improved performance could come by pursuing a more complicated design – a subject for another course.

## Lab Exercises

### Implementation of A Simple RC Filter

1. Assemble the circuit shown in Figure 1 using a decade box for the variable resistor R. The summing amplifier portion of the circuit should already be assembled on your board from our last set of lab exercises. Use the two channels of the function generator to realize the left and right channels. Set one channel to a 1 kHz sinusoid with a 2V peak amplitude and the second channel to a 20 kHz sinusoid with a 1V peak amplitude. Set $C_2$ = 1 nF as in the prelab.

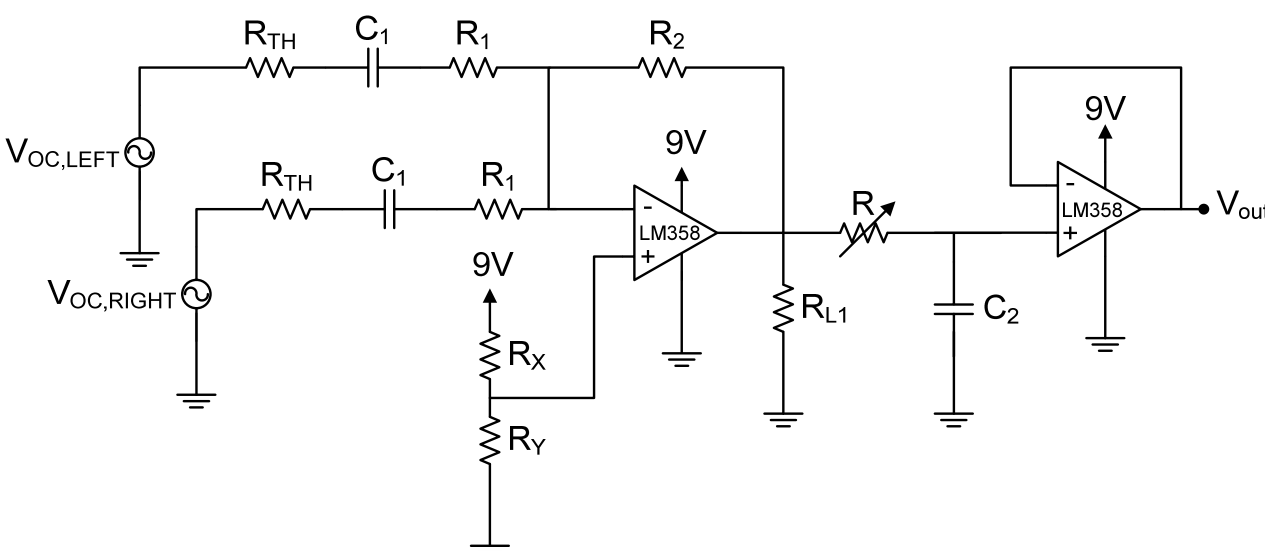


Figure 1: *The summing amplifier with an output filter ready for connection to the output amplifier and speaker.*

1. What are the expected DC voltages at the top or resistor $R_{L1}$ and at the output node of the second op amp? Verify these values using both the DMM and the "mean" measurement function of the oscilloscope.

2. **Set the resistor box to 1kΩ**. Place oscilloscope probes at both the output of the first op amp to ground and at the output of the second op amp to ground. You should experiment with both AC and DC coupling. In the space below, sketch the output waveform at both of the probed nodes. *Save a screenshot for use in your formal report and comment on what is observed.*

3. **Now set the resistor box to 30kΩ.** Place oscilloscope probes at both the output of the first op amp to ground and at the output of the second op amp to ground. In the space below, sketch the output waveform at both of the probed nodes. *Save a screenshot for use in your formal report and comment/explain on what is observed.*

*Have the lab instructor observe the performance of your circuit with the two values of the resistor box and sign off indicating that your circuit is acting as expected.*

4. Provided that the instructor verified the proper operation of your circuit, you are now to obtain both an mp3 player and output stage from the lab instructor. Replace the function generator connections with the left and right channels of the mp3 player and connect the output of your circuit to the input of the output stage. **Set the resistor box to 1kΩ**.

5. Play the mp3 player's audio file, being prepared to adjust the volume by way of the output stage's potentiometer and the mp3 player's volume control. You should hear an acoustic version of a popular song along with a single tone interfering (and definitely annoying) signal. Attempt to adjust the resistance value of the resistor box to clean up the audio track. Once you are satisfied with the sound of the audio signal, leave the resistor box at its current value, power down the circuit and turn off the mp3 player. *Be advised that you will only be able to improve the sound, not return it to its uncontaminated form.*

CHOSEN RESISTOR BOX SETTING: _________

6. Remove both the summing amplifier connection and the output stage. Connect one channel of the function generator to the input of your filter circuit and connect a 1□F capacitor in series with a 10 kΩ resistor at the output. **Set the function generator to provide the necessary DC offset to center the output of the op amp between the supply rails**. The circuit you are to test should look as that in Figure 2.

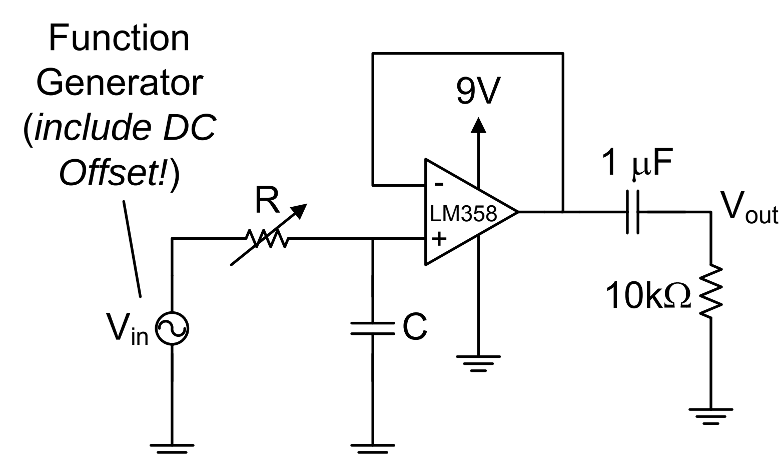


Figure 2: *The test circuit for characterizing the filter used to "clean up" the audio signal.*

7. Complete Table 1 in an effort to characterize the frequency response of your filter circuit. **In addition to the listed frequencies, you are to identify any 3dB frequencies (there should be two), and add additional data points that will make your plot relatively smooth.** *Have the instructor discuss the phase measurement function, the importance of filling the oscilloscope's display for accurate readings and the phase offset equation.*

**TABLE 1: Frequency Response Data For The First-Order Filter**

| Frequency (Hz) | Vin (pp) | Vout (pp) | Gain (V/V) | \|Phase angle\| (degrees) | Input or Output leads? |
|---|---|---|---|---|---|
| 10 | | | | | |
| 50 | | | | | |
| 70 | | | | | |
| 100 | | | | | |
| 300 | | | | | |
| 500 | | | | | |
| 1000 | | | | | |
| 3000 | | | | | |
| 5000 | | | | | |
| 7000 | | | | | |
| 9000 | | | | | |
| 10,000 | | | | | |
| 13,000 | | | | | |
| 15,000 | | | | | |
| 17,000 | | | | | |
| 19,000 | | | | | |
| 20,000 | | | | | |
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***CONGRATULATIONS – YOU HAVE COMPLETED THE AUDIO AMPLIFIER PROJECT CIRCUIT! SEE THE COURSE WEBSITE FOR DETAILS REGARDING THE REQUIRED LAB REPORT.***