Section: Monday / Tuesday Name: ______________________________
(circle one) Partners: ______________________________
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PHYSICS 107 LAB #9: AMPLIFIERS

Equipment: *headphones, 4 BNC cables with clips at one end, 3 BNC T connectors, banana – BNC (Male-Male), banana-BNC (Female-Female), audio amplifier, speaker, little silver power-supply, multimeter, 2N3904, 470Ω, function generator, o'scope, two 5.1k's, 47k, two 4.7k's, 741 Op-Amp, IC test clip, IC extractor, breadboard, 10 k, 1 k.*

OBJECTIVE

1. Get familiar with the behavior of Transistor, Operational-Amplifier, and commercial audio amplifier's performance; in particular, their dependence on the input signal's amplitude and frequency

Overview

Once an acoustic signal is translated into an electrical one, we often want to amplify it. Obviously, the *ideal* amplifier would simply increase the strength of the electrical signal by whatever constant factor (vocab: this factor is referred to as the "gain") you wanted, regardless of how big or small the input signal was and regardless of its frequency. There are a couple of ways a real amplifier can fall short of the ideal – the gain may depend upon the size of the input signal or the frequency of the input signal.

For example, maybe a 2V input leads to a 4V output (so, a gain of 2) while a 4 V input might lead to only a 6V output (so a gain of 1.5). In the extreme case, the output can get 'clipped' when the desired output voltage exceeds the supply voltage that's powering the amplifier – for example, if an amplifier is powered by a 10V supply, then it just can't produce an output that's any higher than 10V; so if such an amplifier is set for a gain of 2, then it will output 6V for a 3V input, 8V for a 4V input, 10V for a 5V input, and still just 10V for a 6V input – it's maxed-out at 10V.

Considering a frequency dependence, maybe signals around a few 100 Hz experience one gain, while much lower or higher frequencies experience a smaller gain; additionally, the amplifier probably 'just can't keep up with' particularly high frequency signals, so turning the frequency up high enough essentially turns *off* the amplifier – the gain goes to 0. A subtler frequency-dependent effect is that the output signal may appear time-shifted relative to the input, that is, the peaks and troughs of the input and output signal may not line up, and how out of synch they get may depend upon the frequency; however, as people are relatively insensitive to the phase of a sound wave, we won't worry about that.

In practice, all real amplifiers show these imperfections, but careful design can minimize them.

The most basic electrical amplifier is a simple circuit with a transistor. As you might guess, this is also the amplifier with the least ideal behavior. However, its deficiencies can largely be compensated for in a carefully designed (and considerably more complex) circuit that involves tens of inter-connected transistors along with a few resistors, capacitors, and diodes. These circuits are so useful that they get manufactured on a single chip (an example of an "integrated circuit.") This device is known as an "operational amplifier" or an "op-amp" for short. While this represents a vast improvement over the single transistor, one can do still better by combining *these* (and more resistors, capacitors,…) together in an "audio amplifier" as you'd by for your stereo system.

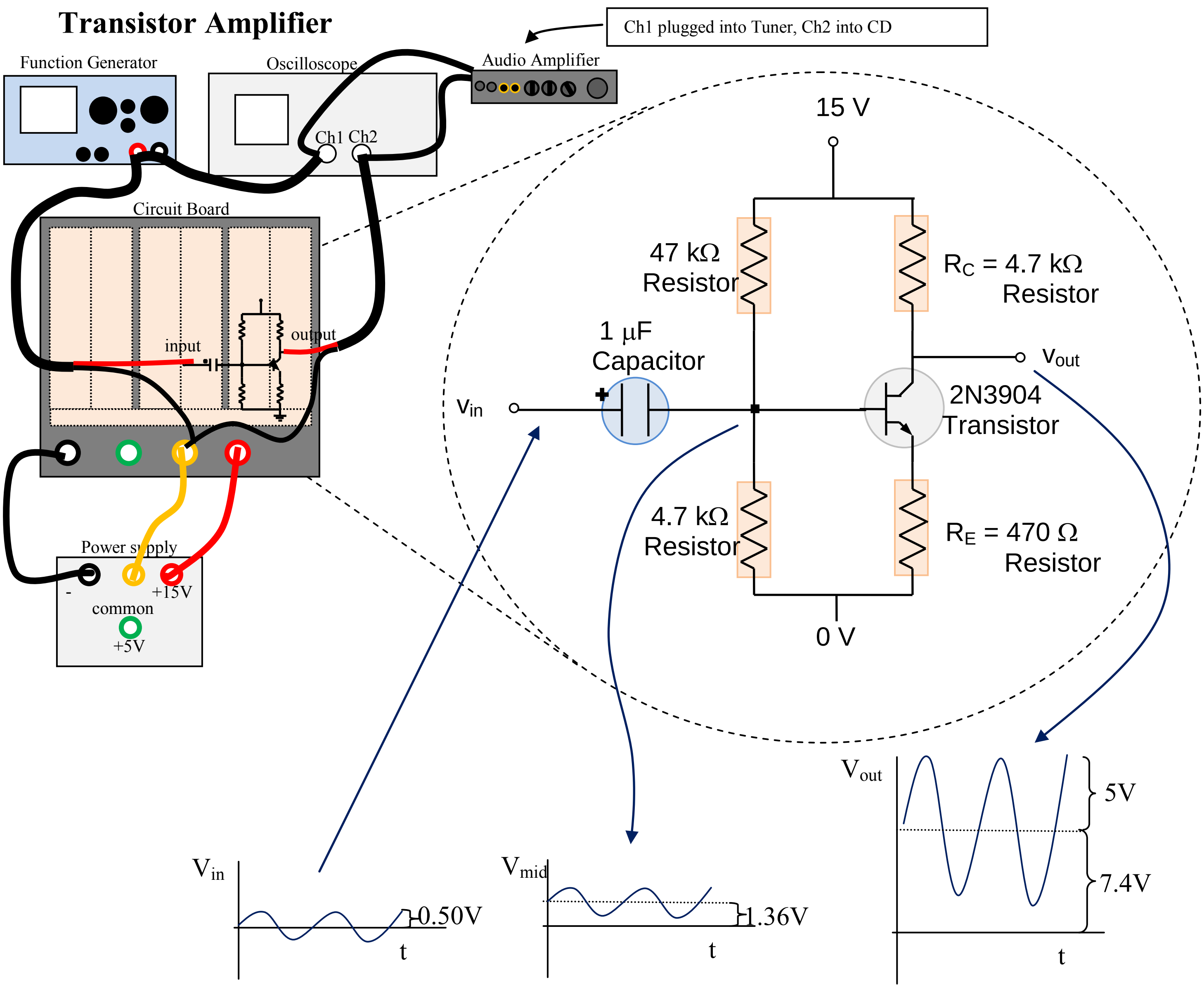
Readings:

Reading: Section 16.4

Set-up & Additional Background

You'll move back and forth between testing two different amplifiers: the simple transistor amplifier and the operational amplifier (which itself is comprised of several transistors).

Transistor Amplifier



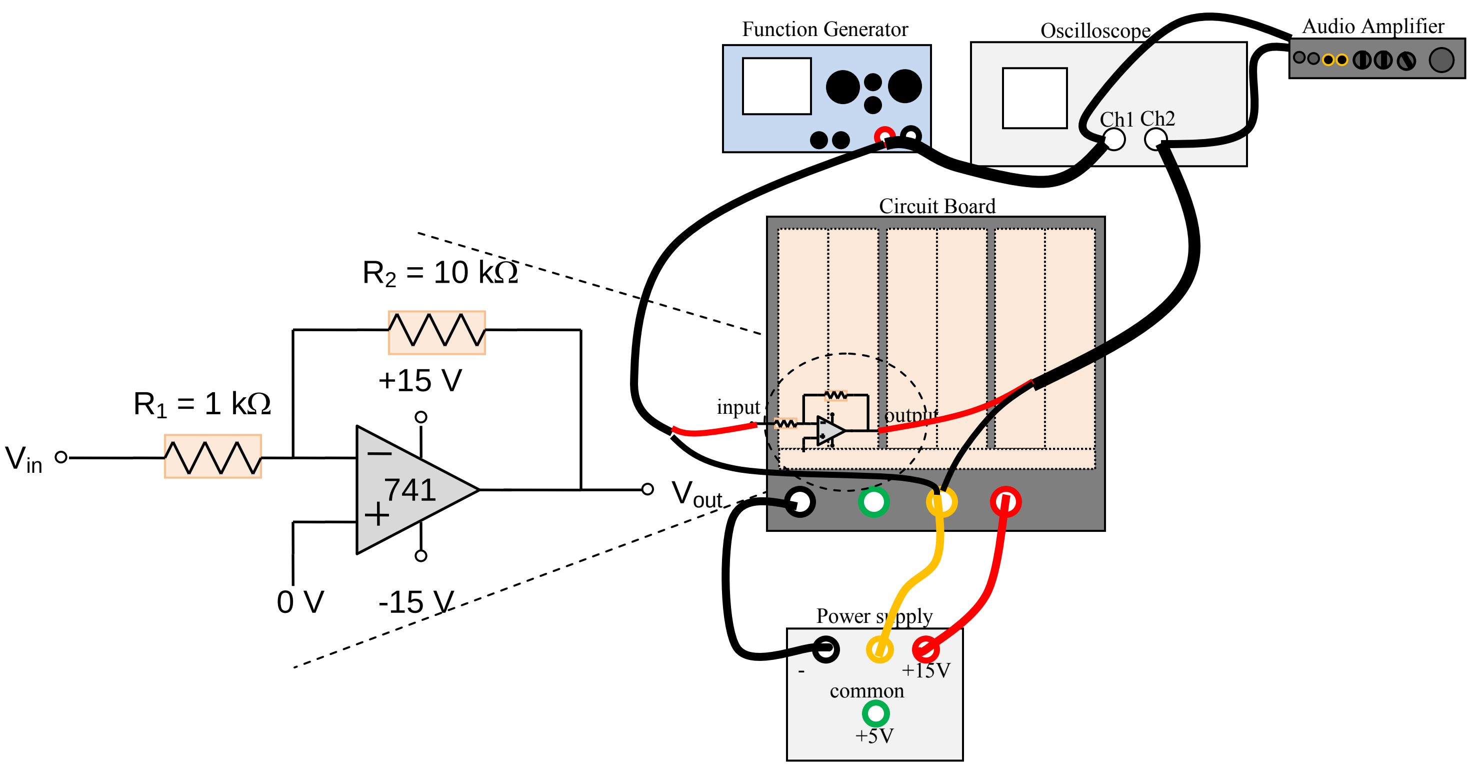
This should already be set up by your instructor, but look it over to make sure things are as they should be. Here's a brief explanation of the circuit: The lines represent wires and the different components are as labeled. The two resistors on the left are arranged as a "voltage divider" so that, when you measure the voltage at a given point is proportional to the resistance between that point and the 0V mark. So $\frac{V_{middle}}{15V} = \frac{4.7k\Omega}{4.7k\Omega + 47k\Omega} \Rightarrow V_{middle} = 1.36V$ (for the transistor to work at all, it's essential that this mid-point value be above about 0.6V.) Now if we apply an oscillating voltage at the input, $v_{in} = v\sin(2\pi ft)$, then that just gets added onto this 1.36V at the mid-point, so $V_{middle} = 1.36V + v_{in}$. The transistor and the two resistors on the right do something similar; the output voltage is roughly

$$V_{out} = 15V - (V_{middle} - 0.6V)\left(\frac{R_C}{R_E}\right).$$

$$\boxed{V_{out} = 7.4V + v_{in} * 10}$$

Depending upon the exact resistances and the voltage at the top of the circuit, the two numbers in this final equation maybe a little different.

Operational Amplifier



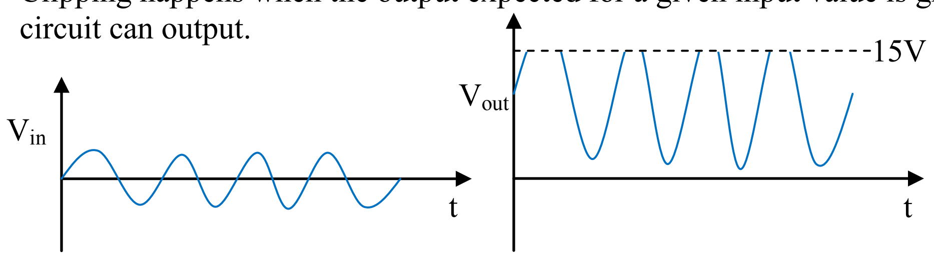
This circuit, with an ideal Operational-Amplifier in it, would simply have a gain of $-\frac{R_2}{R_1}$, or, in this case, -10, where the negative sign means that the output isn't just 10 times larger, it's also flipped. Again, since people are relatively insensitive to such changes in phase, we won't worry about that. Unlike with the single transistor, there is no need to offset the input and there is no offset to the output – if the input is a sine wave, oscillating around 0, the output is a (flipped) sine wave oscillating around zero. Of course, the operational amplifier, just like the transistor, can't output a voltage larger than its power supply, beyond $\pm 15V$, so the largest amplitude input signal this circuit can handle is about 1.5 V (about twice that acceptable for the single transistor.)

Effects

Clipping

Theory

Clipping happens when the output expected for a given input value is greater than the circuit can output.



In this circuit, the maximum output value is a little below the supply voltage, the 15 V at the top of the circuit. Given that, use the boxed equation on page 3 to determine about how large v_{in} can be before the output gets "clipped:"

Transistor Amplifier:
$V_{in\text{-}max.theory}$ = ________________________ V

Experiment

Seeing Effect

With the O'scope looking at the output from the Transistor Amplifier circuit, turn on the function generator and set the frequency to about 10 kHz, then adjust the amplitude until you see the top of the wave form begin to flatten (remember, you can use the two buttons at the bottom of the function generator to change the scale on which you're adjusting the voltage.) When you see that happen, the signal is beginning to clip.

$V_{in\text{-}max.experimental}$ = ________________________ V

Question: Are the predicted and measured maximum input voltages within about 10% of each other?

That the output wave is *not* a simple sine wave when it's clipped means that its spectrum (what we'd see and hear) has higher frequency components. Before switching the scope over to display the spectrum, make sure that the signals are drawn as tall as they can be without extending off the screen's top or bottom. Now, on the Oscilliscope, press the "Math Menu" button (right between the Chanel 1 and Chanel 2 control areas). This should display the spectrum of Channel 2 (the display should say FFT in the upper right corner and should say the source is Ch 2 – if not, ask your instructor to help). You'll probably have to turn the Horizontal scale dial counter-clockwise a good deal to zoom in enough to see the peaks.

Question: As you dial up and down the input signal's amplitude, and thus make the output be more and less dramatically clipped, how does the spectrum vary?

Hearing Effect

Now turn down the frequency to something you wouldn't mind hearing, say a few hundred Hz, and turn on the Audio Amplifier, with the selection dial set to "Tuner" (i.e., the transistor amplifier's output signal) so you can hear the clipped signal. Adjust the function generator's Voltage to make the signal more or less dramatically clipped (note: you can simultaneously adjust the Audio Amplifier's Volume to maintain a roughly constant sound level).

Question: As you make the signal more and more clipped, qualitatively describe what happens to the sound the speaker plays.

When you're done, turn off the Audio Amplifier before proceeding.

Amplitude Dependence

Aside from clipping, an ideal amplifier provides the same gain regardless of how large the input signal is. Now you'll see how good the transistor amplifier circuit is at this.

Seeing Effect
Set the frequency around 1 kHz, and adjust the input signal's amplitude so you can fill in the table below. Meanwhile, adjust the oscilloscope's vertical scale and offset so it draws Ch1 and Ch2 as tall as it can while keeping it completely on screen (if the scope can't 'see' the signal well, then it can't measure it well.)
Note: 1 mV = 0.001 V
Do this while looking at the Transistor Amplifier's output and the again while looking at the Operational Amplifier's output.

Amplitude (Function Generator)	Input peak-to-peak (Ch1 pk-pk)	Transistor Amplifier		Operational Amplifier	
		Output peak-to-peak (Ch2 pk-pk)	Gain: Output/Input (Ch2 / Ch1)	Output peak-to-peak (Ch2 pk-pk)	Gain: Output/Input (Ch2 / Ch1)
0.1 V					
0.2 V					
0.3 V					
0.4V					
0.5V					

Question: What is the percent difference between the largest and smallest gains (aside from when the signal's obviously beginning to "clip") that you determined?

Transistor Amplifier:

Operational Amplifier:

Which amplifier had the most consistent gain?

Question: If the largest signal also had the largest gain, then the effect is to increase the apparent dynamic range of a recording – making the loud parts louder and the quiet parts quieter. Alternatively, if the smallest signal had the largest gain, then the effect compresses the dynamic range. Which happens here?

Transistor Amplifier:

Operational Amplifier:

Question: If you input a perfect pure tone / sine wave, then, would the output be taller or squatter than a true sine wave?

In either case, this implies the presence of higher harmonics in the spectrum.
Before switching the scope over to display the spectrum, make sure that the signals are drawn as tall as they can be without extending off the screen's top or bottom. Now, on the Oscilliscope, press the "Math Menu" button (right between the Chanel 1 and Chanel 2 control areas). This should display the spectrum of Channel 2 (the display should say FFT in the upper right corner and should say the source is Ch 2 – if not, ask your instructor to help). You'll probably have to turn the Horizontal scale dial counter-clockwise a good deal to zoom in enough to see the peaks.

Question: Aside from the fundamental frequency, how many other frequencies are strongly present in the output signal?

Transistor Amplifier:

Operational Amplifier:

Which amplifier produced the 'purest' output (least harmonics)?

Hearing Effect

Turn on the Audio Amplifier and switch between hearing the input signal straight from the function generator (selection dial pointing to "CD") and hearing the output signal from the transistor amplifier (selection dial pointing to "tuner").

Question: Aside from differences in volume (which you can compensate for by adjusting the Volume dial), how would you say the input and output signals sounded different from each other? How does this relate to the output channel's spectrum that you saw on the oscilloscope?

Transistor Amplifier:

Operational Amplifier:

Which amplifier's output sounded most like the input?

When you're done, turn off the Audio Amplifier and press the "Math Menu" button on the oscilloscope (to return to seeing the waveform rather than the spectrum) and then the "Measure" button before proceeding. Note: you'll probably have to dial back the horizontal scale to see the waveform clearly again.

Frequency Dependence

An ideal amplifier provides the same gain for any signal, regardless of its frequency, but real amplifiers may have preferred frequencies and peter out at very high or low frequencies. Now you'll see how this transistor amplifier fares.

Seeing Effect

Set the input signal's amplitude to 0.4V and the frequency to 20Hz and fill in the first row on the table below.
Vary the input signal's frequency to fill in the rest of the table. As before, make sure the signals are as tall as they can be without going off screen.
Repeat for Transistor and Operational Amplifier.

frequency (Function Generator)	Input (Ch1 pk-pk)	Transistor Amplifier		Operational Amplifier	
		Output (Ch2 pk-pk)	Gain (Output/Input)	Output (Ch2 pk-pk)	Gain (Output/Input)
20 Hz					
100 Hz					
200 Hz					
1000 Hz					
2000 Hz					
10, 000 Hz					
20, 000 Hz					

Question: What is the percent difference between the largest and smallest gain values?

Transistor Amplifier:

Operational Amplifier:

Which amplifier had the most consistent gain?

Question: What is the trend in the gains, that is, what range of frequencies have the largest gain and what range have the lowest gain?

Transistor Amplifier:

Operational Amplifier:

Hearing Effect

If you've got an MP3 player on you, you can use that; otherwise, you can use MediaPlayer on the computer. You'll listen to music directly from the source, over a pair of headphones, and then amplified by the transistor amplifier. Ask the instructor to help you switch to input from your music source.

Question: Listening to the music directly, and through your amplifier, how does it sound different through the amplifier? Note: there may be some clicky noise when you listen to it over the amplifier – in all fairness, that's not the amplifier's fault (it's because we've got all these wires out in the open rather than in a nice metal box), so don't bother commenting on that.

Transistor Amplifier:

Operational Amplifier:

Which amplifier most faithfully reproduces the music?

Question: How does your observation relate to the gains you measured for different frequencies? That is, is the sound loudest/quietest for the frequencies with the highest/lowest gains?

Question: Overall, which amplifier does the best job?