# Lab 2 Report - Amplifiers

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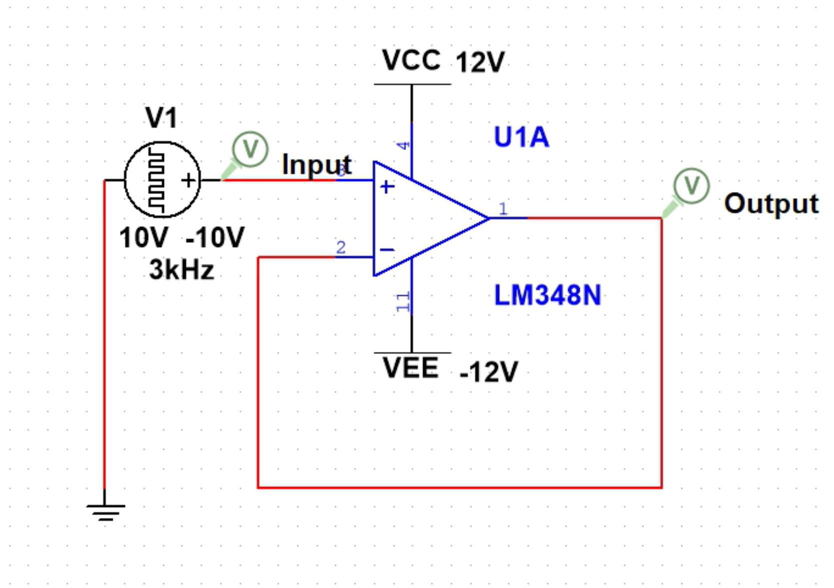
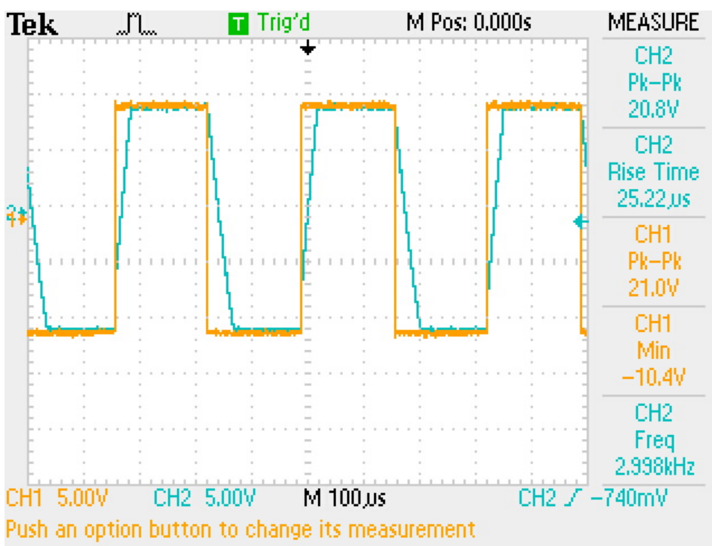
## PROCEDURE 1

In this procedure, we constructed the voltage follower circuit as shown in figure 1.1, attaching the function generator in place of the square wave source, and connecting the oscilloscope to channel 1 for the input wave and channel 2 for the output wave. We then set the function generator to create a square wave with a 50% duty cycle, varying from 10V to –10V with a frequency of 3kHz. Once both the input and output waveforms were shown on the oscilloscope, we printed the waveform, which can be seen in figure 1.2. Comparing the waveform generated experimentally (figure 1.2) and the theoretically generated waveform in the SPICE simulation (figure 1.3), as well as the advertised waveform in the datasheet for the LM348N Op-Amp shows that the experimentally generated waveform differs very little from the expected output based on simulation and advertisement. This result was encouraging, as it showed that the devices we constructed our voltage follower circuit were undamaged and could be relied upon. Additionally, the data we collected showed a slightly higher slew rate than expected from the datasheet, and our calculations, but not particularly far off. So, while our actual behavior indicates the device we were using was non-ideal (at least according to the specifications), the overall behavior was as expected. Continuing in the procedure, we changed the settings on the function generator to create a sine wave with pk-pk voltage of 6V (3V to -3V), and began to vary the frequency of the input voltage until the oscilloscope showed noticeable distortion in the output voltage waveform. Our result for the distortion frequency ended up being very close to the theoretical value, and may indeed be closer, but the resolution of the function generator's frequency could not go any higher. Finally, we changed the input waveform on the function generator to a sine wave varying from 100mV to -100mV, starting with a frequency of 10Hz. As expected from a voltage follower, we got a low-frequency gain of 1, then we increased the frequency until the amplitude had distorted to half of the input amplitude. Notably, this dropoff occurred well before the theoretical dropoff, from the spice simulation (see figure 1.4), but not far from the advertised specification of the op-amp.

In general, our results from this procedure were rather close to the theoretical values (as found in specifications, theoretical mathematical values, and simulation results). So, we can conclude that the circuit functioned as expected in the voltage follower configuration, with minor deviation from the advertised slew rate that we expect is due to manufacturing differences or other environmental factors. The only significant difference from the theory we observed was the drop to gain of 0.5, where we found a notably different result from our simulation (but not the specification). We expect that this error is a result of using SPICE for the first time, so we may not have properly generated the Bode plot.

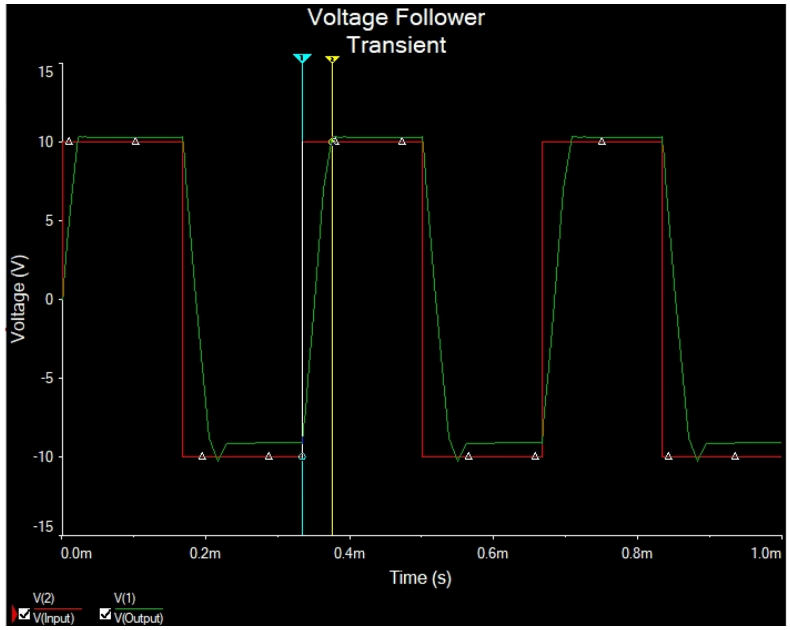



(Figure 1.1)  Voltage follower circuit with test leads on input and output, stimulated by a 20V pk-pk 3kHz square wave input created in SPICE simulation.



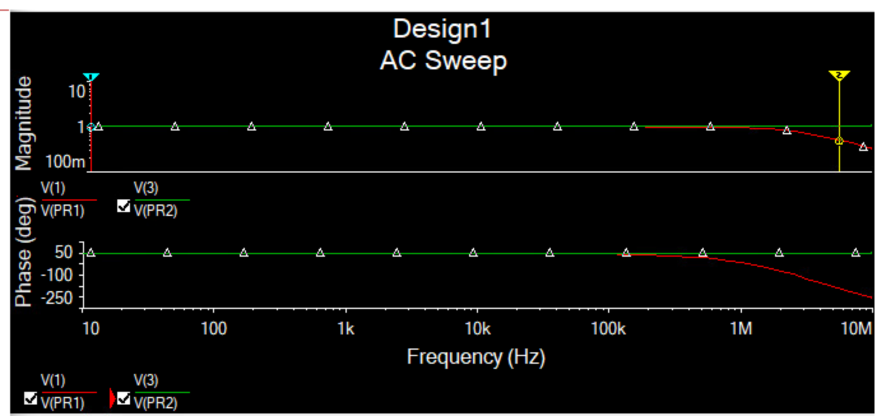

(Figure 1.2)  Oscilloscope reading of voltage follower circuit (channel 1 measuring input voltage, channel 2 measuring output voltage).

| | V(2) V(Input) | V(1) V(Output) |
|---|---|---|
| x1 | 332.9741µ | 332.9741µ |
| y1 | -10.0000 | -9.1008 |
| x2 | 375.5388µ | 375.5388µ |
| y2 | 10.0000 | 10.3146 |
| dx | 42.5647µ | 42.5647µ |
| dy | 20.0000 | 19.4155 |
| dy/dx | 469.8734k | 456.1408k |
| 1/dx | 23.4937k | 23.4937k |




(Figure 1.3) SPICE simulation of the voltage follower circuit's input and output voltage waveforms with cursors to show time between voltage transition and steady state voltage

| | V(1) V(PR1) | V(3) V(PR2) |
|---|---|---|
| x1 | 10.0000 | 10.0000 |
| y1 | 999.9937m | 1.0000 |
| x2 | 5.5727M | 5.5727M |
| y2 | 501.5516m | 1.0000 |
| dx | 5.5727M | 5.5727M |
| dy | -498.4421m | 0.0000 |
| dy/dx | -89.4436n | 0.0000 |
| 1/dx | 179.4463n | 179.4463n |




(Figure 1.4) SPICE simulation bode plot of the output voltage, with cursor showing frequency at which the amplitude reaches 0.5 x input voltage.

# ANALYSIS 1

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**1.1** Slew Interval: 0.676 V/μs

Voltages: 10V, -10V

Specified slew rate is 0.5V/μs on the data sheet and 0.47 V/μs on the SPICE simulation. The differences are likely due to the real component and experiment conditions differing from the manufacturer testing environment or the simulated SPICE components. Regardless, the values do not differ substantially enough to call the component defective or to indicate any significant experimental error.

**1.2** Calculated Frequency: 26,526 Hz
Measured Frequency: 27,000 Hz

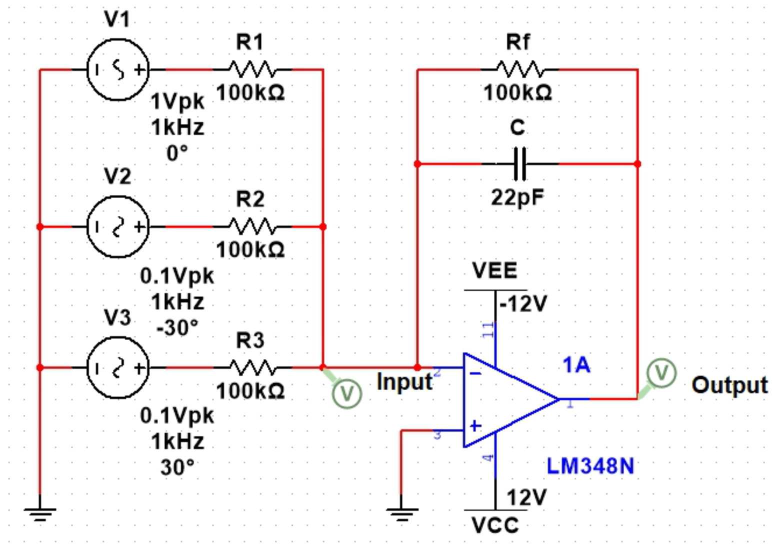
Results are different, but very close (<2% error) to one another.

**1.3** 10Hz Gain: 1
Half Drop-off At: 1.2 Mhz

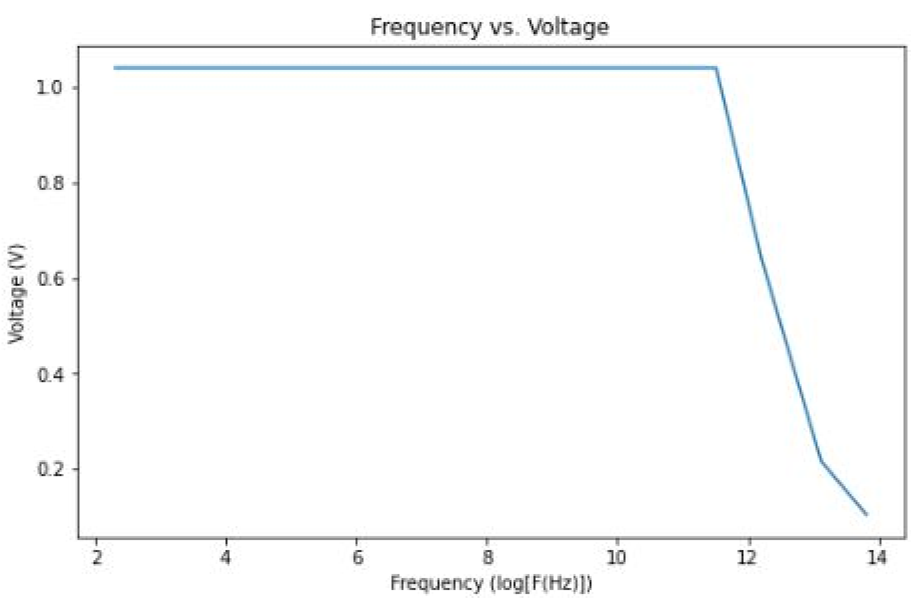
## PROCEDURE 2

In this procedure, we constructed the voltage follower circuit as shown in figure 2.1, attaching the function generator in place of v1 and connecting v2 and v3 to ground. We attached the oscilloscope to channel 1 for the input wave and channel 2 for the output wave. We then set the function generator to create a sinusoidal input with amplitude of 1 and frequency of 1kHz. Checking to make sure the input and outputs matched our expectations, we continued on to testing with various frequencies. Testing at various frequencies, we found that the circuit began dropping off at around 200kHz, which would make the rejection range outside of the reasonable audible spectrum, but may reduce noise in the circuit. Notably, the plot we generated from experimental data drops substantially earlier than the one generated in SPICE. We then moved on to testing our circuit with various sound clips and passing them through the three different inputs, playing them through a speaker (speaker connected at output terminal and down to ground). We tested the three inputs by playing Rick Astley's "Never Gonna Give you Up" (staggered by a short period of time) and we heard three distinct sounds that could be amplified or reduced by adjusting the potentiometers for each input. We then saved a snapshot of the sound wave from the oscilloscope, which can be seen in figure 2.3. The behavior in this snapshot cannot be readily described as sinusoidal, as it does not show obvious periodicity, but it appears that the sound could be potentially represented by a sum of various sinusoids at the frequencies of the sounds.

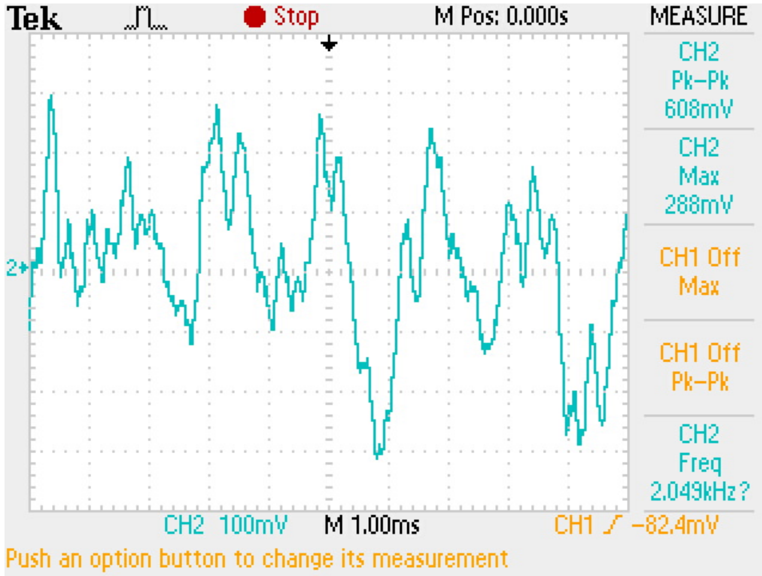
From our experimentation, we believe we properly constructed a low-pass filter combined with a three-channel audio mixer. Our outputs were notably rather quiet, even after adjusting the potentiometers all the way, which we expect is due to the low output voltage of the devices we were using in combination with the relatively large speaker we used. We believe that with a smaller speaker and greater output voltage the audio would be more audible. Otherwise, our circuit behaved as we hoped it would.




(Figure 2.1) Summing amplifier circuit with test leads on input and output, stimulated by three sinusoidal inputs, created in SPICE simulation




(Figure 2.2 ) Logarithmic plot of Voltage vs Frequency from output behavior of low-pass filter




(Figure 2.3 ) Sound wave plot of three simultaneous inputs of Rick Astley's "Never Gonna Give you Up"

## ANALYSIS 2

### 2.1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Frequency | 10 Hz | 20 Hz | 50 Hz | 100 Hz | 200 Hz | 500 Hz | 1 kHz | 2 kHz | 5kHz |
| Output | 1.04 V | 1.04 V | 1.04 V | 1.04 V | 1.04 V | 1.04 V | 1.04 V | 1.04 V | 1.04 V |
| Frequency | 10 kHz | 20 kHz | 50 kHz | 100 kHz | 200 kHz | 500 kHz | 1 Mhz | | |
| Output | 1.04 V | 1.04 V | 1.04 V | 1.04 V | 640 mV | 216 mV | 104 mV | | |

Notable dropoff to around half at 200kHz, much earlier than anticipated from SPICE simulation.

**2.2** Using three delayed plays of ‘Never Gonna Give You Up’, we were able to verify that our summing amplifier does indeed work as designed; we could hear each attached audio input playing on a single speaker through our summing amp circuit.