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E3083 Electronics Circuits Lab
Experiment 5 Lab Report
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Non-Ideal Operational Amplifiers

The Inverting Configuration

To better understand the operation of non-ideal op-amps, we can look at the behavior of an op-amp and a number of its characteristics. By building the circuit seen in *Figure 1*, we can observe that the output voltage—caused by the op-amp input offset and seen in *Figure 2*—is 2.187mV.

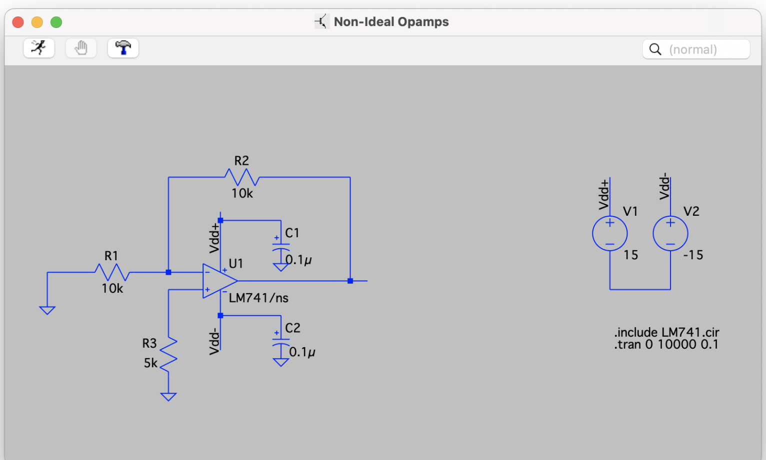

Figure 1: LM741 with no input voltage.

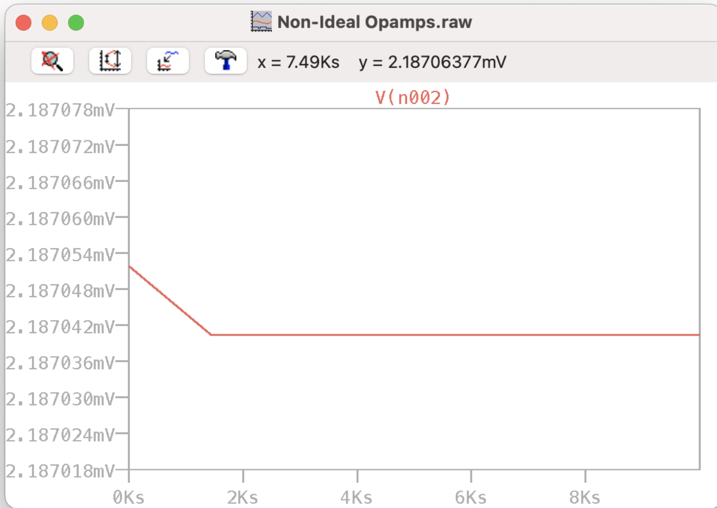

Figure 2: Output voltage of LM741 due to op-amp input offset voltages.

By placing a voltage source in series with the non-inverting input of an ideal op-amp, we would expect to see a voltage gain equal to $A_v(V_{offset})$ where $A_v = 1 + \frac{R_1}{R_2}$. Since $R_1 = R_2 = 10k\Omega$, the gain $A_v = 2$. This means that, for an ideal op-amp like that in *Figure 3*, we should expect to see a gain equal to 4.37408mV. This exact gain is seen in *Figure 4*. From this, we can determine that the input offset voltage seen by the LM741 is equal to 1.0935mV. This is in the typical range for the LM741, which is typically 1mV.

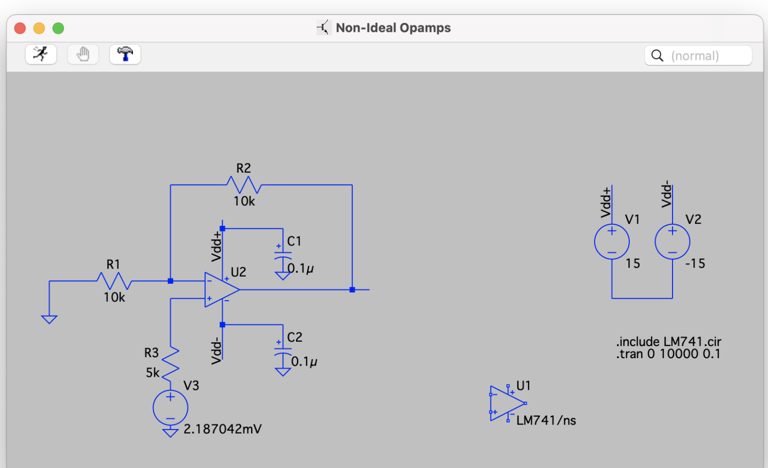

Figure 3: An ideal op-amp with an offset voltage.

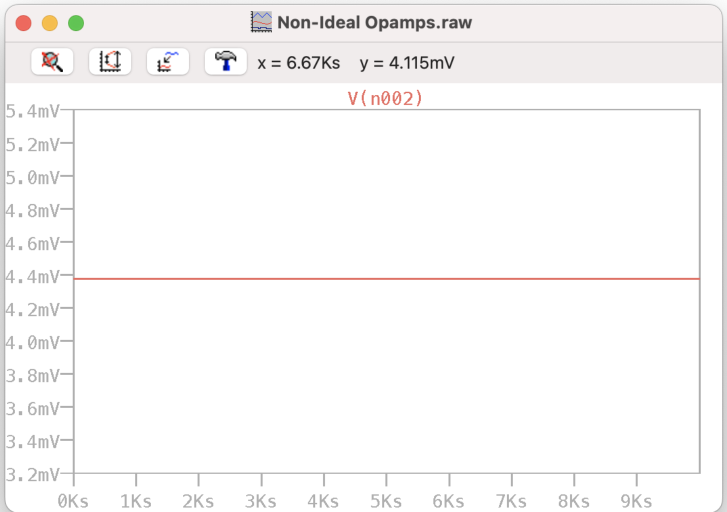

Figure 4: Output of the ideal op-amp with an offset voltage.

By attaching a 10kΩ potentiometer to the offset inputs of the LM741 it can be observed that the offset voltage is zeroed with a resistance of ~5.34kΩ. By varying the potentiometer from 0kΩ—10kΩ, we can observe a range of offset output voltages from ~-26mV—27mV.

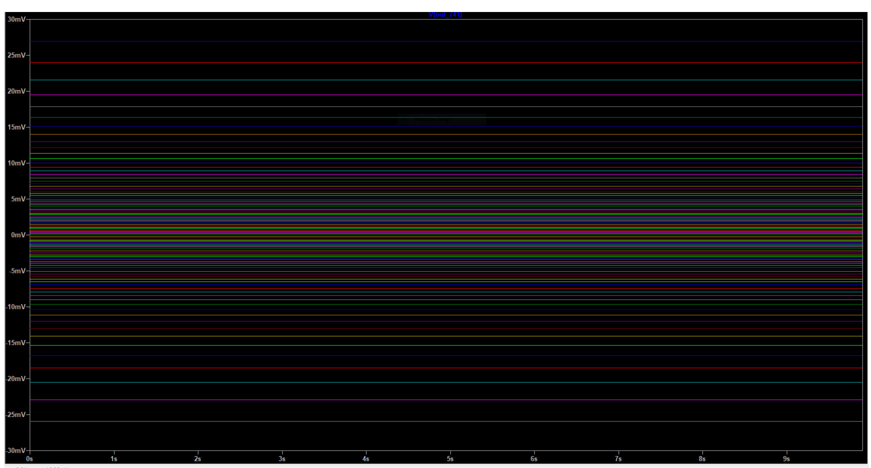

Figure 5: Range of output offset voltages from the 10kΩ resistor.

By shorting R3, we effectively produce an open circuit with no current flow and which produces a voltage of 0.7mV at the output. This resistor is necessary so that we can match the current on the inverting input. This effectively balances the current on both of the inputs and allows for us to have the expected gain. We can then connect a small signal voltage of 0.2Vpp to the input of the LM741. Doing so shows the output seen in *Figure 6*. The signal experiences a gain of 2.

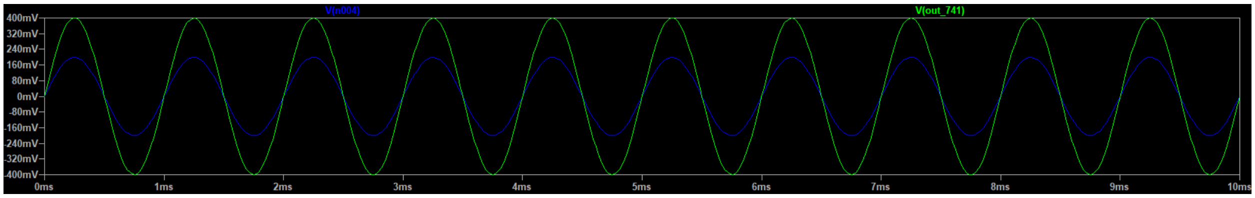

Figure 6: Small signal gain of the LM741 op amp.

The 3dB point can be determined through the following equation: $\frac{V_{out}}{\sqrt{2}}$. For this circuit, we would expect the 3dB point to be reached when V_{out} is equal to 282mV. By varying the small signal input frequency, we can observe that this occurs at 400kHz. We can find that the phase difference between the input signal and the 400kHz output is approximately 0.5µS.

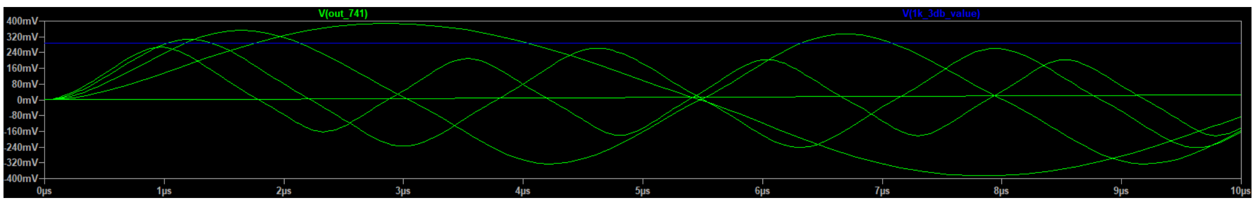

Figure 7: "-3dB" point from varying small signal frequency.

After changing the feedback resistor to 100kΩ, we can calculate that a 50kΩ resistor must be used for R3. We can then find that there is an output offset voltage of -28.6mV. This offset voltage is zeroed at a resistance of 2.3kΩ from the potentiometer. There is an output range of -180mV—120mV from the full range of the potentiometer. The gain of the attached small signal is measured to be 11. In this case, we expect there to be a 3dB point when the output voltage has a peak of 1.56V. This point occurs at a frequency of 80kHz. A phase shift of ~4µs is observed. After disconnecting the offset potentiometer, we can see a shift in the output signal voltage. This is a direct result of the offset shifting the entire output voltage in one direction when connected.

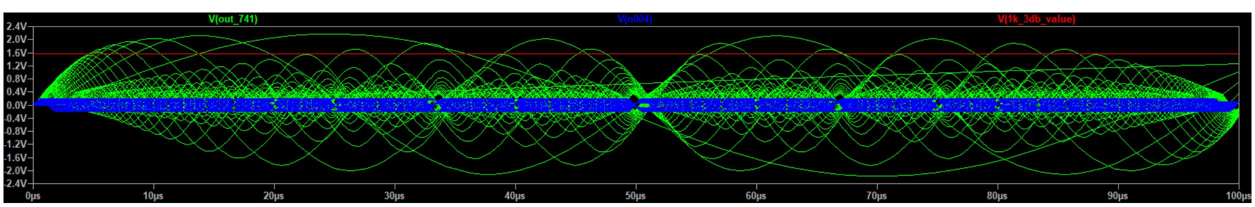

Figure 8: "-3dB" point for a circuit with higher gain.

Increasing the input voltage to ~0.3V produces an output voltage seen in *Figure 9* where the output closely resembles a sawtooth wave. We can use these parameters to find the slew rate using the equation $2\pi f V$. This means that the slew rate for the LM741 is 0.15072V/µS. This is quite off from the slew rate listed on the data sheet of 0.5V/µS—likely the result of different definitions of "triangular" waves.

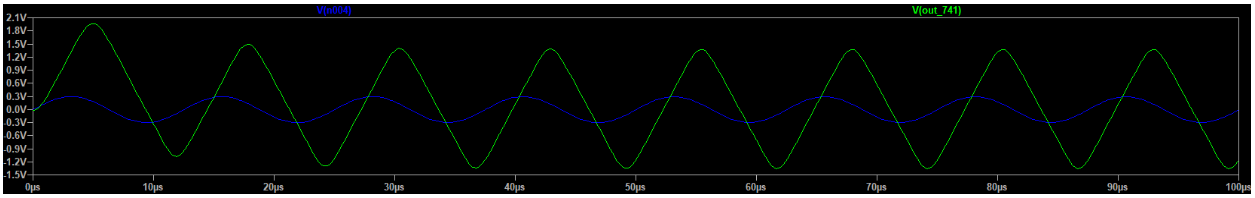

Figure 9: Output of the LM741 with slew rate reached.

By decreasing the input frequency by a factor of 5, to 16kHz, the slew rate is reached at 0.8V. This would suggest a slew rate of 0.080384V/µS—about half of that of the previously found slew rate, and still far off from the specification slew rate. Again, this is likely due to different definitions as to the point where an output becomes "triangular." Nonetheless, this does seem to be consistent with slew limiting and slew rate mechanisms.

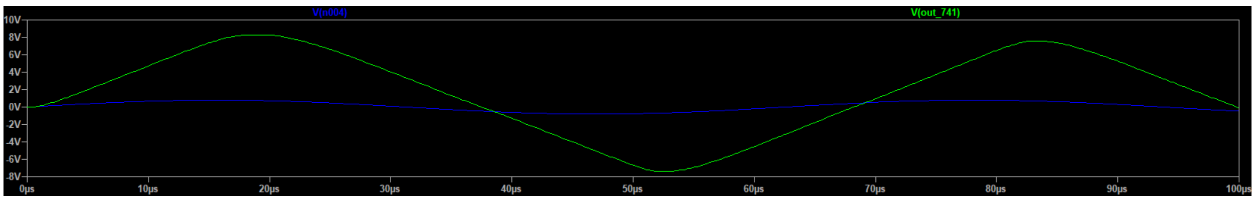

Figure 10: 16kHz slew rate

Setting the frequency of the input signal back to 1kHz, we observe a saturation of the output at 1V above or below the respective power supplies. Connecting a load impedance of 510Ω results in a slightly lower voltage observed on the output. This voltage shift is approximately 0.7V.

Setting the input voltage to create an output of a square wave can be done with a sinusoidal input of approximately 8 V and 1kHz. The output voltage can be seen in *Figure 11*. Then, by increasing the frequency to 20kHz, a triangular wave can be observed. Since the input is still sinusoidal, the output will never be perfectly square. The triangular wave measured in this case led to a slew rate of 1.0048V/µS—again off, but likely due to where the "triangle" was picked.

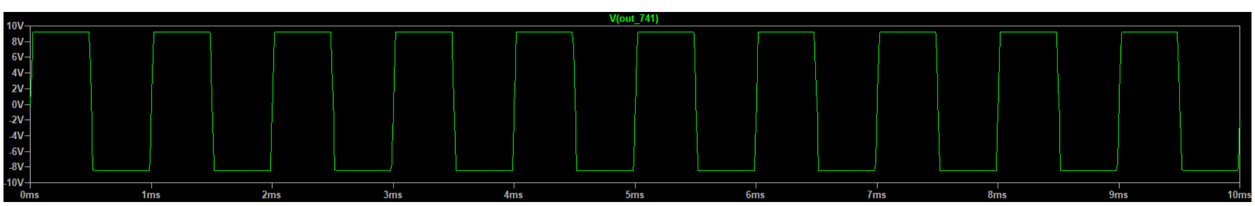

Figure 11: Square wave output voltage.

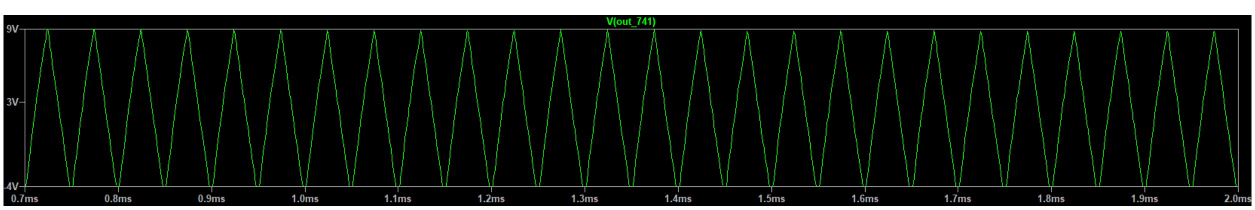

Figure 12: Triangular wave output voltage.

Comparing the LF411 and the LM741 Operational Amplifiers

After replacing the LM741 with the LF411, measurements of its physical characteristics can be obtained. First, the saturation voltage of the LF411 can be found to be 1.5V above or below the respective power supplies. This is seen in *Figure 13*.

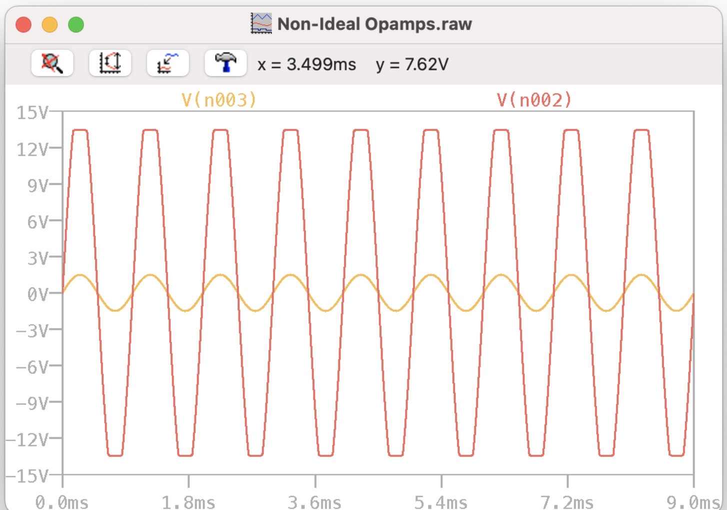

Figure 13: Saturated output voltage of the LF411.

Similarly as with the LM741, we can measure the -3dB bandwidth of the LF411. In doing so, we find that the op amp has approximately a 310kHz bandwidth. This is seen in *Figure 14*. In this case, the LF411 clearly outperforms the LM741 and has an additional bandwidth of 230kHz. While at a frequency of 130kHz, we can increase the input amplitude to about 16V before the slew rate is reached. This would suggest that the LF411 has a slew rate of 13.0624V/µS. This is much closer to the specified slew rate of 13V/µS. When compared to the LM741, the LF411 outperforms with a much higher slew rate.

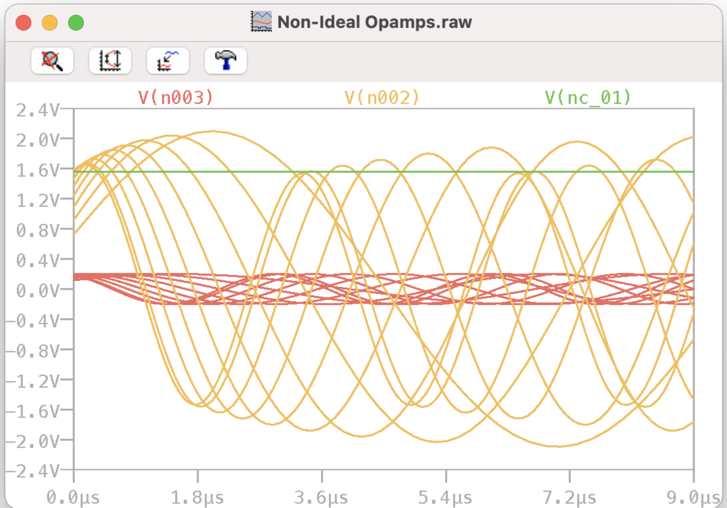

Figure 14: "-3dB" point from varying small signal frequency for the LF411.

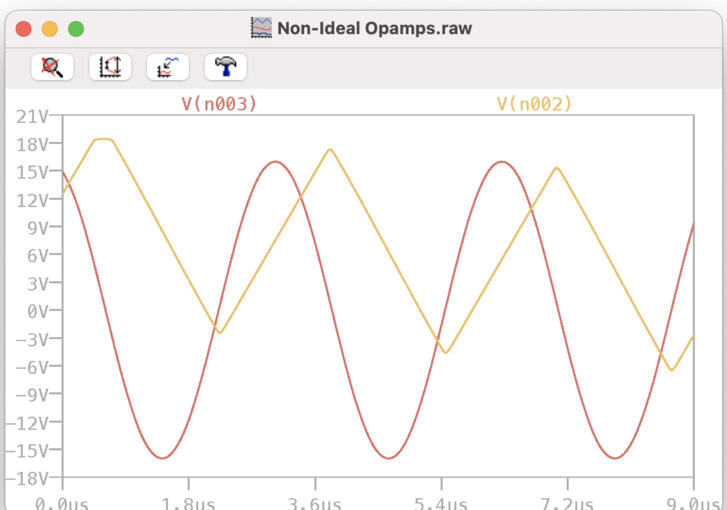

Figure 15: Output of the LF411 with slew rate reached.

Demonstration of Opamp Finite Bandwidth Effects on an Analog Video Signal

Building unity gain buffers for both the LF356 and LF411 and passing a 3.6MHz, 100mV$_{pp}$ sinusoidal signal through the inputs demonstrates some of the physical limitations of the two op amps. The LF356, seen in *Figure 16* shows a significant loss of 54mV in amplitude between the input and the output with a

77.6º phase shift. The LF411, seen in *Figure 17* shows a loss of only 6mV in amplitude between the input and the output with a 83.9º phase shift.

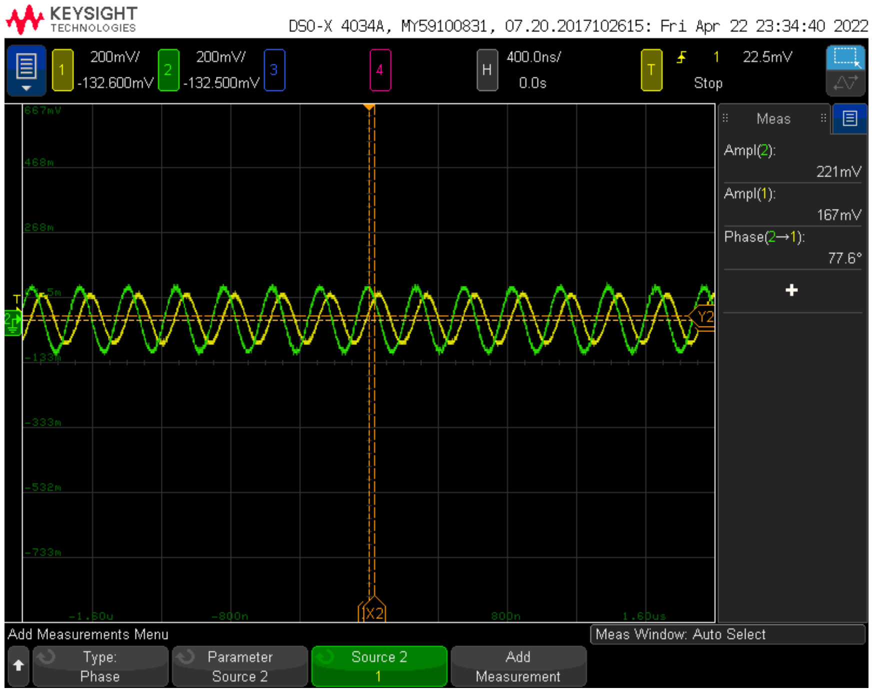

Figure 16: Output of the LF356 at 3.6MHz.

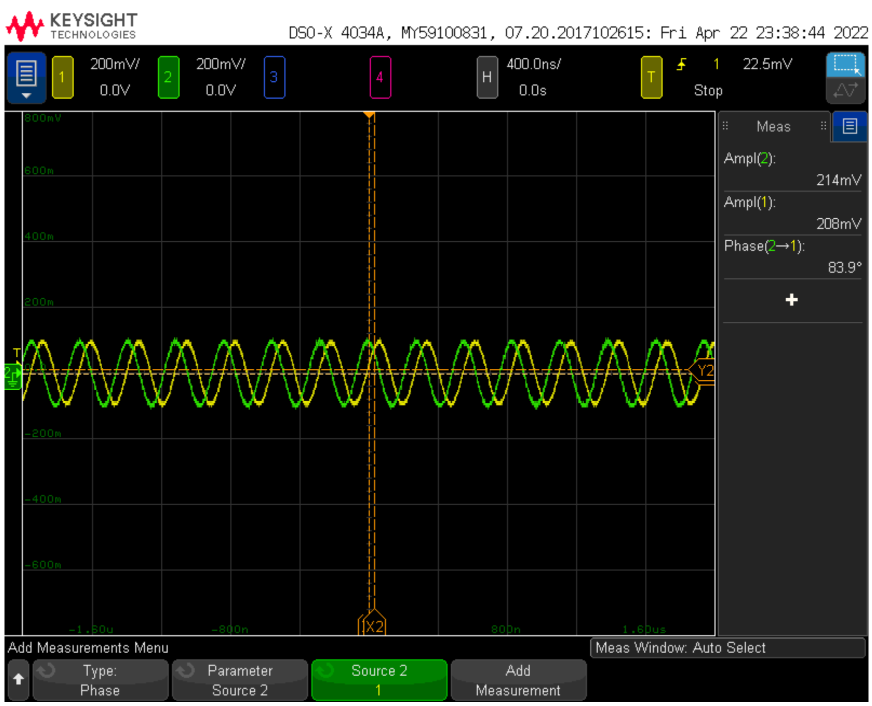

Figure 17: Output of the LF411 at 3.6MHz.

Connecting these circuits to a DVD player and a monitor, we can pass signals from the DVD player through each amplifier and back to the monitor to display. When connected to the LF356 buffer, the output in *Figure 18* can be seen. This output has noise and is slightly off-color, with more distinct yellow and red tones. This is likely due to a shift in the vector scope that manifests between these two colors on the vector scope. When connected to the LF411 buffer, the output in *Figure 19* can be seen. This output has noise and is black and white. This is likely due to losses in bandwidth that prevent frequencies that carry the color scope from being reached while still transmitting the image.

Figure 18: Analog signal output of the LF356 playing Shrek the Third.

Figure 19: Analog signal output of the LF411 playing Shrek the Third.

After constructing an 11x gain amplifier with a pre-amplification voltage divider (x$\frac{1}{11}$) we can observe a breakdown in the amplifier gain. The 3.6MHz signal is too high for the op amp, resulting in an output amplitude of only 50mV and a -536º phase shift. This is much different from the gain seen before, however we have exceeded the bandwidth for this circuit. By lowering the frequency we begin to see higher gains that act more as expected. The output of this circuit is seen in *Figure 20*. When connected to the video signal, this amplifier still transmits video signals, however they are significantly impacted by noise and are quite blurry. The video is also black and white. This is likely due to significant loss at such high frequencies, preventing both color and video information from being passed through the amplifier. The video output can be seen in *Figure 21*.

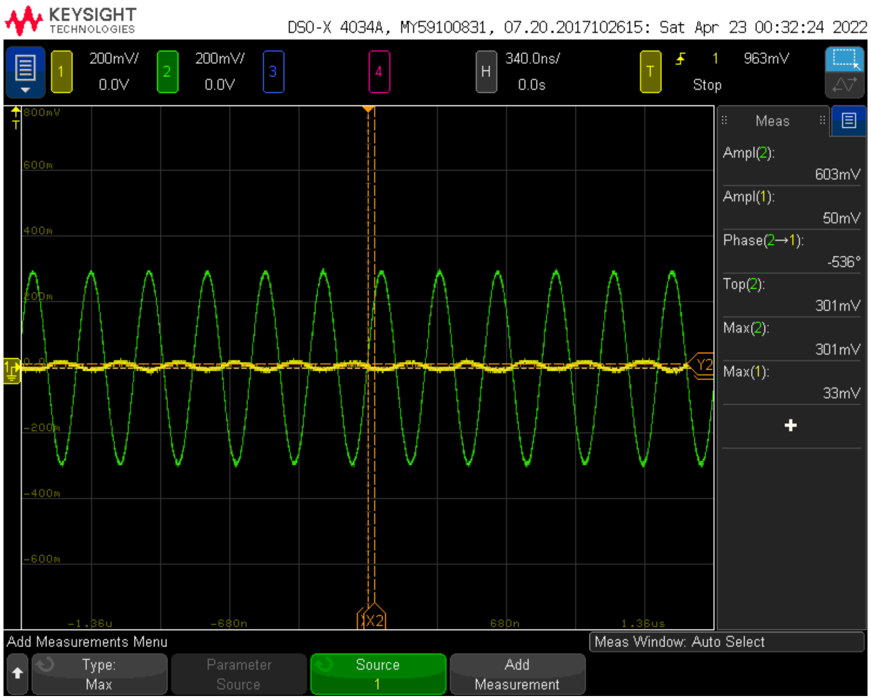

Figure 20: Output of the x11 LF411 with pre-gain voltage division at 3.6MHz.

Figure 21: Analog signal output of the x11 LF411 with pre-gain voltage division playing Shrek the Third.