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Lab 6: Analyzing RC Op-Amp Circuits

Introduction:

This lab was meant to teach us how to use energy storage elements in op-amps. We began by deriving the relationship between V_{out} and V_{in} for the op-amp differentiator and the integrator. Then we simulated the circuits using LTspice and confirmed that our derivations matched with our LTspice graphs. In the lab we built the RC differentiator and found the amplitude of the V_{out} given different frequencies for V_{in}.

Pre-Lab 1: Derivative Configuration

1.1

a) $- C\frac{dV_{in}}{dt} + \frac{-V_{out}}{R} = 0$

$V_{out} = - RC\frac{dV_{in}}{dt}$

b) $\frac{V_{in}}{R} = \frac{1}{L}\int_{-\infty}^{t} V_{out}dt$

$\frac{-L}{R}V_{in} = \int V_{out}dt$

$V_{out} = - \frac{L}{R}\frac{dV_{in}}{dt}$

[RP1]

1.2

a) $V_{out} = - RC(A_{in}2\pi f cos(2\pi f t))$

$V_{out,max} = RCA_{in}2\pi f$

b) $V_{out} = - \frac{L}{R}(A_{in}2\pi f cos(2\pi f t))$

$V_{out,max} = \frac{L}{R}A_{in}2\pi f$

[RP2]

Pre-Lab 2: Derivative Configuration with Capacitor

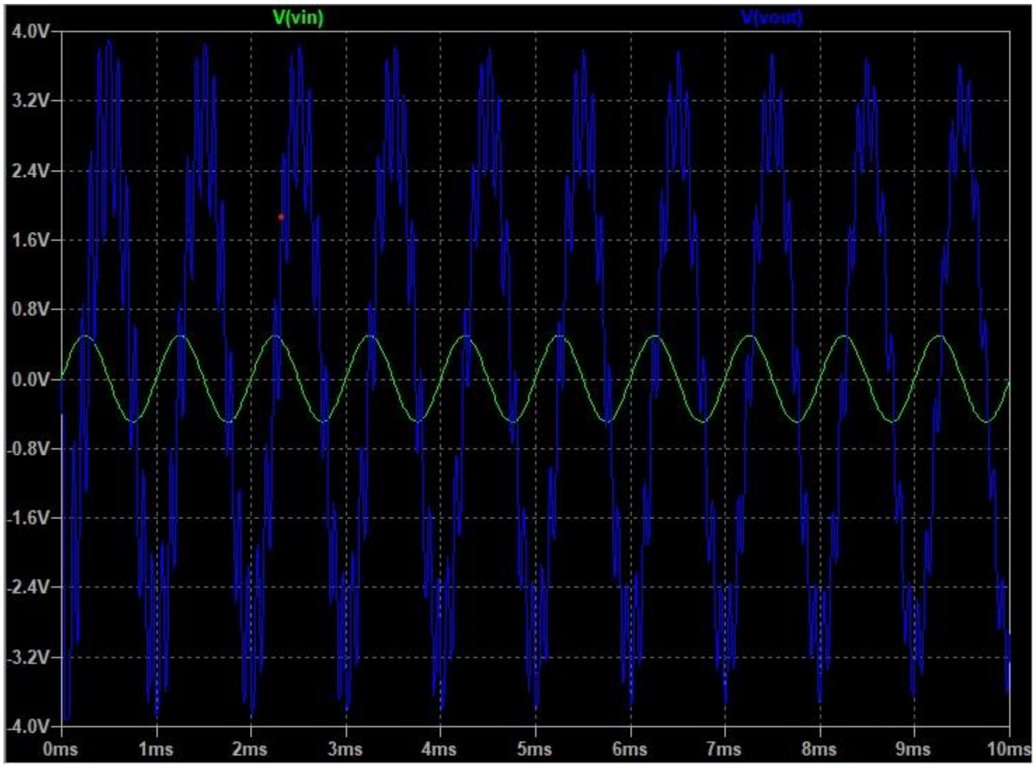


Figure 1. RC Differentiator Op-Amp circuit V_{in} vs. V_{out} plot in LTspice. **[RP3]**

V_{out} is proportional to the derivative of V_{in}, it is not a constant multiplication of the derivative of V_{in}. The value of V_{out} depends on the values of R and C in the circuit. **[RP4]**

$V_{out,max} = RCA_{in}2\pi f = (1000\Omega)(1\mu F)(0.5V)(2\pi)(1000Hz) = \pi$ **[RP5]**

The maximum V_{out} value from the graph is approximately 3.74V which is very close to our calculated value of about 3.14V. **[RP6][RP7]**

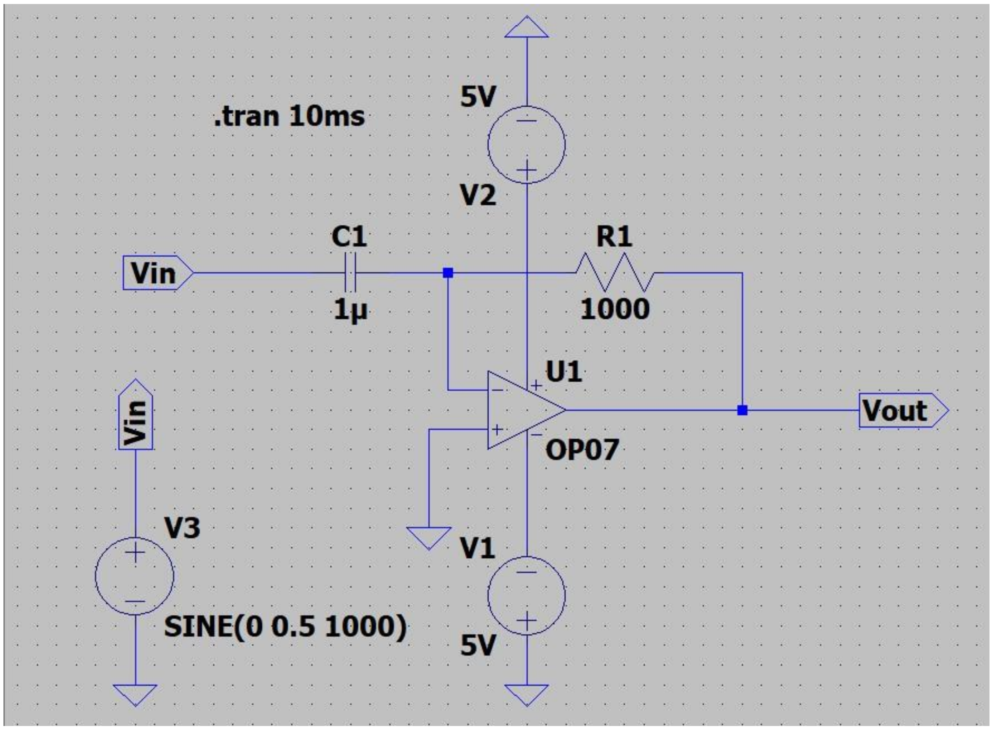


Figure 2. LTspice circuit schematic of RC Differentiator. **[RP8]**

Pre-Lab 3: Derivative Configuration with Inductor

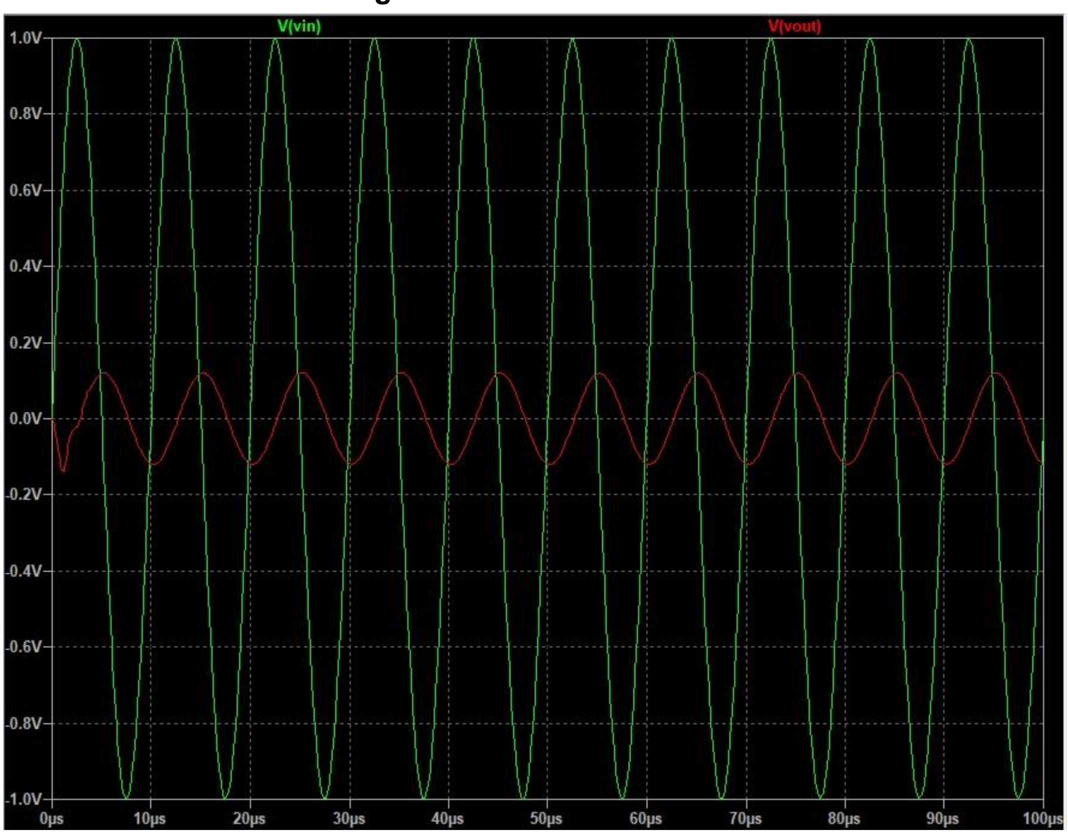


Figure 3. RL Op-Amp circuit V_{in} vs. V_{out} plot in LTspice. **[RP9]**

V_{out} is proportional to the derivative of V_{in}, it is not a constant multiplication of the derivative of V_{in}. The value of V_{out} depends on the values of R and L in the circuit. **[RP10]**

$$V_{out,max} = \frac{100\mu H}{500\Omega}(1V)(2\pi)(100kHz) = \frac{\pi}{25}$$ **[RP11]**

The maximum V_{out} value from the graph is 121.3mV which is pretty close to our calculated $V_{out,max}$ which was 125.6mV. **[RP12][RP13]**

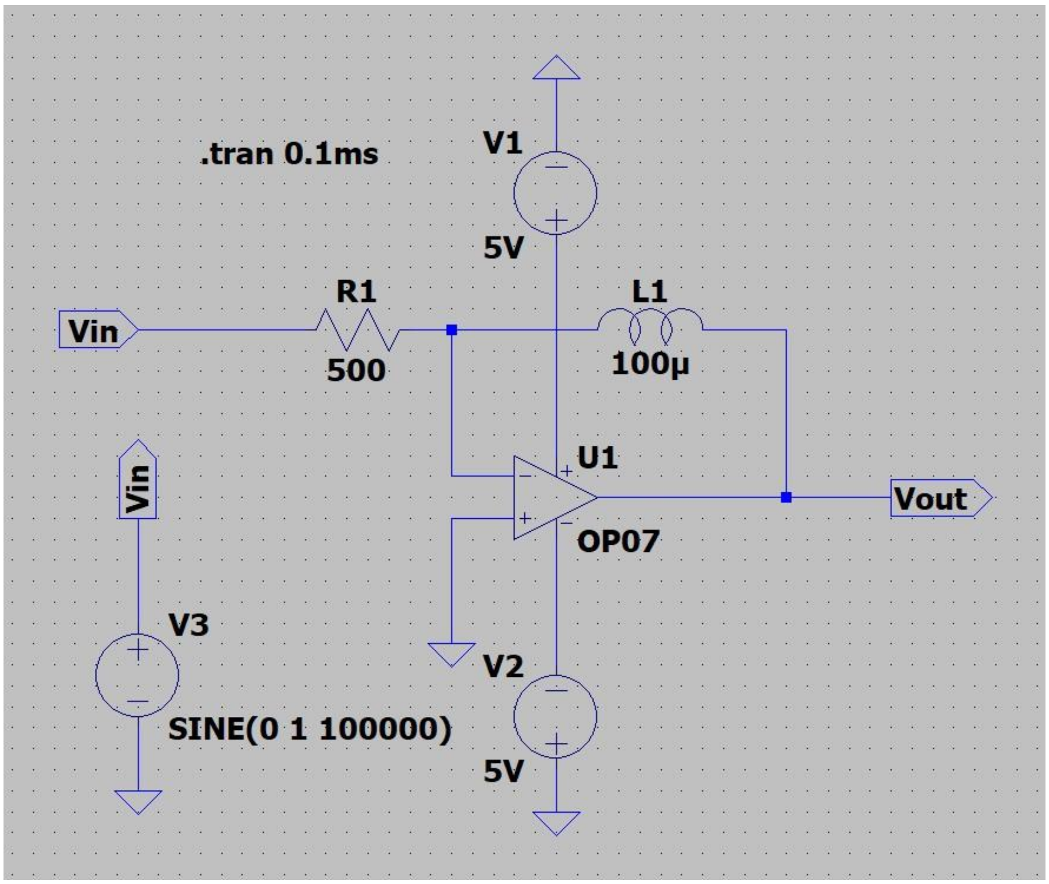
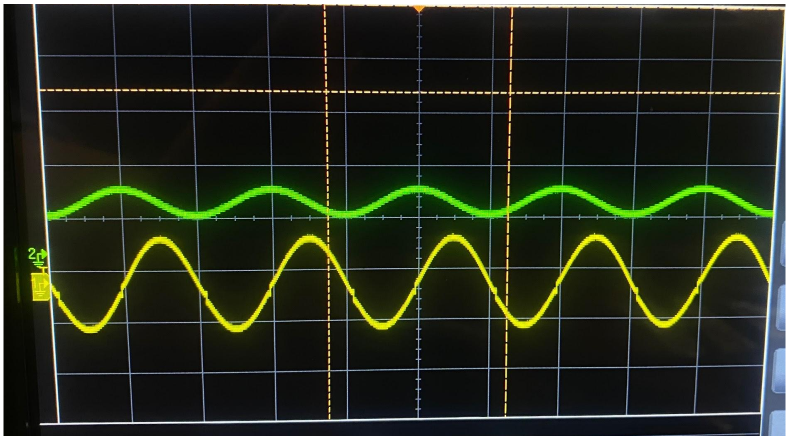


Figure 4. LTspice circuit schematic of LC Op-Amp circuit.**[RP14]**

In-Lab Part 4: Derivative Circuit Implementation



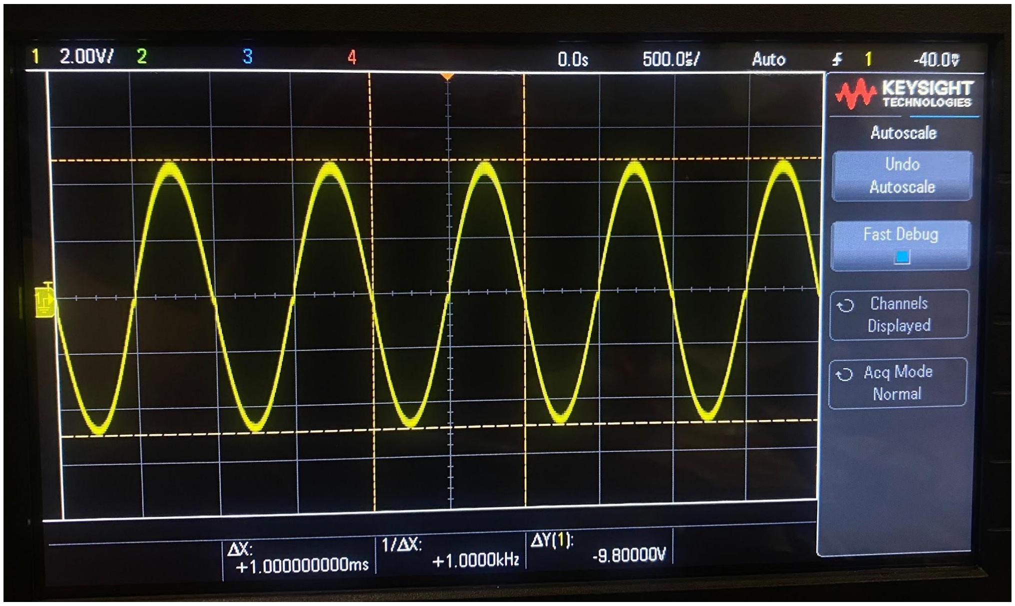
[RP15] Figure 5. RC Differentiator Op-Amp circuit V_{in} vs. V_{out} waveform.

The generated waveform resembles the LTSpice simulation results, with the V_{out} at a -π/2 phase offset from V_{in}. However, the waveform generator does not display any noise in the output signal like LTSpice shows. [RP16]

V_{in} Frequency	250Hz	500Hz	1kHz	2kHz	4kHz
V_{out} Amplitude	0.890 V	1.756 V	3.375 V	5.9 V	8.433 V
V_{out} Phase Offset from V_{in}	-π/2 V	-π/2 V	-π/2 V	-π/2 V	-π/2 V

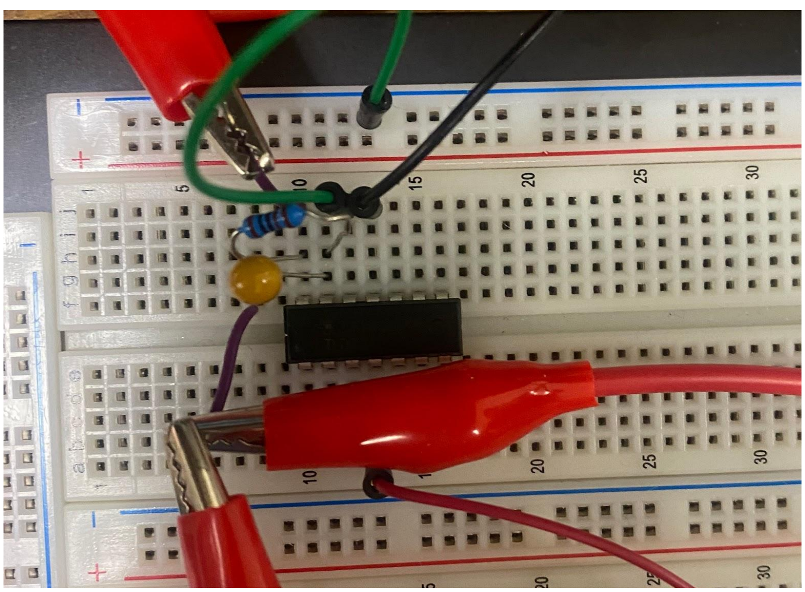
Table 1. V_{out} Amplitude and Phase Offset from various V_{in}. [RP17]

The phase offset does not change no matter how much we increase the frequency. The gain approximately doubles each time we double frequency. [RP18]



[RP19] Figure 6. RC Differentiator Op-Amp circuit V_{in} vs. V_{out} waveform.

[RP20] In RP15, we found that at a 1kHz frequency, the amplitude of V_{out} was 3.375V.
In RP19, we found that at a 1kHz frequency, the amplitude of V_{out} was 4.9V.
Based on these results, it can be seen that a capacitor ten times larger produces a voltage output that is 145% of the original output.



[RP21] Figure 7. RC Differentiator Op-Amp circuit with 10uF Capacitor.

Conclusion:
In conclusion, this lab was successful in teaching us about the use of energy storage elements in op-amps, specifically in the context of differentiator and integrator circuits. By deriving the relationship between Vout and Vin for each circuit and simulating the circuits using LTspice, we

were able to confirm the accuracy of our derivations through visual comparison of the graphs. Additionally, the practical component of the lab involved building an RC differentiator and testing the amplitude of Vout at different frequencies for Vin. From our experiment we found that the V_{out} phase offset from V_{in} did not change and that the gain approximately doubled each time we doubled the frequency. When we switched capacitors for the second part of the lab we noticed that the amplitude of the second capacitor [10μF] was bigger than the amplitude of the first capacitor [1μF] at 1kHz input signal.