CMPE 306

Lab VIII: Op Amps 2: Integrator and Differentiator Circuits

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1. Purpose and Introduction

The purpose of this lab is to study the use of an operational amplifier to implement circuits that provide integration and differentiation of analog input signals.

By the end of this labs session, students will be able to perform the following tasks:

1. Verify the integrator/differentiator operation by means of an LTSPICE simulation.
2. Construct an integrator and a differentiator circuit on the breadboard.
3. Measure and illustrate characteristics of integrator and differentiator circuits.
4. Perform analyses on measured data to demonstrate the limitations of the differentiator and integrator circuits as a function of the frequency of the input signal.

2. Pre-Lab

For Spring 2014, this lab portion should be done using the circuit file provided on Blackboard. Figure 1 shows the first circuit for today's lab. For a pulsed voltage source, instead of the DC voltage value enter the PULSE command with the following parameters: `PULSE(V1 V2 Tdelay Trise Tfall Ton Tperiod Ncycles)`

For the pulsed voltage source circuit of Figure 1, we have an initial voltage (V1) of 0V, a final voltage (V2) of 6V, a time delay (Tdelay) of 0 sec, a pulse rise time (Trise) of 1 ns, a pulse fall time of 1ns, an on interval (Ton) of 0.5 ms, and a period (Tperiod) of 1 ms. I entered 1000 for Ncycles, the number of cycles, but the .tran command discussed below will modify this.

For the capacitor C1 in Figure 1, I have defined an initial condition (ic) of 0V.

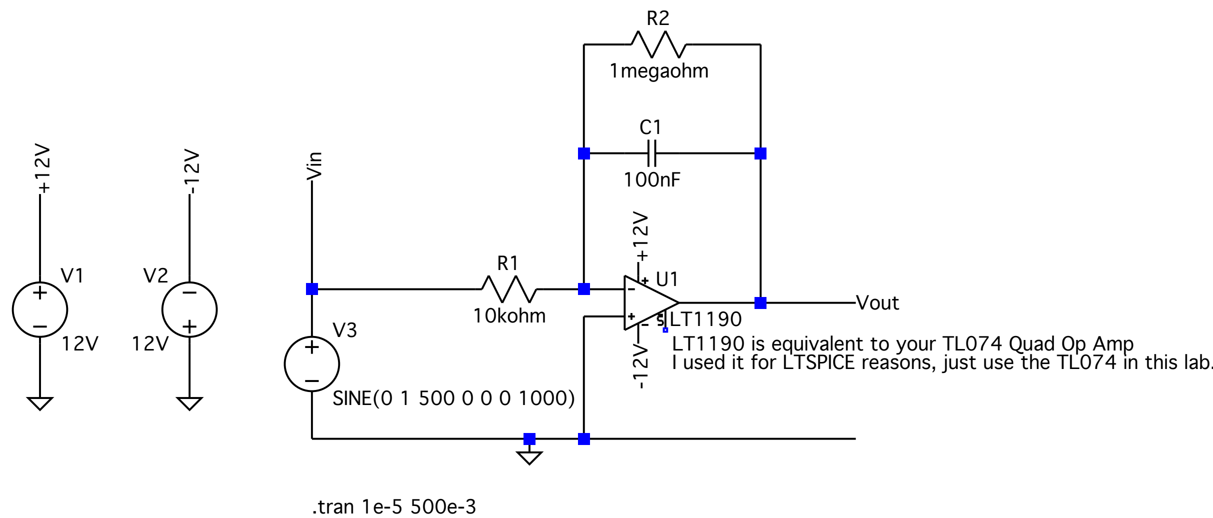

Figure 1 LTSPICE Circuit #1 Showing Sinusoidal Voltage Source and Transient Response Command

1. Load the circuit file LabVIII_RC1.cir containing the circuit of Figure 1. Run the simulation.
2. From plotting window (which should come up immediately), select the Add Traces option. Add the trace for V(vin) and V(vout). You should see a plot that looks like Figure 2. Collaborate with your lab partner to answer the following questions. Why does the blue (vout) curve have the shape it does? Identify the transient and steady state regions.

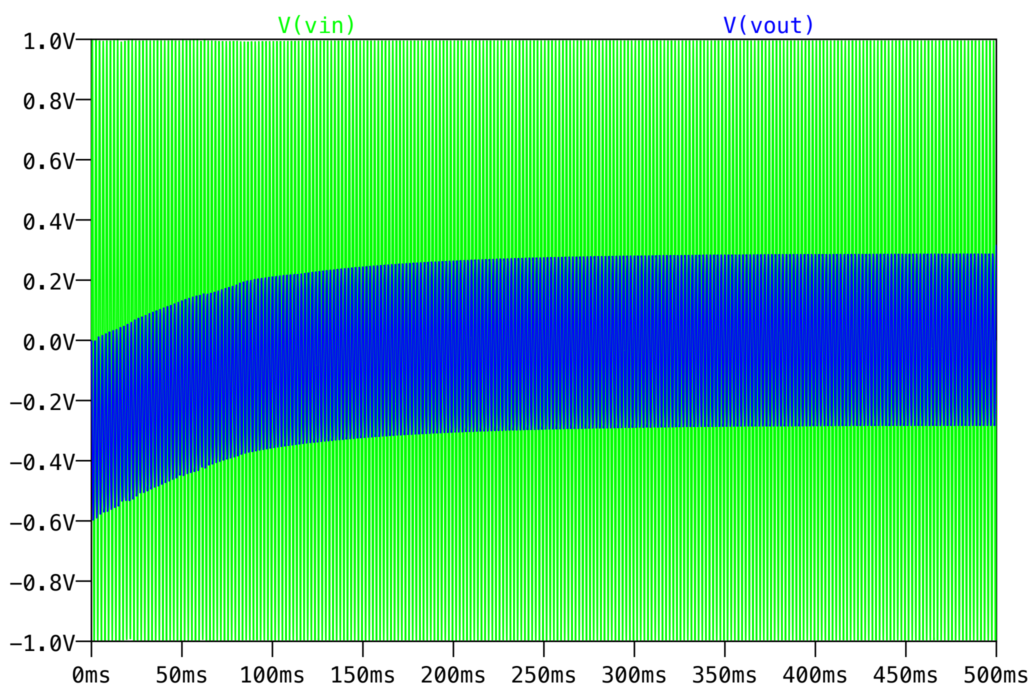

Figure 2: Square Wave input V(vin) and RC output V(vout)

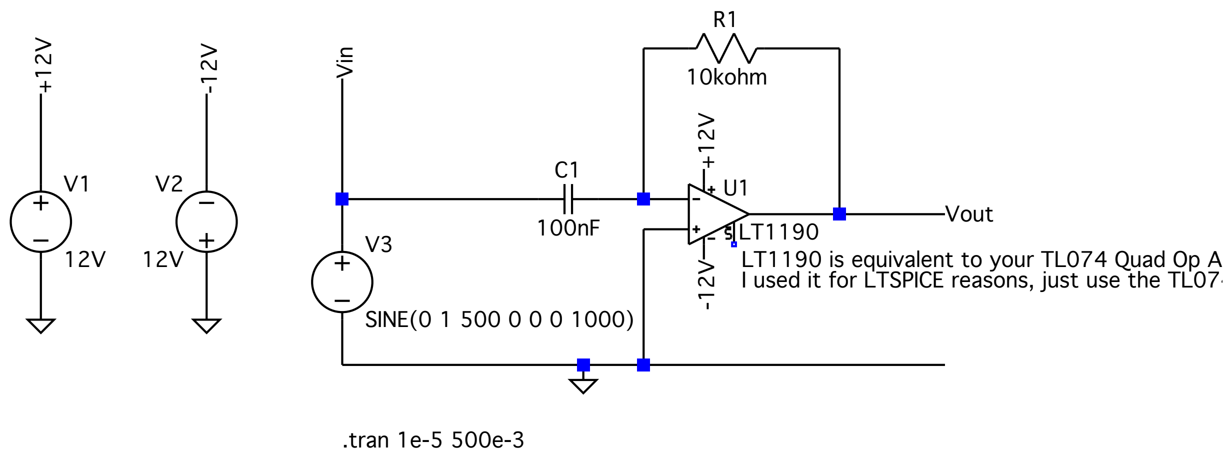

Figure 3 LTSPICE CIrcuit #2 Showing Sinusoidal Voltage Source and Transient Response Command

3. For Spring 2014 only. Perform the following computation to estimate the amplitude of the output sine wave Vout: $V_{out} = G(f) \times V_{in} = -\frac{R_2}{R_1} \times \frac{V_{in}}{\sqrt{1+(2\pi f R_2 C)^2}}$, where $f = 500$ Hz is the frequency of the input sine wave, and $V_{in} = 1\text{V}$ is the amplitude of the input sine wave

4. Change the time scale of the plot and look at the region between 440 ms and 460 ms. The input voltage is a sine wave. Verify that the output voltage is a cosine wave, with the amplitude computed in Step 3. With your partner, discuss how this circuit approximates an *integrator* circuit, where $V_{out}(t) \propto \int_0^t V_{in}(t)\,dt$,[1] where $G(f)$ is the gain factor computed in step 3.

Load the circuit LabVIII_RC2.cir from Blackboard. This circuit is shown in

5. Figure 3. Following the guidance given above, set the voltage source to be the same pulsed source as in Figure 1, and set the capacitor to a value of 100nF with 0V initial condition. Add the transient command.
6. Simulate the circuit, and plot the input and output voltages, as in Step 2.
7. Repeat step 3, this time using the expression $V_{out} = G(f) \times V_{in} = 2\pi f R_1 C V_{in}$. Compare the computation to your simulated output.
8. Change the time scale of the plot and look at the region between 440 ms and 460 ms. The input voltage is a sine wave. Verify that the output voltage is a cosine wave, with the amplitude

[1] The math symbol $\propto$ means "is proportional to", that is, the result is the desired result multiplied by some constant.

computed in Step 3. With your partner, discuss how this circuit approximates a *differentiator* circuit, where $V_{out}(t) \propto \frac{dV_{in}}{dt}$, where $G(f)$ is the gain factor computed in step 3.

9. Provide the plots you generated in LTSPICE in your lab report. You might find it helpful to print them as PDF files and then insert the PDF files.

3. Equipment

This lab exercise uses the following equipment:

1) Tektronix AFG310 Arbitrary Function Generator
2) Tektronix 2012 Digital Storage Oscilloscope
3) BNC-to-BNC cable
4) Two BNC-to-alligator cables.
5) $1\text{M}\Omega$, $10\text{k}\Omega, 20\text{k}\Omega$ resistors, 100nF capacitor, TL074 Quad op amp
6) 100nF and 10nF capacitors.

4. .Procedure

4.1. Op-Amp based integrator circuit

1. Consider the circuit shown in Figure 1 (use Figure 1, *not* Figure 3!) . Use the expression given in Step 3 of the pre-lab to estimate the amplitude of the output response at 500 Hz.
2. Use input of 2 V (peak-to-peak) 500 Hz square wave with zero DC offset to the circuit in 1). **Print out both V_i(t) and V_o(t) (PR1).** Verify the input and output relation prediction in 1).
3. Repeat 2) for 1kHz. Remember that you will need to recomputed the frequency-dependent gain term. **Print out both V_i(t) and V_o(t) (PR2).**
4. Change R_1 to 20k and repeat 2). **Print out both V_i(t) and V_o(t) (PR3).**
5. Change V_i(t) to a triangle wave and repeat 2), 3), and 4). **Print out (PR4~PR6).**
6. Change V_i(t) to a sine wave and repeat 2), 3), and 4). **Print out (PR7~PR9).**
7. **Show lab instructor PR1~PR9**

4.2. Op-Amp based differentiator circuit

Construct the circuit shown in

1. Figure 3 (Figure 3, not Figure 1 or Figure 2!). Compute the expected amplitude of the output using the expression given in Step 7 of the prelab.
2. Configure the AFG to provide a 1V (peak-to-peak) 1 kHz sine wave input.

3. Apply the input to the circuit and print out both $V_{in}(t)$, and $V_{out}(t)$. Compare the amplitudes with the computed amplitude. From Step 1 of this section. **Print the output (PR10).**
4. Change Vi (t) to a triangle wave and repeat 2). **Print out both Vi (t) and Vo(t) (PR11).**
5. **Show lab instructor PR10~PR11**

4.3. Preparation for Next Lab

I haven't finished the next lab yet. We're a little out of sync with the lectures, so I have to juggle things a little. I will attempt to have the new lab posted by Thursday evening.

For the lab report for this week, please include all of the plots that you were asked to save, and all of the values you were asked to record, and the computations you were asked to make. Partners should participate in the derivations. Please indicate in your report if your partner participated or not.

5. Tear Down and Clean Up

1. Turn off the power supply, AFG, and oscilloscope and set the multimeter to the OFF position. Return the multimeter to your TA for storage.
2. Save your images or data to your memory stick. Then close the program and sign off of the computer.
3. Put your resistors and capacitors chip back in your lab kit. Return your lab kit to the TA for storage.
4. Return the BNC cables and BNC-to-alligator cables and hang them neatly in their proper rack.
5. Police your lab area: leave it neat and clean.
6. If you're using your own laptop, there's nothing else to clean up.
7. If you're using the lab computer, save whatever work you want to your USB drive. Close LTSPICE if necessary. Eject your drive.