LAB B: Common electronic circuits

February 27, 2024

Introduction

Welcome to the second lab of your Linear-Electronics course! In this lab, you will explore a diverse range of electronic circuits and amplifiers, building upon your existing knowledge. Let's take a quick glimpse at each section:

1. RL Circuit and RLC Series Resonance Circuit: Experiment with a first-order circuit in the time domain and dive into the use of RLC series resonance circuits as you investigate their behavior with alternating current (AC). Observe resonance phenomena and learn about practical applications in filtering and frequency selection.

2. Ideal & Non-Ideal Operational Amplifiers: Delve into the realm of operational amplifiers, starting with their ideal characteristics and then exploring real-world non-idealities. Gain insights into designing and analyzing complex circuits with OpAmps.

3. Differentiation (OpAmp): Uncover the use of signal processing with OpAmps by studying differentiation. Shape and analyze signals, understanding its applications in various electronic systems.

4. Integration (OpAmp): Learn the use of integration using OpAmps and explore its significance in analog computing and audio processing. Develop a deeper understanding of mathematical operations in electronics.

5. Wien Bridge Filter (Oscillators): Explore the principles of oscillators using the Wien Bridge Filter. Generate stable sinusoidal waveforms and understand the significance of oscillators in electronic systems.

Through hands-on experiments and thoughtful analyses, this lab aims to deepen your comprehension of advanced electronics. Enjoy the journey as you apply your theoretical knowledge!

Hand-in Requirements

Your hand-in document shall be in ".pdf" format and follow this guideline:

`FYS3220_LAB_Y_Vxx_Username.pdf`

Here, Y is the letter of the lab (B in this case), and Hxx is V24 for the 2024 course, and username is your UiO username.

We are quite strict on hand-ins and will require you to have, at the very minimum, all the demands listed at the bottom of the lab. In addition to this, we will require you to provide thorough answers with discussions for most, if not all, tasks.rs.

Questions

You may ask questions at the lab classes, or you may write an email with the subject: "LAB-Y" where Y = B for LAB-B.

`Email of the lab supervisor: florian.dapsance@fys.uio.no`

Working in Pairs

You are free to work in pairs and use the same plots, but keep in mind that the reflections and comments should be your own work and reflect what you know about the subject. In other words: **don't copy-paste each other's answers.**

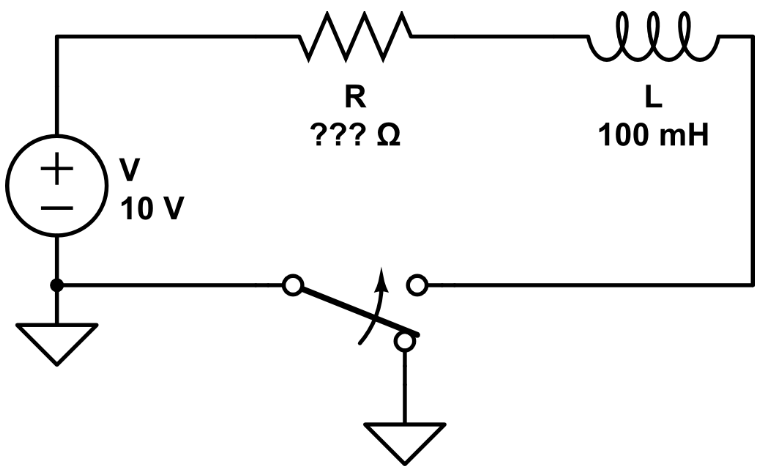
Curriculum

Chapter 6, 11, 12, and some of 13 are covered by this lab. If you are stuck, we highly encourage you to ask questions. This lab will have a higher focus on understanding and discussion than the last lab, and you should spend the majority of time writing and understanding the circuits rather than just doing the step-by-step tasks.

1 RL Circuit and RLC Series Resonance Circuit

In this task, we are to study the changes in both the time and frequency domains. We will first look at a first-order RL circuit before analyzing an RLC resonance circuit. Then, we will examine how the damping term affects the pole location and, in turn, how the change in the pole location affects the circuit as a system. To facilitate a comparison between different outputs from various damping terms, we will draw the same RLC circuit a total of three times.

1.1 RL circuit and time constant

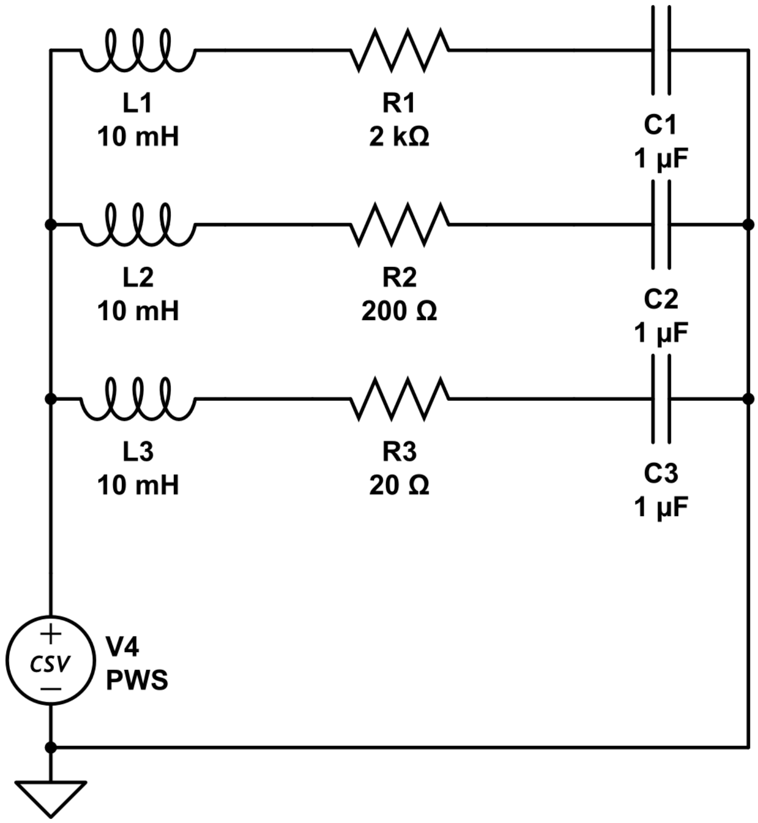


- ☐ Solve the first-order differential equation for the circuit above and find an expression for I(t).

We know that the exponent of an exponential function needs to be a pure number, which means that whatever we have as a coefficient of t in the $I(t)$ equation needs to have units of s^{-1}. Thus, $\frac{1}{\tau}$ is this time constant.

- ☐ Solve for R in the specific case of $\tau = 1$ ms.
- ☐ Simulate the RL circuit for the found R value and show that $\tau = 1$ ms by measuring on the plot. How many τ does it take to reach 99% of the max value? You can use cursor lines in CircuitLab to annotate the plot.

1.2 RLC circuit - Transient Analysis



The current in an RLC circuit with a *short pulse* as the input can be modeled as:

$$I(s) = \frac{V_{in}(s)}{Z(s)} = \frac{V_{in}(s)}{sL + R + \frac{1}{sC}} = \frac{V_{in}(s) \cdot sC}{s^2 LC + sRC + 1}$$

We can find the Transadmittance (see pg. 537 in the textbook), by dividing the current by the input voltage:

$$Y(s) = \frac{I(s)}{V_{in}(s)} = \frac{\frac{1}{L}s}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{\frac{1}{L}s}{(s-p_1)(s-p_2)}$$

We can then find the zero by solving the top part of the fraction, and the poles by solving the bottom using the quadratic formula:

Equation: RCL pole equation

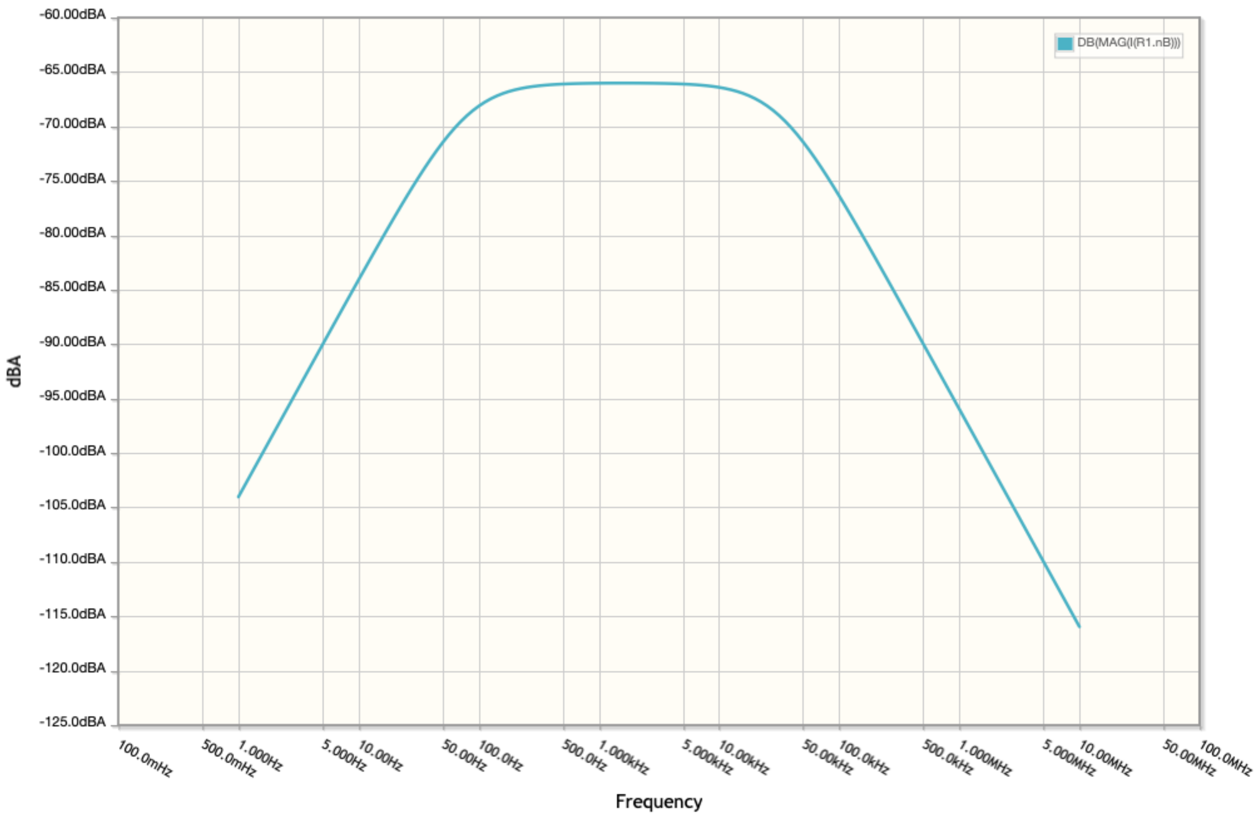
$$D(s) = s^2 + s\frac{R}{L} + \frac{1}{LC} = as^2 + bs + c$$
$$p_1, p_2 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = -\alpha \pm \beta$$

- ☐ Perform a transient analysis of the RLC circuit shown in **Figure: Schematic needed for Section 1**. Plot the **current** going into the resitors. It might be a good idea to multiply the I_{R_1} value by a factor, e.g., 10. Discuss the result based on your knowledge of spring-like systems.
  - Set up the voltage source to give a 1 V pluse and plot the current around that time. (for CSV sources you may write e.i (in the textbox):
  - 0,1
  - 0.1,1
  - 0.2,0
- ☐ Solve the three RCL circuits using **Equation: RCL pole equation**.
- ☐ Fill in the table below (**Table: Pole and alpha/beta values**) with the values you found. Round off the numbers to about one decimal point if necessary. Hint: The poles can be expressed as complex numbers.

	Zeros	α [kHz]	β [kHz]	p_1 [kHz]	p_2 [kHz]
R_1 branch					
R_2 branch					
R_3 branch					

1.3 RCL circuit - AC Analysis

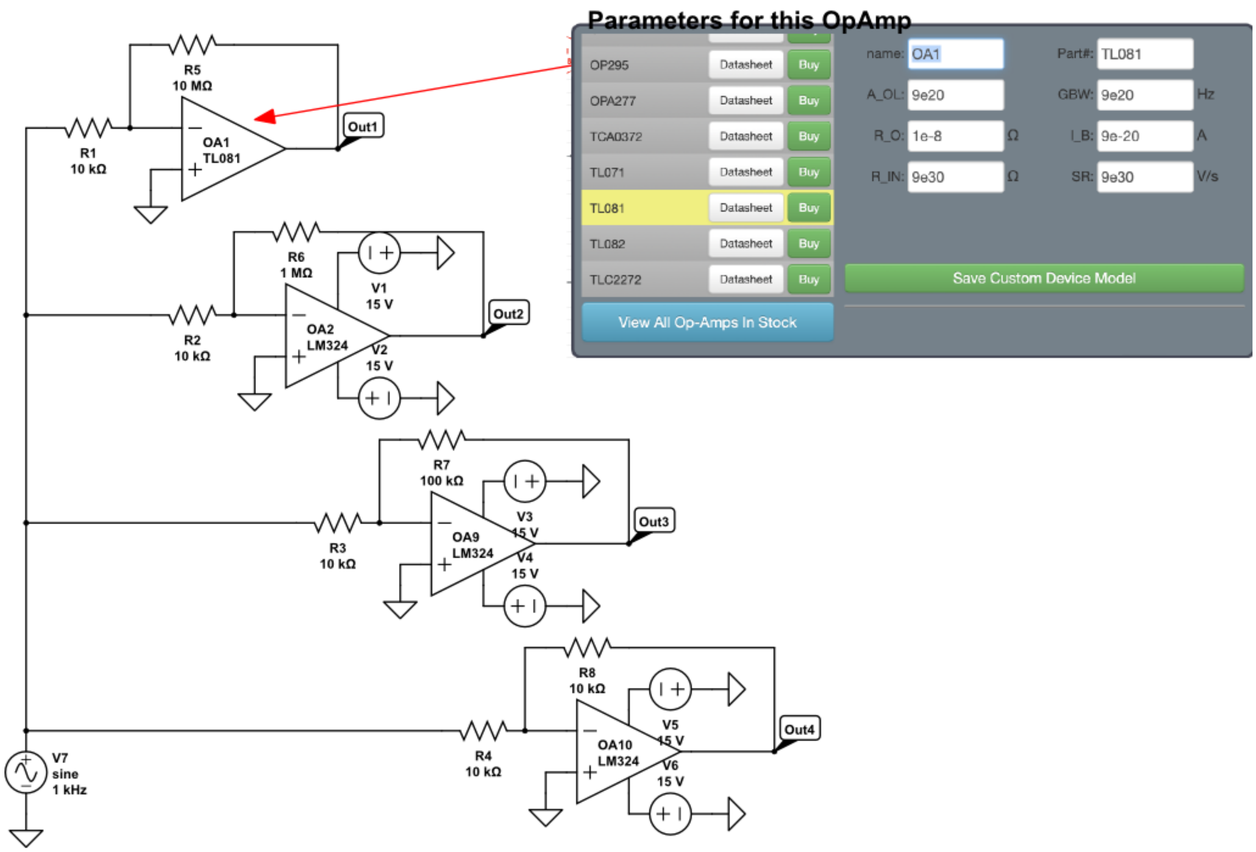
- ☐ Run an “AC -sweep” using the following parameters (you should get something like **Bode Plot R Circuit** (picture below) for just the R_1-circuit, but please plot all three circuits in the same plot):



☐ Discuss and go into detail about the relationship between **Table: Pole and alpha/beta values** and your plot.

2 Ideal & Non-Ideal Operational Amplifiers

Figure: Ideal and Non-Ideal Operational Amplifiers



In this task, we are going to study some aspects of ideal and non-ideal operational amplifiers when connected in the inverting configuration. We know from the textbook (see ch.4 & pg.212 and onward) that even though we can use some known formulas for an ideal OpAmp, that is not always the case with real OpAmps.

2.1 Calculating Gain for our Circuits

- ☐ Assuming that the LM324 works like an ideal OpAmp, calculate the gain for your four circuits so we can reference it later when simulating.
- ☐ Simulate the circuit using an AC-analysis and plot a bodeplot showing all four circuits in the same plot. If you have more than $10^{10}Hz$ as the maximum, then the "ideal" Opamp at the top starts to behave as a non

ideal one.

- ☐ Measure the Bandwidth (BW) for each of the outputs (see Textbook pg.555).
- ☐ Fill in **Table: Gain and BW Values** below with the relevant information.
- ☐ Explain the difference between an ideal OpAmp and a non-ideal one. Bring in the plots and comment on the simulated differences compared to what you know from theory.

	Out1	Out2	Out3	Out4
Are the calculated and simulated gains comparable at f=100 Hz?				
Are the calculated and simulated gains comparable at f=100 kHz?				
Bandwidth (kHz)				

2.2 Series Connection of Non-Ideal OpAmps

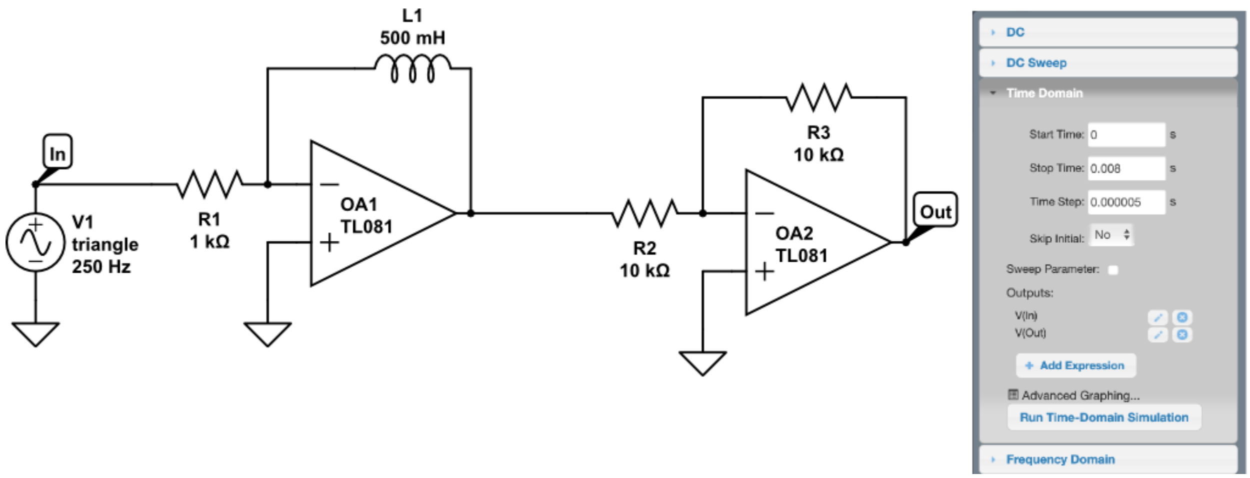
Now that we have seen the effects of the properties of a non-ideal OpAmp on the output gain, we can try some adjustments to see if we can mitigate it.

- ☐ Using your circuit from **Figure: Ideal and Non-Ideal Operational Amplifiers**, reconnect so that the output of the second OpAmp feeds into the forth one (the one at the bottom). Remember to disconnect the line of the 4th from the voltage source.
- ☐ Change the values of R_{f2} (R6 on the figure) and R_{f4} (R8 on the figure) to 31.63 kΩ. Plot a bodeplot of Circuit3 and the newly connected Circuit4.
- ☐ Fill out **Table: Gain and BW Values** with the relevant values.

	Out3	New Out4
Gain (dB)		
Bandwidth (kHz)		

3 Differentiation

Figure: The circuit needed for this chapter. ***NOTE: the values are for the calculation example and will need to be changed for your answer.***



In this part of the lab, we will study a differentiation circuit. We will first calculate the V_{out} using the Laplace transform. Although we have been using Laplace earlier in this lab, it might be useful to look over the Laplace chapter in the textbook before you venture out on this part (see ch.12 in the textbook).

By looking at the values of the "V1" component, we can see that our source will behave like a sawtooth signal with a period of 4ms. This means that from 0ms to 1ms we can look at it through this rising slope function.

$$f(t \in \{0, 1ms\}) = (\frac{1V}{1ms}) \cdot t = 1000V/s$$

If we wish to find out if our circuit behaved correctly, then we need to calculate if it will differentiate the linear function correctly. The steps to do this are as follows:

- We find the transfer function of the circuit H(s) in the s-domain.
- We do a Laplace transform on the output signal and on the transfer function.
- Multiply the output signal by the transfer function.
- Do an inverse Laplace transform and solve for v_{out}.

First, we find H(s) from the equation for the gain of the two ideal OpAmps:

$$\begin{aligned} H(s) &= H1(s) \cdot H2(s) = (-) \cdot Zf1/Zi1 \cdot (-) \cdot Zf2/Zi2 \\ &= Lf1/Ri1 \cdot Rf2/Ri2 = Lf1/Ri1 \end{aligned}$$

$$\begin{aligned} H(s) &= L \cdot s/Ri1 = (500mH)/(1k\Omega) \cdot s \\ &= 0.5 \cdot 10^3 \cdot s = ks \end{aligned}$$

Where k is chosen as the variable for the rise of the function.

Second, we find the Laplace transform of the input. Although the slope of the "VPULSE" is modeled well through `f(t) = at * u(t)`, we still need to add some term to describe the start and stop of the slope. As shown in ch.12.2 of the book, we can use a unit step function to do this. The input function becomes then:

$$f(t) = a \cdot t \cdot u(t) \rightarrow L[a \cdot t \cdot u(t)] = a \cdot 1/s^2 = a/s^2$$

Third, we need the output function. Finding the output signal is simple in the Laplace domain, and we find it by multiplying the input with the transfer function:

$$V_out = V_in \cdot H(s) = a/s^2 \cdot ks = ak/s$$

Fourth, and last, we need to find the output in the time-domain. Inverse Laplace transform can be tricky, but here we normally use a handy lookup table and transform back. $L^-1[1/s] \rightarrow u(t)$. If we apply this to our V_{out} we get:

$$V_{out} = aku(t) = 1000V/s \cdot \frac{500mH}{1k\Omega} \cdot u(t) = \begin{cases} 0V & \text{if } t < 1ms \\ 0.5V & \text{if } t > 1ms \ and \ t < 2ms \\ 0V & \text{if } t > 2ms \end{cases}$$

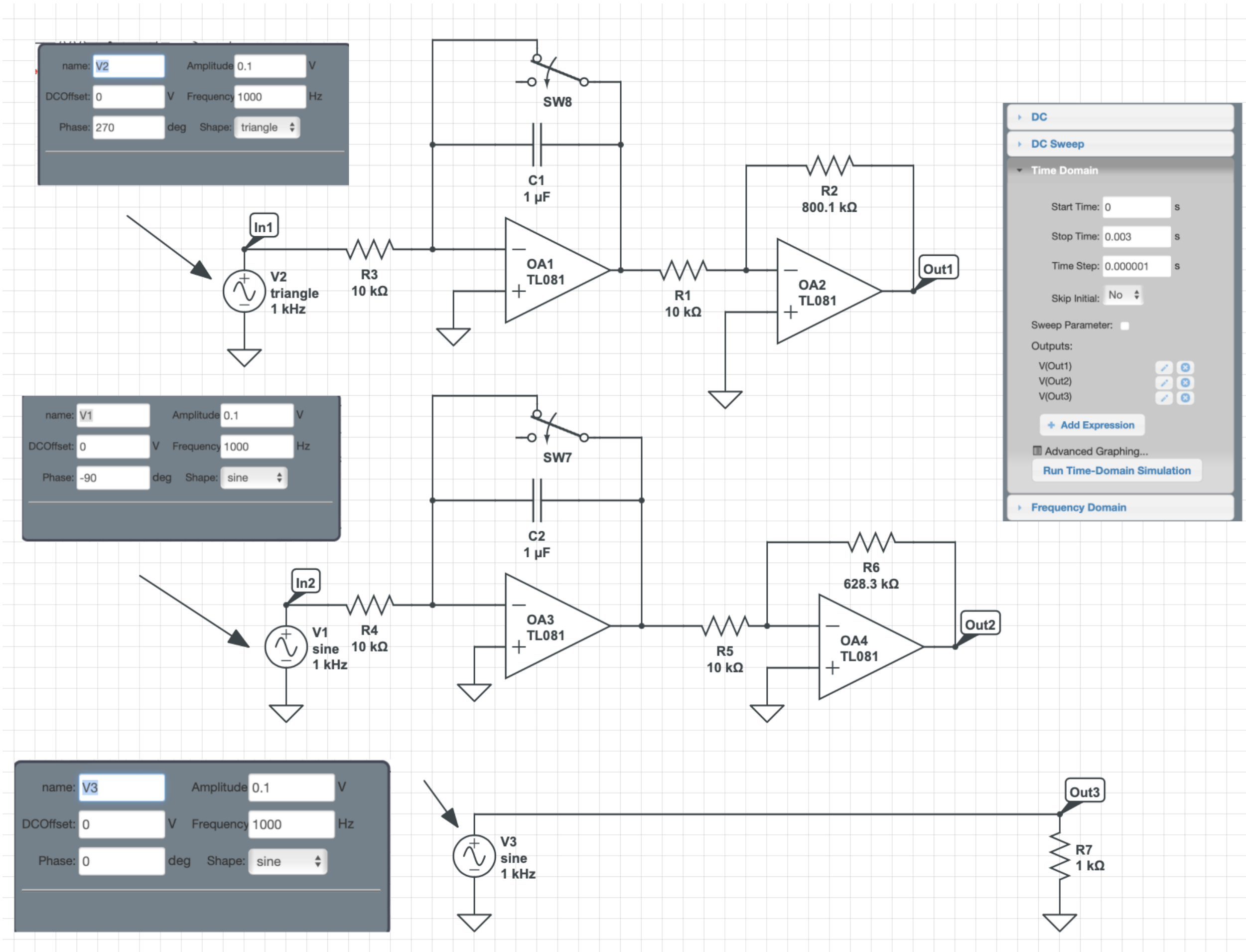
Note that this expression is only valid for the first rising slope of the triangle input signal. When considering the whole periodic triangle wave, one period-lasts 4 ms. Hence, the output signal V_{out} needs to be further defined between 2 ms and 4 ms.by

3.1 Your Differentiation Circuit

- ☐ Replace the inductor L_{f1} and the resistor R_{i1} with:
  - $L_{f1} = 700mH$
  - $R_{i1} = 1.2k\Omega$
- ☐ Calculate your differentiated voltage V_{out}.
- ☐ Perform a transient analysis and comment on how the V_{in} and V_{out} plots compare with your calculations.
- ☐ If you were to replace the linear function present in the voltage source with a sinus signal, what would be the expected output?

4 Integration

Figure: Circuit needed for this section. You might want to add more voltage probes for your answer. ***NOTE: In the middle circuit, the "VSIN" is set up to act as a cosine signal. The switches closes as some small time (t=1us)***



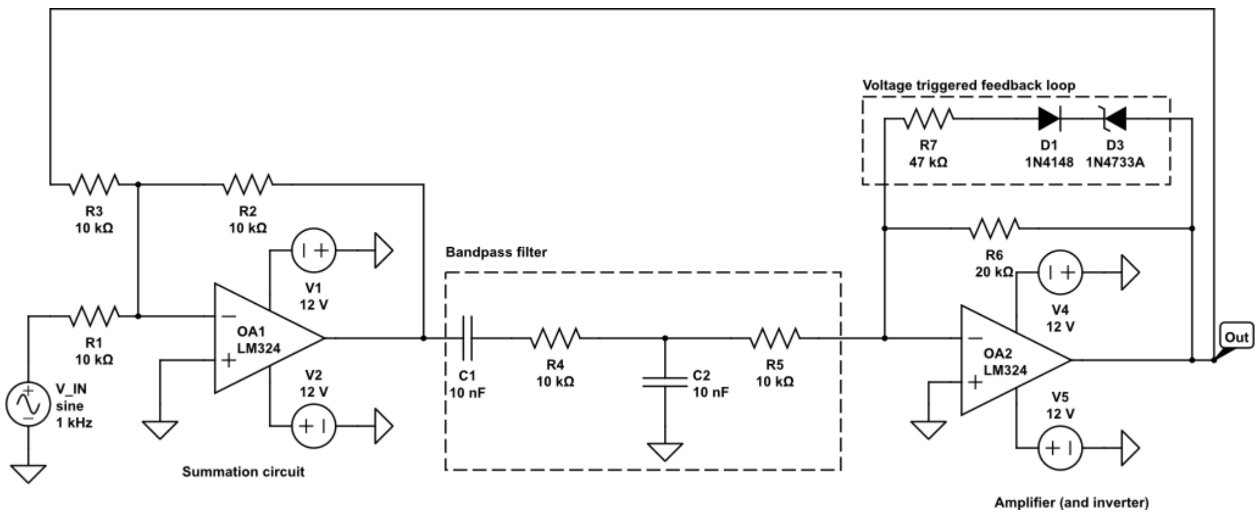
An integrator will integrate the signal that is applied to the circuit and output a voltage equal to the integral of the input. Since we're using operational amplifiers in the inverting configuration, we expect to get the inverted signal at the output. Capacitors behave unexpectedly if there is residual charge on them when we start our transient, and so we have a switch that will make sure they start off with no charge. Since the capacitor is placed between the OpAmps' virtual ground and the output, the entire V_{out} will be over the capacitor.

4.1 Calculation and Simulation of Your Integrating Circuit

- ☐ Calculate the $V_{out}(t)$ of the middle circuit. Comment on why we changed the R_{f22} to such an odd value. *NOTE: You may use either Laplace or KCL to do this.*
- ☐ Simulate the three circuits outputs, and comment on the differences you can see. Use transient analysis.

5 Wien Bridge Filter

Figure: Circuit needed for this section, a wienbridge filter and oscillator. ***NOTE: The diodes will break down and behave like a wire at high voltages.***



In this section, we will study the wien bridge filter, which is a well-used filter in electronics known for generating a stable frequency output.

The circuit in Figure has the transfer function:

$$H(s) = \frac{sGRC}{(sRC)^2 + s(3-G)RC + 1}$$

The denominator resembles the characteristic equation for a second-order system (textbook p.304 and p.659)

5.1 Describing Your System

- ☐ Using the characteristic equation and setting $R_{f2} = 20\ \mathrm{k}\Omega$ (R6 in the figure) so that $G = 2$, calculate the damping factor ζ, the quality factor Q, and the resonance frequency ω. *NOTE: That Q can be defined as:* $2Q = 1/\zeta$.
- ☐ Make a bode plot of your system with $G = 2$ and comment on your found Q and ζ values in relation to the plot. (set the end frequency of the bode plot so that phase has settled)

- ☐ Change $R_{f2} = 29$ kΩ, causing a high Q value. Comment on how this affects the bode plot (no need to add the plot).
- ☐ Change $R_{f2} = 32$ kΩ and $V_{IN} = 10 $kHz. Do a transient analysis. Describe the output as a function of time and explain the reason for the different spikes in the frequency domain (FFT). for example with $R_{f2} = 22$ kΩ).

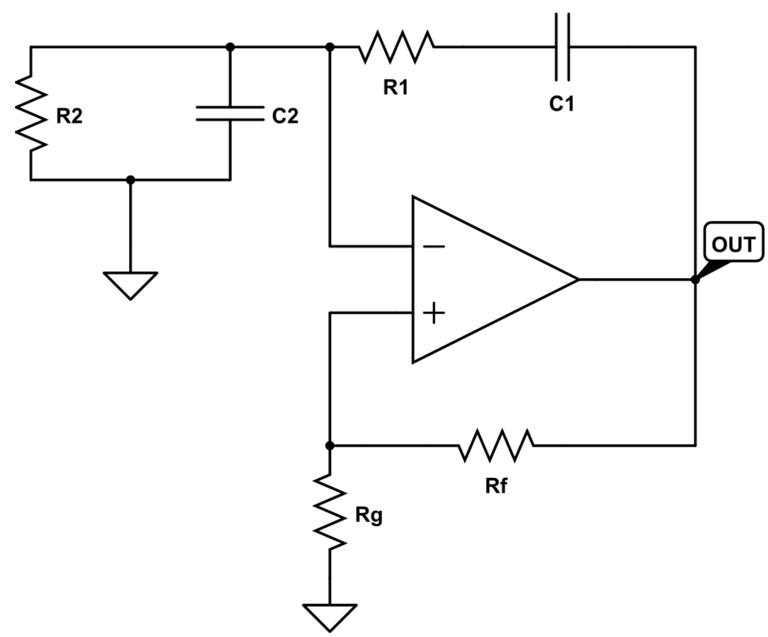
5.2 Sending a Pulse into the System

We will replace our "VSIN" with a "VPULSE".

- ☐ Change $R_{f2} = 35$ kΩ and perform a transient analysis on the circuit (you might want to increase the Final Time to 15 ms). Study the output and comment on why the V_{out} looks like it does. (it might be handy to look at the FFT too.)

5.3 A Wien Bridge Filter Without Input

Figure: A wienbridge filter that does not have an input.



Consider the circuit pictured above. This is also a wienbridge configuration, but it does not have an input like the previous one. However, it still oscillates at some chosen values of R_f and R_g.

- ☐ Comment on how this oscillator works and what enables it to oscillate. What happens if the carefully chosen values of R_f and R_g are slightly off?
- ☐ Our circuit in (a) does not have feedback into the positive port on the "LM324" component, but as shown in the previous subsection, it oscillates quite fine. Comment on the source of the positive feedback.