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ECSE 2050 – Introduction to Electronics
Lab 2 (day 1)
2024-01-18

Pre-Lab Exercise 1

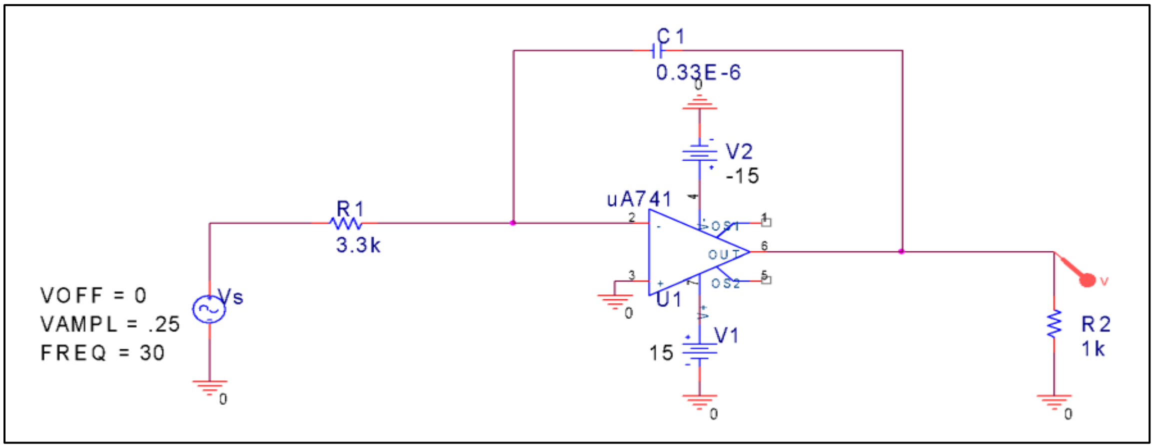
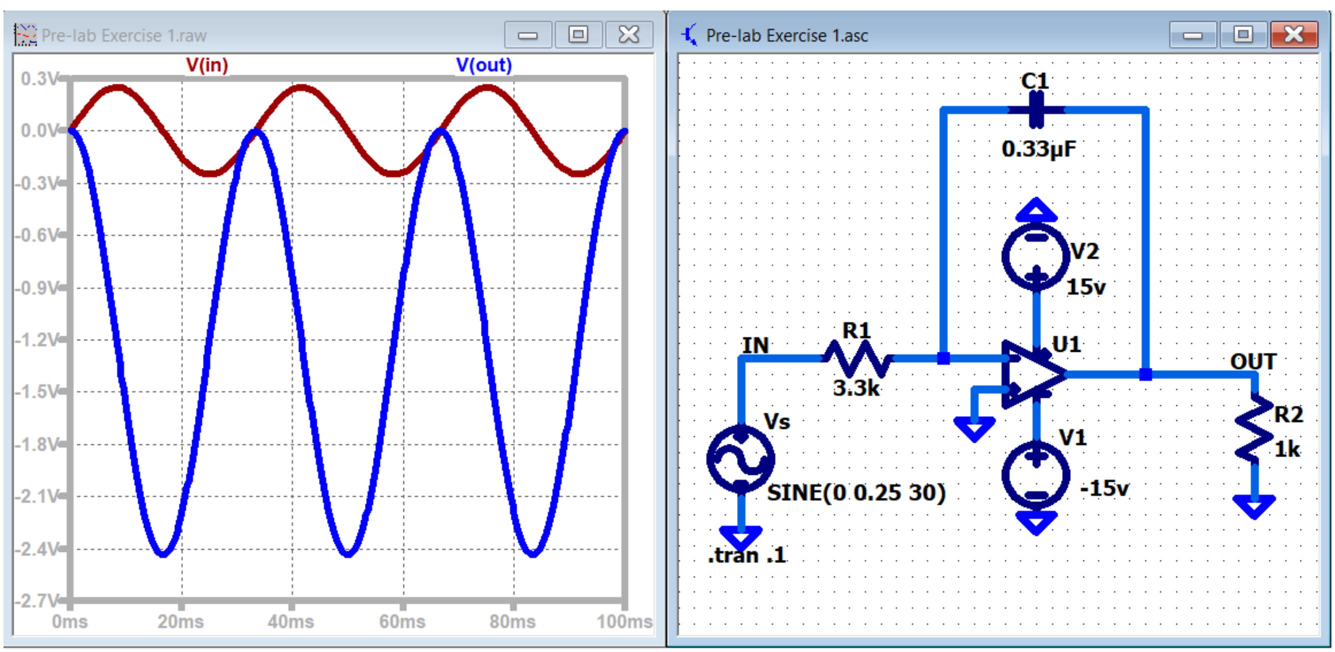


Figure 1: Integrator

1. Implement the above circuit in PSpice, using the µA741 amplifier component. Pay attention to the pin numbers for the component, it is consistent with the pin diagrams provided in Laboratory 0. In the above schematic, the amplifier has been vertically 'flipped' for ease of layout. The power supplies are 15 V / –15 V, as shown above. The input signal is a 30 Hz, 0.25 V amplitude sinusoidal voltage (the Vsin component).

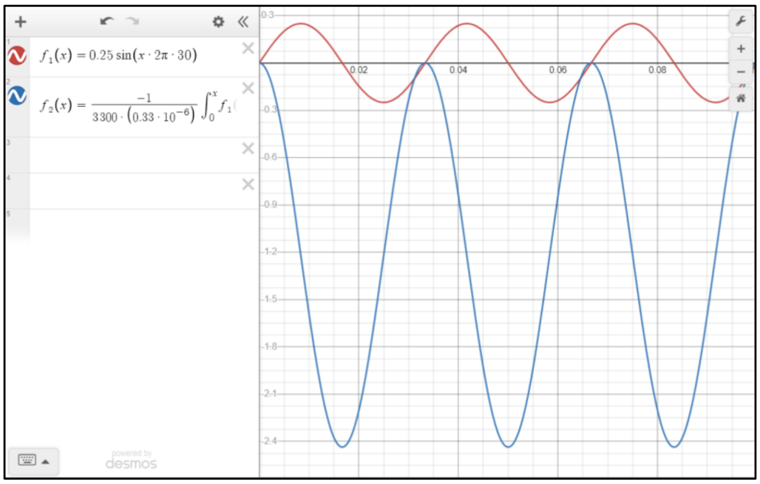


2. Run a transient analysis in PSpice and plot a few periods of the output. Is the output behavior consistent with an integrator?

(see plot above)
The equation for the output of this type of integrator is:

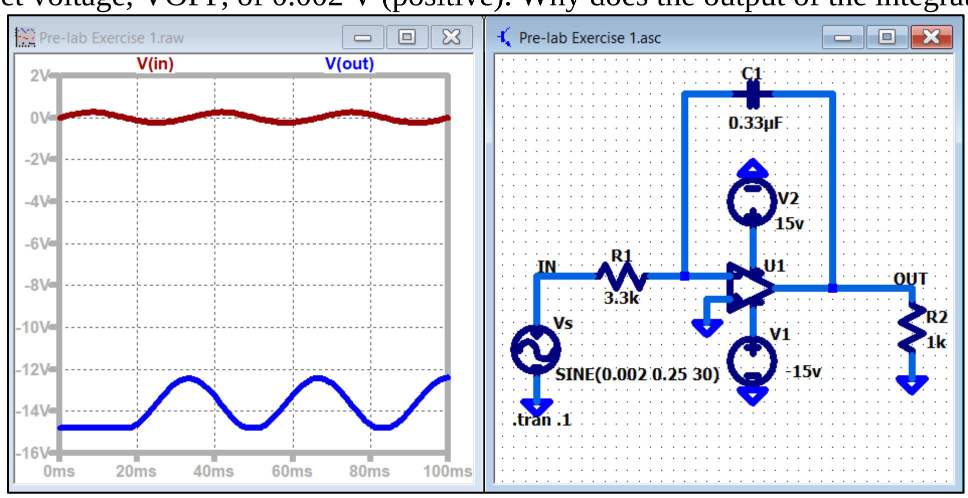
$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\,dt = -\int_0^t V_{in}\frac{dt}{R_{in}.C}$$

Given our R_{in} = 3.3kOhms , and C = 0.33uF = 0.33*10^{-6} F, we would expect the input and output to look as follows:



And this waveform matches the simulation! It is the negative integral of the input, with a gain factor determined by the input resistor R_{in} and the feedback capacitor C_F. So the op-amp integrator is successfully doing its job.

3. Add an offset voltage, VOFF, of 0.002 V (positive). Why does the output of the integrator change?



With the offset voltage added, the output voltage is shifted to a higher voltage offset range, and has run into the -15v saturation point determined by -Vcc.
When the integral is taken again with this extra 0.002 term, it integrates to -0.002t*(amplification factor), which adds to the output wave and makes it more negative.

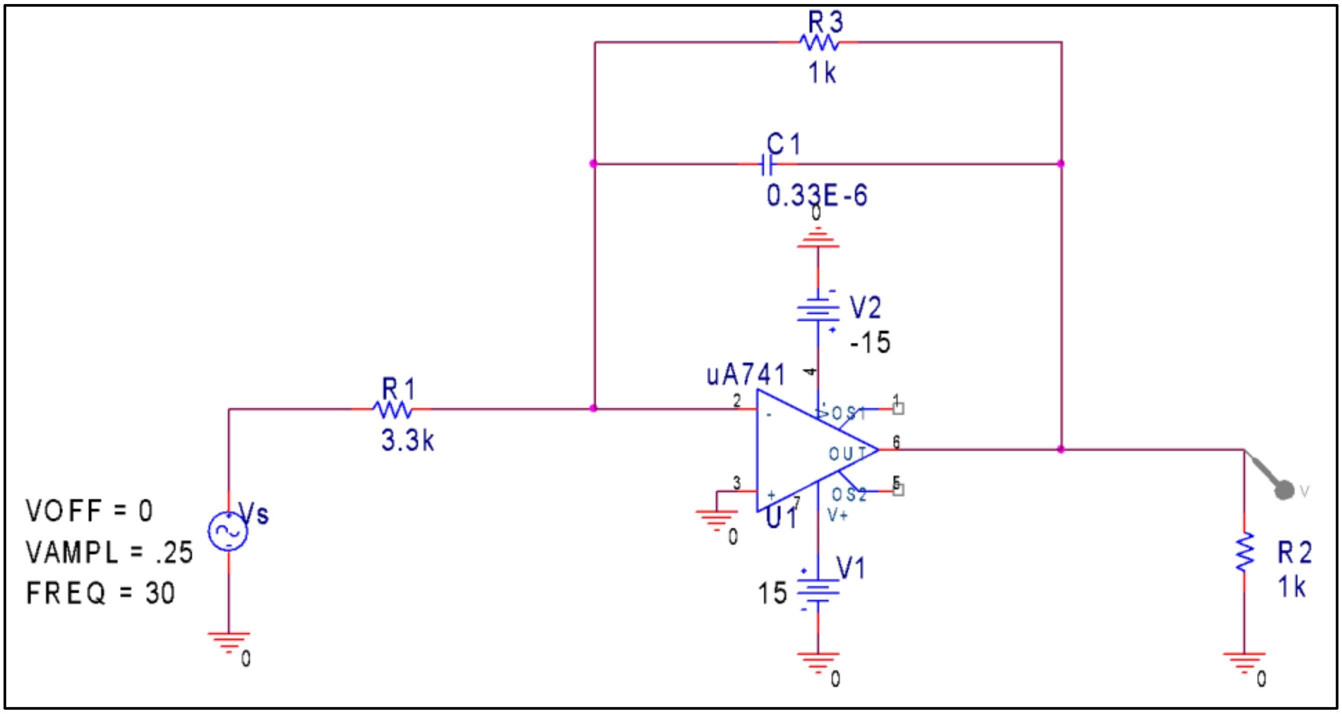
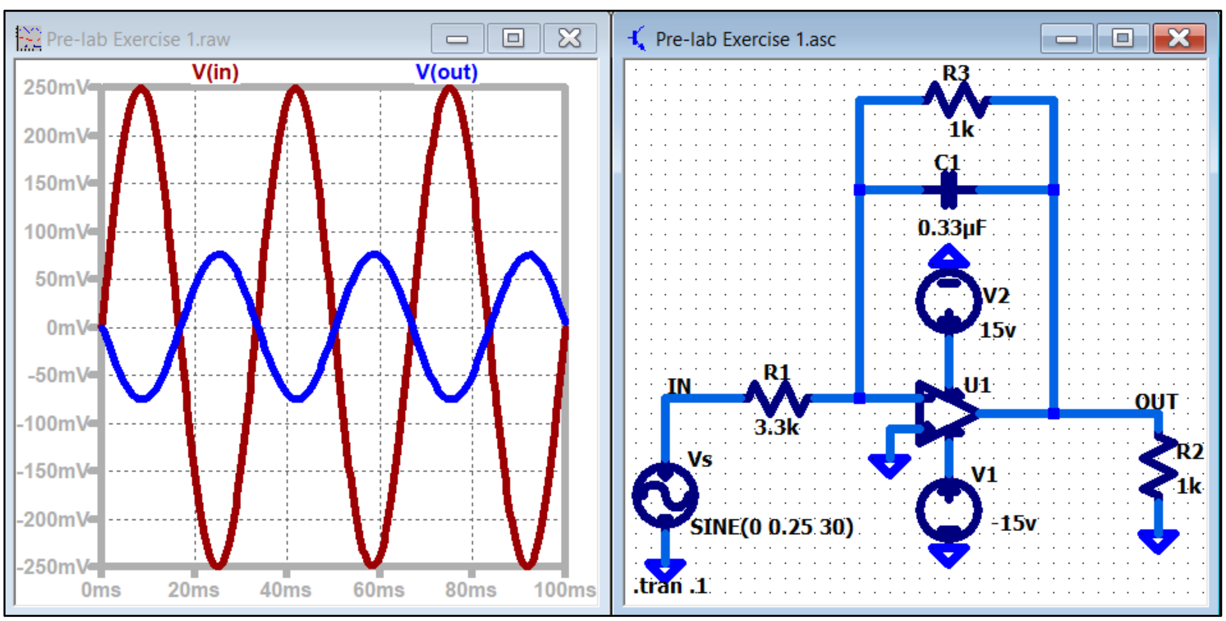


Figure 2: Op Amp with R and C feedback

4. Implement the Miller integrator by adding the 1 kΩ feedback resistor in parallel with the capacitor. Again, run a transient analysis and plot the output. At this frequency (30 Hz), is the PSpice output consistent with an integrator or with an inverter? Does the answer agree with your expectation?



The output is more consistent with an inverter here. The output isn't phase shifted, so we can tell that the sine input signal has likely NOT been integrated into a cosine. The output is also directly inverted from the input. This is interesting, and likely because the capacitor's feedback is now being partially bypassed by the resistor. The capacitor will have a high impedance at low frequency, and a low impedance at high frequencies.

Exercise 1: Integrators

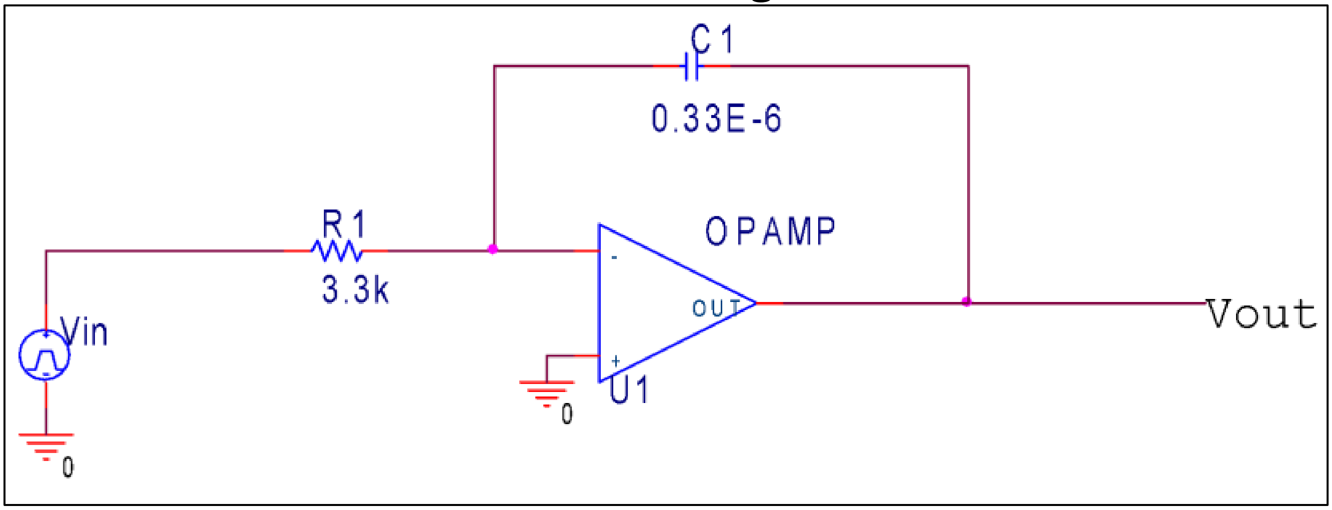


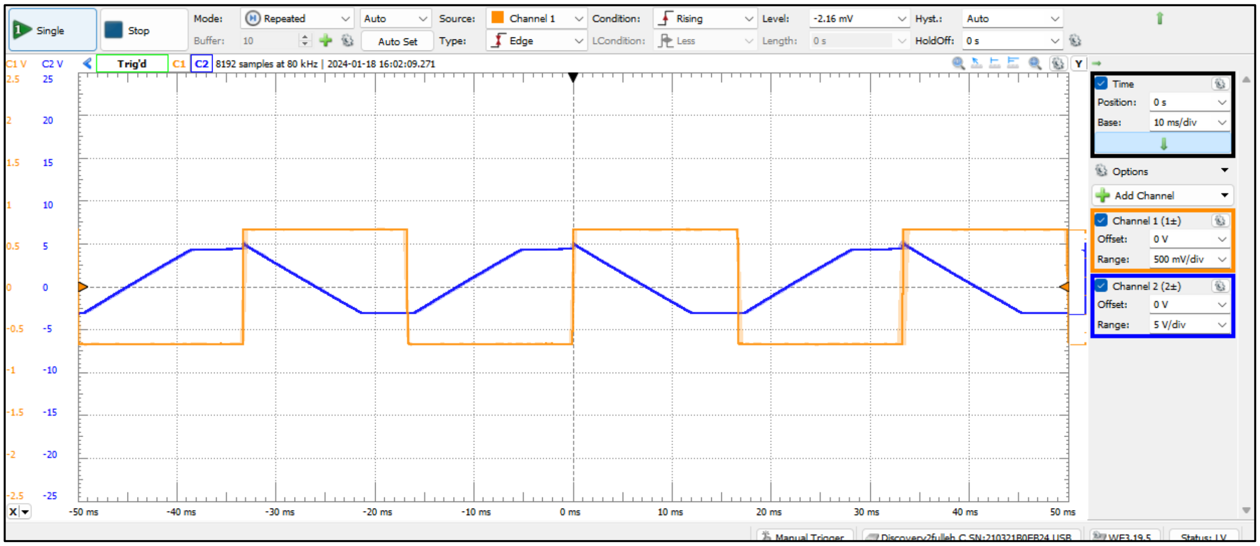
Figure 5: Integrating Amplifier

Build the integrating amplifier circuit shown in Figure 5, using the LF351 (or LF353) amplifier chips. Use the E3630A power supply to provide the +15 V and –15 V levels to power the Op Amp. Note that the "common" supply terminal must share a connection with the signal ground. Initially, you can use an open circuit load. Reminder: The power supply connections for the Op Amp are not shown in the above circuit.

1. Set the function generator to produce a 30 Hz square wave with a 4 V (peak-to-peak) signal and 0 V DC offset, Vmax = 2 V and Vmin = –2 V. Verify the voltage levels using the oscilloscope.
Question: Qualitatively, what is the integral of a square wave? Does the output 'look approximately correct' from a mathematical point of view?

The integral of a square wave should be a triangular wave, with peaks lined up with the rising-edge of the square wave, and minimums lined up with the falling-edges.

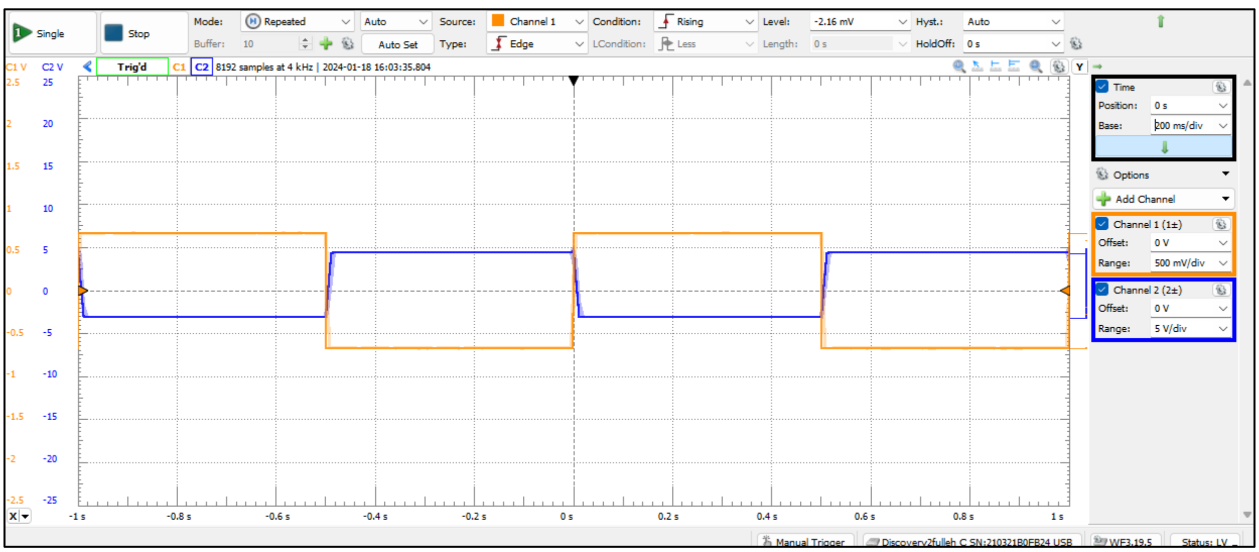
We used the benchtop function generator and oscilloscope initially, but they had some noticeable noise issues. So, we re-ran tests using an Analog Discovery 2 board. We are supplying +5v/-5v instead of +15v/-15v, due to input limitations of the AD2.



The resulting output wave (blue) is triangular as we expected. It is slightly cut off at the peaks and valleys due to the op-amp having enough time to become saturated at +5v/-5v.

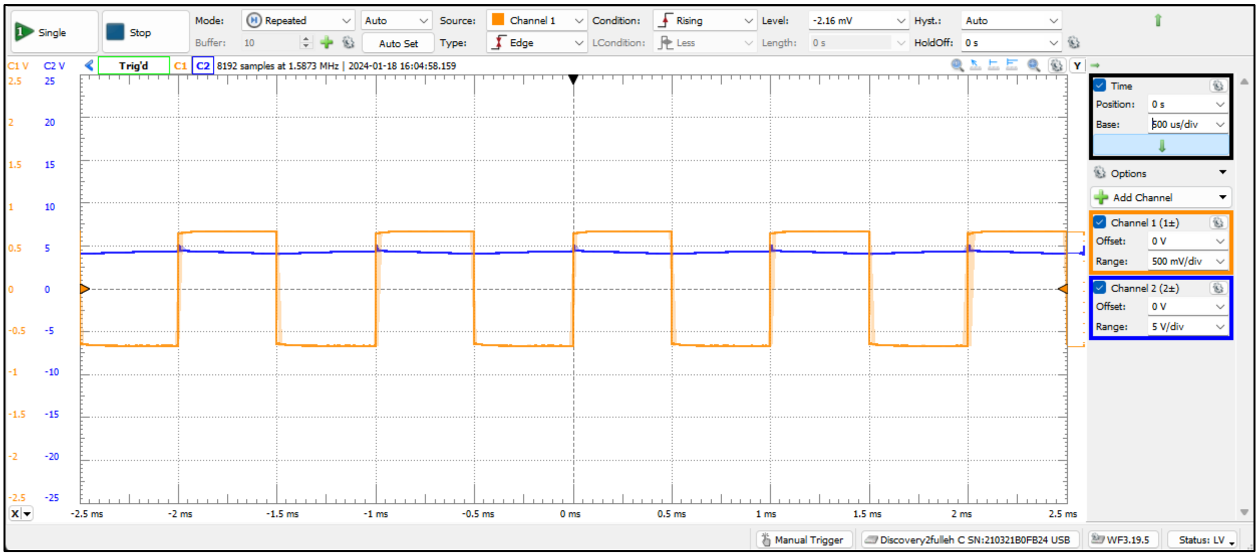
2. Lower the frequency to 1 Hz.

Explain why the output waveform is different.



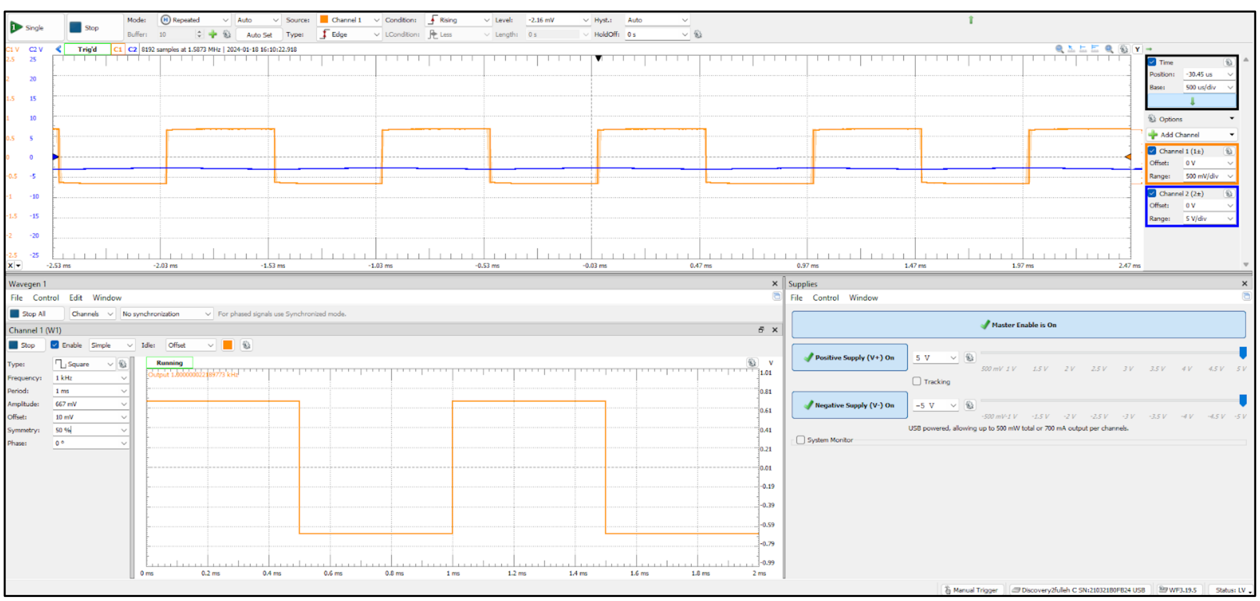
The amplitude of the output waveform is much higher (imagining that it extends past the saturation point). Here, the impedance of the feedback capacitor is higher due to the low frequency. The low frequency gives the capacitor more time to charge/discharge (saturate).

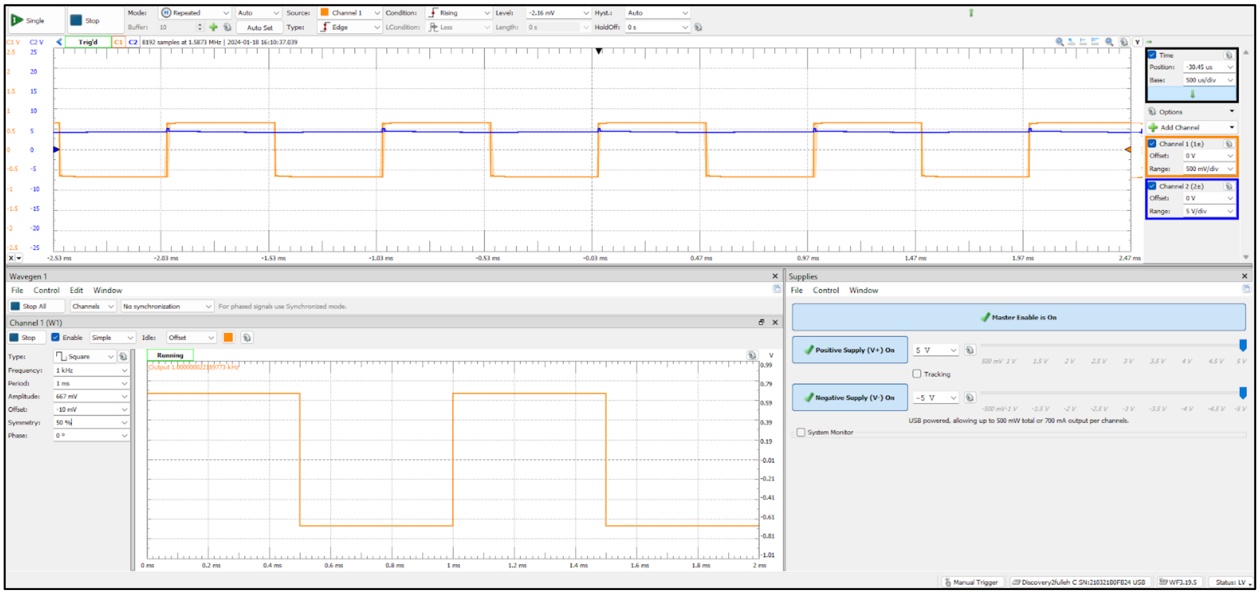
3. Increase the frequency to 1 kHz.
Explain why the output waveform is different.



This output is closer to DC, since at 1kHz there is not much time per cycle for the capacitor to charge or discharge vertically. The capacitor has a lower impedance at this higher frequency,

4. At 1 kHz add a DC offset, slowly toggling between 10 mV / –10 mV (waiting to reach steady state before you toggle the offset). If you don't see any change, increase the values of the DC offset, for example make the DC offset values +25 mV / –25 mV or higher if needed.
Again, explain why the output voltage changes.





The output voltage changes with these DC offsets because the input signal is made asymmetrical about the V=0v axis. Thus, the output signal is "biased" to be more negative, or more positive, based on the offsets. It takes a few seconds for the system to reach steady state after any change in the offset values.

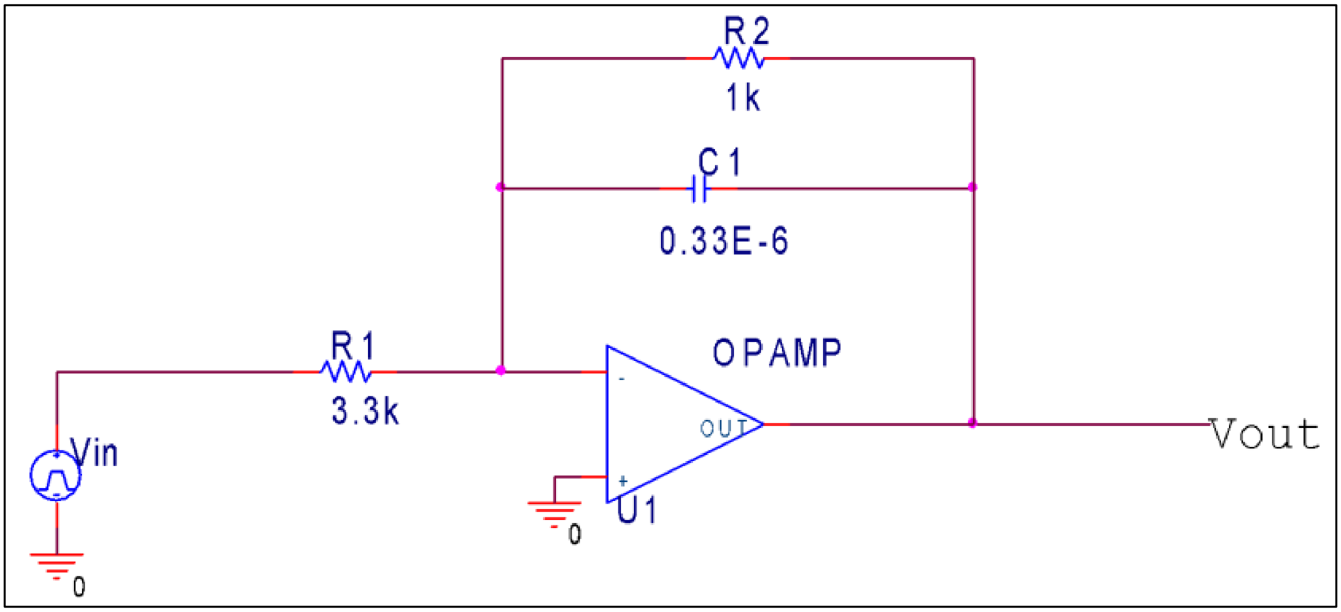


Figure 6: Integrating amplifier

Build the Miller Integrator shown in Figure 6, using the LF351 (or LF353) amplifier chips (just add the R2 resistor to your previous circuit). Use the E3630A power supply to provide the +15 V and –15 V levels to power the Op Amp. Set the Waveform Generator output to a 1 V amplitude sinusoidal signal and set the DC offset to zero.

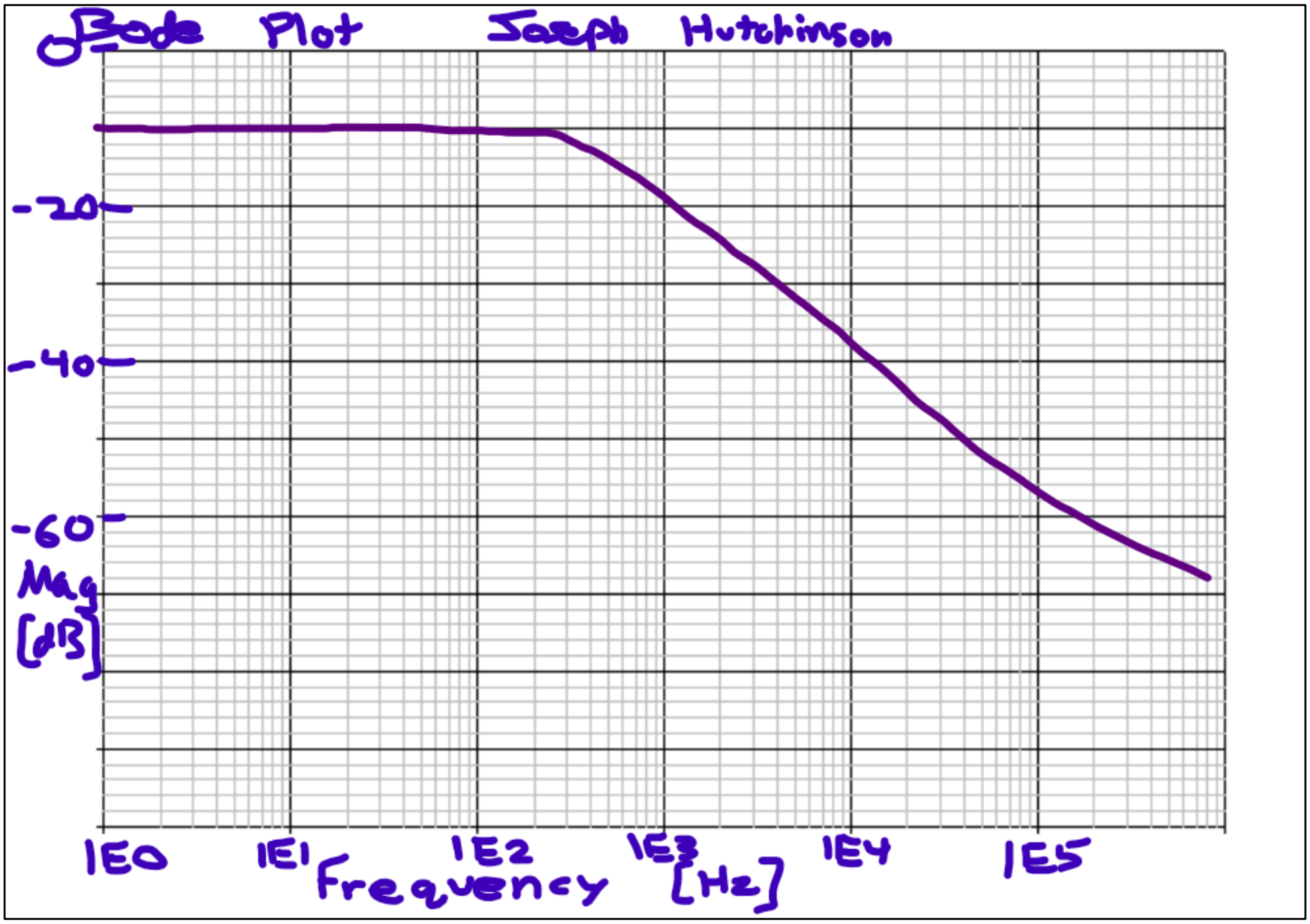
1. Determine the transfer function associated for the above circuit. Sketch the Bode plot of the magnitude for this transfer function. Note: A log-log template is provided on the last page of this document.

$$H(s) = \frac{V_{out}}{V_{[in\}}} = \frac{-Z_f}{Z_{in}}$$

$$H(s) = \frac{-R_2}{R_1 + C_1 R_1 R_2 s} = \frac{-1000}{3300 + (0.33 * 10^{-6} * 3300 * 1000 * s)} = \frac{-1000}{3300 + (1.089 * s)}$$

$$H(s) = \frac{-1000}{1.089(3030.303 + s)} = \frac{-918.2736}{3030.303 + s}$$

$$\boldsymbol{H(s) = \frac{-918.2736}{3030.303 + s}}$$



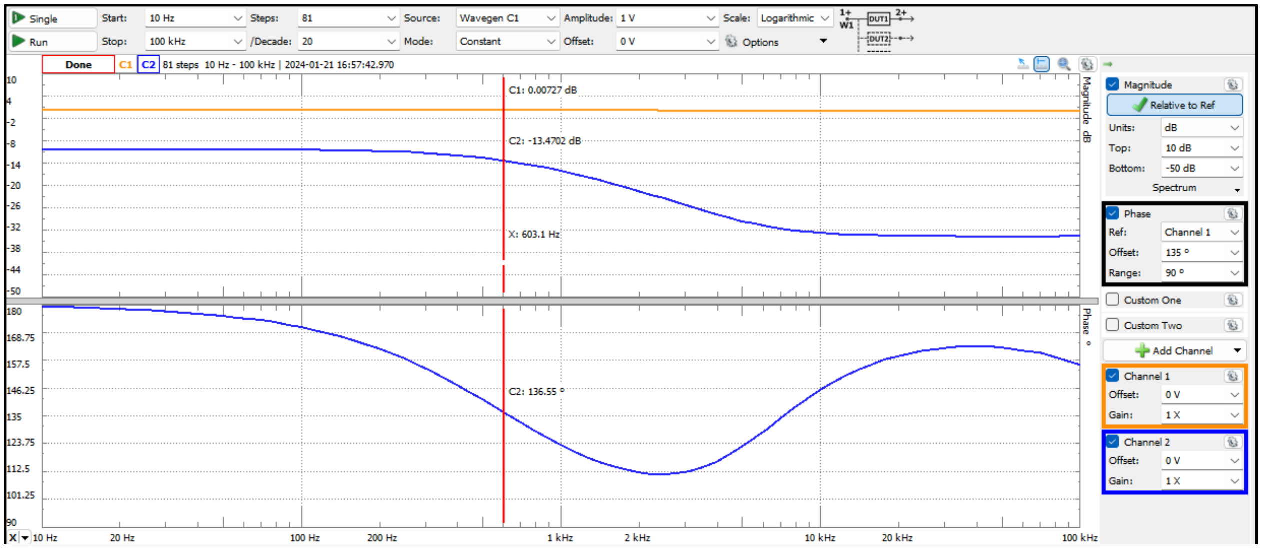
2. Identify any poles (one) and zeros (none).

The denominator has (3030.303+s), so there is a real pole at:

$$s = -3030.303\ \text{rad/s} = \frac{-3030.303}{2\pi}\ \text{Hz} = -482.287\ \text{Hz}$$

We take the magnitude of this, so **there will be a pole at $\mathbf{482.287}$ Hz**
This is the "center" of the negative sloped line the bode plot will have.

3. Use the Network device on the Discovery Board to experimentally sweep the frequency through the range 10 Hz – 100 kHz. This device is similar to the AC sweep in PSpice and can be used to obtain experimental Bode plots.
Question: Is the experimental response consistent with the analytic Bode plot?



Our experimental result IS consistent with the analytic plot. The negative slope begins around 400-500 Hz on the graph obtained by the Discovery Board (cursor is at 600 Hz in screenshot, but the slope begins slightly to the left of that, at around our 482 Hz mark).

4. Experimentally, locate any poles or zeros. Remember, a single pole can be determined by locating 3 dB points relative to the ideal transfer function.
Question: Do experiment and analysis agree?

Using the cursor, we can place the pole at around the 500 Hz mark, which is where the magnitude of the plot begins to fall and the slope becomes negative. So, our experiment agrees with the initial transfer function analysis.