ELEN 115 Lab 2: Single Time Constant Circuits

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Thursday, 2:15 Section

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Lab Objective:

The goal of this lab is to be able construct a RC circuit and analyze its different properties. Specifically how it behaves when looking at different frequencies and times. We will achieve this by doing a full transient and ac analysis of the circuit.

Procedure:

Part 1:

The first part of this lab was to create a single time constant circuit in LTSpice. The circuit created can be seen below in Figure 1.

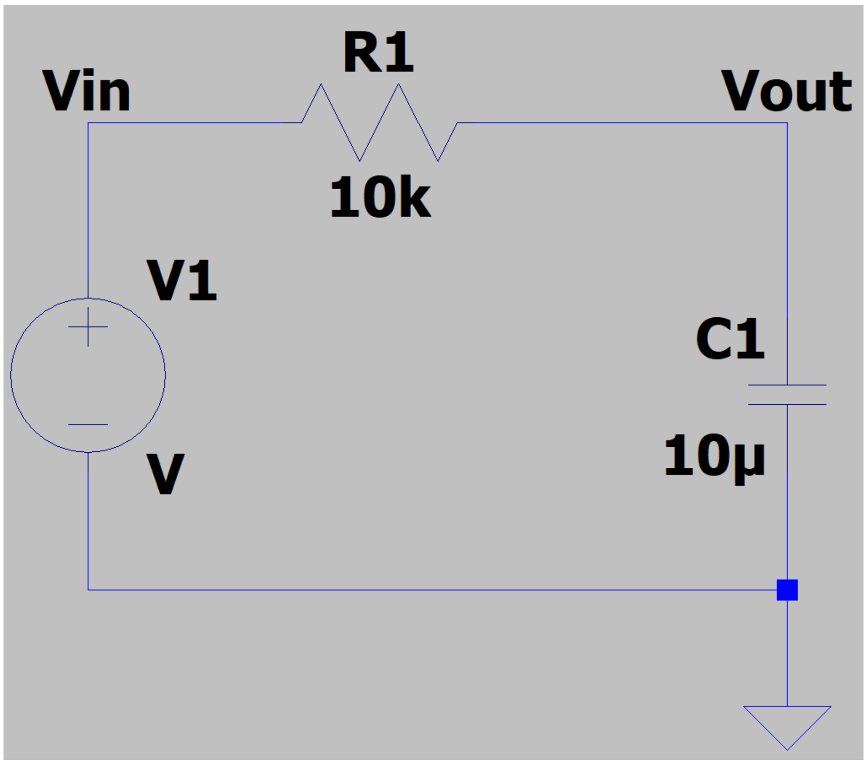


Figure 1: Example of single time constant circuit

Part 2:

The second part of this lab was to do a transient analysis of the circuit with a pulse input. The behavior of the capacitor's charging and discharging was observed under various conditions. Also, the relationship between the current through the capacitor and the time derivative of Vout was observed.

Part 3:

In part 3 of the lab, a transient analysis was done with a sinusoidal voltage source. The source was set to various frequencies to observe how the frequency affected Vout.

Part 4:

Part 4 of the lab involved an AC analysis of the circuit which was done in order to obtain a Bode plot for the circuit. The -3dB cutoff frequency and slope of the Bode plot were observed.

Part 5:

Part 5 of the lab involved some additional questions to further the understanding of the concepts put into practice in the lab.

Results:

In part 2 of the lab, the circuit was simulated with various sources to see how the pulse width affected the charging of the capacitor. It was found that it takes about 5 RC time constants to fully charge the capacitor. Then, the capacitor was given an initial charge of 1 V, and the charging/discharging behavior was observed. It was found that the initial charge makes the capacitor charge slower, but the maximum charge remains the same. After one cycle of the pulse input, the capacitor's charging/discharging was unaffected by the initial charge. The current through the capacitor was also compared to its capacitance times the time derivative of Vout to see that those two are equal. Finally, the capacitance was decreased to observe how decreasing the time constant makes the capacitor charge faster, and vice versa for increasing the time constant. All plots and screenshots can be found in Appendix A.

In part 3 of the lab, the sinusoidal input was set at 1, 10,100, and 1000 Hz. Vout was observed at each frequency, and it was found that the circuit filtered out the 100 and 1000 Hz inputs, but the 1 and 10 Hz inputs were passed through. The cutoff frequency was calculated to be about 15.9 Hz, so the results match the expected behavior of a low pass filter. The frequencies below the cutoff were passed, and the ones above were filtered. All relevant plots and screenshots can be found in Appendix A.

In part 4 of the lab, the AC analysis provided a Bode plot that confirmed the -3dB cutoff frequency to be about 15.9 Hz, and the slope of the line to be about -20 dB/decade. All relevant plots and screenshots can be found in Appendix A.

Finally, in part 5 of the lab, it was found that the time constant when R1 = 1kΩ and C1 =1μF is 1 ms. Also, it was confirmed that iOUT is equal to the capacitance times the time derivative of vOUT. In order to recreate an STC high pass filter with a cutoff frequency 1/10th of our original one, a resistance of 10 kOhms and a capacitance of 10uF was used. Finally, combining the two filters would create a band stop filter that would filter out some set of frequencies between low and high ones. All relevant plots and screenshots can be found in Appendix A.

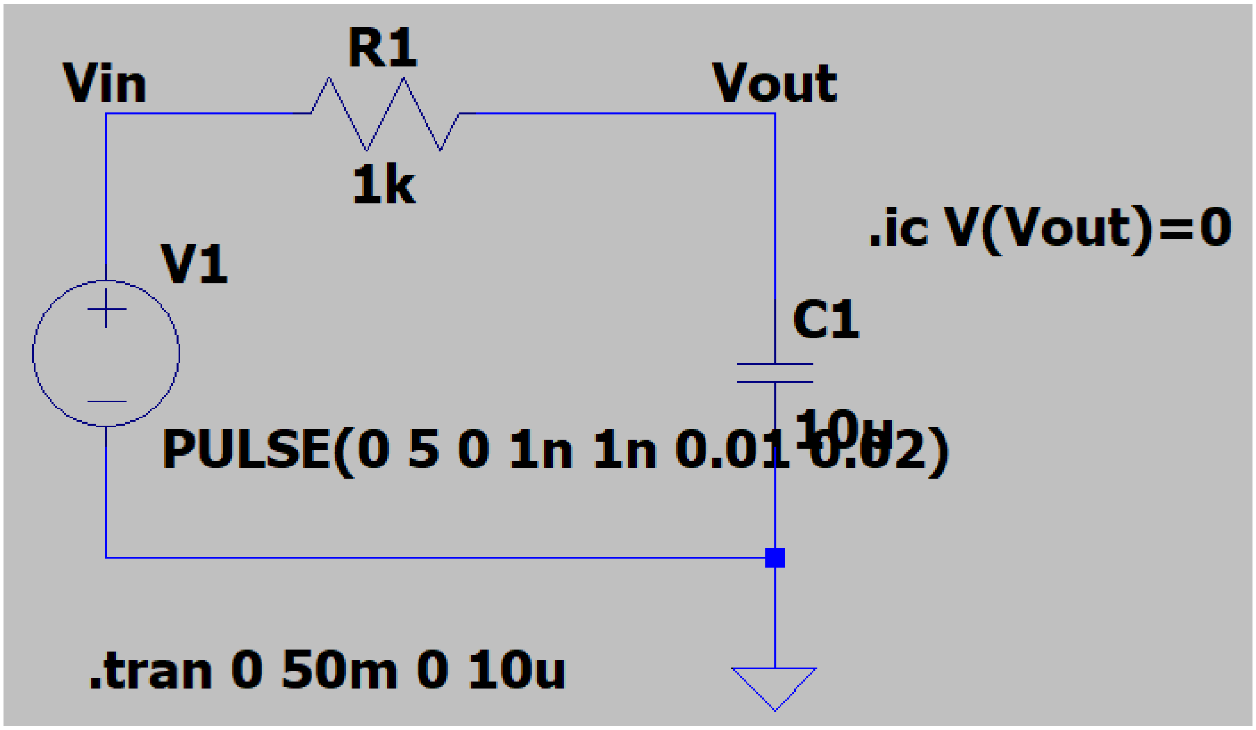
Conclusion:

Overall this lab gave us a deeper understanding of RC Circuits. We saw how by adjusting the frequency we can obtain a better RC circuit and overall filter, meaning that by changing the frequency we can manipulate the circuit so that it cuts off more precisely so that we can control what we pass through. We also saw how the voltage moves through the capacitor over time. We also saw its repetitive cycle of peaking and falling. Finally we were able to get more comfortable with using filters and an RC circuit design.

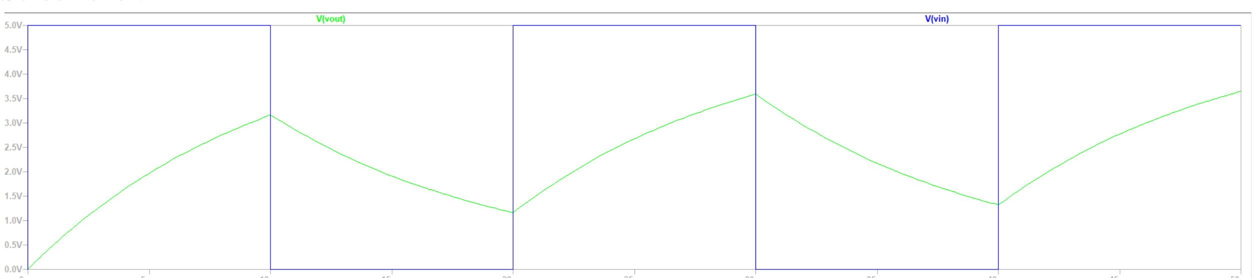
Appendix A:

Lab 2 (STC Circuits) Check Point Worksheet

Part 2: pulse input (cap charging/discharging)
Screenshot of Circuit:



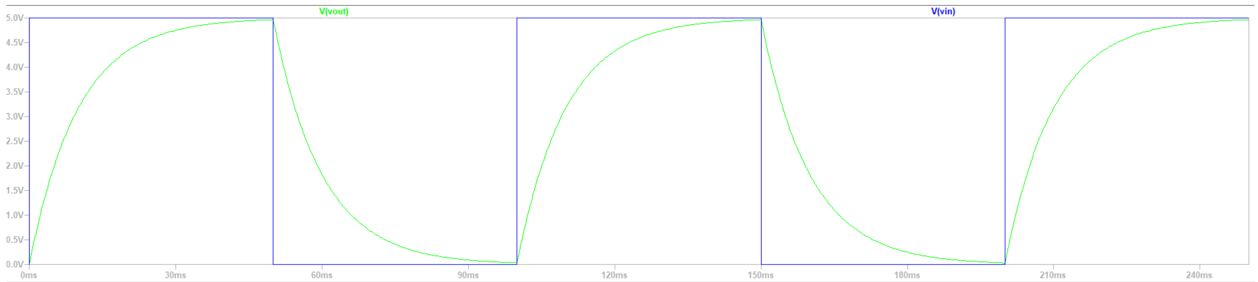
(5) Plot v_{IN} and v_{OUT} as a function of time on the same plot.
Screen shot:



Do the results look as expected? Why or why not?
When Vin = 5V, the cap is charging or discharging?
The capacitor is charging when Vin = 5V.
When Vin = 0V, the cap is charging or discharging?
The capacitor is discharging when Vin = 0V.
RC time constant = 0.01 s or 10 ms
Is this enough time to fully charge/discharge the cap?
It takes roughly five times the RC time constant to fully charge the capacitor, so the pulse time of 10 ms is not long enough to fully charge/discharge the capacitor.

(6) Change the vIN pulse width and period (and transient runtime) to produce a full charge/discharge Vout wave? Want to see it takes 5 RC time constants to reach steady state.

Screen shot:



How many RC time constants does it take for a cap to fully charge/discharge?

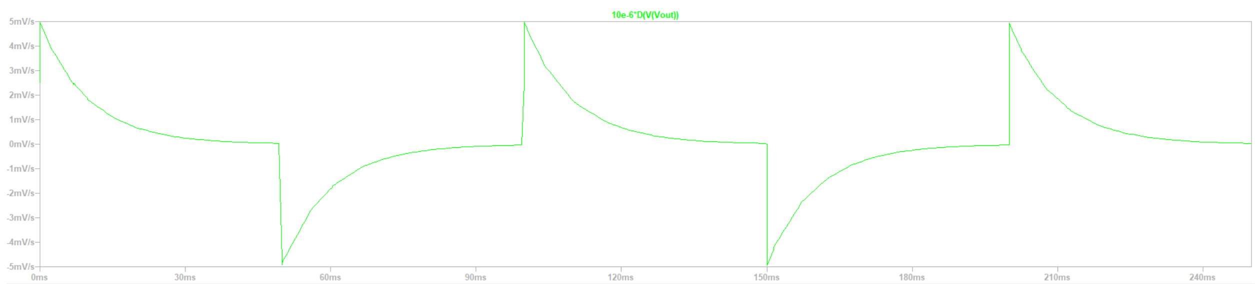
It takes about 5 RC time constants to fully charge/discharge the capacitor.

Does the cap fully charge/discharge this time?

Technically there is still a small amount of charge that the capacitor doesn't charge/discharge, but it is practically fully charged/discharged this time.

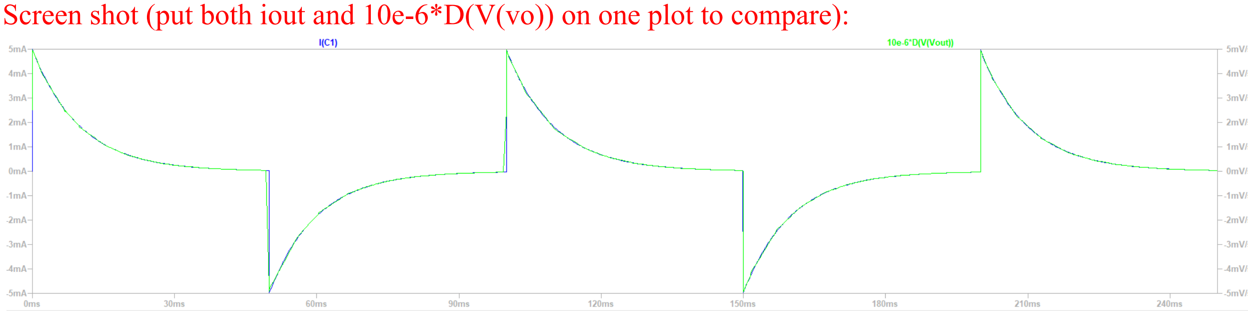
(7) Add on the plot C*dVout/dt (use: 10e-6*D(V(vo)).

Screen shot:



(8) Plot current i_{OUT} as a function of time.

Screen shot (put both iout and 10e-6*D(V(vo)) on one plot to compare):



What does the plot show? Explain its shape.

Is the cap current the derivative of its voltage (times the cap value)?

The plot shows the current initially being 5 mA, but decreasing as the capacitor charges. Once the capacitor begins to discharge, the current reverses, starts at -5 mA, and decreases as it discharges.

Verify if iout is the same as C*dVout/dt?

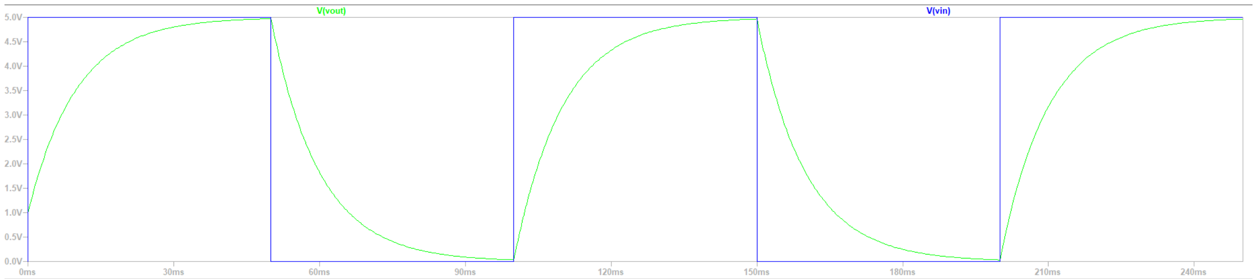
Verified?

The two plots deviate slightly at the points where the voltage source is switching from 0 to 5V, but they follow the same pattern as the capacitor is charging/discharging, so they are the same.

(9) Modify the initial condition on the capacitor C1 (which should still be 10uF) to 1V. Rerun the transient simulations and replot the signals. No need to plot time derivative of Vout

How did the waveforms change? Explain why?

Screen shot:



How does the initial value of the cap voltage compare with before?

The initial value of the capacitor voltage is now 1 V instead of 0 V as it was before.

Does an increased cap voltage initial value affect the final cap voltage?

No, the final value is still 5 V.

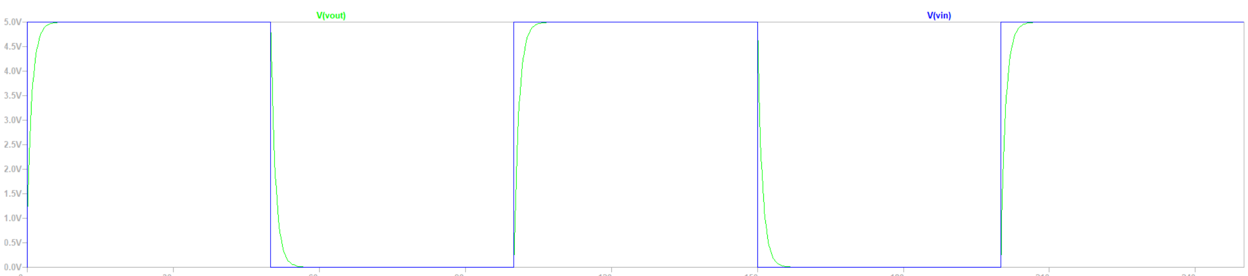
What effect does an increased cap initial voltage have on the cap charging speed?

The capacitor charges slower because it goes from 1 to 5 V in the same amount of time that it was going from 0 to 5 V. After the first cycle of charging/discharging, the charge speed is unaffected however.

(10) Modify the value of C1 = 1uF. Rerun the transient simulations and replot the signals. No need to plot time derivative of Vout

How did the waveforms change? Explain why?

Screen shot:



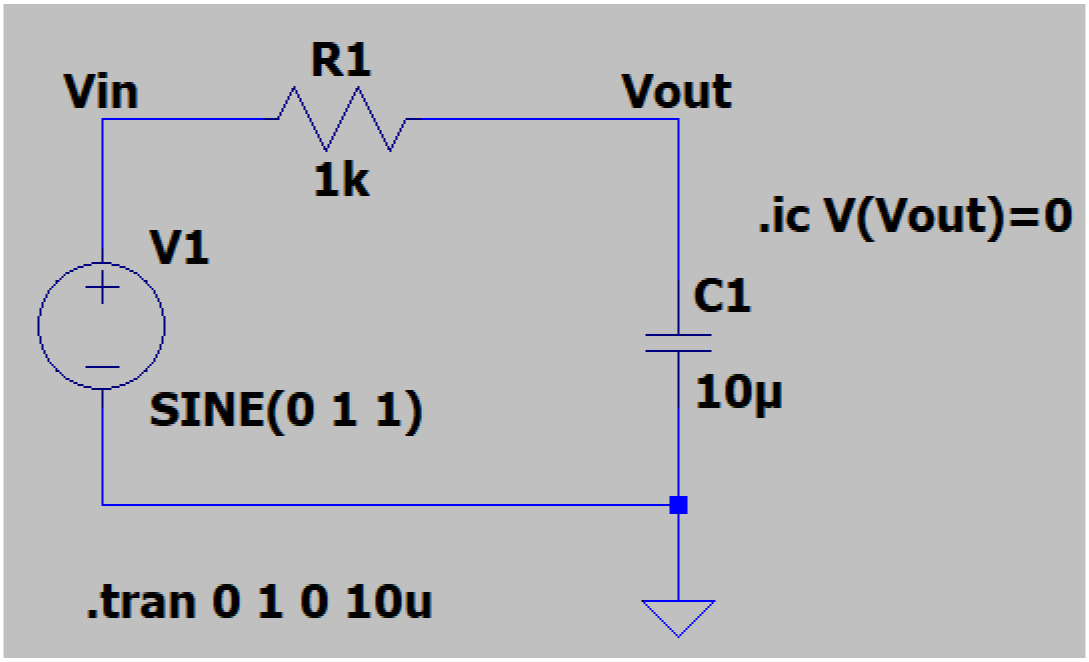
Is RC time constant increased?

The time constant decreased because the capacitor value decreased. It is now 1 ms.

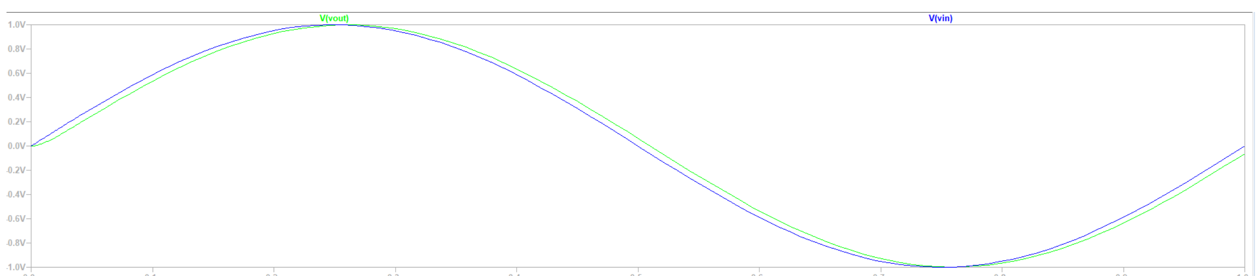
Does an increased RC time constant speed up or slow down the cap charging/discharging?

An increased RC time constant would slow down the capacitor charging/discharging. In this case, we decreased the time constant which sped up the charging/discharging.

Part 3: sinusoidal input (RC circuit's LPF behavior)
Screenshot of Circuit:

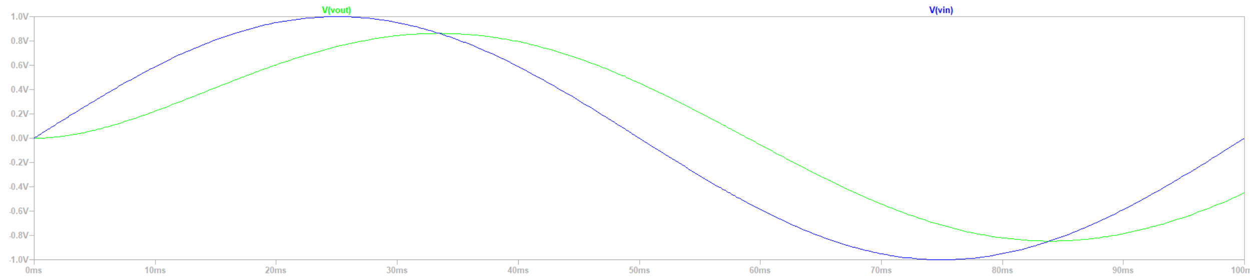


(4)-(5) Plot V_{IN} and V_{OUT} as a function of time. Zoom into seeing two to three time periods. Do the results look as expected? Why or why not?
Screen shot:



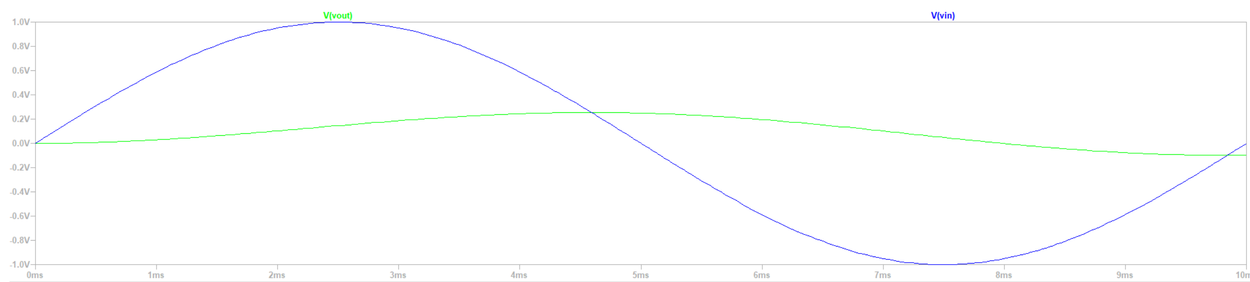
What is the -3dB cutoff frequency f0 of this LPF?
It is equal to 1/(2*pi*R1*C1)= 15.9 Hz.
Is the input signal frequency of 10Hz more or less than the cutoff frequency?
It is less than the cutoff frequency.
Therefore, does the input signal get significantly filtered out by the LPF?
No it does not.

(6) Make the voltage source vIN a sinusoidal source with 1V amplitude and 10Hz frequency. Change the transient duration to 100msec. Repeat steps (3) and (4).
Screen shot:



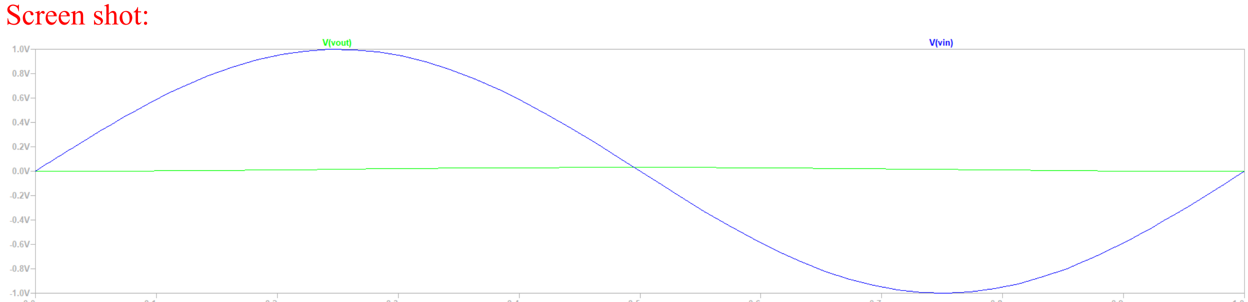
Is the input signal frequency of 10Hz more or less than the cutoff frequency?
It is less than the cutoff frequency.
Therefore, does the input signal get significantly filtered out by the LPF?
No it does not.

(7) Make the voltage source vIN a sinusoidal source with 1V amplitude and 100Hz frequency. Change the transient duration to 10msec. Repeat steps (3) and (4).
Screen shot:



Is the input signal frequency of 100Hz more or less than the cutoff frequency?
It is more than the cutoff frequency.
Therefore, does the input signal get significantly filtered out by the LPF?
It does get significantly filtered out.

(8) Make the voltage source vIN a sinusoidal source with 1V amplitude and 1kHz frequency. Change the transient duration to 1msec. Repeat steps (3) and (4).
Screen shot:



Is the input signal frequency of 1kHz more or less than the cutoff frequency?
It is more than the cutoff frequency.
Therefore, does the input signal get significantly filtered out by the LPF?
It does get significantly filtered out.

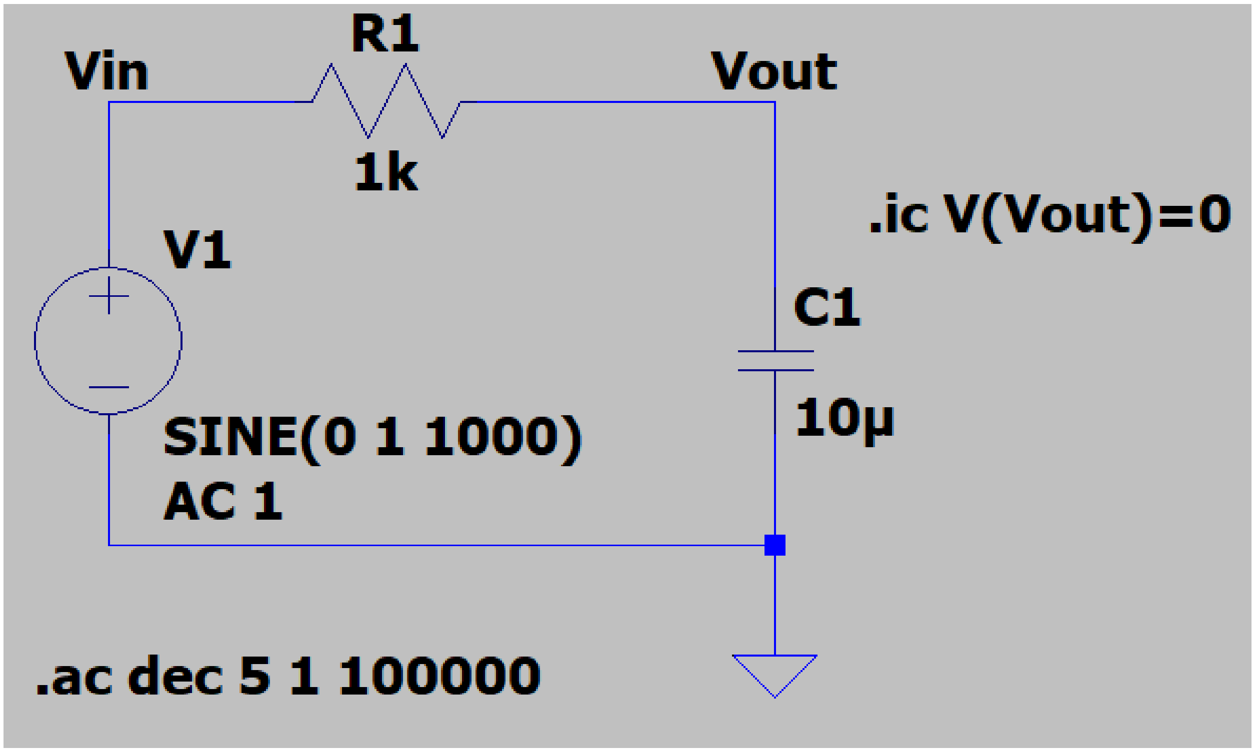
(9) What have you observed while doing steps (2) through (7). What behavior does this RC circuit show?
In conclusion, is this circuit a LPF?
Yes it is.

How do you make this conclusion?

This circuit is a low pass filter because the frequencies below the cutoff weren't affected by the filter, but the ones above the cutoff were significantly reduced.

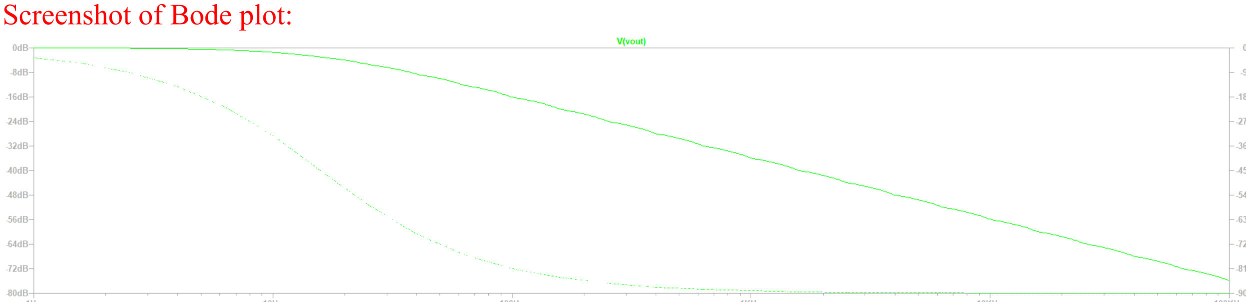
Part 4: AC analysis Bode plot

Screenshot of circuit:

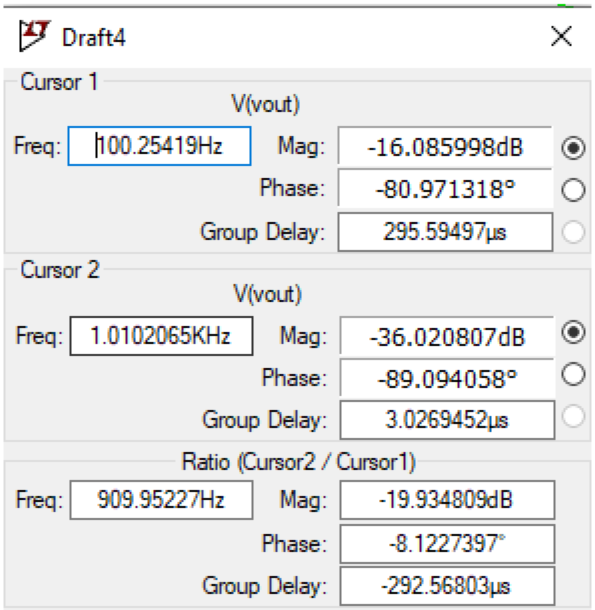


(3) Simulate using AC Analysis. Sweep type: Decade.
Number of Points per decade: at least 5. Start frequency: 1Hz. Stop Frequency 100kHz.
Use cursors to measure the slope of the line to verify -20dB/decade
Measure the -3dB frequency to verify the 1ms time constant

Screenshot of Bode plot:

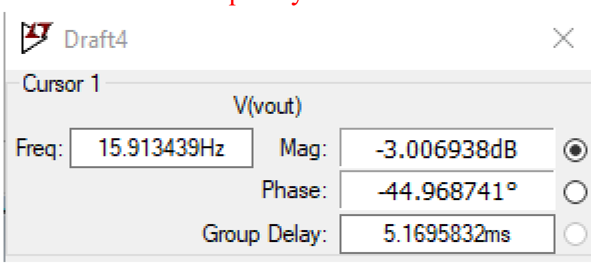


Measured slope of Bode plot line:



The slope is shown as -19.93 which verifies the slope of -20 dB/decade.

Measured -3dB frequency:



The frequency at -3 dB is 15.9 Hz.

Theoretical -3dB cutoff frequency f0:

The theoretical -3dB cutoff frequency was calculated to be 15.9 Hz, so they are the same.

Lab Report Questions:

1. What is the RC time constant when R1 = 1kΩ and C1 =1μF?

a. RC = 0.001 s or 1 ms

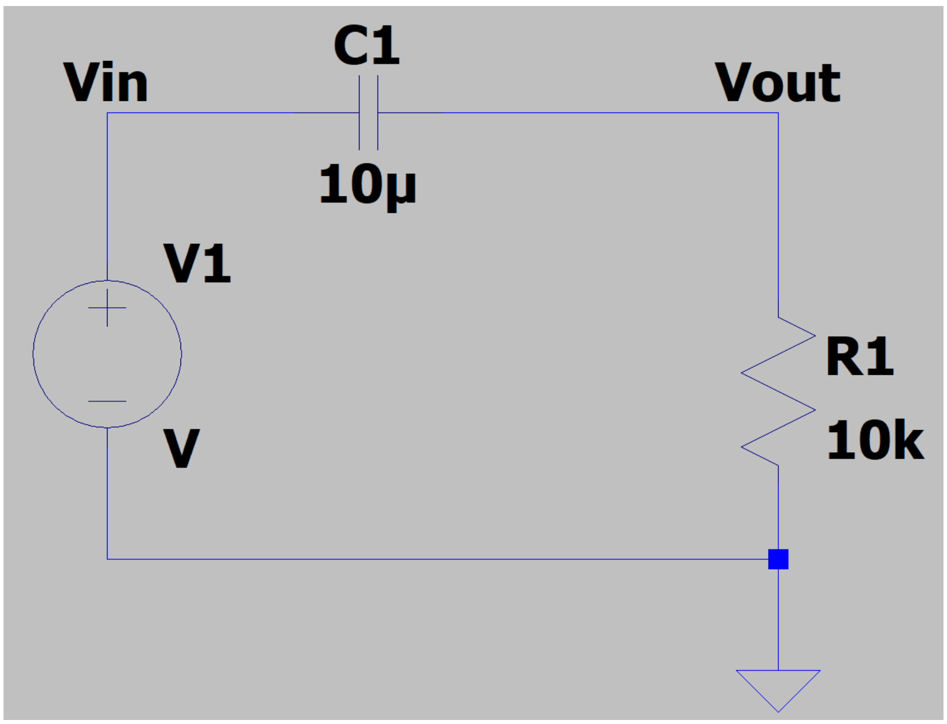
2. From part 2, what did you understand is the relationship between iOUT (current in capacitor) and vOUT (voltage across the capacitor)

iOUT is equal to the capacitance times the time derivative of vOUT

3. Draw the schematic of a single time constant high pass filter. What will be the value of the R and
C to obtain a cutoff frequency 1/10th of the low pass filter you created in the lab.

f0 = 1.59 Hz = 1/(2*pi*R*C)

If C = 10uF and R = 10 kOhms, the f0 will be 1.59 Hz



4. If we took the output of the high pass filter you just designed and made that the input of the low pass filter of the lab, what sort of behavior do we expect at the output of the combined circuit?
Draw a rough bode plot sketch of this behavior.

If we made our output the input of a low pass filter we create a band stop filter that wouldn't pass some frequency in the middle of both filters.