EEE 117 Laboratory

Instructor: Mike Saghaimaroof

Lab 4: Low Pass Filter Analysis & Simulation

Lab Report by Luis Rivera

Lab Session: Monday (6 PM - 9 PM)

Due Date of Lab: 3/28/2016

Date(s) of the lab: 3/7/2016 & 3/14/2016

Lab Partners: Huy Nguyen, Joel Pankito

Introduction:

In this lab, we were to become familiar with a low pass filter provided to us by our lab instructor. From the given circuit we were to find the value of the resistor and capacitor in order to find the phase angles with changing frequencies and see when the phase shift was about 45 degrees which we learned told us the 3dB loss in voltage which was the objective for the lab. Using this information we also needed to become familiar with PSPICE or Multisim Simulations in order to find the DC analysis, AC analysis and Transient analysis of the given circuit.

Purpose:

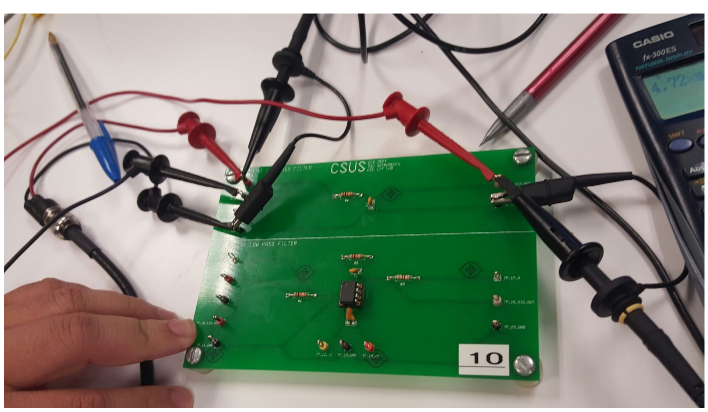
For this lab we needed to become somewhat experts with the tools to analyze our pre-constructed circuit. We were expected to have a good understanding of using the oscilloscope in order to get an accurate depiction of the phase angle and also have an idea of how a low pass filter would behave with a low frequency of about 100 hz and then with a much higher frequency at about 1,000,000hz. This was a two week lab with the first week being all about getting the values using the oscilloscope and then plotting the values in excel in order to get a bode plot while also solving for all of the values required to move onto week 2 which is comparing our values with the ones using the simulation software, which in our case was multisim simulations.

Discussions and Results:

<u>Week One Low Pass Filter Circuit Analysis:</u>

For the first week, we needed to use the pre-constructed circuit given to us by our instructor which looks like the circuit provided below. We used the multimeter instrument to measure the resistor and capacitor value which gave us our RC value needed to the circuit.

Resistor Value	Capacitor Value
10090Ω	472 pF



These values were compared by multiple lab groups as we first had trouble understanding if our capacitor value was supposed to be this low but we also had trouble as we misread the value as being 472 nF which is 1000x greater than the actual value which caused a huge discrepancy with our data which was fixed before we left lab. Below is a simplified table with some values we used while the end of the lab report will have the full table with every value tested.

Frequency(Hz)	ω (rad)	V_{in} (RMS)	V_{out} (RMS)	Mag (V_o/V_{in})	ωRC	Phase Angle °
100	628.32	1 V	0.9634 V	0.9634 V	-0.003	-0.17 °
1000	6283.2	1 V	0.9636 V	0.9636 V	-0.03	-1.714°
5000	31.415k	1 V	0.93936 V	0.93936 V	-0.15	-8.51°
10k	62.831k	1 V	0.9017 V	0.9017 V	-0.30	-16.66°
15k	94.247k	1 V	0.87948 V	0.87948 V	-0.422	-24.17°
20k	125.663k	1 V	0.78715 V	0.78715 V	-0.54	-30.9°
33.5k	210.486k	1 V	.629693 V	0.629693 V	-0.787	-45.07°
50k	314.159k	1 V	0.48231 V	0.48231 V	-0.98	-56.24°
100k	628.318k	1 V	.268431 V	0.268431 V	-1.248	-71.52°
500k	3141.592k	1 V	0.05508 V	0.05508 V	-1.504	-86.176°

In order to find these values, we used excel but in order to make sure they were correct we needed to do some math instead of just blindly following values. The frequency was given to us based on the function generator we used with the circuit which ranged from 100 hz all the way up to 1,000,000 hz and the multimeter was constantly feeding in 1 V Peak to Peak while we used the multimeter to see what our output voltage through the capacitor while the frequencies changed.

To find ω (rad), we multiplied our frequency by 2π

Our Magnitude was just our V_{out} divided by V_{in} -> (V_{out} / V_{in}) which always resulted in the value being the output voltage as we always divided by 1. We used our digital multimeter to read the output but also hand calculated to make sure we were getting reasonable numbers by multiplying

$$V_{out} = V_{in}\left(\frac{Zc}{RL+Zc}\right)$$

To find our Zc value we needed our capacitor value which we found earlier through measurements which resulted in our capacitor being 472 x 10^{-12} F which we can use the equation for equivalent capacitance

$$Z_c = \frac{-1}{j\omega C}$$

Doing this with the first value of 100hz, we get 0.964 V which is extremely close to the measured output of 0.9634

To find our ωRC we needed to use the provided Resistor and Capacitor values which we 10.090kΩ and 472pF and our ω was constantly changing due to changing frequency but for 100 Hz, we would multiply those values together then take the negative arctan to get our phase angle in radians.

$$-\tan^{-1} (628.3185307 * 10090 * (472 \times 10^{-12}))$$

$$=-2.99235 \times 10^{-3} \text{ rads}$$

Once we had that value we could then convert to our phase angle in degrees by multiplying by 180/π

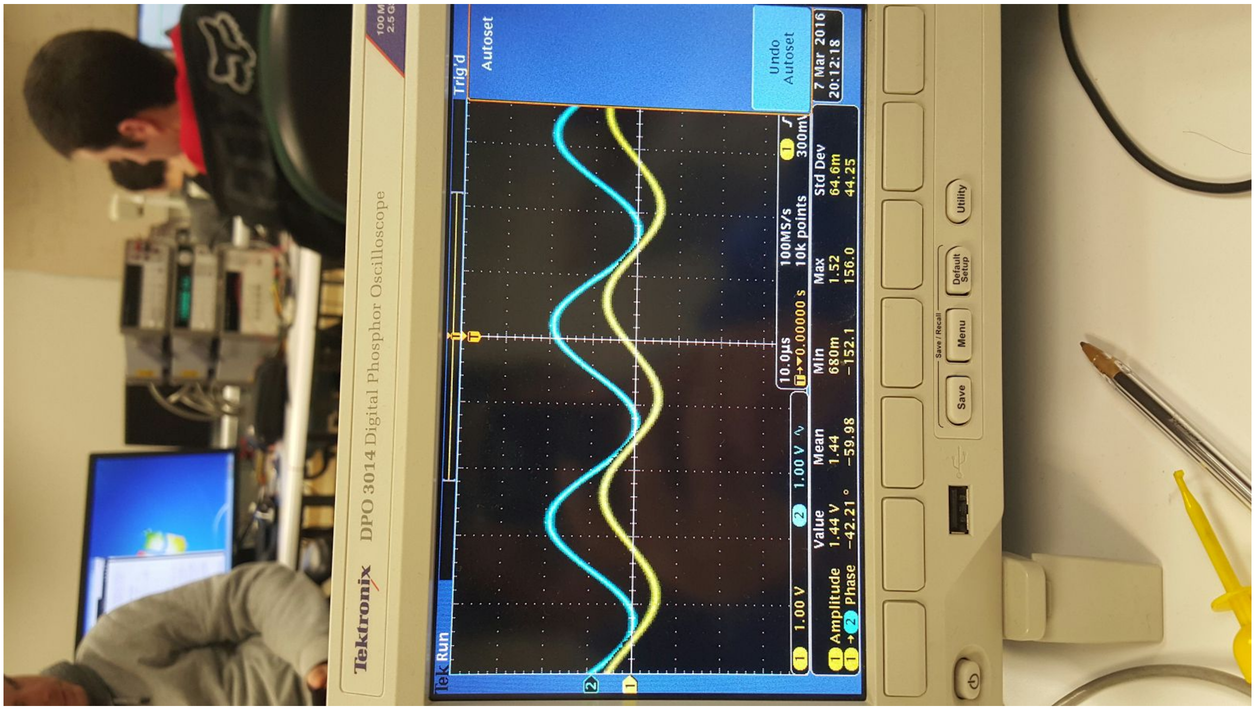
$$(-2.99235 \times 10^{-3}) * (180/\pi)$$

$$= -0.17°$$

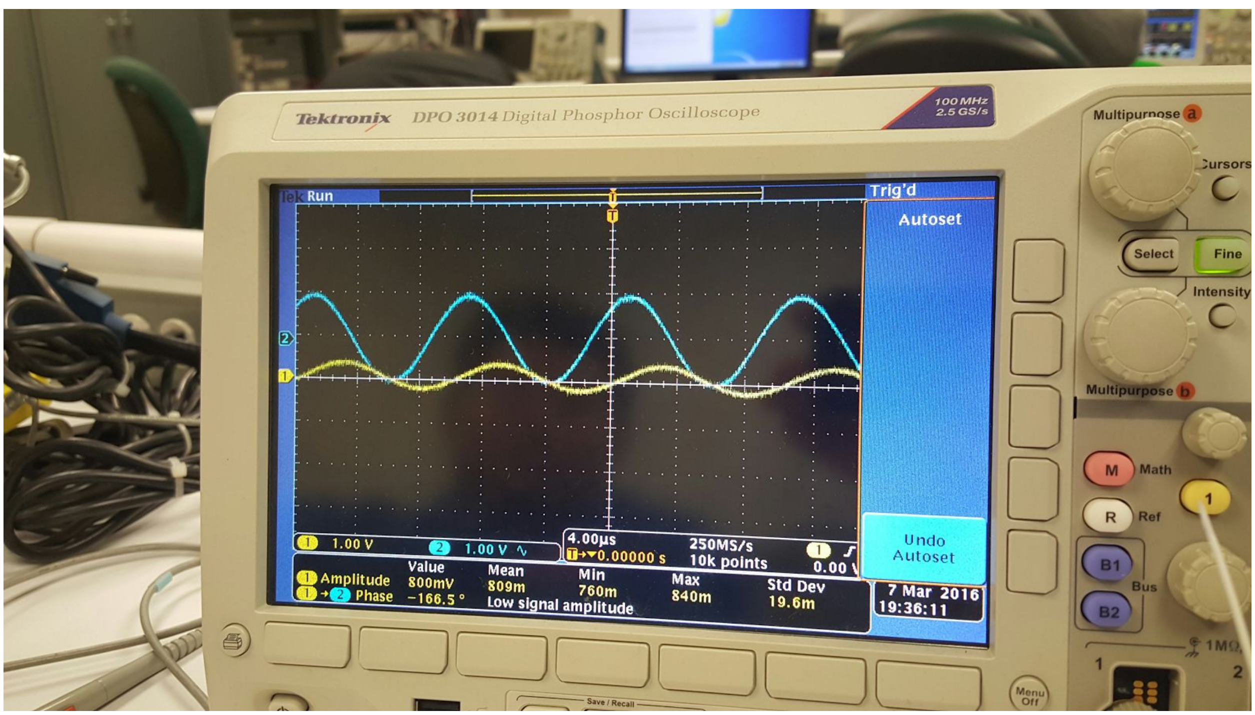
This value correlates to our calculated value through excel and is close to what our oscilloscope showed which means our measurements were correct. We were unable to get an exact value through the oscilloscope as the values were flickering with constant different results, our instructor explained that we were much better off seeing if we were within a certain ballpark of about 5-10 degrees as the oscilloscope was rather unstable with values.

From the Results we can see that around the 33.5k frequency range, the phase angle hits about -45° which is the angle we are looking for as that tells us that our V_{out} has seen a 3 dB loss which also translates to a ωRC value of ±0.707

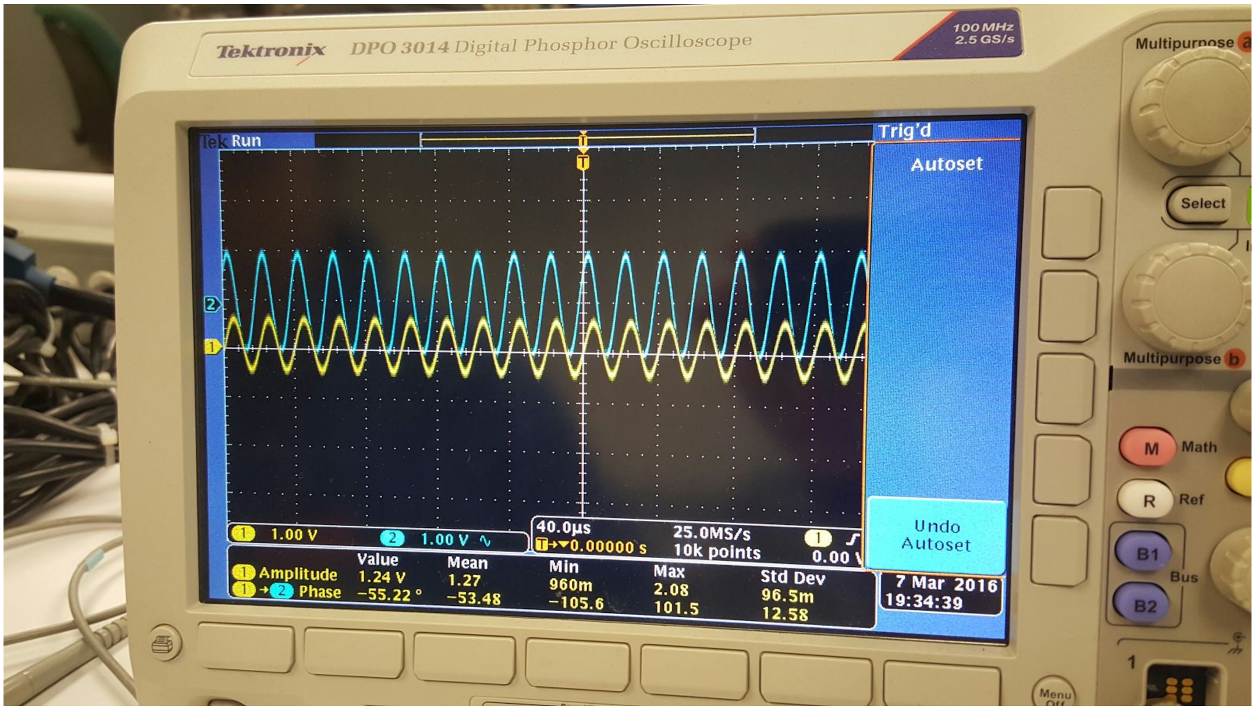
The closest phase shift near -45° around 33.5 k Hz



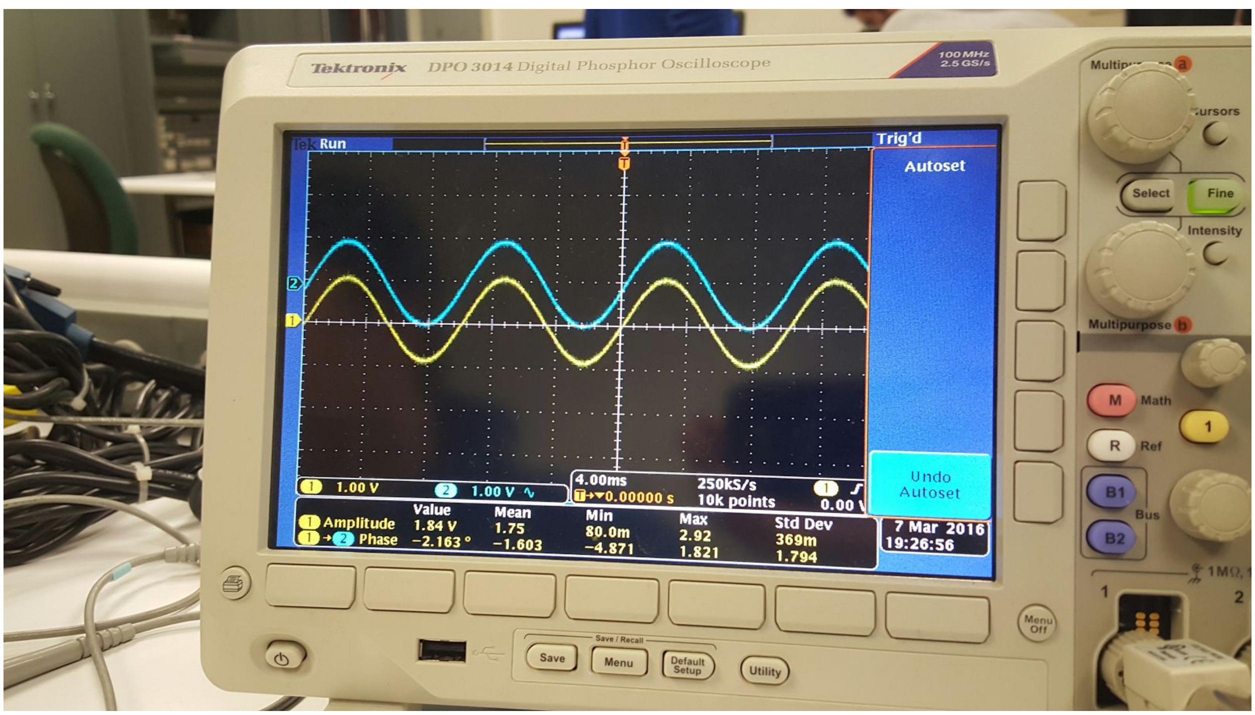
<u>Extremely high frequency with a large phase shift 1,000,000 Hz</u>

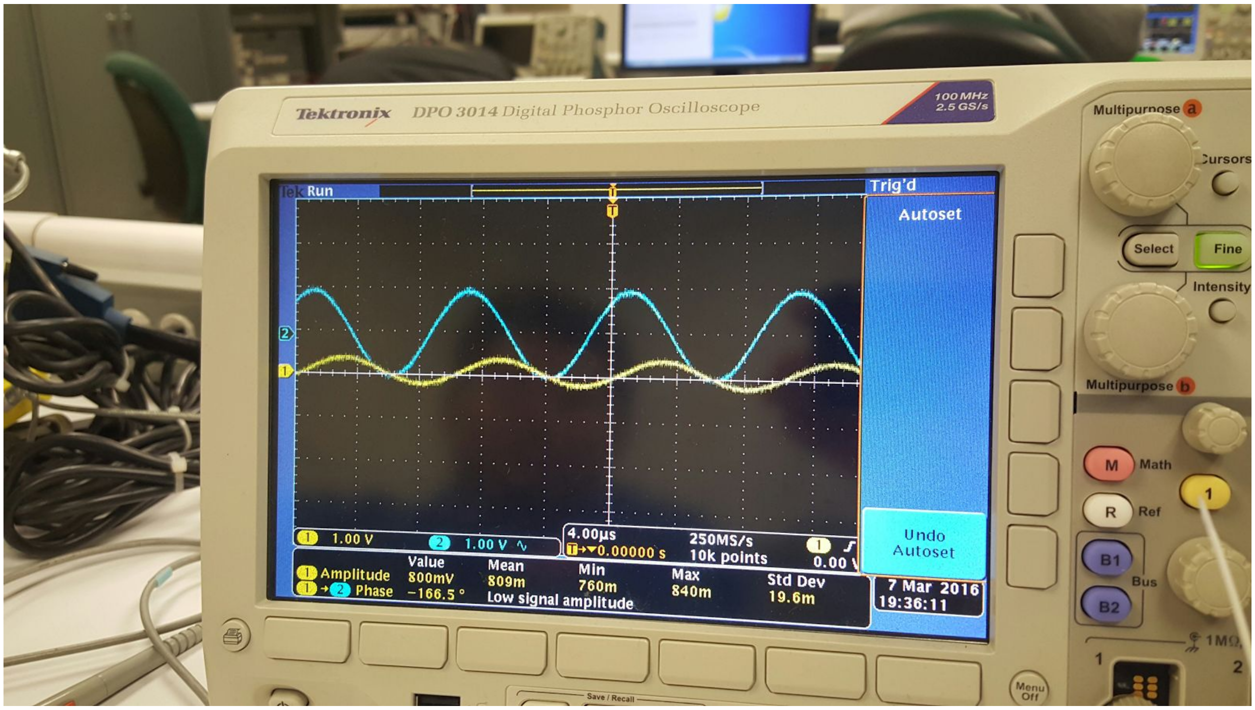


<u>50k HZ Frequency</u>



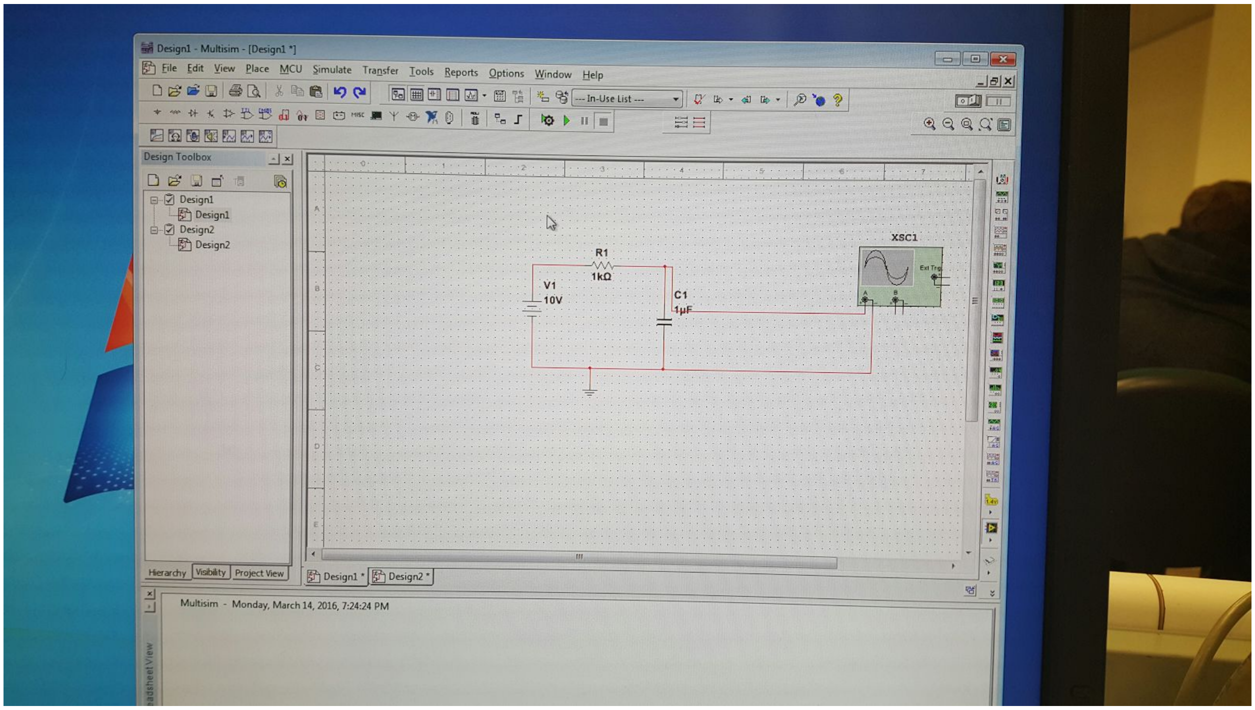
<u>100 Hz Almost no phase shift</u>





Week Two Low Pass Filter Simulation Analysis:

For week two of this two week lab, we as a group needed to familiarize ourselves with simulations of our circuit where we were given the option to run our simulation in either PSPICE or Multisim. Our lab instructor referred us to Lab 7 or 8 which provided us with details on how to set up and run our simulation. This involved us using a 10V source with a 10kΩ resistor in series with a 1µF capacitor and it was attached to a group like the figure provided below.



We wanted to become more comfortable so we decided to use Multisim as it was a program we as a group had much more experience with. We ran into a few hitches due to the simulation not running correctly but after settings things like the initial conditions and the correct resistor and capacitor values we were able to get favorable results.

In order to understand and make sure these results were correct our lab instructor instructed us to do some hand calculations such as finding τ which is just equal to RC which turned out to be $\tau = (10{,}000\Omega * 1 \times 10^{-6}$ F) which ends up turning out to

$= 1 \times 10^{-3}$ s or 1 millisecond

We need to find the 3dB drop which in turn is also known as "a long time" which also equals 5 time constants, as 1 time constant is 1 ms, we can just multiply that by 5 and we find that "a long time" is 5ms.

$\tau = 1$ms

$5\tau = 5$ms

We were given 10 V as our V_c and we needed to find when $V_s(1-\frac{1}{e})$ would equal about .67 or 67% which fits with 3dB loss which is our 45 degree phase angle we found in the previous week but for a different circuit.

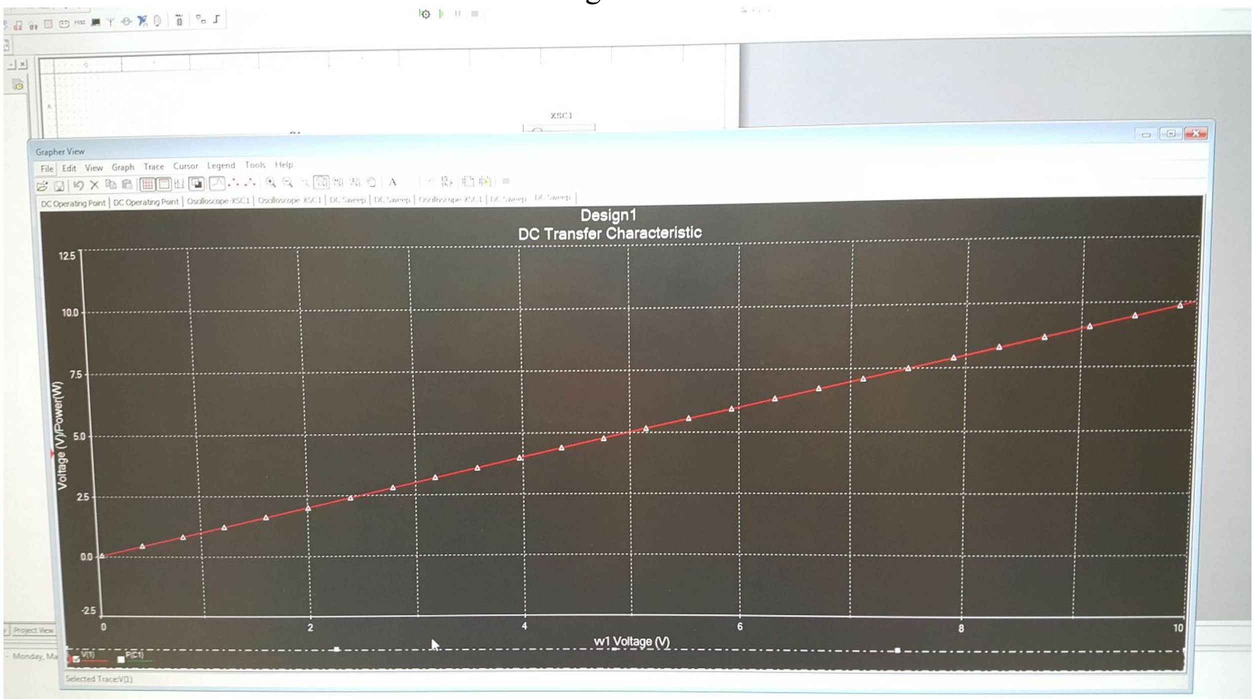
We were asked to use this circuit provided to find three different traces for a bode plot/graph with changing frequencies except through a simulation for a DC circuit, AC circuit, and Transient analysis and needed to find a distinct number of data points which involved $5\tau/500 = \tau/100$ plots

= 1ms / 100

= 10µs per plot

DC Analysis

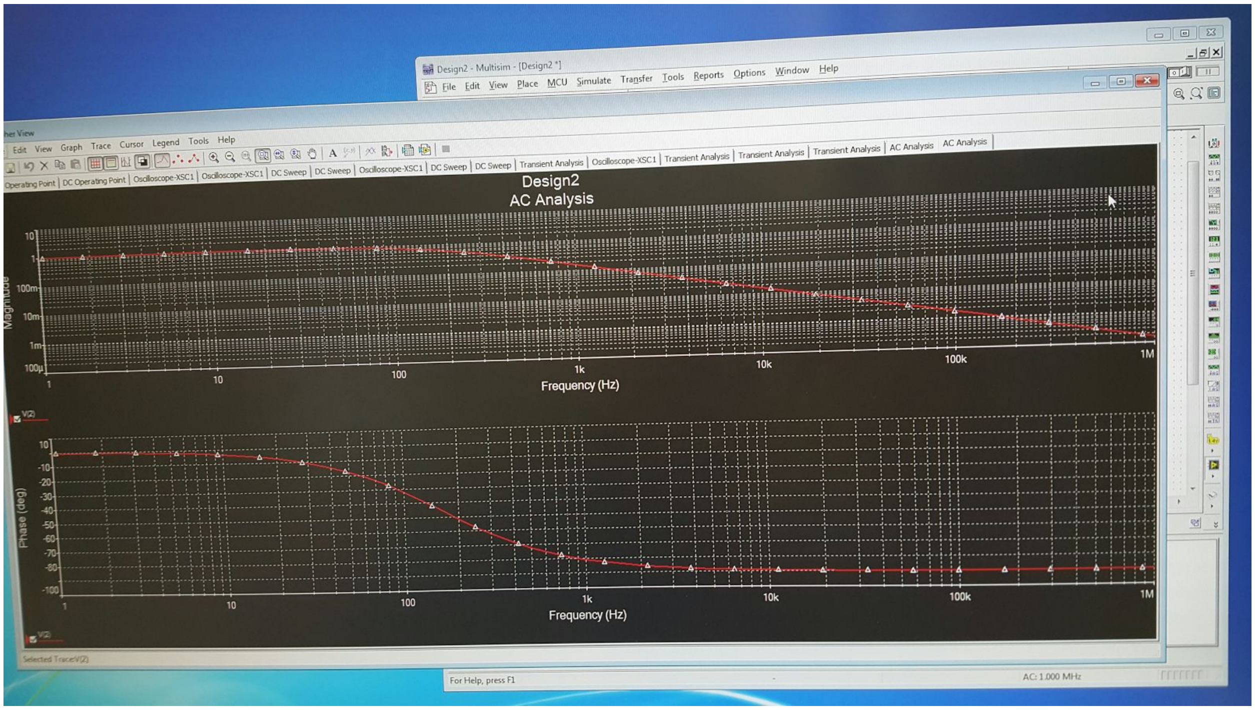
Analyzing the DC circuit was probably the simplest as it was rather simple as it correlates linearly with time, as it ramps up per second, the voltage also ramps up until it reaches the maximum voltage of in this case 10V



The circuit is the same as the one pictured above and as you can see, the slope is linear with a slope of 1 Volt per second until it reaches the peak voltage of 10 at which it will stay at 10 Volts until we end the simulation.

AC Analysis

This analysis was substantially different than the DC analysis as we get a body plot with the ranging frequencies from 1 all the way to 1,000,000 and we can see the shift of magnitude and phase angle occur between 100 and 200 hz but we need to calculate in order to find the exact value of where the phase angle is ±45°



Calculating $\frac{1}{RC} = \frac{1}{(10{,}000\Omega)(1x10\mu F)}$

= 100 rad/s

We know our initial conditions are when t = 0 as that's when we start the simulation which follows the model of a low pass filter as the frequency starts at a magnitude of 1 V as that is what our Voltage was for this AC circuit and after about 100 Hz we see that the change in magnitude begins to occur which follows our model above as the slope starts to go downwards and the phase angle begins to descend from 0° down to -45° which is what we want to see occur in our simulation.

We want our -45 value which from the previous week we learned that

$$-45° = -\tan^{-1}\left(\frac{1}{\omega RC}\right)$$

$$-45° = -\tan^{-1}\frac{1}{\omega(10k\Omega)(1x10\mu F)}$$

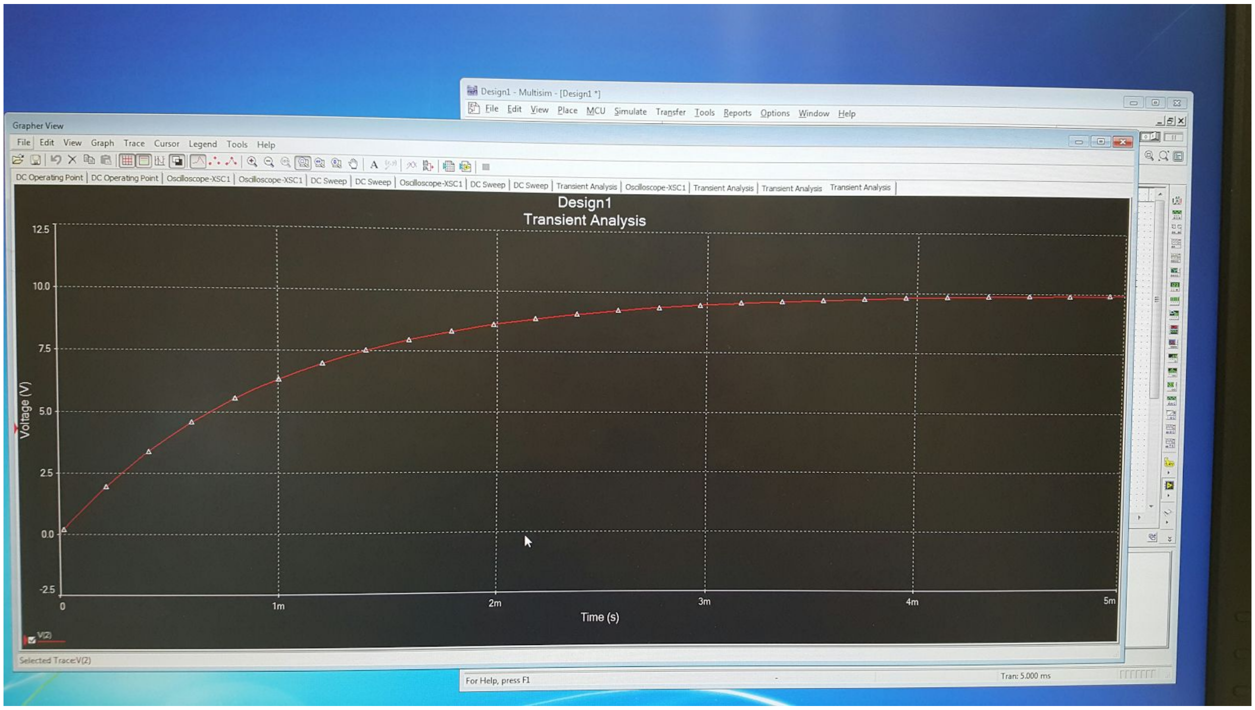
$$-45° = -\tan^{-1}\frac{1}{\omega * 100}$$

$$100 = .05729\,\omega$$

$$\omega = 174.2\ Hz$$

This value is close to what we have pictured and according to the graph the frequency of -45° lies somewhere between 150 hz - 180 hz

Transient Analysis



For our third and final simulation analysis we needed to do a transient analysis which was relatively simple, we know that after one time constant which we calculated to be 1ms we know that the voltage in the circuit will be about 67% of the voltage source which is about 6.7V out of the 10V being input as the capacitor begins to be charged this was solved with the equation

$$V_C = V_S(1 - e^{-t/\tau})$$
$$=10V\,(1 - \tfrac{1}{e})$$
$$= 6.32\ V$$

Which is fairly close to the expected output of about 6.7V which gives us an error calculation of 5.65% which is reasonable as the capacitor and resistor can have a variable miscalculation. After the first time constant we can see that the gain drops off and starts to taper around the 4th time constant and it steadily increases up to a charged capacitor which would have the same voltage as the input voltage of 10V

Summary

In this lab, we used our new knowledge of low pass filters to not only analyze one with the oscilloscope and multimeter but also ran simulations to reinforce our knowledge with a similar low pass filter to create bode plots. We needed to make sure we not only got the correct results in both parts of the lab but also needed to do some hand calculations to have a concrete understanding of the lab. At first this lab looked overwhelming due to the amount of things we needed to solve for and find but in reality it wasn't difficult if one understands the characteristics of a low pass filter like until a certain frequency which can be found through your RC value the magnitude will be the same as the input. One thing we had a lot of trouble with was understanding why the phase angle was negative instead of positive but we were able to figure

out what caused that issue and it allowed us to better understand the concept of bode plots.