

**ELEC 240**  
**Lab 3 - Basic Circuits**

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# 1 Objective

In this lab, we explored Kirchoff's laws, and transfer functions through the use of various circuit elements, such as potentiometers, and software, such as LT Spice.

In the first section of this lab, we explored running various amounts of AC and DC current through a voltage divider of different voltages. We also used a potentiometer as a voltage divider and verified its accuracy. In the second portion of this lab, we measured the transfer function of an RC Circuit by measuring its phase and amplitude with various input frequencies, and we then compared it with the calculated transfer function generated using MATLAB. Finally, we simulated two different RC circuits using LTSpice software and plotted the gain of the circuit at various input frequencies.

# 2 Materials

- Virtual Bench (Software, Oscilloscope, Function Generator, DC Power Supply)
- Computer with LTSpice Software
- BNC Male to Clips cord
- BNC T connector
- Oscilloscope Probe
- Breadboard
- 2 10 cm length wires (with 6 mm stripped on each end)
- Digital Multimeter
- $10k\Omega$  potentiometer
- 2  $47\Omega$  resistors
- 2  $1M\Omega$  resistors
- 2.2  $k\Omega$  resistor
- 2.2 $\mu F$  resistor

# 3 Test Description

In Part A of Experiment 3.1, we explored the frequency range that the DMM on the Virtual Bench could usefully measure by outputting a sine wave from the function generator and recording the maximum voltage recorded by the DMM hooked up to this outputted sine wave. In Part B, we measured the output of a voltage divider and observed how circuits in reality deviate from ideal circuits. In Part C, we used a potentiometer as a voltage divider and verified that turning the slider in equal increments would proportionally increase the resistance of the potentiometer.

In Part A of Experiment 3.2, we measured the transfer function of an RC Circuit that we wired on the breadboard by inputting various AC frequencies and measuring and plotting the resulting voltage signal. In Part B, we simulated an RC circuit by creating a virtual circuit on LTSpice. We then performed AC analysis by plotting the gain of the RC Circuit over a wide frequency range.

### 3.1 Pre-Lab Calculations and Schematics

No pre-lab calculations were needed, but an understanding of how to measure a transfer function of an AC circuit was needed. Depicted below in Fig. 1 is the desired oscilloscope output overlay needed to measure the transfer function:

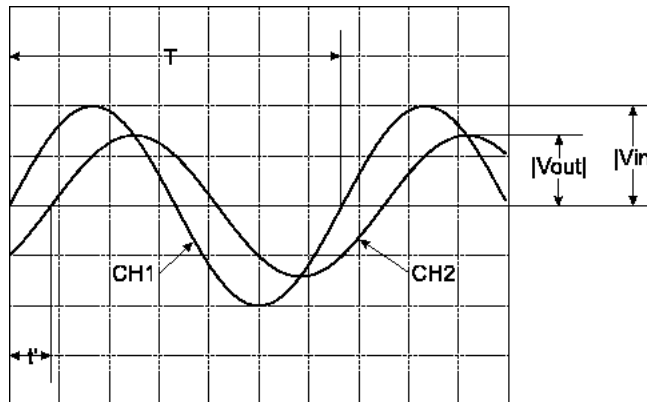


Figure 1: Circuit Output Signal Overlayed with Function Generator Output

To measure the transfer function at a given frequency, we needed to measure both  $|V_{IN}|$  and  $|V_{OUT}|$ , which was achieved by measuring the height of the peaks of CH1 and CH2. To measure the phase  $\Phi$ , we measured the horizontal distance between the peaks of CH1 and CH2. With this technique, we are able to perform AC circuit analysis in Part A of Experiment 3.2.

## 4 Results and Discussion

### 4.1 Experiment 3.1: Resistive Voltage Dividers

#### 4.1.1 Part A

The voltage reading on the DMM by a  $2V_{pp}$  sine wave is  $.704V_{rms}$ , or  $.704 V_{in}$ . The voltage reading on the DMM for a similar square wave is  $1.096 V_{in}$ . Then, readings were done for various frequencies for the same value sine wave as used in the initial test. The results were as follows

Table 1: Voltage read by the DMM of the Sine Wave at given frequencies

Frequency (Hz)	Voltage (V)
5	.641
50	.701
500	.701
5k	.49
50k	.0

It seems that the appropriate frequency for the DMM is 50-500 Hz to be safe, but more reasonably 10Hz-1kHz.

#### 4.1.2 Part B

The voltage divider ratio should be  $\frac{10}{10+10} = \frac{1}{2}V_{in}$  for two  $10k\Omega$  Resistors in series. For the sine wave, the output is  $.351V_{ac}$ , which is 49% of the initial Voltage, consistent with the voltage divider equation At  $47\Omega$

the  $V_{out} = .243$ , which is inconsistent, with the voltage divider equation, indicating that the voltmeter may have inconsistent readings at low voltages. At  $1\text{ M}\Omega$  the output voltage is  $.335$ , indicating that there may be a range of acceptable resistance for the voltmeter, just like we noted an acceptable frequency range.

#### 4.1.3 Part C

Using the same sine wave, but with  $100\text{ Hz}$ , the potentiometer is connected in series and the voltage drop across it is recorded. At the midpoint,  $V_{OUT} = .386$  or  $.55V_{IN}$  this value is reasonable within error for such an analog device. The values of the output voltage at different divisions are given below.

Table 2: Voltage Across the Potentiometer at Each Division

Division (#)	Voltage (V)
1	.76
2	.653
3	.589
4	.506
5	.389
6	.273
7	.181
8	.076
9	.002
10	0.0

It seems as if the values were evenly spaced as if they were only 9 divisions, since the 9th and 10th both had 0V out.

## 4.2 Experiment 3.2: Filters and Transfer Function

### 4.2.1 Part A

Measuring the frequency and the amplitude of the output voltage across an RC circuit. The values recorded can be seen below

Table 3: Frequency and the amplitude of the output voltage across an RC circuit

Frequency (Hz)	Voltage (V)	Phase shift (ms)
20	.99	1.97
50	.96	1.02
100	.88	.869
200	.68	.632
500	.39	.402
1k	.16	.227
2k	.065	.119
5k	.041	.046
10k	.021	.023
20k	.010	.012

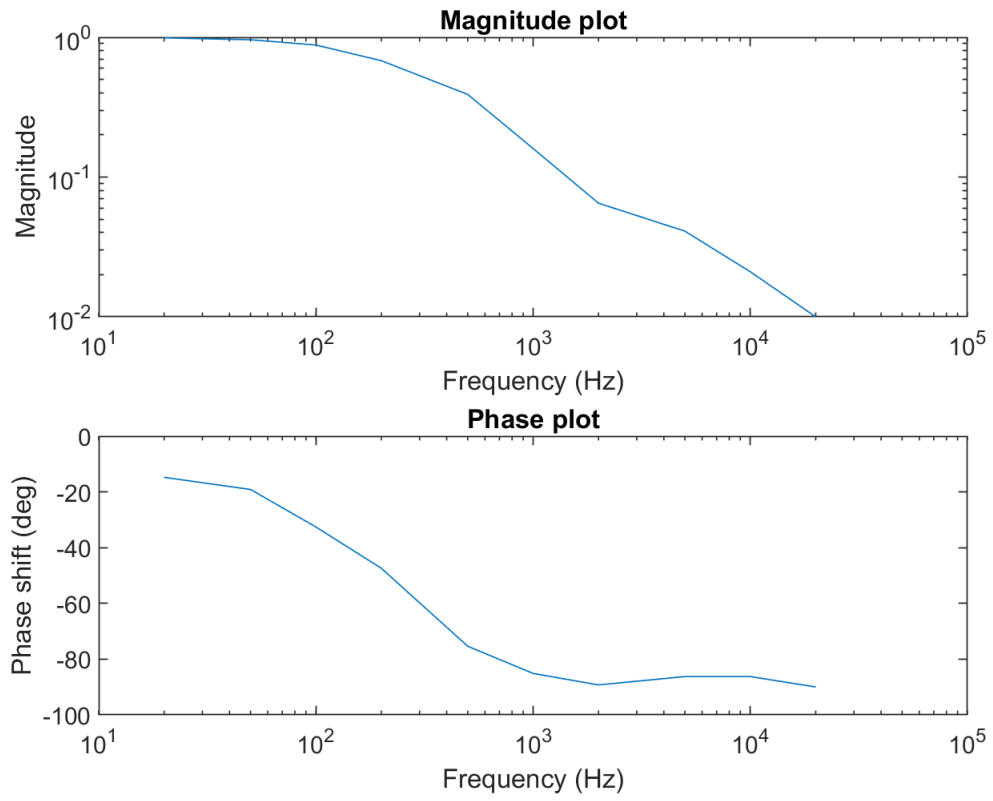


Figure 2: Visualization of the magnitude and phase plots for table 3

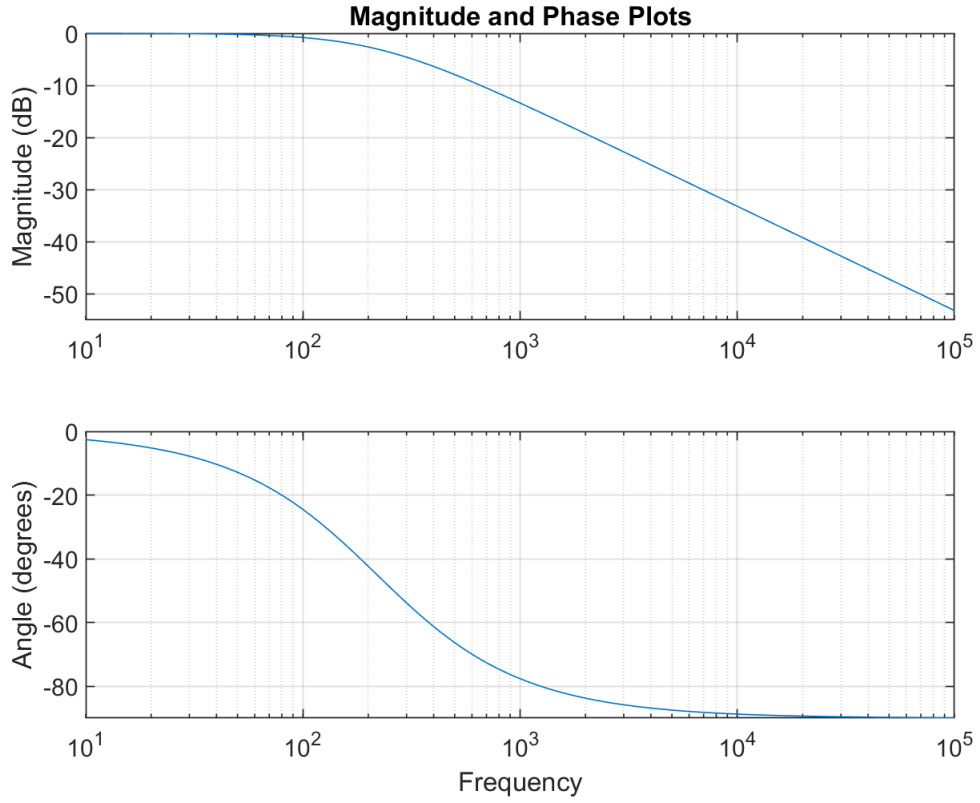


Figure 3: Using the given transfer function, used the supplied magphase function to generate the expected values

These results from Table 3 were then used plotted onto Figure 2, using MATLAB. When compared to the values of Figure 3 it can be seen that the experimental results match up with the calculated results, confirming the transfer function of  $\frac{1}{RCj2\pi f+1}$ , where  $R = 2.2 \text{ k}\Omega$  and  $C = 0.33 \mu\text{F}$ . The experimental results, while scattered, are confirmed by the theoretical results.

### 4.2.2 Part B

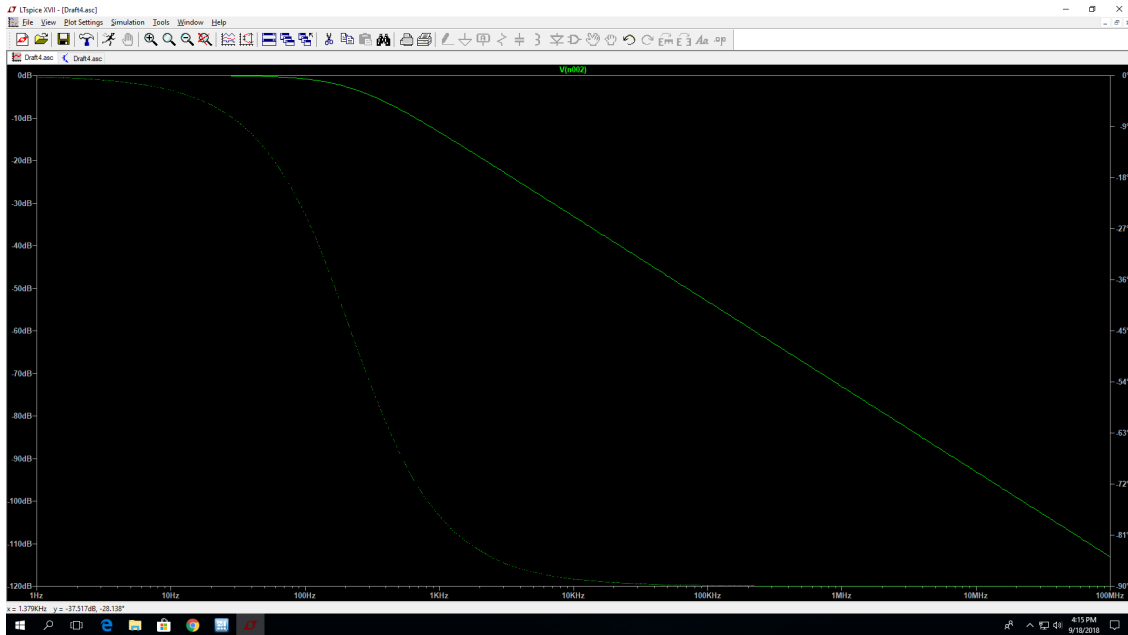


Figure 4: LT Spice AC analysis of simple RC circuit built in lab, as observed, it is a low pass filter

The screenshot of the LT spice AC analysis of an RC circuit can be seen in figure 4, The gain at low frequencies is 0 dB or 1 V/V. The cutoff frequency happens at approx. 220 Hz. At high frequencies the gain rolloff becomes almost linear, with a slope of -1 dB/dec. At low frequencies, the phase is  $0^\circ$  or in phase. At high frequencies the phase is  $-90^\circ$ . This is because a capacitor will ideally lag in voltage when put in a circuit in series, and at low frequencies the capacitor acts more like a resistor.

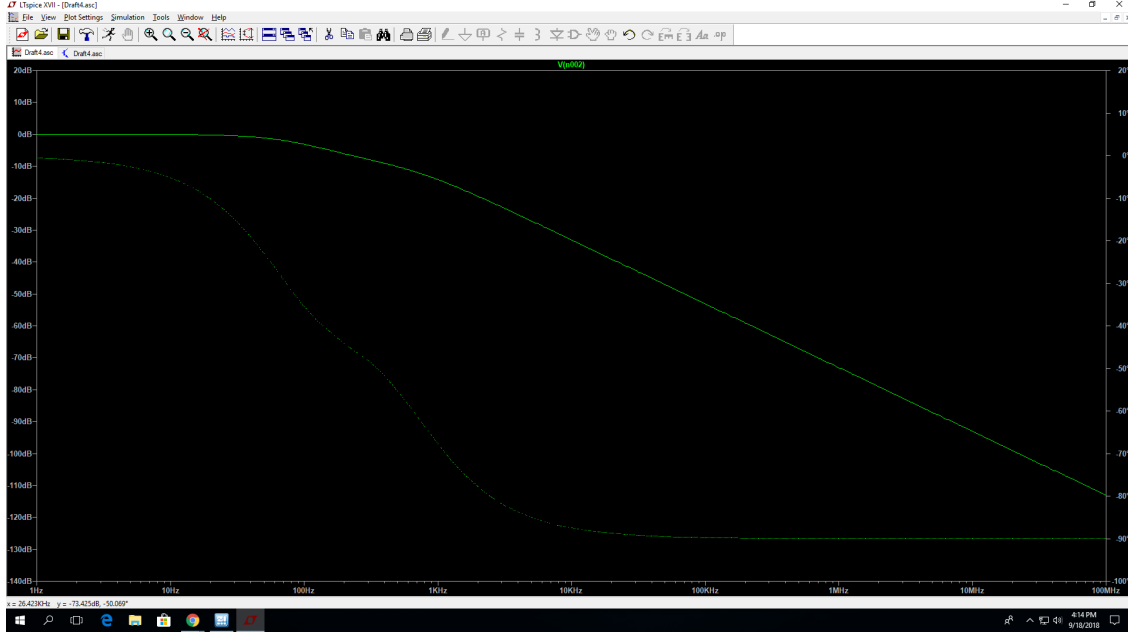


Figure 5: LT Spice AC analysis of the combination RC circuit. It is a low pass filter, but slightly more complex, due to the cascading RC element

After adding the cascading RC circuit, the graph looks a little more interesting, including 2 bumps but a similar DC gain, as seen in Figure 5. However, the cutoff frequency is approximately the same as before. The gain rolloff has changed, and in this case, it seems to have the same slope, maybe around -1 dB/dec. While the phase at high frequencies is  $90^\circ$ , the DC phase is around  $8^\circ$ . Cascading two identical filters can allow the phase to shift, even for low frequencies while keeping the cutoff frequency approximately the same.

## 5 References

- <https://www.ece.rice.edu/~dpr2/elec240/lab3>

## 6 Conclusion

In Part A of Experiment 3.1, we discovered that the useful frequency range of the digital multimeter was roughly 50-500Hz. We hypothesize that this limited frequency rate is due to the physical limitations of the multimeter in how fast it can read the signal; too fast a frequency, the DMM will not be able to fully record the waveform.

In Part B of the same experiment, we found that the voltmeter also has a limited voltage range that it can accurately measure. We received different values for  $V_{OUT}$  for a  $47\Omega$  resistor and a  $1M\Omega$  resistor. We believe that this discrepancy arises from the fact that the voltmeter has a finite internal resistance; when measuring voltage through lower resistor values, this finite internal resistance of the voltmeter will appreciably affect the voltage measurement.

In Part C, we measured a  $10k\Omega$  potentiometer's resistance at its ten predefined intervals to see if the equation  $V_{OUT} = \alpha V_{IN}$  was correct, where  $\alpha$  was a constant that corresponded to a fraction of  $V_{IN}$  (i.e.  $\alpha = 1$  means  $V_{OUT} = 0.1V_{IN}$ ). This assumption is mostly correct according to the data we recorded in Table 2; however, we noticed that  $V_{OUT}$  was essentially zero by the time we set the slider to the 9th position. This may have been due to a slight miscalibration in the potentiometer itself.



In Part A of Experiment 3.2, we used the measurement techniques from the pre-lab section to measure the transfer function of a simple RC circuit that we built from a  $2.2k\Omega$  resistor and a  $0.33\mu F$  capacitor. We found that the measured magnitude and phase plots looked almost exactly like the MATLAB plots that we generated by entering the transfer function  $\frac{1}{RCj2\pi f+1}$  into the *magphase* function. These results validate both our measuring techniques and the calculated transfer function.

In Part B of the same experiment, we used LTSpice to simulate a simple and a slightly more complex RC circuit to observe their various properties. For the simple RC circuit, we found that the rolloff of the gain is approximately 1 dB/dec. We also found that the phase of the RC circuit dropped much more quickly than the gain as frequency increased, going from  $0^\circ$  at 1 Hz to nearly  $-90^\circ$  at 100 kHz. This lag at high frequencies reflects the presence of a capacitor, which acts like a resistor at low frequencies (which do not cause phase shift) but causes high phase shifts at higher frequencies (capacitors take the derivative of voltage, which phase shifts by  $-90^\circ$  by changing a sine to a cosine). We observed a similar magnitude plot for the more complex cascading RC circuit. However, we did note a difference in the phase plot, which had a brief bump around 500 kHz where it would be linear in the simpler RC circuit. Furthermore, the DC phase shift was approximately  $8^\circ$ . Thus, we conclude that putting RC circuits in cascade will maintain the cutoff frequency and the magnitude plot of the transfer function but will shift the phase plot.

## 7 Errors

- *Did not receive a ratio of  $V_{IN}/V_{OUT} = 0.5$  for the  $47\Omega$  resistor:* This is due to the fact that the voltmeter has a finite internal resistance. When a low resistance value is being measured, the effects of this finite internal resistance become higher.
- *Voltmeter recorded a  $V_{OUT}$  of 0 for division #9:* This error is likely due to a miscalibration in the potentiometer that caused it to reach its maximum resistance slightly before the 10th turn of the slider knob.