Electronics

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Abstract

In this laboratory experiment various properties of electronics were shown through the assemblage of six types of circuits, in an attempt to give the student a simple working knowledge of the same sorts of components that could be found in any electronic laboratory device. This was accomplished by creating and analyzing each circuit separately, using known mathematical relations and empirical observations. For the DC circuits a Digital Multimeter was used to make experimental measurements and for the AC circuits an oscilloscope was employed. The last three circuits made use of a 741 Operational amplifier. In Circuit A, consisting of all resistors, the voltage was found to be 4.77kΩ. In Circuit B, a circuit similar to Circuit A but having the very important difference of a 470kΩ resistor in parallel, we found the voltage to be 4.77kΩ once again. Replacing that large resistor with a 1.5kΩ resistor yielded a significantly different V_{eq} value of 2.80kΩ. In the Voltage Divider given two configurations, the V_{out} was determined to be 4.63V in both cases, the second one differing considerably from its theoretical value of 4.17V (see table 0.2). The Low Pass Filter setup yielded an output voltage inversely proportional to the frequency with a significant drop in V_{out} around 3,000Hz. The Inverting Operational Amplifier (Op-AMP) was found to have a frequency range of about 18Hz - 20kHz and a maximum output voltage, V_{max} of 1.365V. Finally, The differentiator showed a nearly direct relationship between frequency and V_{out} (as seen in table 0.4).

0.1 Theory

At the heart of instrumental analysis are electronics. Each widely used device in Chemistry contains complicated electrical components that consist of numbers of resistors, transistors, capacitors, inductors, and etc. The purpose of this lab is to become better acquainted with the components that make up electrical circuits, and how they function together to generate and modify a signal. This will be accomplished by constructing various types of circuits and recording how their design manipulates an initial signal. Studying the mathematical relationships that describe what is happening in these simple circuits will help to give an understanding as to how incredibly complex the guts of a typical electronic device can be. Several components were used to make the expected circuits, and each component has its own separate use. Resistors are made out of insulator material to work against the flow of electricity. This is useful in regulating current and the energy lost in the resistor itself is used as well, for example, in producing light in common household lightbulbs. Also seen in several of the diagrams are grounds, or circuit commons. Consider a circuit common to be a large sink that can take essentially any amount of current without changing its own properties. Using this one can assure the potential goes down to zero at the end of the circuit. The *Low Pass Filter* contains a capacitor, which is essentially two conducting plates along the circuit with space between them. The properties of a capacitor make it useful. When a ΔV is added to the circuit there the capacitor does not impede electron flow, but as a function of time a considerable amount of charge builds up on the plates, negative on one and positive on the other, to the point where eventually the capacitor acts as a perfect insulator and the current drops to zero. For this reason capacitors are especially useful in high and low-pass filters (comprised of a resistor and capacitor), which is seen in the lab. In an AC circuit, at low frequency, the current builds up on the capacitor. At high frequency, the current gets stopped on the resistor. Finally, an operational amplifier was used for the last three circuits. This device is made up of several other components, and its uses are numerous. It can amplify, invert, add, subtract, differentiate, and integrate voltage, given the appropriate configuration. All of these components were combined on a *protoboard*[1], which makes testing circuit configurations fast, easy and inexpensive [fig.

[1]http://www.filtro.net/images/used/protoboard%20203a.jpg

0.1] The circuits we set up obeyed *Ohm's Law*, an empirical law that states $I = \frac{V}{R_{tot}}$ [1] where I is current, V is voltage, and R is resistance. Ohm's Law can be expanded to both series and parallel circuits. For series, $R_{tot} = R_1 + R_2 + \ldots + R_n$ [2]. For parallel, $\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$ [3]. In addition, current is handled differently in parallel circuits because there's more than one path for the current to follow. Because of this, *Kirchoff's Circuit Law* is used, which essentially states that the total currents going into a given point must equal the total currents leaving, $\sum I_{in} = \sum I_{out}$ [4]. Also, for reference, the time constant, τ, in a low-pass filter is considered the resistance multiplied by the capacitance, or $\tau = R * C$. This is useful in determining how long it takes for the capacitor to charge, and also is required in finding V and I in the circuit, though such calculations were not expected in this experiment. It should be mentioned that from the Low Pass Filter on, a *Function Generator* was used to supply alternating current (AC) to the circuit. The voltages were then measured using an oscilloscope; a device that allows one to view voltage signals on a *Cathode Ray Tube* (CRT) in an empirical manner, thus making it easy to take measurements on such an apparatus. This particular oscilloscope was well equipped for taking peak heights and producing them in a digital, readable manner.

0.2 Procedure

A detailed description of what must be performed in this experiment has been provided in two separate handouts by the instructor. However, a brief description for each of the given circuits will follow. Circuit A and B were comprised completely of resistors, both in series and parallel. A *Digital Multimeter* (DMM) was used to measure the resistance values. Note here that the given diagram for Circuit B contains an extra wire which, if connected, shorts the circuit out. Consequently it was left out of the experimental circuit. An R_{eq} value was measured for this circuit and then the 470kΩ resistor was replaced with a 1.5kΩ resistor and another R_{eq} measurement was taken. Two circuits were constructed as voltage dividers, and a DMM was used in each case to find the V_{out} with a constant applied $V_{in} = +5V$. After this a *Low Pass Filter* was assembled. This was similar to the original Voltage Divider except that the second resistor was replaced with a capacitor. This type of circuit takes AC input and gives a V_{out} dependent upon frequency of the V_{in}. An array of frequency-dependent outputs was recorded and

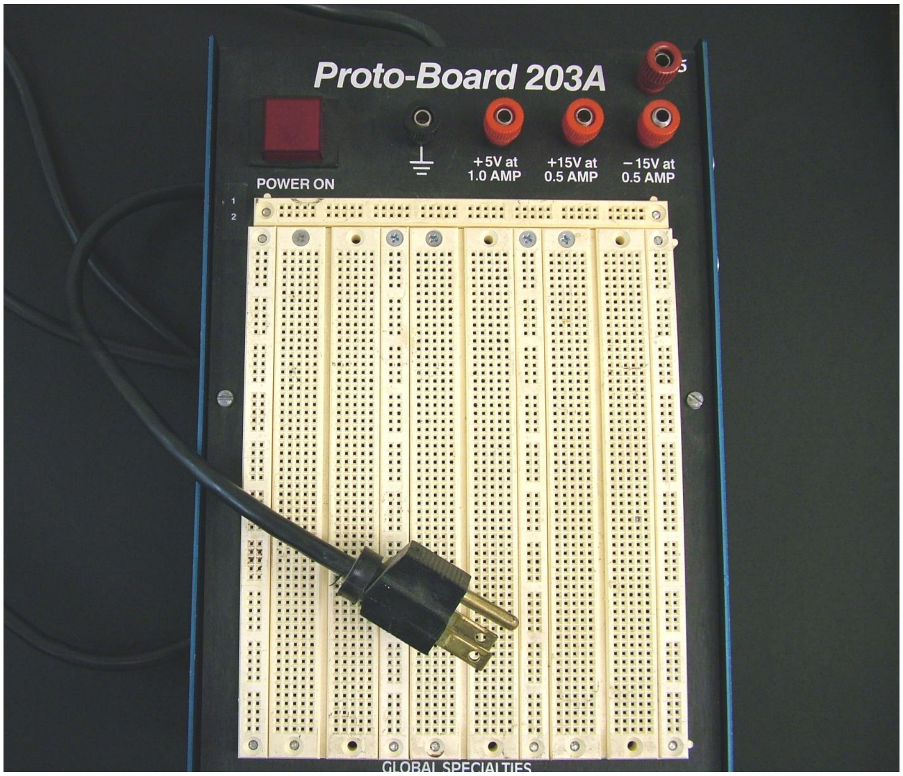

Figure 0.1: Protoboard

set aside for further analysis. The final three circuits involved *Operational Amplifiers* (OP-AMPs). The first circuit was an *Inverting OP-AMP*. This circuit was assembled as shown in the handout and then fed a 1kHz sine wave signal. Using an oscilloscope the V_{out} and V_{in} were displayed and compared visually. Similar steps were employed in the next circuit, called a *Non-inverting Amplifier*. The last circuit, a *Differentiator*, was identical to the Inverting Op-AMP except that the first resistor was replaced with a capacitor. An array of data was collected by varying the frequency and measuring V_{in} and V_{out} values.

0.3 Results

The important Results from Circuits A and B are listed in Table **??**. Here, the 2_{nd} B value is the resistance values of the circuit after the 470kΩ resistor has been replaced. Similarly, Table 0.2 lists the important results for the Voltage divider (see eqns 1-3) in both configurations. For the Low Pass Filter the time constant, τ, was determined to be 0.1ms and the cutoff voltage, V[2], was determined to be 10.6mV. Using this one can approximate the cutoff frequency to be f $\approx$ 1000Hz. Table 0.3 provides the experimentally determined values for a Low Pass Filter. For the Inverting OP-AMP and the Non-inverting OP-AMP both, the gain, A[3] = 10. For the Inverting OP-AMP the maximum output voltage, $V_{max} = 1.365$V, and the frequency range for the amplifier was found to be 18Hz - 20kHz. Values for the frequency-dependent voltage values of the Differentiator are listed in Table 0.4

Circuit	Theoretical R_{eq} (kΩ)	Experimental R_{eq} (kΩ)
A	4.82	4.77
B	4.80	4.77
2_{nd} B	2.82	2.80

Table 0.1: R_{eq} values for Circuits A and B

Setup	Theoretical V_{out} (V)	Experimental V_{out} (V)
1	4.55	4.63
2	4.17	4.63

Table 0.2: V_{out} for the Voltage Divider

0.4 Discussion

The first two circuits were made up completely of resistors and wires. Finding the theoretical equivalent resistance involved simple series and parallel equations. It turned out that in every case, the theoretical resistance was

[2] $V_{out} = 0.707V_{in}$
[3] $A = \frac{R_f}{R_i}$

Frequency (Hz)	V_{in} (mV)	V_{out} (mV)
100	157	154
300	159	149
1,000	158	124
3,000	156	58
10,000	155	24
100,000	155	6

Table 0.3: Frequency-dependent values for a Low Pass Filter

Frequency (Hz)	V_{in} (mV)	V_{out} (mV)
100	142	6
300	142	20
1,000	141	60
3,000	138	200

Table 0.4: Frequency-dependent values for a Differentiator

greater than the experimental resistance. This happened due to the internal resistance inherent in all parts of the circuit; not just the resistor. Comparing the three circuits and their results showed an important property about current. When the massive 470kΩ resistor was in place in Circuit B, the circuit acted essentially as though it were built like Circuit A. This was shown by nearly identical equivalent resistance values between the two circuits. On the other hand the equivalent resistance plummeted when the 470kΩ resistor was replaced with a 1.5kΩ resistor. What this shows is that resistance is inversely proportional to current. Because of this, nearly no current flowed through the 470kΩ resistor and therefore in observation it was as good as an open circuit in that area. Such a negligible amount of current flowed across that the circuit acted like Circuit A. On the other hand, when a much smaller resistor replaced the 470kΩ resistor, the laws of parallel resistance combined with empirical observation showed that the current flowed through both pathways and resulted in a significantly reduced over-

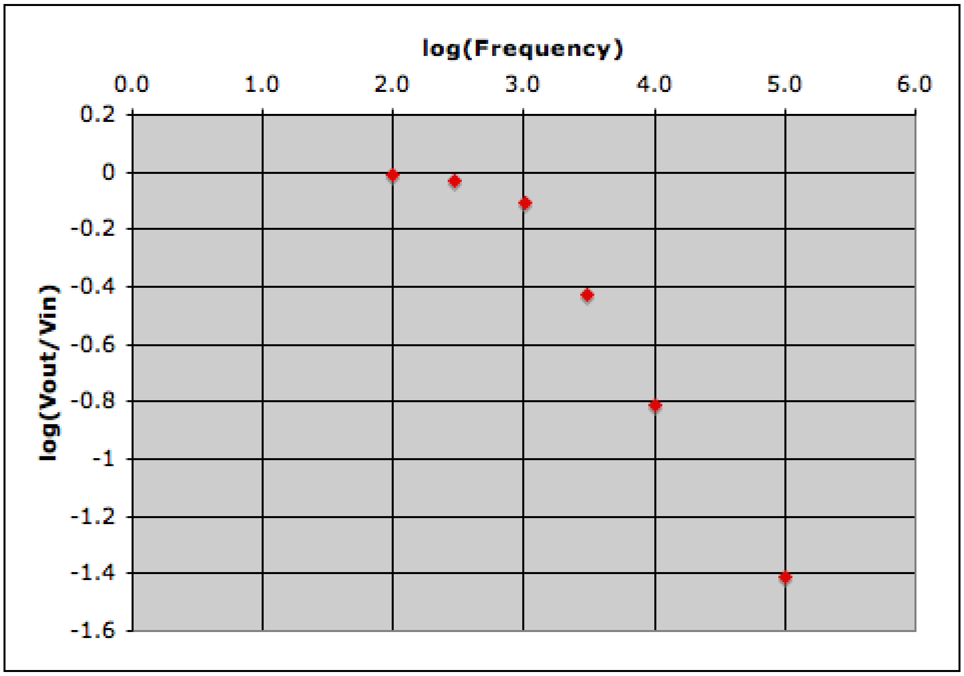

Figure 0.2: Bode Plot for a Low Pass Filter

all resistance. A study of the Voltage Divider showed yet another property of resistors. That is, resistance is directly proportional to the change in voltage, ΔV. With two resistors in series, The heft of the voltage drop was recorded over the second, considerably larger (in terms of resistance) resistor. Adding on another resistor-common set in parallel showed another important concept, or at least that was the intent. Theoretically it was supposed to show that the equivalent resistor representing combined resistors in parallel would take less of a voltage drop than a single resistor, because resistors in parallel allowed for better electron flow, while resistors in parallel restricted electron flow. However, the experimental values for the equivalent resistance came out to be the same. This must have been an error on the part of the experimenters. The most likely explanation is that the wire connecting the second resistor-common pair to the rest of the circuit was loose, and therefore did not have any effect on the original circuit. After this, a circuit very similar to the original voltage divider was constructed, except the second resistor was replaced with a capacitor and it was fed with 1kHz AC voltage. This type of circuit is called a Low Pass

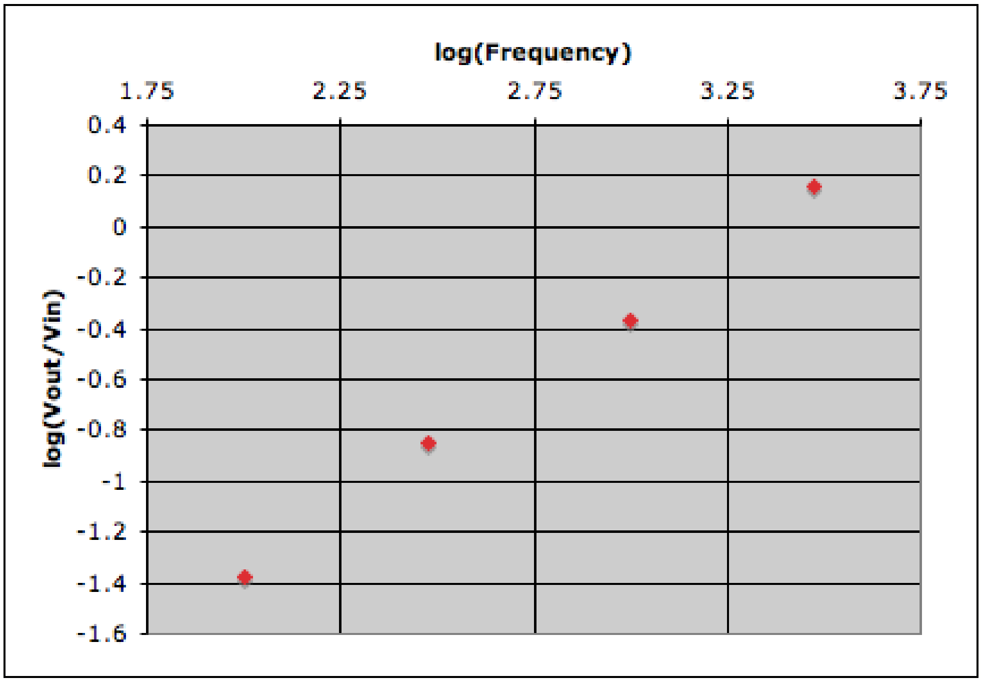

Figure 0.3: Bode Plot for a Differentiator

Filter. It is called this because due to the properties of the capacitor, only signals of low frequency are allowed to pass through. This works because the capacitor takes time to charge and uncharge, so that in an AC circuit it is usually in the process of doing one or the other, which causes it to go back and forth from wire to perfect insulator. An experimental bode plot was created to show this relationship between frequency and output voltage [fig. 0.2]. Note that this occurs over a great span of values so a logarithmic plot is more appropriate. The cutoff frequency is derived by the relation seen in footnote 4. This relationship uses the value 0.707 which suspiciously looks like an rms value and it defines at what point the output voltage starts plummeting. At this point the Low Pass Filter has reached its maximum allowed frequency and doesn't allow higher frequency voltages to pass through and contribute to the output voltage. The next three circuits all include an OP-AMP. The first circuit, an Inverting OP-AMP, takes an input signal, amplifies it, inverts it, and sends it to V_{out}. The effective frequency range of the Inverting OP-AMP spanned three orders of magnitude but got unreliable at both ends. At the minimum end of the spectrum the voltage rapidly dropped off. at the maximum end of the spectrum the voltage gradually dropped off. Note, however, that the minimum end had such a low frequency that taking in accurate data became difficult and increasingly uncertain. Another difficulty in attaining accuracy had to do with the frequency knob on the function generator. It so happened that the values of importance fell on a portion of the knob not calibrated like the rest, which only allowed us to make general estimates about the minimum and maximum frequency. Nevertheless these estimates gave a rough idea as to the effective range of an Inverting OP-AMP. The Non-inverting OP-AMP was created for qualitative observation purposes essentially, and data was not collected for it. What it showed, however, is that unlike the previous circuit, this circuit produced the same signal it received from the input, only greater in magnitude. This contrasts the Inverting OP-AMP because with that circuit the output signal was upside-down relative to the input signal. This is a simple but important difference. By this it can be expected that feeding a positive signal into an Inverting OP-AMP will give a negative signal in response, and vice versa, while the Non-inverting OP-AMP will give a positive signal for a positive signal. When finding the maximum frequency it could be found by noting that at some point the output would transform from a sine wave to a triangle wave. The final circuit, the Differentiator, looked similar to an Inverting OP-AMP but the first resistor had been replaced with a capacitor. A similar bode plot was created using a triangle wave with frequency, V_{in}, and V_{out} data which showed a positive, linear relationship using logarithms, but due to the lack of data points, the reliability of this plot is questionable. The difficulty in harvesting more data points had to do with two factors. at the low f end, the frequency was too low to attain meaningful points. At the high f end, the ringing in the output signal started to make up a considerable portion of the actual signal, so much so that at 3000Hz what were supposed to be horizontal lines started to look like sine waves that linearly decreased in magnitude. Regardless of the ringing, the plot made sense. The circuit was taking a given signal and returning the derivative of that input signal, hence the horizontal lines in response to a triangle wave. Other signals, such as a sine wave, were sent through the circuit and gave the expected derivative results. No data were collected for these other signals.

0.5 Conclusion

In this experiment various fundamental properties of electronics and the components therein were studied using various simple circuits. The vast majority of the circuits constructed acted as expected once they were, in fact, constructed correctly. The five initial circuits had a percent error from theoretical of 1.04%, 0.63%, 0.71%, -1.76%, and 11.0% respectively, with only the last value coming out with a notable difference. The Low-Pass Filter circuit gave an array of data shown in figure 0.2 which matches up roughly with what is expected from a bode plot of a low-pass filter. Similarly the Differentiator gave data (granted, not much data) that produced a fairly consistent line in figure 0.3. With a notable exception of the Differentiator, the circuits and their components worked inexplicably well, considering the price of parts. It would do the experimenter well, however, to stick to one instruction set if there is a disparity between the two.