Electrocardiogram(EKG)

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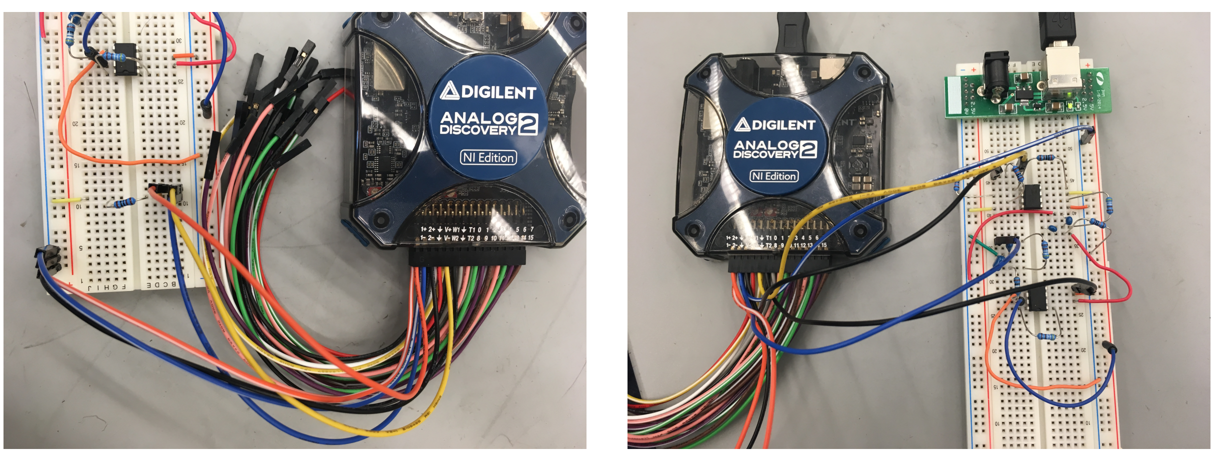
Abstract

The purpose of this lab is to see low pass filters and high pass filters in action. The lab also involved applying multiple filters to smooth out signals at both low and high frequencies. A combined circuit of both amplifiers and filters was ultimately constructed to record the pulse of a “patient”, which was the author himself.

1 Description

The lab began with a warm-up session where three sets of basic RC circuits were constructed and their respective Bode plots were then recorded. In the EKG lab, the setup was divided into two smaller sections centered around each of the AD623 amplifiers in the circuit. With the back of one hand grounded, the electrical signal coming from the left wrist and the right wrist would go into Pin 2 and 3 of the first AD623 after each passing through a 100kΩ resistor, respectively. While Channel ± 1 measured the output voltage of the first AD623 with a reference voltage of 2.5 V after passing through a low pass and a high pass filter, Channel $\pm$ 2 kept track of the output voltage of the second amplifier after a series of low pass filters with the same reference voltage. The Bode plots of Channel ± 1 and ± 2 were taken with a sine wave input of varying frequencies before the circuit was hooked up to the ”patient”.



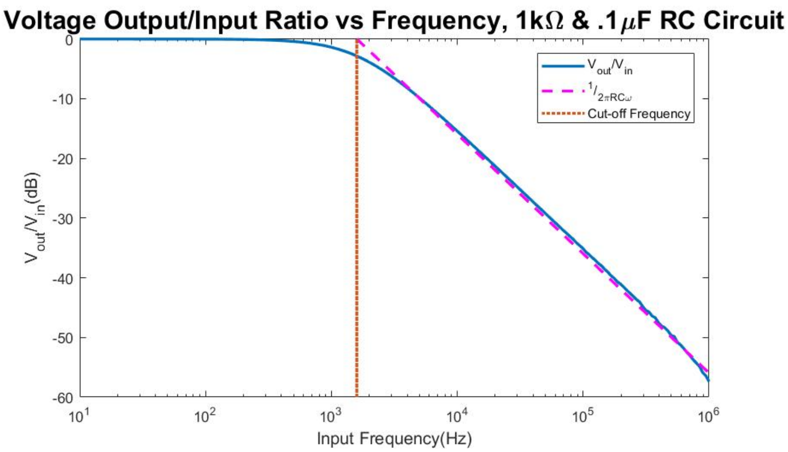
(a) Warm-up lab setup.

(b) The EKG circuit setup.

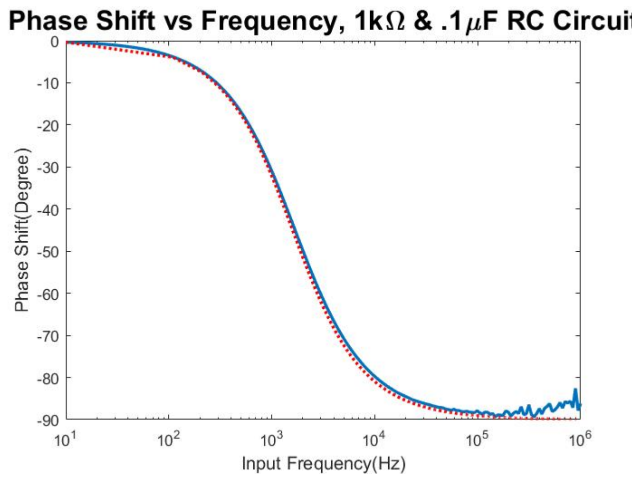
Figure 1: The EKG lab.

2 Evidence

In the lab, five sets of Bode plots were recorded to understand the behaviors of low-/high-pass filters. The Bode plot measurement were taken with a sine wave input from 10Hz to 1MHz. The first circuit was a low pass filter built with $1k\Omega$ resistor and 0.1 μF capacitor, giving a cut-off frequency of 1591.5Hz.



(a) The voltage output and input ratio of the low-pass filter over different frequencies. The cut-off frequency is given out in red.



(b) The phase shift of the voltage output with respect to the input of the low-pass filter. The blue line is the actual data whereas the red line is a mathematical description.

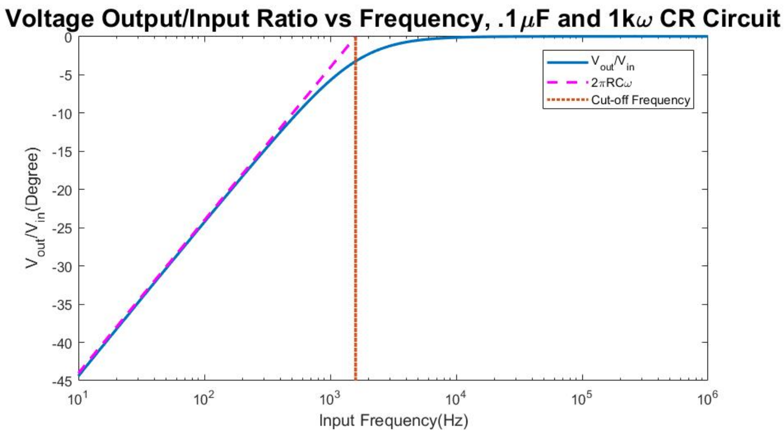
Figure 2: The $1k\Omega$ and $.1\mu F$ low-pass filter Bode plots.

The magenta dash line in Figure 2(a) a mathematical description of the drop in the ratio A based on the equation $A = \frac{1}{2\pi RC\omega}$, which is what the ratio between the output and the input would be in Hz as the input frequency goes to infinity. Meanwhile, the phase shift ϕ is modeled by $\phi = arctan(-RC\omega)$. Then, the placement of the capacitor and the resistor was swapped so that the circuit was a high-pass filter with the same cut-off frequency. The resulting Bode plots is shown in Figure 3.

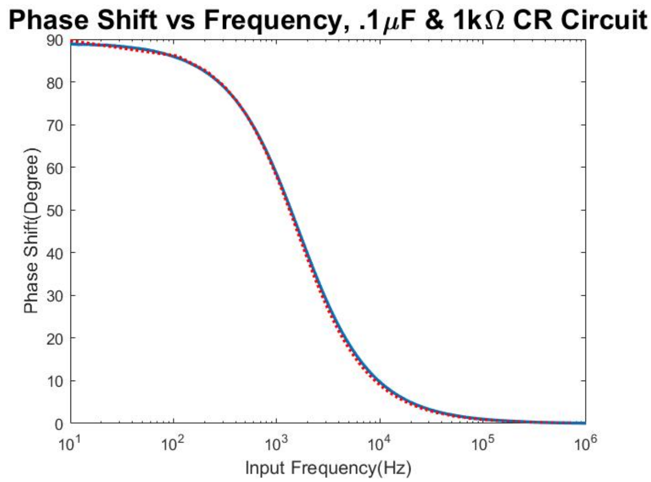
As in the case of Figure 3, as ω goes to infinity, the voltage output/input ratio A is modeled by $A = RC\omega$ while the phase shift ϕ is modeled by $\phi = arctan(\frac{1}{RC\omega})$. Subsequently, the Bode plots of two low-pass filters and one high-pass filter in series were also recorded as shown in Figure 4. The behavior of the high-pass filter, whose cut-off frequency is about 32Hz, is modeled by $A = 2\pi RC\omega$; that of the two low-pass filters in series is given by $A = \frac{1}{(2\pi RC\omega)^2}$.

Next, the circuits of simple high-pass and/or low-pass filters were replaced with the circuit that utilized both types of filters and amplifiers to filter out a person's pulse. Channel ± 1 and Channel ± 2 were plugged in as described in Description. The data of the channels weren't taken at the same time to the internal resistance of Analog Discovery which would otherwise mess measurements up. The Channel ± 1 Bode plot, lacking phase shift information, was provided in Figure 5, and the Channel ± 2 plots were given in Figure 6.

Finally, once the circuit is confirmed to be working, the author's wrists were hooked up to the circuit, and a electrocardiogram was obtained in the form of amplified and filtered voltage difference across the two wrists.

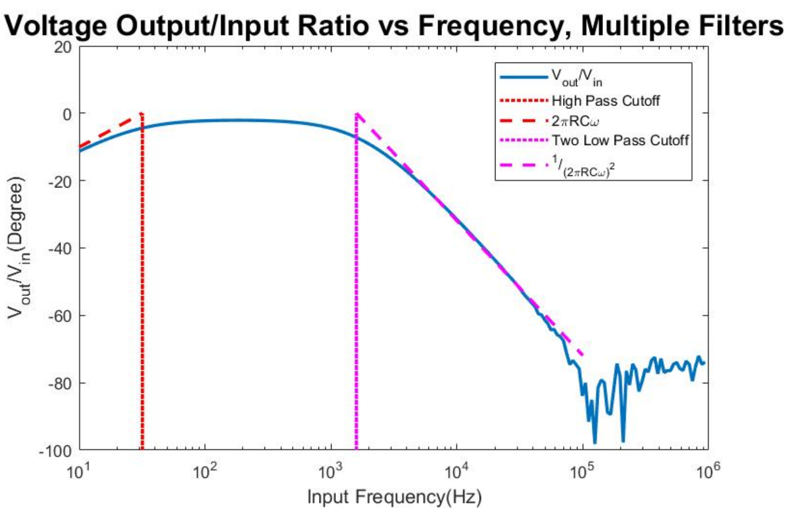


(a) The voltage output and input ratio of the high-pass filter over different frequencies. The cut-off frequency is given out in red.

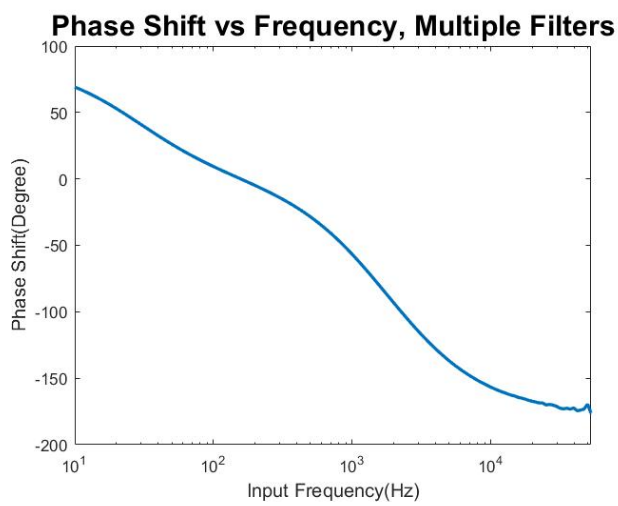


(b) The phase shift of the voltage output with respect to the input of the low-pass filter.The blue line is the actual data whereas the red line is a mathematical description.

Figure 3: The $.1\mu F$ and $1k\Omega$ high-pass filter Bode plots.



(a) The voltage output and input ratio of multiple filters over different frequencies. The two cut-off frequencies are given out in red and magenta.



(b) The phase shift of the voltage output. The blue line is the actual data whereas the red line is a mathematical description.

Figure 4: The multi-filter Bode plots.

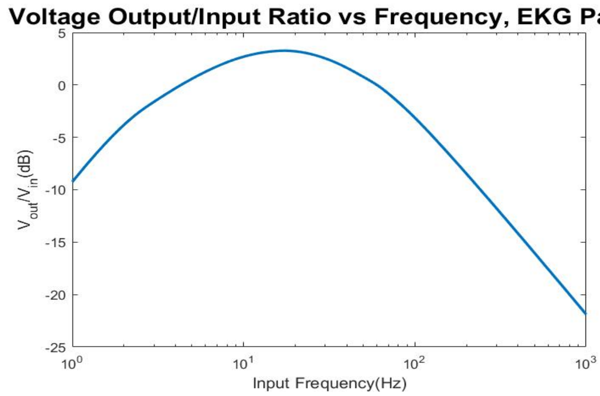
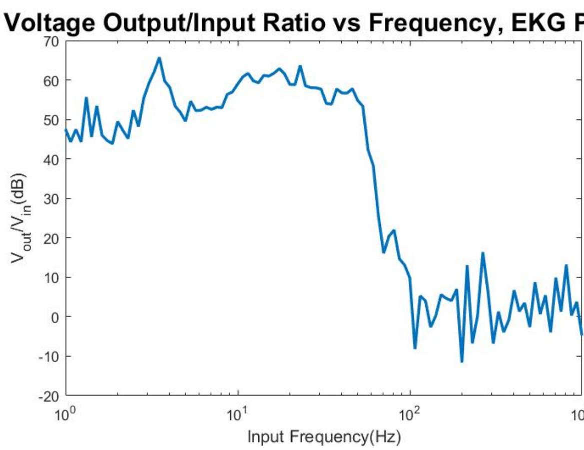
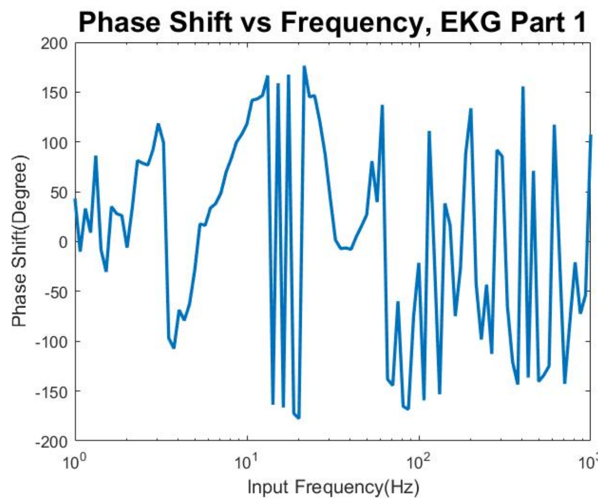


Figure 5: The voltage output and input ratio of the EKG circuit measured at Channel ±1.



(a) The voltage output and input ratio of the EKG circuit measured at Channel ±2.



(b) The phase shift of the voltage output of the EKG circuit measured at Channel ±2.

Figure 6: Bode Plots of the EKG circuit at Channel ±2

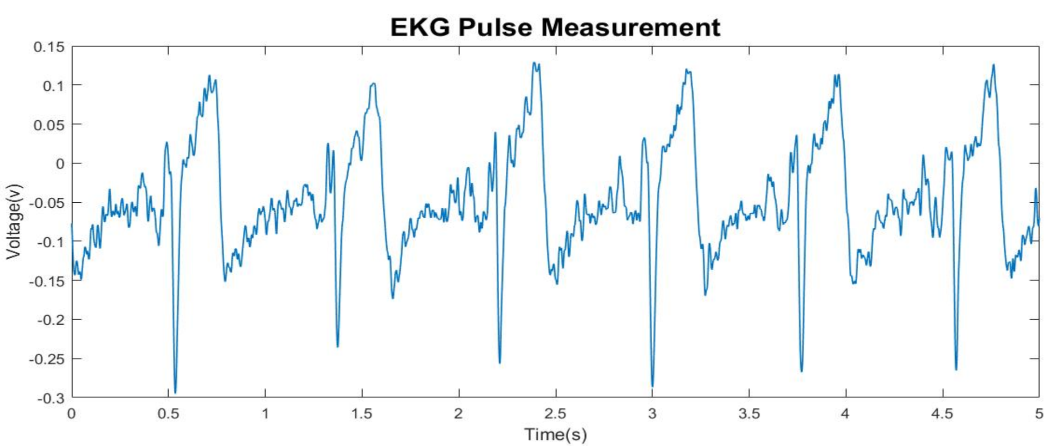


Figure 7: The voltage output and input ratio of the EKG circuit measured at Channel ±1.

3 Interpretation

3.1 Pre-lab Warmup

The Bode plots of the low- and high- pass filters conforms very closely to the behaviors we learned in the book and lecture. To further verify that statement, the following mathematical models are applied to the plots.

$$Low\ Pass\ Filter : A = \frac{1}{2\pi RC\omega} \tag{1}$$

$$\phi = arctan(-RC\omega) \tag{2}$$

$$High\ Pass\ Filter : A = 2\pi RC\omega \tag{3}$$

$$\phi = arctan(\frac{1}{RC\omega}) \tag{4}$$

As it can be seen from Figure 1 and 2, the actual output matches the result nearly perfectly. The weird looking vertical zigzagging towards the end of Figure 2(b) was due to the limit of Analog Discovery: the output voltage was so tiny that the device had a hard time pinpointing the actual characteristics of it. The same source of error can be observed in Figure 4(a) and Figure 6. The modeling holds true even when applied to low- and high-pass filters in series where the results are analyzed in one segment of a high-pass filter and the other of two low-pass filters. Even though some coupling did exist during the measurement, it was practically negligible since the resistor(s) down the chain were so much larger than the one(s) before them that so little current actually got diverted and it became acceptable to analyze the filters independently.

$$A_{high\ pass} = 2\pi RC\omega \tag{5}$$

$$A_{low\ pass} = \frac{1}{(2\pi RC\omega)^2} \tag{6}$$

The reason for a squared ratio for the low-pass part is that there were two low-pass filters in series, and the resulting ratio would just be the product of the ratio of the two individual low-pass filters. As in Figure 4, the modeling works quite well, and the zigzagging towards the end is again due to exceeding the capability of Analog Discovery.

3.2 Electrocardiogram

While the actual reading of the pulse looks to be decently clean and periodical, the Bode plots of Channel ± 2 don't appear as nice. The source(s) of the vertical zigzagging might include the number of data points taken and the ability of Analog Discovery to measure accurately(like the case in previous Bode plots). It could even be the nature of this circuit itself as the voltage input actually passed through two amplifiers, so slight variation in input could also result in unexpected output. However, this circuit was successful in filtering out a lot of noise in the environment, such as the 60Hz AC power supply, by applying three low-pass filters and one high-pass filters at different locations down the circuit. The goal of this lab was achieved.