# ISIM Lab 4: A Simple Electrocardiogram (ECG/EKG)*

Ari Porad

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**Abstract**

A double-amplifier circuit with aggressive noise filtering was used to conduct a 1-lead Electrocardiogram (ECG or EKG). Data was analyzed to produce an EKG plot and to determine that the subject's heart rate was approximately 71 beats per minute. A commercial, FDA-cleared 1-lead EKG was used as a point of comparison and found a heart rate of 73 bpm, suggesting the system was highly accurate. A Bode plot was also computed for the system, showing that it was effective at filtering out non-heart related noise.

## 1 Methodology

For this experiment, we conducted a 1-lead electrocardiogram (EKG or ECG) on a test subject. Wikipedia defines an electrocardiogram as:[1]

> [A] graph of voltage versus time of the electrical activity of the heart using electrodes placed on the skin. These electrodes detect the small electrical changes that are a consequence of cardiac muscle depolarization followed by repolarization during each cardiac cycle (heartbeat). Changes in the normal ECG pattern occur in numerous cardiac abnormalities...

We conducted our EKG by applying adhesive electrodes to our participant (see Figure 3). Leads from these electrodes were fed, in series, through two amplifiers. The left wrist was used as the voltage to be amplified, while the right wrist was used as the reference voltage. These amplifiers were used in order to drastically magnify the very very small changes in voltage measurable across human skin to a level measurable by our O-Scope. Together, they provided a total amplification of 1073 dB (as calculated via Equation 1). Between the two amplifiers were both a high-pass and low-pass filter (with characteristic frequencies of 1.59Hz and 32.48Hz, respectively, see Equation 2), and two more low-pass filters were placed after the final amplifier (both with characteristic frequencies of 32.48Hz, see Equation 2). These filters served to remove as much noise as possible from our data, given that the voltage across an entire human continually fluctuates rapidly. We connected the positive and negative leads of the O-Scope to the output of the final filter and +2.5V, respectively. See Figures 1 & 2.

*These statements have not been evaluated by the Food and Drug Administration. This product is not intended to diagnose, treat, cure, or prevent any disease.

[1] `https://en.wikipedia.org/w/index.php?title=Electrocardiography&oldid=1011218242`

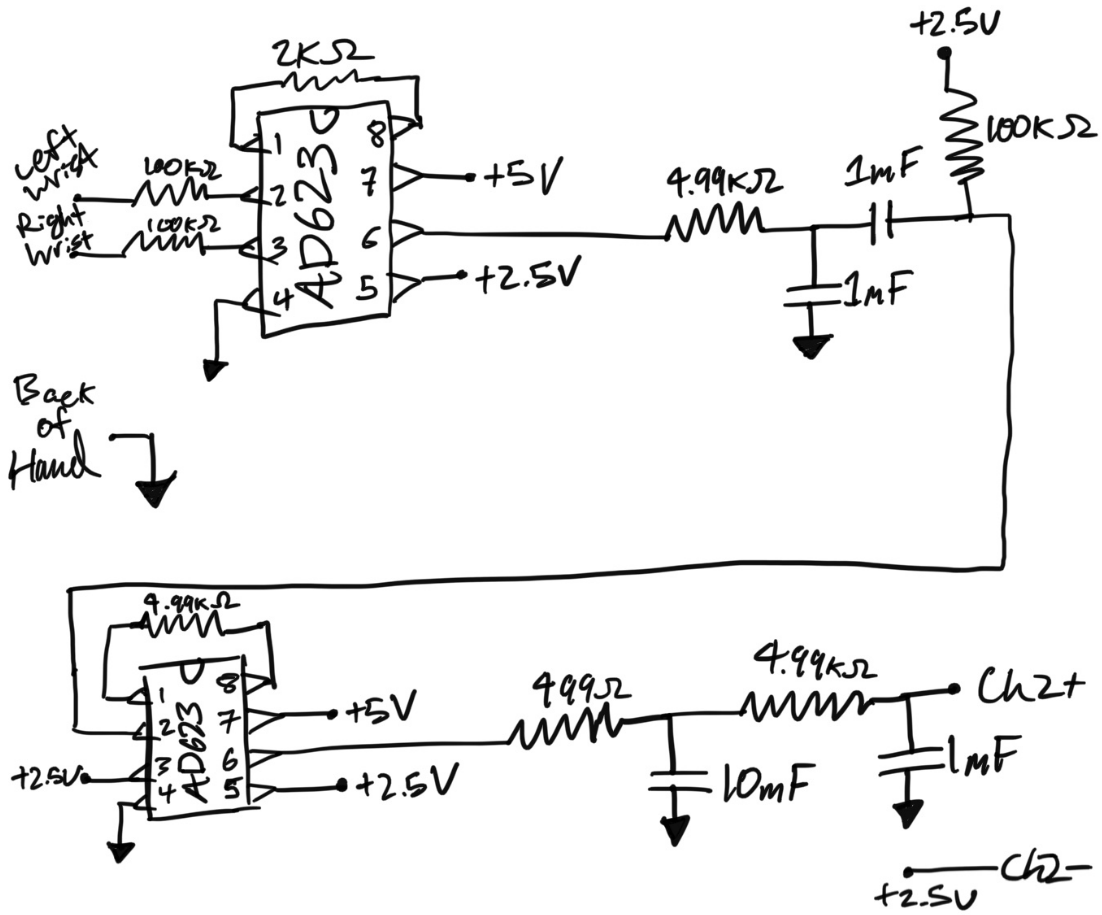


Figure 1: Our measurement circuit, which consists of a double amplifier, with a total of three low-pass filters and one high-pass filter.

$$
\begin{aligned}
G &= 1 + \frac{100k\Omega}{R_G} \\
G_1 &= 1 + \frac{100k\Omega}{2k\Omega} \\
G_2 &= 1 + \frac{100k\Omega}{4.99k\Omega} \\
G_{total} &= G_1 * G_2 = 1073 \text{ dB}
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
f &= \frac{1}{2\pi RC} \\
f_1 &= \frac{1}{2\pi(4990\Omega)(0.000001F)} \\
f_2 &= \frac{1}{2\pi(100000\Omega)(0.000001F)} \\
f_3 &= \frac{1}{2\pi(499\Omega)(0.00001F)} \\
f_4 &= \frac{1}{2\pi(4990\Omega)(0.000001F)}
\end{aligned}
\tag{2}
$$

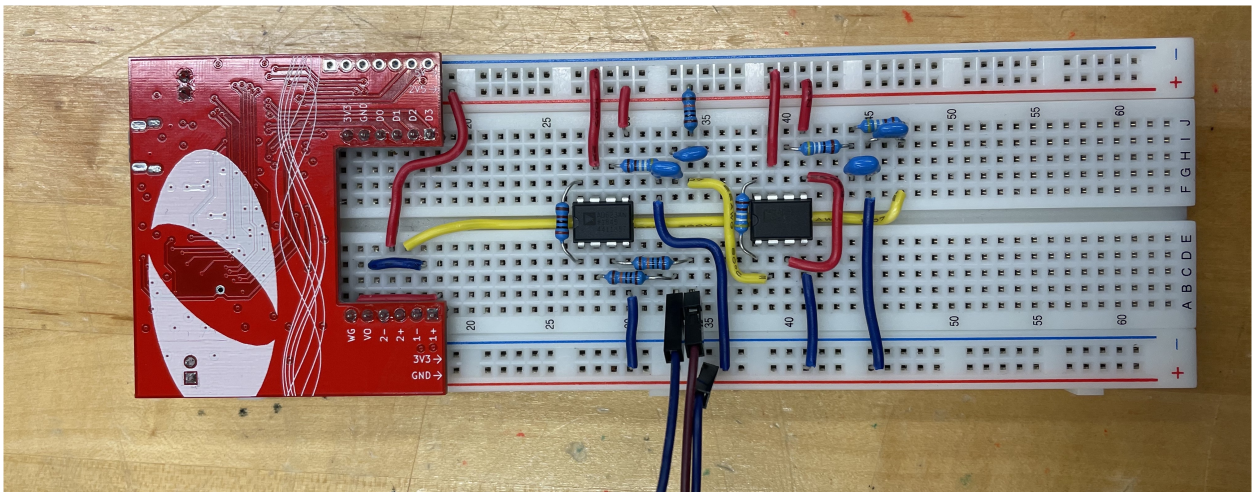

Figure 2: Our breadboard, as used to build our circuit and measure the voltage across our test subject's heart. Longer wires can be seen running to electrodes attached to the test subject.

# 2 Results

## 2.1 EKG Measurement

The EKG we collected from our test subject, shown below in Figure 4, displays eight complete heart beats. By dividing the number of cycles in the frame by the duration of the frame, we were able to calculate that our test subject had a heart rate of 71 beats per minute.

### 2.1.1 Comparison with Commercial EKG Device

For comparison purposes, we also used a commercial, FDA-cleared 1-lead EKG device[2] to measure our subject's heart. It was not possible to conduct both measurements simultaneously because they interfered with each other, so the commercial EKG was run immediately after the conclusion

[2]Specifically, an Apple Watch Series 4's built-in EKG sensor was used: `https://www.theverge.com/2018/9/13/17855006/apple-watch-series-4-ekg-fda-approved-vs-cleared-meaning-safe`

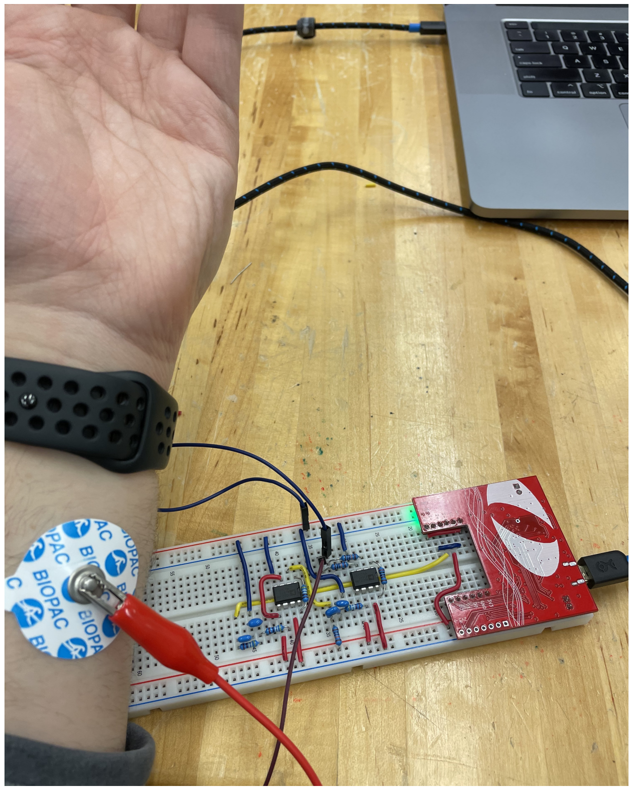

Figure 3: An adhesive electrode applied to our test participant's arm and connected to our measurement system.

of our EKG. The commercial EKG found a heart rate of 73 beats per minute, giving our system an accuracy of approximately 97%. This high degree of accuracy gives us confidence in our approach and our system.

### 2.2 Bode Plot

From this plot, we can observe that our system has a very high gain in the 1-10 Hz range, compared to a very low gain outside that range. Given that most heart rates will fall in that 1-10Hz range, this means that the EKG signal itself will easily pass through our system while other noise will be filtered out, thereby increasing the accuracy of our measurement.

## 3 Finishing Remarks

This experiment demonstrated the ease and effectiveness of measuring an electrocardiogram with a double-amplifier circuit. Further testing is needed across a wide range of subjects to determine overall accuracy.

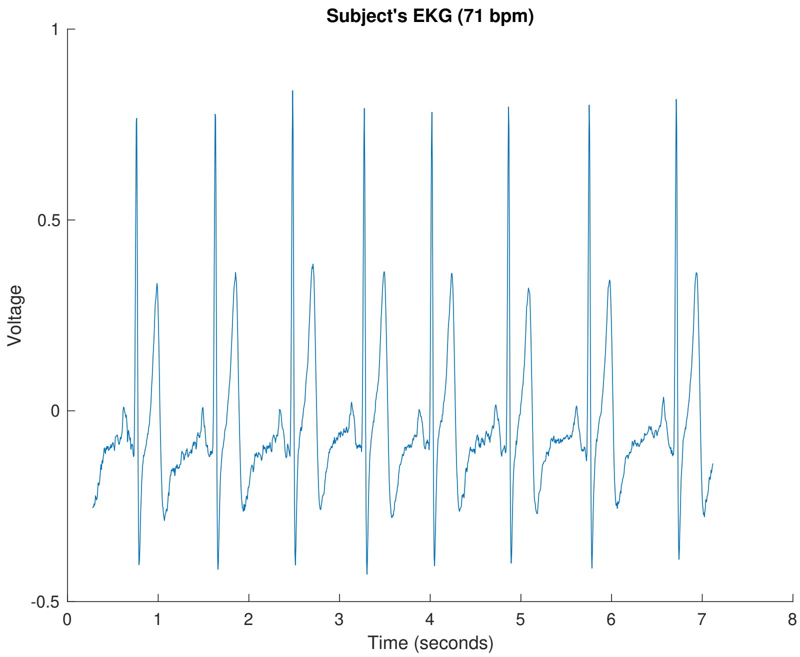


Figure 4: Subject's measured electrocardiogram, showing eight complete heart beats. The subject's computed heart rate was 71 beats per minute.

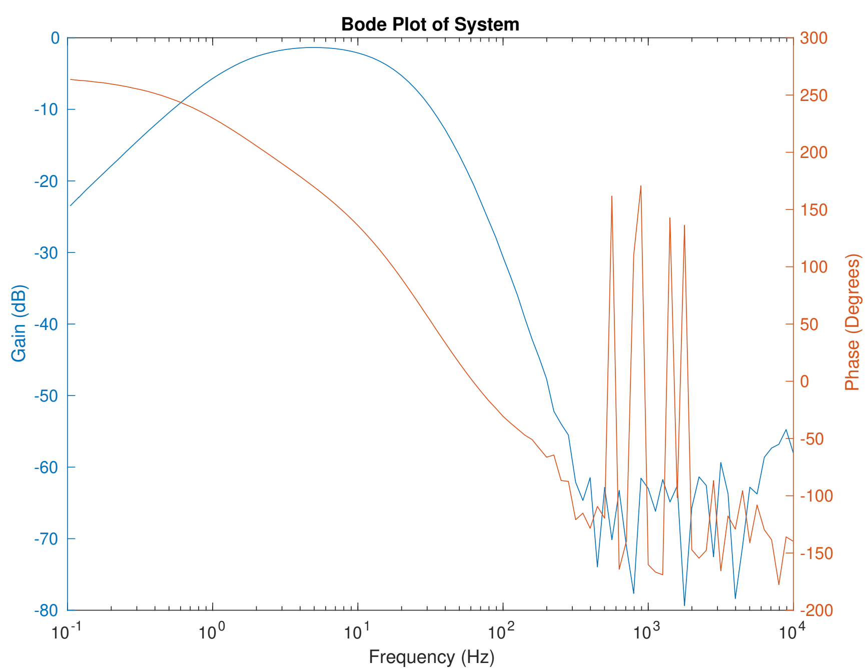


Figure 5: Bode Plot of our system, showing gain and phase shift of our system across a range of frequencies.