EK307 Lab: Acoustic Heart Monitor

- **Laboratory Goal**: Build a device capable of detecting a human heartbeat.
- **Learning Objectives**: Signal conditioning, operational amplifiers, speakers and microphones, sound amplification, event detection.
- **Suggested Tools**: Breadboard, loudspeaker, coaxial cables, op-amps, power supply, oscilloscope, logic gates, comparator, one-shot

**Prelab design question: Please have your answer at the beginning of class**

Your classmate is working on a startup called tachycardiabook.com, also known as TB. TB is disrupting the current social media industry by adding physiological sensing to users’ social media experience. TB’s core technology is correlating changes in users’ heart rate and intensity to the content on the screen of their app.

For 10% of the founder’s shares of TB you are being asked to make a sensor package that can monitor users’ heart rate and intensity. You found a reasonably priced sensor that can detect heart beats by measuring pressure changes on the surface of the skin on the wrist that are caused by small changes in artery dimensions during each beat. The sensor open circuit output is a voltage that ranges between +-0.05 and +-1 millivolt depending on how interesting the content is on the TB app. The Thevenin resistance of the sensor is 1000 Ω.

Design a circuit that will amplify the sensor signal so the maximum output voltage is approximately +-2 Volts. Because of OP AMP limitations you can only get a maximum usable gain of 25 out of each stage. Use any commercially available resistor values between 1kΩ and 330kΩ. Draw the schematic of your amplifier design in your notebook. Be sure to label the resistor values.

**Hints**: The first stage amplifier should have a high input resistance to prevent loading of the sensor. By high, think at least greater than ten times the Thevenin resistance of the sensor. For a brief but good explanation of commercially available resistor values go to: [http://en.wikipedia.org/wiki/Preferred_number](http://en.wikipedia.org/wiki/Preferred_number) Read the section on E Series. Take notice that the E series prescribes the significant digits but you can multiply or divide the values by decades (tens) to get higher and lower values. For example 22 is part of the E12 set. Resistor values typically range from .01 Ohm to 1giga Ohm. Therefore you would expect to see available values of: .022Ω, .22Ω, 2.2Ω, 22Ω, 220Ω, 2.2kΩ, 22kΩ, 220kΩ, 2.2MΩ, 22MΩ, 220MΩ.

**LEVEL 1:**

a) Using the loudspeaker from your parts kit as a microphone, design and construct an amplifier that will allow you to display the acoustic signal produced by your heartbeat. Try placing the microphone on your chest over your heart, in the crook of your neck near the carotid artery, or on your wrist. Find the place where you get the strongest acoustic signal. You should be able to see the heartbeat waveform (Figure 1) on the oscilloscope. Your amplifier must produce a heartbeat waveform on the oscilloscope that is greater than 0.5 V in peak magnitude.
Note: You will need to remain quite still because the microphone will be sensitive to your

![Wiggers Diagram](https://upload.wikimedia.org/wikipedia/commons/thumb/6/61/Wiggers_Diagram.png/1280px-Wiggers_Diagram.png)

Figure 1: A Wiggers diagram displaying cardiac function. Depending where on the body you place your transducer you will measure different signals. If you place the transducer on at an artery such as the carotid you will be measuring the arterial change in dimension as the blood pressure pulse resulting from contraction of the heart causes it to expand (aortic pressure). If you measure on the chest near the heart most of the signal will be from the change in physical dimension of the heart as it beats (phonocardiogram). To measure the electrocardiogram you would use skin electrodes instead of a speaker. (Daniel Chang MD revised original work of DestinyQx; Redrawn as SVG by xavax - Wikimedia Commons, File:Wiggers Diagram.png)

movement. Also, it may help to exercise (i.e. jumping jacks, doing push-ups, or running up and down the atrium stairs) in order to increase the strength of your heart’s acoustic signature. It can be tricky to find the right spot, so some persistence may be necessary.

(It is not acceptable to simulate a heartbeat using the cardiac waveform produced by the function generator.)

b) Measure your heart rate using the oscilloscope. (Suggestion: Set the time scale so that you can see more than one beat of your heart on the screen. You will see lots of electrical noise produced by the amplifier superimposed on the heartbeat signal, but the latter should be observable as a regular pulse amid the noise.) Compare this heart rate measurement to one obtained in the usual way, i.e. putting fingertips on your wrist or neck.
**LEVEL 2:**

c) Complete Level 1, then design and build a circuit that converts the signal produced by your acoustic heart monitor into a digital logic pulse that lights an LED whenever your heart beats. (There are many ways to accomplish this task).

**Background**

**The Loudspeaker**

A loudspeaker is an electro-mechanical transducer that converts electrical energy into acoustic energy. The most common type of loudspeaker is the moving coil type, wherein a coil of wire is suspended in the magnetic field of a circular magnet, as shown in Figure 1.

![Diagram of a loudspeaker/microphone](image)

Figure 1: The anatomy of a loudspeaker / microphone.

When the time-varying current associated with an audio signal flows through the coil, the current produces a Lorentz force \((qv \times B)\) that causes the coil to move back and forth, in concert with the electrical signal. The movement of the coil also causes the diaphragm cone to move back and forth, in turn compressing and decompressing the air and generating sound waves.

Stated another way, the loudspeaker works because the coil is free to move inside the circular magnet. As the current in the coil changes direction, the coil moves backwards and forwards. The coil is attached to the speaker cone, so that as the coil moves backwards and forwards, so does the cone. The vibrating cone makes the sound.

This electromechanical transduction of sound can also work in reverse. Sound waves that cause the cone to vibrate will move the coil through the permanent magnetic field and induce a current. A current induced in this way will contain information about the incident sound waves, and, in this way, the speaker can also be used as a microphone.

The current produced by the speaker/microphone will be very small in amplitude. In order make use of this signal, it will need to first be conditioned so that the laboratory instruments can measure it.
Coaxial Cables

Some common sources of noise include the 60 Hz of the lights and power to the electrical outlets, radio transmitters from local radio stations like WBUR and WTBU, the radio emissions of cell phones when they communicate with cell phone towers, and 802.11 wireless networks.

**Question:** If coaxial cables offer superior noise performance, why aren’t they used for everything?

**Answer:** There are a variety of reasons. If a signal has already been amplified, or the length of cable is short enough, the noise induced in an unshielded cable may be inconsequential. Because of their construction, coaxial cables are larger than single conductor cables and are not as easily bent or routed. Coaxial cables are also typically more expensive than single conductors.

![Coaxial cable diagram](image)

**Figure 2:** The anatomy of a coaxial cable. The outer conductor is used as ground and is connected to the black clip or the outer housing of the BNC connector. The inner conductor carries the signal and is connected to the red clip or center of the BNC connector.