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6.101: Project Proposal
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Simple Heartbeat Monitor for Analog Enthusiasts

Introduction

An electrocardiogram (ECG or EKG) is a simple, non-invasive way of measuring the heart's electrical conduction system by picking up electrical pulses generated by the polarization and depolarization of cardiac tissue and translating it into a waveform. An ECG shows:

- How fast a heart is beating
- Whether a heartbeat is steady or irregular
- The strength and timing of electrical signals as they pass through each part of a heart

ECGs are typically performed for diagnostic and research purposes such as detecting and studying heart problems, and investigating other disorders that can affect heart function.

Although the field of electrocardiography is already well established, we propose a simple and cheap method of visually and audibly displaying the frequency of a heartbeat, which can be used as a learning tool in biomedical courses. In order to do so, we intend to use a circuit design developed earlier on in the 6.101 course to translate a heartbeat into an optical signal, transmit the heart beat along an optical fiber cable, detect and convert the heartbeat into an electrical signal, amplify the heartbeat signal, measure the pulse rate, and display the pulse rate using an analog meter and a speaker. The analog meter will visually indicate the pulse rate on a graded scale, while the speaker will audibly indicate pulse rate by producing a tone whose frequency is proportional to the frequency of the heartbeat.

Materials

The materials listed below will be used to construct the heartbeat monitor. While most items are already available in the MIT EECS Instructional Laboratories' stockroom, the fiber optic detector and receiver, and the voltage controlled oscillator will be ordered from Digi-Key, an electronic components distributor.

- ECG Printed Circuit Board (PCB) designed and built in an earlier 6.101 experiment which dealt with ECG signal measurement
- Avago Technologies Discrete Fiber Optic Laser Diode Transmitter
- Avago Technologies Discrete Fiber Optic Photodiode Receiver
- Optical fiber
- Three LF356 Operational Amplifiers
- Several 1% and 5% resistors

- Voltage Controlled Oscillator (VCO)
- Several capacitors
- Copper wire
- Analog meter
- Speaker

Implementation

The system is broken down into six modules as illustrated in figure 1: Obtaining the ECG signal, transmitting the signal along an optical fiber, detecting the ECG signal, conditioning and amplifying the signal, pulse rate measurement, and visual and audible display of the ECG signal.

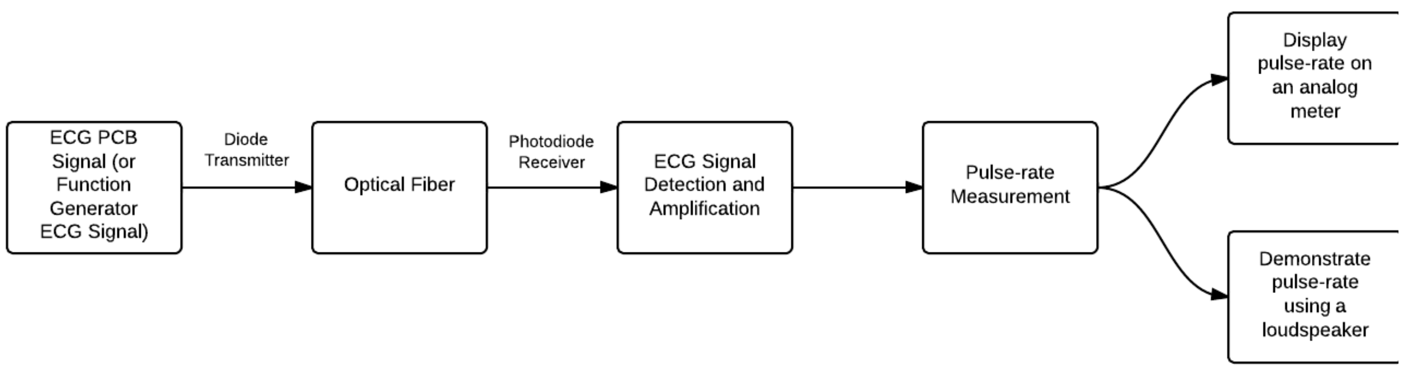

Figure 1: Block diagram of the circuit implementation of a heartbeat monitor

i) Obtaining and Transmitting the ECG signal

First, we take an ECG signal from either a function generator or our ECG board from an earlier 6.101 experiment, and use it to modulate the laser diode transmitter with light at 650 nm. A fiber optic cable then transmits the signal to the main PCB board (to be designed after circuit implementation on a breadboard) where the matching optical receiver detects the signal. Then we demodulate the signal to recover the original ECG signal.

ii) ECG Signal Conditioning and Amplification

Thereafter, the signal is processed, adjusted for the DC offset, amplified, and the noise is filtered out.

iii) Pulse Rate Measurement

The conditioned signal is fed to a pulse rate detection system. This is essentially just a capacitor placed across the signal output such that each pulse charges the capacitor, similar to power supply filters that we built in an earlier 6.101 experiment that dealt with AC to DC voltage conversion. The voltage across the capacitor depends on the frequency of the original signal. If the pulses occur with high frequency (fast heartbeat), the capacitor will not have time to discharge much between pulses and will thus have a high voltage across it, whereas with a low pulse rate the capacitor will discharge so it will have a low voltage across it. In this way, we will convert the ECG signal into a voltage level that indicates the pulse rate.

iv) Visual and Audible Display of the ECG Signal

The pulse rate is then fed to two display systems, the visual meter and the audio speaker. The visual meter is a simple analog meter such as those used in multimeters that will show the pulse rate on its dial. We will calibrate and adjust the range such that 0 corresponds to a low heart rate (~30 beats per minute) and the maximum (~10V) to a high rate (100 beats per minute). We can also easily implement an alarm and flashing LED for heart rates that are too low or too high.

The audible display will have a threshold detection circuit that will beep when the voltage is around the peak and be silent otherwise. The signal will have to be carried on a much higher frequency so that it is audible, and the exact frequency will be dependent on the pulse rate. High pulse rates will be played with a high frequency pitch and low rates with a low pitch. This is accomplished with a Voltage Controlled Oscillator (VCO) circuit controlled by the voltage level across the capacitor that corresponds to the pulse rate. The VCO's output signal will then be fed to a speaker that will produce a tone corresponding with the pulse rate, and that will beep if the frequency is above or below a certain threshold i.e. the heart rate is too high or too low.

Testing

i) ECG Signal Transmission and Amplification

Since each of modules is independent, it will be easy to test each step using the signal from a function generator. The function generator can be programmed to simulate an ECG signal so that it is easy to change the pulse rate. The optical fiber can be tested with any random light source and an oscilloscope. The amplification stage should not prove difficult to build and test since we have implemented other amplifiers in previous 6.101 experiments that dealt with studying operational amplifiers (op-amps).

ii) Pulse Rate Measurement

The pulse rate measurement block can be tested by hooking it up directly to a function generator and calibrated by measuring the output voltage range, and we can easily adjust the range with by changing the gain of the amplifier. The audio block will be tested with a sine wave from a function generator and the threshold can be determined from the voltage level across a capacitor charged and discharged with an ECG signal from a function generator.

iii) Integration of Separate Modules

Integrating the different modules of the system should be straightforward provided that each module works on its own. The completed system can then be tested with either an ECG signal from a function generator or an ECG signal generated from the PCB boards we built in an experiment earlier on in the course.

Project Timeline

Tasks	**Week 1 (4/6 – 4/12)**	**Week 2 (4/13 – 4/19)**	**Week 3 (4/20 – 4/26)**	**Week 4 (4/27 – 5/3)**	**Week 5 (5/4 – 5/10)**
Project Abstract and Draft Proposal					
Circuit Schematic Design					
Parts Ordering and Delivery					
Project Design Presentation					
Implementation of Separate Modules on a Breadboard					
Integration of Modules and Testing					
PCB Schematic Design and Ordering					
Further Testing of Breadboard Circuit Layout					
PCB Soldering of Discrete Components					
PCB Testing					
Project Presentation and Check off					

Project Demonstration and Videotaping					
Project Report					

Labor Distribution

Although we consider the project a team effort, we have divided the work so as to streamline and accelerate the design and implementation of our circuit. Since we already have an ECG PCB from a laboratory experiment earlier on in the semester, our work will primarily deal with the signal transmission, detection, amplification, measurement and display. It is likely that once we have integrated the other modules, we might have to tweak the ECG PCB slightly so that the signal is compatible with the rest of our circuit, but that should not be much of a challenge. While Abby will focus on the ECG signal transmission along the optical fiber, and signal measurement and conversion to display it on an analog meter, Jelimo will focus on signal detection and amplification, and signal demonstration using a loudspeaker.

We will both contribute to the integration of the separate modules and jointly conduct testing of the complete system. Abby will implement the circuit design in Eagle (PCB Schematic Design Software) and Jelimo will verify her design to ensure no mistakes before ordering the PCB. We will both take part in the soldering of the PCB components and jointly conduct testing of the PCB. Both Abby and Jelimo will do the project presentation and demonstration, as well as participate in writing the final project report.

Conclusion

While our system is not likely to ever be realized in practical medical applications because of the trend towards wireless transmission to avoid unnecessary cable connections to electronic medical devices, it is an excellent way to gain insight into the essentials of the design of biomedical instruments. Additionally, several of the concepts learned in 6.101 thus far are used, enhancing our confidence in designing analog systems. Assuming realization of our project well before the deadline, we plan to also transmit music along the same optical fiber at a different wavelength to demonstrate the capability of fiber optics to transmit information using channels at different wavelengths. In any case, we should be able to visually and audibly display the change in pulse rate of an individual doing a variety of physical activities.