

6.101 Introductory Analog Electronics Laboratory

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Project Proposal

Transmitting, Receiving, and Interpreting ECG Waveforms

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I. Overview

An Electrocardiogram (ECG) is a device that records the electrical activity of a patient's heart with the use of electrodes and the device that filters and amplifies the heart rate signal. Typically, these ECG machines are connected to patients on stationary beds. The signal is transmitted via wires to a display alongside the patient where a doctor can administer a diagnosis. Using radio frequency and amplitude modulation, a patient can transmit their heart rate at any time, rather than being immobile. Therefore, our project is to get rid of this form of wired, fixed configuration of the electrocardiogram, and present a potentially more mobile and wireless solution where electrocardiography can occur within a distance of a wireless receiver.

To build our ECG system, we will use an ECG to capture filter and amplify the heartbeat of a user. A transmitting circuit will modulate the signal into the range of the FM broadcast band, whose frequency band ranges from 80-100 MHz. The receiving module of our final project will demodulate the signal and additionally filter out noise from the modulation stage. The output of our receiving module goes into the sensor circuit that detects the ECG waveform and correctly displays the heart rate. We may display the final output waveform using either an oscilloscope or a computer.

For our minimal design, we will start by transmitting and receiving sample waveforms provided by our function generator. Once we have implemented this task, we would like to individually test the sensor circuit module. Our sensor circuit module will consist of a peak-finding circuit that detects peaks from a person's heart rate (the R wave) and also accounts for changes in signal amplitude as the ECG travels around the receiver. Finally we plan on testing the entire project holistically with sample waveforms yet again with the function generator and then finally applying the ECG waveform.

High Level Block Diagram

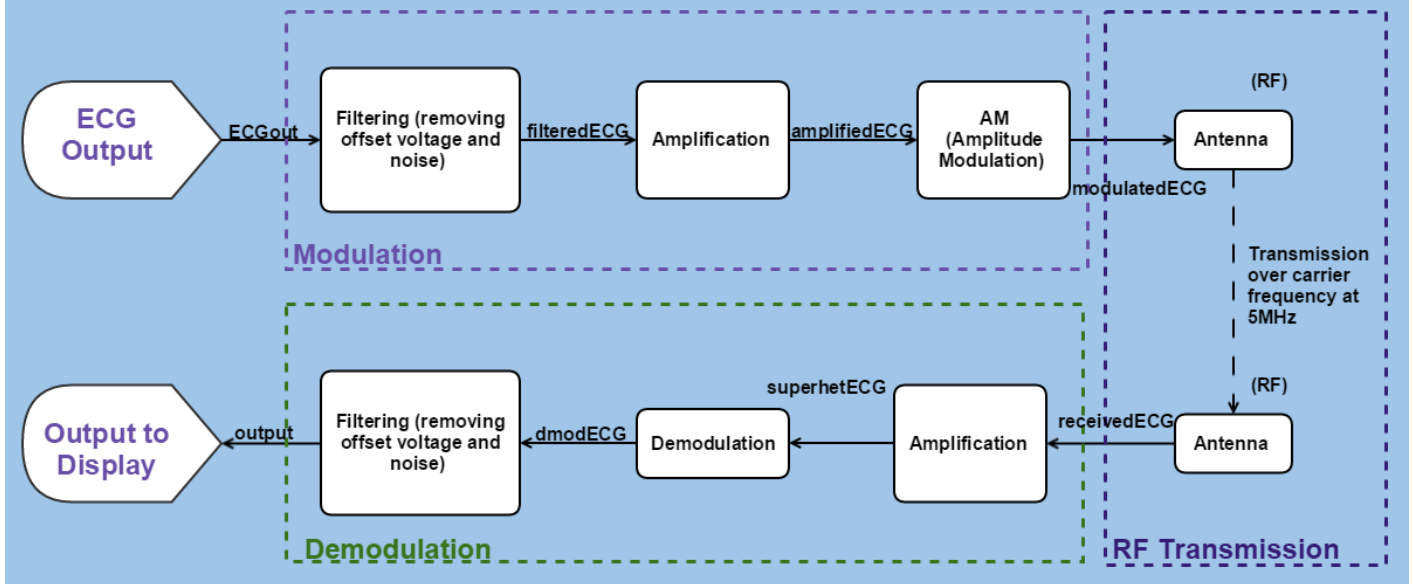


Figure 1: High-level block diagram of the project

II. Modules

1. Pre-transmission processing (Thipok)

Taking the original signal from the ECG as input, the pre-transmission processing module removes any DC voltage offset and removes any noise in the input signal. 6.101 lectures have extensively covered different kinds of filter necessary for this purpose. We will base our design on the ECG signal processing described in Lecture 9, which demonstrates a possible design of ECG processing circuit using instrumentation amplifier, adder circuits, and Sallen-Key low-pass filter. The instrumentation amplifier eliminates error from source impedance, therefore makes the resulting signal suitable for precise measurements. Afterward, we remove common-mode noise using a difference amplifier. A low-pass filter removes high-frequency noise, and an integrator-adder combination removes the DC voltage offset.

Because this module will be implemented on the portable part of the system, it must be power by battery. We plan to use a 9V battery, with a virtual ground at the halfway point between the voltages of the battery's two electrodes. We will first test this module on a breadboard, then implement the circuit on a PCB. Note that the pre-transmission processing module does not involve any high frequency signal. We do not need a special copper-clad breadboard for the prototype.

2. AM: Amplitude Modulation (Thipok)

Amplitude modulation (FM) is one of the main challenges of the project. We modulate the amplitude of our carrier signal with the amplitude of ECG signal. A wide selection of amplitude-modulating integrated circuits is available in the market. However, we will implement our AM circuit with basic components, FETs, BJTs, and op-amps. Similar to the pre-transmission processing, the AM module must be powered solely by a battery.

We decided to use a Wien Oscillator. It is a minimal design that creates sinusoids at the frequencies selected by the resistor and capacitor time constant. Sinusoids were then passed through a Sallen-Key filter. The second-order filter was chosen because of the apparent resultant waveform from the Wien Oscillator was stepwise rather than sinusoidal. Figure 2 shows the circuit diagram of the carrier wave generator. After this filtering stage, the carrier frequency is correctly generated which allows for it to be multiplied by the modulator.

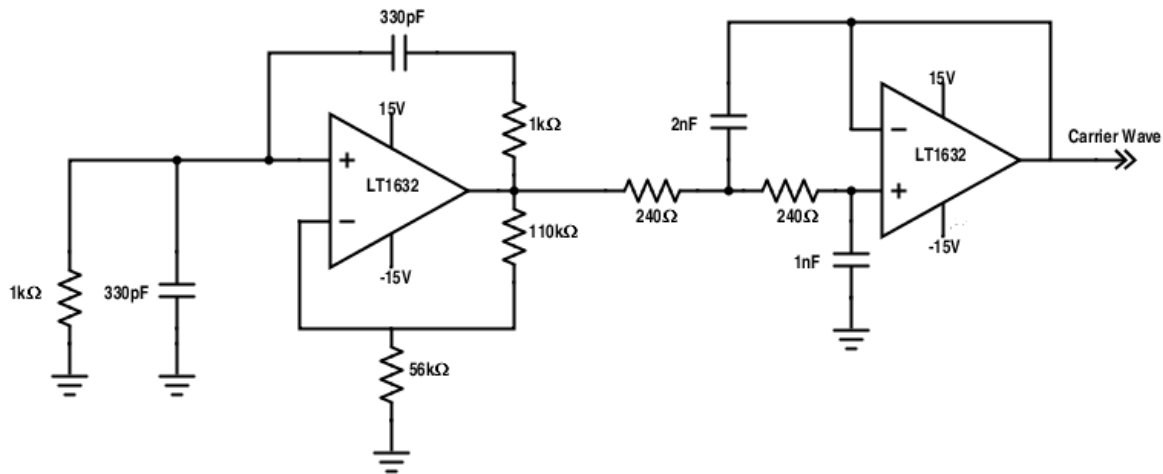


Figure 2: Wien oscillator with Sallen-Key filter, generating a test carrier signal with frequency 455kHz.

A possible option for simple AM modulation circuit is based on a Junction-gate Field-Effect Transistor (JFET). When it is biased in the saturation regime, the current through the drain depends on the gate-source voltage. We can view the JFET as a variable resistor whose value is controlled by the gate-source voltage. Therefore, we input the ECG signal to the gate and the high-frequency carrier signal to the drain. The resulting signal will inherit the carrier's high frequency, but its amplitude will be modulated by the ECG signal.

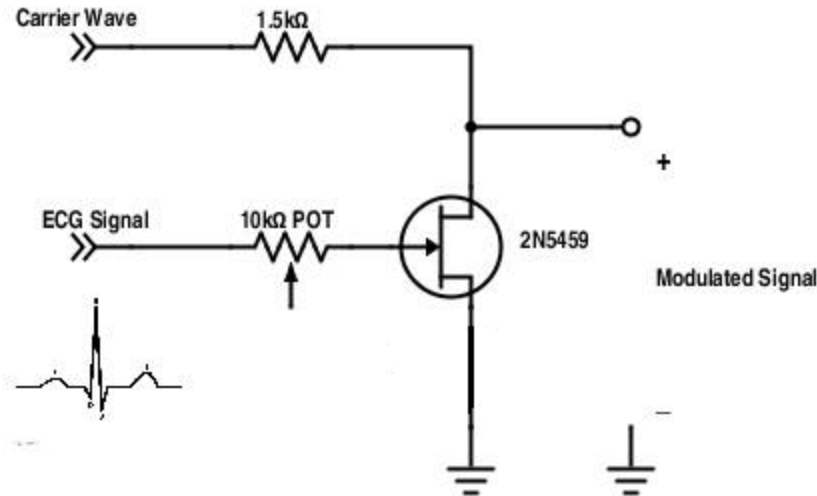


Figure 3: Amplitude Modulations using a JFET

Another important aspect of this module is selecting the right carrier frequency. A broad range of electromagnetic wave's frequency are reserved for broadcasting purposes. For example, the AM radio ranges from 535kHz to 1,705kHz and the FM radio ranges from 88MHz to 108MHz. A carrier frequency in either range may experience background noise from broadcasting stations in the area, and probably turns our receiver into a radio instead. Luckily, the lab building has proper shielding for signals in the radio frequency range. Moreover, audio signals from broadcasting stations and our ECG signals are at different frequency, so basic filtering can easily remove the audio noise. We select a preliminary value for our carrier frequency at 700kHz, which corresponds to the AM radio band. This AM radio frequency allows us to use reliable superheterodyne circuits from commercial radios as reference to demodulate our signal on the receiving end.

We can test the output signal of the AM module by displaying it on an oscilloscope. If we input a single-frequency signal into the AM module, the resulting modulated signal must contain only one frequency, but with an envelope of a lower frequency encompassing it. Figure 4 shows an example of amplitude-modulated waves.

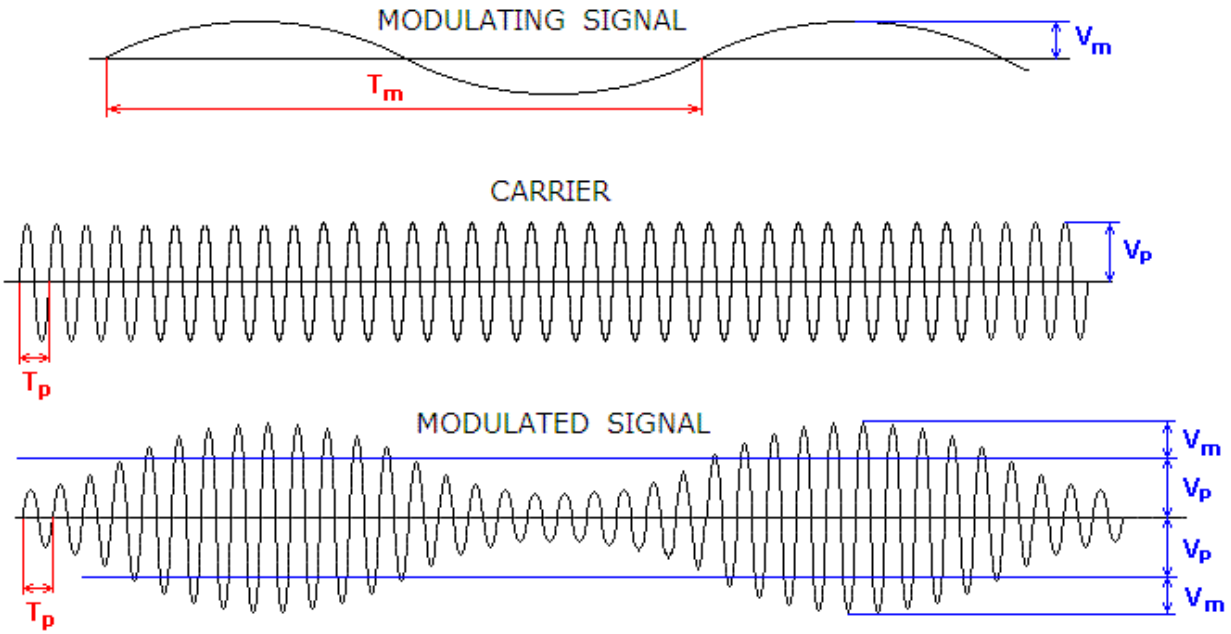


Figure 4: Diagram of Amplitude Modulation

2. RF Transmission (Daniel and Thipok)

The RF Transmission module focuses on the design of antenna pairs to achieve desirable frequency and power. Although our ultimate goal is to build our own antenna pairs, we might begin with commercial antenna, which will allow us to test the frequency modulation and demodulation modules without any transmission error. This pre-made antenna can be either an IC chip or a real wire antenna.

The length and orientation of the antenna is dependent on the carrier frequency. Because we will not know which carrier frequency would experience the least noise, we will have to test a few sets of antenna that span our target carrier-frequency range. To test the transmission power, we will measure and plot the signal fall-out rate for each set of antenna. The experiment is conducted simply by measure the received signal at different distances between the transmitter and the receiver. We select the range of operation to be 10 feet, but might adjust the number after the experiments. Within a small frequency range, we may assume that the signal fall-out rate is independent of the frequency and is only affected by the antenna orientation. With data for both transmitting frequency and power, we will choose the best length-orientation combination for our final design.

It is worth noting that an efficient and effective receiver, such as a superheterodyne receiver, allows more flexibility in the transmitter's design. We may use a smaller and weaker transmitter if the receiver can provide a sufficiently large amplification gain to the received signal. That is, an optimal receiver allows the system to

function well even with an un-optimized transmitter. This approach for antenna design is preferable because the receiving antenna and post-transmission processing circuit do not have to be portable. Therefore we have no size concern for their optimization.

3. Demodulation (Daniel)

Amplitude demodulation is another challenge of our project. Properly demodulation and added filtering allows us to see the original ECG waveform with little added noise or obstructions from external sources. We use a superheterodyne receiver to do this. A superheterodyne receiver is a receiver which mixes the receive signal, allowing us to operate at a lower frequency (455kHz) where it can be more easily amplified and processed to produce the original signal. We decide to approach this issue with a similar model presented in the “Graymark 536” AM radio kit. We decide to amplify the signal in the beginning after mixing the signal at a lower frequency to detect for low amplitude ranges due to the falloff from the distance of the receiver. We then demodulate the lower processing frequency that holds our ECG signal, and send it to the post transmission filtering stage for further amplification and filtering. When tuned to the frequency of interest, this superheterodyne receiver can obtain signals from large distances which allows us to transmit with a small mobile voltage source. After this signal is received we can have it pass through a lowpass filter with a cutoff of 10Hz to get the meaningful ECG signal isolated from the noise.

This is our initial assumption on how to demodulate in analog. We can test this demodulator by applying a function generator with a sinusoid multiplied by a lower frequency sinusoid and view from scope if the signal has been accurately demodulated. Power and voltage requirements are not a concern for the stationary circuit. This module can be implemented on breadboard and doesn’t need to be build on a PCB since our frequencies dealt with after demodulation are low enough where breadboard parasitic capacitance is no longer an issue.



Figure 5: A Graymark 536 commercial AM radio

III. System Integration and Testing (Daniel and Thipok)

The complete system will contain two separate parts, connected by RF transmission. The portable part consists of ECG electrodes, pre-transmission processing circuitry, frequency modulation circuitry, and the transmitting antenna. Every module of this part will be contained on a PCB board and powered by a 9V battery, functioning as a wearable sensor attached to a patient's body. The stationary part consists of the receiver antenna, demodulation circuitry, post-transmission circuitry, and the display system. This part will locate on a tabletop and powered by power supply. Because the output from each module is simply fed as an input to the next module, we do not expect a major issue or complication from system integration.

The challenge lies in system testing. Once we have confirmed that each separate module is functional. We will proceed to testing each pairs of neighboring modules. Afterward, we will test the portable and the stationary parts for correct transmission and receiving, respectively. When the signal is transmitted and received correctly, we eventually connect the entire system together to confirm that the input from ECG electrodes is processed, transmitted, received, and displayed accurately. In final testing step will involve human subjects, most likely Daniel and Thipok. The subject will walk around while wearing portable part of the system. As the displacement from the stationary part varies, the signal must be received and displayed correctly.

IV. Special Components

Components that we need to consider purchasing are copper-clad boards for PCBs, which have low source impedance and would not affect the high frequencies we are operating at. We will also consider buying copper wire for an antenna for testing our modulating and demodulating segments of our project if we are unable to build our own antennas. Also, our receiver will be based on the tunable transformer and materials present in the Graymark radio kit.

V. Conclusion

Our final project offers a wireless solution for physicians to diagnose and monitor patient's ECG waveform without the need for any stationary apparatus or the patient in the general vicinity. We expect to have a mobile ECG that transmits an amplitude-modulated ECG signal at 700kHz, demodulate the signal from a distance of at least 3 meters (10 feet) away by a receiver, and display the clean ECG waveform. Our two main challenges are designing a good receiver with a wide pickup range and building a mobile ECG transmitter. A good receiver should provide sufficient from signal transmitted from long distances. The mobile ECG will allow constant monitoring of a patient's heart throughout a day. Possible sources of complication include the carrier, parasitic

capacitance, and accuracy of the heterodyne receiver. We will document the challenges and their solutions in the project's final report.