ECG circuit to Wifi and Analyzed with App

Savannah Van De Water, Shanessa Siddique, Kelly Yeung, Megan Soto, Paya Vatanshenas

Bioengineering 186B, University of California San Diego
9500 Gilman Dr. San Diego, CA United States

svandewa@ucsd.edu
ssiddiqu@ucsd.edu
kyeung@ucsd.edu
mesoto@ucsd.edu
pvatansh@ucsd.edu

***Abstract*— ECG monitoring is key to diagnosing diseases and assessing a patient's well-being. It would then follow that this monitoring should be done continuously and the information should be uploaded directly to the doctor's computer and analyzed for irregularities through an app. Continual monitoring of one's heart rate by using wifi could be a key step into diagnosing disorders faster. There are a number of key factors in designing an ECG circuit including the type of electrodes, filtering characteristics, amplification, maximum current through circuit (so as to not electrocute the patient), and utilizing the driven right leg circuit to reduce common mode interference. By simulating an ECG circuit with chosen resistor and voltage values to achieve the proper gain, frequency, and noise reduction we show that we can produce a clean ECG signal which can then be transmitted to wifi to a PC. After reaching the PC, we outline how a simple app could analyze the signal, spotting irregularities, and alerting patients and clinicians with the results it compiles. While a lot of factors must be considered, the benefits of creating an ECG circuit that can transmit to wifi has many potential benefits for the health industry**.

***Keywords*— ECG monitoring, wifi transmission, analyze heart rate, Driven right leg circuit, electrodes**

I. Introduction

ECG circuits provide key information when diagnosing a patient. A high heart rate can indicate that the patient is undergoing distress. Those who are sick typically have a higher than normal heart rate due to their body working hard to fight their sickness. Heart rates can also show general anxiety levels of a patient and overall health of patients. For instance, those with higher anxiety levels tend to have higher heart rates. Additionally, athletes who have strong endurance will reflect this by having a slower heart rate. This shows that they have great cardiovascular health and therefore their heart is more efficient at pumping blood, i.e. each heart pump will pump more blood than the average person's so their heart needs to pump less times per minute to pump the same amount of blood. Having a high resting heart rate is very indicative that one may have a sudden heart attack. For instance, the 30 year Farmingham study took resting heart rates of men and women and showed that 30 years later, those who had died unexpectedly of heart attack came from a higher percentage from the category of the people who had a higher resting heart rate[3]. Furthermore, there has been evidence that tracking heart rate variability is a good indicator of mental health in individuals. Heart rate variability can be used to tell how efficient the prefrontal cortex is at modulating social engagement and emotional reactivity[2]. Clearly, heart rate is a useful biosignal for diagnosing patients and predicting risk of future cardiovascular disease. Therefore, it would follow that one would want to be able to track heart rate as fast as possible and be able to send the information through wifi to an application for data processing. By designing an ECG circuit with an Instrumentation amplifier, driven right leg circuit, band pass filter, analog to digital converter, wifi acquisition, and an app, one could effectively analyze heart rate.

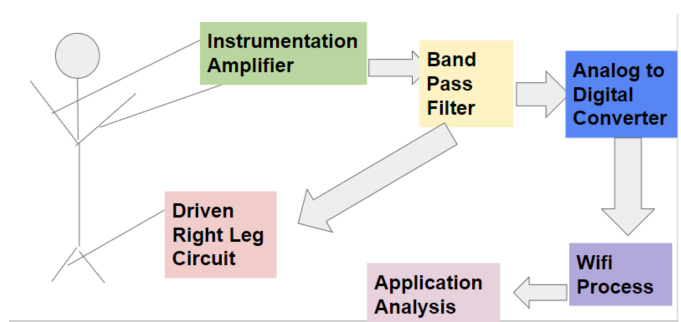


Fig. 1 Block Diagram of ECG to wifi to app outline

II. Circuit Topology

A. *Instrumentation Amplifier*

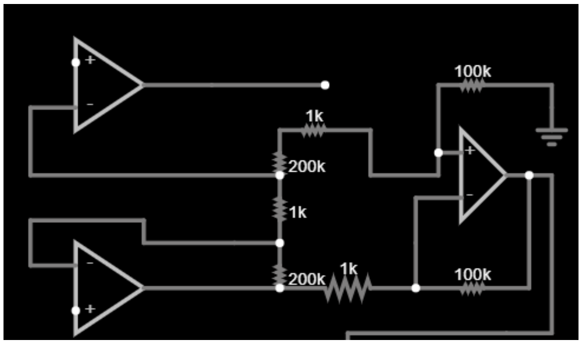


Fig. 2 Instrumentation Amplifier Circuit

The instrumentation amplifier circuit is shown above. The input voltages to the amplifiers are the voltages at the right arm and left arm measured by the Ag/Cl electrodes. Resistor values were chosen to achieve a common mode rejection ratio of greater or equal to 80dB [1]. The gain required is so high because the typical voltage range that one's heart produces naturally is very small, typically at: 0.1-0.5mV. Furthermore the gain of the instrumentation amplifier is calculated by equations:

$Ad = (1 + 2(\frac{200k}{1k})) * \frac{100k}{1k}$= 40,100.

$Adin = 1 + (2 * \frac{200k}{1k})$;$Adout = \frac{100k}{1k}$

$Ac = 0.04 * \frac{100k}{1k}$

CMRR = $\left|\frac{Ad}{Ac}\right| = \frac{401 * \frac{100k}{1k}}{0.04 * \frac{100k}{1k}} = 25 * 401$=40,100

CMRR in dB = 20*log(40,100) = 92dB

Achieving a CMRR of 92dB is good because it means the signal noise ratio output is acceptable (above 40db)

SNRout= 6dB+CMRRdb+SNRindB

Assuming typical values, SNRin = -40dB.

SNRout = $6dB + 92dB - 40dB$ = 48dB

B. *Driven Right Leg Circuit*

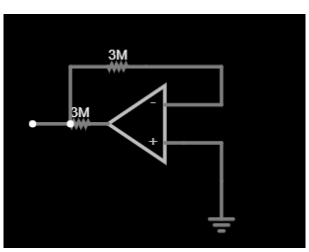


Fig. 3 Driven Right Leg circuit

The Driven Right leg circuit serves to reduce the common mode voltage. Furthermore, to make sure that the current going through the body is safe and no more than 10µA; the resistor value should be significantly large to reduce said current. For our circuit the voltage is from a 9V battery. The current allowed into the body is thus: $\frac{9V}{3M\Omega} = 3\mu A$. This is indeed less than the safety threshold of 10µA; so this current is safe.

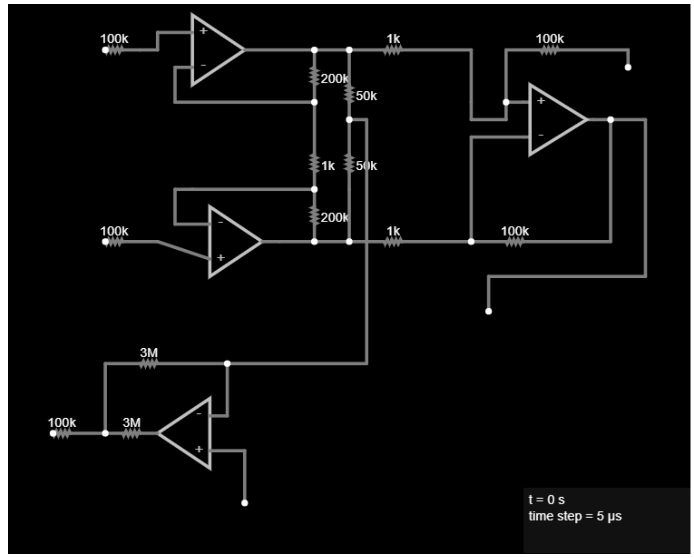


Fig. 4 Driven Right Leg combined with Instrumentation Amplifier Circuit

This figure shows the Driven Right leg circuit attached to the instrumentation amplifier circuit in a way that reduces the common mode voltage[1] by using two 50kΩ resistors with the right leg resistor being a 100kΩresistor. Therefore, the effective right leg resistance voltage becomes:

$$R_{RLeffective} = \frac{100k\Omega}{1+2*\frac{3M\Omega}{50k\Omega}} = 826.45\Omega$$

This shows a common mode voltage reduction by a factor of 121.

C. *Bandpass Filter*

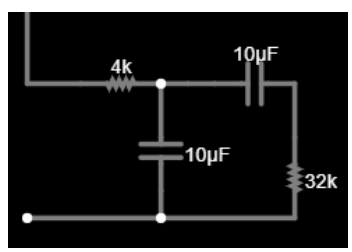


Fig. 5 Band Pass Filter

Finally a bandpass filter is constructed and added to the end of the instrumentation amplifier circuit to filter out unwanted frequencies and isolate the desired frequency from the heart rate. Typical resting heart rate for adults is expected to be about 60 to 100 bpm. While the maximum heart rate for adults doing high levels of exercise is estimated to be about 200bpm with the minimum resting heart rate for athletes being about 40 bpm[4]. Using this data as a guide, the circuit should capture heart rates from 40 bpm to 200 bpm. 40 beats per minute is 0.67 cycles per second (0.67 Hz) and 200bpm corresponds to

3.33Hz. Thus; the bandpass filter is constructed to allow frequencies of 0.5 to 4Hz through. To construct this a low pass filter and high pass filter were made:

Low Pass Frequency = 4Hz = $\frac{1}{2*\Pi*4k\Omega*10\mu F}$

High Pass Frequency = 0.5Hz = $\frac{1}{2*\Pi*32k\Omega*10\mu F}$

The combined circuit with the IA, DRL and band pass filter components is shown below.

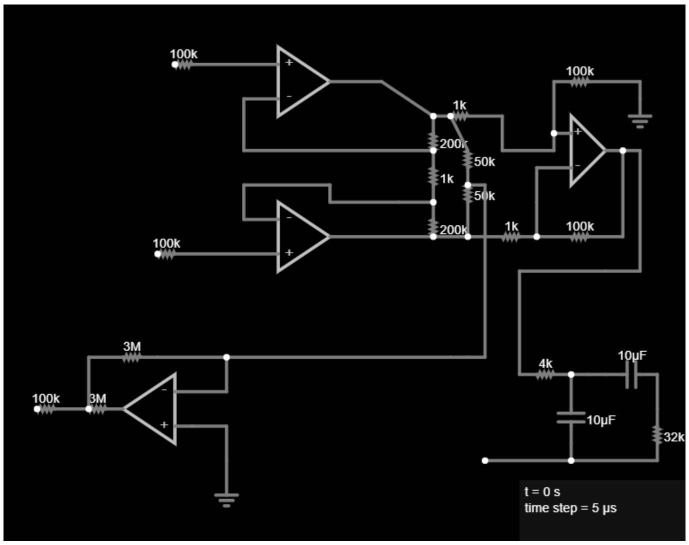


Fig. 6 Combined circuit with the instrumentation amplifier, DRL, and band pass filter components.

D. Sallen-Key Low Pass Filter

The output from the instrumentation amplifier is processed through a Sallen-Key low pass filter consisting of two MCP6022 chips wired with an assortment of resistors and capacitors. The MCP6022[5] can function with low supply voltage and current despite providing high-speed operation and maximum output signal swing, thus serving as an adequate operational amplifier for the purpose of the circuit. Furthermore, the construction of the Sallen-Key filter design is intentional for voltage gain control where the output voltage is increased to be greater than the input voltage, and its linear phase filter type yields a quality transient response. Together, a fourth order 150 Hz low pass filter is created to prevent aliasing by constricting the bandwidth within the limits of the Nyquist frequency. A gain of 56 dB is collectively achieved by the system.

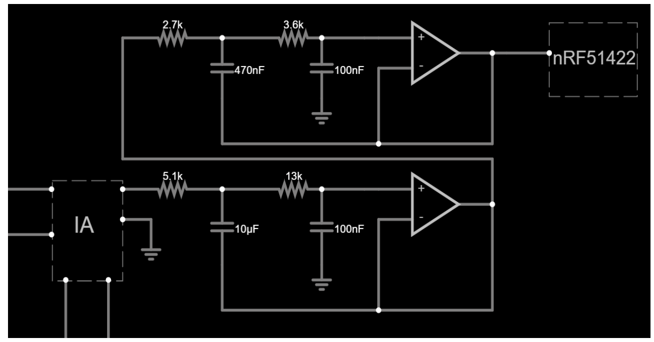


Fig. 7 Circuit diagram section including the fourth-order low pass filter created by the two MCP6022 chips from the output of the instrumentation amplifier to the nRF51422 module.

The filtered signals are then converted from analog to digital via a 10-bit A/D converter[6], providing a high resolution of the signal at a maximum sampling rate of fifteen thousand samples per second. By definition, an analog-to-digital converter[7] (ADC or A/D converter) is an electronic circuit whose analog input is proportional to its digital output so that the converted signal can be read and processed by a microcontroller. Essentially, the input voltage is measured and a proportional binary output is produced. The entire system including the ADC is called a data acquisition system.

Lastly, the main wireless unit is implemented by the radio frequency (RF) module nRF51422[8] which includes a microcontroller and a 2.4 GHz radio. The nRF51422 is an ultra-low power system-on-chip (SoC) built around the 32-bit advanced reduced instruction set computer machine (ARM) Cortex-M0 central processing unit (CPU) with 256 KB flash and 32 KB RAM to avoid the use of an extra microcontroller, allowing the system to be more compact as the SoC embedded 2.4GHz transceiver supports both advanced and adaptive network technology (ANT) and Bluetooth low energy protocols. The transmitted signal is then acquired by a supported ANT USB stick serving as a receiver.

III. Encoding Digital Data from ECG Sensor

Encoding digital data from an ECG sensor in a compressed form is an active area of research, and there have been several different techniques in order to achieve this. With the digital data encoded it can then be sent through Wi-Fi and then the app.

A. Transform-Based Compression

This technique uses mathematical transforms as a way to represent data in a more compact form. This is the most efficient technique as it can achieve higher ratios of compression compared to others. Thus, with this higher ratio of compression, the quality is better due to the preservation of distinct features. This is ideal for videos and pictures as this is a faster technique to get videos in real-time. Furthermore, images and audio signals benefit from this technique as this compression accounts for a wide array of data where it can be preserved. For example, in a study published in the journal Biomedical Signal Processing and Control, researchers used the discrete wavelet transform (DWT) to compress ECG signals, achieving compression ratios of up to 100:1 with minimal loss of diagnostic information[9]. Similarly, a study published in the journal Computers in Biology and Medicine investigated the use of the DWT in combination with principal component analysis (PCA) for ECG signal compression, achieving compression ratios of up to 300:1[10].

B. Predictive Coding

This technique is used where the next set of data is predicted by the previous samples. One common approach to the predictive coding of ECG signals is to use recurrent neural networks (RNNs) such as long short-term memory (LSTM) networks. These networks can learn to capture the temporal dependencies in the ECG signal data and make accurate predictions of future ECG values. Another approach is to use signal processing techniques such as wavelet transforms or Fourier transforms to extract features from the ECG signal data and then use machine learning algorithms such as support vector machines (SVMs) or random forests to make predictions based on these features. Predictive coding techniques have also been investigated for ECG signal compression. For example, in a study published in the journal Biomedical Engineering Online, researchers proposed a linear prediction method based on autoregressive modeling for ECG signal compression, achieving compression ratios of up to 23:1[11]. Another study published in the same journal investigated the use of a hybrid coding scheme combining predictive coding and transform-based coding for ECG signal compression, achieving compression ratios of up to 25:1 with minimal loss of diagnostic information[9]. Similarly, a study published in the journal Computers in Biology and Medicine investigated the use of the DWT in combination with principal component analysis (PCA) for ECG signal compression, achieving compression ratios of up to 300:1[10].

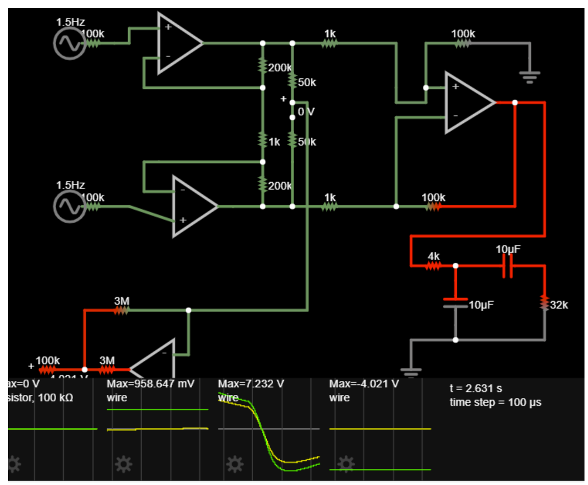
C. Subsampling

The use of subsampling techniques for ECG signal compression has also been investigated in several studies. Subsampling ECG signals involves reducing the sampling rate of the signal while preserving its essential features. This can be useful for reducing the size of the data, making it easier to store and process, while still retaining the important information. For example, in a study published in the journal Biomedical Signal Processing and Control, researchers investigated the use of a subsampling scheme based on the Shannon-Nyquist sampling theorem, achieving compression ratios of up to 10:1[11]. Another study published in the same journal proposed a subsampling scheme based on a non-uniform sampling strategy, achieving compression ratios of up to 50:1 with minimal loss of diagnostic information[12].

D. Data to Wi-Fi

Finally, with the data extracted encoded it is then ready to be used and sent. In order to send data through WiFi you must first establish a WiFi connection. This involves selecting the correct WiFi network and providing any necessary authentication credentials (e.g., a password). Once the WiFi connection is established, the device must create a socket. This is a software endpoint that allows applications to send and receive data over the network, created using the appropriate socket API. With the socket created, the device can now send data over the WiFi network. This is done by calling the appropriate function in the socket API to send data. Similarly, the device can also receive data over the WiFi network by calling the appropriate function in the socket API to receive data. Once all data has been sent and received, the device should close the socket to release any resources used by the socket. The data is then sent through the Wi-Fi to be used by the application for analysis. Our app would be able to use this data which would give the information to our clinics and patients, directly to their own personal devices instantly.

IV. Results



To test the circuit the IA, DRL and bandpass filter portion of the circuit was run through simulation software. At the respective right arm and left arm points an AC voltage source at 1.5 Hz with a 90 degree offset were chosen. Their respective voltage maximums were 0.5mV. The oscilloscopes tracked the common mode voltage at the DRL, which shows as expected as a DC waveform; as well as the voltage at the bandpass filter which shows (as expected) an AC waveform for current and voltage.

V. Discussion

A quick and effective dispersion technique was used to create a high-density CNT-PDMS combination. To increase the flexibility of the electrode, Ag NPs were added to the mixture. Three electrodes were combined with an aPDMS layer, which is utilized to glue the ECG electrode patch to the skin, to create a self-adhesive device. To make a strong contact between the electrodes and skin, many holes were bored in the electrode and filled with aPDMS. To enable the wireless long-term recording of ECG signals, an RF module was paired with an ECG acquisition system. Impedance and ECG data were used to evaluate the polymer electrodes' characteristics.

VI. Conclusion

The Wi-Fi based ECG Monitoring System has the unique qualities of being wireless, portable, and low power consuming. It is anticipated that as this ECG monitoring system advances, it will benefit not just the mobile healthcare system but also people who require long-term ECG monitoring. It is clear from an analysis of the entire system that the current design version is still open to additional development. To promote data sharing and compatibility between many platforms and systems, it is desired to store and transmit ECG data in a common format, such as XML. This incorporates automatic ECG interpretation to identify current or impending heart issues from the user's ECG. The personal data and health status of users can be stored in a database system. This system has the capacity to acquire, transmit, record, and display the ECG signal in real time with accuracy and dependability. This system's main advantage is that it uses a lot less power than conventional wireless medical equipment. Additionally, it analyzes ECG data and recognizes complex ORS information on the smartphone platform to support patients and medical professionals via telemedicine. The wireless technology greatly improved the mobility, flexibility, and usability of the ECG monitoring system for healthcare. As a result, it has a wide range of uses, such as extended ambulatory monitoring, computer-assisted rehabilitation, emergency medical care, and ongoing patient monitoring in hospitals. In summary, this system concept has the potential to alter the way that mobile health care is provided today.

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