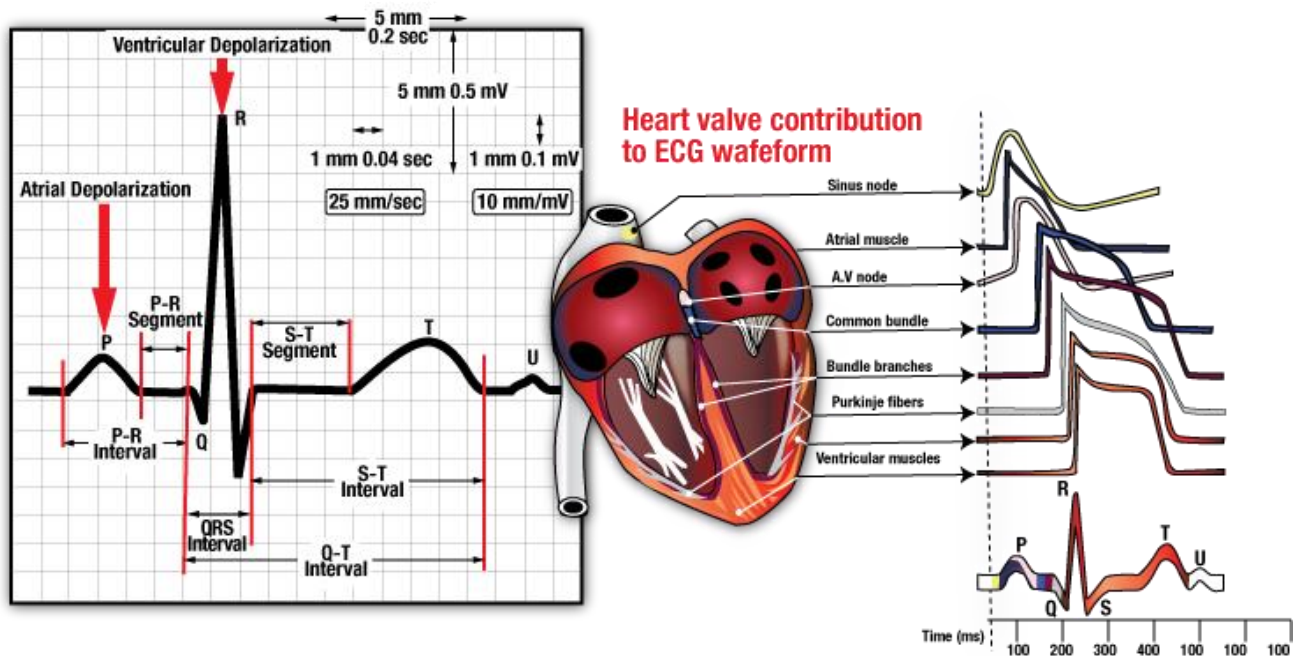


Electrocardiography Circuit Design

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Abstract

Electrocardiography (ECG) is the interpretation of the electrical activity of one's heart over a period of time. Recently, there has been increased interest and demand in ECG measurement devices called Electrocardiograms (also abbreviated ECG) for use in the medical and research fields. This application note will attempt to give the reader a background on ECG signals as well the methods and design techniques that go into designing an ECG demonstration board. It will focus on amplifiers for the small ECG signals as well as some of the various ways of reducing various noises in the system; this includes explaining the Right Leg Drive circuit.

Keywords

Electrocardiography, ECG, Biopotential, Action Potential, Instrumentation Amplifier, INA333, Motion Artifacts Right Leg Drive

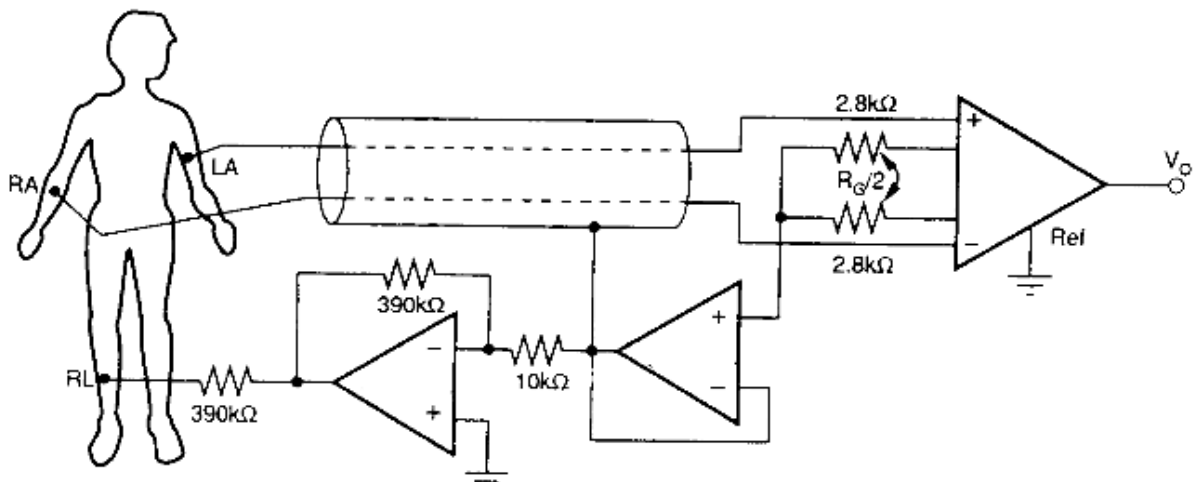


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Electrocardiography

Cells in humans act like little batteries. These cells have different ion concentrations inside and outside of their membranes which create small electric potentials called biopotentials. When there is a disturbance in a biopotential this gives rise to an action potential which is the depolarization and repolarization of the cell as shown in Figure 1.

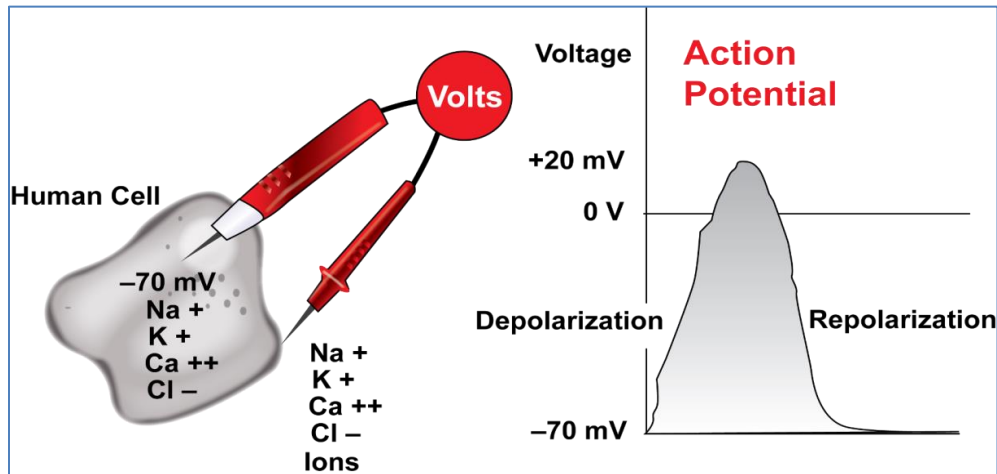


Figure 1: Each living cell acts as a small battery that depolarizes and repolarizes when there is a disturbance.

Essentially, the action potentials from different nodes in the heart are what make up electrocardiograph (ECG) signals. ECG signals are comprised of the superposition of the different action potentials from the heart beating as shown in Figure 2. ECG machines use electrodes to convert the ionic signals from the body into electrical signals to be displayed and used for data analysis. However, due to the size of the signals and outside noise, ECG requires amplification and filtering to produce high quality signals.

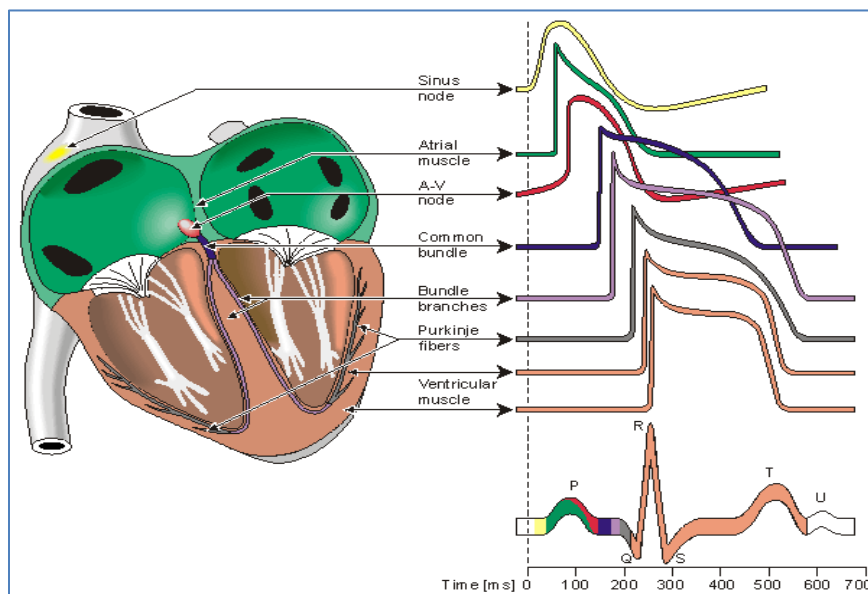


Figure 2: Superposition of all the action potentials produces the ECG signal.

Circuit Design

An ECG's job is to amplify the small signal measured from the heart as well as to filter outside and internal noise. The amplification is mainly implemented through a differential amplifier whereas filtering is completed through common and differential mode filtering. There is also the Right Leg Drive circuit which cancels noise and maintains the common mode voltage.

Amplifier

ECG signals vary from the microvolt to the millivolt range. Due to this small range, the signals measured need to be amplified in order to be better interpreted. Typical biopotential amplifiers have high input impedance and are designed for safety first. This is due to the fact that the signal amplified is being drawn from a living organism so precautions must be taken in order to prevent macro and micro shock. Isolation and protection circuitry are used to limit current through electrodes to safe levels. The output impedance of the amplifier should be very low to drive any external load with minimal distortion. Again, due to the small size of the signal, the gain should be large. Typically a gain of over 1000 is implemented in biopotential amplifier circuits. The amplifiers should have a high common mode rejection ratio to eliminate large offset signals. Finally, most biopotential amplifiers are differential. Differential amplifiers are used to make sure that noise from the inputs are not amplified thus yielding a higher integrity signal.

Differential amplifiers with such characteristics are difficult to find. Thus combinations of differential amplifiers are used to construct what is called an instrumentation amplifier. A basic three-op-amp instrumentation amplifier is shown in Figure 3.

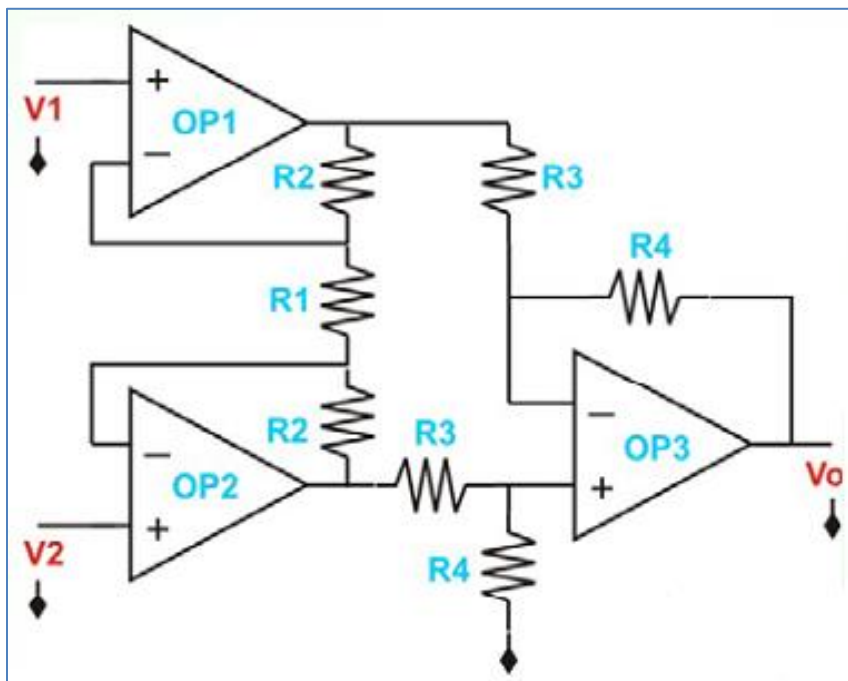


Figure 3: Basic Instrumentation Amplifier

There are two stages for the instrumentation amplifier that help make it meet the characteristics of an ideal biopotential amplifier. The first stage is the input stage of the amplifier followed by the gain stage. Figure 4 breaks down the two stages.

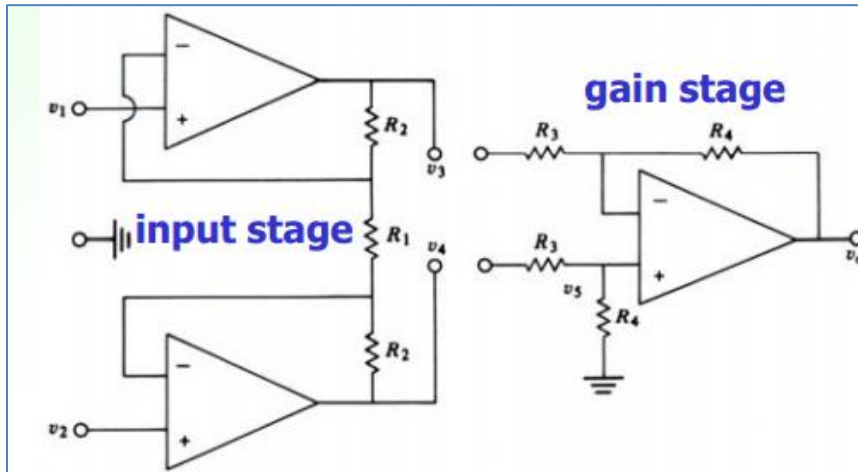


Figure 4: Input and gain stages of instrumentation amplifier

The input stage ideally supplies no common mode gain thus eliminating common mode noise. The three op-amps give the input stage high input impedance and the configuration gives a gain of $G_d = \frac{v_3 - v_4}{v_1 - v_2} = \frac{2R_2 + R_1}{R_1}$. The input stage also buffers the gain stage. Finally, the outputs of the input stage are the inputs of gain stage. The gain stage has low impedance and supplies a differential gain. Overall the amplifier amplifies only the differential component with a gain of $G_d = \frac{2R_2 + R_1}{R_1} * \frac{R_4}{R_3}$ and provides a high common mode rejection ratio. Texas Instruments supplies such an amplifier for use in the medical industry. Figure 5 shows the schematic of TI's most common instrumentation amplifier the INA333. This single chip allows the user flexibility in adjusting the gain while also reducing circuit design error.

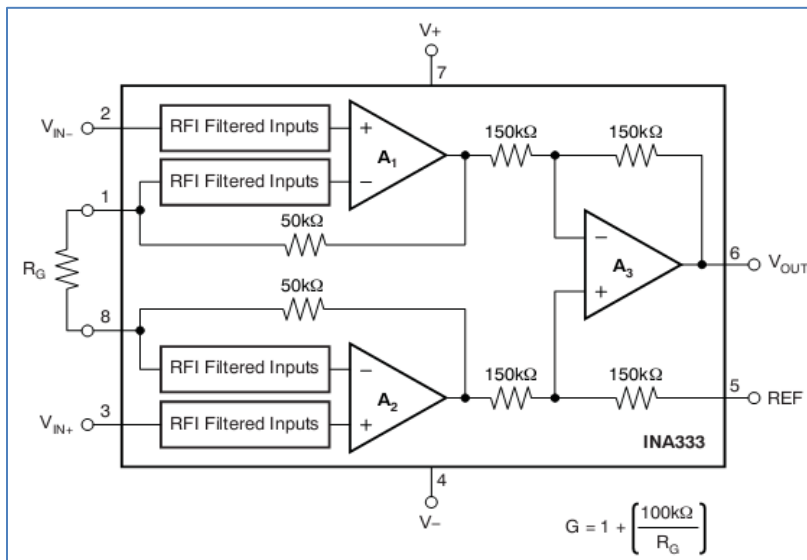


Figure 5: Schematic of INA333

Filtering

ECGs are subject to many different kinds of noise internally and externally. Figure 6 shows the different kinds of artifacts that ECGs typically experience.

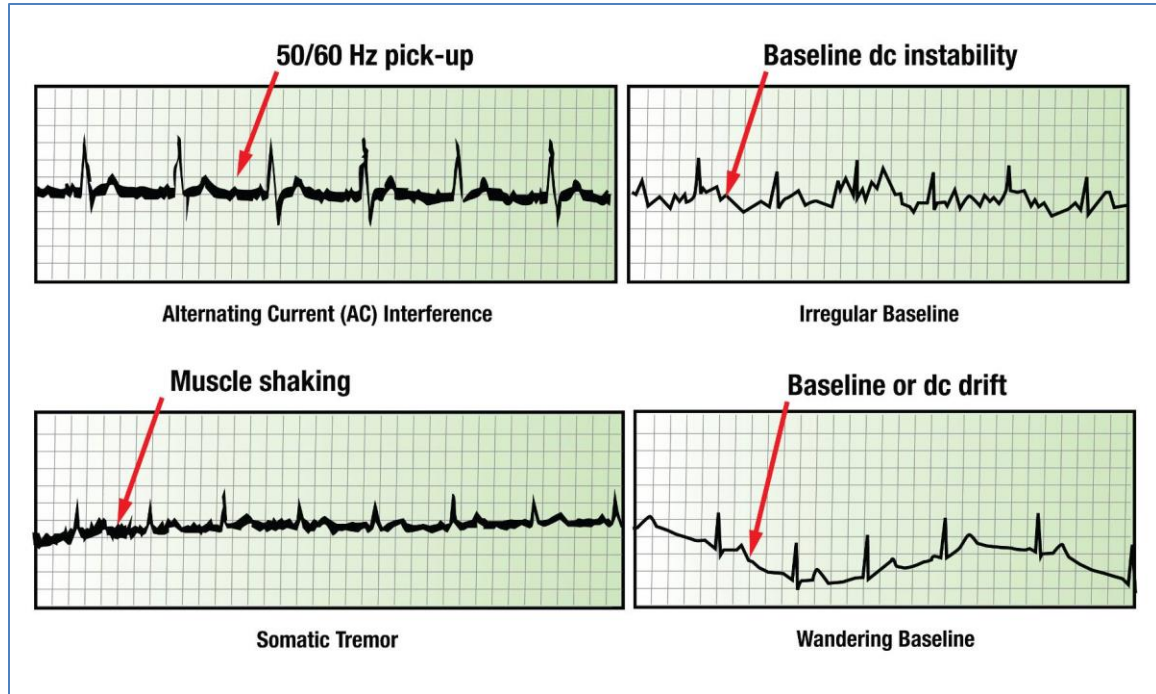


Figure 6: ECG artifacts

These artifacts can be filtered digitally as well as through analog practices. For example, the analog band stop filter shown in figure 7 can be used to modulate 60 Hz noise from power lines based on what resistor, capacitor, and inductor values are chosen.

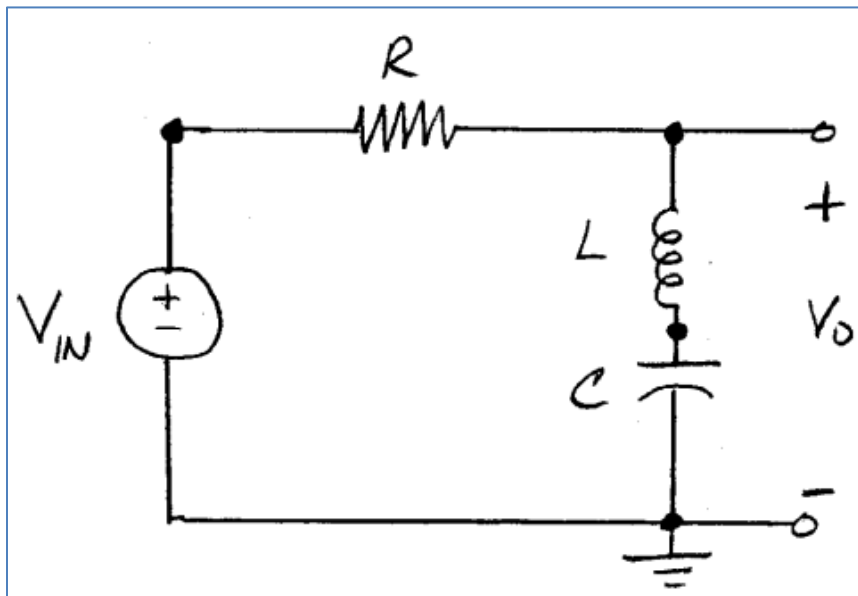


Figure 7: Second order band stop filter

Digitally, Matlab allows one to implement filters with the help of FFTs. For example, an FFT can extract the ECG and muscle shaking frequency components. From there, one can design a filter to obtain only the ECG components of the signal. For ECG circuits however, typically low pass filters will suffice to eliminate outside noise due to the frequency of a heartbeat.

Right Leg Drive

The motivation of the right leg drive circuit is to reduce interference from the amplifier. It is possible to amplify an ECG signal and create a DC common mode bias electrically off the inputs of the differential amplifier. However, when this is done there is extreme susceptibility to common mode interference which is where the need for the right leg drive comes in. The right leg drive inverts and amplifies the average common mode signal back into the patient's right leg as shown in figure 8. This action cancels 60 Hz noise from AC power and creates a cleaner ECG output signal. The more gain that can be used in the feedback loop also improves the common mode rejection ratio. Canceling noise in this way relaxes the attenuation needed from the common mode rejection of the instrumentation amplifier.

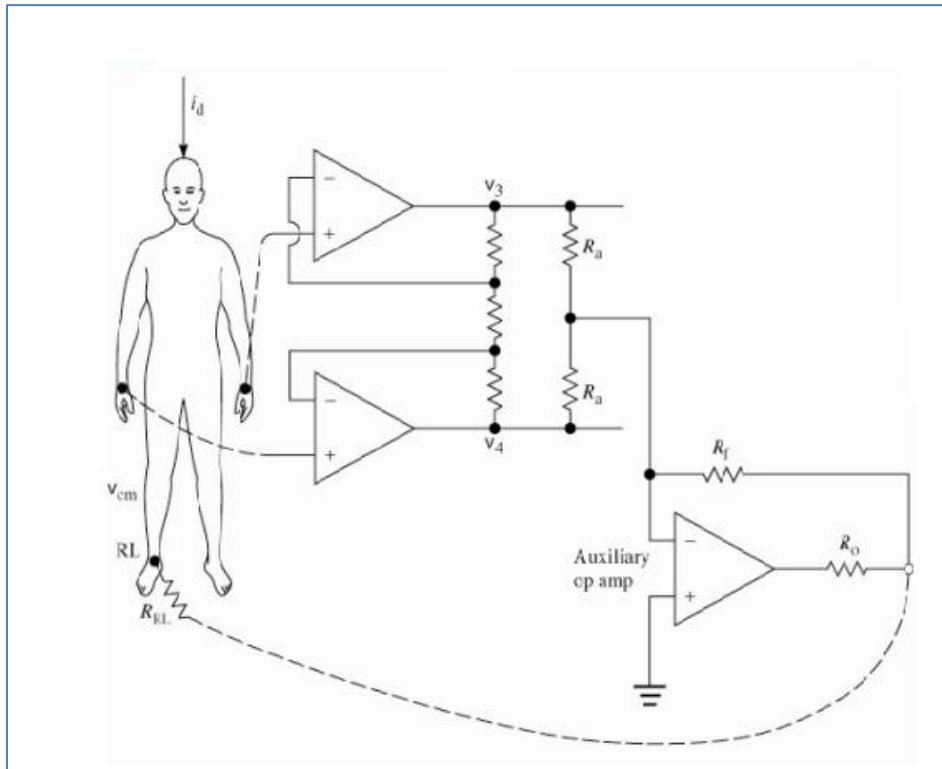


Figure 8: Right leg drive connection

ECG Circuit

Finally, the components of the system described above are assembled together to complete a usable ECG measuring circuit shown in figure 9.

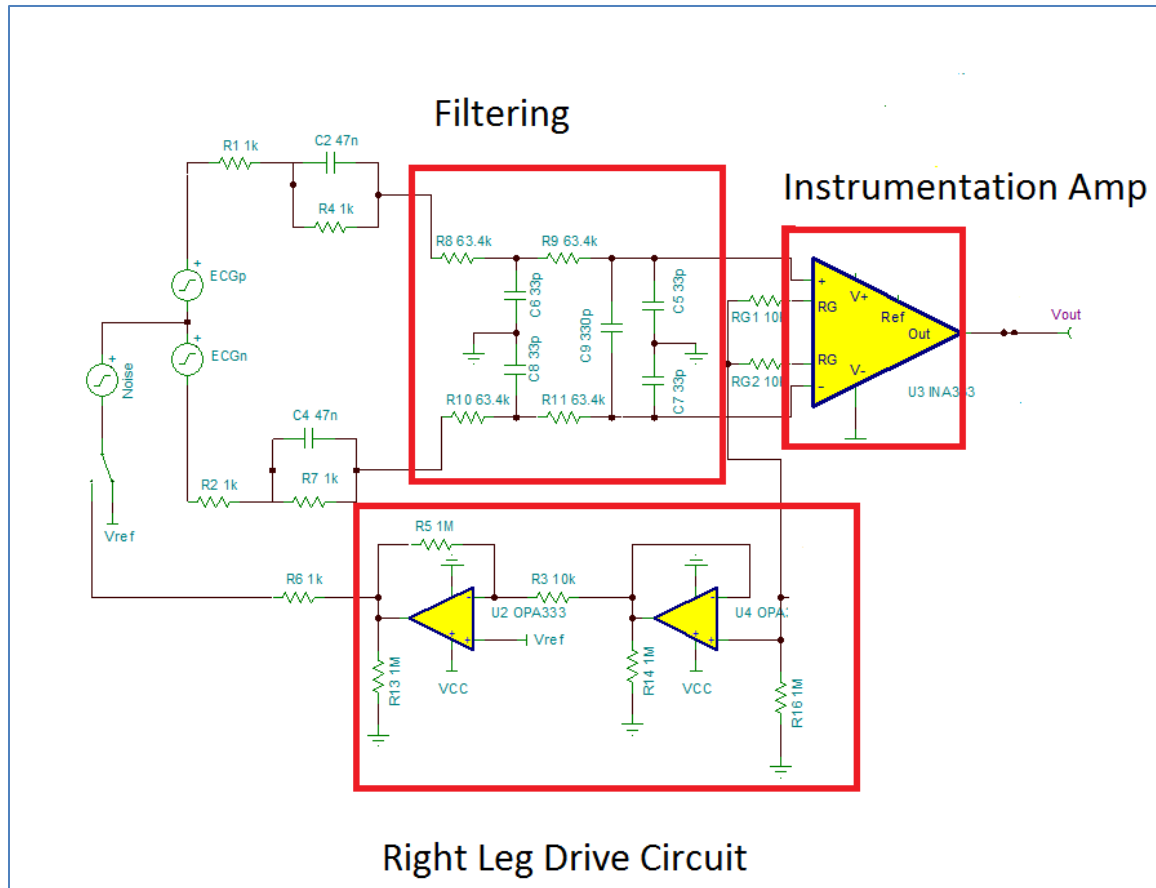


Figure 9: ECG circuit

References

A precision low-level DAS/ECG Cardiotachometer Demo Board, a Texas Instruments technical presentation created by John Brown.

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ECE 445 Biopotential amplifiers prepared by Professor Andrew Mason

INA333 data sheet

http://www.ti.com/product/ina333?DCMP=A_Signal%252520Chain_Precision_Amps%252520&%252520Linear&247SEM