# Design Considerations for Amplifiers Used in Electrocardiograms

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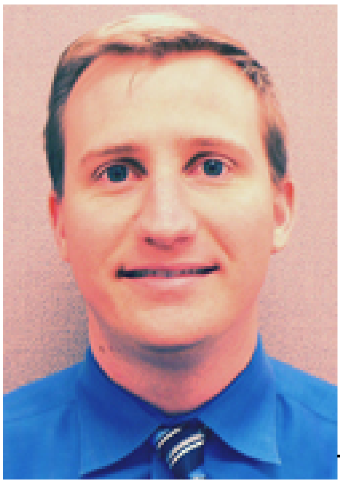

The use of Electrocardiograms (ECGs) has increased dramatically over the years, and technological advances continue to make the results from such devices more and more useful. When designing an ECG, several considerations must be taken into account, one of which is the amplifier used within the signal conditioning of such a system.

**Overview of an Electrocardiogram**

An ECG is used to monitor the electrical activity of the heart. As the walls of the heart contract, an electrical current spreads throughout the body, creating varying voltage potentials. Electrodes placed on the skin sense these voltage potentials, making it possible to monitor the activity of the heart.

The simplest ECGs provide a waveform view of the heart’s movements, either on a screen or printed directly to paper. More advanced machines will offer other features such as the capability to store waveforms, wireless data transfer, and varying levels of post-signal processing. Figure 1 shows a high-level block diagram of an ECG. The amplifiers used in the signal-conditioning circuitry are highlighted in green in the lower-left portion of the diagram.

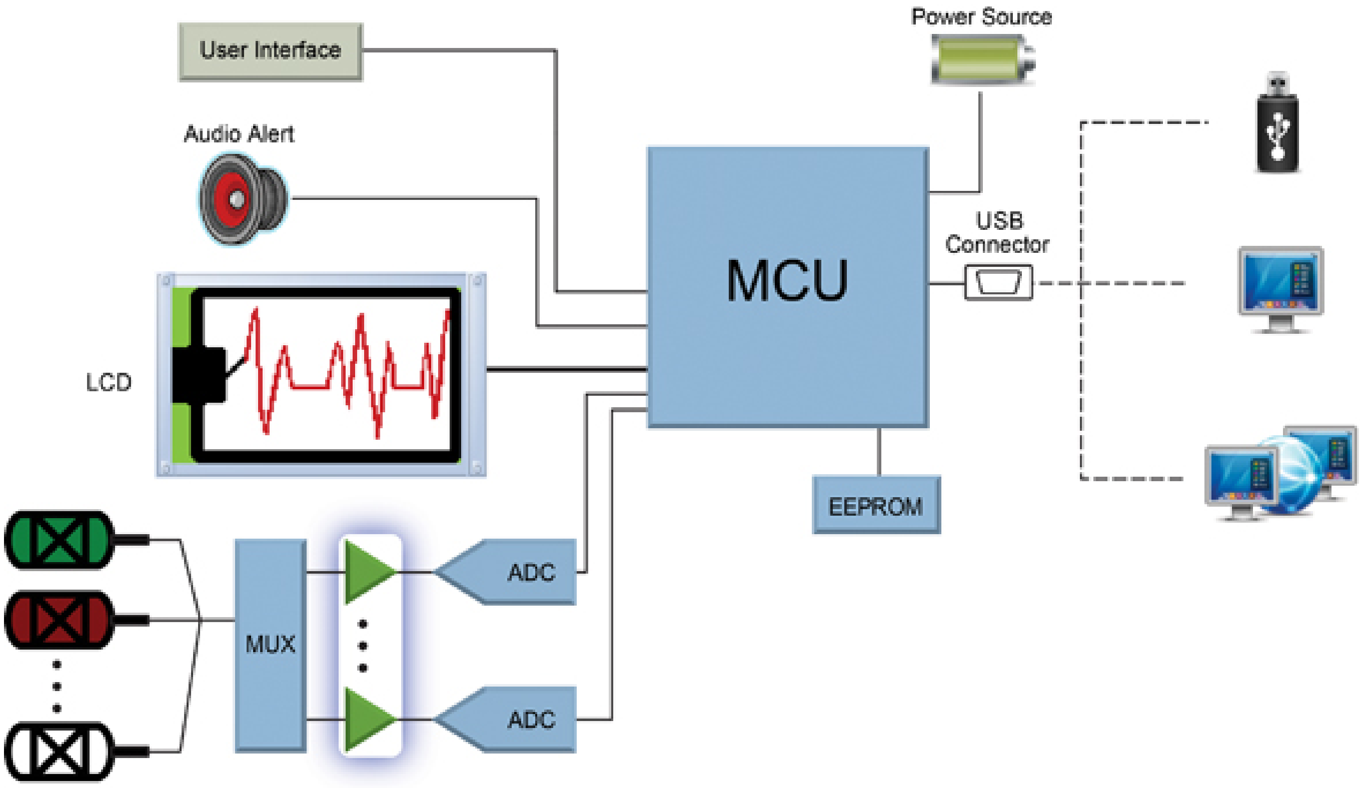


**Figure 1. Block diagram of An ECG system.**

## Signal-Conditioning Challenges

Depending upon the system and the type of analysis that is required, the most popular setups have three, five or even 10 electrodes attached to various places on the body. The voltages present on the skin range in magnitude from 100 µV up to 3 mV. However, each electrode can have a DC potential close to 300 mV. Therefore, the front-end detection circuitry must be able to detect a very small voltage in the presence of a relatively large common-mode voltage. Another challenge is contending with various noise sources, such as 50 Hz or 60 Hz interference from overhead lights or monitors, movement of the patient, and electromagnetic interference from other pieces of equipment.

Since the signal of interest is extremely small in magnitude, an amplifier is used to extract the cardiac signal from the common-mode voltage and noise, and to provide signal gain. Some of the amplifier parameters that are critical in such applications include common-mode rejection, input offset voltage and offset voltage drift, output swing, and amplifier noise.

## Common-Mode Rejection

As mentioned previously, the electrodes placed on the skin of the patient may have a DC potential on the order of several hundred millivolts, while the signal of interest is typically less than one millivolt. An instrumentation amplifier configuration is ideal for this type of situation, in which the amplifier will cancel any signal common to the differential inputs (either from the electrodes or any common mode noise such as 60 Hz interference), while amplifying the cardiac signal of interest. In this case, it is important to consider the common-mode rejection of the amplifier circuitry not only at DC, but across frequency, especially at line level frequencies of 50 or 60 Hz. An amplifier with a high common-mode rejection will remove more of the unwanted noise and result in a higher accuracy measurement.

**Input Offset Voltage and Offset Voltage Drift**
Since the voltage of interest is relatively small, the amplifier needs to provide gain, increasing the resolution of the detector circuitry. Due to the high amount of gain required in this application, the offset voltage of the amplifier is critical. Any voltage offset due to the amplifier will also be multiplied by the gain of the circuit. For example, assume that the contraction of the heart creates a 1 mV potential on a given electrode placed on the skin. Assuming the amplifier circuitry is setup for a gain of 1000, the output of the amplifier circuitry will ideally be 1 V. However, if the input offset of the amplifier is 100 µV, then this will create an error at the output of 100 mV, which in this example is an error of ten percent. It is important to remember that the input offset error of the amplifier is input referred, and therefore will scale with the gain of the amplifier.

Like all electrical components, amplifiers will change behavior over time and temperature. This is certainly true of the amplifier’s voltage offset. The voltage offset is a source of error, and as the offset drifts, this error could become even greater. This error source can be minimized by selecting a low-drift amplifier, such as an amplifier with an auto-zero based topology, or implementing periodic system calibrations to calibrate out the offset and drift.

**Amplifier Output Swing and Noise**
In the example used previously, a 1 mV potential from the electrode produced a voltage change of 1 V on the output of the amplifier circuitry. For a 5 V single-supply system, this would suggest that the amplifier circuitry could accurately detect voltages from zero to 5 mV, assuming the amplifier output could swing to both supply rails. If the amplifier did not support a rail-to-rail output swing, the overall range of voltages that could be accurately detected would be less, hence limiting the dynamic range of the detection circuitry.

Another important parameter that must be considered when evaluating amplifiers for this type of application is amplifier noise. Keep in mind that an amplifier’s noise may not be constant over frequency, especially at low frequencies where 1/f noise can become the dominant source of noise. In an ECG application, the signal bandwidth of interest is typically from DC up to 100 Hz, so 1/f noise will be yet another source of error.

**Conclusion**
Originally, ECG machines were intended to simply display the electrical activity of the heart. Due to advancements in electronic and mechanical design, today’s ECGs include the capability to do various amounts of autonomous signal analysis, provide real-time displays, and even enable portable devices to record cardiac electrical activity over an extended period of time. These advanced features rely on accurately capturing and conditioning the cardiac signals, making amplifier selection and design a critical factor in the success of an ECG system.