

# The Inner Workings of an EKG

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Although the electrical charges produced by the heart have been measured for over a century using a machine known as an electrocardiograph (EKG or ECG), it was not until the early 1900s that Dutch scientist Willem Einthoven began his work in the field of study. When he got involved, the only way to measure the heart's electrical activity was to open up the patient and expose their heart directly to the measuring equipment. Realizing that it would be of much greater use to be able to measure these electrical pulses noninvasively, Einthoven set out to find a way to overcome the fact that the electrical impulses weakened greatly when travelling through the skin. Eventually, he developed the string galvanometer, which greatly improved the sensitivity of the EKG by allowing it to measure mere millivolts. He was awarded the Nobel Prize in Physiology or Medicine for his work (NobelPrize.org).

Today, EKGs are very widely used to detect and study the heart and to identify and study abnormalities. EKGs provide a visual output of the heart's electrical activity, which doctors can analyze to determine if the patient's heart is enlarged, overworked, or suffering from a variety of other problems (American Heart Association Inc. 2008). "One big goal of EKGs," maintains Dr. Aaron Lawrence, "is to determine if the rhythm is normal, whether or not the electrical pathway is messed up." Heart attacks cause permanent changes in the electrical activity of the heart. Knowing this, EKGs can be used to detect this damage (Lawrence 2011). This is because a cardiac infarction can cause some dead tissue in the heart which hampers the flow of electric charge and clearly changes the EKG's output. Different changes in a patient's EKG can indicate different problems. For example, an irregular heartbeat, which presents in an EKG as unevenly timed pulses, can be indicative of an arrhythmia (NobelPrize.org).

When at rest, the cells in the heart are polarized with a net negative charge on the inside and a net positive charge on the outer surface. Membrane pumps are nature's regulators for these charges. When the pacemaker cells spontaneously depolarize, a chain reaction of depolarization occurs through the other cardiac cells. The cells all then repolarize through another chain reaction. The cells that initiate the process are concentrated in the upper area of the right atrium and are known as the sinoatrial node. When the sinoatrial node "fires," the electrical current is carried to the farthest reaches of the heart by long, thin cells called electrical conducting cells which are very efficient at moving the current very quickly. Most of the heart is comprised of myocardial cells, which are much less efficient. These cells are responsible for most of the heart's actual pumping action. When the current reaches a myocardial cell, an excess of calcium is released into the cell and allows actin and myosin, the proteins responsible for contraction, to interact in a process termed excitation-contraction coupling (Thaler 2009). This is the journey that the current takes and is recorded and displayed by the EKG.

The EKG typically outputs a wave similar to the one pictured in Figure 1. Note in Figure 1 the parts of the wave are labeled. In short, the P wave indicates the very beginning of the heartbeat. This is when the atrium first depolarizes and contracts, causing the blood to flow into the ventricles. The QRS interval is representative of the other ventricles contracting and forcing the blood to flow through the rest of the heart and into the body. Finally, the T wave is the heart repolarizing itself in preparation for the next beat (Ramsey Electronics, LLC).

Because the voltage being measured by the EKG is in the range of mere microvolts, it can easily be overcome by the outside noise present on the body. As such,

it is important that the circuitry be capable of removing this outside noise while boosting the desired voltage. The circuitry used in the EKG for this project is known as a differential circuit and is often used in operational amplifiers for this purpose by pulling the original signals out of this outside noise. Very large resistors are included throughout the circuit to effectively limit the amperage, as it is unwise to apply nontrivial current to the skin around the heart. Doing so could interfere with the heart's natural flow of current and could cause serious injury or even death to the patient. A resistor is used as a gain control with a range from about 100 ohms to about 10,000 ohms, which makes it well suited for the very low voltage being measured. There are several resistor/capacitor combinations in the circuit that eliminate high frequency noises. This filtering process is desirable because the nerves in the heart fire on a relatively slow basis of every few milliseconds, making high frequency noise extraneous to what is being measured. The output of the device is coupled to an LED light is on the front of the EKG to provide visual feedback in the event that an oscilloscope is not present for use. In addition, a stereo output is available for a headset/a pair of speakers. For safety reasons, the EKG is powered by a 9-volt battery (Ramsey Electronics, LLC).

The EKG, thanks to the work done by Einthoven, has become one of modern medicine's greatest tools. Considered a painless, virtually risk-free non-invasive test, it has found its way into hospitals worldwide for the purpose of detecting and monitoring a patient's heart for abnormalities (SeattleChildren.org).

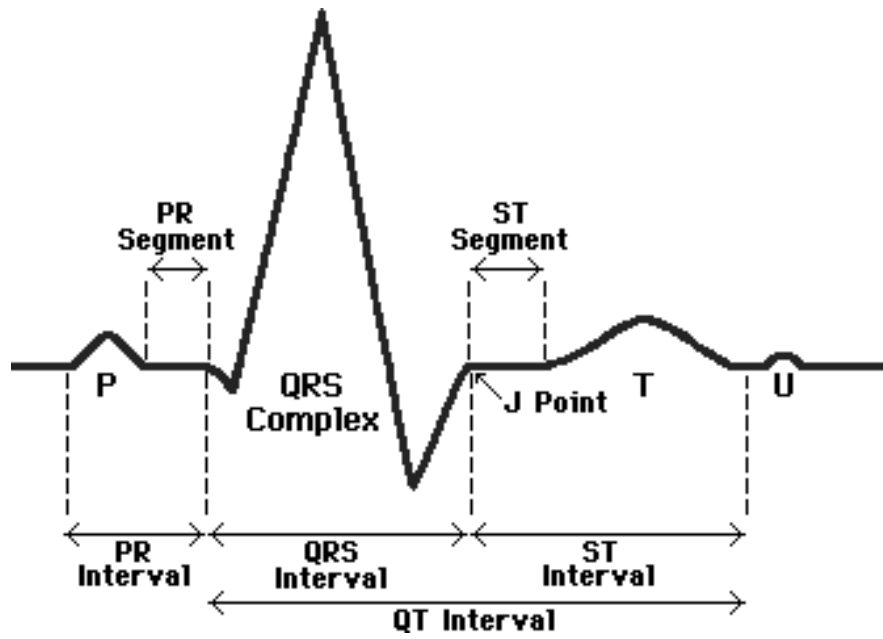


Figure 1. A typical heartbeat as it appears on an EKG output (Rondoni)



Figure 2. The circuitry used in the EKG

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