ECG Amplifier

September, 2022

1 ECG Introduction

An electrocardiogram (ECG) amplifier is an electronic component that converts relatively weak electrical signals from the heart to signals that can be output to a monitoring system. Electrodes on the body are typically where the signals are picked up first. A buffer amplifier then processes the signals and can amplify them up to ten times. ECG machines often have a differential pre-amplifier that can further enhance the electrical signal up to 100 times more. In addition to an ECG amplifier, heart monitoring machines generally consist of several components, which can include diodes, capacitors, and other parts on a circuit board.

Operational amplifiers are often used in such machines. They can reject direct current and high frequency noise interference. Various other electronic filters are often used to prevent interference from other electronic devices. An ECG amplifier can be built into a circuit along with the electronic filters and a gain stage, which typically amplifies the useful direct current.

The ECG amplifier can be built into an electrocardiogram, or the signal amplifier can be a separate component. Some versions can record data from humans and animals, in addition to isolated organs, and be set to measure different electrical signals. Most ECG amplifier types are separated from the main power circuits, because any crossover could cause a surge leading to an electrical shock. An optical isolator is often used to prevent such a problem from occurring. Typically built into the power circuit, the primary amplifier generates a current that can be used for an output.

Some ECG machines use a paper-strip recorder to display the readings. Other types transfer data to a computer, magnetic tape, or an oscilloscope that can display the activity of electrical signals. The data are usually converted to a digital format before being transferred to an output device. An ECG, therefore, generally includes an analog-to-digital converter in addition to an amplifier.

Three types of signals from the heart can be processed through an ECG amplifier. The first one is from the pacemaker, or sinoatrial node of the heart. A second signal comes from the atria, or

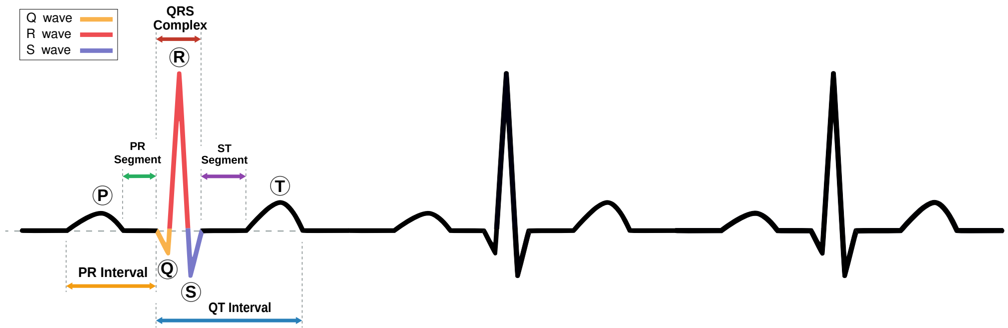

Fig 1: ECG of a heart in normal sinus rhythm

chamber where blood enters the heart, and ventricle, which contracts to push blood out of the heart. An electrical signal representing the non-contracting phase of the ventricle is the third component of an ECG reading. With the signal amplified, physicians can read each pulse as a wave, which can be used to diagnose medical conditions such as heart damage and high blood pressure.

There are three main components to an ECG: the P wave, which represents depolarization of the atria; the QRS complex, which represents depolarization of the ventricles; and the T wave, which represents repolarization of the ventricles. The QRS interval starts at the end of the PR interval (or beginning of the Q wave) to the end of the S wave. In adults, the QRS complex normally lasts 80 to 100 ms.

2 Instrumentation Amplifier

Instrumentation amplifiers are actually made up of 2 parts: a buffered amplifier XOP1, XOP2 and a basic differential amplifier XOP3. The differential amplifier part is often essential when measuring sensors. Why? A sensor produces a signal between its terminals. However, for some applications, neither terminal may be connected to the same ground potential as your measuring circuit. The terminals may be biased at a high potential or riding on a noise voltage. The differential amplifier rescues the signal by directly measuring the difference between the sensor's terminals.

The buffered amplifier XOP1 and XOP2 not only provides gain, but prevents the sensor resistance from affecting the resistors in the op amp circuit, and vice-versa.

The instrumentation amp offers two useful functions: amplify the difference between inputs and reject the signal that's common to the inputs. The latter is called Common Mode Rejection (CMR).

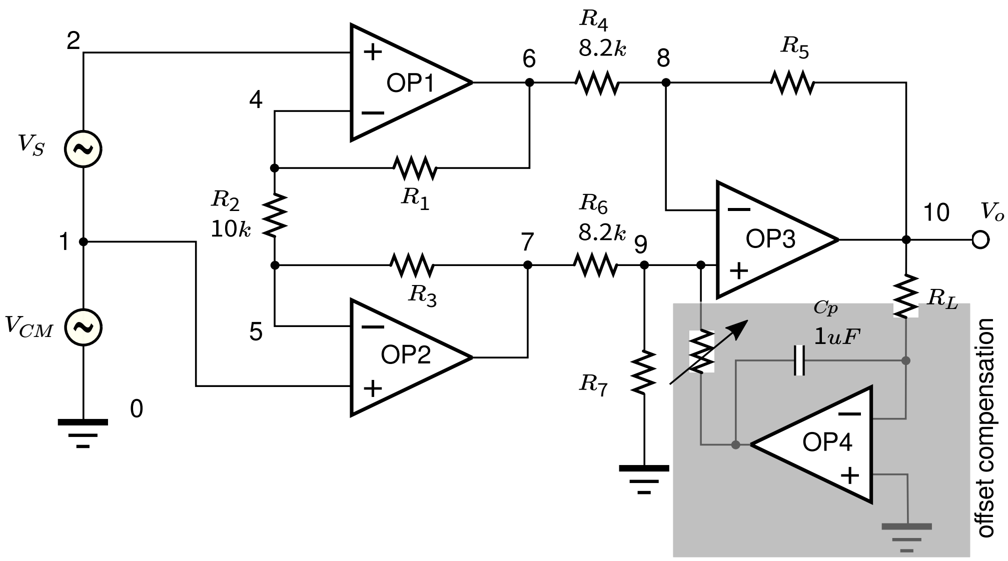

Fig 2: Simulation Diagram of a Tripple Amplifier

The signal gain is accomplished by XOP1 and XOP2 while XOP3 typically forms a differential gain of 1. You can calculate the overall gain by

$$\frac{V_o}{V_S} = \left(1 + 2\frac{R_1}{R_2}\right)\frac{R_5}{R_4}$$

where $R_1 = R_3$ and $R_5/R_4 = R_7/R_6$.

3 Simulation

The SPICE circuit applies a differential signal V_S (1V@100Hz) and a common mode signal V_{CM} (5V@10Hz) to the amplifier's inputs. With R_1 = 10k, R_2 = 2k and R_4,R_5,R_6,R_7 = 10k, the circuit delivers a differential gain of V_o/V_S = (1+ 2 × 10/2) = 11. Run a simulation and check out the input $V(2)$ and output $V(10)$ voltages. Did the circuit amplify the 100Hz input and reject the 10Hz common mode signal?

Suppose you need more gain to amplify a small signal (10mV) from a pressure or temperature sensor. Design a circuit to punch up the level to the 1 to 10V range that's practical for an ADC input. (For example, R1=10k and R2 = 200 makes a gain of (1 + 2× 10000/200) = 101 increasing the 10 mV signal to 1.01 V) You can change the input signal value to 10 mV in the VS statement

```
VS    2    1      sin(0  10mV  100Hz)
```

Test drive your new circuit. Remember the 10mV signal is still riding on the whopping 5V common-mode signal.

One way to test CMR is to kill voltage source V_S and see how much of V_{CM} gets through to the output. Set V_S to 0V by the statement

```
VS    2     1       sin(0  0  100Hz)
```

To get a closer view of the output, plot $V(10)$ only. Try the circuit and see how much V_{CM} squeaks through.

One factor that determines the health of CMR is the matching of resistor values. (The other is the CMR of the op amp device itself which is ideal for this op amp model. We'll look at modeling op amp CMR in the future.)

Suppose just one of the resistors is off by only 0.1%. Change any one of resistors R_4,R_5,R_6 or R_7 to 10.1k or 9.99k. Set V_S to 0V as described in the section above. Can you see an increase in the output from V_{CM}? For precise measurements, an error of only a few milli-volts can wreck the required performance of your measuring system.

The op amp is modeled using a subcircuit named OPAMP1. Although the guts of an op amp can contain 20 transistors or more, this model mimics only the higher level (or macro) functions of the device. The result is a simple model requiring only a handful of components.

Subcircuits are handy ways of inserting a particular circuit into one or more places of the main circuit. They're easy to define and use.

```
3 OPAMP INSTRUMENTATION AMPLIFIER
*
Vs      2   1   sin(0  1  100Hz)
Vcm     1   0   sin(0  5  10Hz)
*
* BUFFERED AMPLIFIER
XOP1    2   4   6    OPAMP1     gain1=10k
R1      4   6   10k
R2      4   5   200
R3      5   7   10k
XOP2    1   5   7    OPAMP1     gain1=10k
* DIFFRENTIAL AMPLIFIER
R4      6   8   10k
R5      8   10  10k
```

```
R6       7   9   10k
R7       9   0   10k
XOP3     9   8   10    OPAMP1    gain1=10k


.param gain=10k
* OPAMP MACRO MODEL, SINGLE-POLE
* connections:      non-inverting input
*                   |   inverting input
*                   |   |   output
*                   |   |   |
.subckt OPAMP1      1   2   6   gain1={gain}
* Input Impedance
Rin      1   2    10Meg
* GAIN BANDWIDTH PRODUCT = 10MHz
* DC GAIN (100k) AND POLE 1 (100Hz)
Egain   3   0   1   2   {gain1}
RP1      3   4   1k
CP1      4   0   1.5915uF
* Output Buffer and Resistance
Ebuffer 5   0   4   0   1
Rout     5   6   10
.ends

* Analysis
.control
tran      1ms  100ms
* View Results
plot  v(2) v(10)*10
.endc
.end
```

References

[1] Andrew Kirmayer, **What Is an ECG Amplifier?** [2022-08-29], https://www.easytechjunkie.com/what-is-an-ecg-amplifier.htm

[2] Wikipedia, **Electrocardiography**[2022-09-01], https://en.wikipedia.org/wiki/Electrocardiography

[3] eCircuit Center, **3 Op Amp Instrumentation Amplifier**, http://www.ecircuitcenter.com/Circuits/instamp1/instamp1.htm

Vocabulary

electrocardiogram: 心电图

electrode: 电极

monitor: 监视

enhance: 增强

interference: 干扰

pacemaker: 起搏器

sinoatrial: 窦房

atria: 心房

ventricle: 心室

sinus: 窦性

rhythm: 心律, 节奏

depolarization: 去极化

repolarization: 再极化

squeak: 产生毛刺