INSTRUMENTATION AMPLIFIER

What is an Instrumentation Amplifier?

An instrumentation amplifier is mainly used for amplifying a signal. This amplifier comes under the family of the differential amplifier because it increases the difference among two inputs. The main function of this amplifier is to reduce excess noise that is chosen by the circuit. The capacity to refuse noise is familiar to every IC which are known as the CMRR (common-mode rejection ratio).

The important features of an instrumentation amplifier are

1. High Open loop gain
2. High CMRR
3. High gain stability with low temperature coefficient
4. Low output impedance
5. Low DC Offset

Characteristics of an Instrumentation Amplifier

An instrumentation amplifier is used to amplify very low-level signals, rejecting noise and interference signals. Examples can be heartbeats, blood pressure, temperature, earthquakes and so on. Therefore, the essential characteristics of a good instrumentation amplifier are as follows.

- Inputs to the **instrumentation amplifiers** will have very low signal energy. Therefore, the instrumentation amplifier should have high gain and should be accurate.
- The gain should be easily adjustable using a single control.
- It must have High Input Impedance and Low Output Impedance to prevent loading.
- The Instrumentation amplifier should have High CMRR since the transducer output will usually contain common mode signals such as noise when transmitted over long wires.
- It must also have a High Slew Rate to handle sharp rise times of events and provide a maximum undistorted output voltage swing.

Instrumentation Amplifier using Op Amp

The instrumentation amplifier using op-amp circuit is shown in figure 1. The op-amps 1 & 2 are non-inverting amplifiers and op-amp 3 is a difference amplifier. These three op-amps together, form an instrumentation amplifier. Instrumentation amplifier's final output V_o is the amplified difference of the input signals applied to the input terminals of op-amp 3. Let the outputs of op-amp 1(A_1) and op-amp 2(A_2) be V_1' and V_2' respectively.

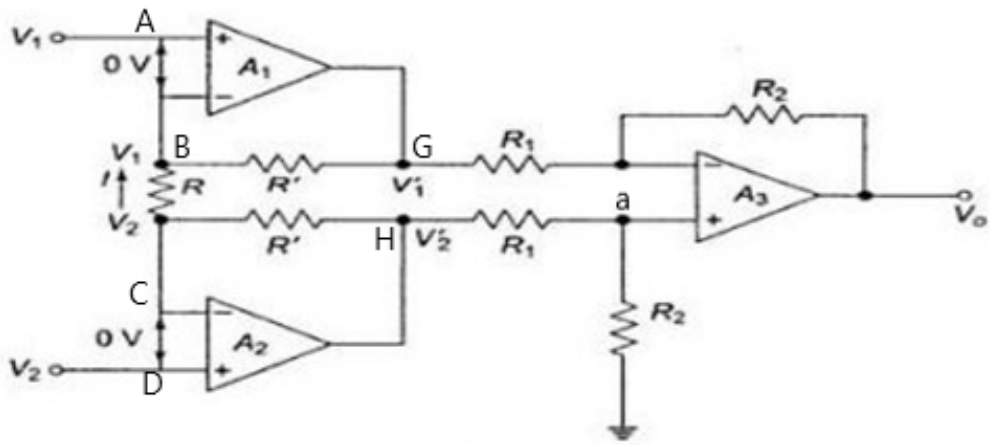

Figure 1. An improved Instrumentation Amplifier

[source:"Linear Integrated Circuits"by D.Roy Choudhry, Shail Bala Jain, Page-158]

The Instrumentation amplifier works in two modes: (i) Common Mode (ii) Differential Mode

Common Mode Operation:

The potential at node A is the input voltage V_1. Hence the potential at node B is also V_1, from the virtual short concept. Thus, the potential at node G is also V_1'.

The potential at node D is the input voltage V_2. Hence the potential at node C is also V_2, from the virtual short. Thus, the potential at node H is also V_2'.

The differential voltage between the two inputs of the operational amplifier is always zero.

If $V_1 = V_2$, the current through the resistor R is zero. The output follows the input and so it acts as voltage follower.Therefore, $V_1' = V_1$ and $V_2' = V_2$

Differential Mode Operation:

In differential mode operation the two input voltages are different. Therefore voltage at node 'a' is defined as:

Voltage at node 'a' is $V_a = V_2' * \left(\frac{R_2}{R_1+R_2}\right)$

Output Voltage $V_o = V_1' * \left(-\frac{R_2}{R_1}\right) + V_a * \left(1 + \frac{R_2}{R_1}\right)$

Substituting V_a

Output Voltage $V_o = V_1' * \left(-\frac{R_2}{R_1}\right) + V_2' * \left(\frac{R_2}{R_1+R_2}\right)\left(1 + \frac{R_2}{R_1}\right)$

Simplifying,

$$\mathbf{Vo} = \left(\frac{R_2}{R_1}\right)[\mathbf{V_2' - V_1'}] \qquad \mathbf{(1)}$$

To find V_1' and V_2':

Consider the Op-amp A_1,Since no current enters the Op-amp, current through R' will be equal to current through R

$$\left(\frac{V_1^{'}-V_1}{R^{'}}\right) = \left(\frac{V_2-V_1}{R}\right)$$

Simplifying,

$$V_1^{'} - V_1 = \left(\frac{R^{'}}{R}\right)\left(V_2 - V_1\right)$$

$$V_1^{'} = \left(\frac{R^{'}}{R}\right)\left(V_2 - V_1\right) + V_1 \qquad \mathbf{(2)}$$

Similarly consider the Op-amp A_2,

$$V_2^{'} = \left(\frac{R^{'}}{R}\right)\left(V_2 - V_1\right) + V_2 \qquad (3)$$

Substitute (2) and (3) in (1)

$$\mathbf{V_o} = \left(\frac{R_2}{R_1}\right)[\mathbf{V_2' - V_1'}]$$

$$V_o = \frac{R_2}{R_1}\left\{\left[\left(\frac{R^{'}}{R}\right)\left(V_2 - V_1\right) + V_2\right] - \left[\left(\frac{R^{'}}{R}\right)\left(V_2 - V_1\right) + V_1\right]\right\}$$

Simplifying,

$$V_o = \frac{R_2}{R_1}\left(\frac{2R^{'}}{R} + 1\right)\left(V_2 - V_1\right)$$

The overall gain of the amplifier is given by the term

$$\frac{R_2}{R_1}\left(\frac{2R^{'}}{R} + 1\right)$$

The overall voltage gain of an instrumentation amplifier can be controlled by adjusting the value of resistor R.The common mode signal attenuation for the instrumentation amplifier is provided by the difference amplifier.

Advantages of Instrumentation Amplifier

The advantages of the instrumentation amplifier include the following.

- The gain of a three op-amp instrumentation amplifier circuit can be easily varied by adjusting the value of only one resistor R.

- The gain of the amplifier depends only on the external resistors used.
- The input impedance is very high due to the emitter follower configurations of amplifiers 1 and 2
- The output impedance of the instrumentation amplifier is very low due to the difference amplifier3.
- The CMRR of the op-amp 3 is very high and almost all of the common mode signal will be rejected.

Applications of Instrumentation Amplifier

The applications of the instrumentation amplifier include the following.

- These amplifiers mainly involve where the accuracy of high differential gain is required, strength must be preserved in noisy surroundings, as well as where huge common-mode signals are there. Some of the applications are
- Instrumentation amplifiers are used in data acquisition from small output transducers like thermocouples, strain gauges, measurements of Wheatstone bridge**, etc.**
- These amplifiers are used in navigation, medical, radar, etc.
- These amplifiers are used to enhance the S/N ratio **(**signal to noise**)** in audio applications like audio signals with low amplitude.
- These amplifiers are used for imaging as well as video data acquisition in the conditioning of high-speed signal.
- These amplifiers are used in RF cable systems for amplification of the high-frequency signal.