The Design of Instrumentation Amplifier with Offset Control

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OBJECTIVE

Designing and observing the instrumentation amplifier with offset control, calculating CMRR and cut-off frequencies.

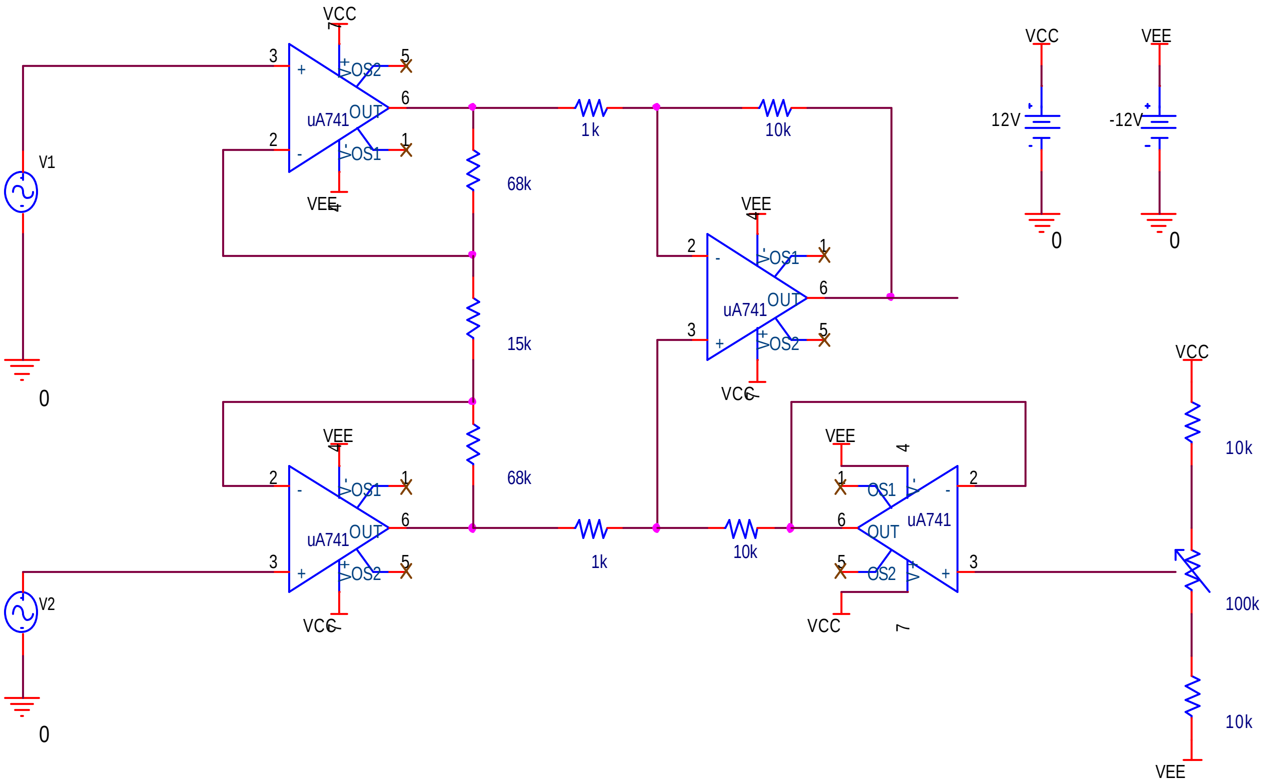
REQUIRED EQUIPMENT

4 x 741 Operational Amplifier
2 x 68 kΩ Resistor
4 x 10 kΩ Resistor
2 x 1 kΩ Resistor
1 Oscilloscope

1 x 15 kΩ Resistor
1 x 100 kΩ Potentiometer
1 ± 12 V Power Supply
1 Signal Generator
1 Multimeter

THEORY and METHOD

An instrumentation amplifier (IA) is a difference amplifier meeting the extremely high common – mode and differential – mode input impedances, very low output impedance and extremely high common – mode rejection ratio. The instrumentation amplifier can be used to amplify a low – level signal in the presence of large common – mode signals, such as in process of control systems and biomedical systems.



In figure above the first operational amplifiers from left side are referred as input stage, and the other operational amplifier is referred output stage. The voltage across 15 kΩ is $V_1 - V_2$ is used to calculate first stage amplifier gain. By the input voltage constraint, the 68 kΩ resistances carry the same current as 15 kΩ.

$$(V_{O1} - V_{O2}) = \frac{1}{R_G} \; (R_3 + R_G + R_3)(V_1 - V_2)$$

$$(V_{O1} - V_{O2}) = \left(1 + \frac{2R_3}{R_G}\right)(V_1 - V_2)$$

where R_3 is 68 kΩ, R_G is 15 kΩ in the figure.

This input stage is also referred as a difference – input, difference – output amplifier. After this calculation, we have to calculate output stage gain in order to obtain overall gain for instrumentation amplifier.

$$V_O = \frac{R_2}{R_1} (V_{O2} - V_{O1})$$

Combining the equations;

$$V_O = A\,(V_2 - V_1)$$

$$A = A_i \text{ x } A_{II} = \left(1 + \frac{2R_3}{R_G}\right)\left(\frac{R_2}{R_1}\right)$$

Theoretically the gain of our design is :

$$A = \left(1 + \frac{2x68k}{15k}\right)\left(\frac{10k}{1k}\right) = 100\,,\,667$$

There are applications that call for prescribed amount of offset at the output of an instrumentation amplifier. Because the instrumentation amplifier output is usually bipolar, it must be suitably offset so as to ensure a unipolar range. In figure above the 4th amplifier is used to ensure offset voltage range for IA output. This voltage is obtained from the wiper of potentiometer (100 kΩ) and is buffered by 741 type operational amplifier. With component values shown in figure, V_{REF} is variable from -10 V to +10 V. Therefore, gain is described again with offset;

A = 100,667 + V_{REF}

PROCEDURES and ANALYSIS

When applying difference mode input voltage :

- Vin (V_1) = 20 mV then obtained Vout = 1.96 V A = 98
  Vin (V_2) = 0 V
- Vin (V_1) = 30 mV then obtained Vout = 2.97 V A = 99
  Vin (V_2) = 0V
- Vin (V_1) = 40 mV then obtained Vout = 3.9 V A= 97.5
  Vin (V_2) = 0V

Aort = 98,167 = A_{DM}

When applying common mode input voltage :

We used multimeter to measure the input and output voltages because common mode signals are very low to measure with oscilloscope.

- Vin (RMS) = 0.632 V then obtained Vout (RMS) ˜ 1 mV A = 1.58×10^{-3}
- Vin (RMS) = 1.202 V then obtained Vout (RMS) ˜ 2 mV A = 1.66×10^{-3}
- Vin (RMS) = 2.412 V then obtained Vout (RMS) ˜ 3 mV A = 1.24×10^{-3}

Aort = 1.493×10^{-3} = A_{CM}

Measuring CMRR :

$$= 20 \log \left|\frac{Adm}{Acm}\right| = 20 \log \left|\frac{98.167}{1.493x10^{-3}}\right| = 96{,}358$$

Measuring roll-off frequencies :

Ideally operational amplifiers have infinite bandwidth, this means that all frequencies will be amplified equally. However, practical operational amplifiers tend to roll-off at high frequencies. The point where the gain is 3 dB from the full gain dc value is called the open – loop -3 dB point.

We measured the lower roll-off frequency by decreasing applied frequency of the signal generators then we measured about **2 – 4 Hz** at low frequencies. However, oscilloscope is not sensitive to measure low frequencies. Low frequency measuring might be inconvenience.
When we measured the higher roll-off frequency by increasing applied frequency of the signal generators then we measured **60.8 kHz** at high frequencies.

The effects of offset circuit design :

When the input signal to an ideal operational amplifier is exactly zero, the output will be exactly zero. This is referred to as zero offset. Practical devices usually exhibits some degree of offset. This comes from minor imbalances within the circuitry of the operational amplifier itself.

In many circuits some sort of provision for correcting the input offset must be provided. This is necessary for highly critical applications.

In our design, we add one more operational amplifier to make provision for correcting input offset and 100 kΩ pot as shown figure below. With this configuration, V_{REF} is variable from -10 V to +10 V.