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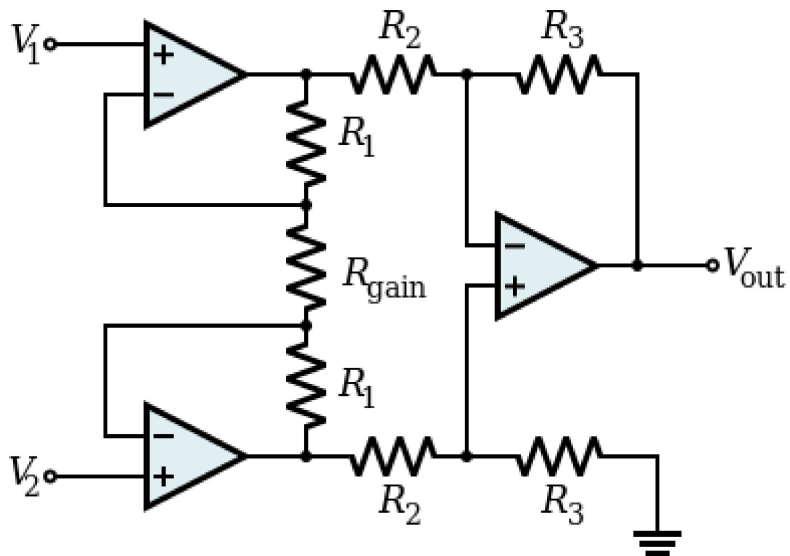# Instrumentation amplifier

An **instrumentation** (or **instrumentational**) **amplifier** is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short and long-term are required.

Typical instrumentation amplifier schematic

Although the instrumentation amplifier is usually shown schematically identical to a standard operational amplifier (op-amp), the electronic instrumentation amp is almost always internally composed of 3 op-amps. These are arranged so that there is one op-amp to buffer each input (+,−), and one to produce the desired output with adequate impedance matching for the function.[1][2]

The most commonly used instrumentation amplifier circuit is shown in the figure. The gain of the circuit is

$$\frac{V_{\text{out}}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{\text{gain}}}\right)\frac{R_3}{R_2}$$

The rightmost amplifier, along with the resistors labelled R_2 and R_3 is just the standard differential amplifier circuit, with gain = R_3/R_2 and differential input resistance = $2 \cdot R_2$. The two amplifiers on the left are the buffers. With R_{gain} removed (open circuited), they are simple unity gain buffers; the circuit will work in that state, with gain simply equal to R_3/R_2 and high input impedance because of the buffers. The buffer gain could be increased by putting resistors between the buffer inverting inputs and ground to shunt away some of the negative feedback; however, the single resistor R_{gain} between the two inverting inputs is a much more elegant method: it increases the differential-mode gain of the buffer pair while leaving the common-mode gain equal to 1. This increases the common-mode rejection ratio (CMRR) of the circuit and also enables the buffers to handle much larger common-mode signals without clipping than would be the case if they were separate and had the same gain. Another benefit of the method is that it boosts the gain using a single resistor rather than a pair, thus avoiding a resistor-matching problem, and very conveniently allowing the gain of the circuit to be changed by changing the value of a single resistor. A set of switch-selectable resistors or even a potentiometer can be used for R_{gain}, providing easy changes to the gain of the circuit, without the complexity of having to switch matched pairs of resistors.

The ideal common-mode gain of an instrumentation amplifier is zero. In the circuit shown, common-mode gain is caused by mismatch in the resistor ratios R_2/R_3 and by the mis-match in common mode gains of the two input op-amps. Obtaining very closely matched resistors is a significant difficulty in fabricating these circuits, as is optimizing the common mode performance.[3]

An instrumentation amp can also be built with two op-amps to save on cost, but the gain must be higher than two (+6 dB).[4][5]

Instrumentation amplifiers can be built with individual op-amps and precision resistors, but are also available in integrated circuit form from several manufacturers (including Texas Instruments, Analog Devices, Linear Technology and Maxim Integrated Products). An IC instrumentation amplifier typically contains closely matched laser-trimmed resistors, and therefore offers excellent common-mode rejection. Examples include AD8221 (http://www.analog.com/ en/amplifiers-and-comparators/instrumentation-amplifiers/ad8221/products/product.html), MAX4194 (http://ww w.maxim-ic.com/quick_view2.cfm/qv_pk/2006), LT1167 (http://www.linear.com/1167) and INA128 (http://focus.ti. com/docs/prod/folders/print/ina128.html).

Instrumentation Amplifiers can also be designed using "Indirect Current-feedback Architecture", which extend the operating range of these amplifiers to the negative power supply rail, and in some cases the positive power supply rail. This can be particularly useful in single-supply systems, where the negative power rail is simply the circuit ground (GND). Examples of parts utilizing this architecture are MAX4208/MAX4209 (http://www.maxim-ic.com/quick_vie w2.cfm/qv_pk/4925) and AD8129/AD8130 (http://www.analog.com/en/audiovideo-products/video-ampsbuffersfilte rs/ad8129/products/product.html).

Feedback-free instrumentation amplifier is the high input impedance differential amplifier designed without the external feedback network. This allows reduction in the number of amplifiers (one instead of three), reduced noise (no thermal noise is brought on by the feedback resistors) and increased bandwidth (no frequency compensation is needed). Chopper stabilized (or zero drift) instrumentation amplifiers such as the LTC2053 (http://www.linear.com/p roduct/LTC2053) use a switching input front end to eliminate DC offset errors and drift.

See also

- Isolation amplifier
- Operational amplifier applications

References

1. R.F. Coughlin, F.F. Driscoll *Operational Amplifiers and Linear Integrated Circuits* (2nd Ed.1982. ISBN 0-13-637785-8) p.161.
2. Moore, Davis, Coplan *Building Scientific Apparatus* (2nd Ed. 1989 ISBN 0-201-13189-7)p.407.
3. Smither, Pugh and Woolard: 'CMRR Analysis of the 3-op-amp instrumentation amplifier', Electronics letters, Volume 13, Issue 20, 29 September 1977, page 594.
4. "Don't fall in love with one type of instrumentation amp - 2002-05-30 07:00:00" (http://edn.com/design/analog/434 6481/Don-t-fall-in-love-with-one-type-of-instrumentation-amp). EDN. Retrieved 2014-10-28.
5. "Amplifiers for bioelectric events: a design with a minimal number of parts" (http://www.biosemi.com/publications/a rtikel7.htm). Biosemi.com. Retrieved 2011-10-03.

External links

- Opamp Instrumentation Amplifier (http://www.ecircuitcenter.com/Circuits/instamp1/instamp1.htm)
- The instrumentation amplifier (http://www.allaboutcircuits.com/vol_3/chpt_8/10.html)
- Lessons In Electric Circuits — Volume III — The instrumentation amplifier (http://www.ibiblio.org/kuphaldt/electric Circuits/Semi/SEMI_8.html#xtocid100169)
- A Practical Review of Common Mode and Instrumentation Amplifiers (http://www.analog.com/static/imported-files/ tech_articles/25406877Common.pdf) (PDF)
- The Instrumentation Amplifier (https://web.archive.org/web/20051103024038/http://www.univie.ac.at/cga/courses/ BE513/Instrumentation/)
- A Designer's Guide to Instrumentation Amplifiers (3rd Edition) (http://www.analog.com/en/education/education-libr ary/dh-designers-guide-to-instrumentation-amps.html)

- Three is a Crowd for Instrumentation Amplifiers (http://www.maxim-ic.com/appnotes.cfm/appnote_number/4034/)
- Instrumentation Amplifier Solutions, Circuits and Applications (http://www.linear.com/products/instrumentation_amplifiers)
- Fixed-gain CMOS differential amplifiers with no external feedback for a wide temperature range (Cryogenics) (https://dx.doi.org/10.1016/j.cryogenics.2008.12.014)

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