Instrumentational Amplifiers

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INTRODUCTION

One of the most useful analog subsystems is the true instrumentation amplifier. It can faithfully amplify low level signals in the presence of high common mode noise. This aspect of its performance makes it especially useful as the input amplifier of a signal processing system. Other features of the instrumentation amplifier are high input impedance, low input current, and good linearity.

It has never been easy to design a high performance instrumentation amplifier; however, the availability of high performance IC's considerably simplifies the problem. IC op amps are available today that can give very low drifts as well as low bias currents; however, most of the circuits have some drawbacks.

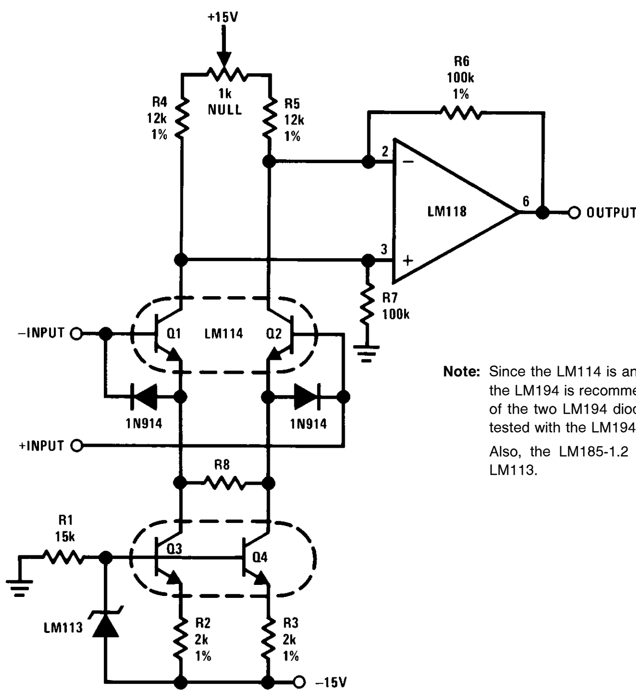
The most commonly used instrumentation amplifier designs utilize either 2 or 3 op amps and several precision resistors. These are capable of excellent performance; however, for high performance they require very precisely matched resistors. The common mode rejection of these designs depends on resistor matching and overall gain. Since op amps are now available with exceedingly high CMRR, this is no longer a problem. The CMRR of the instrumentation amplifier is approximately equal to half resistor mismatch plus the gain. For a 1% resistor mismatch the CMRR is limited to 46 dB plus the gain—referred to the input.

Referred to the output, the common mode error is independent of gain and fixed by the resistor mismatch. For 1% match the error is 0.5%, and for 0.1% match the error is 0.05%. These errors are not trivial in high precision systems.

An instrumentation amplifier is shown here that compares favorably with multiple op amp designs, yet does not require precisely matched resistors. Further, the design allows a single resistor to adjust the gain. In comparing this instrumentation amp to multiple op amp types there are of course some drawbacks. The gain linearity and accuracy are not as good as the multiple op amp circuits.

The errors appearing in multiple op amp circuits are independent of the output signal level. For example, a common mode error at the output of 0.5% of full scale is a 33% error if the desired output signal is only 1.5% of full scale. With the new circuit maximum errors at full scale output and the percentage of output error decreases at lower output levels.

Figure 1 shows a general purpose instrumentation amplifier optimized for wide bandwidth. It can provide gains from under 1 to over 1000 with a single resistor adjustment. Gain linearity is worst for unity-gain at 0.4%, and gain stability is better than 1.5% from −55°C to +125°C. Typically over a 0°C to +70°C range gain stability is 0.2%. Common mode rejection ratio is about 100 dB—independent of gain.



Note: Since the LM114 is an obsolete part, substitution of the LM194 is recommended, along with the removal of the two LM194 diodes. This circuit has not been tested with the LM194 included.

Also, the LM185-1.2 could be substituted for the LM113.

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FIGURE 1. Instrumentation Amplifier

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Transistor pair, Q1 and Q2, are operated open-loop as the input stage to give a floating, fully differential input. Current sources, Q3 and Q4, set the operating current of the input pair. To obtain good linearity the output current of Q3 and Q4 are set at about twice the current in R8 at full differential voltage. The temperature sensitivity of the transconductance of Q1 and Q2 is compensated by making their operating current directly proportional to absolute temperature. It has been shown that by biasing the base of transistor current sources at 1.22V, the output current varies as absolute temperature. The LM113 diode provides a constant 1.22V to the current sources. Both the compensated gm of Q1 and Q2 and the large degeneration from R8 give the amplifier stable gain over a wide temperature range.

In operation, transistors Q1 and Q2 convert a differential input voltage to a differential output current at their collectors. This is fed into a standard differential amplifier to obtain a single ended output voltage. Since the diff amp does not see the common mode input voltage, 1% resistors are adequate. Gain is set by the ratio of R8 (plus the r_e of Q1 and Q2) to the sum of R6 and R7.

As mentioned previously this circuit is optimized for wide bandwidth: however, it is easily modified for other applications. If low bias current is needed, all resistors can be increased by a factor of 100 and an LM108 substituted for the LM318. Other possible improvements are cascaded current sources and a modified Darlington input stage.

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