

by Adolfo A. Garcia

# Designing the LT1167 Instrumentation Amplifier into a Single 5V Supply Application

## Introduction

In many single-supply applications, the need for precision amplifiers that can operate from 5V (or less) remains strong. While there are many precision, single-supply operational amplifiers currently available on the market that can be configured into 2- and 3-amplifier instrumentation circuits, these designs require great attention to detail to achieve accuracy and precision. Furthermore, although there are single-supply instrumentation amplifier devices on the market, these products trade DC and AC performance for low supply voltage/current operation. Dual-supply instrumentation amplifiers still offer the best performance.

Achieving high precision performance in a single-supply application is practical because the majority of sensor applications provide an output signal centered about the midpoint of a circuit's supply voltage or a reference voltage. Examples of such sensors include strain gauges, load cells and pressure transducers. In these applications, the signal-conditioning circuit is not required to

operate near the sensor or circuit's positive supply voltage or ground (common). Even though the signal conditioning circuitry need not operate at the extremes of the supply voltage range, the output voltage swing of the circuit should be as large as possible for maximum dynamic range.

The circuit illustrated in Figure 1 achieves high precision performance while operating from a single 5V supply. The trick here is to reference the dual-supply instrumentation amplifier's inputs to a stable midpoint supply and then follow the instrumentation amplifier with a single-supply precision operational amplifier with a rail-to-rail output stage. This "composite" instrumentation amplifier uses an LT1167 (a high performance instrumentation amplifier in an SO-8 package) for the input stage and an LT1498 (a high speed, precision, rail-to-rail input/output, dual operational amplifier) for the output stage. A stable 5V supply midpoint is provided by the LT1634, a micropower 2.5V precision shunt reference.

## Circuit Operation

Here's how the circuit works: The output of the LT1634 shunt reference (U3) is applied to the input of an LT1498 (U2A) configured as a voltage follower. The output of U2A provides a low impedance source required by the LT1167's output reference pin (U1-5) which exhibits a 20k input resistance and an input current of 50 $\mu$ A. A low impedance source is required to maintain the LT1167's high common mode rejection performance. In addition, U2A's output stage can source load currents to 20mA for biasing other external circuitry, without affecting the LT1634's accuracy. The other half of the LT1498 (U2B) is configured as a gain-of-3 inverter so that its output can swing  $\pm 2.5$ V "rail-to-rail" with only  $\pm 0.82$ V drive from the LT1167. The primary reason for choosing an inverting amplifier configuration for the output stage is to make available system DC offset adjustments. Trim networks can be connected to the inverting terminal of U2B without affecting the static or dynamic behavior of the circuit. However, the trim range should be designed so as not to adversely affect the output dynamic range of the circuit.

The LT1167's high linearity performance is maintained on a single 5V supply because its front end has been configured to operate on dual supplies and its output drive level has been relaxed. Because the entire circuit has been level shifted above ground by the LT1634, the circuit's final output voltage must be measured with respect to 2.5V, not 0V.

An expression for the gain of this composite instrumentation amplifier combines the gain equations of the LT1167 and the gain-of-3 inverter.

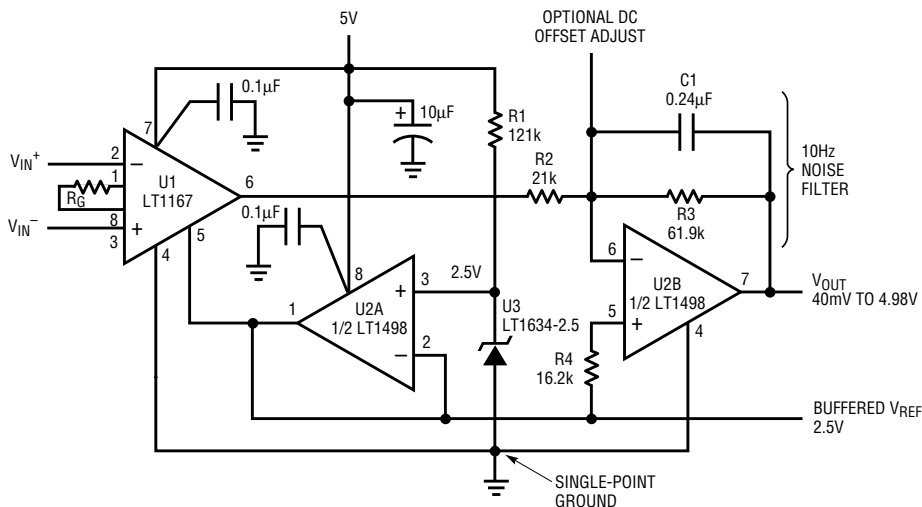


Figure 1. Single-supply instrumentation amplifier with rail-to-rail output stage

This is given by:

$$\text{GAIN} = \left[ 1 + \left( \frac{49.4\text{k}\Omega}{R_G} \right) \right] \times \left( \frac{R3}{R2} \right)$$

A gain-of-100 composite configuration is realized with  $R_G = 1.5\text{k}$ . Other gain settings can be realized with various values of  $R_G$ , as illustrated in Table 1.

Even though the inputs to the circuit are not required to operate at the positive rail or at ground, wide input common mode operation is always beneficial. In this configuration, the LT1167 input stage can accept signals up to 3.7V (common mode plus differential mode) with no loss of precision. In fact, at low circuit gains, the circuit's common mode input voltage range spans 2.25V to 3.45V. This wide input common mode range allows room for the full-scale differential input voltage to drive the output  $\pm 2.5\text{V}$  about the reference point ( $V_{\text{REF}}$ ). Here's another application hint regarding this circuit: though the LT1167's input bias currents are less than 1nA, the differential input terminals still require a DC return path to ground. For more information regarding this topic, please consult the LT1167 data sheet.

The static and dynamic performance of the composite instrumentation amplifier is summarized in Table 1.

**Table 1. Performance summary of 5V single-supply instrumentation amplifier with rail-to-rail outputs**


Circuit Gain	$R_G$ ( $\Omega$ )	$V_{\text{OS}}$ , RTI* ( $\mu\text{V}$ )	$\text{TCV}_{\text{OS}}$ , RTI* ( $\mu\text{V}/^\circ\text{C}$ )	Nonlinearity	Bandwidth (kHz) w/o C1	0.1Hz to 10Hz Noise, RTI* ( $\mu\text{V}_{\text{P-P}}$ )
10	20.5k	1300	6.5	< 0.006%	900	2
30	5.36k	450	2.3	< 0.006%	850	0.7
100	1.5k	160	0.8	< 0.006%	500	0.4
300	487	100	0.5	< 0.006%	160	0.3
1000	147	90	0.4	< 0.006%	40	0.3

\*RTI is an acronym for error "referred to input."

The transient response of the circuit as a function of gain and load is well behaved, and is attributable to the LT1498's wideband rail-to-rail output stage. Its 10MHz gain-bandwidth product and 6V/ $\mu\text{s}$  slew rate ensure that the small-signal performance of the circuit is dominated by the LT1167. Capacitor C1 is recommended for low frequency applications (signal bandwidths <20Hz) to eliminate or significantly reduce noise pickup. Noise can also be injected into the circuit via the input terminals of the LT1167, especially if the sensor is located remotely from the signal conditioning circuitry. This type of noise can cause a shift in the input offset voltage of the LT1167, thereby producing an error. This effect

is commonly known as RFI rectification. A differential filter can be easily added to the LT1167's input terminals to reduce the effects of RFI rectification. Please consult the LT1167 data sheet for additional information on this topic.

## Conclusion

As this design idea illustrates, the precision DC performance of a dual-supply instrumentation amplifier can be successfully applied to single-supply, bridge-type sensor applications using a precision rail-to-rail dual operational amplifier. The combination of the LT1167, the LT1498 and the LT1634 yields a cost-effective solution for 14-bit signal conditioning applications. 

For more information on parts featured in this issue, see <http://www.linear-tech.com/go/ltmag>

for  
the latest information  
on LTC products,  
visit  
[www.linear-tech.com](http://www.linear-tech.com)