

Comparing dual-supply discrete and integrated instrumentation amplifiers

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Introduction

The advantages and disadvantages of designing a discrete instrumentation amplifier (IA) versus an integrated IA are numerous and often debated. Some of the variables to consider include printed circuit board (PCB) area, gain range, performance (over temperature) and cost. The purpose of this article is to compare three dual-supply IA circuits: a discrete IA using a quad operational amplifier (op amp), a general-purpose IA with an integrated gain-setting resistor (R_G) and a precision IA with an external R_G .

Dual-supply circuits

Figure 1 is a simplified schematic of a discrete, dual-supply IA using the Texas Instruments (TI) TLV9064 quad op-amp circuit. In this circuit, three of the four amplifier channels (A, B and C) are connected as a traditional three-op-amp IA. The reference voltage (V_{REF}) connects to ground. With no use for the fourth channel, D, it is therefore connected as a buffer to mid-supply (ground) through a resistor for transient robustness. All resistors labeled “R” have a value of 10 k Ω ; R_G sets the differential gain. The differential input voltage is $V_{IN+} - V_{IN-}$ and the output voltage is V_{OUT} . Some components, such as the load resistor (10 k Ω) and decoupling capacitors, are not shown. Drawing all circuits from a package perspective illustrates the number of external discrete components.

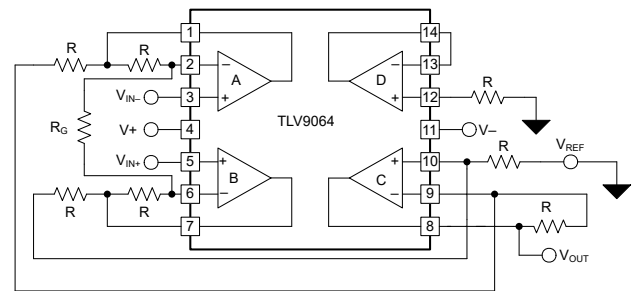


Figure 1. A discrete dual-supply IA using a quad op amp.

Equation 1 gives the transfer function for this circuit:

$$V_{OUT} = (V_{IN+} - V_{IN-}) \times \left[1 + \frac{20 \text{ k}\Omega}{R_G} \right] \quad (1)$$

Designers will typically select a discrete IA when PCB area and performance are secondary to cost and gain range. TI’s **TLV9064IRUCR** op amp was selected for this comparison because it is a rail-to-rail input/output device (RRIO) with a wide bandwidth (10 MHz) and a low typical initial input offset voltage ($V_{OS(typ)} = 300 \mu\text{V}$), and comes in a small package (RUC = X2QFN = 4 mm²). While there are less expensive RRIO quad op amps in RUC/X2QFN packages, they come at the expense of bandwidth and typical offset voltage.

To be consistent with the design priorities of discrete IAs, inexpensive $\pm 1\%$ tolerance, $\pm 100\text{-ppm}/^\circ\text{C}$ drift resistors were installed. Not only do these resistors differ in initial value, they will likely drift significantly over temperature. Since R_G is external, the gain for this configuration is primarily limited by the input offset voltage of the op amps.

Figure 2 is a simplified schematic of the TI **INA350ABS**, a general-purpose dual-supply IA with an integrated R_G . V_{REF} connects to ground. This circuit integrates all resistors in the IA. The differential input voltage is $V_{IN+} - V_{IN-}$ and the output voltage is V_{OUT} . Some components, such as the load resistor (10 k Ω) and decoupling capacitors, are not shown. The gain of the IA is set based on the switch connected to pin 1 (open = 20 V/V, closed = 10 V/V). In an actual application, the switch would not be present. To enable the device, connect pin 8 (SHDN) to $V+$ or leave it floating.

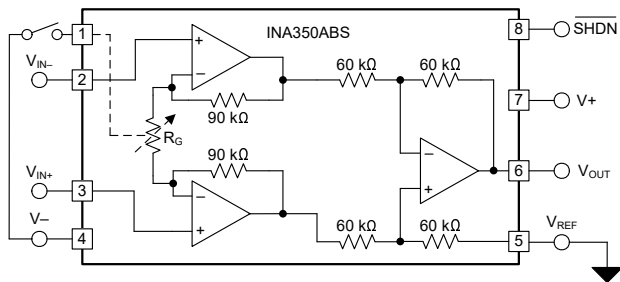


Figure 2. General-purpose dual-supply IA with an integrated R_G .

Equation 2 gives the transfer function for this circuit:

$$V_{OUT} = (V_{IN+} - V_{IN-}) \times \left[10 \frac{V}{V} \text{ or } 20 \frac{V}{V} \right] \quad (2)$$

Designers will typically select this IA when their requirements necessitate a balance of cost, performance and PCB area. The **INA350ABSIDSGR** IA was chosen for this comparison because of its affordability, performance, small package (lead DSG = WSON = 4 mm²), selectable gain (10 V/V or 20 V/V) and low typical input offset voltage ($V_{OS(typ)} = 200 \mu\text{V}$). This implementation needs no external components. For designs that require higher gains, the **INA350CDS** has gains of 30 V/V or 50 V/V.

Figure 3 is a simplified schematic of the TI **INA333** precision dual-supply IA with an external R_G . V_{REF} connects to ground. In this circuit, the IA integrates all resistors except R_G . The differential input voltage is $V_{IN+} - V_{IN-}$ and the output voltage is V_{OUT} . Some components, such as the load resistor (10 k Ω) and decoupling capacitors, are not shown.

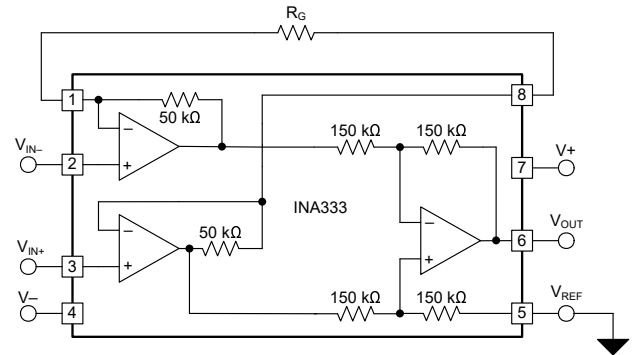


Figure 3. Precision dual-supply IA with an external R_G .

Equation 3 gives the transfer function for this circuit:

$$V_{OUT} = (V_{IN+} - V_{IN-}) \times \left[1 + \frac{100 \text{ k}\Omega}{R_G} \right] \quad (3)$$

Designers typically use a precision IA when performance is the highest priority. The **INA333AIDRGR** precision IA was selected for this comparison because it is low voltage (5 V), has excellent precision ($G = 1 \text{ V/V}$, $V_{OS(typ)} = 35 \mu\text{V}$) and comes in a small package (DRG = WSON = 9 mm²). The performance over temperature depends on the selection of the external R_G . Therefore, to be consistent with the primary design priority – performance – we used a precision R_G for a gain of 10 V/V ($\pm 0.05\%$, $\pm 10 \text{ ppm}/^\circ\text{C}$). Because the precision op amps are integrated, this implementation has excellent gain range (1 V/V to 1,000 V/V). The overall cost is usually greater than the other two solutions, however, given the integrated precision op amps and required precision R_G .

PCB layout

A PCB specifically designed for this comparison, containing the three circuits outlined above in a circular region, upon which the nozzle of a temperature forcing unit would fit. Care was taken to present the same input signal to each circuit, alleviating any concern for “leakage.” Each output was routed separately to ensure isolation.

Figure 4 shows a simplified layout of each IA circuit to compare the relative sizes of each solution, including decoupling capacitors. For comparison purposes, the smallest device packages were used, along with resistors and capacitors in the 0402 package.

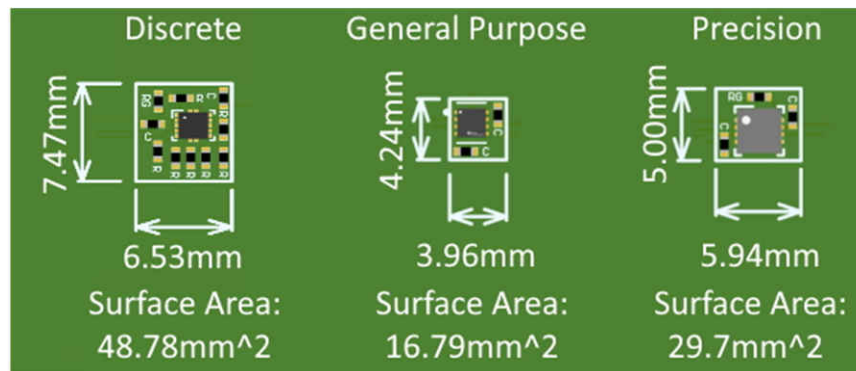


Figure 4. Simplified PCB layout comparison for dual-supply IA circuits.

As you can see, the discrete IA implementation is significantly larger than the two integrated solutions. And with the integrated R_G and overall smaller die size, the general-purpose IA layout is almost half the size of the precision IA layout.

Measurement results

Gain and offset errors were used as a measure of the relative performance of each circuit across temperature. As a baseline measurement, the precision dual-supply IA was put in a gain of 1 V/V ($R_G = \text{open}$). For each sweep, the input signals were scaled such that the output voltage ranged from -2 V to +2 V.

Table 1 depicts the baseline gain and offset errors for the precision IA, $G = 1$ V/V across temperature. The table includes the data sheet’s typical gain and offset error values at 25°C, to validate the measurement system.

Temperature	-40°C		0°C		25°C		100°C		125°C	
	Gain	Offset	Gain	Offset	Gain	Offset	Gain	Offset	Gain	Offset
Measured (data sheet typical)	0.00270%	10.1 μ V	0.00019%	9.1 μ V	-0.00281% (\pm 0.01%)	7.5 μ V (\pm 35 μ V)	-0.00523%	23.5 μ V	-0.00572%	31.2 μ V

Table 1. Precision IA gain and offset error vs. temperature ($G = 1$ V/V).

Table 2 depicts the gain and offset error (referred-to-output [RTO]) for all IAs in a gain of 10 V/V and across temperature. The green shading indicates the highest-performing implementation at each temperature.

Temperature	-40°C		0°C		25°C		100°C		125°C	
Error Type	Gain	Offset	Gain	Offset	Gain	Offset	Gain	Offset	Gain	Offset
Discrete IA	-0.60853%	-4.09 mV	-0.70079%	-3.67 mV	-0.73929%	-4.07 mV	-0.90846%	-4.07 mV	-0.95486%	-3.69 mV
General-purpose IA	-0.02532%	2.07 mV	-0.03182%	2.05 mV	-0.00250%	2.04 mV	0.00876%	2.12 mV	-0.00970%	2.21 mV
Precision IA	0.17320%	-58.8 μV	0.08103%	-43.2 μV	0.02941%	-35.2 μV	-0.06125%	-2.2 μV	-0.07883%	33.8 μV

Table 2. Gain and offset error (RTO) vs. temperature (Gain = 10 V/V).

From a performance perspective, **Table 1** and **Table 2** show that without an external R_G , the precision dual-supply IA is superior to all other solutions. From a gain error perspective, the general-purpose and precision IA solutions are comparable. This is primarily because of the external R_G required for the $G = 10$ V/V precision IA implementation, whereas the general-purpose solution integrates R_G . When looking at the offset error, the precision IA solution is clearly the most accurate, while the general-purpose offset error is about half that of the discrete solution. Overall, the discrete IA has significantly worse performance when compared to both integrated solutions.

Conclusion

While many designers typically implement a discrete solution in low-cost applications, new general-purpose IAs (TI’s **INA350**, for example) will likely yield lower overall cost and better performance. Depending on the gain, precision IAs such as the **INA333** can offer superior performance and gain range, although the external R_G is an important factor in performance, especially over temperature.

Table 3 summarizes the comparison.

	PCB Area	Gain Range	Performance	Cost
Discrete IA	48.78 mm ²	1 V/V to @100 V/V	Good	\$\$
General-purpose IA	16.79 mm ²	10, 20, 30, 50 V/V	Better	\$
Precision IA	29.7 mm ²	1 V/V to 1,000 V/V	Best	\$\$\$\$

Table 3. Comparison of dual-supply IA circuit solutions.

The next time you are designing a dual-supply IA, weigh the trade-offs outlined in this article. For applications that require the greatest accuracy, precision IAs are the obvious choice. For applications that require cost-effective performance, the choice is no longer as easy as building a discrete IA. New general-purpose IAs can provide significantly better performance than discrete solutions, while taking up less PCB area and lowering system costs at the same time.

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