# Basic Two Op Amp In-Amp Configuration

In-amps are based on op amps, and there are two basic configurations that are extremely popular. The first is based on two op amps, and the second on three op amps. The circuit shown in Figure 1 is referred to as the *two op amp in-amp*. Dual precision IC op amps are used in most cases for good matching, such as the OP297 or the OP284. The resistors are usually a thin film laser trimmed array on the same chip. The in-amp gain can be easily set with an external resistor, $R_G$. Without $R_G$, the gain is simply 1 + R2/R1. In a practical application, the R2/R1 ratio is chosen for the desired minimum in-amp gain.

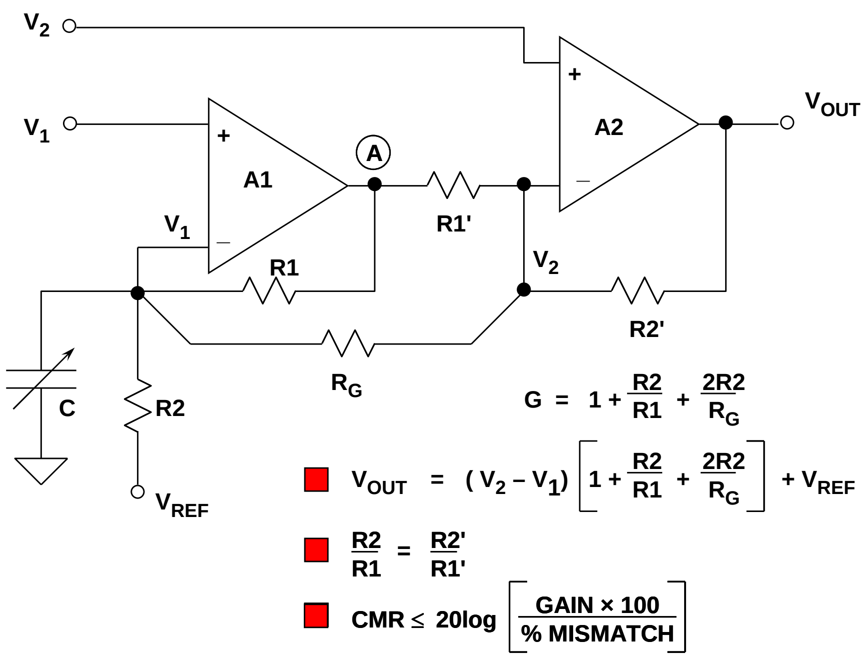



***Figure 1: The Two Op Amp Instrumentation Amplifier***

The input impedance of the two op amp in-amp is inherently high, permitting the impedance of the signal sources to be high and unbalanced. The dc common-mode rejection is limited by the matching of R1/R2 to R1'/R2'. If there is a mismatch in any of the four resistors, the dc common mode rejection is limited to:

$$\mathrm{CMR} \le 20\log\left[\frac{\mathrm{GAIN}\times 100}{\%\mathrm{MISMATCH}}\right]. \qquad \text{Eq. 1}$$

Notice that the net CMR of the circuit increases proportionally with the working gain of the in-amp, an effective aid to high performance at higher gains.

IC in-amps are particularly well suited to meeting the combined needs of ratio matching and temperature tracking of the gain-setting resistors. While thin film resistors fabricated on silicon have an initial tolerance of up to ±20%, laser trimming during production allows the ratio error between the resistors to be reduced to 0.01% (100 ppm). Furthermore, the tracking between the temperature coefficients of the thin film resistors is inherently low and is typically less than 3 ppm/ºC (0.0003%/ºC).

When dual supplies are used, $V_{REF}$ is normally connected directly to ground. In single supply applications, $V_{REF}$ is usually connected to a low impedance voltage source equal to one-half the supply voltage. The gain from $V_{REF}$ to node "A" is R1/R2, and the gain from node "A" to the output is R2'/R1'. This makes the gain from $V_{REF}$ to the output equal to unity, assuming perfect ratio matching. Note that it is critical that the source impedance seen by $V_{REF}$ be low, otherwise CMR will be degraded.

One major disadvantage of the two op amp in-amp design is that common mode voltage input range must be traded off against gain. The amplifier A1 must amplify the signal at $V_1$ by 1 + R1/R2. If R1 >> R2 (a low gain example in Figure 1), A1 will saturate if the $V_1$ common mode signal is too high, leaving no A1 headroom to amplify the wanted differential signal. For high gains (R1<< R2), there is correspondingly more headroom at node "A", allowing larger common mode input voltages.

The ac common mode rejection of this configuration is generally poor because the signal path from $V_1$ to $V_{OUT}$ has the additional phase shift of A1. In addition, the two amplifiers are operating at different closed-loop gains (and thus at different bandwidths). The use of a small trim capacitor "C" as shown in Fig. 1 can improve the ac CMR somewhat.

A low gain (G = 2) single supply two op amp in-amp configuration results when $R_G$ is not used, and is shown above in Figure 2.

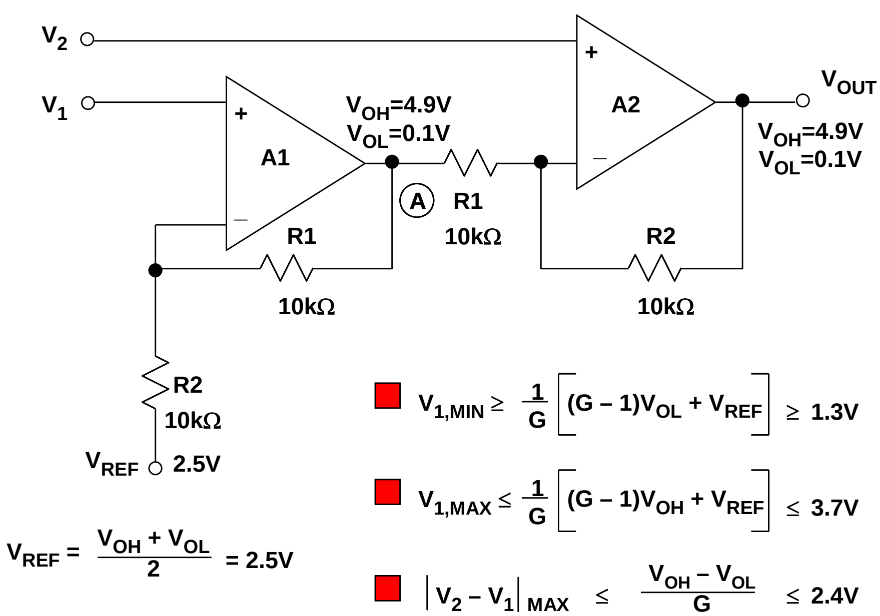
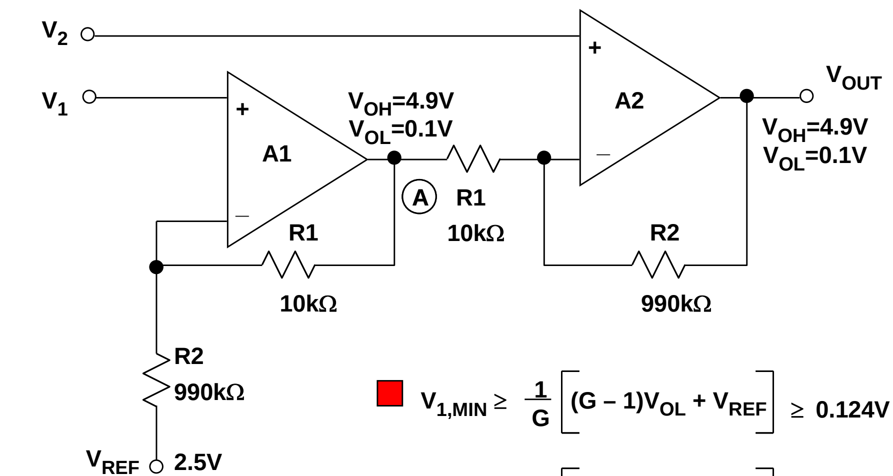



***Figure 2: Two Op Amp In-Amp Single-Supply Restrictions for $V_S$ = +5V, G = 2***

The input common mode and differential signals must be limited to values which prevent saturation of either A1 or A2. In the example, the op amps remain linear to within 0.1 V of the supply rails, and their upper and lower output limits are designated $V_{OH}$ and $V_{OL}$, respectively. These saturation voltage limits would be typical for a single-supply, rail-rail output op amp (such as the AD822, for example).

Using the Fig. 2 equations, the voltage at $V_1$ must fall between 1.3 V and 2.4 V to prevent A1 from saturating. Notice that $V_{REF}$ is connected to the average of $V_{OH}$ and $V_{OL}$ (2.5 V). This allows for bipolar differential input signals with $V_{OUT}$ referenced to +2.5 V.

A high gain (G = 100) single supply two op amp in-amp configuration is shown below in Figure 3. Using the same equations, note that voltage at $V_1$ can now swing between 0.124 V and 4.876 V. $V_{REF}$ is again 2.5 V, to allow for bipolar input and output signals.




$$V_{REF} = \frac{V_{OH} + V_{OL}}{2} = 2.5V$$

- $V_{1,MIN} \geq \frac{1}{G}\left[(G-1)V_{OL} + V_{REF}\right] \geq 0.124V$
- $V_{1,MAX} \leq \frac{1}{G}\left[(G-1)V_{OH} + V_{REF}\right] \leq 4.876V$
- $\left|V_2 - V_1\right|_{MAX} \leq \frac{V_{OH} - V_{OL}}{G} \leq 0.048V$

***Figure 3: Two Op Amp In-Amp Single-Supply Restrictions for $V_S$ = +5V, G = 100***

All of these discussions show that the conventional two op amp in-amp architecture is fundamentally limited, when operating from a single power supply. These limitations can be viewed in one sense as a restraint on the allowable input CM range for a given gain. Or, alternately, it can be viewed as limitation on the allowable gain range, for a given CM input voltage.

Nevertheless, there are ample cases where a combination of gain and CM voltage cannot be supported by the basic two op amp structures of Figs. 1 through 3, even with perfect amplifiers (i.e., zero output saturation voltage to both rails).

In summary, regardless of gain, the basic structure of the common two op amp in-amp does not allow for CM input voltages of zero when operated on a single supply. The only route to removing these restrictions for single supply operation is to modify the in-amp architecture.

**THE AD627 SINGLE-SUPPLY TWO OP AMP IN-AMP**

The above-mentioned CM limitations can be overcome with some key modifications to the basic two op amp in-amp architecture. These modifications are implemented in the circuit shown in Figure 4 below, which represents the AD627 in-amp architecture.

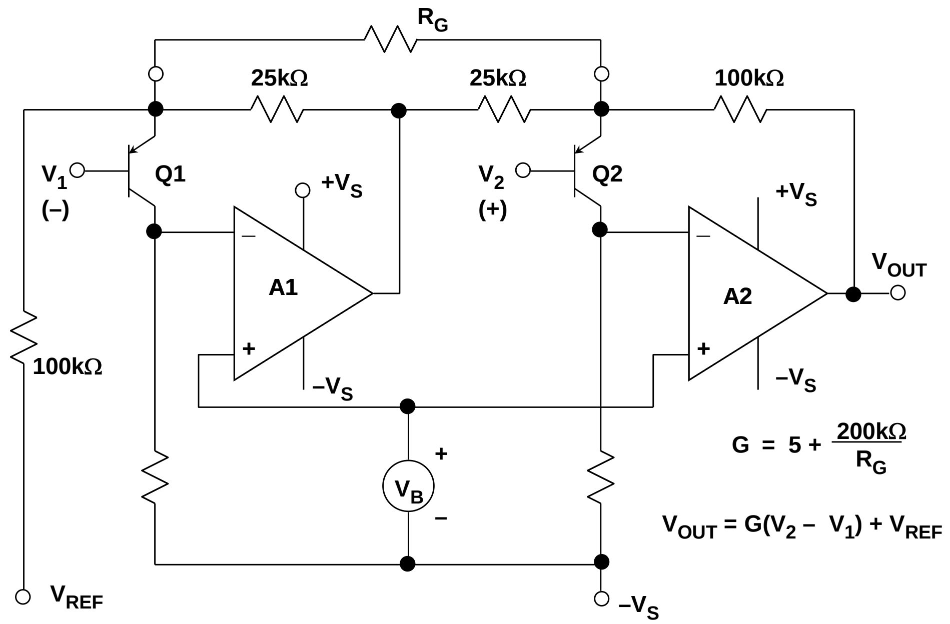



***Figure 4: The AD627 In-Amp Architecture***

In this circuit, each of the two op amps is composed of a PNP common emitter input stage and a gain stage, designated Q1/A1, and Q2/A2, respectively. The PNP transistors not only provide gain but also level shift the input signal positive by about 0.5 V, thereby allowing the common mode input voltage to go to 0.1 V below the negative supply rail. The maximum positive input voltage allowed is 1 V less than the positive supply rail.

The AD627 in-amp delivers rail-to-rail output swing, and operates over a wide supply voltage range (+2.7 V to ±18 V). Without the external gain setting resistor $R_G$, the in-amp gain is a minimum of 5. Gains up to 1000 can be set with the addition of this external resistor. Common mode rejection of the AD627B at 60 Hz with a 1 kΩ source imbalance is 85 dB when operating on a single +3 V supply and G = 5.

Even though the AD627 is a two op amp in-amp, it is worthwhile noting that it is not subject to the same CM frequency response limitations as the basic circuit of Fig. 1. A patented circuit keeps the AD627 CMR flat out to a much higher frequency than would otherwise be achievable with a conventional discrete two op amp in-amp.

The AD627 data sheet has a detailed discussion of allowable input/output voltage ranges as a function of gain and power supply voltages. An interactive in-amp common-mode range/gain calculator design tool is available to assist the user in performing the basic common-mode range and gain calculations for in-amps.

Key specifications for the AD627 are summarized in Figure 5 below. Although it has been designed as a low power, single-supply device, the AD627 is capable of operating on traditional higher voltage supplies such as ±15 V, with excellent performance.

- **Wide Supply Range : +2.7V to ±18V**
- **Input Voltage Range: $-V_S - 0.1V$ to $+V_S - 1V$**
- **85µA Supply Current**
- **Gain Range: 5 to 1000**
- **75µV Maximum Input Offset Volage (AD627B)**
- **10ppm/°C Maximum Offset Voltage TC (AD627B)**
- **10ppm Gain Nonlinearity**
- **85dB CMR @ 60Hz, 1kΩ Source Imbalance (G = 5)**
- **3µV p-p 0.1Hz to 10Hz Input Voltage Noise (G = 5)**

***Figure 5: AD627 In-Amp Key Specifications***

## REFERENCES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