op amps remain linear to within 0.1V 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. 2-8 equations, the voltage at $V_1$ must fall between 1.3V and 2.4V to prevent A1 from saturating. Notice that $V_{REF}$ is connected to the average of $V_{OH}$ and $V_{OL}$ (2.5V). This allows for bipolar differential input signals with $V_{OUT}$ referenced to $+2.5V$.

A high gain ($G = 100$) single supply two op amp in-amp configuration is shown below in Figure 2-9. Using the same equations, note that voltage at $V_1$ can now swing between 0.124V and 4.876V. $V_{REF}$ is again 2.5V, to allow for bipolar input and output signals.

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

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

**Figure 2-9:** 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. 2-7 through 2-9, 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.

2.9