SINGLE-SUPPLY OPERATION OF OPERATIONAL AMPLIFIERS

One of the most common applications questions on operational amplifiers concerns operation from a single supply voltage. "Can the model OPAxyz be operated from a single supply?" The answer is almost always yes. Operation of op amps from single supply voltages is useful when negative supply voltages are not available. Furthermore, certain applications using high voltage and high current op amps can derive important benefits from single supply operation.

Consider the basic op amp connection shown in Figure la. It is powered from a dual supply (also called a balanced or split supply). Note that there is no ground connection to the op amp. In fact, it could be said that the op amp doesn't know where ground potential is. Ground potential is somewhere between the positive and negative power supply voltages, but the op amp has no electrical connection to tell it exactly where.
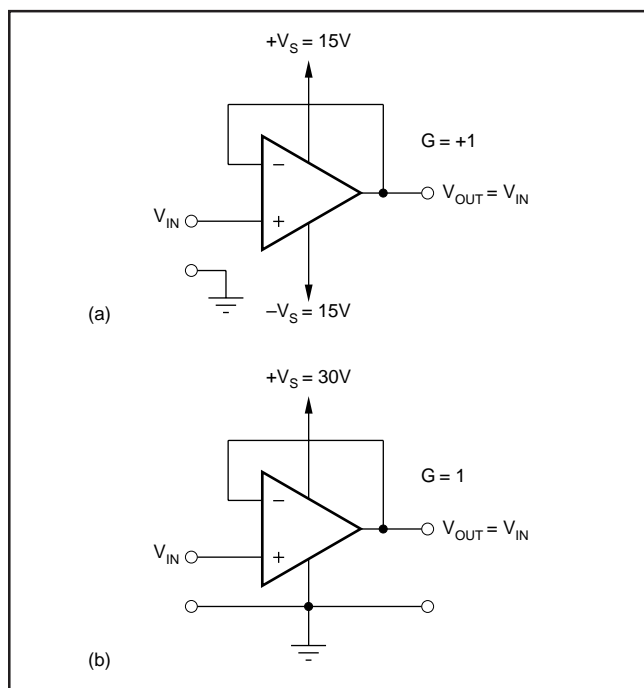

FIGURE 1.   A simple unity-gain buffer connection of an op amp illustrates the similarity of split-supply operation (a) to single-supply operation in (b).

The circuit shown is connected as a voltage follower, so the output voltage is equal to the input voltage. Of course, there are limits to the ability of the output to follow the input. As the input voltage swings positively, the output at some point near the positive power supply will be unable to follow the input. Similarly the negative output swing will be limited to somewhere close to $-V_S$. A typical op amp might allow

output to swing within 2V of the power supply, making it possible to output –13V to +13V with ±15V supplies.

Figure 1b shows the same unity-gain follower operated from a single 30V power supply. The op amp still has a total of 30V across the power supply terminals, but in this case it comes from a single positive supply. Operation is otherwise unchanged. The output is capable of following the input as long as the input comes no closer than 2V from either supply terminal of the op amp. The usable range of the circuit shown would be from +2V to +28V.

Any op amp would be capable of this type of single-supply operation (with somewhat different swing limits). Why then are some op amps specifically touted for single supply applications?

Sometimes, the limit on output swing near ground (the "negative" power supply to the op amp) poses a significant limitation. Figure 1b shows an application where the input signal is referenced to ground. In this case, input signals of less than 2V will not be accurately handled by the op amp. A "single-supply op amp" would handle this particular application more successfully. There are, however, many ways to use a standard op amp in single-supply applications which may lead to better overall performance. The key to these applications is in understanding the limitations of op amps when handling voltages near their power supplies.

There are two possible causes for the inability of a standard op amp to function near ground in Figure 1b. They are (1) limited common-mode range and (2) output voltage swing capability.

These performance characteristics are easily visualized with the graphical representation shown in Figure 2. The range over which a given op amp properly functions is shown in relationship to the power supply voltage. The common-mode range, for instance, is sometimes shown plotted with respect to another parameter such as temperature. A ±15V supply is assumed in the preparation of this plot, but it is easy to imagine the negative supply as being ground.

In Figure 2a, notice that the op amp has a common-mode range of –13V to +13.5V. For voltages on the input terminals of the op amp of more negative than –13V or more positive than +13.5V, the differential input stage ceases to properly function.

Similarly, the output stages of the op amp will have limits on output swing close to the supply voltage. This will be load-dependent and perhaps temperature-dependent also. Figure 2b shows output swing ability of an op amp plotted with respect to load current. It shows an output swing capability of –13.8V to +12.8V for a l0kΩ load (approximately ±1mA) at 25°C.
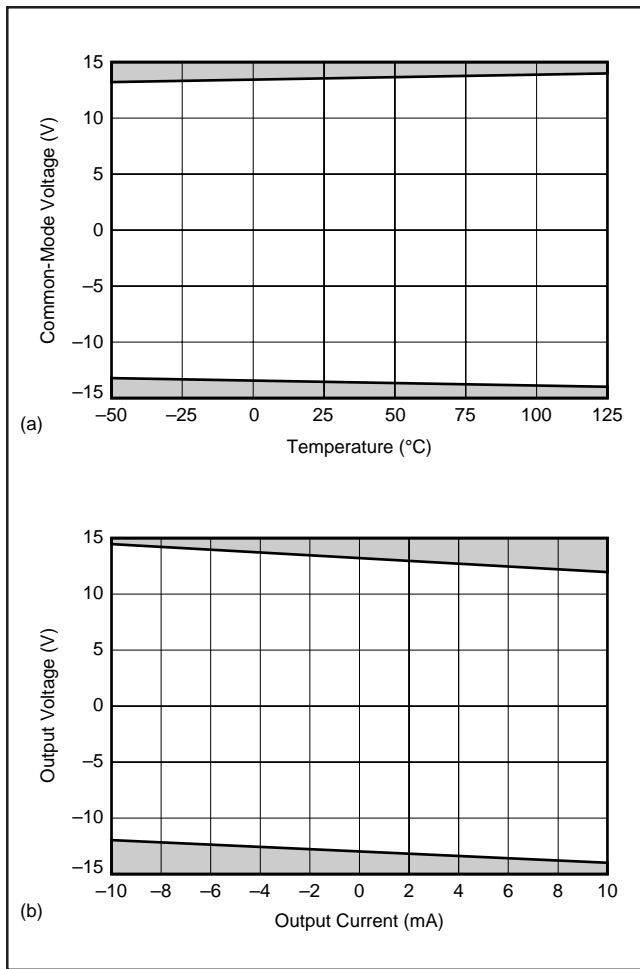
FIGURE 2. The Common-mode Range of an Op Amp is Usually Dependent on Temperature. This behavior is shown plotted in (a). Output voltage swing will be affected by output current. (b). Often the op amp load is connected to ground, so load current is always positive. Furthermore, as the output voltage approaches zero, load current approaches zero, increasing the available output swing. A split power supply voltage (normally ±15V) is assumed in preparation of these plots.

So the circuit of Figure 1b is limited to +13V output by output swing capability and –13V by negative common-mode range. A single-supply op amp is specifically designed to have a common-mode range which extends all the way to the negative supply (ground). Also, its output stage is usually designed to swing close to ground.

It would be convenient if all op amps were designed to have this capability, but significant compromises must be made to achieve these goals. Increased common-mode range, for instance, often comes at the sacrifice of performance characteristics such as offset voltage, offset drift, and noise. General purpose applications may tolerate op amp performance with these compromises, but high accuracy or other special purpose applications may require a different approach.

Fortunately, there are many ways to use high performance and special purpose op amps in single-supply applications.

As demonstrated in Figure 1b, an op amp with typical common mode and output characteristics functions well on a single supply as long as the input and output voltages are constrained to the necessary limits. Circuit configurations must be used which operate within these limits.

Figure 3 shows a circuit, for instance, which references the input and output to a "floating ground" created with a zener diode. The zener diode is biased with a current set by R_Z. Since V_{IN} and V_{OUT} are both referenced to the same floating ground, the zener voltage accuracy or stability is not critical. V_{IN} and V_{OUT} can now be bipolar signals (with respect to floating ground). With $+V = 30V$ and $V_Z = 15V$, operation is similar to standard split supply operation. The load current in this circuit, however, flows to the floating ground where it will add to the zener diode current (negative load currents subtract from zener current). The zener diode must be selected to handle this additional current. If the zener current is allowed to approach zero, the floating ground voltage will fall rapidly as the zener turns off. R_l must be selected so that the zener diode current remains positive under all op amp load conditions.
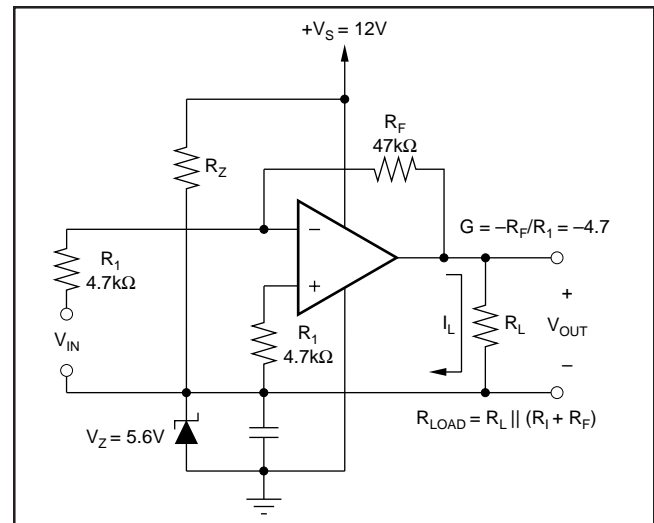

FIGURE 3. Bipolar Signals Can be Handled When Input and Output are Referenced to a Floating Ground. Changing load current causes a variation in zener current which must be evaluated.

Figure 4 shows operation in a noninverting gain configuration. In this circuit, the feedback components present an additional load to the op amp equal to the sum of the two resistors. This current must also be considered when planning for the variation in current flowing in the zener diode. Again, the zener current should not be allowed to approach zero or exceed a safe value.

Notice that in this example, a single +12V supply is shown. Often, single-supply applications use supply voltages which are considerably less than the 30V total (±15V) at which the performance of most op amps is specified. While modern op amps generally perform well at less than their characterized voltage, this needs to be verified. Some op amps, although they are specified to operate at lower voltage,
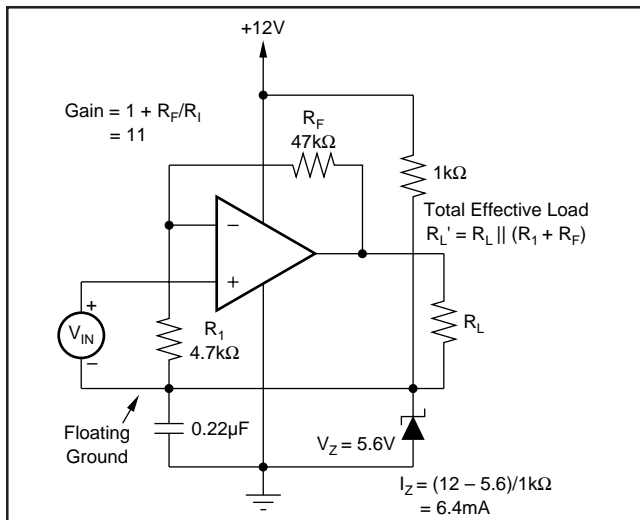
FIGURE 4. As with Conventional Split-Supply Operation, a Noninverting Gain Configuration Can Be Acheived. The feed back components create an additional load for the op amp which flows in the zener diode. Basic performance characteristics of the circuit are the same as for split supply operation.

suffer degraded power supply and common-mode rejection as their minimum operating voltage is approached.

Extremes of common-mode voltage on some amplifiers may produce unexpected behavior. Certain types of FET input op amps, for instance, exhibit much greater input bias current when the common-mode voltage relative to either of the power supplies exceeds 15V to 20V. This could occur with single-supply operation of 30V and common-mode voltage unbalanced nearer one supply or the other. The actual amplifier performance should be verified with the expected worst-case common-mode voltage conditions.

Resistor voltage dividers are sometimes used to establish floating ground (Figure 5). The impedance of the ground is determined by the parallel combination of the divider resistors. Unless these resistors are made very low in value (consuming significant power supply current), this will lead to higher "ground" impedance. But with careful attention to the effects of varying load current in the reference point, this approach may prove useful. In fact, it may not be important in some applications that a truly "solid" ground be established since input and output are referenced to the same node. Good bypassing, however, will help avoid transient disturbances of V_G, or oscillation problems by providing a lower high frequency impedance without low value divider resistors.

Appropriate voltage points often exist in related circuitry which can be useful in establishing a floating ground. In Figure 6, a +5V source used to power logic circuitry is used as a floating ground. Beware that most regulators used to supply these voltages are designed to source current to a load only. If sufficient op amp load current flows into the 5V line, its voltage will rise. Again, load currents should be evaluated to assure that the floating ground voltage remains

well defined. Normally other system components would sufficiently load the regulator to allow for plenty of op amp load current.

Particularly demanding applications may require that a buffer op amp be used to establish a very low impedance floating ground. Input to the buffer (Figure 7) could come from any of the previously discussed techniques. The buffer can both source and sink load current up to the output current limits
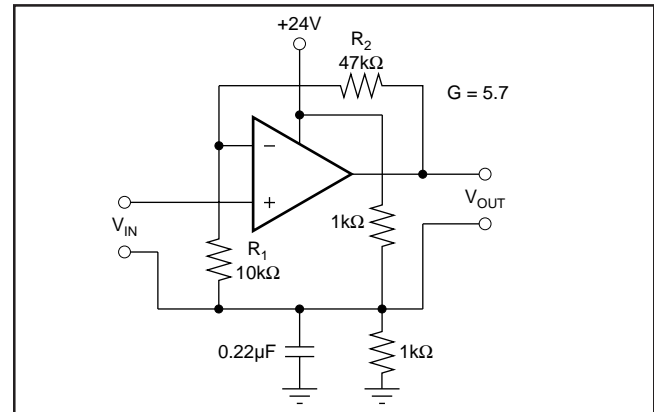

FIGURE 5. Even Though the Impedance of the Voltage Divider is in Series with R_1 to Ground, the Gain of this Noninverting Circuit is Determined Solely by R_1 and R_2. Since the input and output are referenced to the same floating ground, its impedance does not affect the voltage gain of the circuit.
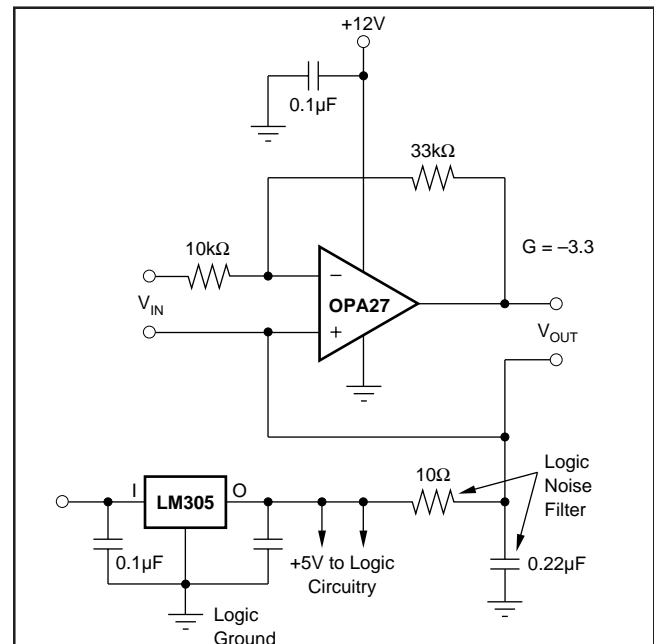

FIGURE 6. Many Systems Have a +5V Logic Supply or Other Appropriate Voltage Source which Can Be Used as a Floating Reference Potential for Analog Circuitry. Be sure logic noise does not enter the analog system by providing an adequate decoupling network or additional bypassing.
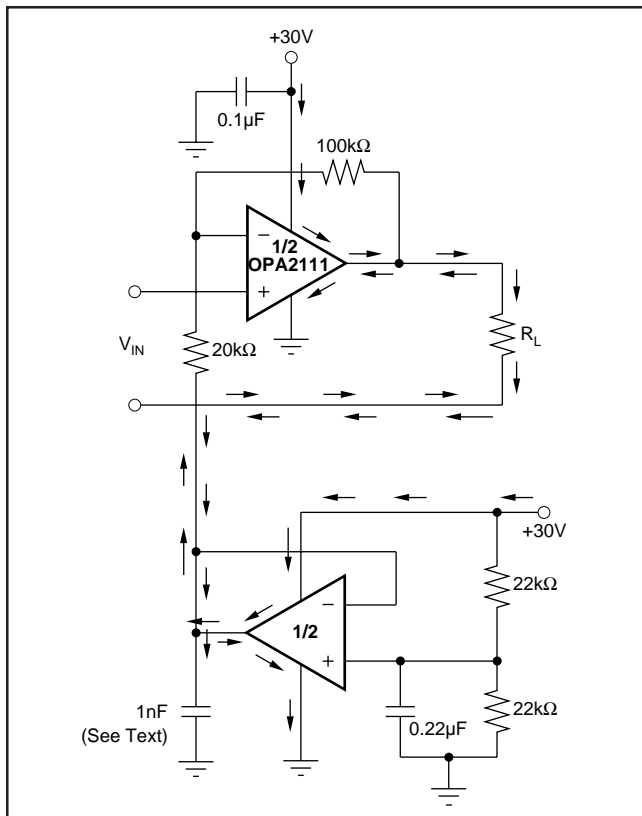
FIGURE 7. A Very-Low Floating Ground Impedance is Provided by Using One Section of the OPA2111 Op Amp Connected as a Unity-Gain Buffer. Input to the buffer is a voltage divider which can be heavily bypassed. The arrows indicate the direction of positive and negative load current flow.
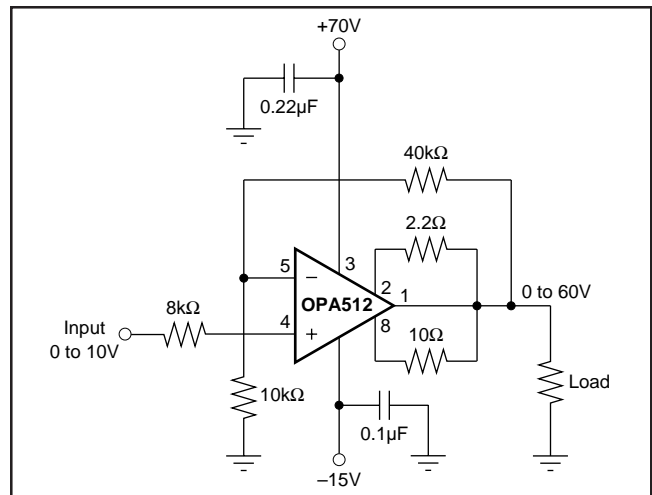

FIGURE 8. Unbalanced Power Supplies are Often Used with Power Op Amps to Achieve Higher Unipolar Output Voltage Yet Provide Output Swing Down to 0V. The negative supply voltage in this OPA512 circuit is made large enough to provide the common-mode voltage and output swing requirements of the application.

of the op amp used as the buffer. The closed-loop output impedance of the op amp provides a very solid reference ground. Frequency response and open-loop output impedance characteristics of the buffer op amp will determine the high frequency floating ground impedance. Bypassing the output of the buffer amp may help lower the high frequency impedance, but don't exceed a safe capacitive load of the buffer amp or oscillations may result.

Figure 8 shows a technique often used with high voltage and high current op amps. Here, an unbalanced power supply is used to produce the desired output voltage swing. In applications such as a programmable power source, the output voltage is required to go all the way to the ground. A small negative supply is used to provide the necessary common-mode voltage and output stage requirements to allow full output swing to ground. A much larger positive voltage supply can now be used to maximize the available output voltage.

A higher current limit (lower value current limit resistor is set for positive output current in this circuit since the primary purpose is to source current to a load connected to ground. Be sure to consider the safe operating area constraints carefully in this type of operation. Unequal supplies mean that larger voltages will be present across the conducting

output transistor, thus requiring greater safe operating area. See *Understanding Power Amplifier Specifications*, Application Bulletin AB-123, for information on evaluation of safe operating area.

Other signal processing circuits which are normally powered from a split supply can be operated from a single supply as well. These include such devices as instrumentation amplifiers, current transmitters, analog multipliers, log amps, etc. The principles in assuring proper operation are the same as for op amps.

The INA105 difference amplifier provides an instructive example. This device is comprised internally (Figure 9) of a precision op amp and four precision matched resistors. In a majority of applications pin 1 is connected to ground. This is the output voltage reference pin. If pin 1 is referenced to a floating ground using one of the previously described techniques, operation is similar to split-supply operation. Unlike the op amp applications previously described, however, the differential input terminals (pins 2 and 3) will be capable of accommodating common-mode voltages equal to and even greater than the supply voltages. Voltages applied to the input resistors are divided down, maintaining common-mode voltages to the op amp within operating limits. In this case, the voltage at pin 1 in conjunction with the required output swing determines the technique required for single-supply operation.

True instrumentation amplifiers (Figure 10) usually have an op amp at their input. Therefore, common-mode range of the input op amp again becomes a concern. Input voltages must be confined to within the specified common-mode range of the device. The output section of the instrument amp is like the difference amplifier and output voltages swing requirements will dictate the techniques required.
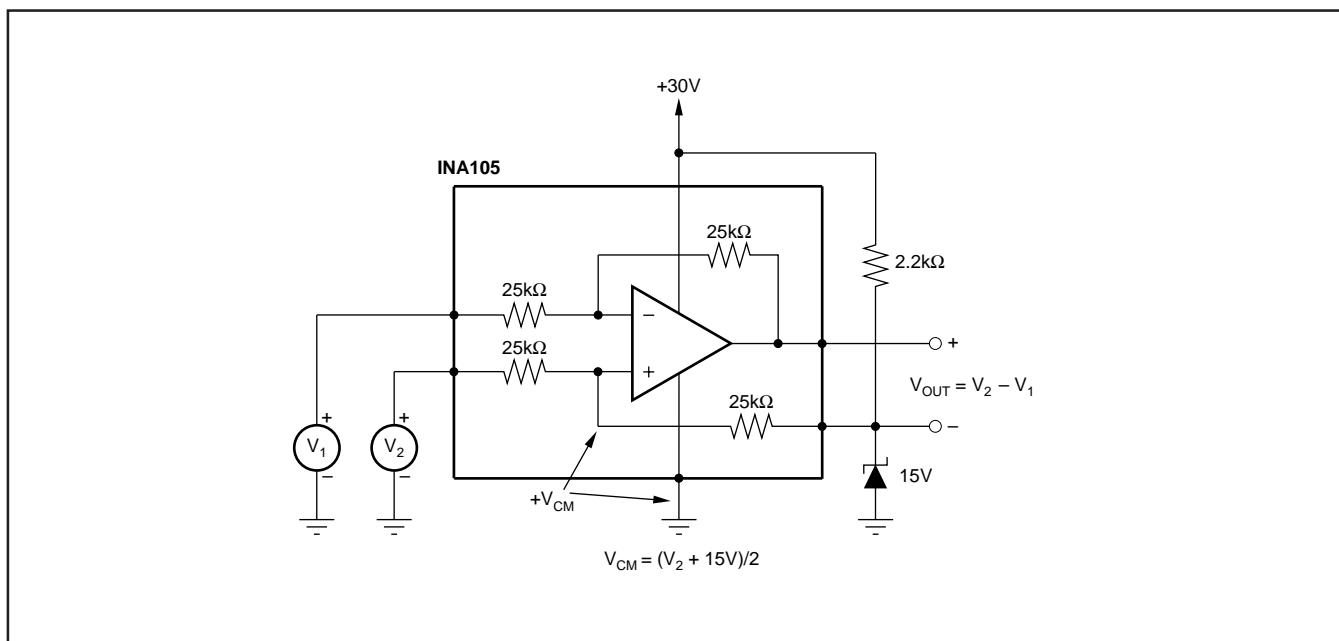
FIGURE 9. The Input Voltage to this Simple Difference Amplifier is Divided Down by the Input Resistors Before Being Applied to the Op Amp. Thus it is able to handle voltages which are equal to or greater than the power supply voltage.
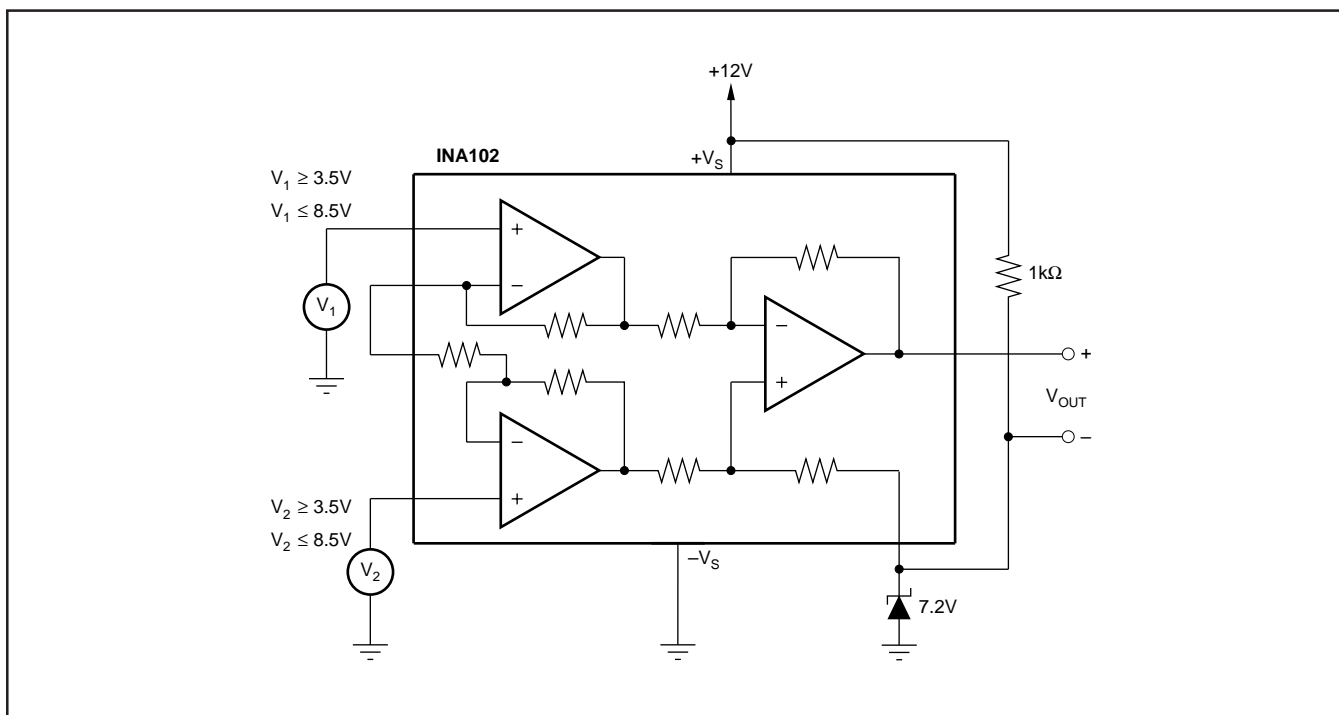

FIGURE 10. Inputs to the Instrumentation Amplifier Are Applied Directly to the Active Circuitry of the Input Op Amps and Therefore are Subject to the Common-Mode Range Limitations of these Op Amps.

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