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Single-Supply Op Amp Design Techniques

Ron Mancini

This application report describes single-supply op amp applications, their portability and their design techniques. The single-supply op amp design is more complicated than a spilt- or dual-supply op amp, but single-supply op amps are more popular because of their portability. New op amps, such as the TLC247X, TLC07X, and TLC08X have excellent single-supply parameters. When used in the correct applications, these op amps yield almost the same performance as their split-supply counterparts. The single-supply op amp design normally requires some form of biasing.

Introduction

Most portable systems have one battery, thus, the popularity of portable equipment results in increased single supply applications. Split- or dual-supply op amp circuit design is straight forward because the op-amp inputs and outputs are referenced to the normally grounded center tap of the supplies. In the majority of split-supply applications, signal sources driving the op-amp inputs are referenced to ground. Thus, with one input of the op amp referenced to ground, as shown in Figure 1, there is no need to consider input common-mode voltage problems.

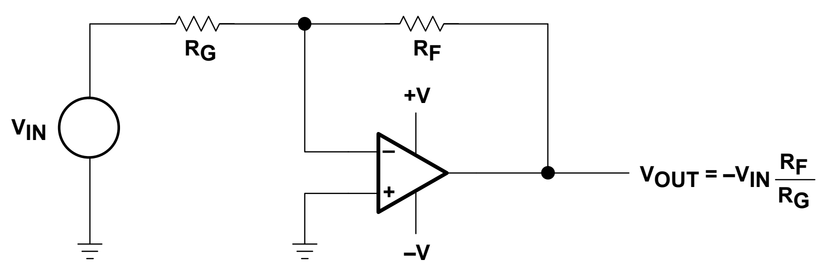

Figure 1. Split-Supply Op Amp Circuit

When the signal source is not referenced to ground (see Figure 2), the voltage difference between ground and the reference voltage shows up amplified in the output voltage. Sometimes this situation is okay, but other times the difference voltage must be stripped out of the output voltage. An input-bias voltage is used to eliminate the difference voltage when it must not appear in the output voltage (see Figure 3). The voltage (V_{REF}) is in both input circuits, hence it is named a common-mode voltage. Voltage-feedback op amps, like those used in this application note, reject common-mode voltages because their input circuit is constructed with a differential amplifier (chosen because it has natural common-mode voltage rejection capabilities).

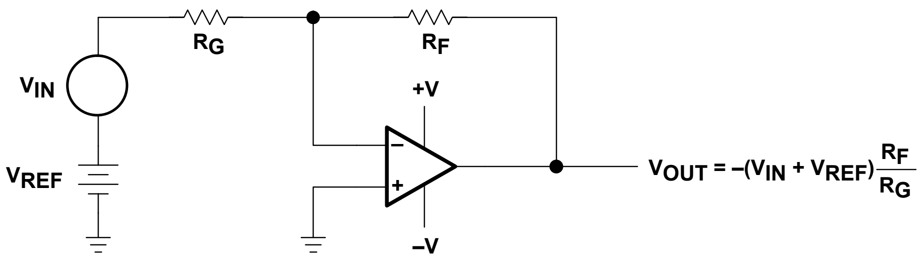

Figure 2. Split-Supply Op Amp Circuit With Reference-Voltage Input

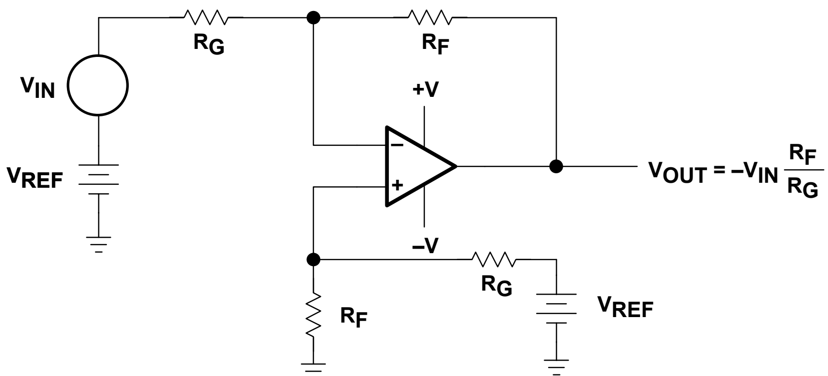

Figure 3. Split-Supply Op Amp Circuit With Common-Mode Voltage

When signal sources are referenced to ground, single-supply op amp circuits exhibit a large input common-mode voltage. Figure 4 shows a single-supply op amp circuit that has its input voltage referenced to ground. The input voltage is not referenced to the midpoint of the supplies like it would be in a split-supply application, rather it is referenced to the lower power supply rail. This circuit does not operate when the input voltage is positive because the output voltage would have to go to a negative voltage, hard to do with a positive supply. It operates marginally with small negative input voltages because most op amps do not function well when the inputs are connected to the supply rails.

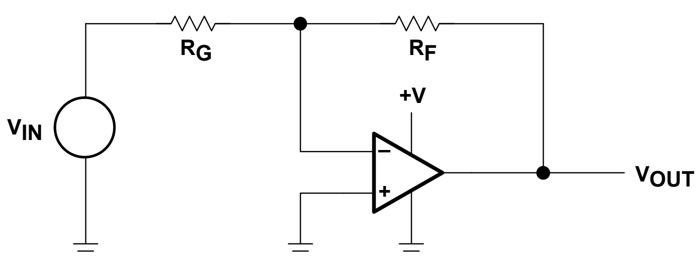

Figure 4. Single-Supply Op Amp Circuit

The constant requirement to account for inputs connected to ground or other reference voltages makes it difficult to design single-supply op amp circuits. This application note develops an orderly procedure which leads to a working design every time. If you do not have a good working knowledge of op amp equations, please reference the *Understanding Basic Analog....* series of application notes available from Texas Instruments. Application note SLAA068 titled, *Understanding Basic Analog-Ideal Op Amps* develops the ideal op amp equations. Circuit equations are written with the ideal op amp assumptions as specified in *Understanding Basic Analog-Ideal Op Amps*; the assumptions are tabulated below for your reference.

PARAMETER NAME	PARAMETERS SYMBOL	VALUE
Input current	I_{IN}	0
Input offset voltage	V_{OS}	0
Input impedance	Z_{IN}	∞
Output impedance	Z_{OUT}	0
Gain	a	∞

Unless otherwise specified, all op amps circuits are single-supply circuits. The single supply may be wired with the negative or positive lead connected to ground, but as long as the supply polarity is correct, the wiring does not affect circuit operation.

Use of a single-supply limits the polarity of the output voltage. When the supply voltage (V_{CC}) = 10 V, the output voltage is limited to the range $0 \leq V_{OUT} \leq 10$. This limitation precludes negative output voltages when the circuit has a positive supply voltage, but it does not preclude negative input voltages when the circuit has a positive supply voltage. As long as the voltage on the op-amp input leads does not become negative, the circuit can handle negative input voltages.

Beware of working with negative (positive) input voltages when the op amp is powered from a positive (negative) supply because op-amp inputs are highly susceptible to reverse voltage breakdown. Also, insure that all possible start-up conditions do not reverse bias the op-amp inputs when the input and supply voltage are opposite polarity.

Circuit Analysis

The complexities of single-supply op amp design are illustrated with the following example. Notice that the biasing requirement complicates the analysis by presenting several conditions that are not realizable. It is best to wade through this material to gain an understanding of the problem, especially since a cookbook solution is given later in this chapter. The previous chapter assumed that the op amps were ideal, and this chapter starts to deal with op amp deficiencies. The input and output voltage swing of many op amps are limited as shown in Figure 7, but if one designs with the selected rail-to-rail op amps, the input/output swing problems are minimized. The inverting circuit shown in Figure 5 is analyzed first.