One Resistor Takes The Heat From Single-Supply Op-Amps

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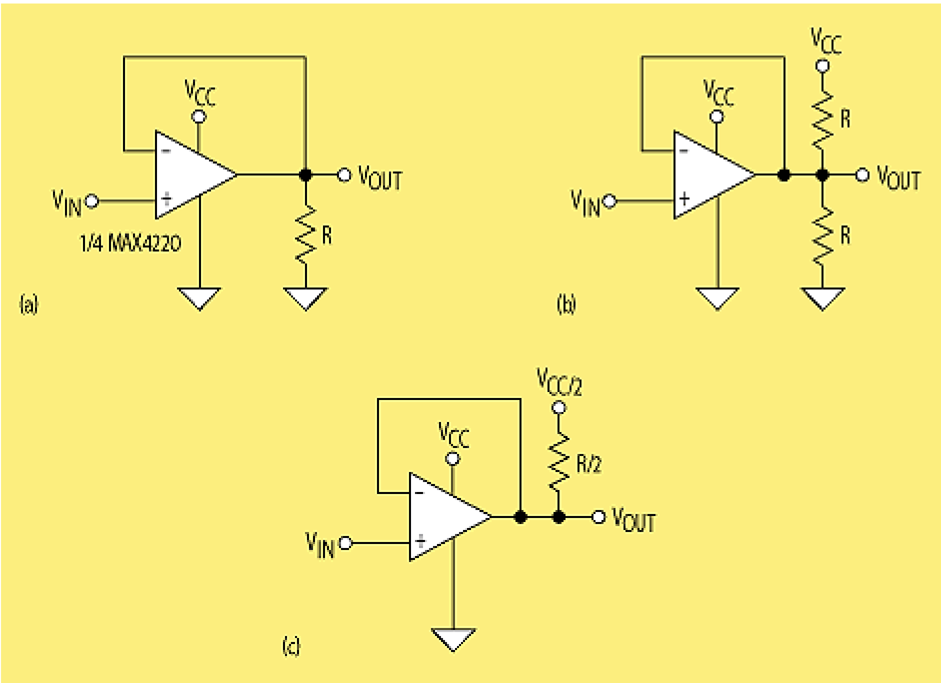
To maximize signal swing, the output of a single-supply op amp is usually biased at half the supply voltage (Fig. 1a). For ground-referenced loads, however, this configuration can result in maximum power dissipation in the IC.



1. The power dissipated in a single-supply op amp biased at mid-VCC (a) is reduced by adding a load-value pull-up to VCC (b). A Thevenin-equivalent circuit aids analysis (c).

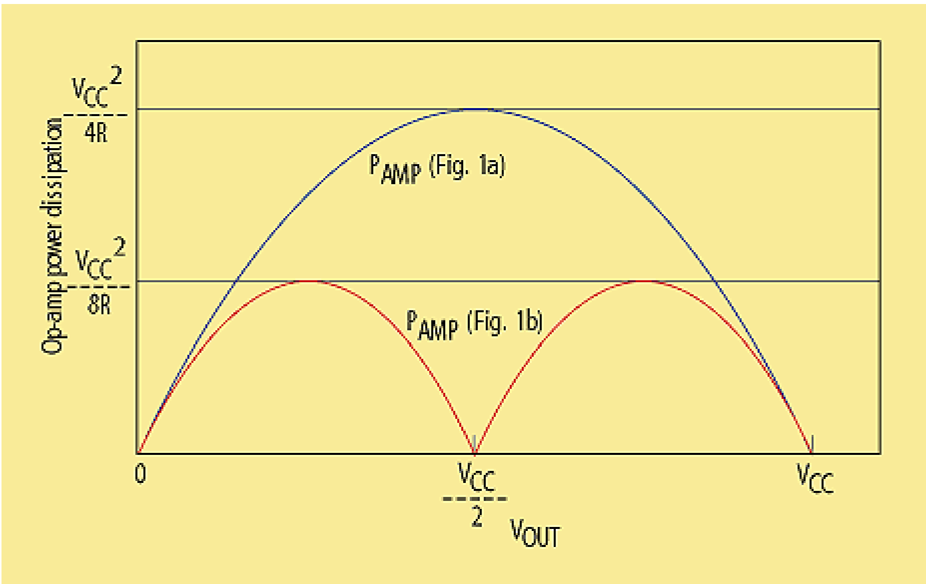
A simple and effective solution is realized by connecting a pull-up resistor, with a value equal to the load resistor, between the output and the positive supply voltage (Fig. 1b). Use of this type of resistor enables the op amp to operate at higher ambient temperatures and drive lower-resistance loads. As a result, the op amp is limited only by its maximum ratings for output voltage and current, rather than by package power dissipation.

For example, consider the MAX4220 quad op amp, in which each output drives a 30-Ω resistor to ground. If VCC = 5 V, the device would exceed its package power rating. But remember that since the pull-ups are connected, each op amp's output current is zero. So connecting 30-Ω pull-ups at each output minimizes the IC's power dissipation. Power is now dissipated in the pull-up resistors and not in the op amps.

Calculating power dissipation for the op amp in Figure 1a is straightforward

$$P_{DC} = \frac{(V_{CC} - V_{OUT})V_{OUT}}{R}$$

Solving the differential equation dPDC/dVOUT = 0 for VOUT shows that the op amp's maximum power dissipation (VCC2/4R) is reached when VOUT = VCC/2. The corresponding power calculation for the circuit in Figure 1b, which uses a pull-up resistor, is simpler when the load circuit is converted to its Thevenin equivalent (Fig. 1c):
Solving dPDC/dVOUT = 0 for these two equations shows that the maximum power dissipation (VCC2/8R) occurs for VOUT = 3/4VCC and for VOUT = 1/4VCC. Note that this maximum power level would be twice as much if there were no pull-up resistor (Fig. 2). The amplifier with no pull-up resistor delivers maximum output current at the VCC/2-quiescent point. With a pull-up resistor like the one in Figure 1b, the op amp delivers no output current at all!



2. The maximum power dissipation, occurring at the quiescent point, of the op amp in Figure 1a is twice that of the op amp in Figure 1b.

$$P_{DC} = \frac{(V_{CC} - V_{OUT})(V_{OUT} - \frac{1}{2}V_{CC})}{\frac{1}{2}R}$$

$\left(\text{for } V_{OUT} \geq \frac{1}{2}V_{CC}\right)$, and

$$P_{DC} = \frac{V_{OUT}(\frac{1}{2}V_{CC} - V_{OUT})}{\frac{1}{2}R}$$

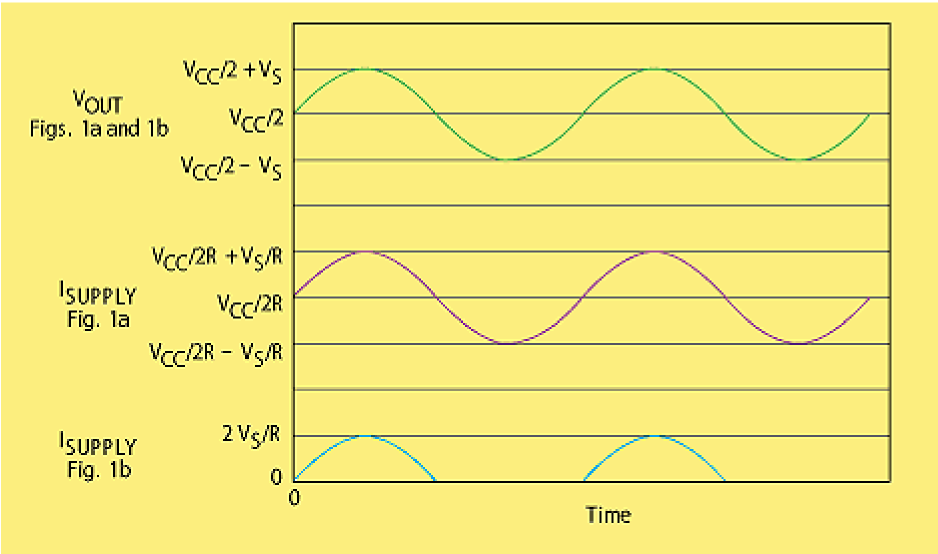
$\left(\text{for } V_{OUT} \leq \frac{1}{2}V_{CC}\right)$

Similar power advantages accrue for ac applications. Consider a sinusoidal signal superimposed on a dc level of $V_{CC}/2$:

$$V_{OUT} - \frac{1}{2}V_{CC}$$

where Vp is the peak value of the sinusoidal signal.

Figure 3 illustrates the resulting waveforms. To calculate power dissipation in the op amp, a power-balance equation is employed in which the supply power equals the sum of the power dissipated in the load and in the op amp. In turn, the op-amp dissipation equals the supply power minus the load power.

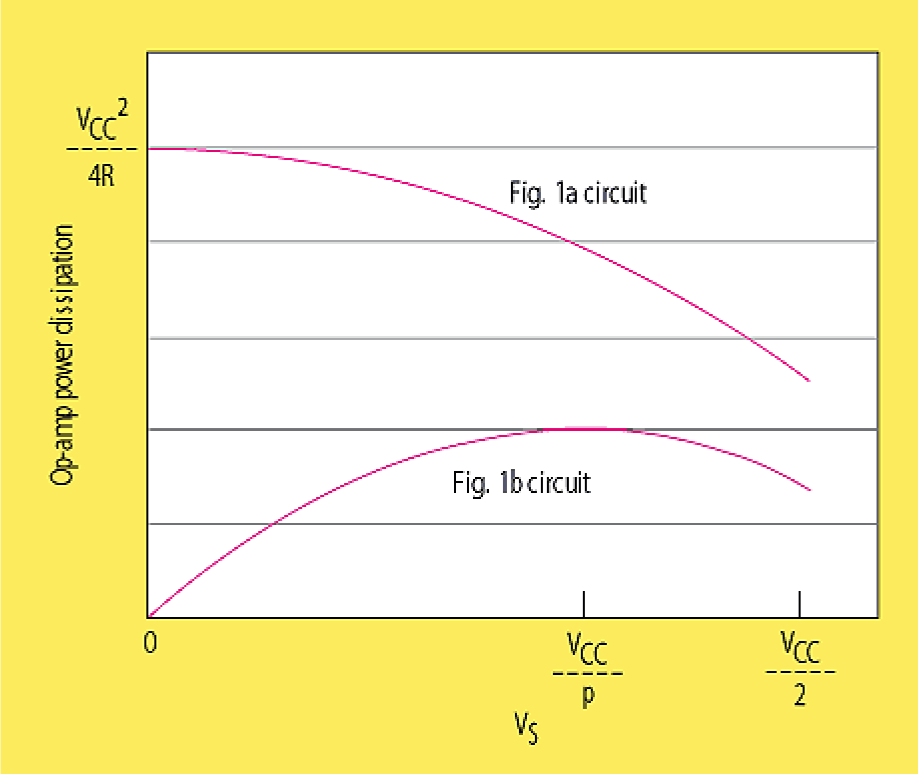


3. These waveforms illustrate the op-amp voltage and current relationships for the circuits shown in Figures 1a and 1b.

In the case of Figure 1a, supply power equals the average supply current ($V_{CC}/2R$) times V_{CC} (i.e., $V_{CC}2/2R$). The power in the load is $(1/R)(1/2V_{CC})2 + (1/R)(Vp/21/2)2$, which is the sum of the dc and ac components. Therefore, the supply power minus the load power for the Figure 1a circuit is $P_{AC} = (V_{CC}2/4R) - (Vp2/2R)$, as shown in Figure 4.

For the circuit in Figure 1b, the supply power equals the average supply current $2Vp/\pi R$ multiplied by V_{CC}. This is demonstrated in Figure 3 (i.e., $2VpV_{CC}/\pi R$). Power in the load is $2(Vp/21/2)2/R$. The supply power minus the load power is $P_{AC} = (2V_{CC}Vp/\pi R) - (Vp2/R)$ (Fig. 4, again). By solving the equation $dP_{AC}/dVp = 0$ for Vp, it's clear that the op amp in Figure 1b achieves its maximum power dissipation when $Vp = V_{CC}/\pi$.

Although overall circuit power isn't reduced, this technique is useful for decreasing the power dissipation within an op amp. Doing so keeps the device within its power limitations.



4. The power dissipation in the op amp of Figure 1a is always significantly greater than the dissipation in the op amp of Figure 1b.