Technical Article

Designing with Low-power Op Amps, Part 3: Saving Power with the Shutdown Amplifier

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Note: Carolina Gomez collected the data for this article.

In my previous articles, I walked through optimizing an operational amplifier (op amp) circuit for power savings and talked about some of the applications that can take advantage of amplifiers with low-voltage-supply capabilities. In this installment of the "Designing with low-power op amps" series, I will show you how to save power with a more specialized device: the shutdown amplifier.

Shutdown Functionality

Sometimes circuit designers want to save power but can't use an op amp with low quiescent current (I_Q) because of the trade-offs in bandwidth, noise and stability that often arise with a low-power amplifier. A common solution to this problem is to select a shutdown amplifier that you can put into a low-power state by toggling its shutdown or enable pin, as shown in Figure 1. Disabling or shutting down the amplifier adjusts its biasing circuitry so as to dramatically reduce the device's I_Q draw. A shutdown amplifier combines the performance of a higher-bandwidth op amp when the device turns on and significant power savings when the device turns off.

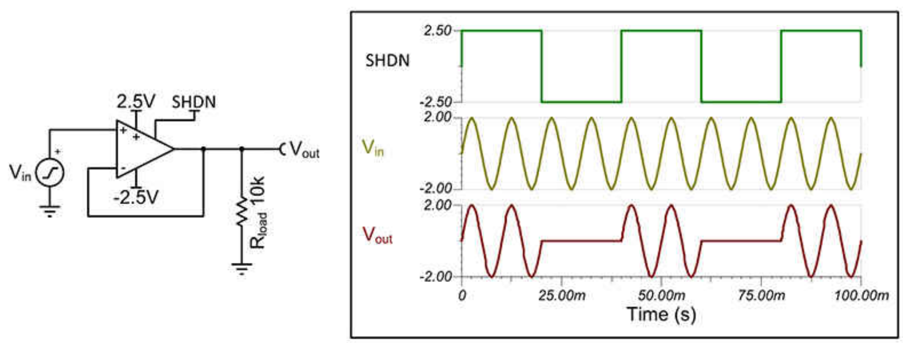

Figure 1. TLV9002S Shutdown Toggle

Benefits of a Shutdown Pin

The primary benefit of a shutdown amplifier is straightforward: you can put the amplifier into a low-power state. But why is a shutdown pin necessary at all when you can toggle the supply pin instead? As it turns out, the shutdown amplifier has other, less obvious advantages, such as protection from input voltages and a defined output state while in shutdown.

Most amplifiers have input electrostatic discharge (ESD) diodes from their input pins to the supply rails. These diodes are designed to protect against short-term ESD events, but they can be damaged when applying an input voltage above the V+ rail or below the V- rail. As shown in Figure 2, the input ESD structures may become damaged if you turn an amplifier off through the supply pins and apply an input signal. When turning an amplifier off using the shutdown pin, however, its supply rails remain present and allow the input pins to continue seeing normal input voltage levels. This is true of most shutdown amplifiers. When in doubt, consult the product's data sheet or ask an engineer on the TI E2E™ forums.

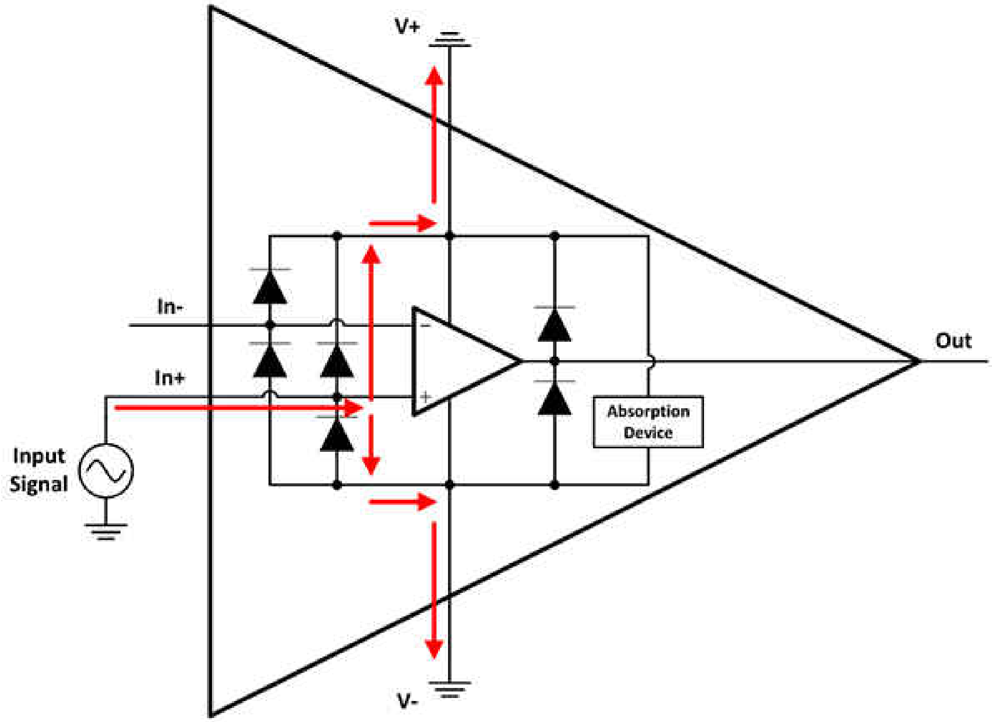

Figure 2. Turning on an Op Amp's ESD Diodes with an Input Signal

Another advantage to using the shutdown pin to turn off a device is that it can put the output into a known state. When an op amp goes into shutdown mode, the data sheet will often describe the output as becoming a high impedance node. When an op amp is merely turned off through the supply rails, the behavior of the output pin is undefined. Again, if in doubt, you can double-check this feature in the product data sheet. As highlighted in the technical article, "So what exactly is an op amp shutdown pin supposed to do?" other potential benefits of shutdown pins include digital logic compatibility, cost savings, space savings and a reduction in design complexity.

Shutdown Power Savings

For a shutdown application, you can use the I_Q of the amplifier, its shutdown I_Q (I_{QSD}), its supply voltage (V_{supply}), and its expected time both out of shutdown (t_{on}) and in shutdown (t_{off}) to estimate the quiescent power savings available. If the resistive loading is negligible, then the quiescent power savings will match the total power savings. For the sake of simplicity, let's assume that this is the case. Under this assumption, Figure 3 calculates the average power consumed by a device that toggles on and off. Similarly, Figure 4 calculates the average power saved versus a device that is always left on:

$$P_{Avg\ Consumed} = V_{supply} \times \left[\left(\%t_{on} \times I_Q\right) + \left(\%t_{off} \times I_{QSD}\right)\right]$$

Figure 3.

$$P_{Avg\ Saved} = \left(V_{supply} \times I_Q\right) - P_{Avg\ Consumed}$$

Figure 4.

Let's now use some real-world measurements with Figure 3 and Figure 4 to estimate the potential shutdown power savings. For this example, consider the TLV9042S device in a unity gain buffer configuration. The input is tied to mid supply and the output is left without a load, as shown in Figure 5. My colleague, Carolina, powered on the unit at three common supply-voltage levels and measured the corresponding I_Q, then placed the device into shutdown and measured the I_Q again at each of the supply levels. Table 1 displays the measurements. Note that these results are slightly better than the data-sheet specification because the I_{QSD} per channel is slightly lower for the dual-channel TLV9042 than for the single-channel TLV9041, whose more conservative value is quoted in the data sheet.

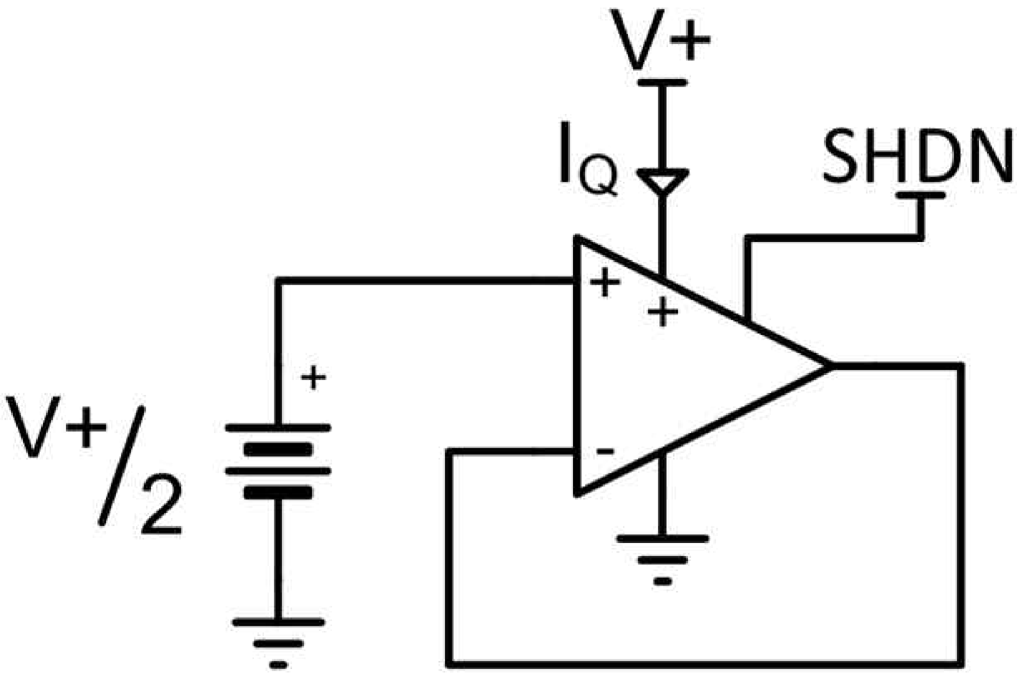

Figure 5. TLV9042S I_Q And I_{QSD} Measurement Setup

Table 1. TLV9042S Measured Current Consumption in Shutdown Mode

Device	Supply voltage (V+)	I_Q per channel	I_{QSD} per channel
TLV9042SIRUGR	1.2 V	9.545 µA	50.965 nA
	3.3 V	9.465 µA	52.730 nA
	5.0 V	9.445 µA	53.335 nA

With the data from Table 1, you can now estimate the possible power savings for different low-power applications using the shutdown feature of the TLV9042S device. Depending on the low-power application, such as a photodiode amplifier or a battery-powered smoke detector, different duty cycles will help maximize power savings without sacrificing system functionality. With help from Figure 3 and Figure 4, along with the data in Table 1, it is possible to estimate the power consumed at different supply voltage levels when using the shutdown feature of the TLV9042S instead of leaving it always on. See the results in Table 2, where you can see that toggling the shutdown pin can lead to significant power savings.

Table 2. TLV9042S Measured Power Consumption by Duty Cycle and Supply Voltage

Supply voltage (V+)	Duty cycle	$P_{Avg\ Consumed}$ (µW)	$P_{Avg\ Saved}$ (µW)
1.2 V	80%	9.175	2.279
1.2 V	10%	1.200	10.254

Table 2. TLV9042S Measured Power Consumption by Duty Cycle and Supply Voltage (continued)

Supply voltage (V+)	Duty cycle	$P_{Avg\ Consumed}$ (µW)	$P_{Avg\ Saved}$ (µW)
1.2 V	1%	0.175	11.279
1.2 V	0.1%	0.073	11.381
3.3 V	1%	0.485	30.750
5 V	1%	0.736	46.489

Conclusion

Now that I've discussed the power-saving benefits of using a low-power op amp with shutdown capability, in the next installment I'll cover one of the most common challenges with low-power op amp applications: stability.

Additional resources

- Catch up on other installments in the "Designing with low-power op amps" series.
- For a deeper understanding of the shutdown capability of a related product family, see the application report, "Designing for TLV90xxS Operational Amplifiers with Shutdown."