Application Report

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Quiescent Current vs Shutdown Current for Load Switch Power Consumption

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ABSTRACT

This application note covers the terminology of quiescent current and shutdown current for TI's load switches. This application note is targeted towards designers using load switches who wish to better understand quiescent and shutdown current in order to maximize battery life. This application note applies to any of the TI TPS229xx family of load switches.

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1 Integrated Load Switch Overview

Before explaining the different types of current, we first define a load switch. A load switch is similar to a relay; it gives users the ability to turn a power rail on or off. Load switches primarily consist of three components: a MOSFET that is in series with the supply rail (pass FET), a driving circuit, and a control circuit (see Figure 1). Integrated load switches combine this circuitry into a single IC while often incorporating additional features and reducing the solution size compared to the discrete implementation. Since the load switch is integrated into a simple solution, we are also able to simplify the system analysis by combining the currents coming from the individual circuit blocks.

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The block diagram in Figure 1 shows the main blocks of an integrated load switch. For more information about the actual circuit blocks, refer to the Application Report; *Load Switches: What are They, Why Do You Need Them, And How Do You Choose The Right One?* (SLVA652).

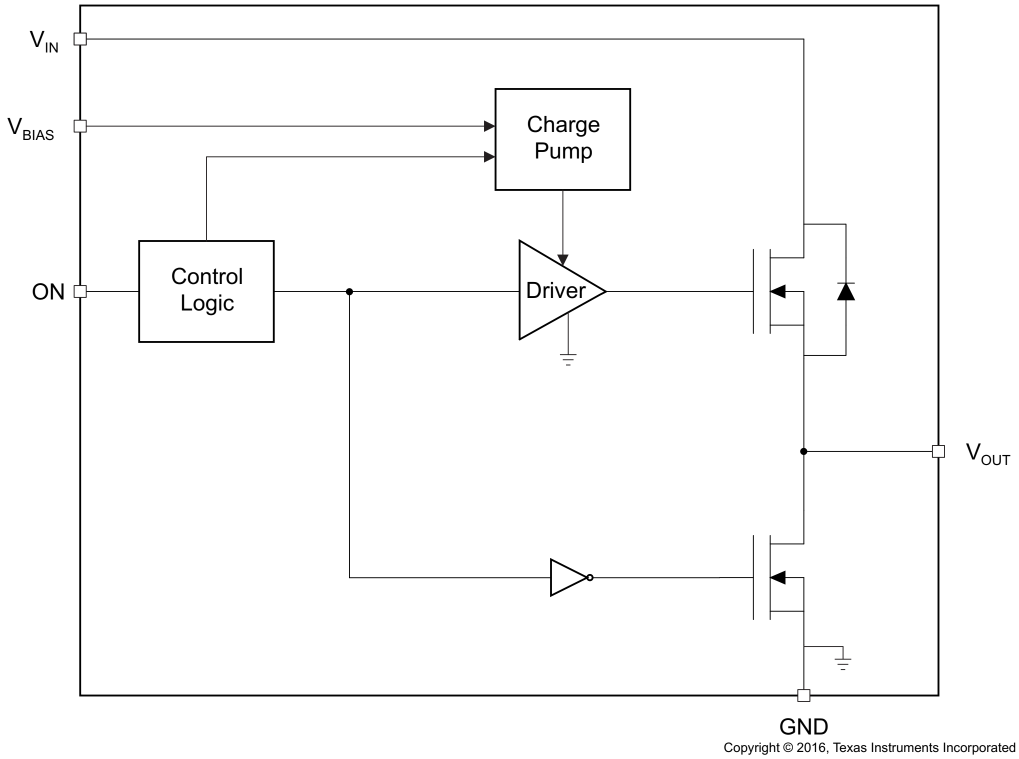


Figure 1. Functional Block Diagram

Trying to account for all of the currents in a load switch is very complex. In order to clearly explain the different current paths through the device, this document splits the integrated load switch into two main components: the pass FET, and the controller. As discussed previously, the pass FET is the main MOSFET that is in series with the power supply rail and the load. The controller consists of the other circuit blocks used to control the FET. This includes the control logic, driver, charge pump, and any additional features a load switch may have including quick output discharge (QOD). QOD can be grouped with the controller because it has negligible impact on both the quiescent and shutdown current.

2 Quiescent Current Overview

For most TI load switches, quiescent current is the current drawn when the device is enabled and there is no load on the output. This current is a result of the power needed for the many different parts of the load switch, like the charge pump, gate driver, or control logic. Simply put, load switches typically have quiescent current in order to provide a low on-resistance (R_{ON}) across input voltages.

Since quiescent current has a slightly different meaning for load switches compared to other semiconductors, we should clarify a few things. First, note that the quiescent current goes through the device to the ground pin, and not through the pass FET. Second, the typical quiescent current for a load switch is in the microamp (µA) range. This means for an output load in milliamps (mA) or higher, like an LED, the quiescent current becomes negligible since the quiescent current becomes a smaller percentage of the current needed to power the entire system. Equation 1 shows the overall power dissipated by a load switch.

$$P_d = I_{OUT}^2 \times R_{ON} + V_{supply} \times I_Q \quad (1)$$

In this equation, P_d is the power dissipation of the load switch, I_{OUT} is the load current, R_{ON} is the on-resistance of the device, V_{supply} is the supply voltage, and I_Q is the quiescent current. For an example, use the TPS22954 device and assume that the device is driving a 1 amp load at 5 volts. Using the typical values for TPS22954, we can see that the power from the quiescent current is only 1.2% of the overall power.

$$P_d = 1^2 A \times 14\ m\Omega + 5\ V \times 34\ \mu A = 0.014\ W + 0.00017\ W \quad (2)$$

This is a key concept to understand when deciding on a load switch since the load current is often large enough to make the quiescent current negligible.

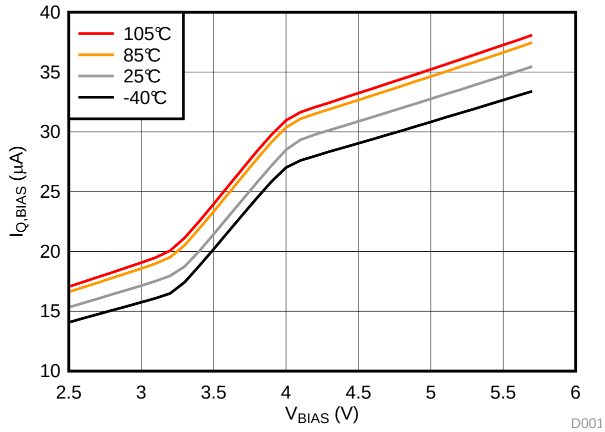
Finally, some load switches have a V_{BIAS} pin that powers the internal circuit blocks, allowing for better performance at lower V_{IN} voltages. Including a V_{BIAS} pin does not have a direct effect on the quiescent current; it allows the R_{ON} to stay flat at lower V_{IN} voltages instead of increasing. This is because using V_{BIAS} within the recommended specifications provides sufficient voltage in order to fully power the charge pump and gate driver, and those blocks have a direct impact on the R_{ON}. Using Equation 2, it is clear that keeping the R_{ON} at its lowest value reduces the load switch power consumption at low V_{IN} values.

3 Quiescent Current Response to Changing Conditions

The quiescent current of a load switch varies based on different biasing conditions, such as the supply voltage and the temperature.

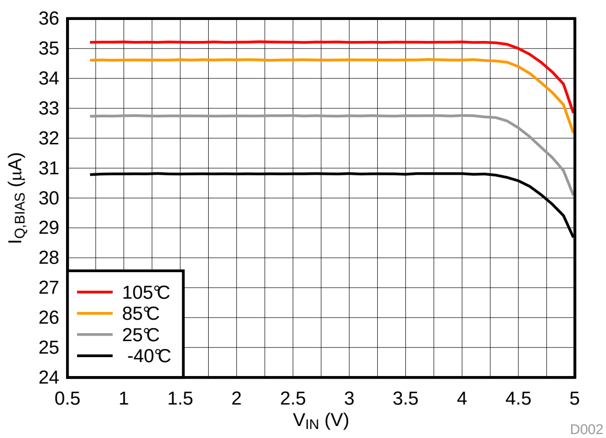
An increasing supply voltage results in an increased quiescent current. Although some load switches have different internal circuit configurations, the increased quiescent current is typically due to the charge pump that drives the gate of the FET.

If the load switch has both a V_{BIAS} and V_{IN} pin, graphs similar to the TPS22953/54 in Figure 2 and Figure 3 show the relationship between quiescent current and voltage. These graphs show that the V_{IN} voltage has little effect on the quiescent current since there is a V_{BIAS} pin. This is expected since, as discussed, the purpose of the V_{BIAS} pin is to power the internal circuitry.



V_{IN} = 1.8 V, V_{EN} = 5.7 V, V_{OUT} = 0 V

Figure 2. TPS22953/54 V_{BIAS} Quiescent Current vs V_{BIAS}



V_{BIAS} = 5 V, V_{EN} = 5.7 V, V_{OUT} = 0 V

Figure 3. TPS22953/54 V_{BIAS} Quiescent Current vs V_{IN}

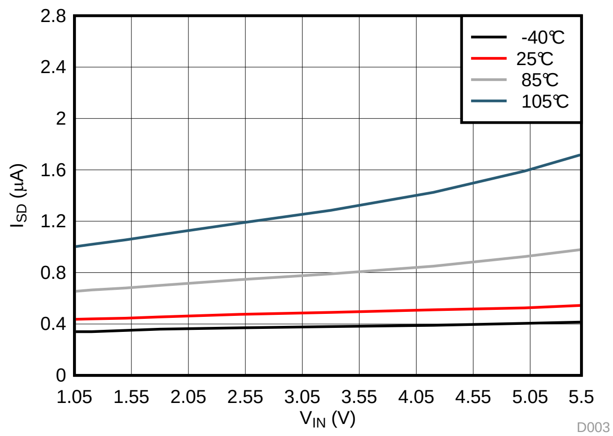
The quiescent current is also a factor of temperature. In both Figure 2 and Figure 3, the increasing temperature results in an increase in quiescent current. This is due to the temperature dependence for the control circuitry. For example, the charge pump runs slightly faster at hotter temperatures resulting in increased current consumption. Based on the current and voltage dependencies, a designer sees a lower quiescent current with lower supply voltages and lower temperatures.

4 Shutdown Current Overview

For most TI load switches, shutdown current is the current drawn when the device is disabled and there is zero voltage on the output (V_{OUT} = 0 V). Since the load switch is disabled, the load no longer contributes to the overall system power. The shutdown current is comprised of the FET leakage and controller circuitry that remains on like circuitry to protect the FET. The shutdown current is important when considering the overall system current. This is because when a load switch turns off a load, the shutdown current is the contribution to the overall system power instead of the load current. For example, a load switch with a shutdown current of 200 nanoamps (nA) can turn off a Bluetooth® module and significantly reduce the current that the Bluetooth consumes to 200 nA.

5 Shutdown Current Response to Changing Conditions

The shutdown current of a load switch also varies based off different biasing conditions. The voltage across the FET is one factor that affects the shutdown current. As the voltage across the FET increases, the shutdown current increases as well. This is because the pass FET of the load switch is a nonlinear resistor, and increasing the voltage results in an increase of current. To show an example of this, the TPS22914/15 devices are used. In Figure 4, the shutdown current from TPS22914/15 shows the nonlinear effect of the input voltage on the shutdown current.



V_{ON} = 0 V, I_{OUT} = 0 A

Figure 4. Shutdown Current for TPS22914/915

Another factor that affects the shutdown current is the temperature. As the ambient temperature increases, the shutdown current of the load switch increases as well. The graph in Figure 4 shows that this increase can be nonlinear. For the shutdown current, this is mostly due to the temperature dependence of the MOSFET itself. Minimal shutdown current is seen at lower input voltages and colder ambient temperatures.

6 System Design Considerations for Optimum Power Consumption

Now that we have identified and described the different types of currents that pertain to load switches, we can talk about how to optimize a system's power consumption by using a load switch to control a load. This can be done by showing two design examples to emphasize the benefits of the load switch's shutdown and quiescent current.

7 Designing for Optimum Shutdown Current

Optimum shutdown current is needed for higher efficiency. An example of this is in battery powered designs since the shutdown current is used to maximize battery life. Figure 5 and Equation 3 illustrate a design example showing the benefits of optimizing shutdown current. The design example uses a resistive load for simplicity, but this concept can be applied to different applications such as sensor networks or wireless communication.

With a battery that has a 200 mAh lifetime, a load that continuously uses 60 mA of current only provides battery life for 3 hours and 20 minutes. The first way to improve the battery life in this system is to add a load switch to disconnect the load when it is not needed. In this design example, the system needs to be active once every 5 seconds. If the load switch is used, the system can be turned on for only 500 ms; the amount of time needed to perform an action such as taking and processing data, and then turned off for 4.5 s. The system still uses 60 mA for the 500 ms, but during the off time, the current consumed is reduced to only 500 nA. This is a substantial improvement, allowing the battery to operate for at least 26 hours instead of the initial 3 hours and 20 minutes.

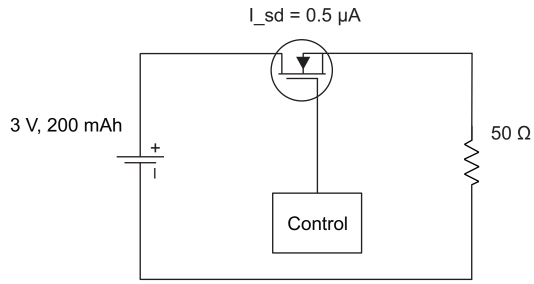


Figure 5. Load Switch Battery Example: Shutdown Current

$$\text{Battery Life [hours]} = \frac{200\text{ mAh}}{\left(\frac{60\text{ mA} \times 0.500\text{ s} + 0.5\ \mu\text{A} \times 4.5\text{ s}}{0.500\text{ s} + 4.5\text{ s}}\right)} = 26.36\text{ hours} \quad (3)$$

To design for maximum battery life, it is essential to utilize the shutdown current of the load switch. If the system was a sensory node, you only want the system powered when it is taking and processing data. The device should be in the off state as much as possible in order to maximize the battery life. In space-constrained designs, utilizing the shutdown current also allows the system to use a smaller battery to achieve the same battery life as an always-on system.

8 Designing for Optimum Quiescent Current

We can use the same diagram with different values to show when quiescent current should be a design consideration. Instead of using the same method that shows the system's on and off time, we can assume that the load switch is being used for its current limit, or thermal protection feature, or both. This means that the designer wants to protect the load from being damaged if too much current is being consumed. The new values are shown in Figure 6 where the quiescent current is 0.02 mA at 3 V. A 10 mA load shows the impact of the quiescent current.

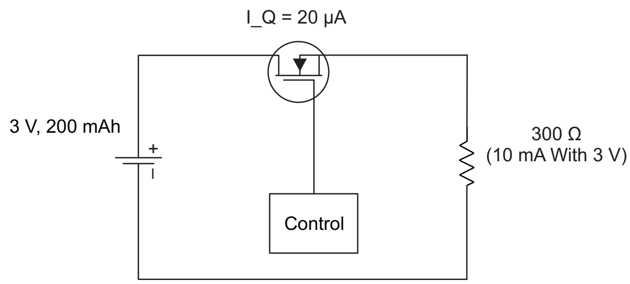


Figure 6. Load Switch Battery Example: Quiescent Current

$$\text{Total System Current [mA]} = I_{LOAD} + I_Q = 10\text{ mA} + 0.02\text{ mA} = 10.02\text{ mA} \quad (4)$$

TI's load switches have low quiescent current such that 10 mA of load current is still 99.6% of the 10.02 mA calculated for the total system current. Unless the system has load current close to the range of the quiescent current or there are prolonged periods of open load, the quiescent current should be a minor consideration of the total system current.

9 Key Takeaways

Understanding the quiescent and shutdown current for load switches and their dependence on voltage and temperature improves a designer's ability to select the perfect load switch device for their application. Here are the key things that a designer should take from this document:

1. The device's ambient temperature has an effect on the shutdown and quiescent current values. If the device is expected to be hotter than room temperature, be sure to refer to the datasheet graphs to see the device response to temperature.
2. The load switch input, bias voltage, or both, have an effect on its quiescent and shutdown current values. Always consider the operating voltage when looking at these currents and use the datasheet to estimate the typical values at given voltages.
3. To save battery power, take advantage of a load switch's shutdown current. Effectively using a load switch to turn off unused loads reduces a system's power consumption and maximizes battery life.
4. Quiescent current of a load switch is negligible when the load current is a factor greater than the quiescent current.
5. To increase battery life by saving power in the system, go to www.ti.com/loadswitch. There you can find TI's portfolio of load switches to suit your application.

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