Application Report
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Understanding Undervoltage Lockout in Power Devices

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ABSTRACT

Many integrated circuits include an undervoltage lockout (UVLO) function to disable the device at low supply voltages. Below the minimum supply voltage the function and performance of a device may be undefined, making it impossible to predict system behavior. This application note explains how to correctly understand the undervoltage lockout specification in the data sheets of TI's power products.

Contents

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1 The Need for an Undervoltage Lockout Function

Many power devices are designed to operate with low supply voltages, but they still need a certain minimum voltage to operate correctly. This is especially important in battery-powered applications, where the available voltage decreases as the battery discharges.

When the supply voltage is too low, a number of things can happen, including:

- The bandgap reference may generate the wrong voltage
- Logic functions may generate the wrong control signals
- Power transistors may be switched only partially on or partially off

An undervoltage lockout (UVLO) function makes sure that a device does nothing until the supply voltage is high enough for predictable behavior, giving rise to robust system performance.

2 Operating Modes

Figure 1 is a graphical representation of the different modes a device typically operates in.

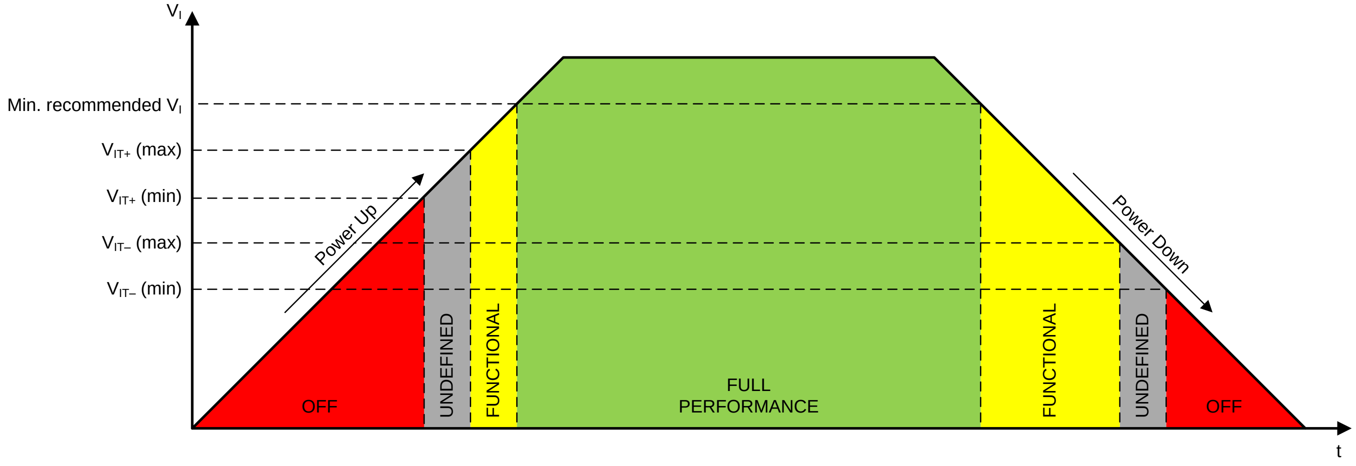

Figure 1. Operating Modes

2.1 *Off*

When the supply voltage is below the UVLO threshold, the device is off (shown by the red regions). All the internal blocks except the UVLO circuit itself are disabled. The input supply current when the device is off is typically very small.

2.2 *Functional*

When the supply voltage is above the maximum UVLO threshold but below the recommended minimum operating voltage (shown by the yellow regions), all device functions are enabled, but full performance is not specified. For example, a DC/DC converter operating in this region may regulate correctly but not be able to deliver its full output current.

2.3 *Full Performance*

Full performance is specified only if the supply voltage lies within the recommended operating conditions (shown by the green region).

In mission-critical applications, such as spacecraft, the UVLO threshold is typically *above* the minimum operating voltage for which the system achieves full performance. Such systems are extremely robust, but they are not cost-effective for most commercial applications, because the resulting components are over-designed for the majority of use cases.

2.4 *Undefined*

UVLO thresholds are specified with some tolerance to allow for process and temperature variations. Thus there is a range of supply voltages (the gray regions) within which the user cannot be sure if the device is functional or not. This does not mean that the device behavior is completely unpredictable. It means the device is either off or functional, but which of the two states the device operates in is unspecified, because it depends on where exactly in the gray region the UVLO threshold lies.

3 Hysteresis and UVLO "Bouncing"

UVLO circuits are typically designed to include some hysteresis. When a device switches on, the current it draws can cause the supply voltage to drop. Without hysteresis, that voltage drop would immediately turn the device off again. This is particularly true in systems where the supply voltage has a relatively high impedance, or is supplied via long cables. In a well-designed system, the worst-case voltage drop caused by the device turning on is less than the UVLO hysteresis (less some margin). In systems whose supply voltage impedance is relatively high, the drop that occurs when the device turns on (or the sudden increase that occurs when the device turns off) can exceed the UVLO hysteresis, and the device can turn on and off a number of times before settling down to a stable state. To minimize the probability of this happening, we could increase the UVLO hysteresis; however, "more hysteresis" means either raising the upper threshold or lowering the falling threshold. The first means the system needs an even higher supply voltage to start, and the second typically means higher device cost (to implement fancy techniques and larger power transistors). Neither of these is particularly attractive to customers, and we try to strike the right balance between cost and performance. A UVLO hysteresis of a few hundred millivolts is typical for TI's power devices and is perfectly adequate in well-designed systems with a reasonable supply voltage impedance.

Note that the falling threshold of the UVLO function is often more accurately defined than the rising threshold. This is because the bandgap reference from which the UVLO thresholds are derived operates in an untrimmed (that is, less accurate) state until the device turns on. Once the device is turned on, the output voltage of the bandgap is initialized and achieves full accuracy, and therefore the falling threshold is accurate.

It is important to consider UVLO bouncing during production as well as in the final application. Some systems work properly in the final application, where a short, low-impedance connection exists between the battery and the circuit board, but fail to start up correctly in the production line, where long cables (several meters) are used to connect the device to a test power supply.

Figure 2 and Figure 3 contrast the behavior of a system with low- and high-impedance supply voltage connections. With a low-impedance connection (Figure 2), the power-down behavior is well controlled; with a high-impedance connection (Figure 3), the device bounces around its UVLO threshold and restarts temporarily before finally turning off.

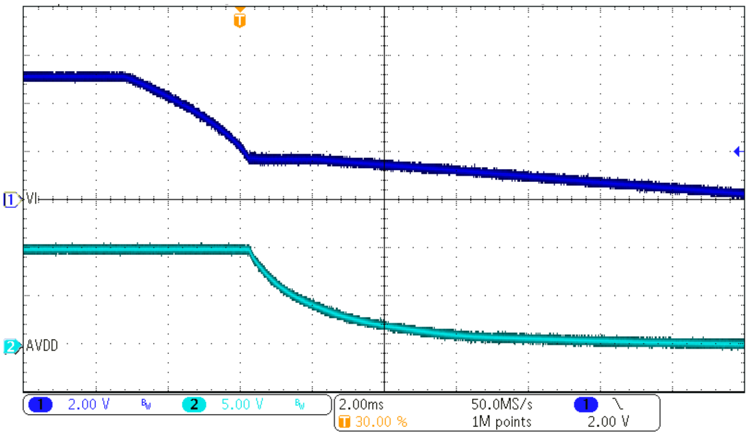

Figure 2. Power-Down Behavior With Low-Impedance Supply

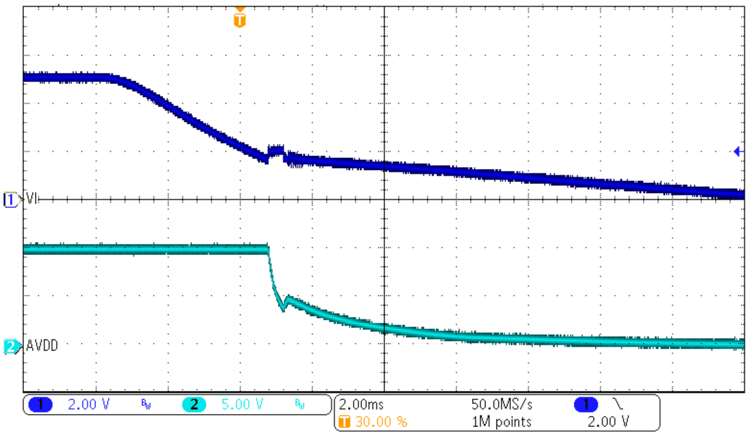

Figure 3. Power-Down Behavior With High-Impedance Supply

4 Power Cycle

Some power devices feature protection functions that latch the device in a safe state following an abnormal operating condition such as overcurrent or thermal shutdown. Normal operation is typically recovered by applying a "power cycle" to the device. This means bringing the supply voltage below the UVLO falling threshold and then bringing it above the UVLO rising threshold.

5 Data Sheet Parameters

5.1 Recommended Operating Conditions

Look in the *Recommended Operating Conditions* table for the range of input supply voltages for which the device will give its full performance. If your application does not need full performance (for example, because your load is smaller than the maximum current the device can support) you *may* be able to use lower supply voltages than the minimum recommended value. However, you must take care to verify that your final circuit includes sufficient margin. One way to do this is to verify the performance of the circuit over all operating conditions (including temperature) using a supply voltage a few hundred millivolts lower than the lowest you intend to use in your application.

Table 1. Recommended Operating Conditions

		MIN	NOM	MAX	Unit
V_I	Input voltage range	2.8		5.5	V

5.2 Electrical Characteristics

A well-specified UVLO function should have minimum and maximum values for the rising and falling thresholds and the hysteresis (see Table 2). These values should be valid for the entire operating temperature range of the device. Typical values are of limited use, because robust system design requires known limits over temperature, and typical values are (a) not limits, and (b) only valid at 25°C.

Table 2. Electrical Characteristics

Parameter		Test Conditions	MIN	TYP	MAX	Unit
V_{IT+}	Positive-going UVLO threshold voltage (V_{DD})		2.3	2.5	2.7	V
V_{IT-}	Negative-going UVLO threshold voltage (V_{DD})		2.1	2.3	2.5	V
V_{hys}	UVLO hysteresis		0.1	0.2	0.3	V

While it is true for each individual device that the difference between rising and falling edge threshold voltages is equal to the hysteresis voltage, the values specified in the data sheet are statistically derived and apply to all devices. For example, Table 2 shows that the maximum rising and falling edge threshold voltages are 2.7 V and 2.5 V respectively, but that the maximum hysteresis voltage is 0.3 V (not 0.2 V, as one might expect).

Not all data sheets have their UVLO functions as completely specified as the one in Table 2. If some parameters are missing, contact the factory via the E2E forum for clarification.

The device specified in Table 1 and Table 2 has the following behavior:

- During power up, the device *may* start functioning when $V_I \geq 2.3$ V, but it will *certainly* start functioning as soon as $V_I \geq 2.7$ V. Full performance is only specified when $V_I \geq 2.8$ V.
- During power down, the device *may* stop functioning when $V_I \leq 2.5$ V, but it will *certainly* stop functioning as soon as $V_I \leq 2.1$ V. Full performance is no longer specified when $V_I \leq 2.8$ V.
- During power up and power down, the UVLO function of the device has at least 0.1 V of hysteresis, but not more than 0.3 V.

6 Summary

The UVLO function in power devices is a useful feature that enables robust system behavior across a wide range of operating conditions. When using a device, take care to familiarize yourself with its UVLO characteristics and understand what they mean for your application. If the UVLO parameters in a data sheet are unclear, use the E2E forum to ask for clarification.

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