

Demystifying Input Supply Current in DC/DC Regulators: From Shutdown to Full Load



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Quiescent current can be one of the most confusing specifications of a DC/DC converter, especially if you're not familiar with the detailed operation of a switching regulator. Because manufacturers use different terminology and definitions, you will often see "quiescent current," " I_Q " or "input supply current" used interchangeably.

In this paper, I will try to clear up some of the confusion by focusing on the current required from the input supply flowing into a buck (step-down) regulator. When reading through a data sheet, it is best to focus on the conditions that existed when the input current was taken, rather than get caught up in the terminology. Let's look at some of the most important supply currents that a typical user would be interested in. See **Figure 1**.

Shutdown current

Shutdown current usually refers to the supply current measured when the regulator is shut off. Under these conditions, the output from the regulator is zero, with the nominal input voltage present and the "off" logic level applied to the enable (or shutdown) input. It may seem strange that any current is required when the regulator is off. In fact, many converters draw only small leakage currents when they are off, usually in the nanoampere range. The data sheet should specify this current over the full temperature range, since leakage currents increase rapidly with increasing temperature. However, some regulators need to keep certain housekeeping functions running even when in shutdown mode. These functions require a finite amount of bias current to power the internal circuits, perhaps in the microampere range. For a regulator with internal power metal-oxide

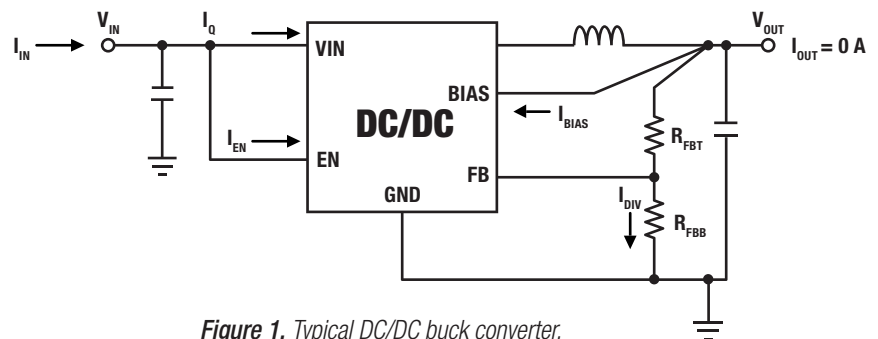


Figure 1. Typical DC/DC buck converter.

semiconductor field-effect transistors, there will be some leakage current from the input to the switch pin. This current will flow through the inductor and toward the load. In some cases this may be a concern for the application. Again, the data sheet should specify the switch leakage parameter. The sum of all of these currents is important when powering the regulator from a battery (such as in automotive or portable applications), since it is the least amount of current that will be drawn from the input supply.

EN input current

Some current may sneak into the enable (or shutdown) control pin. While in most cases the enable pin is a simple complementary metal-oxide semiconductor logic input, drawing only nanoamperes of current, that may not always be true. A few regulators on the market may use this input to supply current to some of the internal circuits; check the data sheet to be sure. You must account for the current if you're using a voltage divider on the EN input.

Nonswitching current

A somewhat more confusing term is the nonswitching current, which refers to the input supply current when the regulator is enabled but not producing an output voltage. This current is usually measured open loop, with the voltage on the feedback pin high enough to stop the regulator from switching, thus producing no output voltage. Why should you care about the current drawn when the regulator is on but not producing a useful output? The simple answer is that you may not care, since these are not the conditions used in the application of the regulator. But there are at least two good reasons why this specification shows up in the data sheet. First, with the regulator in a known state, this current is a good measure of the health of the internal circuits and can easily be measured in a production environment during the

manufacture of the integrated circuit. Secondly, and more important, this current is part of the total supply current used by the regulator when operating at no load.

No-load input current

A more useful supply-current specification is the operating current required at no load. In this condition the converter is regulating the output voltage but the load current is zero. This mode is usually called sleep mode or standby mode. Most regulators will reduce the switching frequency and/or skip switching cycles in order to reduce the input current to a minimum when there is no load (or a very light load) on the output. Many converters switch to sleep mode automatically, depending on load current, but some require the system controller to tell the regulator to change modes. With the system also in standby mode, the load on the regulator will be very light, so users need to know how much current will be required from the input supply.

You can usually find this current specification in the data sheet; check the conditions carefully, however, to be sure that the current listed is actually the no-load operating current. As an example, see this portion of the [LM63625-Q1](#) data sheet in **Figure 2**.

System characteristics					
The following specifications apply only to the typical applications circuit component values. Specifications in the typical (TYP) column apply to $T_J = 25^\circ\text{C}$ only. Specifications in the minimum (MIN) and maximum (MAX) columns apply to the case of typical components over the temperature range of $T_J = -40^\circ\text{C}$ to 150°C . These specifications are not ensured by production testing.					
PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY VOLTAGE (VIN PIN)					
I_{SUPPLY}	Input supply current when in regulation	$V_{\text{IN}} = 12\text{ V}, V_{\text{OUT}} = 3.3\text{ V}, I_{\text{OUT}} = 0\text{ A}, R_{\text{FBT}} = 1\text{ M}\Omega$	23		μA

Figure 2. Example of input supply-current specification.

The parameter, I_{SUPPLY} , is the total input current required to regulate at the specified input and output voltage at no load. This device will automatically go into sleep mode at light loads.

Sometimes you may not find this input current in the data sheet, or it is not specified under the conditions that you are interested in. In such cases, **Equation 1** estimates the no-load input current for a buck regulator:

$$I_{IN} = I_Q + I_{EN} + \frac{V_{OUT}}{V_{IN}} \times (I_{BIAS} + I_{DIV}) \quad (1)$$

Let's go through this equation. The first term, labeled I_Q , is the nonswitching quiescent current discussed earlier. The next term, I_{EN} , is the current going into the EN pin of the regulator.

The I_{BIAS} term needs further explanation. Many DC/DC converters have an internal low-dropout regulator (LDO) that supplies power to the internal circuits of the converter. In modern regulators, the

input of the LDO is often available as an external pin on the converter. It is usually called the bias pin; check the data sheet to be sure you have the right pin. With this input connected to the output of the regulator, the bias current acts as an extra load on the output of the converter. The load is downconverted just like any other load by the ratio of the input voltage to output voltage. This connection is preferable because it reduces the current seen at the input and therefore improves efficiency.

The term I_{DIV} is the current used by the feedback voltage divider, calculated with **Equation 2**:

$$I_{DIV} = \frac{V_{OUT}}{R_{FBB} + R_{FBT}} \quad (2)$$

Equation 1 gives a best-case estimate, since it does not take into account the losses in the converter. Let's use the LM61460-Q1 as an example. Another excerpt from its data sheet, shown in **Figure 3**, lists the typical values of I_Q , I_{BIAS} and I_{EN} .

Electrical characteristics						
The following specifications apply only to the typical applications circuit component values. Specifications in the typical (TYP) column apply to $T_J = 25^\circ\text{C}$ only. Specifications in the minimum (MIN) and maximum (MAX) columns apply to the case of typical components over the temperature range of $T_J = -40^\circ\text{C}$ to 150°C . These specifications are not ensured by production testing.						
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY VOLTAGE AND CURRENT						
$V_{IN_OPERATE}$	Input operating voltage ⁽¹⁾	Needed to start up	3.95			V
		Once operating	3.0			
$V_{IN_OPERATE_H}$	Hysteresis ⁽¹⁾			1		V
I_Q	Operating quiescent current (not switching); measured at VIN pin ⁽²⁾	$V_{FB} = +5\%$, $V_{BIAS} = 5\text{ V}$		0.6	6	μA
I_{BIAS}	Current into BIAS pin (not switching, maximum at $T_J = 125^\circ\text{C}$) ⁽²⁾	$V_{FB} = +5\%$, $V_{BIAS} = 5\text{ V}$, Auto Mode		24	31.2	μA
I_{SD}	Shutdown quiescent current; measured at VIN pin	$EN = 0\text{ V}$, $T_J = 25^\circ\text{C}$		0.6	6	μA
ENABLE						
V_{EN}	Enable input threshold voltage - rising			1.263		V
V_{EN_ACC}	Enable input threshold voltage - rising deviation from typical		-8.1		8.1	%
V_{EN_HYST}	Enable threshold hysteresis as percentage of V_{EN} (TYP)		24	28	32	%
V_{EN_WAKE}	Enable wake-up threshold		0.4			V
I_{EN}	Enable pin input current	$V_{IN} = EN = 13.5\text{ V}$		2.3		nA

Figure 3. LM61460-Q1 electrical characteristics.

If you are converting a 12-V input to a 5-V output, with a total feedback divider resistance of 1 MΩ, **Equation 3** provides this value of no-load input current:

$$I_{IN} = 0.6 \mu A + 2.3 \mu A + \frac{5}{12} \times (24 \mu A + 4 \mu A) = 14 \mu A \quad (3)$$

Notice that, for this device, the data sheet also specifies the no-load input supply current at one typical condition, as shown in **Figure 4**.

I_{O-VIN}	Operating quiescent current ⁽¹⁾	$V_{OUT} = 3.3V, I_{OUT} = 0 A,$ Auto mode, $R_{FBT} = 1 M\Omega$	7	μA
		$V_{OUT} = 5V, I_{OUT} = 0 A,$ Auto mode, $R_{FBT} = 1 M\Omega$	10	

Figure 4. LM61460-Q1 input-current specification.

The calculated value in Equation 3 is somewhat different, but it is close enough for a rough estimate. The equations are meant to show how the no-load input current depends on the input voltage, output voltage and other factors. You can see that the input current will increase for larger output voltages and smaller input voltages. So the best thing to do is to use the equations to estimate the no-load input supply current and then measure the actual value under real application conditions.

Input supply current

It is also possible to calculate the input current of a DC/DC converter by using the efficiency curves, but not at no load. By definition, the efficiency is zero at no load, so you must use the method outlined earlier in this paper to estimate the no-load supply current.

At any other load, you can use the efficiency curves in the data sheet, along with **Equation 4**:

$$I_{IN} = \frac{V_{OUT}}{\eta \times V_{IN}} \times I_{OUT} \quad (4)$$

where η is the efficiency under the conditions of interest.

Again using an example from the LM63625-Q1 data sheet, the efficiency is about 80% for an input voltage of 13.5 V, an output voltage of 5 V, a load of 1 mA and a device set for a pulse-width modulation (PWM) frequency of 400 kHz; see **Figure 5**.

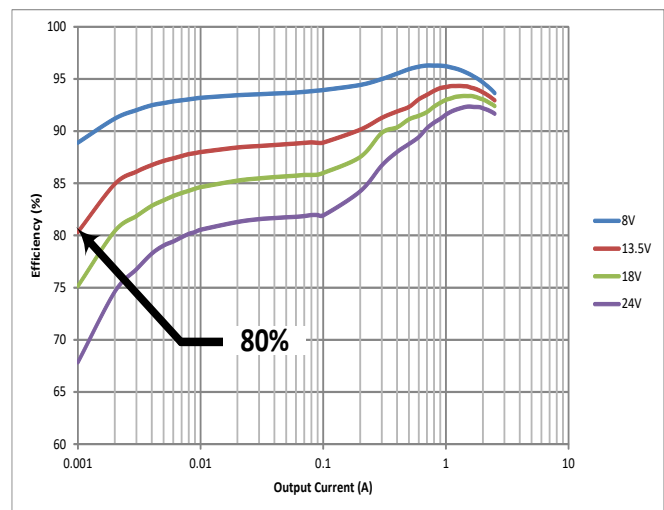


Figure 5. Efficiency example for the LM63625-Q1.

Equation 5 calculates an input current of about 500 μA :

$$I_{IN} = \frac{5 \times 0.001}{0.8 \times 13.5} \cong 500 \mu A \quad (5)$$

Notice that I mentioned the switching frequency in the above example. The LM63625-Q1 goes into sleep mode at light loads such as 1 mA in order to improve the efficiency. At these light loads, the efficiency depends to some extent on the value of the power inductance, which is selected based on the PWM frequency. Keep this in mind when looking for a data-sheet curve to use as a basis for your efficiency or I_{IN} estimate.

You can use **Equation 4** with any set of conditions, not just for very light loads. You can also use the efficiency curves found in the data sheet to estimate the efficiency for conditions not found in the data sheet. First, find a curve that comes close to your input voltage, output voltage, load and switching frequency. Then use the rules in **Table 1** to approximately scale the efficiency.

Parameter	Effect on efficiency
Input voltage	Decreases with increasing voltage
Output voltage	Increases with increasing voltage
Switching frequency	Decreases with increasing frequency

Table 1. Variation of efficiency with system parameters.

Conclusion

Using various parameters found in the data sheet to estimate your input supply current is not difficult, as long as you make sure that the values you are looking at are applicable (or close) to your specific application conditions. I hope that I have helped clarify what some of the parameters mean and how to use them correctly. By focusing on where the current flows and how to use the values given in the data sheet – rather than getting caught up in the terminology – you can make a reasonable estimate of the input supply current.

References

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- [LM636x5-Q1 data sheet.](#)
- [LM61460-Q1 data sheet.](#)

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