

# I<sub>Q</sub>: What it is, what it isn't, and how to use it

**By Chris Glaser**  
Applications Engineer

## Introduction

A device's quiescent current, or I<sub>Q</sub>, is an important yet often misused parameter for low-power, energy-efficient designs. In many battery-powered applications, such as metering, wearables, building security and the Internet of Things (IoT), the current drawn from the battery in a standby condition with light or no load defines the total run time of the system. In integrated switch converters, the I<sub>Q</sub> is only one portion of this battery current. This article defines I<sub>Q</sub> and how it is measured, explains what I<sub>Q</sub> is not and how it should not be used, and gives design considerations on how to use I<sub>Q</sub> while avoiding common measurement errors. This article applies to any of the Texas Instruments (TI) TPS61xxx, TPS62xxx, TPS63xxx, or TPS650xx devices.

## What I<sub>Q</sub> is

Unless otherwise noted in the datasheet for a part, I<sub>Q</sub> is defined as the current drawn by the IC in a no-load and nonswitching but enabled condition. "No load" means that no current leaves the IC to the output. Typically, this would be current leaving via the SW pin on buck converters or via the V<sub>OUT</sub> pin on boost converters. All of the I<sub>Q</sub> simply travels inside the IC to ground. "Nonswitching" means that no power switch in the IC is on (closed). This includes the main or control switch as well as the synchronous rectifier if both are integrated into the IC. In other words, the IC is in a high-impedance condition with a power stage that is completely disconnected from the output (except for integrated MOSFET body diodes on some devices that cannot be turned off). "Enabled" means that the IC is turned on via its EN pin and is not in a UVLO or other shutdown condition. I<sub>Q</sub> measures operating current, not shutdown current, so the device must be on. Lastly, I<sub>Q</sub> is meaningful only in power-save mode, so if this mode is an option for the particular device, it must be enabled. If the device runs in pulse-width-modulation (PWM) mode, then the input current to the power stage and switching losses

more than dwarfs the miniscule amount of current, the I<sub>Q</sub>, required to run the device.

I<sub>Q</sub> fundamentally comes from two inputs: V<sub>IN</sub> and V<sub>OUT</sub>. The datasheet lists whether the I<sub>Q</sub> comes from either or both pins. Figure 1 shows the I<sub>Q</sub> specification from the datasheet for the TI TPS61220/21/22,<sup>1</sup> which are boost converters that draw their I<sub>Q</sub> from both V<sub>IN</sub> and V<sub>OUT</sub>. Typically, a buck converter draws I<sub>Q</sub> only from its input, while a boost converter or buck-boost converter draws I<sub>Q</sub> from both the input and the output.

I<sub>Q</sub> measures the current required to operate the device's basic functionality, which includes powering things like the internal precision reference voltage, an oscillator, a thermal shutdown or UVLO circuit, the device's state machine or other logic gates, etc. I<sub>Q</sub> does not include any input current to the power stage or gate drivers, as it is measured in a nonswitching condition where these currents are zero. The reason for measuring I<sub>Q</sub> in this condition is that it is solely dependent on the IC, whereas the power-stage input current and gate-drive current are dependent on the selected external components, which in most cases dictate how often the IC switches in its power-save mode. Thus, I<sub>Q</sub> is an IC measurement, whereas including the other two currents is a system measurement. TI does not control and cannot guarantee such a system measurement but does control and can specify an IC measurement. In fact, TI guarantees the I<sub>Q</sub> specification and, for devices whose datasheets specify a maximum value for the I<sub>Q</sub>, tests it on each and every device that is produced. This is done by enabling the device, setting it to the test conditions specified in its datasheet, and then artificially raising (with externally applied voltages) the output voltage, FB pin, and any other pin voltages high enough to cause the IC not to switch. With no load and power-save mode enabled (if available), the input current to the IC becomes the I<sub>Q</sub>.

## What I<sub>Q</sub> isn't

I<sub>Q</sub> is not the no-load input current. As previously mentioned, the I<sub>Q</sub> is simply the "overhead" current required to operate the IC's basic functionality. It does not include the

**Figure 1. I<sub>Q</sub> specification from TPS61220/21/22 datasheet**

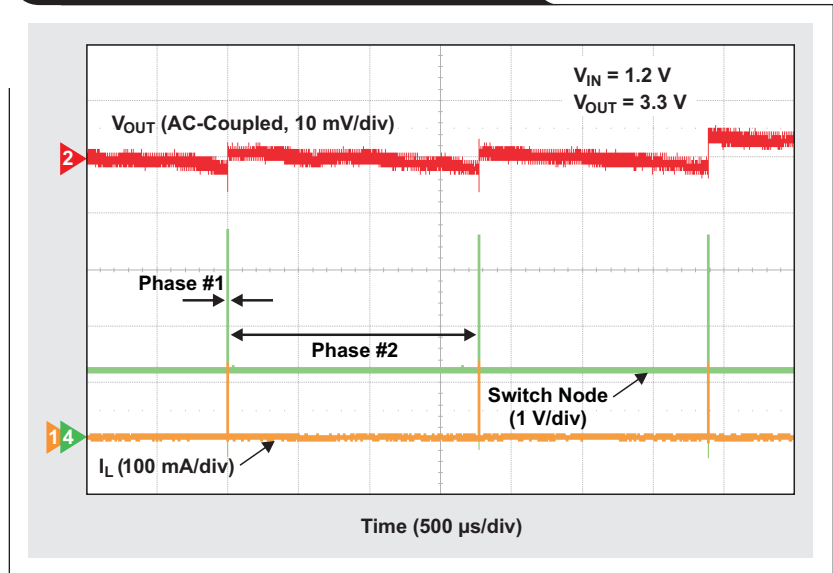
DC/DC STAGE						
PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
	I <sub>Q</sub> Quiescent current	V <sub>IN</sub>	I <sub>O</sub> = 0 mA, V <sub>EN</sub> = V <sub>IN</sub> = 1.2 V, V <sub>OUT</sub> = 3.3 V		0.5	0.9
	V <sub>OUT</sub>			5	7.5	μA

input current into the power stage (current that is actually transferred to the output) or current required to operate the gate drivers. Even at no load, the device still switches to keep the output regulated. Some losses always exist at the output, such as loss from the voltage divider used to set the output voltage; leakage current into the load or through the output capacitor; pull-up resistors; etc. Because these losses cause voltage decay at the output capacitor, the IC must switch every so often to replenish the power lost. So, a no-load input-current measurement violates the requirements that the IC must be in a nonswitching condition and that no current may leave the IC to recharge  $V_{OUT}$ . As an example, Figure 2 shows no-load operation for the TPS61220 boost converter, with an input voltage of 1.2 V and an output voltage of 3.3 V. The IC switches approximately every 1.75 ms to regulate the output voltage. This period depends on  $V_{IN}$ ,  $V_{OUT}$ , and the external components and affects how much average input current is drawn. During phase #1, the IC is switching—either the high-side MOSFET or the synchronous rectifying MOSFET is on. The input current is dominated by the current into the power stage, which averages about 70 mA (half of the peak current in the inductor).

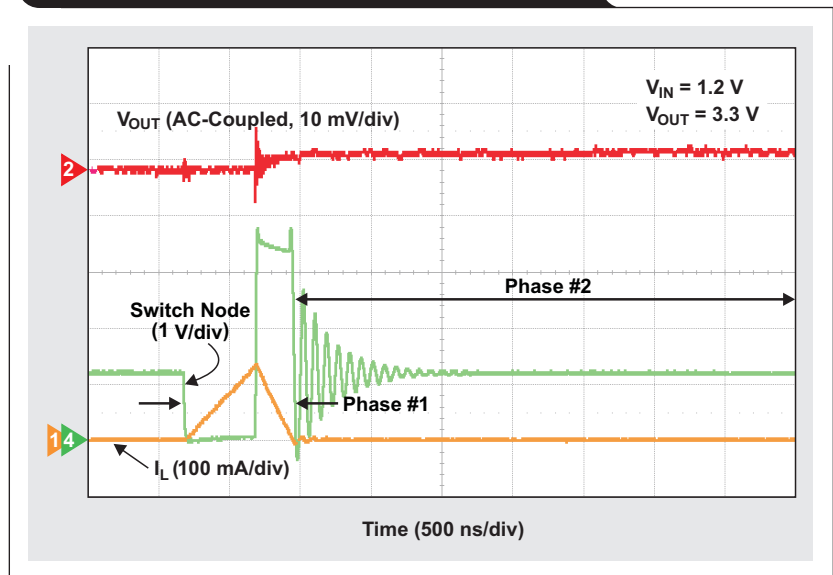
Figure 3 shows an enlarged view of phase #1. Once the output voltage drops below the threshold, the TPS61220 begins a switching pulse by turning the control MOSFET on. The SW pin goes low, causing the inductor current to ramp up. It then turns off the control MOSFET and turns on the rectifying MOSFET, allowing current to flow to the output. The output voltage increases as this energy is transferred into the output capacitor. When the inductor current reaches zero, all the energy has been delivered to the output; so the rectifying MOSFET turns off, and the IC goes into a sleep mode (phase #2). At this point, both MOSFETs are off (open), so the SW pin is in a state of high impedance. The inductor and parasitic capacitances on that pin ring until it reaches its DC value, which equals the input voltage.

During phase #2, the IC is high impedance, and the output voltage drops due to leakage at the output. Because the IC is not switching, the current consumed by the IC during this time is the  $I_Q$ . Phases #1 and #2 define a switching period over which the average input current is calculated. Due to the high input current during the

**Figure 2. No-load operation of TPS61220**



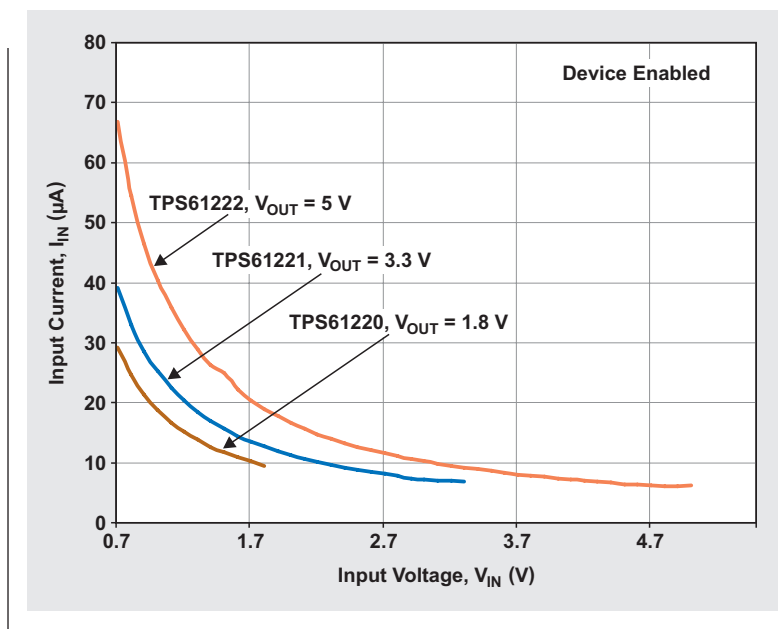
**Figure 3. Switching pulse of TPS61220 during no-load operation**



switching time (phase #1), the average input current over this time must be higher than the IC's  $I_Q$ . However, because the duration of phase #1 is very short, the average input current is usually only slightly greater than the input current that is due to the  $I_Q$ .

To address this difference between the  $I_Q$  and the no-load input current, the datasheets of some ICs have typical specifications for the no-load input current in the electrical characteristics table. Others have graphs that show the

**Figure 4. Graph of no-load input current from TPS61220/21/22 datasheet**



no-load input current for a particular circuit. Figure 4 shows such a graph from the TPS61220/21/22 datasheet.<sup>1</sup> Alternatively, Figure 5 shows the  $I_Q$  specification in an electrical characteristics table. This table is taken from the datasheet for the TI TPS62120/22,<sup>2</sup> which are high-efficiency buck converters. The typical specification of 13 µA is valid only for the specific test conditions stated. For both the TPS61220 and TPS62120, note that the no-load input current is higher than the IC's  $I_Q$ . Figure 4 shows that the no-load input current to the TPS61221 boost converter is 20 µA with a  $V_{IN}$  of 1.2 V and a  $V_{OUT}$  of 3.3 V. This is much higher than the  $I_Q$  in Figure 1 of 5 µA at  $V_{OUT}$  and 0.5 µA at  $V_{IN}$  with the same test conditions. This difference is explained later in this article under item #3 of “Design considerations.”

**How to use  $I_Q$**

Knowing the  $I_Q$  assists the designer in comparing the low-power performance of different ICs. However, an IC's  $I_Q$  is only part of the system's input current, which is affected

by three things: each IC's internal design (its  $I_Q$ ), the external components around each IC, and the overall system configuration. Because the input current is a combination of these three items,  $I_Q$  losses may or may not be the dominant loss for a particular system and may or may not be the determining factor in the battery's run time.

If the end application truly operates the IC at no output load, then an IC with lower  $I_Q$  typically has lower no-load input current, which results in longer battery run time. This assumes that both ICs have a power-save mode and that it is enabled. However, power-save modes can behave differently among different ICs, resulting in vastly different no-load input currents.

If the application does not run at no load but instead runs in a “standby” or “hibernate” mode in which the processor or another load still draws some current, then the usefulness of  $I_Q$  quickly decreases. To demonstrate, consider the TPS62120 powering TI's MSP430™ and other circuitry that altogether consume 100 µA at 2 V. With an 8-V input, the TPS62120 is running at 60% efficiency (see

**Figure 5. No-load input-current specification from TPS62120/22 datasheet**

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>SUPPLY</b>						
$I_Q$	Quiescent current	$I_{OUT} = 0mA$ , Device not switching, $EN = VIN$ , regulator sleeps		11	18	µA
		$I_{OUT} = 0mA$ , Device switching, $V_{IN} = 8V$ , $V_{OUT} = 1.8V$		13		µA

Figure 6. Efficiency graph for TPS62120

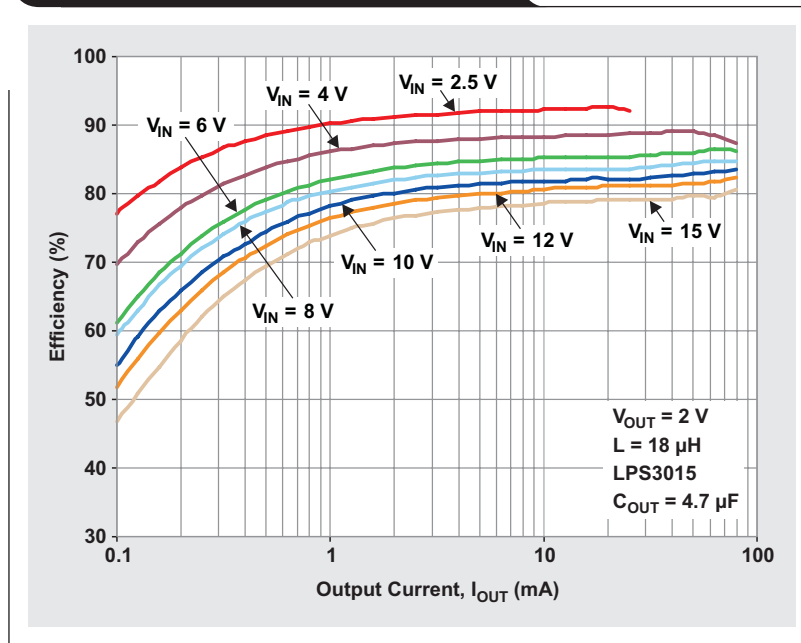


Figure 6<sup>2</sup>), resulting in an input current of

$$\frac{2 \text{ V} \times 100 \text{ } \mu\text{A}}{0.6 \times 8 \text{ V}} = 42 \text{ } \mu\text{A}.$$

This input current includes the  $I_Q$  (11  $\mu\text{A}$ ), which is a very significant portion of the total input current (about 26%). If, however, the standby load increases to 1 mA, the input current at 8 V is

$$\frac{2 \text{ V} \times 1 \text{ mA}}{0.8 \times 8 \text{ V}} = 313 \text{ } \mu\text{A}.$$

Now the 11  $\mu\text{A}$  of  $I_Q$  is not significant at all (about 3.5%). To accurately estimate the input current in a system's standby mode, the load current drawn must be known. Simply using the  $I_Q$  in place of this light-load input current does not accurately estimate the battery current drawn.

Any efficiency graph in a datasheet indicates the total circuit efficiency and includes the  $I_Q$  losses. Therefore, the  $I_Q$  losses should not be added to the losses given in the graphs.

## Design considerations

Numerous errors can be made when  $I_Q$  values are measured or taken from a datasheet. The following five considerations will help the designer avoid these errors.

**1. The  $I_Q$  of an IC cannot be changed.** Nothing can be done from outside the IC that affects the  $I_Q$ . The  $I_Q$  does vary over input voltage and temperature, but the behavior of the IC's internal circuitry sets this variation. If the IC is operated in forced PWM mode or a load is attached to the output, then the  $I_Q$  is no longer applicable to the circuit, and the input current becomes applicable

instead. Many things can be done in an application that affect the input current, but not the  $I_Q$ .

### 2. Specified operating conditions need to be considered.

$I_Q$  is specified only for an IC's recommended operating conditions and for certain test conditions, specifically an input voltage and an output voltage. For any IC, the specified  $I_Q$  is not guaranteed when the input voltage is above the recommended maximum (but less than the absolute maximum) or when the input voltage is below the recommended minimum (but above the UVLO level). For a buck converter,  $I_Q$  is valid only when the input voltage is greater than the output voltage and when the device is not in dropout (100% mode). For a boost converter, the input voltage must be less than the output voltage so that the IC is not in down mode.

**3. Input current is often linked to the output.** The majority of the  $I_Q$  for a synchronous boost usually comes from the output voltage. Since this power must ultimately come from the input, the input current in a no-load condition is substantially higher than the  $I_Q$  because the input current for a boost converter must be greater than its output current. Consider the TPS61220 boosting from 1.2 V to 3.3 V. With an  $I_Q$  of 5  $\mu\text{A}$  at  $V_{OUT}$  and 0.5  $\mu\text{A}$  at  $V_{IN}$ , and assuming 100% conversion efficiency, the input current from the  $I_Q$  alone is

$$\frac{3.3 \text{ V} \times 5 \text{ } \mu\text{A}}{1.2 \text{ V}} + 0.5 \text{ } \mu\text{A} = 14.25 \text{ } \mu\text{A}.$$

The circuit actually draws about 20  $\mu\text{A}$  of input current at no load (as shown in Figure 4) simply because of non- $I_Q$  losses such as switching losses and gate-drive

losses. The important point is that this 20  $\mu\text{A}$  of input current is much greater than the IC's  $I_Q$  of 5.5  $\mu\text{A}$  because the TPS61220 is a boost converter that draws most of its  $I_Q$  from the output voltage.

**4. Look for all possible input-current paths.** When measuring the  $I_Q$  on an evaluation module (EVM) or other board, the designer should ensure that the input current to the board is going entirely into the IC and not to other places on the board. Leakages from capacitors or other devices, even if the devices are disabled, may be significant due to the small  $I_Q$  values and may affect the input current to the board. In addition, on some EVMs and most end-equipment boards, the input voltage or output voltage is routed to pull-up resistors, indicator LEDs, or other devices that may sink current under some conditions. Obviously, this current draw is not part of the IC's  $I_Q$ . Finally, the IC's  $I_Q$  is of no importance as a system parameter, since total input current is actually what is needed; and that is easily measured at the required test conditions.

**5. Measurement techniques can make a big difference.** To get accurate measurements of the low-power input current or the efficiency in power-save mode, it is critical to follow the test setup detailed in Reference 3.

**Conclusion**

$I_Q$  is an important IC design parameter in modern low-power DC/DC converters and partially defines the current drawn from the battery in light-load conditions. The  $I_Q$  is

not the IC's no-load input current, as the IC consumes the  $I_Q$  current only in a no-load, enabled, and nonswitching condition. Due to leakage at the output, the IC must switch to keep the output voltage regulated. Instead of using an IC's  $I_Q$  as an estimate of the battery's current draw, the designer should measure and use the no-load input current to the system. An even better way to estimate the battery's current draw is to define the system's load when the system is in low-power mode and then measure the battery's actual current draw at this operating point. Doing this instead of simply using  $I_Q$  allows accurate prediction of battery run times.

**References**

For more information related to this article, you can download an Acrobat® Reader® file at [www.ti.com/lit/litnumber](http://www.ti.com/lit/litnumber) and replace “*litnumber*” with the **TI Lit. #** for the materials listed below.

<b>Document Title</b>	<b>TI Lit. #</b>
1. “Low input voltage step-up converter in 6 pin SC-70 package,” TPS61220/21/22 Datasheet. . . . .	slvs776
2. “15V, 75mA high efficient buck converter,” TPS62120/22 Datasheet . . . . .	slvsad5
3. Jatan Naik, “Performing accurate PFM mode efficiency measurements,” Application Report . . . . .	slva236

**Related Web sites**

- [power.ti.com](http://power.ti.com)
- [www.ti.com/sc/device/TPS61220](http://www.ti.com/sc/device/TPS61220)
- [www.ti.com/sc/device/TPS62120](http://www.ti.com/sc/device/TPS62120)

# ***TI Worldwide Technical Support***

---

## **TI Support**

Thank you for your business. Find the answer to your support need or get in touch with our support center at

[www.ti.com/support](http://www.ti.com/support)

China: <http://www.ti.com.cn/guidedsupport/cn/docs/supporthome.tsp>

Japan: <http://www.tij.co.jp/guidedsupport/jp/docs/supporthome.tsp>

## **Technical support forums**

Search through millions of technical questions and answers at TI's E2E™ Community (engineer-to-engineer) at

[e2e.ti.com](http://e2e.ti.com)

China: <http://www.deyisupport.com/>

Japan: <http://e2e.ti.com/group/jp/>

## **TI Training**

From technology fundamentals to advanced implementation, we offer on-demand and live training to help bring your next-generation designs to life. Get started now at

[training.ti.com](http://training.ti.com)

China: <http://www.ti.com.cn/general/cn/docs/gencontent.tsp?contentId=71968>

Japan: <https://training.ti.com/jp>

**Important Notice:** The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

**A011617**

E2E and MSP430 are trademarks of Texas Instruments.  
Acrobat and Reader are registered trademarks of Adobe Systems Incorporated. All other trademarks are the property of their respective owners.

© 2011, 2019 Texas Instruments Incorporated.  
All rights reserved.



**SLYT412**

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale ([www.ti.com/legal/termsofsale.html](http://www.ti.com/legal/termsofsale.html)) or other applicable terms available either on [ti.com](http://ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2019, Texas Instruments Incorporated