TPS23752 Maintain Power Signature Operation in Sleep Mode

Johnny Guo, Eric Wright, Jean Picard

ABSTRACT
The TPS23752 is a 20-pin integrated circuit combining a Power-over-Ethernet (PoE) powered device (PD) interface and a current-mode DC/DC controller optimized specifically for applications requiring high efficiency over a wide load range. The TPS23752 integrates the additional Sleep Mode feature. Sleep Mode disables the converter, minimizing power consumption while still generating the Maintain Power Signature required by IEEE 802.3at. This application report supplies an explanation of the operation of the TPS23752 Sleep Mode and gives some relative experiment results.

Contents
1 Introduction ......................................................................................................................... 2
2 Operation of Sleep Mode .................................................................................................... 2
3 Test Result of Sleep Mode ................................................................................................. 6
  3.1 Entering Sleep Mode ..................................................................................................... 6
  3.2 Input Current in Sleep Mode ....................................................................................... 8
  3.3 Exiting Sleep Mode ...................................................................................................... 9
  3.4 Maximum LED Current Measurement ...................................................................... 11
4 Conclusion ......................................................................................................................... 12
5 References ......................................................................................................................... 12

Figures
Figure 1. TPS23752 Sleep Mode Functionality Block Diagram ........................................... 3
Figure 2. TPS23752 Pulsed MPS Current in Sleep Mode .................................................... 4
Figure 3. LEDs Connection For Higher Brightness ............................................................ 4
Figure 4. WAKE Pin Connection with Low CTR Optocoupler ........................................... 5
Figure 5. TPS23752 Sleep Mode Operation ........................................................................ 5
Figure 6. Entering Sleep Mode with MODE Low ............................................................... 7
Figure 7. Entering Sleep Mode with MODE High ................................................................ 7
Figure 8. Input Current in Sleep Mode with MODE Low (I_{LED} = 0 mA) ......................... 8
Figure 9. Input Current in Sleep Mode with MODE Low (I_{LED} = 4 mA) ......................... 8
Figure 10. Input Current in Sleep Mode with MODE High ................................................ 9
Figure 11. Exiting Sleep Mode with MODE Low and SLPb High ..................................... 10
Figure 12. Exiting Sleep Mode with MODE High and SLPb High ..................................... 10
Figure 13. Input Current in Sleep Mode with MODE Low (I_{LED} = 9.081 mA) ............... 11

Tables
Table 1. Sleep Mode Supply Current .................................................................................. 3
Table 2. Sleep Mode Related Connector Functionality ...................................................... 6
Table 3. Maximum LED Current Measurement Result ...................................................... 11
1 Introduction

The TPS23752 is a 20-pin integrated circuit that combines a Power-over-Ethernet (PoE) powered device (PD) interface and a current-mode DC/DC controller optimized specifically for applications requiring high efficiency over a wide load range. TPS23752 integrates the additional Sleep Mode feature. The Maintain Power Signature (MPS) is an electrical signature presented by the PD, assuring the PSE that it is still present after operating voltage is applied. A valid MPS consists of a minimum DC current of 10 mA (or a 10-mA pulsed current for at least 75 ms every 325 ms) and an AC impedance lower than 26.3 kΩ in parallel with 0.05 μF.

The Sleep Mode permits power savings at night (or some other system-driven criteria) by turning the active load circuits off while maintaining enough functionality for the PD to respond to a local power-up request. The Sleep Mode is initiated by command of a local device controller (microprocessor) when the SLPb input is driven low. Sleep Mode is latched by this event, the converter is disabled. The TPS23752 signals the PSE that it wants to remain powered during sleep by drawing enough current to satisfy the IEEE 802.3at MPS requirements. The input current consists of the TPS23752 bias current and the LED sink current, assuming no additional loading on Vc or VB. The MPS current draw is inhibited when APD is active. A local pushbutton switch is monitored by the WAKE pin and the latched sleep state exits when the button is pressed.

2 Operation of Sleep Mode

Figure 1 shows the TPS23752 Sleep Mode functionality block diagram. Four pins related with Sleep Mode are described as below.

LED: The LED pin drives an external status LED. Connect the LED and its series current limiting resistor from Vc to the LED pin. While in Sleep Mode, the controller pulls the LED pin to ARTN. LED current can be set up as application requirement. If a status LED is not required, leave this pin open.

MODE: If this input is low when SLPb transitions low, the pulsed MPS function is enabled during Sleep Mode. Otherwise, a DC MPS current of 10.6 mA (typical) is drawn during Sleep Mode. Either MPS ensures that the PSE does not disconnect power from the PD while it is asleep. MODE is latched when SLPb falls, and is ignored during sleep. An MPS is not generated if the APD pin is held high (> 1.5 V). During normal operation, pulling MODE low causes the LED pin to pull low.

SLPb: The SLPb pin controls entry into Sleep Mode. The sleep state is latched active by a falling SLPb, which is then ignored during the Sleep Mode. This mode of operation disables converter switching, increases the current limit of the internal Vc regulator, and pulls the LED output low. Cycling Vdd or pulling the WAKE pin low terminates the Sleep Mode and restores normal operation.

WAKE: This pin performs several functions. During Sleep Mode, it outputs a current-limited 2.5 V. Pressing the external wakeup button during Sleep Mode connects the WAKE pin to the optocoupler and makes the TPS23752 exit Sleep Mode. The optocoupler alerts the system controller that the button has been pressed during sleep operation. Note that the WAKE pin is at VB during normal operation.
The Sleep Mode supply current is shown in Table 1.

Table 1. Sleep Mode Supply Current

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep supply current when APD is enabled</td>
<td>V_{APD} = 2 V, SLPb ↓, measure I_{VDD}</td>
<td>0.5</td>
<td>1.0</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>MPS supply current</td>
<td>Pulsed mode(1): VMODE = 0 V, SLPb ↓, measure I_{VDD}, 0 ≤ I_{LED} ≤ 10 mA</td>
<td>10.0</td>
<td>10.6</td>
<td>11.5</td>
<td>mApk</td>
</tr>
<tr>
<td></td>
<td>DC mode: VMODE = V_B, SLPb ↓, measure I_{VDD}, 0 ≤ I_{LED} ≤ 10 mA</td>
<td>10.0</td>
<td>10.6</td>
<td>11.5</td>
<td>mA</td>
</tr>
<tr>
<td>MPS pulsed mode duty cycle</td>
<td>MPS pulsed current duty cycle(1)</td>
<td>28.80%</td>
<td>28.88%</td>
<td>28.95%</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>MPS pulsed current ON time</td>
<td>75</td>
<td>87.5</td>
<td>ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MPS pulsed current OFF time(1)</td>
<td>215</td>
<td>250</td>
<td>ms</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: Parameters provided for reference only and do not constitute part of TI published specifications for purposes of TI product warranty.

Figure 1. TPS23752 Sleep Mode Functionality Block Diagram
Entering Sleep Mode is triggered by a falling edge signal on the SLPb pin. When in Sleep Mode, the DC/DC converter is disabled, V_{DD} regulates V_C to 12.8 V, and the 2.5-V regulator provides voltage at some low current to WAKE pin. The MPS regulator provides a control signal to the internal MOSFET connected with the V_C pin, thus an MPS is generated at the input side. The LED pin also draws current from V_C and shares the same current-sensing resistor with the V_C internal MOSFET.

TPS23752 senses the LED current and draws the extra current to satisfy the IEEE 802.3at MPS requirement. Figure 2 shows the MPS current in pulsed MPS mode. LED current can be set as application requirement. Some applications require more LED current to be drawn from Vc to LED in Sleep Mode for higher LED brightness. This means that except for sleep supply current (I_{VDD}), no more current should be consumed inside the controller. In pulsed MPS mode, LED current should be traded off with input power consumption in order to have higher LED brightness while being able to meet energy saving standard (for example, 0.5-W Energy Star standard). Equation 1 shows the calculation of the average input current. LED current is adjustable with the series resistor and I_{VDD} consumption in Sleep Mode during the (1 – D_{MPS}) period is typically 0.5 mA.

\[ I_{IN\_avg} = (D_{MPS} \times 10.6 \, mA) + [(1 – D_{MPS}) \times (I_{VDD} + I_{LED})] \]  

(1)

Figure 2. TPS23752 Pulsed MPS Current in Sleep Mode

When the PD is powered by an adapter, LED current is still generated in Sleep Mode, but no MPS current is driven from adapter.

Figure 3. LEDs Connection For Higher Brightness
Usually $V_c$ (12.8 V) is used to power LEDs. To achieve the highest brightness LED, it is possible to connect 3 or more LEDs in series, as shown in Figure 3, without drawing more power from the 48-V bus. So the power consumed by $R_{\text{LED}}$ is lower without more waste.

When the wakeup button is pressed, an internal current comparator detects the WAKE current and when $I_{\text{WAKE}} > 150 \mu\text{A}$, the TPS23752 exits Sleep Mode and changes to the normal operation state. The WAKE pin now connects back to the internal 5.33 kΩ pull-up resistor $R_{\text{WKPLUP}}$.

With the TPS23752, the Sleep Mode signals are referenced to AGND after the hot swap, meaning that no costly optocoupler and diodes are required for any of the three sleep and wakeup signals, if in a non-isolated application.

When an optocoupler with low CTR is used for the WAKE signal, more wakeup current is required. Use the application circuit shown in Figure 4 to ensure the processor wakeup signal when the wakeup button is pressed.

![Figure 4. WAKE Pin Connection with Low CTR Optocoupler](image)

![Figure 5. TPS23752 Sleep Mode Operation](image)
For Sleep Mode operation, Figure 5 shows the status switching operation. “Sleep 0” stands for the pulsed-MPS Sleep Mode status that SLPb transitions low with the MODE pin low, “Sleep 1” stands for the DC MPS Sleep Mode status that SLPb transitions low with the MODE pin high.

3 Test Result of Sleep Mode

For the Sleep Mode test, use the TPS23752EVM-145 board with the Sleep Mode functionality. The opto-isolated circuits and associated circuits support the sleep or low-power mode of the TPS23752. The typical input and output voltage is 48 V and 5 V. In order to clearly observe the MPS (input current) when entering and exiting Sleep Mode, we connect a resistive load of 10.2 Ω to the 5 V output (input current is about 60 mA). For Sleep Mode control, install a shunt on J8 while J6 is shorted to enable pulsed MPS. Install a shunt on J8 while J6 is open to enable DC MPS. Table 2 lists the detailed Sleep Mode related connector functionality.

<table>
<thead>
<tr>
<th>Connector</th>
<th>Label</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J6</td>
<td>SLP</td>
<td>Shorting pin 1 to pin 2 causes the TPS23752 to enter Sleep Mode. Sleep Mode is entered when the SLPb pin is pulled low during normal operation.</td>
</tr>
<tr>
<td>J8</td>
<td>MODE</td>
<td>Install a shunt on J8 while J6 is shorted to enable pulsed MPS. Remove the shunt from J8 while J6 is shorted, enabling DC MPS.</td>
</tr>
<tr>
<td>S1</td>
<td>WAKE</td>
<td>Depressing S1 when the TPS23752 is in Sleep Mode restarts the DC/DC converter.</td>
</tr>
</tbody>
</table>

3.1 Entering Sleep Mode

Enter the Sleep Mode test by shorting pin 1 to pin 2 of J6, pulling the SLPb pin low, thus causing the TPS23752 to enter Sleep Mode. Test with both MODE pin in low and high voltage when shorting J6.

Figure 6 and 7, respectively; illustrate entering Sleep Mode with the MODE pin low and high. With the MODE pin low, pulsed MPS is enabled as shown in Figure 6. The input current drops from DC 60 mA to 10.6 mA pulsed current for about 84 ms every 292 ms. The WAKE pin voltage drops from 5 V to 2.5 V. Because power pin 2 of J6 and J8 is connected with the output of the DC/DC converter, when TPS23752 enters Sleep Mode, the DC/DC converter turns down and the output voltage falls to zero, so the voltage of the SLPb pin and the MODE pin rise to high voltage, after entering Sleep Mode. With the MODE pin high, a valid MPS consisting of a DC current of 10.6 mA is enabled as shown in Figure 7. After the TPS23752 enters Sleep Mode, the voltage of the MODE pin remains high and the SLPb pin voltage rises to high.
Figure 6. Entering Sleep Mode with MODE Low

Figure 7. Entering Sleep Mode with MODE High
3.2 Input Current in Sleep Mode

Figure 8. Input Current in Sleep Mode with MODE Low (IL_{LEDS} = 0 mA)

Figure 9. Input Current in Sleep Mode with MODE Low (IL_{LEDS} = 4 mA)
Figure 10. Input Current in Sleep Mode with MODE High

Figure 8, 9, and 10 show the MPS current of the PD when in Sleep Mode with the MODE pin low and high when entering Sleep Mode. When entering Sleep Mode with the MODE pin low, a valid MPS of 10.6 mA pulsed current for about 84 ms every 292 ms is enabled, as shown in Figure 8 and 9, with different LED currents set to 0 mA and 4 mA. With the MODE pin high when entering Sleep Mode, an MPS consisting of a 10.6 mA DC current is enabled, as shown in Figure 10.

3.3 Exiting Sleep Mode

Exit the Sleep Mode test by depressing S1 when the TPS23752 is in Sleep Mode thus restarting the DC/DC converter.

Figure 11 and 12, respectively, show exiting Sleep Mode with the MODE pin low and high when entering Sleep Mode. Pressing wakeup button S1 causes the TPS23752 to exit Sleep Mode. The input current rises back to 60 mA. The MODE pin voltage turns to low in Figure 11 because of output voltage established, but remains high in Figure 12. The reason the WAKE pin voltage drops a little from 2.5 V and then rises to 5 V is because when S1 is still pressed, the WAKE pin connects back to the internal 5.33-kΩ pull-up resistor, R_WKPLUP, the voltage on WAKE pin is determined by all the connections to the pin. After S1 is disconnected, the WAKE pin voltage rises to about 5 V near to V_B.
Figure 11. Exiting Sleep Mode with MODE Low and SLPb High

Figure 12. Exiting Sleep Mode with MODE High and SLPb High
3.4 Maximum LED Current Measurement

For some applications, more LED current is drawn from Vc in order to have the highest LED brightness possible, while meeting the 0.5-W Energy Star standard when in Sleep Mode. Connect 3 LEDs in series to the VC pin as shown in Figure 3. Table 3 shows the test result for the average input current and input power consumption with different RLED. Figure 13 shows the pulsed MPS current of the PD when in Sleep Mode with 9.081 mA LED current (RLED = 365 Ω).

<table>
<thead>
<tr>
<th>VIN (V)</th>
<th>IIN_avg (mA)</th>
<th>PIN (W)</th>
<th>VLED (V) (1)</th>
<th>RLED (Ω)</th>
<th>ILED (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>8.654</td>
<td>0.493</td>
<td>8.649</td>
<td>511</td>
<td>7.061</td>
</tr>
<tr>
<td>48</td>
<td>8.607</td>
<td>0.413</td>
<td>8.633</td>
<td>511</td>
<td>7.053</td>
</tr>
<tr>
<td>48</td>
<td>9.802</td>
<td>0.471</td>
<td>8.727</td>
<td>383</td>
<td>8.768</td>
</tr>
<tr>
<td>48</td>
<td>10.103</td>
<td>0.485</td>
<td>8.752</td>
<td>365</td>
<td>9.081</td>
</tr>
<tr>
<td>48</td>
<td>10.420</td>
<td>0.500</td>
<td>8.765</td>
<td>332</td>
<td>9.681</td>
</tr>
</tbody>
</table>

Note 1: LED part number: Everlight 23-21C/T1D-CP2Q2TY/2A. VLED is the forward voltage of 3 LEDs in series.

Figure 13. Input Current in Sleep Mode with MODE Low (ILED = 9.081 mA)
4 Conclusion

The Maintain Power Signature when the TPS23752 enters Sleep Mode is valid and consists of a DC current of 10.6 mA or a 10.6-mA pulsed current according to the MODE pin select. The PD assures the PSE that it is still present after entering Sleep Mode according to IEEE 802.3at standard.

5 References

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

<table>
<thead>
<tr>
<th>Audio</th>
<th>Amplifiers</th>
<th>Data Converters</th>
<th>DLP® Products</th>
<th>DSP</th>
<th>Clocks and Timers</th>
<th>Interface</th>
<th>Logic</th>
<th>Power Mgmt</th>
<th>Microcontrollers</th>
<th>RFID</th>
<th>OMAP Applications Processors</th>
<th>Wireless Connectivity</th>
</tr>
</thead>
</table>

Applications

<table>
<thead>
<tr>
<th>Automotive and Transportation</th>
<th>Communications and Telecom</th>
<th>Computers and Peripherals</th>
<th>Consumer Electronics</th>
<th>Energy and Lighting</th>
<th>Industrial</th>
<th>Medical</th>
<th>Security</th>
<th>Space, Avionics and Defense</th>
<th>Video and Imaging</th>
</tr>
</thead>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2013, Texas Instruments Incorporated