

## HIGH EFFICIENCY CHARGE PUMP FOR 7 WLEDs DRIVER WITH 1 WIRE INTERFACE

### FEATURES

- 2.7 V to 6.0 V Input Voltage Range
- 1× and 1.5× Charge Pump
- Auto Switching Between 1× and 1.5× Modes
- 750 kHz Charge Pump Frequency
- Seven Individually-regulated WLED Current Sinks
- Single-Wire Interface for Dimming and ON/OFF Control
- 25 mA max LED Current for Six Current Sinks
- One 80 mA Current Sink
- Open WLED Detection
- Built-in Soft Start and Current Limit
- 16-pin, 3 mm × 3 mm QFN Package

### APPLICATIONS

- Cellular Phones
- Portable Navigation Displays
- Multi-display Handheld Devices

### DESCRIPTION

The TPS60255 is a high-efficiency, constant frequency charge pump DC/DC converter that uses 1× and 1.5× conversion to maximize efficiency for the input voltage range. By using adaptive 1×/1.5× charge-pump modes and very low dropout current regulators, the TPS60255 achieves high efficiency for the entire one-cell lithium battery range. The protection features include soft start, over-current limit, thermal shut down, and over-voltage detection. The device automatically detects and removes unused current sinks from the control loop.

This device drives six 25 mA current sinks and one 80 mA current sink. These current regulators are programmed by three independent brightness registers and five ON/OFF bits using a single-wire interface (EasyScale™). This offers flexible applications for a variety of lighting control in portable devices.

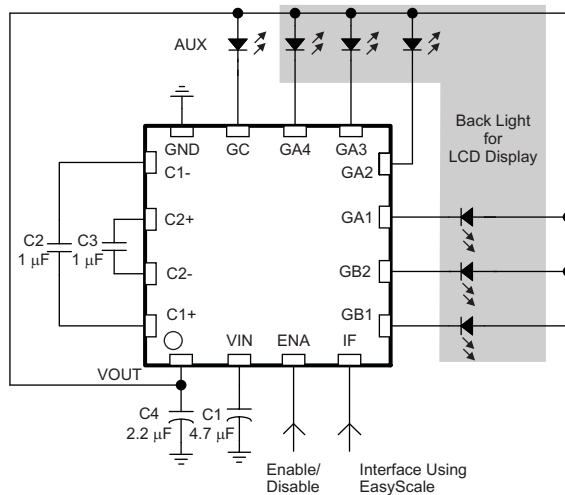


Figure 1. Typical Application

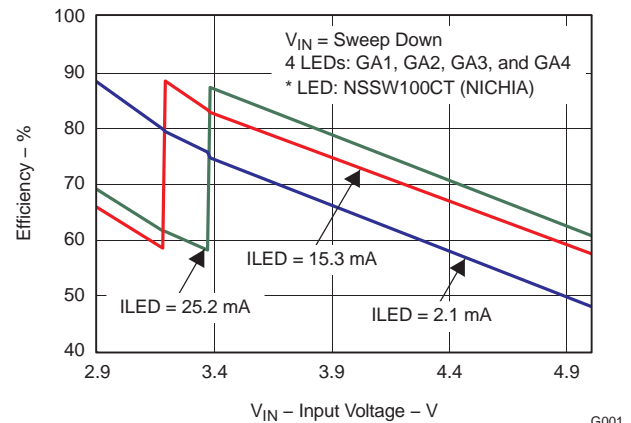


Figure 2. Characteristic Curve

### ORDERING INFORMATION<sup>(1)</sup>

| PART NUMBER | PACKAGE MARKING | PACKAGE                      | T <sub>A</sub> |
|-------------|-----------------|------------------------------|----------------|
| TPS60255RTE | BUF             | 16-Pin 3 mm × 3 mm QFN (RTE) | –40°C to +85°C |

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at [www.ti.com](http://www.ti.com).



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These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

## ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                 |  | VALUE      | UNIT |
|-----------------|--|------------|------|
| V <sub>I</sub>  | Input voltage range (all pins)         | –0.3 to 7  | V    |
|                 | HBM ESD Rating <sup>(2)</sup>          | 2          | kV   |
|                 | CDM ESD Rating <sup>(3)</sup>          | 500        | V    |
|                 | MM ESD Rating <sup>(4)</sup>           | 200        | V    |
| T <sub>A</sub>  | Operating temperature range            | –40 to 85  | °C   |
| T <sub>J</sub>  | Maximum operating junction temperature | 150        | °C   |
| T <sub>ST</sub> | Storage temperature                    | –55 to 150 | °C   |

- (1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) The Human body model (HBM) is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. The testing is done according JEDEC EIA/JESD22-A114.
- (3) Charged Device Model
- (4) Machine Model (MM) is a 200 pF capacitor discharged through a 500 nH inductor with no series resistor into each pin. The testing is done according JEDEC EIA/JESD22-A115.

## DISSIPATION RATINGS

| PACKAGE     | THERMAL RESISTANCE, R <sub>θJA</sub> | T <sub>A</sub> ≤ 25°C POWER RATING | DERATING FACTOR ABOVE T <sub>A</sub> = 25°C | T <sub>A</sub> = 85°C POWER RATING |
|-------------|--------------------------------------|------------------------------------|---|------------------------------------|
| QFN 3×3 RTE | 48.7°C/W                             | 2.05 W                             | 1.13 W                                      | 0.821 W                            |

## RECOMMENDED OPERATING CONDITIONS

|                     |                                | MIN | NOM | MAX | UNIT |
|---------------------|--------------------------------|-----|-----|-----|------|
| V <sub>I</sub>      | Input voltage range            | 2.7 |     | 6.0 | V    |
| I <sub>O(max)</sub> | Maximum output current         |     | 230 |     | mA   |
| C1                  | Input capacitor                |     | 1.0 |     | μF   |
| C4                  | Output capacitor               | 2.2 | 4.7 |     | μF   |
| C2, C3              | Flying capacitor               |     | 1.0 |     | μF   |
| T <sub>A</sub>      | Operating ambient temperature  | –40 |     | 85  | °C   |
| T <sub>J</sub>      | Operating junction temperature | –40 |     | 125 | °C   |

## ELECTRICAL CHARACTERISTICS

V<sub>I</sub> = 3.5 V, T<sub>A</sub> = –40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

| PARAMETER              | TEST CONDITIONS                         | MIN                     | TYP | MAX | UNIT |   |
|------------------------|---|-------------------------|-----|-----|------|---|
| <b>SUPPLY VOLTAGE</b>  |   |                         |     |     |      |   |
| V <sub>IN</sub>        | Input voltage range                     | 2.7                     |     | 6.0 | V    |   |
| I <sub>Q</sub>         | Operating quiescent current             |                         |     | 8   | mA   |   |
|                        | 1.5X Mode, I <sub>O</sub> = 61 mA       |                         |     | 3.2 | mA   |   |
|                        | 1X mode, I <sub>O</sub> = 61 mA         |                         |     | 68  | μA   |   |
|                        | 1X mode, I <sub>O</sub> = 100 μA        |                         |     |     |      |   |
| I <sub>SD</sub>        | Shutdown current                        |                         |     | 1   | μA   |   |
| V <sub>UVLO1</sub>     | UVLO threshold voltage 1 <sup>(1)</sup> | V <sub>IN</sub> falling |     | 2.5 | V    |   |
| V <sub>HYS_UVLO1</sub> | UVLO 1 hysteresis                       | V <sub>IN</sub> rising  | 200 |     | mV   |   |
| V <sub>UVLO2</sub>     | UVLO threshold voltage 2 <sup>(2)</sup> | V <sub>IN</sub> falling | 1.2 | 1.3 | 1.45 | V |

- (1) Shut down charge pump and power stage, but keep register values.
- (2) Shut down completely and come up with all zeros after device restart.

**ELECTRICAL CHARACTERISTICS (continued)**
 $V_I = 3.5\text{ V}$ ,  $T_A = -40^\circ\text{C}$  to  $85^\circ\text{C}$ , typical values are at  $T_A = 25^\circ\text{C}$  (unless otherwise noted)

| PARAMETER               |  | TEST CONDITIONS   | MIN                  | TYP       | MAX      | UNIT          |
|-------------------------|--|---|----------------------|-----------|----------|---------------|
| $V_{ENA\_H}$            | Enable high threshold voltage  |   | 1.5                  |           | $V_{IN}$ | V             |
| $V_{ENA\_L}$            | Enable low threshold voltage   |   |                      |           | 0.4      | V             |
| $T_S$                   | Soft start time <sup>(3)</sup>   |   |                      | 0.5       |          | ms            |
| <b>CHARGE PUMP</b>      |  |   |                      |           |          |               |
| $V_{OUT}$               | Overvoltage limit  |   |                      | 6.6       |          | V             |
| $F_s$                   | Switching frequency  |   | 625                  | 750       | 875      | kHz           |
| $R_O$                   | Open loop output impedance   | $1\times$ Mode, $(V_{IN} - V_O) + I_O$  |                      | 1.0       | 1.2      | $\Omega$      |
|                         |  | $1.5\times$ Mode, $(V_{IN} \times 1.5 - V_O) + I_O$<br>$V_{IN} = 3.1\text{ V}$ , $I_O = 230\text{ mA}$  |                      | 2.8       | 3.5      |               |
| <b>CURRENT SINK</b>     |  |   |                      |           |          |               |
| $K_{m\_GB}$             | Current matching of Group B at light load condition <sup>(4)</sup>             | $T_A = 0^\circ$ to $40^\circ\text{C}$ , $I_{GB\_LED} = 100\ \mu\text{A} \times 2$<br>$3.1\text{ V} \leq V_{IN} \leq 4.2\text{ V}$ , $V_{DX} = 0.4\text{ V}$ |                      | $\pm 0.1$ | $\pm 2$  | %             |
| $K_m$                   | LED to LED current matching of Group A and B (6 LEDs) <sup>(4)</sup>           | $I_{GAB\_LED} = 15.3\text{ mA} \times 6$<br>$3.1\text{ V} \leq V_{IN} \leq 4.2\text{ V}$  |                      | $\pm 0.1$ | $\pm 5$  | %             |
| $K_a$                   | Current accuracy   | $I_{LED} = 15.3\text{ mA}$  |                      |           | $\pm 10$ | %             |
|                         |  | $I_{LED} = 1.0\text{ mA}$ , $T_A = 25^\circ\text{C}$  |                      |           | $\pm 15$ |               |
| $I_{G\_AB\_M}$          | Maximum LED current of GA1-4 and GB1-2   | $V_{GX} = 0.2\text{ V}$   | 21.5                 | 25.2      | 28.9     | mA            |
| $I_{GC\_M}$             | Maximum LED current of GC  | $V_{GX} = 0.2\text{ V}$   |                      | 80        |          | mA            |
| $V_{DropOut}$           | LED Drop out voltage   | See table note <sup>(5)</sup>   |                      | 60        | 100      | mV            |
| $V_{TH\_GU}$            | $1\times$ Mode to $1.5\times$ mode transition threshold voltage <sup>(6)</sup> | $V_{GX}$ falling, measured on the lowest<br>$V_{GX}$ , $I_O = 61\text{ mA}$   |                      | 105       | 120      | mV            |
| $V_{TH\_GD}$            | $1.5\times$ mode to $1\times$ mode Transition threshold voltage                | Measured as $V_{IN} - (V_{out} - V_{GX\_MIN})$<br>$I_O = 61\text{ mA}$  | 520                  | 550       | 590      | mV            |
| <b>INTERFACE TIMING</b> |  |   |                      |           |          |               |
| $t_{Start}$             | Start time   |   | 3.5                  |           |          | $\mu\text{s}$ |
| $t_{H\_LB}$             | High Time Low Bit, logic 0 detection   | Signal level on IF pin is $> 1.2\text{ V}$  | 3.5                  |           | 300      | $\mu\text{s}$ |
| $t_{L\_LB}$             | Low Time Low Bit, logic 0 detection  | Signal level on IF pin $< 0.4\text{ V}$   | $2 \times t_{H\_LB}$ |           | 600      | $\mu\text{s}$ |
| $t_{L\_HB}$             | Low Time High Bit, logic 1 detection   | Signal level on IF pin $< 0.4\text{ V}$   | 3.5                  |           | 300      | $\mu\text{s}$ |
| $t_{H\_HB}$             | High Time High Bit, logic 1 detection  | Signal level on IF pin is $> 1.2\text{ V}$  | $2 \times t_{L\_HB}$ |           | 600      | $\mu\text{s}$ |
| $t_{EOS}$               | End of Stream  | $t_{EOS}$   | 3.5                  |           | 600      | $\mu\text{s}$ |
| $t_{ACKN}$              | Duration of Acknowledge Condition (IF line pulled low by the device)           | $V_{IN} 2.7\text{ V}$ to $6\text{ V}$   | 600                  |           | 750      | $\mu\text{s}$ |
| $t_{valACK}$            | Acknowledge Valid Time   |   |                      |           | 3.5      | $\mu\text{s}$ |

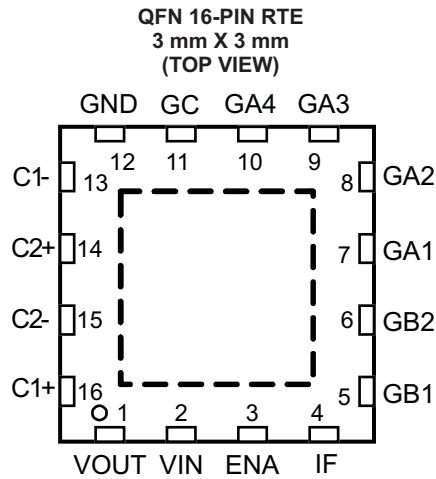
(3) Measurement Condition: From enabling the LED driver to 90% output voltage after  $V_{IN}$  is already up.

(4) LED current matching is defined as:  $|I - I_{AVG}|_{max} / I_{AVG}$

(5) Dropout Voltage is defined as  $V_{GX}$  (LED cathode) to GND voltage at which current into the LED drops 10% from the LED current at  $V_{GX} = 0.2\text{ V}$ .

(6) As  $V_{IN}$  drops,  $V_{GX}$  eventually falls below the switchover threshold of 100 mV, and TPS60255 switches to  $1.5\times$  mode. See the [Operating Principle](#) section for details about the mode transition thresholds.

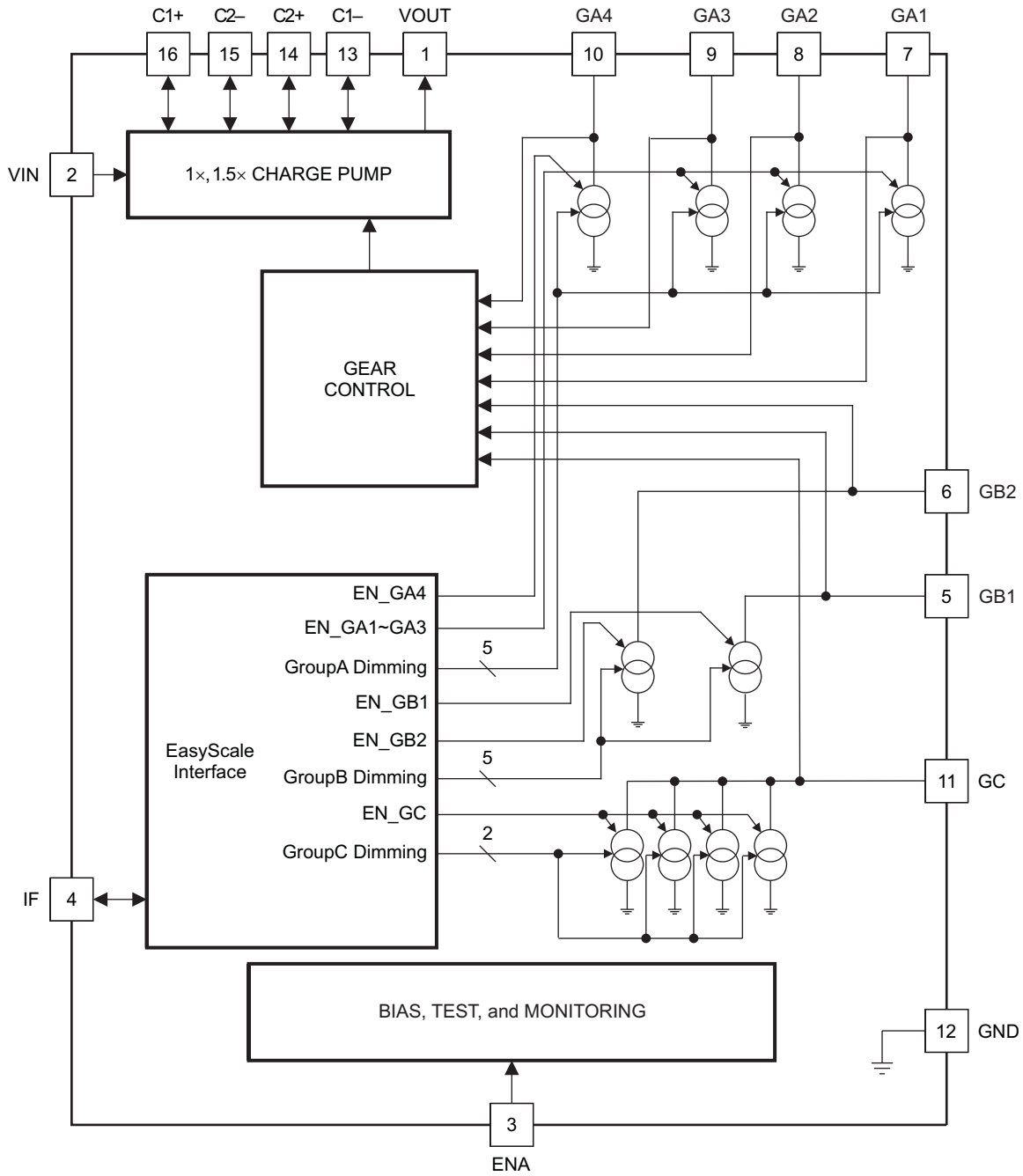
**PIN ASSIGNMENTS**



**TERMINAL FUNCTIONS**

| TERMINAL |     | I/O | DESCRIPTION  |
|----------|-----|-----|--|
| NAME     | NO. |     |  |
| VOUT     | 1   | O   | Connect the output capacitor and the anode of the white LEDs to this pin |
| VIN      | 2   | I   | Supply voltage input   |
| ENA      | 3   | I   | Hardware Enable/Disable Pin (High = Enable)                              |
| IF       | 4   | I   | Single wire interface for on/off and brightness control.                 |
| GB1      | 5   | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GB2      | 6   | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GA1      | 7   | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GA2      | 8   | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GA3      | 9   | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GA4      | 10  | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GC       | 11  | I   | Current sink input. Connect the cathode of the white LED to this pin.    |
| GND      | 12  | –   | Ground   |
| C1–      | 13  | –   | Connect to the flying capacitor C1                                       |
| C2+      | 14  | –   | Connect to the flying capacitor C2                                       |
| C2–      | 15  | –   | Connect to the flying capacitor C2                                       |
| C1+      | 16  | –   | Connect to the flying capacitor C1                                       |

**FUNCTIONAL BLOCK DIAGRAM**



TYPICAL CHARACTERISTICS

Table of Characteristic Graphs

| Title  | Description  | Figure    |
|--|--|-----------|
| Load efficiency  | Efficiency vs Input Voltage, main LED current = 2.1 mA, 15.3 mA, and 25.2mA  | Figure 3  |
| Input Current  | Input Current vs Input voltage, main LED current = 2.1 mA, 15.3 mA, and 25.2 mA  | Figure 4  |
| Shut down current  | Shut Down Current vs Input voltage   | Figure 5  |
| Output Accuracy  | Output Current Accuracy vs Temperature, main LED current = 15.3 mA   | Figure 6  |
| Output Impedance   | Switch Resistance vs. Temperature, 1X mode, I <sub>O</sub> = 230 mA  | Figure 7  |
| Output Impedance   | Switch Resistance vs. Temperature, 1.5X mode, I <sub>O</sub> = 230 mA  | Figure 8  |
| 1× → 1.5× Mode Transition Up<br>1.5× → 1× Mode Transition down | Output Voltage vs Input Voltage, main LED current = 15.3 mA  | Figure 9  |
| Normal Operation (1× mode)                                     | Input Voltage, Input Current, GA1 Current, V <sub>IN</sub> = 4.0 V,<br>LED current : GA1 = GA2 = GA3 = GA4 = GB1 = GB2 = 25.2 mA         | Figure 11 |
| Open Lamp Detection (1× mode)                                  | Input Voltage, Input Current, GA1 Current, V <sub>IN</sub> = 4.0 V,<br>LED current : GA1 = GA2 = GA3 = GB1 = GB2 = 25.2 mA (GA4 is open) | Figure 12 |

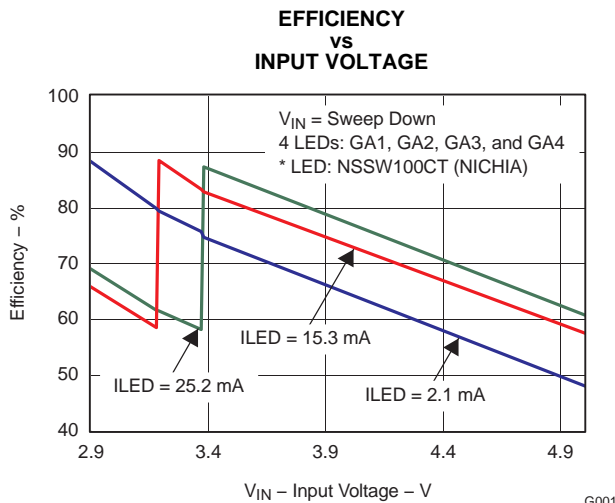


Figure 3.

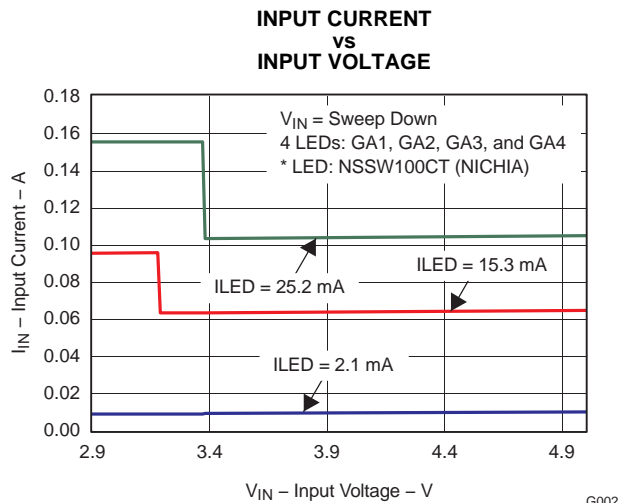


Figure 4.

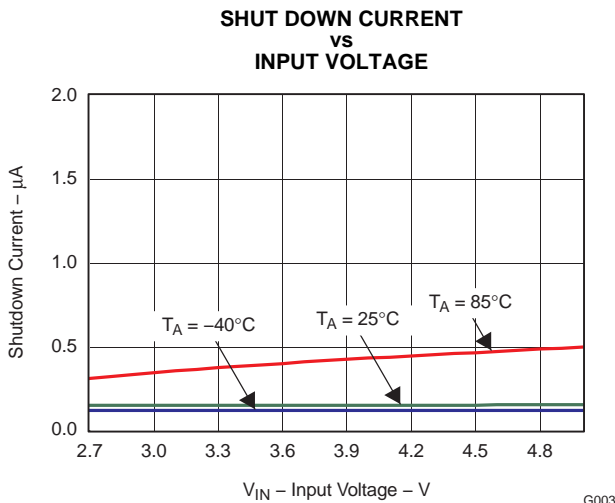


Figure 5.

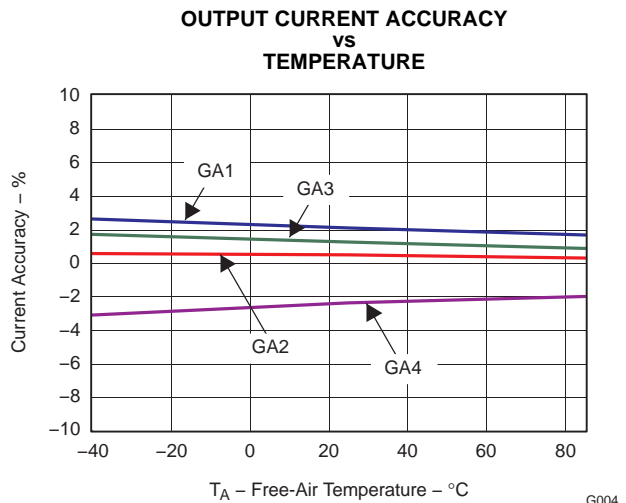


Figure 6.

**SWITCH RESISTANCE  
vs  
TEMPERATURE**  
1x mode,  $I_o = 230$  mA

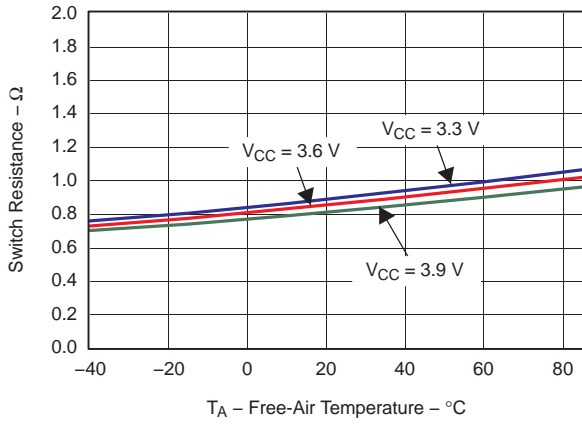


Figure 7.

G005

**SWITCH RESISTANCE  
vs  
TEMPERATURE**  
1.5x mode,  $I_o = 230$  mA

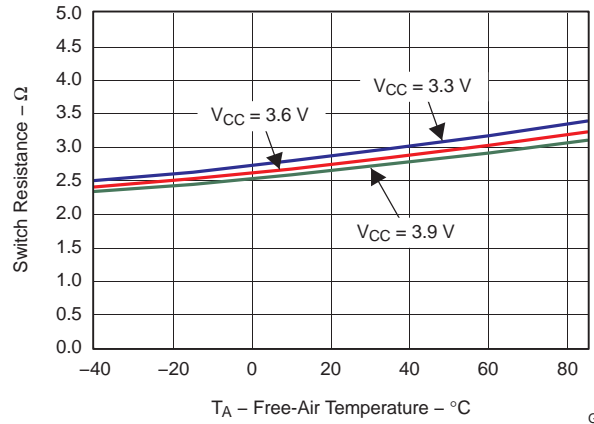


Figure 8.

G006

**INPUT VOLTAGE  
vs  
OUTPUT VOLTAGE  
TRANSITION**

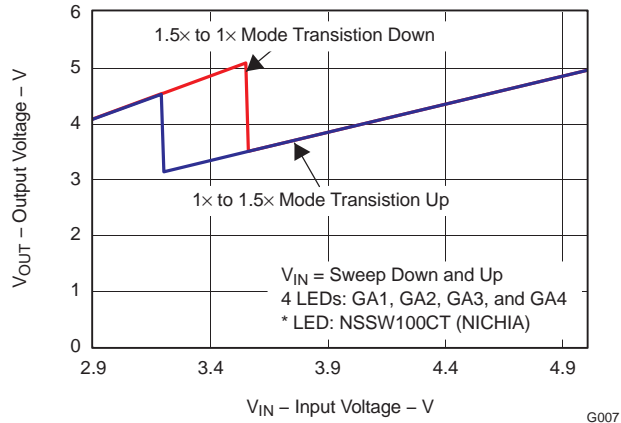


Figure 9.

G007

## APPLICATION INFORMATION

### APPLICATION OVERVIEW

Most of the current mobile telephone handsets fall into one of these designs:

- **Clam Shell** (Figure 17)—a main display on the inside, a secondary display on the outside, and a keypad backlight.
- **Slide type** (Figure 18)—slide-up and slide-down design, with a main display and two keypads (inside and outside).
- **Bar** (Figure 19)—a main display and a keypad backlight.

Charge pumps are becoming increasingly attractive for driving LEDs for the display backlight and keypad backlight in handsets, where board space and maximum converter height are critical constraints. Its major advantage is use of only capacitors as storage elements. TPS60255 is well suited for use in all three major phone designs.

The device provides six 25 mA current regulators and one 80 mA current regulator. The current regulators are divided into three groups (A, B, and C), with each group having its own independent current program register and ON/OFF control. This promotes dividing and combining the groups for various LED driving configurations including LCD backlight, keypad backlight, and camera flash light. See [APPLICATIONS CIRCUITS](#) for example cell phone application circuits.

The TPS60255 adopts 1× and 1.5× charge pump configuration. The device monitors the voltage of the current feedback pins (Gx pins) and automatically switches between 1× and 1.5× mode to ensure current regulation regardless the variations of input voltage and LED forward voltage.

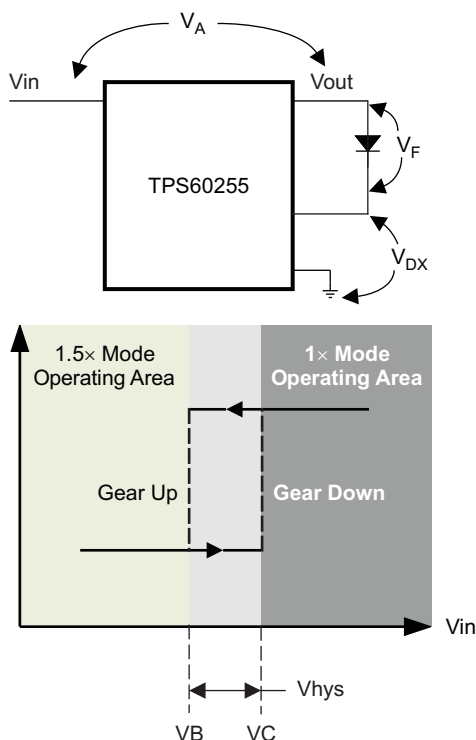
The TPS60255 uses only four external components, the input/output capacitors and two charge-pump-flying-capacitors. This combined with the 16-pin, 3 mm × 3 mm QFN package (0.8 mm height), provides for a small, low-profile total solution.

### OPERATING PRINCIPLES

The TPS60255 charge-pump provides regulated LED current from a 2.7 V to 6.0 V input source. It operates in two modes. The 1× mode, where the input is connected to the output through a pass element, and a high efficiency 1.5× charge pump mode. The IC maximizes power efficiency by operating in 1× and 1.5× modes as input voltage and LED current conditions require. The mode of operation is automatically selected by comparing the forward voltage of the WLED plus the voltage of current sink for each LED with the input voltage.

The IC starts up in 1× mode, and automatically transitions to 1.5× mode if the voltage at any current sink input (GAx, GBx, or GC) falls below the 100-mV transition voltage. The IC returns to 1× mode as the input voltage rises. In 1.5× mode, the internal oscillator determines the charge/discharge cycles for the flying capacitors. During a charge cycle, the flying capacitors are connected in series and charged up to the input voltage. After the on-time of the internal oscillator expires, the flying capacitors are reconfigured to be in parallel and then connected in series to the input voltage. This provides an output of 1.5× of the input voltage. After the off-time of the internal oscillator expires, another charge cycle initiates and the process repeats.





**Figure 10. Input Voltage Hysteresis Between 1× and 1.5× Modes**

As shown in [Figure 10](#), there is input hysteresis voltage between 1× and 1.5× modes to ensure stable operation during mode transition. For the single-cell Li-ion battery input voltage range, the TPS60255 operates in 1× mode when a fully charged battery is installed. Once the battery voltage drops below the  $V_B$  level, the WLED driver operates in the 1.5× mode. Once in 1.5× mode with the same LED current condition, the battery voltage must rise to the  $V_C$  level in order to transition from 1.5× to 1× mode. This hysteresis ensures stable operation when there is some input voltage fluctuation at the 1×/1.5× mode transition.

The input transition voltage ( $V_B$ ) depends on the drop out voltage of the charge pump stage ( $V_A$ ), WLED forward voltage ( $V_F$ ), and the mode transition threshold voltage ( $V_{TH\_GU}$ ). The input transition voltage is calculated as:

$$V_B = V_A + V_F + V_{TH\_GU}$$

$$V_A = R_{O\_1X} \times I_O$$

where  $R_{O\_1X}$  is the 1× mode output impedance and  $I_O$  is the total output current. See the [ELECTRICAL CHARACTERISTICS](#) table for output impedance specifications.

The TPS60255 switches to 1.5× mode when the input voltage is below  $V_B$  and remains in the 1.5× mode as long as the input is lower than  $V_C$ . When the input voltage rises above  $V_C$ , 1.5× Mode is exited.  $V_C$  is calculated as:

$$V_C = V_F + 550\text{mV}$$

The input voltage mode transition hysteresis voltage ( $V_{HYS}$ ) between the 1× and 1.5× modes is calculated as:

$$V_{HYS} = V_C - V_B = 550\text{ mV} - V_{TH\_GU} - V_A, \text{ where } V_{TH\_GU} = 100\text{ mV}$$

Note that  $V_A$  is the key factor in determining  $V_{HYS}$  and is dependant on the 1× mode charge pump output impedance and WLED current.

**Example:** If we choose LWE67C (Osram) and set  $I_{led} = 15.3\text{ mA}$ , then  $V_F = 3.55\text{ V}$  according to the LED characteristics curve.

Total load current,  $I_O = 15.3\text{ mA} \times 6 = 91.8\text{ mA}$

$V_B = R_{O1X} * I_O + V_{TH\_GU} + V_F = 1 * 0.0918 + 0.1 + 3.55 = 3.748$  (Gear up voltage)

$V_C = V_F + 550 \text{ mV} = 3.55 + 0.55 = 4.1$  (Gear down voltage)

### LED CURRENT SINKS (Group A, B, and C)

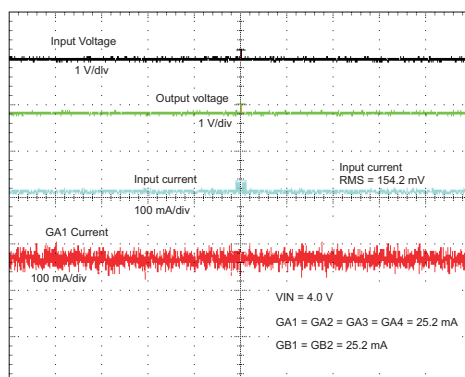
The TPS60255 has constant current sinks which drive seven individual LED current paths. Each current sink regulates the LED current to a constant value determined by the single-wire EasyScale interface. The internal register addressing controls the LED channels GA1 to GA4 independent of the GB1 to GB2 or the auxiliary current path GC.

All the LED channels sink up to 25 mA of current, except GC which has an 80 mA maximum current. Using the EasyScale interface, a user can assign GC to a torch, keypad light, or low/weak camera flash with 80 mA current using four dimming steps (full scale, 70%, 40%, and 20%).

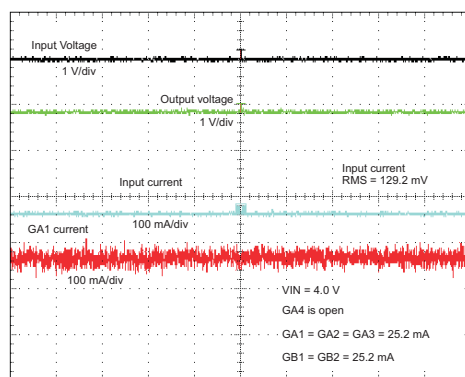
These optimized current sinks minimize the voltage headroom required to drive each LED and maximize power efficiency by increasing the amount of time the controller stays in 1× mode before transitioning to the 1.5× mode.

## OPEN LAMP DETECTION

In system production, it is often necessary to leave LED-current-paths open depending on the phone model. For example, one phone can use two LEDs to backlight the main display, while another uses four LEDs. Rather than use two different integrated circuits for these different phone applications, the TPS60255 can be used in both applications. In traditional LED driver applications when an LED current path is open, the current sink voltage falls to ground and the current regulation circuitry drives the output to a maximum voltage in an attempt to regulate the current for the missing LED path. This can severely reduce the system efficiency. The TPS60255 uses seven internal comparators to detect when one or more open LED condition occurs and prevent activation of 1.5X mode transition due to missing LEDs.



**Figure 11. Normal Operation (1× Mode)**



**Figure 12. Open Lamp Detection (1× Mode)**

## CAPACITOR SELECTION

The TPS60255 is optimized to work with ceramic capacitors having a dielectric of X5R or better. The two flying capacitors must be the same value for proper operation. The 750-kHz switching frequency requires the flying capacitor to be less than 4.7 $\mu$ F. Using 1 $\mu$ F ceramic capacitors for both charge-pump-flying-capacitors is recommended. For good input voltage filtering, low ESR ceramic capacitors are recommended. A 1 $\mu$ F ceramic input capacitor is sufficient for most of the applications. For better input voltage filtering this value can be increased to 4.7 $\mu$ F. The output capacitor determines the amount of ripple on the output. A 4.7 $\mu$ F output capacitor is recommended for the output capacitor. If better output filtering and lower ripple are desired, a larger output capacitor may be used.

## EasyScale: Single-pin serial interface for ON/OFF and brightness control

### General

EasyScale is a simple, but very flexible single-pin interface. The interface is based on a master/slave structure, where the master is typically a microcontroller or application processor. The advantage of EasyScale compared to other single-pin interfaces is that its bit detection is largely independent of the bit transmission rate. It can automatically detect bit rates from 1.2 Kbps up to 95 Kbps.

### Protocol

All bits are transmitted MSB first and LSB last. [Figure 14](#) (Timing & Bit coding) shows the protocol without acknowledge (Bit RFA = 0) and [Figure 15](#) shows the protocol with acknowledge (Bit RFA = 1) request.

Prior to both bytes ([Table 1](#)—device address byte and [Table 2](#)—data byte), a start condition must be applied. For this, the IF pin must be pulled high for at least  $t_{start}$  (3.5 $\mu$ s) before the bit transmission starts with the falling edge. If the IF pin is already at high level, no start condition is needed prior to the device address byte.

The transmission of each byte is closed with an End of Stream condition for at least  $t_{EOS}$  (3.5 $\mu$ s).

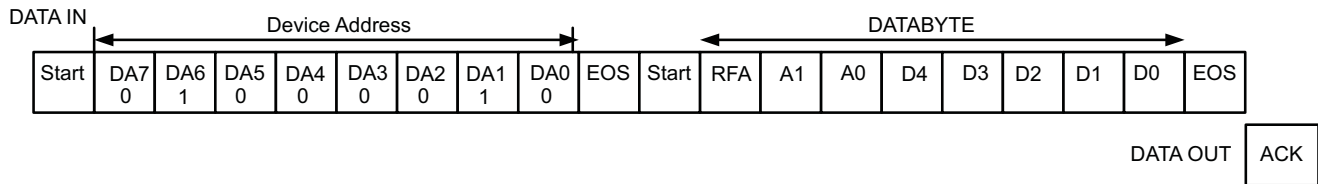


Figure 13. EasyScale Protocol Overview

Table 1. EasyScale Bit Description for Address Byte

| BIT NUMBER | NAME | TRANSMISSION DIRECTION | DESCRIPTION            |
|------------|------|------------------------|------------------------|
| 7 (MSB)    | DA7  | IN                     | DA7 MSB Device Address |
| 6          | DA6  |                        | DA6                    |
| 5          | DA5  |                        | DA5                    |
| 4          | DA4  |                        | DA4                    |
| 3          | DA3  |                        | DA3                    |
| 2          | DA2  |                        | DA2                    |
| 1          | DA1  |                        | DA1                    |
| 0 (LSB)    | DA0  |                        | DA0 LSB device address |

Table 2. EasyScale Bit Description for Data Byte

| BIT NUMBER | NAME | TRANSMISSION DIRECTION | DESCRIPTION  |
|------------|------|------------------------|--|
| 7(MSB)     | RFA  | IN                     | Request For Acknowledge, if high, Acknowledge condition applied by the device  |
| 6          | A1   |                        | Address Bit 1  |
| 5          | A0   |                        | Address Bit 0  |
| 4          | D4   |                        | Data Bit 4   |
| 3          | D3   |                        | Data Bit 3   |
| 2          | D2   |                        | Data Bit 2   |
| 1          | D1   |                        | Data Bit 1   |
| 0 (LSB)    | D0   |                        | Data Bit 0   |
|            | ACK  | OUT                    | Acknowledge condition active 0, this condition is only applied when the RFA bit is set. Open drain output, that is, line needs to be pulled high by the host with a pullup resistor.<br>This feature can only be used if the master has an open drain output stage. In case of a push pull output stage, Acknowledge condition can not be requested. |

## Bit Detection

The bit detection is based on a Logic Detection scheme, where the criterion is the relation between  $t_{LOW}$  and  $t_{HIGH}$ .

It can be simplified to:

- **High Bit:**  $t_{High} > t_{Low}$ , but with  $t_{High}$  at least twice the duration of  $t_{Low}$ , see Figure 16.
- **Low Bit :**  $t_{High} < t_{Low}$ , but with  $t_{Low}$  at least twice the duration of  $t_{High}$ , see Figure 16.

The bit detection starts with a falling edge on the IF pin and ends with the next falling edge. Depending on the relation between  $t_{High}$  and  $t_{Low}$ , the logic 0 or 1 is detected.

## Acknowledge

The acknowledge condition is applied only if:

- Acknowledge is requested by a set RFA bit.
- The transmitted device address matches with the device's address.
- All 16 bits are received correctly.

If the device turns on the internal ACKN-MOSFET and pulls the IF pin low for the time  $t_{ACKN}$ , which is 512  $\mu$ s maximum, then the Acknowledge condition is valid after an internal delay time  $t_{valACK}$ . This means that the internal ACKN-MOSFET is turned on after  $t_{valACK}$ , when the last falling edge of the protocol was detected. The master controller keeps the line low in this period. The master device can detect the acknowledge condition with its input by releasing the IF pin after  $t_{valACK}$  and read back a logic 0. The IF pin can be used again after the acknowledge condition ends.

Note that the acknowledge condition can only be requested in case the master device has an open drain output.

For a push-pull output stage, using a series resistor in the IF line to limit the current to 500  $\mu$ A is recommended to:

- Prevent an accidental request of acknowledge.
- Protect the internal ACKN-MOSFET.

## MODE Selection

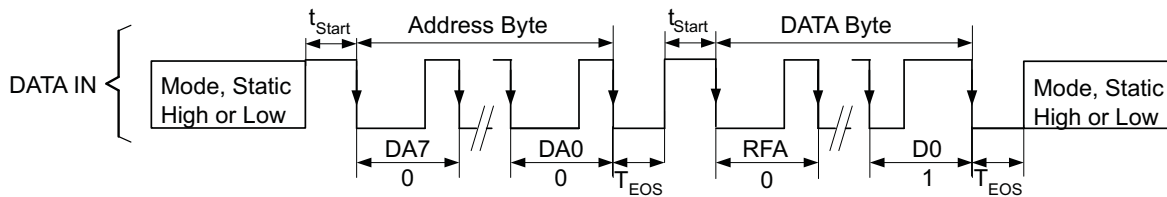


Figure 14. EasyScale Protocol Without Acknowledge (RFA=0)

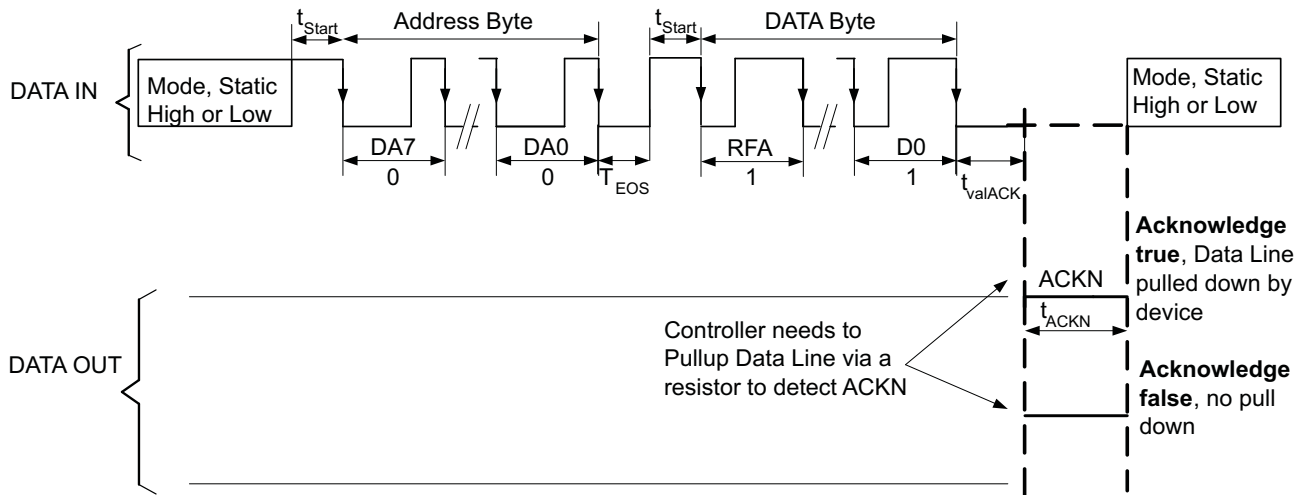


Figure 15. EasyScale Protocol With Acknowledge (RFA=1)

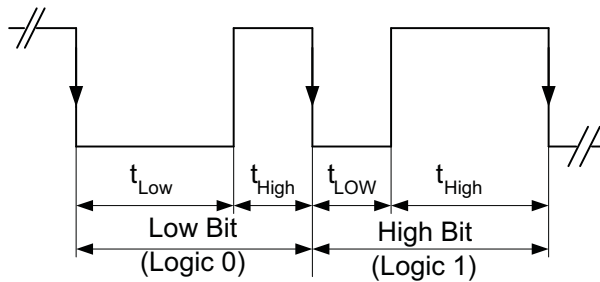


Figure 16. EasyScale Bit Coding

### Control Registers of TPS60255 Using EasyScale

#### Group B Display Current Control Register

| Group B DISP CURRENT | A1 | A0 | D4  | D3  | D2  | D1  | D0  |
|----------------------|----|----|-----|-----|-----|-----|-----|
| BIT data             | 0  | 0  | IB4 | IB3 | IB2 | IB1 | IB0 |

Bit 4 to Bit 0 (IB4 to IB0) 5-bit command (32 steps) to set the current for Group B  
 For LED currents between 100  $\mu$ A and 1.0 mA, one step = 100  $\mu$ A.  
 For LED currents between 1.0 mA and 25.2 mA, one step = 1.1 mA.

#### Group A Display Current Control Register

| Group A DISP CURRENT | A1 | A0 | D4  | D3  | D2  | D1  | D0  |
|----------------------|----|----|-----|-----|-----|-----|-----|
| BIT data             | 0  | 1  | IA4 | IA3 | IA2 | IA1 | IA0 |

Bit 4 to Bit 0  
(IA4 to IA0)

5-bit command (32 steps) to set the current for Group A

 For LED currents between 100  $\mu$ A and 1.0 mA, one step = 100  $\mu$ A.

For LED currents between 1.0 mA and 25.2 mA, one step = 1.1 mA.

**Current Control Register Values**
**Table 3. Current Control Register Value for Group A and B**

| Number | Current (mA) | D4<br>IA4 (IB4) | D3<br>IA3 (IB3) | D2<br>IA2 (IB2) | D1<br>IA1 (IB1) | D0<br>IA0 (IB0) |
|--------|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0      | 0.1          | 0               | 0               | 0               | 0               | 0               |
| 1      | 0.2          | 0               | 0               | 0               | 0               | 1               |
| 2      | 0.3          | 0               | 0               | 0               | 1               | 0               |
| 3      | 0.4          | 0               | 0               | 0               | 1               | 1               |
| 4      | 0.5          | 0               | 0               | 1               | 0               | 0               |
| 5      | 0.6          | 0               | 0               | 1               | 0               | 1               |
| 6      | 0.7          | 0               | 0               | 1               | 1               | 0               |
| 7      | 0.8          | 0               | 0               | 1               | 1               | 1               |
| 8      | 0.9          | 0               | 1               | 0               | 0               | 0               |
| 9      | 1.0          | 0               | 1               | 0               | 0               | 1               |
| 10     | 2.1          | 0               | 1               | 0               | 1               | 0               |
| 11     | 3.2          | 0               | 1               | 0               | 1               | 1               |
| 12     | 4.3          | 0               | 1               | 1               | 0               | 0               |
| 13     | 5.4          | 0               | 1               | 1               | 0               | 1               |
| 14     | 6.5          | 0               | 1               | 1               | 1               | 0               |
| 15     | 7.6          | 0               | 1               | 1               | 1               | 1               |
| 16     | 8.7          | 1               | 0               | 0               | 0               | 0               |
| 17     | 9.8          | 1               | 0               | 0               | 0               | 1               |
| 18     | 10.9         | 1               | 0               | 0               | 1               | 0               |
| 19     | 12.0         | 1               | 0               | 0               | 1               | 1               |
| 20     | 13.1         | 1               | 0               | 1               | 0               | 0               |
| 21     | 14.2         | 1               | 0               | 1               | 0               | 1               |
| 22     | 15.3         | 1               | 0               | 1               | 1               | 0               |
| 23     | 16.4         | 1               | 0               | 1               | 1               | 1               |
| 24     | 17.5         | 1               | 1               | 0               | 0               | 0               |
| 25     | 18.6         | 1               | 1               | 0               | 0               | 1               |
| 26     | 19.7         | 1               | 1               | 0               | 1               | 0               |
| 27     | 20.8         | 1               | 1               | 0               | 1               | 1               |
| 28     | 21.9         | 1               | 1               | 1               | 0               | 0               |
| 29     | 23.0         | 1               | 1               | 1               | 0               | 1               |
| 30     | 24.1         | 1               | 1               | 1               | 1               | 0               |
| 31     | 25.2         | 1               | 1               | 1               | 1               | 1               |

**Enable Control Register**

| ENABLE   | A1 | A0 | D4     | D3     | D2     | D1    | D0     |
|----------|----|----|--------|--------|--------|-------|--------|
| BIT data | 1  | 0  | EN_OLD | EN_GB1 | EN_GB2 | EN_GA | EN_GA4 |

Bit 4 (EN\_OLD)

- 1: Open Lamp Detection Enabled
- 0: Open Lamp Detection Disabled

Bit 3 (EN\_GB1)

- 1: Enable GB1
- 0: Disable GB1

Bit 2 (EN\_GB2)

- 1: Enable GB2
- 0: Disable GB2

Bit 1 (EN\_GA)

- 1: Enable GA1 to GA3
- 0: Disable GA1 to GA3

Bit 0 (EN\_GA4)

- 1: Enable GA4
- 0: Disable GA4

**GC Brightness and Operation Mode Control Register**

| Aux<br>DISP<br>CURRENT | A1 | A0 | D4    | D3    | D2  | D1  | D0    |
|------------------------|----|----|-------|-------|-----|-----|-------|
| BIT data               | 1  | 1  | Mode1 | Mode0 | GC0 | GC1 | EN_GC |

Bit 4 to Bit 3

| Mode1 | Mode0 | TPS6055 Mode  |
|-------|-------|---|
| 0     | 0     | Auto-switchover Mode. The TPS60255 selects 1× or 1.5× mode automatically as described in the <a href="#">OPERATING PRINCIPLES</a> section.    |
| 1     | 1     | Shut down, All LED current shuts down.  |
| 1     | 0     | 1× Mode. TPS60255 remains in 1× mode regardless of the input voltage. LED current can not regulate at lower input voltages when in this mode. |
| 0     | 1     | 1.5× Mode. TPS60255 remains in 1.5× mode regardless of the input voltage  |

Bit 2 to Bit 1

2-bit command (four steps) to set the current for GC

| GC0 | GC1 | Dimming Step |
|-----|-----|--------------|
| 0   | 0   | 20 %         |
| 1   | 0   | 40 %         |
| 0   | 1   | 70 %         |
| 1   | 1   | 100 %        |



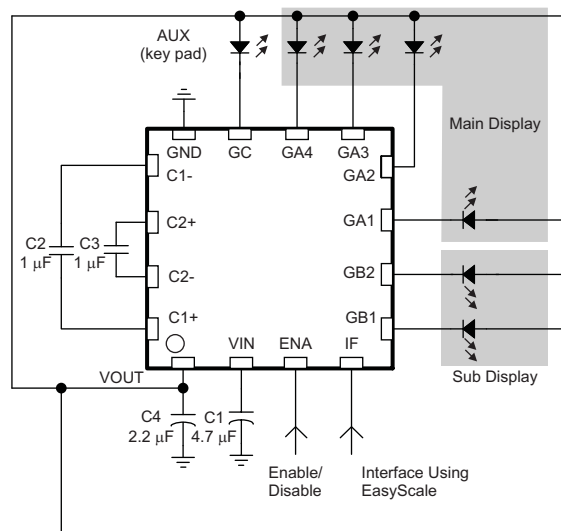
Bit 0

EN\_GC  
 1: Enable GC  
 0: Disable GC

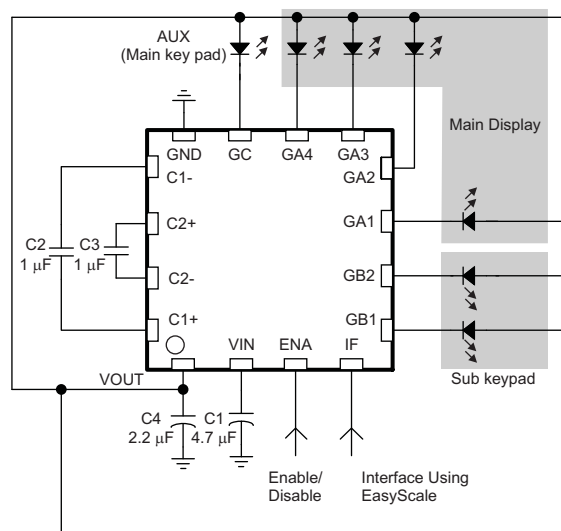
### ADDITIONAL APPLICATION CIRCUITS

These application circuits apply to the common designs for mobile telephones:

- **Clam Shell** (Figure 17)—application circuit for driving four LEDs for main display and two LEDs for the subdisplay.
- **Slide** (Figure 18)—application circuit for driving four LEDs for LCD display backlight and LEDs for both sub- and main keypad backlight.
- **Bar** (Figure 19)—application circuit for driving four LEDs for LCD display backlight and LEDs for key pad backlight.



**Figure 17. Application Circuit—Clam Shell Mobile Phone Design**



**Figure 18. Application Circuit—Slide Mobile Phone Design**

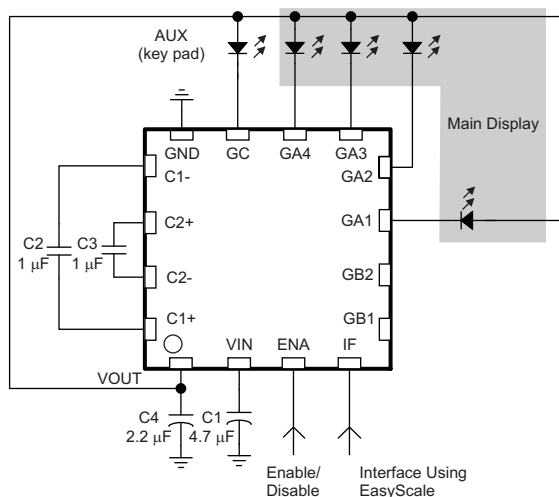


Figure 19. Application Circuit—Bar Mobile Phone Design

**PACKAGING INFORMATION**

| Orderable Device | Status <sup>(1)</sup> | Package Type | Package Drawing | Pins | Package Qty | Eco Plan <sup>(2)</sup> | Lead/Ball Finish | MSL Peak Temp <sup>(3)</sup> |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|
| TPS60255RTER     | ACTIVE                | QFN          | RTE             | 16   | 3000        | Green (RoHS & no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR          |
| TPS60255RTERG4   | ACTIVE                | QFN          | RTE             | 16   | 3000        | Green (RoHS & no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR          |
| TPS60255RTET     | ACTIVE                | QFN          | RTE             | 16   | 250         | Green (RoHS & no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR          |
| TPS60255RTETG4   | ACTIVE                | QFN          | RTE             | 16   | 250         | Green (RoHS & no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR          |

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

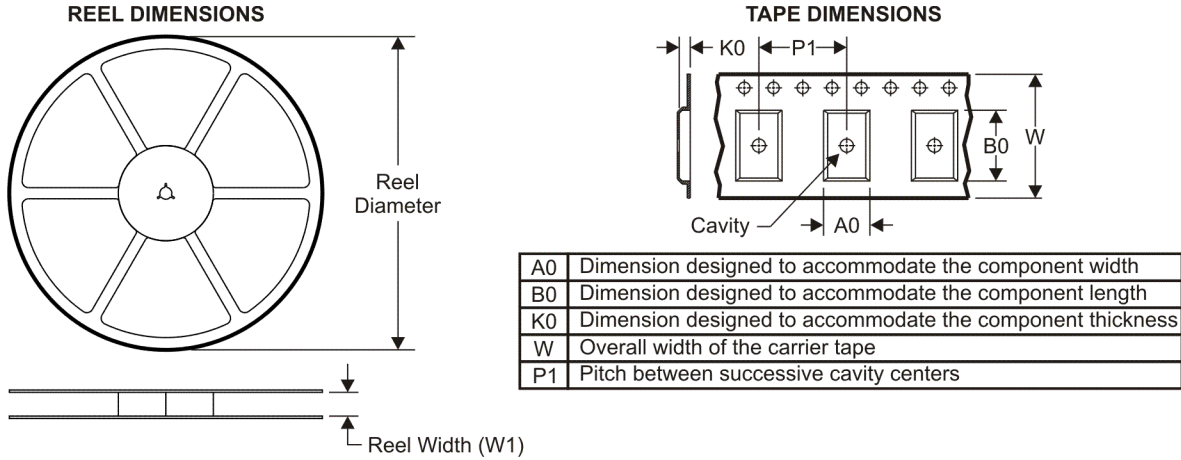
**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

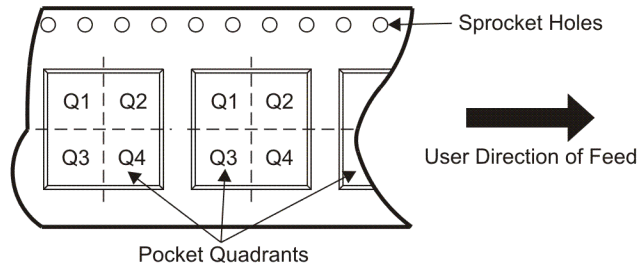
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**TAPE AND REEL INFORMATION**



**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**



\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS60255RTER | QFN          | RTE             | 16   | 3000 | 330.0              | 12.4               | 3.3     | 3.3     | 1.6     | 8.0     | 12.0   | Q2            |
| TPS60255RTET | QFN          | RTE             | 16   | 250  | 330.0              | 12.4               | 3.3     | 3.3     | 1.6     | 8.0     | 12.0   | Q2            |

**TAPE AND REEL BOX DIMENSIONS**

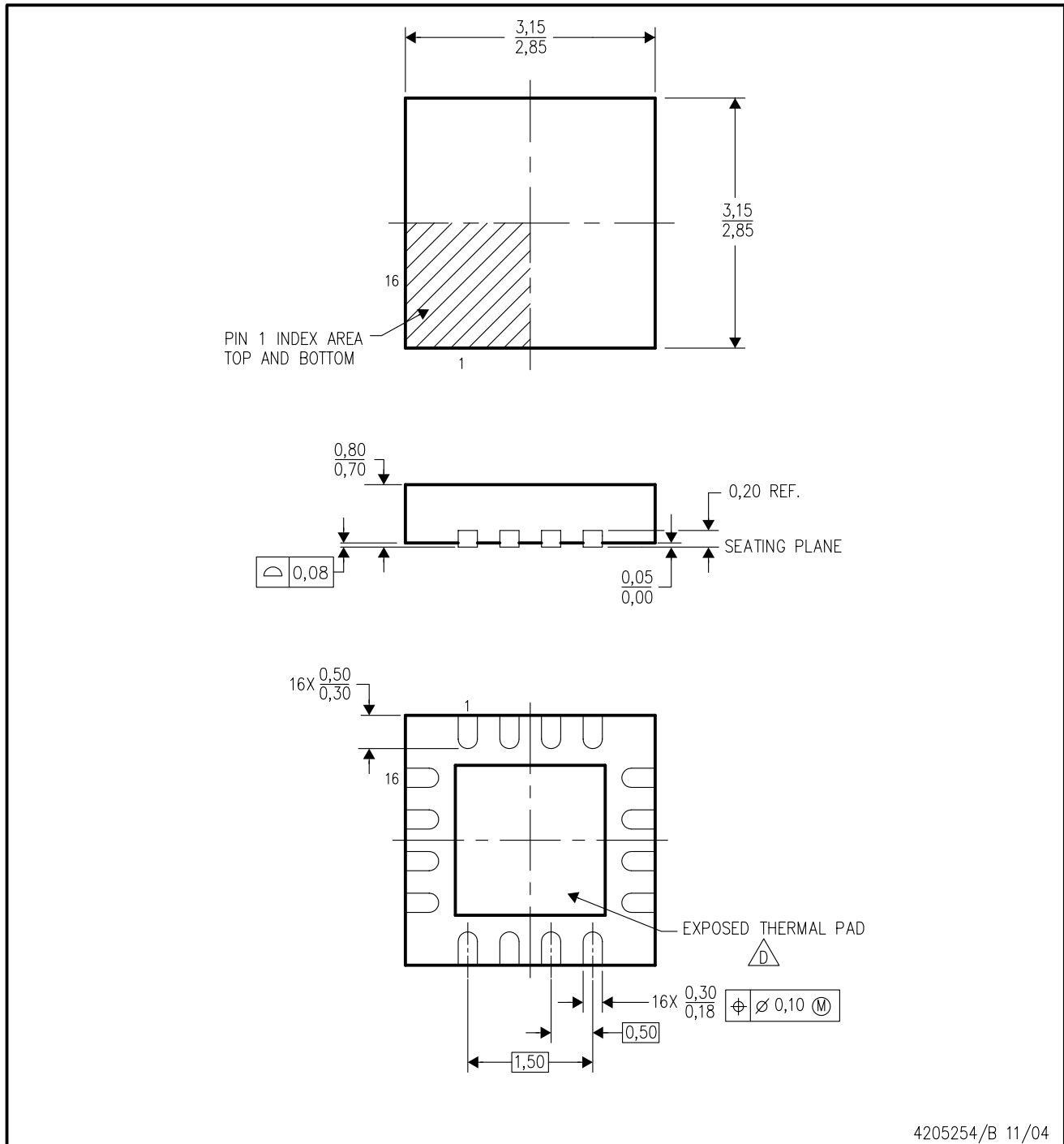


\*All dimensions are nominal


| Device       | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS60255RTER | QFN          | RTE             | 16   | 3000 | 340.5       | 338.1      | 20.6        |
| TPS60255RTET | QFN          | RTE             | 16   | 250  | 340.5       | 338.1      | 20.6        |

RTE (S-PQFP-N16)

PLASTIC QUAD FLATPACK



4205254/B 11/04

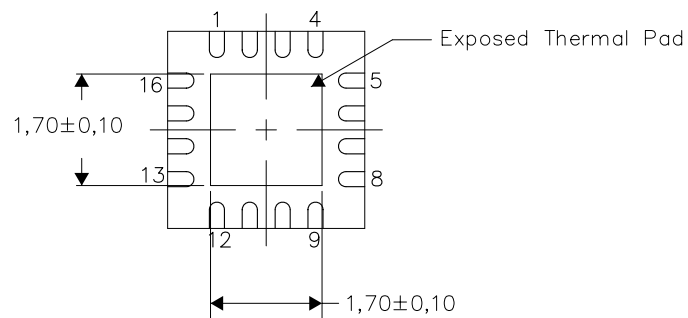
- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - B. This drawing is subject to change without notice.
  - C. Quad Flatpack, No-leads (QFN) package configuration.
  -  The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
  - E. Falls within JEDEC MO-220.

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, Quad Flatpack No-Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at [www.ti.com](http://www.ti.com).

The exposed thermal pad dimensions for this package are shown in the following illustration.

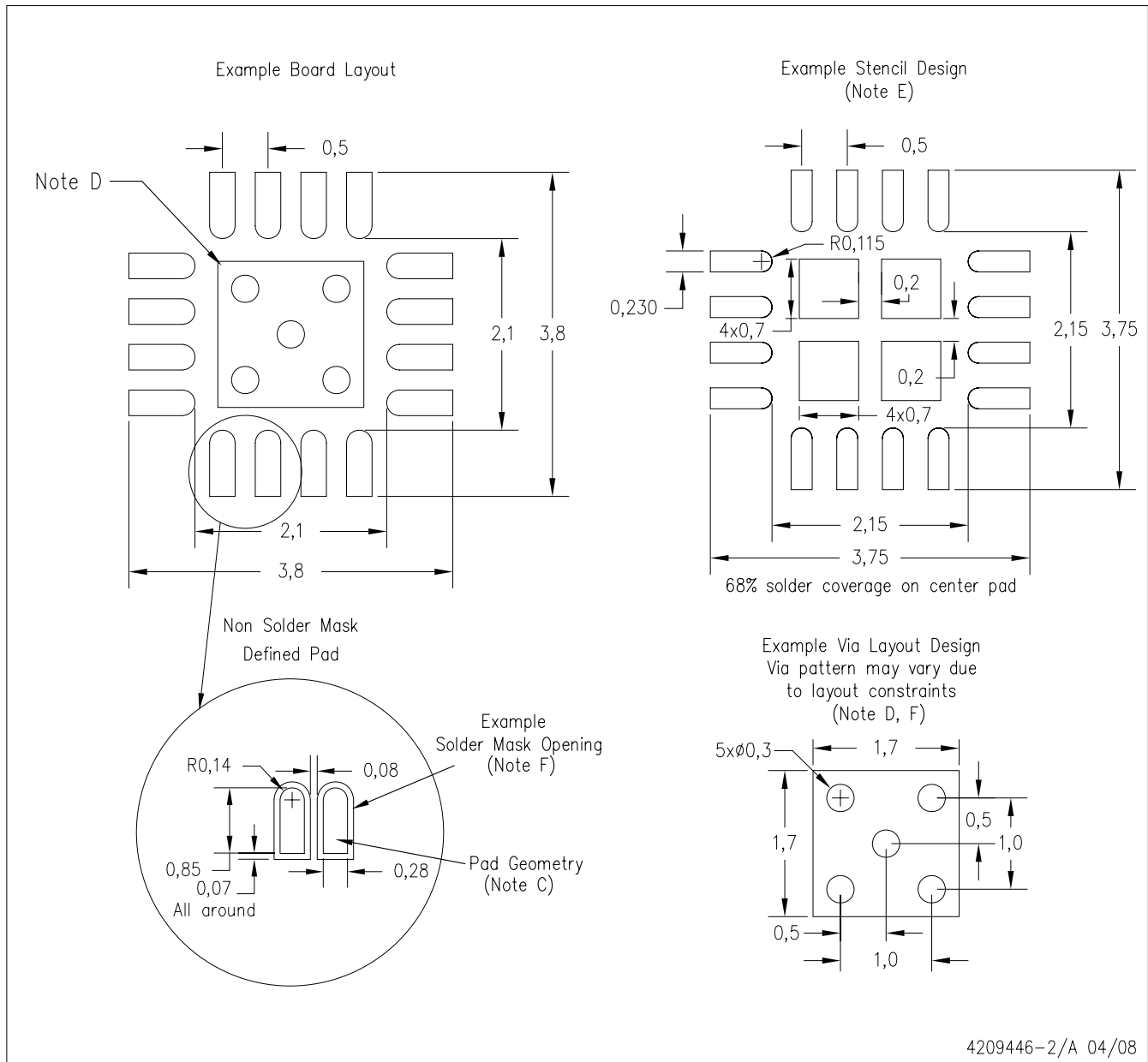


Bottom View

NOTE: All linear dimensions are in millimeters

Exposed Thermal Pad Dimensions

RTE (S-PWQFN-N16)



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat-Pack Packages, Texas Instruments Literature No. SCBA017, SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at [www.ti.com](http://www.ti.com) <<http://www.ti.com>>.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
  - Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.



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| DSP                         | <a href="http://dsp.ti.com">dsp.ti.com</a>                         |
| Clocks and Timers           | <a href="http://www.ti.com/clocks">www.ti.com/clocks</a>           |
| Interface                   | <a href="http://interface.ti.com">interface.ti.com</a>             |
| Logic                       | <a href="http://logic.ti.com">logic.ti.com</a>                     |
| Power Mgmt                  | <a href="http://power.ti.com">power.ti.com</a>                     |
| Microcontrollers            | <a href="http://microcontroller.ti.com">microcontroller.ti.com</a> |
| RFID                        | <a href="http://www.ti-rfid.com">www.ti-rfid.com</a>               |
| RF/IF and ZigBee® Solutions | <a href="http://www.ti.com/lprf">www.ti.com/lprf</a>               |

### Applications

|                    |  |
|--------------------|--|
| Audio              | <a href="http://www.ti.com/audio">www.ti.com/audio</a>                   |
| Automotive         | <a href="http://www.ti.com/automotive">www.ti.com/automotive</a>         |
| Broadband          | <a href="http://www.ti.com/broadband">www.ti.com/broadband</a>           |
| Digital Control    | <a href="http://www.ti.com/digitalcontrol">www.ti.com/digitalcontrol</a> |
| Medical            | <a href="http://www.ti.com/medical">www.ti.com/medical</a>               |
| Military           | <a href="http://www.ti.com/military">www.ti.com/military</a>             |
| Optical Networking | <a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a> |
| Security           | <a href="http://www.ti.com/security">www.ti.com/security</a>             |
| Telephony          | <a href="http://www.ti.com/telephony">www.ti.com/telephony</a>           |
| Video & Imaging    | <a href="http://www.ti.com/video">www.ti.com/video</a>                   |
| Wireless           | <a href="http://www.ti.com/wireless">www.ti.com/wireless</a>             |

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