

TPS60200, TPS60201, TPS60202, TPS60203 REGULATED 3.3 V, 100-mA LOW-RIPPLE CHARGE PUMP LOW POWER DC/DC CONVERTERS

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features

- Regulated 3.3-V Output Voltage With up to 100-mA Output Current From a 1.8-V to 3.6-V Input Voltage
- Less Than 5-mV_(PP) Output Voltage Ripple Achieved With Push-Pull Topology
- Integrated Low-Battery and Power-Good Detector
- Switching Frequency Can Be Synchronized to External Clock Signal
- Extends Battery Usage With up to 90% Efficiency and 35- μ A Quiescent Supply Current
- Reliable System Shutdown Because Output Capacitor Is Discharged When Device Is Disabled
- Easy-To-Design, Low-Cost, Low-EMI Power Supply Since No Inductors Are Used

- 0.05- μ A Shutdown Current, Battery Is Isolated From Load in Shutdown Mode
- Compact Converter Solution in UltraSmall 10-pin MSOP With Only Four External Capacitors Required
- Evaluation Module Available (TPS60200EVM-145)

applications

- Replaces DC/DC Converters With Inductors in Battery Powered Applications Like:
 - Two Battery Cells to 3.3-V Conversion
 - MP3 Portable Audio Players
 - Battery-Powered Microprocessor Systems
 - Backup-Battery Boost Converters
 - PDA's, Organizers, and Cordless Phones
 - Handheld Instrumentation
 - Glucose Meters and Other Medical Instruments

description

The TPS6020x step-up, regulated charge pumps generate a 3.3-V \pm 4% output voltage from a 1.8-V to 3.6-V input voltage. The devices are typically powered by two Alkaline, NiCd or NiMH battery cells and operate down to a minimum supply voltage of 1.6 V. Continuous output current is a minimum of 100 mA for the TPS60200 and TPS60201 and 50 mA for the TPS60202 and TPS60203, all from a 2-V input. Only four external capacitors are needed to build a complete low-ripple dc/dc converter. The push-pull operating mode of two single-ended charge pumps assures the low output voltage ripple as current is continuously transferred to the output.

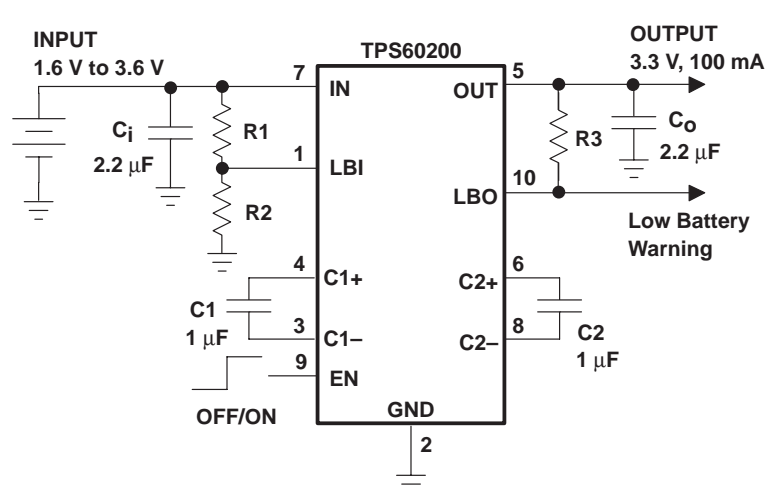
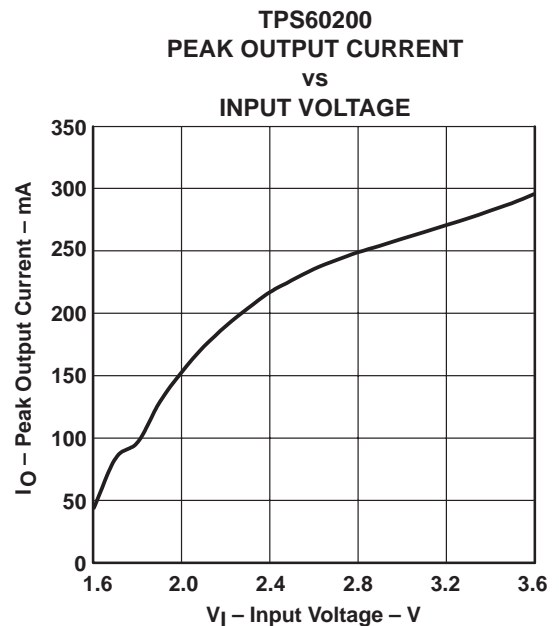


Figure 1. Typical Application Circuit With Low-Battery Warning



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**TEXAS
INSTRUMENTS**

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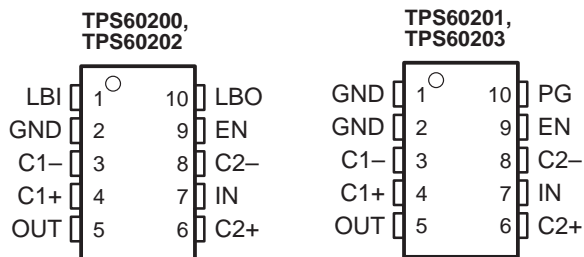
description (continued)

The devices operate in the newly developed LinSkip mode. In this operating mode, the device switches seamlessly from the power saving pulse-skip mode at light loads to the low-noise constant-frequency, linear-regulation mode once the output current exceeds the LinSkip threshold of about 7 mA. Even in pulse-skip mode the output ripple is maintained at a very low level because the output resistance of the charge pump is still regulated.

Three operating modes can be programmed using the EN pin. EN = low disables the device, shuts down all internal circuits and disconnects the output from the input. EN = high enables the device and programs it to run from the internal oscillator. The devices operate synchronized to an external clock signal if EN is clocked; thus switching harmonics can be controlled and minimized. The devices include a low-battery detector that issues a warning if the battery voltage drops below a user-defined threshold voltage or a power-good detector that goes active when the output voltage reaches about 90% of its nominal value.

Device options with either a low-battery or power good detector are available. This dc/dc converter requires no inductors therefore EMI of the system is reduced to a minimum. It is available in the small 10-pin MSOP package (DGS).

DGS PACKAGES



AVAILABLE OPTIONS

| T _A | PART NUMBER† | MARKING DGS PACKAGE | OUTPUT CURRENT (mA) | OUTPUT VOLTAGE (V) | DEVICE FEATURES |
|----------------|--------------|---------------------------|---------------------------|--------------------------|----------------------|
| -40°C to 85°C | TPS60200DGS | AEX | 100 | 3.3 | Low-battery detector |
| | TPS60201DGS | AEY | 100 | 3.3 | Power-good detector |
| | TPS60202DGS | AEZ | 50 | 3.3 | Low-battery detector |
| | TPS60203DGS | AFA | 50 | 3.3 | Power-good detector |

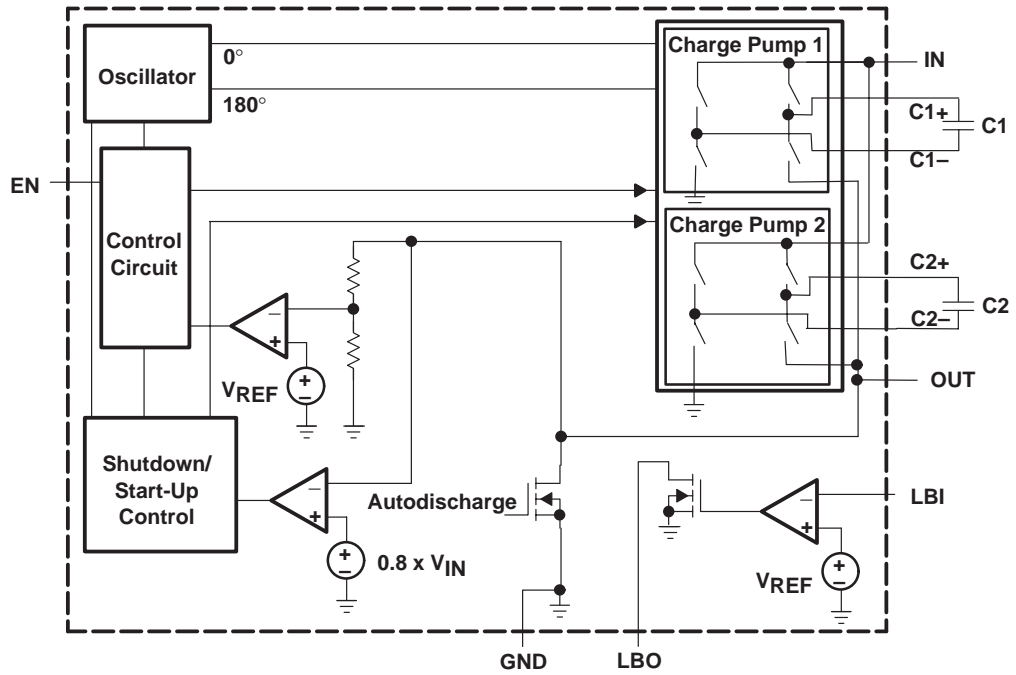
† The DGS package is available taped and reeled. Add R suffix to device type (e.g. TPS60200DGSR) to order quantities of 3000 devices per reel.

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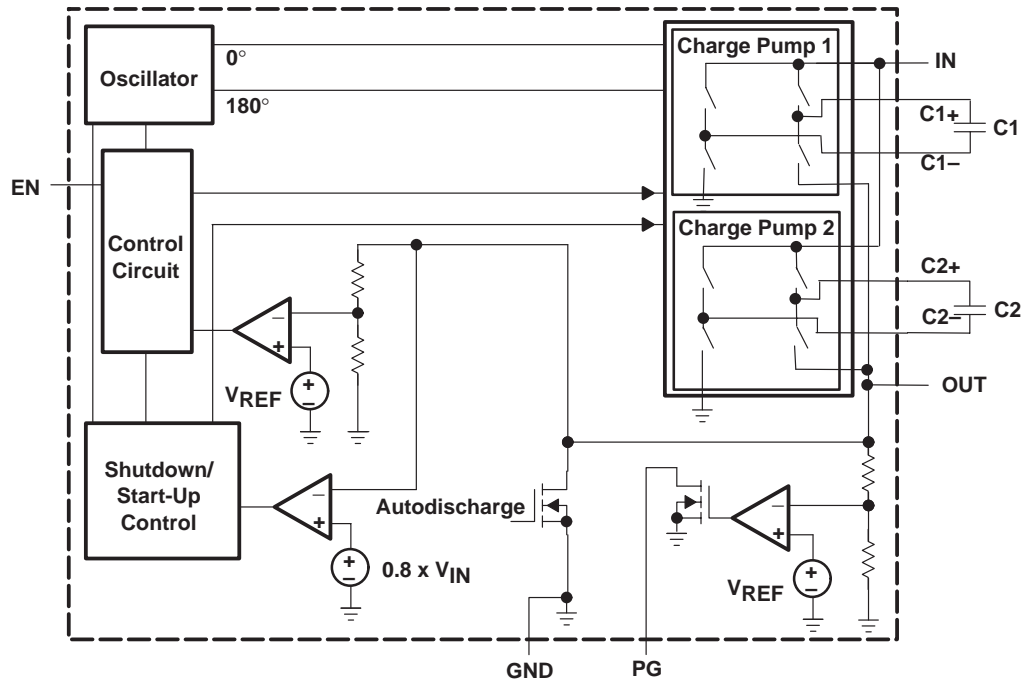
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functional block diagrams

TPS60200 and TPS60202 with low-battery detector



TPS60201 and TPS60203 with power-good detector



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Terminal Functions

| TERMINAL NAME | NO. | I/O | DESCRIPTION |
|---------------|-----|-----|--|
| C1+ | 4 | | Positive terminal of the flying capacitor C1 |
| C1– | 3 | | Negative terminal of the flying capacitor C1 |
| C2+ | 6 | | Positive terminal of the flying capacitor C2 |
| C2– | 8 | | Negative terminal of the flying capacitor C2 |
| EN | 9 | I | Device-enable input. Three operating modes can be programmed with the EN pin. – EN = Low disables the device. Output and input are isolated in the shutdown mode and the output capacitor is automatically discharged. – EN = High lets the device run from the internal oscillator. – If an external clock signal is applied to the EN pin, the device is in Sync-Mode and runs synchronized at the frequency of the external clock signal. |
| GND | 2 | | Ground |
| IN | 7 | I | Supply input. Bypass IN to GND with a capacitor of the same size as C _O . |
| LBI/GND | 1 | I | Low-battery detector input for TPS60200 and TPS60202. A low-battery warning is generated at the LBO pin when the voltage on LBI drops below the threshold of 1.18 V. Connect LBI to GND if the low-battery detector function is not used. For the devices TPS60201 and TPS60203, this pin has to be connected to ground (GND pin). |
| LBO/PG | 10 | O | Open-drain low-battery detector output for TPS60200 and TPS60202. This pin is pulled low if the voltage on LBI drops below the threshold of 1.18 V. A pullup resistor should be connected between LBO and OUT or any other logic supply rail that is lower than 3.6 V. Open-drain power-good detector output for TPS60201 and TPS60203. As soon as the voltage on OUT reaches about 90% of its nominal value this pin goes active high. A pullup resistor should be connected between PG and OUT or any other logic supply rail that is lower than 3.6 V. |
| OUT | 5 | O | Regulated 3.3-V power output. Bypass OUT to GND with the output filter capacitor C _O . |

detailed description

operating principle

The TPS6020x charge pumps provide a regulated 3.3-V output from a 1.8-V to 3.6-V input. They deliver up to 100-mA load current while maintaining the output at 3.3 V ± 4%. Designed specifically for space critical battery powered applications, the complete converter requires only four external capacitors. The device is using the push-pull topology to achieve lowest output voltage ripple. The converter is also optimized for smallest board space. It makes use of small sized capacitors, with the highest output current rating per output capacitance and package size.

The TPS6020x circuits consist of an oscillator, a 1.18-V voltage reference, an internal resistive feedback circuit, an error amplifier, two charge pump power stages with high current MOSFET switches, a shutdown/start-up circuit, a control circuit, and an auto-discharge transistor (see functional block diagrams).

push-pull operating mode

The two single-ended charge pump power stages operate in the so-called push-pull operating mode, i.e. they operate with a 180°C phase shift. Each single-ended charge pump transfers charge into its transfer capacitor (C1 or C2) in one half of the period. During the other half of the period (transfer phase), the transfer capacitor is placed in series with the input to transfer its charge to C_O. While one single-ended charge pump is in the charge phase, the other one is in the transfer phase. This operation assures an almost constant output current which ensures a low output ripple.

If the clock were to run continuously, this process would eventually generate an output voltage equal to two times the input voltage (hence the name voltage doubler). In order to provide a regulated fixed output voltage of 3.3 V, the TPS6020x devices use either pulse-skip or constant-frequency linear-regulation control mode. The mode is automatically selected based on the output current. If the load current is below the LinSkip current threshold, it switches into the power-saving pulse-skip mode to boost efficiency at low output power.



detailed description (continued)

constant-frequency mode

When the output current is higher than the LinSkip current threshold, the charge pump runs continuously at the switching frequency $f_{(OSC)}$. The control circuit, fed from the error amplifier, controls the charge on C1 and C2 by controlling the gates and hence the $r_{DS(ON)}$ of the integrated MOSFETs. When the output voltage decreases, the gate drive increases, resulting in a larger voltage across C1 and C2. This regulation scheme minimizes output ripple. Since the device switches continuously, the output signal contains well-defined frequency components, and the circuit requires smaller external capacitors for a given output ripple. However, constant-frequency mode, due to higher operating current, is less efficient at light loads. For this reason, the device switches seamlessly into the pulse-skip mode when the output current drops below the LinSkip current threshold.

pulse-skip mode

The regulator enters the pulse-skip mode when the output current is lower than the LinSkip current threshold of 7 mA. In the pulse-skip mode, the error amplifier disables switching of the power stages when it detects an output voltage higher than 3.3 V. The controller skips switching cycles until the output voltage drops below 3.3 V. Then the error amplifier reactivates the oscillator and switching of the power stages starts again. A 30-mV output voltage offset is introduced in this mode.

The pulse-skip regulation mode minimizes operating current because it does not switch continuously and deactivates all functions except the voltage reference and error amplifier when the output is higher than 3.3 V. Even in pulse-skip mode the $r_{DS(ON)}$ of the MOSFETs is controlled. This way the energy per switching cycle that is transferred by the charge pump from the input to the output is limited to the minimum that is necessary to sustain a regulated output voltage, with the benefit that the output ripple is kept to a minimum. When switching is disabled from the error amplifier, the load is also isolated from the input.

start up, shutdown, and auto-discharge

During start-up, i.e. when EN is set from logic low to logic high, the output capacitor is directly connected to IN and charged up with a limited current until the output voltage V_O reaches $0.8 \times V_I$. When the start-up comparator detects this limit, the converter begins switching. This precharging of the output capacitor guarantees a short start-up time. In addition, the inrush current into an empty output capacitor is limited. The converter can start into a full load, which is defined by a 33- Ω or 66- Ω resistor, respectively.

Driving EN low disables the converter. This disables all internal circuits and reduces the supply current to only 0.05 μ A. The device exits shutdown once EN is set high. When the device is disabled, the load is isolated from the input. This is an important feature in battery operated products because it extends the products shelf life.

Additionally, the output capacitor will automatically be discharged after EN is taken low. This ensures that the system, when switched off, is in a stable and reliable condition since the supply voltage is removed from the supply pins.

synchronization to an external clock signal

The operating frequency of the charge pump is limited to 400 kHz in order to avoid interference in the sensitive 455-kHz IF band. The device can either run from the integrated oscillator, or an external clock signal can be used to drive the charge pump. The maximum frequency of the external clock signal is 800 kHz. The switching frequency used internally to drive the charge pump power stages is half of the external clock frequency. The external clock signal is applied to the EN pin. The device will switch off if the signal on EN is hold low for more than 10 μ s.

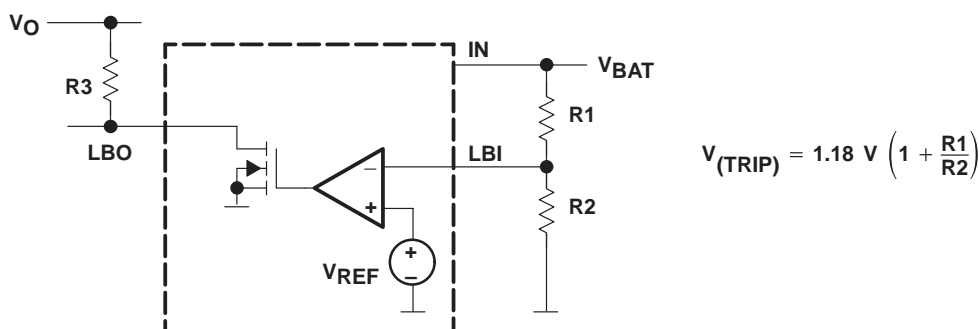
When the load current drops below the LinSkip current threshold, the devices will enter the pulse-skip mode but stay synchronized to the external clock signal.

detailed description (continued)

low-battery detector (TPS60200 and TPS60202)

The low-battery comparator trips at $1.18 \text{ V} \pm 4\%$ when the voltage on pin LBI ramps down. The voltage $V_{(TRIP)}$ at which the low-battery warning is issued can be adjusted with a resistive divider as shown in Figure 2. The sum of resistors R1 and R2 is recommended to be in the 100-k Ω to 1-M Ω range. When choosing R1 and R2, be aware of the input leakage current into the LBI pin.

LBO is an open drain output. An external pullup resistor to OUT, or any other voltage rail in the appropriate range, in the 100-k Ω to 1-M Ω range is recommended. During start-up, the LBO output signal is invalid for the first 500 μs . LBO is high impedance when the device is disabled. If the low-battery comparator function is not used, connect LBI to ground and leave LBO unconnected. The low-battery detector is disabled when the device is switched off.



$$V_{(TRIP)} = 1.18 \text{ V} \left(1 + \frac{R1}{R2} \right)$$

Figure 2. Programming of the Low-Battery Comparator Trip Voltage

A 100 nF ceramic capacitor should be connected in parallel to R2 if large line transients are expected. These voltage drops can inadvertently trigger the low-battery comparator and produce a wrong low-battery warning signal at the LBO pin.

Formulas to calculate the resistive divider for low-battery detection, with $V_{LBI} = 1.13 \text{ V}$ to 1.23 V and the sum of resistors R1 and R2 equal 1 M Ω :

$$R2 = 1 \text{ M}\Omega \times \frac{V_{LBI}}{V_{Bat}} \tag{1}$$

$$R1 = 1 \text{ M}\Omega - R2 \tag{2}$$

Formulas to calculate the minimum and maximum battery voltage:

$$V_{Bat(min)} = V_{LBI(min)} \times \frac{R1_{(min)} + R2_{(max)}}{R2_{(max)}} \tag{3}$$

$$V_{Bat(max)} = V_{LBI(max)} \times \frac{R1_{(max)} + R2_{(min)}}{R2_{(min)}} \tag{4}$$

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detailed description (continued)

Table 1. Recommended Values for the Resistive Divider From the E96 Series ($\pm 1\%$)

| $V_{(IN)}/V$ | $R1/k\Omega$ | $R2/k\Omega$ | $V_{TRIP(MIN)}/V$ | $V_{TRIP(MAX)}/V$ |
|--------------|--------------|--------------|-------------------|-------------------|
| 1.6 | 267 | 750 | 1.524 | 1.677 |
| 1.7 | 301 | 681 | 1.620 | 1.785 |
| 1.8 | 340 | 649 | 1.710 | 1.887 |
| 1.9 | 374 | 619 | 1.799 | 1.988 |
| 2.0 | 402 | 576 | 1.903 | 2.106 |

power-good detector (TPS60201 and TPS60203)

The power-good output is an open-drain output that pulls low when the output is out of regulation. When the output rises to within 90% of its nominal voltage, the power-good output is released. Power-good is high impedance in shutdown. In normal operation, an external pullup resistor must be connected between PG and OUT, or any other voltage rail in the appropriate range. The resistor should be in the 100-k Ω to 1-M Ω range. If the PG output is not used, it should remain unconnected.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)[†]

| | | |
|--|----------------------------------|------------------------------|
| Voltage range: | IN, OUT, EN, LBI, LBO, PG to GND | –0.3 V to 3.6 V |
| | C1+, C2+ to GND | –0.3 V to ($V_O + 0.3$ V) |
| | C1–, C2– to GND | –0.3 V to ($V_I + 0.3$ V) |
| Continuous total power dissipation | | See dissipation rating table |
| Continuous output current TPS60200, TPS60201 | | 150 mA |
| Continuous output current TPS60202, TPS60203 | | 75 mA |
| Storage temperature range, T_{stg} | | –55°C to 150°C |
| Maximum junction temperature, T_J | | 150°C |

[†] 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.

DISSIPATION RATING TABLE 1 FREE-AIR TEMPERATURE

| PACKAGE | $T_A \leq 25^\circ\text{C}$ POWER RATING | DERATING FACTOR ABOVE $T_A = 25^\circ\text{C}$ | $T_A = 70^\circ\text{C}$ POWER RATING | $T_A = 85^\circ\text{C}$ POWER RATING |
|---------|---|---|--|--|
| DGS | 424 mW | 3.4 mW/°C | 187 mW | 136 mW |

The thermal resistance junction to ambient of the DGS package is $R_{TH-JA} = 294^\circ\text{C/W}$.

recommended operating conditions

| | MIN | NOM | MAX | UNIT |
|---------------------------------------|-----|-----|-----|---------------|
| Input voltage range, V_I | 1.6 | | 3.6 | V |
| Input capacitor, C_i | | 2.2 | | μF |
| Flying capacitors, C1, C2 | | 1 | | μF |
| Output capacitor, C_O | | 2.2 | | μF |
| Operating junction temperature, T_J | –40 | | 125 | °C |



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electrical characteristics at $C_i = 2.2 \mu\text{F}$, $C_1 = C_2 = 1 \mu\text{F}$, $C_o = 2.2 \mu\text{F}$, $T_A = -40^\circ\text{C}$ to 85°C , $V_I = 2.4 \text{ V}$, $\text{EN} = V_I$ (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--|---|------------------|------|------------------|------------------|
| $I_{O(\text{MAX})}$ Maximum continuous output current | TPS60200 and TPS60201, $V_I = 2 \text{ V}$ | 100 | | | mA |
| | TPS60202 and TPS60203, $V_I = 2 \text{ V}$ | 50 | | | mA |
| V_O Output voltage | $1.6 \text{ V} < V_I < 1.8 \text{ V}$, $0 < I_O < 0.25 \times I_{O(\text{MAX})}$ | 3 | | | V |
| | $1.8 \text{ V} < V_I < 2 \text{ V}$, $0 < I_O < 0.5 \times I_{O(\text{MAX})}$ | 3.17 | | 3.43 | V |
| | $2 \text{ V} < V_I < 3.3 \text{ V}$, $0 < I_O < I_{O(\text{MAX})}$ | 3.17 | | 3.43 | V |
| | $3.3 \text{ V} < V_I < 3.6 \text{ V}$, $0 < I_O < I_{O(\text{MAX})}$ | 3.17 | | 3.47 | V |
| V_{PP} Output voltage ripple | $I_O = I_{O(\text{MAX})}$ | | 5 | | mV _{PP} |
| $I_{\text{(Q)}}$ Quiescent current (no-load input current) | $I_O = 0 \text{ mA}$, $V_I = 1.8 \text{ V}$ to 3.6 V | | 35 | 70 | μA |
| $I_{\text{(SD)}}$ Shutdown supply current | $\text{EN} = 0 \text{ V}$ | | 0.05 | 1 | μA |
| $f_{\text{(OSC)}}$ Internal switching frequency | | 200 | 300 | 400 | kHz |
| $f_{\text{(SYNC)}}$ External clock signal frequency | | 400 | 600 | 800 | kHz |
| | External clock signal duty cycle | | 30% | 70% | |
| V_{IL} EN input low voltage | $V_I = 1.6 \text{ V}$ to 3.6 V | | | $0.3 \times V_I$ | V |
| V_{IH} EN input high voltage | $V_I = 1.6 \text{ V}$ to 3.6 V | $0.7 \times V_I$ | | | V |
| $I_{\text{kg(EN)}}$ EN input leakage current | $\text{EN} = 0 \text{ V}$ or V_I | | 0.01 | 0.1 | μA |
| Output capacitor auto discharge time | EN is set from V_I to GND, Time until $V_O < 0.5 \text{ V}$ | | 0.6 | | ms |
| Output resistance in shutdown | $\text{EN} = 0 \text{ V}$ | | 70 | | Ω |
| LinSkip threshold | $V_I = 2.2 \text{ V}$ | | 7 | | mA |
| Output load regulation | $10 \text{ mA} < I_O < I_{O(\text{MAX})}$; $T_A = 25^\circ\text{C}$ | | 0.01 | | %/mA |
| Output line regulation | $2 \text{ V} < V_I < 3.3 \text{ V}$, $I_O = 0.5 \times I_{O(\text{MAX})}$, $T_A = 25^\circ\text{C}$ | | 0.6 | | %/V |
| $I_{\text{(SC)}}$ Short circuit current | $V_I = 2.4 \text{ V}$, $V_O = 0 \text{ V}$ | | 60 | | mA |

electrical characteristics for low-battery comparator of devices TPS60200 and TPS60202 at $T_A = -40^\circ\text{C}$ to 85°C , $V_I = 2.4 \text{ V}$ and $\text{EN} = V_I$ (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|--|------|------|------|---------------|
| $V_{\text{(LBI)}}$ LBI trip voltage | $V_I = 1.6 \text{ V}$ to 2.2 V , $T_C = 0^\circ\text{C}$ to 70°C | 1.13 | 1.18 | 1.23 | V |
| LBI trip voltage hysteresis | For rising voltage at LBI | | 10 | | mV |
| $I_{\text{(LBI)}}$ LBI input current | $V_{\text{(LBI)}} = 1.3 \text{ V}$ | | 2 | 50 | nA |
| $V_{\text{(LBO)}}$ LBO output voltage low | $V_{\text{(LBI)}} = 0 \text{ V}$, $I_{\text{(LBO)}} = 1 \text{ mA}$ | | | 0.4 | V |
| $I_{\text{kg(LBO)}}$ LBO leakage current | $V_{\text{(LBI)}} = 1.3 \text{ V}$, $V_{\text{(LBO)}} = 3.3 \text{ V}$ | | 0.01 | 0.1 | μA |

NOTE: During start-up of the converter the LBO output signal is invalid for the first 500 μs .

electrical characteristics for power-good comparator of devices TPS60201 and TPS60203 at $T_A = -40^\circ\text{C}$ to 85°C , $V_I = 2.4 \text{ V}$ and $\text{EN} = V_I$ (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|-------------------|-------------------|-------------------|---------------|
| $V_{\text{(PG)}}$ Power-good trip voltage | $T_C = 0^\circ\text{C}$ to 70°C | $0.87 \times V_O$ | $0.91 \times V_O$ | $0.95 \times V_O$ | V |
| $V_{\text{hys(PG)}}$ Power-good trip voltage hysteresis | V_O decreasing, $T_C = 0^\circ\text{C}$ to 70°C | | 1% | | |
| $V_{\text{(PG)}}$ Power-good output voltage Low | $V_O = 0 \text{ V}$, $I_{\text{(PG)}} = 1 \text{ mA}$ | | | 0.4 | V |
| $I_{\text{kg(PG)}}$ Power-good leakage current | $V_O = 3.3 \text{ V}$, $V_{\text{(PG)}} = 3.3 \text{ V}$ | | 0.01 | 0.1 | μA |

NOTE: During start-up of the converter the PG output signal is invalid for the first 500 μs .



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TYPICAL CHARACTERISTICS

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NOTE: All typical characteristics were measured using the typical application circuit of Figure 18 (unless otherwise noted).

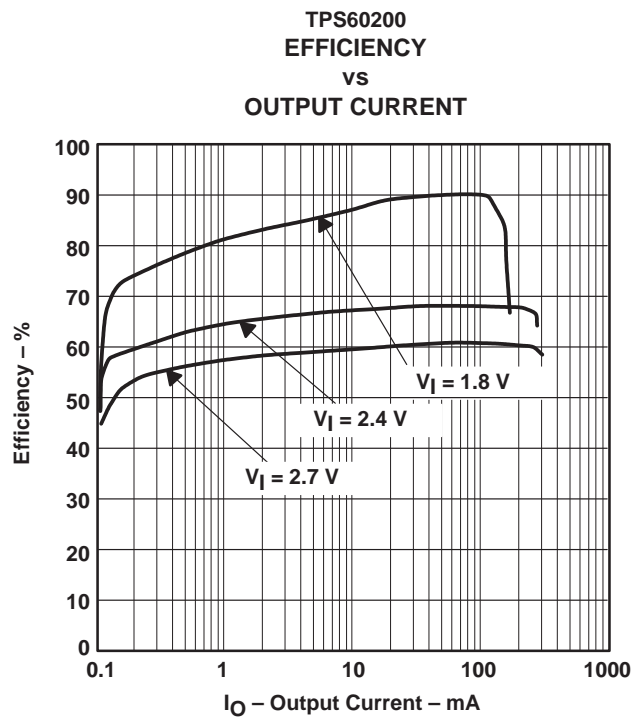


Figure 3

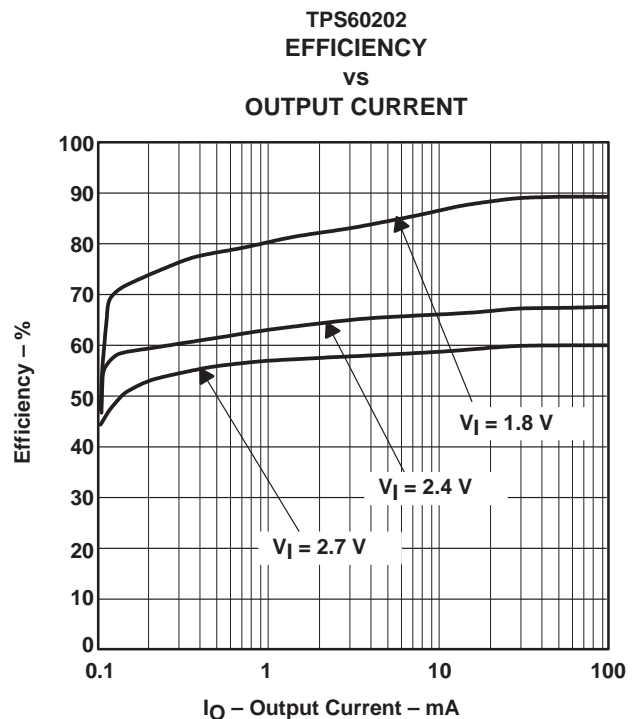


Figure 4

TPS60200, TPS60201, TPS60202, TPS60203
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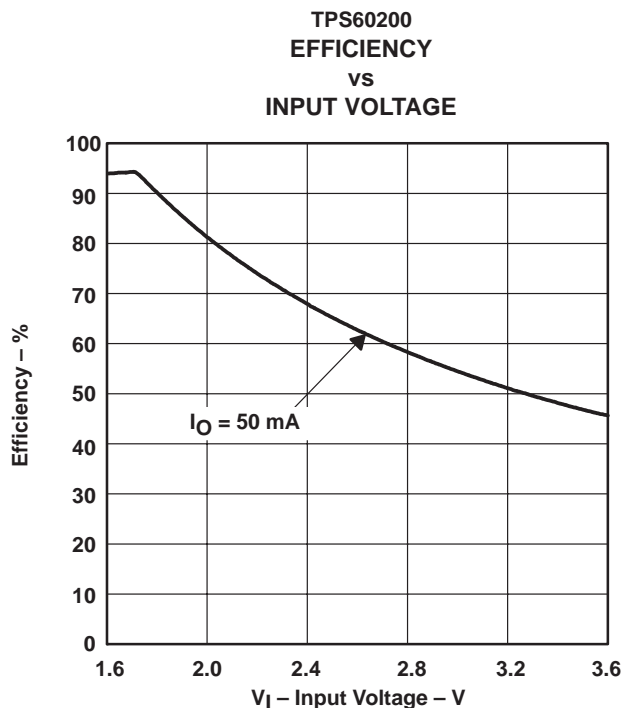


Figure 5

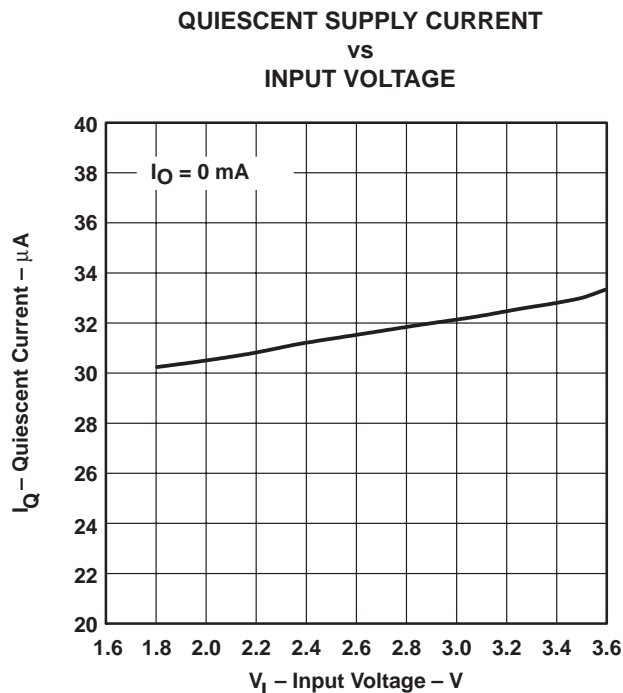


Figure 6

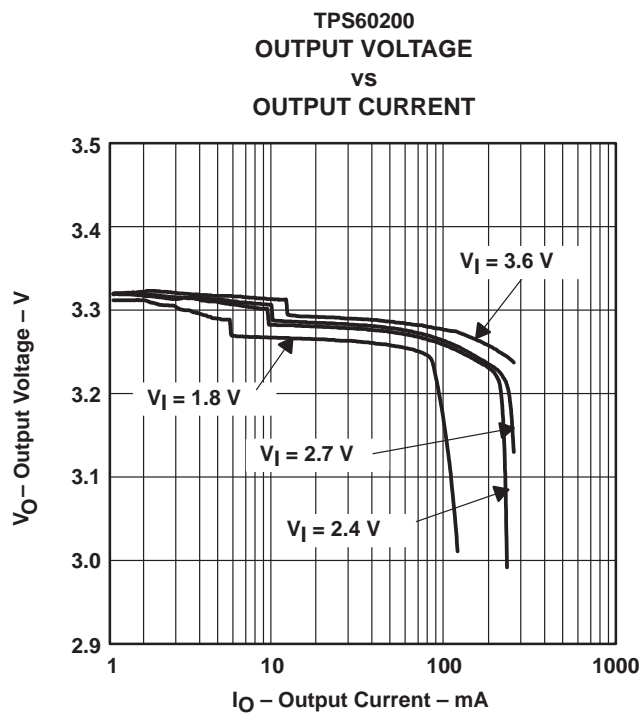


Figure 7

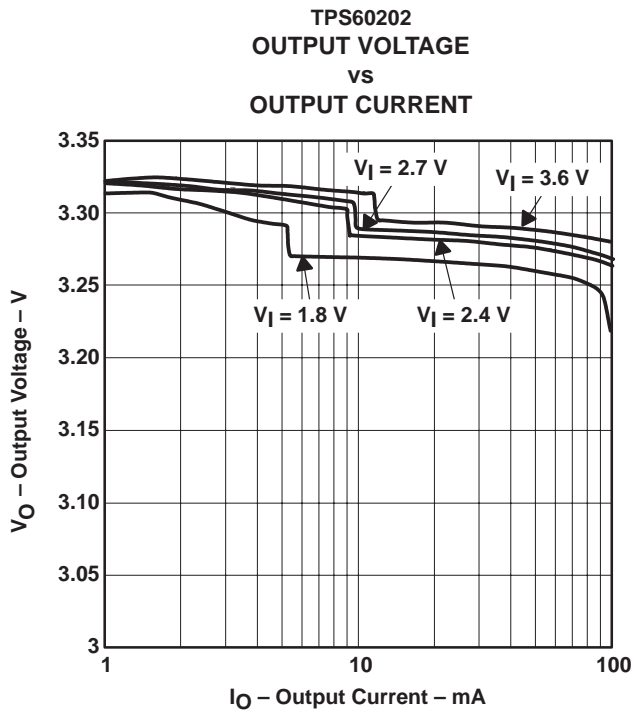


Figure 8



TYPICAL CHARACTERISTICS

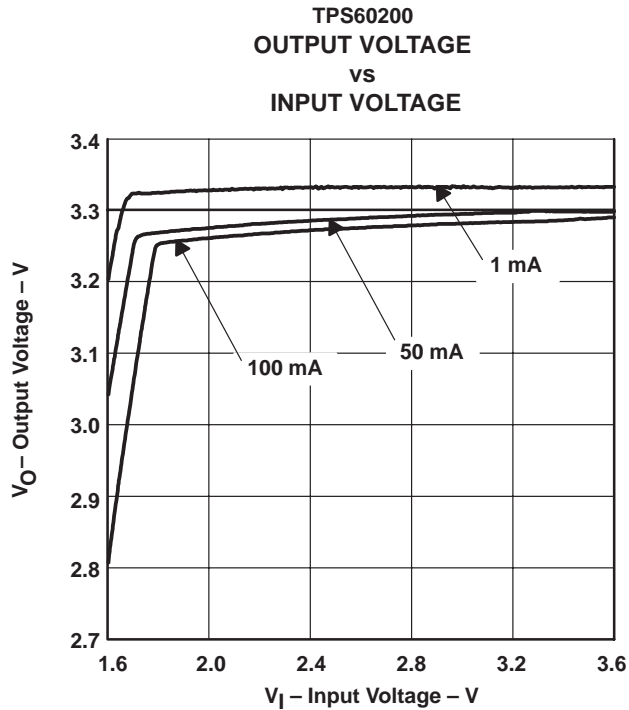


Figure 9

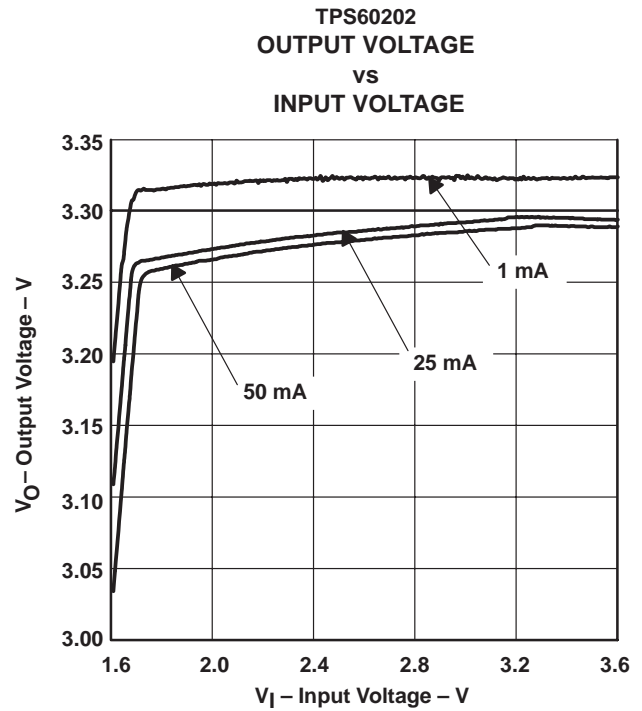


Figure 10

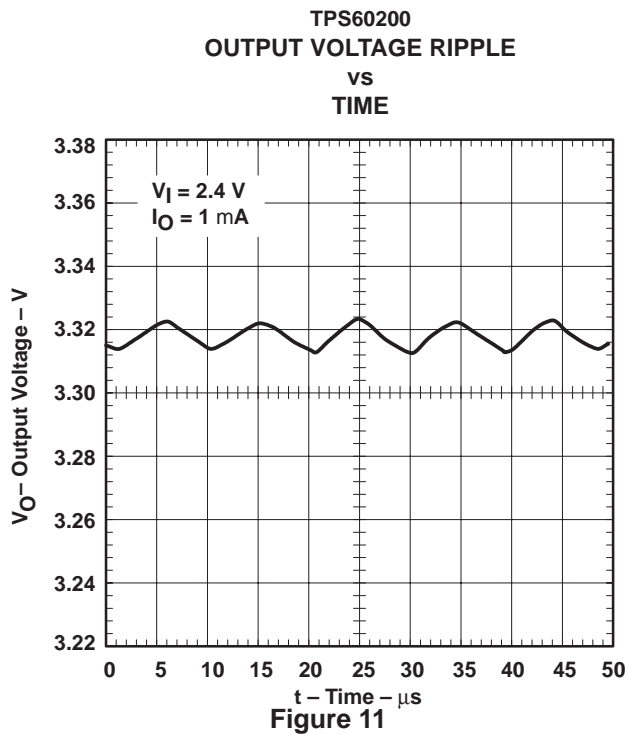


Figure 11

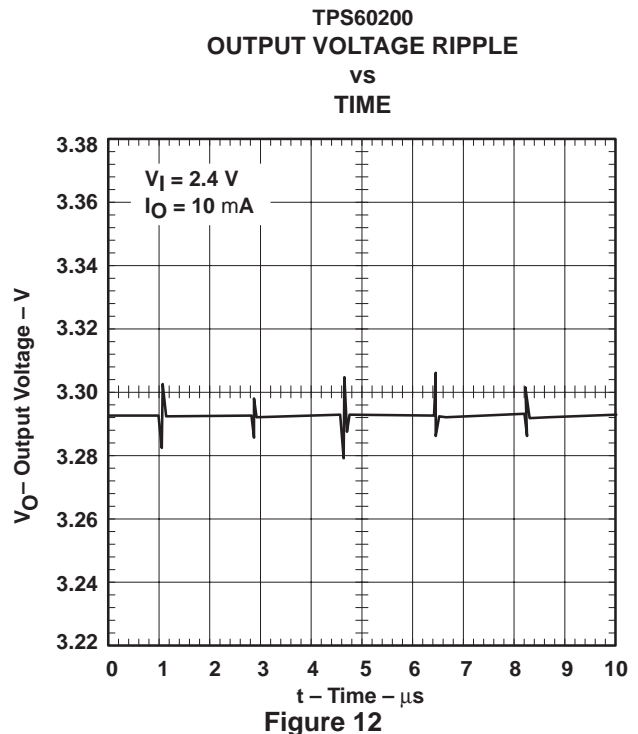


Figure 12

TPS60200, TPS60201, TPS60202, TPS60203
 REGULATED 3.3 V, 100-mA LOW-RIPPLE CHARGE PUMP
 LOW POWER DC/DC CONVERTERS

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TYPICAL CHARACTERISTICS

TPS60200
 OUTPUT VOLTAGE RIPPLE
 VS
 TIME

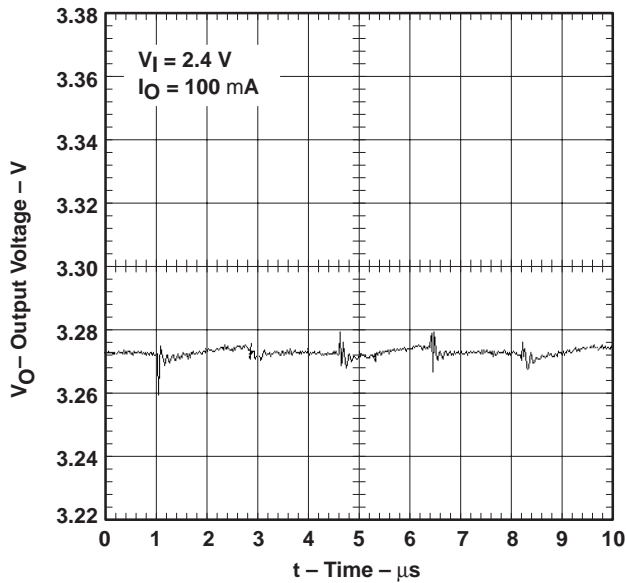


Figure 13

START-UP TIMING

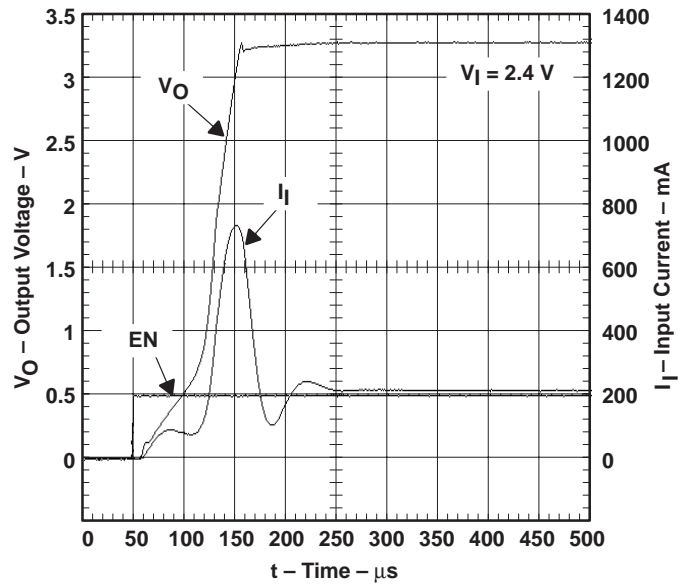


Figure 14

TPS60200
 LOAD TRANSIENT RESPONSE

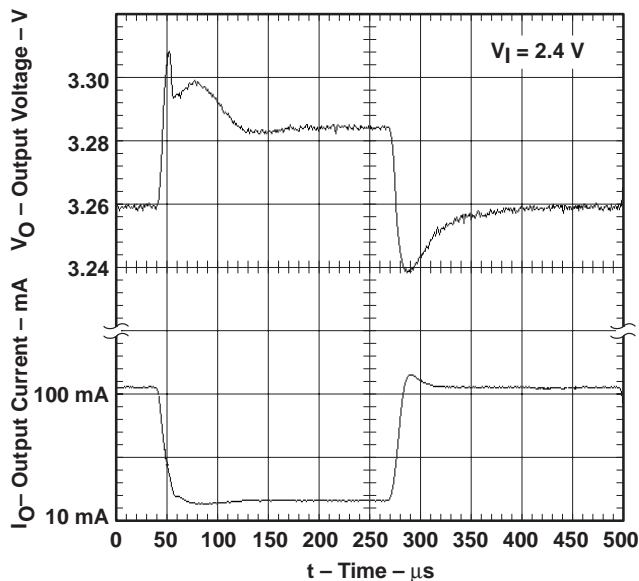


Figure 15

TPS60200
 LINE TRANSIENT RESPONSE

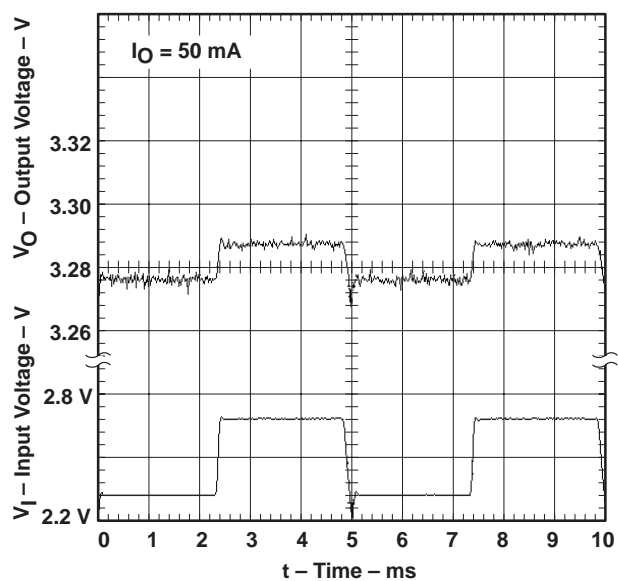


Figure 16



TYPICAL CHARACTERISTICS

TPS60200
 PEAK OUTPUT CURRENT
 vs
 INPUT VOLTAGE

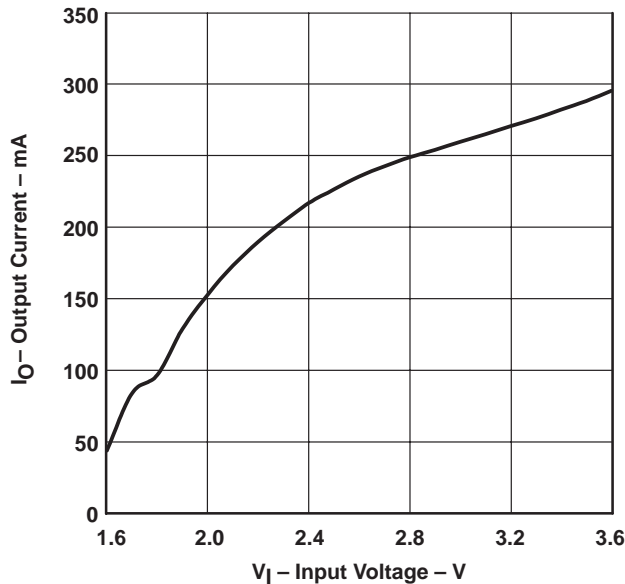


Figure 17

APPLICATION INFORMATION

capacitor selection

The TPS6020x devices require only four external capacitors to achieve a very low output voltage ripple. The capacitor values are closely linked to the required output current. Low ESR (<0.1 Ω) capacitors should be used at input and output. In general, the transfer capacitors (C1 and C2) will be the smallest, a 1-μF value is recommended for maximum load operation. With smaller capacitor values, the maximum possible load current is reduced and the LinSkip threshold is lowered.

The input capacitor improves system efficiency by reducing the input impedance. It also stabilizes the input current of the power source. The input capacitor should be chosen according to the power supply used and the distance from the power source to the converter IC. C_i is recommended to be about two to four times as large as the flying capacitors C1 and C2.

The output capacitor (C_o) should be at minimum the size of the input capacitor. The minimum required capacitance is 2.2 μF. Larger values will improve the load transient performance and will reduce the maximum output ripple voltage.

Only ceramic capacitors are recommended for input, output, and flying capacitors. Depending on the material used to manufacture them, ceramic capacitors might lose their capacitance over temperature and voltage. Ceramic capacitors of type X7R or X5R material will keep their capacitance over temperature and voltage, whereas Z5U- or Y5V-type capacitors will decrease in capacitance. Table 2 lists recommended capacitor values.

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Table 2. Recommended Capacitor Values (Ceramic X5R and X7R)

| LOAD CURRENT, I_L (mA) | FLYING CAPACITORS, C_1/C_2 (μ F) | INPUT CAPACITOR, C_i (μ F) | OUTPUT CAPACITOR, C_o (μ F) | OUTPUT VOLTAGE RIPPLE IN LINEAR MODE, $V_{(P-P)}$ (mV) | OUTPUT VOLTAGE RIPPLE IN SKIP MODE, $V_{(P-P)}$ (mV) |
|--------------------------------|--|--|---|---|---|
| 0–100 | 1 | 2.2 | 2.2 | 3 | 20 |
| 0–100 | 1 | 4.7 | 4.7 | 3 | 10 |
| 0–100 | 1 | 2.2 | 10 | 3 | 7 |
| 0–100 | 2.2 | 4.7 | 4.7 | 3 | 10 |
| 0–50 | 0.47 | 2.2 | 2.2 | 3 | 20 |
| 0–25 | 0.22 | 2.2 | 2.2 | 5 | 15 |
| 0–10 | 0.1 | 2.2 | 2.2 | 5 | 15 |

Table 3. Recommended Capacitor Types

| MANUFACTURER | PART NUMBER | SIZE | CAPACITANCE | TYPE |
|--------------|----------------|------|--------------|---------|
| Taiyo Yuden | UMK212BJ104MG | 0805 | 0.1 μ F | Ceramic |
| | EMK212BJ224MG | 0805 | 0.22 μ F | Ceramic |
| | EMK212BJ474MG | 0805 | 0.47 μ F | Ceramic |
| | LMK212BJ105KG | 0805 | 1 μ F | Ceramic |
| | LMK212BJ225MG | 0805 | 2.2 μ F | Ceramic |
| | EMK316BJ225KL | 1206 | 2.2 μ F | Ceramic |
| | LMK316BJ475KL | 1206 | 4.7 μ F | Ceramic |
| | JMK316BJ106ML | 1206 | 10 μ F | Ceramic |
| AVX | 0805ZC105KAT2A | 0805 | 1 μ F | Ceramic |
| | 1206ZC225KAT2A | 1206 | 2.2 μ F | Ceramic |

Table 4. Recommended Capacitor Manufacturers

| MANUFACTURER | CAPACITOR TYPE | INTERNET SITE |
|--------------|-----------------|---|
| Taiyo Yuden | X7R/X5R ceramic | http://www.t-yuden.com/ |
| AVX | X7R/X5R ceramic | http://www.avxcorp.com/ |



APPLICATION INFORMATION

typical operating circuit TPS60200 and TPS60202

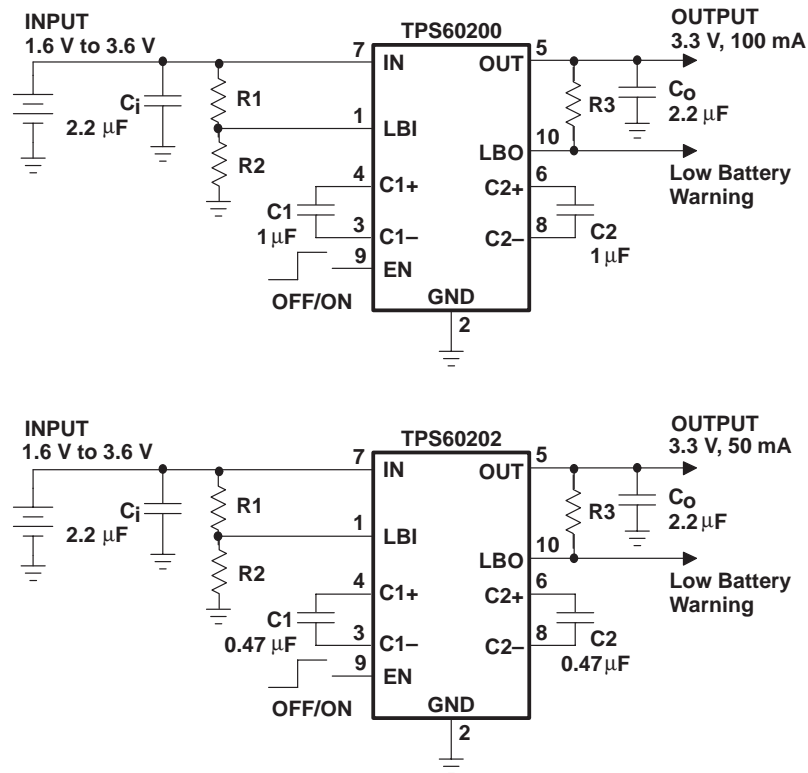


Figure 18. Typical Operating Circuit TPS60200 and TPS60202 With Low-Battery Detector

TPS60200, TPS60201, TPS60202, TPS60203
 REGULATED 3.3 V, 100-mA LOW-RIPPLE CHARGE PUMP
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APPLICATION INFORMATION

typical operating circuit TPS60201 and TPS60203

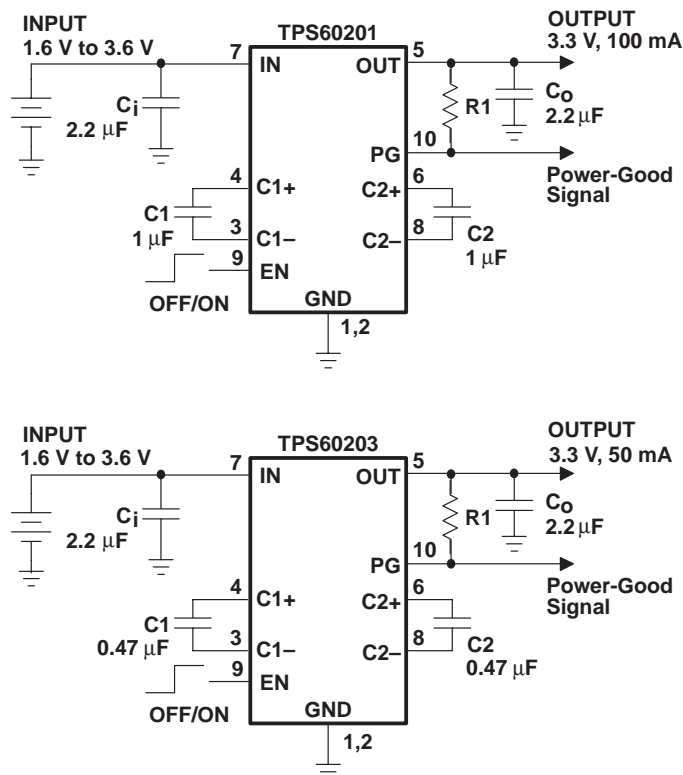


Figure 19. Typical Operating Circuit TPS60201 and TPS60203 With Power-Good Detector

power dissipation

The power dissipated in the TPS6020x devices depends mainly on input voltage and output current and is approximated by:

$$P_{(DISS)} = I_O \times (2 \times V_I - V_O) \quad \text{for } I_{(Q)} \ll I_O \quad (5)$$

By observing equation 5, it can be seen that the power dissipation is worst for highest input voltage V_I and highest output current I_O . For an input voltage of 3.6 V and an output current of 100 mA the calculated power dissipation $P_{(DISS)}$ is 390 mW. This is also the point where the charge pump operates with its lowest efficiency.

With the recommended maximum junction temperature of 125°C and an assumed maximum ambient operating temperature of 85°C, the maximum allowed thermal resistance junction to ambient of the system can be calculated.

$$R_{\Theta JA(max)} = \frac{T_{J(MAX)} - T_A}{P_{DISS(max)}} = \frac{125^\circ\text{C} - 85^\circ\text{C}}{390 \text{ mW}} = 102^\circ\text{C/W} \quad (6)$$

APPLICATION INFORMATION

power dissipation (continued)

P_{DISS} must be less than that allowed by the package rating. The thermal resistance junction to ambient of the used 10-pin MSOP is 294°C/W for an unsoldered package. The thermal resistance junction to ambient with the IC soldered to a printed circuit using a board layout as described in the application information section, the $R_{\theta JA}$ is typically 200°C/W , which is higher than the maximum value calculated above. However in a battery powered application, both V_I and T_A will typically be lower than the worst case ratings used in equation 6, and power dissipation should not be a problem in most applications.

layout and board space

Careful board layout is necessary due to the high transient currents and switching frequency of the converter. All capacitors should be placed in close proximity to the device. A PCB layout proposal for a one-layer board is given in Figure 20.

An evaluation module for the TPS60200 is available and can be ordered under product code TPS60200EVM-145. The EVM uses the layout shown in Figure 20. All components including the pins are shown. The EVM is built so that it can be connected to a 14-pin dual in line socket, therefore, the space needed for the IC, the external parts, and 8 pins is $17,9\text{ mm} \times 10,2\text{ mm} = 182,6\text{ mm}^2$.

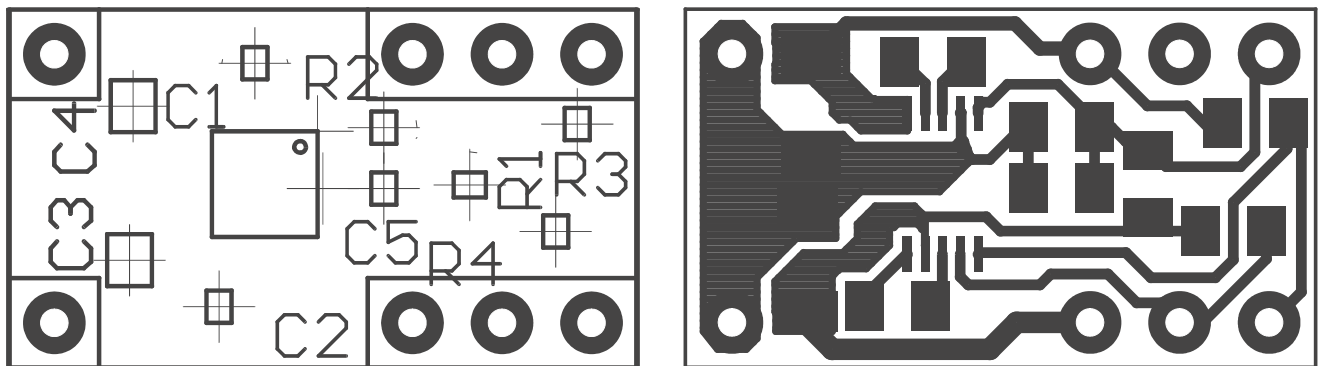


Figure 20. Recommended Component Placement and Board Layout

Table 5. Component Identification

| IC1 | TPS60200 |
|--------|---------------------------------|
| C1, C2 | Flying capacitors |
| C3 | Input capacitors |
| C4 | Output capacitors |
| C5 | Stabilization capacitor for LBI |
| R1, R2 | Resistive divider for LBI |
| R3 | Pullup resistor for LBO |
| R4 | Pullup resistor for EN |

Capacitor C5 should be included if large line transients are expected. This capacitor suppresses toggling of the LBO due to these line changes.

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device family products

Other charge pump dc-dc converters in this family are:

Table 6. Product Identification

| PART NUMBER | DESCRIPTION |
|--------------------|---|
| TPS60100 | 2-cell to regulated 3.3 V, 200-mA low-noise charge pump |
| TPS60101 | 2-cell to regulated 3.3 V, 100-mA low-noise charge pump |
| TPS60110 | 3-cell to regulated 5.0 V, 300-mA low-noise charge pump |
| TPS60111 | 3-cell to regulated 5.0 V, 150-mA low-noise charge pump |
| TPS60120 | 2-cell to regulated 3.3 V, 200-mA high efficiency charge pump with low battery comparator |
| TPS60121 | 2-cell to regulated 3.3 V, 200-mA high efficiency charge pump with power-good comparator |
| TPS60122 | 2-cell to regulated 3.3 V, 100-mA high efficiency charge pump with low battery comparator |
| TPS60123 | 2-cell to regulated 3.3 V, 100-mA high efficiency charge pump with power-good comparator |
| TPS60130 | 3-cell to regulated 5.0 V, 300-mA high efficiency charge pump with low battery comparator |
| TPS60131 | 3-cell to regulated 5.0 V, 300-mA high efficiency charge pump with power-good comparator |
| TPS60132 | 3-cell to regulated 5.0 V, 150-mA high efficiency charge pump with low battery comparator |
| TPS60133 | 3-cell to regulated 5.0 V, 150-mA high efficiency charge pump with power-good comparator |
| TPS60140 | 2-cell to regulated 5.0 V, 100-mA charge pump voltage tripler with low battery comparator |
| TPS60141 | 2-cell to regulated 5.0 V, 100-mA charge pump voltage tripler with power-good comparator |



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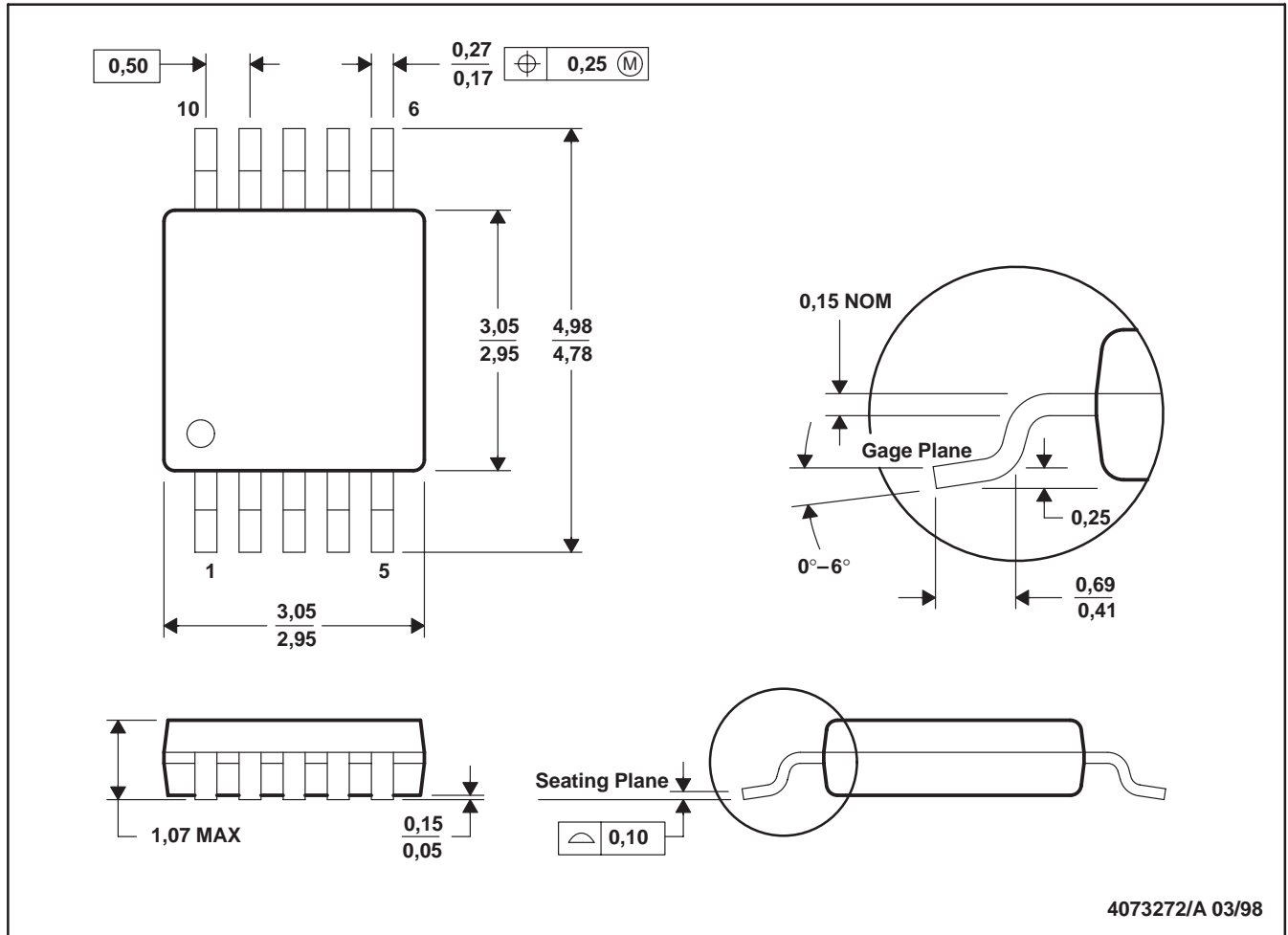
TPS60200, TPS60201, TPS60202, TPS60203
 REGULATED 3.3 V, 100-mA LOW-RIPPLE CHARGE PUMP
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MECHANICAL DATA

DGS (S-PDSO-G10)

PLASTIC SMALL-OUTLINE PACKAGE



- NOTES: A. All linear dimensions are in millimeters.
 B. This drawing is subject to change without notice.
 C. Body dimensions do not include mold flash or protrusion.

PACKAGING INFORMATION

| Orderable Device | Status ⁽¹⁾ | Package Type | Package Drawing | Pins | Package Qty | Eco Plan ⁽²⁾ | Lead/Ball Finish | MSL Peak Temp ⁽³⁾ |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|
| TPS60200DGS | ACTIVE | MSOP | DGS | 10 | 80 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60200DGSR | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60200DGSRG4 | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60201DGS | ACTIVE | MSOP | DGS | 10 | 80 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60201DGSR | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60202DGS | ACTIVE | MSOP | DGS | 10 | 80 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60202DGSR | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60202DGSRG4 | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60203DGS | ACTIVE | MSOP | DGS | 10 | 80 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60203DGSR | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |
| TPS60203DGSRG4 | ACTIVE | MSOP | DGS | 10 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-1-260C-UNLIM |

⁽¹⁾ 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.

⁽²⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS) 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.

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)

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

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