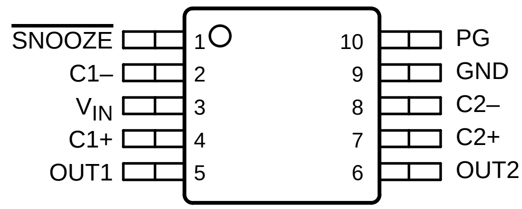
## features

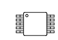
- **Regulated 3-V or 3.3-V Output Voltage With up to 20-mA Output Current From a 0.9-V to 1.8-V Input Voltage Range**
- **High Power Conversion Efficiency (up to 90%) Over Wide Output Current Range, Optimized for 1.2-V Battery Voltage**
- **Snooze Mode for Improved Efficiency at Low-Output Current**
- **Additional Output With 2 Times $V_I$ (OUT1)**
- **Device Quiescent Current Less Than 2 µA**
- **Supervisor Included; Open Drain or Push-Pull Power Good Output**
- **No Inductors Required/Low EMI**
- **Only Five Small, 1-µF Ceramic Capacitors Required**
- **Microsmall 10-Pin MSOP Package**

## applications

- **Pagers**
- **Battery-Powered Toys**
- **Portable Measurement Instruments**
- **Home Automation Products**
- **Medical Instruments (Like Hearing Instruments)**
- **Metering Applications Using MSP430 Microcontroller**
- **Portable Smart Card Readers**

**DGS PACKAGES**
**(TOP VIEW)**



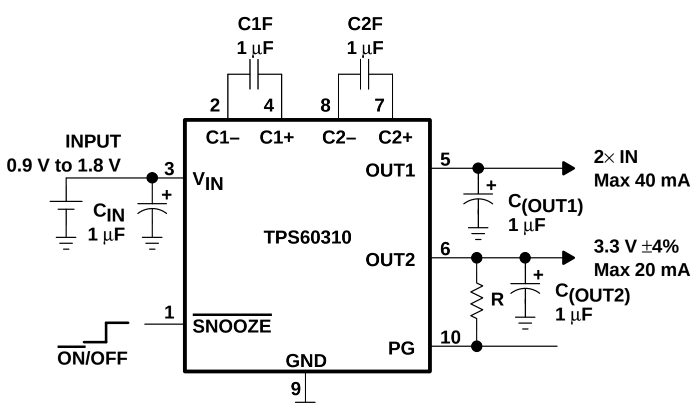
**ACTUAL SIZE**
**3,05 mm x 4,98 mm**

## description

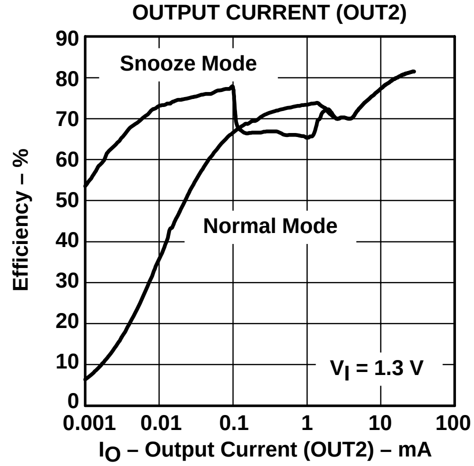
The TPS6031X step-up, regulated charge pumps generate a 3-V ±4% or 3.3-V ±4% output voltage from a 0.9-V to 1.8-V input voltage (one alkaline, NiCd, or NiMH battery).

Only five small 1-µF ceramic capacitors are required to build a complete high-efficiency dc/dc charge pump converter. To achieve the high efficiency over a wide input voltage range, the charge pump automatically selects between a 3x or 4x conversion mode.

## typical application circuit




**EFFICIENCY**
**vs**
**OUTPUT CURRENT (OUT2)**




Snooze mode improves efficiency at an output current in the range of 1 µA to 100 µA.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

## description (continued)

Output 1 (OUT1) can deliver a maximum of 40 mA, from a 1-V input, with output 2 (OUT2) not loaded. OUT2 can deliver a maximum of 20 mA, from a 1-V input, with OUT1 not loaded. Both outputs can be loaded at the same time, but the total output current of the first voltage doubler must not exceed 40 mA. For example, the load at OUT1 is 20 mA and the load at output 2 is 10 mA.

In snooze mode, the devices operate with a typical operating current of 2 µA, while the output voltage is maintained at 3.3 V ±10% or 3 V ±10%, respectively. This is lower than the self-discharge current of most batteries. Load current in snooze mode is limited to 2 mA. If the load current increases above 2 mA, the output voltage drops further and the devices automatically exits the snooze mode and operate in normal mode to regulate to the nominal output voltage with higher output currents. The device is set into the snooze mode by taking the $\overline{\text{SNOOZE}}$ pin low, and is set into normal operating mode by taking the $\overline{\text{SNOOZE}}$ pin high.

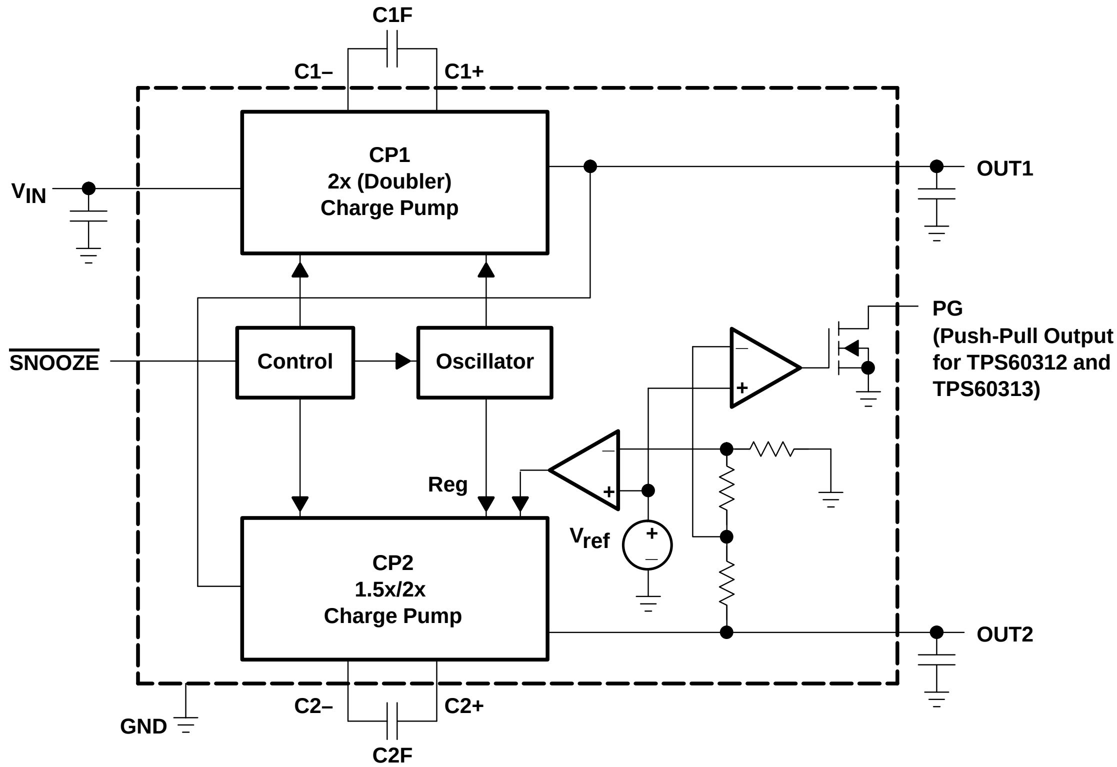
A power-good function supervises the output voltage of OUT2 and can be used for power up and power down sequencing. Power-good (PG) is offered as either open-drain or push-pull output.

**AVAILABLE OPTIONS**

| PART NUMBER† | MARKING DGS PACKAGE | OUTPUT CURRENT 1 [mA]‡ | OUTPUT CURRENT 2 [mA]§ | OUTPUT VOLTAGE 1 [V] | OUTPUT VOLTAGE 2 [V] | FEATURE |
|---|---|---|---|---|---|---|
| TPS60310DGS | ATG | 40 | 20 | 2 x $V_{IN}$ | 3.3 | Open-drain power-good output |
| TPS60311DGS | ATI | 40 | 20 | 2 x $V_{IN}$ | 3 | Open-drain power-good output |
| TPS60312DGS | ATK | 40 | 20 | 2 x $V_{IN}$ | 3.3 | Push-pull power-good output |
| TPS60313DGS | ATL | 40 | 20 | 2 x $V_{IN}$ | 3 | Push-pull power-good output |

† The DGS package is available taped and reeled. Add R suffix to device type (e.g. TPS60310DGSR) to order quantities of 2500 devices per reel.
‡ If OUT2 is not loaded.
§ If OUT1 is not loaded.

## TPS60310 and TPS60311 functional block diagram




## Terminal Functions

| TERMINAL NAME | TERMINAL NO. | I/O | DESCRIPTION |
|---|---|---|---|
| C1+ | 4 | | Positive terminal of the flying capacitor C1F |
| C1– | 2 | | Negative terminal of the flying capacitor C1F |
| C2+ | 7 | | Positive terminal of the flying capacitor C2F |
| C2– | 8 | | Negative terminal of the flying capacitor C2F |
| GND | 9 | | GROUND |
| OUT1 | 5 | O | $2 \times V_{IN}$ power output. Bypass OUT1 to GND with the output filter capacitor $C_{(OUT1)}$. |
| OUT2 | 6 | O | Regulated 3.3-V power output (TPS60310, TPS60312) or 3-V power output (TPS60311, TPS60313), respectively<br>Bypass OUT2 to GND with the output filter capacitor $C_{(OUT2)}$. |
| PG | 10 | O | Power good detector output. As soon as the voltage on OUT2 reaches about 98% of its nominal value this pin goes high.<br>Open drain output on TPS60310 and TPS60311. A pullup resistor should be connected between PG and OUT1 or OUT2.<br>Push-pull output stage on TPS60312 and TPS60313 |
| $\overline{\text{SNOOZE}}$ | 1 | I | Snooze mode enable input<br>– $\overline{\text{SNOOZE}}$ = Low enables the snooze mode at low output current.<br>– $\overline{\text{SNOOZE}}$ = High disables the snooze mode. |
| $V_{IN}$ | 3 | I | Supply input. Bypass $V_{IN}$ to GND with a ≥ 1-µF capacitor. |

## detailed description

### operating principle

The TPS6031X charge pumps are voltage quadruplers that provide a regulated 3.3-V or 3-V output from a 0.9-V to 1.8-V input. They deliver a maximum load current of 20 mA. Designed specifically for space critical battery powered applications, the complete converter requires only five external capacitors and enables the design to use low-cost, small-sized, 1-µF ceramic capacitors. The TPS6031X circuits consist of an oscillator, a voltage reference, an internal resistive feedback circuit, two error amplifiers, two charge pump stages with MOSFET switches, a shutdown/start-up circuit, and a control circuit.

### snooze mode

The devices contain a circuit which dramatically reduces the quiescent current at light loads. This so called snooze mode must be enabled by pulling the $\overline{\text{SNOOZE}}$ pin low. When the output current decreases below the snooze mode threshold, the device enters the snooze mode. In snooze mode, the main error amplifier with 4% error and 50-µA supply current is disabled and a 10%, 2-µA regulator controls the output voltage.

### start-up procedure

The start-up performance of the device is independent of the level of the snooze input. When voltage is applied to the input, CP1 will first enter a dc start-up mode during which the capacitor on OUT1 is charged up to about $V_{IN}$. After that, it starts switching to boost the voltage further up to about two times $V_{IN}$. CP1 first enters a dc start-up mode during which the capacitor on OUT1 is charged up to about $V_{IN}$. CP2 then follows and charges up the capacitor on OUT2 to about the voltage on OUT1, after that, it also starts switching and boosts up the voltage to its nominal value. The voltage at the $\overline{\text{SNOOZE}}$ pin must not exceed the highest voltage applied to the device.

**NOTE:**

During start-up with $V_{OUT}$ = 0 V, the highest voltage is the input voltage.

### power-good detector

The power-good output is an open-drain output on the TPS60310 and TPS60311 or a push-pull output on the TPS60312 and TPS60313. The PG-output pulls low when the output of OUT2 is out of regulation. When the output rises to within 98% of regulation, the power-good output goes active high. In shutdown, power-good is pulled low. In normal operation, an external pullup resistor with the TPS60310 and TPS60311 is typically used to connect the PG pin to VOUT. The resistor should be in the 100-kΩ to 1-MΩ range. If the PG output is not used, it should remain unconnected. Output current at PG (TPS60312, TPS60313) reduces maximum output current at OUT2.

In snooze mode, the output voltage is sampled at a rate up to 2 ms and is applied to the power-good comparator. In normal mode, the output voltage is measured continuously.

## absolute maximum ratings over operating free-air temperature (unless otherwise noted)†

Input voltage, $V_I$ (IN to GND) (see Note 1) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . –0.3 V to 2 V
Output voltage, $V_O$ (OUT1, OUT2, EN, PG to GND) (see Note 1) . . . . . . . . . . . . . . . . . . . . . . . –0.3 V to 3.6 V
Voltage, (C1+ to GND) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . –0.3 V to $V_{O(OUT1)}$ + 0.3 V
Voltage, (C1– to GND, C2– to GND) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . –0.3 V to $V_{IN}$ + 0.3 V
Voltage, (C2+ to GND) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . –0.3 V to $V_{O(OUT2)}$ + 0.3 V
Continuous power dissipation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . See Dissipation Rating Table
Output current, $I_O$ (OUT1) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 80 mA
Output current, $I_O$ (OUT2) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 40 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.

NOTE 1: The voltage at $\overline{\text{SNOOZE}}$ and PG can exceed IN up to the maximum rated voltage without increasing the leakage current drawn by these pins.

**DISSIPATION RATING TABLE**

| PACKAGE | $T_A$ <25°C POWER RATING | DERATING FACTOR ABOVE $T_A$ = 25°C | $T_A$ = 70°C POWER RATING | $T_A$ = 85°C POWER RATING |
|---|---|---|---|---|
| DGS | 424 mW | 3.4 mW/°C | 271 mW | 220 mW |

NOTE: The thermal resistance junction to ambient of the DGS package is $R_{TH-JA}$ = 294°C/W.

## recommended operating conditions

| | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|
| Input voltage, $V_I$ | 0.9 | | 1.8 | V |
| Output current (OUT2), $I_{O(OUT2)}$ | | | 20 | mA |
| Output current (OUT1), $I_{O(OUT1)}$ | | | 40 | mA |
| Input capacitor, $C_I$ | 1 | | | µF |
| Flying capacitors, C1F, C2F | | 1 | | µF |
| Output capacitors, $C_{O(1)}$, $C_{O(2)}$ | 1 | | | µF |
| Operating junction temperature, $T_J$ | –40 | | 125 | °C |

## electrical characteristics at $C_{IN}$ = C1F = C2F = $C_{(OUT1)}$ = $C_{(OUT2)}$ = 1 µF, $T_C$ = –40°C to 85°C, $V_{IN}$ = 1 V, $V_{(SNOOZE)}$ = $V_{IN}$ (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Supply voltage range | | 0.9 | | 1.8 | V |
| $I_{O(OUT1)}$ | Maximum output current for TPS60310, TPS60312 | $V_{IN}$ ≥ 1.1 V, $I_{O(OUT2)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 40 | | | mA |
| | | $V_{IN}$ = 0.9 V, $I_{O(OUT2)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 20 | | | |
| $I_{O(OUT2)}$ | | $V_{IN}$ ≥ 1.1 V, $I_{O(OUT1)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 20 | | | |
| | | $V_{IN}$ = 0.9 V, $I_{O(OUT1)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 10 | | | |
| $I_{O(OUT1)}$ | Maximum output current for TPS60311, TPS60313 | $V_{IN}$ ≥ 1.1 V, $I_{O(OUT2)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 40 | | | mA |
| | | $V_{IN}$ = 0.9 V, $I_{O(OUT2)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 20 | | | |
| $I_{O(OUT2)}$ | | $V_{IN}$ ≥ 1 V, $I_{O(OUT1)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 20 | | | |
| | | $V_{IN}$ = 0.9 V, $I_{O(OUT1)}$ = 0 mA, $I_{(PG,1)}$ = 0 mA | 12 | | | |
| $V_{O(OUT2)}$ | Output voltage for TPS60310, TPS60312 | 1.1 V < $V_{IN}$ < 1.8 V, $I_{O(OUT1)}$ = 0 mA 0 < $I_{O(OUT2)}$ < 20 mA | 3.17 | 3.3 | 3.43 | V |
| | | 0.9 V < $V_{IN}$ < 1.1 V, $I_{O(OUT1)}$ = 0 mA, $I_{O(OUT2)}$ < 10 mA | 3.17 | 3.3 | 3.43 | |
| | | 0.9 V < $V_{IN}$ < 1.8 V, $V_{(SNOOZE)}$ = 0 V, 0 < $I_{O(OUT2)}$ < 1 mA or 0 < $I_{O(OUT1)}$ < 2 mA | 2.85 | 3.3 | 3.6 | V |
| $V_{O(OUT2)}$ | Output voltage for TPS60311, TPS60313 | 1 V < $V_{IN}$ < 1.8 V, $I_{O(OUT1)}$ = 0 mA, 0 < $I_{O(OUT2)}$ < 20 mA | 2.88 | 3 | 3.12 | V |
| | | $V_{IN}$ > 1.65 V, $I_{O(OUT1)}$ = 0 mA, 25 µA < $I_{O(OUT2)}$ < 20 mA | 2.88 | 3 | 3.15 | |
| | | 0.9 V < $V_{IN}$ < 1.8 V, $V_{(SNOOZE)}$ = 0 V, 0 < $I_{O(OUT2)}$ < 1 mA or 0 < $I_{O(OUT1)}$ < 2 mA | 2.6 | 3.3 | 3.27 | V |
| $V_{P-P}$ | Output voltage ripple — OUT2 | $I_{O(OUT2)}$ = 20 mA, $I_{O(OUT1)}$ = 0 mA | | 30 | | $mV_{P-P}$ |
| | Output voltage ripple — OUT1 | $I_{O(OUT1)}$ = 40 mA, $I_{O(OUT2)}$ = 0 mA | | 60 | | |
| $I_Q$ | Quiescent current (no-load input current) | $I_O$ = 0 mA, $V_{IN}$ = 1.8 V | | 35 | 70 | µA |
| $I_{(SQ)}$ | Quiescent supply current in snooze mode | $V_{IN}$ = 1.65 V, $V_{(SNOOZE)}$ = 0 V, $T_C$ = 60°C | | 2 | 10 | µA |
| | | $V_{IN}$ = 1.65 V, $V_{(SNOOZE)}$ = 0 V, $T_C$ ≤ 25°C | | 1.5 | 4 | |
| $f_{OSC}$ | Internal switching frequency | | 470 | 700 | 900 | kHz |
| $V_{IL(EN)}$ | EN input low voltage | $V_{IN}$ = 0.9 V to 1.8 V | | | $0.3 \times V_{IN}$ | V |
| $V_{IH(EN)}$ | EN input high voltage | $V_{IN}$ = 0.9 V to 1.8 V | $0.7 \times V_{IN}$ | | | V |
| $I_{lkg}$ | EN input leakage current | $V_{(EN)}$ = 0 V or $V_{IN}$ or $V_{O(OUT2)}$ or $V_{O(OUT1)}$ | | 0.01 | 0.1 | µA |
| | LinSkip switching threshold | $V_{IN}$ = 1.25 V | | 7.5 | | mA |
| | Snooze mode threshold | $V_{IN}$ = 1.25 V, $I_{O(OUT1)}$ | 2 | | 8 | mA |
| | | $V_{IN}$ = 1.25 V, $I_{O(OUT2)}$ | 1 | | 4 | mA |

## electrical characteristics at $C_{IN}$ = C1F = C2F = $C_{(OUT1)}$ = $C_{(OUT2)}$ = 1 µF, $T_C$ = –40°C to 85°C, $V_{IN}$ = 1 V, $V_{(SNOOZE)}$ = $V_{IN}$ (unless otherwise noted) (continued)

| PARAMETER | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| Short circuit current | $V_{IN}$ = 1.8 V | $V_{O(OUT2)}$ = 0 V | 5 | 20 | 50 | mA |
| | | $V_{O(OUT1)}$ = 0 V | 2 | 80 | 150 | |
| Output load regulation | $V_{IN}$ = 1.25 V, $T_C$ = 25°C<br>2 mA < $I_{O(OUT2)}$ < 20 mA | | | 0.1 | | %/mA |
| Output line regulation | 1 V < $V_{IN}$ < 1.65 V, $T_C$ = 25°C,<br>$I_{O(OUT)}$ = 10 mA | | | 0.75 | | %/V |
| | 1 V < $V_{IN}$ < 1.65 V, $T_C$ = 25°C,<br>$I_{O(OUT2)}$ = 1 mA, $V_{(SNOOZE)}$ = 0 V | | | 1 | | %/V |
| No load start-up time | | | | 400 | | µs |
| Impedance of first charge pump stage | | | | 4.0 | | Ω |
| Start-up performance at OUT2 (minimum start-up load resistance) | $V_{IN}$ ≥ 1.1 V | | 165 | | | Ω |
| | $V_{IN}$ ≥ 1 V | | 330 | | | |
| | $V_{IN}$ = 0.9 V | | 1000 | | | |
| Startup performance at OUT1 (minimum start-up load resistance) | $V_{IN}$ = 1 V | | 500 | | | Ω |

## electrical characteristics for power good comparator of devices TPS6031X at $T_C$ = –40°C to 85°C, $V_{IN}$ = 1 V and $V_{(SNOOZE)}$ = $V_{IN}$ (unless otherwise noted)

| PARAMETER | | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $V_{(PG)}$ | Power-good trip voltage | | $V_O$ ramping positive | | $V_O$ – 1% | $V_O$ | V |
| $V_{hys}$ | Power-good trip voltage hysteresis | | $V_O$ ramping negative | | 10% | | |
| $V_{OL}$ | Power-good output voltage low | | $V_O$ = 0 V, $I_{(PG)}$ = 1.6 mA | | | 0.3 | V |
| $I_{lkg}$ | Power-good leakage current | TPS60310 | $V_O$ = 3.3 V, $V_{(PG)}$ = 3.3 V | | 0.01 | 0.1 | µA |
| | | TPS60311 | $V_O$ = 3 V, $V_{(PG)}$ = 3 V | | 0.01 | 0.1 | |
| $V_{OH}$ | Power-good output voltage high | TPS60312 | $I_{O(PG)}$ = –5 mA | 3 | | | V |
| | | TPS60313 | | 2.7 | | | |
| $I_{O(PG,1)}$ | Output current at power good (source) | TPS60312,<br>TPS60313 | | –5 | | | mA |
| $I_{O(PG,0)}$ | Output current at power good (sink) | All devices | $V_{(PG)}$ = 0 V | 1.6 | | | mA |
| $R_{(PG,1)}$ | Output resistance at power good | TPS60312,<br>TPS60313 | $V_{(PG)}$ = $V_{O(OUT2)}$ | | 15 | | Ω |
| $R_{(PG,0)}$ | | All devices | $V_{(PG)}$ = 0 V | | 100 | | Ω |

## TYPICAL CHARACTERISTICS

### Table of Graphs

| | | | FIGURE |
|---|---|---|---|
| $\eta$ | Efficiency | vs Output current (TPS60310 and TPS60311) | 1, 2 |
| $I_S$ | Supply current | vs Output current | 3 |
| $I_Q$ | Quiescent current | vs Input voltage | 4 |
| $V_{O(OUT2)}$ | Output voltage at OUT2 | vs Output current (TPS60310 and TPS60311) | 5, 6 |
| $V_{O(OUT1)}$ | Output voltage at OUT1 | vs Output current at 25°C, $V_I$ = 0.9 V, 1.1 V, 1.25 V, 1.4 V, 1.6 V, 1.8 V | 7 |
| $V_{O(OUT2)}$ | Output voltage at OUT2 | vs Input voltage (TPS60310 and TPS60311) | 8, 9 |
| $V_{O(OUT1)}$ | Output voltage at OUT1 | vs Input voltage (TPS60310 and TPS60311) | 10 |
| $V_{O(OUT2)}$ | Output voltage at OUT2 | vs Free-air temperature (TPS60310, TPS60312, TPS60311, and TPS60313) | 11, 12 |
| $V_{O(OUT2)}$ | Output voltage ripple at OUT2 | | 13 |
| | Minimum input voltage | vs Output current for TPS60310, TPS60312, TPS60311, and TPS60313 | 14, 15 |
| | Start-up timing enable | | 16 |
| | Switching frequency | vs Input voltage | 17 |
| | Load transient response | | 18 |
| | Line transient response | | 19 |
| $V_O$ | Output voltage | vs Time | 20 |
| | Output voltage ripple in Snooze mode | | 21 |

## TYPICAL CHARACTERISTICS

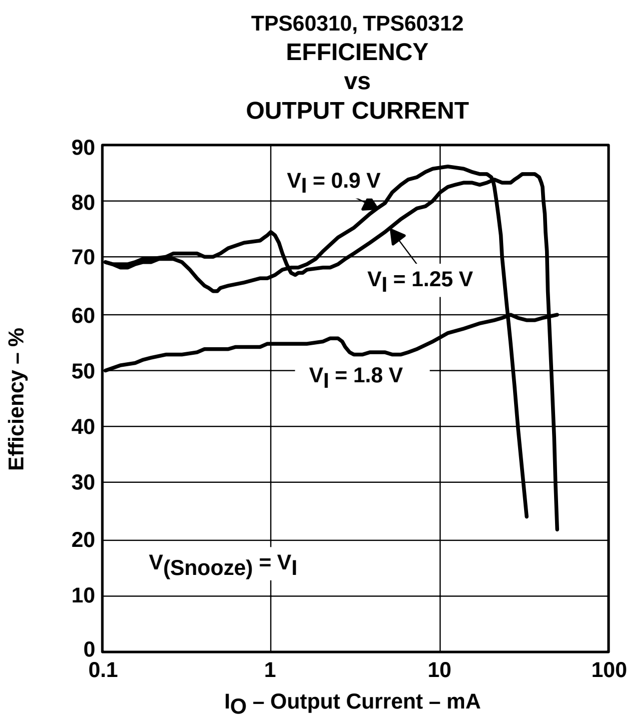



Figure 1

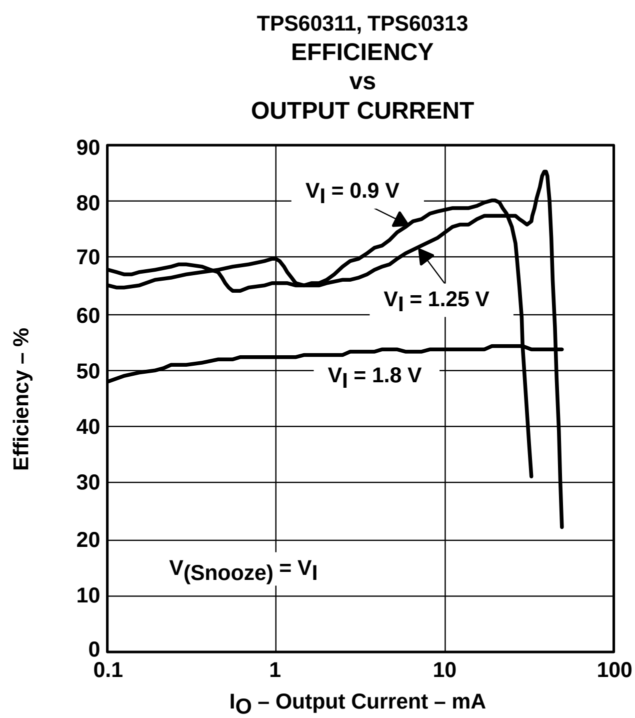



Figure 2

## TYPICAL CHARACTERISTICS

**TPS60310**
**SUPPLY CURRENT vs OUTPUT CURRENT**

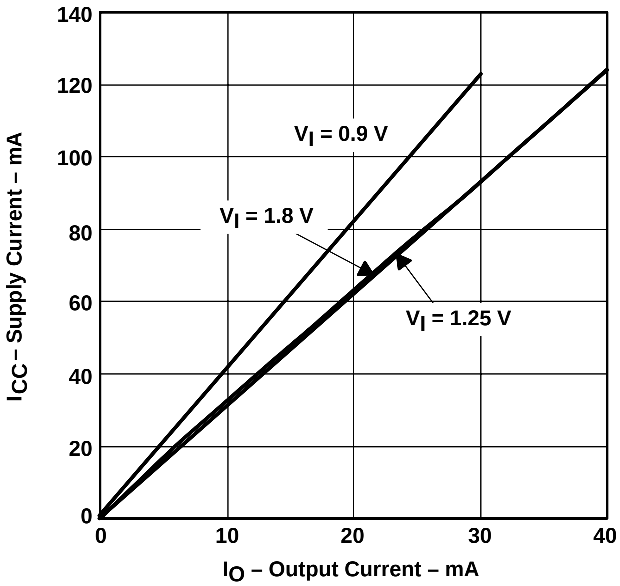



Figure 3

**TPS6031X**
**QUIESCENT CURRENT vs INPUT VOLTAGE**

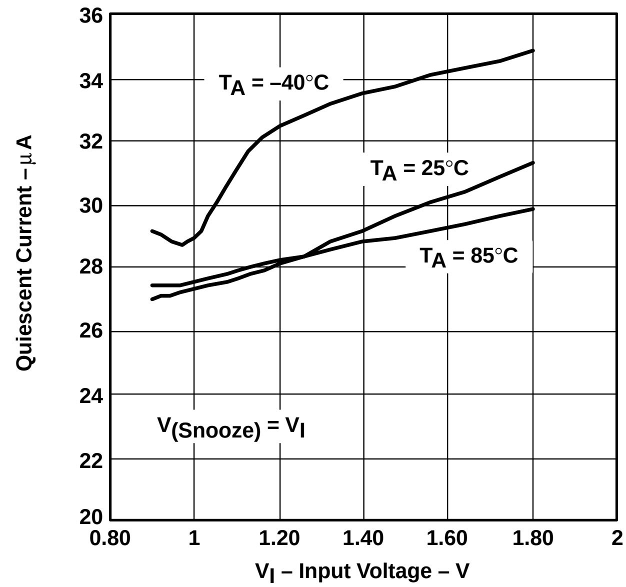



Figure 4

**TPS60310, TPS60312**
**OUTPUT VOLTAGE (OUT2) vs OUTPUT CURRENT (OUT2)**

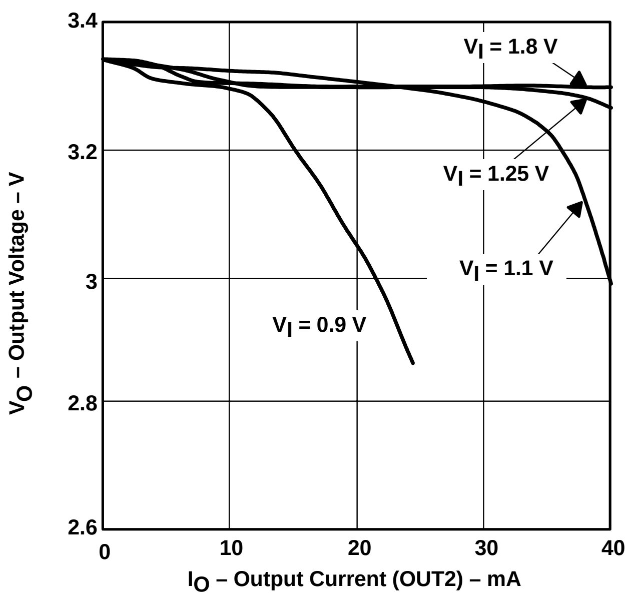



Figure 5

**TPS60311, TPS60313**
**OUTPUT VOLTAGE (OUT2) vs OUTPUT CURRENT (OUT2)**

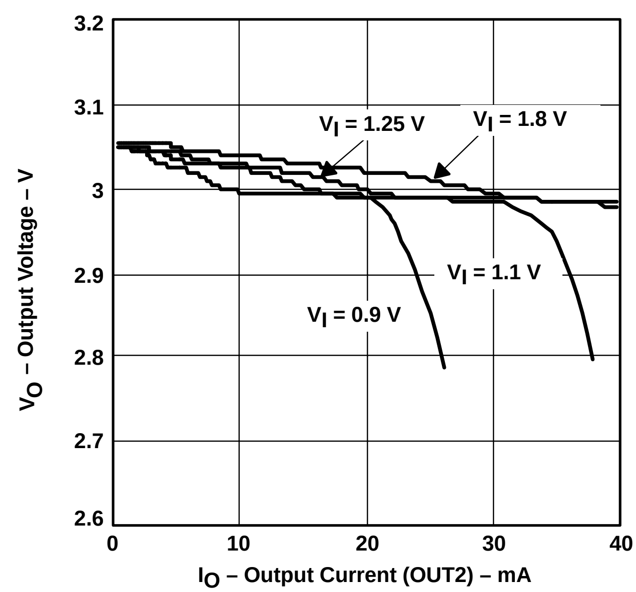



Figure 6

## TYPICAL CHARACTERISTICS

**TPS60310, TPS60312**
**OUTPUT VOLTAGE (OUT1) vs OUTPUT CURRENT (OUT1)**

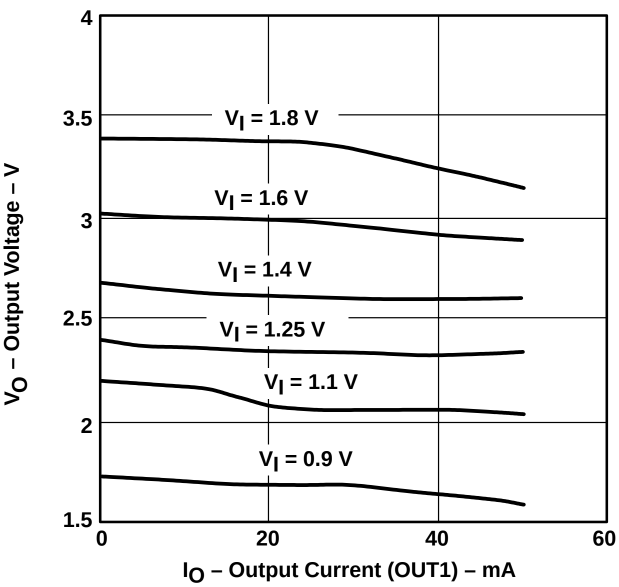



Figure 7

**TPS60310, TPS60312**
**OUTPUT VOLTAGE (OUT2) vs INPUT VOLTAGE**

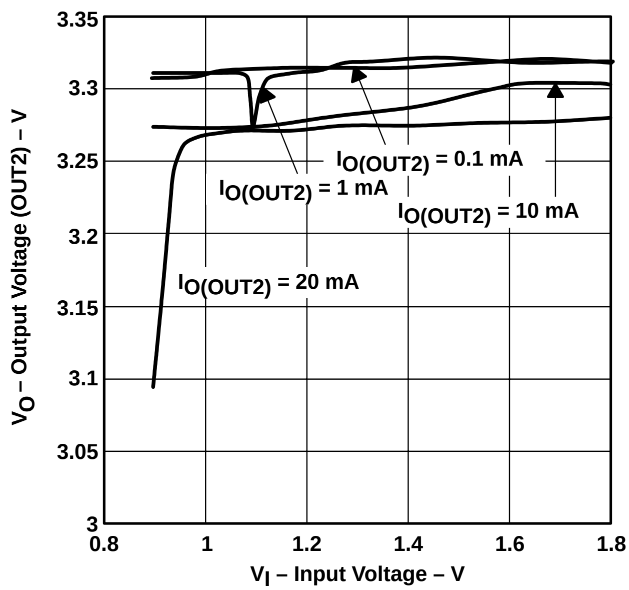



Figure 8

**TPS60310, TPS60312**
**OUTPUT VOLTAGE (OUT2) vs INPUT VOLTAGE**

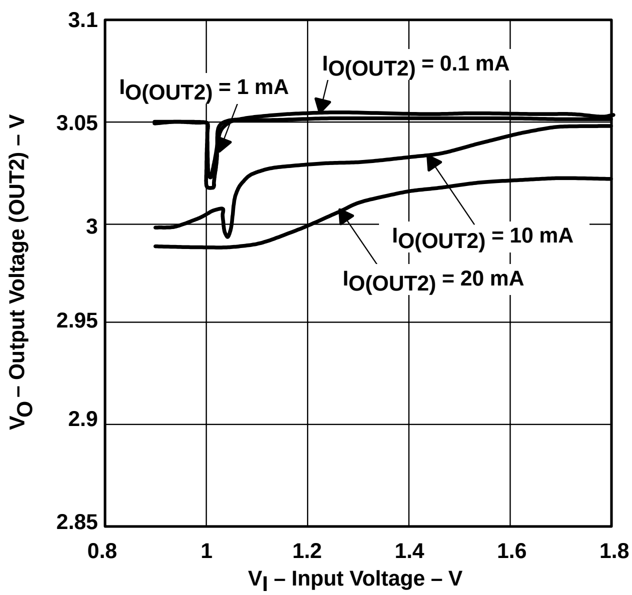



Figure 9

**TPS6031x**
**OUTPUT VOLTAGE (OUT1) vs INPUT VOLTAGE**

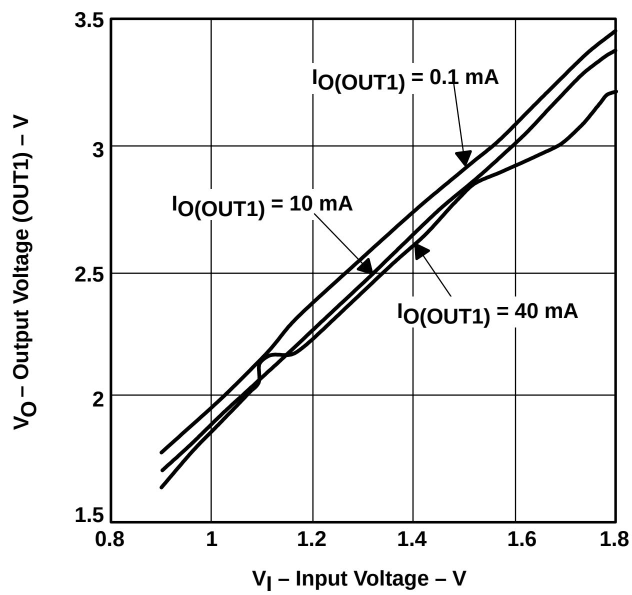



Figure 10

## TYPICAL CHARACTERISTICS

TPS60310, TPS60312
OUTPUT VOLTAGE (OUT2)
vs
FREE-AIR TEMPERATURE

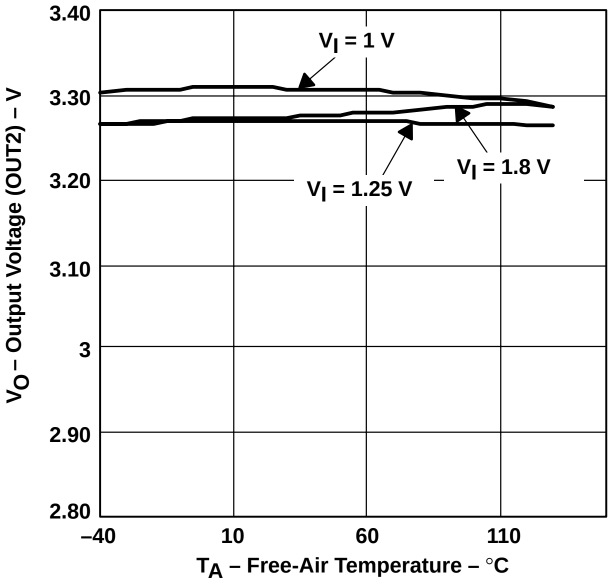



Figure 11

TPS60311, TPS60313
OUTPUT VOLTAGE (OUT2)
vs
FREE-AIR TEMPERATURE

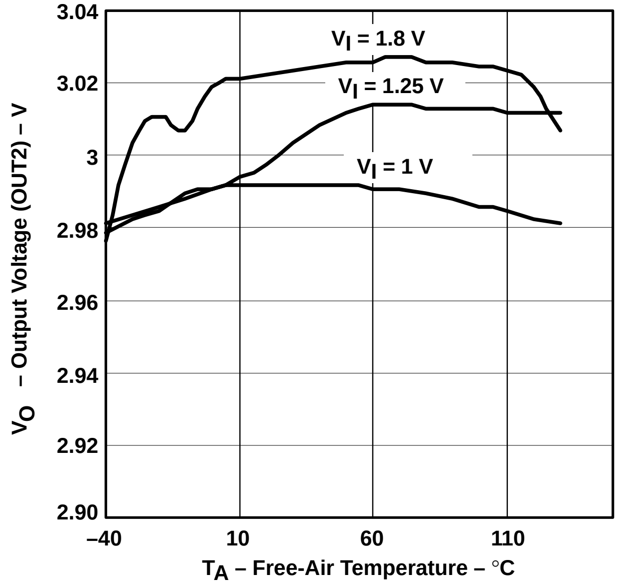



Figure 12

TPS6031x
OUTPUT VOLTAGE RIPPLE (OUT2)

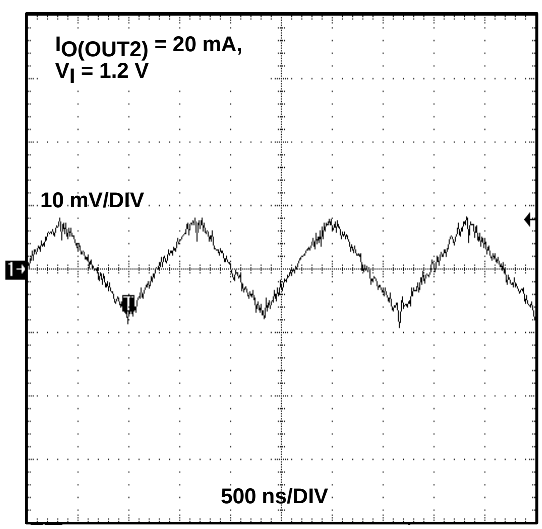



Figure 13

TPS60310, TPS60312
MINIMUM INPUT VOLTAGE
vs
OUTPUT CURRENT

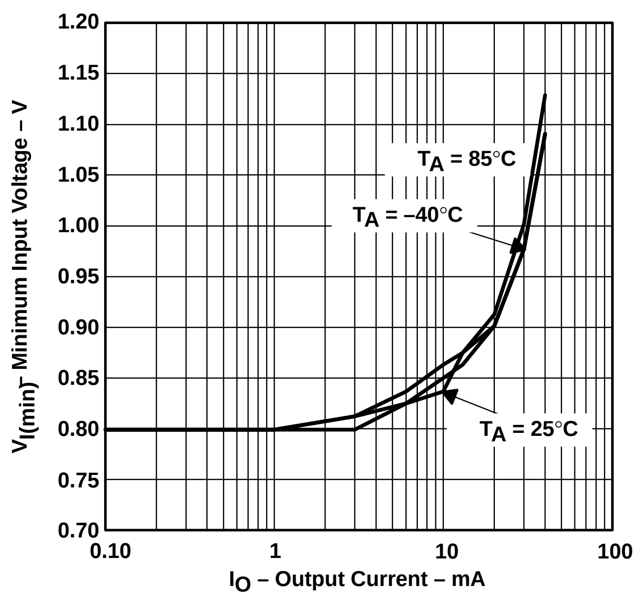



Figure 14

## TYPICAL CHARACTERISTICS

**TPS60311, TPS60313**
**MINIMUM INPUT VOLTAGE**
**vs**
**OUTPUT CURRENT**

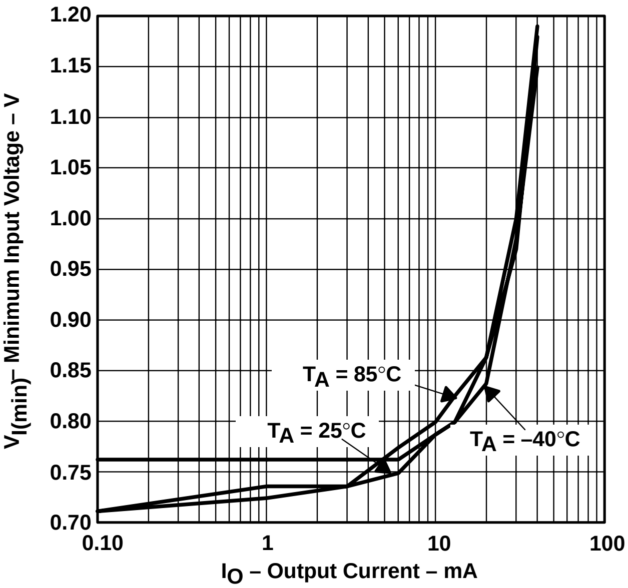



Figure 15

**START-UP TIMING ENABLE**

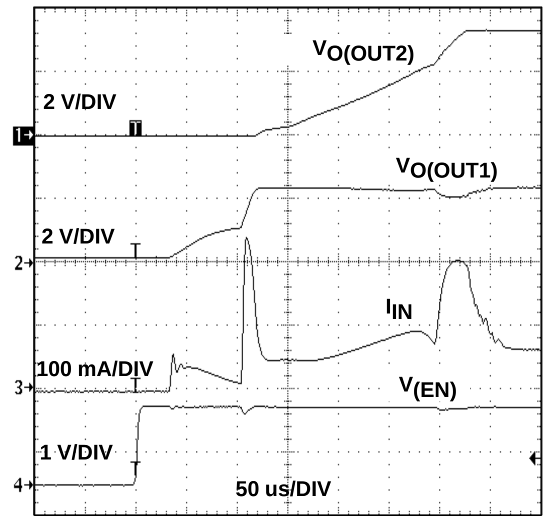



Figure 16

**SWITCHING FREQUENCY**
**vs**
**INPUT VOLTAGE**

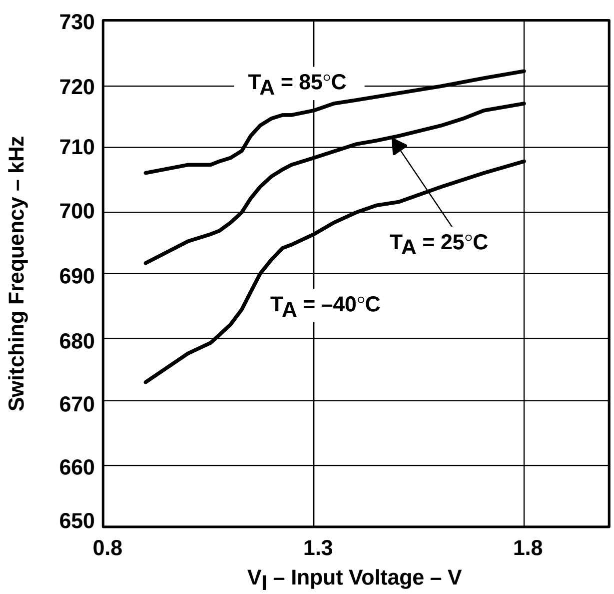



Figure 17

**LOAD TRANSIENT RESPONSE**

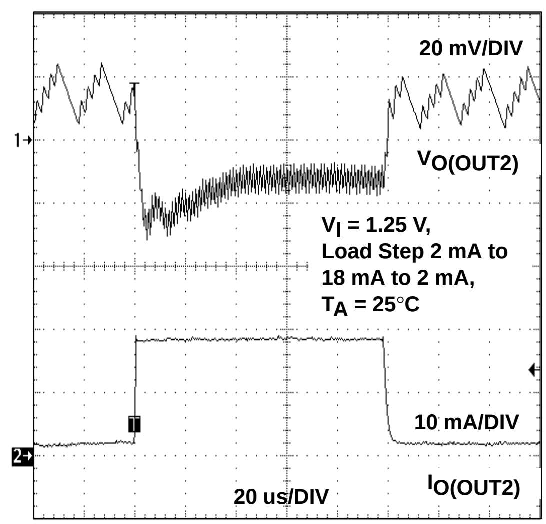



Figure 18

## TYPICAL CHARACTERISTICS

**LINE TRANSIENT RESPONSE**

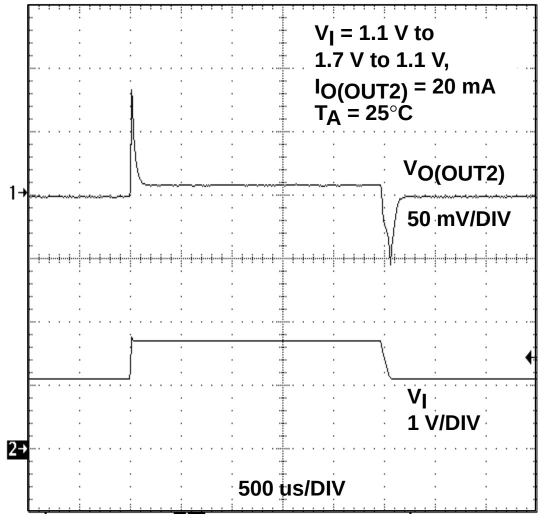



**Figure 19**

**OUTPUT VOLTAGE vs TIME**

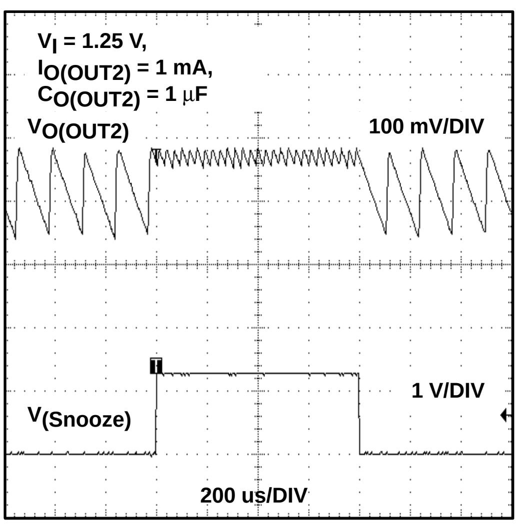



**Figure 20**

**OUTPUT VOLTAGE RIPPLE IN SNOOZE MODE**

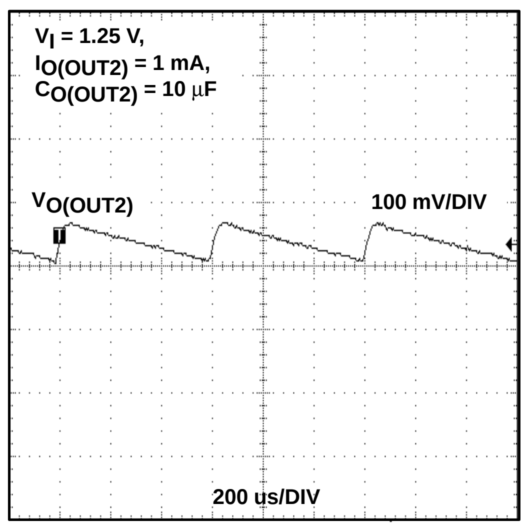



**Figure 21**

## APPLICATION INFORMATION

### design procedure

#### capacitor selection

The TPS6031X devices require only five external capacitors. Their values are closely linked to the required output current and the output noise and ripple requirements. It is possible to only use 1-µF capacitors of the same type.

The input capacitor improves system efficiency by reducing the input impedance and stabilizing the input current.

The minimum required capacitance of the output capacitor ($C_O$) that can be selected is 1 µF. Depending on the maximum allowed output ripple voltage, larger values can be chosen. Table 1 shows capacitor values recommended for low output voltage ripple operation. A recommendation is given for the smallest size.

**Table 1. Recommended Capacitor Values for Low-Output Voltage Ripple Operation**

| $V_{IN}$ [V] | $I_{O(OUT2)}$ [mA] | $C_{IN}$ [µF] | $C_{XF}$ [µF] | $C_{OUT}$ [µF] | $V_{P-P}$ [mV] AT 20 mA/ $V_{IN}$ = 1.1 V |
|---|---|---|---|---|---|
| | | CERAMIC | CERAMIC | CERAMIC | |
| 0.9...1.8 | 0…20 | 1 | 1 | 1 | 16 |
| 0.9…1.8 | 0…20 | 1 | 1 | 2.2 | 10 |
| 0.9…1.8 | 0…20 | 1 | 1 | 10 // 0.1 | 6 |

**Table 2. Recommended Capacitors**

| MANUFACTURER | PART NUMBER | SIZE | CAPACITANCE | TYPE |
|---|---|---|---|---|
| Taiyo Yuden | UMK212BJ104MG | 0805 | 0.1 µF | Ceramic |
| | LMK212BJ105KG | 0805 | 1 µF | Ceramic |
| | LMK212BJ225MG | 0805 | 2.2 µF | Ceramic |
| | JMK316BJ475KL | 1206 | 4.7 µF | Ceramic |
| AVX | 0805ZC105KAT2A | 0805 | 1 µF | Ceramic |
| | 1206ZC225KAT2A | 1206 | 2.2 µF | Ceramic |

Table 3 lists the manufacturers of recommended capacitors. However, ceramic capacitors will provide the lowest output voltage ripple due to their typically lower ESR.

**Table 3. Recommended Capacitor Manufacturers**

| MANUFACTURER | CAPACITOR TYPE | INTERNET |
|---|---|---|
| Taiyo Yuden | X7R/X5R ceramic | www.t-yuden.com |
| AVX | X7R/X5R ceramic | www.avxcorp.com |
| Vishay | X7R/X5R ceramic | www.vishay.com |
| Kemet | X7R/X5R ceramic | www.kemet.com |
| TDK | X7R/X5R ceramic | www.component.tdk.com |

## APPLICATION INFORMATION

### capacitor selection (continued)

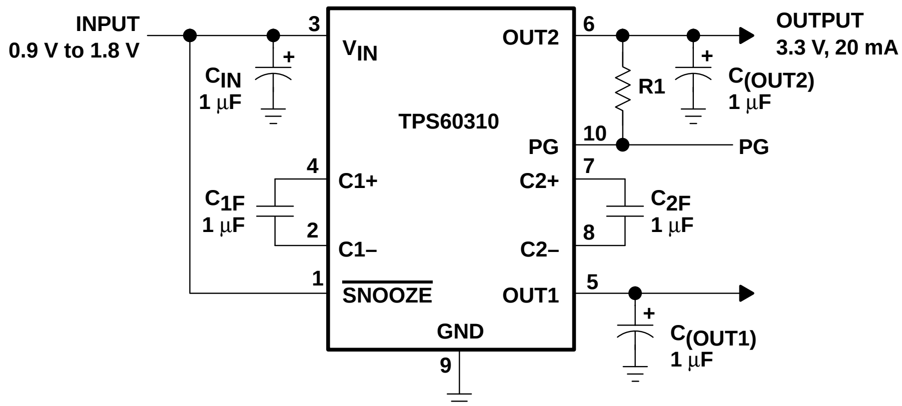



**Figure 22. Typical Operating Circuit**

For the maximum output current and best performance, five ceramic capacitors of 1 µF are recommended. For lower currents or higher allowed output voltage ripple, other capacitors can be used. It is recommended that the input and output capacitors have a minimum value of 1 µF. This value is necessary to assure a stable operation of the system due to the linear mode. With flying capacitors lower than 1 µF, the maximum output power decreases. This means that the device works in the linear mode with lower output currents.

### output filter design

The power-good output is capable of driving light loads up to 5 mA (see Figure 23). Therefore, the output resistance of the power-good pin with the output capacitor, can be used as an RC-filter.

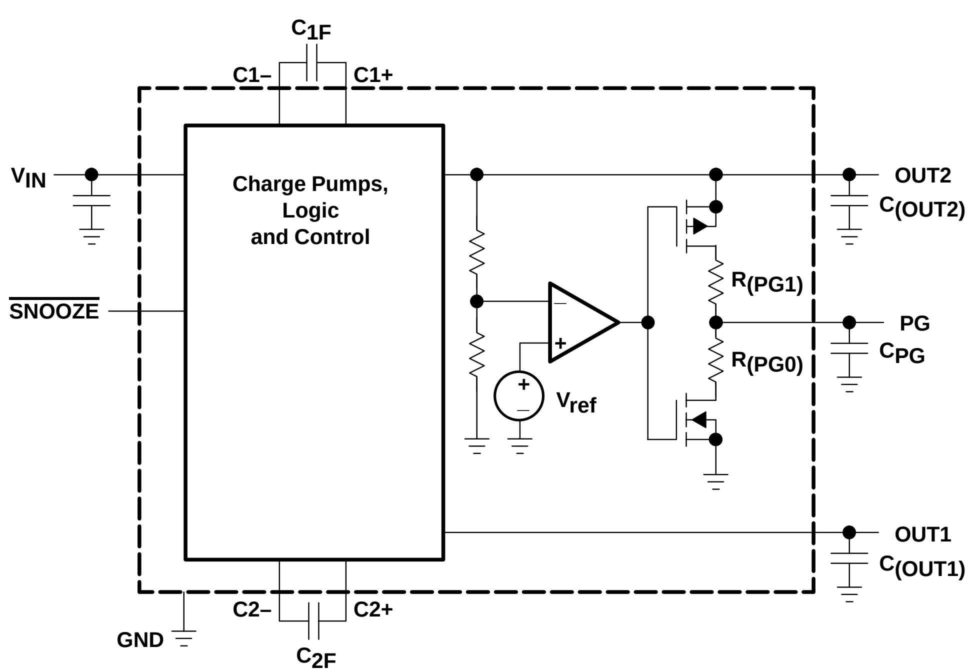



**Figure 23. TPS60312, TPS60313 Push-Pull Power-Good Output-Stage as Filtered Supply**

## APPLICATION INFORMATION

**output filter design (continued)**

Due to $R_{(PG,1)}$, an output filter can easily be formed with an output capacitor ($C_{PG}$). Cutoff frequency is given by:

$$f_C = \frac{1}{2\pi R_{(PG,1)} C_{PG}} \tag{1}$$

and ratio $V_O/V_I$ for the ac ripple is:

$$\left|\frac{V_{(PG,1)}}{V_{O(OUT2)}}\right| = \frac{1}{\sqrt{1 + \left(2\pi f R_{(PG,1)} C_{PG}\right)^2}} \tag{2}$$

with $R_{(PG,1)} = 15\ \Omega$, $C_{PG} = 0.1\ \mu F$, and f = 600 kHz (at nominal switching frequency)

$$\left|\frac{V_{(PG,1)}}{V_{O(OUT2)}}\right| = 0.175 \tag{3}$$

Load current sourced by power-good output reduces maximum output current at OUT2. During start-up (power-good going high) current charging $C_{PG}$ discharges $C_{(OUT2)}$. Therefore, $C_{PG}$ must not be larger than $C_{PG} \le 0.1\ C_{(OUT2)}$ or the device does not start. By charging $C_{PG}$ through $C_{(OUT2)}$, the output voltage at OUT2 decreases. If the capacitance of $C_{PG}$ is to large, the circuit detects power bad. The power-good output goes low and discharges $C_{PG}$. Then the cycle starts again. Figure 24 shows a configuration with an LC-post filter to further reduce output ripple and noise.

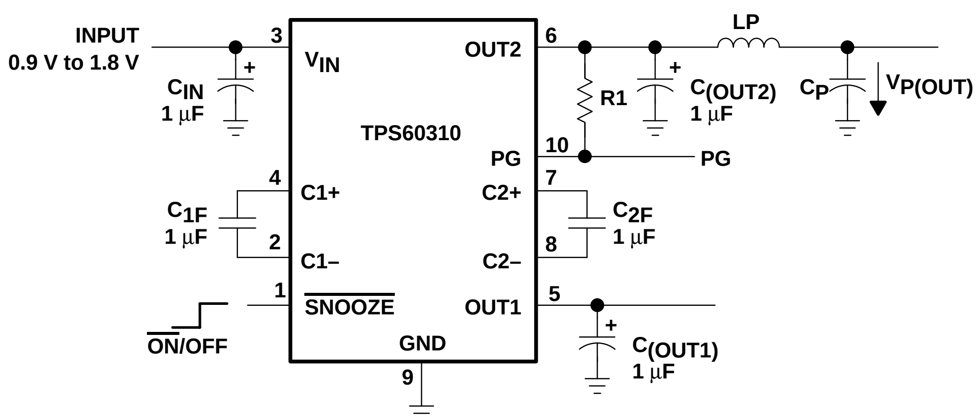



**Figure 24. LC-Post Filter**

**Table 4. Recommended Values for Lowest Output Voltage Ripple**

| $V_{IN}$ [V] | $I_{O(OUT2)}$ [mA] | $C_{IN}$[µF] CERAMIC | $C_{XF}$[µF] CERAMIC | $C_{OUT}$[µF] CERAMIC | $L_P$[µH] | $C_P$[µF] CERAMIC | $V_{P(OUT)}$ $V_{P-P}$[mV] |
|---|---|---|---|---|---|---|---|
| 0.9…1.8 | 20 | 1 | 1 | 1 | 0.1 | 0.1 (X7R) | 16 |
| 0.9…1.8 | 20 | 1 | 1 | 1 | 0.1 | 1 // 0.1 (X7R) | 12 |
| 0.9…1.8 | 20 | 1 | 1 | 1 | 1 | 0.1 (X7R) | 14 |
| 0.9…1.8 | 20 | 1 | 1 | 1 | 1 | 1 // 0.1 (X7R) | 3 |

## APPLICATION INFORMATION

### output filter design (continued)

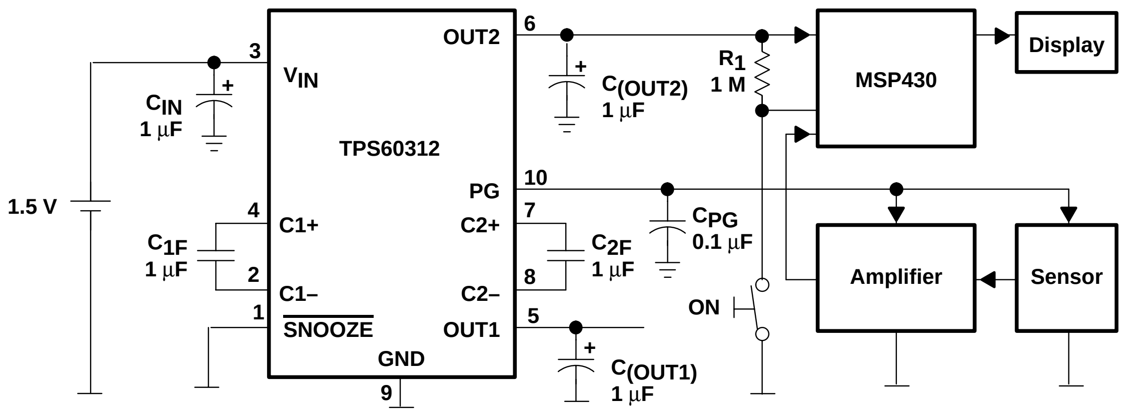



**Figure 25. Application With MSP430; PG as Supply for Analog Circuits**

### power dissipation

As given in the data sheet, the thermal resistance of the unsoldered package is $R_{\theta JA}$ = 294°C/W. Soldered on the EVM, a typical thermal resistance of $R_{\theta JA(EVM)}$ = 200°C/W was measured.

The thermal resistance can be calculated using equation 4.

$$R_{\theta JA} = \frac{T_J - T_A}{P_D} \tag{4}$$

Where:

$T_J$ is the junction temperature.
$T_A$ is the ambient temperature.
$P_D$ is the power that needs to be dissipated by the device.

The maximum power dissipation can be calculated using equation 5.

$$P_D = V_{IN} \times I_{IN} - V_O \times I_O = V_{IN(max)} \times (3 \times I_O + I_{(SUPPLY)}) - V_O \times I_O \tag{5}$$

The maximum power dissipation happens with maximum input voltage and maximum output current:

At maximum load the supply current is approximately 2 mA.

$$P_D = 1.8\ V \times (3 \times 20\ mA + 2\ mA) - 3.3\ V \times 20\ mA = 46\ mW \tag{6}$$

With this maximum rating and the thermal resistance of the device on the EVM, the maximum temperature rise above ambient temperature can be calculated using equation 7.

$$\Delta T_J = R_{\theta JA} \times P_D = 200°C/W \times 46\ mW = 10°C \tag{7}$$

This means that internal dissipation increases $T_J$ by 10°C.

The junction temperature of the device must not exceed 125°C.

This means the IC can easily be used at ambient temperatures up to:

$$T_A = T_{J(max)} - \Delta T_J = 125°C - 10°C = 115°C \tag{8}$$

### layout and board space

All capacitors should be soldered as close as possible to the IC. A PCB layout proposal for a two-layer board is shown in Figure 26. Care has been taken to connect all capacitors as close as possible to the circuit to achieve optimized output voltage ripple performance. The bottom layer is not shown in Figure 26. It only consists of a ground-plane with a single track between the two vias that can be seen in the left part of the top layer.

## APPLICATION INFORMATION

### layout and board space (continued)

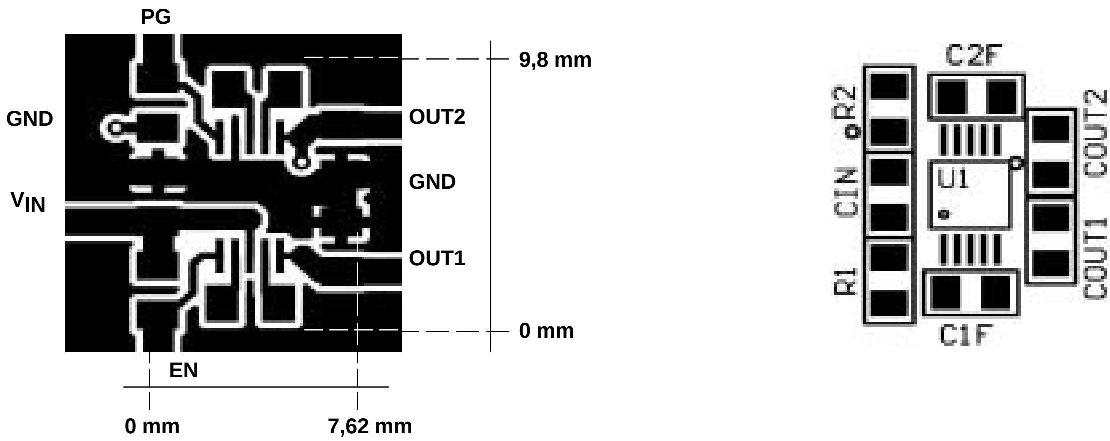



**Figure 26. Recommended PCB Layout for TPS6031X (top layer)**

## device family products

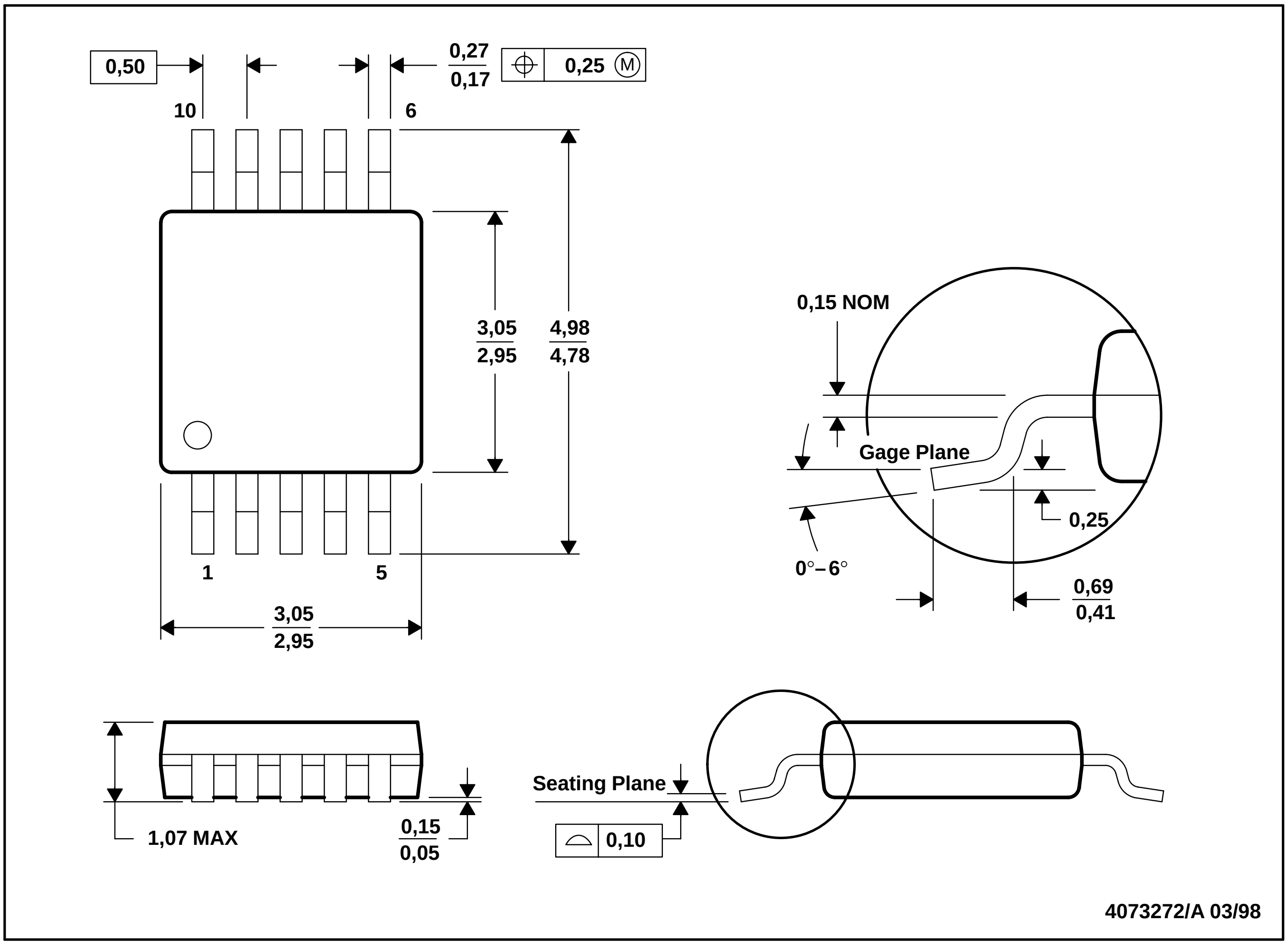
Other charge pump dc-dc converters in this family are:

**Table 5. 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-V, 300-mA low-noise charge pump |
| TPS60111 | 3-cell to regulated 5-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 |
| TPS60124 | 2-cell to regulated 3-V, 200-mA high-efficiency charge pump with low-battery comparator |
| TPS60125 | 2-cell to regulated 3-V, 200-mA high-efficiency charge pump with power-good comparator |
| TPS60130 | 3-cell to regulated 5-V, 300-mA high-efficiency charge pump with low-battery comparator |
| TPS60131 | 3-cell to regulated 5-V, 300-mA high-efficiency charge pump with power-good comparator |
| TPS60132 | 3-cell to regulated 5-V, 150-mA high-efficiency charge pump with low-battery comparator |
| TPS60133 | 3-cell to regulated 5-V, 150-mA high-efficiency charge pump with power-good comparator |
| TPS60140 | 2-cell to regulated 5-V, 100-mA charge pump voltage tripler with low-battery comparator |
| TPS60141 | 2-cell to regulated 5-V, 100-mA charge pump voltage tripler with power-good comparator |
| TPS60200 | 2-cell to regulated 3.3-V, 100-mA low-ripple charge pump with low-battery comparator in MSOP10 |
| TPS60201 | 2-cell to regulated 3.3-V, 100-mA low-ripple charge pump with power-good comparator in MSOP10 |
| TPS60202 | 2-cell to regulated 3.3-V, 50-mA low-ripple charge pump with low-battery comparator in MSOP10 |
| TPS60203 | 2-cell to regulated 3.3-V, 50-mA low-ripple charge pump with power-good comparator in MSOP10 |
| TPS60210 | 2-cell to regulated 3.3-V, 100-mA low-ripple charge pump with ultralow operating current and low-battery comparator in MSOP10 |
| TPS60211 | 2-cell to regulated 3.3-V, 100-mA low-ripple charge pump with ultralow operating current and power-good comparator in MSOP10 |
| TPS60212 | 2-cell to regulated 3.3-V, 100-mA low-ripple charge pump with ultralow operating current and low-battery comparator in MSOP10 |
| TPS60213 | 2-cell to regulated 3.3-V, 50-mA low-ripple charge pump with ultralow operating current and power-good comparator in MSOP10 |

## MECHANICAL DATA

**DGS (S-DPS-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 finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS60310DGS | ACTIVE | VSSOP | DGS | 10 | 80 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATG | Samples |
| TPS60310DGSG4 | ACTIVE | VSSOP | DGS | 10 | 80 | TBD | Call TI | Call TI | -40 to 85 | | Samples |
| TPS60310DGSR | ACTIVE | VSSOP | DGS | 10 | 2500 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATG | Samples |
| TPS60311DGS | ACTIVE | VSSOP | DGS | 10 | 80 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATI | Samples |
| TPS60311DGSR | ACTIVE | VSSOP | DGS | 10 | 2500 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATI | Samples |
| TPS60312DGS | ACTIVE | VSSOP | DGS | 10 | 80 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATK | Samples |
| TPS60312DGSR | ACTIVE | VSSOP | DGS | 10 | 2500 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATK | Samples |
| TPS60313DGS | ACTIVE | VSSOP | DGS | 10 | 80 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATL | Samples |
| TPS60313DGSR | ACTIVE | VSSOP | DGS | 10 | 2500 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | ATL | Samples |

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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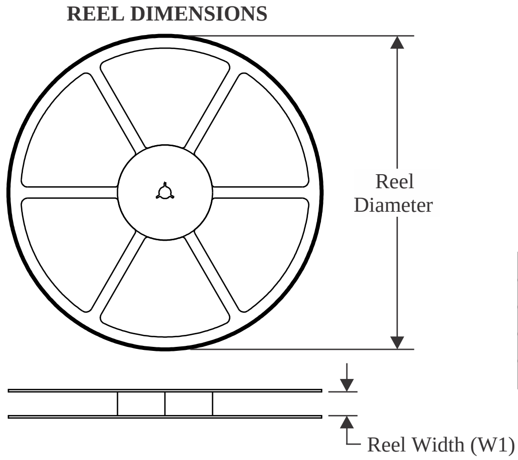
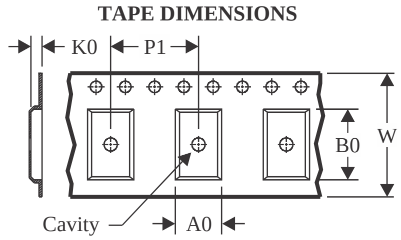
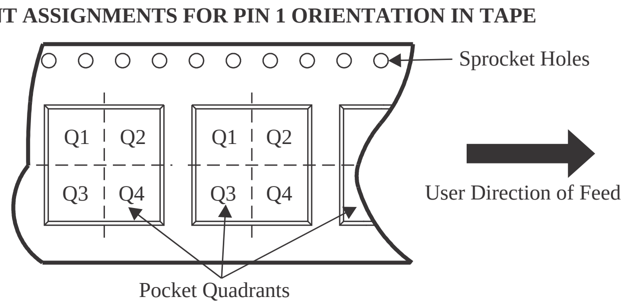
## TAPE AND REEL INFORMATION



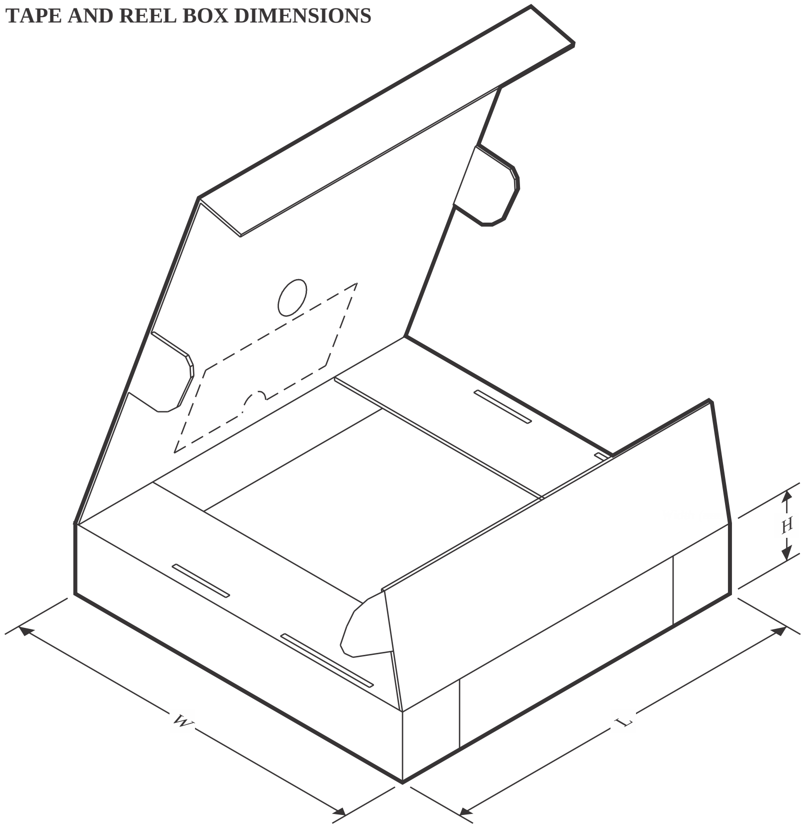

| | |
|---|---|
| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS60310DGSR | VSSOP | DGS | 10 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| TPS60311DGSR | VSSOP | DGS | 10 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| TPS60312DGSR | VSSOP | DGS | 10 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| TPS60313DGSR | VSSOP | DGS | 10 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |

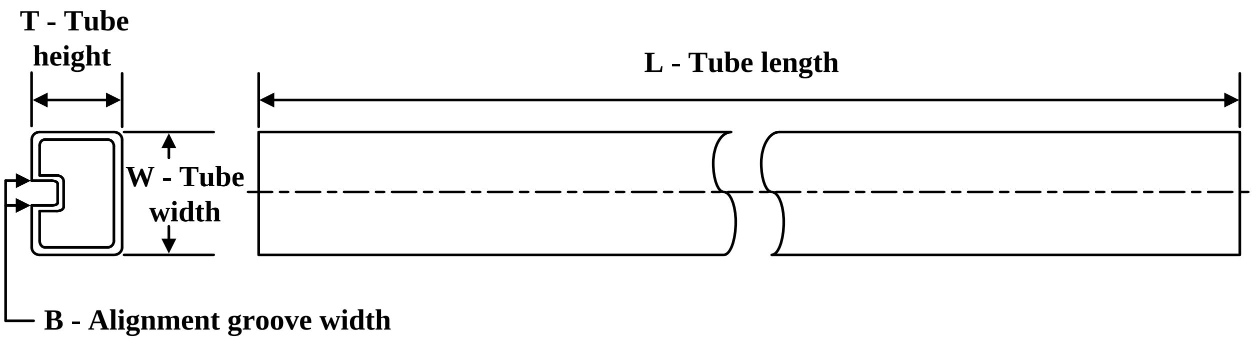
TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| TPS60310DGSR | VSSOP | DGS | 10 | 2500 | 350.0 | 350.0 | 43.0 |
| TPS60311DGSR | VSSOP | DGS | 10 | 2500 | 350.0 | 350.0 | 43.0 |
| TPS60312DGSR | VSSOP | DGS | 10 | 2500 | 350.0 | 350.0 | 43.0 |
| TPS60313DGSR | VSSOP | DGS | 10 | 2500 | 350.0 | 350.0 | 43.0 |

## TUBE




*All dimensions are nominal

| Device | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (µm) | B (mm) |
|---|---|---|---|---|---|---|---|---|
| TPS60310DGS | DGS | VSSOP | 10 | 80 | 331.47 | 6.55 | 3000 | 2.88 |
| TPS60311DGS | DGS | VSSOP | 10 | 80 | 331.47 | 6.55 | 3000 | 2.88 |
| TPS60312DGS | DGS | VSSOP | 10 | 80 | 331.47 | 6.55 | 3000 | 2.88 |
| TPS60313DGS | DGS | VSSOP | 10 | 80 | 331.47 | 6.55 | 3000 | 2.88 |

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