

TPS60130, TPS60131, TPS60132, TPS60133 REGULATED 5-V, 300 mA HIGH EFFICIENCY CHARGE PUMP DC/DC CONVERTERS

SLVS258A – NOVEMBER 1999 – REVISED DECEMBER 1999

features

- Up to 90% Efficiency From 2.7-V to 5.4-V Input Voltage Range Because of Special Switching Topology
- Up to 300-mA Output Current (TPS60130 and TPS60131)
- No Inductors Required, Low EMI
- Regulated 5-V $\pm 4\%$ Output
- Only Four External Components Required
- 60- μ A Quiescent Supply Current
- 0.05- μ A Shutdown Current
- Load Disconnected in Shutdown
- Space-Saving, Thermally-Enhanced PowerPAD™ Package
- Evaluation Module Available (TPS60130EVM-143)

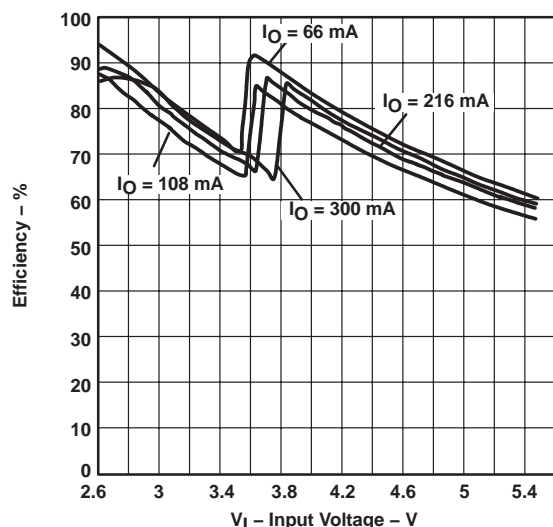
applications

- Battery-Powered Applications
- Three Battery Cells to 5-V Conversion or Point-of-Use 3.3 V to 5-V Conversion
- Lilon Battery to 5-V Conversion
- Portable Instruments
- Battery-Powered Microprocessor Systems
- Backup-Battery Boost Converters
- PDA's, Organizers, Laptops
- Handheld Instrumentation
- Medical Instruments (e.g., Glucose Meters)
- PCMCIA and 5-V Smart Card Supply

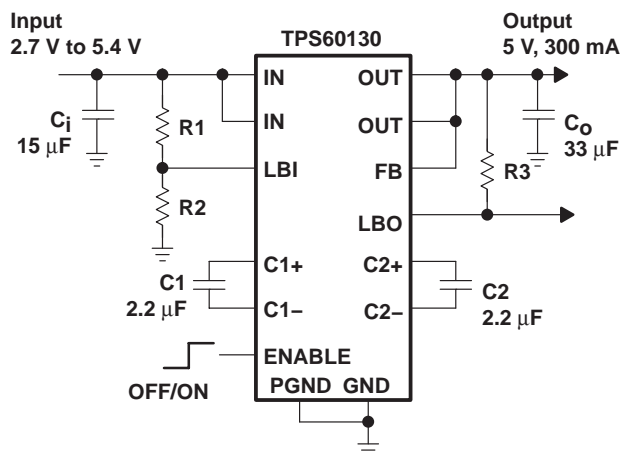
description

The TPS6013x step-up, regulated charge pumps generate a 5-V $\pm 4\%$ output voltage from a 2.7-V to 5.4-V input voltage (three alkaline, NiCd, or NiMH batteries or one Lithium or Lilon battery). The output current is 300 mA for the TPS60130/ TPS60131 and 150 mA for the TPS60132/ TPS60133, all from a 3-V input. Only four external capacitors are needed 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 1.5x or doubler conversion mode. From a 3-V input, all ICs can start with full load current.

efficiency (TPS60130, TPS60131)



typical operating circuit



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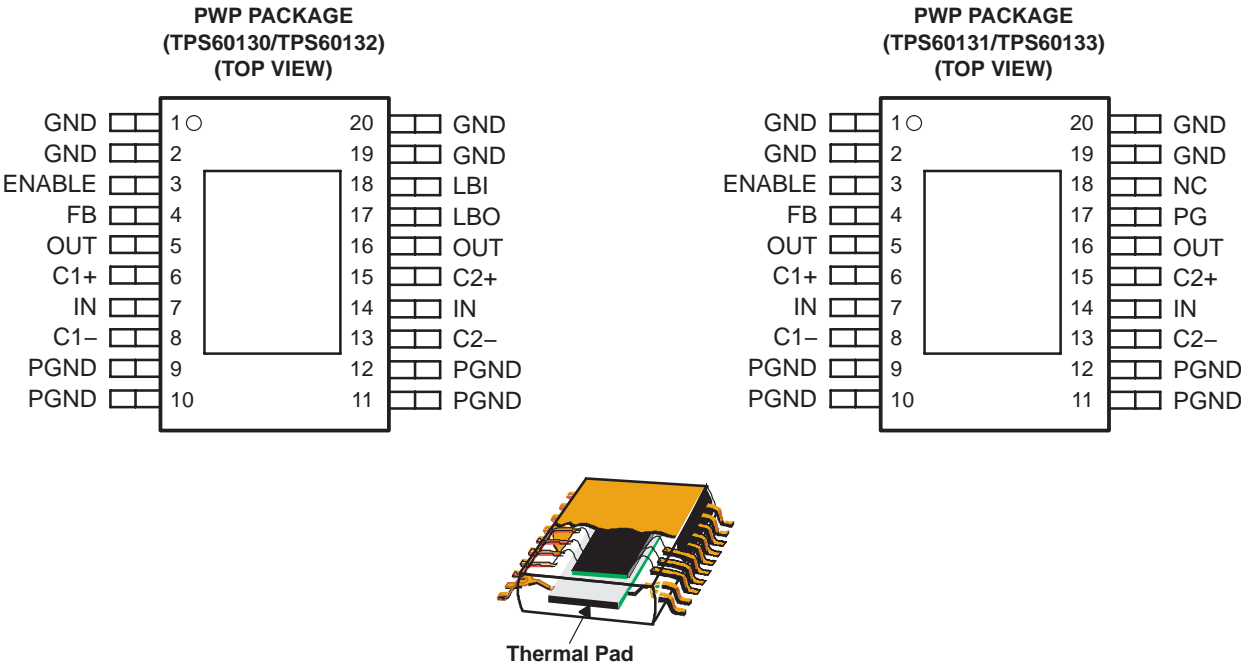
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REGULATED 5-V, 300 mA HIGH EFFICIENCY CHARGE PUMP
DC/DC CONVERTERS

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description (continued)

The devices feature the power-saving pulse-skip mode to extend battery life at light loads. TPS60130 and TPS60132 include a low-battery comparator; TPS60131 and TPS60133 feature a power-good output. The logic shut-down function reduces the supply current to 1 μ A (max) and disconnects the load from the input. Special current-control circuitry prevents excessive current from being drawn from the battery during startup. This dc/dc converter requires no inductors and therefore EMI is of low concern. It is available in the small, thermally enhanced 20-pin PowerPAD™ package (PWP).



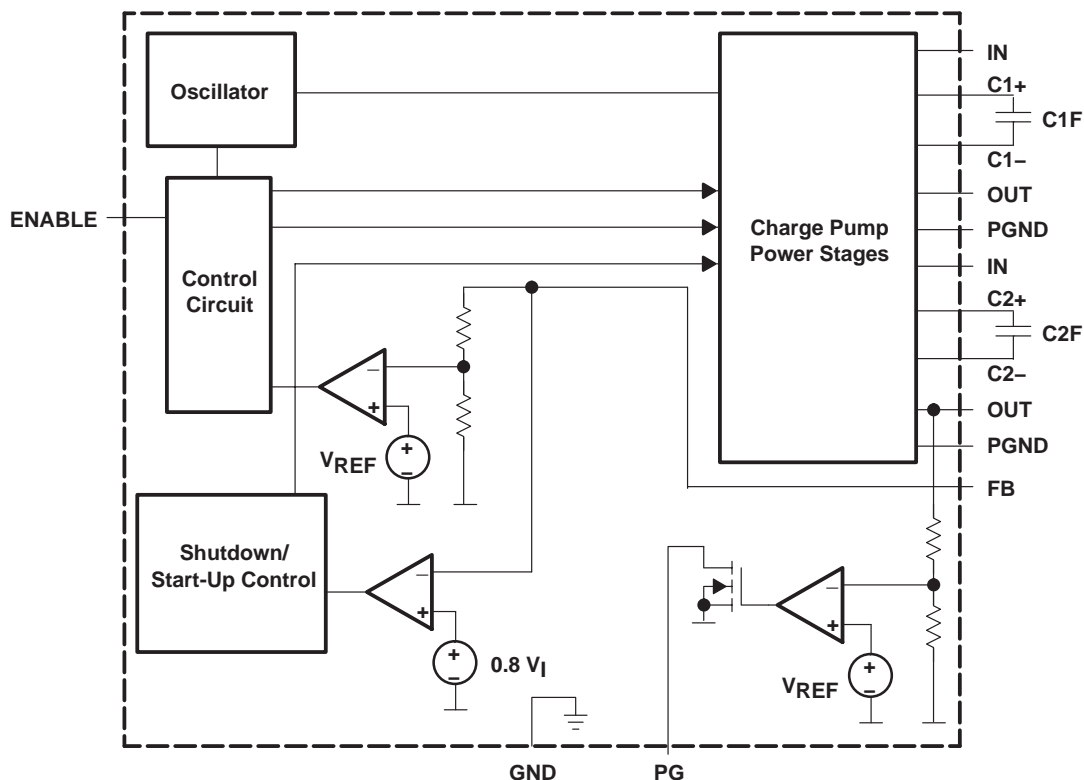
AVAILABLE OPTIONS

| T _A | PART NUMBER† | PACKAGE | | DEVICE FEATURES | |
|----------------|--------------|---------|---------------------------------|-----------------------|----------------------|
| -40°C to 85°C | TPS60130PWP | PWP | 20-Pin thermally enhanced TSSOP | 3-cell to 5 V, 300 mA | Low battery detector |
| | TPS60131PWP | | | | Power good detector |
| | TPS60132PWP | | | 3-cell to 5 V, 150 mA | Low battery detector |
| | TPS60133PWP | | | | Power good detector |

† The PWP package is available taped and reeled. Add R suffix to device type (e.g. TPS60130PWPR) to order quantities of 2000 devices per reel.

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TPS60130/TPS60132



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Terminal Functions

| TERMINAL NAME | NO. | I/O | DESCRIPTION |
|------------------|-----------------|-----|--|
| C1+ | 6 | | Positive terminal of the flying capacitor C1 |
| C1– | 8 | | Negative terminal of the flying capacitor C1 |
| C2+ | 15 | | Positive terminal of the flying capacitor C2 |
| C2– | 13 | | Negative terminal of the flying capacitor C2 |
| ENABLE | 3 | I | Enable input. Connect ENABLE to IN for normal operation. When ENABLE is a logic low, the device turns off and the supply current decreases to 0.05 μ A. The output is disconnected from the input when the device is disabled. |
| FB | 4 | I | Feedback input. Connect FB to OUT as close to the load as possible to achieve best regulation. A resistive divider is on the chip to match internal reference voltage of 1.21 V. |
| GND | 1, 2, 19, 20 | | Ground. Analog ground for internal reference and control circuitry. Connect to PGND terminals through a short trace. |
| IN | 7, 14 | I | Supply input. Bypass IN to PGND with a capacitor that has half of the capacitance of the output capacitor. Connect both IN terminals together through a short trace. |
| LBO/PG | 17 | O | Low battery detector output (TPS60130 and TPS60132) or power good output (TPS60131 and TPS60133). Open drain output of the low battery or power good comparator. It can sink 1 mA. A 100-k Ω to 1-M Ω pullup resistor to OUT is recommended. Leave the terminal unconnected if the low battery or power good detector is not used. |
| LBI/NC | 18 | I | Low battery detector input (TPS60130 and TPS60132 only). The voltage at this input is compared to the internal 1.21 V reference voltage. Connect this terminal to ground if the low-battery detection function is not used. On the TPS60131 and TPS60133, this terminal is not connected. |
| OUT | 5, 16 | O | Regulated 5-V power output. Connect both OUT terminals through a short trace and bypass OUT to GND with the output filter capacitor C _O . |
| PGND | 9–12 | | Power ground. Charge-pump current flows through this pin. Connect all PGND terminals together. |

detailed description

operating principle

The TPS6013x charge pumps provide a regulated 5-V output from a 2.7-V to 5.4-V input. They deliver a maximum load current of 300 mA or 150 mA, respectively. Designed specifically for space-critical, battery-powered applications, the complete charge pump circuit requires four external capacitors. The circuit is optimized for efficiency over a wide input voltage range.

The TPS6013x charge pumps consist of an oscillator, a 1.21-V bandgap reference, an internal resistive feedback circuit, an error amplifier, high current MOSFET switches, a shutdown/startup circuit, a low-battery or power-good comparator, and a control circuit (see functional block diagrams).

The device consists of two single-ended charge pumps. These charge pumps are automatically configured to amplify the input voltage with a conversion factor of 1.5 or 2. The conversion ratio is dependent on the input voltage and load current. This assures high efficiency over a wide input voltage range and is further described in the *adaptive mode switching* section below.

adaptive mode switching

The ON-resistance of the MOSFETs that are in the charge path of the flying capacitors is regulated when the charge pump operates in voltage doubler mode. It is changed depending on the output voltage that is fed back into the control loop. This way, the time-constant during the charging phase can be modified and increased versus a time-constant for fully switched-on MOSFETs. The ON-resistance of both switches and the capacitance of the flying capacitor define the time constant. The MOSFET switches in the discharge path of the charge pump are always fully switched on to their minimum $r_{DS(on)}$. With the time-constant during charge phase being bigger than the time constant in discharge phase, the voltage on the flying capacitors stabilizes to the lowest possible value necessary to get a stable V_O .



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adaptive mode switching (continued)

The voltage on the flying capacitors is measured and compared with the supply voltage V_I . If the voltage across the flying capacitors is smaller than half of the supply voltage, then the charge pump switches into the 1.5x conversion-mode. The charge pump switches back from a 1.5x conversion-mode to a voltage doubler mode if the load current in 1.5x conversion-mode can no more be delivered.

With this control mode the device runs in *doubler*-mode at low V_I and in 1.5x conversion-mode at high V_I to optimize the efficiency. The most desirable transfer mode is automatically selected depending on both V_I and I_L . This means that at light loads the device selects the 1.5x conversion-mode already at smaller supply voltages than at heavy loads.

The TPS60130 output voltage is regulated using the *ACTIVE-CYCLE*-regulation. An active cycle controlled charge pump utilizes two methods to control the output voltage. At high load currents it varies the on-resistances of the internal switches and keeps the ratio ON/OFF time (=frequency) constant. That means the charge pump runs at a fixed frequency. It also keeps the output voltage ripple as low as in linear-mode. At light loads the internal resistance and also the amount of energy transferred per pulse is fixed and the charge pump regulates the voltage by means of a variable ratio of ON-to-OFF time. In this operating point it runs like a skip mode controlled charge pump with a very high internal resistance, which also enables a low ripple in this operation mode. Since the charge pump does effectively switch at lower frequencies at light loads, it achieves a low quiescent current.

pulse-skip mode

In pulse-skip mode the error amplifier disables switching of the power stages when it detects an output higher than 5 V. The oscillator halts and the IC then skips switching cycles until the output voltage drops below 5 V. The error amplifier reactivates the oscillator and starts switching the power stages again. The pulse-skip regulation mode minimizes operating current because it does not switch continuously and deactivates all functions except bandgap reference, error amplifier, and low-battery/power-good comparator when the output is higher than 5 V. When switching is disabled from the error amplifier, the load is also isolated from the input. In pulse-skip mode, a special current control circuitry, limits the peak current. This assures moderate output voltage ripple and also prevents the device from drawing excessive current spikes out of the battery.

start-up procedure

During start-up, i.e. when ENABLE is set from logic low to logic high, the output capacitor is 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 voltage limit, the IC begins switching. This start-up charging of the output capacitor assures a short start-up time and eliminates the need of a Schottky diode between IN and OUT. The IC starts with a maximum load, which is defined by a 16- Ω or 33- Ω resistor, respectively.

shutdown

Driving ENABLE low places the device in shutdown mode. This disables all switches, the oscillator, and control logic. The device typically draws 0.05 μ A (1 μ A max) of supply current in this mode. Leakage current drawn from the output is as low as 1 μ A max. The device exits shutdown once ENABLE is set to a high level. The typical no-load shutdown exit time is 10 μ s. When the device is in shutdown, the load is isolated from the input.

undervoltage lockout

The TPS6013x devices have an undervoltage lockout feature that deactivates the device and places it in shutdown mode when the input voltage falls below 1.6 V.

low-battery detector (TPS60130 and TPS60132)

The internal low-battery comparator trips at $1.21 \text{ V} \pm 5\%$ when the voltage on pin LBI ramps down. The battery voltage at which the comparator initiates a low battery warning at the LBO output can easily be programmed with a resistive divider as shown in Figure 3. The sum of resistors R1 and R2 is recommended to be in the 100-k Ω to 1-M Ω range.



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low-battery detector (TPS60130 and TPS60132) (continued)

LBO is an open drain output. An external pullup resistor to OUT, 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 μ s. 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.

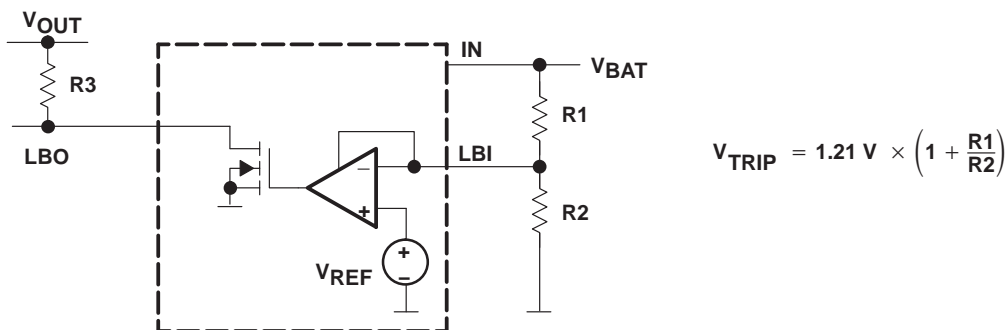


Figure 1. Programming of the Low-Battery Comparator Trip Voltage

Formulas to calculate the resistive divider for low battery detection, with $V_{LBI} = 1.15 \text{ V} - 1.27 \text{ V}$:

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

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

Formulas to calculate the minimum and maximum battery voltage that triggers the low battery detector:

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

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

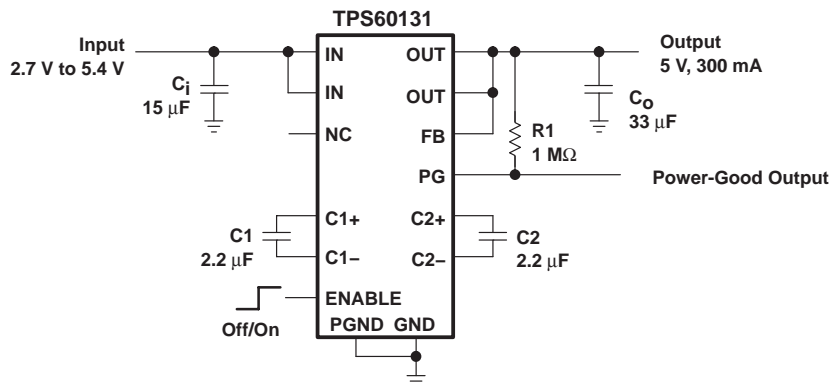
Table 1. Recommended Values for the Resistive Divider from the E96 Series ($\pm 1\%$), $V_{LBI} = 1.15 \text{ V} - 1.27 \text{ V}$

| V_{BAT}/V | $R1/\text{k}\Omega$ | $R2/\text{k}\Omega$ | $V_{BAT(MIN)}/\text{V}$ | | $V_{BAT(MAX)}/\text{V}$ | |
|--------------------|---------------------|---------------------|-------------------------|--------|-------------------------|-------|
| 2.7 | 562 | 453 | 2.548 | -5.61% | 2.877 | 6.57% |
| 2.8 | 576 | 442 | 2.619 | -6.47% | 2.958 | 5.66% |
| 2.9 | 590 | 422 | 2.726 | -6.00% | 3.081 | 6.26% |
| 3.0 | 590 | 402 | 2.804 | -6.53% | 3.172 | 5.72% |
| 3.1 | 604 | 383 | 2.928 | -5.56% | 3.313 | 6.88% |
| 3.2 | 619 | 374 | 3.016 | -5.76% | 3.414 | 6.70% |
| 3.3 | 649 | 374 | 3.106 | -5.88% | 3.518 | 6.62% |

A 100 nF bypass 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.

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The PG pin is an open-drain output that is pulled low when the output is out of regulation. When the output voltage rises to about 90% of its nominal voltage, power-good output is released. PG is high impedance when the device is disabled. An external pullup resistor must be connected between PG and OUT. The pullup resistor should be in the 100 k Ω to 1 M Ω range. If the power-good function is not used, the PG-pin should remain unconnected.



absolute maximum ratings (see Note 1)†

| | |
|---|------------------------------|
| Input voltage range, V_I (IN, OUT, ENABLE, FB, LBI, LBO/PG) | –0.3 V to 5.5 V |
| Differential input voltage, V_{ID} (C1+, C2+ to GND) | –0.3 V to (V_O + 0.3 V) |
| Differential input voltage, V_{ID} (C1–, C2– to GND) | –0.3 V to (V_I + 0.3 V) |
| Continuous total power dissipation | See Dissipation Rating Table |
| Continuous output current: TPS60130, TPS60131 | 400 mA |
| TPS60132, TPS60133 | 200 mA |
| Storage temperature range, T_{stg} | –55°C to 150°C |
| Lead temperature 1,6 mm (1/16 inch) from case for 10s | 260°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: $V_{(ENABLE)}$, $V_{(LBI)}$ and $V_{(LBO/PG)}$ can exceed V_I up to the maximum rated voltage without increasing the leakage current drawn by these inputs.

| 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 |
|---------|---|---|--|--|
| PWP | 700 mW | 5.6 mW/ $^\circ\text{C}$ | 448 mW | 364 mW |

| PACKAGE | $T_C \leq 62.5^\circ\text{C}$ POWER RATING | DERATING FACTOR ABOVE $T_C = 62.5^\circ\text{C}$ | $T_C = 70^\circ\text{C}$ POWER RATING | $T_C = 85^\circ\text{C}$ POWER RATING |
|---------|---|---|--|--|
| PWP | 25 mW | 285.7 mW/ $^\circ\text{C}$ | 22.9 mW | 18.5 mW |

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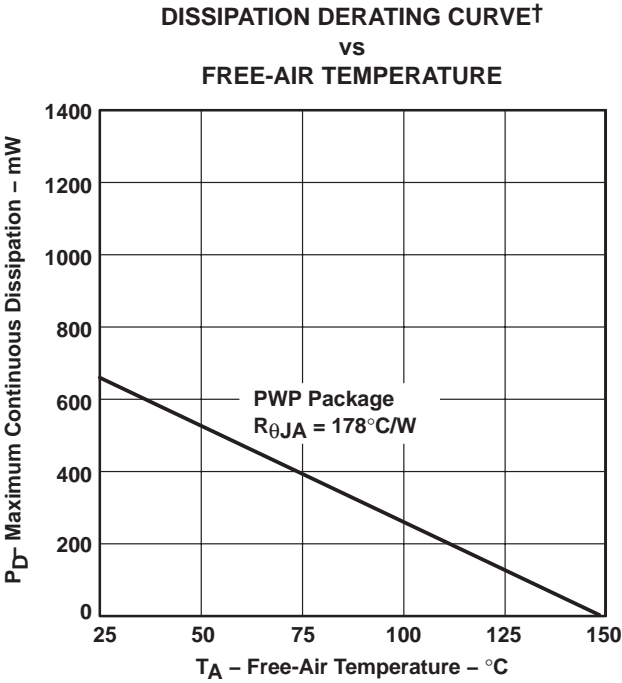


Figure 3

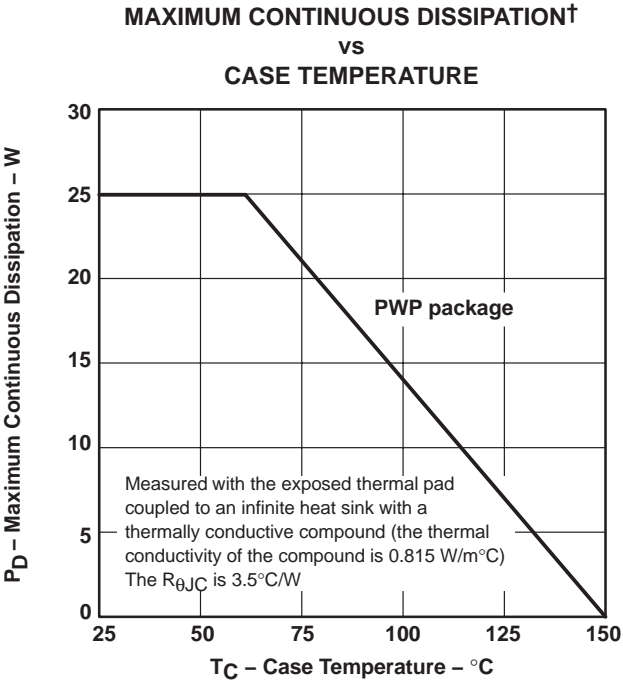


Figure 4

† Dissipation rating tables and figures are provided for maintenance of junction temperature at or below absolute maximum temperature of 150°C. It is recommended not to exceed a junction temperature of 125°C.

recommended operating conditions

| | | MIN | MAX | UNIT |
|--|-----------------------|-----|-----|------|
| Input voltage, V _I | | 2.7 | 5.4 | V |
| Output current, I _O | TPS60130 and TPS60131 | 300 | | mA |
| | TPS60132 and TPS60133 | 150 | | |
| Operating junction temperature, T _J | | 125 | | °C |

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electrical characteristics at $C_I = 15 \mu\text{F}$, $C_{1F} = C_{2F} = 2.2 \mu\text{F}$, $C_O = 33 \mu\text{F}$, $T_C = -40^\circ\text{C}$ to 85°C , $V_I = 3 \text{ V}$, $V_{(\text{FB})} = V_O$ and $V_{(\text{ENABLE})} = V_I$ (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--------------------------------|--|---|-------------------|------------------|-------------------|---------------|
| V_I | Input voltage | | 2.7 | | 5.4 | V |
| $V_{(\text{UVLO})}$ | Input undervoltage lockout threshold | $T_C = 25^\circ\text{C}$ | | 1.6 | 1.8 | V |
| $I_{O(\text{MAX})}$ | Maximum output current | TPS60130/TPS60131 | 300 | | | mA |
| | | TPS60132/TPS60133 | 150 | | | mA |
| V_O | Output voltage | $2.7 \text{ V} < V_I < 3 \text{ V}$, $0 < I_O < I_{O(\text{MAX})}/2$, $T_C = 0^\circ\text{C}$ to 70°C | 4.8 | | 5.2 | V |
| | | $3 \text{ V} < V_I < 5 \text{ V}$, $0 < I_O < I_{O(\text{MAX})}$ | 4.8 | | 5.2 | V |
| | | $5 \text{ V} < V_I < 5.4 \text{ V}$, $0 < I_O < I_{O(\text{MAX})}$ | 4.8 | | 5.25 | V |
| $I_{\text{kg}}(\text{OUT})$ | Output leakage current | $V_I = 3.6 \text{ V}$, $V_{(\text{ENABLE})} = 0 \text{ V}$ | | | 1 | μA |
| I_Q | Quiescent current (no-load input current) | $V_I = 3.6 \text{ V}$ | | 60 | 100 | μA |
| $I_{Q(\text{SDN})}$ | Shutdown supply current | $V_I = 3.6 \text{ V}$, $V_{(\text{ENABLE})} = 0 \text{ V}$ | | 0.05 | 1 | μA |
| $f_{\text{OSC}(\text{INT})}$ | Internal switching frequency | | 210 | 320 | 450 | kHz |
| V_{IL} | Enable input voltage low | $V_I = 2.7 \text{ V}$ | | $0.3 \times V_I$ | | V |
| V_{IH} | Enable input voltage high | $V_I = 5.4 \text{ V}$ | $0.7 \times V_I$ | | | V |
| $I_{\text{kg}}(\text{ENABLE})$ | Enable input leakage current | $V_{(\text{ENABLE})} = V_{\text{GND}}$ or V_I | | 0.01 | 0.1 | μA |
| | Output load regulation | $V_I = 3.8 \text{ V}$, $1 \text{ mA} < I_{O(\text{max})}$, $T_C = 25^\circ\text{C}$ | | 0.002% | | mA |
| | Output line regulation | $3 \text{ V} < V_I < 5 \text{ V}$, $I_O = 150 \text{ mA}$, $T_C = 25^\circ\text{C}$ | | 0.2 | | %/V |
| | Short circuit current limit | $V_I = 3.6 \text{ V}$, $V_O = 0 \text{ V}$, $T_C = 25^\circ\text{C}$ | | 115 | | mA |
| $V_{(\text{LBITRIP})}$ | LBI trip voltage | TPS60130/TPS60132 $V_I = 2.7 \text{ V}$ to 3.3 V , Hysteresis 0.8% for rising LBI, $T_C = 0^\circ\text{C}$ to 70°C | 1.15 | 1.21 | 1.27 | V |
| $I_{\text{I}}(\text{LBI})$ | LBI input current | TPS60130/TPS60132 $V_{(\text{LBI})} = 1.3 \text{ V}$ | | | 100 | nA |
| $V_{O(\text{LBO})}$ | LBO output voltage low (see Note 2) | TPS60130/TPS60132 $V_{(\text{LBI})} = 0 \text{ V}$, $I_{(\text{LBO})}(\text{SINK}) = 1 \text{ mA}$ | | | 0.4 | V |
| $I_{\text{kg}}(\text{LBO})$ | LBO leakage current | TPS60130/TPS60132 $V_{(\text{LBI})} = 1.3 \text{ V}$, $V_{(\text{LBO})} = 5 \text{ V}$ | | 0.01 | 0.1 | μA |
| $V_{(\text{PGTRIP})}$ | Power-good trip voltage | TPS60131/TPS60133 $T_C = 0^\circ\text{C}$ to 70°C | $0.86 \times V_O$ | $0.9 \times V_O$ | $0.94 \times V_O$ | V |
| $V_{\text{hys}}(\text{PG})$ | Power-good trip voltage hysteresis | TPS60131/TPS60133 V_O ramping negative, $T_C = 0^\circ\text{C}$ to 70°C | | 0.8% | | |
| $V_{O(\text{PG})}$ | Power-good output voltage low (see Note 2) | TPS60131/TPS60133 $V_O = 0 \text{ V}$, $I_{(\text{PG})}(\text{SINK}) = 1 \text{ mA}$ | | | 0.4 | V |
| $I_{\text{kg}}(\text{PG})$ | Power-good leakage current | TPS60131/TPS60133 $V_O = 5 \text{ V}$, $V_{(\text{PG})} = 5 \text{ V}$ | | 0.01 | 0.1 | μA |

NOTE 2: During start-up the LBO and PG output signal is invalid for the first 500 μs .



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PARAMETER MEASUREMENT INFORMATION

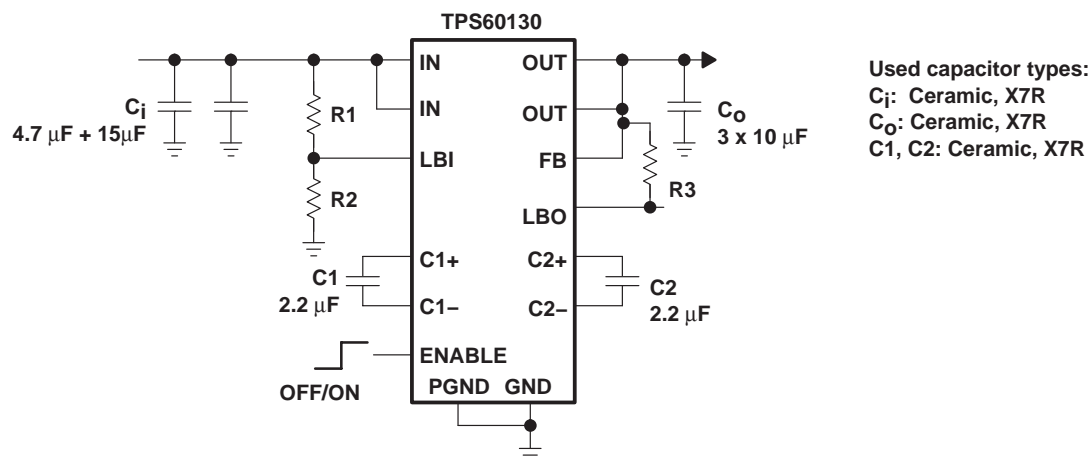


Figure 5. Circuit Used For Typical Characteristics Measurements

TYPICAL CHARACTERISTICS

Table of Graphs

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TYPICAL CHARACTERISTICS

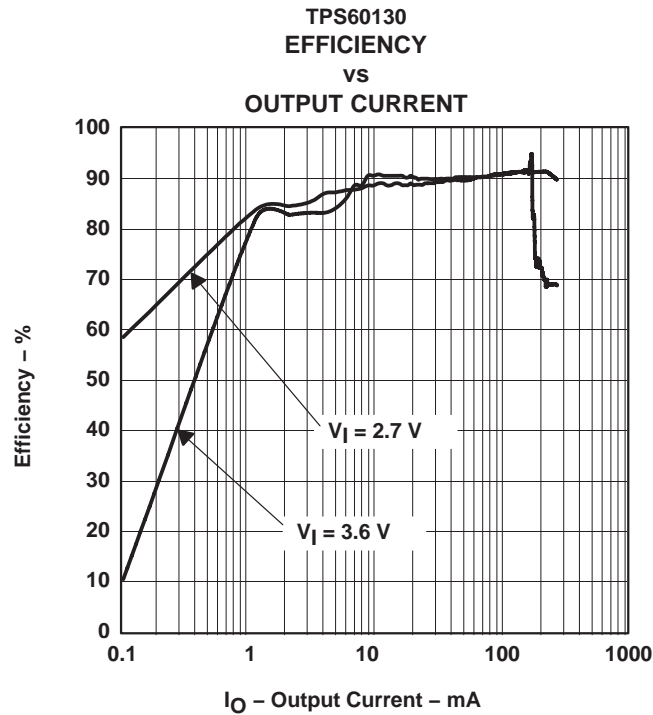


Figure 6

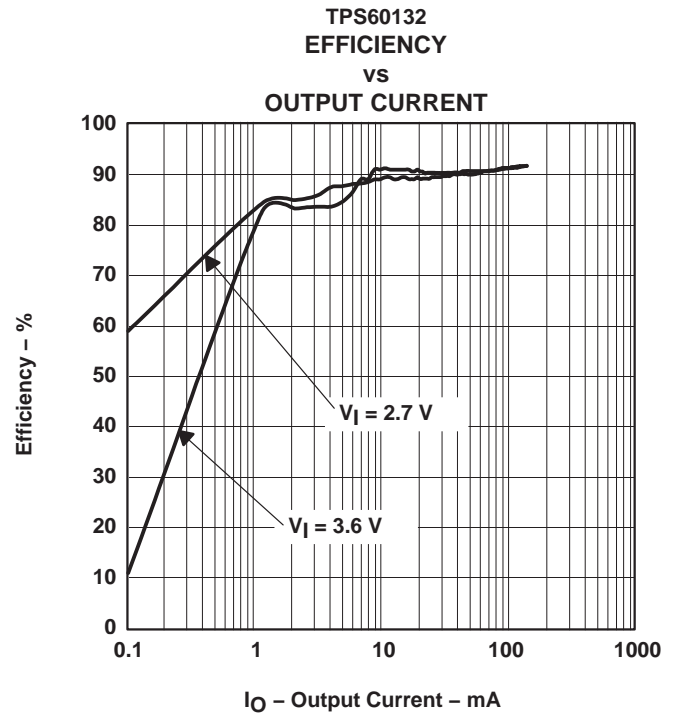


Figure 7

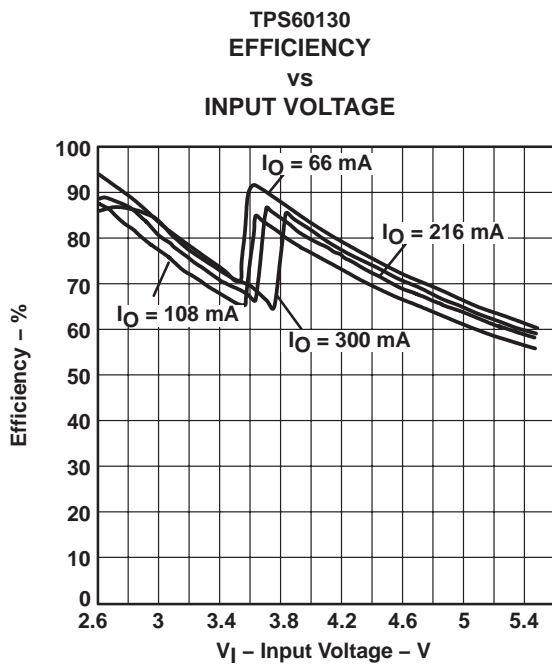


Figure 8

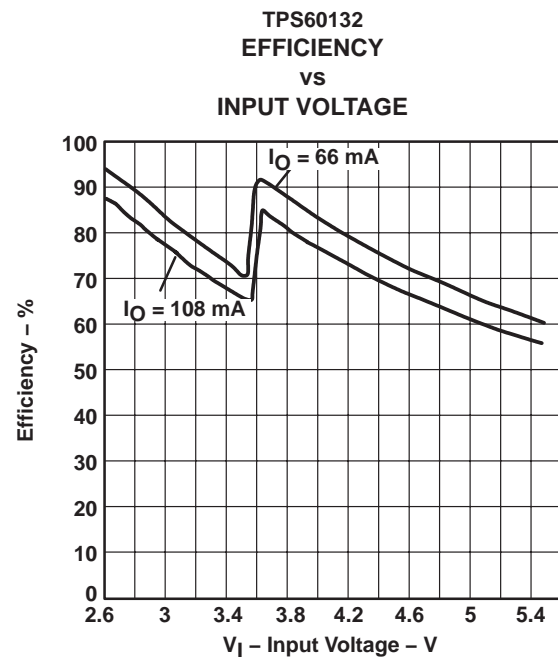


Figure 9

TPS60130, TPS60131, TPS60132, TPS60133

REGULATED 5-V, 300 mA HIGH EFFICIENCY CHARGE PUMP

DC/DC CONVERTERS

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TYPICAL CHARACTERISTICS

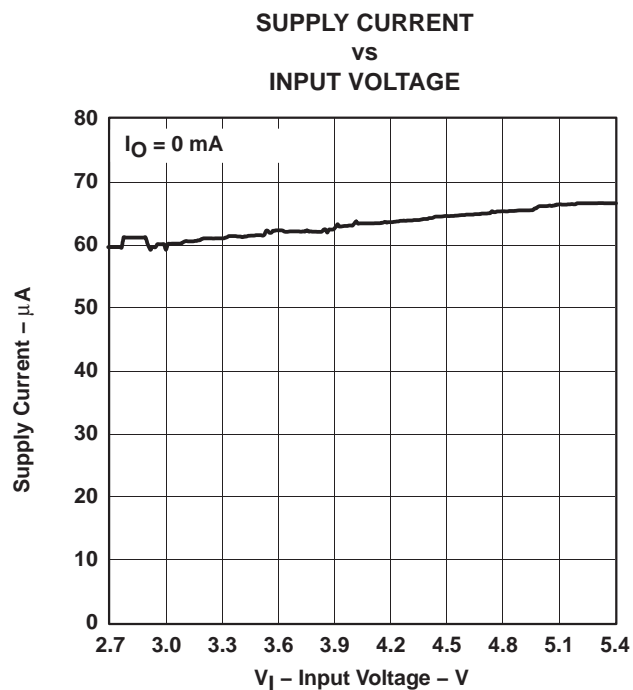


Figure 10

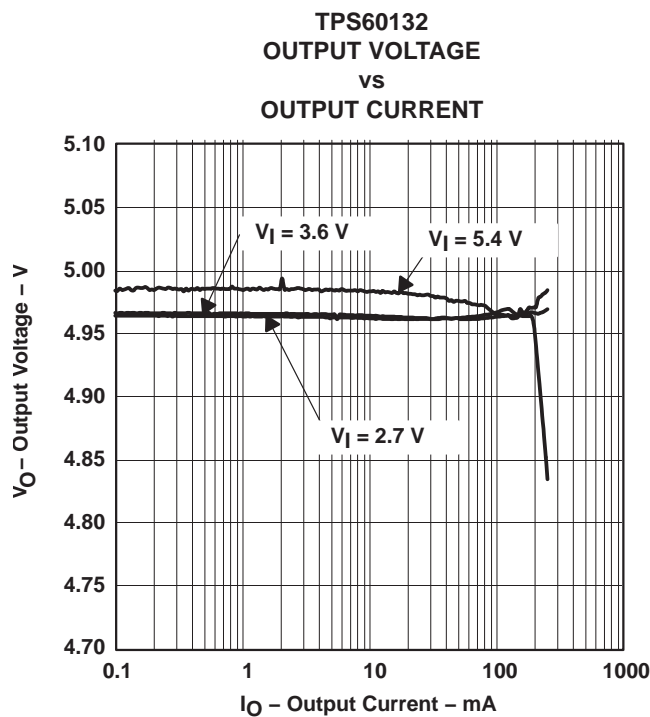


Figure 11

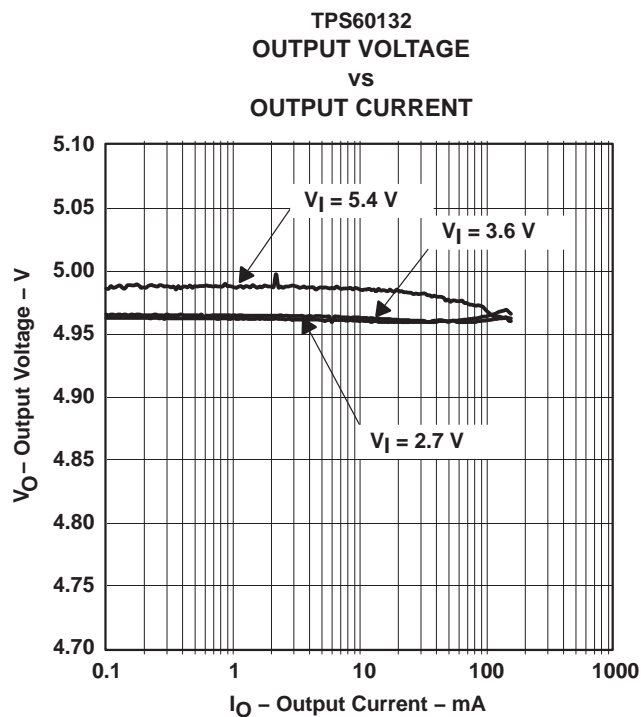


Figure 12

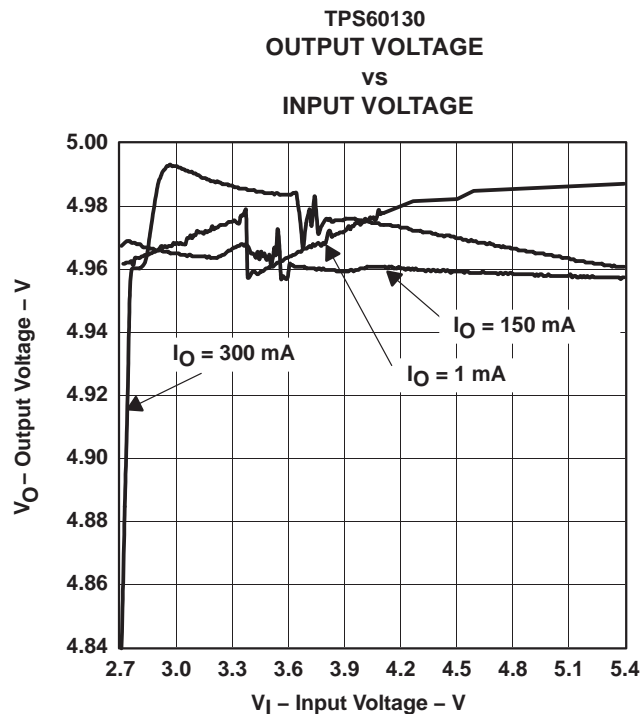
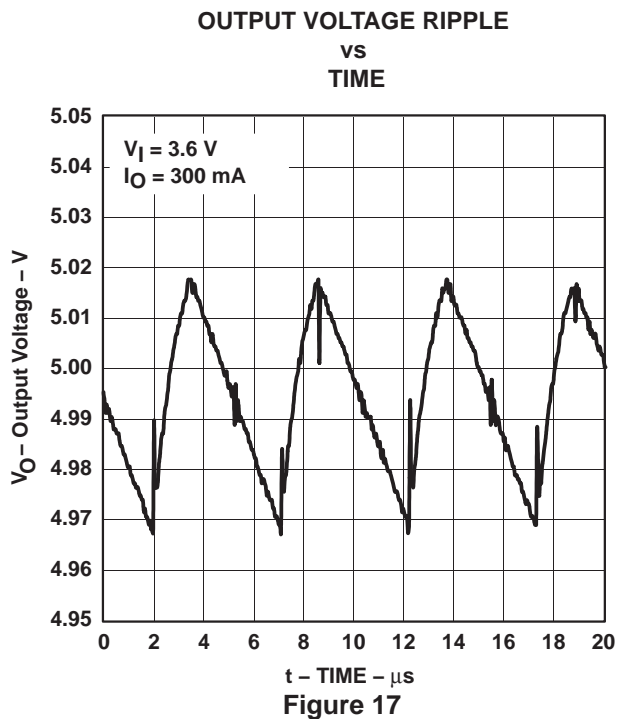
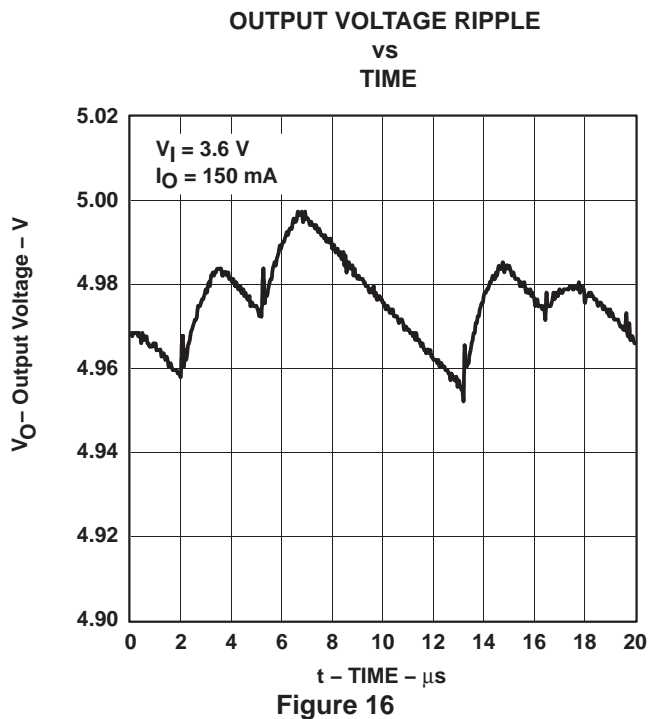
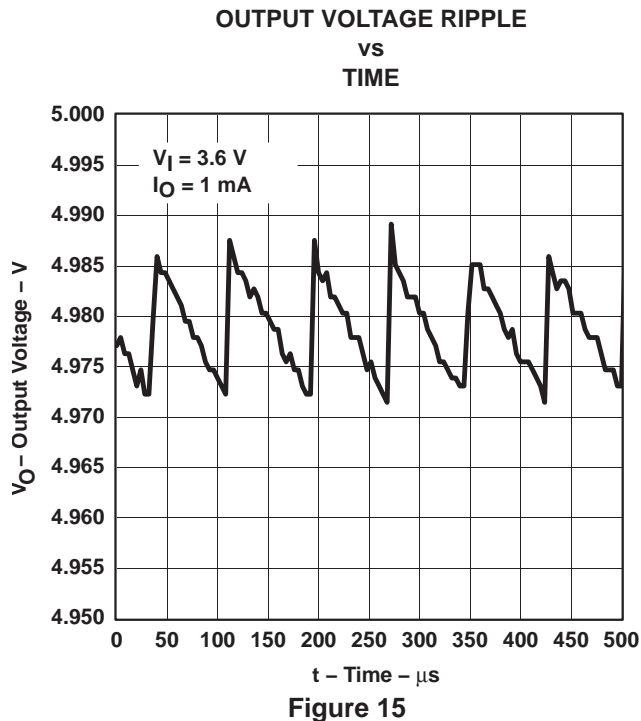
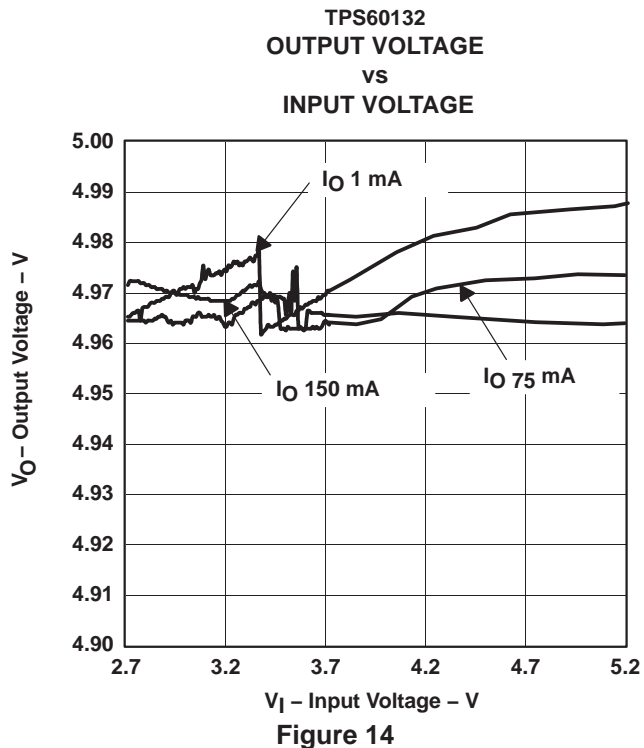


Figure 13

TPS60130, TPS60131, TPS60132, TPS60133 REGULATED 5-V, 300 mA HIGH EFFICIENCY CHARGE PUMP DC/DC CONVERTERS

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TYPICAL CHARACTERISTICS



TPS60130, TPS60131, TPS60132, TPS60133 REGULATED 5-V, 300 mA HIGH EFFICIENCY CHARGE PUMP DC/DC CONVERTERS

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TYPICAL CHARACTERISTICS

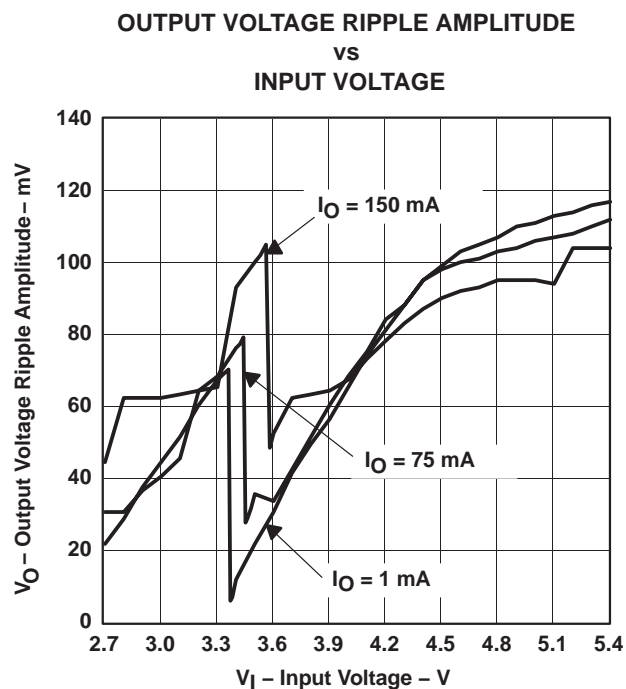


Figure 18

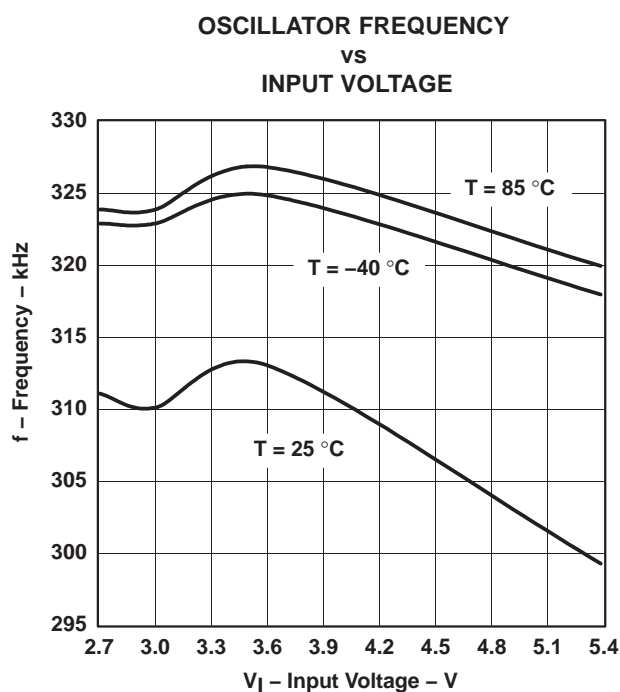


Figure 19

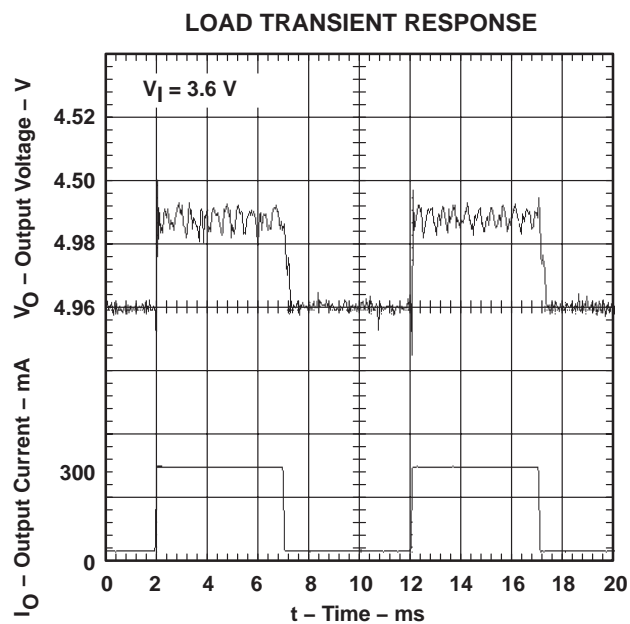


Figure 20

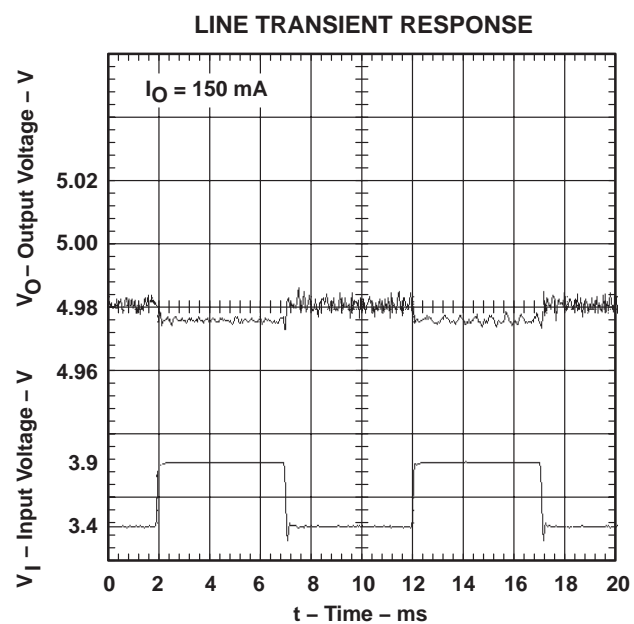


Figure 21

TYPICAL CHARACTERISTICS

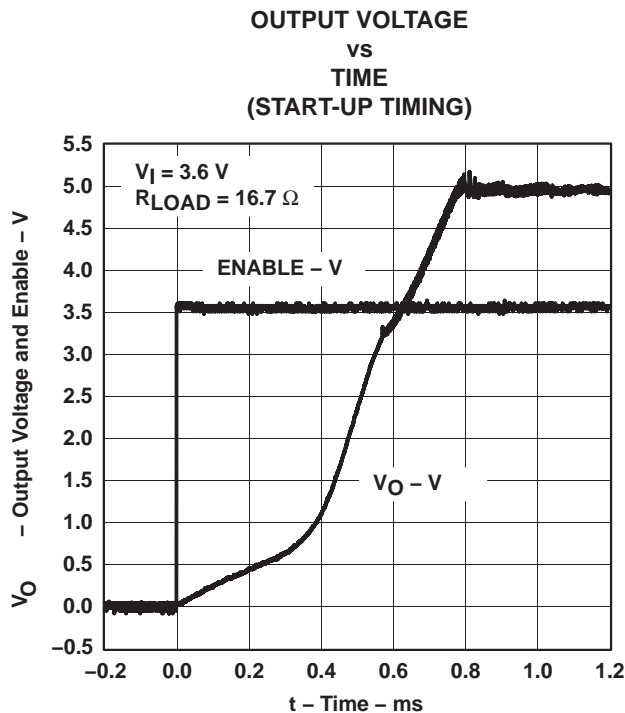


Figure 22

APPLICATION INFORMATION

capacitor selection

The TPS6013x charge pumps require only four external capacitors as shown in the basic application circuit. Their capacitance values and types are closely linked to the output current and output noise/ripple requirements. For lowest noise and ripple, low ESR ($< 0.1 \Omega$) capacitors should be used for input and output capacitors.

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 power source to the converter IC. The input capacitor also has an impact on the output voltage ripple. The lower the ESR of the input capacitor C_i , the lower is the output ripple. C_i is recommended to be about two to four times as large as $C_{(XF)}$.

The output capacitor C_o can be selected from 5-times to 50-times larger than $C_{(XF)}$, depending on the ripple tolerance. The larger C_o , the lower will be the output voltage ripple. C_i and C_o can be either ceramic or low-ESR tantalum; aluminum capacitors are not recommended.

Generally, the flying capacitors $C_{(XF)}$ will be the smallest. Only ceramic capacitors are recommended, due to their low ESR and because they retain their capacitance at the switching frequency. Because the device regulates the output voltage using the pulse-skip technique, a larger flying capacitor will lead to a higher output voltage ripple if the size of the output capacitor is not increased. Be aware that, depending on the material used to manufacture them, ceramic capacitors might lose their capacitance over temperature. 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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capacitor selection (continued)

Table 2. Recommended Capacitor Values

| PART | V _I (V) | I _O (mA) | C _i (μF) | | C _(XF) (μF) | C _o (μF) | | V _{PP(TYP)} (V) |
|----------------------|-----------------------|------------------------|------------------------|------------------|---------------------------|------------------------|-----------------------|-----------------------------|
| | | | TANTALUM | CERAMIC (X7R) | | TANTALUM | CERAMIC (X7R) | |
| TPS60130 TPS60131 | 3.6 | 225 | | 10 | 2.2 | 22 | 4.7 | 90 |
| | | | | | | | 22 | 60 |
| | | 300 | | 10 | 2.2 | 33 | 4.7 | 120 |
| | | | | | | | 22 and 10 in parallel | 45 |
| TPS60132 TPS60133 | 3.6 | 75 | | 4.7 | 1 | | 10 | |
| | | 150 | 4.7 | 2.2 | | 15 | 22 | 100 |
| | | | | 4.7 | | | 22 | 90 |

The TPS6013x devices are charge pumps that regulate the output voltage using pulse-skip regulation mode. The output voltage ripple is therefore dependent on the values and the ESR of the input, output and flying capacitors. The only possibility to reduce the output voltage ripple is to choose the appropriate capacitors. The lowest output voltage ripple can be achieved using ceramic capacitors because of their low ESR and their frequency characteristic.

Ceramic capacitors typically have an ESR that is more than 10 times lower than tantalum capacitors and they retain their capacitance at frequencies more than 10 times higher than tantalum. Many different tantalum capacitors act as an inductance for frequencies higher than 200 kHz. This behavior increases the output voltage ripple. Therefore the best choice for a minimized ripple is the ceramic capacitor. For applications that do not need a higher performance in output voltage ripple, tantalum capacitors with a low ESR are a possibility for input and output capacitor, but a ceramic capacitor should be connected in parallel. Be aware that the ESR of tantalum capacitors is indirectly proportional to the physical size of the capacitor.

Table 2 is a good starting point for choosing the capacitors. If the output voltage ripple is too high for the application, it can be improved by selecting the appropriate capacitors. The first step is to increase the capacitance at the output. If the ripple is still too high, the second step would be to increase the capacitance at the input.

For the TPS60130 and TPS60131, the smallest board space can be achieved using Sprague's 595D-series tantalum capacitors for input and output. However, high capacitance ceramic capacitors will become competitive in package size soon.

The smallest size for the lower-current devices TPS60132 and TPS60133 can be achieved using the suggested ceramic capacitors.

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APPLICATION INFORMATION

capacitor selection (continued)

Tables 3 and 4 lists the manufacturers of recommended capacitors. In most applications surface-mount tantalum capacitors will be the right choice. However, ceramic capacitors provide the lowest output voltage ripple due to their typically lower ESR.

Table 3. Recommended Capacitors

| MANUFACTURER | PART NUMBER | CAPACITANCE | CASE SIZE | TYPE |
|--------------|-----------------|-------------|-----------|----------|
| Taiyo Yuden | LMK212BJ105KG-T | 1 µF | 0805 | Ceramic |
| | LMK212BJ225MG-T | 2.2 µF | 0805 | Ceramic |
| | LMK316BJ475KL-T | 4.7 µF | 1206 | Ceramic |
| | LMK325BJ106MN-T | 10 µF | 1210 | Ceramic |
| | LMK432BJ226MM-T | 22 µF | 1812 | Ceramic |
| AVX | 0805ZC105KAT2A | 1 µF | 0805 | Ceramic |
| | 1206ZC225KAT2A | 2.2 µF | 1206 | Ceramic |
| | TPSC475035R0600 | 4.7 µF | Case C | Tantalum |
| | TPSC156025R0500 | 15 µF | Case C | Tantalum |
| | TPSC336010R0375 | 33 µF | Case C | Tantalum |
| Sprague | 595D156X0016B2T | 15 µF | Case B | Tantalum |
| | 595D226X0016B2T | 22 µF | Case B | Tantalum |
| | 595D336X0016B2T | 33 µF | Case B | Tantalum |
| | 595D336X0016C2T | 33 µF | Case C | Tantalum |
| Kemet | T494C156K010AS | 15 µF | Case C | Tantalum |
| | T494C226K010AS | 22 µF | Case C | Tantalum |
| | T494C336K010AS | 33 µF | Case C | Tantalum |

NOTE: Case code compatibility with EIA 535BAAC and CECC30801 molded chips.

Table 4. Recommended Capacitor Manufacturers

| MANUFACTURER | CAPACITOR TYPE | INTERNET SITE |
|--------------|--|---|
| Taiyo Yuden | X7R/X5R ceramic | http://www.t-yuden.com/ |
| AVX | X7R/X5R ceramic TPS-series tantalum | http://www.avxcorp.com/ |
| Sprague | 595D-series tantalum 593D-series tantalum | http://www.vishay.com/ |
| Kemet | T494-series tantalum | http://www.kemet.com/ |

power dissipation

The power dissipated in the TPS6013x depends on output current and the mode of operation (1.5x or doubler voltage conversion mode). It is described by the following equation:

$$P_{DISS} = \left(\frac{1}{\eta} - 1 \right) V_O \times I_O \quad (\text{Efficiency } \eta \text{ mainly depends on } V_I \text{ and also on } I_O. \text{ See efficiency graphs.})$$

P_{DISS} must be less than that allowed by the package rating. See the absolute maximum ratings for 20-pin PWP package power-dissipation limits and deratings.



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APPLICATION INFORMATION

board layout

Careful board layout is necessary due to the high transient currents and switching frequency of the converter. All capacitors should be soldered in close proximity to the IC. Connect ground and power ground pins through a short, low-impedance trace. A PCB layout proposal for a two-layer board is given in Figure 23. The bottom layer of the board carries only ground potential for best performance. The layout also provides improved thermal performance as the exposed lead frame is soldered to the PCB.

An evaluation module for the TPS60130 is available and can be ordered under product code TPS60130EVM-143. The EVM uses the layout shown in Figure 23.

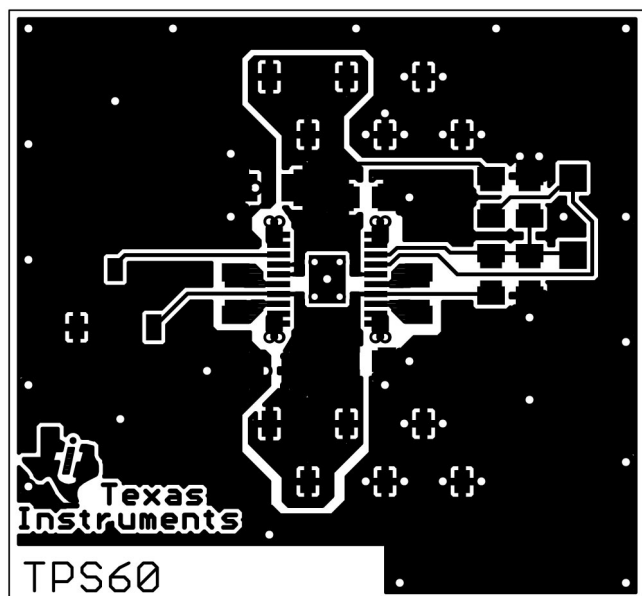


Figure 23. Recommended PCB Layout for TPS6013X

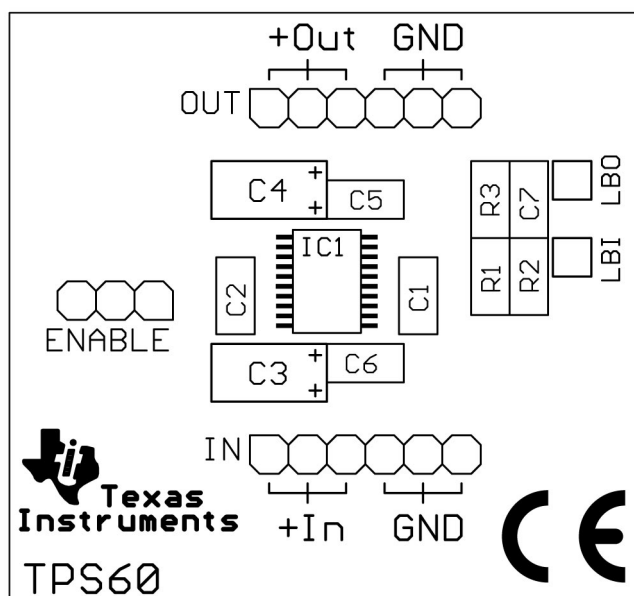


Figure 24. Component Placement for TPS6013X EVM

Table 5. Component Identification

| | |
|--------|---------------------------------|
| IC1 | TPS6013x |
| C1, C2 | Flying capacitors |
| C3, C6 | Input capacitors |
| C4, C5 | Output capacitors |
| C7 | Stabilization capacitor for LBI |
| R1, R2 | Resistive divider for LBI |
| R3 | Pullup resistor for LBO |

The best performance of the converter is achieved with the additional bypass capacitors C5 and C6 at input and output. Capacitor C7 should be included if the large line transients are expected. The capacitors are not required. They can be omitted in most applications.

APPLICATION INFORMATION

application proposals

paralleling of two TPS6013x to deliver 600 mA total output current

Two TPS60130x devices can be connected in parallel to yield higher load currents. The circuit of Figure 25 can deliver up to 600 mA at an output voltage of 5 V. The devices can share the output capacitors, but each one requires its own transfer capacitors and input capacitor. If both a TPS60130 and a TPS60131 are used, it is possible to monitor the battery voltage with the TPS60130 using the low-battery comparator function and to supervise the output voltage with the TPS60131 using the power-good comparator. Make the layout of the charge pumps as similar as possible, and position the output capacitor the same distance from both devices.

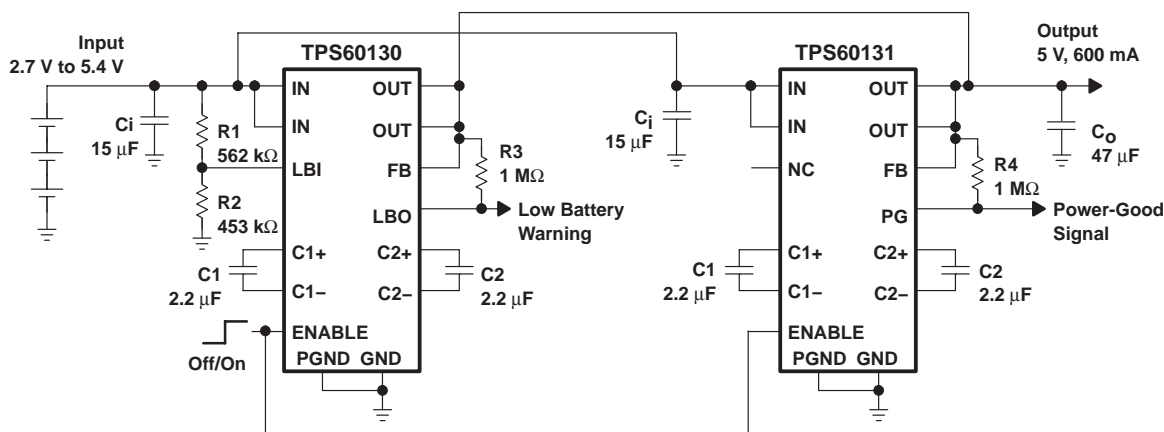


Figure 25. Paralleling of Two TPS6013x Charge Pumps

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APPLICATION INFORMATION

TPS6013x operated with ultra-low quiescent current

Because the output of the TPS6013x is isolated from the input when the devices are disabled, and because the internal resistive divider is disconnected in shutdown, an ultra-low quiescent current mode can be implemented. In this mode, the output voltage is sustained because the converter is periodically enabled to refresh the output capacitor. The necessary external control signal that is applied to the ENABLE-pin is generated from a microcontroller. For a necessary supply current for the system of 1 mA and a minimum supply voltage of 4.5 V with a 33- μ F output capacitor, the refresh has to be done after 9 ms. Longer refresh periods can be achieved with a larger output capacitor.

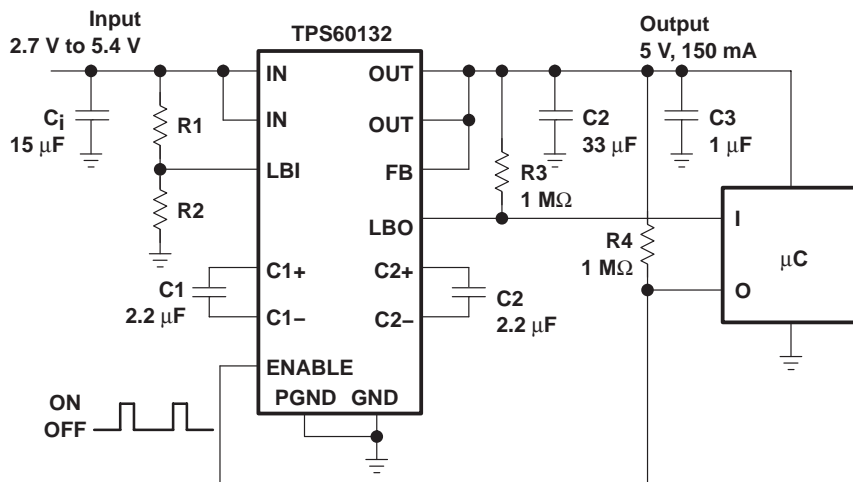


Figure 26. TPS60132 in Ultra-Low Quiescent Current Mode

regulated discharge of the output capacitors after disabling of the TPS6013x

During shutdown of the charge pump TPS6013x the output is isolated from the input. Therefore the discharging of the output capacitor depends on the load and on the leakage current of the capacitor. In certain applications it is necessary to completely remove the supply voltage from the load in shutdown mode. That means the output capacitor of the charge pump has to be actively discharged when the charge pump is disabled. Figure 10 shows one solution to this problem.

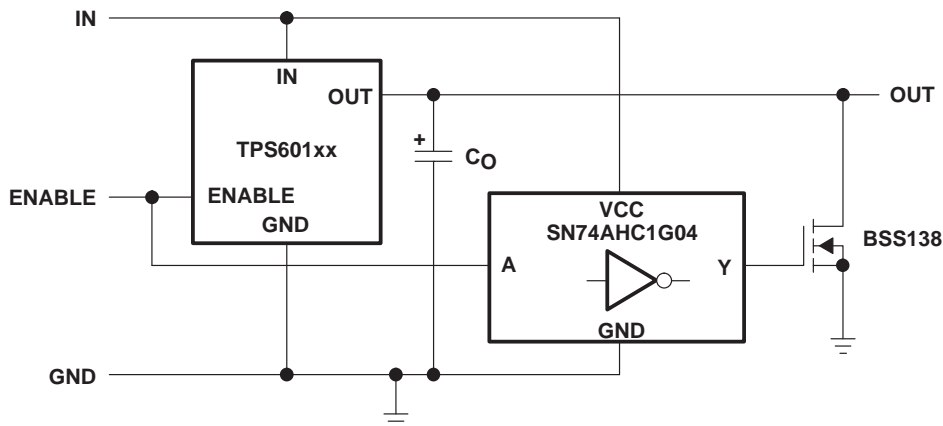


Figure 27. Block Diagram of the Regulated Discharge of the Output Capacitor

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APPLICATION INFORMATION

related information

application reports

For more application information see:

- PowerPAD™ Application Report, Literature Number SLMA002
- *TPS6010x/TPS6011x Charge Pump Application Report*, Literature Number SLVA070
- Powering the TMS320C5420 Using the TPS60100, TPS76918, and the TPS3305-18, Literature Number SLVA082.

device family products

Other devices in this family are:

| PART NUMBER | DATASHEET LITERATURE CODE | DESCRIPTION |
|-------------|---------------------------------|---|
| TPS60100 | SLVS213B | Regulated 3.3-V, 200-mA low-noise charge pump dc-dc converter |
| TPS60101 | SLVS214A | Regulated 3.3-V, 100-mA low-noise charge pump dc-dc converter |
| TPS60110 | SLVS215A | Regulated 5-V, 300-mA low-noise charge pump dc-dc converter |
| TPS60111 | SLVS216A | Regulated 5-V, 150-mA low-noise charge pump dc-dc converter |
| TPS60120 | SLVS257 | Regulated 3.3-V, 200-mA high efficiency charge pump dc-dc converter with low-battery comparator |
| TPS60121 | SLVS257 | Regulated 3.3-V, 200-mA high efficiency charge pump dc-dc converter with power-good comparator |
| TPS60122 | SLVS257 | Regulated 3.3-V, 100-mA high efficiency charge pump dc-dc converter with low-battery comparator |
| TPS60123 | SLVS257 | Regulated 3.3-V, 100-mA high efficiency charge pump dc-dc converter with power-good comparator |



PACKAGING INFORMATION

| Orderable Device | Status ⁽¹⁾ | Package Type | Package Drawing | Pins | Package Qty | Eco Plan ⁽²⁾ | Lead/Ball Finish | MSL Peak Temp ⁽³⁾ |
|------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|
| TPS60130PWP | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60130PWPG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60130PWPR | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60130PWPRG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60131PWP | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60131PWPG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60131PWPR | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60131PWPRG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60132PWP | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60132PWPG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60132PWPR | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60133PWP | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60133PWPG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60133PWPR | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| TPS60133PWPRG4 | ACTIVE | HTSSOP | PWP | 20 | | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |

⁽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), 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)

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

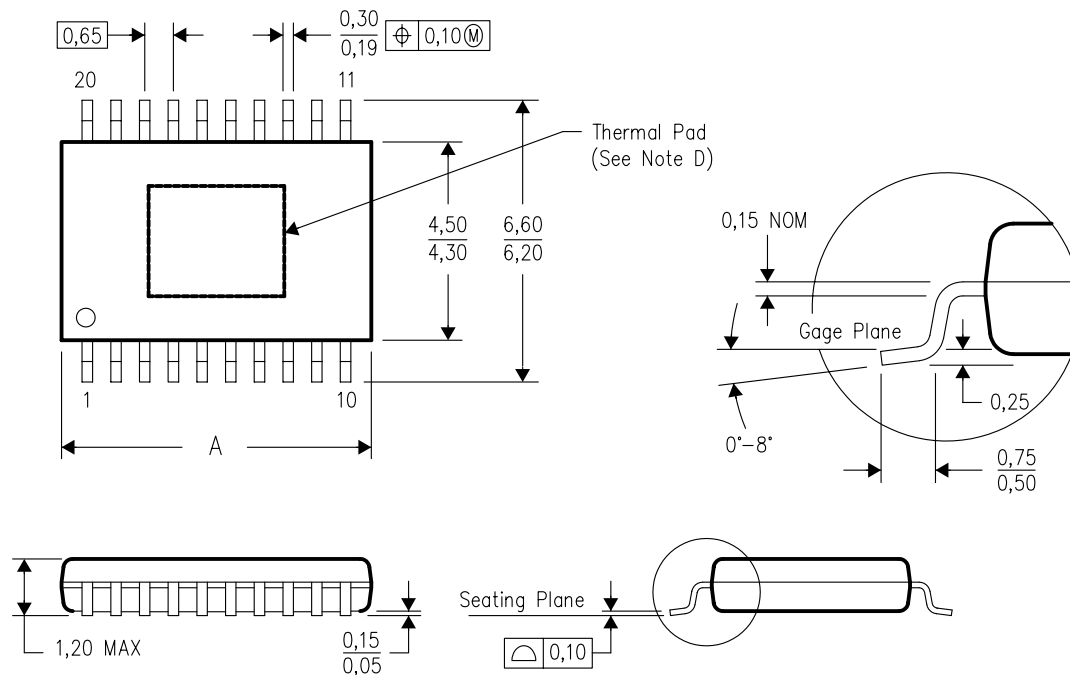
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PWP (R-PDSO-G**)

PowerPAD™ PLASTIC SMALL-OUTLINE PACKAGE

20 PIN SHOWN



| PINS ** | 14 | 16 | 20 | 24 | 28 |
|---------|------|------|------|------|------|
| DIM | | | | | |
| A MAX | 5,10 | 5,10 | 6,60 | 7,90 | 9,80 |
| A MIN | 4,90 | 4,90 | 6,40 | 7,70 | 9,60 |

4073225/H 12/05

- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - Body dimensions do not include mold flash or protrusions. Mold flash and protrusion shall not exceed 0.15 per side.
 - This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <<http://www.ti.com>>.
 - Falls within JEDEC MO-153

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Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265

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