Texas Instruments

TPS62180, TPS62182

SLVSBB8A – AUGUST 2014 – REVISED AUGUST 2014

TPS6218x 4-V to 15-V, 6-A, 2-Phase Step-Down Converters with AEE™

1 Features

- Dual Phase Balanced Peak Current Mode
- Input Voltage Range: 4 V to 15 V
- Output Voltage Range: 0.9 V to 6 V
- Output Current up to 6 A
- Typical Quiescent Current of 28 µA
- Output Voltage Accuracy of ±1% (PWM Mode)
- Automatic Efficiency Enhancement (AEE™)
- Phase Shifted Operation
- Automatic Power Save Mode
- Adjustable Soft Start
- Power Good Output
- Undervoltage Lockout
- HICCUP Over Current Protection
- Over Temperature Protection
- NanoFree™ 2.14 mm x 3.14 mm DSBGA Package

2 Applications

- Low Profile POL Supply
- NVDC Powered Systems
- Dual/Triple Cell Li-ion Battery
- Ultra Portable/Embedded/Tablet PC
- Computing Network Solutions
- Micro Server, SSD

3 Description

The TPS6218x is a synchronous dual-phase step-down DC-DC converter for low profile power rails. It operates with two identical, current balanced phases that are peak current controlled enabling use in height limited applications.

With a wide operating input voltage range of 4 V to 15 V, the device is ideally suited for systems powered from multi-cell Li-Ion batteries or 12-V rails. The output current of 6 A is continuously provided by two phases of 3 A each, allowing the use of low profile external components. The phases operate out of phase, reducing switching noise significantly.

The TPS6218x automatically enters Power Save Mode to maintain high efficiency down to very light loads. It also incorporates an *A*utomatic *E*fficiency *E*nhancement (*AEE*™) for the entire duty cycle range.

The device features a Power Good signal, as well as an adjustable soft start. The quiescent current is typically 28 µA, it is able to run in 100% mode, and it has no duty cycle limitation even at lowest output voltage.

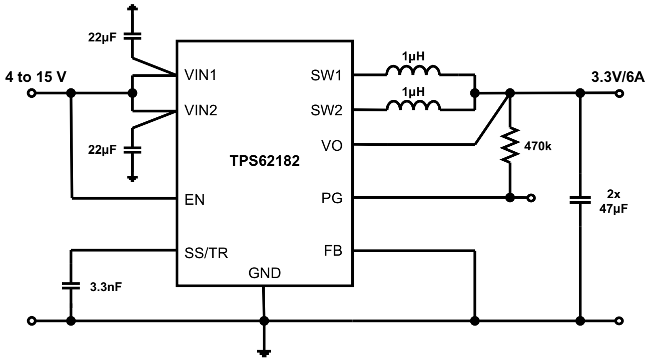
The TPS6218x, available in adjustable and fixed output voltage options, is packaged in a small 24-bump, 0.5 mm pitch DSBGA package.

Device Information(1)

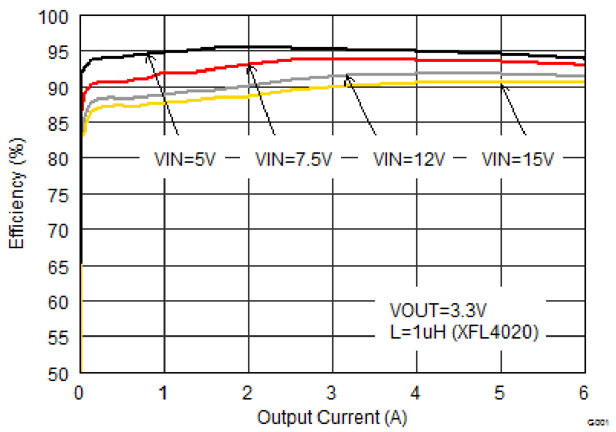
PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS62180	DSBGA (24)	2.14 mm x 3.14 mm
TPS62182	DSBGA (24)	2.14 mm x 3.14 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

4 Simplified Schematic



Efficiency vs Output Current



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5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

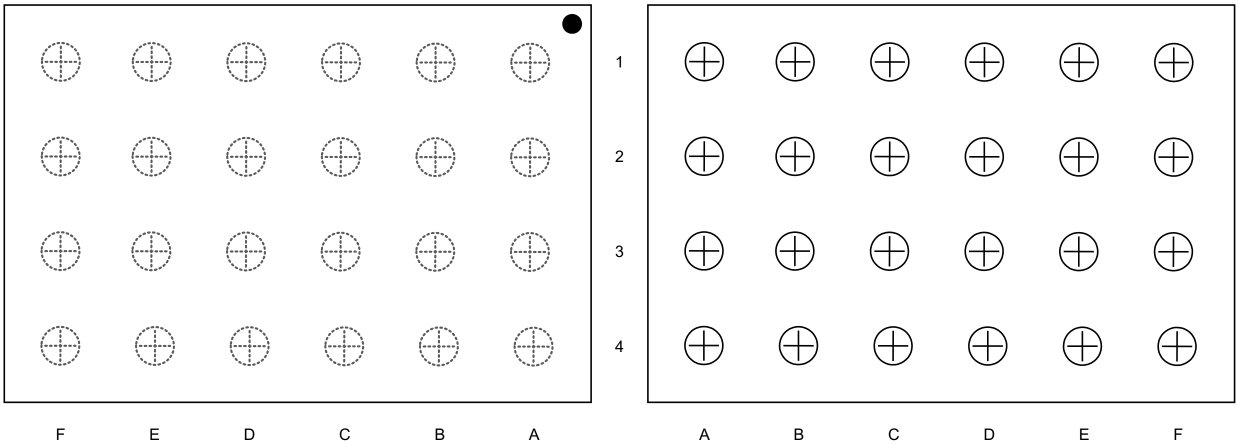
Changes from Original (August 2014) to Revision A	Page
• Released to Production	1

6 Device Comparison Table

PART NUMBER	OUTPUT VOLTAGE	T_J
TPS62180	Adjustable	-40°C to 125°C
TPS62182	3.3 V	-40°C to 125°C

7 Pin Configuration and Functions

24-Pin DSBGA
YZF Package
(Top View - Left, Bottom View - Right)



Pin Functions

PIN[1]		DESCRIPTION
NAME	NUMBER	
AGND	C4	Analog Ground. Connect on PCB directly with PGND.
EN	E4	Enable input (High = enabled, Low = disabled)
FB	B4	Output voltage feedback. Connect resistive voltage divider to this pin and AGND. On TPS62182, connect to AGND.
PG	F4	Output power good (High = VOUT ready, Low = VOUT below nominal regulation); open drain (requires pull-up resistor)
PGND	A3, B3, C3, D3, E3, F3	Common power ground.
SS/TR	D4	Soft-Start and Tracking Pin. An external capacitor connected to this pin sets the internal voltage reference rise time.
SW1	A2, B2, C2	Switch node for Phase 1 (master), connected to the internal MOSFET switches. Connect inductor 1 between SW1 and output capacitor.
SW2	D2, E2, F2	Switch node for Phase 2 (follower), connected to the internal MOSFET switches. Connect inductor 2 between SW2 and output capacitor.
VIN1	A1, B1, C1	Supply voltage for Phase 1.
VIN2	D1, E1, F1	Supply voltage for Phase 2.
VO	A4	Output Voltage Connection

(1) For more information about connecting pins, see Detailed Description and Application Information sections.

8 Specifications

8.1 Absolute Maximum Ratings[1]

Over operating junction temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Pin voltage range[2]	VIN1, VIN2	–0.3	17	V
	EN, PG, SW1, SW2	–0.3	V_{IN} + 0.3	V
	SS/TR	–0.3	V_{IN} + 0.3, but ≤ 7	V
	FB, VO	–0.3	7	V
Power good sink current	PG		10	mA
Operating junction temperature range	T_J	–40	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) All voltages are with respect to network ground pin.

8.2 Handling Ratings

		MIN	MAX	UNIT
T_{stg}	Storage temperature range	–65	150	°C
V_{ESD}[1]	Human Body Model (HBM) ESD stress voltage[2]	–1	1	kV
	Charge device model (CDM) ESD stress voltage	–0.5	0.5	

(1) Electrostatic discharge (ESD) to measure device sensitivity and immunity to damage caused by assembly line electrostatic discharges in to the device.

(2) Level listed above is the passing level per ANSI, ESDA, and JEDEC JS-001. JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

8.3 Recommended Operating Conditions

Over operating junction temperature range (unless otherwise noted)

		MIN	TYP	MAX	UNIT
Supply voltage range, V_{IN}		4		15	V
Output voltage range, V_{OUT}		0.9		6	V
Maximum Output current, $I_{OUT(max)}$	0.9V ≤ V_{OUT} ≤ 3.3V	6			A
	3.3V < V_{OUT}		6		
Operating junction temperature, T_J		–40		125	°C

8.4 Thermal Information

THERMAL METRIC[1]		TPS6218x	UNIT
		YZF (24 PINS)	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	61.5	°C/W
$R_{\theta JCtop}$	Junction-to-case (top) thermal resistance	0.3	
$R\theta_{JB}$	Junction-to-board thermal resistance	10.1	
ψ_{JT}	Junction-to-top characterization parameter	0.1	
ψ_{JB}	Junction-to-board characterization parameter	10.1	
$R_{\theta JCbot}$	Junction-to-case (bottom) thermal resistance	n/a	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

8.5 Electrical Characteristics

Over operating junction temperature range (T_J = –40°C to +125°C) and V_{IN} = 4 V to 15 V.
Typical values at V_{IN} = 12 V and T_J = 25°C (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SUPPLY							
V_{IN}	Input voltage range			4		15	V
I_Q	Operating quiescent current	EN = High, I_{OUT} = 0 mA, Device not switching, (T_J = –40°C to +85°C)			28	55	µA
I_{SD}	Shutdown current	EN = Low (≤ 0.3 V), (T_J = –40°C to +85°C)			2.8	15	µA
V_{UVLO}	Undervoltage lockout threshold [1]	Falling input voltage		3.5	3.6	3.7	V
		Hysteresis			300		mV
T_{SD}	Thermal shutdown	Rising junction temperature			160		°C
		Hysteresis			20		
CONTROL (EN, SS/TR, PG)							
V_{H_EN}	High-level input threshold voltage (EN)			0.97	1	1.03	V
V_{L_EN}	Low-level input threshold voltage (EN)			0.87	0.9	0.93	V
I_{LKG_EN}	Input leakage current (EN)	EN = V_{IN} or GND			0.01	1.2	µA
$I_{SS/TR}$	SS/TR pin source current			4.5	5	5.5	µA
V_{TH_PG}	Power good threshold voltage	Rising (%V_{OUT})		94%	96%	98%	
		Falling (%V_{OUT})		90%	92%	94%	
V_{OL_PG}	Power good output low voltage	I_{PG}= -2 mA				0.3	V
I_{LKG_PG}	Input leakage current (PG)				1	100	nA
POWER SWITCH							
$R_{DS(ON)}$	High-side MOSFET ON-resistance	V_{IN} = 7.5 V	Phase 1		27	65	mΩ
			Phase 2				
	Low-side MOSFET ON-resistance		Phase 1		21	45	mΩ
			Phase 2				
I_{LIM}	High-side MOSFET current limit	Each phase, V_{IN} = 7.5 V		4.0	4.7	5.5	A
T_{PSD}	Phase shift delay time	Phase 2 after Phase 1, PWM mode			250		ns
OUTPUT							
V_{REF}	Internal reference voltage			0.792	0.8	0.808	V
I_{LKG_FB}	Input leakage current (FB)	V_{FB} = 0.8 V			1	100	nA
$R_{DISCHARGE}$	Output discharge resistance	EN = Low			60		Ω
V_{OUT}	Output voltage range (TPS62180)	$V_{IN} \geq V_{OUT}$		0.9		6	V
	Output voltage (TPS62182)				3.3		V
	Feedback voltage accuracy (TPS62180) [2]	PWM Mode, $V_{IN} \geq V_{OUT}$ + 1 V		–1%		1%	
		Power Save Mode, V_{OUT} = 3.3 V, I_{load} ≥ 1 mA, L = 1 µH, C_{OUT} = 2 x 47 µF, (T_J = –40°C to +85°C)		–1%		2%	
		Power Save Mode, V_{OUT} = 1.8 V, I_{load} ≥ 1 mA, L = 1 µH, C_{OUT} = 4 x 47 µF, (T_J = –40°C to +85°C)					
		Power Save Mode, V_{OUT} = 0.9 V, I_{load} ≥ 1 mA, L = 1 µH, C_{OUT} = 4 x 47 µF, (T_J = –40°C to +85°C)		–1%		3%	
	Output voltage accuracy (TPS62182) [2]	PWM Mode, $V_{IN} \geq V_{OUT}$ + 1 V		–1%		1%	
		Power Save Mode, I_{load} ≥ 1 mA, L = 1 µH, C_{OUT} = 2 x 47 µF, (T_J = –40°C to +85°C)		–1%		2%	
	Load regulation	V_{OUT} = 3.3 V, PWM Mode operation			0.04		%/A
	Line regulation	4 V ≤ V_{IN} ≤ 15 V, V_{OUT} = 3.3 V, I_{OUT} = 4 A			0.01		%/V
t_{HICCUP}	Hiccup on time				0.9		ms
	Hiccup off time				5		

(1) The minimum V_{IN} value of 4 V is not violated by UVLO threshold and hysteresis variations.
(2) The accuracy in Power Save Mode can be improved by increasing the output capacitor value, reducing the output voltage ripple.

8.6 Typical Characteristics

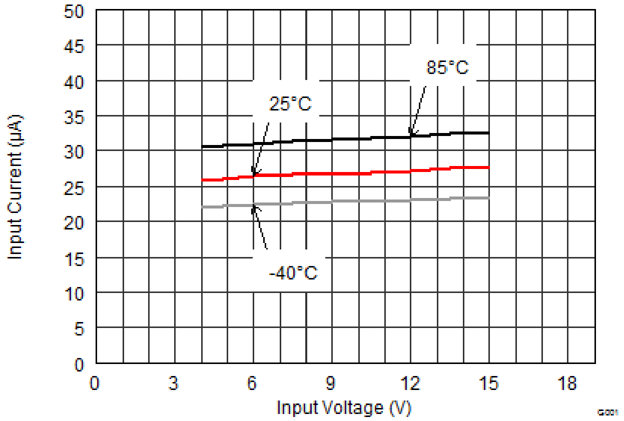


Figure 2. Quiescent Current

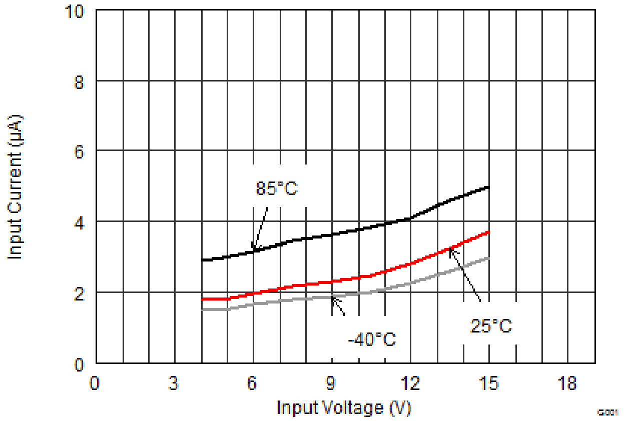


Figure 3. Shutdown Current

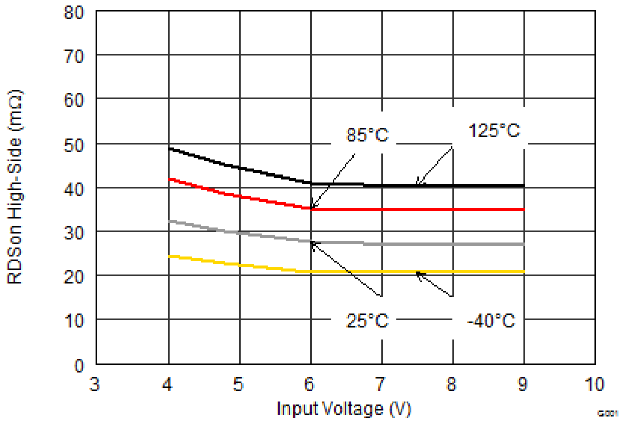


Figure 4. High-Side Switch Resistance

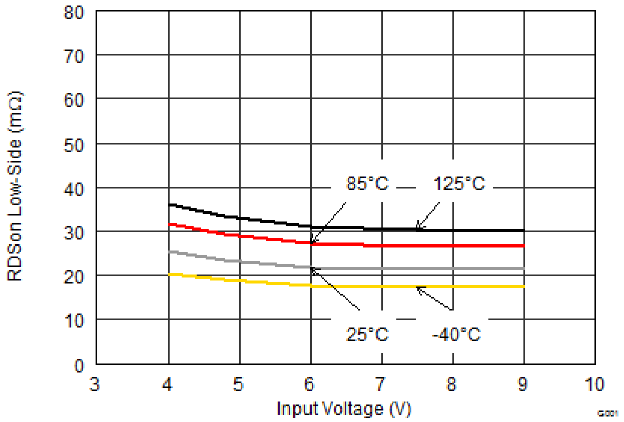


Figure 5. Low-Side Switch Resistance

9 Detailed Description

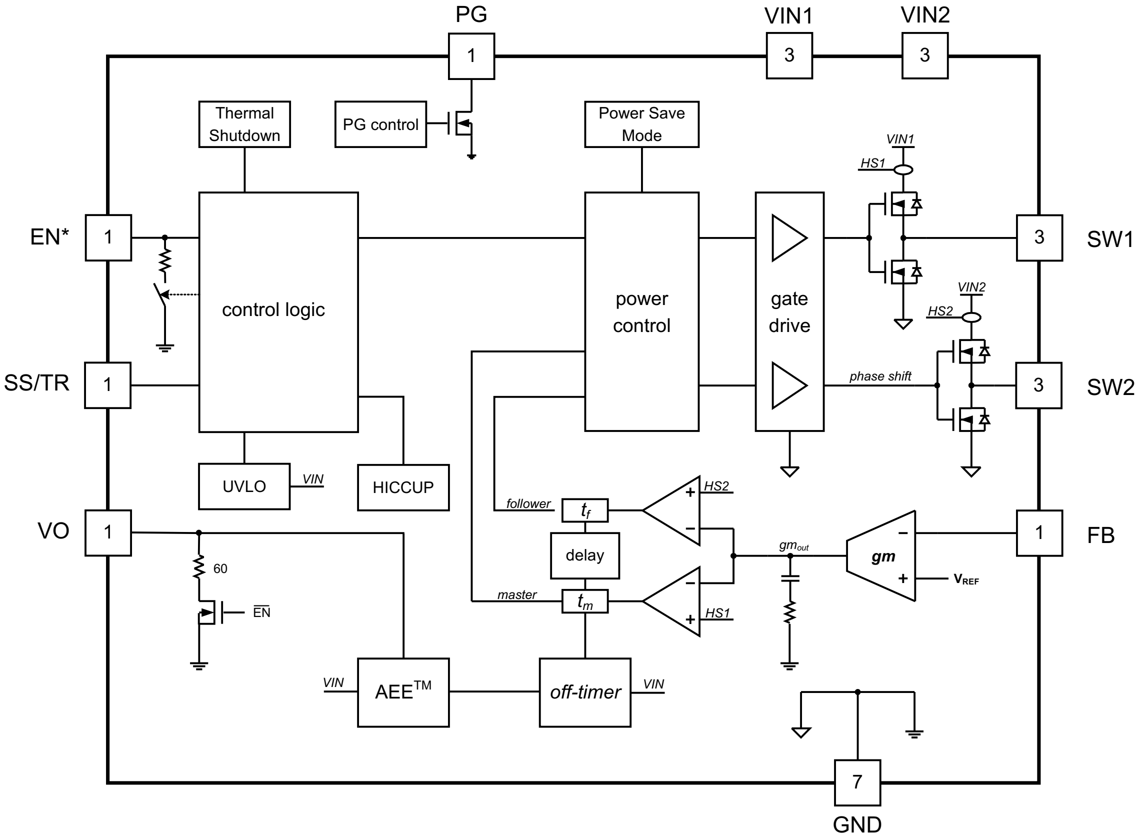
9.1 Overview

The TPS6218x is a high efficiency synchronous switched mode step-down converter based on a peak current control topology. It is designed for smallest solution size low-profile applications, converting multi-cell Li-Ion supply voltages to output voltages of 0.9 V to 6 V. While an outer voltage loop sets the regulation threshold for the current loop based on the actual V_{OUT} level, the inner current loop adapts the peak inductor current for every switching cycle. The regulation network is internally compensated. The switching frequency is set by an OFF-time control and features Power Save Mode (PSM) and AEE (Automatic Efficiency Enhancement) to keep the efficiency high over the whole load current and duty cycle range. The switching frequency is set depending on V_{IN} and V_{OUT} and remains unchanged for steady state operating conditions.

The TPS6218x is a dual phase converter, sharing the load current among the phases. Identical in construction, the follower control loop is connected with a fixed delay to the master control loop. Both the phases use the same regulation threshold and cycle-by-cycle peak current setpoint. This ensures a phase-shifted as well as current-balanced operation. Using the advantages of the dual phase topology, a 6-A continuous output current is provided with high performance and smallest system solution size.

While the TPS62180 offers an adjustable output voltage, the TPS62182 supports a fixed 3.3-V output voltage, saving external components.

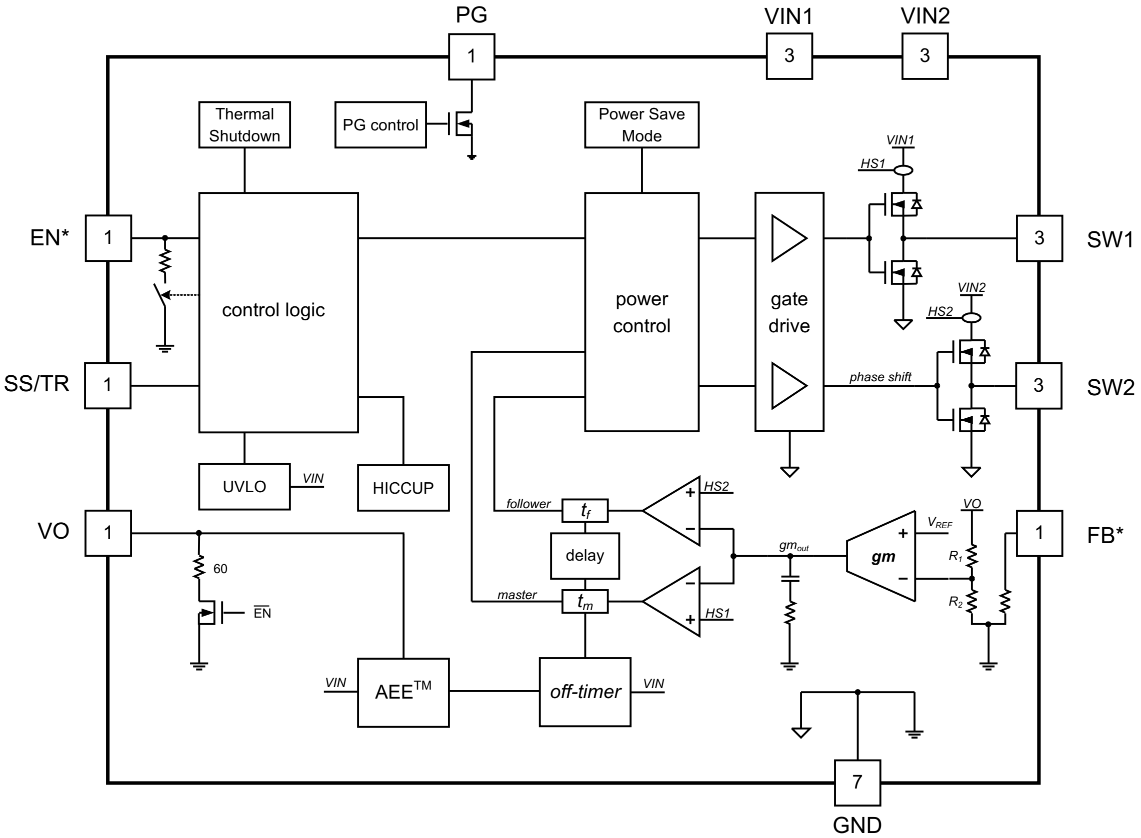
9.2 Functional Block Diagram



*Pin is connected to a pull down resistor internally
(see Feature Description section)

Figure 6. TPS62180 (Adjustable output voltage)

Functional Block Diagram (continued)



*Pin is connected to a pull down resistor internally
(see Feature Description section)

Figure 7. TPS62182 (Fixed output voltage)

9.3 Feature Description

9.3.1 Enable / Shutdown (EN)

The device starts operation, when V_{IN} is present and Enable (EN) is set High. The EN threshold is 1 V for rising and 0.9 V for falling voltages, providing a threshold accuracy of ±3%. That makes it suitable for precise switching on and off in accurate power sequencing arrangements as well as for slowly rising EN control voltage signals (see Using the Accurate EN Threshold for more details).

The device is disabled by pulling EN Low. A discharge resistor of about 60 Ω is then connected to the output. At the EN pin, an internal pull down resistor of about 350 kΩ keeps the Low state, if EN gets high impedance or floating afterwards.

The EN pin can be connected to V_{IN} to always enable the device. A delay of 1 ms, after V_{IN} exceeds V_{UVLO}, ensures safe operating conditions before the device starts switching. If V_{IN} is already present, a soft start sequence is initiated about 100 µs after EN is pulled High.

9.3.2 Soft Start / Tracking (SS/TR)

The soft start circuit controls the output voltage slope during startup. This avoids excessive inrush current and ensures a controlled output voltage rise time. It also prevents unwanted voltage drop from high impedance power sources or batteries. When EN is set to start device operation, the device starts switching and V_{OUT} rises with a slope, controlled by the external capacitor connected to the SS/TR pin. It is not recommended to leave the SS/TR pin floating, because V_{OUT} may overshoot. Typical startup operation is shown in Application Performance Curves.

Feature Description (continued)

The device can track an external voltage (see Tracking). The device can monotonically start into a pre-biased output.

9.3.3 Power Good (PG)

The TPS6218x has a built in power good (PG) function. The PG pin goes High, when the output voltage has reached its nominal value. Otherwise, including when disabled, in UVLO or in thermal shutdown, PG is Low. The PG pin is an open drain output that requires a pull-up resistor and can sink typically 2 mA. If not used, the PG pin can be left floating or grounded.

9.3.4 Undervoltage Lockout (UVLO)

The undervoltage lockout (UVLO) prevents misoperation of the device, if the input voltage drops below the UVLO threshold. It is set to 3.6 V typically with a hysteresis of typically 300mV. (See also Device Functional Modes).

9.3.5 Thermal Shutdown

The junction temperature T_J of the device is monitored by an internal temperature sensor. If T_J exceeds 160°C (typ.), the device goes in thermal shutdown with a hysteresis of typically 20°C. Both the power FETs are turned off, the discharge resistor is connected to the output and the PG pin goes Low. Once T_J has decreased enough, the device resumes normal operation with Soft Start.

9.4 Device Functional Modes

9.4.1 Pulse Width Modulation (PWM) Operation

The TPS6218x is based on a predictive OFF-time peak current control topology, operating with PWM in continuous conduction mode for heavier loads. Since the OFF-time is automatically adjusted according to the actual V_{IN} and V_{OUT}, it provides highest efficiency over the entire input and output voltage range. The OFF-time is calculated as:

$$t_{OFF} = \left[\frac{V_{IN}}{5V_{OUT}} 500ns \right] + 50ns \tag{1}$$

While the OFF-time is predicted, the ON-time is set depending on the converter's duty cycle and calculated as:

$$t_{ON} = \frac{t_{OFF} \cdot V_{OUT}}{V_{IN} - V_{OUT}} \tag{2}$$

Thereby the switching frequency is fixed for a given input and output voltage and is calculated as:

$$f_{SW} = \frac{1-D}{t_{OFF}} = \frac{1}{t_{OFF}} \left(1 - \frac{V_{OUT}}{V_{IN}} \right) \tag{3}$$

Both the master and follower phases regulate to the same level of V_{OUT} with separate current loops, using the same peak current setpoint, cycle by cycle. This provides excellent peak current balancing, independent of inductor dc resistance matching. Since the follower phase operates with a fixed delay to the master phase, also cycle by cycle, phase shifted operation is obtained.

The device features an automatic transition into Power Save Mode, entered at light loads, running in discontinuous conduction mode (DCM).

Device Functional Modes (continued)

9.4.2 Power Save Mode (PSM) Operation

As the load current decreases, the converter enters Power Save Mode operation. During PSM, the converter operates with a reduced switching frequency maintaining highest efficiency due to minimum quiescent current. Power Save Mode is based on a fixed peak current architecture, where the peak current (I_{PEAK}) is set depending on V_{IN}, V_{OUT}, and L. After each single pulse, a pause time until the internal V_{OUT_Low} level threshold is reached completes the switching cycle in PSM.

The switching frequency for PSM in one phase operation is calculated as :

$$f_{PSM} = \frac{2I_{OUT} \cdot V_{OUT}\left(V_{IN} - V_{OUT}\right)}{L \cdot I_{PEAK}^{2} \cdot V_{IN}} \tag{4}$$

Equation 4 shows the linear relationship of output current and switching frequency. Typical values of the fixed peak current are shown in Figure 8.

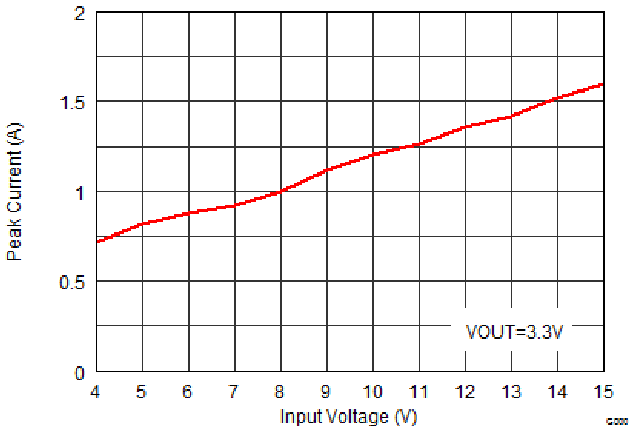


Figure 8. Typical Fixed Peak Current (I_{PEAK}) in Power Save Mode

If the load decreases to very light loads and only one phase is needed, either phase (master or follower) might be active. The load current level at which Power Save Mode is entered is calculated as follows:

$$I_{load(PSM)} = \Delta I_L \tag{5}$$

Equation 7 is used to calculate ΔI_L.

9.4.3 Minimum Duty Cycle and 100% Mode Operation

When the input voltage comes close to the output voltage, the device enters 100% mode and both high-side FETs are continuously switched on as long as V_{OUT} remains below its setpoint. The minimum V_{IN} to maintain output voltage regulation is calculated as:

$$V_{IN(\min)} = V_{OUT(\min)} + I_{OUT}\left[\frac{R_{DS(ON)}}{2} + DCR_{L1} // DCR_{L2}\right] \tag{6}$$

Device Functional Modes (continued)

This allows the conversion of small input to output voltage differences, for example for lthe ongest operation time in battery powered applications. In 100% duty cycle mode, the low-side FET is switched off.

While the maximum ON-time is not limited, the AEE feature, explained in the next section, secures a minimum ON-time of about 100 ns.

9.4.4 Automatic Efficiency Enhancement (AEE)

AEE provides highest efficiency over the entire input voltage and output voltage range by automatically adjusting the converter's switching frequency. This is achieved by setting the predictive off-time of the converter.

The efficiency of a switched mode converter is determined by the power losses during the conversion. The efficiency decreases, if V_{OUT} decreases and/or V_{IN} increases. In order to keep the efficiency high over the entire duty cycle range (V_{OUT}/V_{IN} ratio), the switching frequency is adjusted while maintaining the ripple current. The following equation shows the relation between the inductor ripple current, switching frequency and duty cycle.

$$\Delta I_L = V_{OUT} \cdot \left(\frac{1-D}{L \cdot f_{SW}} \right) = V_{OUT} \cdot \left(\frac{1-\frac{V_{OUT}}{V_{IN}}}{L \cdot f_{SW}} \right) \tag{7}$$

Efficiency increases by decreasing switching losses, preserving high efficiency for varying duty cycles, while the ripple current amplitude remains low enough to deliver the full output current without reaching current limit. The AEE feature provides an efficiency enhancement for various duty cycles, especially for lower Vout values, where fixed frequency converters suffer from a significant efficiency drop. Furthermore, this feature compensates for the very small duty cycles of high V_{IN} to low V_{OUT} conversion, which limits the control range in other topologies.

Figure 9 shows the typical switching frequency over the input voltage range.

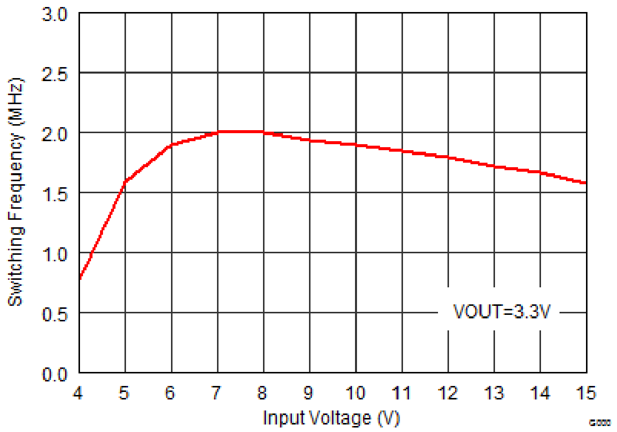


Figure 9. Typical Switching Frequency vs Input Voltage

Device Functional Modes (continued)

9.4.5 Phase-Shifted Operation

While, for a buck converter, the input current source provides the average current that is needed to support the output current, an input capacitance is needed to support pulse currents. One of the natural benefits of a two- (or multi-) phase converter is the possibility to operate out of phase, which decreases the pulse currents and switching noise. In PWM mode, the TPS6218x devices run with a fixed delay of typically 250 ns between the phases. This ensures that the phases run phase-delayed, limiting input RMS current and corresponding noise. If in PSM, both phases run, the phase delay is about 100 ns.

9.4.6 Current Limit, Current Balancing, and Short Circuit Protection

Each phase has a separate integrated peak current limit. While its minimum value limits the output current of the phase, the maximum number gives the current that must be considered to flow in any operating case. If the current limit of a phase is reached, the peak current setpoint is unable to increase further. The device provides its maximum output current. Detecting this heavy load or short circuit condition for about 0.9 ms, the device switches off for about 5 ms and then restarts again with a soft start cycle. As long as the overload condition is present, the device hiccups that way, limiting the output power.

The two phases are peak current balanced with a variation within about ±10% at 6-A output current (see Figure 10). Since the control topology does not depend on inductor or output current measurements, the current balancing accuracy is independent of inductor matching (binning) and does not need matched power routing.

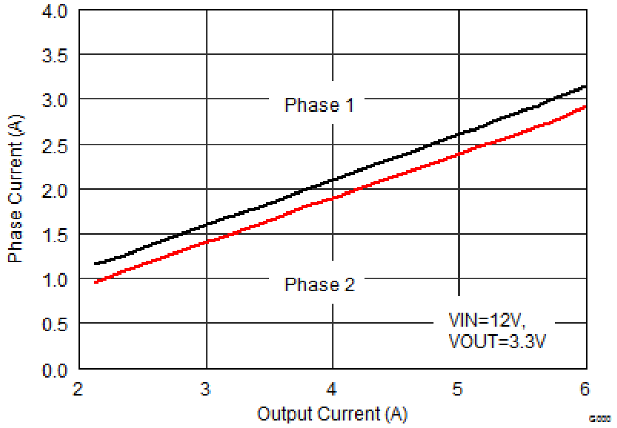


Figure 10. Typical Current Balancing vs Load Current

9.4.7 Tracking

V_{OUT} can track a voltage that is applied at the SS/TR pin. The tracking range at the SS/TR pin is 50 mV to 1.2 V and the FB pin voltage tracks this as given in Equation 8:

$$V_{FB} \approx 0.64 \cdot V_{SS/TR} \tag{8}$$

Due to the factor of about 0.64, the minimum output voltage for tracking is 1.25 V. Once the SS/TR pin voltage reaches about 1.2 V, the internal voltage is clamped to the internal feedback voltage and the device goes to normal regulation. This works for falling tracking voltage as well. If, in this case, the SS/TR voltage decreases, the device does not sink current from the output. Thus, the resulting decrease of the output voltage may be slower than the SS/TR pin voltage if the load is light. When driving the SS/TR pin with an external voltage, do not exceed the voltage rating of the SS/TR pin which is V_{IN}+0.3 V.

Device Functional Modes (continued)

Note: If the voltage at the FB pin is below its typical value of 0.8 V, the output voltage accuracy may have a wider tolerance than specified.

9.4.8 Operation with Fixed V_{OUT}

The TPS62182 provides a fixed output voltage of 3.3 V (±1%). In this case, the feedback divider is integrated and the FB pin is internally connected to GND with a resistor of about 350 kΩ. It is recommended to connect the FB pin to PCB ground to improve thermal behavior.

10 Application and Implementation

10.1 Application Information

The TPS62180/2 are switched mode step-down converters, able to convert a 4-V to 15-V input voltage into a lower 0.9-V to 6-V output voltage, providing up to 6 A. It needs a minimum amount of external components. Apart from the LC output filter and the input capacitors only an optional pull-up resistor for Power Good (PG) and a small capacitor for adjustable soft start are used. The TPS62180 with an adjustable output voltage needs an additional resistive divider to set the output voltage level.

10.2 Typical Applications

10.2.1 Typical TPS62180 Application

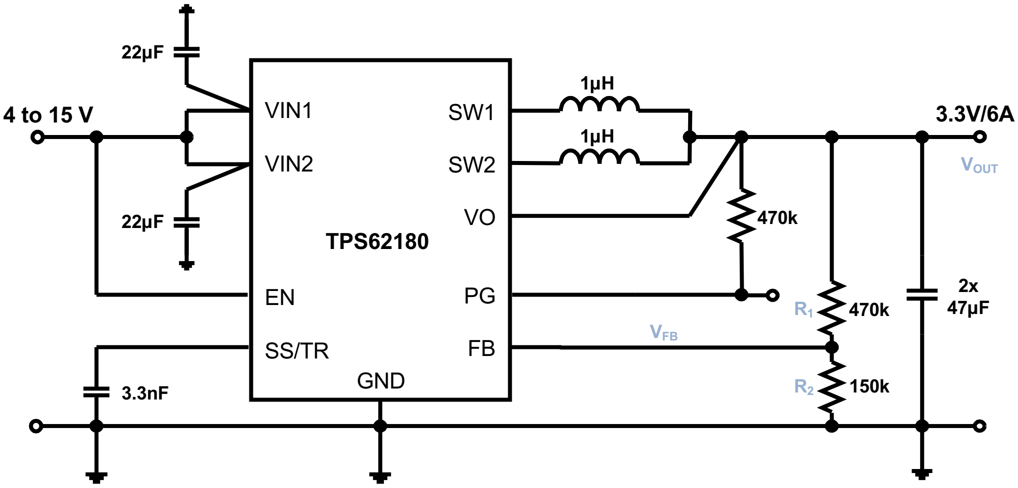


Figure 11. Typical 4-V to 15-V Input, 3.3-V Output Converter

10.2.1.1 Design Requirements

The design guideline provides a component selection to operate the device within the recommended operating conditions. The component selection is given as follows:

Table 1. Components Used for Application Characteristics

REFERENCE NAME	DESCRIPTION / VALUE	MANUFACTURER
TPS62180YZF	2 phase step down converter, 2 x 3 mm WCSP	Texas Instruments
L1, L2	Inductor XFL4020-102ME, 1 µH ±20%, 4 x 4 x 2.1 mm	Coilcraft
C_{IN}	Ceramic capacitor GRM21BR61E226ME44, 2 x 22 µF, 25 V, X5R, 0805	muRata
C_{OUT}	Ceramic capacitor GRM21BR60J476ME15, 2 x 47 µF, 6.3 V, X5R, 0805	muRata
C_{SS}	Ceramic capacitor, 3.3 nF	Standard
R1	Chip resistor, value depending on V_{OUT}	Standard
R2	Chip resistor, value depending on V_{OUT}	Standard
R3	Chip resistor, 470 kΩ, 0603, 1/16 W, 1%	Standard

10.2.1.2 Detailed Design Procedure

10.2.1.2.1 Programming the Output Voltage

The output voltage of the TPS62180 is programmed using an external resistive divider. While the voltage at the FB pin is regulated to 0.8 V, the output voltage range is specified from 0.9 up to 6 V. The value of the output voltage is set by selection of the resistive divider (from VOUT to FB to AGND) from Equation 9.

$$\frac{R_1}{R_2} = \frac{V_{OUT}}{V_{FB}} - 1 \quad (9)$$

The current through those resistors contributes to the light load efficiency, which makes larger resistor values beneficial. However, to get sufficient noise immunity a minimum current of 5 µA is recommended. Using this, the resistor values are calculated by converting Equation 9 as follows:

$$R_2 = \frac{V_{FB}}{I_{FB}} = \frac{0.8V}{5\mu A} = 160k\Omega \quad (10)$$

Inserting the R_2 value in Equation 11, R_1 can be obtained.

$$R_1 = R_2 \cdot \left(\frac{V_{OUT}}{V_{FB}} - 1 \right) \quad (11)$$

Calculating for V_{OUT} = 3.3 V gives R_1 = 500 kΩ. Using standard resistor values R_1 = 470 kΩ and R_2 = 150 kΩ are chosen.

For applications requiring lowest current consumption, the use of fixed output voltage options is recommended. Using the TPS62182, the FB pin can be left floating, but it is recommended to connect it to AGND which decreases thermal resistance.

In case the FB pin of the adjustable output voltage version gets opened or an over voltage appears at the output, an internal clamp limits the output voltage to about 7.4 V.

10.2.1.2.2 Output Filter Selection

Since the TPS6218x is compensated internally, it is optimized for a range of external component values, which is specified below. Table 2 and Table 3 are used to simplify the output filter component selection.

Table 2. Recommended LC Output Filter Combinations for $V_{OUT} \geq 1.8$ V(1)

	2 x 47 µF	4 x 47 µF	6 x 47 µF	8 x 47 µF
0.47 µH				
1.0 µH	√	√	√	√
1.5 µH				

(1) The values in the table are the nominal values of inductors and ceramic capacitors. The effective capacitance can vary by +20 and –60%.

Table 3. Recommended LC Output Filter Combinations for $V_{OUT} < 1.8$ V(1)

	2 x 47 µF	4 x 47 µF	6 x 47 µF	8 x 47 µF
0.68 µH				
1.0 µH		√	√	
1.5 µH				

(1) The values in the table are nominal values of inductors and ceramic capacitors.

For the output capacitors, a voltage rating of 6.3 V and an X5R dielectric are chosen. If space allows for higher voltage rated capacitors in larger case sizes, the dc bias effect is lowered and the effective capacitance value increases.

10.2.1.2.3 Inductor Selection

The TPS6218x is designed to work with two inductors of 1 µH nominal. They have to be selected for adequate saturation current and a low dc resistance (DCR). The minimum inductor current rating $I_{L(min)}$ that is needed under static load conditions is calculated using Equation 12 and Equation 13. A current imbalance of 10% at most is incorporated.

$$I_{peak(\max)} = I_{L(\min)} = \frac{1.1 \cdot I_{OUT(\max)}}{2} + \frac{\Delta I_{L(\max)}}{2} \tag{12}$$

$$\Delta I_{L(\max)} = V_{OUT} \cdot \left(\frac{1 - \frac{V_{OUT}}{V_{IN(\max)}}}{L_{(\min)} \cdot f_{SW}} \right) \tag{13}$$

This calculation gives the minimum saturation current of the inductor needed and an additional margin of about 20% is recommended to cover dynamic overshoot due to load transients. For low profile solutions, the physical inductor size and the power losses have to be traded off. Smallest solution size (for example with chip inductors) are less efficient than bigger inductors with lower losses due to lower DCR and/or core losses. The following inductors have been tested with the TPS6218x:

Table 4. List of Inductors

TYPE	INDUCTANCE [µH]	CURRENT RATING MIN/TYP [A] (1)	DCR MAX [mΩ]	DIMENSIONS (LxBxH) [mm]	MANUFACTURER
DFE201612E-1R0M	1 ±20%	4.0/4.4	48	2.0 x 1.6 x 1.2	TOKO
DFE252012F-1R0M	1 ±20%	4.7/5.3	40	2.5 x 2.0 x 1.2	TOKO
DFE252012P-1R0M	1 ±20%	3.8/4.5	42	2.5 x 2.0 x 1.2	TOKO
PIFE32251B-1R0MS	1 ±20%	4.2/4.7	42	3.2 x 2.5 x 1.2	CYNTEC
PIME031B-1R0MS	1 ±20%	4.5/5.4	55	3.7 x 3.3 x 1.2	CYNTEC
PISB25201T-1R0MS	1 ±20%	3.6/3.9	62	2.5 x 2.0 x 1.0	CYNTEC
IHLP1212AB-11	1 ±20%	/5.0	37.5	3.6 x 3.0 x 1.2	VISHAY
IHLP1212AE-11	1 ±20%	/5.3	33	3.6 x 3.0 x 1.5	VISHAY
XFL4015-122ME_	1.2±20%	/4.5	20.7	4.0 x 4.0 x 1.5	COILCRAFT
XFL4020-102ME_	1 ±20%	/5.4	11.9	4.0 x 4.0 x 2.1	COILCRAFT
TFM201610-GHM	1 ±20%	3.6/3.8	60	2.0 x 1.6 x 1.0	TDK
TFM252010-GHM	1 ±20%	3.5/4.0	56	2.5 x 2.0 x 1.0	TDK

(1) I_{SAT} at 30% drop of inductance ($\Delta I_L/I_L$).

The TPS6218x is not designed to operate with only one inductor.

10.2.1.2.4 Output Capacitor Selection

The TPS6218x provides a wide output voltage range of 0.9 V to 6 V. While stability is a critical criteria for the output filter selection, the output capacitor value also determines transient response behavior, ripple and accuracy of V_{OUT}. Table 5 gives recommendations to achieve various transient design targets using 1-µH inductors and small sized output capacitors (see Table 1).

Table 5. Recommended Output Capacitor Values

OUTPUT VOLTAGE [V]	LOAD STEP [A]	(NOMINAL) CAPACITOR VALUE[1]	TYPICAL TRANSIENT RESPONSE ACCURACY	
			±mV	±%
0.9	2-6-2[2]	4 x 47 µF	90	10
		6 x 47 µF	70	8
1.8	2-6-2[2]	2 x 47 µF	150	8
		4 x 47 µF	120	7
		8 x 47 µF	90	5
3.3	2-6-2[2]	2 x 47 µF	170	5
		4 x 47 µF	135	4
		8 x 47 µF	100	3

(1) Ceramic capacitors have a dc bias effect where the effective capacitance differs significantly from the nominal value, depending on package size, voltage rating and dielectric material.
(2) The transient load step is tested with 1-µs/step rising/falling slopes.

The architecture of the TPS6218x allows the use of tiny ceramic output capacitors with low equivalent series resistance (ESR). These capacitors provide low output voltage ripple and are recommended. To keep its low resistance up to high frequencies and to get narrow capacitance variation with temperature, it is recommended to use X7R or X5R dielectrics. Using even higher values than demanded for stability and transient response has further advantages like smaller voltage ripple and tighter dc output accuracy in Power Save Mode.

10.2.1.2.5 Input Capacitor Selection

The input current of a buck converter is pulsating. Therefore, a low ESR input capacitor is required to prevent large voltage transients and provide peak currents. The recommended value for most applications is 2 x 22 µF, split between the VIN1 and VIN2 inputs and placed as close as possible to these pins and PGND pins. If additional capacitance is needed, it can be added as bulk capacitance. To ensure proper operation, the effective capacitance at the VIN pins must not fall below 2 x 2 µF (close) + 10 µF bulk (effective capacitances).

Low ESR multilayer ceramic capacitors are recommended for best filtering. Increasing with input voltage, the dc bias effect reduces the nominal capacitance value significantly. To decrease input ripple current further, larger values of input capacitors can be used.

10.2.1.2.6 Soft Start Capacitor Selection

The TPS6218x provides a user programmable soft start time. A constant current source of 5 µA, internally connected to the SS/TR pin, allows control of the startup slope by connecting a capacitor to this pin. The current source charges the capacitor and the soft start time is given by:

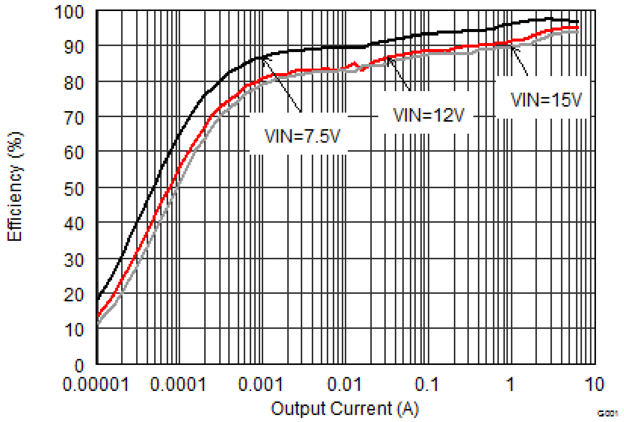
$$C_{SS} = t_{SS} \cdot \frac{5\mu A}{1.25V} \tag{14}$$

where C_{SS} is the soft-start capacitance required at the SS/TR pin and t_{ss} is the resulting soft-start ramp time.

The SS/TR pin should not be left floating and a minimum capacitance of 220 pF is recommended. Using Equation 14, and inserting t_{SS} = 750 µs, a value of 3 nF is calculated. 3.3 nF is chosen as a standard value for this example.

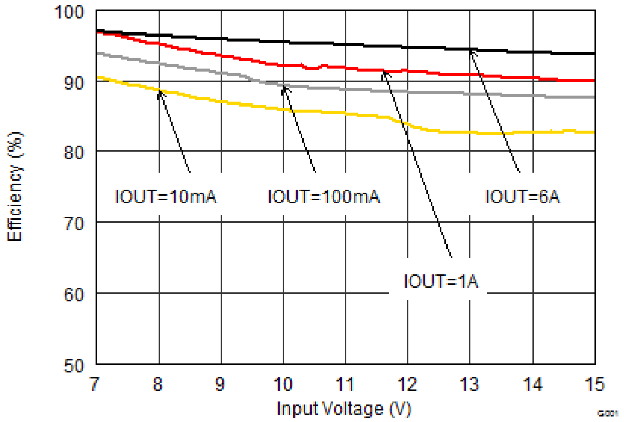
10.2.1.3 Application Performance Curves

V_{IN} = 12 V, V_{OUT} = 3.3 V, T_A = 25°C, (unless otherwise noted)



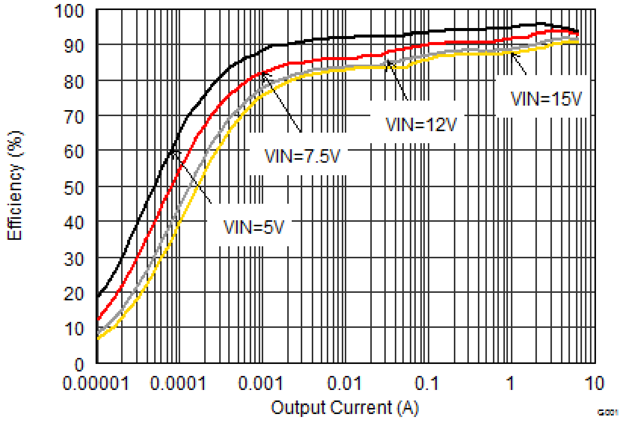
V_{OUT} = 6 V

Figure 12. Efficiency vs Load Current



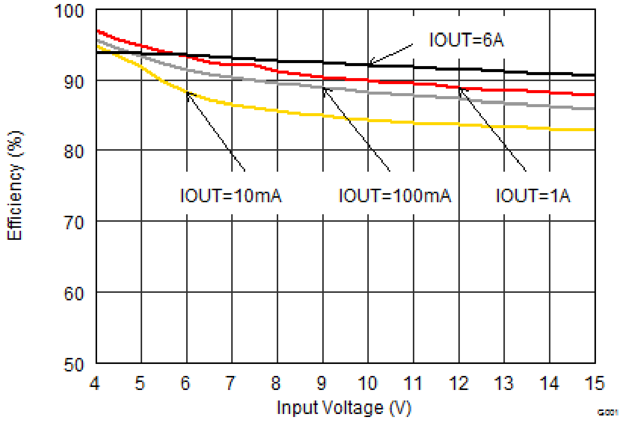
V_{OUT} = 6 V

Figure 13. Efficiency vs Input Voltage



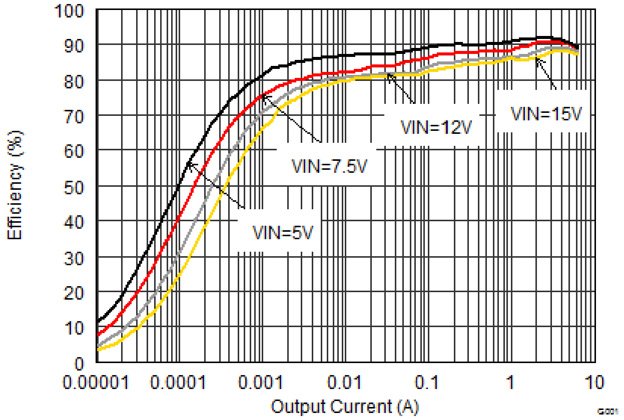
V_{OUT} = 3.3 V

Figure 14. Efficiency vs Load Current



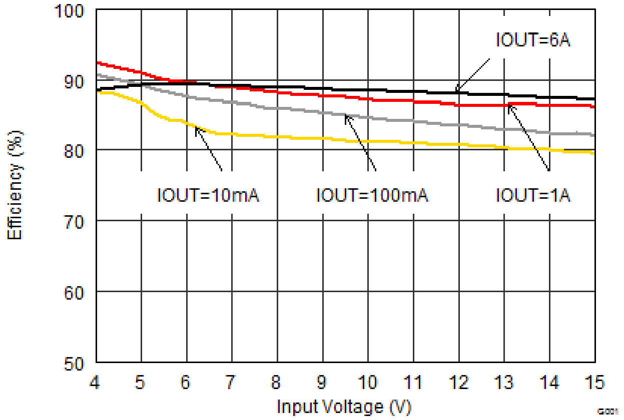
V_{OUT} = 3.3 V

Figure 15. Efficiency vs Input Voltage



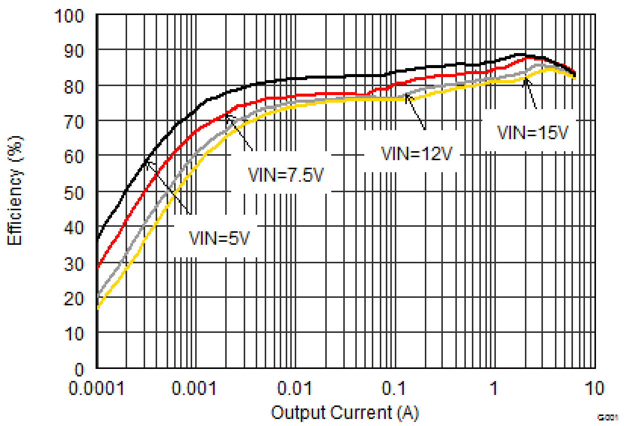
V_{OUT} = 1.8 V

Figure 16. Efficiency vs Load Current



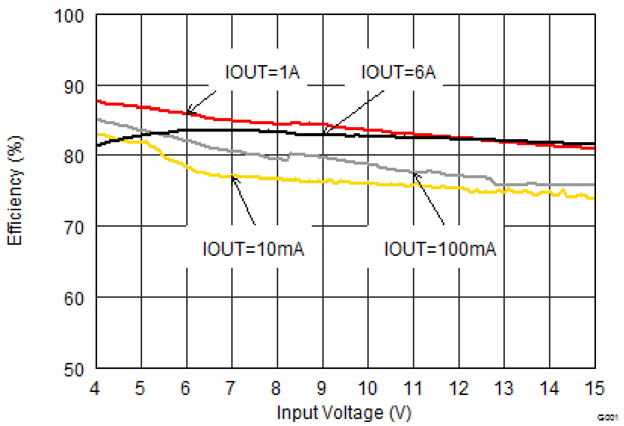
V_{OUT} = 1.8 V

Figure 17. Efficiency vs Input Voltage



V_{OUT} = 0.9 V

Figure 18. Efficiency vs Load Current



V_{OUT} = 0.9 V

Figure 19. Efficiency vs Input Voltage

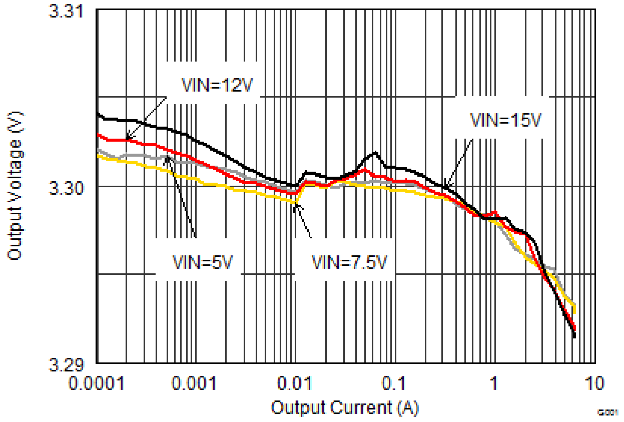


Figure 20. Output Voltage vs Output Current (Load regulation)

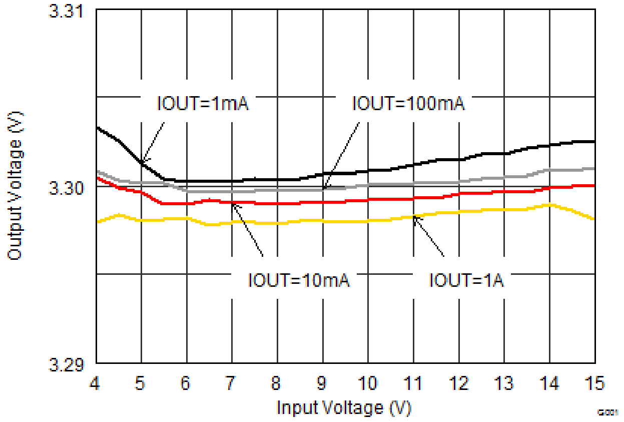


Figure 21. Output Voltage vs Input Voltage (Line regulation)

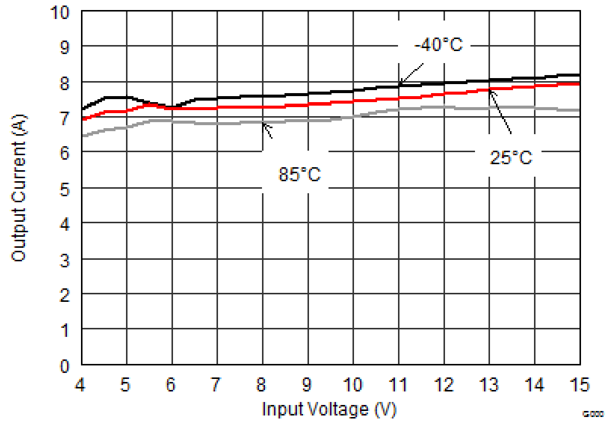


Figure 22. Maximum Output Current vs Input Voltage

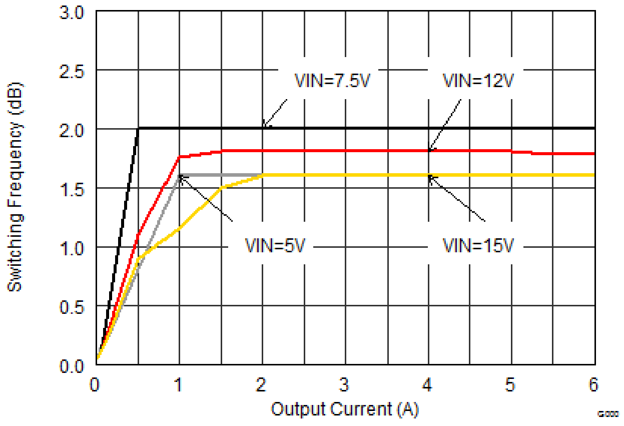


Figure 23. Switching Frequency vs Output Current

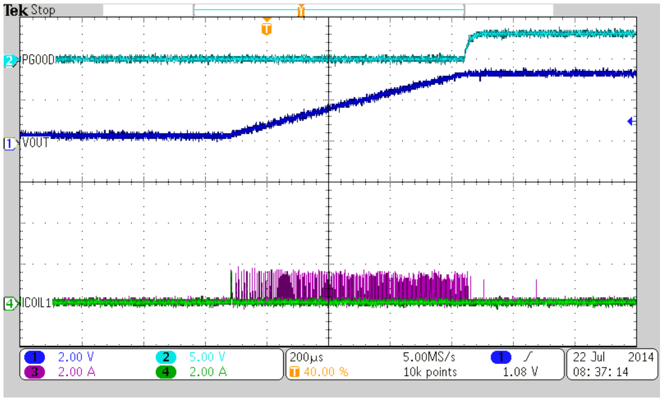


Figure 24. Startup into 33 Ω (100 mA)

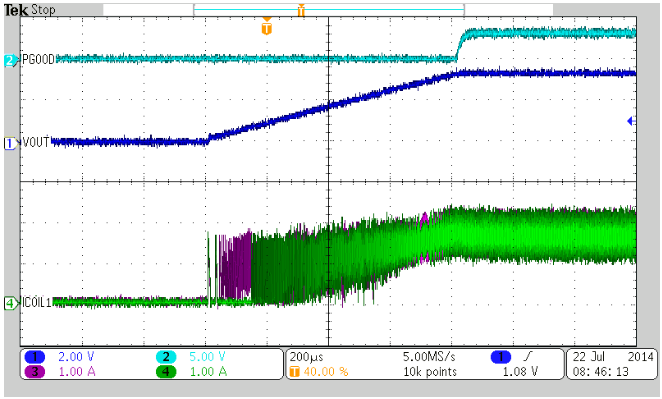


Figure 25. Startup into 1 Ω (3.3 A)

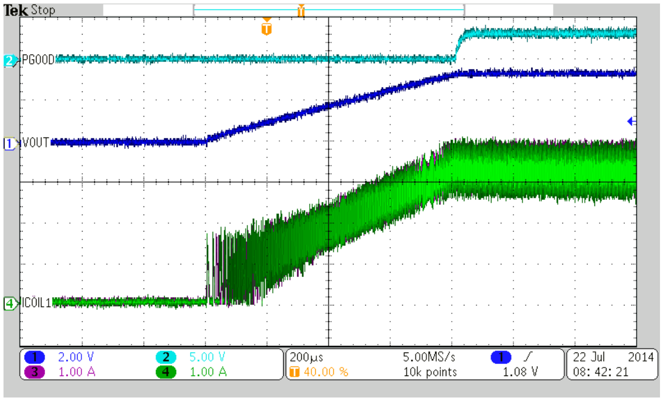


Figure 26. Startup into 0.5 Ω (6.6 A)

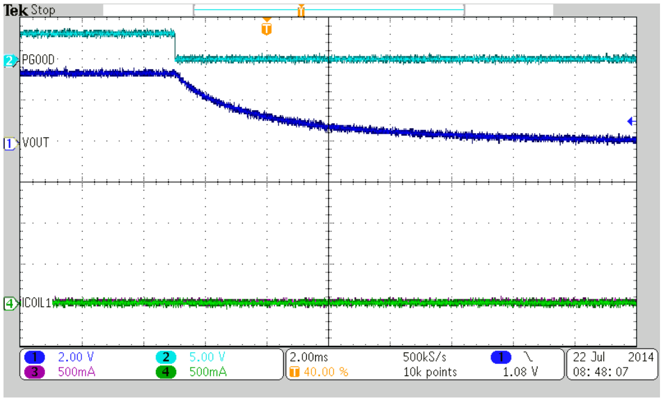
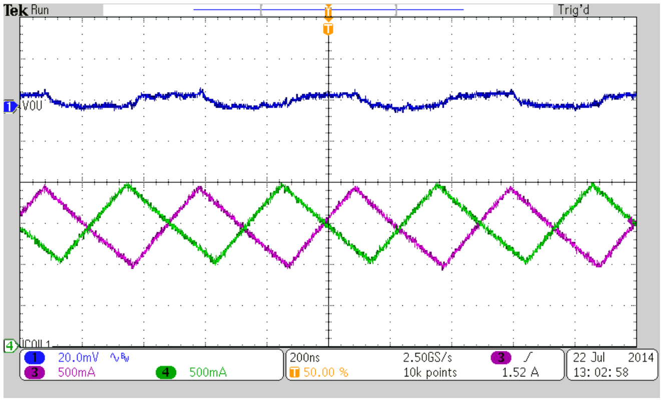
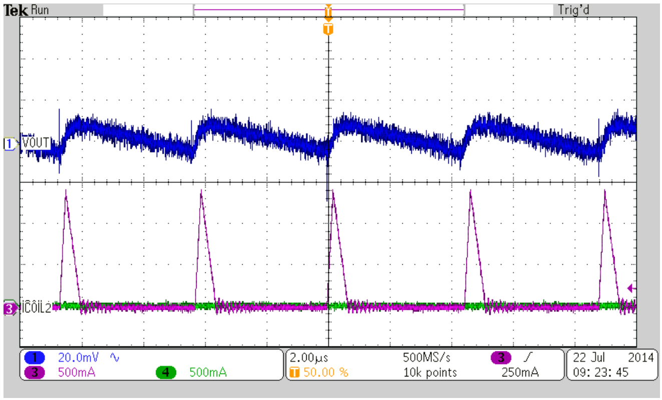


Figure 27. Output Discharge (No load)



I_{OUT} = 3 A

Figure 28. Typical Operation (PWM)



I_{OUT} = 100 mA

Figure 29. Typical Operation (PSM)

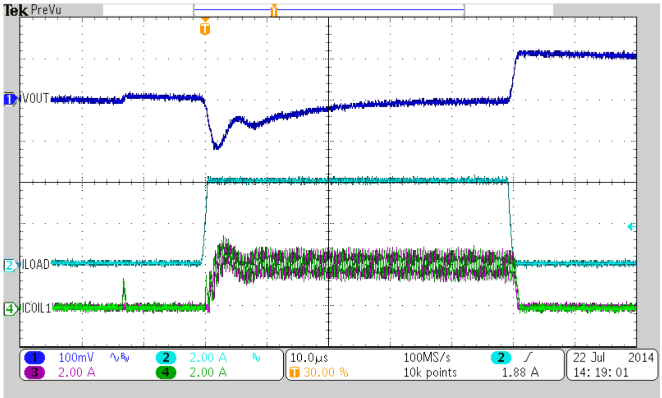


Figure 30. Load Transient Response (PSM-PWM)

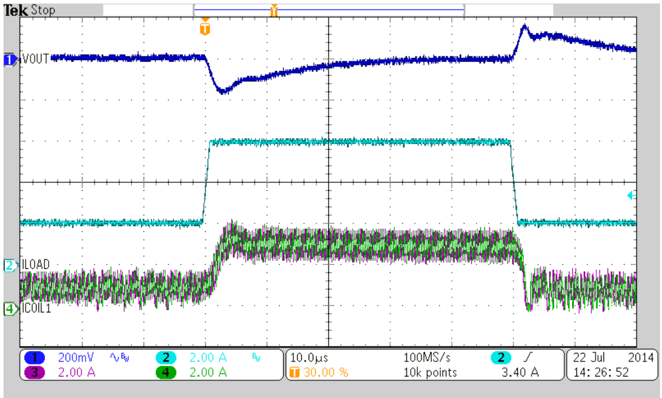
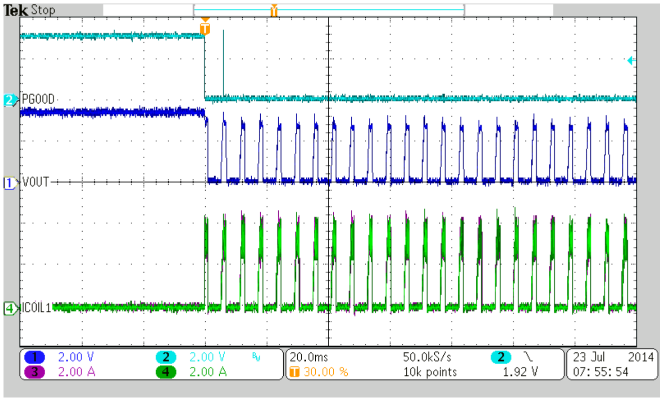
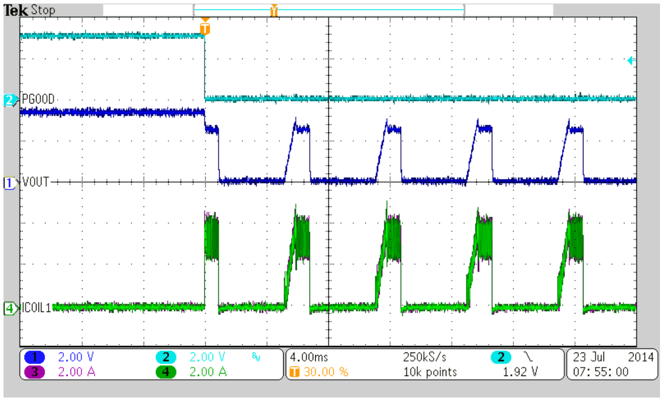


Figure 31. Load Transient Response (PWM-PWM)



R_{LOAD} = 0.33 Ω

Figure 32. HICCUP at Overload Condition



R_{LOAD} = 0.33 Ω

Figure 33. HICCUP at Overload Condition

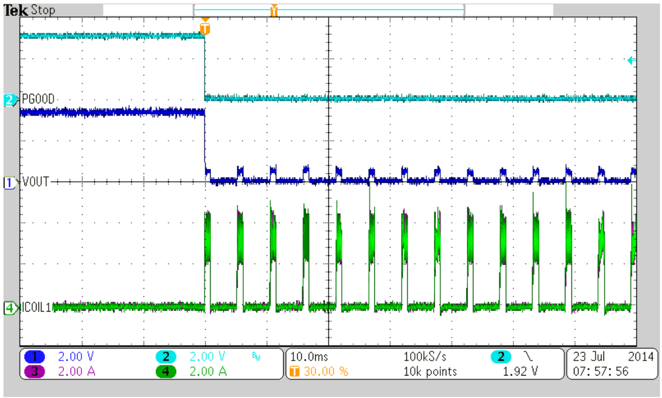


Figure 34. HICCUP at Short Circuit

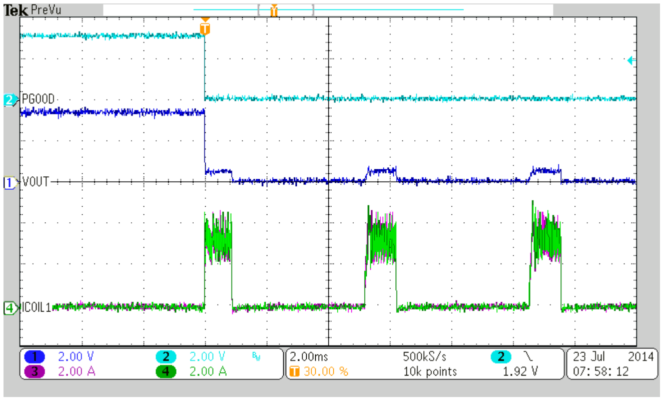


Figure 35. HICCUP at Short Circuit

10.2.2 TPS62180 Low Profile Solution

This design example is based on Figure 11 again, providing a low profile solution, using low profile inductors.

10.2.2.1 Design Requirements

The input parameters used for this design are given as follows:

Table 6. Components Used for Application Characteristics

REFERENCE NAME	DESCRIPTION / VALUE	MANUFACTURER
TPS62180YZF	2 phase step down converter, 2 x 3 mm WCSP	Texas Instruments
L1, L2	Inductor DFE252012P, 1 µH ±20%, 2.5 x 2 x 1.2 mm	Toko
C_{IN}	Ceramic capacitor GRM21BR61E226ME44, 2 x 22 µF, 25 V, X5R, 0805	muRata
C_{OUT}	Ceramic capacitor GRM21BR60J476ME15, 2 x 47 µF, 6.3 V, X5R, 0805	muRata
C_{SS}	Ceramic capacitor, 10 nF	Standard
R1	Chip resistor, value depending on V_{OUT}	Standard
R2	Chip resistor, value depending on V_{OUT}	Standard
R3	Chip resistor, 470 kΩ, 0603, 1/16 W, 1%	Standard

10.2.2.2 Detailed Design Procedure

As opposed to the previous example, the solution size, including height, is limited and the soft start time is longer. This is achieved by using smaller inductors, as well as using a different soft start capacitor.

10.2.2.2.1 Inductor

Using Table 4, the 1-µH DFE252012P is chosen with dimensions of 2.5 x 2.0 x 1.2 mm. The larger DCR of 42 mΩ maximum causes some efficiency drop.

10.2.2.2.2 Input and Output Capacitors

Since electrical design parameters are unchanged, the same values as chosen in the previous example are used for these capacitors.

10.2.2.2.3 Soft Start Capacitor

Using Equation 14 again, and inserting t_{SS} = 2.5 ms gives a capacitance of 10 nF, which is chosen.

10.2.2.2.4 Using the Accurate EN Threshold

The TPS6218x provides a very accurate EN threshold voltage. This can be used to switch on the device according to a V_{IN} or another voltage level by using a resistive divider as shown below.

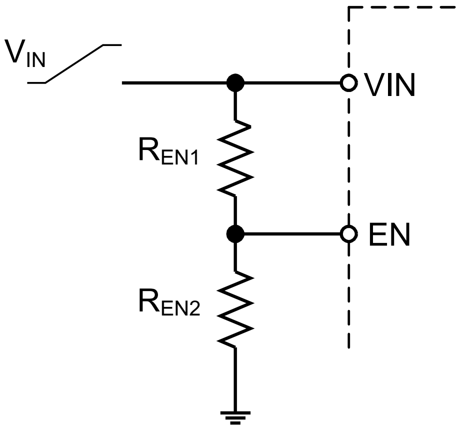


Figure 36. Resistive Divider for Controlled EN Threshold

The values of R_{EN1} and R_{EN2}, needed to set EN = High at a specific V_{IN} can be calculated according to Kirchhoff's laws, shown in Equation 15 and used in the following example:

$$V_{IN} = V_{EN\_threshold} \cdot \frac{R_{EN1} + R_{EN2}}{R_{EN2}} \tag{15}$$

For a typical 8-V input rail, the device turn on target value is set to 5.5 V. The current through the resistive divider is set to 10 µA, which indicates a total resistance of about 800 kΩ. Appropriate standard resistor values, fitting Equation 15, are R_{EN1} = 680 kΩ and R_{EN2} = 150 kΩ. As a result, the device switches on, when V_{IN} has reached 5.5 V and the current through the divider is 9.6 µA. The device switches off at a threshold of 0.9 V. Using Equation 15 again, this case gives a level of V_{IN} = 5.0 V.

Figure 43 to Figure 46 show thresholds and appropriate device behavior with a startup time of about 800 µs.

10.2.2.3 Application Performance Curves

V_{IN} = 12 V, V_{OUT} = 3.3 V, T_A = 25°C, (unless otherwise noted)

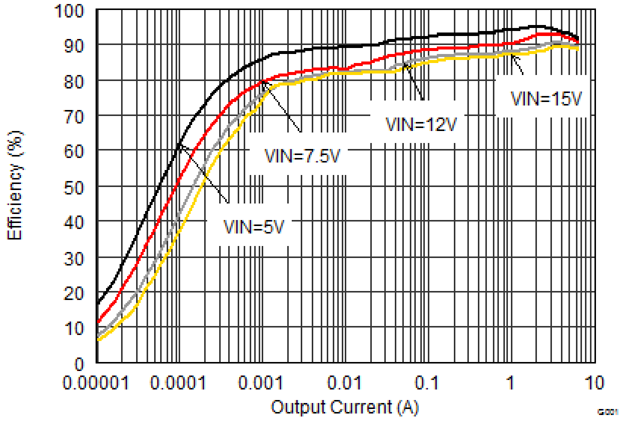


Figure 37. Efficiency vs Load Current

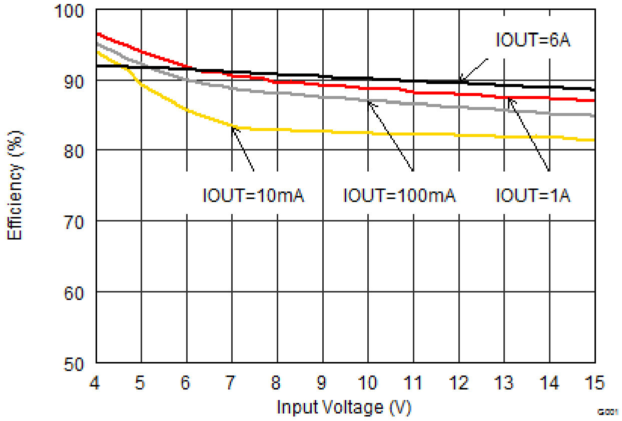
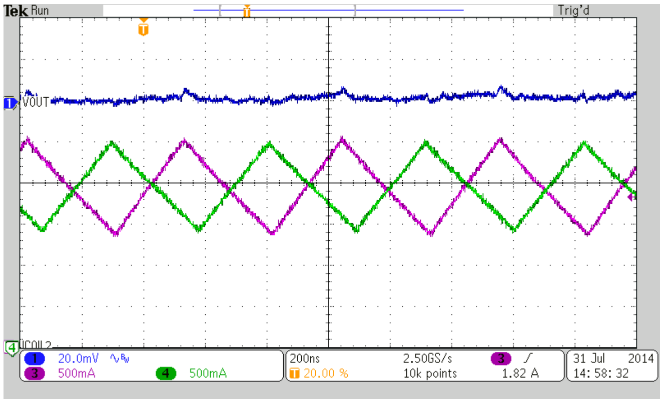
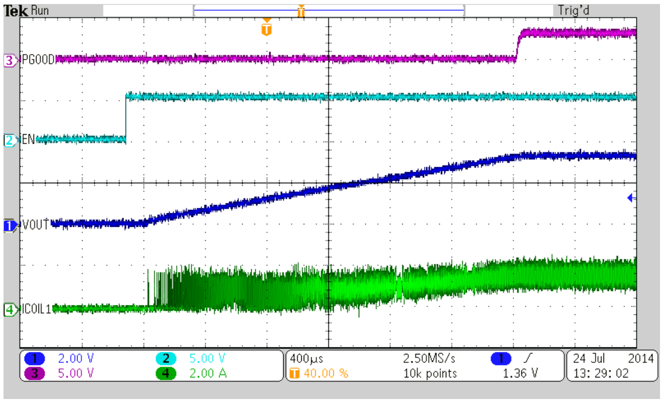


Figure 38. Efficiency vs Input Voltage



V_{IN} = 8 V, I_{OUT} = 4 A

Figure 39. Typical Operation (PWM)



C_{SS} = 10 nF

Figure 40. Startup into 1 Ω (3.3 A)

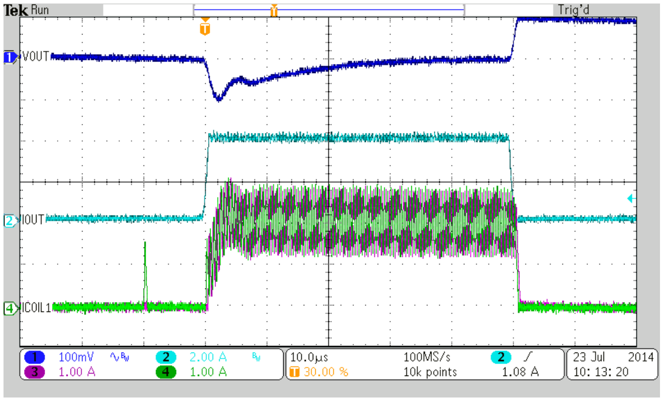


Figure 41. Load Transient Response (PSM-PWM)

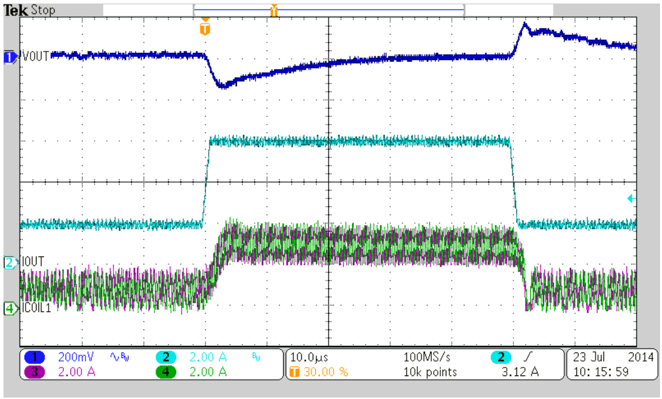
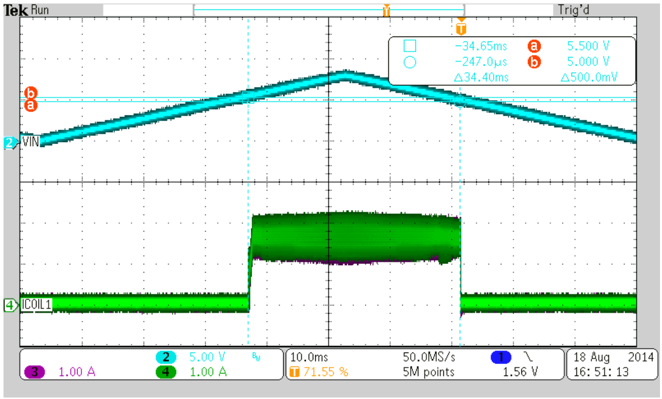


Figure 42. Load Transient Response (PWM-PWM)



V_{IN} = 5.5 V (Rising), V_{IN} = 5.0 V (Falling)

Figure 43. Accurate EN Threshold

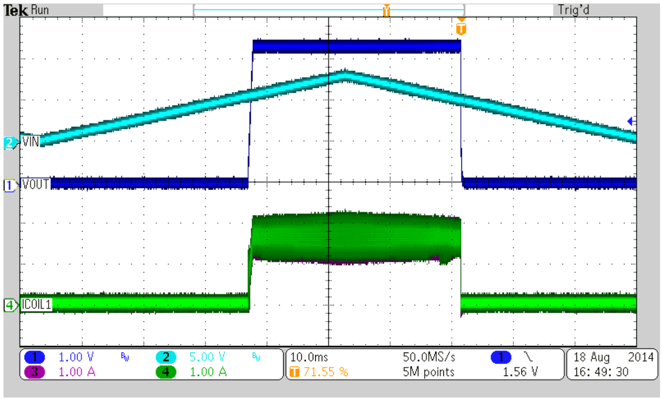
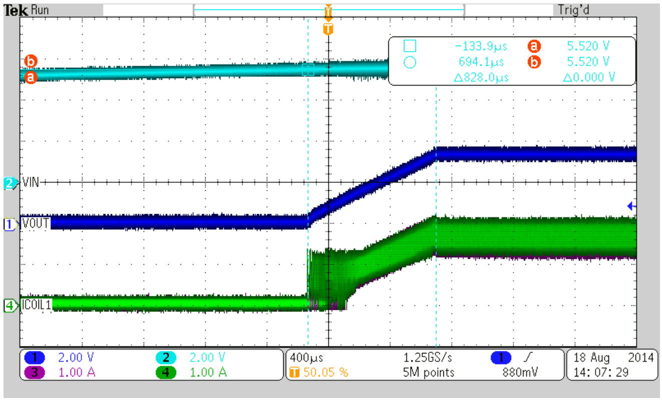
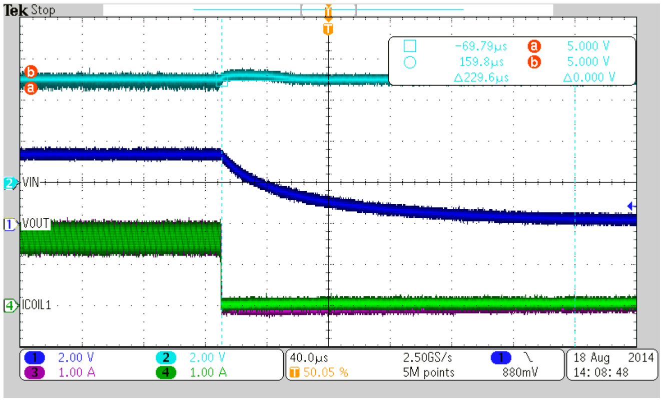


Figure 44. Accurate EN Threshold Showing V_{OUT}



V_{IN} = 5.5 V (Rising)

Figure 45. Accurate EN Threshold



V_{IN} = 5.0 V (Falling)

Figure 46. Accurate EN Threshold

10.3 TPS62180 Output Voltage Application Examples

This section provides typical schematics for commonly used output voltage values.

10.3.1 Application Schematic Examples

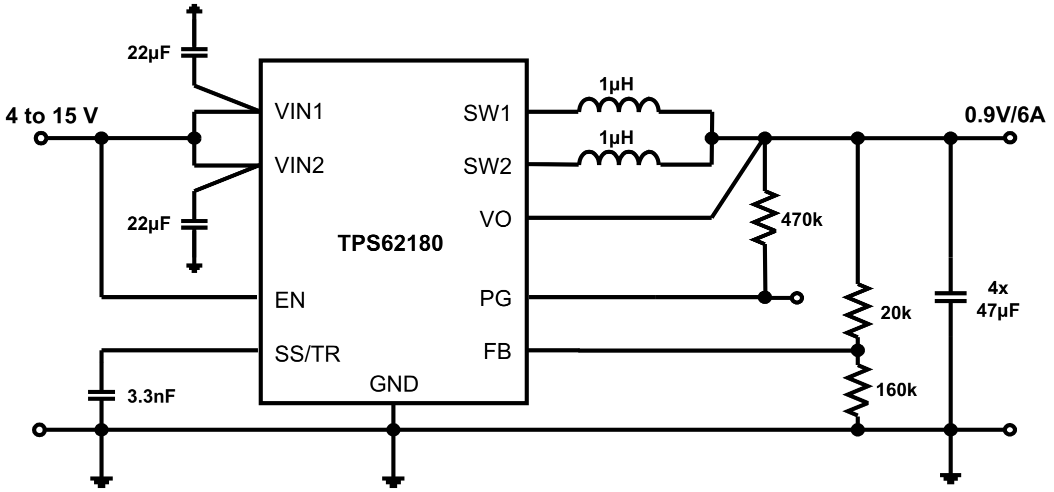


Figure 47. 0.9-V/6-A Power Supply

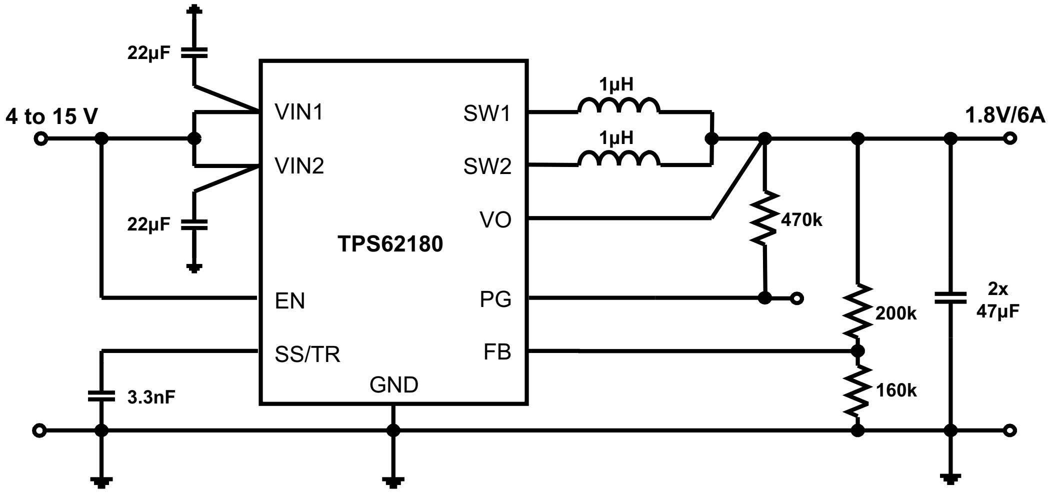


Figure 48. 1.8-V/6-A Power Supply

TPS62180 Output Voltage Application Examples (continued)

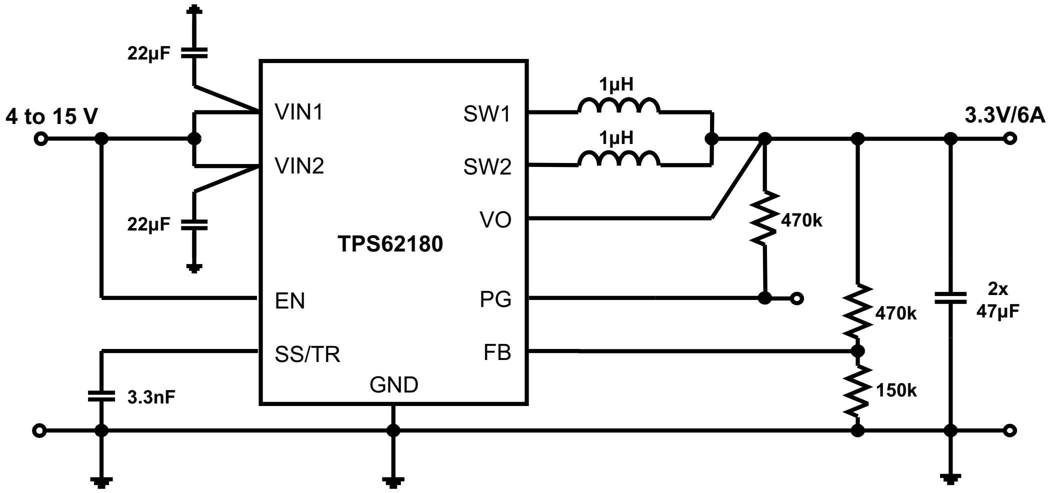


Figure 49. 3.3-V/6-A Power Supply

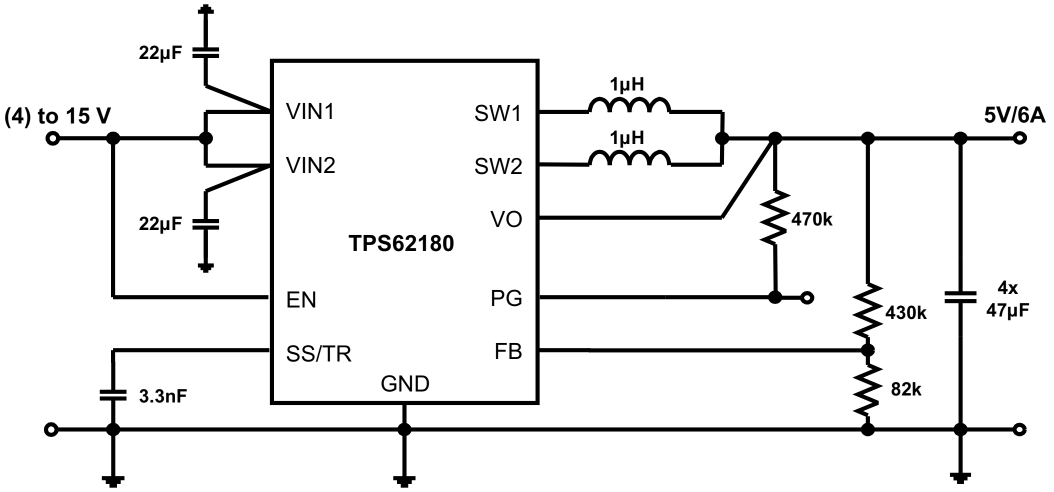


Figure 50. 5-V/6-A Power Supply

10.3.2 Design Requirements

Based on Figure 11, the schematics shown in Figure 47 through Figure 50 show different output voltage divider values to get different V_{OUT}. Another design target is to have about 5-µA current through the divider.

10.3.3 External Component Selection

The values for the voltage divider are derived using the procedure given in Programming the Output Voltage. While Equation 10 and Equation 11 are used to calculate R2 and R1, the values are aligned with standard resistor values.

11 Power Supply Recommendations

The TPS6218x are designed to operate from a 4-V to 15-V input voltage supply. The input power supply's output current needs to be rated according to the output voltage and the output current of the power rail application.

12 Layout

12.1 Layout Guidelines

The PCB layout of the TPS6218x demands careful attention to ensure proper operation, thermal profile, low noise emission and to achieve best performance. A poor layout can lead to issues like poor regulation, stability and accuracy weaknesses, increased EMI radiation and noise sensitivity. While the TPS6218x provides very high power density, the PCB layout also contributes significantly to the thermal performance.

12.1.1 PCB layout

A recommended PCB layout for the TPS62180 dual phase solution is shown below. It ensures best electrical and optimized thermal performance considering the following important topics:

- The input capacitors must be placed as close as possible to the appropriate pins of the device. This provides low resistive and inductive paths for the high di/dt input current. The input capacitance is split, as is the V_{IN} connection, to avoid interference between the input lines.

- The SW node connection from the IC to the inductor conducts high currents. It should be kept short and can be designed in parallel with an internal or bottom layer plane, to provide low resistance and enhanced thermal behavior.

- The V_{OUT} regulation loop is closed with C_{OUT} and its ground connection. If a ground layer or plane is used, a direct connection by vias, as shown, is recommended. Otherwise the connection of C_{OUT} to GND must be short for good load regulation.

- The FB node is sensitive to dv/dt signals. Therefore the resistive divider should be placed close to the FB pin, avoiding long trace distance. Using the TPS62182 (fixed output voltage version), the FB pin can be left floating, but it is good practice and recommended to connect it to AGND for best thermal characteristics.

12.2 Layout Example

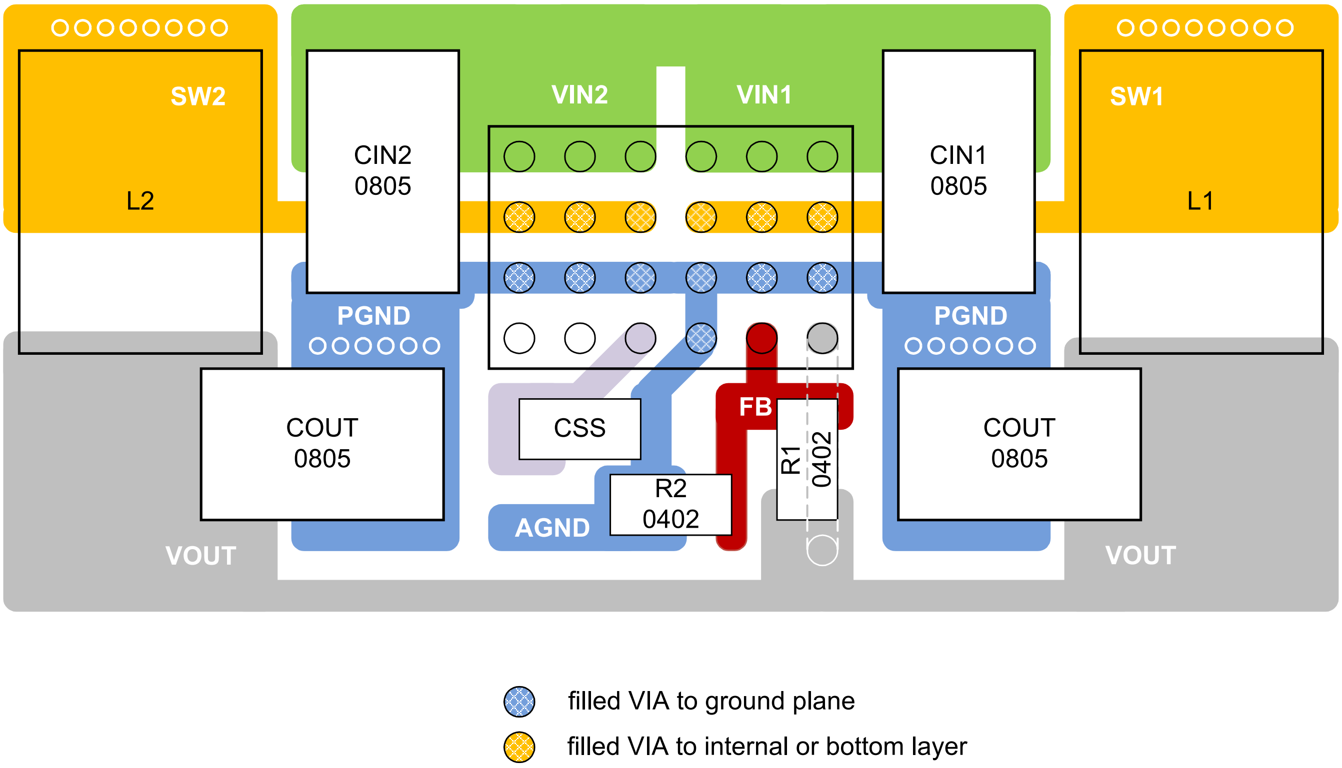


Figure 51. TPS62180 Board Layout

13 Device and Documentation Support

13.1 Device Support

13.1.1 Third-Party Products Disclaimer

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13.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 7. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
TPS62180	Click here	Click here	Click here	Click here	Click here
TPS62182	Click here	Click here	Click here	Click here	Click here

13.3 Trademarks

AEE, NanoFree are trademarks of Texas Instruments.

13.4 Electrostatic Discharge Caution

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

13.5 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS62180YZFR	ACTIVE	DSBGA	YZF	24	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 125	ELC180	Samples
TPS62180YZFT	ACTIVE	DSBGA	YZF	24	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 125	ELC180	Samples
TPS62182YZFR	ACTIVE	DSBGA	YZF	24	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 125	ELC182	Samples
TPS62182YZFT	ACTIVE	DSBGA	YZF	24	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 125	ELC182	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] 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.

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

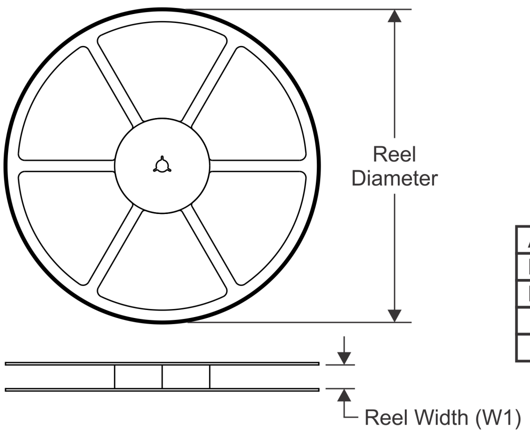
[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

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

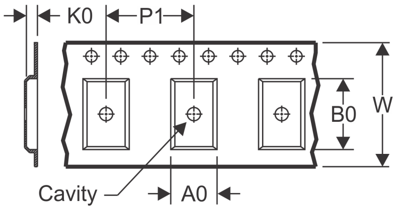
PACKAGE OPTION ADDENDUM

TAPE AND REEL INFORMATION

REEL DIMENSIONS

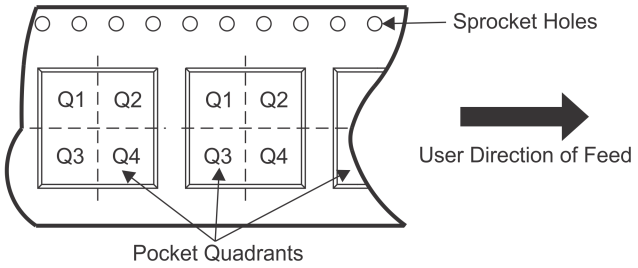


TAPE DIMENSIONS



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

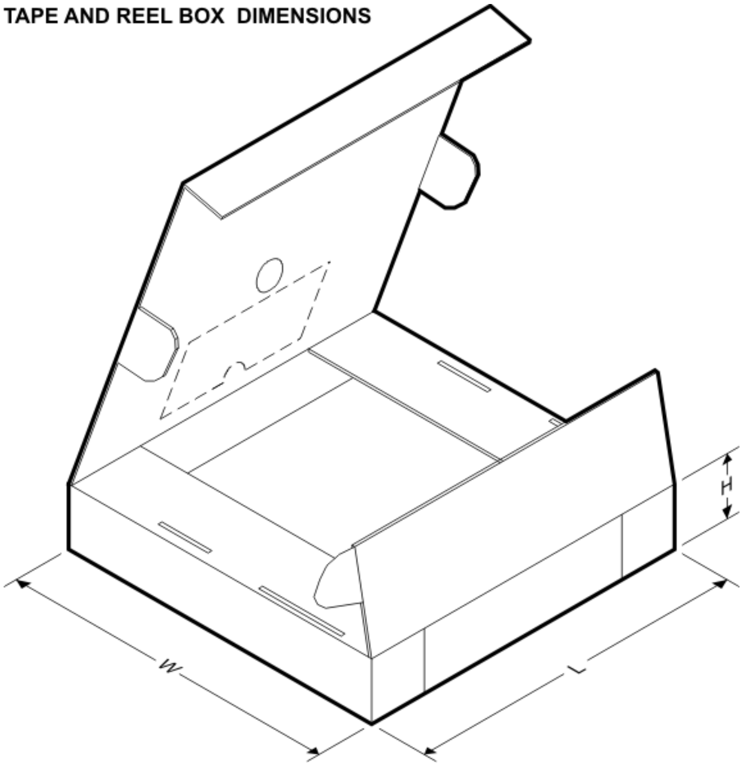
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS62180YZFR	DSBGA	YZF	24	3000	330.0	12.4	2.25	3.25	0.81	4.0	12.0	Q1
TPS62180YZFT	DSBGA	YZF	24	250	330.0	12.4	2.25	3.25	0.81	4.0	12.0	Q1
TPS62182YZFR	DSBGA	YZF	24	3000	330.0	12.4	2.25	3.25	0.81	4.0	12.0	Q1
TPS62182YZFT	DSBGA	YZF	24	250	330.0	12.4	2.25	3.25	0.81	4.0	12.0	Q1

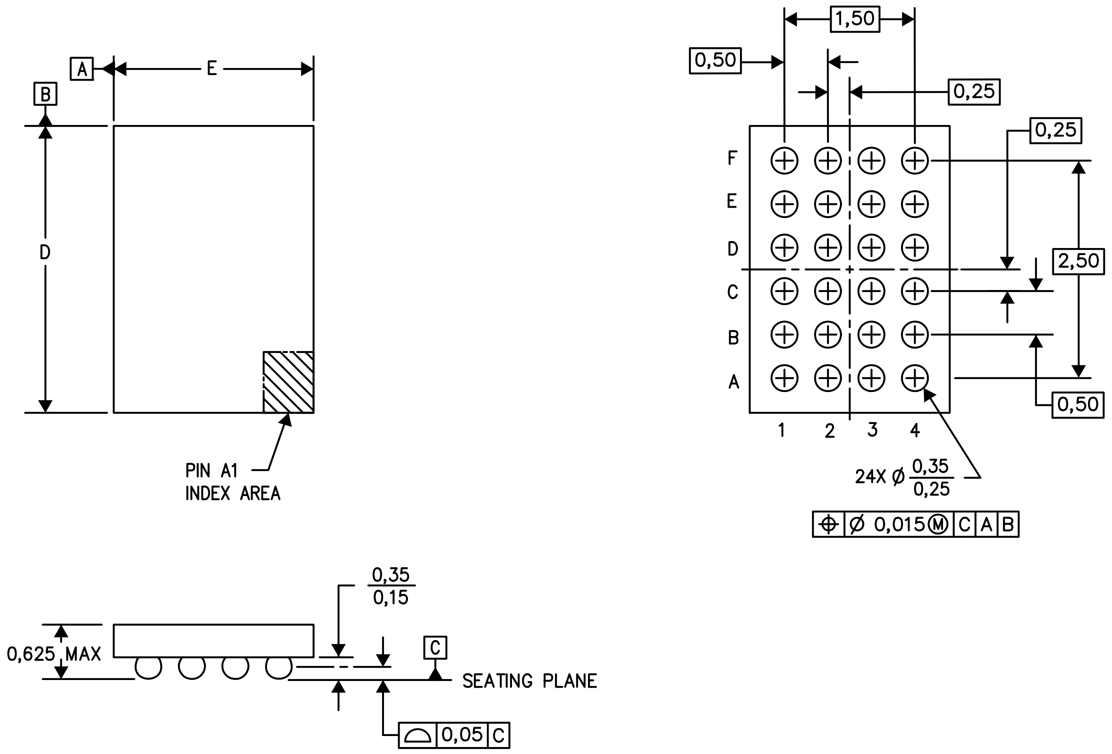
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS62180YZFR	DSBGA	YZF	24	3000	367.0	367.0	35.0
TPS62180YZFT	DSBGA	YZF	24	250	367.0	367.0	35.0
TPS62182YZFR	DSBGA	YZF	24	3000	367.0	367.0	35.0
TPS62182YZFT	DSBGA	YZF	24	250	367.0	367.0	35.0

YZF (R-XBGA-N24) DIE-SIZE BALL GRID ARRAY



D: Max = 3.13 mm, Min = 3.07 mm

E: Max = 2.13 mm, Min = 2.07 mm

4205058-6/P 07/13

NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
- B. This drawing is subject to change without notice.
- C. NanoFree™ package configuration.

NanoFree is a trademark of Texas Instruments.

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