TPS54262-EP 2-A 60-V Step-Down DC-DC Converter With Low I(q) and Voltage Supervisor

1 Features

- Asynchronous Switch Mode Regulator
- Qualified for Automotive Applications
- 3.6-V to 48-V Operating Range, Withstands Transients up to 60 V
- 2-A Maximum Load Current
- 50-µA Typical Quiescent Current
- 200-kHz to 2.2-MHz Switching Frequency
- 0.8 V ± 1.5% Voltage Reference
- High-Voltage Tolerant Enable Input
- Soft Start on Enable Cycle
- Slew Rate Control on Internal Power Switch
- Low-Power Mode for Light-Load Conditions
- Programmable Delay for Power-On Reset
- External Compensation for Error Amplifier
- Reset Function Filter Time for Fast Negative Transients
- Programmable Overvoltage, Undervoltage Output Monitor
- Thermal Sensing and Shutdown
- Switch Current Limit Protection
- Short Circuit and Overcurrent Protection of FET
- Junction Temperature Range: –55°C to 150°C
- 20-Pin HTSSOP PowerPAD™ Package
- **Supports Defense, Aerospace, and Medical Applications:**
  - Controlled Baseline
  - One Assembly/Test Site
  - One Fabrication Site
  - Available in Extended (–55°C to 125°C) Temperature Range
  - Extended Product Life Cycle
  - Extended Product-Change Notification
  - Product Traceability

2 Applications

- Automotive Telematics and eCall
- Automotive Infotainment and Cluster
  - Head Unit
  - Navigation
  - Display

3 Description

The TPS54262-EP device is a 60-V, 2-A step-down switch-mode power supply with a low-power mode and a programmable voltage supervisor with an integrated NMOS switching FET. Integrated input voltage line feed forward topology improves line transient regulation of the voltage mode buck regulator. The regulator has a cycle-by-cycle current limit. The device also features low-power mode operation under light-load conditions which reduces the supply current to 50 µA (typical). By pulling the EN pin low, the supply shutdown current is reduced to 1 µA (typical).

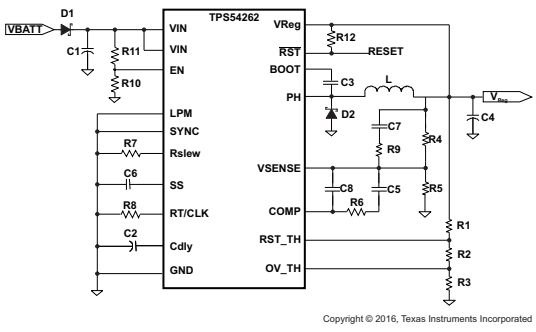
An open-drain reset signal indicates when the nominal output drops below the reset threshold set by an external resistor divider network. The output voltage start-up ramp is controlled by a soft-start capacitor. There is an internal undervoltage shutown which is activated when the input supply ramps down to 2.6 V. The device features a short circuit protection circuit, which protects the device during overload condition and also has a thermal shutdown protection.

Device Information(1)

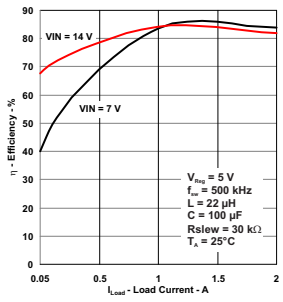
PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS54262-EP	HTSSOP (20)	6.50 mm × 4.40 mm

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

Simplified Schematic



Typical Converter Efficiency



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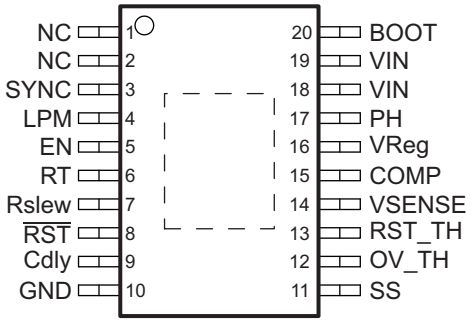
4 Revision History

DATE	REVISION	NOTES
December 2016	*	Initial release.

5 Pin Configuration and Functions

PWP Package
20-Pin HTSSOP
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
NC	1	NC	Connect to ground.
NC	2	NC	Connect to ground.
SYNC	3	I	External synchronization clock input to override the internal oscillator clock. An internal pulldown resistor of 62 kΩ (typical) is connected to ground. Connect this pin to GND if not used.
LPM	4	I	Low-power mode control using digital input signal. An internal pulldown resistor of 62 kΩ (typical) is connected to ground.
EN	5	I	Enable pin, internally pulled up. Must be externally pulled up or down to enable or disable the device.
RT	6	O	External resistor to ground to program the internal oscillator frequency.
Rslew	7	O	External resistor to ground to control the slew rate of internal switching FET.
$\overline{\text{RST}}$	8	O	Active low, open-drain reset output connected to external bias voltage through a resistor, asserted high after the device starts regulating.
Cdly	9	O	External capacitor to ground to program power on reset delay.
GND	10	O	Ground pin, must be electrically connected to the exposed pad on the PCB for proper thermal performance.
SS	11	O	External capacitor to ground to program soft-start time.
OV_TH	12	I	Sense input for overvoltage detection on regulated output, an external resistor network is connected between VReg and ground to program the overvoltage threshold.
RST_TH	13	I	Sense input for undervoltage detection on regulated output, an external resistor network is connected between VReg and ground to program the reset and undervoltage threshold.
VSENSE	14	I	Inverting node of error amplifier for voltage mode control.
COMP	15	O	Error amplifier output to connect external compensation components.
VReg	16	I	Internal low-side FET to load output during start-up or limit overshoot.
PH	17	O	Source of the internal switching FET.
VIN	18	I	Unregulated input voltage. Pin 18 and pin 19 must be connected externally.
VIN	19	I	Unregulated input voltage. Pin 18 and pin 19 must be connected externally.
BOOT	20	O	External bootstrap capacitor to PH to drive the gate of the internal switching FET.

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

			MIN	MAX	UNIT
Input voltage	EN		–0.3	60	V
	VIN		–0.3	60	
	VReg		–0.3	20	
	LPM		–0.3	5.5	
	OV_TH		–0.3	5.5	
	RST_TH		–0.3	5.5	
	SYNC		–0.3	5.5	
	VSENSE		–0.3	5.5	
Output voltage	BOOT		–0.3	65	V
	PH	DC voltage	–0.3	60	
		DC voltage, T_J = –55°C	–0.85		
		DC voltage, T_J = 125°C	–0.5		
		30-ns transient pulse	–2		
		200-ns transient pulse	–1		
	RT		–0.3	5.5	
	$\overline{RST}$		–0.3	5.5	
	Cdly		–0.3	8	
	SS		–0.3	8	
	COMP		–0.3	7	
Operating virtual junction temperature, T_J			–55	150	°C
Storage temperature, T_{stg}			–55	165	°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.

6.2 ESD Ratings

		VALUE	UNIT
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±2000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±750	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

			MIN	NOM	MAX	UNIT
V_I	Unregulated buck supply input voltage (VIN, EN)		3.6		48	V
V_{Reg}	Regulated output voltage	In continuous conduction mode (CCM)	0.9		18	V
		Power up in low-power mode (LPM) or discontinuous conduction mode (DCM)	0.9		5.5	V
	Bootstrap capacitor (BOOT)		3.6		56	V
	Switched outputs (PH)		3.6		48	V
	Logic levels ($\overline{RST}$, VSENSE, OV_TH, RST_TH, Rslew, SYNC, RT)		0		5.25	V
	Logic levels (SS, Cdly, COMP)		0		6.5	V
T_A	Operating ambient temperature		–55		125	°C

6.4 Thermal Information

THERMAL METRIC[1]		TPS54262-EP PWP (HTSSOP) 20 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	37.1	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	20.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	8.7	°C/W
ψ_{JT}	Junction-to-top characterization parameter	0.3	°C/W
ψ_{JB}	Junction-to-board characterization parameter	8.7	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	1.2	°C/W

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

6.5 DC Electrical Characteristics

VIN = 7 V to 48 V, EN = VIN, T_J = –55°C to 150°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		TEST[1]	MIN	TYP	MAX	UNIT
INPUT POWER SUPPLY								
VIN	Supply voltage on VIN	Normal mode: after initial start-up		Info	3.6		48	V
		Low-power mode	Falling threshold (LPM disabled)			8		
			Rising threshold (LPM activated)			8.5		
			High voltage threshold (LPM disabled)		29	31	34	
$I_{q\text{-}Normal}$	Quiescent current, normal mode	Open loop test – maximum duty cycle VIN = 7 V to 48 V		PT		5	10	mA
$I_{q\text{-}LPM}$	Quiescent current, low-power mode	I_{Load} < 1 mA, VIN = 12 V	T_A = 25°C	PT		50	70	µA
			–55 < T_J < 150°C				75	
		I_{Load} < 1 mA, VIN = 24 V	T_A = 25°C				75	
			–55 < T_J < 150°C				75	
I_{SD}	Shutdown current	EN = 0 V, device is off	T_A = 25°C, VIN = 12 V	PT		1	4	µA
TRANSITION TIMES (LOW POWER – NORMAL MODES)								
t_{d1}	Transition delay, normal mode to low-power mode	VIN = 12 V, V_{Reg} = 5 V, I_{Load} = 1 A to 1 mA		CT		100		µs
t_{d2}	Transition delay, low-power mode to normal mode	VIN = 12 V, V_{Reg} = 5 V I_{Load} = 1 mA to 1 A		CT		5		µs
SWITCH MODE SUPPLY; V_{Reg}								
V_{Reg}	Regulator output	VSENSE = 0.8 V_{ref}		Info	0.9		18	V
VSENSE	Feedback voltage	V_{Reg} = 0.9 V to 18 V (open loop)		CT	0.788	0.8	0.812	V
$R_{DS(ON)}$	Internal switch resistance	Measured across VIN and PH, I_{Load} = 500 mA		PT			500	mΩ
I_{CL}	Switch current limit, cycle by cycle	VIN = 12 V		Info	2.5	3.2	4.1	A
$t_{ON\text{-}Min}$	Duty cycle pulse width	Bench CHAR only		Info	50	100	150	ns
$t_{OFF\text{-}Min}$		Bench CHAR only		Info	100	200	250	ns
f_{sw}	Switching frequency	Set using external resistor on RT pin		PT	0.2		2.2	MHz
f_{sw}	Internal oscillator frequency tolerance			PT	–10%		10%	
I_{Sink}	Start-up condition	OV_TH = 0 V, V_{Reg} = 10 V		Info			1	mA
I_{Limit}	Prevent overshoot	0 V < OV_TH < 0.8 V, V_{Reg} = 10 V		Info			80	mA

(1) PT: Production tested
CT: Characterization tested only, not production tested
Info: User information only, not production tested

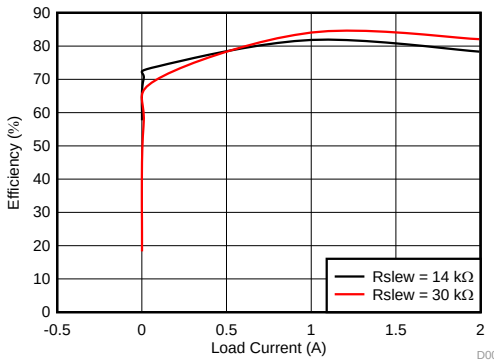
DC Electrical Characteristics (continued)

VIN = 7 V to 48 V, EN = VIN, T_J = –55°C to 150°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	TEST(1)	MIN	TYP	MAX	UNIT
ENABLE (EN)							
V_{IL}	Low input threshold voltage		PT			0.7	V
V_{IH}	High input threshold voltage		PT	1.7			V
I_{lkg}	Leakage current into EN terminal	EN = 60 V	PT		100	135	µA
		EN = 12 V			8	15	
RESET DELAY (Cdly)							
I_O	External capacitor charge current	EN = high	PT	1.4	2	3	µA
$V_{Threshold}$	Switching threshold voltage	Output voltage in regulation	PT		2		V
LOW-POWER MODE (LPM)							
V_{IL}	Low input threshold voltage	VIN = 12 V	PT			0.7	V
V_{IH}	High input threshold voltage	VIN = 12 V	PT	1.7			V
I_{lkg}	Leakage current into LPM terminal	LPM = 5 V	PT		65	95	µA
RESET OUTPUT ($\overline{RST}$)							
t_{rdly}	POR delay timer	Based on Cdly capacitor	PT	3.2		7	ms/nF
VReg_RST	Reset threshold voltage for V_{Reg}	Check RST output	PT	0.768		0.832	V
$t_{nRSTdly}$	Filter time	Delay before $\overline{RST}$ is asserted low	PT	10	20	35	µs
SOFT START (SS)							
I_{SS}	Soft-start source current		PT	40	50	60	µA
SYNCHRONIZATION (SYNC)							
V_{IL}	Low input threshold voltage		PT			0.7	V
V_{IH}	High input threshold voltage		PT	1.7			V
I_{lkg}	Leakage current	SYNC = 5 V	PT		65	95	µA
SYNC (f_{ext})	External input clock frequency	VIN = 12 V, V_{Reg} = 5 V, 180 kHz < f_{sw} < f_{ext} < 2 × f_{sw} < 2.2 MHz	CT	180		2200	kHz
$SYNC_{trans}$	External clock to internal clock	No external clock, VIN = 12 V, V_{Reg} = 5 V	Info		32		µs
$SYNC_{trans}$	Internal clock to external clock	External clock = 1 MHz, VIN = 12 V, V_{Reg} = 5 V	Info		2.5		µs
$SYNC_{CLK}$	Minimum duty cycle		CT	30%			
$SYNC_{CLK}$	Maximum duty cycle		CT			70%	
Rslew							
I_{Rslew}	Rslew = 50 kΩ		CT		20		µA
I_{Rslew}	Rslew = 10 kΩ		CT		100		µA
OVERVOLTAGE SUPERVISORS (OV_TH)							
VReg_OV	Threshold voltage for V_{Reg} during overvoltage	Internal switch is turned off	PT	0.768		0.832	V
	V_{Reg} = 5 V	Internal pulldown on V_{Reg}, OV_TH = 1 V			70(2)		mA
THERMAL SHUTDOWN							
T_{SD}	Thermal shutdown junction temperature		CT		175		°C
T_{HYS}	Hysteresis		CT		30		°C

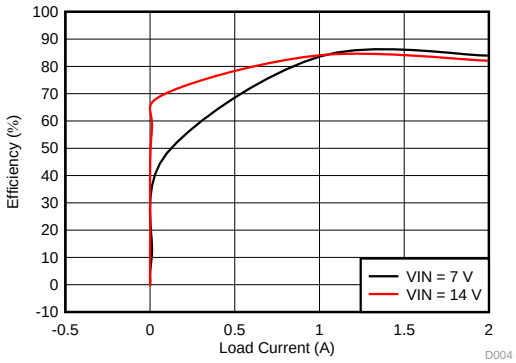
(2) This is the current flowing into the VReg pin when voltage at OV_TH pin is 1 V.

6.6 Typical Characteristics



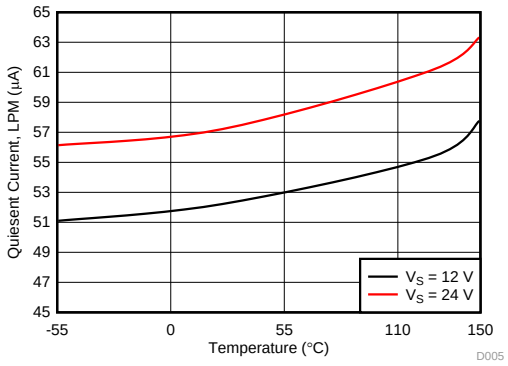
VIN = 14 V V_{Reg} = 5 V f_{sw} = 500 kHz
L = 22 µH C = 100 µF T_A = 25°C

Figure 1. Efficiency vs Load Current for Different Rslew Resistors



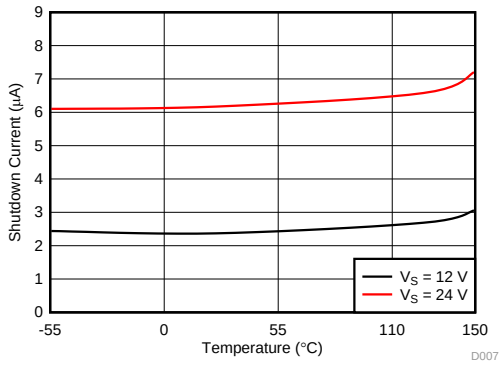
V_{Reg} = 5 V f_{sw} = 500 kHz L = 22 µH
C = 100 µF Rslew = 30 kΩ T_A = 25°C

Figure 2. Efficiency vs Load Current for Different Vin



EN not connected to VIN

Figure 3. LPM, Quiescent Current Variation With Temperature



EN not connected to VIN

Figure 4. Shutdown Current Variation With Temperature

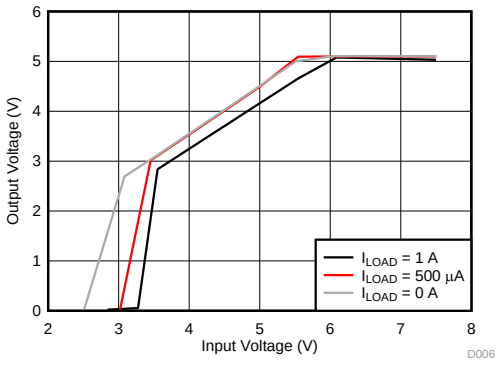
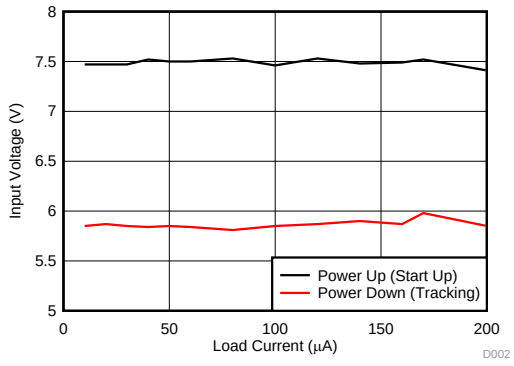


Figure 5. Output Voltage vs Input Voltage for Different Load Currents (1)



V_{Reg} = 5 V T_A = 25°C

Figure 6. Input Voltage vs Load Current During Power Up and Power Down (1)

(1) Figure 5 shows the dropout operation during low input conditions.
Figure 6 shows the following plots:
(a) Power Up (Start Up): Input voltage required to achieve the 5-V regulation during power up over the range of load currents
(b) Power Down (Tracking): Input voltage at which the output voltage drops approximately by 0.7 V from the programmed 5-V regulated voltage

Typical Characteristics (continued)

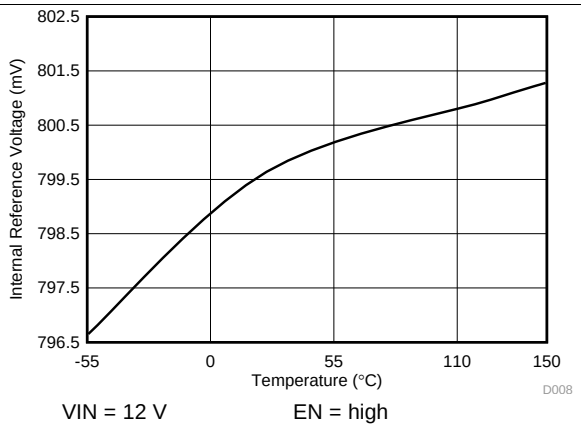


Figure 7. Internal Reference Voltage

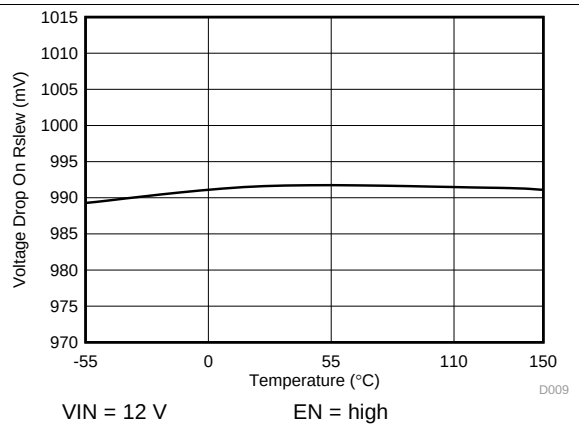


Figure 8. Voltage Drop ON Rslew for Current Reference (Slew Rate / Rslew)

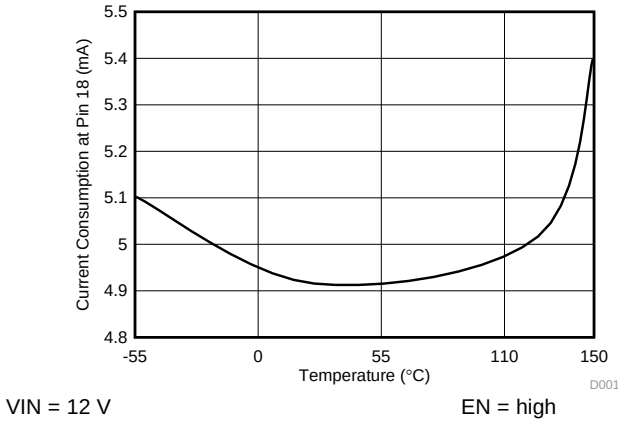


Figure 9. Current Consumption With Temperature

7 Detailed Description

7.1 Overview

The TPS54262-EP device is a 60-V, 2-A DC-DC step down (buck) converter using voltage-control mode scheme. The device features a supervisory function for power-on-reset during system power on. Once the output voltage has exceeded the threshold set by RST_TH pin, a delay of 1 ms/nF (based on capacitor value on Cdly terminal) is invoked before the $\overline{RST}$ line is released high. Conversely on power down, once the output voltage falls below the same set threshold, the $\overline{RST}$ line is pulled low only after a deglitch filter of approximately 20 µs (typical) expires. This is implemented to prevent reset from being triggered due to fast transient line noise on the regulated output supply.

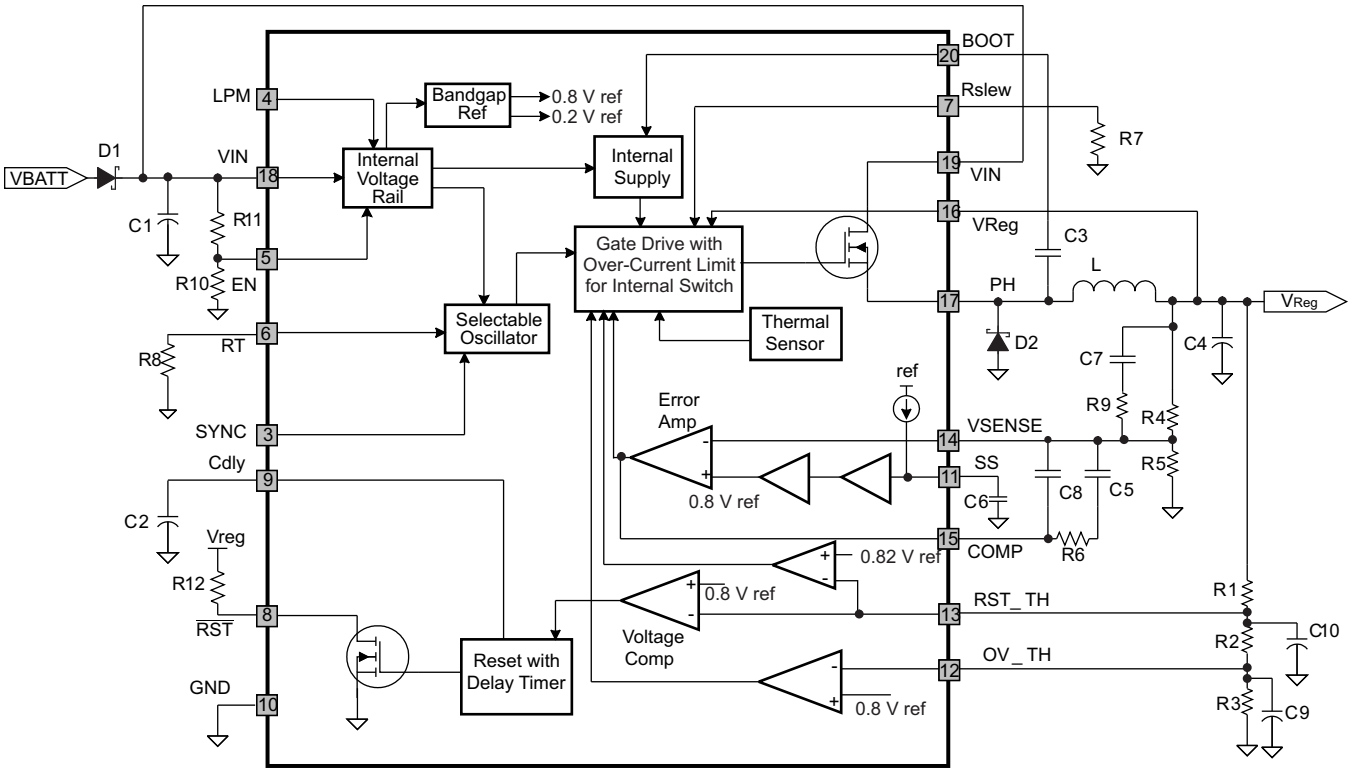
An overvoltage monitor function is used to limit regulated output voltage to the threshold set by OV_TH pin. Both the RST_TH and OV_TH monitoring voltages are set to be a prescale of the output voltage, and thresholds based on the internal bias voltages of the voltage comparators (0.8-V typical).

Detection of undervoltage on the regulated output is based on the RST_TH setting and will invoke $\overline{RST}$ line to be asserted low. Detection of overvoltage on the output is based on the OV_TH setting and will not invoke the $\overline{RST}$ line to be asserted low. However, the internal switch is commanded to turn OFF.

In systems where power consumption is critical, low-power mode (LPM) is implemented to reduce the non-switching quiescent current during light-load conditions. After the device has been operating in discontinuous conduction mode (DCM) for at least 100 µs (typical), depending upon the load current, it may enter in pulse skip mode (PSM). The operation of when the device enters DCM is dependent on the selection of the external components.

If thermal shutdown is invoked due to excessive power dissipation, the internal switch is disabled and the regulated output voltage starts to decrease. Depending on the load current, the regulated output voltage could decay and the RST_TH threshold may assert the $\overline{RST}$ output low.

7.2 Functional Block Diagram



7.3 Feature Description

The TPS54262-EP device is a DC-DC converter using a voltage-control mode scheme with an input voltage feed-forward technique. The device can be programmed for a range of output voltages with a wide input voltage range. The following sections provide details regarding setting up the device, detailed functionality, and the modes of operation.

7.3.1 Unregulated Input Voltage

The input voltage is supplied through VIN pins (pin 18 and 19) which must be externally protected against voltage levels greater than 60 V and reverse input polarity. An external diode is connected to protect these pins from reverse input polarity. The input current drawn from this pin is pulsed, with fast rise and fall times. Therefore, this input line requires a filter capacitor to minimize noise. Additionally, for EMI considerations, an input filter inductor may also be required.

NOTE

For design considerations, VIN/V_{Reg} ratios should always be set such that the minimum required duty cycle pulse (t_{ON-Min}) is greater than 150 ns. The minimum off time ($t_{OFF-Min}$) is 250 ns for all conditions.

7.3.2 Regulated Output Voltage

The regulated output voltage (V_{Reg}) is fed back to the device through VReg pin (pin 16). Typically, an output capacitor of value within range of 10 µF to 400 µF is connected at this pin. TI also recommends using a filter capacitor with low ESR characteristics to minimize ripple in regulated output voltage. The VReg pin is also internally connected to a load of approximately 100 Ω, which is turned ON in the following conditions:

- During start-up condition, when the device is powered up with no-load, or whenever EN is toggled, the internal load connected to VReg pin is turned ON to charge the bootstrap capacitor to provide gate drive voltage to the switching transistor.
- During normal operating conditions, when the regulated output voltage (V_{Reg}) exceeds the overvoltage threshold (VReg_OV, preset by external resistors R1, R2, and R3), the internal load is turned ON, and this pin is pulled down to bring the regulated output voltage down.
- When VIN is less than typical VIN falling threshold level while LPM is disabled. From device specifications, VIN typical falling threshold (LPM disabled) = 8 V (see *DC Electrical Characteristics*).
- When $\overline{RST}$ is low.

7.3.3 Regulation and Feedback Voltage

The regulated output voltage (V_{Reg}) can be programmed by connecting external resistor network at VSENSE pin (pin 14). The output voltage is selectable from 0.9 V to 18 V according to the following relationship:

$$V_{Reg} = V_{ref}\left(1 + \frac{R4}{R5}\right) \quad (1)$$

where

- R4, R5 = feedback resistors (see *Functional Block Diagram*)
- V_{ref} = 0.8 V (typical)

The overall tolerance of the regulated output voltage is given by Equation 2.

$$tol_{VReg} = tol_{Vref} + \frac{R4}{R4 + R5} \times (tol_{R4} + tol_{R5}) \quad (2)$$

where

- tol_{Vref} = tolerance of internal reference voltage (tol_{Vref} = ± 1.5%)
- tol_{R4},tol_{R5} = tolerance of feedback resistors R4, R5

For a tighter tolerance on V_{Reg}, lower-value feedback resistors can be selected. However, for proper operation in low-power mode (see Figure 17), TI recommends keeping R4 + R5 around 250 kΩ (typical).

The output tracking depends upon the loading conditions and is explained in Table 1 and is shown in Figure 6.

Feature Description (continued)

Table 1. Load Conditions

LOAD CONDITION	OUTPUT TRACKING
Nominal load in CCM	V_{Reg} tracks VIN approximately as: V_{Reg} = 95% (VIN – I_{Load} × 0.5)
No load/light load in LPM	To enable the tracking feature, following conditions should be met: 1) f_{SW} < 600 kHz 2) V_{Reg} < 8 V, typical (related to VIN falling threshold when LPM is disabled)

7.3.4 Enable and Shutdown

The EN pin (pin 5) provides electrical ON/OFF control of the regulator. Once the EN pin voltage exceeds the upper threshold voltage (V_{IH}), the regulator starts operating and the internal soft start begins to ramp. If the EN pin voltage is pulled below the lower threshold voltage (V_{IL}), the regulator stops switching and the internal soft start resets. Connecting this pin to ground or to any voltage less than V_{IL} disables the regulator and causes the device to shut down. This pin must have an external pullup or pulldown to change the state of the device.

7.3.5 Soft Start

An external soft-start capacitor is connected to SS pin (pin 11) to set the minimum time to reach the desired regulated output voltage (V_{Reg}) during power-up cycle. This prevents the output voltage from overshooting when the device is powered up. This is also useful when the load requires a controlled voltage slew rate, and also helps to limit the current drawn from the input voltage supply line.

For proper operation, the following conditions must be satisfied during power up and after a short circuit event:

- VIN – V_{Reg} > 2.5 V
- Load current < 1 A, until $\overline{RST}$ goes high

The power-up current limit (30% of the typical current limit value) is released after the feedback voltage (at VSENSE pin) is high enough such that $\overline{RST}$ is asserted high. The recommended value of soft-start capacitor is 100 nF (typical) for start-up load current of 1 A (maximum).

7.3.6 Oscillator Frequency

The oscillator frequency can be set by connecting an external resistor (R8 in *Functional Block Diagram*) to RT pin (pin 6). Figure 10 shows the relation between the resistor value (RT) and switching frequency (f_{sw}). The switching frequency can be set in the range 200 kHz to 2200 kHz. In addition, the switching frequency can be imposed externally by a clock signal (f_{ext}) at the SYNC pin.

7.3.6.1 Selecting the Switching Frequency

A power supply switching at a higher switching frequency allows use of lower value inductor and smaller output capacitor compared to a power supply that switches at a lower frequency. Typically, the user will want to choose the highest switching frequency possible because this will produce the smallest solution size. The switching frequency that can be selected is limited by the following factors:

- The input voltage
- The minimum target regulated voltage
- Minimum on-time of the internal switching transistor
- Frequency shift limitation

Selecting lower switching frequency results in using an inductor and capacitor of a larger value, where as selecting higher switching frequency results in higher switching and gate drive power losses. Therefore, a tradeoff must be made between physical size of the power supply and the power dissipation at the system/ application level.

The minimum and maximum duty cycles can be expressed in terms of input and output voltage as shown in Equation 3.

$$D_{Min} = \frac{V_{Reg\text{-}Min}}{VIN_{Max}} \quad \text{and} \quad D_{Max} = \frac{V_{Reg\text{-}Min}}{VIN_{Min}} \tag{3}$$

where

- D_{Min} = minimum duty cycle
- D_{Max} = maximum duty cycle
- VIN_{Min} = minimum input voltage
- VIN_{Max} = maximum input voltage
- $V_{Reg\text{-}Min}$ = minimum regulated output voltage
- $V_{Reg\text{-}Max}$ = maximum regulated output voltage

Maximum switching frequency can be calculated using Equation 4.

$$f_{sw\text{-}Max} = \frac{V_{Reg\text{-}Min} / VIN_{Max}}{t_{ON\text{-}Min}} \tag{4}$$

where

- $f_{sw\text{-}Max}$ = maximum switching frequency
- $t_{ON\text{-}Min}$ = minimum on-time of the NMOS switching transistor

Knowing the switching frequency, the value of resistor to be connected at RT pin can be calculated using the graph shown in Figure 10. Consider the oscillator tolerance (±10%) while selecting the external RT resistor. For example if f_{sw} = 2.2 MHz is required, select the RT resistor which corresponds to f_{sw} = 2 MHz in Figure 10 to allow +10% oscillator tolerance.

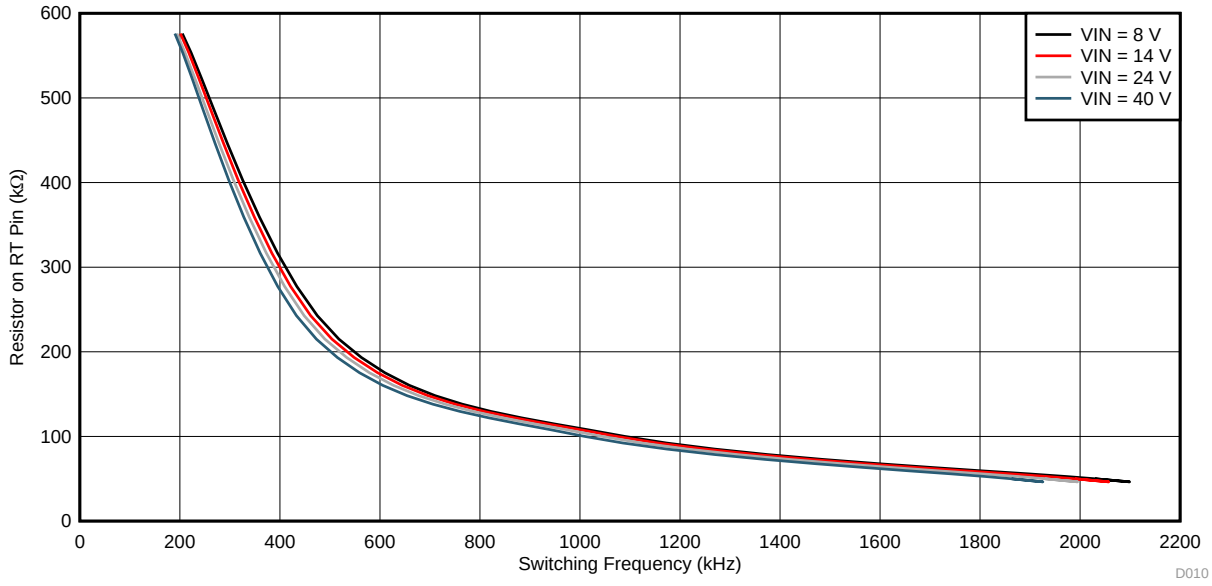


Figure 10. Switching Frequency vs Resistor Value

7.3.6.2 Synchronization With External Clock

An external clock signal can be supplied to the device through SYNC pin (pin 3) to synchronize the internal oscillator frequency with an external clock frequency. The synchronization input overrides the internal fixed oscillator signal. The synchronization signal must be valid for approximately two clock cycles before the transition is made for synchronization with the external frequency input. If the external clock input does not transition low or high for 32 µs (typical), the system defaults to the internal clock set by the resistor connected to the RT pin. The SYNC input can have a frequency according to Equation 5.

$$180\ \text{kHz} < f_{sw} < f_{ext} < 2 \times f_{sw} < 2.2\ \text{MHz} \quad (5)$$

where

- f_{sw} = oscillator frequency determined by resistor connected to the RT pin
- f_{ext} = frequency of the external clock fed through SYNC pin

For example, if the resistor connected at RT pin is selected such that the switching frequency (f_{sw}) is 500 kHz, then the external clock can have a frequency (f_{ext}) from 500 kHz to 1000 kHz. But, if the resistor connected at RT pin is selected such that the switching frequency (f_{sw}) is 1500 kHz, then the external clock can have a frequency (f_{ext}) from 1500 kHz to 2200 kHz only.

If the external clock goes off for less than 32 µs, the NMOS switching FET is turned off and the output voltage starts decreasing. Depending upon the load conditions, the output voltage may hit the undervoltage threshold and reset threshold before the external clock appears. The NMOS switching FET stays OFF until the external clock appears again. If the output voltage hits the reset threshold, the $\overline{\text{RST}}$ pin is asserted low after a deglitch time of 20 µs (typical).

If the external clock goes off for more than 32 µs, the NMOS switching FET is turned off and the output voltage starts decreasing. Under this condition the default internal oscillator clock set by RT pin overrides the external after 32 µs and the NMOS switching FET resumes switching. When the external clock appears again (such that 180 kHz < f_{sw} < f_{ext} < 2 × f_{sw} < 2.2 MHz), the NMOS switching FET starts switching at the frequency determined by the external clock.

7.3.7 Slew Rate Control

The slew rate of the NMOS switching FET can be set by using an external resistor (R7 in *Functional Block Diagram*). The range of rise times and fall times for different values of slew resistor are shown in Figure 11 and Figure 12.

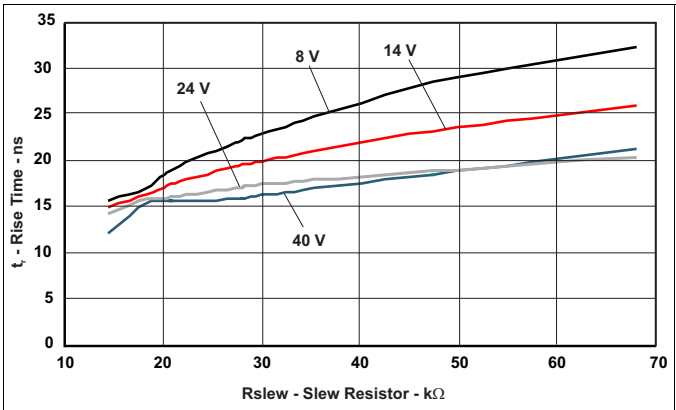


Figure 11. FET Rise Time

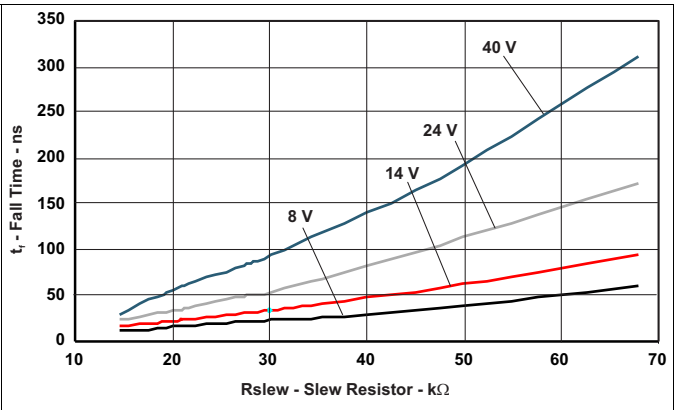


Figure 12. FET Fall Time

7.3.8 Reset

The $\overline{RST}$ pin (pin 8) is an open-drain output pin used to indicate external digital devices and loads if the device has powered up to a programmed regulated output voltage properly. This pin is asserted low until the regulated output voltage (V_{Reg}) exceeds the programed reset threshold (VREG_RST, see Equation 8) and the reset delay timer (set by Cdly pin) has expired. Additionally, whenever the EN pin is low or open, $\overline{RST}$ is immediately asserted low regardless of the output voltage. There is a reset filter timer to prevent reset being invoked due to short negative transients on the output line. If thermal shutdown occurs due to excessive thermal conditions, this pin is asserted low when the switching FET is commanded OFF and the output falls below the reset threshold.

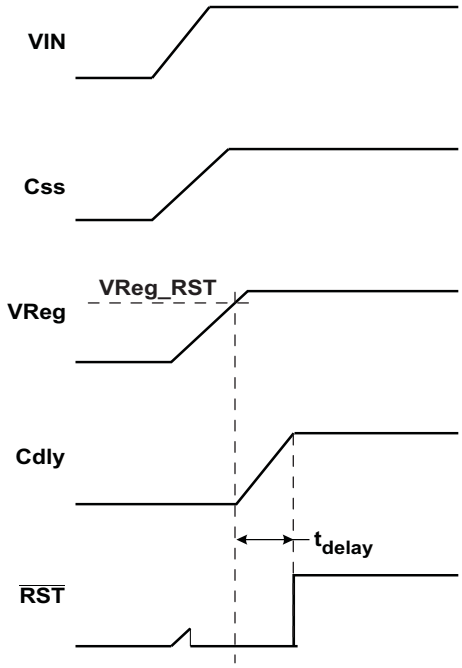


Figure 13. Power-On Condition and Reset Line

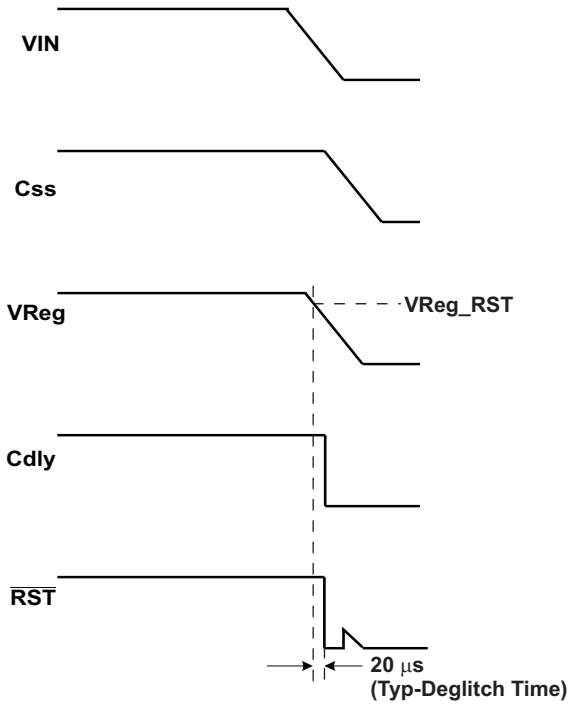


Figure 14. Power-Down Condition and Reset Line

7.3.9 Reset Delay

The delay time to assert the $\overline{\text{RST}}$ pin high after the supply has exceeded the programmed VReg_RST voltage (see Equation 8 to calculate VReg_RST) can be set by external capacitor (C2 in *Functional Block Diagram*) connected to the Cdly pin (pin 9). The delay may be programmed in the range of 2.2 ms to 200 ms using a capacitor in the range of 2.2 nF to 200 nF. The delay time is calculated using Equation 6:

$$\text{PORdly} = \frac{1\,\text{ms}}{\text{nF}} \times \text{C} \tag{6}$$

where

- C = capacitor on Cdly pin

7.3.10 Reset Threshold and Undervoltage Threshold

The undervoltage threshold (VReg_UV) level for proper regulation in low-power mode and the reset threshold level (VReg_RST) to initiate a reset output signal can be programmed by connecting an external resistor string to the RST_TH pin (pin 13). The resistor combination of R1, R2, and R3 is used to program the threshold for detection of undervoltage. Voltage bias on R2 + R3 sets the reset threshold.

Undervoltage threshold for transient and low-power mode operation is given by the Equation 7. The recommended range for VReg_UV is 73% to 95% of V_{Reg}.

$$\text{VReg\_UV} = \frac{\text{R1} + \text{R2} + \text{R3}}{\text{R2} + \text{R3}} \times 0.82\ \text{V} \tag{7}$$

Reset threshold is given by Equation 8. The recommended range for VReg_RST is 70% to 92% of V_{Reg}.

$$\text{VReg\_RST} = \frac{\text{R1} + \text{R2} + \text{R3}}{\text{R2} + \text{R3}} \times 0.8\ \text{V} \tag{8}$$

7.3.11 Overvoltage Supervisor

The overvoltage monitoring of the regulated output voltage, V_{Reg} can be achieved by connecting an external resistor string to the OV_TH pin (pin 12). The resistor combination of R1, R2, and R3 is used to program the threshold for detection of overvoltage. The bias voltage of R3 sets the overvoltage threshold and the accuracy of regulated output voltage in hysteretic mode during transient events.

$$VReg\_OV = \frac{R1 + R2 + R3}{R3} \times 0.8\ V \quad (9)$$

Recommended range for VReg_OV is 106% to 110% of V_{Reg}.

7.3.12 Noise Filter on RST_TH and OV_TH Terminals

External capacitors may be required to filter the noise added to RST_TH and OV_TH terminals. The noise is more pronounced with fast falling edges on the PH pin. Therefore, selecting a smaller Rslew resistor (R7 in *Functional Block Diagram*) for a higher slew rate will require more external capacitance to filter the noise.

The RC time constant depends on external components (R2, R3, C9 and C10 in *Functional Block Diagram*) connected to RST_TH and OV_TH pins. For proper noise filtering, improved loop transient response and better short circuit protection, Equation 10 must be satisfied.

$$(R2 + R3) \times (C9 + C10) < 2\ \mu s \quad (10)$$

To meet this requirement, TI recommends to use lower values of external capacitors and resistors. The value of the time constant is also affected by the PCB capacitance and the application setup. Therefore, in some cases the external capacitors (C9, C10) on RST_TH and OV_TH terminals may not be required. Users can place a footprint on the application PCB and only populate it if necessary. Also, the external resistors (R1, R2, R3) must be sized appropriately to minimize any significant effect of board leakage.

For most cases, TI recommends keeping the external capacitors (either from board capacitance or by connecting external capacitors) between 10 pF to 100 pF; therefore, to meet time constant requirement in Equation 10, the total external resistance (R1 + R2 + R3) should be less than 200 kΩ.

7.3.13 Boot Capacitor

An external boot strap capacitor (C3 in *Functional Block Diagram*) is connected to pin 20 (BOOT) to provide the gate drive voltage for the internal NMOS switching FET. TI recommends X7R or X5R grade dielectrics because of their stable values over temperature. The capacitor value may need to be adjusted higher for high V_{Reg} and/or low frequencies applications (for example, 100 nF for 500 kHz/5 V and 220 nF for 500 kHz/8 V).

7.3.14 Short Circuit Protection

The TPS54262-EP features an output short circuit protection. Short circuit conditions are detected by monitoring the RST_TH pin, and when the voltage on this node drops below 0.2 V, the switching frequency is decreased and current limit is folded back to protect the device. The switching frequency is folded back to approximately 25 kHz and the current limit is reduced to 30% of the typical current limit value.

7.3.15 Overcurrent Protection

The device features overcurrent protection to protect it from load currents greater than 2 A. Overcurrent protection is implemented by sensing the current through the NMOS switching FET. The sensed current is compared to a current reference level representing the overcurrent threshold limit (I_{CL}). If the sensed current exceeds the overcurrent threshold limit, the overcurrent indicator is set true. The system will ignore the overcurrent indicator for the leading edge blanking time at the beginning of each cycle to avoid any turnon noise glitches.

Once overcurrent indicator is set true, overcurrent protection is triggered. The NMOS switching FET is turned off for the rest of the cycle after a propagation delay. The overcurrent protection scheme is called cycle-by-cycle current limiting. If the sensed current continues to increase during cycle-by-cycle current limiting, the temperature of the part will start rising, the TSD will kick in and shutdown switching until the part cools down.

7.3.16 Internal Undervoltage Lockout (UVLO)

This device is enabled on power up once the internal bandgap and bias currents are stable; this happens typically at VIN = 3.4 V (minimum). On power down, the internal circuitry is disabled at VIN = 2.6 V (maximum).

7.3.17 Thermal Shutdown (TSD)

The TPS54262-EP protects itself from overheating with an internal thermal shutdown (TSD) circuit. If the junction temperature exceeds the thermal shutdown trip point, the NMOS switching FET is turned off. The device is automatically restarted under the control of soft-start circuit when the junction temperature drops below the thermal shutdown hysteretic trip point. During low-power mode operation, the thermal shutdown sensing circuitry is disabled for reduced current consumption. If V_{Reg} drops below VReg_UV, thermal shutdown monitoring is activated.

7.3.18 Loop Control Frequency Compensation – Type 3

Type 3 compensation has been used in the feedback loop to improve the stability of the convertor and regulation in the output in response to the changes in input voltage or load conditions. This becomes important because the ceramic capacitors used to filter the output have a low Equivalent Series Resistance (ESR). Type 3 compensation is implemented by connecting external resistors and capacitors to the COMP pin (output of the error amplifier, pin 15) of the device as shown in Figure 15.

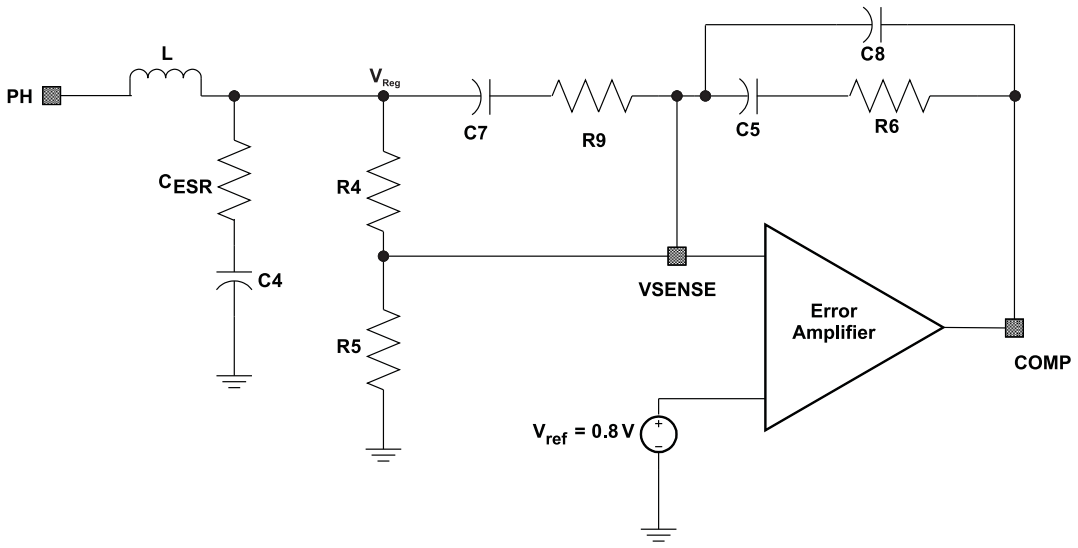


Figure 15. Type 3 Compensation

The crossover frequency should be less than 1/5th to 1/10th of the switching frequency, and should be greater than five times the double pole frequency of the LC filter.

$f_c < f_{sw} \times (0.1 \text{ to } 0.2)$

where

- f_{sw} = switching frequency (11)

The modulator break frequencies as a function of the output LC filter are derived from Equation 12 and Equation 13. The LC output filter gives a double pole that has a –180° phase shift.

$$f_{LC} = \frac{1}{2\pi\sqrt{LC}}$$

where

- L = output inductor
- C = output capacitor (C4 in functional block diagram) (12)

The ESR of the output capacitor C gives a ZERO that has a 90° phase shift.

$$f_{ESR} = \frac{1}{2\pi C \times ESR}$$

where

- ESR = Equivalent series resistance of a capacitor at a specified frequency (13)

The regulated output voltage, V_{Reg} is given by Equation 14.

$$V_{Reg} = V_{ref}\left(1 + \frac{R4}{R5}\right) \quad (14)$$

$$\frac{V_{Reg}}{0.8} = \frac{R4 + R5}{R5} \quad (15)$$

For VIN = 8 V to 50 V, the VIN/V_{ramp} modulator gain is approximately 10 and has a tolerance of about 20%.

$$\text{Gain} = A_{mod} = \frac{VIN}{V_{ramp}} = 10 \quad (16)$$

Therefore,

$$\text{Gain (dB)} = 20 \times \log\left(\frac{VIN}{V_{ramp}}\right) = 20 \times \log(10) = 20\ \text{dB} \quad (17)$$

Also, V_{ramp} is fixed for the following range of VIN. V_{ramp} = 1 V for VIN < 8 V, and V_{ramp} = 5 V for VIN > 48 V.

The frequencies for poles and zeros are given by following equations.

$$fp1 = \frac{(C5 + C8)}{2\pi \times R6 \times (C5 \times C8)} \quad (18)$$

$$fp2 = \frac{1}{2\pi \times R9 \times C7} \quad (19)$$

$$fz1 = \frac{1}{2\pi \times R6 \times C5} \quad (20)$$

$$fz2 = \frac{1}{2\pi \times (R4 + R9) \times C7} \quad (21)$$

Guidelines for selecting compensation components selection are provided in the *Application and Implementation* section of this document.

7.3.18.1 Bode Plot of Converter Gain

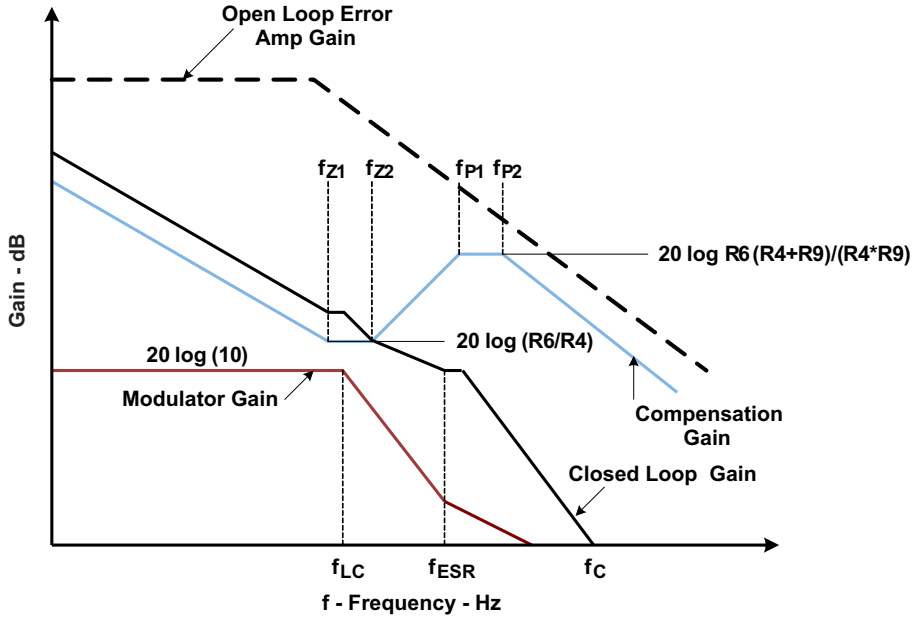


Figure 16. Bode Plot of Converter Gain Plot

7.4 Device Functional Modes

TPS54262-EP operates in the following modes based on the output loading conditions, input voltage, and LPM pin configuration. These operating conditions and modes of operations are shown in Figure 17.

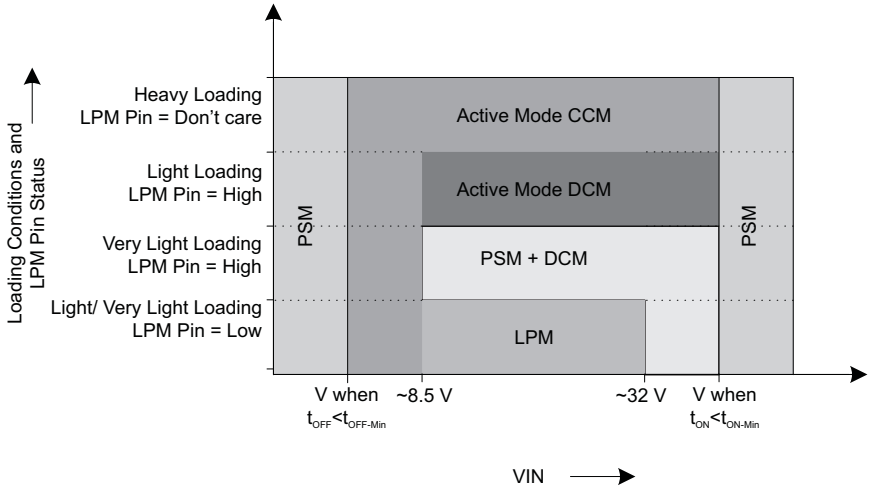


Figure 17. Modes of Operation

7.4.1 Active Mode Continuous Conduction Mode (CCM)

In this mode of operation the switcher operates in continuous conduction mode, and the inductor current is always non-zero if the total load current (internal and external) is greater than $I_{L\_DISCONT}$ shown in Equation 22.

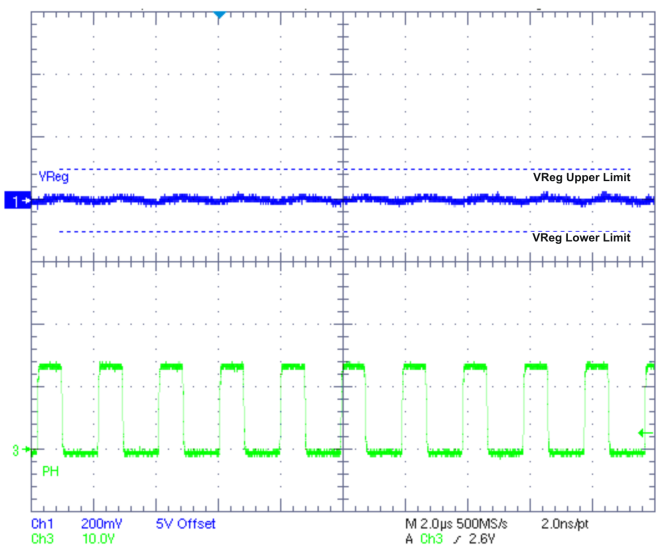
$$I_{L\_DISCONT} = I_{L\_LPM} = \frac{(1-D)\cdot V_{Reg}}{2\cdot f_{sw}\cdot L} \quad (22)$$

where

- D = duty cycle
- L = output inductor
- V_{Reg} = output voltage
- f_{sw} = switching frequency

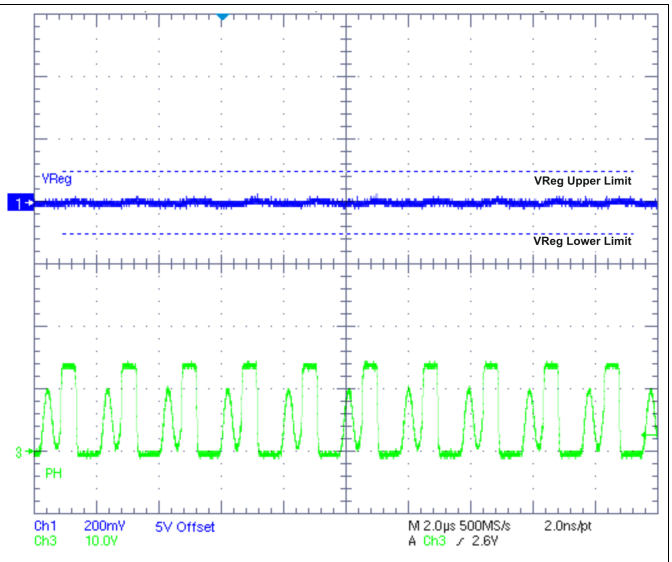
For VIN < 8.5 V, the device enables an internal approximately 100-Ω load. This, combined with the external load, can cause the device to enter into CCM even under light external loading conditions (see *Device Functional Modes*). This mode of operation is shown in Figure 18 is also called the Normal mode of operation.

Device Functional Modes (continued)



VIN = 14 V ILoad = 1 A f_{sw} = 500 kHz
LPM pin = don't care

Figure 18. Active Mode CCM



VIN = 14 V ILoad = 55 mA f_{sw} = 500 kHz
LPM pin = disable

Figure 19. Active Mode DCM

7.4.2 Active Mode Discontinuous Conduction Mode (DCM)

In this mode of operation the switcher operates in discontinuous conduction mode, and the inductor current becomes zero if the total load current (internal and external) is less than $I_{L\_DISCONT}$ shown in Equation 23.

$$I_{L\_DISCONT} = I_{L\_LPM} = \frac{(1-D)\cdot V_{Reg}}{2\cdot f_{sw}\cdot L} \tag{23}$$

The device enters in this mode of operation when LPM pin is set high (disabled) and output loading is less than $I_{L\_DISCONT}$. This mode of operation is shown in Figure 19.

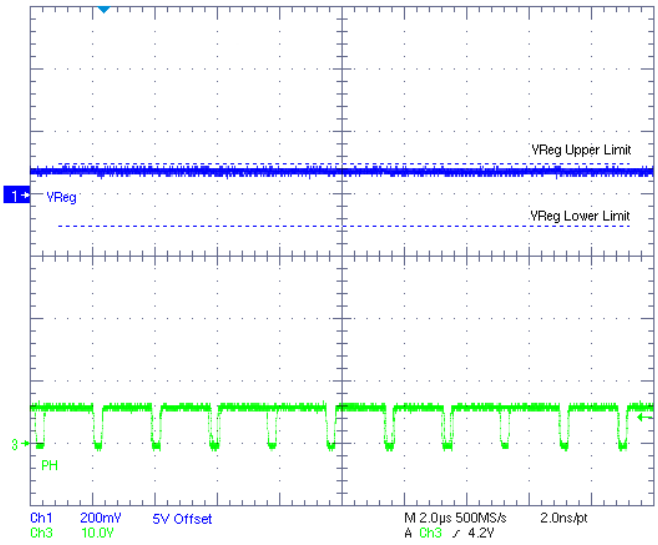
7.4.3 Pulse Skip Mode (PSM)

In this mode of operation the switcher operates in discontinuous conduction mode, and the inductor current becomes zero. The device enters in this mode of operation in the following conditions:

- At low input voltages when V_{Reg} starts losing regulation and the OFF time (t_{OFF}) of the switching FET tends to be close to or slightly less than the minimum OFF time ($t_{OFF\text{-}Min}$). If OFF time is much smaller than $t_{OFF\text{-}Min}$, there is a risk that the part stops switching and regulation is lost until power is re-cycled with OFF time greater than $t_{OFF\text{-}Min}$. This mode of operation is shown in Figure 21. Comparing Figure 20 and Figure 21, pulse skipping occurs in Figure 21 but not in Figure 20 under similar output loading conditions.

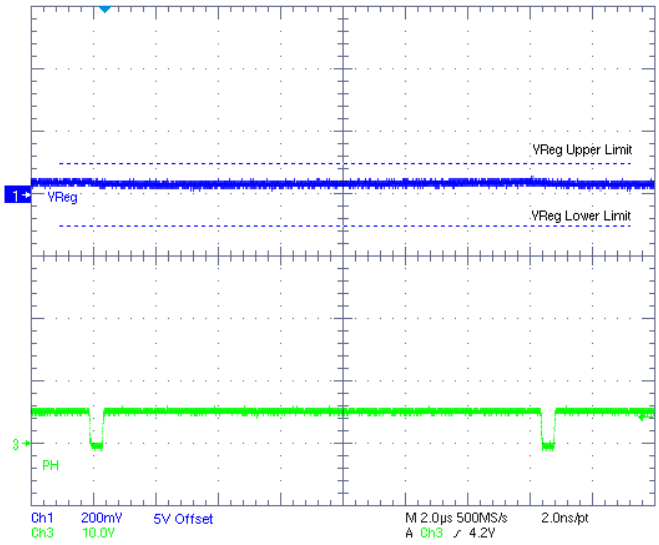
$$VIN - I_{Load}\times R_{DS(ON)} \lesssim V_{Reg} \quad \text{and} \quad \left(1 - \frac{V_{Reg}}{VIN}\right)\times\frac{1}{f_{sw}} > t_{OFF\text{-}Min} \tag{24}$$

Device Functional Modes (continued)



VIN = 6.2 V ILoad = 50 mA f_{sw} = 500 kHz
LPM pin = don't care

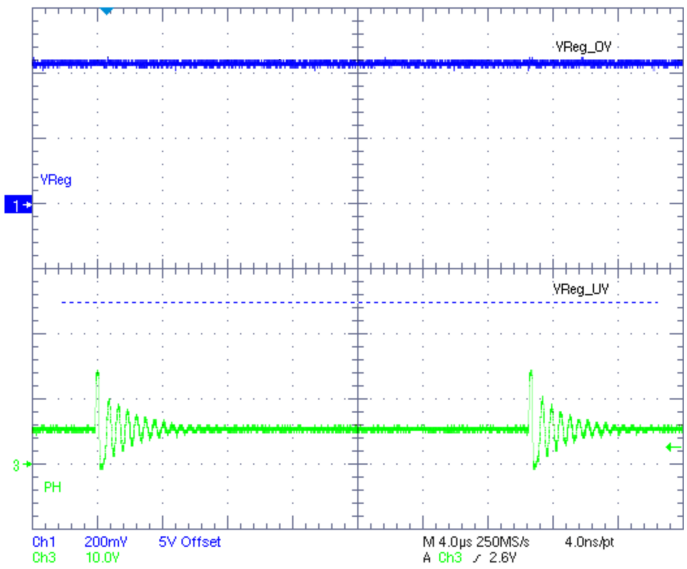
Figure 20. Active Mode CCM



VIN = 5.5 V ILoad = 50 mA f_{sw} = 500 kHz
LPM pin = don't care

Figure 21. PSM at Low VIN

- Likewise, at higher input voltages when the ON time (t_{ON}) of the switching FET becomes close to or slightly less than the minimum ON time (t_{ON-Min}) and the V_{Reg} start losing regulation, the device enters in PSM. If ON time is much smaller than t_{ON-Min}, there is a risk that the part stops switching and regulation is lost until power is recycled with ON time greater than t_{ON-Min}.
- At nominal input voltages during very light output loading. This mode of operation is shown in Figure 22. Comparing Figure 19 and Figure 22, in both cases the device is operating in discontinuous conduction mode; however, pulse skipping happens in Figure 22 because of very light output loading for similar input voltage. LPM pin must be set high (disabled) for this to happen.



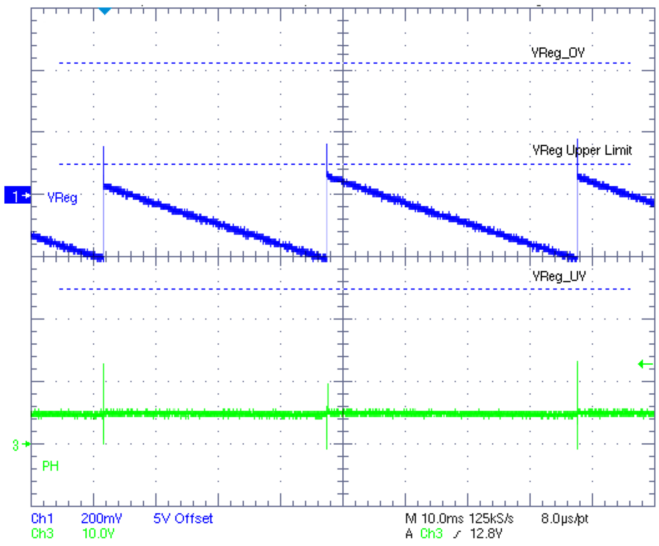
VIN = 14 V ILoad = 50 µA f_{sw} = 500 kHz
LPM pin = disable

Figure 22. PSM at Nominal VIN

Device Functional Modes (continued)

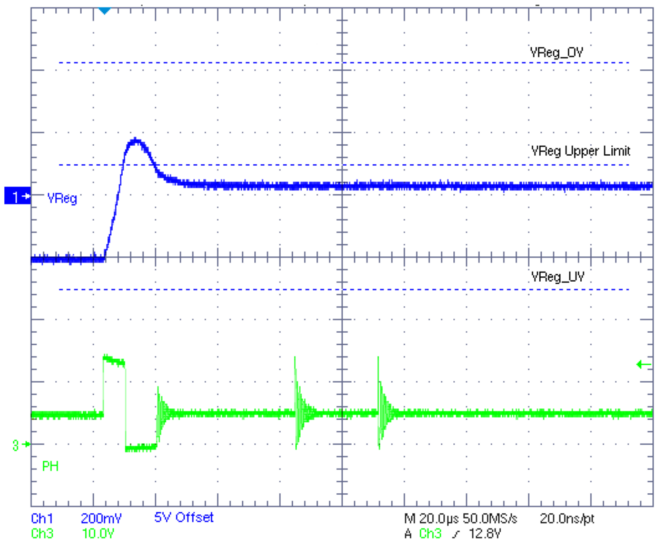
7.4.4 Low-Power Mode (LPM)

In this mode of operation the device briefly operates in discontinuous conduction mode and then turns off until V_{Reg} < VReg_UV threshold and this cycle is repeated. The LPM pin must be enabled to enable LPM mode of operation. When total load is less than $I_{L\_DISCONT}$, the device operates in LPM for VIN approximately 8.5 V to approximately 32 V. This mode of operation is shown in Figure 23 and Figure 24 (zoomed out).



VIN = 14 V ILoad = 50 mA f_{sw} = 500 kHz
LPM pin = enable

Figure 23. Low-Power Mode



VIN = 14 V ILoad = 50 mA f_{sw} = 500 kHz
LPM pin = enable

Figure 24. Low-Power Mode (Zoom In)

Any transition from low-power mode to active mode CCM occurs within 5 µs (typical). In low-power mode, the converter operates as a hysteretic controller with the threshold limits set by VReg_UV (see Equation 7, *Functional Block Diagram* and Figure 25), for the lower limit and approximately V_{Reg} for the upper limit. To ensure tight regulation in the low-power mode, R2 and R3 values are set accordingly (see discussion on *Noise Filter on RST_TH and OV_TH Terminals*). The device operates in both automatic (LPM pin is connected to ground) and digitally controlled (status of LPM pin is controlled by an external device, for example by a microcontroller) low-power mode. The digital low-power mode can over-ride the automatic low-power mode function by applying the appropriate signal on the LPM terminal. The part goes into active mode CCM for at least 100 µs, whenever RST_TH or VReg_UV is tripped.

Table 2. LPM Pin Status

LPM PIN STATUS	MODES OF OPERATION
High	Device is forced in normal mode.
	At light loads, the device operates in DCM with a switching frequency determined by the external resistor connected to RT pin.
	At very light loads, the device operates in PSM with a reduced switching frequency (see Figure 17).
Low or open	Device automatically changes between normal mode and low-power mode depending on the load current.

Table 3. Modes of Operation

MODES OF OPERATION	DESCRIPTION
Normal mode (active mode)	All circuits including overvoltage threshold circuit (OV_TH) are enabled.
	At heavy loads, the device operates in continuous conduction mode irrespective of the status of LPM pin. OR At light loads, the device operates in discontinuous conduction mode (DCM) only if LPM pin is externally set high.
Low-power mode	OV_TH circuit is disabled. The device is in DCM, and LPM pin should be forced low.

When the device is operating in low-power mode, and if the output is shorted to ground, a reset is asserted. The thermal shutdown and current limiting circuitry is activated to protect the device. The LPM pin is active low and is internally pulled down; therefore, the low-power mode is automatically enabled unless this pin is driven high externally (for example, by a microcontroller) and the device is in continuous conduction mode. However, the low-power mode operation is initiated only when the device enters discontinuous mode of operation at light loads, and the LPM pin is low (or connected to ground).

7.4.5 Hysteretic Mode

The device enters in this mode of operation when the main loop fails to respond during line and load transients and regulate within specified tolerances. The device exits this mode of operation when the main control loop responds, after the error amplifier stabilizes, and controls the output voltage within tighter tolerance.

The power up conditions in different modes of operations are explained in Table 4.

Table 4. Power-Up Conditions

MODE OF OPERATION	POWER-UP CONDITIONS
CCM	VIN > 3.6 V (minimum)
LPM/DCM	V_{Reg} < 5.5 V and (VIN – V_{Reg}) > 2.5 V (applicable only for f_{sw} > 600 kHz)

7.4.6 Output Tolerances in Different Modes of Operation

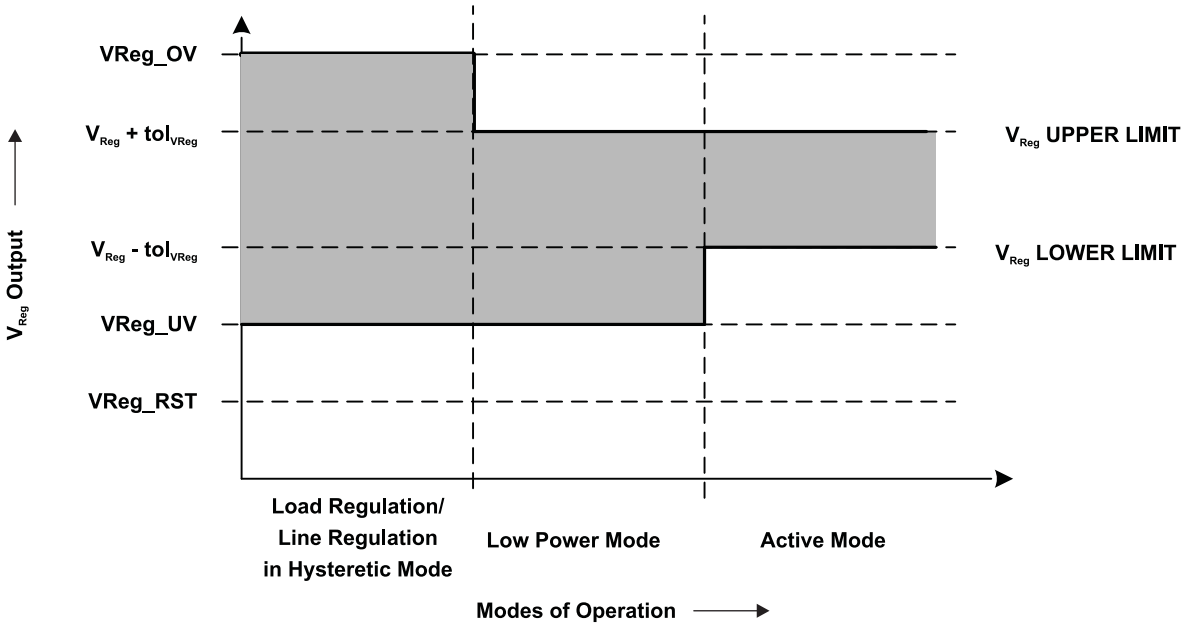


Figure 25. Output Tolerances Diagram

Table 5. Mode of Operation Descriptions

MODE OF OPERATION	V_{Reg} LOWER LIMIT	V_{Reg} UPPER LIMIT	COMMENTS
Hysteretic mode	VReg_UV	VReg_OV	Minimum to maximum ripple on output
Low-power mode	VReg_UV	V_{Reg} + tol_{VReg}	Minimum to maximum ripple on output
Active mode (Normal)	V_{Reg} – tol_{VReg}	V_{Reg} + tol_{VReg}	Minimum to maximum ripple on output

Table 6. Supervisor Thresholds Descriptions

SUPERVISOR THRESHOLDS	V_{Reg} TYPICAL VALUE	TOLERANCE	COMMENTS
VReg_OV	$\frac{R1+R2+R3}{R3} \times 0.8\ V$	$\pm\ (tol_{Vref} + (\frac{R1\ +\ R2}{R1\ +\ R2\ +\ R3}) \times (tol_{R1} + tol_{R2} + tol_{R3})$	Overvoltage threshold setting
VReg_RST	$\frac{R1+R2+R3}{R2+R3} \times 0.8\ V$	$\pm\ (tol_{Vref} + (\frac{R1}{R1\ +\ R2\ +\ R3}) \times (tol_{R1} + tol_{R2} + tol_{R3})$	Reset threshold setting

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The TPS54262-EP step-down DC-DC converter features an integrated NMOS switching FET and voltage supervisor circuit. It is designed to provide up to a 2-A output current from an input voltage source of 3.6 V to 48 V, and it can withstand transient voltages up to 60 V on its input pin. The device's input voltage line feed forward topology improves line transient regulation of the voltage mode buck regulator. The device also features low-power mode operation under light-load conditions, which reduces the supply current to 50 μA (typical). It can work for wide switching frequency range (200 kHz to 2.2 MHz), which allows regulator design to be optimized for efficiency or solution size.

8.2 Typical Application

This section explains considerations for the external components selection. Figure 26 shows the interconnection between external components and the device for a typical DC-DC step-down application.

The following examples demonstrate the design of a high frequency switching regulator using ceramic output capacitors. A few parameters must be known to start the design process. These parameters are typically determined at the system level.

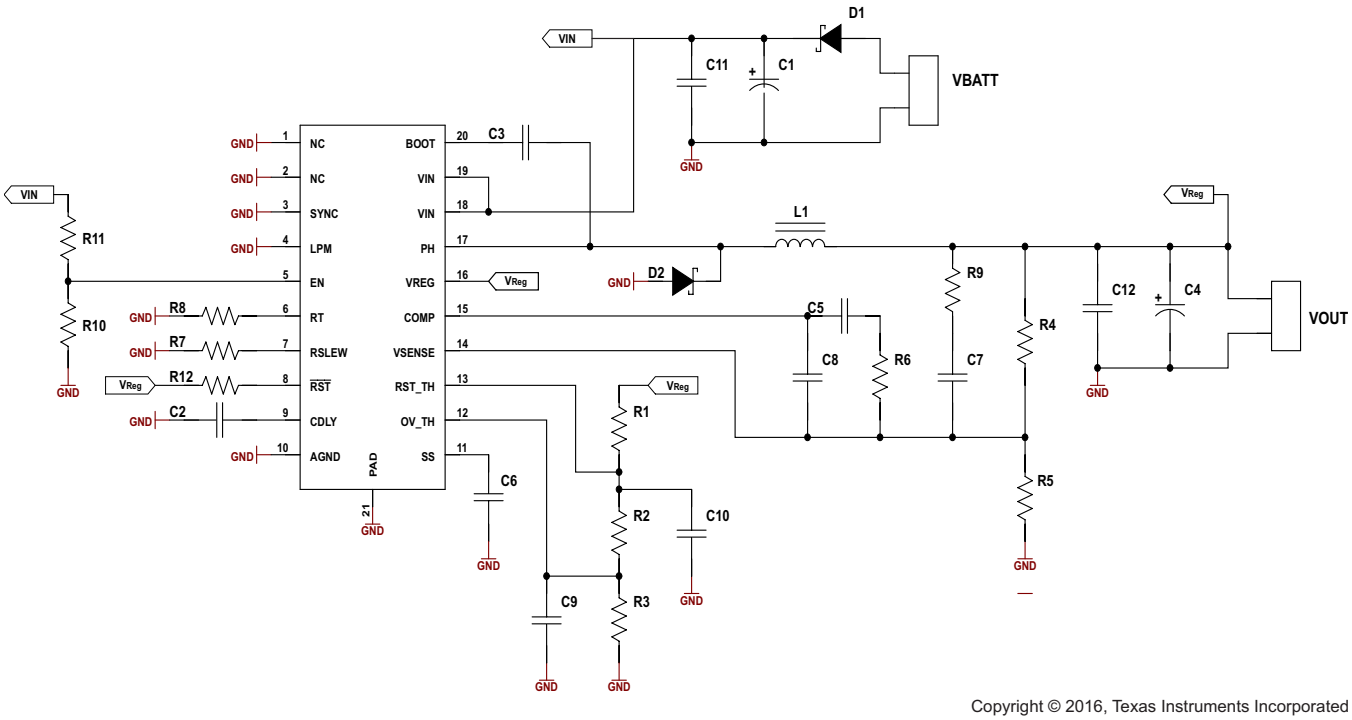


Figure 26. Typical Application Schematic

Typical Application (continued)

8.2.1 Design Requirements

The input voltage is supplied through VIN pins (pin 18 and 19), which must be externally protected against voltage levels greater than 60 V and reverse input polarity. An external diode is connected to protect these pins from reverse input polarity. The input current drawn from this pin is pulsed, with fast rise and fall times. Therefore, this input line requires a filter capacitor to minimize noise. Additionally, for EMI considerations, an input filter inductor may also be required.

For design considerations, VIN/VReg ratios must always be set such that the minimum required duty cycle pulse (t_{ON-Min}) is greater than 150 ns. The minimum off time ($t_{OFF-Min}$) is 250 ns for all conditions. The *Detailed Design Procedure* section provides the necessary equations and guidelines for selecting external components for this regulator.

8.2.2 Detailed Design Procedure

8.2.2.1 Component Selection

8.2.2.1.1 Input Capacitors (C1, C11)

Input filter capacitor (C11) is used to filter out high frequency noise in the input line. Typical values of C11 are 0.1 µF to 0.01 µF. For higher frequency noise, low capacitor values are recommended.

To minimize the ripple voltage, input ceramic de-coupling capacitor (C1) of type X5R or X7R should be used. The DC voltage rating for the input decoupling capacitor must be greater than the maximum input voltage. This capacitor must have an input ripple current rating higher than the maximum input ripple current of the converter for the application; and is determined by Equation 25.

$$I_{RMS} = I_{Load}\sqrt{\frac{V_{Reg}(VIN_{Min} - V_{Reg})}{VIN_{Min}^{2}}} \tag{25}$$

The input capacitors for power regulators are chosen to have a reasonable capacitance-to-volume ratio and fairly stable over temperature. The value of the input capacitance also determines the input ripple voltage of the regulator, shown by Equation 26.

$$\Delta VIN = \frac{0.25 \times I_{Load\text{-}Max}}{C1 \times f_{SW}} \tag{26}$$

Input ceramic filter capacitors should be located in close proximity to the VIN terminal. Surface mount capacitors are recommended to minimize lead length and reduce noise coupling.

8.2.2.1.2 Output Capacitor (C4, C12)

The selection of the output capacitor will determine several parameters in the operation of the converter (for example, voltage drop on the output capacitor and the output ripple). The capacitor value also determines the modulator pole and the roll-off frequency due to the LC output filter double pole. This is expressed in Equation 12.

The minimum capacitance needed to maintain desired output voltage during high to low load transition and prevent over shoot is given by Equation 27.

$$C4 = \frac{L \times (I_{Load\text{-}Max}^{2} - I_{Load\text{-}Min}^{2})}{V_{Reg\text{-}Max}^{2} - V_{Reg\text{-}Min}^{2}} \tag{27}$$

where

- L = output inductor
- $I_{Load\text{-}Max}$ = maximum load current
- $I_{Load\text{-}Min}$ = minimum load current
- $V_{Reg\text{-}Max}$ = maximum tolerance of regulated output voltage
- $V_{Reg\text{-}Min}$ = minimum tolerance of regulated output voltage

Typical Application (continued)

During a load step from no load to full load or changes in the input voltage, the output capacitor must hold up the output voltage above a certain level for a specified time and not issue a reset, until the main regulator control loop responds to the change. The minimum output capacitance required to allow sufficient drop on the output voltage without issuing a reset is determined by Equation 28.

$$C4 > \frac{2 \times \Delta I_{Load}}{f_{SW} \times \Delta V_{Reg}}$$

where

- ΔV_{Reg} = transient response during load stepping (28)

The minimum capacitance needed for output voltage ripple specification is given by Equation 29.

$$C4 > \frac{1}{8 \times f_{SW} \times \frac{V_{Reg\text{-}Ripple}}{I_{Ripple}}} \quad (29)$$

Additional capacitance deratings for temperature, aging, and DC bias must be factored in, and so a value of 100 µF with ESR calculated using Equation 30 of less than 100 mΩ should be used on the output stage.

Maximum ESR of the output capacitor is based on output ripple voltage specification in Equation 30. The output ripple voltage is a product of the output capacitor ESR and ripple current.

$$R_{ESR} < \frac{V_{Reg\text{-}Ripple}}{I_{Ripple}} \quad (30)$$

Output capacitor root mean square (RMS) ripple current is given by Equation 31. This is to prevent excess heating or failure due to high ripple currents. This parameter is sometimes specified by the manufacturers.

$$I_{Load\text{-}RMS} = \frac{V_{Reg} (VIN_{Max} - V_{Reg})}{\sqrt{12} \times VIN_{Max} \times f_{sw} \times L1} \quad (31)$$

Filter capacitor (C12) of value 0.1 µF (typical) is used to filter out the noise in the output line.

8.2.2.1.3 Soft-Start Capacitor (C6)

The soft-start capacitor determines the minimum time to reach the desired output voltage during a power-up cycle. This is useful when a load requires a controlled voltage slew rate, and helps to limit the current draw from the input voltage supply line. TI recommends a 100-nF capacitor for start-up loads of 1 A (maximum).

8.2.2.1.4 Bootstrap Capacitor (C3)

A 0.1-µF ceramic capacitor must be connected between the PH and BOOT terminals for the converter to operate and regulate to the desired output voltage. TI recommends using a capacitor with X5R or better grade dielectric material, and the voltage rating on this capacitor of at least 25 V to allow for derating.

8.2.2.1.5 Power-On Reset Delay (PORdly) Capacitor (C2)

The value of this capacitor can be calculated using Equation 6.

8.2.2.1.6 Output Inductor (L1)

Use a low EMI inductor with a ferrite type shielded core. Other types of inductors may be used; however, they must have low EMI characteristics and should be placed away from the low-power traces and components in the circuit.

Typical Application (continued)

To calculate the minimum value of the inductor, the ripple current should be first calculated using Equation 32.

$$I_{Ripple} = K_{IND} \times I_{Load} \quad (32)$$

where

- I_{Load} = maximum output load current
- I_{Ripple} = allowable peak to peak inductor ripple current, typically 20% of maximum I_{Load}
- K_{IND} = coefficient that represents the amount of inductor ripple current relative to the maximum output current.

The inductor ripple current is filtered by the output capacitor; therefore, K_{IND} is typically in the range of 0.2 to 0.3, depending on the ESR and the ripple current rating of the output capacitor (C4).

The minimum value of output inductor can be calculated using Equation 33.

$$L_{Min} = \frac{(VIN_{Max} - V_{Reg}) \times V_{Reg}}{f_{sw} \times I_{Ripple} \times VIN_{Max}} \quad (33)$$

where

- VIN_{Max} = maximum input voltage
- V_{Reg} = regulated output voltage
- f_{sw} = switching frequency

The RMS and peak currents flowing in the inductor are given by Equation 34 and Equation 35.

$$I_{L,RMS} = \sqrt{I_{Load}^2 + \frac{I_{Ripple}^2}{12}} \quad (34)$$

$$I_{L,pk} = I_{Load} + \frac{I_{Ripple}}{2} \quad (35)$$

8.2.2.1.7 Flyback Schottky Diode (D2)

The TPS54262-EP requires an external Schottky diode connected between the PH and power ground termination. The absolute voltage at PH pin should not go beyond the values in *Absolute Maximum Ratings*. The Schottky diode conducts the output current during the off state of the internal power switch. This Schottky diode must have a reverse breakdown voltage higher than the maximum input voltage of the application. A Schottky diode is selected for its lower forward voltage. The Schottky diode is selected based on the appropriate power rating, which factors in the DC conduction losses and the AC losses due to the high switching frequencies; this is determined by Equation 36.

$$P_{diode} = \frac{(VIN_{Max} - V_{Reg}) \times I_{Load} \times V_{fd}}{VIN_{Max}} + \frac{(VIN - V_{fd})^2 \times f_{sw} \times C_J}{2} \quad (36)$$

where

- P_{diode} = power rating
- V_{fd} = forward conducting voltage of Schottky diode
- C_J = junction capacitance of the Schottky diode

Recommended part numbers are PDS 360 and SBR8U60P5.

8.2.2.1.8 Resistor to Set Slew Rate (R7)

The slew rate setting is asymmetrical; that is, for a selected value of R7, the rise time and fall time are different. R7 can be approximately determined from Figure 11 and Figure 12. The minimum recommended value is 10 kΩ.

8.2.2.1.9 Resistor to Select Switching Frequency (R8)

See *Selecting the Switching Frequency*, Figure 10 and Equation 4.

Typical Application (continued)

8.2.2.1.10 Resistors to Select Output Voltage (R4, R5)

To minimize the effect of leakage current on the VSENSE terminal, the current flowing through the feedback network should be greater than 5 mA to maintain output accuracy. Higher resistor values help improve the converter efficiency at low-output currents, but may introduce noise immunity problems. See Equation 1. TI recommends fixing R4 to a standard value (for example, 187 kΩ) and calculate R5.

8.2.2.1.11 Resistors to Set Undervoltage, Overvoltage, and Reset Thresholds (R1, R2, R3)

8.2.2.1.11.1 Overvoltage Resistor Selection

Using Equation 9, the value of R3 can be determined to set the overvoltage threshold at up to 106% to 110% of V_{Reg}. The sum of R1, R2, and R3 resistor network to ground should be approximately 100 kΩ .

8.2.2.1.11.2 Reset Threshold Resistor Selection

Using Equation 8 the value of R2 + R3 can be calculated, and knowing R3 from the OV_TH setting, R2 can be determined. Suggested value of reset threshold is 92% of V_{Reg}.

8.2.2.1.11.3 Undervoltage Threshold for Low-Power Mode and Load Transient Operation

This threshold is set above the reset threshold to ensure the regulator operates within the specified tolerances during output load transient of low load to high load and during discontinuous conduction mode. The typical voltage threshold can be determined using Equation 7. Suggested value of undervoltage threshold is 95% of V_{Reg}.

8.2.2.1.12 Low-Power Mode (LPM) Threshold

An approximation of the output load current at which the converter is operating in discontinuous mode can be obtained from Equation 23 with ± 30% hysteresis. The values used in Equation 3 for minimum and maximum input voltage will affect the duty cycle and the overall discontinuous mode load current. These are the nominal values, and other factors are not taken into consideration like external component variations with temperature and aging.

8.2.2.1.13 Enable Pin Pull-Up Resistor (R11) and Voltage Divider Resistor (R10)

An external pull-up resistor, R11= 30.1 kΩ, is recommended to enable the device for operation and R10 can be left open.

Based on the application needs, if the device needs to be turned on at certain input voltage using EN pin threshold, R10 can be used as a voltage divider resistor along with pull-up resistor (R11=30.1 kΩ) and R10 can be calculated accordingly.

8.2.2.1.14 Pull-Up Resistor (R12) at $\overline{\text{RST}}$ Pin

A standard pull-up resistor, R12 = 2 K Ω can be used at this pin

8.2.2.1.15 Type 3 Compensation Components (R5, R6, R9, C5, C7, C8)

First, make the ZEROs close to double pole frequency, using Equation 12, Equation 13, and Equation 11.

fz1 = (50% to 70%) f_{LC}

fz2 = f_{LC}

Second, make the POLEs above the crossover frequency, using Equation 18 and Equation 19.

fp1 = f_{ESR}

fp2 = ½f_{sw}

8.2.2.1.15.1 Resistors

From Equation 1, knowing V_{Reg} and R4 (fix to a standard value), R5 can be calculated as shown in Equation 37:

$$R5 = \frac{R4}{\frac{V_{Reg}}{V_{ref}} - 1} \quad (37)$$

Typical Application (continued)

Using Equation 11 and Equation 15, R6 can be calculated as shown in Equation 38:

$$R6 = \frac{f_c \times V_{Ramp} \times R4}{VIN \times f_{LC}} \quad (38)$$

R9 can be calculated as shown in Equation 39:

$$R9 = \frac{R4}{\left(\frac{f_{SW}}{2f_{LC}} - 1\right)} \quad (39)$$

8.2.2.1.15.2 Capacitors

Using Equation 20, C5 can be calculated as shown in Equation 40:

$$C5 = \frac{1}{\pi \times R6 \times f_{LC}} \quad (40)$$

C7 can be calculated as shown in Equation 41:

$$C7 = \frac{1}{\pi \times R9 \times f_{SW}} \quad (41)$$

C8 can be calculated as shown in Equation 42:

$$C8 = \frac{C5}{2\pi \times R6 \times C5 \times f_{ESR} - 1} \quad (42)$$

8.2.2.1.16 Noise Filter on RST_TH and OV_TH Terminals (C9, C10)

These capacitors may be required in some applications to filter the noise on RST_TH and OV_TH pins. Typical capacitor values for RST_TH and OV_TH pins are from 10 pF to 100 pF for total resistance on RST_TH/OV_TH divider of less than 200 kΩ. See *Noise Filter on RST_TH and OV_TH Terminals*.

8.2.2.2 Design Example 1

For this example, we will start with the following known and target parameters:

Table 7. Design Parameters – Example 1(1)

PARAMETER TYPE	PARAMETER NAME	PARAMETER VALUE
Known	Input voltage, VIN	Minimum = 8 V, Maximum = 28 V, Typical = 14 V
Target	Output voltage, V_{Reg}	5 V ± 2%
	Maximum output current, $I_{Load\text{-}Max}$	1.8 A
	Ripple/ transient occurring in input voltage, ΔVIN	1% of VIN (minimum)
	Reset threshold, VReg_RST	92% of V_{Reg}
	Overvoltage threshold, VReg_OV	106% of V_{Reg}
	Undervoltage threshold, VReg_UV	95% of V_{Reg}
	Transient response 0.25 A to 2-A load step, ΔV_{Reg}	5% of V_{Reg}
	Power-on Reset delay, PORdly	2.2 ms

(1) For the circuit diagram, see Figure 26.

8.2.2.2.1 Calculate the Switching Frequency (f_{sw})

To reduce the size of output inductor and capacitor, higher switching frequency can be selected. It is important to understand that higher switching frequency results in higher switching losses, causing the device to heat up. This may result in degraded thermal performance. To prevent this, proper PCB layout guidelines must be followed (see *Layout Guidelines*).

Based upon the discussion in section *Selecting the Switching Frequency*, calculate the maximum and minimum duty cycle.

Knowing V_{Reg} and tolerance on V_{Reg}, the $V_{Reg-Max}$ and $V_{Reg-Min}$ are calculated to be:

$V_{Reg-Max}$ = 102% of V_{Reg} = 5.1 V and $V_{Reg-Min}$ = 98% of V_{Reg} = 4.9 V.

Using Equation 3, the minimum duty cycle is calculated to be, D_{Min} = 17.5%

Knowing: t_{ON-Min} = 150 ns from the device specifications, and using Equation 4, maximum switching frequency is calculated to be, f_{sw-Max} = 1166 kHz

Because the oscillator can also vary by ±10%, the switching frequency can be further reduced by 10% to add margin. Also, to improve efficiency and reduce power losses due to switching, the switching frequency can be further reduced by about 550 kHz. Therefore, f_{sw} = 500 kHz.

From Figure 10, R8 can be approximately determined to be, R8 = 205 kΩ.

8.2.2.2.2 Calculate the Ripple Current (I_{Ripple})

Using Equation 32, for K_{IND} = 0.2 (typical), inductor ripple current is calculated to be: I_{Ripple} = 0.36 A.

The ripple current is chosen such that the converter enters discontinuous mode (DCM) at 20% of maximum load. The 20% is a typical value, it could go higher to a maximum of up to 40%.

8.2.2.2.3 Calculate the Inductor Value (L1)

Using Equation 33, the inductor value is calculated to be, L_{Min} = 22.8 µH. A closest standard inductor value can be used.

8.2.2.2.4 Calculate the Output Capacitor and ESR (C4)

8.2.2.2.4.1 Calculate Capacitance

To calculate the capacitance of the output capacitor, first determine the minimum load current. Typically, in standby mode the load current is 100 µA; however, this really depends on the application. With this value of minimum load current and using Equation 27, Equation 28, and Equation 29, C4 is calculated to be, C4 > 34 µF .

To allow wider operating conditions and improved performance in low-power mode, TI recommends using a 100-µF capacitor. A higher value of the output capacitor allows improved transient response during load stepping.

8.2.2.2.4.2 Calculate ESR

Using Equation 30, ESR is calculated to be, R_{ESR} < 555 mΩ.

Capacitors with lowest ESR values should be selected. To meet both the requirements, capacitance and low ESR, several low ESR capacitors may be connected in parallel. In this example, we will select a capacitor with ESR value as 30 mΩ.

Filter capacitor (C12) of value 0.1 µF can be added to filter out the noise in the output line.

8.2.2.2.5 Calculate the Feedback Resistors (R4, R5)

To keep the quiescent current low and avoid instability problems, TI recommends selecting R4 and R5 such that, R4 + R5 is approximately 250 kΩ.

Using Equation 1 and using a fixed standard value of R4 = 187 kΩ, R5 is calculated to be, R5 = 35.7 kΩ .

8.2.2.2.6 Calculate Type 3 Compensation Components

8.2.2.2.6.1 Resistances (R6, R9)

Using Equation 16, for VIN_{Typ} = 14 V, V_{Ramp} is calculated to be, V_{Ramp} = 1.4 V.

Using Equation 12, f_{LC} is calculated to be, f_{LC} = 3.33 kHz.

Using V_{Ramp}, f_{LC} from above, assuming f_c as 1/10th of f_{sw} and Equation 38, R6 is calculated to be, R6 = 280.65 kΩ.

Using Equation 39, R9 is calculated to be, R9 = 2.53 kΩ.

8.2.2.2.6.2 Capacitors (C5, C8, C7)

Using Equation 40, C5 is calculated to be, C5 = 340.45 pF.

Using Equation 13, f_{ESR} is calculated to be, f_{ESR} = 53.06 kHz.

Using Equation 42, C8 is calculated to be, C8 = 11.04 pF.

Using Equation 41, C7 is calculated to be, C7 = 250.07 pF.

8.2.2.2.7 Calculate Soft-Start Capacitor (C6)

The recommended value of soft-start capacitor is 100 nF (typical).

8.2.2.2.8 Calculate Bootstrap Capacitor (C3)

The recommended value of bootstrap capacitor is 0.1 µF (typical).

8.2.2.2.9 Calculate Power-On Reset Delay Capacitor (C2)

To achieve 2.2-ms delay, the reset delay capacitor can be calculated using Equation 6 to be C2 = 2.2 nF.

8.2.2.2.10 Calculate Input Capacitor (C1, C11)

Typical values for C11 are 0.1 µF and 0.01 µF.

Input capacitor (C1) should be rated more than the maximum input voltage (VIN_{Max}). The input capacitor should be big enough to maintain supply in case of transients in the input line. Using Equation 26, C1 is calculated to be, C1 = 1.2 µF. For improved transient response, TI recommends a higher value of C1 such as 220 µF.

8.2.2.2.11 Calculate Resistors to Control Slew Rate (R7)

The value of slew rate resistor (R7) can be approximately determined from Figure 11 and Figure 12 at different typical input voltages. The minimum recommended value is 10 kΩ. To achieve rise time, t_r = 20 ns and fall time, t_f = 35 ns, the slew rate resistor is approximately of value 30 kΩ.

8.2.2.2.12 Resistors to Select Undervoltage, Overvoltage and Reset Threshold Values (R1, R2, R3)

The sum of these three resistors should be approximately equal to 100 kΩ. In this example,

- VReg_OV = 106% of V_{Reg} = 5.3 V
- VReg_RST = 92% of V_{Reg} = 4.6 V
- VReg_UV = 95% of V_{Reg} = 4.75 V

Using Equation 9, R3 = 15 kΩ.

Using Equation 8, R2 = 2.29 kΩ.

Using Equation 7, R1 = 82.6 kΩ

8.2.2.2.13 Diode D1 and D2 Selection

Diode D1 is used to protect the IC from the reverse input polarity connection. The diode should be rated at maximum load current. Only Schottky diode should be connected at the PH pin. The recommended part numbers are PDS360 and SBR8U60P5.

8.2.2.2.14 Noise Filter on RST_TH and OV_TH Terminals (C9 and C10)

Typical capacitor values for RST_TH and OV_TH pins are from 10 pF to 100 pF for total resistance on RST_TH/OV_TH divider of less than 200 kΩ.

8.2.2.2.15 Power Budget and Temperature Estimation

Using Equation 43, conduction losses for typical input voltage are calculated to be, P_{CON} = 0.289 W.

Assuming slew resistance R7 = 30 kΩ, from Figure 11 and Figure 12, rise time, t_r = 20 ns and fall time, t_f = 35 ns. Using Equation 44, switching losses for typical input voltage are calculated to be, P_{SW} = 0.693 W.

Using Equation 45, gate drive losses are calculated to be, P_{Gate} = 3 mW.

Using Equation 46, power supply losses are calculated to be, P_{IC} = 1.8 mW.

Using Equation 47, the total power dissipated by the device is calculated to be, P_{Total} = 987 mW.

Using Equation 49, and knowing the thermal resistance of package = 35°C/W, the rise in junction temperature due to power dissipation is calculated to be, ΔT = 34.5°C.

Using Equation 50, for a given maximum junction temperature 150°C, the maximum ambient temperature at which the device can be operated is calculated to be, $T_{A\text{-}Max}$ = 115°C (approximately).

8.2.2.3 Design Example 2

For this example, start with the following known and target parameters:

Table 8. Design Parameters – Example 2 (1)

PARAMETER TYPE	PARAMETER NAME	PARAMETER VALUE
Known	Input voltage, VIN	Minimum = 8 V, Maximum = 28 V, Typical = 14 V
Target	Output voltage, V_{Reg}	3.3 V ± 2%
	Maximum output current, $I_{Load\text{-}Max}$	2 A
	Ripple/ transient occurring in input voltage, ΔVIN	1% of VIN (minimum)
	Reset threshold, VReg_RST	92% of V_{Reg}
	Overvoltage threshold, VReg_OV	106% of V_{Reg}
	Undervoltage threshold, VReg_UV	95% of V_{Reg}
	Transient response 0.25-A to 2-A load step, ΔV_{Reg}	5% of V_{Reg}
	Power on Reset delay, PORdly	2.2 ms

(1) For the circuit diagram, see Figure 26.

8.2.2.3.1 Calculate the Switching Frequency (f_{sw})

To reduce the size of output inductor and capacitor, higher switching frequency can be selected. It is important to understand that higher switching frequency results in higher switching losses, causing the device to heat up. This may result in degraded thermal performance. To prevent this, proper PCB layout guidelines must be followed (see Layout Guidelines).

Based upon the discussion in section *Selecting the Switching Frequency*, calculate the maximum and minimum duty cycle.

Knowing V_{Reg} and tolerance on V_{Reg}, the $V_{Reg\text{-}Max}$ and $V_{Reg\text{-}Min}$ are calculated to be:

$V_{Reg\text{-}Max}$ = 102% of V_{Reg} = 3.366 V and $V_{Reg\text{-}Min}$ = 98% of V_{Reg} = 3.234 V.

Using Equation 3, the minimum duty cycle is calculated to be, D_{Min} = 11.55%

Knowing $t_{ON\text{-}Min}$ = 150 ns from the device specifications, and using Equation 4, maximum switching frequency is calculated to be, $f_{sw\text{-}Max}$ = 770 kHz.

Because the oscillator can also vary by ±10%, the switching frequency can be further reduced by 10% to add margin. Also, to improve efficiency and reduce power losses due to switching, the switching frequency can be further reduced by about 100 kHz. Therefore f_{sw} = 593 kHz.

From Figure 10, R8 can be approximately determined to be, R8 = 170 kΩ.

8.2.2.3.2 Calculate the Ripple Current (I_{Ripple})

Using Equation 32, for K_{IND} = 0.2 (typical), inductor ripple current is calculated to be: I_{Ripple} = 0.4 A.

The ripple current is chosen such that the converter enters discontinuous mode (DCM) at 20% of maximum load. The 20% is a typical value, although it could go higher to a maximum of up to 40%.

8.2.2.3.3 Calculate the Inductor Value (L1)

Using Equation 33, the inductor value is calculated to be, L_{Min} = 12.3 µH. A closest standard inductor value can be used.

8.2.2.3.4 Calculate the Output Capacitor and ESR (C4, C12)

8.2.2.3.4.1 Calculate Capacitance

To calculate the capacitance of the output capacitor, minimum load current must be first determined. Typically, in standby mode the load current is 100 µA; however, this really depends on the application. With this value of minimum load current and using Equation 27, Equation 28, and Equation 29, C4 is calculated to be, C4 > 56 µF .

To allow wider operating conditions and improved performance in low-power mode, TI recommends using a 100-µF capacitor. An output capacitor with a higher value allows improved transient response during load stepping.

8.2.2.3.4.2 Calculate ESR

Using Equation 30, ESR is calculated to be, R_{ESR} < 330 mΩ.

Capacitors with lowest ESR values should be selected. To meet both the requirements, capacitance and low ESR, several low ESR capacitors may be connected in parallel. In this example, we will select a capacitor with ESR value as 30 mΩ.

Filter capacitor (C12) of value 0.1 µF can be added to filter out the noise in the output line.

8.2.2.3.5 Calculate the Feedback Resistors (R4, R5)

To keep the quiescent current low and avoid instability problems, TI recommends selecting R4 and R5 such that, R4 + R5 is approximately 250 kΩ.

Using Equation 1 and using a fixed standard value of R4 = 187 kΩ, R5 is calculated to be, R5 = 59.8 kΩ .

8.2.2.3.6 Calculate Type 3 Compensation Components

8.2.2.3.6.1 Resistances (R6, R9)

Using Equation 16, for VIN_{Typ} = 14 V, V_{Ramp} is calculated to be, V_{Ramp} = 1.4 V.

Using Equation 12, f_{LC} is calculated to be, f_{LC} = 4.54 kHz.

Using V_{Ramp}, f_{LC} from above, assuming f_c as 1/10th of f_{sw} and Equation 38, R6 is calculated to be, R6 = 244 kΩ.

Using Equation 39, R9 is calculated to be, R9 = 2.9 kΩ.

8.2.2.3.6.2 Capacitors (C5, C8, C7)

Using Equation 40, C5 is calculated to be, C5 = 287.04 pF.

Using Equation 13, f_{ESR} is calculated to be, f_{ESR} = 53.06 kHz.

Using Equation 42, C8 is calculated to be, C8 = 12.84 pF.

Using Equation 41, C7 is calculated to be, C7 = 184.4 pF.

8.2.2.3.7 Calculate Soft-Start Capacitor (C6)

The recommended value of soft-start capacitor is 100 nF (typical).

8.2.2.3.8 Calculate Bootstrap Capacitor (C3)

The recommended value of bootstrap capacitor is 0.1 µF (typical).

8.2.2.3.9 Calculate Power-On Reset Delay Capacitor (C2)

To achieve 2.2-ms delay, the reset delay capacitor can be calculated using Equation 6 to be C2 = 2.2 nF.

8.2.2.3.10 Calculate Input Capacitor (C1, C11)

Typical values for C11 are 0.1 µF and 0.01 µF.

Input capacitor (C1) should be rated more than the maximum input voltage (VIN_{Max}). The input capacitor should be big enough to maintain supply in case of transients in the input line. Using Equation 26, C1 is calculated to be, C1 = 10.53 µF. For improved transient response, TI recommends a higher value of C1 such as 220 µF.

8.2.2.3.11 Calculate Resistors to Control Slew Rate (R7)

The value of slew rate resistor (R7) can be approximately determined from Figure 11 and Figure 12 at different typical input voltages. The minimum recommended value is 10 kΩ. To achieve rise time, t_r = 20 ns and fall time, t_f = 35 ns, the slew rate resistor is approximately of value 30 kΩ.

8.2.2.3.12 Resistors to Select Undervoltage, Overvoltage and Reset Threshold Values (R1, R2, R3)

The sum of these three resistors should be approximately equal to 100 kΩ. In this example,

VReg_OV = 106% of V_{Reg} = 3.498 V
VReg_RST = 92% of V_{Reg} = 3.036 V
VReg_UV = 95% of V_{Reg} = 3.135 V

Using Equation 9, R3 = 22.87 kΩ.

Using Equation 8, R2 = 3.48 kΩ.

Using Equation 7, R1 = 73.65 kΩ

8.2.2.3.13 Diode D1 and D2 Selection

Diode D1 is used to protect the IC from the reverse input polarity connection. The diode should be rated at maximum load current. Only Schottky diode should be connected at the PH pin. The recommended part numbers are PDS360 and SBR8U60P5.

8.2.2.3.14 Noise Filter on RST_TH and OV_TH Terminals (C9 and C10)

Typical capacitor values for RST_TH and OV_TH pins are from 10 pF to 100 pF for total resistance on RST_TH/OV_TH divider of less than 200 kΩ.

8.2.2.3.15 Power Budget and Temperature Estimation

Using Equation 43, conduction losses for typical input voltage are calculated to be, P_{CON} = 0.235 W.

Assuming slew resistance R7 = 30 kΩ, from Figure 17 and Figure 18, rise time, t_r = 20 ns and fall time, t_f = 35 ns. Using Equation 19, switching losses for typical input voltage are calculated to be, P_{SW} = 0.913 W.

Using Equation 44, gate drive losses are calculated to be, P_{Gate} = 3.5 mW.

Using Equation 46, power supply losses are calculated to be, P_{IC} = 1.8 mW.

Using Equation 47, the total power dissipated by the device is calculated to be, P_{Total} = 1.15 W.

Using Equation 49, and knowing the thermal resistance of package = 35°C/W, the rise in junction temperature due to power dissipation is calculated to be, ΔT = 40.4°C.

Using Equation 50, for a given maximum junction temperature 150°C, the maximum ambient temperature at which the device can be operated is calculated to be, $T_{A\text{-}Max}$ approximately 105°C.

8.2.3 Application Curves

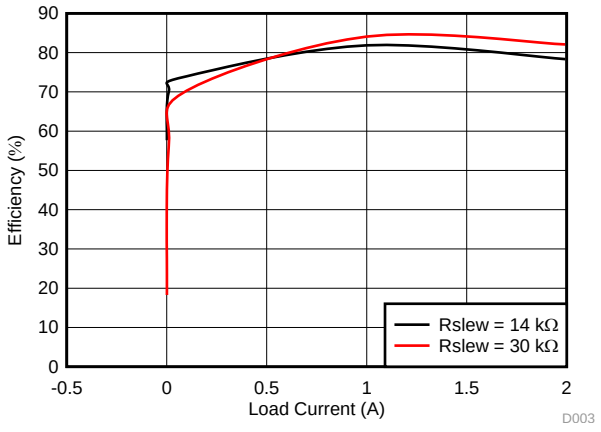


Figure 27. Efficiency vs Load Current for Different Rslew Resistors

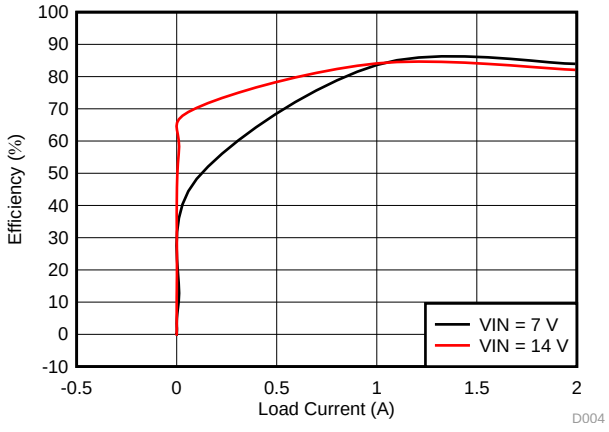


Figure 28. Efficiency vs Load Current for Different VIN

9 Power Supply Recommendations

The design of the TPS54262-EP devices is for operation using an input supply range from 3.6 V to 48 V. Both the VIN input pins must be shorted together at the board level. One high frequency filter capacitor in the range from 0.1 uF to 0.01 uF is recommended at VIN pin. Additionally, to minimize the ripple voltage, use a ceramic bulk capacitor of type X5R or X7R at the VIN pin. See Equation 25 and Equation 26 for calculating the value of this bulk capacitor. If there is a possibility for a reverse-voltage condition to occur, place a series Schottky diode in the power routing.

10 Layout

10.1 Layout Guidelines

A proper layout is critical for the operation of a switched-mode power supply, even more at high switching frequencies. Therefore, the PCB layout of the TPS54262-EP device demands careful attention to ensure operation and to get the performance specified. A poor layout can lead to issues like poor regulation (line and load), stability and accuracy weaknesses, increased EMI radiation, and noise sensitivity. See Figure 29 for recommended layout example for TPS54262-EP device.

- It is critical to provide a low-inductance, low-impedance ground path and hence use wide and short traces for the main current paths.
- The input capacitor, catch diode, output capacitor, and inductor should be placed as close as possible to the IC pins and use thick traces (low impedance path) to connect them.
- Route the feedback trace so that there is minimum interaction with any noise sources associated with the switching components. Recommended practice is to place the inductor away from the feedback trace to prevent EMI noise.
- Place compensation network components away from switching components and route their connections away from noisy area.
- In a two-sided PCB, TI recommends having ground planes on both sides of the PCB to help reduce noise and ground-loop errors. Connect the ground connection for the input and output capacitors and IC ground to this ground plane.
- In a multilayer PCB, the ground plane separates the power plane (where high switching currents and components are placed) from the signal plane (where the feedback trace and components are) for improved performance.
- Also, arrange the components such that the switching-current loops curl in the same direction. Place the high-current components such that during conduction the current path is in the same direction. Doing so prevents magnetic field reversal caused by the traces between the two half cycles, helping to reduce radiated EMI.
- Add multiple thermal via's on the device thermal pad for better thermal performance.

10.2 Layout Example

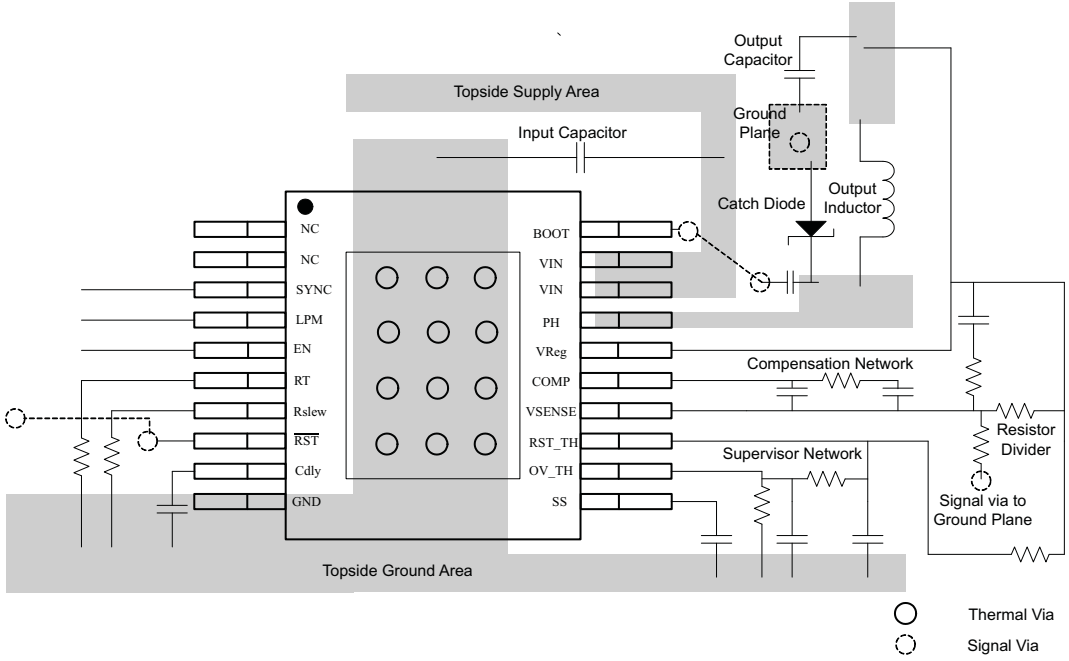


Figure 29. PCB Layout Example

10.3 Power Dissipation and Temperature Considerations

The power dissipation losses are applicable for continuous conduction mode operation (CCM). The total power dissipated by the device is the sum of the following power losses.

Conduction losses, P_{CON}

$$P_{CON} = I_{Load}^2 \times R_{DS(ON)} \times \frac{V_{Reg}}{VIN} \quad (43)$$

Switching losses, P_{SW}

$$P_{SW} = \frac{1}{2} VIN \times I_{Load} \times (t_r + t_f) \times f_{SW} \quad (44)$$

Gate drive losses, P_{Gate}

$$P_{Gate} = V_{drive} \times Q_g \times f_{sw} \quad (45)$$

Power supply losses, P_{IC}

$$P_{IC} = VIN \times I_{q\text{-}Normal} \quad (46)$$

Therefore, the total power dissipated by the device is given by Equation 47.

$$P_{Total} = P_{CON} + P_{SW} + P_{Gate} + P_{IC}$$

where

- VIN = unregulated input voltage
- I_{Load} = output load current
- t_r = FET switching rise time (t_r= 40 ns (maximum))
- t_f = FET switching fall time
- f_{sw} = switching frequency
- V_{drive} = FET gate drive voltage (V_{drive} = 6 V (typical), V_{drive} = 8 V (maximum))
- Q_g = 1×10^{-9} C
- $I_{q\text{-}Normal}$ = quiescent current in normal mode (Active Mode CCM) (47)

For device under operation at a given ambient temperature (T_A), the junction temperature (T_J) can be calculated using Equation 48.

$$T_J = T_A + (R_{th} \times P_{Total}) \quad (48)$$

Therefore, the rise in junction temperature due to power dissipation is shown in Equation 49.

$$\Delta T = T_J - T_A = (R_{th} \times P_{Total}) \quad (49)$$

For a given maximum junction temperature ($T_{J\text{-}Max}$), the maximum ambient temperature ($T_{A\text{-}Max}$) in which the device can operate is calculated using Equation 50.

$$T_{A\text{-}Max} = T_{J\text{-}Max} - (R_{th} \times P_{Total})$$

where

- T_J = junction temperature in °C
- T_A = ambient temperature in °C
- R_{th} = thermal resistance of package in W/°C
- $T_{J\text{-}Max}$ = maximum junction temperature in °C
- $T_{A\text{-}Max}$ = maximum ambient temperature in °C (50)

There are several other factors that also affect the overall efficiency and power losses. Examples of such factors are AC and DC losses in the inductor, voltage drop across the copper traces on PCB, power losses in the flyback catch diode and so forth. The previous discussion does not include such factors.

Power Dissipation and Temperature Considerations (continued)

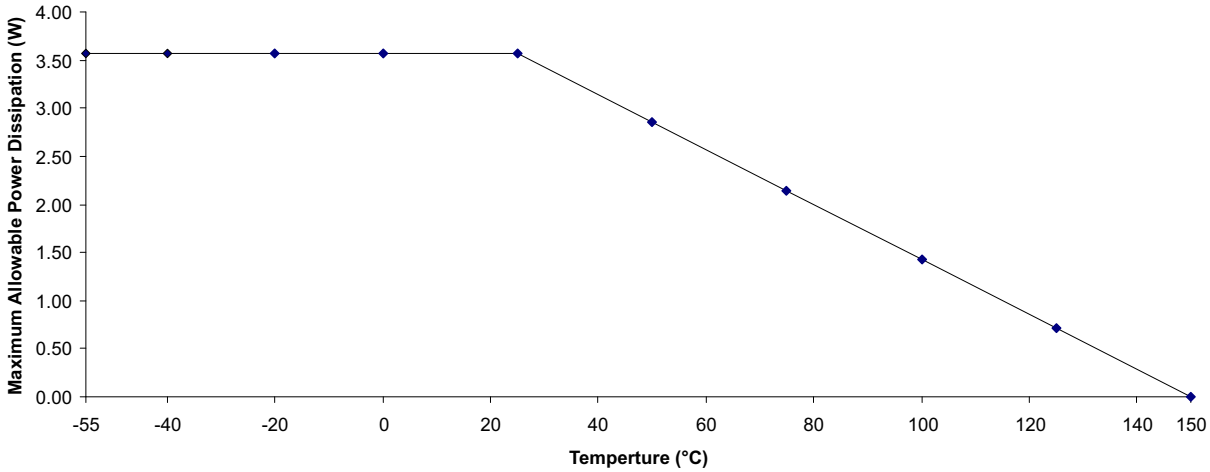


Figure 30. Power Dissipation vs Ambient Temperature

NOTE

The output current rating for the regulator may must be derated for ambient temperatures above 85°C. The derated value will depend on calculated worst-case power dissipation and the thermal management implementation in the application.

11 Device and Documentation Support

11.1 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.3 Trademarks

PowerPAD, E2E are trademarks of Texas Instruments.
All other trademarks are the property of their respective owners.

11.4 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

11.5 Glossary

SLYZ022 — *TI Glossary*.

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

12 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 finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS54262MPWPREP	ACTIVE	HTSSOP	PWP	20	2000	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	54262M1	Samples
TPS54262MPWPTEP	ACTIVE	HTSSOP	PWP	20	250	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	54262M1	Samples
V62/16626-01XE	ACTIVE	HTSSOP	PWP	20	250	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-55 to 125	54262M1	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

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

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

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

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

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

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

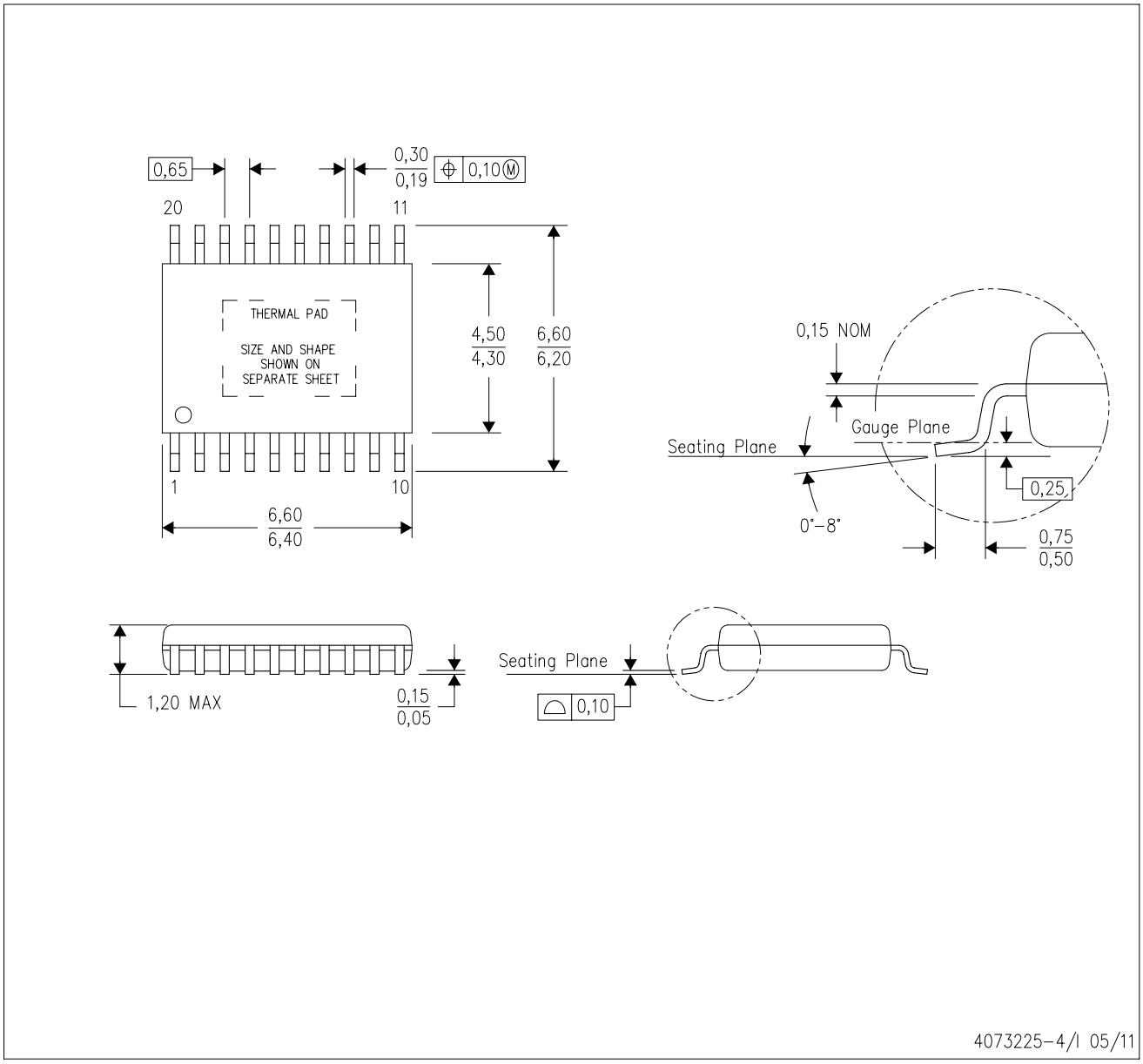
OTHER QUALIFIED VERSIONS OF TPS54262-EP :

- Automotive: TPS54262-Q1

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

PWP (R–PDSO–G20) PowerPAD™ PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusions. Mold flash and protrusion shall not exceed 0.15 per side.
D. 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>.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
E. Falls within JEDEC MO–153

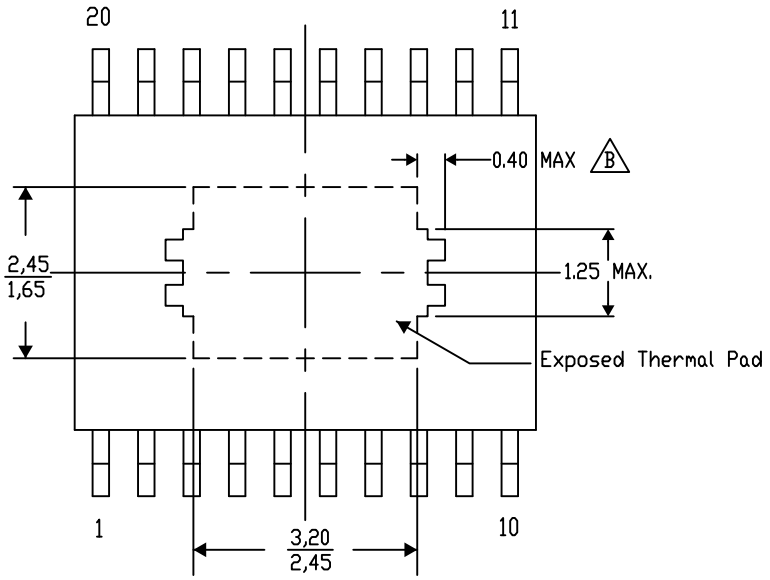
PWP (R–PDSO–G20) PowerPAD™ SMALL PLASTIC OUTLINE

THERMAL INFORMATION

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

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

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



Top View

Exposed Thermal Pad Dimensions

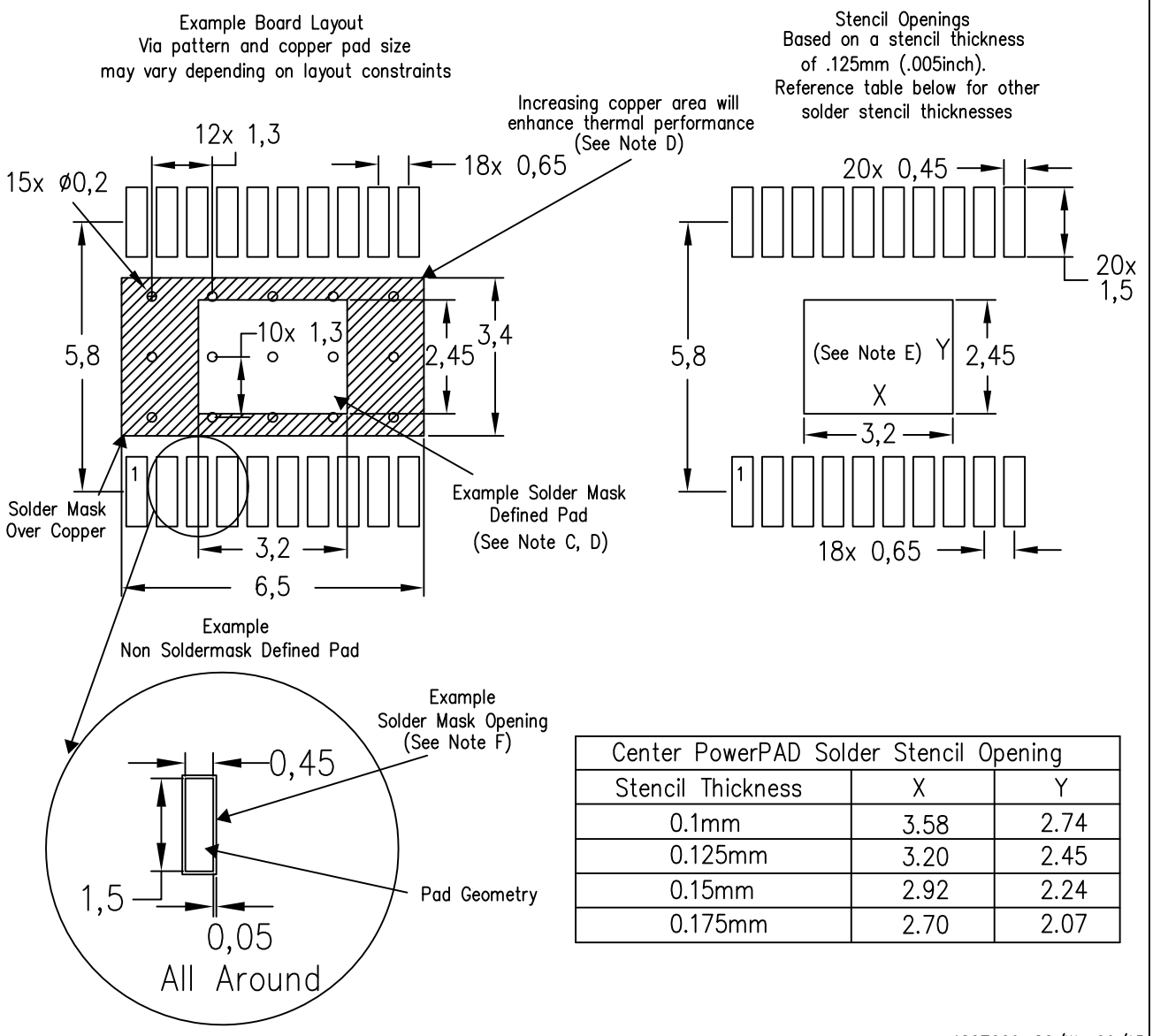
4206332–18/AO 01/16

NOTE: A. All linear dimensions are in millimeters

B. Exposed tie strap features may not be present.

PowerPAD is a trademark of Texas Instruments

PWP (R–PDSO–G20) PowerPAD™ PLASTIC SMALL OUTLINE



Center PowerPAD Solder Stencil Opening		
Stencil Thickness	X	Y
0.1mm	3.58	2.74
0.125mm	3.20	2.45
0.15mm	2.92	2.24
0.175mm	2.70	2.07

4207609–26/W 09/15

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. 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, SLMA004, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http://www.ti.com>. Publication IPC–7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.
F. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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