TEXAS INSTRUMENTS

TPS548A23 4V to 16V Input, 12A, Remote Sense Synchronous Buck Converter

1 Features

- 4V to 16V input voltage range
- 3.1V to 5.3V external VCC bias support
- 8.4mΩ and 3.3mΩ MOSFETs (V_{VCC} = 3.3V)
- 12A continuous output current
- Optimized 19-pin WQFN-HR package for efficiency and thermal performance
- ±1.25% output voltage accuracy with internal feedback, T_J = –40°C to +150°C
- 0.5V to 5.5V output voltage range
- Differential remote sense
- D-CAP4 with ultra-fast load-step response
- Supports all ceramic output capacitors
- Selectable auto-skip Eco-mode for high light-load efficiency
- Programmable valley current limit
- 600kHz, 800kHz, 1.0MHz, 1.2MHz selectable switching frequency
- Programmable soft-start time
- Prebiased start-up capability
- Open-drain power-good output
- Overvoltage and undervoltage fault protection
- 3mm × 3mm (0.4mm pin pitch), 19-pin QFN package
- Pin-to-pin compatible with 20A TPS548B23

2 Applications

- Rack server and blade server
- Data center switches
- Wireless infrastructure
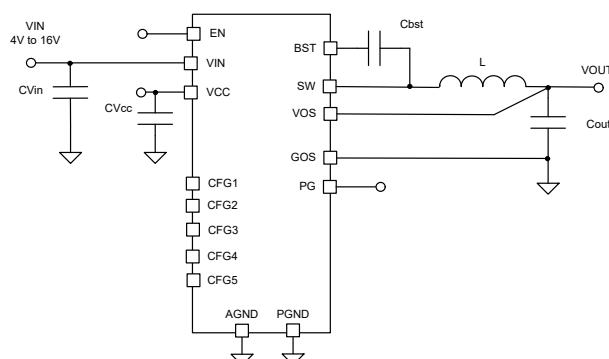
3 Description

The TPS548A23 device is a small, high-efficiency, synchronous buck converter with an adaptive on-time D-CAP4 control mode. The control method provides low minimum on-time and fast load-transient response across the entire output voltage range without requiring an external compensation network. Because external compensation is not required, the device is easy to use and requires few external components. The device is well-designed for space-constrained data center applications.

The TPS548A23 device has differential remote sense, high-performance integrated MOSFETs, a ±1.0% reference voltage for external feedback, and supports ±1.25% output voltage accuracy with internal reference. The device features accurate load and line regulation and Eco-mode or Forced Continuous Conduction Mode (FCCM) operation. Pin strap options allow for configuration of the overcurrent limit, fault response, internal or external feedback, output voltage selection, switching frequency, and soft-start time.

The internal 3.0V LDO can be over-driven with an external 3.1V to 5.3V supply through the VCC pin to improve efficiency and reduce power dissipation.

The TPS548A23 device is a lead-free device. The device is RoHS compliant without exemption.

Package Information

PART NUMBER	PACKAGE[1]	PACKAGE SIZE[2]
TPS548A23	VAN (WQFN-HR,19)	3mm × 3mm

(1) For more information, see Section 10.
(2) The package size (length × width) is a nominal value and includes pins, where applicable.

Simplified Schematic

Table of Contents

Product Folder Links: *TPS548A23*

4 Pin Configuration and Functions
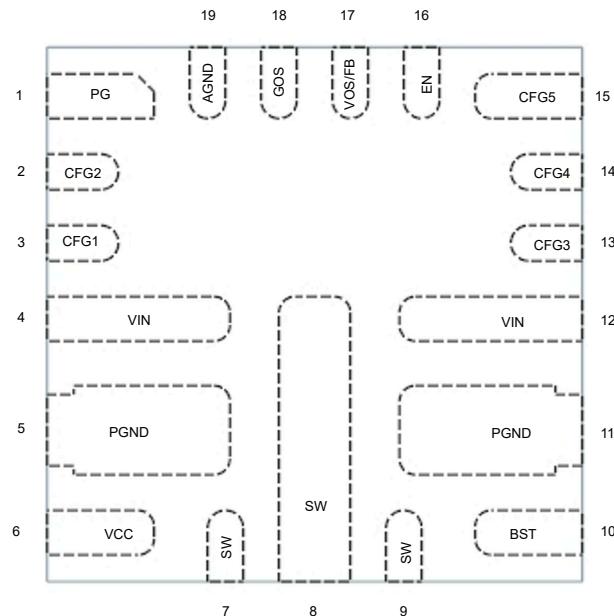
Figure 4-1. VAN Package, 19-Pin, 3mm × 3mm (0.4mm Pin Pitch) WQFN-HR (Top View)
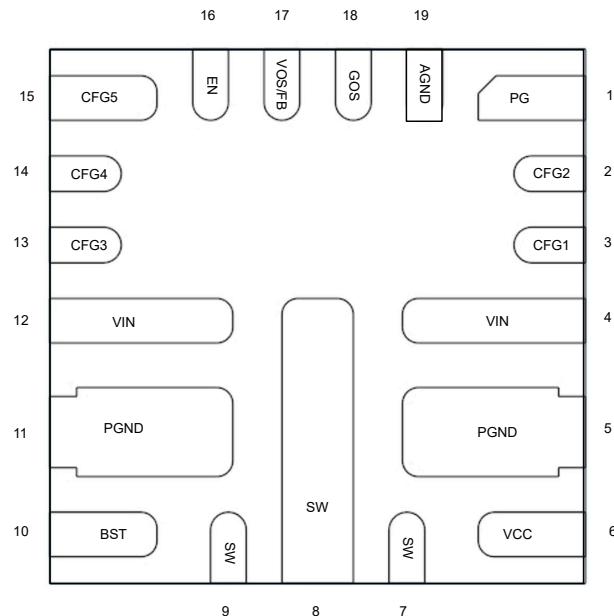
Figure 4-2. VAN Package, 19-Pin, 3mm × 3mm (0.4mm Pin Pitch) WQFN-HR (Bottom View)

Table 4-1. Pin Functions

PIN		TYPE[1]	DESCRIPTION
NAME	NO		
PG	1	O	Open-drain power-good status signal. Connect an external pullup resistor to a voltage source. When the FB voltage moves outside the specified limits, PG goes low after the specified delay.
CFG2	2	I	Multifunction select pin. Connection to AGND, VCC, or floating this pin selects between the operating frequency, and the overcurrent limit. When configured for external FB operation, connecting a resistor between this pin and AGND sets the OCP limit.
CFG1	3	I	Multifunction select pin. Connection to AGND, VCC, or floating this pin selects between the operating frequency, and the over current limit. When configured for external FB operation, connecting a resistor between this pin and AGND selects switching frequency, SS time.
VIN	4, 12	P	Power-supply input pins for both the power stage MOSFETs and the internal LDO. Place the decoupling input capacitors from VIN pins to PGND pins as close as possible. A capacitor from each VIN to PGND close to IC is required.
PGND	5, 11	G	Ground return for the power stage. This pin is internally connected to the source of the low-side MOSFET. Place as many vias as possible beneath the PGND pins and as close as possible to the PGND pins. This action minimizes parasitic impedance and also lowers thermal resistance.
VCC	6	P	Internal 3V LDO output. A 3.1V to 5.3V external bias can be connected to this pin to save the power losses on the internal LDO. The voltage source on this pin powers both the internal circuitry and gate driver. Bypass with a 1µF, > 6.3V rating, ceramic capacitor from VCC pin to PGND. Place this capacitor as close to the VCC and PGND pins as possible.
SW	7, 8, 9	O	Output switching terminal of the power converter. Connect this pin to the output inductor.
BST	10	I/O	Supply for the internal high-side MOSFET gate driver (boost terminal). Connect the bootstrap capacitor from this pin to SW node.
CFG3	13	I	Multifunction select pins. Connecting CFGx to AGND, VCC, or floating these pins selects the output voltage setting/configuration (internal or external FB) and forced continuous conduction mode (FCCM) or skip-mode operation.
CFG4	14	I	
CFG5	15	I	
EN	16	I	Enable pin. The enable pin turns the DC/DC switching converter on or off. Floating EN pin before start-up disables the converter. The recommended maximum voltage applied to the EN pin is 5.5V. TI *does not* recommend connecting the EN pin to VIN pin directly.
VOS/FB	17	I	Output voltage feedback input. Positive input of the differential remote sense circuit, connect to the Vout sense point on the load side. When configured for external feedback, a resistor divider from the VOUT to GOS (tapped to FB pin) sets the output voltage.
GOS	18	I	Negative input of the differential remote sense circuit. Connect to a ground sense point near the load.
AGND	19	G	Analog ground return and reference for the internal control circuits

(1)   I = Input, O = Output, P = Supply, G = Ground

5 Specifications

5.1 Absolute Maximum Ratings

Over operating junction temperature range (unless otherwise noted) [(1)]

		MIN	MAX	UNIT
Pin voltage	VIN	−0.3	19	V
Pin voltage	SW - PGND, DC	−0.3	19	V
Pin voltage	SW - PGND, transient < 10ns	−3	21	V
Pin voltage	VIN – SW, DC	−0.3	19	V
Pin voltage	VIN – SW, transient < 10ns	−3	25	V
Pin voltage	BOOT - PGND	−0.3	24.5	V
Pin voltage	BOOT – SW	−0.3	5.5	V
Pin voltage	EN	−0.3	7	V
Pin voltage	VOS/FB, PG, CFGx, VCC	−0.3	6	V
Pin voltage	GOS, PGND	−0.3	0.3	V
Sink current	PG		15	mA
T_J	Operating junction temperature	−40	150	°C
T_{stg}	Storage temperature	−55	150	°C

(1)   Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.

5.2 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 ANSI/ESDA/JEDEC JS-002 [(2)]	±500	

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

5.3 Recommended Operating Conditions

Over operating junction temperature range (unless otherwise noted)

			MIN	NOM	MAX	UNIT
V_{IN}	Input voltage range	VIN	4		16	V
V_{VCC}	External bias range	VCC, V_{VIN} ≤ 16V	3.1		5.3	V
	Pin voltage	V_{GOS} versus V_{AGND}	−0.1		0.1	V
		EN, PG, VOS/FB	−0.1		5.5	V
	Pin voltage	CFGx	0		V_{CC}	V
V_{OUT}	Output voltage range	VOUT	0.5		5.5	V
I_{PG}	Power-good sinking current	PG			10	mA
I_{OUT}	Output current	SW			12	A
IL_{PEAK}	Maximum peak inductor current	SW			21	A
T_J	Operating junction temperature		−40		150	°C

5.4 Thermal Information

THERMAL METRIC[1]		TPS548A23		UNIT
		VAN (WQFN-HR, JEDEC LAYOUT)	VAN (WQFN-HR, APPLICATION LAYOUT, 6-LAYER PCB)	
		19 PINS	19 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	59	19.0[2]	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	36	Not applicable [3]	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	13.6	Not applicable [3]	°C/W
ψ_{JT}	Junction-to-top characterization parameter	1.9	Not applicable [3]	°C/W
ψ_{JB}	Junction-to-board characterization parameter	13.5	Not applicable [3]	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	n/a	Not applicable [3]	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application note.
(2) Measured on TPS548B23EVM with 1.0W dissipated in the device.
(3) The thermal test or simulation setup is not applicable to an application layout.

5.5 Electrical Characteristics

T_J = –40°C to +150°C, V_{VCC} = 3.3V (external), V_{VIN} = 4V to 16V. Typical values are at T_J = 25°C and V_{VIN} = 12V (unless otherwise noted).

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY						
$I_{Q(VIN)}$	VIN quiescent current	Non-switching, V_{EN} = 2V, V_{FB} = V_{FB_REG} + 50mV, no external bias on VCC pin		970		µA
$I_{Q(VIN)}$	VIN quiescent current with external VCC bias	T_J = 25°C, V_{IN} = 12V, V_{EN} = 2V, V_{FB} = V_{FB_REG} + 10mV (non-switching), 3.3V external bias on VCC pin		230	290	µA
$I_{SD(VIN)}$	VIN shutdown supply current	V_{IN} = 12 V, V_{EN} = 0 V, no external bias on VCC pin		9.5	20	µA
$I_{Q(VCC)}$	VCC quiescent current	T_J = 25°C, V_{IN} = 12V, V_{EN} = 2V, V_{FB} = V_{FB_REG} + 10mV (non-switching), 3.3 V external bias on VCC pin		860		µA
$I_{SD(VCC)}$	VCC shutdown current	V_{EN} = 0V, V_{IN} = 0V, 3.3V external bias on VCC pin		90		µA
I_{VCC}	VCC external bias current [1]	T_J = 25°C, V_{IN} = 12V, V_{EN} = 2V, regular switching, f_{SW} = 600kHz, 3.3V external bias on VCC pin		10		mA
I_{VCC}	VCC external bias current [1]	T_J = 25°C, V_{IN} = 12V, V_{EN} = 2V, regular switching, f_{SW} = 1200kHz, 3.3V external bias on VCC pin		16		mA
INTERNAL LDO (VCC)						
V_{VCC}	Internal LDO output voltage		2.85	3.0	3.1	V
I_{VCC}	Internal LDO short-circuit current limit	V_{VIN} = 12V		210		mA
$VCC_{UVLO(R)}$	VCC UVLO rising threshold	V_{VIN} = 4V		2.73	2.85	V
$VCC_{UVLO(F)}$	VCC UVLO falling threshold	V_{VIN} = 4V		2.58		V
$VCC_{UVLO(H)}$	VCC UVLO hysteresis	V_{VIN} = 4V		0.15		V
	FB threshold to turn off VCC LDO	V_{FB} falling, EN = 0V		50	85	mV
UVLO						
$VIN_{UVLO(R)}$	VIN UVLO rising threshold	V_{IN} rising		3.88	3.95	V
$VIN_{UVLO(F)}$	VIN UVLO falling threshold	V_{IN} falling		3.71	3.78	V
$VIN_{UVLO(H)}$	VIN UVLO hysteresis			0.17		V
ENABLE						
$V_{EN(R)}$	EN voltage rising threshold	EN rising, enable switching	1.15	1.2	1.25	V
$V_{EN(F)}$	EN voltage falling threshold	EN falling, disable switching	1.06	1.12	1.18	V
$V_{EN(H)}$	EN voltage hysteresis			80		mV

Product Folder Links: *TPS548A23*

5.5 Electrical Characteristics (continued)

T_J = –40°C to +150°C, V_{VCC} = 3.3V (external), V_{VIN} = 4V to 16V. Typical values are at T_J = 25°C and V_{VIN} = 12V (unless otherwise noted).

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$I_{EN(Hys)}$	EN pin hysteresis current	EN > $V_{EN(R)}$	2.0	5	7.5	µA
	EN internal pulldown resistance	EN pin to AGND	0.74	1	1.27	MΩ
$V_{ENSTB(R)}$	EN standby rising threshold	EN rising, enable internal LDO, no switching		0.7		V
$V_{ENSTB(F)}$	EN standby falling threshold	EN Falling, disable internal LDO	0.3	0.6		V
PINSTRAP						
CFGx_high	CFGx logic high voltage level	VCC = 5.0V		4.2	4.4	V
		VCC = 3.3V		2.4	2.85	V
CFGx_low	CFGx logic low voltage level	VCC = 5.0V	0.5	0.6		V
		VCC = 3.3V	0.3	0.4		V
START-UP						
t_{SS}	Soft-start time	V_{FB} from 10% to 90%, t_{SS} = 1ms setting		1		ms
		V_{FB} from 10% to 90%, t_{SS} = 2ms setting		2		ms
		V_{FB} from 10% to 90%, t_{SS} = 3ms setting		3		ms
t_{EN_DLY}	EN HIGH to start of switching delay	no external bias on VCC		1300	2000	µs
REFERENCE VOLTAGE (FB)						
V_{VOS_REG}	Output voltage regulation accuracy	Internal feedabck configuration, T_J = 0°C to +85°C	– 0.9 %		+0.9 %	
		Internal feedback configuration	– 1.25 %		+1.25 %	
V_{FB_REG}	Feedback regulation voltage	External Feedback Configuration, T_J = 0°C to +85°C	498.5	501	503.5	mV
		External Feedback Configuration	495	500	505	mV
$I_{FB(LKG)}$	FB input leakage current	V_{FB} = V_{FB_REG}			250	nA
DIFFERENTIAL REMOTE SENSE AMPLIFIER						
I_{GOSNS}	Leakage current out of GOS pin	V_{GOS} - V_{AGND} = 100mV			80	µA
SWITCHING FREQUENCY						
$f_{SW(FCCM)}$	Switching frequency, FCCM operation	V_{VIN} = 12V, V_{OUT} = 3.3V, F_{SW} = 600kHz, No load	510	600	690	kHz
		V_{VIN} = 12V, V_{OUT} = 3.3V, F_{SW} = 800kHz, No load	680	800	920	kHz
		V_{VIN} = 12V, V_{OUT} = 3.3V, F_{SW} = 1.0MHz, No load	850	1000	1150	kHz
		V_{VIN} = 12V, V_{OUT} = 3.3V, F_{SW} = 1.2MHz, No load	1020	1200	1380	kHz
POWER STAGE						
$R_{DSON(HS)}$	High-side MOSFET on-resistance	$V_{BOOT-SW}$ = 5.0V		7.5		mΩ
		$V_{BOOT-SW}$ = 3.3V		8.4		mΩ
$R_{DSON(LS)}$	Low-side MOSFET on-resistance	V_{VCC} = 5.0V		2.7		mΩ
		V_{VCC} = 3.3V		3.3		mΩ
$t_{ON(min)}$	Minimum ON pulse width [1]			40		ns
$t_{OFF(min)}$	Minimum OFF pulse width [1]				150	ns
	Output discharge resistor on SW pin	V_{IN} = 12V, V_{SW} = 1V, power conversion disabled		75		Ω
$I_{BOOT(LKG)}$	Leakage current into BOOT pin	$V_{BOOT-SW}$ = 3.3V, enabled, not switching.		23	30	µA
POWER GOOD						
$V_{PGTH(RISE\_OV)}$	Power-Good threshold	FB rising, PG high to low	113%	116%	119%	
$V_{PGTH(RISE\_UV)}$	Power-Good threshold	FB rising, PG low to high	89%	92.5%	95%	
$V_{PGTH(FALL\_UV)}$	Power-Good threshold	FB falling, PG high to low	77%	80%	83%	
t_{PG_DLY}	PG delay going from low to high during startup	See timing diagram		1.1	1.5	ms
	PG delay going from high to low			4	6.2	µs

5.5 Electrical Characteristics (continued)

T_J = –40°C to +150°C, V_{VCC} = 3.3V (external), V_{VIN} = 4V to 16V. Typical values are at T_J = 25°C and V_{VIN} = 12V (unless otherwise noted).

| PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$I_{PG(LKG)}$	PG pin leakage current when open drain output is high	V_{PG} = 4.5V			6	µA
	PG pin output low-level voltage	I_{PG} = 7mA			500	mV
	PG pin output low-level when VIN and VCC are low	V_{VIN} = 0V, V_{VCC} = 0V, V_{EN} = 0V, PG pulled up to 3.3V through a 100kΩ resistor			850	mV
	PG pin output low-level when VIN and VCC are low	V_{VIN} = 0V, V_{VCC} = 0V, V_{EN} = 0V, PG pulled up to 3.3V through a 10kΩ resistor			1000	mV
OVERCURRENT PROTECTION						
	OC limit high clamp	Valley current on LS FET, CFG3-5 = GND, 0Ω ≤ R_{ILIM} ≤ 4.32kΩ	11.5	13	14.5	A
$I_{LS(OC)}$	Low-side valley current limit (External Feedback Configuration)	Valley current on LS FET, R_{ILIM} = 5.25kΩ	9.0	10.4	11.8	A
$I_{LS(OC)}$	Low-side valley current limit (External Feedback Configuration)	Valley current on LS FET, R_{ILIM} = 10.5kΩ	4.4	5.2	6.0	A
		Valley current on LS FET, R_{ILIM} = 20.0kΩ	2	2.7	3.4	A
R_{ILIM}	ILIM pin resistance range		0		20	kΩ
$I_{LS(OC)}$		Valley current on LS FET, CFG3-5 = VCC, CFG1 = VCC	11.5	13	14.5	A
$I_{LS(OC)}$	Low-side valley current limit (Internal Feeback Configuration)	Valley current on LS FET, CFG3-5 = VCC, CFG1 = GND	9	10	11	A
$I_{LS(OC)}$		Valley current on LS FET, CFG3-5 = VCC, CFG1 = Float	6	7	8	A
$I_{LS(NOC)}$	Low-side negative current limit	Sinking current limit on LS FET		–9	–7.5	A
I_{ZC}	Zero-cross detection current threshold to enter DCM, open loop	V_{IN} = 12V		–750		mA
$I_{ZC(HYS)}$	Zero-cross detection current threshold hysteresis after entering DCM, open loop	V_{IN} = 12V		1000		mA
OUTPUT OVP AND UVP						
V_{OVP}	Overvoltage-protection (OVP) threshold voltage	V_{FB} rising	113%	116%	119%	
t_{OVPDLY}	OVP delay	With 100mV overdrive		650		ns
V_{UVP}	Undervoltage-protection (UVP) threshold voltage	V_{FB} falling	77%	80%	83%	
t_{UVPDLY}	UVP filter delay			70		µs
	Hiccup wait time	Hiccup mode enabled		14 × t_{SS}		ms
THERMAL SHUTDOWN						
$T_{J(SD)}$	Thermal shutdown threshold [1]	Temperature rising		165		°C
$T_{J(HYS)}$	Thermal shutdown hysteresis [1]			15		°C

(1) This parameter is provided for reference only, and do not consitute part of TI's published device specifications for purpose of TI's product warranty.

5.6 Typical Characteristics

V_{IN}=12V V_{CC} = Internal F_{SW} = 600kHz
L_{OUT} = 550nH L_{DCR} = 1.4mΩ FCCM
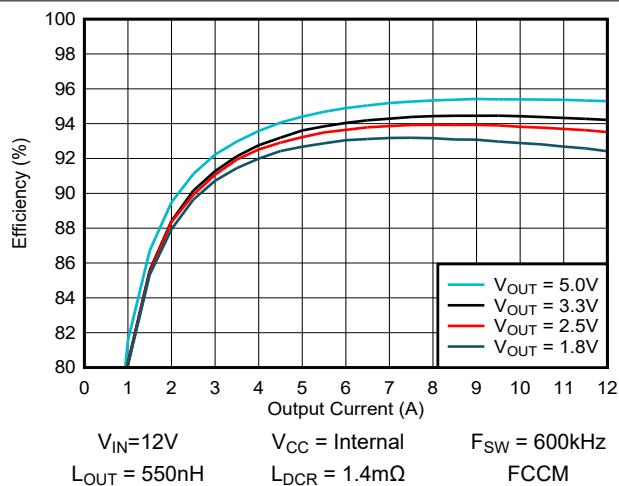
Figure 5-1. Efficiency with $V_{OUT} \geq 1.8V$

V_{IN}=12V V_{CC} = Internal F_{SW} = 600kHz
L_{OUT} = 160nH L_{DCR} = 0.75mΩ FCCM
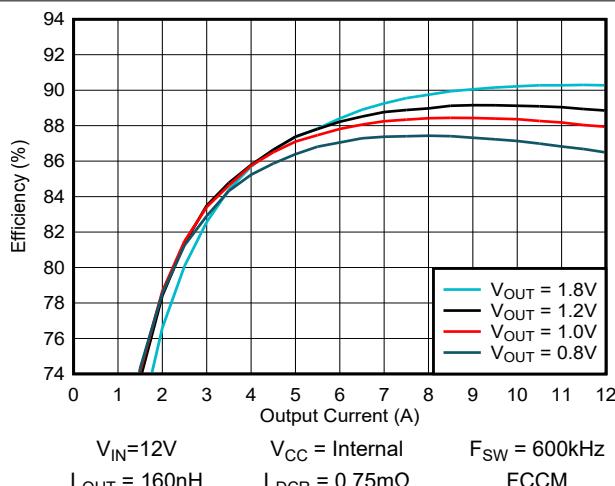
Figure 5-2. Efficiency with $V_{OUT} \leq 1.8V$

V_{IN}=12V V_{CC} = Internal V_{OUT} = 3.3V
L_{OUT} = 550nH L_{DCR} = 1.4mΩ FCCM
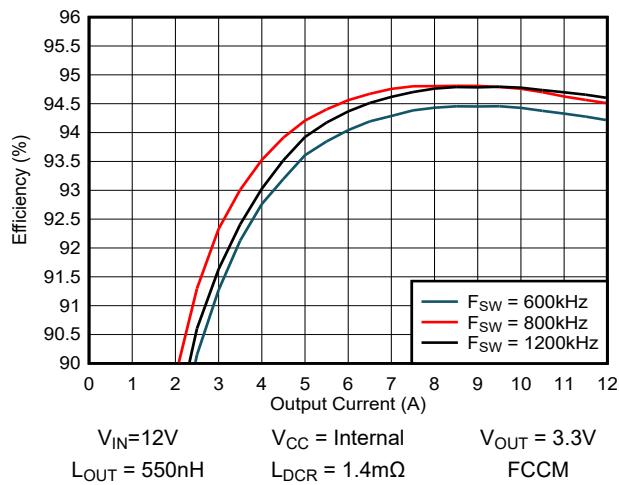
Figure 5-3. Efficiency vs F_{SW} with V_{OUT} = 3.3V

V_{IN}=12V V_{CC} = Internal V_{OUT} = 1.8V
L_{OUT} = 160nH L_{DCR} = 0.75mΩ FCCM
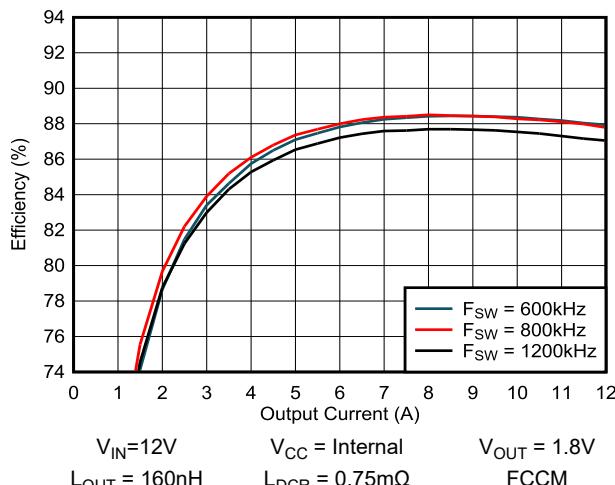
Figure 5-4. Efficiency vs F_{SW} with V_{OUT} = 1.8V

V_{IN}=12V V_{OUT} = 3.3V F_{SW} = 600kHz
L_{OUT} = 550nH L_{DCR} = 1.4mΩ FCCM
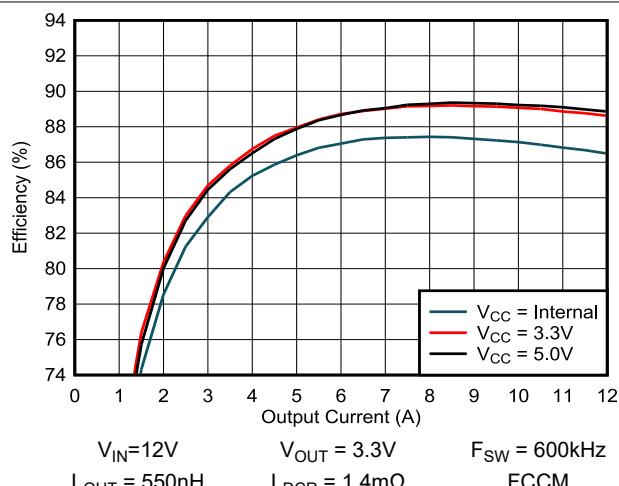
Figure 5-5. Efficiency vs V_{CC} Bias with V_{OUT} = 3.3V

V_{IN}=12V V_{OUT} = 1.8V F_{SW} = 600kHz
L_{OUT} = 160nH L_{DCR} = 0.75mΩ FCCM
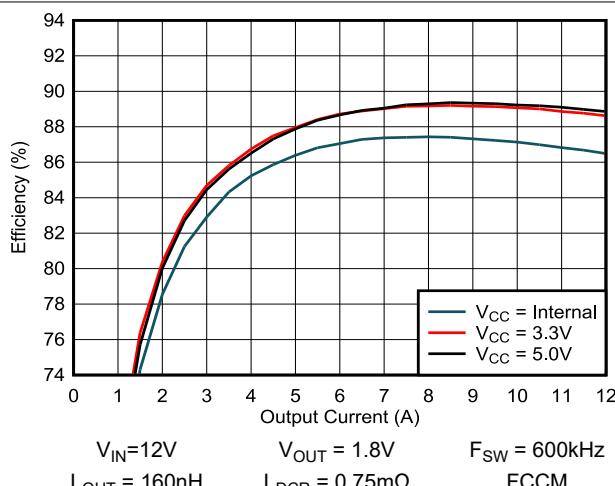
Figure 5-6. Efficiency vs V_{CC} Bias with V_{OUT} = 1.8V

Product Folder Links: *TPS548A23*

5.6 Typical Characteristics (continued)

V_{IN} = 12V V_{EN} = 2V   Internal VCC LDO
V_{FB} = V_{INTREF} + 50mV
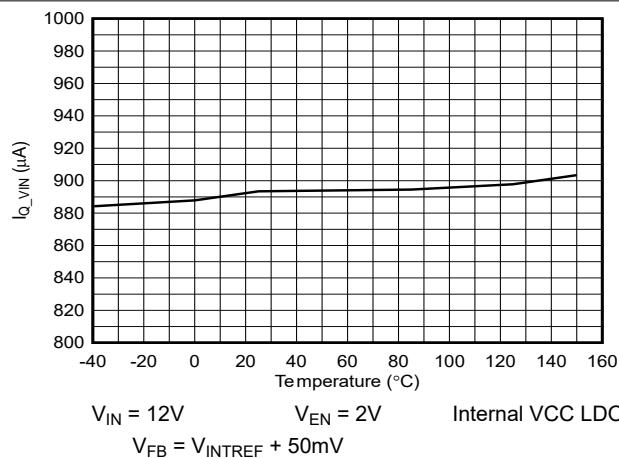
Figure 5-7. $I_{Q(VIN)}$ vs Junction Temperature

V_{IN} = 12V V_{EN} = 0V   Internal VCC LDO
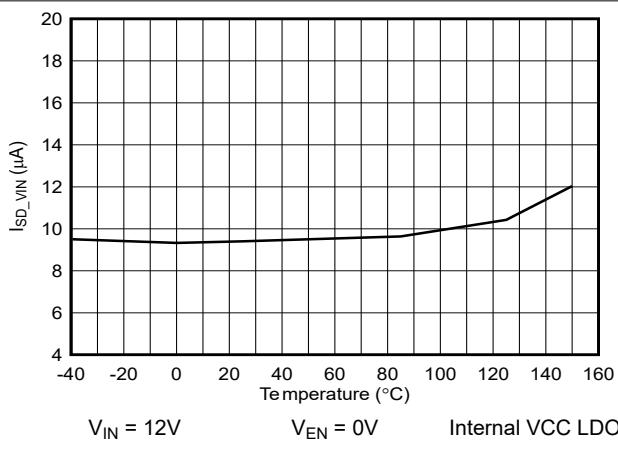
Figure 5-8. $I_{SD(VIN)}$ vs Junction Temperature


V_{IN} = 12V I_{VCC} = 2mA
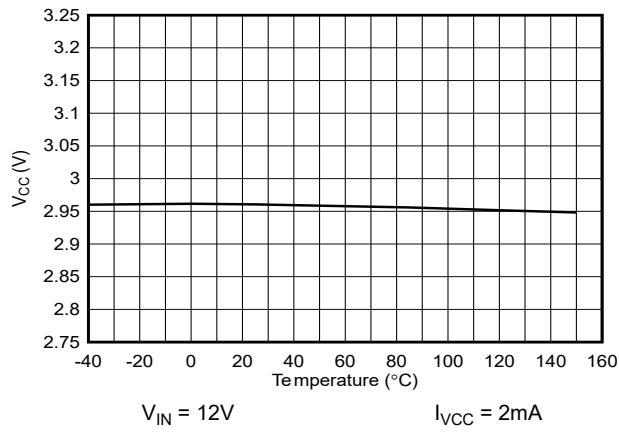
Figure 5-9. V_{CC} LDO vs Junction Temperature


V_{IN} = 12V
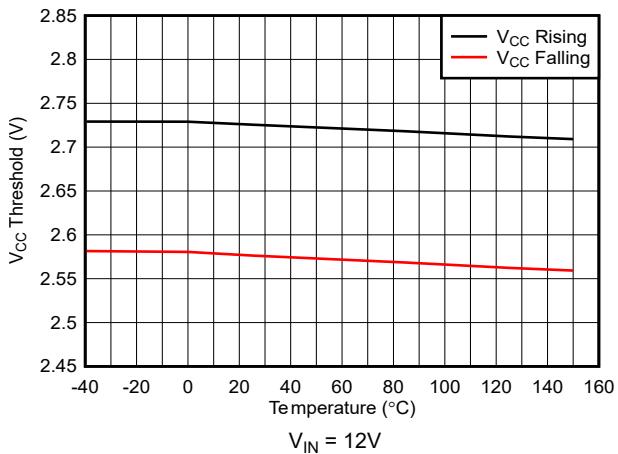
Figure 5-10. V_{CC} Pin Undervoltage Lockout vs Junction Temperature

V_{IN} = 12V
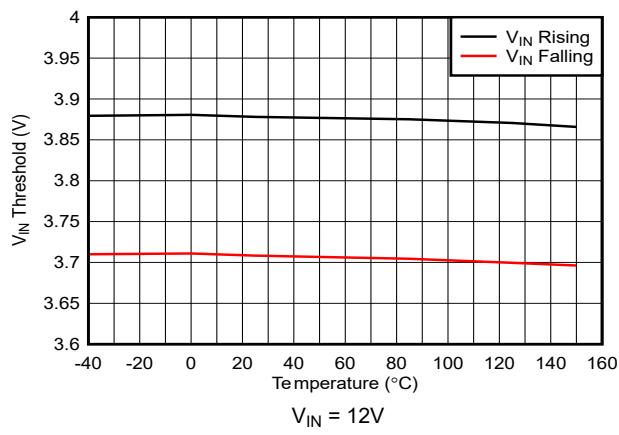
**Figure 5-11. V_{IN} Pin Undervoltage Lockout vs Junction Temperature**

V_{IN} = 12V
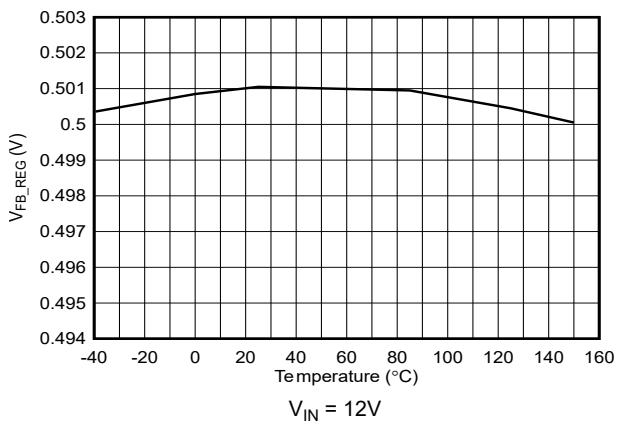
Figure 5-12. V_{FB_REG} vs Junction Temperature

Product Folder Links: *TPS548A23*

5.6 Typical Characteristics (continued)

$V_{IN} = 12V$

Figure 5-13. V_{EN} Pin Thresholds vs Junction Temperature

$T_{AMB} = 25°C$ FCCM $I_{OUT} = 5A$

$$\text{Voltage conversion ratio} = \frac{V_{OUT}}{V_{IN}}$$
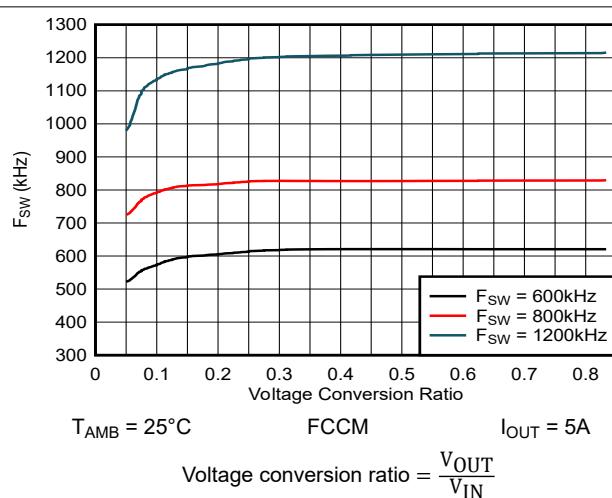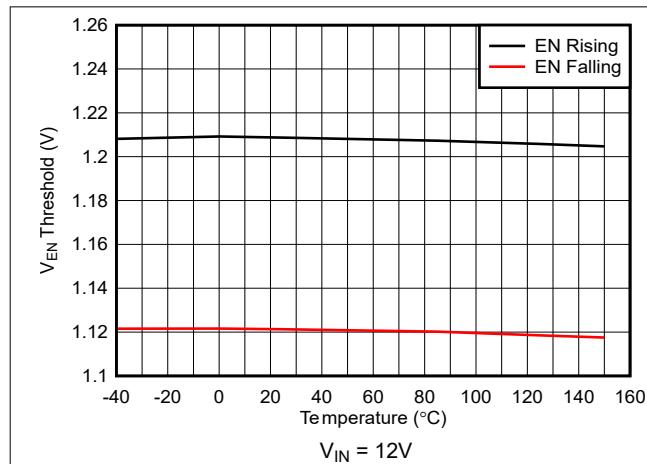
Figure 5-14. Switching Frequency vs Voltage Conversion Ratio

$T_{AMB} = 25°C$ $F_{SW} = 1200kHz$ $I_{OUT} = 5A$

FCCM
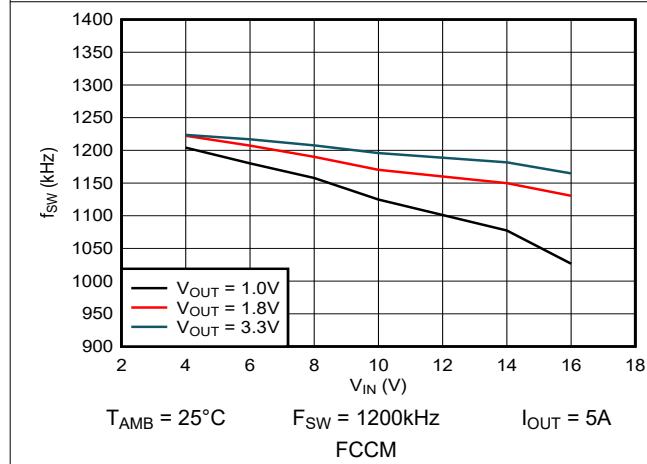
Figure 5-15. Switching Frequency vs Input Voltage

$T_{AMB} = 25°C$ $F_{SW} = 1200kHz$ $V_{IN} = 12V$

FCCM
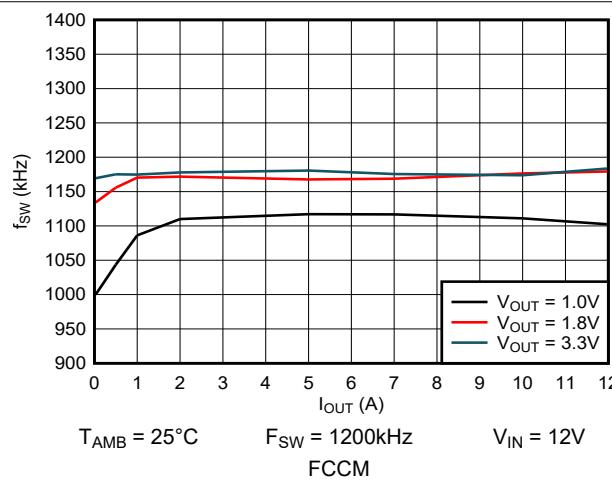
Figure 5-16. Switching Frequency vs Output Current

$T_{AMB} = 25°C$ $F_{SW} = 1200kHz$ $V_{IN} = 12V$

PFM
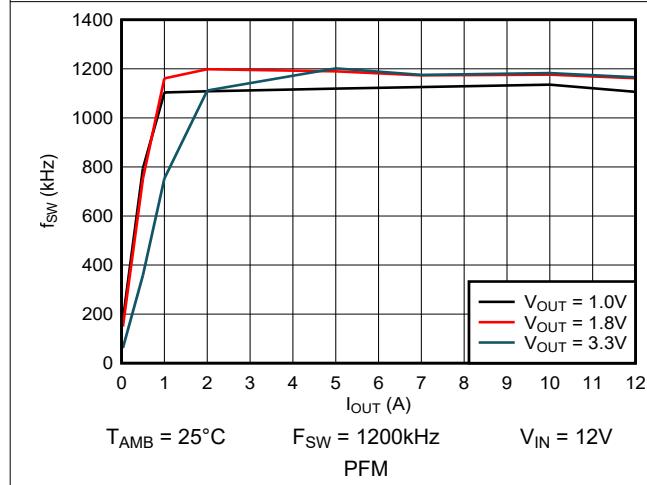
Figure 5-17. Switching Frequency vs Output Current

$T_{AMB} = 25°C$ $F_{SW} = 800kHz$ $I_{OUT} = 5A$

FCCM
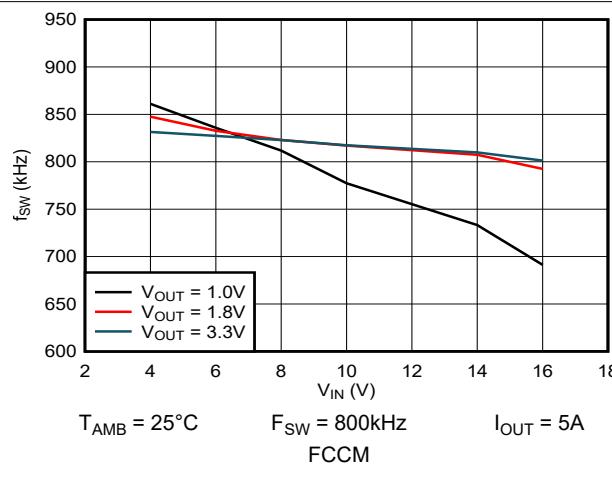
Figure 5-18. Switching Frequency vs Input Voltage

Product Folder Links: *TPS548A23*

5.6 Typical Characteristics (continued)

T_{AMB} = 25°C F_{SW} = 800kHz V_{IN} = 12V

FCCM
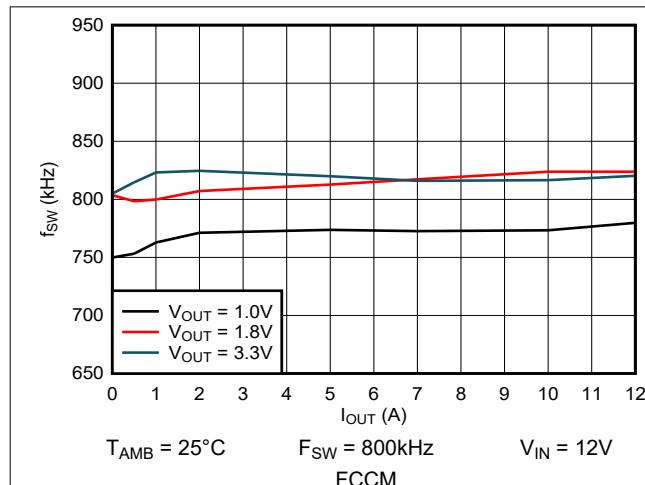
Figure 5-19. Switching Frequency vs Output Current

T_{AMB} = 25°C F_{SW} = 800kHz V_{IN} = 12V

PFM
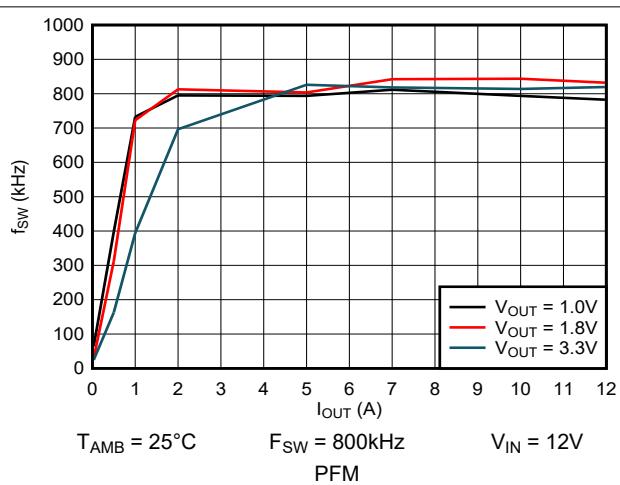
Figure 5-20. Switching Frequency vs Output Current

T_{AMB} = 25°C F_{SW} = 600kHz I_{OUT} = 5A

FCCM
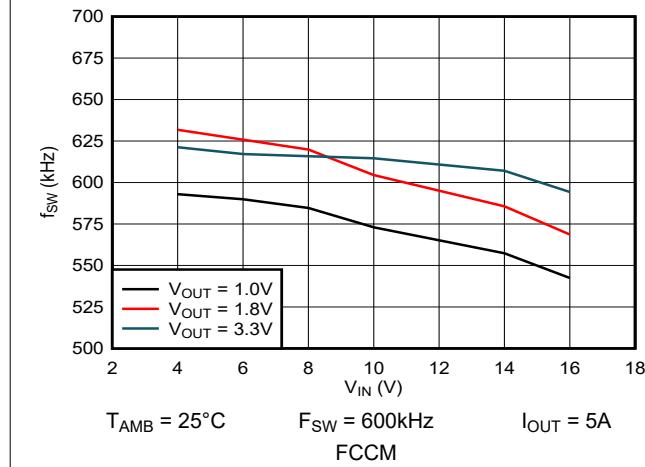
Figure 5-21. Switching Frequency vs Input Voltage

T_{AMB} = 25°C F_{SW} = 600kHz V_{IN} = 12V

FCCM
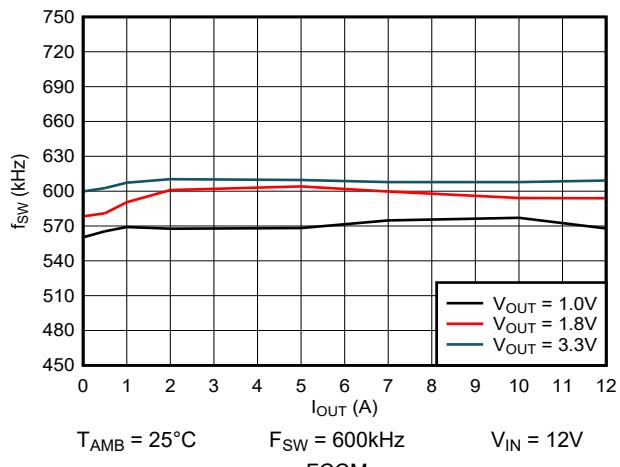
Figure 5-22. Switching Frequency vs Output Current

T_{AMB} = 25°C F_{SW} = 600kHz V_{IN} = 12V

PFM
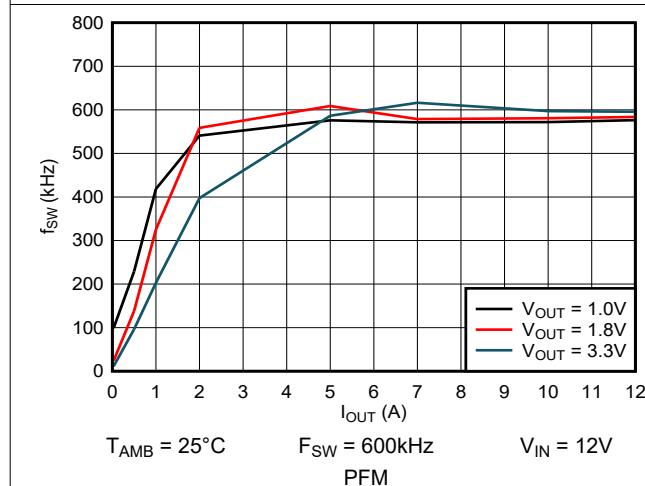
Figure 5-23. Switching Frequency vs Output Current

V_{IN} = 12V F_{SW} = 600kHz I_{OUT} = 0A

FCCM
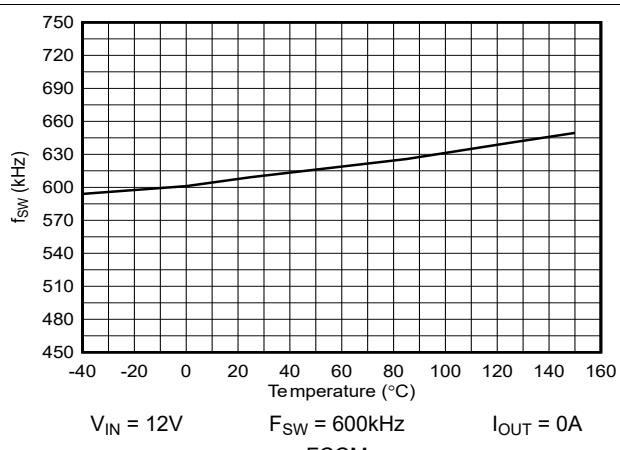
Figure 5-24. Switching Frequency vs Junction Temperature

Product Folder Links: *TPS548A23*

5.6 Typical Characteristics (continued)

V_{IN} = 12V F_{SW} = 800kHz I_{OUT} = 0A
FCCM
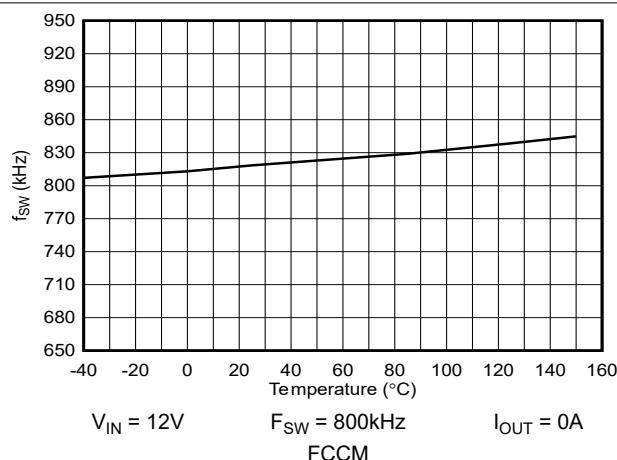
Figure 5-25. Switching Frequency vs Junction Temperature

V_{IN} = 12V F_{SW} = 1000kHz I_{OUT} = 0A
FCCM
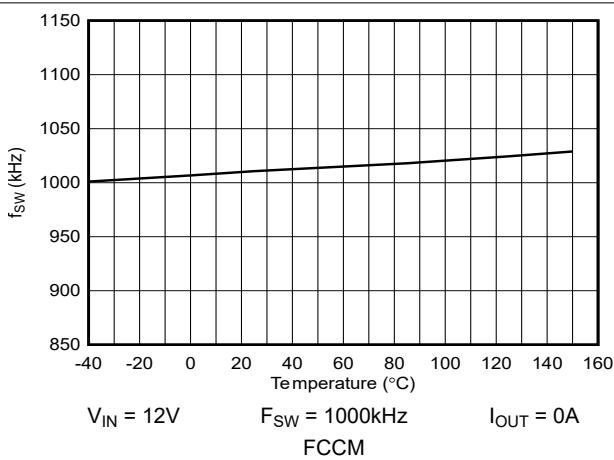
Figure 5-26. Switching Frequency vs Junction Temperature

V_{IN} = 12V F_{SW} = 1200kHz I_{OUT} = 0A
FCCM
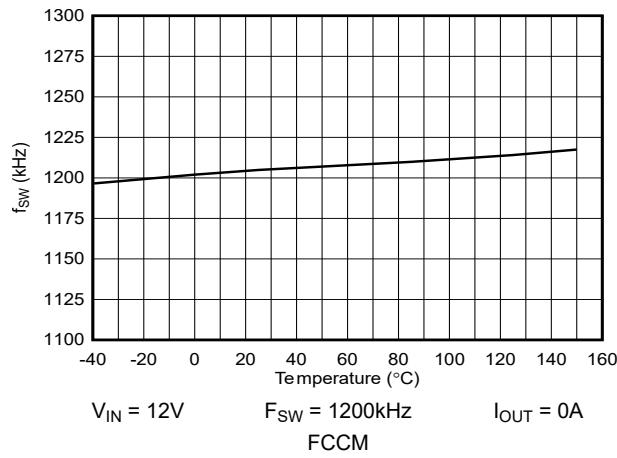
Figure 5-27. Switching Frequency vs Junction Temperature

V_{IN} = 12V
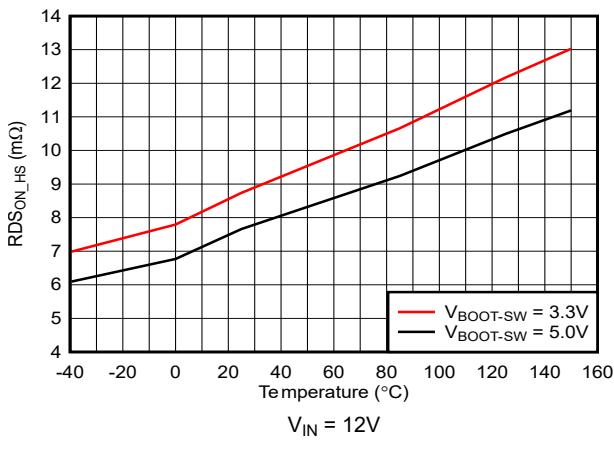
Figure 5-28. R$_{DSON(HS)}$ vs Junction Temperature

V_{IN} = 12V
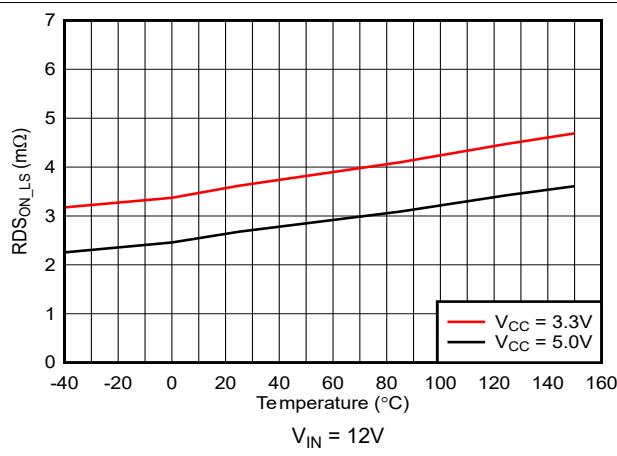
Figure 5-29. R$_{DSON(LS)}$ vs Junction Temperature

V_{IN} = 12V
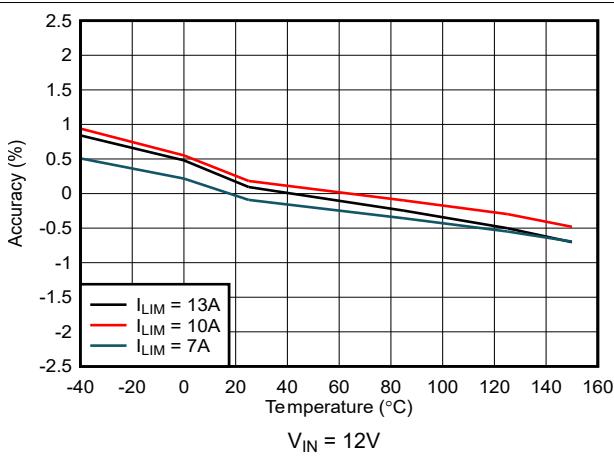
Figure 5-30. Low-Side Valley Current Limit Accuracy (Internal) vs Junction Temperature

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Product Folder Links: *TPS548A23*

5.6 Typical Characteristics (continued)

V_{IN} = 12V
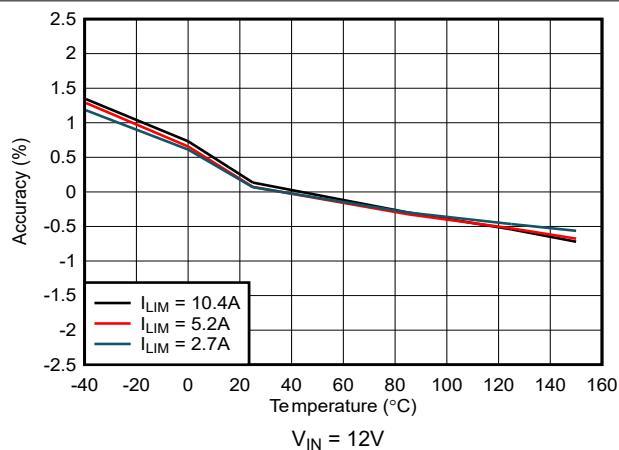
Figure 5-31. Low-Side Valley Current Limit Accuracy (External) vs Junction Temperature

V_{IN} = 12V
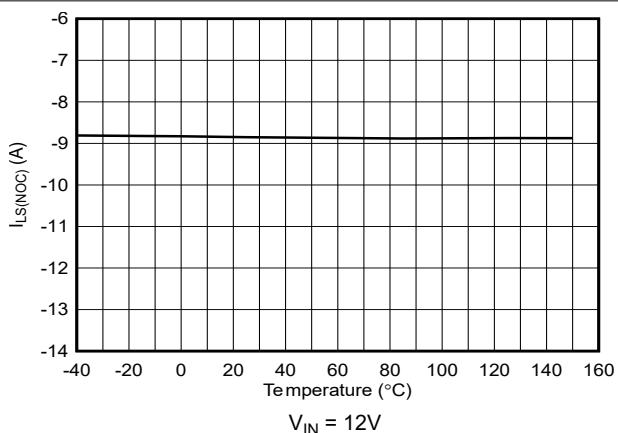
Figure 5-32. Low-Side Negative Overcurrent Limit vs Junction Temperature

Product Folder Links: *TPS548A23*

6 Detailed Description

6.1 Overview

The TPS548A23 device is a high-efficiency, single-channel, small-sized synchronous buck converter. The device is designed for low output voltage point-of-load applications with 12A or lower output current in server, storage, and similar computing applications. The TPS548A23 features proprietary D-CAP4 mode control combined with adaptive on-time architecture. This combination builds modern low-duty-ratio and ultra-fast load-step-response DC/DC converters in an excellent fashion. The output voltage set by the feedback voltage divider ranges from 0.5 to 5.5V. The conversion input voltage ranges from 4V to 16V, and the VCC input voltage ranges from 3.1V to 5.3V. The D-CAP4 modulator uses emulated current information to control the modulation. The D-CAP4 modulator reduces loop gain variation with different output voltages providing better transient response in higher output voltage applications. An advantage of this control scheme is that this control scheme does not require a phase-compensation network outside which makes the device easy-to-use and also allows low external component count. Another advantage of this control scheme is that this control scheme supports stable operation with all low ESR output capacitors (such as ceramic capacitors and low ESR polymer capacitors). Lastly, adaptive on-time control tracks the preset switching frequency over a wide range of input and output voltages while increasing switching frequency as needed during load-step transients.

6.2 Functional Block Diagram
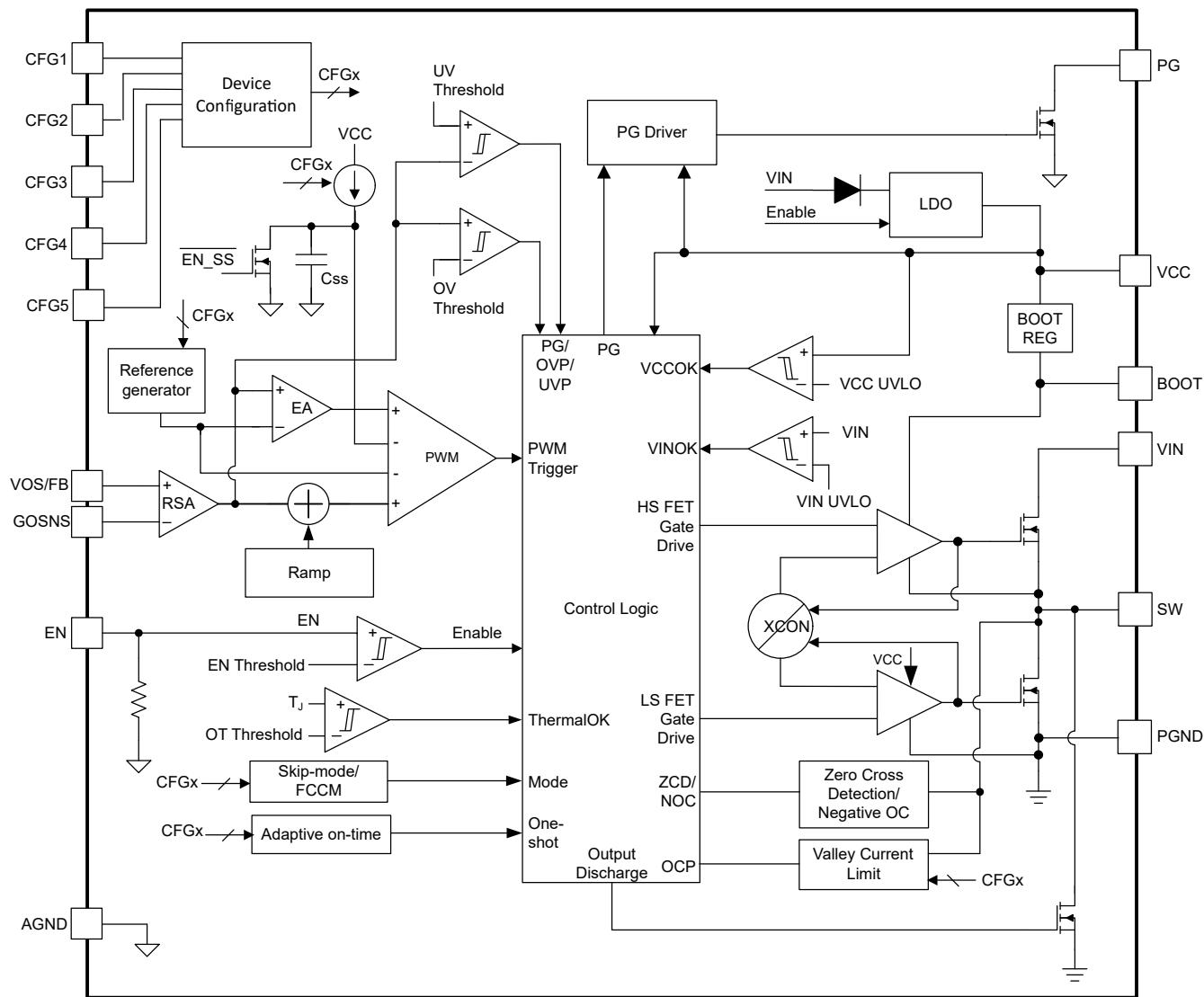
6.3 Feature Description

6.3.1 D-CAP4 Control

The device uses D-CAP4 control to achieve a fast load transient response while maintaining ease-of-use. The D-CAP4 control architecture includes an internal ripple generation network enabling the use of very low-ESR output capacitors such as multi-layered ceramic capacitors (MLCC) and low ESR polymer capacitors. No external current sensing network or voltage compensators are required with D-CAP4 control architecture. The role of the internal ripple generation network is to emulate the ripple component of the inductor current information and then combine with the voltage feedback signal to regulate the loop operation.

D-CAP4 control architecture reduces loop gain variation across V_{OUT}, enabling a fast load transient response across the entire output voltage range with one ramp setting. The R-C time-constant of the internal ramp circuit sets the zero frequency of the ramp, similar to other R-C based internal ramp generation architectures. The reduced variation in loop gain also mitigates the need for a feedforward capacitor to optimize the transient response. The ramp amplitude varies with V_{IN} to minimize variation in loop gain across input voltage, commonly referred to as input voltage feedforward. Lastly, the device uses internal circuitry to correct for the dc offset caused by the injected ramp, and significantly reduces the dc offset caused by the output ripple voltage, especially with light load current.

For any control topologies supporting no external compensation, there is a minimum range, maximum range, or both, for the output filter the control topologies can support. The output filter used for a typical buck converter is a low-pass L-C circuit. This L-C filter has double pole that Equation 1 describes.

$$f_P = \frac{1}{2 \times \pi \times \sqrt{L_{OUT} \times C_{OUT}}}$$

(1)

At low frequencies, the overall loop gain is set by the output set-point resistor divider network and the internal gain of the device. The low frequency L-C double pole has a 180-degree drop in phase. At the output filter frequency, the gain rolls off at a –40dB per decade rate and the phase drops rapidly. The internal ripple generation network introduces a high-frequency zero that reduces the gain roll off from –40dB to –20dB per decade and increases the phase by 90 degrees per decade above the zero frequency.

The inductor and capacitor selected for the output filter must be such that the f_P double pole of Equation 1 is located no higher than the value given in Table 6-1, then adjusted based on the nominal duty cycle in the application using Equation 2. Equation 2 scales up the $f_{P(TABLE)}$ because, as the duty cycle increases the gain of the D-CAP4 ramp decreases, so the maximum L-C double pole also increases.

$$f_{P(MAX)} = f_{P(TABLE)} \times \left(1 + \left(\frac{V_{OUT}}{V_{IN(typ)}} \right)^2 \right)$$

(2)

Table 6-1. Maximum L-C Double Pole

SWITCHING FREQUENCY (kHz)	MAXIMUM L-C DOUBLE POLE FREQUENCY (kHz)
600	14.9
800	19.9
1000	24.9
1200	29.9

An L-C double pole frequency that violates these guidelines for each setting can be possible, but must be validated in the application with measurements.

After identifying the application requirements, the output inductance is typically designed so the inductor peak-to-peak ripple current is approximately between 15% and 40% of the maximum output current in the application. Choosing very small output capacitance leads to a high frequency L-C double pole which causes the overall loop gain to stay high until the L-C double pole frequency. Given the zero from the internal ripple generation network is a relatively high frequency as well, the loop with very small output capacitance can have too high of

a crossover frequency which can cause instability. In general, where reasonable (or smaller) output capacitance is desired, output ripple requirement and load transient requirement can be used to determine the necessary output capacitance for stable operation.

If MLCCs are used, consider the derating characteristics to determine the final output capacitance for the design. For example, when using an MLCC with specifications of 10µF, X5R and 6.3V, the derating by DC bias and AC bias are 80% and 50%, respectively. The effective derating is the product of these two factors, which in this case is 40% and 4µF. Consult with capacitor manufacturers for specific characteristics of the capacitors to be used in the application.

As a simplified rule, if an output capacitor with an ESR zero that is less than 10 × the L-C double pole frequency, TI recommends to ignore when calculating the L-C double pole frequency for stability purposes. The L-C double pole frequency must be recalculated using only the low ESR MLCCs. For more accurate analysis when using mixed type output capacitors, TI recommends simulations or measurements.

For the maximum output capacitance recommendation, select the inductor and capacitor values so that the L-C double pole frequency is no less than 1/100th of the operating frequency. With this starting point, verify the small signal response on the board using the following criteria: The phase margin at the loop crossover is greater than 45 degrees. The actual maximum output capacitance can go higher as long as phase margin is greater than 45 degrees. However, a small signal measurement (Bode plot) must be done to confirm the design.

For large output filters with an L-C double pole near 1/100th of the operating frequency, additional phase boost can be required. A feedforward capacitor placed in parallel with R_{FB_HS} can boost the phase. See also the *Optimizing Transient Response of Internally Compensated dc-dc Converters With Feedforward Capacitor application note*.

Besides boosting the phase, a feedforward capacitor feeds more V_{OUT} node information into the FB node through AC coupling. This feedforward during load transient event enables faster response of the control loop to a V_{OUT} deviation. However, this feedforward during steady state operation also feeds more V_{OUT} ripple and noise into FB. High ripple and noise on FB usually leads to more jitter, or even double-pulse behavior. To determine the final feedforward capacitor value impacts to phase margin, consider load transient performance, ripple, and noise on FB. TI recommends using frequency analysis equipment to measure the crossover frequency and the phase margin.

6.3.2 Internal VCC LDO and Using External Bias On the VCC Pin

The TPS548A23 has an internal 3.0V LDO featuring input from VIN and output to VCC. When the EN voltage rises above the enable threshold ($V_{ENSTB(R)}$), the internal LDO is enabled and starts regulating output voltage on the VCC pin. The VCC voltage provides the bias voltage for the internal analog circuitry and also provides the supply voltage for the gate drivers.

Bypass the VCC pin with a 1µF, at least 6.3V rating ceramic capacitor. An external bias that is above the output voltage of the internal LDO can override the internal LDO. This override enhances the efficiency of the converter because the VCC current now runs off this external bias instead of the internal linear regulator. An external bias between 3.1V and 5.3V can be used to provide additional efficiency enhancement by reducing the R_{DSON} of the integrated power MOSFETs.

The VCC UVLO circuit monitors the VCC pin voltage and disables the whole converter when VCC falls below the VCC UVLO falling threshold. Maintaining a stable and clean VCC voltage is required for a smooth operation of the device.

Considerations when using an external bias on the VCC pin are as follows:
- When the external bias is applied on the VCC pin early enough (for example, before EN signal comes in), the internal LDO pass device is always off and the internal analog circuits have a stable power supply rail at the power enable.
- This consideration is not recommended. When the external bias is applied on the VCC pin late (for example, after EN signal comes in), any power-up and power-down sequencing can be applied as long as there is no excess current pulled out of the VCC pin. With this sequence, be cautious of external discharge paths on the

Product Folder Links: *TPS548A23*

VCC pin which can pull a current higher than the current limit of the internal VCC LDO. A load exceeding the current limit of the internal VCC LDO can potentially pull the VCC voltage low and turn off the VCC LDO through the UVLO, thereby shutting down the converter output.

- A good power-up sequence is when at least one of VIN UVLO rising threshold or EN rising threshold is satisfied later than VCC UVLO rising threshold. For example, a practical power-up sequence is: VIN applied first, then the external bias applied, and then EN signal goes high.

6.3.2.1 Powering the Device From a Single Bus

The device works well when powered by a single V_{IN} configuration. In a single V_{IN} configuration, the internal LDO is typically powered by a 5V or 12V bus and generates a 3V output to bias the internal analog circuitry and power MOSFET gate drivers. The V_{IN} input range under this configuration is 4V to 16V for up to 12A load current. Figure 6-1 shows an example for this single V_{IN} configuration.

V_{IN} and EN are the two signals to enable the device. For start-up sequence, any sequence between the V_{IN} and EN signals can power the device up correctly.
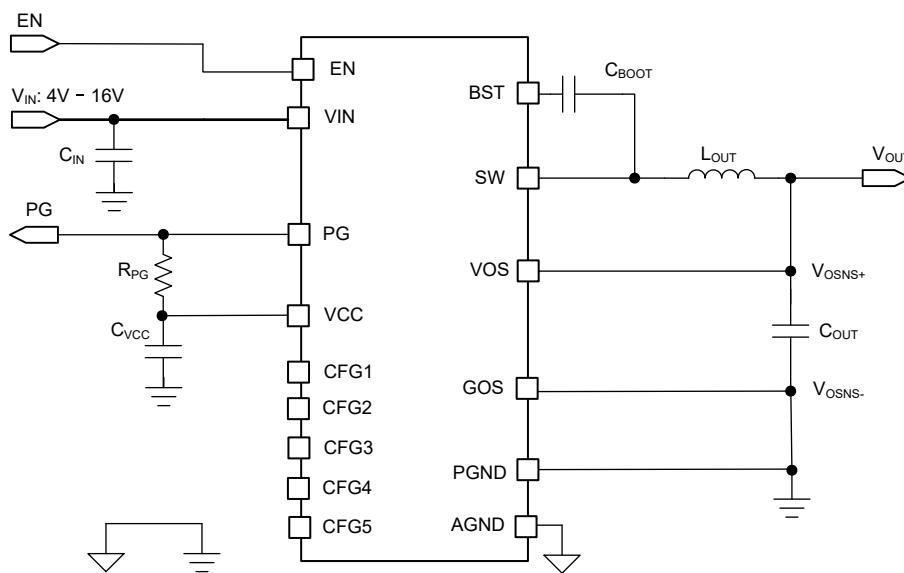
Figure 6-1. Single V_{IN} Configuration for a 12V Bus

6.3.2.2 Powering the Device From a Split-Rail Configuration

When an external bias, which is at a different level from main V_{IN} bus, is applied onto the VCC pin the device can be configured to split-rail by using both the main V_{IN} bus and VCC bias. Connecting a valid VCC bias to VCC pin overrides the internal LDO, thus saves power loss on the internal LDO. This configuration helps to improve overall system level efficiency but requires a valid VCC bias. A 3.3V or 5.0V rail is the common choice as VCC bias. With a stable VCC bias, the recommended V_{IN} input range under this configuration remains the same, from 4V to 16V.

The noise of the external bias affects the internal analog circuitry. To make sure of a proper operation, a clean, low-noise external bias and good local decoupling capacitor from VCC pin to PGND pin are required. Figure 6-2 shows an example for this split rail configuration.

The VCC external bias current during nominal operation varies with the bias voltage level and also the operating frequency. For example, by setting the device to skip-mode, the VCC pin draws less current from the external bias when the frequency decreases under a light load condition. The typical VCC external bias current under FCCM operation is listed in The external bias must be capable of supplying this current or the external bias voltage can drop and the internal LDO can no longer be overridden.

Under split rail configuration, V_{IN}, VCC bias, and EN are the signals to enable the part. For start-up sequence, TI recommends that at least one of VIN UVLO rising threshold or EN rising threshold is satisfied later than VCC UVLO rising threshold. A practical start-up sequence example is:

1. V_{IN} applied
2. External VCC bias applied
3. EN signal goes high

Similarly, for power-down sequence, TI recommends that at least one of the VIN UVLO falling threshold or the EN falling threshold is satisfied before the external VCC bias supply turns off. If the external VCC bias supply turns off first, the internal LDO of the device prevents the VCC voltage from dropping below 3.0V and be loaded by other circuits powered by the external VCC bias supply.
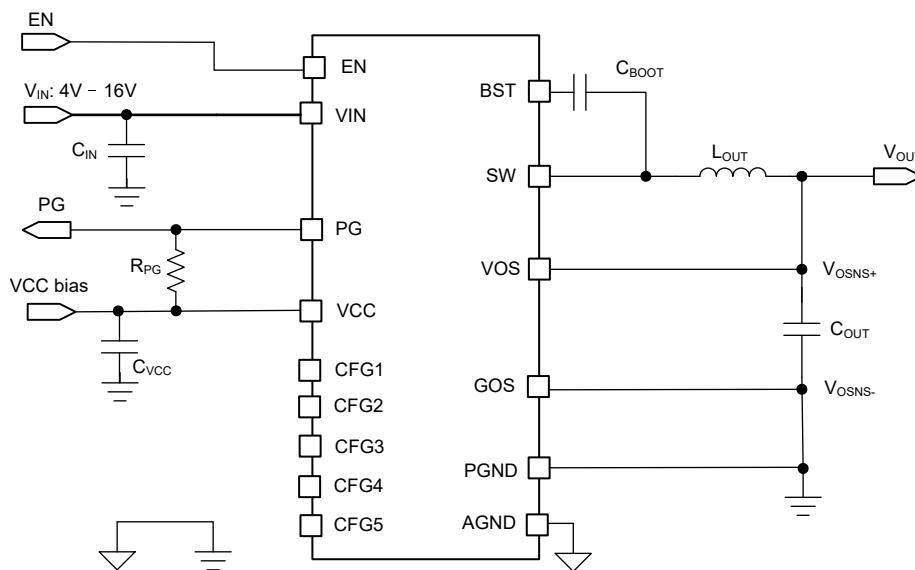
Figure 6-2. Split-Rail Configuration With External VCC Bias

6.3.3 Multifunction Configuration (CFG1-5) Pins

Through the multifunction configuration pins (CFG 1-5), the device can be configure for a variety of different operating modes. The CFG1-2 pins are used to set the device switching frequency, overcurrent threshold, soft-start time, and either hiccup or latch-up fault recovery operation, while the CFG3-5 pins provide select ability for either internal or external feedback, as well as FCCM or PFM operation.

Note

The selection of either internal or external feedback operation through the CFG3-5 pins changes the functions of the CFG1-2 pins. See also Section 6.3.3.1 and Section 6.3.3.2.

The CFGx states are set and latched during the internal power-on delay period. Changing the CFGx pins after the power-on delay does not change the status of the device.

6.3.3.1 Multifunction Configuration (CFG1-2) Pins (Internal Feedback)

When the device is configured for internal feedback operation with the CFG 3-5 pins (see Table 6-4), the switching frequency and current limit are programmed by tying the CFG1-2 pins either high (VCC), low (GND) or left floating based on the following table:

Note

When the device is configured for internal feedback operation, the soft-start time is set to 1ms, and the fault recovery is configured for hiccup.

Table 6-2. CFG 1-2 Pin Selection (Internal Feedback Configuration)

CFG1	VALLEY OCP (A)	CFG2	SWITCHING FREQUENCY (f_{SW}) (kHz)[1]
VCC	13	VCC	600
GND	10	GND	800
Float	7	Float	1200

(1)   Switching frequency is based on 3.3V output voltage. Frequency varies with output voltage.

6.3.3.2 Multifunction Configuration (CFG1-2) Pins (External Feedback)

When the device is configured for external feedback operation with the CFG 3-5 pins (see Table 6-4), the switching frequency, fault recovery mode, overcurrent threshold, and soft-start time are programmed by connecting resistors between the CFG1-2 pins and AGND. A ±1% tolerance resistor with a typical temperature coefficient of ±100ppm/°C is required for accurate detection across the device operating range.

The switching frequency, fault recovery mode, and soft-start time are programmed by connecting a resistor between the CFG1 pin and AGND based on the following table:

Table 6-3. CFG1 Pin Selection Table (External Feedback Configuration)

CFG1 PIN RESISTANCE TO AGND (kΩ)	SWITCHING FREQUENCY (f_{SW}) (kHz)[1]	FAULT RECOVERY MODE	SOFT-START TIME (ms)
0 (GND)	600	Hiccup	1
4.99	800	Hiccup	1
7.50	1000	Hiccup	1
10.5	1200	Hiccup	1
13.3	600	Latch Off	1
16.9	800	Latch Off	1
21.0	1000	Latch Off	1
24.9	1200	Latch Off	1
30.1	600	Hiccup	2
35.7	800	Hiccup	2
42.2	1000	Hiccup	2
48.7	1200	Hiccup	2
56.2	600	Latch Off	2
64.9	800	Latch Off	2
75.0	1000	Latch Off	2
86.6	1200	Latch Off	2
102	600	Hiccup	3
118	800	Hiccup	3
137	1000	Hiccup	3
158	1200	Hiccup	3
182	600	Latch Off	3
210	800	Latch Off	3
243	1000	Latch Off	3
≥280 (FLOAT)	1200	Latch Off	3

(1)   Switching frequency is based on 3.3V output voltage. Frequency varies with output voltage.

The valley overcurrent protection is programmed with resistor (R_{ILIM}) between CFG2 and AGND using based on Equation 4.

Product Folder Links: *TPS548A23*

$$I_{LIM\_VALLEY} = \frac{K_{OCL}}{R_{ILIM}} \tag{3}$$

$$R_{ILIM} = \frac{K_{OCL}}{I_{LIM\_VALLEY}} \tag{4}$$

where

- I_{LIM_VALLEY} is valley overcurrent limit threshold for load current in A
- R_{ILIM} is ILIM resistor value in Ω
- K_{OCL} is a constant of 54.4×10^3 for the calculation

Additionally, use Equation 6 to calculate the maximum output current for a given I_{LIM_VALLEY} setting.

$$I_{OUT\_MAX} = I_{LIM\_VALLEY} + \frac{1}{2} \times I_{RIPPLE} \tag{5}$$

$$I_{OUT\_MAX} = I_{LIM\_VALLEY} + \frac{1}{2} \times \frac{(V_{IN} - V_O) \times V_O}{V_{IN}} \times \frac{1}{L \times f_{SW}} \tag{6}$$

where

- I_{OUT_MAX} is the maximum output current in A
- I_{LIM_VALLEY} is valley overcurrent limit threshold for load current in A
- V_{IN} is input voltage value in V
- V_O is output voltage value in V
- L is output inductor value in μH
- f_{SW} is switching frequency in MHz

Note

TI recommends a ±1% tolerance resistor because a worse tolerance resistor provides less accurate OCL threshold.

To protect the device from an unexpected connection to the ILIM pin, an internal fixed OCL clamp is implemented. This internal OCL clamp limits the maximum valley current on the low-side MOSFET to 13A when the ILIM pin has too small of a resistance to AGND, or is accidentally shorted to ground.

6.3.3.3 Multifunction Configuration (CFG3-5) Pins

The CFG3-5 pins select the device output voltage configuration as well as FCCM or PFM operation based on the following table.

Table 6-4. CFG 3-5 Pin Selection Table

CFG3	CFG4	CFG5	V_{FB} CONFIG	V_{OUT}(V)	F_{SW} MODE
VCC	VCC	VCC	internal	5.0	FCCM
VCC	GND	VCC	internal	3.3	FCCM
VCC	Float	VCC	internal	2.5	FCCM
VCC	VCC	GND	internal	1.8	FCCM
VCC	GND	GND	internal	1.5	FCCM
VCC	Float	GND	internal	1.2	FCCM
VCC	VCC	Float	internal	1.1	FCCM
VCC	GND	Float	internal	1.05	FCCM
VCC	Float	Float	internal	1.0	FCCM
GND	VCC	VCC	internal	0.95	FCCM
GND	GND	VCC	internal	0.9	FCCM
GND	Float	VCC	internal	0.85	FCCM
GND	VCC	GND	internal	0.8	FCCM
GND	GND	GND	external	0.5	FCCM
GND	Float	GND	internal	5.0	PFM
GND	VCC	Float	internal	3.3	PFM

Table 6-4. CFG 3-5 Pin Selection Table (continued)

CFG3	CFG4	CFG5	V_{FB} CONFIG	V_{OUT}(V)	F_{SW} MODE
GND	GND	Float	internal	2.5	PFM
GND	Float	Float	internal	1.8	PFM
Float	VCC	VCC	internal	1.5	PFM
Float	GND	VCC	internal	1.2	PFM
Float	Float	VCC	internal	1.1	PFM
Float	VCC	GND	internal	1.0	PFM
Float	GND	GND	internal	0.95	PFM
Float	Float	GND	internal	0.9	PFM
Float	VCC	Float	internal	0.85	PFM
Float	GND	Float	internal	0.8	PFM
Float	Float	Float	external	0.5	PFM

6.3.4 Enable

When the EN pin voltage rises above the enable threshold voltage ($V_{EN(R)}$) and VIN rises above the VIN UVLO rising threshold, the device enters the internal power-up sequence.

The EN pin has an internal filter to avoid unexpected ON or OFF due to small glitches. The time constant of this RC filter is 2µs. For example, when applying 3.3V voltage source on the EN pin that jumps from 0V to 3.3V with an ideal rising edge, the internal EN signal reaches 2.1V after 2µs, which is 63.2% of applied 3.3V voltage level.

An internal pulldown resistor is implemented between the EN pin and AGND pin. With this pulldown resistor, floating the EN pin before start-up keeps the device in the disabled state. A resistor divider to the EN pin can be used to increase the input voltage the device begins the start-up sequence. The internal pulldown resistor must be accounted for when using an external resistor divider. To reduce impact to the EN rising and falling threshold, this internal pulldown resistor is 1MΩ. During nominal operation when the power stage switches, this large internal pulldown resistor can not have enough noise immunity to hold EN pin low for the device to enter the disabled state.

If an external resistor divider is connected to the EN pin, an additional 5µA current source is activated when the EN voltage exceeds the rising threshold to provide a programmable hysteresis based on the enable falling threshold voltage ($V_{EN(F)}$) and external resistors.

The recommended operating condition for the EN pin is a maximum of 5.5V. *Do not* connect the EN pin to the VIN pin directly if VIN can exceed 5.5V.

6.3.5 Soft Start

The device implements an internally fixed 1ms soft-start time when configured for internal feedback operation and a selectable (1ms, 2ms, or 3ms) soft-start time when configured for external feedback operation.

If hiccup mode is enabled, the SS time also sets the hiccup wait-time before a restart try. After a fault triggers the hiccup response an internal timer sets the hiccup wait time to 14 × t_{SS}.

6.3.6 Power Good

The device has a power-good (PG or PGOOD) output that goes high to indicate when the converter output is in regulation. The power-good output is an open-drain output and must be pulled up to the VCC pin or an external voltage source (< 5.5V) through a pullup resistor (typically 30.1kΩ) to go high. The recommended power-good pullup resistor value is 1kΩ to 100kΩ.

Note

For systems using an external voltage source to pull up the PG pin, TI recommends that this same external voltage source also be used to bias the VCC pin.

After the soft-start ramp finishes, the power-good signal becomes high after a internal delay t_{PG_DLY}. An internal soft-start done signal goes high when the SS voltage reaches $V_{SS(DONE)}$ to indicate the soft-start ramp has finished. If the FB voltage drops to 80% of the V_{REF} voltage or exceeds 116% of the V_{REF} voltage, the power-

good signal latches low after a 4µs internal delay. The power-good signal can only be pulled high again after re-toggling EN or a reset of VIN.

If an OV event causes the FB voltage to exceed the OV threshold during soft start, but the FB voltage drops below the OV threshold before soft-start is completed, the power-good signal does not latch low until FB exceeds the OV threshold or drops below UV threshold. The OV or UV event must occur after the soft-start ramp finishes for the power-good signal to latch low. FB exceeding the OV threshold during soft start does, however, trigger the OV fault, and the devices response to OV (described in Section 6.3.7) typically pulls the output voltage below the UV threshold.

If the input supply fails to power up the device (for example, VIN and VCC both stay at zero volts) and this pin is pulled up through an external resistor, the power-good pin clamps low to the low-level specified in the POWER GOOD section in the *Electrical Characteristics*
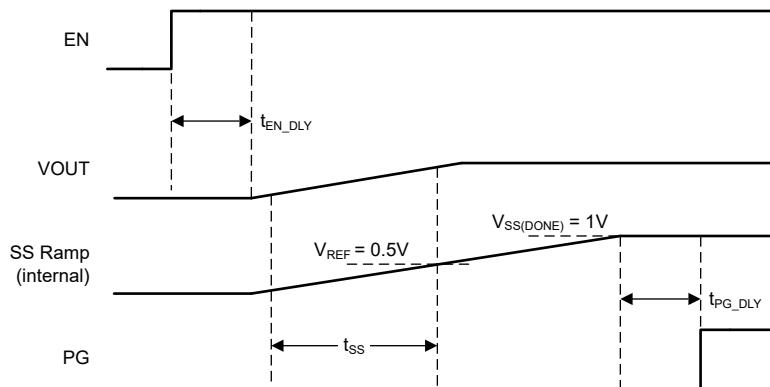
Figure 6-3. EN, SS, & PG Timing Diagram

6.3.7 Overvoltage and Undervoltage Protection

The device monitors a resistor-divided feedback voltage to detect overvoltage and undervoltage events. The OVP function enables when the output is enabled. The UVP function enables after the soft-start period is complete.

After soft-start is complete, if the FB voltage becomes lower than 80% of the V_{REF} voltage, the UVP comparator trips and an internal UVP delay counter begins counting. After the 70µs UVP delay time, depending on the selected fault recovery mode, the device either hiccups and re-starts after a sleep time of 14 × the soft-start period or latches off both high-side and low-side MOSFETs. The latch-off fault can be cleared with a reset of VIN or by toggling the EN pin.

When the output is enabled, the FB voltage must rise above the 92.5% PG low-to-high threshold to clear the UVP comparator. If the FB voltage does not exceed the 92.5% threshold by the end of the soft-start period, the device responds to the undervoltage event.

During the UVP delay time, if the FB voltage becomes higher than the 92.5% PG low-to-high threshold, the undervoltage event is cleared and the timer is reset to zero. When the output voltage falls below the 80% UVP threshold again, the 70-µs timer re-starts.

When the FB voltage becomes higher than 116% of the V_{REF} voltage, the OVP comparator trips and the circuit latches the fault condition and drives the PG pin low. The high-side MOSFET turns off and the low-side MOSFET turns on until reaching a negative current limit I_{NOCL}. Upon reaching the negative current limit, the low-side MOSFET is turned off, and the high-side MOSFET is turned on again, for a proper on-time (determined by $V_O/V_{IN}/f_{SW}$). The device operates in this mode until the output voltage is pulled down under the UVP threshold. The device then responds to the undervoltage event as described above.

If there is an overvoltage condition prior to the output being enabled (such as a high prebiased output), the device responds to the overvoltage event as described above at the beginning of the soft-start period. The device waits until the completion of the soft-start period for UVP to be enabled, and depending on the selected

fault recovery mode, the device either hiccups and re-starts after a sleep time of 14 × the soft-start period or latches off .

6.3.8 Output Voltage Setting (External Feedback Configuration)

By either floating or GNDing all of the CFG 3-5 pins, the device is configured for external feedback operation, and the output voltage is programmed by the voltage-divider resistors, R_{FB_T} and R_{FB_B}. Connect R_{FB_T} between the FB pin and the positive node of the load, and connect R_{FB_B} between the FB pin and GOS pin. The FB pin is regulated to the internal reference (V_{REF}). The recommended R_{FB_B} value is 10kΩ, ranging from 1kΩ to 20kΩ. Use Equation 7 to determine R_{FB_T}.

$$R_{FB\_T} = \frac{V_O - V_{FB\_REG}}{V_{FB\_REG}} \times R_{FB\_B} \tag{7}$$

To improve the overall V_{OUT} accuracy, using a ±1% accuracy or better resistor for the FB voltage divider is highly recommended. Regardless of remote sensing or single-ended sensing, the FB voltage divider, R_{FB_T} and R_{FB_B}, must always be placed as close as possible to the device.

6.3.9 Remote Sense

The device integrates a remote sense amplifier across the VOS/FB and GOS pins. The remote sense function compensates for voltage drop on the PCB traces helping to maintain V_{OUT} accuracy under steady state operation and load transient events.

The FB voltage divider resistors (if used) must be kept near the device to minimize the trace length connected to the FB pin. The connections from the FB voltage divider resistors and the GOS pin to the remote location must be a pair of PCB traces with Kelvin sensing across a bypass capacitor of 0.1µF or higher. To maintain stable output voltage and minimize the ripple, the pair of remote sensing lines must stay away from any noise sources such as inductor and SW nodes, or high frequency clock lines. TI recommends to shield the pair of remote sensing lines with ground planes above and below.

Single-ended V_{OUT} sensing is often used for local sensing. For this configuration, connect the higher FB resistor, R_{FB_HS}, to a high-frequency local bypass capacitor of 0.1µF or higher, and short GOS to AGND.

The recommended GOS operating range (relative to the AGND pin) is −100mV to +100mV.

6.3.10 Low-side MOSFET Zero-Crossing

The device uses a zero-crossing (ZC) circuit to perform the zero inductor current detection during skip-mode operation. The ZC threshold is set to a small negative value before the low-side MOSFET is turned off, entering discontinuous conduction mode (DCM) operation. After entering DCM, the ZC threshold hysteresis increases the threshold to a small positive value after entering DCM. As a result, the device delivers better light-load efficiency.

When the load current increases enough such that the device exits DCM, the ZC circuit must detect 16 consecutive cycles of negative inductor current below the ZC threshold before returning to DCM. Only one cycle without ZC detection is required to exit DCM.

When the output is enabled, the ZC circuit is also enabled during the first 32 switching cycles while the device is in soft start. If the device is configured for FCCM, ZC is disabled and the device transitions to FCCM when soft start is complete. See *Soft Start* for a description on soft-start completion. If there are not at least 32 switching cycles before soft-start is done, such as during start-up with a high output prebias, the ZC is not disabled until the first high-side MOSFET on-time after soft-start done is complete.

6.3.11 Current Sense and Positive Overcurrent Protection

For a buck converter, during the on-time of the high-side MOSFET, the switch current increases at a linear rate determined by the input voltage, output voltage, on-time, and output inductor value. During the on-time of the low-side MOSFET, the current decreases linearly. The average value of the switch current equals the load current.

The output overcurrent limit (OCL) in the device is implemented using a cycle-by-cycle valley current detect control circuit. The inductor current is monitored during the on-time of the low-side MOSFET by measuring the low-side MOSFET drain-to-source current. If the measured drain-to-source current of the low-side MOSFET is above the current limit threshold, the low-side MOSFET stays ON until the current level becomes lower than the current limit threshold. This type of behavior reduces the average output current sourced by the device.

During an overcurrent condition, the current to the load exceeds the current to the output capacitors. Thus, the output voltage tends to decrease. Eventually, when the output voltage falls below the undervoltage-protection threshold (80%), the UVP comparator detects the fall and shuts down the device after a wait time of 70 µs. Depending on the fault recovery configuration, the device either hiccups or latches off, as described in *Overvoltage and Undervoltage Protection.*

Note

If an OCL condition happens during start-up, the device still has cycle-by-cycle current limit based on low-side valley current, but the UVP comparator does not shut down the device until after soft start has completed.

See also Section 6.3.3 on setting the currently limit protection threshold.

6.3.12 Low-side MOSFET Negative Current Limit

The device has a fixed, cycle-by-cycle negative overcurrent limit ($I_{LS(NOC)}$). Similar with the positive overcurrent limit, the inductor current is monitored during the on-time of the low-side MOSFET. To prevent too large negative current flowing through the low-side MOSFET, when the device detects a –9A current (typical threshold) through the low-side MOSFET, the device turns off the low-side MOSFET and then turns on the high-side MOSFET for the on-time set by the one-shot timer (determined by $V_{IN}/V_{OUT}/f_{SW}$). After the high-side MOSFET on-time expires, the low-side MOSFET turns on again.

The device must not trigger the –9A negative current limit threshold during nominal operation, unless a small inductor value that is too small is chosen or the inductor becomes saturated. This negative current limit is used to discharge output capacitors after an output OVP event. See also *Overvoltage and Undervoltage*.

6.3.13 Output Voltage Discharge

When the device is disabled through EN, the device enables the output voltage discharge mode. This mode forces both high-side and low-side MOSFETs to latch off, but turns on the internal discharge MOSFET, which is connected from SW to PGND, to discharge the output voltage. After the FB voltage drops below 50mV, the discharge MOSFET and the internal VCC LDO is turned off.

When the EN pin goes low to disable the converter and while the VCC voltage is sufficient to turn on the discharge switch, the output voltage discharge mode is activated.

6.3.14 UVLO Protection

The device monitors the voltage on both the VIN and the VCC pins. If the VCC pin voltage is lower than the VCC_{UVLO} falling threshold voltage, the device shuts off. If the VCC voltage increases beyond the VCC_{UVLO} rising threshold voltage, the device turns back on. VCC UVLO is a non-latch protection.

When the VIN pin voltage is lower than the VIN_{UVLO} falling threshold voltage but the VCC pin voltage is still higher than VCC_{UVLO} rising threshold voltage, the device stops switching and discharges the SS pin. After the VIN voltage increases beyond the VIN_{UVLO} rising threshold voltage, the device re-initiates the soft start and switches again. VIN UVLO is a non-latch protection.

6.3.15 Thermal Shutdown

The device monitors internal junction temperature. If the temperature exceeds the threshold value (typically 165°C), the device stops switching and discharges the SS pin. When the temperature falls approximately 15°C below the threshold value, the device turns back on with a re-initiated soft start. Thermal shutdown is a non-latch protection.

6.4 Device Functional Modes

6.4.1 Auto-Skip (PFM) Eco-mode Light Load Operation

If Skip (PFM)-mode is selected through the CFG3-5 pins, the device automatically reduces the switching frequency at light-load conditions to maintain high efficiency. See the *Multifunction Configuration (CFG3-5) Pins* section on how to select the PFM mode.

As the output current decreases from heavy load condition, the inductor current also decreases until the valley of the inductor ripple current touches the zero-crossing threshold (*Low-side MOSFET Zero-Crossing*). The zero-crossing threshold sets the boundary between the continuous-conduction and discontinuous-conduction modes. The synchronous MOSFET turns off when this zero-crossing threshold is detected. As the load current decreases further, the converter runs into discontinuous-conduction mode (DCM). The on-time is maintained to a level approximately the same as during continuous-conduction mode operation so that discharging the output capacitor with a smaller load current to the level of the reference voltage requires more time. Use Equation 8 to calculate the transition point to light-load operation $I_{OUT(LL)}$ (for example: the boundary between continuous- and discontinuous-conduction mode).

For low output ripple, TI recommends using only ceramic output capacitors for designs that operate in skip-mode.

$$I_{OUT(LL)} = \frac{1}{2} \times \frac{(V_{IN} - V_O) \times V_O}{V_{IN}} \times \frac{1}{L \times f_{SW}}$$

(8)

6.4.2 Forced Continuous-Conduction Mode

If FCCM mode is selected through the CFG3-5 pins, the controller operates in continuous-conduction mode (CCM) during light-load conditions. See the *Multifunction Configuration (CFG3-5) Pins* section on how to select the FCCM mode.

During FCCM, the switching frequency is maintained to an almost constant level over the entire load range, which is designed for applications requiring tight control of the switching frequency and output ripple at the cost of reduced light-load efficiency. Use Equation 8 to calculate the typical light-load operation boundary. Below this calculated load current, the device operates in FCCM.

Product Folder Links: *TPS548A23*

7 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, as well as validating and testing their design implementation to confirm system functionality.

7.1 Application Information

The TPS548A23 device is a high-efficiency, single-channel, small-sized, synchronous buck converter. The device is designed for low output voltage point-of-load applications with 12A or lower output current in server, storage, and similar computing applications. The TPS548A23 features proprietary D-CAP4 mode control combined with adaptive on-time architecture. This combination builds modern low-duty-ratio and ultra-fast load-step-response DC/DC converters in an excellent fashion. The output voltage ranges from 0.5V to 5.5V. The conversion input voltage ranges from 4V to 16V, and the VCC input voltage ranges from 3.1V to 5.3V. The D-CAP4 mode uses emulated current information to control the modulation. An advantage of this control scheme is that this control scheme does not require an external phase-compensation network, which makes the device easy-to-use and also allows for a low external component count. Another advantage of this control scheme is that the control scheme supports stable operation with all low ESR output capacitors (such as ceramic capacitor and low ESR polymer capacitor). Adaptive on-time control tracks the preset switching frequency over a wide range of input and output voltages while increasing switching frequency as needed during a load-step transient.

7.2 Typical Application

The schematic shows a typical application for the TPS548A23. This example describes the design procedure of converting an input voltage range of 8V to 16V down to 3.3V with a maximum output current of 12A.
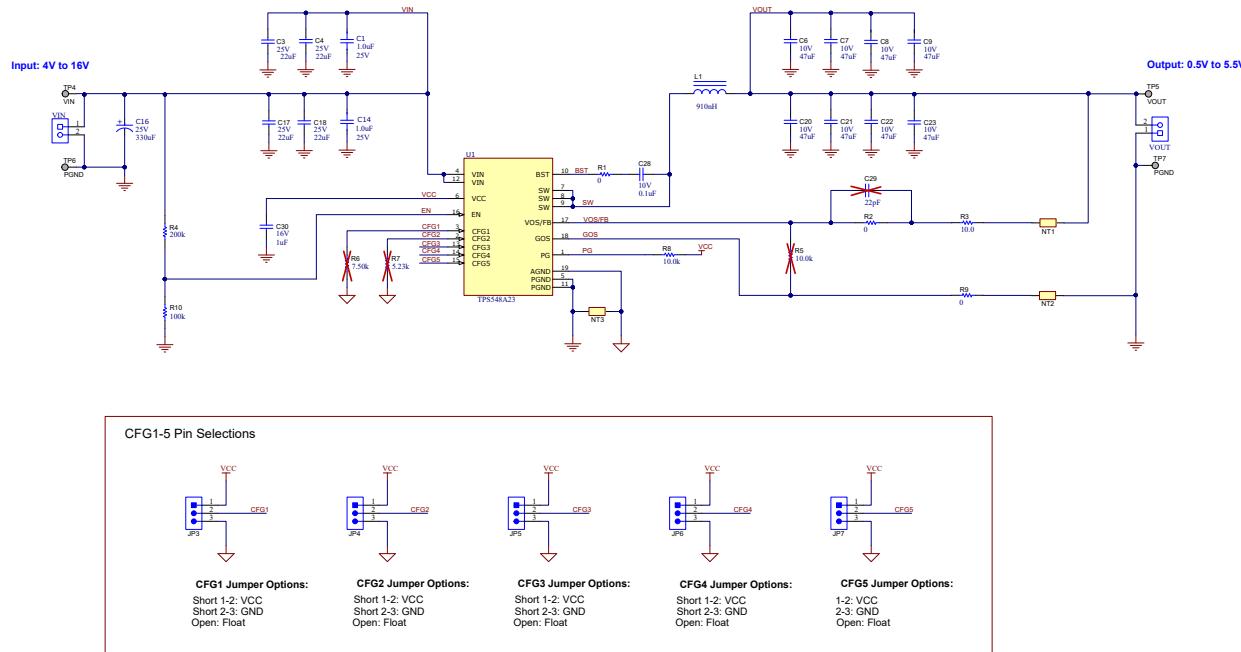
Figure 7-1. Application Circuit Diagram

Product Folder Links: *TPS548A23*

7.2.1 Design Requirements

This design uses the parameters listed in the following table.

Table 7-1. Design Example Specifications

SPECIFICATION	TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IN} voltage range			8	12	16	V
Input current	V_{IN} = 8V, I_{OUT} = 12A			5.55		A
V_{IN} start voltage	Set by EN pin resistor divider			3.84		V
Output voltage setpoint				3.3		V
Output current range	V_{IN} = 8V to 16V		0		12	A
Load transient response	I_{OUT} = 0A to 10A	Voltage change		–99		mV
	I_{OUT} = 10A to 0A	Voltage change		99		mV
Output ripple voltage	I_{OUT} = 12A			16		mVPP
Soft-start time	From start of switching to V_{FB} = 0.5V, t_{SS} = 2ms setting		1.4	2	2.6	ms
Current limit	OCP = 13A setting by CFG1 pin selection		11.5	13	14.5	A
Switching frequency (f_{SW})	f_{SW} = 800kHz setting by CFG2 pin selection			800		kHz
IC case temperature	I_{OUT} = 12A, 15-minute soak			52.7		°C

7.2.2 Detailed Design Procedure

The external component selection is a simple process using D-CAP4 mode. Select the external components using the following steps.

7.2.2.1 Output Voltage Setting Point

The CFG3-5 pins select the device output voltage configuration as well as FCCM or PFM operation based on Table 6-4. For this design, use the internal FB configuration option.

If an output voltage other than those is available in Table 6-4 is needed, the external feedback configuration allows the output voltage to be programmed by a voltage-divider resistors, R1 and R2. Connect R1 between the FB pin and the output, and connect R2 between the FB pin and GOS. The recommended R2 value is 10kΩ, but the value can also be set to another value between the range of 1kΩ to 20kΩ. Use Equation 9 to determine R1.

$$R1 = R2 \times \left(\frac{V_{OUT}}{0.5V} - 1 \right) \tag{9}$$

7.2.2.2 Choose the Switching Frequency

For this design, use the internal feedback mode, and the switching frequency is configured by tying the CFG2 pin to VCC (600kHz), GND (800kHz), or by leaving floating (1.2MHz). See also Table 6-2.

If the external feedback configuration is being used, the CFG1 pin is used to select between four switching frequencies (600kHz, 800kHz, 1MHz, or 1.2MHz) See also Table 6-3 for more information using the CFG1 pin configuration in external feedback mode.

Switching frequency selection is a tradeoff between higher efficiency and smaller system design size. Lower switching frequency yields higher overall efficiency but relatively bigger external components. Higher switching frequencies cause additional switching losses which impact efficiency and thermal performance. For this design, connect CFG2 pin to AGND to set the switching frequency to 800kHz

When selecting the switching frequency of a buck converter, the minimum on-time and minimum off-time must be considered. Equation 10 calculates the maximum f_{SW} before being limited by the minimum on-time. When hitting the minimum on-time limits of a converter with D-CAP4 control, the effective switching frequency changes to keep the output voltage regulated. This calculation ignores resistive drops in the converter to give a worst case estimation.

$$f_{SW}(max) = \frac{V_{OUT}}{V_{IN}(max)} \times \frac{1}{t_{ON\_MIN}} = \frac{3.3\,V}{16\,V} \times \frac{1}{40\,ns} = 5156\,kHz \tag{10}$$

Equation 11 calculates the maximum f_{SW} before being limited by the minimum off-time. When hitting the minimum off-time limits of a converter with D-CAP4 control, the operating duty cycle maxes out and the output voltage begins to drop with the input voltage. This equation requires the DC resistance of the inductor, R_{DCR}, selected in the following step so this preliminary calculation assumes a resistance of 1.4mΩ. If operating near the maximum f_{SW} limited by the minimum off-time, the variation in resistance across temperature must be considered when using Equation 12. The selected f_{SW} of 800kHz is below the two calculated maximum values.

$$f_{SW}(max) = \frac{V_{IN}(min) - V_{OUT} - I_{OUT}(max) \times \left(R_{DCR} + R_{DS(ON)\_HS}\right)}{t_{OFF\_MIN}(max) \times \left(V_{IN}(min) - I_{OUT}(max) \times \left(R_{DS(ON)\_HS} - R_{DS(ON)\_LS}\right)\right)} \tag{11}$$

$$f_{SW}(max) = \frac{8\,V - 3.3\,V - 12\,A \times (1.4\,m\Omega + 9.5\,m\Omega)}{150\,ns \times (8\,V - 12\,A \times (9.5\,m\Omega - 3.3\,m\Omega))} = 3843\,kHz \tag{12}$$

7.2.2.3 Choose the Inductor

To calculate the value of the output inductor (L_{OUT}), use Equation 13. The output capacitor filters the inductor-ripple current ($I_{IND(ripple)}$). Therefore, selecting a high inductor-ripple current impacts the selection of the output capacitor because the output capacitor must have a ripple-current rating equal to or greater than the inductor-ripple current. Larger ripple current increases output ripple voltage, but improves signal-to-noise ratio and helps to stabilize operation. Generally speaking, the inductance value must set the ripple current at approximately 15% to 40% of the maximum output current for a balanced performance.

For this design, the inductor-ripple current is set to 30% of 12A output current. With a 800kHz switching frequency, 16V as maximum V_{IN}, and 3.3V as the output voltage, Based on these parameters, Equation 13 calculates an inductance of 0.91µH. A nearest standard value of 0.91µH is chosen.

$$L = \frac{(V_{IN}(max) - V_{OUT}) \times V_{OUT}}{I_{RIPPLE} \times V_{IN}(max) \times f_{SW}} = \frac{(16\,V - 3.3\,V) \times 3.3\,V}{0.3 \times 12A \times 16\,V \times 800\,kHz} = 0.91\,\mu H \tag{13}$$

The inductor requires a low DCR to achieve good efficiency. The inductor also requires enough room above peak inductor current before saturation. Use Equation 14 to estimate the inductor current ripple. For this design, by tying the CFG1 pin to VCC, $I_{OC(valley)}$ is set to 13A, thus peak inductor current under maximum V_{IN} is calculated as 13.8A with Equation 15.

$$I_{RIPPLE} = \frac{(V_{IN}(max) - V_{OUT}) \times V_{OUT}}{L \times V_{IN}(max) \times f_{SW}} = \frac{(16\,V - 3.3\,V) \times 3.3\,V}{0.91\mu H \times 16\,V \times 800\,kHz} = 3.6\,A \tag{14}$$

$$I_{L(PEAK)} = I_{OUT} + \frac{I_{RIPPLE}}{2} = 12\,A + \frac{3.6\,A}{2} = 13.8\,A \tag{15}$$

$$I_{L(RMS)} = \sqrt{I_{OUT}^2 + \frac{I_{RIPPLE}^2}{12}} = \sqrt{12\,A^2 + \frac{3.6\,A^2}{12}} = 12.04\,A \tag{16}$$

7.2.2.4 Choose the Output Capacitor

There are three considerations for selecting the value of the output capacitor:
1. Stability
2. Steady state output voltage ripple
3. Regulator transient response to a change load current

First, calculate the minimum output capacitance based on these three requirements. Equation 17 calculates the minimum capacitance to keep the LC double pole below the $f_{P(MAX)}$ in Table 6-1 to meet stability requirements. This requirement helps to keep the LC double pole close to the internal zero. Equation 18 calculates the minimum capacitance to meet the steady state output voltage ripple requirement of 16mV. These calculations

are for CCM operation and does not include the portion of the output voltage ripple caused by the ESR or ESL of the output capacitors.

$$C_{OUT\_STABLITY} > \left(\frac{1}{2\pi \times f_{P(TABLE)} \times \left(1 + \left(\frac{V_{OUT}}{V_{IN(TYP)}}\right)^2\right)} \right)^2 \times \frac{1}{L_{OUT}} = \left(\frac{1}{2\pi \times 19.9\text{kHz} \times \left(1 + \left(\frac{3.3V}{12V}\right)^2\right)} \right)^2 \times \frac{1}{0.91\mu H} \quad (17)$$

$$= 61\mu F$$

$$C_{OUT\_RIPPLE} > \frac{I_{RIPPLE}}{8 \times V_{RIPPLE} \times f_{SW}} = \frac{3.6A}{8 \times 16mV \times 800kHz} = 35.2\mu F \quad (18)$$

Equation 20 and Equation 21 calculate the minimum capacitance to meet the transient response requirement of 99mV with a 10A step. These equations calculate the necessary output capacitance to hold the output voltage steady while the inductor current ramps up or ramps down after a load step.

$$C_{OUT\_UNDERSHOOT} > \frac{L \times I_{STEP}^2 \times \left(\frac{V_{OUT}}{V_{IN(min)} \times f_{SW}} + t_{OFF\_MIN(max)}\right)}{2 \times V_{TRANS} \times V_{OUT} \times \left(\frac{V_{IN(min)} - V_{OUT}}{V_{IN(min)} \times f_{SW}} - t_{OFF\_MIN(max)}\right)} \quad (19)$$

$$C_{OUT\_UNDERSHOOT} > \frac{0.91\mu H \times 10A^2 \times \left(\frac{3.3V}{8V \times 800kHz} + 150ns\right)}{2 \times 99mV \times 3.3V \times \left(\frac{8V - 3.3V}{8V \times 800kHz} - 150ns\right)} = 158.6\mu F \quad (20)$$

$$C_{OUT\_OVERSHOOT} > \frac{L \times I_{STEP}^2}{2 \times V_{TRANS} \times V_{OUT}} = \frac{0.91\mu H \times 10A^2}{2 \times 99mV \times 3.3V} = 139.3\mu F \quad (21)$$

The output capacitance needed to meet the overshoot requirement is the highest value, so this sets the required minimum output capacitance for this example. Stability requirements can also limit the maximum output capacitance. Equation 22 calculates the recommended maximum output capacitance. This calculation keeps the LC double pole above 1/100th the f_{SW}.

$$C_{OUT\_STABILITY} < \left(\frac{50}{\pi \times f_{SW}}\right)^2 \times \frac{1}{L} = \left(\frac{50}{\pi \times 800kHz}\right)^2 \times \frac{1}{0.91\mu H} = 435\mu F \quad (22)$$

Using more output capacitance is possible, but the stability must be checked through a bode plot or transient response measurement. The selected output capacitance is 8 × 47µF, 10V ceramic capacitors. When using ceramic capacitors, the capacitance must be derated due to DC and AC bias effects. The selected capacitors derate to 48% the nominal value giving an effective total capacitance of 180µF. This effective capacitance meets the minimum and maximum requirements.

This application uses all ceramic capacitors so the effects of ESR on the ripple and transient were ignored. If using non ceramic capacitors, as a starting point, the ESR must be below the values calculated in Equation 23 to meet the ripple requirement and Equation 24 to meet the transient requirement. For more accurate calculations or if using mixed output capacitors, the impedance of the output capacitors must be used to determine if the ripple and transient requirements can be met.

$$R_{ESR\_RIPPLE} < \frac{V_{RIPPLE}}{I_{RIPPLE}} = \frac{26mV}{3.6A} = 7.2m\Omega \quad (23)$$

$$R_{ESR\_TRANS} < \frac{V_{TRANS}}{I_{STEP}} = \frac{99mV}{10A} = 9.9m\Omega \quad (24)$$

Product Folder Links: *TPS548A23*

7.2.2.5 Choose the Input Capacitors (C$_{IN}$)

The device requires input bypass capacitors between both pairs of VIN and PGND pins to bypass the power-stage. The bypass capacitors must be placed as close as possible to the pins of the IC as the layout allows. At least 20µF nominal of ceramic capacitance and two high frequency ceramic bypass capacitors are required. A 0.1µF to 1µF capacitor must be placed as close as possible to both VIN pins 4 and 12 on the same side of the board of the device to provide the required high frequency bypass, to reduce the high frequency overshoot and undershoot on across the power-stage on the VIN and SW pins. TI recommends at least 1µF of bypass capacitance as close as possible to each VIN pin to minimize the input voltage ripple. The ceramic capacitors must be a high-quality dielectric of X6S or better for the high capacitance-to-volume ratio and stable characteristics across temperature. In addition to this requirement, more bulk capacitance can be needed on the input depending on the application to minimize variations on the input voltage during transient conditions.

Use Equation 25 to calculate the input capacitance required to meet a specific input ripple target. A recommended target input voltage ripple is 5% the minimum input voltage, 400mV in this example. The calculated input capacitance is 9.1µF. This example meets these two requirements with 2 × 10µF ceramic capacitors.

$$C_{IN} > \frac{V_{OUT} \times I_{OUT} \times \left(1 - \frac{V_{OUT}}{V_{IN(min)}}\right)}{f_{SW} \times V_{IN(min)} \times V_{IN\_RIPPLE}} = \frac{3.3V \times 12A \times \left(1 - \frac{3.3V}{8V}\right)}{800\,kHz \times 8V \times 400mV} = 9.1\mu F \tag{25}$$

The capacitor must also have an RMS current rating greater than the maximum input RMS current in the application. Use Equation 27 to calculate the input RMS current the input capacitors must support. The result is 5.9A in this example. The ceramic input capacitors have a current rating greater than this value.

$$I_{CIN(RMS)} = \sqrt{\frac{V_{OUT}}{V_{IN(min)}} \times \left(\frac{(V_{IN(min)} - V_{OUT})}{V_{IN(min)}} \times I_{OUT}^2 + \frac{I_{RIPPLE}^2}{12}\right)} \tag{26}$$

$$I_{CIN(RMS)} = \sqrt{\frac{3.3V}{8V} \times \left(\frac{(8V - 3.3V)}{8V} \times 12^2 + \frac{3.6^2}{12}\right)} = 5.9A \tag{27}$$

For applications requiring bulk capacitance on the input, such as ones with low input voltage and high current, TI recommends the selection process in *How to select input capacitors for a buck converter* analog design journal.

7.2.2.6 VCC Bypass Capacitor

At a minimum, a 1.0µF, at least 6.3V rating, X5R ceramic bypass capacitor is needed on VCC pin located as close to the pin as the layout allows. Use the smallest sized capacitor possible, such as an 0402 package, to minimize the loop from the VCC pin to the PGND pin.

7.2.2.7 BOOT Capacitor

At a minimum, a 0.1µF, 10V, X5R ceramic bypass capacitor is needed between the BOOT and SW pins located as close to the pin as the layout allows.

7.2.2.8 PG Pullup Resistor

The PG pin is open-drain, so a pullup resistor is required when using this pin. The recommended value is between 1kΩ and 100kΩ.

7.2.3 Application Curves

L = 0.55µH   V_OUT = 3.3V   C_OUT = 6x47µF
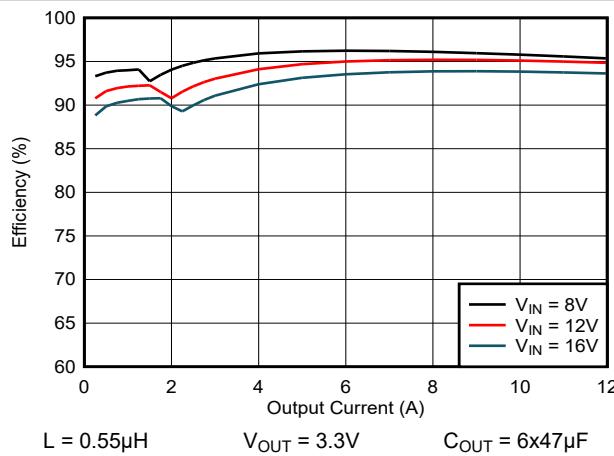
Figure 7-2. Efficiency - PFM Mode

L = 0.55µH   V_OUT = 3.3V   C_OUT = 6x47µF
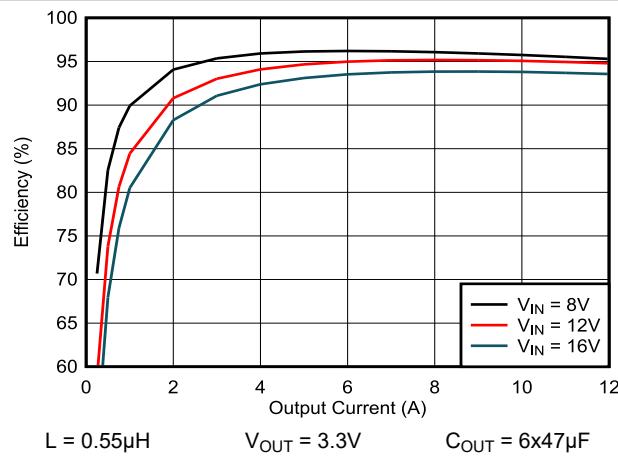
Figure 7-3. Efficiency - FCCM Mode

L = 0.55µH   V_OUT = 3.3V   C_OUT = 6x47µF
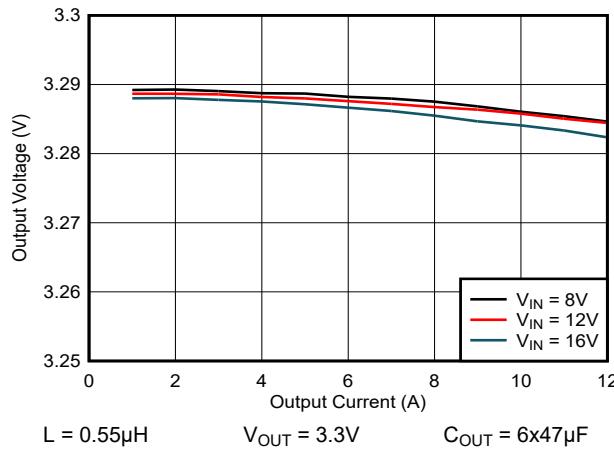
Figure 7-4. Load Regulation

L = 0.55µH   V_OUT = 3.3V   C_OUT = 6x47µF
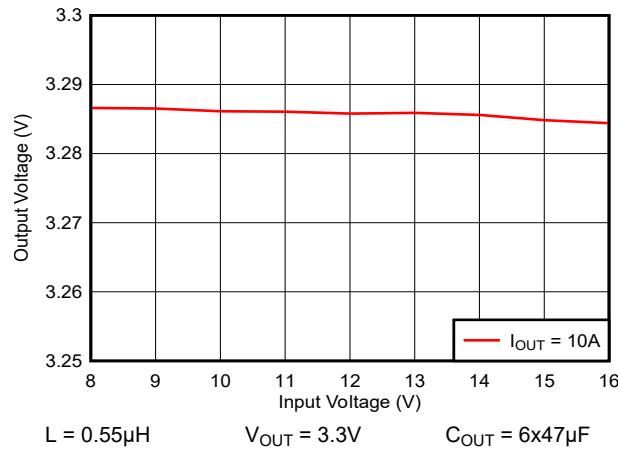
Figure 7-5. Line Regulation

L = 0.55µH   I_OUT = 0A to 10A at 1A/µs   C_OUT = 6x47µF

V_OUT = 3.3V   CH1 = 50mV/div
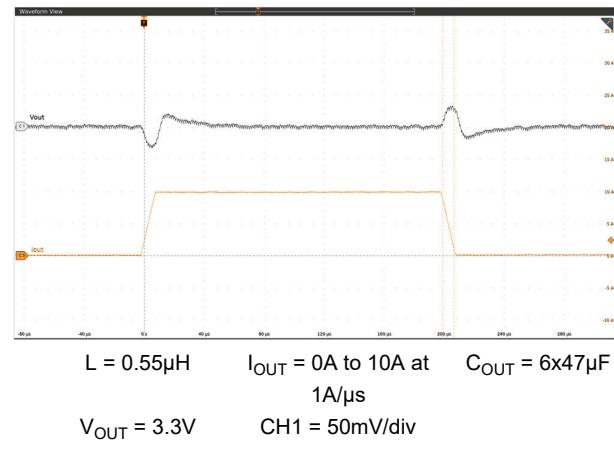
Figure 7-6. Load Transient

L = 0.55µH   I_OUT = 10A   C_OUT = 6x47µF
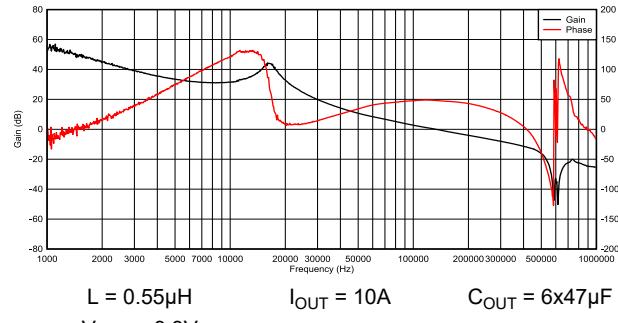
V_OUT = 3.3V

Figure 7-7. Frequency Response
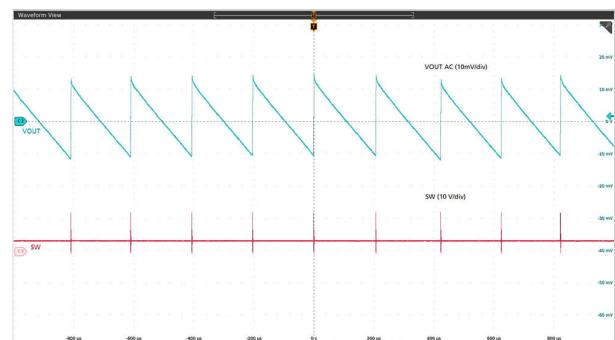
L = 0.55µH I_{OUT} = 10mA C_{OUT} = 6x47µF
V_{OUT} = 3.3V

Figure 7-8. Output Voltage Ripple – PFM Mode
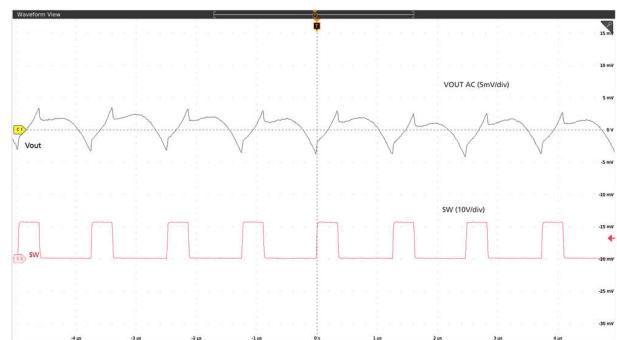
L = 0.55µH I_{OUT} = 12A C_{OUT} = 6x47µF
V_{OUT} = 3.3V

Figure 7-9. Output Voltage Ripple - FCCM Mode
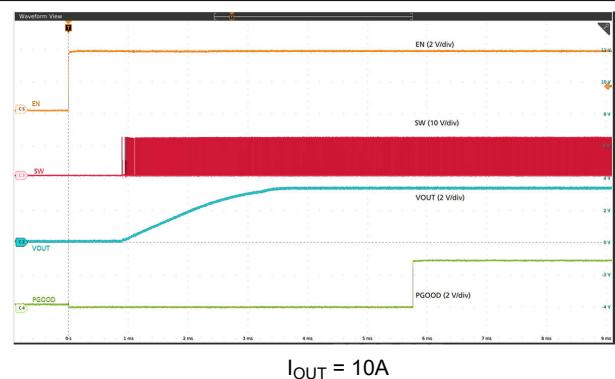
I_{OUT} = 10A

Figure 7-10. Start-Up With EN
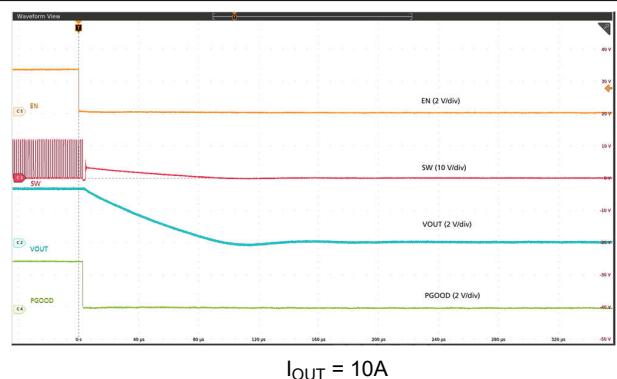
I_{OUT} = 10A

Figure 7-11. Shutdown With EN

7.3 Power Supply Recommendations

The device is designed to operate from an input voltage supply range between 4V and 16V. Both input supplies (VIN and VCC bias) must be well regulated. Proper bypassing of input supplies (VIN and VCC bias) is also critical for noise performance, as are PCB layout and grounding scheme. See the recommendations in *Layout.*

Product Folder Links: *TPS548A23*

7.4 Layout

7.4.1 Layout Guidelines

Before beginning a design using the device, consider the following:

- Make VIN, PGND, and SW traces as wide as possible to reduce trace impedance and improve heat dissipation.
- Place the power components (including input and output capacitors, the inductor, and the IC) on the top side of the PCB. To shield and isolate the small signal traces from noisy power lines, insert at least one solid ground inner plane.
- Placement of the VIN decoupling capacitors are important for the power MOSFET robustness. A 1µF/25V/0402 ceramic high-frequency bypass capacitor on each VIN pin (pins 4 and 12) is required, connected to the adjacent PGND pins (pins 5 and 11 respectively). Place the remaining ceramic input capacitance next to these high frequency bypass capacitors. The remaining input capacitance can be placed on the other side of the board, but use as many vias as possible to minimize impedance between the capacitors and the pins of the IC.
- Place as many vias as possible below and near the PGND pins. This action minimizes parasitic impedance and also lowers thermal resistance.
- Use vias near both VIN pins and provide a low impedance connection between them through an internal layer. A via can also be placed below each of the VIN pins.
- Place the VCC decoupling capacitor as close as possible to the device, with a short return to PGND (pin 5). Make sure the VCC decoupling loop is small and use traces with a width of 12 mil or wider to route the connection.
- Place the BOOT capacitor as close as possible to the BOOT and SW pins. Use traces with a width of 12 mil or wider to route the connection.
- The PCB trace, which connects the SW pin and high-voltage side of the inductor, is defined as switch node. The switch node must be as short and wide as possible.
- If using external feedback, always place the feedback resistors near the device to minimize the FB trace distance, no matter single-end sensing or remote sensing.
  - For remote sensing, the connections from the FB voltage divider resistors to the remote location must be a differential pair of PCB traces, and must implement Kelvin sensing across a bypass capacitor of 0.1µF or higher. The ground connection of the remote sensing signal must be connected to GOS pin. The V_{OUT} connection of the remote sensing signal must be connected to the feedback resistor divider with the bottom feedback resistor terminated to the GOS pin. To maintain stable output voltage and minimize the ripple, the pair of remote sensing lines must stay away from any noise sources such as inductor and SW nodes, or high frequency clock lines. TI recommends to shield the pair of remote sensing lines with ground planes above and below.
  - For single-end sensing, connect the top feedback resistor between the FB pin and the output voltage to a high-frequency local output bypass capacitor of 0.1µF or higher, and short GOS to AGND with a short trace.
- Connect the AGND pin (pin 19) to the PGND pins (pins 5 and 11) beneath the device.
- Avoid routing the PG signal and any other noisy signals in the application near noise sensitive signals, such as VOS/FB and GOS to limit coupling.
- See *Layout Example* for the layout recommendation.

7.4.2 Layout Example
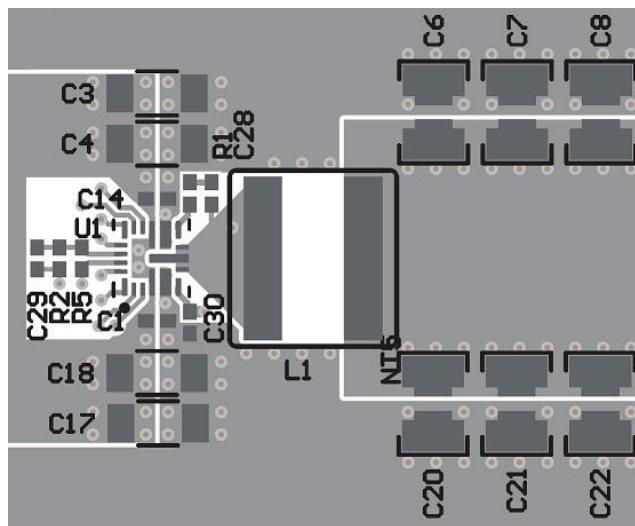
Figure 7-12. Layout Recommendation

For a more detailed layout example, please reference the *TPS548B23 Step-Down Converter Evaluation Module EVM user's guide*.

8 Device and Documentation Support

8.1 Documentation Support

8.1.1 Related Documentation

- Texas Instruments, *Optimizing Transient Response of Internally Compensated DC-DC Converters with Feedforward Capacitor* application note
- Texas Instruments, *Non-isolated Point-of-load Solutions for VR13.HC in Rack Server and Datacenter Applications* application note
- Texas Instruments, *TPS548B23 Step-Down Converter Evaluation Module* EVM user's guide
- Texas Instruments, *How to select input capacitors for a buck converter* analog design journal

8.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Notifications* 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.

8.3 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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8.5 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.

8.6 Glossary

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

9 Revision History

DATE	REVISION	NOTES
November 2025	*	Initial Release

10 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.

PACKAGE OPTION ADDENDUM

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
TPS548A23VANR	Active	Production	WQFN-HR (VAN) | 19	5000 | LARGE T&R	Yes	SN	Level-2-260C-1 YEAR	-40 to 125	T48A23

(1) Status: For more details on status, see our product life cycle.

(2) Material type: When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) RoHS values: Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) Lead finish/Ball material: Parts 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.

(5) MSL rating/Peak reflow: The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) Part marking: There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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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.

TAPE AND REEL INFORMATION

REEL DIMENSIONS
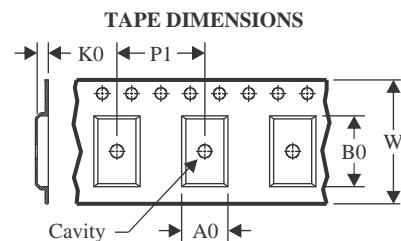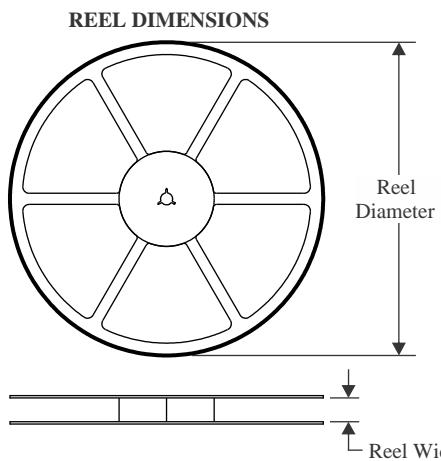
TAPE DIMENSIONS

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

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE
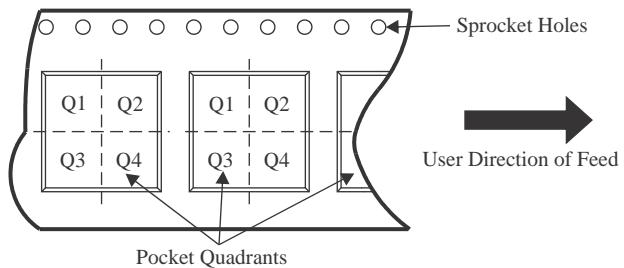
*All dimensions are nominal

| Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS548A23VANR	WQFN-HR	VAN	19	5000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2

TAPE AND REEL BOX DIMENSIONS
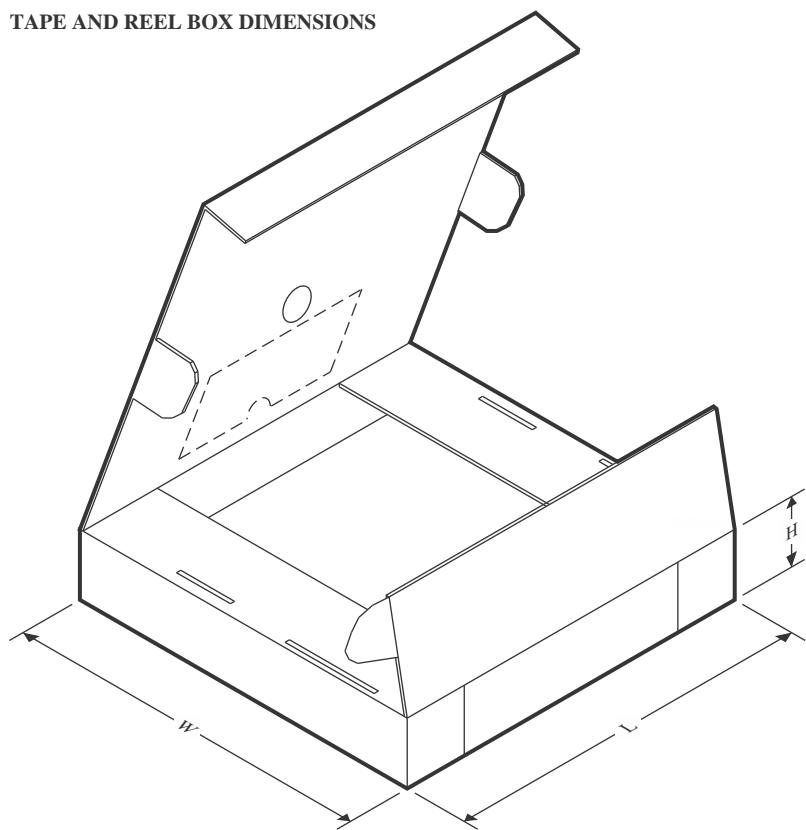
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS548A23VANR	WQFN-HR	VAN	19	5000	367.0	367.0	35.0

PIN 1 INDEX AREA

B 3.1
2.9

A

3.1
2.9

0.8
0.7

C

SEATING PLANE

0.05
0.00

0.08 C

0.45
0.35

0.000 PKG ℄

4X 1.125
0.925

0.1 Ⓜ C A B
0.05 Ⓜ C

4X (0.15)

0.5

0.5

4X 0.7
0.5

(0.1) TYP

2X (0.4)

6X 0.3
0.2

7

9

10

0.1 Ⓜ C A B
0.05 Ⓜ C

2X 1.225

6

1.7
1.5

2X 0.65

2X 0.025

2X 0.55
0.45

0.000 PKG ℄

2X (0.25)

0.1 Ⓜ C A B
0.05 Ⓜ C

2X 0.4

2X 0.8

2X 1.225

15

10X 0.25
0.15

1

0.1 Ⓜ C A B
0.05 Ⓜ C

PIN 1 ID
(45° X 0.1)

19

16

0.6 0.2 0.2 0.6

10X 0.5
0.3
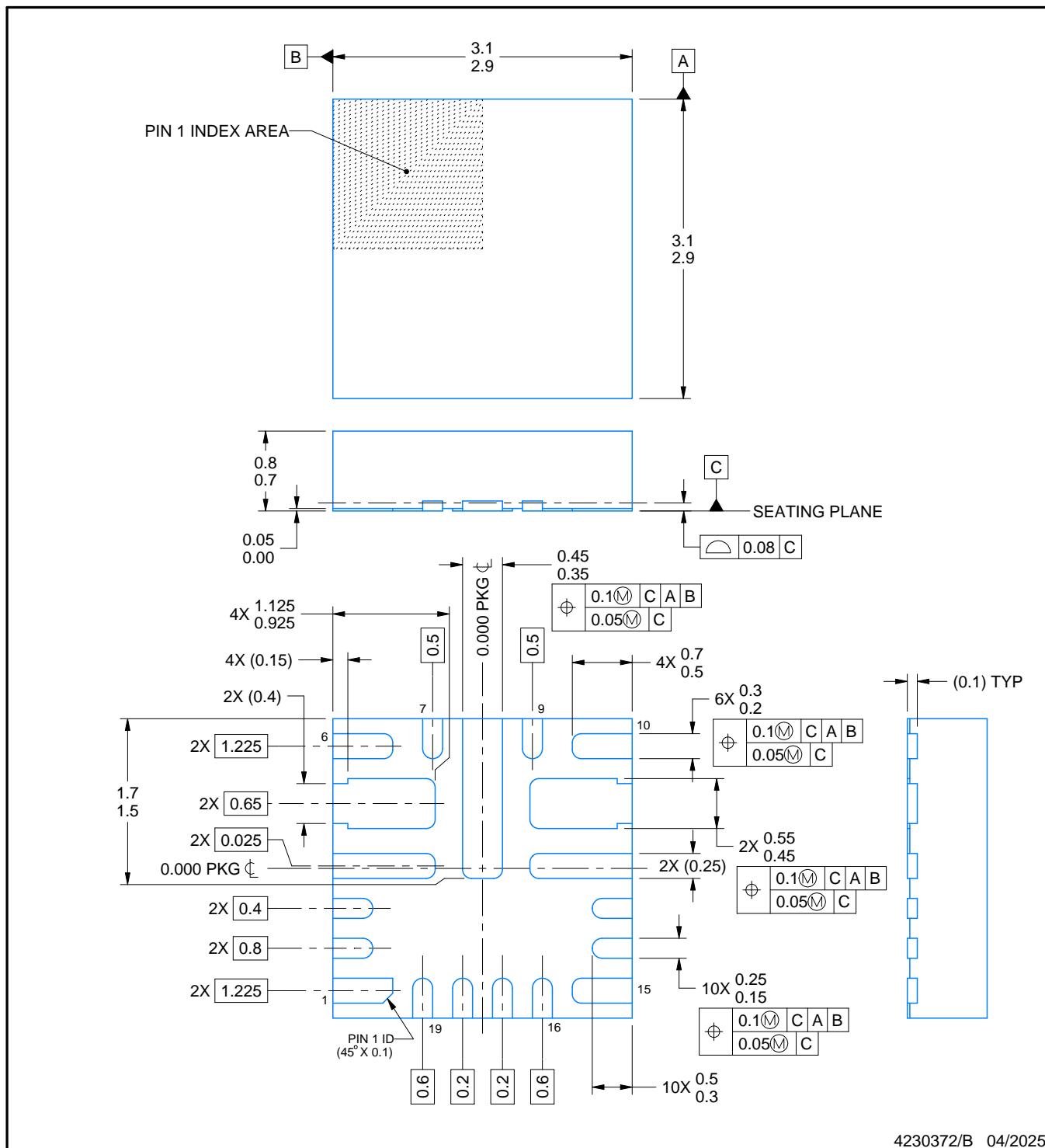
4230372/B 04/2025

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

TEXAS
INSTRUMENTS
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LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 25X

0.05 MAX
ALL AROUND

METAL EDGE

EXPOSED
METAL

SOLDER MASK
OPENING

NON SOLDER MASK
DEFINED
(PREFERRED)

0.05 MIN
ALL AROUND

METAL UNDER
SOLDER MASK

EXPOSED
METAL

SOLDER MASK
OPENING

SOLDER MASK
DEFINED

SOLDER MASK DETAILS

4230372/B   04/2025
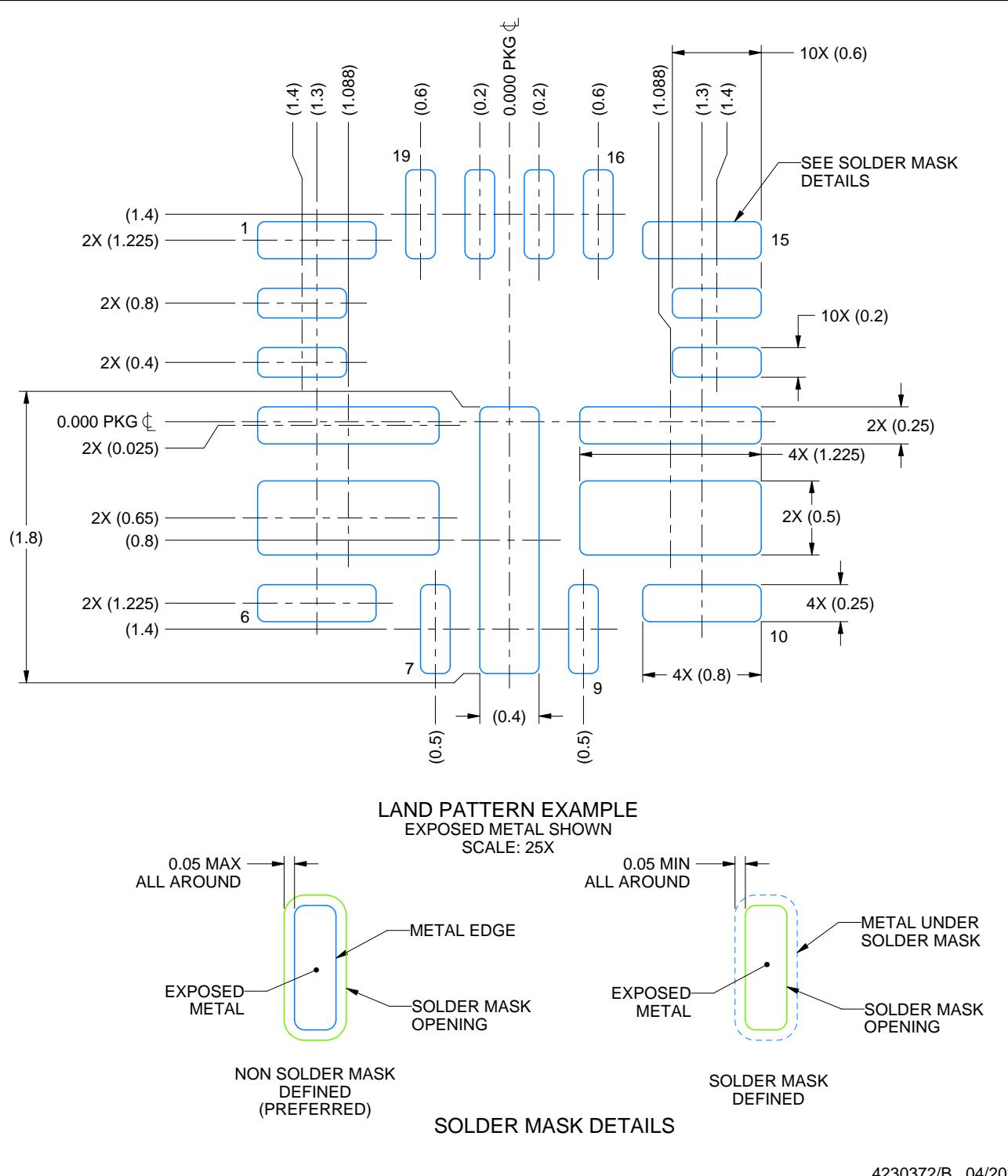
NOTES: (continued)

3. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
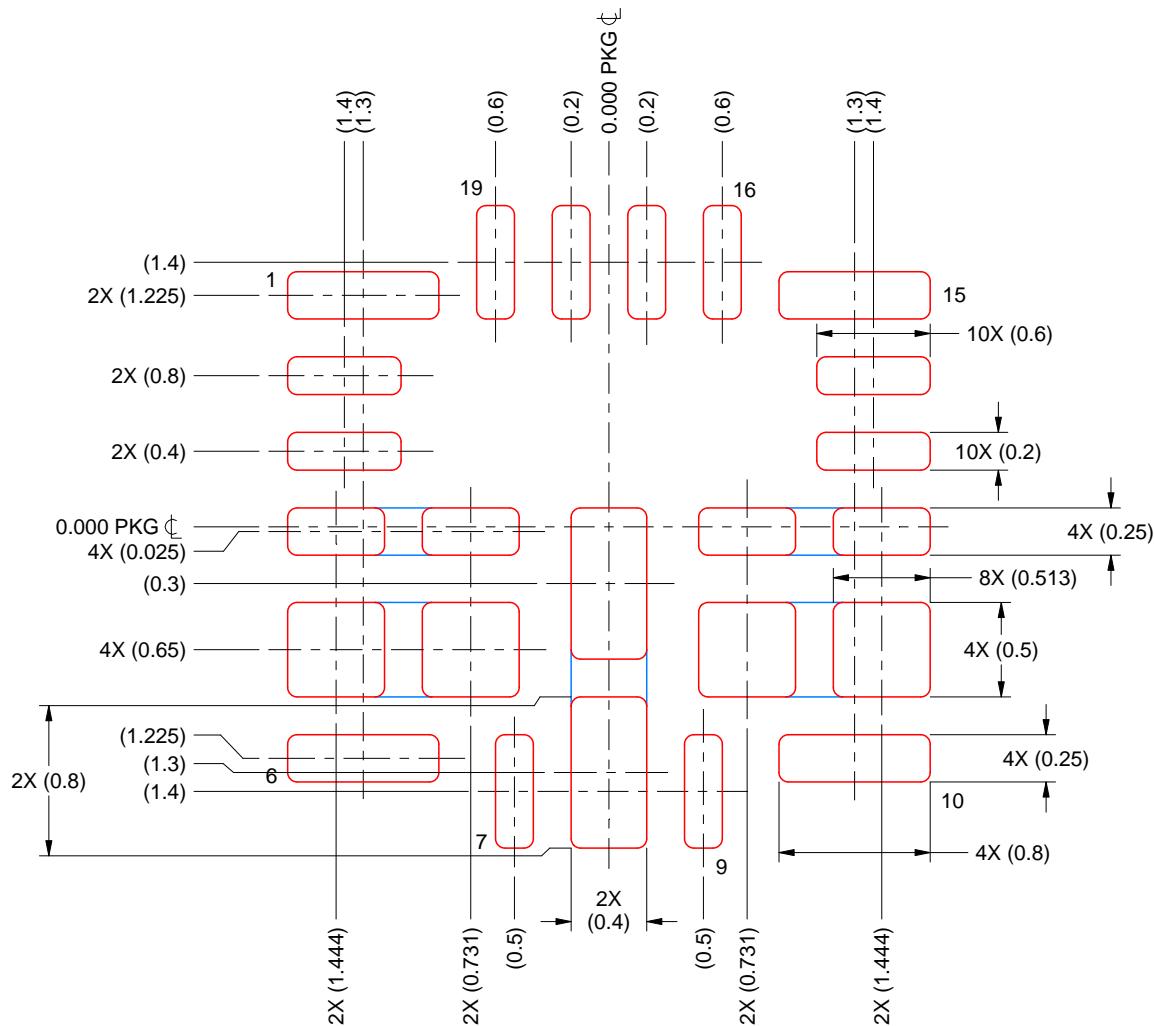
SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE: 25X

PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
PADS 4, 5, 11 & 12: 84%
PAD 8: 89%

4230372/B   04/2025

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate
   design recommendations.

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