3.3-V/5-V Input, 6-A, D-CAP+™ Mode Synchronous Step-Down Integrated FETs Converter

Check for Samples: TPS51317

FEATURES

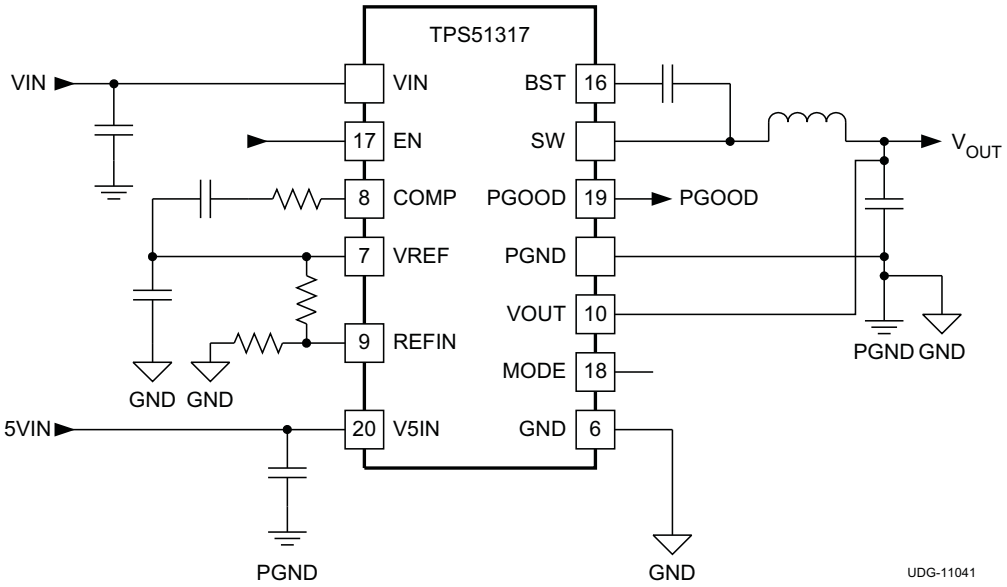
- **Integrated FETs Converter w/TI Proprietary D-CAP+™ Mode Architecture**
- **Minimum External Components Count**
- **Support all MLCC Output Capacitor and SP/POSCAP**
- **Auto-Skip Mode and Ripple Reduction Mode**
- **Optimized Efficiency at Light and Heavy Loads**
- **Selectable 800-kHz, 1-MHz, 1.2-MHz and 1.5-MHz Frequency**
- **Up to 6.0-V Conversion Voltage Range**
- **Adjustable Output Voltage Range From 0.6 V to 2 V**
- **Small 3.5 mm × 4 mm, 20-Pin QFN Package**

APPLICATIONS

- **Low-Voltage Applications Stepping Down from 5-V or 3.3-V Rail**

DESCRIPTION

The TPS51317 is a fully integrated synchronous buck regulator employing D-CAP+™ mode architechture. It is used for 3.3-V and 5-V step-down systems where space is a consideration, high-performance and optimized component count are required. The TPS51317 features four switching frequency settings (up to 1.5 MHz), synchronous operation in SKIP, droop support, external tracking support, pre-bias startup, output soft discharge, integrated bootstrap switch, power good function, enable function and complete protection functions, and both output ceramic and SP/POS capacitor support. It supports supply and conversion voltages up to 6.0 V, and output voltages adjustable from 0.6 V to 2.0V. The TPS51317 is available in the 3.5 mm × 4 mm 20-pin QFN package (Green RoHs compliant and Pb free) and is specified from -40°C to 85°C.



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D-CAP+ is a trademark of Texas Instruments.

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

Table 1. ORDERING INFORMATION(1)

T_A	PACKAGE(2)	ORDERING NUMBER	PINS	OUTPUT SUPPLY	MINIMUM QUANTITY	ECO PLAN
-40°C to 85°C	Plastic QFN (RGB)	TPS51317RGBR	20	Tape and reel	3000	Green (RoHS and no Pb/Br)
		TPS51317RGBT	20	Mini reel	250	

(1) For the most current package and ordering information, see the *Package Option Addendum* at the end of this document, or visit the TI website at www.ti.com.
(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

THERMAL INFORMATION

THERMAL METRIC(1)		TPS51317 RGB 20 PINS	UNITS
θ_{JA}	Junction-to-ambient thermal resistance(2)	35.5	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance(3)	39.6	
θ_{JB}	Junction-to-board thermal resistance(4)	12.4	
ψ_{JT}	Junction-to-top characterization parameter(5)	0.5	
ψ_{JB}	Junction-to-board characterization parameter(6)	12.5	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance(7)	3.7	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.
(2) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
(3) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
(4) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
(5) The junction-to-top characterization parameter, ψ_{JT}, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA}, using a procedure described in JESD51-2a (sections 6 and 7).
(6) The junction-to-board characterization parameter, ψ_{JB}, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA} , using a procedure described in JESD51-2a (sections 6 and 7).
(7) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

ABSOLUTE MAXIMUM RATINGS(1)

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

		VALUE		UNIT
		MIN	MAX	
Input voltage range	VIN, V5IN, BST (with respect to SW)	–0.3	7.0	V
	BST	–0.3	14.0	
	SW	–2	7	
	EN	–0.3	7	
	MODE, REFIN	–0.3	3.6	
	VOUT	–1	3.6	
Output voltage range	COMP, VREF	–0.3	3.6	V
	PGOOD	–0.3	7.0	
	PGND	–0.3	0.3	
Junction temperature	T_J	–40	150	
Storage temperature	T_{stg}	–55	150	˚C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds			300	˚C

(1) Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

		VALUE			UNIT
		MIN	TYP	MAX	
Input voltage range	VIN	–0.1		6.5	V
	V5IN	4.5		6.5	
	BST	–0.1		13.5	
	SW	–1.0		6.5	
	EN	–0.7		6.5	
	VOUT, MODE, REFIN	–0.1		3.5	
Output voltage range	COMP, VREF	–0.1		3.5	V
	PGOOD	–0.1		5.5	
	PGND	–0.1		0.1	
Operating temperature range, T_A		-40		85	°C

ELECTRICAL CHARACTERISTICS

over recommended free-air temperature range, V_{V5IN} = 5.0 V, PGND = GND (unless otherwise noted)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY: VOLTAGE, CURRENTS AND 5 V UVLO						
I_{VINSD}	VIN shutdown current	EN = 'LO'		0.02	5	µA
V_{5VIN}	5VIN supply voltage	V5IN voltage range	4.5	5.0	6.5	V
I_{5VIN}	5VIN supply current	EN ='HI', V5IN supply current		1.1	2	mA
I_{5VINSD}	5VIN shutdown current	EN = 'LO', V5IN shutdown current		0.2	7.0	µA
V_{V5UVLO}	V5IN UVLO	Ramp up; EN = 'HI'	4.20	4.37	4.50	V
$V_{V5UVHYS}$	V5IN UVLO hysteresis	Falling hysteresis		440		mV
$V_{VREFUVLO}$	REF UVLO(1)	Rising edge of VREF, EN = 'HI'		1.8		V
$V_{VREFUVHYS}$	REF UVLO hysteresis(1)			100		mV
$V_{POR5VFILT}$	Reset	OVP latch is reset by V5IN falling below the reset threshold	1.5	2.3	3.1	V
VOLTAGE FEEDBACK LOOP: VREF, VOUT, AND VOLTAGE GM AMPLIFIER						
V_{OUTTOL}	VOUT accuracy	V_{REFIN} = 1 V, No droop	–1%	0%	1%	
V_{VREF}	VREF	I_{VREF} = 0 µA	1.98	2.00	2.02	V
		I_{VREF} = 50 µA	1.975	2.000	2.025	
I_{REFSNK}	VREF sink current	V_{VREF} = 2.05 V		2.5		mA
G_M	Transconductance			1.00		mS
V_{CM}	Common mode input voltage range(1)		0		2	V
V_{DM}	Differential mode input voltage		0		80	mV
$I_{COMPSNK}$	COMP pin maximum sinking current	V_{COMP} = 2 V, (V_{REFIN} - V_{OUT}) = 80 mV		80		µA
$I_{COMPSRC}$	COMP pin maximum sourcing current	V_{COMP} = 2 V		-80		µA
V_{OFFSET}	Input offset voltage	T_A = 25°C		0		mV
R_{DSCH}	Output voltage discharge resistance			42		Ω
f_{-3dbVL}	–3dB Frequency(1)		4.5	6.0	7.5	MHz
CURRENT SENSE: CURRENT SENSE AMPLIFIER, OVERCURRENT AND ZERO CROSSING						
A_{CSINT}	Internal current sense gain	Gain from the current of the low-side FET to PWM comparator when PWM = "OFF"	43	53	57	mV/A
I_{OCL}	Positive overcurrent limit (valley)			7.6		A
$I_{OCL(neg)}$	Negative overcurrent limit (valley)			–9.3		A
V_{ZXOFF}	Zero crossing comp internal offset			0		mV
DRIVERS: BOOT STRAP SWITCH						
$R_{DSONBST}$	Internal BST switch on-resistance	I_{BST} = 10 mA, T_A = 25°C			10	Ω
I_{BSTLK}	Internal BST switch leakage current	V_{BST} = 14 V, V_{SW} = 7 V			1	µA
PROTECTION: OVP, UVP, PGOOD, and THERMAL SHUTDOWN						
V_{PGDLL}	PGOOD deassert to lower (PGOOD → Low)	Measured at the VOUT pin wrt/ V_{REFIN}		84%		
$V_{PGHYSHL}$	PGOOD high hysteresis			8%		
V_{PGDLH}	PGOOD de-assert to higher (PGOOD → Low)	Measured at the VOUT pin wrt/ V_{REFIN}		116%		
$V_{PGHYSHH}$	PGOOD high hysteresis			-8%		
$V_{INMINPG}$	Minimum VIN voltage for valid PGOOD	Measured at the VIN pin with a 2-mA sink current on PGOOD pin	0.9	1.3	1.5	V
V_{OVP}	OVP threshold	Measured at the VOUT pin wrt/ V_{REFIN}	117%	120%	123%	
V_{UVP}	UVP threshold	Measured at the VOUT pin wrt/ V_{REFIN}, device latches OFF, begins soft-stop	65%	68%	71%	
TH_{SD}	Thermal shutdown(1)	Latch off controller, attempt soft-stop.		145		°C
$TH_{SD(hys)}$	Thermal Shutdown hysteresis(1)	Controller re-starts after temperature has dropped		10		°C

(1) Ensured by design, not production tested.

ELECTRICAL CHARACTERISTICS (continued)

over recommended free-air temperature range, V_{V5IN} = 5.0 V, PGND = GND (unless otherwise noted)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
TIMERS: ON-TIME, MINIMUM OFF-TIME, SS, AND I/O TIMINGS						
$t_{ONESHOTC}$	PWM one-shot (2)	V_{VIN} = 5 V, V_{VOUT} = 1.05 V, f_{SW} = 860 KHz		240		ns
		V_{VIN} = 5 V, V_{VOUT} = 1.05 V, f_{SW} = 1 MHz		210		
		V_{VIN} = 5 V, V_{VOUT} = 1.05 V, f_{SW} = 1.2 MHz		175		
		V_{VIN} = 5 V, V_{VOUT} = 1.05 V, f_{SW} = 1.5 MHz		140		
$t_{MIN(off)}$	Minimum OFF time	V_{VIN} = 5 V, V_{VOUT} = 1.05 V, f_{SW} = 1 MHz, DRVL on, SW = PGND, V_{VOUT} < V_{REFIN}		360		ns
$t_{INT(SS)}$	Soft-start time	From EN = HI to VOUT =95%, default setting		1.6		ms
$t_{INT(SSDLY)}$	Internal soft-start delay time	From EN = HI to VOUT ramp starts		260		µs
t_{PGDDLY}	PGOOD startup delay time	External tracking		8		ms
$t_{PGDPDLYH}$	PGOOD high propagation delay time	50 mV over drive, rising edge	0.8	1	1.2	ms
$t_{PGDPDLYL}$	PGOOD low propagation delay time	50 mV over drive, falling edge		10		µs
t_{OVPDLY}	OVP delay time	Time from the VOUT pin out of +20% of REFIN to OVP fault		10		µs
$t_{UVDLYEN}$	Undervoltage fault enable delay	Time from EN_INT going high to undervoltage fault is ready		2		ms
		External tracking from VOUT ramp starts		8		
t_{UVPDLY}	UVP delay time	Time from the VOUT pin out of –30% of REFIN to UVP fault		256		µs
LOGIC PINS: I/O VOLTAGE AND CURRENT						
V_{PGDPD}	PGOOD pull-down voltage	PGOOD low impedance, I_{SINK} = 4 mA, V_{V5IN} = 4.5 V			0.3	V
I_{PGDLKG}	PGOOD leakage current	PGOOD high impedance, forced to 5.5 V	–1	0	1	µA
V_{ENH}	EN logic high	EN, VCCP logic	2			V
V_{ENL}	EN logic low	EN, VCCP logic			0.5	V
I_{EN}	EN input current				1	µA
V_{MODETH}	MODE threshold voltage(3)	Threshold 1	80	130	180	mV
		Threshold 2	200	250	300	
		Threshold 3	370	420	470	
		Threshold 4	1.77	1.80	1.85	V
I_{MODE}	MODE current			15		µA

(2) Ensured by design, not production tested.
(3) See Table 4 for descriptions of MODE parameters.

TPS51317
RGB PACKAGE
(Top View)

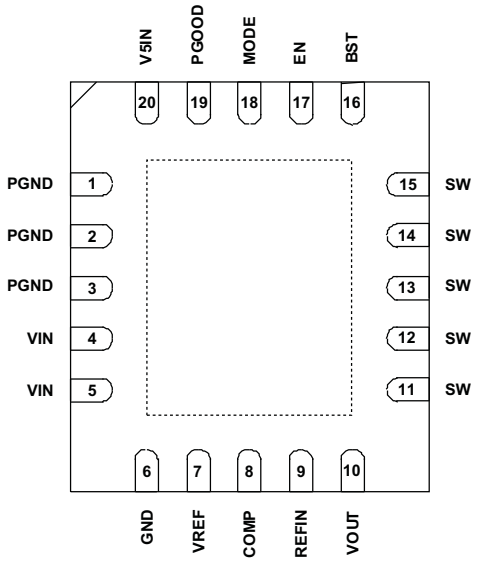
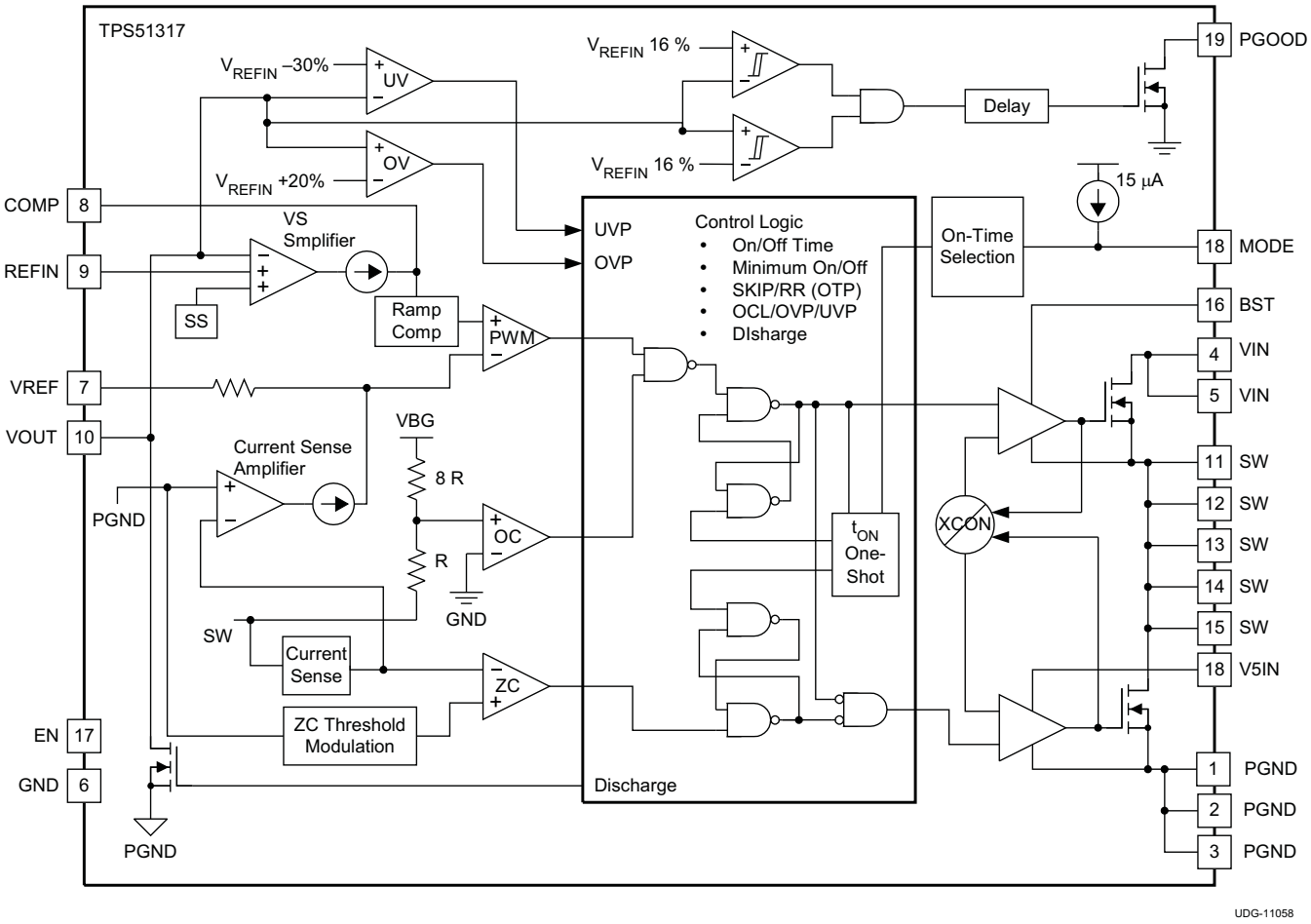


Table 2. PIN FUNCTIONS

PIN		I/O	DESCRIPTION
NO.	NAME		
16	BST	I	Power supply for internal high-side gate driver. Connect a 0.1-µF bootstrap capacitor between this pin and the SW pin.
8	COMP	O	Connect series R-C filter between this pin and VREF for loop compensation.
17	EN	I	Enable of the SMPS (3.3-V logic compatible).
6	GND	–	Signal ground.
18	MODE	I	Allows selection of switching frequencies light-load modes. (See Table 4)
1	PGND	I	Power ground. Source terminal of the rectifying low-side power FET. Positive input for current sensing.
2			
3			
19	PGOOD	O	Power good output. Connect pull-up resistor.
9	REFIN		Target output voltageinput pin. Apply voltage between 0.6 V to 2.0 V.
11	SW	I/O	Switching node output. Connect to the external inductor. Also serve as current-sensing negative input.
12			
13			
14			
15			
20	V5IN	I	5-V power supply for analog circuits and gate drive.
4	VIN	I	Power supply input pin. Drain terminal of the switching high-side power FET.
5			
10	VOUT	I	Output voltage monitor input pin.
7	VREF	O	2.0-V reference output. Connect a 0.22-µF ceramic capacitor to GND.

BLOCK DIAGRAM



APPLICATION SCHEMATIC WITH TPS51317

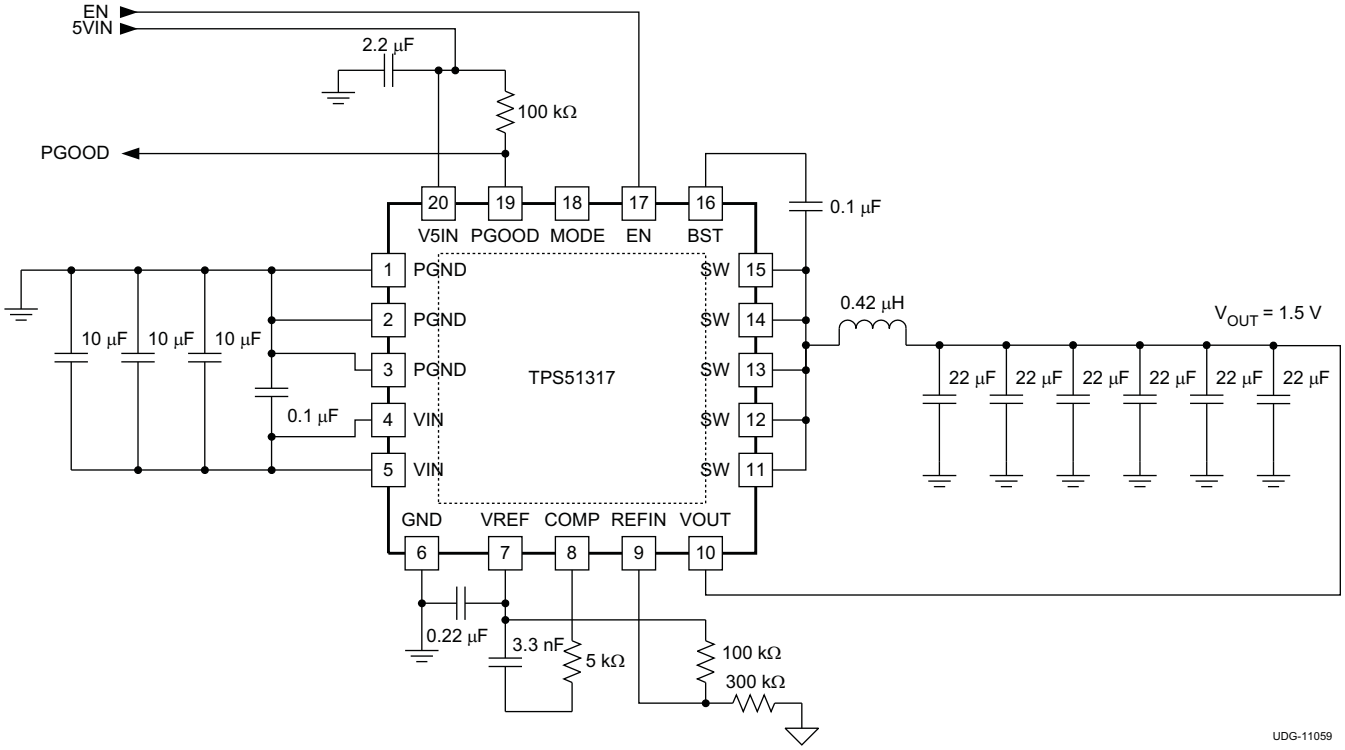


Figure 1. Application Using Non-Droop Configuration

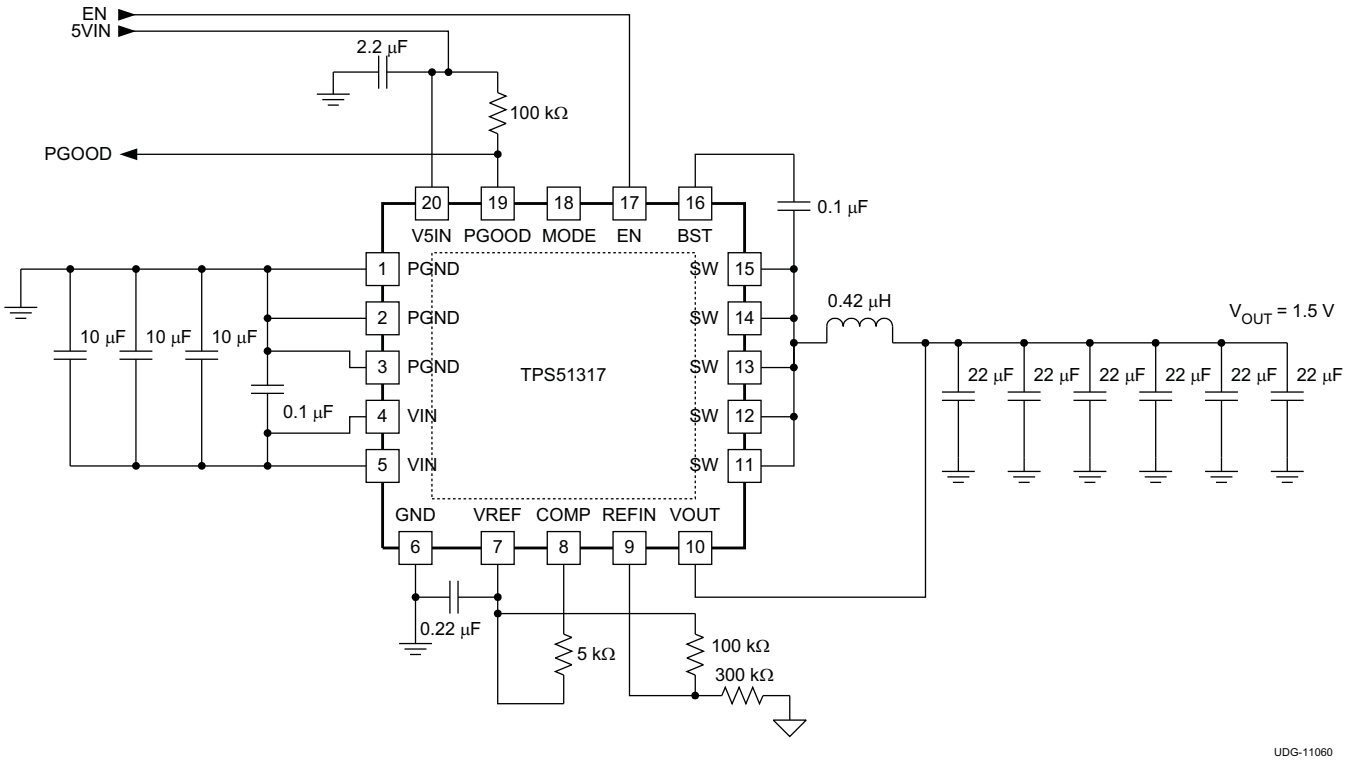


Figure 2. Application Using Droop Configuration

Application Circuit List of Materials

Recommended parts for key external components for the circuits in Figure 1 and Figure 2 are listed in Table 3.

Table 3. Key External Component Recommendations (Figure 1 and Figure 2)

FUNCTION	MANUFACTURER	PART NUMBER
Output Inductor	Nec-Tokin	MPCG0740LR42C
Ceramic Output Capacitors	Panasonic	ECJ2FB0J226M
	Murata	GRM21BR60J226ME39L

APPLICATION INFORMATION

Functional Overview

The TPS51317 is a D-CAP+™ mode adaptive on-time converter. Integrated high-side and low-side FET supports output current to a maximum of 6-ADC. The converter automatically runs in discontinuous conduction mode (DCM) to optimize light-load efficiency. Multiple switching frequencies are provided to enable optimization of the power chain for the cost, size and efficiency requirements of the design (see Table 4).

In adaptive on-time converters, the controller varies the on-time as a function of input and output voltage to maintain a nearly constant frequency during steady-state conditions. In conventional constant on-time converters, each cycle begins when the output voltage crosses to a fixed reference level. However, in the TPS51317, the cycle begins when the current feedback reaches an error voltage level which is the amplified difference between the reference voltage and the feedback voltage.

PWM Operation

Referring to Figure 3, in steady state, continuous conduction mode, the converter operates in the following way.

Starting with the condition that the top FET is off and the bottom FET is on, the current feedback (V_{CS}) is higher than the error amplifier output (V_{COMP}). V_{CS} falls until it hits V_{COMP}, which contains a component of the output ripple voltage. V_{CS} is not directly accessible by measuring signals on pins of TPS51317. The PWM comparator senses where the two waveforms cross and triggers the on-time generator.

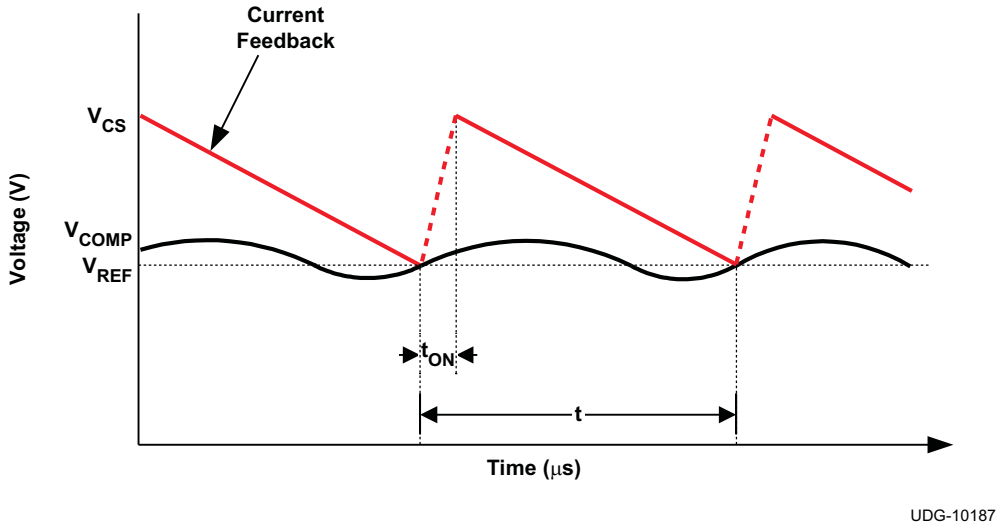


Figure 3. D-CAP+™ Mode Basic Waveforms

The current feedback is an amplified and filtered version of the voltage between PGND and SW during low-side FET on-time. The TPS51317 also provides a single-ended differential voltage (V_{OUT}) feedback to increase the system accuracy and reduce the dependence of circuit performance on layout.

PWM Frequency and Adaptive on Time Control

In general, the on-time (at the SW node) can be estimated by Equation 1.

$$t_{ON} = \frac{V_{OUT}}{V_{IN}} \times \frac{1}{f_{SW}} \quad (1)$$

where

- f_{SW} is the frequency selected by the connection of the MODE pin

The on-time pulse is sent to the top FET. The inductor current and the current feedback rises to peak value. Each ON pulse is latched to prevent double pulsing. Switching frequency settings are shown in .

Non-Droop Configuration

The TPS51317 can be configured as a non-droop solution. The benefit of a non-droop approach is that load regulation is flat, therefore, in a system where tight DC tolerance is desired, the non-droop approach is recommended. For the Intel system agent application, non-droop is recommended as the standard configuration.

The non-droop approach can be implemented by connecting a resistor and a capacitor between the COMP and the VREF pins. The purpose of the type II compensation is to obtain high DC feedback gain while minimizing the phase delay at unity gain cross over frequency of the converter.

The value of the resistor (R_C) can be calculated using the desired unity gain bandwidth of the converter, and the value of the capacitor (C_C) can be calculated by knowing where the zero location is desired. An application tool that calculates these values is available from your local TI Field Application Engineer.

Figure 4 shows the basic implementation of the non-droop mode using the TPS51317.

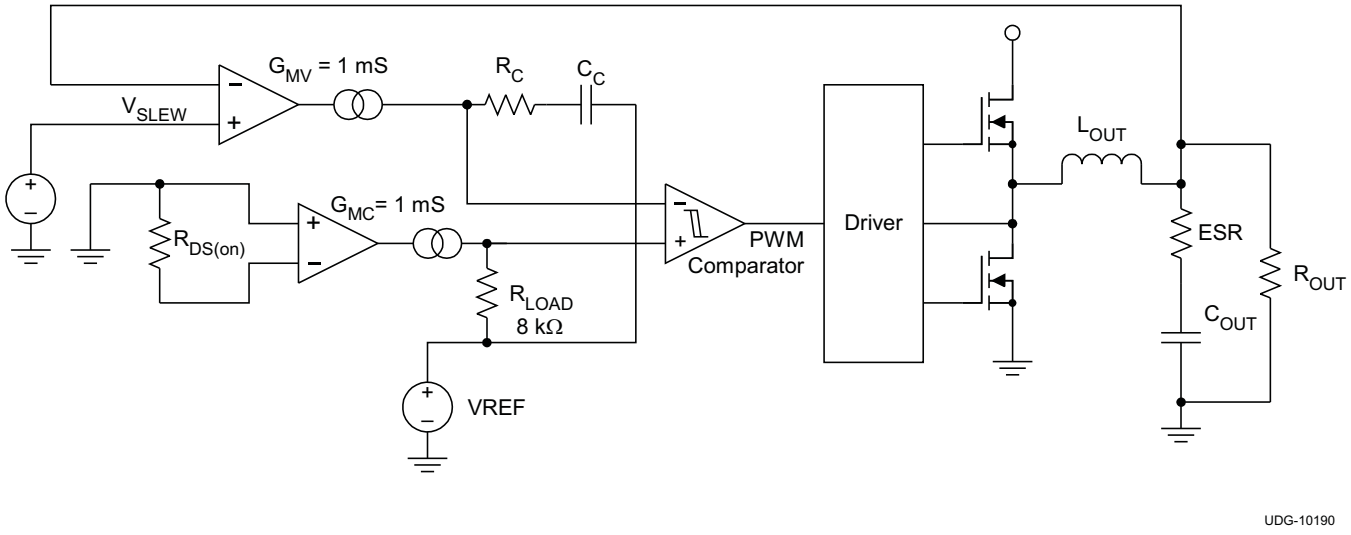


Figure 4. Non-Droop Mode Basic Implementation

Figure 5 shows shows the load regulation using non-droop configuration.

Figure 6 shows the transient response of TPS51317 using non-droop configuration, where C_{OUT} = 6 x 22 µF. The applied step load is from 0 A to 3 A.

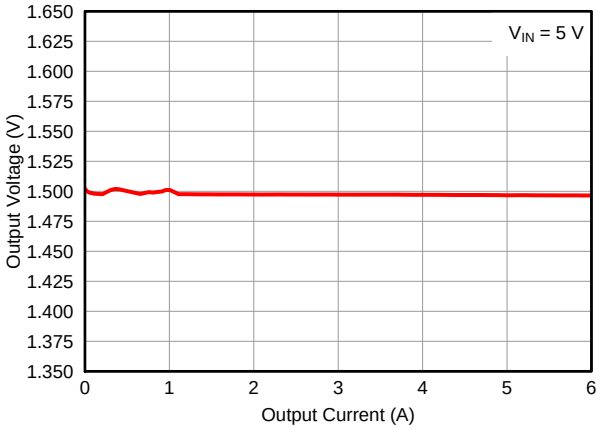


Figure 5. 1.5-V Load Regulation (V_{IN} = 5 V) Non-Droop Configuration

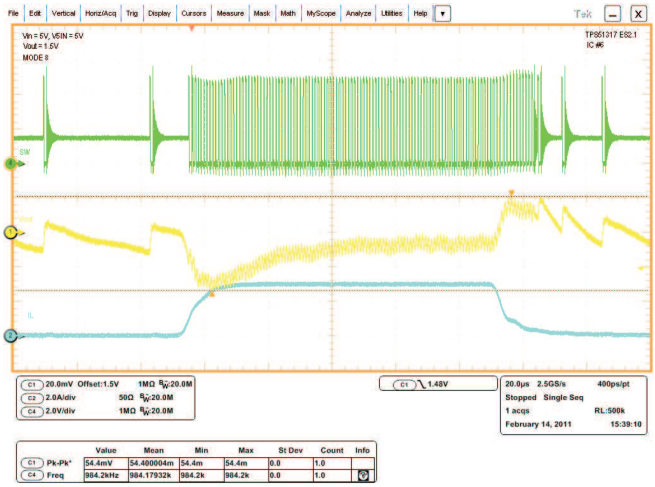


Figure 6. Non-Droop Configuration Transient Response

Droop Configuration

The terminology for droop is the same as *load line* or *voltage positioning* as defined in the Intel CPU V_{CORE} specification. Based on the actual tolerance requirement of the application, load-line set points can be defined to maximize either cost savings (by reducing output capacitors) or power reduction benefits.

Accurate droop voltage response is provided by the finite gain of the droop amplifier. The equation for droop voltage is shown in Equation 2.

$$V_{DROOP} = \frac{A_{CSINT} \times I(L)}{R_{DROOP} \times G_M}$$

where

- low-side on-resistence is used as the current sensing element
- A_{CSINT} is a constant, which nominally is 53 mV/A.
- I(L) is the DC current of the inductor, or the load current
- R_{DROOP} is the value of resistor from the COMP pin to the VREF pin
- G_M is the transconductance of the droop amplifier with nominal value of 1 mS (2)

Equation 3 can be used to easily derive R_{DROOP} for any load line slope/droop design target.

$$R_{LOAD\_LINE} = \frac{V_{DROOP}}{I(L)} = \frac{A_{CSINT}}{R_{DROOP} \times G_M} \therefore R_{DROOP} = \frac{A_{CSINT}}{R_{LOAD\_LINE} \times G_M} \quad (3)$$

Figure 7 shows the basic implementation of the droop mode using the TPS51317.

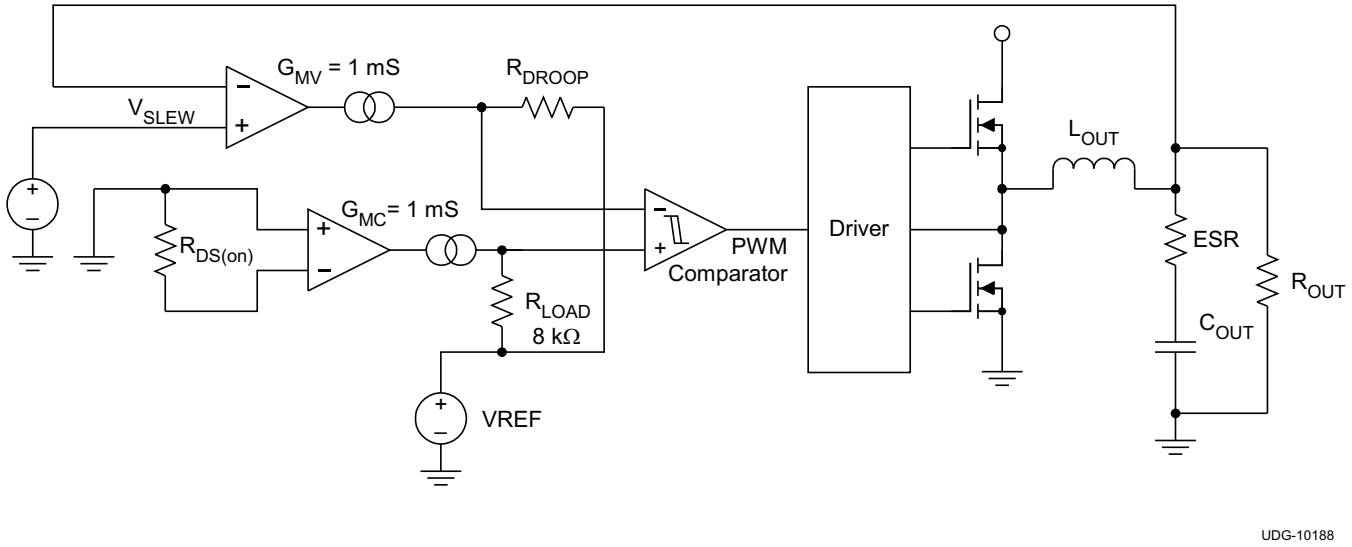


Figure 7. DROOP Mode Basic Implementation

The droop (voltage positioning) method was originally recommended to reduce the number of external output capacitors required. The effective transient voltage range is increased because of the active voltage positioning (see Figure 8).

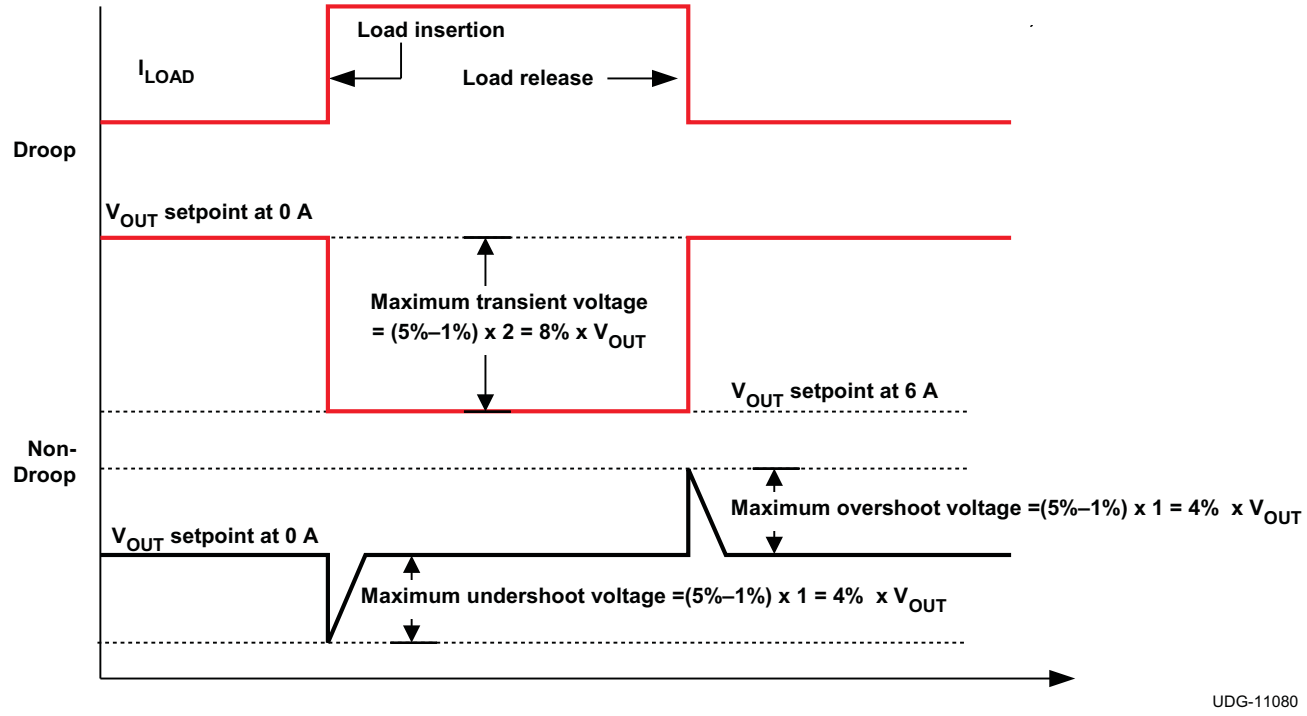


Figure 8. DROOP vs Non-DROOP in Transient Voltage Window

In applications where the DC and the AC tolerances are not separated, which means there is not a strict DC tolerance requirement, the droop method can be used.

Table 4. Mode Definitions

MODE	MODE RESISTANCE (kΩ)	LIGHT-LOAD POWER SAVING MODE	SWITCHING FREQUENCY (f_{SW}) (MHz)
1	0	SKIP	0.86
2	12	SKIP	1.2
3	22	SKIP	1.5
4	33	RR(1)	1.0
5	47	RR(1)	0.86
6	68	PWM	1.2
7	100	PWM	1.5
8	OPEN	SKIP	1.0

(1) Ripple reduction is a special light-load power saving feature. See (Light-Load Power Saving Features)

Figure 9 shows the load regulation of the 1.5-V rail using an R_{DROOP} value of 5 kΩ.

Figure 10 shows the transient response of the TPS51317 using droop configuration and C_{OUT} = 6 × 22 µF. The applied step load is from 0 A to 3 A.

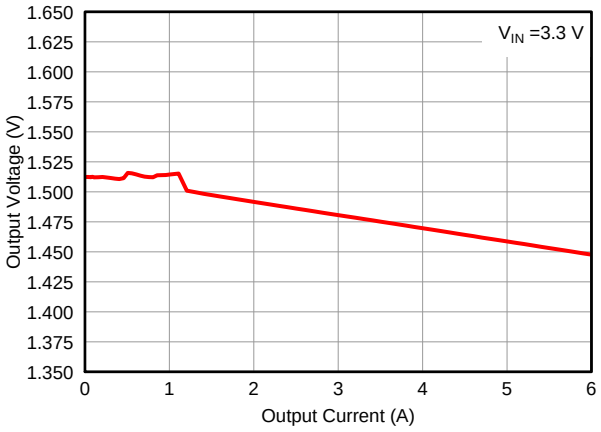


Figure 9. 1.5-V Load Regulation (V_{IN} = 5 V)

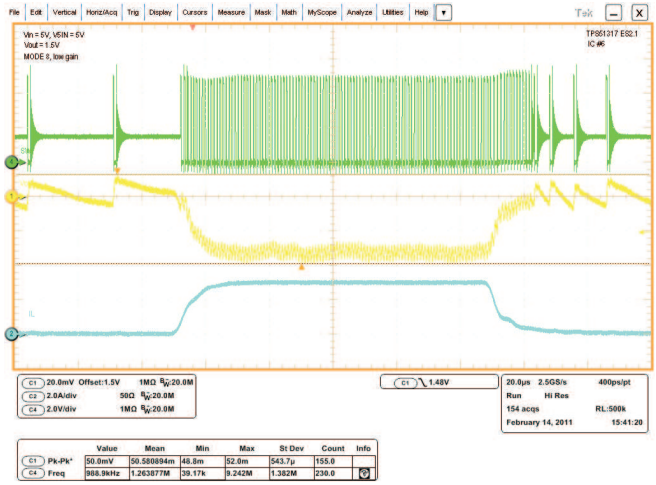


Figure 10. Droop Configuration Transient Response, C_{OUT} = 6 x 22 µF and 0 A to 3 A

Light-Load Power Saving Features

The TPS51317 has an automatic pulse-skipping mode to provide excellent efficiency over a wide load range. The converter senses inductor current and prevents negative flow by shutting off the low-side gate driver. This saves power by eliminating re-circulation of the inductor current. Further, when the bottom FET shuts off, the converter enters discontinuous mode, and the switching frequency decreases, thus reducing switching losses as well.

TPS51317 also provides a special light-load power saving feature, called ripple reduction. Essentially, it reduces the on-time in SKIP mode to effectively reduce the output voltage ripple associated with using an all MLCC capacitor output power stage design.

Power Sequences

Non-Tracking Startup

The TPS51317 can be configured for non-tracking application. When non-tracking is configured, output voltage is regulated to the REFIN voltage which taps off the voltage dividers from the 2VREF. Either the EN pin or the V5IN pin can be used to start up the device. The TPS51317 uses internal voltage servo DAC to provide a precise 1.6-ms soft-start time during soft-start initialization. (See Figure 11)

Tracking Startup

TPS51317 can also be configured for tracking application. When tracking configuration is desired, output voltage is also regulated to the REFIN voltage which comes from external power source. In order for TPS51317 to differentiate between a non-tracking configuration or a tracking configuration, there is a minimum delay time of 260 µs required between the time when the EN pin or the 5VIN pin is validated to the time when the REFIN pin voltage can be applied, in order for the TPS51317 to track properly (see Figure 12). The valid REFIN voltage range is between 0.6 V to 2 V.

Protection Features

The TPS51317 offers many features to protect the converter power chain as well as the system electronics.

5-V Undervoltage Protection (UVLO)

The TPS51317 continuously monitors the voltage on the V5IN pin to ensure that the voltage level is high enough to bias the device properly and to provide sufficient gate drive potential to maintain high efficiency. The converter starts with approximately 4.3 V and has a nominal of 440 mV of hysteresis. If the 5-V UVLO limit is reached, the converter transitions the phase node into a off function. And the converter remains in the off state until the device is reset by cycling 5 V until the 5-V POR is reached (2.3-V nominal). The power input does not have an UVLO function

Power Good Signals

The TPS51317 has one open-drain *power good* (PGOOD) pin. During startup, there is a 1-ms power good high propagation delay. The PGOOD pin de-asserts as soon as the EN pin is pulled low or an undervoltage condition on V5IN or any other faults that require latch off action is detected.

Output Overvoltage Protection (OVP)

In addition to the power good function described above, the TPS51317 has additional OVP and UVP thresholds and protection circuits.

An OVP condition is detected when the output voltage is approximately 120% × V_{REFIN}. In this case, the converter de-asserts the PGOOD signals and performs the overvoltage protection function. The converter remains in this state until the device is reset by cycling 5 V until the 5-V POR threshold (2.3 V nominal) is reached.

Output Undervoltage Protection (UVP)

Output undervoltage protection works in conjunction with the current protection described in the Overcurrent Protection and Overcurrent Limit sections. If the output voltage drops below 70% of V_{REFIN}, after an 8-µs delay, the device latches OFF. Undervoltage protection can be reset only by EN or a 5-V POR.

Overcurrent Protection

Both positive and negative overcurrent protection are provided in the TPS51317:

- Overcurrent Limit (OCL)
- Negative OCL (level same as positive OCL)

Overcurrent Limit

If the sensed current value is above the OCL setting, the converter delays the next ON pulse until the current drops below the OCL limit. Current limiting occurs on a pulse-by-pulse basis. The TPS51317 uses a valley current limiting scheme where the DC OCL trip point is the OCL limit plus half of the inductor ripple current. The minimum valley OCL is 6 A over process and temperature.

During the overcurrent protection event, the output voltage likely droops until the UVP limit is reached. Then, the converter de-asserts the PGOOD pin, and then latches OFF after an 8-µs delay. The converter remains in this state until the device is reset.

$$I_{OCL(dc)} = I_{OCL(valley)} + \frac{1}{2} \times I_{P-P} \quad (4)$$

Negative OCL

The negative OCL circuit acts when the converter is sinking current from the output capacitor(s). The converter continues to act in a *valley* mode, the absolute value of the negative OCL set point is typically -6.5 A.

Thermal Protection

Thermal Shutdown

The TPS51317 has an internal temperature sensor. When the temperature reaches a nominal 145°C, the device shuts down until the temperature cools by approximately 10°C. Then the converter restarts.

Startup Timing Diagrams

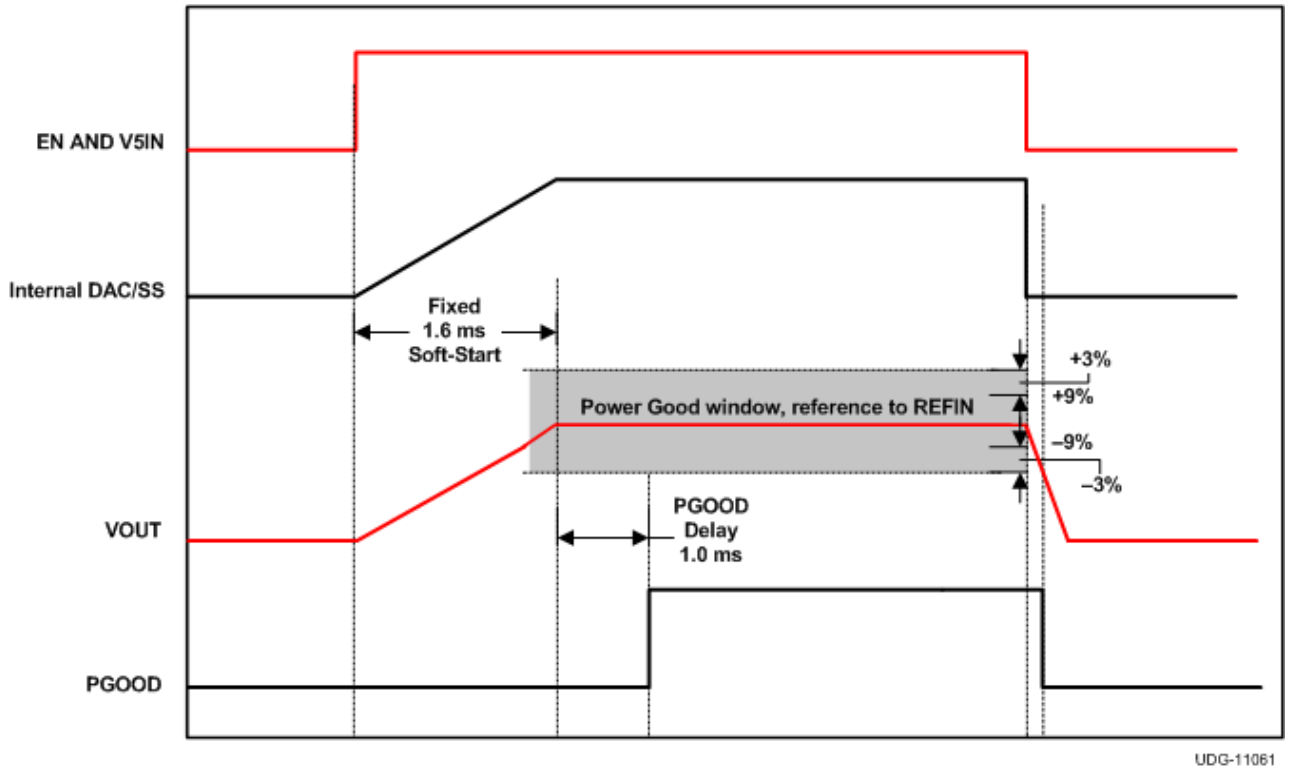


Figure 11. Non-Tracking Start-Up

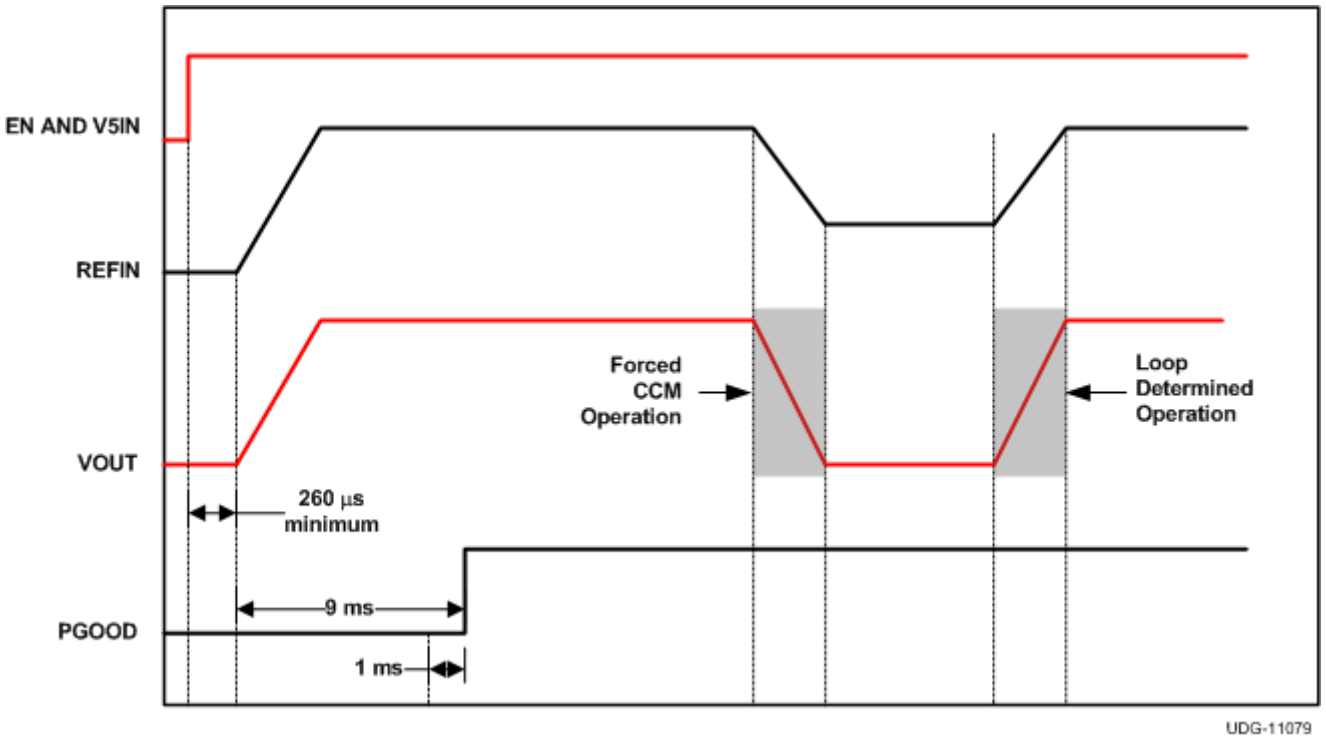


Figure 12. Tracking Start-Up

TYPICAL CHARACTERISTICS

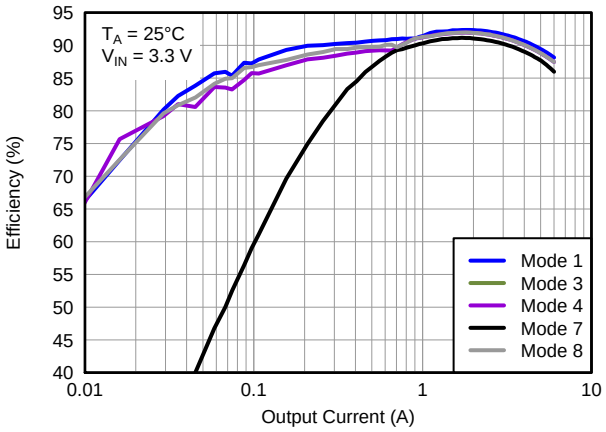


Figure 13. Efficiency vs Output Current

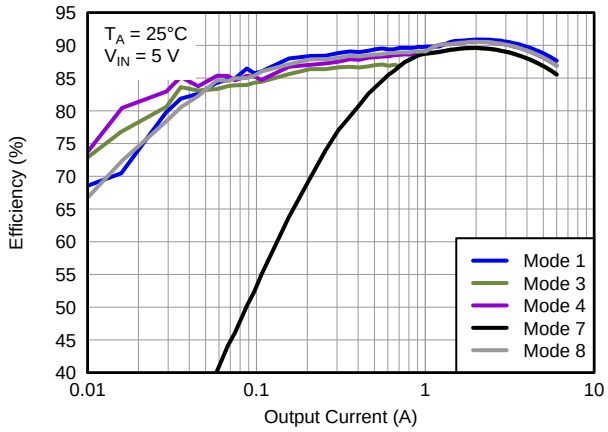


Figure 14. Efficiency vs Output Current

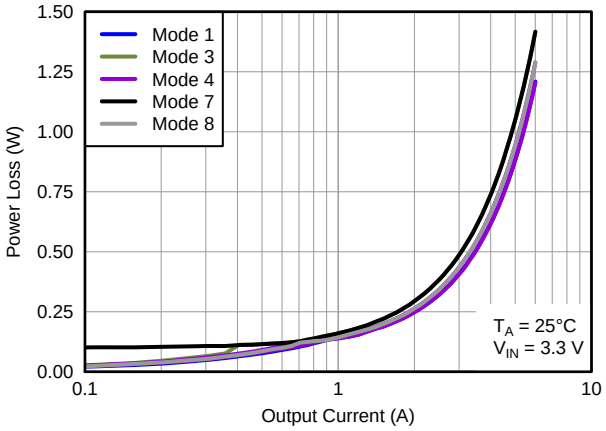


Figure 15. Power Loss

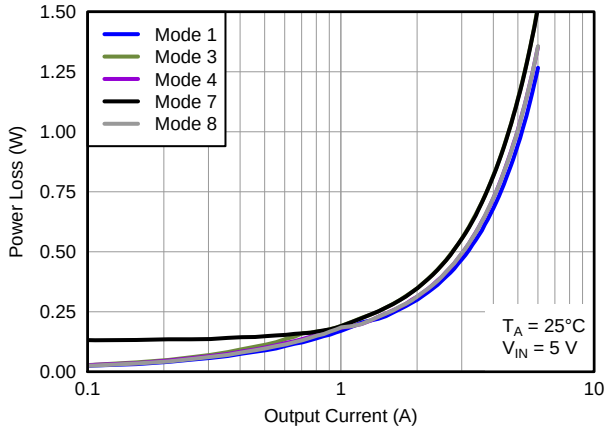


Figure 16. Power Loss

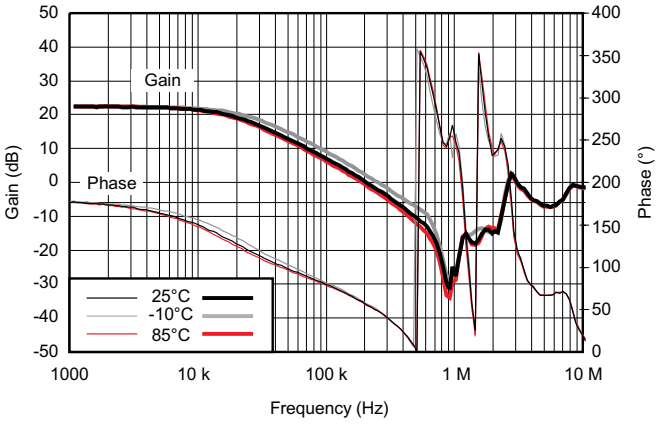


Figure 17. Bode Plot (Non-Droop Mode) V_{IN} = 5 V, V_{OUT} = 0.8 V, I_{LOAD} = 5 A

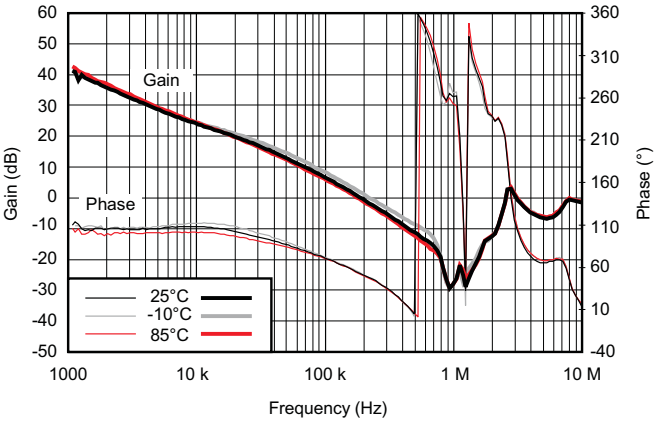


Figure 18. Bode Plot (Droop Mode), V_{IN} = 5 V, V_{OUT} = 0.8 V, I_{LOAD} = 5 A

DESIGN PROCEDURE

The simplified design procedure is done for a non-droop application using the TPS51317 converter.

Step One

Determine the specifications.

The Rail requirements provide the following key parameters:

1. V_{OUT} = 1.5 V
2. $I_{CC(max)}$ = 6 A
3. $I_{DYN(max)}$ = 3 A
4. $I_{CC(tdc)}$ = 3 A

Step Two

Determine system parameters.

The input voltage range and operating frequency are of primary interest. For example:

1. V_{IN} = 5 V
2. f_{SW} = 1 MHz

Step Three

Determine inductor value and choose inductor.

Smaller values of inductor have better transient performance but higher ripple and lower efficiency. Higher values have the opposite characteristics. It is common practice to limit the ripple current to 25% to 50% of the maximum current. In this case, use 40%:

$$I_{P-P} = 6\,A \times 0.4 = 2.4\,A \tag{5}$$

At f_{SW} = 1 MHz, with a 5-V input and a 1.5-V output:

$$L = \frac{V \times dT}{I_{P-P}} = \frac{(V_{IN} - V_{OUT}) \times \left(\frac{V_{OUT}}{(f_{SW} \times V_{IN})}\right)}{I_{P-P}} = \frac{(5-1.5) \times \left(\frac{1.5}{(1 \times 5)}\right)}{1.5\,A} = 0.43\,\mu H \tag{6}$$

For this application, a 0.42-µH, 1.55-mΩ inductor from NEC-TOKIN with part number MPCG0740LR42C is chosen.

Step Four

Set the output voltage.

$$V_{OUT} = \frac{V_{VREF}}{R_{UPPER} + R_{LOWER}} \times R_{LOWER} \tag{7}$$

The output voltage is determined by the 2-V reference (VREF) and the resistor dividers (R_{UPPER} and R_{LOWER}). The output voltage is regulated to the REFIN pin. Because the 2-V reference current capability is limited to less than 50 µA, care should be taken when selecting the resistor dividers. For the current reference design of 1.5 V (see application schematics shown in Figure 1 and Figure 2, R_{UPPER} = 100 kΩ, R_{LOWER} = 300 kΩ.

Step Five

Calculate OCL.

The DC OCL level of TPS51317 design is determined by Equation 8,

$$I_{OCL(dc)} = I_{OCL(valley)} + \frac{1}{2} \times I_{P-P} = 6\,A + \frac{1}{2} \times 1.5\,A = 6.75\,A \tag{8}$$

The minimum valley OCL is 6 A over process and temperature, and I_{P-P} = 1.5 A, the minimum DC OCL is calculated to be 6.75A.

Step Six

Determine the output capacitance.

To determine COUT based on transient and stability requirement, first calculate the the minimum output capacitance for a given transient.

Equation 10 and Equation 9 can be used to estimate the amount of capacitance needed for a given dynamic load step/release. Please note that there are other factors that may impact the amount of output capacitance for a specific design, such as ripple and stability. Equation 10 and Equation 9 are used only to estimate the transient requirement, the result should be used in conjunction with other factors of the design to determine the necessary output capacitance for the application.

$$C_{OUT(min\_under)} = \frac{L \times \Delta I_{LOAD(max)}^{2} \times \left(\frac{V_{VOUT} \times t_{SW}}{V_{IN(min)}} + t_{MIN(off)} \right)}{2 \times \Delta V_{LOAD(insert)} \times \left(\left(\frac{V_{IN(min)} - V_{VOUT}}{V_{IN(min)}} \right) \times t_{SW} - t_{MIN(off)} \right) \times V_{VOUT}} \quad (9)$$

$$C_{OUT(min\_over)} = \frac{L_{OUT} \times \left(\Delta I_{LOAD(max)} \right)^{2}}{2 \times \Delta V_{LOAD(release)} \times V_{VOUT}} \quad (10)$$

Equation 9 and Equation 10 calculate the minimum C_{OUT} for meeting the transient requirement, which is 84 µF assuming the following:

- ±3% voltage allowance for load step and release
- MLCC capacitance derating of 60% due to DC and AC bias effect

In this reference design, 6, 22-µF capacitors are used in order to provide this amount of capacitance.

Step Seven

Determine the stability based on the output capacitance C_{OUT}.

In order to achieve stable operation. The 0-dB frequency, f_0 should be kept less than 1/5 of the switching frequency (1 MHz). (See Figure 4)

$$f_0 = \frac{1}{2\pi} \times \frac{G_M}{C_{OUT}} \times \frac{R_C}{R_S} = 190\,kHz$$

where

- $R_S = R_{DS(on)} \times G_{MC} \times R_{LOAD}$ (11)

$$R_C = \frac{f_0 \times R_S \times 2\pi \times C_{OUT}}{G_M} = \frac{190\,kHz \times 53m\Omega \times 2\pi \times 80\,\mu F}{1mS} \approx 5k\Omega \quad (12)$$

Using 6, 22-µF capacitors, the compensation resistance, R_C can be calculated to be approximately 5 kΩ.

The purpose of the comparator capacitor (C_C) is to reduce the DC component to obtain high DC feedback gain. However, as it causes phase delay, another zero to cancel this effect at f_0 is needed. This zero can be determined by values of C_C and the compensation resistor, R_C.

$$f_Z = \frac{1}{2\pi \times R_C \times C_C} = \frac{f_0}{10} \quad (13)$$

And since R_C has previously been derived, the value of C_C is calculated to be 2.2 nF. In order to further boost phase margin, a value of 3.3-nF is chosen for this reference design.

Step Eight

Select decoupling and peripheral components.

For TPS51317 peripheral capacitors use the following minimum values of ceramic capacitance. X5R or better temperature coefficient is recommended. Tighter tolerances and higher voltage ratings are always appropriate.

- V5IN decoupling ≥ 22 µF, ≥ 10 V
- VREF decoupling 0.22 µF to 1 µF, ≥ 4 V
- Bootstrap capacitors ≥ 0.1 µF, ≥ 10 V
- Pull-up resistors on PGOOD, 100 kΩ

Layout Considerations

Good layout is essential for stable power supply operation. Follow these guidelines for an efficient PCB layout.

- Connect PGND pins (or at least one of the pins) to the thermal PAD underneath the device. Also connect GND pin to the thermal PAD underneath the device. Use four vias to connect the thermal pad to internal ground planes.
- Place VIN, V5IN and 2VREF decoupling capacitors as close to the device as possible.
- Use wide traces for the VIN, VOUT, PGND and SW pins. These nodes carry high current and also serve as heat sinks.
- Place feedback and compensation components as close to the device as possible.
- Keep COMP analog signal away from noisy signals (SW, BST).

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
TPS51317RGBR	ACTIVE	VQFN	RGB	20	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	
TPS51317RGBT	ACTIVE	VQFN	RGB	20	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	

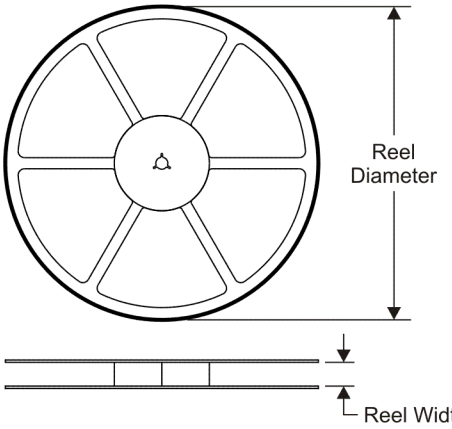
(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers,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

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

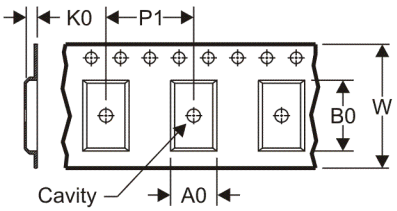
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

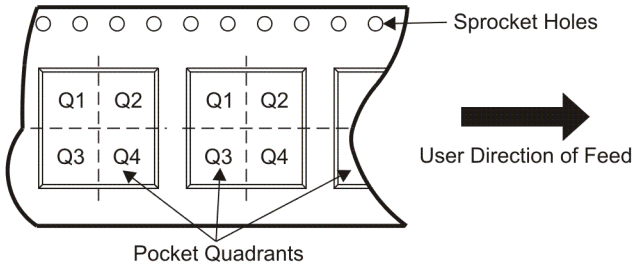


TAPE DIMENSIONS



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

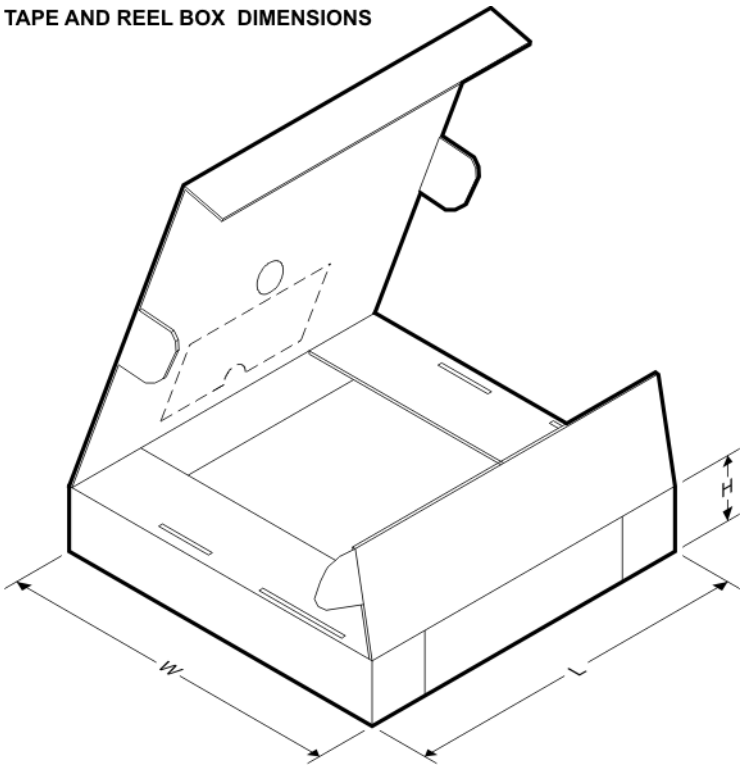
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TPS51317RGBR	VQFN	RGB	20	3000	330.0	12.4	3.8	4.3	1.5	8.0	12.0	Q1
TPS51317RGBT	VQFN	RGB	20	250	180.0	12.4	3.8	4.3	1.5	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS51317RGBR	VQFN	RGB	20	3000	346.0	346.0	29.0
TPS51317RGBT	VQFN	RGB	20	250	190.5	212.7	31.8

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