TPS65295 complete DDR4 memory power solution

1 Features

- Synchronous buck converter (VDDQ)
  - Input voltage range: 4.5 V to 18 V
  - Output voltage fixed at 1.2 V
  - D-CAP3™ mode control for fast transient response
  - Continual output current: 8 A
  - Advanced Eco-mode™ pulse skip
  - Integrated 22-mΩ and 8.6-mΩ $R_{DS(on)}$ internal power switch
  - 600-kHz switching frequency
  - Internal soft start: 1.6 ms
  - Cycle-by-cycle overcurrent protection
  - Latched output OV and UV protections
- Synchronous buck converter (VPP)
  - Input voltage range: 3 V to 5.5 V
  - Output voltage fixed at 2.5 V
  - D-CAP3™ mode control for fast transient response
  - Continual output current: 1 A
  - Advanced Eco-mode™ pulse skip
  - Integrated 150-mΩ and 120-mΩ $R_{DS(on)}$ internal power switch
  - 580-kHz switching frequency
  - Internal soft start: 1 ms
  - Cycle-by-cycle overcurrent protection
  - Latched output OV and UV protections
- 1-A LDO (VTT)
  - 1-A continual sink and source current
  - Requires only 10 µF of ceramic output capacitor
  - Support high-z in S3
  - ±30-mV VTT output accuracy (DC+AC)
- Buffered reference (VTTREF)
  - Buffered, low noise, ±10-mA capability
  - 0.8% output accuracy
- Low quiescent current: 150 µA
- Power good indicator
- Output discharge function
- Power up and power down sequencing control
- Non-latch for OT and UVLO protections
- 18-pin 3.0-mm × 3.0-mm HotRod™ VQFN package

2 Applications

- DDR4 memory power supplies
- Notebook, PC computers, and servers
- Ultrabook, tablet computers
- Single-board computer, computer on module

3 Description

The TPS65295 device provides a complete power solution for DDR4 memory system with the lowest total cost and minimum space. It meets the JEDEC standard for DDR4 power-up and power-down sequence requirement. The TPS65295 integrates two synchronous buck converters (VPP and VDDQ) and a 1-A sink and source tracking LDO (VTT) and a buffered low noise reference (VTTREF). The TPS65295 employs D-CAP3™ mode coupled with 600-kHz switching frequency for ease-of-use, fast transient, and support for ceramic output capacitors without an external compensation circuit.

The VTTREF tracks ½ VDDQ within excellent 0.8% accuracy. The VTT, which provides both 1-A sink and source continual current capabilities, requires only 10-µF of ceramic output capacitor.

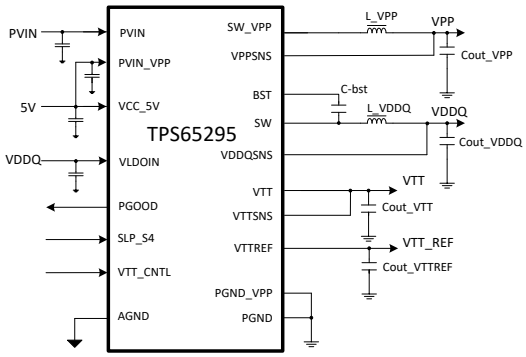
The TPS65295 provides rich functions as well as excellent power supply performance. It supports flexible power state control, placing VTT at high-Z in S3 and discharging VDDQ, VTT, and VTTREF in S4/S5 state. OVP, UVP, OCP, UVLO and thermal shutdown protections are also available. The part is available in a thermally enhanced 18-pin HotRod™ VQFN package and is designed to operate under the –40°C to 125°C junction temperature range.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS65295	VQFN (18)	3.00 mm × 3.00 mm

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

Typical Application



An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

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4 Revision History

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

DATE	REVISION	NOTES
February 2019	*	Initial release.

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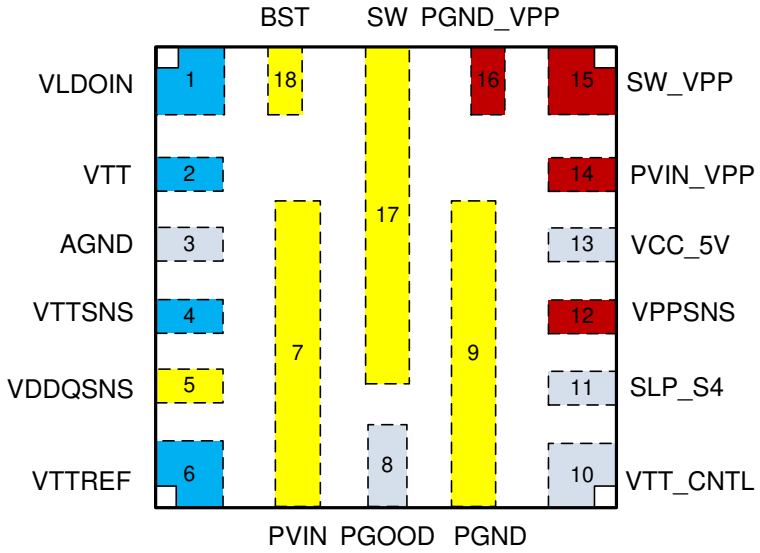
5 Pin Configuration and Functions

RJE Package
18-Pin VQFN
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
VLDOIN	1	P	Power supply input for VTT LDO. Connect VDDQ in typical application.
VTT	2	O	VTT 1-A LDO output. Recommend to connect to 10-µF or larger capacitance for stability.
AGND	3	G	Signal ground.
VTTSNS	4	I	VTT output voltage feedback.
VDDQSNS	5	I	VDDQ output voltage feedback.
VTTREF	6	O	Buffered VTT reference output. Recommend to connect to 0.22-µF or larger capacitance for stability.
PVIN	7	P	Input power supply for VDDQ buck.
PGOOD	8	O	Power good signal open-drain output. PGOOD goes high when VPP and VDDQ output voltage are within the target range.
PGND	9	G	Power ground for VDDQ buck.
VTT_CNTL	10	I	VTT_CNTL signal input for VTT LDO enable control. For detail control setup, please refer toTable 1.
SLP_S4	11	I	SLP_S4 signal input for VDDQ buck and VPP buck enable control. For detail control setup, please refer toTable 1.
VPPSNS	12	I	VPP output voltage feedback.
VCC_5V	13	P	Power supply for VPP and VDDQ buck converter control logic circuit.
PVIN_VPP	14	P	Input power supply for VPP buck.
SW_VPP	15	O	VPP switching node connection to the inductor and bootstrap capacitor.
PGND_VPP	16	G	Power ground for VPP buck.
SW	17	O	VDDQ switching node connection to the inductor and bootstrap capacitor.
BST	18	I	High-side MOSFET gate driver bootstrap voltage input for VDDQ buck. Connect a capacitor between the BST pin and the SW pin.

6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Input voltage	PVIN	–0.3	20	V
	VBST	–0.3	25	V
	VBST-SW	–0.3	6	V
	VTT_CNTL, SLP_S4, VCC_5V, PVIN_VPP, VLDOIN, VDDQSNS, VTTSNS, VPPSNS	–0.3	6	V
	PGND, AGND,PGND_VPP	–0.3	0.3	V
Output voltage	SW DC	–0.3	20	V
	SW (20-ns transient)	–3	22	V
	SW_VPP DC	–0.3	7	V
	SW_VPP (20-ns transient)	–3	8	V
	PGOOD, VTT,VTTREF	–0.3	6	V
T_J	Operating junction temperature	–40	150	°C
T_{stg}	Storage temperature	–55	150	°C

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

6.2 ESD Ratings

		VALUE	UNIT
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±2000	V
	Charged-device model (CDM), per JEDEC specification JESD22- V C101 (2)	±500	V

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

6.3 Recommended Operating Conditions

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

		MIN	MAX	UNIT
Input voltage	PVIN	4.5	18	V
	VBST	–0.3	23	V
	VBST-SW	–0.3	5.5	V
	VTT_CNTL, SLP_S4, VCC_5V, PVIN_VPP, VLDOIN, VDDQSNS, VTTSNS, VPPSNS	–0.3	5.5	V
	PGND, AGND,PGND_VPP	–0.3	0.3	V
Output voltage	SW DC	–0.3	18	V
	SW (20-ns transient)	–3	20	V
	SW_VPP DC	–0.3	5.5	V
	SW_VPP (20-ns transient)	–3	6.5	V
	PGOOD, VTT,VTTREF	–0.3	5.5	V
$I_{VDDQOUT}$	VDDQ Output current		8	A
T_J	Operating junction temperature	–40	125	°C

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6.4 Thermal Information

THERMAL METRIC[1]		TPS65295 RJE (VQFN) 18 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	58.1	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	26.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	17.7	°C/W
ψ_{JT}	Junction-to-top characterization parameter	0.5	°C/W
ψ_{JB}	Junction-to-board characterization parameter	17.7	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

6.5 Electrical Characteristics

T_J=-40°C to 125°C, V_{PVIN}=12V, V_{PVIN_VPP}=5V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT SUPPLY VOLTAGE						
I_{VCC_5V}	VCC_5V supply current	V_{SLP_S4} = V_{VTT_CNTL} = 0 V		5		µA
		V_{SLP_S4} = 5 V, V_{VTT_CNTL} = 0 V, no load		110		µA
		V_{SLP_S4} = V_{VTT_CNTL} = 5 V, no load		150		µA
VIN	PVIN input voltage range		4.5		18	V
UVLO						
UVLO	VCC_5V under-voltage lockout	Wake up VCC_5V voltage		4.1	4.5	V
		Shut down VCC_5V voltage	3.3	3.6		V
		Hysteresis VCC_5V voltage		500		mV
VDDQ						
$V_{VDDQSNS}$	VDDQ sense voltage		1.188	1.2	1.212	V
$I_{VDDQSNS}$	VDDQSNS input current	$V_{VDDQSNS}$ =1.2 V		40		µA
$I_{VDDQDIS}$	VDDQ discharge current	V_{SLP_S4} = V_{VTT_CNTL} = 0 V, $V_{VDDQSNS}$ = 0.5 V		12		mA
t_{VDDQSS}	VDDQ soft-start time			1.6	2.65	ms
$t_{VDDQDLY}$	VDDQ ramp up delay time			2		ms
R_{DSONH}	High-side switch resistance	T_J = 25°C, V_{PVIN} = 19V, V_{VCC_5V} = 5V		22		mΩ
R_{DSONL}	Low-side switch resistance	T_J = 25°C, V_{PVIN} = 19V, V_{VCC_5V} = 5V		8.6		mΩ
$I_{VDDQOCL}$	Low-side valley current limited	V_{OUT} = 1.2 V, L = 0.68 µH	8.2	9.8	11.5	A
f_{sw}	VDDQ switching freqency			600		kHz
$t_{OFF(MIN)}$	Minimum off time			198		ns
PGOOD (VDDQ, VPP)						
V_{THPG}	PGOOD threshold	VDDQSNS / VPPSNS falling (Fault)		87		%
		VDDQSNS / VPPSNS rising (Good)		93		%
		VDDQSNS / VPPSNS rising (Fault)		115		%
		VDDQSNS / VPPSNS falling (Good)		110		%
I_{PGMAX}	PG sink current	V_{PGOOD} =0.5V, V_{SLP_S4} =V_{VTT_CNTL} = 5 V, no load		46		mA
t_{PGDLY}	PG start-up delay	PG from low to high		1		ms
VPP						
V_{VPPSNS}	VPP sense voltage		2.45	2.5	2.55	V
I_{VPPSNS}	VPPSNS input current	V_{VPPSNS} =2.5 V		20		µA

Electrical Characteristics (continued)

T_J=-40°C to 125°C, V_{PVIN}=12V, V_{PVIN_VPP}=5V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{VPPDIS}	VPP discharge current	V_{SLP_S4} = V_{VTT_CNTL} = 0 V, V_{VPPSNS} = 0.5 V		12		mA
t_{VPPSS}	VPP soft-start time			1 .0	2	ms
R_{DSONH}	High-side switch resistance	T_J = 25°C, V_{PVIN_VPP} = 5V, V_{VCC_5V} = 5V		150		mΩ
R_{DSONL}	Low-side switch resistance	T_J = 25°C, V_{PVIN_VPP}=5V, V_{VCC_5V} = 5V		120		mΩ
I_{VPPOCL}	Low-side valley current limited	V_{OUT} = 2.5 V, L = 4.7 µH	1.05	1.6	2.1	A
f_{sw}	VPP switching frequency			580		kHz
$t_{OFF(MIN)}$	Minimum off time			195		ns
t_{OOA}	OOA mode operation period	V_{VPPSNS} =2.5 V		31		µs
OVP AND UVP (VDDQ, VPP)						
V_{OVP}	OVP threshold voltage	OVP detect voltage	120	125	130	%
V_{UVP1}	UVP threshold voltage	UVP detect voltage	55	60	65	%
t_{OVPDLY}	OVP delay			20		µs
t_{UVPDLY}	UVP delay			250		µs
VTTREF OUTPUT						
V_{VTTREF}	Output voltage			1/2* $V_{VDDQSNS}$		V
V_{VTTREF}	Output voltage tolerance to VDDQ	T_J = 25°C, $\|I_{VTTREF}\|$ ≤100 µA, $V_{VDDQSNS}$ = 1.2 V	49.2		50.8	%
		T_J = 25°C, $\|I_{VTTREF}\|$ ≤10mA, $V_{VDDQSNS}$ = 1.2 V	49		51	
$I_{VTTREFOCLSRC}$	Source current limit	$V_{VDDQSNS}$ = 1.2 V, V_{VTTREF}= 0 V	10	18		mA
$I_{VTTREFOCLSnk}$	Sink current limit	$V_{VDDQSNS}$ = 1.2 V, V_{VTTREF}= 1.2 V	10	18		mA
$I_{VTTREFDIS}$	VTTREF discharge current	T_J = 25°C, V_{SLP_S4} = V_{VTT_CNTL} = 0 V, V_{VTTREF} = 0.5 V	0.8	1.3		mA
VTT OUTPUT						
V_{VTT}	Output voltage			V_{VTTREF}		V
V_{VTTTOL}	Output voltage tolerance	$\|I_{VTT}\|$ ≤10 mA, $V_{VDDQSNS}$ = 1.2 V, I_{VTTREF}= 0 A	–20		20	mV
		T_J = 25°C,$\|I_{VTT}\|$ ≤1A, $V_{VDDQSNS}$ = 1.2 V, I_{VTTREF}= 0 A	–30		30	
$I_{VTTOCLSRC}$	Source current limit	$V_{VDDQSNS}$ = 1.2 V, V_{VTT}= V_{VTTSNS}= 0.5 V, I_{VTTREF}=0 A	1	1.7		A
$I_{VTTOCLSnk}$	Sink current limit	$V_{VDDQSNS}$ = 1.2 V, V_{VTT}= V_{VTTSNS}= 0.7 V, I_{VTTREF}=0 A	1	1.7		A
I_{VTTLK}	Leakage current	T_J = 25°C, V_{SLP_S4} = 5 V, V_{VTT_CNTL} = 5 V, V_{VTT} =V_{VTTREF}			5	µA
$I_{VTTSNSBIAS}$	VTTSNS input bias current	V_{SLP_S4} = 5 V, V_{VTT_CNTL} = 5 V, V_{VTT} =V_{VTTREF}	–0.5	0	0.5	
$I_{VTTSNSLK}$	VTTSNS leakage current	V_{SLP_S4} = 5 V, V_{VTT_CNTL} = 0 V, V_{VTT} =V_{VTTREF}	–1	0	1	
I_{VTTDLY}	VTT output delay relative to VTT_CNTL				35	us
I_{VTTDIS}	VTT discharge current	T_J = 25°C, V_{SLP_S4} = V_{VTT_CNTL} = 0 V, $V_{VDDQSNS}$ = 1.2 V, V_{VTT} =0.5V, I_{VTTREF} =0 A		5.7		mA
SLP_S4, VTT_CNTL LOGIC THRESHOLD						
V_{IH}	SLP_S4/VTT_CNTL high-level voltage		1.6			V

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Electrical Characteristics (continued)

T_J=-40°C to 125°C, V_{PVIN}=12V, V_{PVIN_VPP}=5V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IL}	SLP_S4/VTT_CNTL low-level voltage				0.5	V
R_{TOGND}	SLP_S4/VTT_CNTL resistance to GND			500		kΩ
THERMAL PROTECTION						
T_{OTP}	OTP trip threshold			150		°C
T_{OTPHSY}	OTP hysteresis			20		°C

6.6 Typical Characteristics

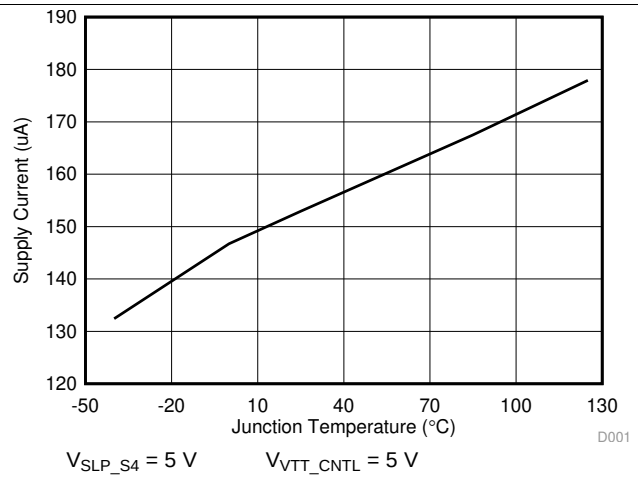

Figure 1. VCC_5V Supply Current vs Junction Temperature

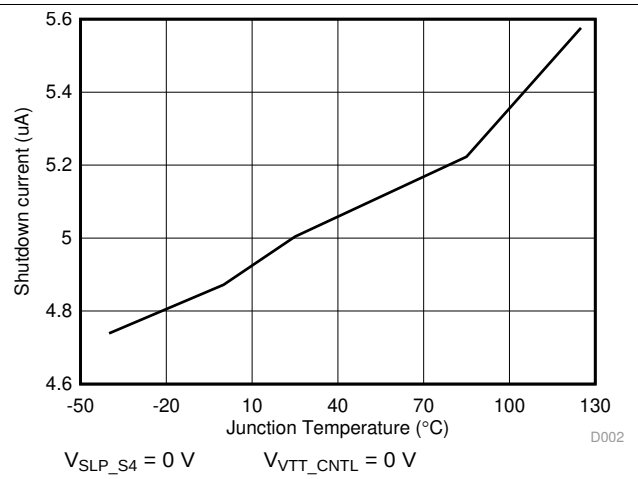

Figure 2. VCC_5V Shutdown Current vs Temperature

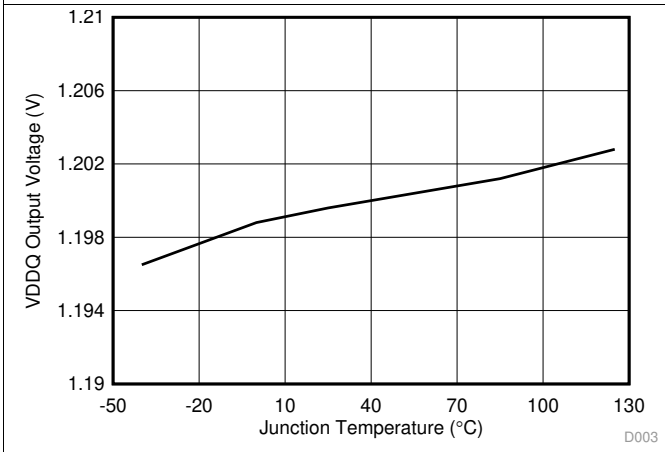

Figure 3. VDDQ Output Voltage vs Junction Temperature

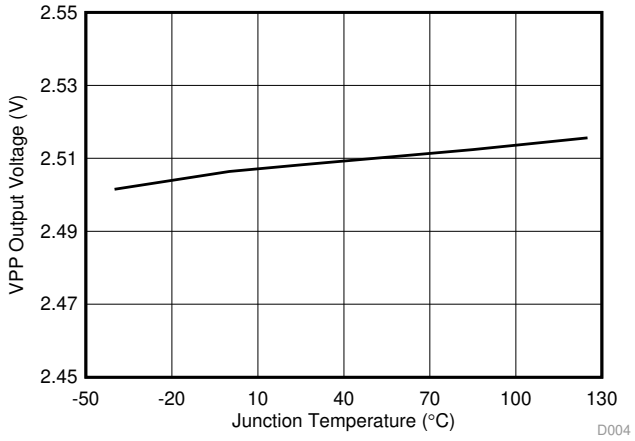

Figure 4. VPP Output Voltage vs Junction Temperature

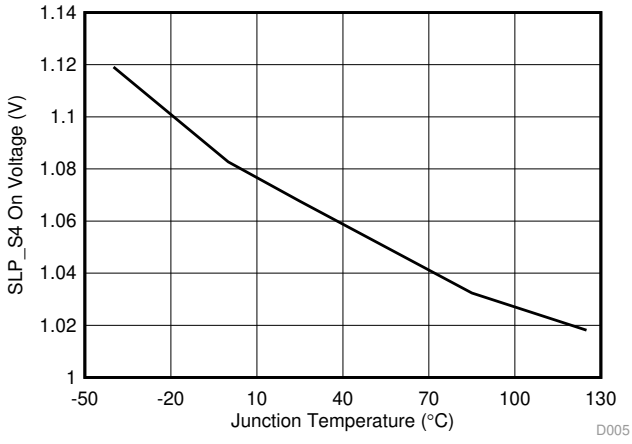

Figure 5. Enable On Voltage (SLP_S4) vs Junction Temperature

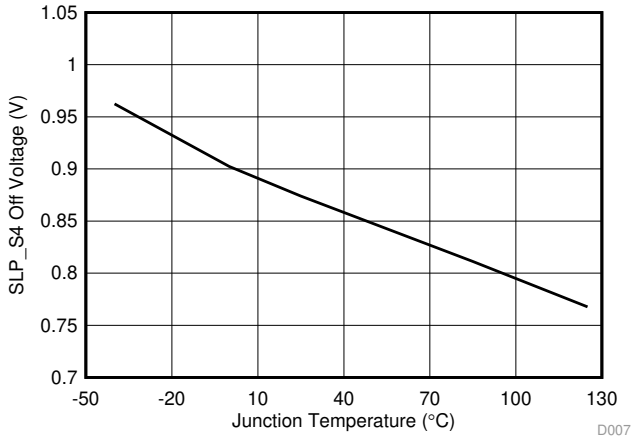

Figure 6. Enable Off Voltage (SLP_S4) vs Junction Temperature

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Typical Characteristics (continued)

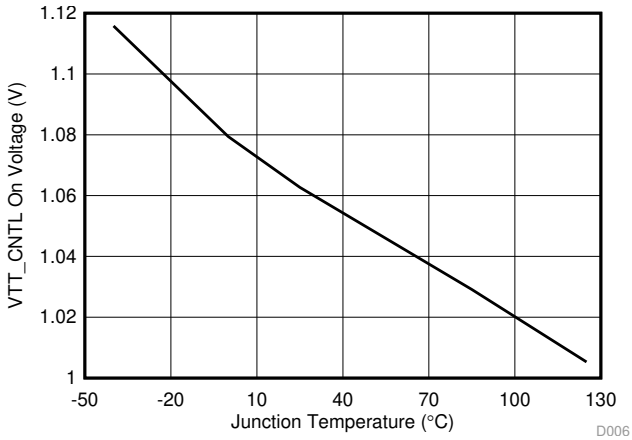

Figure 7. Enable On Voltage (VTT_CNTL) vs Junction Temperature

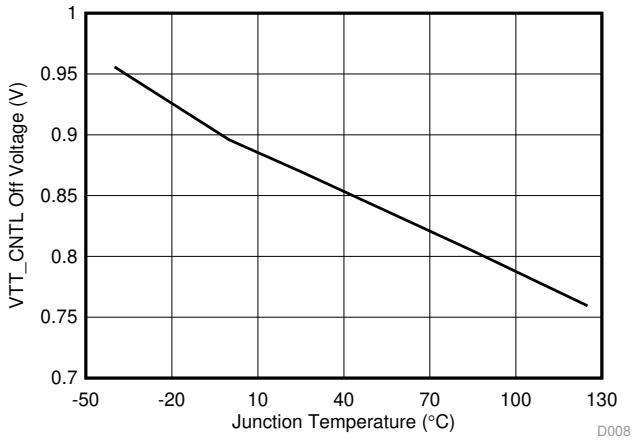

Figure 8. Enable Off Voltage (VTT_CNTL) vs Junction Temperature

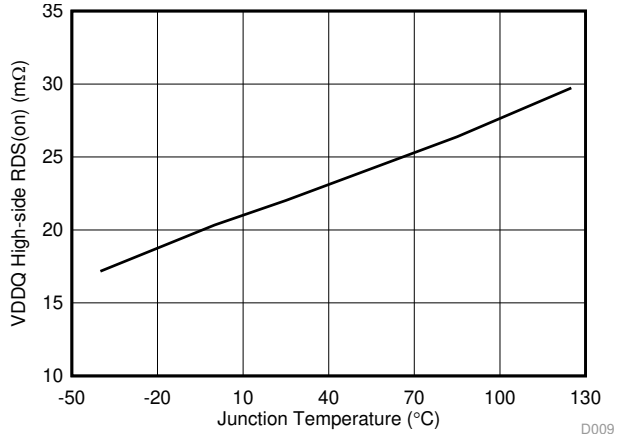

Figure 9. VDDQ High-Side $R_{DS(on)}$ vs Junction Temperature

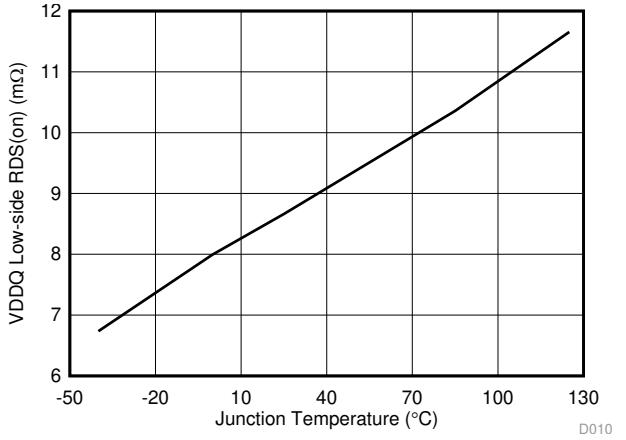

Figure 10. VDDQ Low-Side $R_{DS(on)}$ vs Junction Temperature

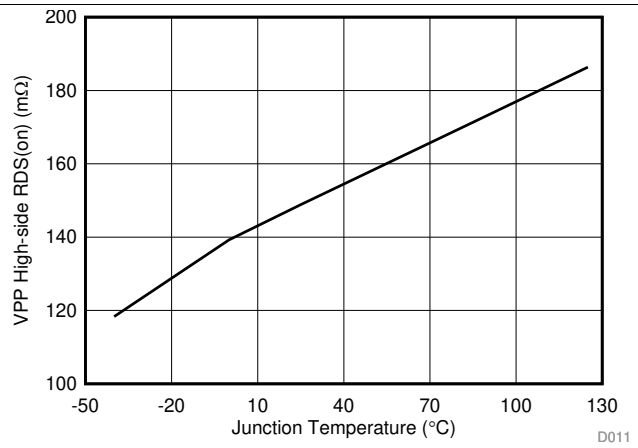

Figure 11. VPP High-Side $R_{DS(on)}$ vs Junction Temperature

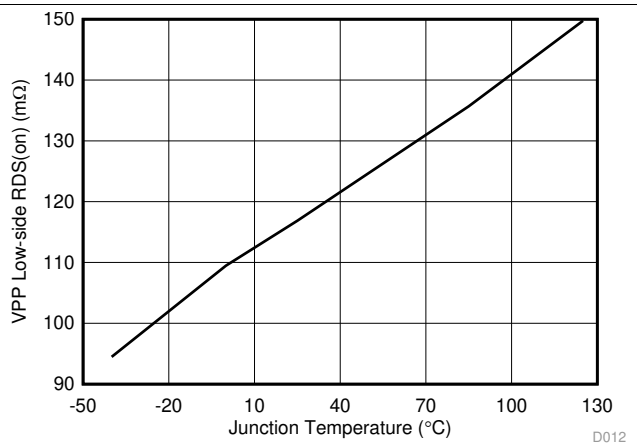

Figure 12. VPP Low-Side $R_{DS(on)}$ vs Junction Temperature

Typical Characteristics (continued)

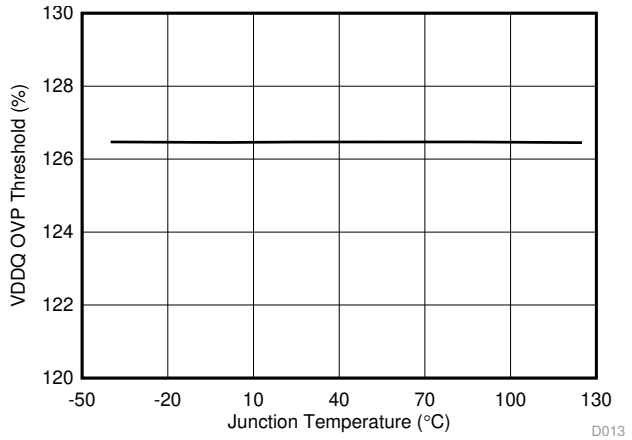

Figure 13. VDDQ OVP Threshold vs Junction Temperature

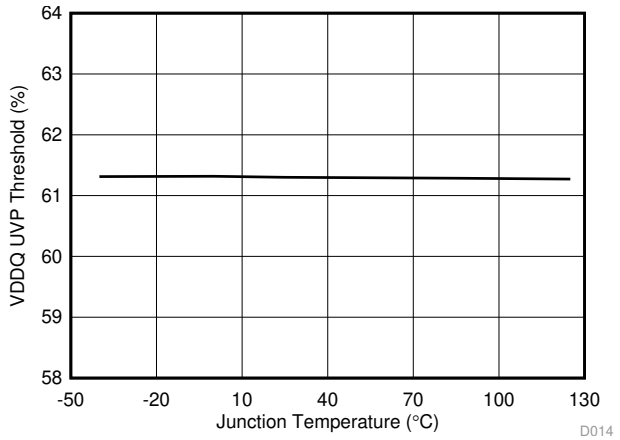

Figure 14. VDDQ UVP Threshold vs Junction Temperature

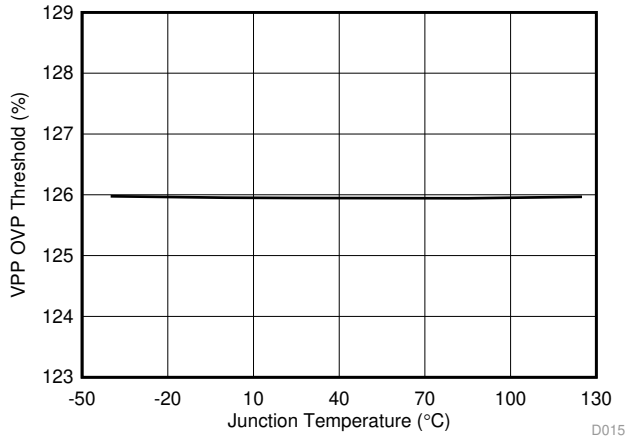

Figure 15. VPP OVP Threshold vs Junction Temperature

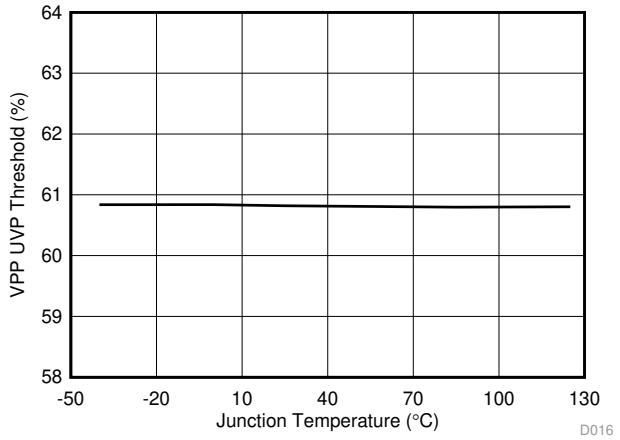

Figure 16. VPP UVP Threshold vs Junction Temperature

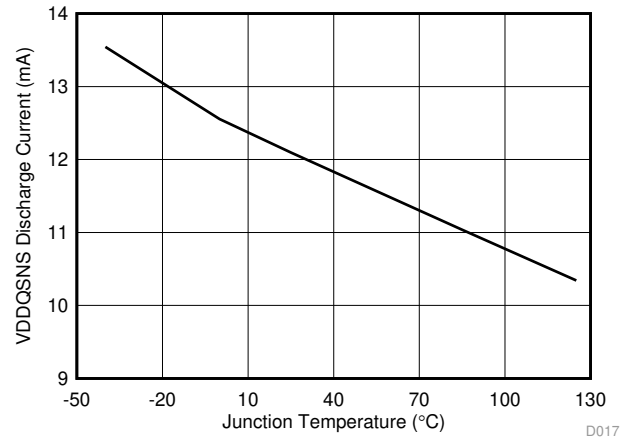

Figure 17. VDDQSNS Discharge Current vs Junction Temperature

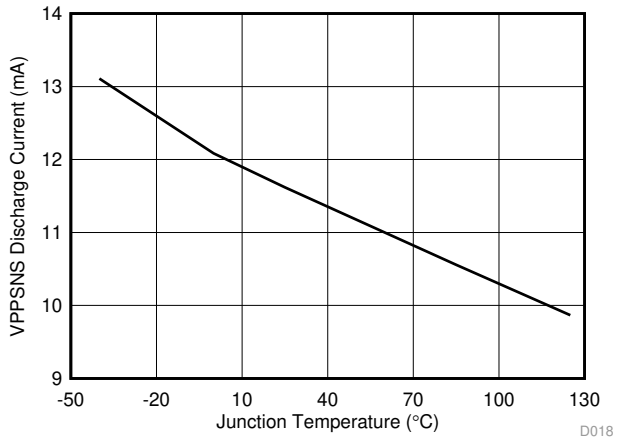

Figure 18. VPPSNS Discharge Current vs Junction Temperature

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Typical Characteristics (continued)

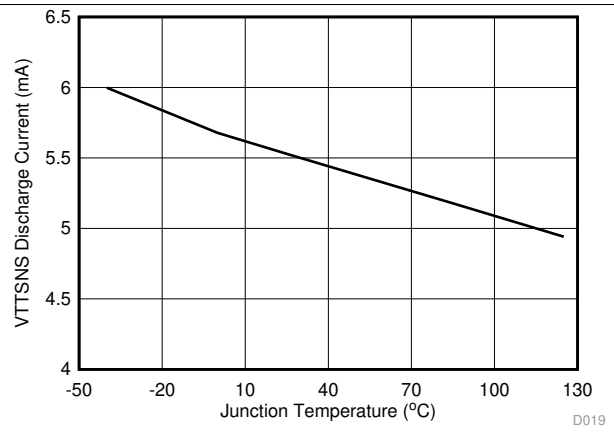

Figure 19. VTTSNS Discharge Current vs Junction Temperature

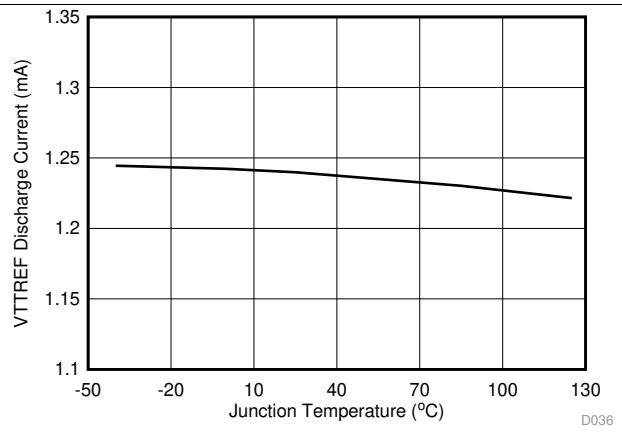

Figure 20. VTTREF Discharge Current vs Junction Temperature

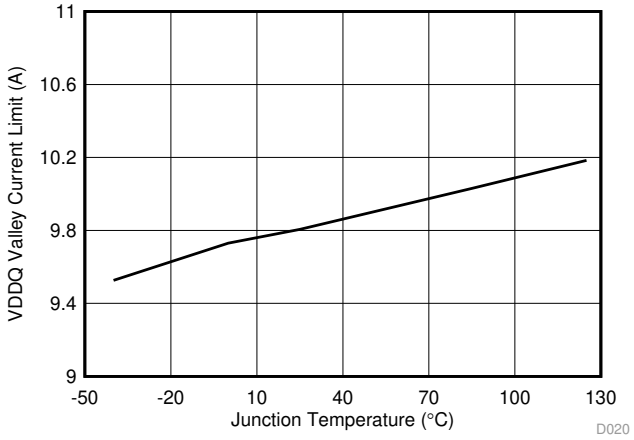

Figure 21. VDDQ Valley Current Limit vs Junction Temperature

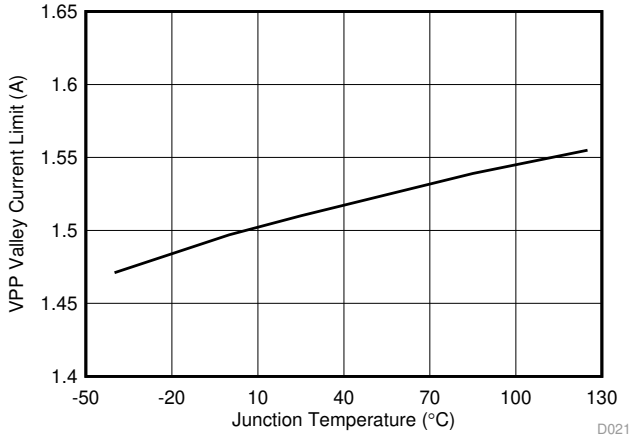

Figure 22. VPP Valley Current Limit vs Junction Temperature

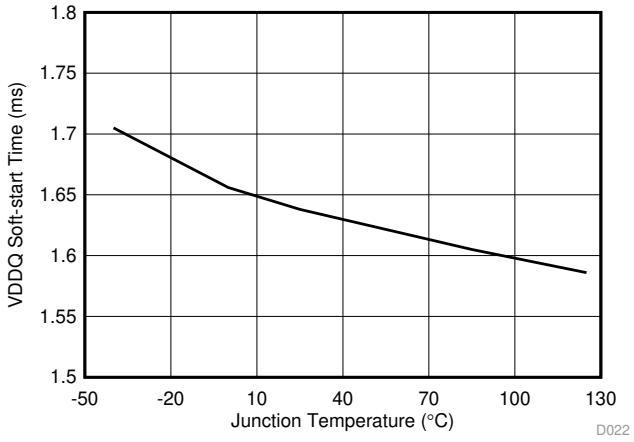

Figure 23. VDDQ Soft-Start Time vs Junction Temperature

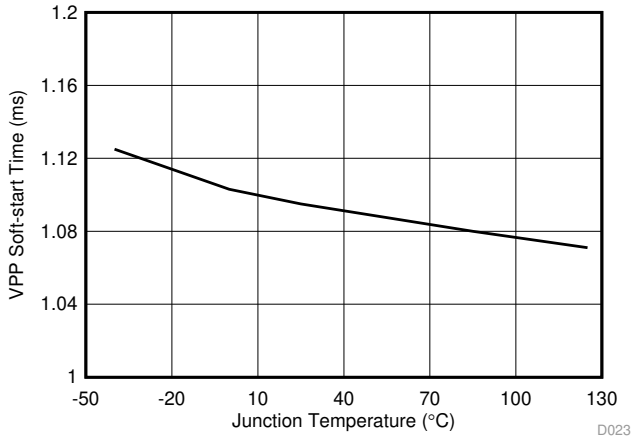

Figure 24. VPP Soft-Start Time vs Junction Temperature

Typical Characteristics (continued)

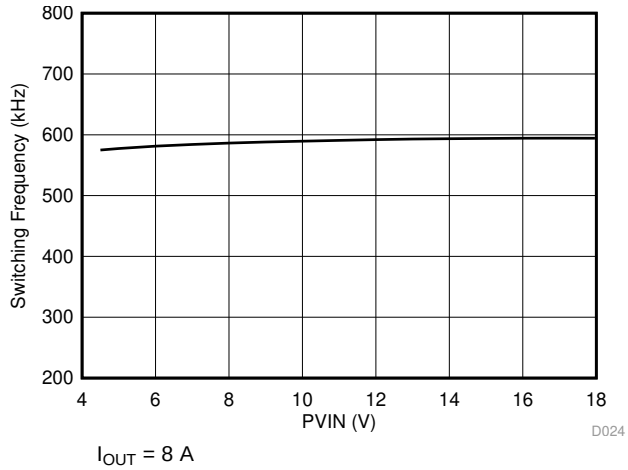

Figure 25. VDDQ Switching Frequency vs Input Voltage

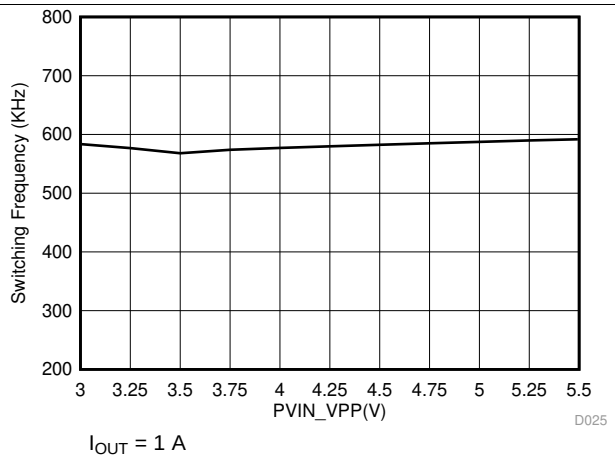

Figure 26. VPP Switching Frequency vs Input Voltage

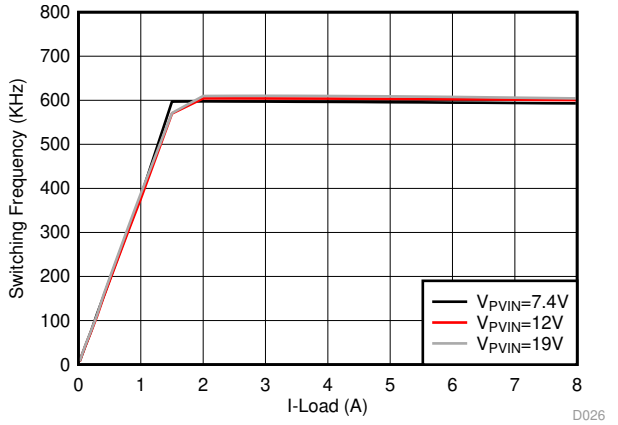

Figure 27. VDDQ Switching Frequency vs Load Current

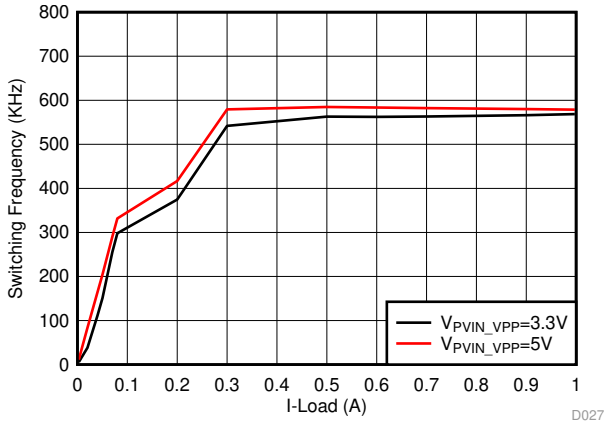

Figure 28. VPP Switching Frequency vs Load Current

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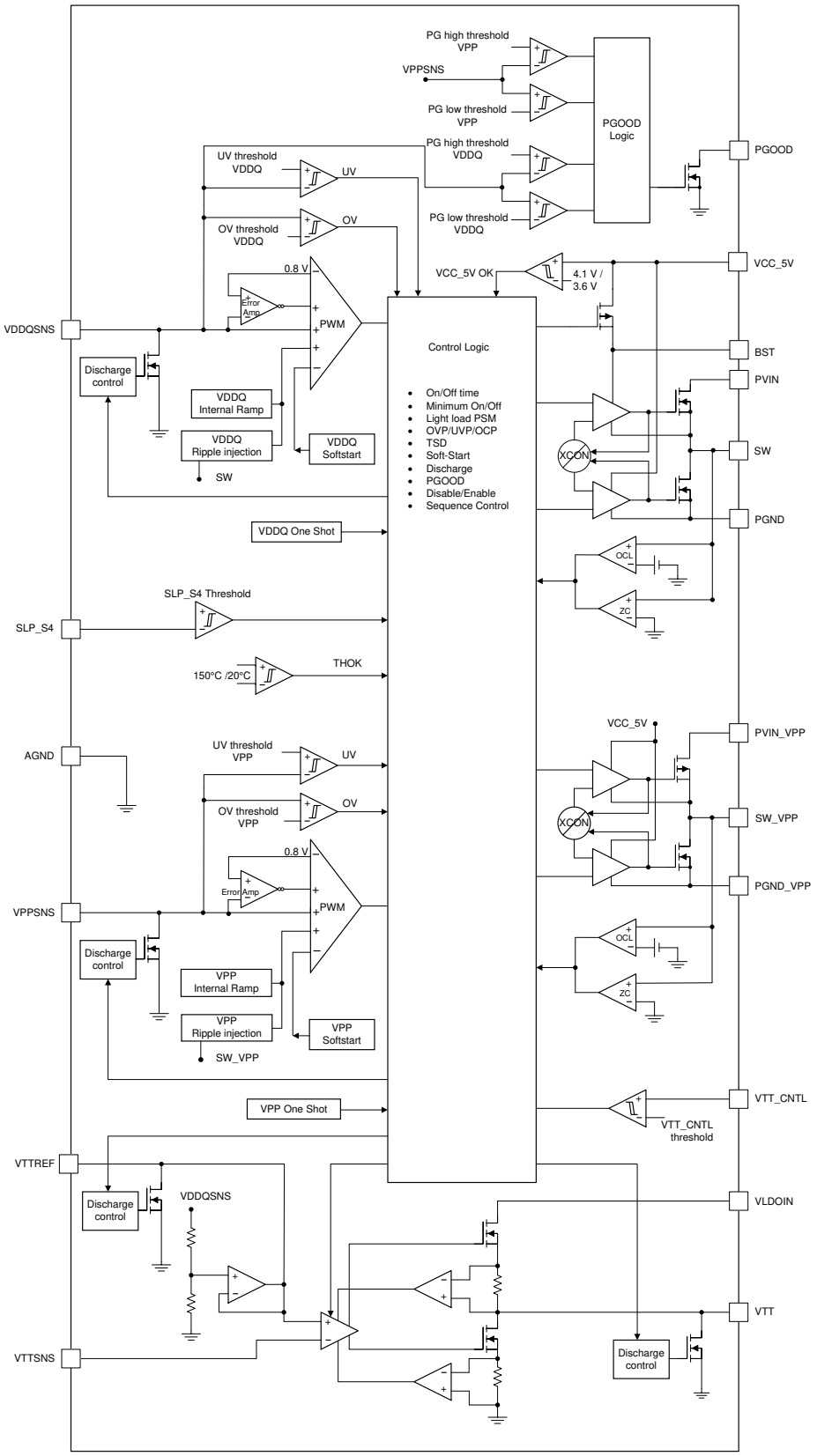
7 Detailed Description

7.1 Overview

The TPS65295 integrates two synchronous step-down buck converters and two LDOs to support complete DDR4 power solution. The VDDQ buck converter has the fixed 1.2-V output and supports continuous 8-A output current, and it can operate from 4.5-V to 18-V PVIN input voltage. The VPP buck converter has the fixed 2.5-V output and supports continuous 1-A output current, and can operate from 3-V to 5.5-V PVIN_VPP input voltage. The VTTREF LDO tracks the ½ VDDQ output and has about 10-mA both sink and source current capability. The VTT LDO tracks the VTTREF output and has continuous 1-A both sink and source current capability.

7.2 Functional Block Diagram



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7.3 Feature Description

7.3.1 PWM Operation and D-CAP3™ Control

The main control loop of the two bucks is adaptive on-time pulse width modulation (PWM) controller that supports a proprietary DCAP3™ mode control. The DCAP3™ mode control combines adaptive on-time control with an internal compensation circuit for pseudo-fixed frequency and low external component count configuration with both low-ESR and ceramic output capacitors. It is stable even with virtually no ripple at the output. The TPS65295 also includes an error amplifier that makes the output voltage very accurate.

At the beginning of each cycle, the high-side MOSFET is turned on. This MOSFET is turned off after internal one-shot timer expires. This one-shot duration is set proportional to the converter input voltage, VIN, and is inversely proportional to the output voltage, VO, to maintain a pseudo-fixed frequency over the input voltage range, hence it is called adaptive on-time control. The one-shot timer is reset and the high-side MOSFET is turned on again when the feedback voltage falls below the reference voltage. An internal ripple generation circuit is added to reference voltage for emulating the output ripple, this enables the use of very low-ESR output capacitors such as multi-layered ceramic caps (MLCC). No external current sense network or loop compensation is required for DCAP3™ control topology.

Both VDDQ buck and VPP buck include an error amplifier that makes the output voltage very accurate. For any control topology that is compensated internally, there is a range of the output filter it can support. The output filter used with the TPS65295 is a low-pass L-C circuit. This L-C filter has a double-pole frequency described in Equation 1.

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

At low frequencies, the overall loop gain is set by the internal output set-point resistor divider network and the internal gain of the TPS65295. The low-frequency L-C double pole has a 180 degree in phase. At the output filter frequency, the gain rolls off at a –40 dB 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 –40 dB to –20 dB per decade and increases the phase to 90 degree one decade above the zero frequency. The internal ripple injection high-frequency zero is related to the switching frequency. The inductor and capacitor selected for the output filter must be such that the double pole is placed close enough to the high-frequency zero, so that the phase boost provided by this high-frequency zero provides adequate phase margin for the stability requirement. The crossover frequency of the overall system should usually be targeted to be less than one-fifth of the switching frequency (F_{SW}).

7.3.2 Advanced Eco-mode™ Control

The VDDQ buck and VPP buck are designed with advanced Eco-mode™ control schemes to maintain high light load efficiency. As the output current decreases from heavy load conditions, the inductor current is also reduced and eventually comes to a point where the rippled valley touches zero level, which is the boundary between continuous conduction and discontinuous conduction modes. The rectifying MOSFET is turned off when the zero inductor current is detected. As the load current further decreases, the converter runs into discontinuous conduction mode. The on-time is kept almost the same as it was in the continuous conduction mode, so that it takes longer time to discharge the output capacitor with smaller load current to the level of the reference voltage. This makes the switching frequency lower, proportional to the load current, and keeps the light load efficiency high. The light load current where the transition to Eco-mode™ operation happens ($I_{OUT(LL)}$) can be calculated from Equation 2.

$$I_{OUT(LL)} = \frac{1}{2 \times L_{OUT} \times F_{SW}} \times \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{V_{IN}} \tag{2}$$

After identifying the application requirements, design the output inductance (L_{OUT}) so that the inductor peak-to-peak ripple current is approximately between 20% and 30% of the $I_{OUT(max)}$ (peak current in the application). It is also important to size the inductor properly so that the valley current does not hit the negative low-side current limit.

Feature Description (continued)

7.3.3 Soft Start and Prebiased Soft Start

The VDDQ buck has an internal 1.6-ms soft start and VPP buck has an internal 1-ms soft start. Provide the voltage supply to PVIN, PVIN_VPP and VCC_5V before asserting SLP_S4 to be high, when the SLP_S4 pin becomes high, the internal soft-start function begins ramping up the reference voltage to the PWM comparator.

If the output capacitor is prebiased at start-up, the devices initiate switching and start ramping up only after the internal reference voltage becomes greater than the feedback voltage. This scheme ensures that the converters ramp up smoothly into regulation point.

7.3.4 Power Good

The Power Good (PGOOD) pin is an open-drain output. Once the VDDQSNS and VPPSNS pins voltage are between 90% and 110% of the target output voltage, the PGOOD is deasserted and floats after a 1-ms de-glitch time. A pullup resistor of 100 kΩ is recommended to pull the voltage up to VCC_5V. The PGOOD pin is pulled low when:

- the VDDQSNS pin voltage or VPPSNS pin voltage is lower than 85% or greater than 115% of the target output voltage
- in an OVP, UVP, or thermal shutdown event
- during the soft-start period.

7.3.5 Overcurrent Protection and Undervoltage Protection

Both VDDQ and VPP bucks have the overcurrent protection and undervoltage protection, and the implementation is same. The output overcurrent limit (OCL) is implemented using a cycle-by-cycle valley detect control circuit. The switch current is monitored during the OFF state by measuring the low-side FET drain to source voltage. This voltage is proportional to the switch current. To improve accuracy, the voltage sensing is temperature compensated.

During the on-time of the high-side FET switch, the switch current increases at a linear rate determined by Vin, Vout, the on-time and the output inductor value. During the on-time of the low-side FET switch, this current decreases linearly. The average value of the switch current is the load current I_{OUT}. If the monitored current is above the OCL level, the converter maintains low-side FET on and delays the creation of a new set pulse, even the voltage feedback loop requires one, until the current level becomes OCL level or lower. In subsequent switching cycles, the on-time is set to a fixed value and the current is monitored in the same manner.

There are some important considerations for this type of overcurrent protection. When the load current is higher than the overcurrent threshold by one half of the peak-to-peak inductor ripple current, the OCL is triggered and the current is being limited, the output voltage tends to drop because the load demand is higher than what the converter can support. When the output voltage falls below 60% of the target voltage, the UVP comparator detects it, the output will be discharged and latched after a wait time of 256 µs. When the overcurrent condition is removed, the output voltage is latched till the SLP_S4 is toggled or repower the VCC_5V power input.

7.3.6 Overvoltage Protection

Both VDDQ and VPP bucks have the overvoltage protection feature and have the same implementation. When the output voltage becomes higher than 125% of the target voltage, the OVP comparator output goes high, and then the output will be discharged and latched after a wait time of 20 µs. When the over current condition is removed, the output voltage is latched till the SLP_S4 is toggled or repower the VCC_5V power input.

7.3.7 UVLO Protection

Undervoltage Lockout protection (UVLO) monitors the VCC_5V power input. When the voltage is lower than UVLO threshold voltage, the device is shut off and outputs are discharged. This is a non-latch protection.

7.3.8 Output Voltage Discharge

The VPP buck, VDDQ buck, VTT LDO, and VTTREF LDO block all have the discharge function by using internal MOSFETs, which are connected to the corresponding output terminals VPPSNS, VDDQSNS, VTT, and VTTREF. The discharge is slow due to the lower current capability of these MOSFETs.

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Feature Description (continued)

7.3.9 Thermal Shutdown

The TPS65295 monitors the internal die temperature. If the temperature exceeds the threshold value (typically 150°C), the device is shut off and the output will be discharged. This is a non-latch protection. The device restarts switching when the temperature goes below the thermal shutdown recover threshold.

7.4 Device Functional Modes

7.4.1 Light Load Operation for VDDQ Buck and VPP Buck

When the load is light on the VDDQ or VPP output, the buck enters pulse skip mode after the inductor current crosses zero. This is the Eco-mode™ which improves the efficiency at light load with a lower switching frequency. Each switching cycle is followed by a period of energy saving sleep time. The sleep time ends when the VDDQSNS or VPPSNS voltage falls below the Eco-mode™ threshold voltage. As the output current decreases, the period time between switching pulses increases.

7.4.2 Output State Control

The TPS65295 has two enable input pins, SLP_S4 and VTT_CNTL, to provide simple control scheme of output state. All of VPP, VDDQ, VTTREF and VTT are turned on at S0 state (SLP_S4=VTT_CNTL=high). In S3 state (VTT_CNTL=low, SLP_S4=high), VPP, VDDQ, and VTTREF voltages are kept on while VTT is turned off and left at high impedance state (high-Z). The VTT output floats and does not sink or source current in this state. In S4/S5 states (SLP_S4=VTT_CNTL =low), all of the three outputs are turned off and discharged to GND. Each state code represents as follow: S0 = full ON, S3 = suspend to RAM (STR), S4 = suspend to disk (STD), S5 = soft OFF (see Table 1).

Table 1. VTT_CNTL and SLP_S4 Control for Output State

STATE	VTT_CNTL	SLP_S4	VPP	VDDQ	VTTREF	VTT
S0	HI	HI	ON	ON	ON	ON
S3	LO	HI	ON	ON	ON	OFF (High-Z)
S5/S4	LO	LO	OFF (discharge)	OFF (discharge)	OFF (discharge)	OFF (discharge)

7.4.3 Output Sequence Control

There are specific sequencing requirements for the DDR4 VDDQ and VPP rails. The TPS65295 follows the DDR4 power rail sequence requirements as shown in Figure 29 and Figure 30. VPP is greater than VDDQ at all times during ramp up, operating, and ramp down. The VTT output ramp and stable within 35 µs after VTT_CNTL asserted.

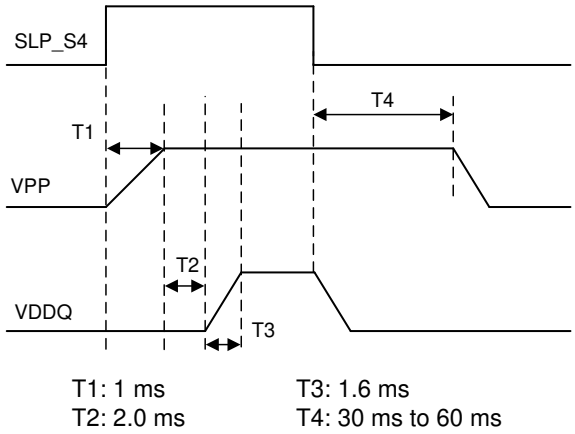

Figure 29. Power Sequence, VPP and VDDQ vs SLP_S4

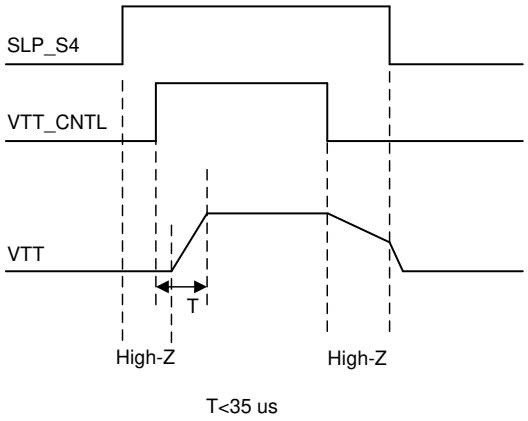

Figure 30. Power Sequence, VTT vs VTT_CNTL

8 Application and Implementation

NOTE

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

8.1 Application Information

The schematic of Figure 31 shows a typical application for TPS65295. For VDDQ buck, the PVIN supports 4.5-V to 18-V input range with 1.2-V VDDQ output, the continuous current capability is 8 A. Usually the PVIN_VPP and VCC_5V can share one 5-V power input and supports 2.5-V VPP output with 1-A continuous current capability, of course the PVIN_VPP can be lowered down to a 3.3-V power supply. The VLDOIN power input usually is connected to VDDQ output, while also it can be connected to external 1.2-V power supply input. The VTTREF output voltage will follow the ½ VDDQSNS voltage, and VTT output voltage will follow the VTTREF output voltage, this is required by DDR4 power supply standard.

8.2 Typical Application

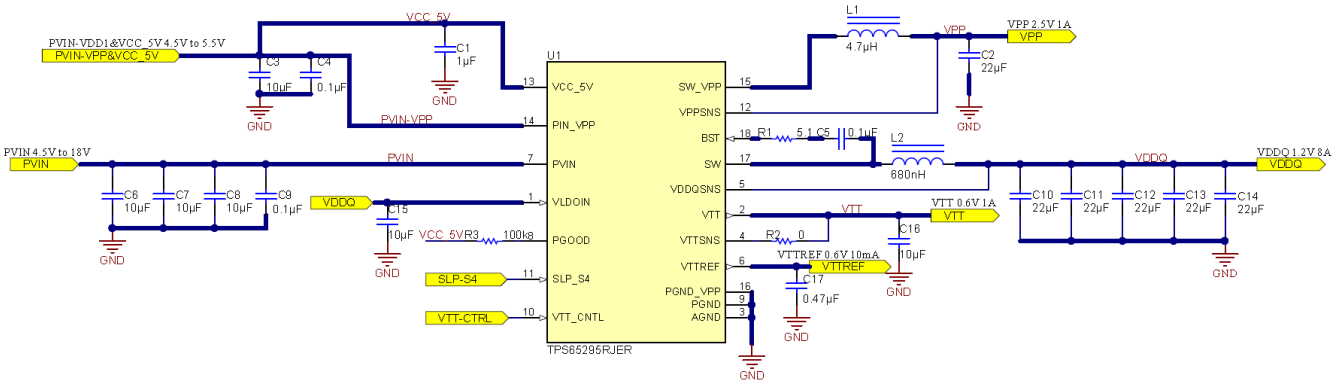

Figure 31. Application Schematic

8.2.1 Design Requirements

Table 2 lists the design parameters for this example.

Table 2. Design Parameters

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
VDDQ OUTPUT						
V_{OUT}	Output voltage			1.2		V
I_{OUT}	Output current			8		A
ΔV_{OUT}	Transient response	8-A load step		±60		mV
V_{IN}	Input voltage		4.5	12	18	V
$V_{OUT(ripple)}$	Output voltage ripple			40		$mV_{(P-P)}$
F_{SW}	Switching frequency			600		kHz
VPP OUTPUT						
V_{OUT}	Output voltage			2.5		V
I_{OUT}	Output current			1		A
ΔV_{OUT}	Transient response	1-A load step		±125		mV
V_{IN}	Input voltage		3	5	5.5	V

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Typical Application (continued)

Table 2. Design Parameters (continued)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
$V_{OUT(ripple)}$	Output voltage ripple			40		$mV_{(P-P)}$
F_{SW}	Switching frequency			580		kHz
OTHERS						
V_{VCC_5V}	Start VCC_5V input voltage	VCC_5V Input voltage rising		Internal UVLO		V
	Stop VCC_5V input voltage	VCC_5V Input voltage falling		Internal UVLO		V
	Light load operating mode			ECO		
T_A	Ambient temperature			25		°C

8.2.2 Detailed Design Procedure

8.2.2.1 External Component Selection

8.2.2.1.1 Inductor Selection

The inductor ripple current is filtered by the output capacitor. A higher inductor ripple current means the output capacitor should have a ripple current rating higher than the inductor ripple current. See Table 3 for recommended inductor values.

The RMS and peak currents through the inductor can be calculated using Equation 3 and Equation 4. It is important that the inductor is rated to handle these currents.

$$I_{L(rms)} = \sqrt{\left(I^2_{OUT} + \frac{1}{12} \times \left(\frac{V_{OUT} \times \left(V_{IN(max)} - V_{OUT}\right)}{V_{IN(max)} \times L_{OUT} \times F_{SW}}\right)^2\right)} \tag{3}$$

$$I_{L(peak)} = I_{OUT} + \frac{I_{OUT(ripple)}}{2} \tag{4}$$

During transient and short-circuit conditions, the inductor current can increase up to the current limit of the device so it is safe to choose an inductor with a saturation current higher than the peak current under current limit condition.

8.2.2.1.2 Output Capacitor Selection

After selecting the inductor the output capacitor needs to be optimized. In DCAP3, the regulator reacts within one cycle to the change in the duty cycle so the good transient performance can be achieved without needing large amounts of output capacitance. The recommended output capacitance range is given in Table 3.

Ceramic capacitors have very low ESR, otherwise the maximum ESR of the capacitor should be less than $V_{OUT(ripple)}/I_{OUT(ripple)}$.

Table 3. Recommended Component Values

V_{OUT} (V)	F_{sw} (kHz)	L_{OUT} (µH)	$C_{OUT(min)}$ (µF)	$C_{OUT(max)}$ (µF)
1.2	600	0.68	88	132
	600	0.56	88	132
	600	0.47	88	132
2.5	580	6.8	20	66
	580	4.7	20	66
	580	3.3	20	66

For VTT output, high quality X5R or X7R 10-µF capacitor is recommended and a 0.47 µF is recommended for VTTREF output.

8.2.2.1.3 Input Capacitor Selection

The TPS65295 requires input decoupling capacitors on both power supply input PVIN and PVIN_VPP, and the bulk capacitors are needed depending on the application. The minimum input capacitance required is given in Equation 5.

$$C_{IN(min)} = \frac{I_{OUT} \times V_{OUT}}{V_{INripple} \times V_{IN} \times F_{SW}} \tag{5}$$

TI recommends using a high-quality X5R or X7R input decoupling capacitors of 30 µF on the VDDQ buck input voltage pin PVIN, and 10 µF on the VPP buck input voltage pin PVIN_VPP. The voltage rating on the input capacitor must be greater than the maximum input voltage. The capacitor must also have a ripple current rating greater than the maximum input current ripple of the application. The input ripple current is calculated by Equation 6:

$$I_{CIN(rms)} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN(min)}} \times \frac{(V_{IN(min)} - V_{OUT})}{V_{IN(min)}}} \tag{6}$$

An additional 0.1-µF capacitor from PVIN to ground and from PVIN_VPP to ground is optional to provide additional high frequency filtering. One ceramic capacitor of 10 µF is recommended for the decoupling capacitor on VLDOIN pin for providing stable power on VTT LDO block. A 1-µF ceramic capacitor is needed for the decoupling capacitor on VCC_5V input.

8.2.2.1.4 Bootstrap Capacitor and Resistor Selection

A 0.1-µF ceramic capacitor serialized with a 5.1-Ω resistor is recommended between the BST and SW pin for proper operation. TI recommends using a ceramic capacitor.

8.2.3 Application Curves

Figure 32 through Figure 60 apply to the circuit of Figure 31. V_{IN} = 12 V. T_A = 25°C unless otherwise specified.

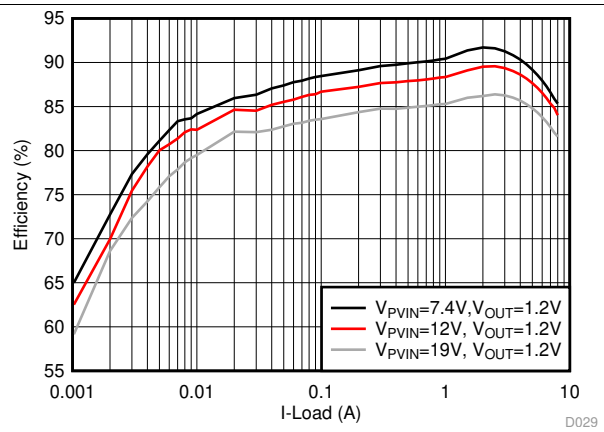

Figure 32. VDDQ Efficiency Curve, V_{OUT} = 1.2 V

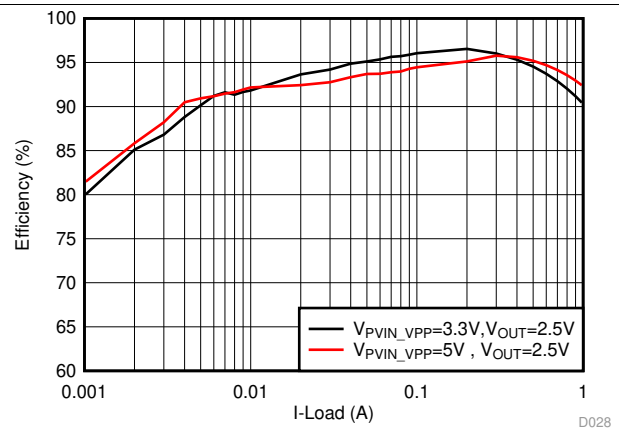

Figure 33. VPP Efficiency Curve, V_{OUT} = 2.5 V

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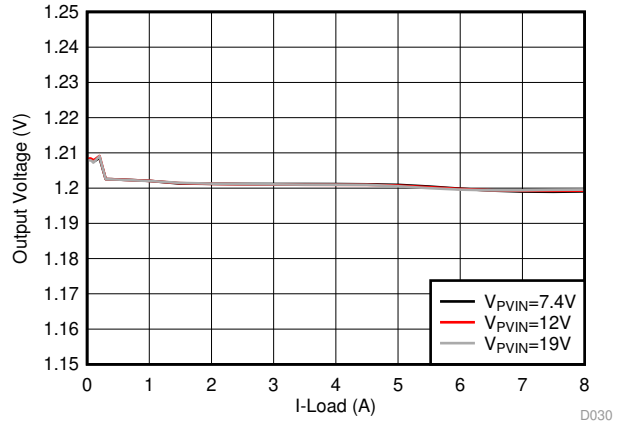

Figure 34. VDDQ Load Regulation, V_{OUT} = 1.2 V

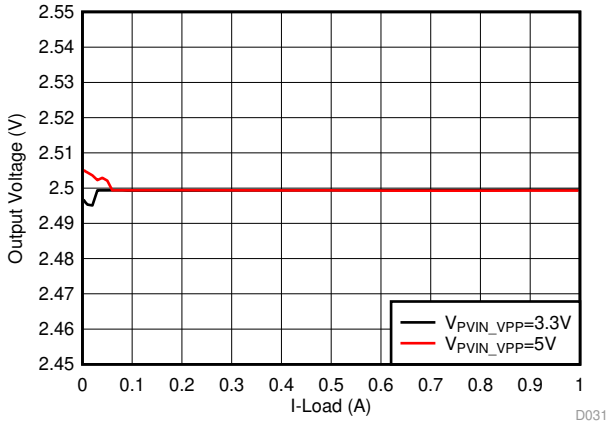

Figure 35. VPP Load Regulation, V_{OUT} = 2.5 V

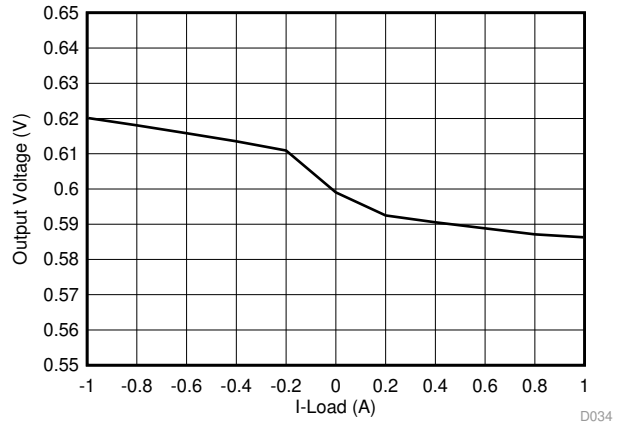

Figure 36. VTT Load Regulation, V_{OUT} = 0.6 V

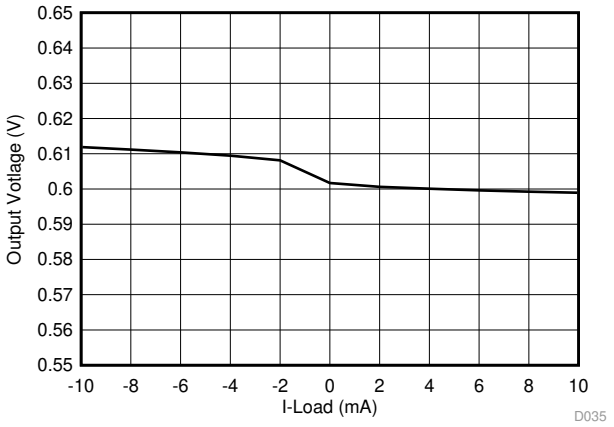

Figure 37. VTTREF Load Regulation, V_{OUT} = 0.6 V

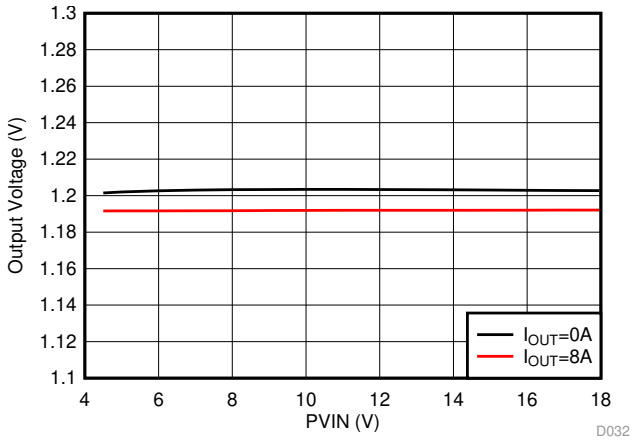

Figure 38. VDDQ Line Regulation,V_{OUT} = 1.2 V

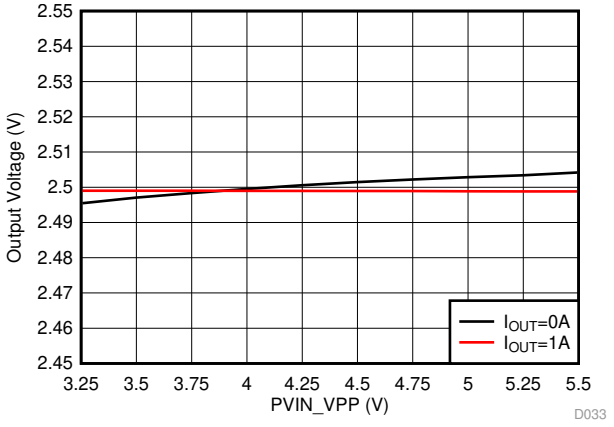

Figure 39. VPP Line Regulation, V_{OUT} = 2.5 V

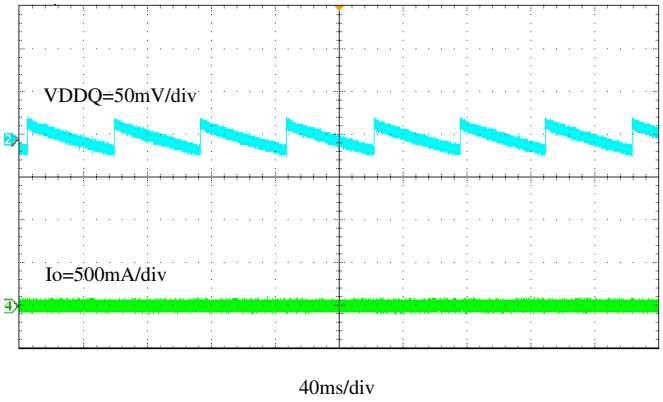

Figure 40. VDDQ Output Voltage Ripple, I_{OUT} = 0 A

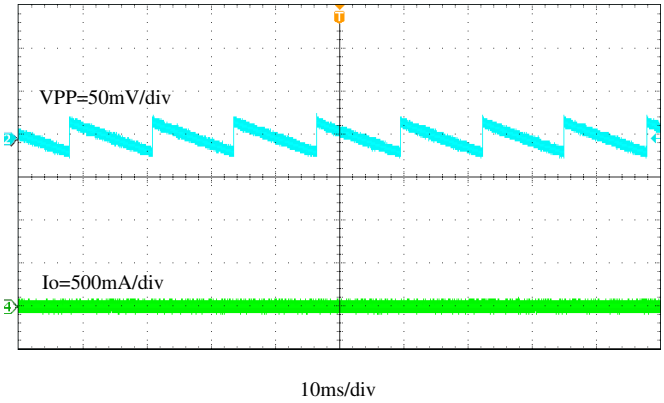

Figure 41. VPP Output Voltage Ripple, I_{OUT} = 0 A

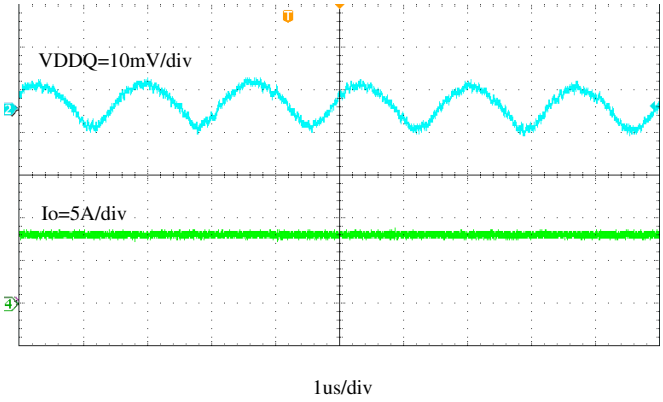

Figure 42. VDDQ Output Voltage Ripple, I_{OUT} = 8 A

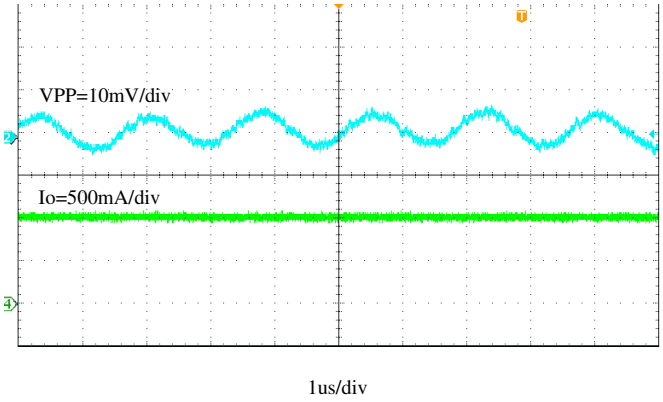

Figure 43. VPP Output Voltage Ripple, I_{OUT} = 1 A

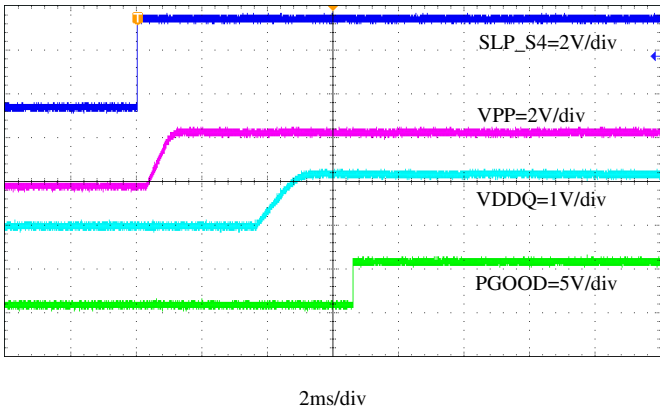

Figure 44. Start-Up Through SLP_S4, I_{VPPOUT} = 0 A, $I_{VDDQOUT}$ = 0 A

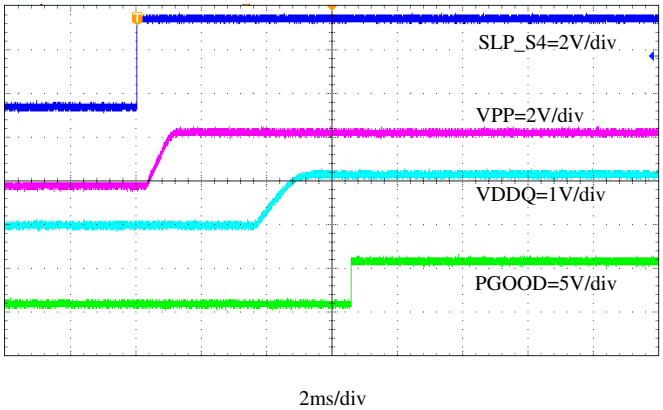

Figure 45. Start-Up Through SLP_S4, I_{VPPOUT} = 1 A, $I_{VDDQOUT}$ = 8 A

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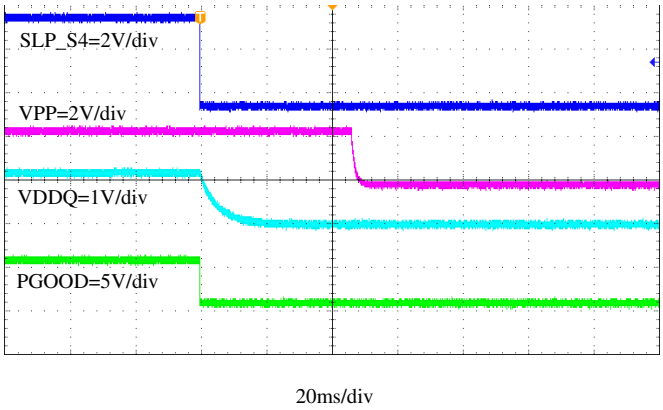


Figure 46. Shutdown Through SLP_S4, I_{VPPOUT} = 0 A, $I_{VDDQOUT}$ = 0 A

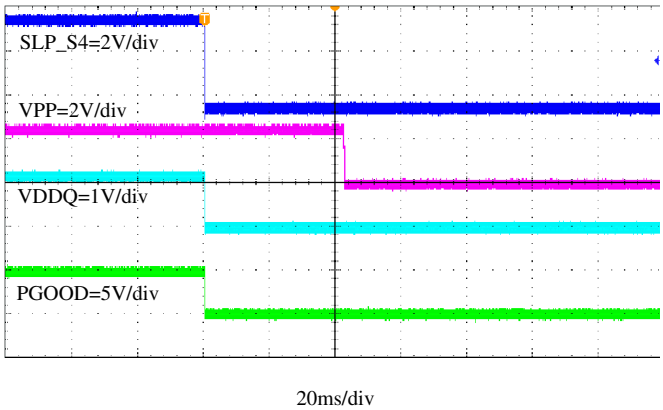
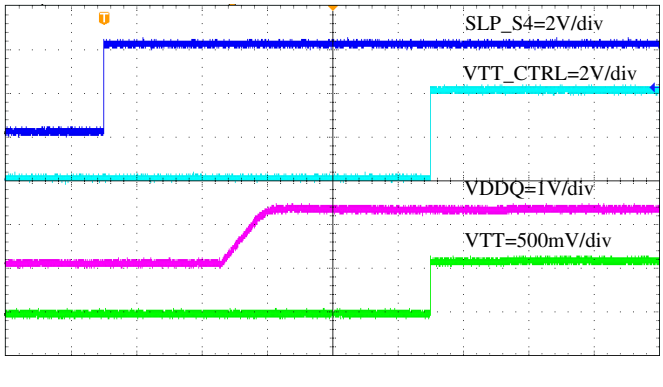
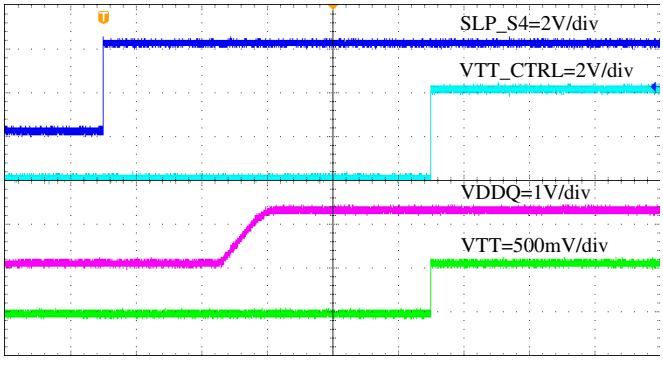


Figure 47. Shutdown Through SLP_S4, I_{VPPOUT} = 1 A, $I_{VDDQOUT}$ = 8 A



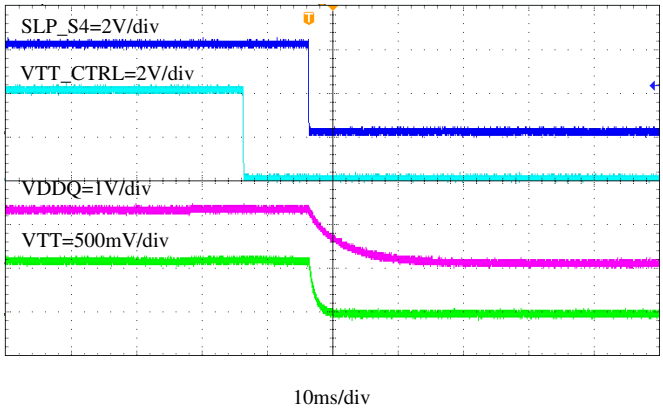
$I_{VDDQOUT}$ = 0 A I_{VTT} = 0 A I_{VTTREF} = 0 A

Figure 48. VTT Start-Up Through VTT_CNTL



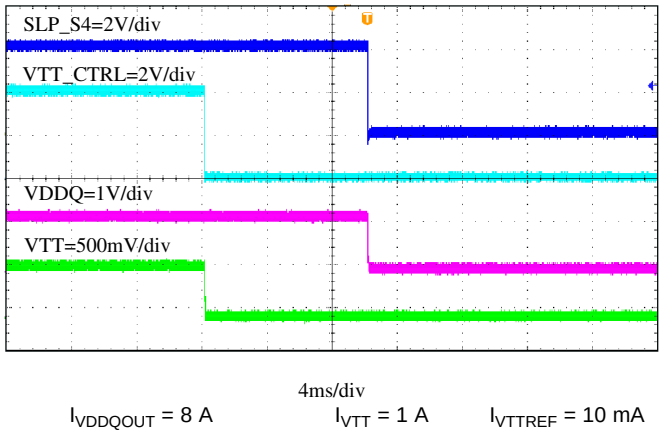
$I_{VDDQOUT}$ = 8 A I_{VTT} = 1 A I_{VTTREF} = 10m A

Figure 49. VTT Start-Up Through VTT_CNTL



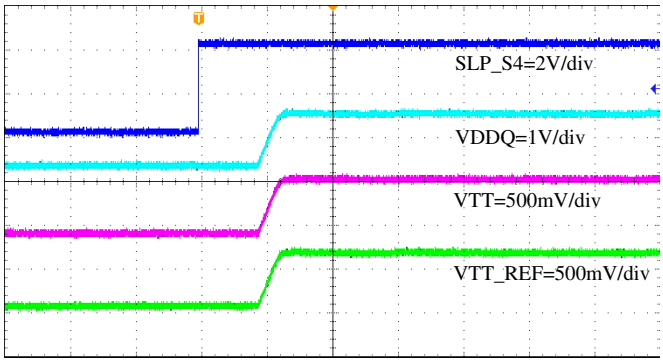
$I_{VDDQOUT}$ = 0 A I_{VTT} = 0 A I_{VTTREF} = 0 A

Figure 50. VTT Shutdown Through VTT_CNTL



$I_{VDDQOUT}$ = 8 A I_{VTT} = 1 A I_{VTTREF} = 10 mA

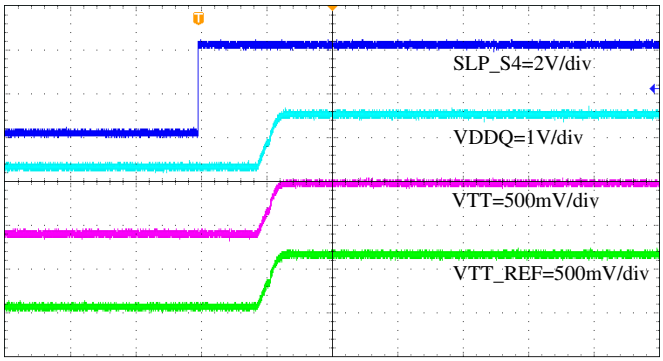
Figure 51. VTT Shutdown Through VTT_CNTL



4ms/div

$I_{VDDQOUT}$ = 0 A I_{VTT} = 0 A I_{VTTREF} = 0 A

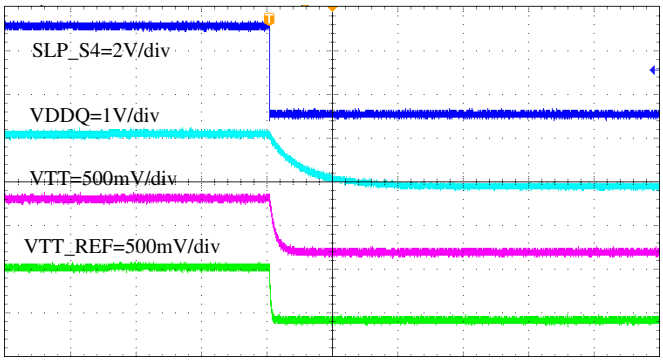
Figure 52. VTT Start-Up Through SLP_S4



4ms/div

$I_{VDDQOUT}$ = 8 A I_{VTT} = 1 A I_{VTTREF} = 10 mA

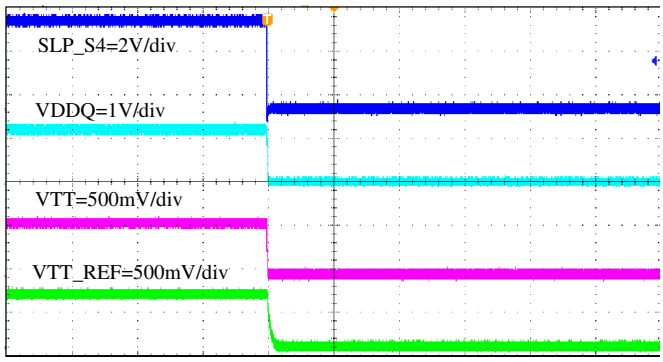
Figure 53. VTT Start-Up Through SLP_S4



10ms/div

$I_{VDDQOUT}$ = 0 A I_{VTT} = 0 A I_{VTTREF} = 0 A

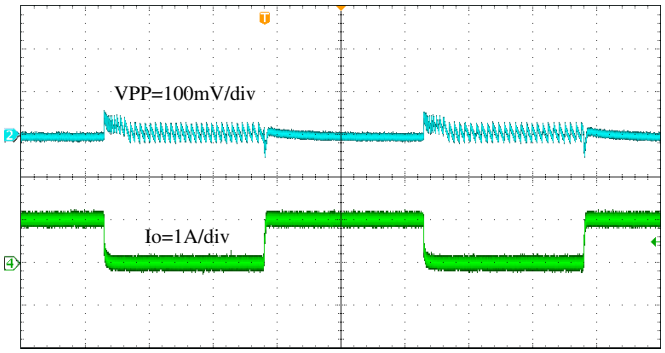
Figure 54. VTT Shutdown Through SLP_S4



4ms/div

$I_{VDDQOUT}$ = 8 A I_{VTT} = 1 A I_{VTTREF} = 10 mA

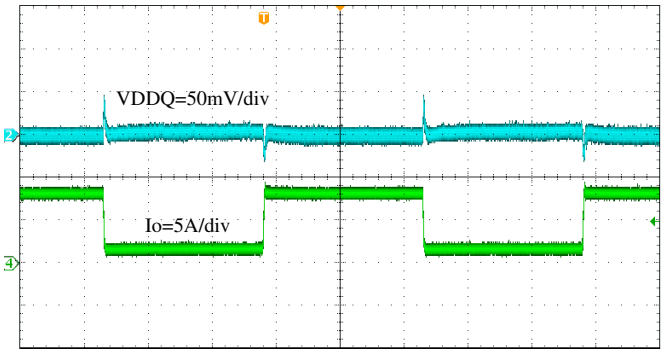
Figure 55. VTT Shutdown Through SLP_S4



400us/div

Slew Rate=2.5A/us

Figure 56. VPP Transient Response, 0 A to 1 A



400us/div

Slew Rate=2.5A/us

Figure 57. VDDQ Transient Response, 1.6 A to 8 A

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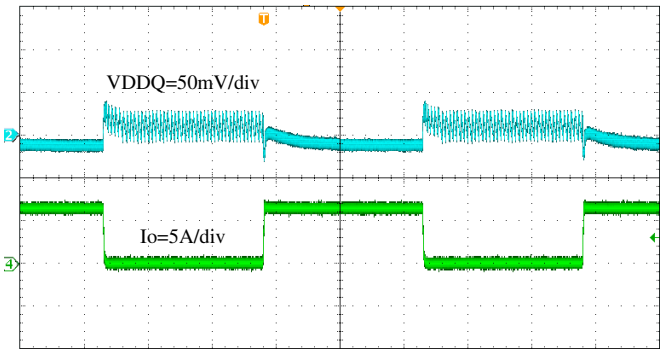
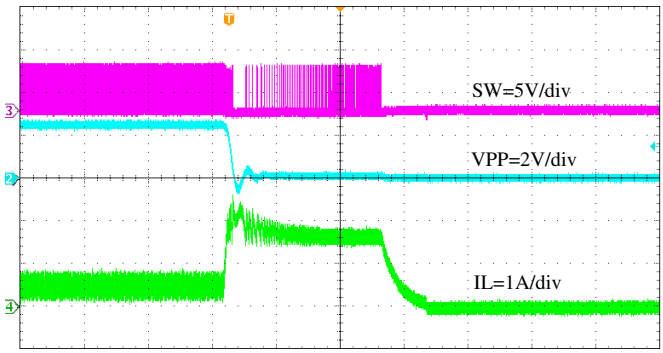


400us/div

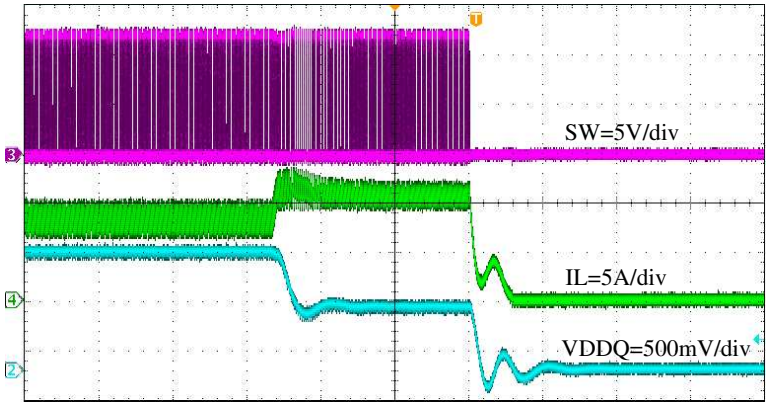
Slew Rate=2.5A/us

Figure 58. VDDQ Transient Response, 0.1 A to 6.4 A



100us/div

Figure 59. VPP Normal Operation to Output Hard Short



100us/div

Figure 60. VDDQ Normal Operation to Output Hard Short

9 Power Supply Recommendations

TPS65295 is designed for DDR4 complete power solution. PVIN is the power input for VDDQ buck, PVIN_VPP is the power input for VPP buck, VLDOIN input is for VTT LDO power supply, VCC_5V is power supply for internal control logic. Below lists the power on sequence scenarios.

- SLP_S4 is high before PVIN or PVIN_VPP has the power input, VCC_5V power supply must be provided after or same time with PVIN or PVIN_VPP, otherwise the output will be latched, this latch can be recovered by toggling the SLP_S4 pin or re-power the VCC_5V
- SLP_S4 is low before PVIN and PVIN_VPP has the power input, then there is no power supply input sequence requirement for VCC_5V, PVIN and PVIN_VPP.

10 Layout

10.1 Layout Guidelines

- Recommend a four-layer PCB for good thermal performance and with maximum ground plane. 3-inch × 3-inch, four-layer PCB with 2-oz. copper used as example.
- Place the decoupling capacitors right across PVIN, PVIN_VPP, and VLDOIN as close as possible.
- Place output inductors and capacitors with IC at the same layer, SW routing should be as short as possible to minimize EMI, and should be a width plane to carry big current, enough vias should be added to the PGND connection of output capacitor and also as close to the output pin as possible. Reserve some space between VDDQ choke and VPP choke, just minimize radiation crosstalk.
- Place BST resistor and capacitor with IC at the same layer, close to BST and SW plane, >15 mil width trace is recommended to reduce line parasitic inductance.
- VPPSNS/VDDQSNS/VTTSNS could be 10 mil and must be routed away from the switching node, BST node or other high efficiency signal.
- PVIN and PVIN_VPP trace must be wide to reduce the trace impedance and provide enough current capability.
- Output capacitors for VTT and VTTREF should be put as close as output pin.

10.2 Layout Example

Figure 61 shows the recommended top-side layout. Component reference designators are the same as the circuit shown in Figure 31.

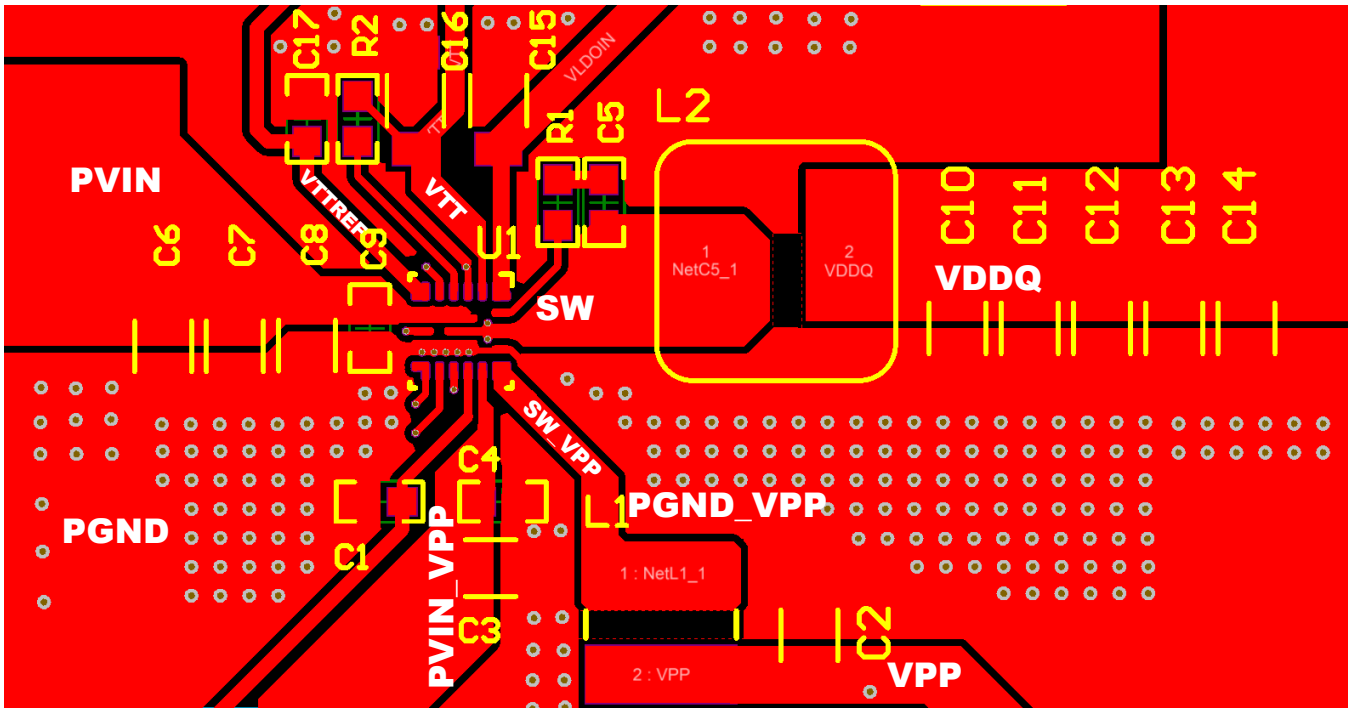


Figure 61. Top-Side Layout

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11 Device and Documentation Support

11.1 Device Support

11.1.1 Third-Party Products Disclaimer

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

11.3 Community 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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11.4 Trademarks

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11.5 Electrostatic Discharge Caution

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

11.6 Glossary

SLYZ022 — *TI Glossary*.

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

12 Mechanical, Packaging, and Orderable Information

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

12.1 Package Option Addendum

12.1.1 Packaging Information

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish(3)	MSL Peak Temp (4)	Op Temp (°C)	Device Marking(5)(6)
TPS65295RJER	PRE_PROD	VQFN-HR	RJE	18	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJET	PRE_PROD	VQFN-HR	RJE	18	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	65295

(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.
PRE_PROD Unannounced device, not in production, not available for mass market, nor on the web, samples not available.
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) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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

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

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

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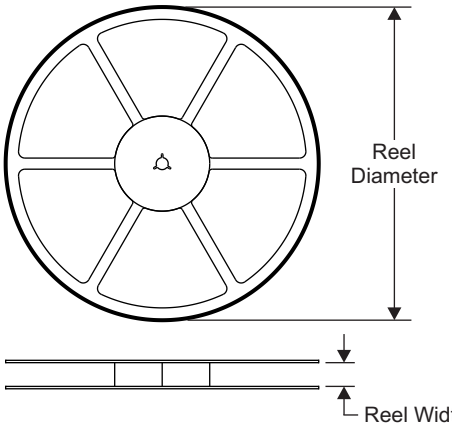
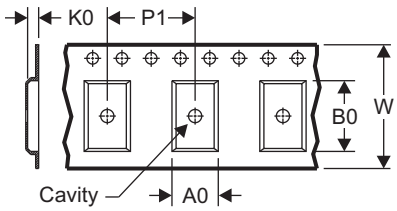
12.1.2 Tape and Reel Information

REEL DIMENSIONS

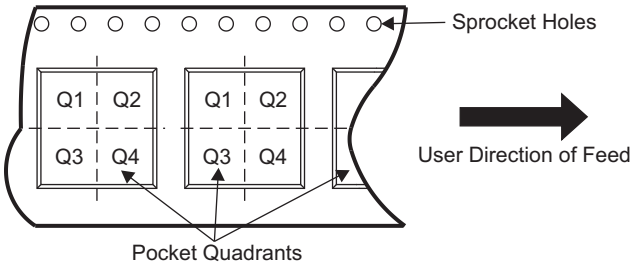


TAPE DIMENSIONS



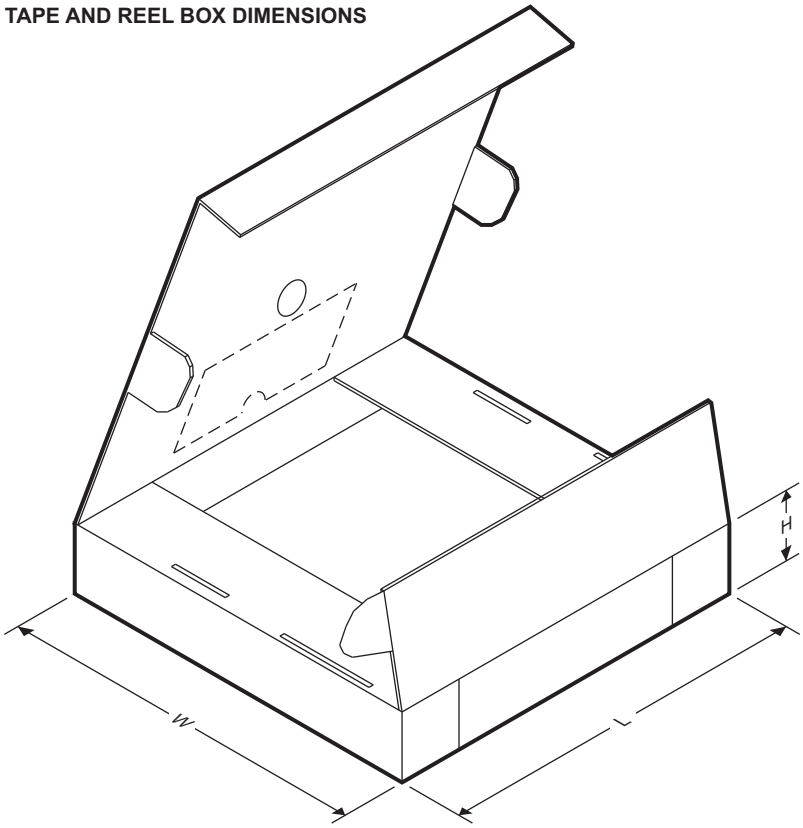
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



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
TPS65295RJER	VQFN-HR	RJE	18	3000	330	12.4	3.3	3.3	1.1	8	12	Q2
TPS65295RJET	VQFN-HR	RJE	18	250	180	12.4	3.3	3.3	1.1	8	12	Q2

TAPE AND REEL BOX DIMENSIONS



Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS65295RJER	VQFN-HR	RJE	18	3000	367	367	35
TPS65295RJET	VQFN-HR	RJE	18	250	210	185	35

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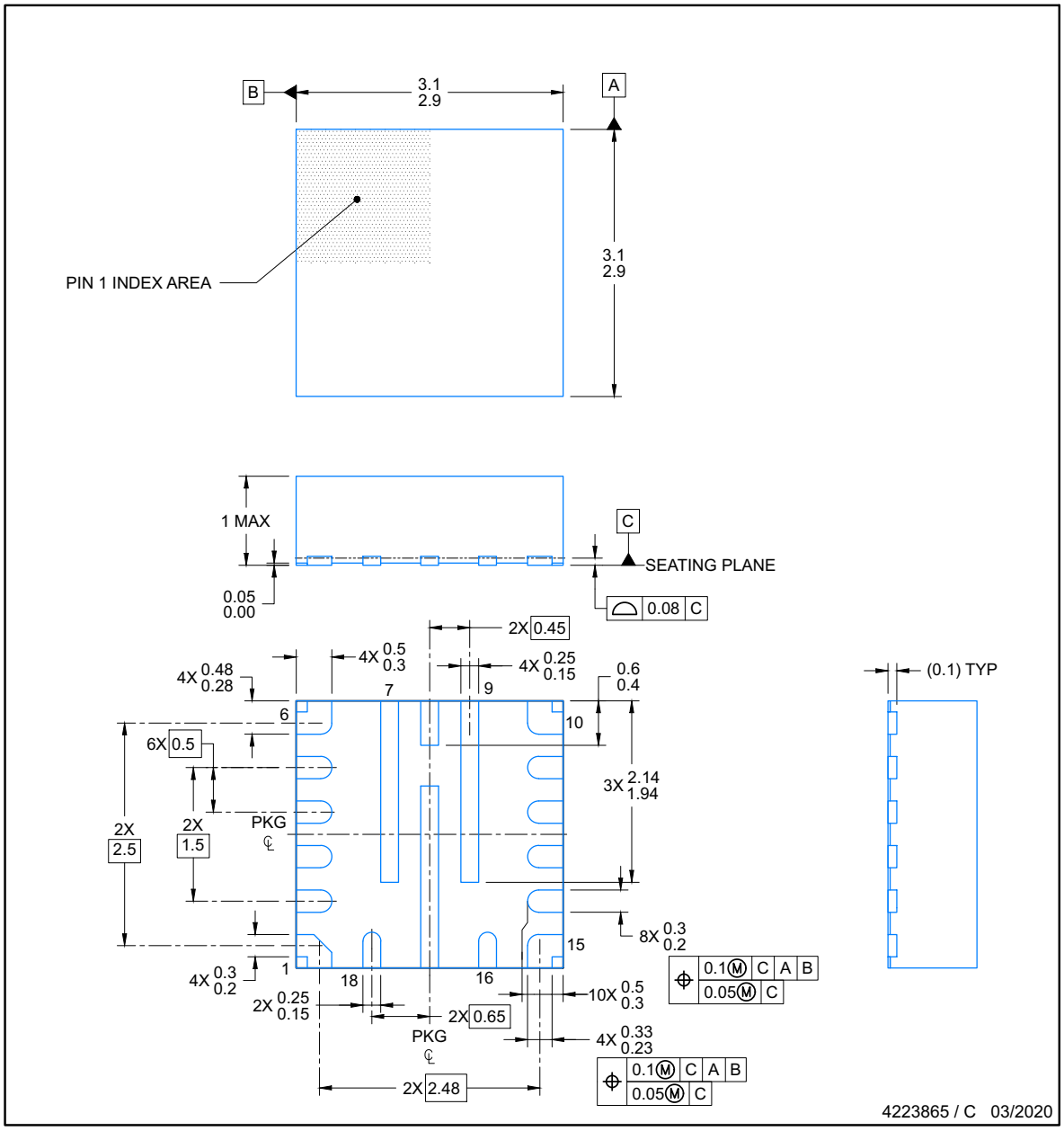
PACKAGE OUTLINE

RJE0018B

VQFN-HR - 1 mm max height

PLASTIC QUAD FLATPACK- NO LEAD



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.

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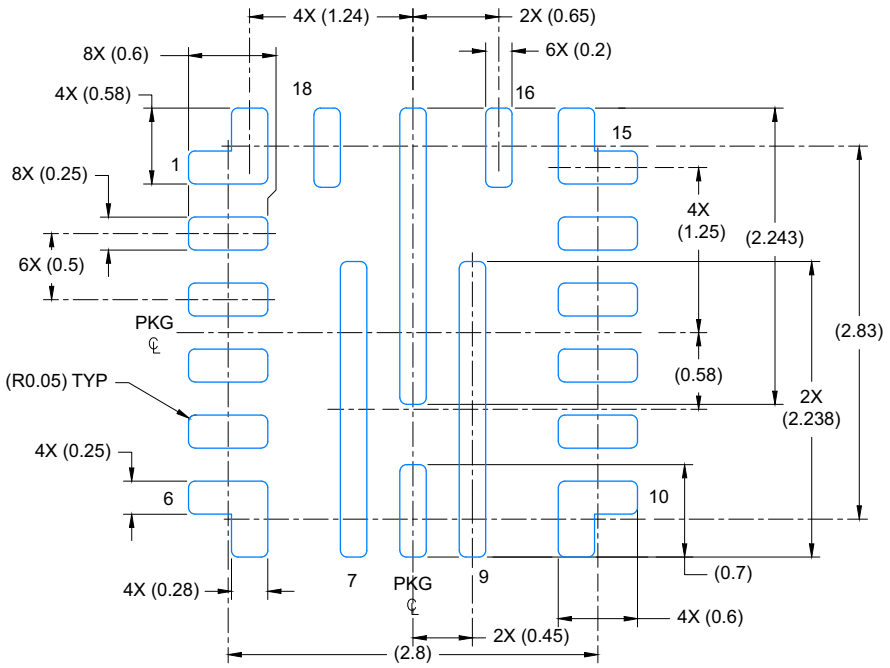
EXAMPLE BOARD LAYOUT

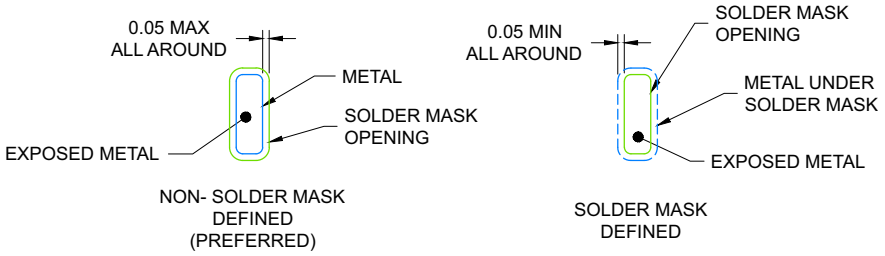
RJE0018B

VQFN-HR - 1 mm max height

PLASTIC QUAD FLATPACK- NO LEAD



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 20X



SOLDER MASK DETAILS

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NOTES: (continued)

3. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271) .
4. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

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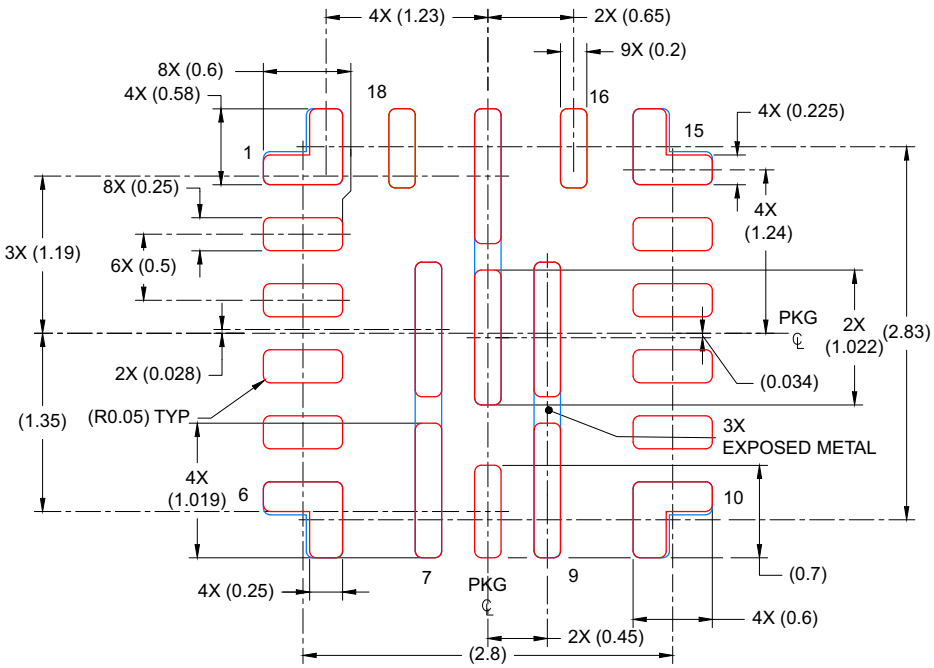
EXAMPLE STENCIL DESIGN

RJE0018B

VQFN-HR - 1 mm max height

PLASTIC QUAD FLATPACK- NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL

PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
PADS 1, 6, 10 &15: 93% & PADS 7-9,17:89%
SCALE: 20X

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NOTES: (continued)

5. 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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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)
TPS65295RJER	Active	Production	VQFN-HR (RJE) | 18	3000 | LARGE T&R	Yes	Call TI | Sn	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJER.A	Active	Production	VQFN-HR (RJE) | 18	3000 | LARGE T&R	Yes	Call TI	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJER.B	Active	Production	VQFN-HR (RJE) | 18	3000 | LARGE T&R	Yes	Call TI	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJET	Active	Production	VQFN-HR (RJE) | 18	250 | SMALL T&R	Yes	Call TI | Sn	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJET.A	Active	Production	VQFN-HR (RJE) | 18	250 | SMALL T&R	Yes	SN	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJETG4	Active	Production	VQFN-HR (RJE) | 18	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	65295
TPS65295RJETG4.A	Active	Production	VQFN-HR (RJE) | 18	250 | SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	65295

(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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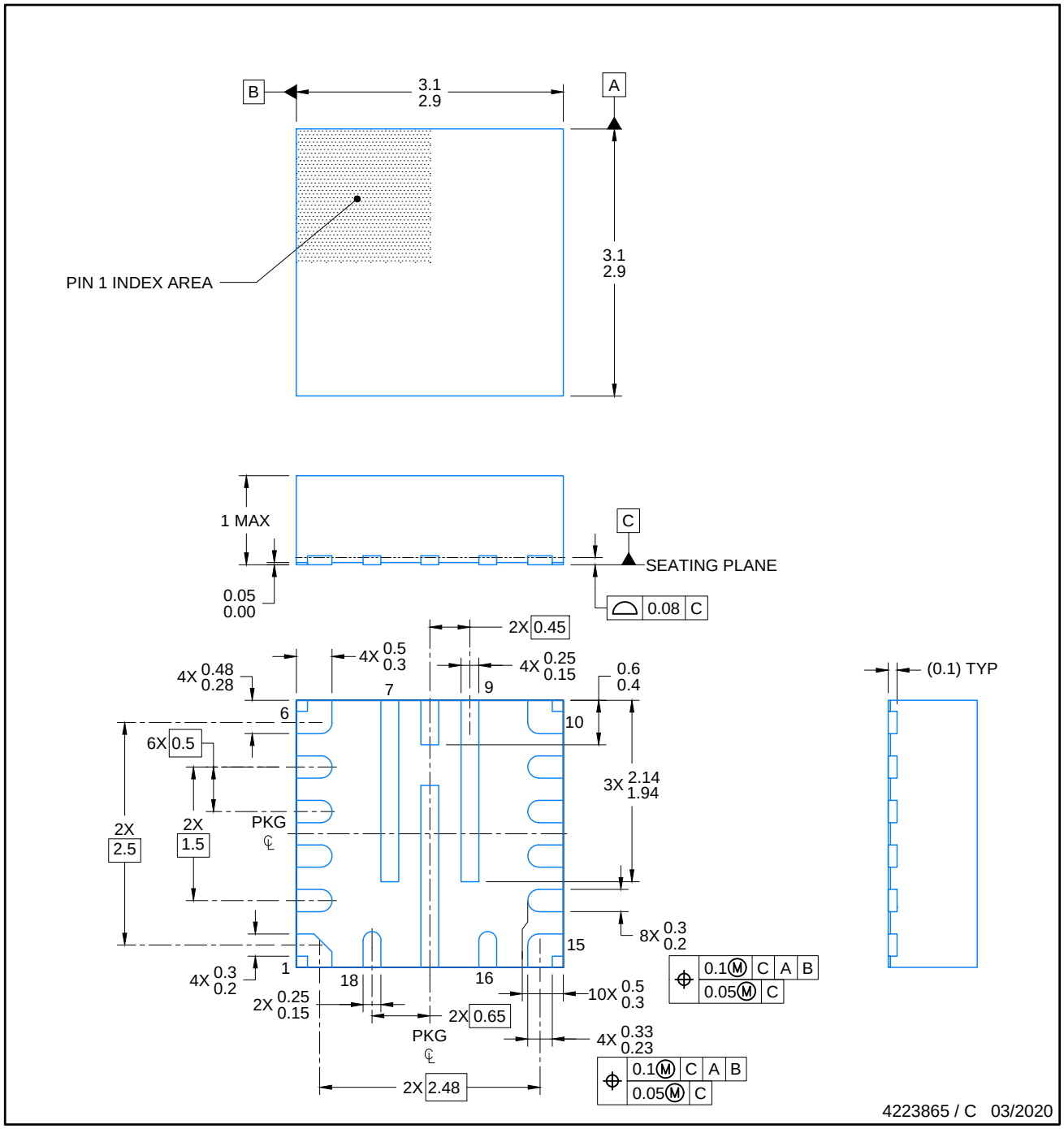
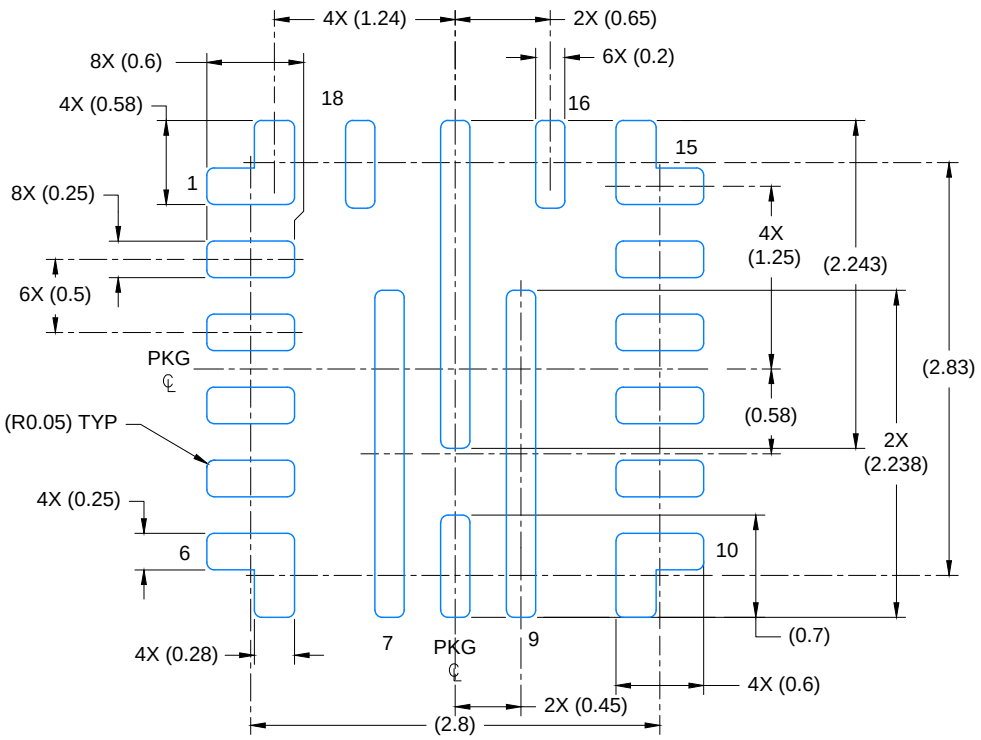
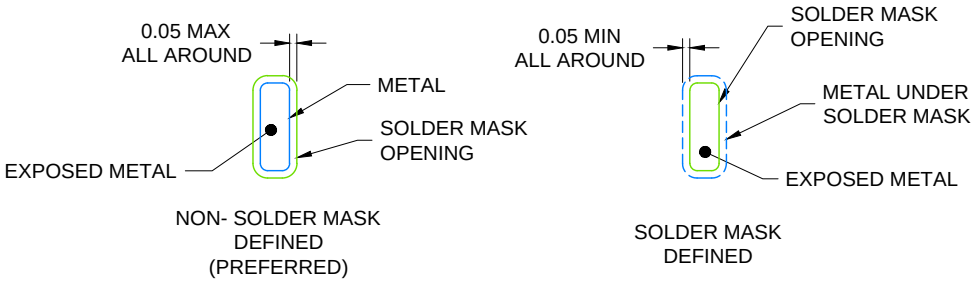


NOTES:

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.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 20X



SOLDER MASK DETAILS

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NOTES: (continued)

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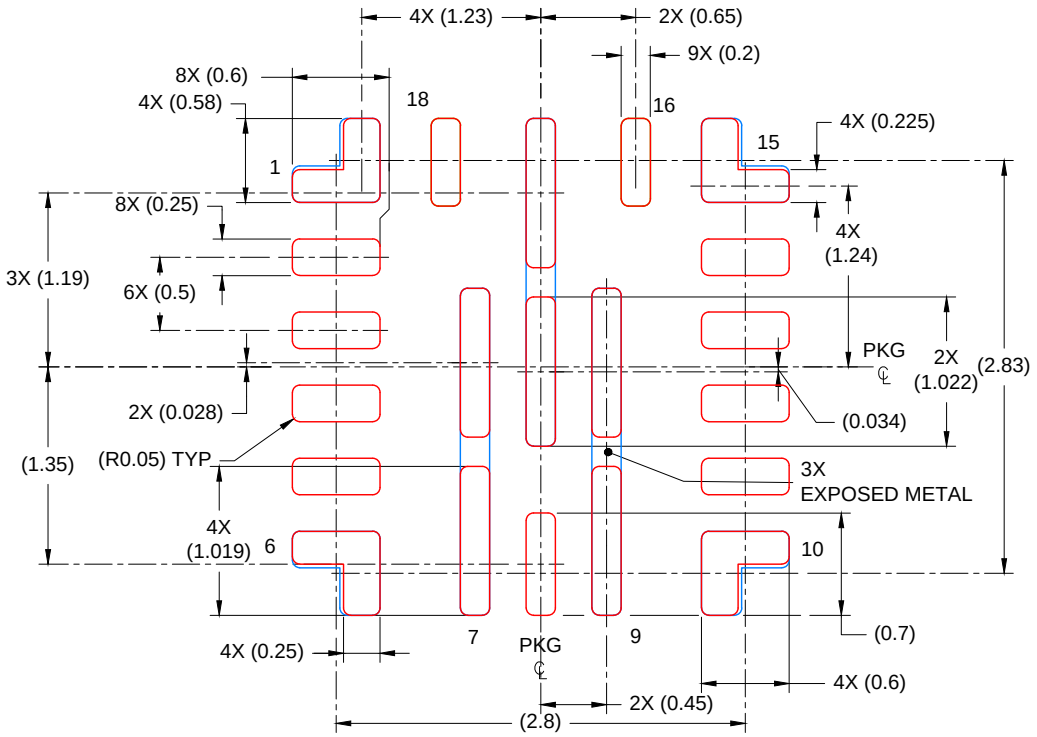

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