

# TPS650250 Power Management IC for Li-Ion Powered Systems

## 1 Features

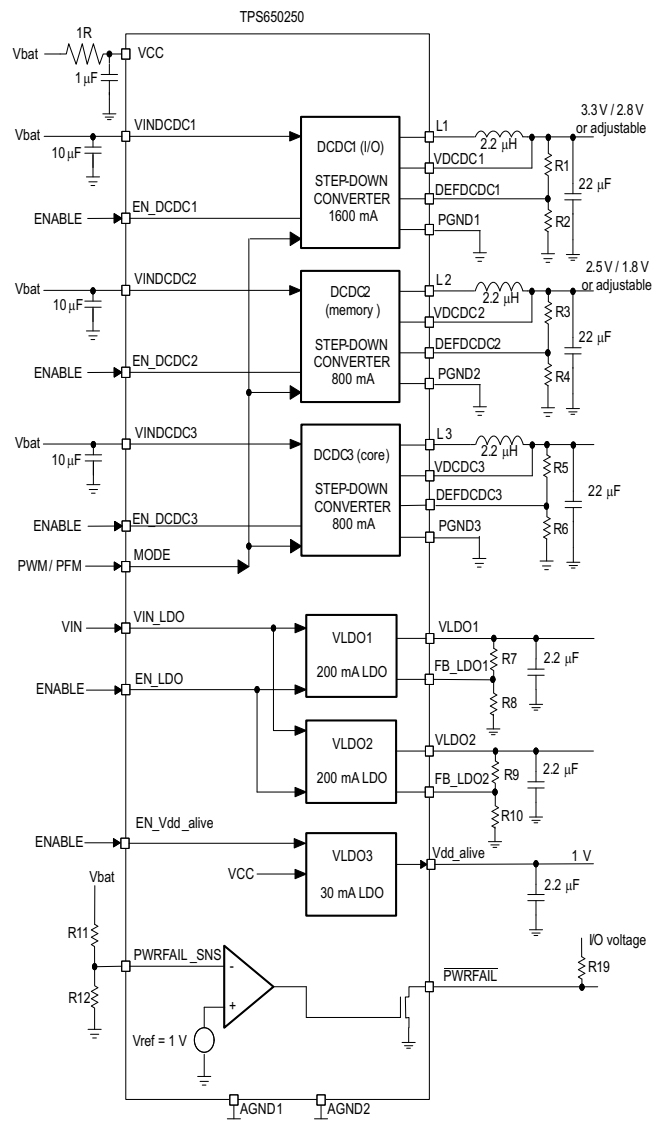
- 1.6 A, 97% Efficient Step-Down Converter for System Voltage (VDCDC1)
  - 3.3 V, 2.8 V, or Adjustable
- 0.8 A, up to 95% Efficient Step-Down Converter for Memory Voltage (VDCDC2)
  - 1.8 V, 2.5 V, or Adjustable
- 0.8 A, 90% Efficient Step-Down Converter for Processor Core (VDCDC3)
- Adjustable Output Voltage on VDCDC3
- 30-mA LDO for Vdd\_alive
- 2 × 200 mA General-Purpose LDOs (LDO1 and LDO2)
- Dynamic Voltage Management for Processor Core
- LDO1 and LDO2 Voltage Externally Adjustable
- Separate Enable Pins for Inductive Converters
- 2.25-MHz Switching Frequency
- 85- $\mu$ A Quiescent Current
- Thermal Shutdown Protection

## 2 Applications

- Cellular, Smart Phones
- GPS
- Digital Still Cameras
- Split Supply DSP and  $\mu$ P Solutions
- Samsung ARM-Based Processors

## 3 Description

The TPS650250 device is an integrated Power Management IC for applications powered by one Li-Ion or Li-Polymer cell, which require multiple power rails. The TPS650250 provides three highly efficient, step-down converters targeted at providing the core voltage, peripheral, I/O and memory rails in a processor-based system. All three step-down converters enter a low-power mode at light load for maximum efficiency across the widest possible range of load currents. The converters can be forced into fixed frequency PWM mode by pulling the MODE pin high.



### Device Information<sup>(1)</sup>

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS650250	VQFN (32)	5.00 mm x 5.00 mm

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



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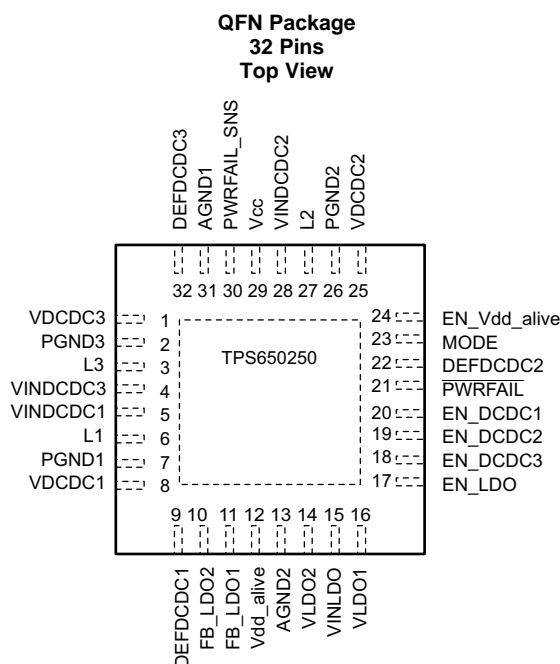
## 4 Revision History

Changes from Original (December 2008) to Revision A	Page
<ul style="list-style-type: none"> <li>• Added <i>Handling Rating</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i>, <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section.....</li> </ul>	1

## 5 Description (continued)

The TPS650250 also integrates two general-purpose 200-mA LDO voltage regulators, which are enabled with an external input pin. Both LDOs operate with an input voltage range from 1.5 V to 6.5 V, allowing them to be supplied from one of the step-down converters or directly from the battery. The output voltage of the LDOs can be set with an external resistor divider for maximum flexibility. Additionally, a 30-mA LDO is typically used to provide power in a processor-based system to a voltage rail that is always on. TPS650250 comes in a small 5-mm x 5-mm 32-pin QFN package (RHB).

## 6 Pin Configuration and Functions



### Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
<b>SWITCHING REGULATOR SECTION</b>			
AGND1	31		Analog ground connection. All analog ground pins are connected internally on the chip.
AGND2	13		Analog ground connection. All analog ground pins are connected internally on the chip.
PowerPad	–		Connect the power pad to analog ground.
VINDCDC1	5	I	Input voltage for VDCDC1 step-down converter. This must be connected to the same voltage supply as VINDCDC2, VINDCDC3 and VCC.
L1	6		Switch pin of VDCDC1 converter. The VDCDC1 inductor is connected here.
VDCDC1	8	I	VDCDC1 feedback voltage sense input, connect directly to VDCDC1.
PGND1	7		Power ground for VDCDC1 converter.
VINDCDC2	28	I	Input voltage for VDCDC2 step-down converter. This must be connected to the same voltage supply as VINDCDC1, VINDCDC3 and VCC.
L2	27		Switch pin of VDCDC2 converter. The VDCDC2 inductor is connected here.
VDCDC2	25	I	VDCDC2 feedback voltage sense input, connect directly to VDCDC2.
PGND2	26		Power ground for VDCDC2 converter.
VINDCDC3	4	I	Input voltage for VDCDC3 step-down converter. This must be connected to the same voltage supply as VINDCDC1, VINDCDC2 and VCC.
L3	3		Switch pin of VDCDC3 converter. The VDCDC3 inductor is connected here.
VDCDC3	1	I	VDCDC3 feedback voltage sense input, connect directly to VDCDC3.

## Pin Functions (continued)

PIN		I/O	DESCRIPTION
NAME	NO.		
PGND3	2		Power ground for VDCDC3 converter.
Vcc	29	I	Power supply for digital and analog circuitry of DCDC1, DCDC2 and DCDC3 DC-DC converters. This must be connected to the same voltage supply as VINDCDC3, VINDCDC1 and VINDCDC2.
DEFDCDC1	9	I	Input signal indicating default VDCDC1 voltage, 0 = 2.8V, 1 = 3.3V . This pin can also be connected to a resistor divider between VDCDC1 and GND. In this case the output voltage of the DCDC1 converter can be set in a range from 0.6V to VINDCDC1.
DEFDCDC2	22	I	Input signal indicating default VDCDC2 voltage, 0 = 1.8V, 1 = 2.5V . This pin can also be connected to a resistor divider between VDCDC2 and GND. In this case the output voltage of the DCDC2 converter can be set in a range from 0.6V to VINDCDC2.
DEFDCDC3	32	I	This pin must be connected to a resistor divider between VDCDC3 and GND. The output voltage of the DCDC3 converter can be set in a range from 0.6V to VINDCDC3.
EN_DCDC1	20	I	VDCDC1 enable pin. A logic high enables the regulator, a logic low disables the regulator.
EN_DCDC2	19	I	VDCDC2 enable pin. A logic high enables the regulator, a logic low disables the regulator.
EN_DCDC3	18	I	VDCDC3 enable pin. A logic high enables the regulator, a logic low disables the regulator.
<b>LDO REGULATOR SECTION</b>			
VINLDO	15	I	Input voltage for LDO1 and LDO2.
VLDO1	16	O	Output voltage of LDO1.
VLDO2	14	O	Output voltage of LDO2.
EN_LDO	17	I	Enable input for LDO1 and LDO2. Logic high enables the LDOs, logic low disables the LDOs.
EN_Vdd_alive	24	I	Enable input for Vdd_alive LDO. Logic high enables the LDO, logic low disables the LDO.
Vdd_alive	12	O	Output voltage for Vdd_alive.
FB_LDO1	11	I	Feedback pin for LDO1.
FB_LDO2	10	I	Feedback pin for LDO2.
<b>CONTROL AND I2C SECTION</b>			
MODE	23	I	Select between Power Safe Mode and forced PWM Mode for DCDC1, DCDC2 and DCDC3. In Power Safe Mode PFM is used at light loads, PWM for higher loads. If PIN is set to high level, forced PWM Mode is selected. If Pin has low level, then Device operates in Power Safe Mode.
PWRFAIL	21	O	Open drain output. Active low when PWRFAIL comparator indicates low VBAT condition.
PWRFAIL_SNS	30	I	Input for the comparator driving the /PWRFAIL output.

## 7 Specifications

### 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) <sup>(1)</sup>

	MIN	MAX	UNIT
Input voltage range on all pins except A/PGND pins with respect to AGND	-0.3	7	V
Voltage range on pins VLDO1, VLDO2, FB_LDO1, FB_LDO2	-0.3	3.6	V
Current at VINDCDC1, L1, PGND1, VINDCDC2, L2, PGND2, VINDCDC3, L3, PGND3	2000	2000	mA
Peak current at all other pins	500	500	mA
Continuous total power dissipation	See <a href="#">Dissipation Ratings</a>		
T <sub>A</sub> Operating free-air temperature	-40	85	°C
T <sub>J</sub> Maximum junction temperature	125	125	°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.

## 7.2 Handling Ratings

		MIN	MAX	UNIT
$T_{stg}$	Storage temperature range	-65	150	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup>		V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins <sup>(2)</sup>		

(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.

## 7.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
$V_{CC}$	Input voltage range step-down converters, VINDCDC1, VINDCDC2, VINDCDC3	2.5		6.0	V
$V_O$	Output voltage range for step-down converter, VDCDC1 <sup>(1)</sup>	0.6		VINDCDC1	V
	Output voltage range for mem step-down converter, VDCDC2 <sup>(1)</sup>	0.6		VINDCDC2	V
	Output voltage range for core step-down converter, VDCDC3	0.6		VINDCDC3	V
$V_I$	Input voltage range for LDOs, VINLDO1, VINLDO2	1.5		6.5	V
$V_O$	Output voltage range for LDOs	1		3.3	V
$I_O$	Output current at L, V1DCDC1			1600	mA
L1	Inductor at L1 <sup>(2)</sup>	1.5	2.2		μH
$C_I$	Input capacitor at VINDCDC1 <sup>(2)</sup>	10			μF
$C_O$	Output capacitor at VDCDC1 <sup>(2)</sup>	10	22		μF
$I_O$	Output current at L2, VDCDC2			800	mA
L2	Inductor at L2 <sup>(2)</sup>	1.5	2.2		μH
$C_I$	Input capacitor at VINDCDC2 <sup>(2)</sup>	10			μF
$C_O$	Output capacitor at VDCDC2 <sup>(2)</sup>	10	22		μF
$I_O$	Output current at L3, VDCDC3			800	mA
L3	Inductor at L3 <sup>(2)</sup>	1.5	2.2		μH
$C_I$	Input capacitor at VINDCDC3 <sup>(2)</sup>	10			μF
$C_O$	Output capacitor at VDCDC3 <sup>(2)</sup>	10	22		μF
$C_I$	Input capacitor at VCC <sup>(2)</sup>	1			μF
$C_I$	Input capacitor at VINLDO <sup>(2)</sup>	1			μF
$C_O$	Output capacitor at VLDO1, VLDO2 <sup>(2)</sup>	2.2			μF
$I_O$	Output current at VLDO1, VLDO2			200	mA
$C_O$	Output capacitor at Vdd_alive <sup>(2)</sup>	2.2			μF
$I_O$	Output current at Vdd_alive			30	mA
$T_A$	Operating ambient temperature	-40		85	°C
$T_J$	Operating junction temperature	-40		125	°C
$R_{CC}$	Resistor from VINDCDC3, VINDCDC2, VINDCDC1 to $V_{CC}$ used for filtering <sup>(3)</sup>		1	10	Ω

(1) When using an external resistor divider at DEFDCDC2, DEFDCDC1.

(2) See applications section for more information, for  $V_O > 2.85V$  choose 3.3μH inductor.

(3) Up to 2.5mA can flow into  $V_{CC}$  when all 3 converters are running in PWM, this resistor will cause the UVLO threshold to be shifted accordingly.

### 7.4 Thermal Information

THERMAL METRIC <sup>(1)</sup>		TPS650250	
		QFN	UNIT
		32 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	31.8	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	21.8	
R <sub>θJB</sub>	Junction-to-board thermal resistance	5.8	
ψ <sub>JT</sub>	Junction-to-top characterization parameter	0.2	
ψ <sub>JB</sub>	Junction-to-board characterization parameter	5.7	
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	1.3	

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

### 7.5 Dissipation Ratings

PACKAGE <sup>(1)</sup>	R <sub>θJA</sub>	T <sub>A</sub> ≤ 25°C POWER RATING	DERATING FACTOR ABOVE T <sub>A</sub> = 25°C	T <sub>A</sub> = 70°C POWER RATING	T <sub>A</sub> = 85°C POWER RATING
RHB	35 K/W	2.85 W	28m W/K	1.57 W	1.14 W

(1) The thermal resistance junction to ambient of the RHB package is measured on a high K board. The thermal resistance junction to power pad is 1.5k/W.

### 7.6 Electrical Characteristics

V<sub>INDCDC1</sub> = V<sub>INDCDC2</sub> = V<sub>INDCDC3</sub> = V<sub>CC</sub> = V<sub>INLDO</sub> = 3.6V, T<sub>A</sub> = -40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>CONTROL SIGNALS: EN_DCDC1, EN_DCDC2, EN_DCDC3, EN_LDO, MODE, EN_VDD_ALIVE</b>						
V <sub>IH</sub>	High level input voltage		1.45		V <sub>CC</sub>	V
V <sub>IL</sub>	Low level input voltage		0		0.4	V
I <sub>H</sub>	Input bias current			0.01	0.1	µA
<b>SUPPLY PINS: V<sub>CC</sub>, V<sub>INDCDC1</sub>, V<sub>INDCDC2</sub>, V<sub>INDCDC3</sub></b>						
I <sub>(qPFM)</sub>	Operating quiescent current	PFM All 3 DCDC converters enabled, zero load and no switching, LDOs enabled	V <sub>CC</sub> = 3.6V	135	170	µA
		PFM All 3 DCDC converters enabled, zero load and no switching, LDO1, LDO2 = OFF, V <sub>dd_alive</sub> = ON		75	100	
		PFM DCDC1 and DCDC2 converters enabled, zero load and no switching, LDO1, LDO2 = OFF, V <sub>dd_alive</sub> = ON		55	80	
		PFM DCDC1 converter enabled, zero load and no switching, LDO1, LDO2 = OFF, V <sub>dd_alive</sub> = ON		40	60	
I <sub>VCC(PWM)</sub>	Current into V <sub>CC</sub> : PWM	All 3 DCDC converters enabled & running in PWM, LDOs off	V <sub>CC</sub> = 3.6V	2		mA
		PWM DCDC1 and DCDC2 converters enabled and running in PWM, LDOs off		1.5	2.5	
		PWM DCDC1 converter enabled and running in PWM, LDOs off		0.85	2	
I <sub>q</sub>	Quiescent current	All converters disabled, LDO1, LDO2 = OFF, V <sub>dd_alive</sub> = OFF	V <sub>CC</sub> = 3.6V	16		µA
		All converters disabled, LDO1, LDO2 = OFF, V <sub>dd_alive</sub> = ON		26		
<b>VLDO1 AND VLDO2 LOW DROPOUT REGULATORS</b>						
I <sub>(q)</sub>	Operating quiescent current	Current per LDO into VINLDO		16	30	µA
I <sub>(SD)</sub>	Shutdown current	Total current into VINLDO, VLDO = 0V		0.6	2	µA

**Electrical Characteristics (continued)**

VINDCDC1 = VINDCDC2 = VINDCDC3 = VCC = VINLDO = 3.6V, T<sub>A</sub> = –40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>I</sub>	Input voltage range for LDO1, LDO2		1.5		6.5	V
V <sub>O</sub>	LDO1 output voltage range		1		3.3	V
	LDO2 output voltage range		1		3.3	V
VFB	LDO1 and LDO2 feedback voltage			1.0		V
I <sub>O</sub>	Maximum output current for LDO1, LDO2	V <sub>I</sub> = 1.8V, V <sub>O</sub> = 1.3V	200			mA
I <sub>O</sub>	Maximum output current for LDO1, LDO2	V <sub>I</sub> = 1.5V; V <sub>O</sub> = 1.3V		120		mA
I <sub>SC</sub>	LDO1 and LDO2 short circuit current limit	V <sub>LDO1</sub> = GND, V <sub>LDO2</sub> = GND			400	mA
	Minimum voltage drop at LDO1, LDO2	I <sub>O</sub> = 50mA, VINLDO = 1.8V			120	mV
	Minimum voltage drop at LDO1, LDO2	I <sub>O</sub> = 50mA, VINLDO = 1.5V		65	150	mV
	Minimum voltage drop at LDO1, LDO2	I <sub>O</sub> = 200mA, VINLDO = 1.8V			300	mV
	Output voltage accuracy for LDO1, LDO2	I <sub>O</sub> = 10mA	–2%		1%	
	Line regulation for LDO1, LDO2	V <sub>INLDO1,2</sub> = V <sub>LDO1,2</sub> + 0.5V (min. 2.5V) to 6.5V, I <sub>O</sub> = 10mA	–1%		1%	
	Load regulation for LDO1, LDO2	I <sub>O</sub> = 0mA to 200mA	–1%		1%	
	Regulation time for LDO1, LDO2	Load change from 10% to 90%		10		μs
<b>VDD_ALIVE LOW DROPOUT REGULATOR</b>						
Vdd_alive	Vdd_alive LDO output voltage, TPS6502500 to TPS6502504	I <sub>O</sub> = 0mA		1.0		V
I <sub>O</sub>	Output current for Vdd_alive				30	mA
I <sub>(SC)</sub>	Vdd_alive short circuit current limit	Vdd_alive = GND			100	mA
	Output voltage accuracy for Vdd_alive	I <sub>O</sub> = 0mA	–1%		1%	
	Line regulation for Vdd_alive	V <sub>CC</sub> = Vdd_alive + 0.5 V to 6.5 V, I <sub>O</sub> = 0mA	–1%		1%	
	Regulation time for Vdd_alive	Load change from 10% to 90%		10		μs
<b>ANALOGIC SIGNALS DEFDCDC1, DEFDCDC2, DEFDCDC3</b>						
V <sub>IH</sub>	High level input voltage		1.3		VCC	V
V <sub>IL</sub>	Low level input voltage		0		0.1	V
I <sub>H</sub>	Input bias current			0.001	0.05	μA

**Electrical Characteristics (continued)**

VINDCDC1 = VINDCDC2 = VINDCDC3 = VCC = VINLDO = 3.6V, T<sub>A</sub> = -40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>THERMAL SHUTDOWN</b>						
T <sub>SD</sub>	Thermal shutdown	Increasing junction temperature		160		°C
	Thermal shutdown hysteresis	Decreasing junction temperature		20		°C
<b>INTERNAL UNDER VOLTAGE LOCK OUT</b>						
UVLO	Internal UVLO	VCC falling	-3%	2.35	3%	V
V <sub>UVLO_HYST</sub>	internal UVLO comparator hysteresis			120		mV
<b>VOLTAGE DETECTOR COMPARATOR</b>						
PWRFAIL_SNS	Comparator threshold	Falling threshold	-2%	1.0	2%	V
	Hysteresis		40	50	60	mV
	Propagation delay	25mV overdrive			10	µs
V <sub>OL</sub>	Power fail output low voltage	I <sub>OL</sub> = 5 mA			0.3	V

**7.7 Electrical Characteristics VDCDC1**

VINDCDC1 = VINDCDC2 = VINDCDC3 = VCC = VINLDO = 3.6V, T<sub>A</sub> = -40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>VDCDC1 STEP-DOWN CONVERTER</b>						
V <sub>I</sub>	Input voltage range, VINDCDC1		2.5		6	V
I <sub>O</sub>	Maximum output current	V <sub>O</sub> = 3.3V	1600			mA
I <sub>SD</sub>	Shutdown supply current in VINDCDC1	EN_DCDC1 = GND		0.1	1	µA
R <sub>DS(on)</sub>	P-channel MOSFET on-resistance	VINDCDC1 = VGS = 3.6V		125	261	mΩ
I <sub>LP</sub>	P-channel leakage current	VINDCDC1 = 6V			2	µA
R <sub>DS(on)</sub>	N-channel MOSFET on-resistance	VINDCDC1 = VGS = 3.6V		130	260	mΩ
I <sub>LN</sub>	N-channel leakage current	V <sub>DS</sub> = 6V		7	10	µA
I <sub>LIMF</sub>	Forward current limit (P- and N-channel)	2.5V < V <sub>INMAIN</sub> < 6V	1.75	1.97	2.15	A
f <sub>S</sub>	Oscillator frequency		1.95	2.25	2.55	MHz
VDCDC1	Fixed output voltage MODE=0 (PWM/PFM)	2.8V	VINDCDC1 = 3.3V to 6V; 0 mA ≤ I <sub>O</sub> ≤ 1.0A			2%
		3.3V				2%
	Fixed output voltage MODE=1 (PWM)	2.8V	VINDCDC1 = 3.7V to 6V; 0 mA ≤ I <sub>O</sub> ≤ 1.0A			1%
		3.3V				1%
	Adjustable output voltage with resistor divider at DEFDCDC1 MODE = 0 (PWM/PFM)	VINDCDC1 = VDCDC1 +0.4V (min 2.5V) to 6V; 0mA ≤ I <sub>O</sub> ≤ 1.6A				2%
	Adjustable output voltage with resistor divider at DEFDCDC1; MODE = 1 (PWM)	VINDCDC1 = VDCDC1 +0.4V (min 2.5V) to 6V; 0mA ≤ I <sub>O</sub> ≤ 1.6A				1%
	Line regulation	VINDCDC1 = VDCDC1 + 0.3V (min. 2.5 V) to 6V; I <sub>O</sub> = 10mA		0		%/V
	Load regulation	I <sub>O</sub> = 10mA to 1.6A		0.25		%/A
t <sub>SS</sub>	Soft start ramp time	VDCDC1 ramping from 5% to 95% of target value		750		µs
R(L1)	Internal resistance from L1 to GND			1		MΩ

## 7.8 Electrical Characteristics VDCDC2

VINDCDC1 = VINDCDC2 = VINDCDC3 = VCC = VINLDO = 3.6V, T<sub>A</sub> = –40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT		
<b>VDCDC2 STEP-DOWN CONVERTER</b>								
V <sub>I</sub>	Input voltage range, VINDCDC2		2.5		6	V		
I <sub>O</sub>	Maximum output current		V <sub>O</sub> = 2.5V		800	mA		
I <sub>SD</sub>	Shutdown supply current in VINDCDC2		EN_DCDC2 = GND		0.1	1	μA	
R <sub>DS(on)</sub>	P-channel MOSFET on-resistance		VINDCDC2 = V <sub>GS</sub> = 3.6V		140	300	mΩ	
I <sub>LP</sub>	P-channel leakage current		VINDCDC2 = 6.0V			2	μA	
R <sub>DS(on)</sub>	N-channel MOSFET on-resistance		VINDCDC2 = V <sub>GS</sub> = 3.6V		150	297	mΩ	
I <sub>LN</sub>	N-channel leakage current		V <sub>DS</sub> = 6V		7	10	μA	
I <sub>LIMF</sub>	Forward current limit (P- and N-channel)		2.5V < VINDCDC2 < 6V		1.05	1.16	1.29	A
f <sub>S</sub>	Oscillator frequency		1.95	2.25	2.55	MHz		
VDCDC2	Fixed output voltage MODE = 0 (PWM/PFM)	1.8V	VINDCDC2 = 2.5V to 6V; 0 mA ≤ I <sub>O</sub> ≤ 1.6A		–2%	2%		
		2.5V	VINDCDC2 = 3V to 6V; 0 mA ≤ I <sub>O</sub> ≤ 1.6A		–2%	2%		
	Fixed output voltage MODE = 1 (PWM)	1.8V	VINDCDC2 = 2.5V to 6V; 0 mA ≤ I <sub>O</sub> ≤ 1.6A		–2%	2%		
		2.5V	VINDCDC2 = 3V to 6V; 0 mA ≤ I <sub>O</sub> ≤ 1.6A		–1%	1%		
	Adjustable output voltage with resistor divider at DEFDCDC2 MODE = 0 (PWM)		VINDCDC2 = VDCDC2 + 0.5V (min 2.5V) to 6V; 0mA ≤ I <sub>O</sub> ≤ 1.6A		–2%	2%		
	Adjustable output voltage with resistor divider at DEFDCDC2; MODE = 1 (PWM)		VINDCDC2 = VDCDC2 + 0.5V (min 2.5V) to 6V; 0mA ≤ I <sub>O</sub> ≤ 1.6A		–1%	1%		
	Line regulation		VINDCDC2 = VDCDC2 + 0.3 V (min. 2.5 V) to 6V; I <sub>O</sub> = 10mA		0.0		%/V	
	Load regulation		I <sub>O</sub> = 10mA to 1.6A		0.25		%/A	
t <sub>SS</sub>	Soft start ramp time		VDCDC2 ramping from 5% to 95% of target value		750		μs	
R(L2)	Internal resistance from L2 to GND				1		MΩ	

## 7.9 Electrical Characteristics VDCDC3

VINDCDC1 = VINDCDC2 = VINDCDC3 = VCC = VINLDO = 3.6V, T<sub>A</sub> = –40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT		
<b>VDCDC3 STEP-DOWN CONVERTER</b>								
V <sub>I</sub>	Input voltage range, VINDCDC3		2.5		6.0	V		
I <sub>O</sub>	Maximum output current		V <sub>O</sub> = 1.6V		800	mA		
I <sub>SD</sub>	Shutdown supply current in VINDCDC3		EN_DCDC3 = GND		0.1	1	μA	
R <sub>DS(on)</sub>	P-channel MOSFET on-resistance		VINDCDC3 = V <sub>GS</sub> = 3.6V		310	698	mΩ	
I <sub>LP</sub>	P-channel leakage current		VINDCDC3 = 6V		0.1	2	μA	
R <sub>DS(on)</sub>	N-channel MOSFET on-resistance		VINDCDC3 = V <sub>GS</sub> = 3.6V		220	503	mΩ	
I <sub>LN</sub>	N-channel leakage current		V <sub>DS</sub> = 6.0V		7	10	μA	
I <sub>LIMF</sub>	Forward current limit (P- and N-channel)		2.5V < VINDCDC3 < 6V		1.00	1.20	1.40	A
f <sub>S</sub>	Oscillator frequency		1.95	2.25	2.55	MHz		
VDCDC3	Adjustable output voltage with resistor divider at DEFDCDC2 MODE = 0 (PWM)		VINDCDC3 = VDCDC3 + 0.5V (min 2.5V) to 6V; 0mA ≤ I <sub>O</sub> ≤ 0.8A		–2%	2%		
	Adjustable output voltage with resistor divider at DEFDCDC2; MODE = 1 (PWM)		VINDCDC3 = VDCDC3 + 0.5V (min 2.5V) to 6V; 0mA ≤ I <sub>O</sub> ≤ 0.8A		–1%	1%		

**Electrical Characteristics VDCDC3 (continued)**

VINDCDC1 = VINDCDC2 = VINDCDC3 = VCC = VINLDO = 3.6V, T<sub>A</sub> = -40°C to 85°C, typical values are at T<sub>A</sub> = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
	Line regulation	VINDCDC3 = VDCDC3 + 0.3V (min. 2.5 V) to 6V; I <sub>O</sub> = 10mA		0.0		%/V
	Load regulation	I <sub>O</sub> = 10mA to 600mA		0.25		%/A
t <sub>SS</sub>	Soft start ramp time	VDCDC3 ramping from 5% to 95% of target value		750		µs
R(L3)	Internal resistance from L3 to GND			1		MΩ

**7.10 Typical Characteristics**

**Table 1. Table of Graphs**

			FIGURE
η	Efficiency VDCDC1	vs Load current PWM/PFM; V <sub>O</sub> = 3.3V	<a href="#">Figure 1</a>
η	Efficiency VDCDC1	vs Load current PWM; V <sub>O</sub> = 3.3V	<a href="#">Figure 2</a>
η	Efficiency VDCDC2	vs Load current PWM/PFM; V <sub>O</sub> = 1.8V	<a href="#">Figure 3</a>
η	Efficiency VDCDC2	vs Load current PWM; V <sub>O</sub> = 1.8V	<a href="#">Figure 4</a>
η	Efficiency VDCDC3	vs Load current PWM/PFM; V <sub>O</sub> = 1.3V	<a href="#">Figure 5</a>
η	Efficiency VDCDC3	vs Load current PWM; V <sub>O</sub> = 1.3V	<a href="#">Figure 6</a>

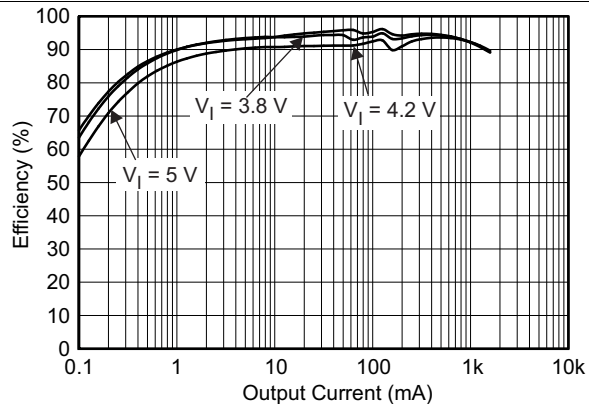


Figure 1. DCDC1: Efficiency vs Output Current

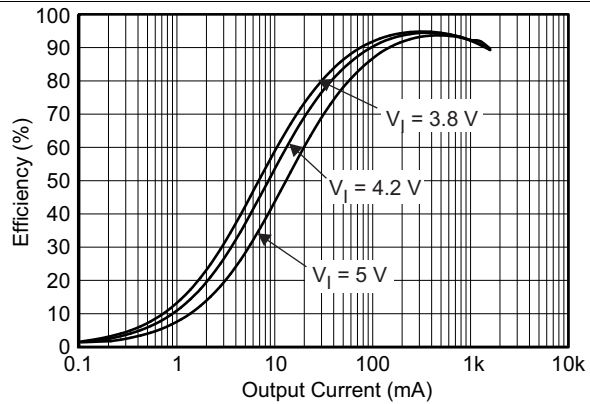


Figure 2. DCDC1: Efficiency vs Output Current

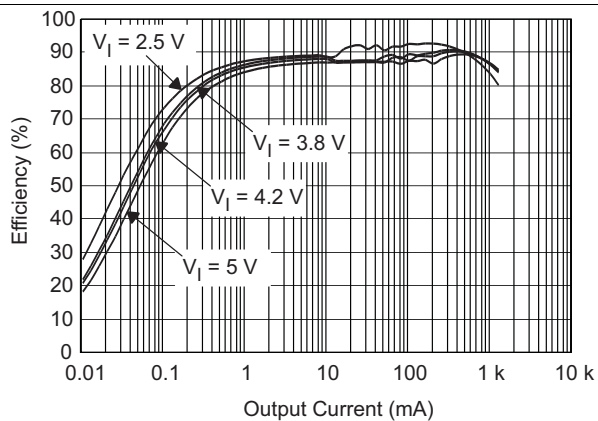


Figure 3. DCDC2: Efficiency vs Output Current

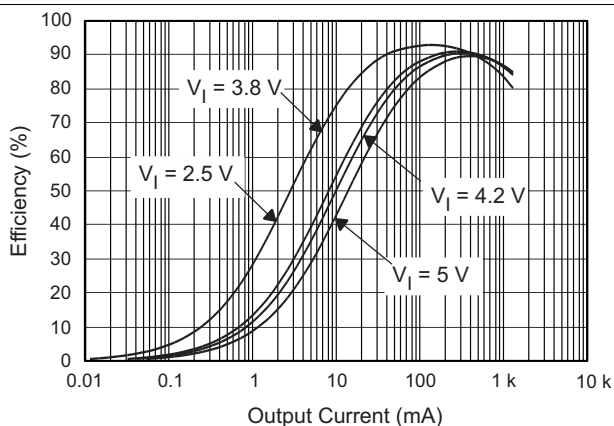


Figure 4. DCDC2: Efficiency vs Output Current

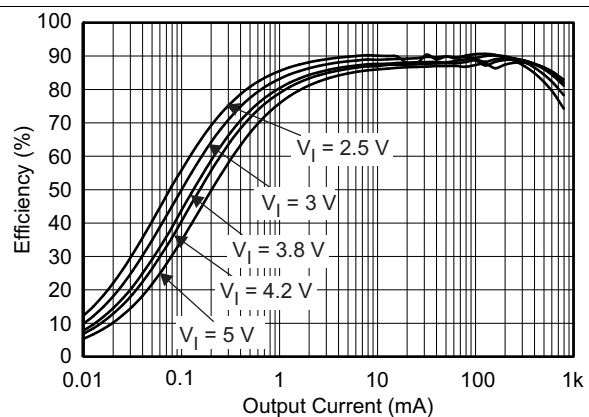


Figure 5. DCDC3: Efficiency vs Output Current

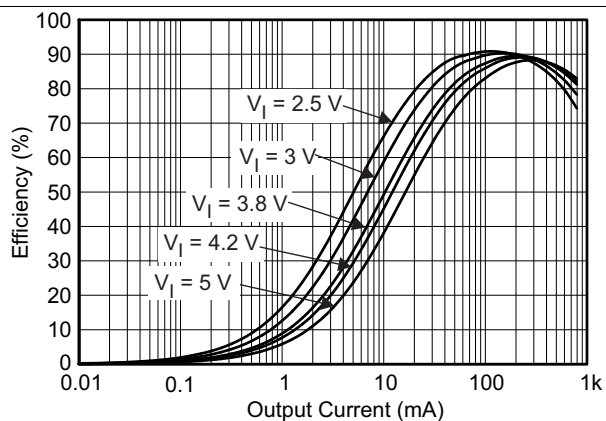


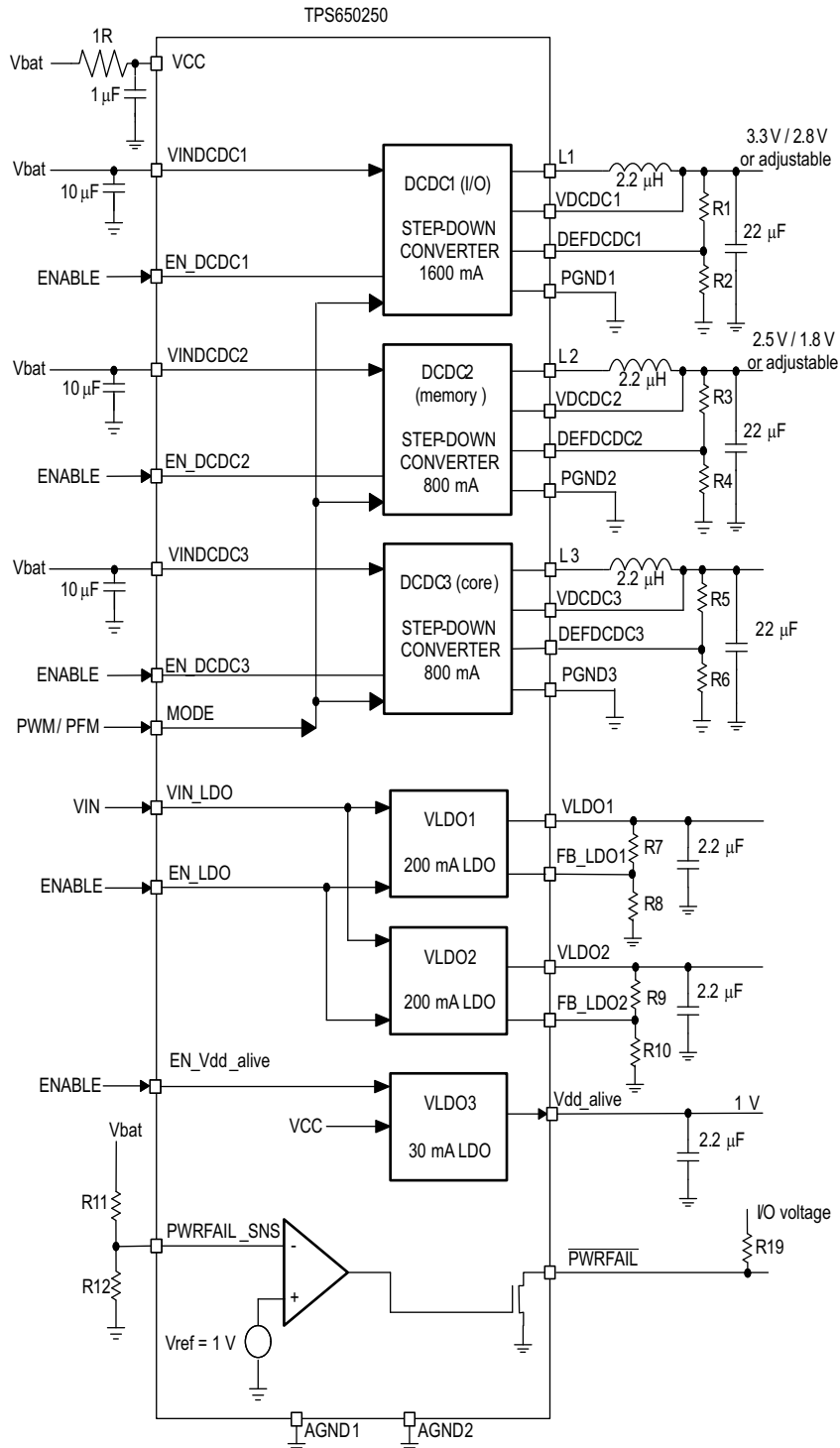
Figure 6. DCDC3: Efficiency vs Output Current

## 8 Detailed Description

### 8.1 Overview

The TPS650250 integrates three step-down converters, two general purpose LDOs and one always on low power LDO for applications powered by one LI-Ion or Li-Polymer cell.

### 8.2 Functional Block Diagram



## 8.3 Feature Description

### 8.3.1 Step-Down Converters, VDCDC1, VDCDC2 AND VDCDC3

The TPS650250 incorporates three synchronous step-down converters operating typically at 2.25 MHz fixed frequency PWM (Pulse Width Modulation) at moderate to heavy load currents. At light load currents the converters automatically enter Power Save Mode and operate with PFM (Pulse Frequency Modulation). VDCDC1 delivers up to 1.6 A, VDCDC2 and VDCDC3 are capable of delivering up to 0.8 A of output current.

The converter output voltages can be programmed via the DEFDCDC1, DEFDCDC2 and DEFDCDC3 pins. The pins can either be connected to GND, VCC or to a resistor divider between the output voltage and GND. The VDCDC1 converter defaults to 2.8 V or 3.3 V depending on the DEFDCDC1 configuration pin, if DEFDCDC1 is tied to ground the default is 2.80 V, if it is tied to VCC the default is 3.3 V. When the DEFDCDC1 pin is connected to a resistor divider, the output voltage can be set in the range of 0.6 V to VINDCDC1 V. Reference the section on Output Voltage Selection for details on setting the output voltage range.

The VDCDC2 converter defaults to 1.8 V or 2.5 V depending on the DEFDCDC2 configuration pin, if DEFDCDC2 is tied to ground the default is 1.8 V, if it is tied to VCC the default is 2.5 V. When the DEFDCDC2 pin is connected to a resistor divider, the output voltage can be set in the range of 0.6 V to VINDCDC2 V.

On the DEFDCDC3 pin for the VDCDC3 converter, a resistor divider must be connected to set the output voltage. This pin does not accept a logic signal like DEFDCDC1 or DEFDCDC2. The value for the resistor divider can be changed during operation, so voltage scaling can be implemented by changing the resistor value.

During PWM operation the converters use a unique fast response voltage mode controller scheme with input voltage feed-forward to achieve good line and load regulation allowing the use of small ceramic input and output capacitors. At the beginning of each clock cycle initiated by the clock signal, the P-channel MOSFET switch is turned on and the inductor current ramps up until the comparator trips and the control logic turns off the switch. The current limit comparator also turns off the switch in case the current limit of the P-channel switch is exceeded. After the adaptive dead time used to prevent shoot through current, the N-channel MOSFET rectifier is turned on and the inductor current ramps down. The next cycle is initiated by the clock signal again turning off the N-channel rectifier and turning on the P-channel switch.

The three DC-DC converters operate synchronized to each other, with the VDCDC1 converter as the master. A 180° phase shift between the VDCDC1 switch turn on and the VDCDC2 and a further 90° shift to the VDCDC3 switch turn on decreases the input RMS current and smaller input capacitors can be used. This is optimized for a typical application where the VDCDC1 converter regulates a Li-Ion battery voltage of 3.7 V to 3.3 V, the VDCDC2 converter from 3.7 V to 2.5 V and the VDCDC3 converter from 3.7 V to 1.5 V.

### 8.3.2 Power Save Mode Operation

As the load current decreases, the converters enter Power Save Mode operation. During Power Save Mode the converters operate in a burst mode (PFM mode) with a frequency between 1.125 MHz and 2.25 MHz for one burst cycle. However, the frequency between different burst cycles depends on the actual load current and is typically far less than the switching frequency, with a minimum quiescent current to maintain high efficiency.

In order to optimize the converter efficiency at light load the average current is monitored and if in PWM mode the inductor current remains below a certain threshold, then Power Save Mode is entered. The typical threshold to enter Power Save Mode can be calculated as follows:

$$\begin{aligned}
 I_{\text{PFMDCDC1enter}} &= \frac{V_{\text{INDCDC1}}}{24 \Omega} \\
 I_{\text{PFMDCDC2enter}} &= \frac{V_{\text{INDCDC2}}}{26 \Omega} \\
 I_{\text{PFMDCDC3leave}} &= \frac{V_{\text{INDCDC3}}}{39 \Omega}
 \end{aligned} \tag{1}$$

During Power Save Mode the output voltage is monitored with a comparator and by maximum skip burst width. As the output voltage falls below the threshold, set to the nominal  $V_O$ , the P-channel switch turns on and the converter effectively delivers a constant current as defined below.

## Feature Description (continued)

$$I_{\text{PFMDCDC1leave}} = \frac{V_{\text{INDCDC 1}}}{18 \Omega}$$

$$I_{\text{PFMDCDC2leave}} = \frac{V_{\text{INDCDC 2}}}{20 \Omega}$$

$$I_{\text{PFMDCDC3enter}} = \frac{V_{\text{INDCDC 3}}}{29 \Omega} \quad (2)$$

If the load is below the delivered current then the output voltage rises until the same threshold is crossed in the other direction. All switching activity ceases, reducing the quiescent current to a minimum until the output voltage has again dropped below the threshold. The power save mode is exited, and the converter returns to PWM mode if either of the following conditions are met:

1. The output voltage drops 2% below the nominal  $V_O$  due to increased load current
2. The PFM burst time exceeds  $16 \times 1/f_s$  (7.1  $\mu\text{s}$  typical)

These control methods reduce the quiescent current to typically 14  $\mu\text{A}$  per converter and the switching activity to a minimum thus achieving the highest converter efficiency. Setting the comparator thresholds at the nominal output voltage at light load current results in a very low output voltage ripple. The ripple depends on the comparator delay and the size of the output capacitor; increasing capacitor values makes the output ripple tend to zero. Power Save Mode can be disabled by pulling the MODE pin high. This forces all DC-DC converters into fixed frequency PWM mode.

### 8.3.3 Soft Start

Each of the three converters has an internal soft start circuit that limits the inrush current during start-up. The soft start is realized by using a very low current to initially charge the internal compensation capacitor. The soft start time is typically 750  $\mu\text{s}$  if the output voltage ramps from 5% to 95% of the final target value. If the output is already pre-charged to some voltage when the converter is enabled, then this time is reduced proportionally. There is a short delay of typically 170  $\mu\text{s}$  between the converter being enabled and switching activity actually starting. This is to allow the converter to bias itself properly, to recognize if the output is pre-charged, and if so, to prevent discharging of the output while the internal soft start ramp catches up with the output voltage.

### 8.3.4 100% Duty Cycle Low Dropout Operation

The TPS650250x converters offer a low input to output voltage difference while still maintaining operation with the use of the 100% duty cycle mode. In this mode the P-channel switch is constantly turned on. This is particularly useful in battery-powered applications to achieve the longest operation time by taking full advantage of the whole battery voltage range. The minimum input voltage required to maintain DC regulation depends on the load current and output voltage and can be calculated as:

$$V_{\text{in}_{\text{min}}} = V_{\text{out}_{\text{min}}} + I_{\text{out}_{\text{max}}} \times (R_{\text{DSon}_{\text{max}}} + R_L) \quad (3)$$

With:

$I_{\text{out}_{\text{max}}}$  = Maximum load current (note: ripple current in the inductor is zero under these conditions)

$R_{\text{DSon}_{\text{max}}}$  = Maximum P-channel switch  $R_{\text{DSon}}$

$R_L$  = DC resistance of the inductor

$V_{\text{out}_{\text{min}}}$  = Nominal output voltage minus 2% tolerance limit

### 8.3.5 Low Dropout Voltage Regulators

The low dropout voltage regulators are designed to operate well with low value ceramic input and output capacitors. They operate with input voltages down to 1.5 V. The LDOs offer a maximum dropout voltage of 300 mV at the rated output current. Each LDO sports a current limit feature. Both LDOs are enabled by the EN\_LDO pin. The LDOs also have reverse conduction prevention. This allows the possibility to connect external regulators in parallel in systems with a backup battery. The TPS650250 step-down and LDO voltage regulators automatically power down when the  $V_{\text{CC}}$  voltage drops below the UVLO threshold or when the junction temperature rises above 160°C.

## Feature Description (continued)

### 8.3.6 Undervoltage Lockout

The undervoltage lockout circuit for the five regulators on the TPS650250x prevents the device from malfunctioning at low input voltages and from excessive discharge of the battery. It disables the converters and LDOs. The UVLO circuit monitors the V<sub>cc</sub> pin; the threshold is set internally to 2.35 V with 5% (120 mV) hysteresis. Note that when any of the DC-DC converters are running there is an input current at the V<sub>cc</sub> pin, which can be up to 3 mA when all three converters are running in PWM mode. This current needs to be taken into consideration if an external RC filter is used at the V<sub>cc</sub> pin to remove switching noise from the TPS650250x internal analog circuitry supply. See the V<sub>cc</sub>-Filter section for details on the external RC filter.

### 8.3.7 PWRFAIL

The PWRFAIL signal is generated by a voltage detector at the PWRFAIL\_SNS input. The input signal is compared to a 1 V threshold (falling edge) with 5% (50 mV) hysteresis. PWRFAIL is an open drain output which is actively low when the input voltage at PWRFAIL\_SNS is below the threshold.

## 8.4 Device Functional Modes

The TPS650250x power-up sequencing is designed to be entirely flexible and customer driven; this is achieved simply by providing separate enable pins for each switch-mode converter and a common enable signal for LDO1 and LDO2. The relevant control pins are described in [Table 2](#).

**Table 2. Control Pins for DCDC Converters**

PIN NAME	INPUT/ OUTPUT	FUNCTION
DEFDCDC3	I	Defines the default voltage of the VDCDC3 switching converter set with an external resistor divider.
DEFDCDC2	I	Defines the default voltage of the VDCDC2 switching converter. DEFDCDC2 = 0 defaults VDCDC2 to 1.8V, DEFDCDC2 = VCC defaults VDCDC2 to 2.5V.
DEFDCDC1	I	Defines the default voltage of the VDCDC1 switching converter. DEFDCDC1 = 0 defaults VDCDC1 to 2.80V, DEFDCDC1 = VCC defaults VDCDC1 to 3.3V.
EN_DCDC3	I	Set EN_DCDC3 = 0 to disable or EN_DCDC3 = 1 to enable the VDCDC3 converter
EN_DCDC2	I	Set EN_DCDC2 = 0 to disable or EN_DCDC2 = 1 to enable the VDCDC2 converter
EN_DCDC1	I	Set EN_DCDC1 = 0 to disable or EN_DCDC1 = 1 to enable the VDCDC1 converter

## 9 Application and Implementation

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### 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.

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### 9.1 Application Information

This device integrates three step-down converters and three LDOs which can be used to power the voltage rails needed by a processor. A typical configuration for using the TPS650250 PMIC to power the Samsung processor S3C6400-533MHz is shown in [Figure 7](#).

## 9.2 Typical Application

### 9.2.1 Typical Configuration For The Samsung Processor S3C6400-533MHz

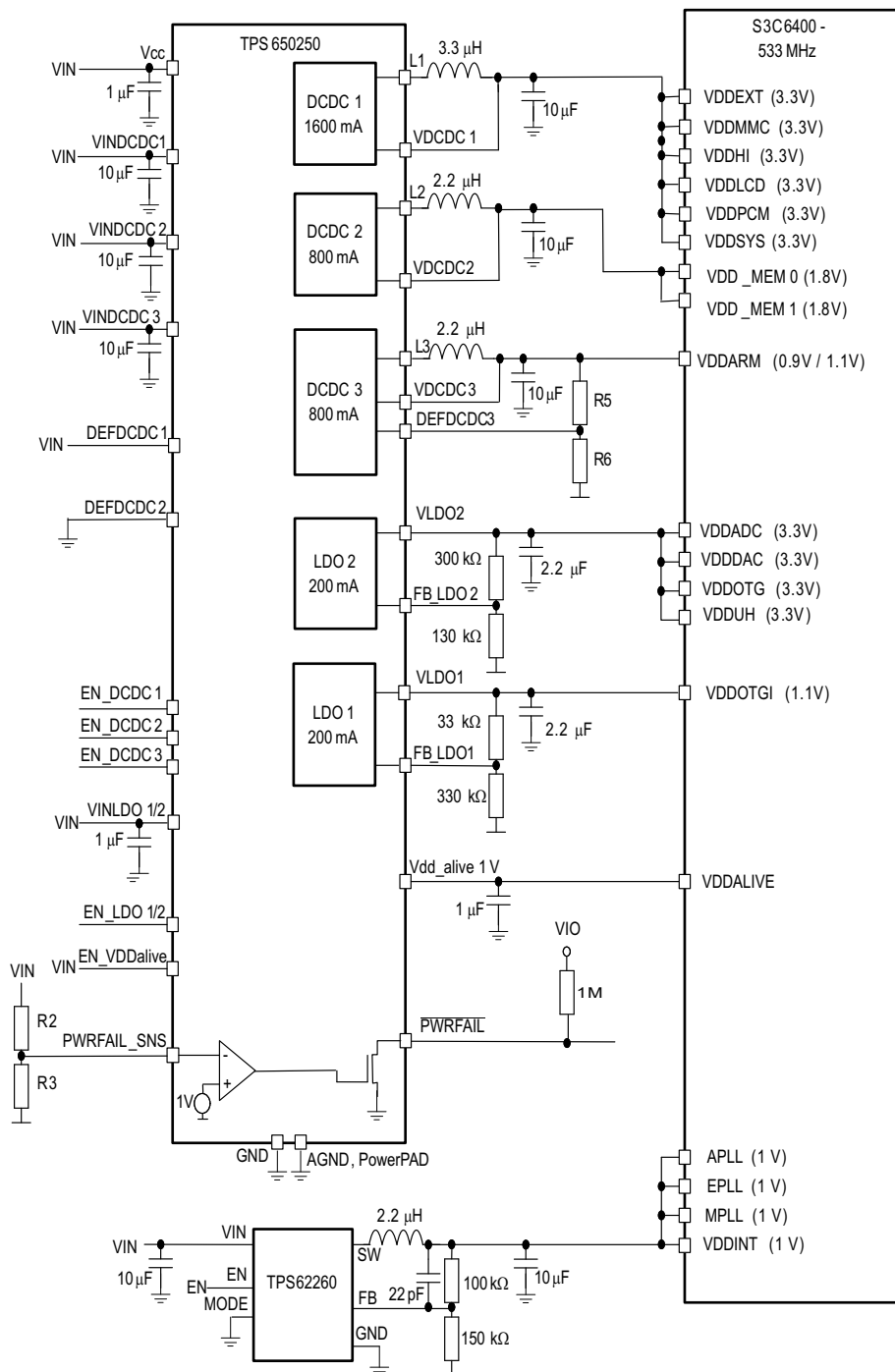


Figure 7. Samsung Processor Configuration

### 9.2.2 Design Requirements

The design parameters for the Samsung Processor Configuration are shown below.

## Typical Application (continued)

**Table 3. Design Parameters**

Design Parameter	Value
Input Voltage Range	4.5 V to 5.5 V
DCDC1 Output Voltage	3.3 V
DCDC2 Output Voltage	1.8 V
DCDC3 Output Voltage	1.0 V
LDO1 Output Voltage	1.1 V
LDO2 Output Voltage	3.3 V

### 9.2.3 Detailed Design Procedure

This section describes the application design procedure for the TPS650250 PMIC.

#### 9.2.3.1 Inductor Selection for the DCDC Converters

The three converters operate with 2.2  $\mu\text{H}$  output inductors. Larger or smaller inductor values can be used to optimize performance of the device for specific conditions. The selected inductor has to be rated for its DC resistance and saturation current. The DC resistance of the inductor influences directly the efficiency of the converter. Therefore, an inductor with the lowest DC resistance should be selected for the highest efficiency.

For a fast transient response, a 2.2  $\mu\text{H}$  inductor in combination with a 22  $\mu\text{F}$  output capacitor is recommended. For an output voltage above 2.8 V, an inductor value of 3.3  $\mu\text{H}$  minimum is required. Lower values result in an increased output voltage ripple in PFM mode. The minimum inductor value is 1.5  $\mu\text{H}$ , but an output capacitor of 22  $\mu\text{F}$  minimum is needed in this case.

[Equation 4](#) calculates the maximum inductor current under static load conditions. The saturation current of the inductor should be rated higher than the maximum inductor current as calculated with [Equation 4](#). This is recommended because during heavy load transient the inductor current rises above the calculated value.

$$\Delta I_L = V_{out} \times \frac{1 - \frac{V_{out}}{V_{in}}}{L \times f} \quad I_{Lmax} = I_{outmax} + \frac{\Delta I_L}{2} \quad (4)$$

With:

f = Switching frequency (2.25 MHz typical)

L = Inductor value

$\Delta I_L$  = Peak-to-peak inductor ripple current

$I_{Lmax}$  = Maximum inductor current

The highest inductor current occurs at maximum  $V_{in}$ .

Open core inductors have a soft saturation characteristic and they can usually handle higher inductor currents versus a comparable shielded inductor.

A more conservative approach is to select the inductor current rating just for the maximum switch current of the corresponding converter. Consideration must be given to the difference in the core material from inductor to inductor which has an impact on efficiency especially at high switching frequencies. See [Table 4](#) and the typical applications for possible inductors.

**Table 4. Tested Inductors**

DEVICE	INDUCTOR VALUE	TYPE	COMPONENT SUPPLIER
DCDC3 Converter	3.3 $\mu\text{H}$	LPS3015-332 (output current up to 1 A)	Coilcraft
	2.2 $\mu\text{H}$	LPS3015-222 (output current up to 1 A)	Coilcraft
	3.3 $\mu\text{H}$	VLCF4020T-3R3N1R5	TDK
	2.2 $\mu\text{H}$	VLCF4020T-2R2N1R7	TDK

**Table 4. Tested Inductors (continued)**

DEVICE	INDUCTOR VALUE	TYPE	COMPONENT SUPPLIER
DCDC3 Converter	2.2 $\mu$ H	LPS3010-222	Coilcraft
	2.2 $\mu$ H	LPS3015-222	Coilcraft
	2.2 $\mu$ H	VLFC4020-2R2	TDK

### 9.2.3.2 Output Capacitor Selection

The advanced Fast Response voltage mode control scheme of the inductive converters implemented in the TPS650250x allows the use of small ceramic capacitors with a typical value of 10  $\mu$ F for each converter, without having large output voltage under and overshoots during heavy load transients. Ceramic capacitors having low ESR values have the lowest output voltage ripple and are recommended. Refer to [Table 5](#) for recommended components.

If ceramic output capacitors are used, the capacitor RMS ripple current rating will always meet the application requirements. For completeness, the RMS ripple current is calculated as:

$$I_{\text{RMS}C_{\text{out}}} = V_{\text{out}} \times \frac{1 - \frac{V_{\text{out}}}{V_{\text{in}}}}{L \times f} \times \frac{1}{2 \times \sqrt{3}} \quad (5)$$

At nominal load current the inductive converters operate in PWM mode and the overall output voltage ripple is the sum of the voltage spike caused by the output capacitor ESR plus the voltage ripple caused by charging and discharging the output capacitor:

$$\Delta V_{\text{out}} = V_{\text{out}} \times \frac{1 - \frac{V_{\text{out}}}{V_{\text{in}}}}{L \times f} \times \left( \frac{1}{8 \times C_{\text{out}} \times f} + \text{ESR} \right) \quad (6)$$

Where the highest output voltage ripple occurs at the highest input voltage,  $V_{\text{in}}$ .

At light load currents the converters operate in Power Save Mode and output voltage ripple is dependent on the output capacitor value. The output voltage ripple is set by the internal comparator delay and the external capacitor. Typical output voltage ripple is less than 1% of the nominal output voltage.

### 9.2.3.3 Input Capacitor Selection

Because of the nature of the buck converter having a pulsating input current, a low ESR input capacitor is required for best input voltage filtering and minimizing interference with other circuits caused by high input voltage spikes. Each DC-DC converter requires a 10  $\mu$ F ceramic input capacitor on its input pin  $V_{\text{INDCDCx}}$ . The input capacitor can be increased without any limit for better input voltage filtering. The  $V_{\text{cc}}$  pin should be separated from the input for the DC-DC converters. A filter resistor of up to 10  $\Omega$  and a 1  $\mu$ F capacitor should be used for decoupling the  $V_{\text{cc}}$  pin from switching noise. Note that the filter resistor may affect the UVLO threshold since up to 3 mA can flow via this resistor into the  $V_{\text{cc}}$  pin when all converters are running in PWM mode.

**Table 5. Possible Capacitors**

CAPACITOR VALUE	CASE SIZE	COMPONENT SUPPLIER		COMMENTS
22 $\mu$ F	1206	TDK	C3216X5R0J226M	Ceramic
22 $\mu$ F	1206	Taiyo Yuden	JMK316BJ226ML	Ceramic
22 $\mu$ F	0805	TDK	C2012X5R0J226MT	Ceramic
22 $\mu$ F	0805	Taiyo Yuden	JMK212BJ226MG	Ceramic
10 $\mu$ F	0805	Taiyo Yuden	JMK212BJ106M	Ceramic
10 $\mu$ F	0805	TDK	C2012X5R0J106M	Ceramic

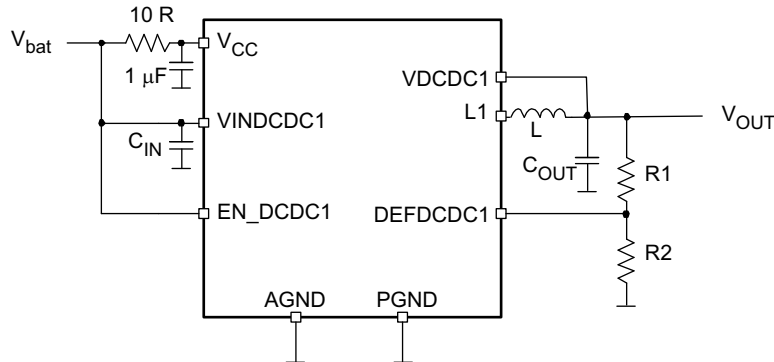
### 9.2.3.4 Output Voltage Selection

The DEFDCDC1, DEFDCDC2, and DEFDCDC3 pins are used to set the output voltage for each step-down converter. See [Table 6](#) for the default voltages if the pins are pulled to GND or to  $V_{\text{cc}}$ .

**Table 6. Voltage Options**

PIN	LEVEL	DEFAULT OUTPUT VOLTAGE
DEFDCDC1	VCC	3.3 V
	GND	2.80 V
DEFDCDC2	VCC	2.5 V
	GND	1.8 V
DEFDCDC3	external voltage divider	0.6 V to VinDCDC3

If a different voltage is needed, an external resistor divider can be added to the DEFDCDC1 or DEFDCDC2 pin as shown in Figure 8:



**Figure 8. External Resistor Divider Added**

When a resistor divider is connected to DEFDCDC1 or DEFDCDC2, the output voltage can be set from 0.6 V up to the input voltage  $V_{bat}$ . The total resistance ( $R1+R2$ ) of the voltage divider should be kept in the 1 MΩ range in order to maintain a high efficiency at light load.  $V_{DEFDCDCx} = 0.6V$

$V_{OUT} = V_{DEFDCDCx} \times \frac{R1 + R2}{R2}$	$R1 = R2 \times \left( \frac{V_{OUT}}{V_{DEFDCDCx}} \right) - R2$
--	---

**9.2.3.5 Voltage Change on VDCDC3**

The output voltage of VDCDC3 is set with an external resistor divider at DEFDCDC3. This pin must not be connected to GND or VINDCDC3. The value of the resistor divider can be changed during operation to allow dynamic voltage scaling.

**9.2.3.6 Vdd\_alive Output**

The Vdd\_alive LDO is typically connected to the Vdd\_alive input of the Samsung application processor. It provides an output voltage of 1 V at 30 mA. It is recommended to add a capacitor of 2.2 μF minimum to the Vdd\_alive pin. The LDO can be disabled by pulling the EN\_Vdd\_alive pin to GND.

**9.2.3.7 LDO1 and LDO2**

The LDOs in the TPS650250 are general purpose LDOs which are stable using ceramics capacitors. The minimum output capacitor required is 2.2 μF. The LDOs output voltage can be changed to different voltages between 1 V and 3.3 V using an external resistor divider. Therefore they can also be used as general purpose LDOs in the application. The supply voltage for the LDOs needs to be connected to the VINLDO pin, giving the flexibility to connect the lowest voltage available in the system and therefore providing the highest efficiency.

The total resistance ( $R5+R6$ ) of the voltage divider should be kept in the 1 MΩ range in order to maintain high efficiency at light load.  $V_{FBLDOx} = 1.0 V$ .

$$V_{OUT} = V_{FBLDOx} \times \frac{R5 + R6}{R6}$$

$$R5 = R6 \times \left( \frac{V_{OUT}}{V_{FBLDOx}} \right) - R6$$

### 9.2.3.8 Vcc-Filter

An RC filter connected at the Vcc input is used to keep noise from the internal supply for the bandgap and other analog circuitry. A typical value of 1  $\Omega$  and 1  $\mu$ F is used to filter the switching spikes, generated by the DC-DC converters. A larger resistor than 10  $\Omega$  should not be used because the current into Vcc of up to 2.5 mA causes a voltage drop at the resistor causing the undervoltage lockout circuitry connected at Vcc internally to switch off too early.

### 9.2.4 Application Curves

The application curves were taken using the following inductor/output capacitor combinations

CONVERTER	INDUCTOR	OUTPUT CAPACITOR	OUTPUT CAPACITOR VALUE
DCDC1	VLCF4020-3R3	C2012X5R0J226M	22 $\mu$ F
DCDC2	VLCF4020-2R2	C2012X5R0J226M	22 $\mu$ F
DCDC3	LPS3010-222	C2012X5R0J226M	22 $\mu$ F

**Table 7. Table of Application Curves**

		FIGURE
	Line transient response VDCDC1	<a href="#">Figure 9</a>
	Line transient response VDCDC2	<a href="#">Figure 10</a>
	Line transient response VDCDC3	<a href="#">Figure 11</a>
	Load transient response VDCDC1	<a href="#">Figure 12</a>
	Load transient response VDCDC2	<a href="#">Figure 13</a>
	Load transient response VDCDC3	<a href="#">Figure 14</a>
	Output voltage ripple DCDC2; PFM mode	<a href="#">Figure 15</a>
	Output voltage ripple DCDC2; PWM mode	<a href="#">Figure 16</a>
	Load regulation for Vdd_alive	<a href="#">Figure 17</a>
	Start-up VDCDC1 to VDCDC3	<a href="#">Figure 18</a>
	Start-up LDO1 and LDO2	<a href="#">Figure 19</a>

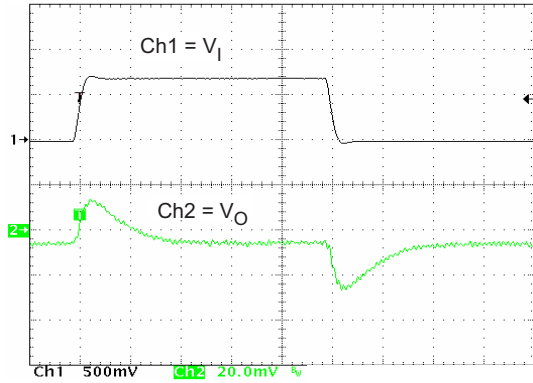


Figure 9. VDCDC1 Line Transient Response

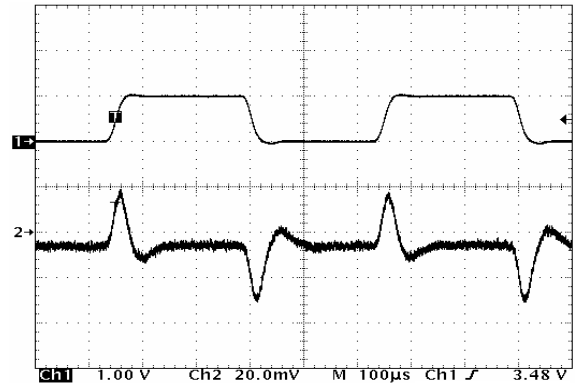


Figure 10. VDCDC2 Line Transient Response

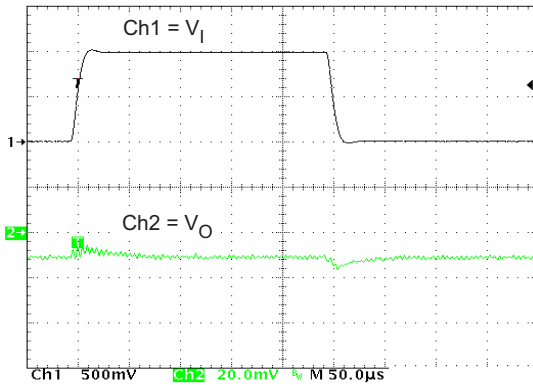


Figure 11. VDCDC3 Line Transient Response

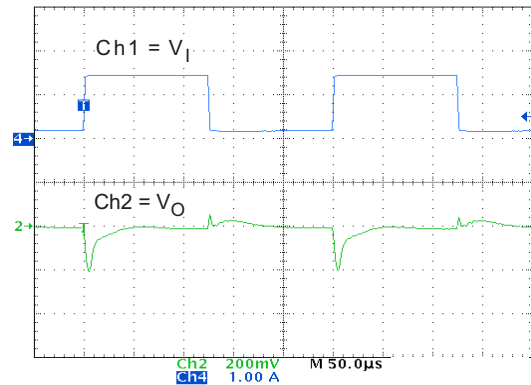


Figure 12. VDCDC1 Load Transient Response

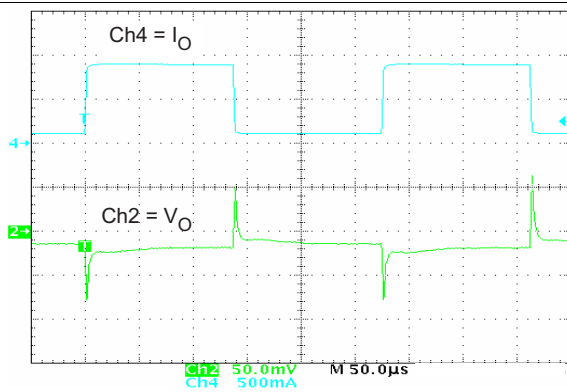


Figure 13. VDCDC2 Load Transient Response

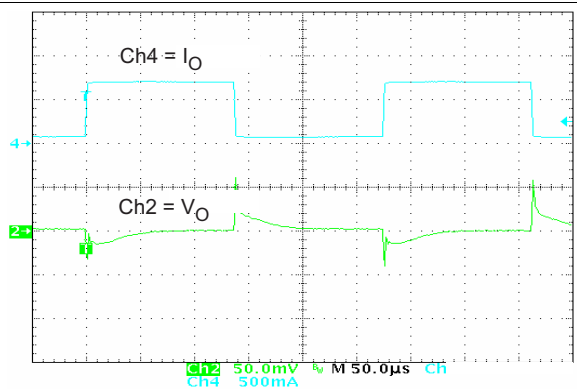


Figure 14. VDCDC3 Load Transient Response

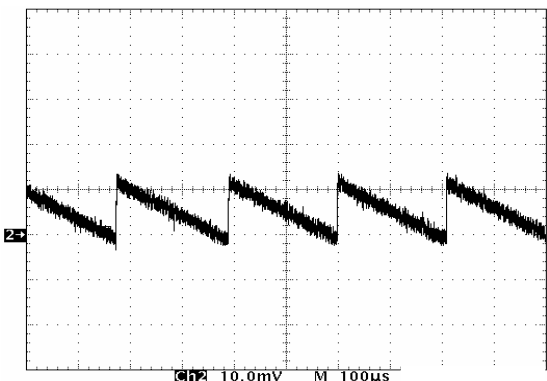


Figure 15. VDCDC2 Output Voltage Ripple

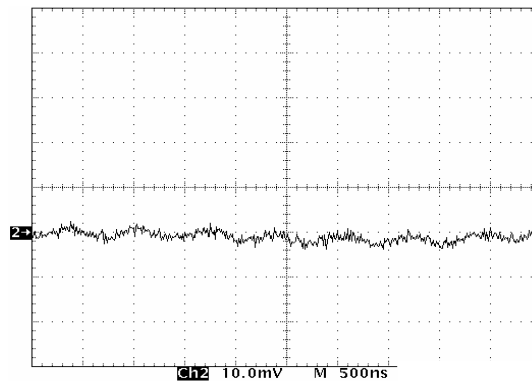


Figure 16. VDCDC2 Output Voltage Ripple

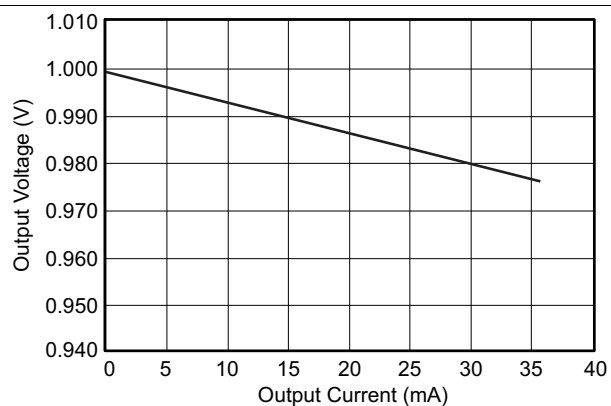


Figure 17. VDD\_ALIVE Output Voltage vs Output Current

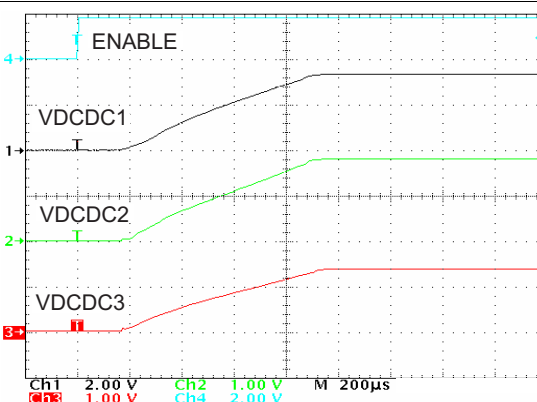


Figure 18. Startup VDCDC1, VDCDC2, VDCDC3

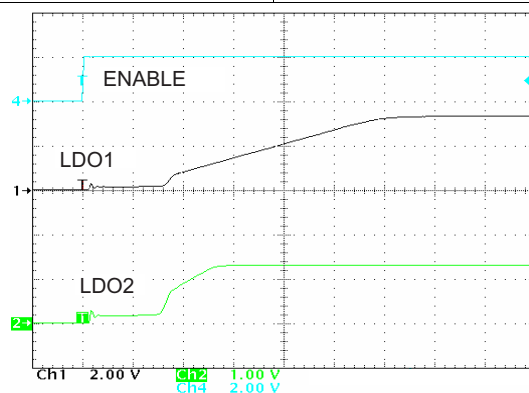


Figure 19. Startup LDO1 and LDO2

## 10 Power Supply Recommendations

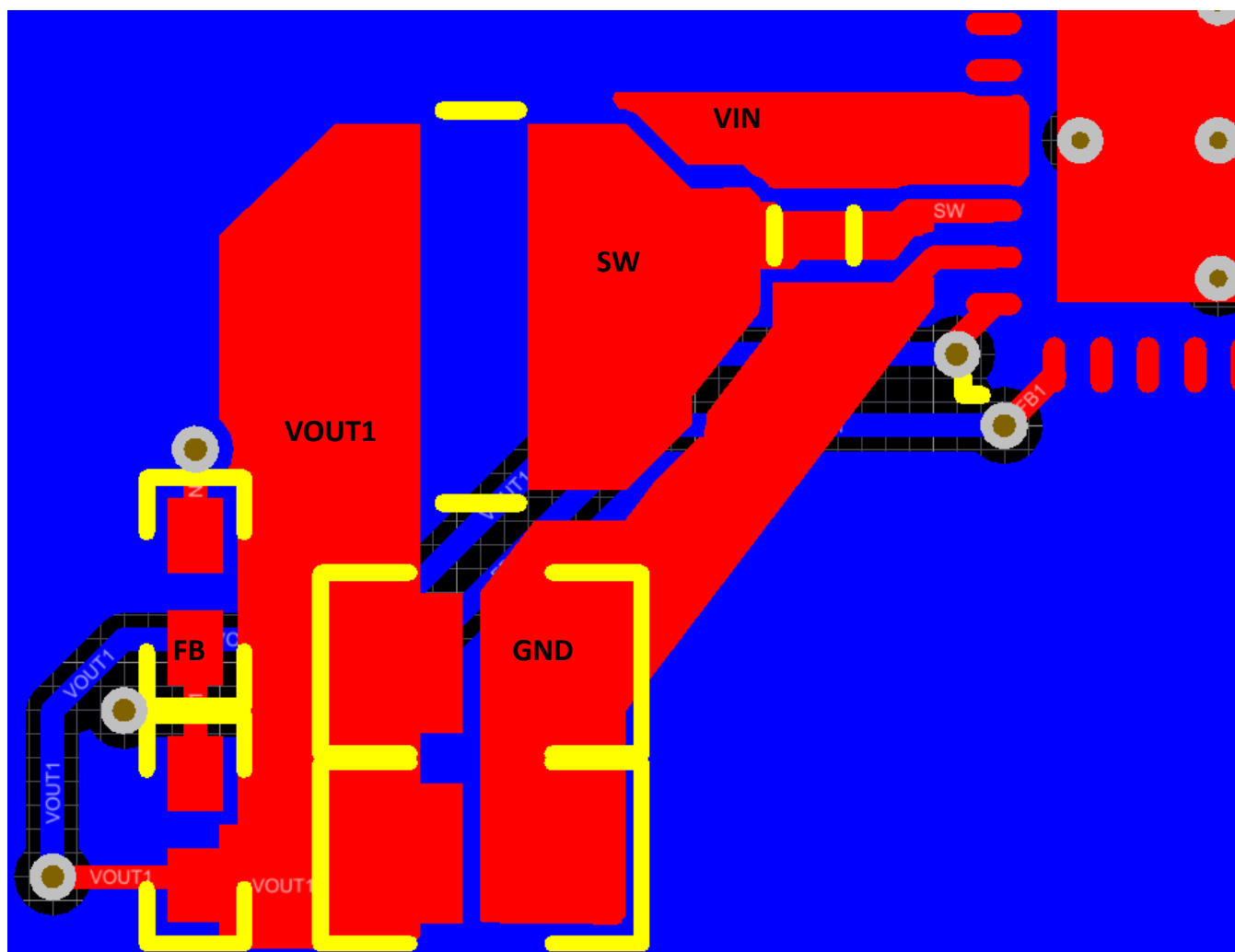
The TPS650250 is designed to operate from an input voltage supply range between 3.5 V and 5.5 V. The input supply should be well regulated. If the input supply is located more than a few inches from the TPS650250, additional bulk capacitance may be required in addition to the ceramic bypass capacitors.

## 11 Layout

### 11.1 Layout Guidelines

- The VINDCDC1, VINDCDC2 and VINDCDC3 terminals should be bypassed to ground with a low ESR ceramic bypass capacitor. The typical recommended bypass capacitance is 10 uF ceramic with a X5R or X7R dielectric.
- The VINLDO terminal should be bypassed to ground with a low ESR ceramic bypass capacitor. The typical recommended bypass capacitance is 1 uF ceramic with a X5R or X7R dielectric.
- The optimum placement is closest to the individual voltage terminals and the AGNDx terminals.
- The AGNDx terminals should be tied to the pcb ground plane at the terminal of the IC.
- The cross sectional area loop from the input capacitor to the VINDCDCx input and corresponding PGNDx terminal should be minimized as much as possible.
- Route the feedback signal for each of the step-down converters next to the current path of the converter in order to decrease the cross sectional area of the feedback loop which minimizes noise injection into the loop.
- Do not route any noise sensitive signals under or next to any of the step-down inductors. Ensure a keepout region directly under the inductors or at least provide ground shielding.
- It is recommended to have the layer directly underneath the IC to be a solid copper ground plane.

## 11.2 Layout Example



**Figure 20. Layout Example of VDCDC1**

The most important layout practice is the placement of the input capacitor. The input capacitor should be placed as close as possible to the VINDCDCx and GND pins of the converters in order to minimize the parasitic inductance and loop.

The second most important layout practice is to minimize the feedback cross-sectional loop of the converters. Route the feedback trace along a close path of the VOUT and switch nodes.

## 12 Device and Documentation Support

### 12.1 Device Support

#### 12.1.1 Third-Party Products Disclaimer

TI'S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

### 12.2 Trademarks

All trademarks are the property of their respective owners.

### 12.3 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.

### 12.4 Glossary

[SLYZ022](#) — *TI Glossary*.

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

## 13 Mechanical, Packaging, and Orderable Information

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

## PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS650250RHBR	ACTIVE	VQFN	RHB	32	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	TPS 650250	<a href="#">Samples</a>
TPS650250RHBT	ACTIVE	VQFN	RHB	32	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	TPS 650250	<a href="#">Samples</a>

(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.

**OBSELETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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

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

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

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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

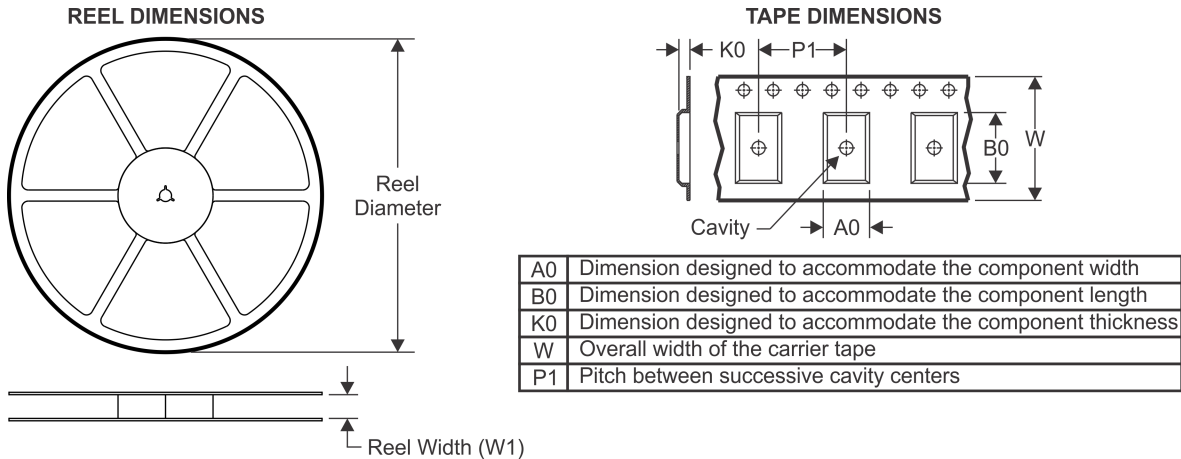
**OTHER QUALIFIED VERSIONS OF TPS650250 :**

- Automotive: [TPS650250-Q1](#)

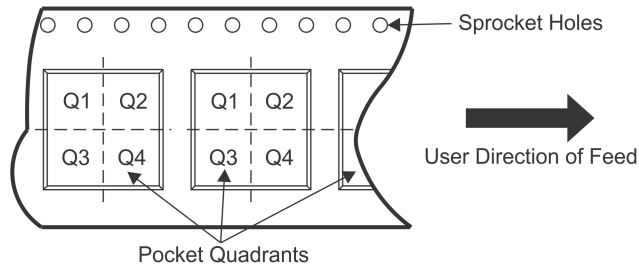
**NOTE: Qualified Version Definitions:**

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

## TAPE AND REEL INFORMATION



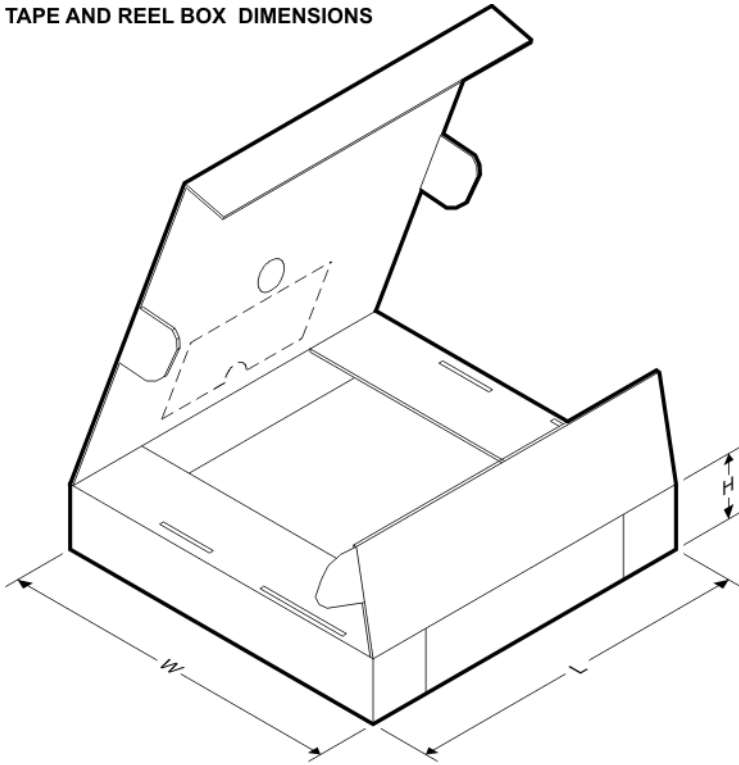
### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



\*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
TPS650250RHBR	VQFN	RHB	32	3000	330.0	12.4	5.3	5.3	1.5	8.0	12.0	Q2
TPS650250RHBT	VQFN	RHB	32	250	180.0	12.4	5.3	5.3	1.5	8.0	12.0	Q2

## TAPE AND REEL BOX DIMENSIONS



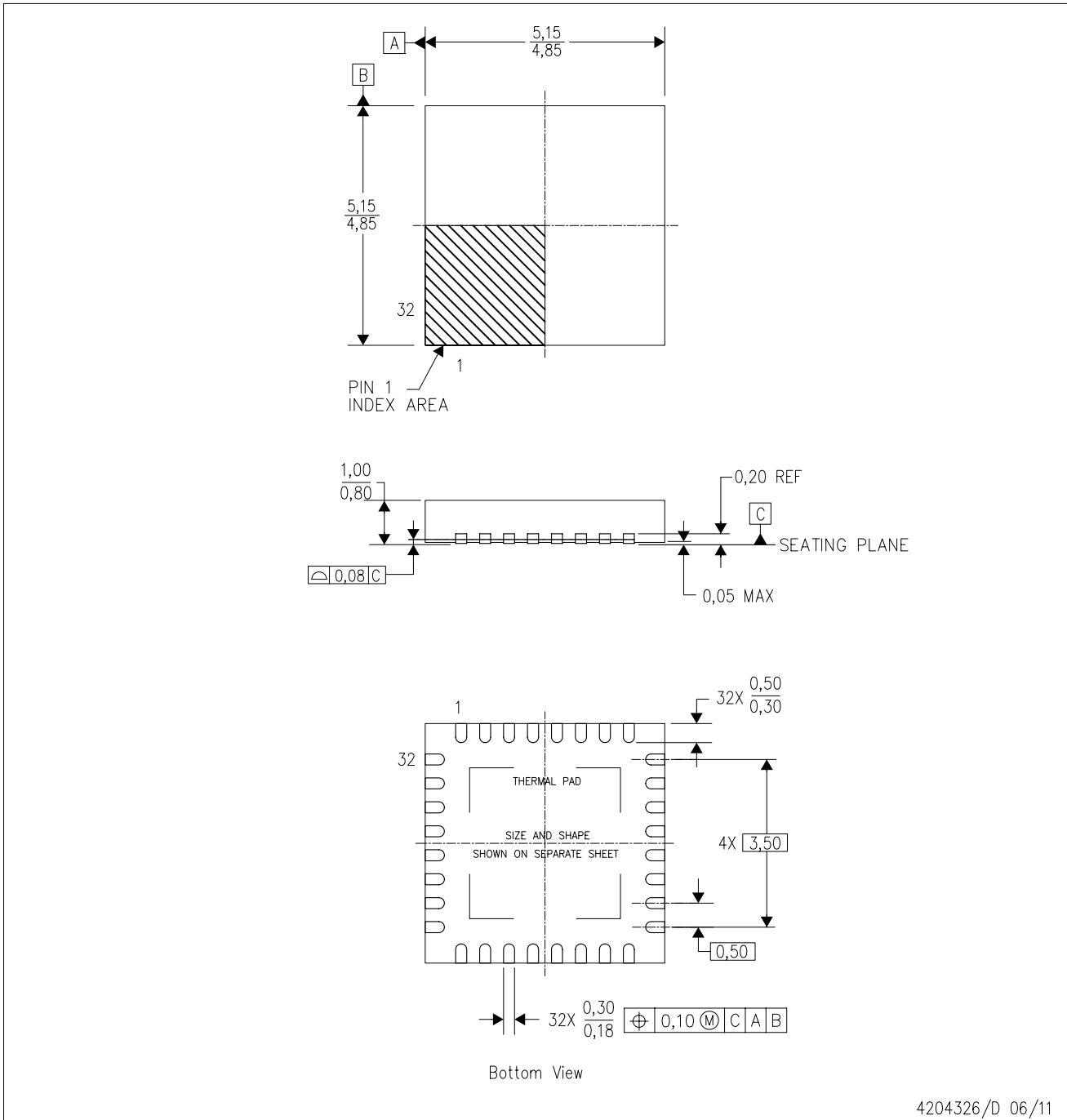
\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS650250RHBR	VQFN	RHB	32	3000	367.0	367.0	35.0
TPS650250RHBT	VQFN	RHB	32	250	210.0	185.0	35.0

# MECHANICAL DATA

RHB (S-PVQFN-N32)

PLASTIC QUAD FLATPACK NO-LEAD



4204326/D 06/11

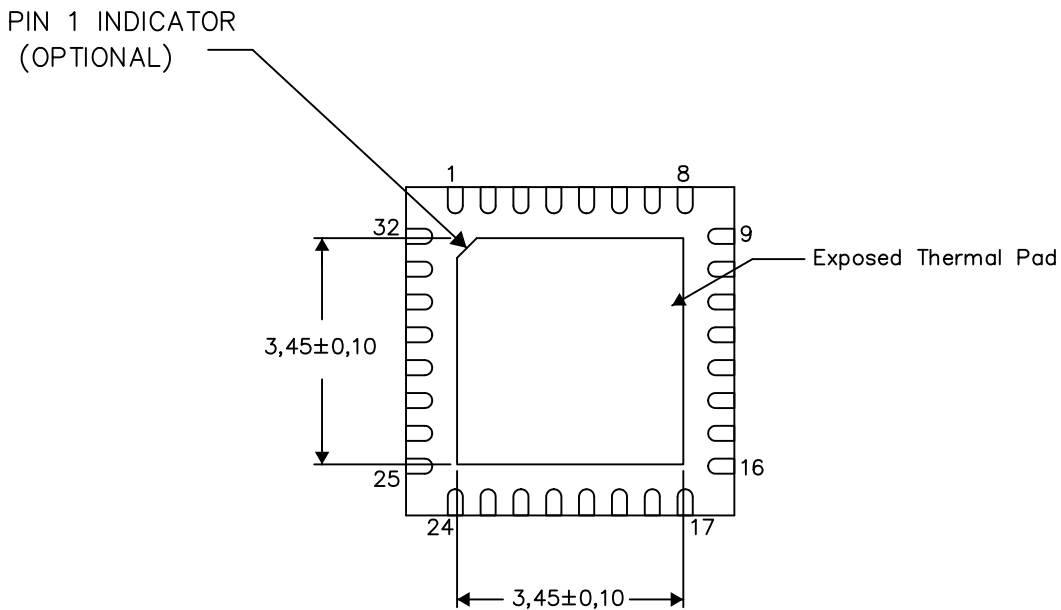
- NOTES:
- All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - This drawing is subject to change without notice.
  - QFN (Quad Flatpack No-Lead) Package configuration.
  - The package thermal pad must be soldered to the board for thermal and mechanical performance.
  - See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
  - Falls within JEDEC MO-220.

THERMAL INFORMATION

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

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at [www.ti.com](http://www.ti.com).

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



Bottom View

Exposed Thermal Pad Dimensions

NOTE: A. All linear dimensions are in millimeters

