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## TPS65186 PMIC for E Ink® Vizplex™ Enabled Electronic Paper Display

### 1 Features

- Single Chip Power-Management Solution for E Ink® Vizplex™ Electronic Paper Displays
- Generates Positive and Negative Gates, Source Driver Voltages, and Back-Plane Bias From a Single, Low-Voltage Input Supply
- Supports 9.7 Inch and Larger Panel Size
- 3-V to 6-V Input Voltage Range
- Boost Converter for Positive Rail Base
- Inverting Buck-Boost Converter for Negative Rail Base
- Two Adjustable LDOs for Source Driver Supply
  - LDO1: 15 V, 120 mA (VPOS)
  - LDO2: -15 V, 120 mA (VNEG)
- Accurate Output Voltage Tracking
  - VPOS – VNEG =  $\pm 50$  mV
- Two Charge Pumps for Gate Driver Supply
  - CP1: 22 V, 10 mA (VDDH)
  - CP2: -20 V, 12 mA, (VEE)
- Adjustable VCOM Driver for Accurate Panel-Backplane Biasing
  - 0 V to -5.11 V
  - $\pm 1.5\%$  accuracy ( $\pm 10$  mV)
- 9-Bit Control (10-mV Nominal Step Size)
- Integrated 10- $\Omega$ , 3.3-V Power Switch for Disabling System Power Rail to E-Ink Panel

### 2 Applications

- Power Supply for Active Matrix E Ink Vizplex Panels
- EPD Power Supplies
- E-Book Readers
- EPSON® S1D13522 (ISIS) Timing Controller
- EPSON® S1D13521 (Broadsheet) Timing Controller
- Application Processors With Integrated or Software Timing Controller (OMAP™)

### 3 Description

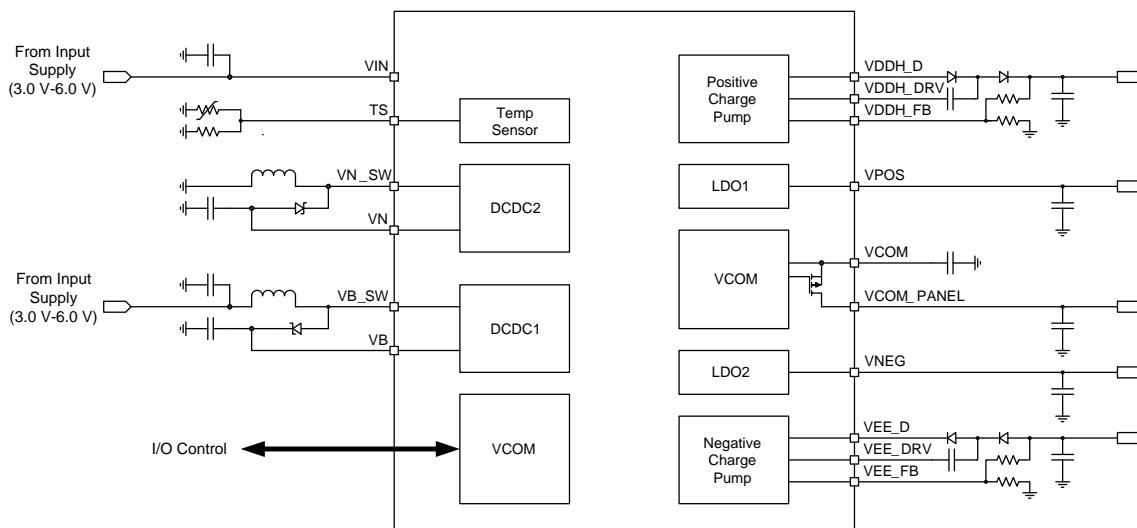
The TPS65186 device is a single-chip power supply designed to for E Ink Vizplex displays used in portable e-reader applications, and the device supports panel sizes up to 9.7 inches and greater. Two high-efficiency DC-DC boost converters generate  $\pm 16$ -V rails that are boosted to 22 V and -20 V by two charge pumps to provide the gate driver supply for the Vizplex panel. Two tracking LDOs create the  $\pm 15$ -V source driver supplies that support up to 120-mA of output current. All rails are adjustable through the I<sup>2</sup>C interface to accommodate specific panel requirements.

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

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS65186	VQFN (48)	7.00 mm $\times$ 7.00 mm

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

#### Typical Application Schematic



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**.

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

[www.ti.com](http://www.ti.com)**Table of Contents**

<b>1</b>	<b>Features</b>	<b>1</b>	8.4	Device Functional Modes	24
<b>2</b>	<b>Applications</b>	<b>1</b>	8.5	Programming	26
<b>3</b>	<b>Description</b>	<b>1</b>	8.6	Register Maps	27
<b>4</b>	<b>Revision History</b>	<b>2</b>	<b>9</b>	<b>Application and Implementation</b>	<b>44</b>
<b>5</b>	<b>Description (continued)</b>	<b>3</b>	9.1	Application Information	44
<b>6</b>	<b>Pin Configuration and Functions</b>	<b>3</b>	9.2	Typical Application	44
<b>7</b>	<b>Specifications</b>	<b>5</b>	<b>10</b>	<b>Power Supply Recommendations</b>	<b>46</b>
7.1	Absolute Maximum Ratings	5	<b>11</b>	<b>Layout</b>	<b>46</b>
7.2	ESD Ratings	5	11.1	Layout Guidelines	46
7.3	Recommended Operating Conditions	5	11.2	Layout Example	46
7.4	Thermal Information	6	<b>12</b>	<b>Device and Documentation Support</b>	<b>47</b>
7.5	Electrical Characteristics	6	12.1	Device Support	47
7.6	Timing Requirements: Data Transmission	10	12.2	Community Resources	47
7.7	Typical Characteristics	12	12.3	Trademarks	47
<b>8</b>	<b>Detailed Description</b>	<b>15</b>	12.4	Electrostatic Discharge Caution	47
8.1	Overview	15	12.5	Glossary	47
8.2	Functional Block Diagram	16	<b>13</b>	<b>Mechanical, Packaging, and Orderable</b>	<b>47</b>
8.3	Feature Description	17	<b>Information</b>		

**4 Revision History**

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

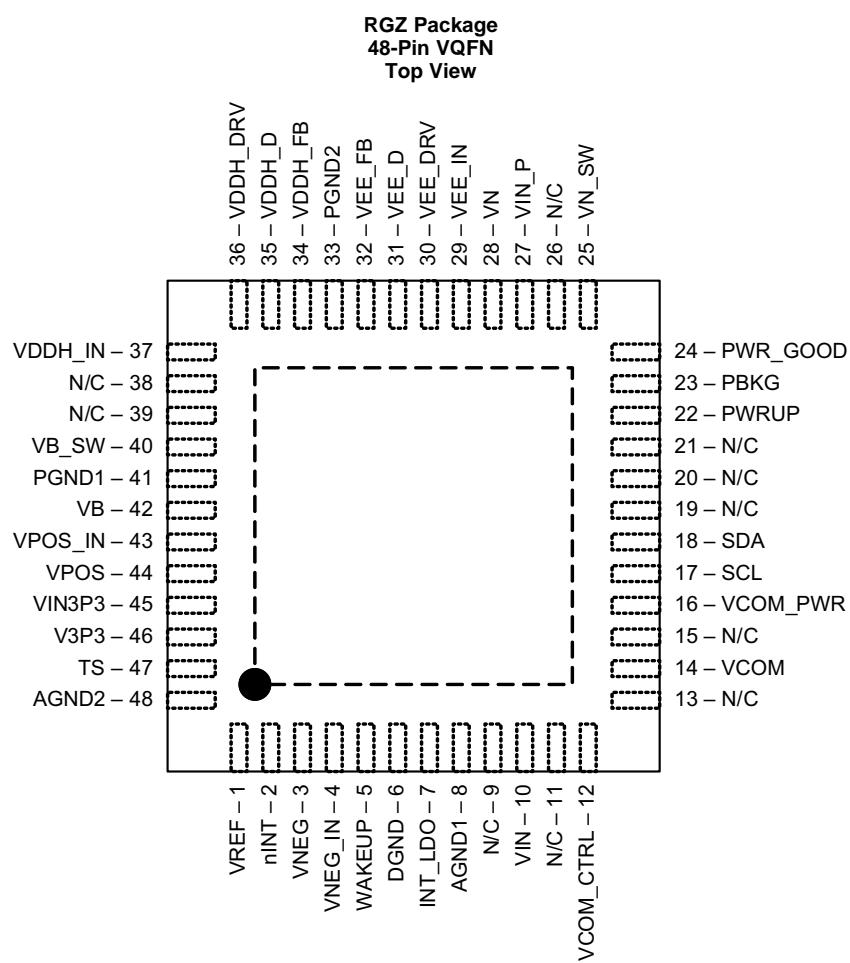
<b>Changes from Original (July 2011) to Revision A</b>	<b>Page</b>
• Added <i>ESD Ratings</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i> , <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section	1
• Changed $R_{OUT}$ from “TBD” to “5 $\Omega$ ”	8

## 5 Description (continued)

Accurate back-plane biasing is provided by a linear amplifier that can be adjusted from 0 V to –5.11 V with 9-bit control through the serial interface; it can also source or sink current depending on panel condition. The TPS65186 supports automatic panel kickback voltage measurement, which eliminates the need for manual VCOM calibration in the production line. The measurement result can be stored in nonvolatile memory to become the new VCOM power-up default value.

TPS65186 is available in a 48-pin 7-mm × 7-mm<sup>2</sup> VQFN with 0.5-mm pitch.

## 6 Pin Configuration and Functions



### Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
AGND1	8	—	Analog ground for general analog circuitry
AGND2	48	—	Reference point to external thermistor and linearization resistor
DGND	6	—	Digital ground. Connect to ground plane.
INT_LDO	7	O	Filter pin for 2.7-V internal supply
nINT	2	O	Open drain interrupt pin (active low)
N/C	9, 11, 13, 15, 19, 20, 21, 26, 38, 39	—	Not internally connected

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**Pin Functions (continued)**

PIN		I/O	DESCRIPTION
NAME	NO.		
PBKG	23	—	Die substrate. Connect to VN (–16 V) with short, wide trace. Wide copper trace will improve heat dissipation.
PGND1	41	—	Power ground for DCDC1
PGND2	33	—	Power ground for CP1 (VDDH) and CP2 (VEE) charge pumps
PWR_GOOD	24	O	Open-drain power good output pin. Pin is pulled low when one or more rails are disabled or not in regulation. DCDC1, DCDC2, and VCOM have no effect on this pin. <sup>(1)</sup>
PWRUP	22	I	Power-up pin. Pull this pin high to power up all output rails. <sup>(1)</sup>
SCL	17	I	Serial interface (I <sup>2</sup> C) clock input
SDA	18	I/O	Serial interface (I <sup>2</sup> C) data input/output
TS	47	I	Thermistor input pin. Connect a 10-kΩ NTC thermistor and a 43-kΩ linearization resistor between this pin and AGND.
V3P3	46	O	Output pin of 3.3-V power switch
VB	42	I	Feedback pin for boost converter (DCDC1) and supply for VPOS LDO and VDDH charge pump
VB_SW	40	O	Boost converter switch out (DCDC1)
VCOM	14	I	Filter pin for panel common-voltage driver
VCOM_CTRL	12	I	VCOM enable. Pull this pin high to enable the VCOM amplifier. When pin is pulled low and VN is enabled, VCOM discharge is enabled. <sup>(2)</sup>
VCOM_PWR	16	I	Internal supply input pin to VCOM buffer. Connect to the output of DCDC2.
VDDH_D	35	O	Base voltage output pin for positive charge pump (CP1)
VDDH_DRV	36	O	Driver output pin for positive charge pump (CP1)
VDDH_FB	34	I	Feedback pin for positive charge pump (CP1)
VDDH_IN	37	I	Input supply pin for positive charge pump (CP1)
VEE_D	31	I	Base voltage output pin for negative charge pump (CP2)
VEE_DRV	30	O	Driver output pin for negative charge pump (CP2)
VEE_FB	32	I	Feedback pin for negative charge pump (CP2)
VEE_IN	29	I	Input supply pin for negative charge pump (CP2) (VEE)
VIN	10	I	Input power supply to general circuitry
VIN3P3	45	I	Input pin to 3.3-V power switch
VIN_P	27	I	Input power supply to inverting buck-boost converter (DCDC2)
VN	28	I	Feedback pin for inverting buck-boost converter (DCDC2) and supply for VNEG LDO and VEE charge pump
VNEG	3	O	Negative supply output pin for panel source drivers
VNEG_IN	4	I	Input pin for LDO2 (VNEG)
VN_SW	25	O	Inverting buck-boost converter switch out (DCDC2)
VREF	1	O	Filter pin for 2.25-V internal reference to ADC
VPOS	44	O	Positive supply output pin for panel source drivers
VPOS_IN	43	I	Input pin for LDO1 (VPOS)
WAKEUP	5	I	Wake-up pin (active high). Pull this pin high to wake up from sleep mode. IC accepts I <sup>2</sup> C commands after WAKEUP pin is pulled high but power rails remain disabled until PWRUP pin is pulled high. <sup>(3)</sup>
PowerPad	—	—	PowerPad, internally connected to PBKG. Connect to VN with short, wide trace. Wide copper trace will improve heat dissipation. PowerPad must not be connected to ground.

(1) There will be 0-ns of deglitch for PWRx.

(2) There will be 62.52-μs of deglitch for VCOM\_CTRL.

(3) There will be 93.75-μs of deglitch for WAKEUP.

## 7 Specifications

### 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) <sup>(1)(2)</sup>

	MIN	MAX	UNIT
Input voltage at VIN <sup>(2)</sup> , VIN_P, VIN3P3	-0.3	7	V
Ground pins to system ground	-0.3	0.3	V
Voltage at SDA, SCL, WAKEUP, PWRUP, VCOM_CTRL, VDDH_FB, VEE_FB, PWR_GOOD, nINT	-0.3	3.6	V
Voltage on VB, VB_SW, VPOS_IN, VDDH_IN	-0.3	20	V
Voltage on VN, VEE_IN, VCOM_PWR, VNEG_IN	-20	0.3	V
Voltage from VIN_P to VN_SW	-0.3	30	V
Peak output current	Internally limited		mA
Continuous total power dissipation	2		W
T <sub>J</sub> Operating junction temperature	-10	125	°C
T <sub>A</sub> Operating ambient temperature <sup>(3)</sup>	-10	85	°C
T <sub>stg</sub> Storage temperature	-65	150	°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.

(2) All voltage values are with respect to network ground terminal.

(3) TI recommends that copper plane in proper size on board be in contact with die thermal pad to dissipate heat efficiently. Thermal pad is electrically connected to PBKG, which is supposed to be tied to the output of buck-boost converter. Thus wide copper trace in the buck-boost output will help heat dissipated efficiently.

### 7.2 ESD Ratings

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

(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

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

	MIN	NOM	MAX	UNIT
Input voltage at VIN, VIN_P, VIN3P3	3	3.7	6	V
Voltage at SDA, SCL, WAKEUP, PWRUP, VCOM_CTRL, VDDH_FB, VEE_FB, PWR_GOOD, nINT	0	3.6		V
T <sub>A</sub> Operating ambient temperature	-10	85		°C
T <sub>J</sub> Operating junction temperature	-10	125		°C

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**7.4 Thermal Information**

THERMAL METRIC <sup>(1)</sup>		TPS65186	UNIT
		RGZ [VQFN]	
		48 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	30	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	15.6	°C/W
R <sub>θJB</sub>	Junction-to-board thermal resistance	6.6	°C/W
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	0.2	°C/W
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	6.6	°C/W
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	0.9	°C/W

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

**7.5 Electrical Characteristics**

 V<sub>IN</sub> = 3.7 V, T<sub>A</sub> = –10°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>INPUT VOLTAGE</b>					
V <sub>IN</sub>	Input voltage range	3	3.7	6	V
V <sub>UVLO</sub>	Undervoltage lockout threshold	V <sub>IN</sub> falling	2.9		V
V <sub>HYS</sub>	Undervoltage lockout hysteresis	V <sub>IN</sub> rising	400		mV
<b>INPUT CURRENT</b>					
I <sub>Q</sub>	Operating quiescent current into V <sub>IN</sub>	Device switching, no load	5.5		mA
I <sub>STD</sub>	Operating quiescent current into V <sub>IN</sub>	Device in standby mode	130		µA
I <sub>SLEEP</sub>	Shutdown current	Device in sleep mode	3.5	10	µA
<b>INTERNAL SUPPLIES</b>					
V <sub>I<sub>INT_LDO</sub></sub>	Internal supply		2.7		V
C <sub>I<sub>INT_LDO</sub></sub>	Nominal output capacitor	Capacitor tolerance ±10%	1	4.7	µF
V <sub>REF</sub>	Internal supply		2.25		V
C <sub>REF</sub>	Nominal output capacitor	Capacitor tolerance ±10%	3.3	4.7	µF
<b>DCDC1 (POSITIVE BOOST REGULATOR)</b>					
V <sub>IN</sub>	Input voltage range	3	3.7	6	V
PG	Power good threshold	Fraction of nominal output voltage	90%		
	Power good time-out	Not tested in production	50		ms
V <sub>OUT</sub>	Output voltage range		16		V
	DC set tolerance		–4.5%	4.5%	
I <sub>OUT</sub>	Output current		250		mA
R <sub>DS(ON)</sub>	MOSFET ON-resistance	V <sub>IN</sub> = 3.7 V	350		mΩ
I <sub>LIMIT</sub>	Switch current limit		1.5 <sup>(1)</sup>		A
	Switch current accuracy		–30%	30%	
f <sub>SW</sub>	Switching frequency		1		MHz
L <sub>DCDC1</sub>	Inductor		2.2		µH
C <sub>DCDC1</sub>	Nominal output capacitor	Capacitor tolerance ±10%	1	2 × 4.7	µF
ESR	Output capacitor ESR		20		mΩ

(1) Contact TI for 1-A, 2-A, or 2.5-A option.

## Electrical Characteristics (continued)

$V_{IN} = 3.7 \text{ V}$ ,  $T_A = -10^\circ\text{C}$  to  $85^\circ\text{C}$ , Typical values are at  $T_A = 25^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>DCDC2 (INVERTING BUCK-BOOST REGULATOR)</b>						
$V_{IN}$	Input voltage range		3	3.7	6	V
PG	Power good threshold	Fraction of nominal output voltage		90%		
	Power good time-out	Not tested in production		50		ms
$V_{OUT}$	Output voltage range			-16		V
	DC set tolerance		-4.5%		4.5%	
$I_{OUT}$	Output current			250		mA
$R_{DS(ON)}$	MOSFET ON-resistance	$V_{IN} = 3.7 \text{ V}$		350		$\text{m}\Omega$
$I_{LIMIT}$	Switch current limit			1.5 <sup>(1)</sup>		A
	Switch current accuracy		-30%		30%	
$L_{DCDC1}$	Inductor			4.7		$\mu\text{H}$
$C_{DCDC1}$	Nominal output capacitor	Capacitor tolerance $\pm 10\%$	1	3x4.7		$\mu\text{F}$
ESR	Capacitor ESR			20		$\text{m}\Omega$
<b>LDO1 (VPOS)</b>						
$V_{POS\_IN}$	Input voltage range		15.2	16	16.8	V
PG	Power good threshold	Fraction of nominal output voltage		90%		
	Power good time-out	Not tested in production		50		ms
$V_{SET}$	Output voltage set value	$V_{IN} = 16 \text{ V}$ , $VSET[2:0] = 0x3h$ to $0x6h$	14.25	15	15	V
$V_{INTERVAL}$	Output voltage set resolution	$V_{IN} = 16 \text{ V}$		250		mV
$V_{OUTTOL}$	Output tolerance	$V_{SET} = 15 \text{ V}$ , $I_{LOAD} = 20 \text{ mA}$	-1%		1%	
$V_{DROPOUT}$	Dropout voltage	$I_{LOAD} = 120 \text{ mA}$		250		mV
$V_{LOADREG}$	Load regulation – DC	$I_{LOAD} = 10\%$ to $90\%$			1%	
$I_{LOAD}$	Load current range			120		mA
$I_{LIMIT}$	Output current limit		120			mA
$C_{LDO1}$	Nominal output capacitor	Capacitor tolerance $\pm 10\%$	1	4.7		$\mu\text{F}$
<b>LDO2 (VNEG)</b>						
$V_{NEG\_IN}$	Input voltage range		16.8	16	-15.2	V
PG	Power good threshold	Fraction of nominal output voltage		90%		
	Power good time-out	Not tested in production		50		ms
$V_{SET}$	Output voltage set value	$V_{IN} = -16 \text{ V}$ $VSET[2:0] = 0x3h$ to $0x6h$	-15	-15	-14.25	V
$V_{INTERVAL}$	Output voltage set resolution	$V_{IN} = -16 \text{ V}$		250		mV
$V_{OUTTOL}$	Output tolerance	$V_{SET} = -15 \text{ V}$ , $I_{LOAD} = -20 \text{ mA}$	-1%		1%	
$V_{DROPOUT}$	Dropout voltage	$I_{LOAD} = 120 \text{ mA}$		250		mV
$V_{LOADREG}$	Load regulation – DC	$I_{LOAD} = 10\%$ to $90\%$ of $I_{LOAD,MAX}$			1%	
$I_{LOAD}$	Load current range			120		mA
$I_{LIMIT}$	Output current limit		120			mA
$C_{LDO2}$	Nominal output capacitor	Capacitor tolerance $\pm 10\%$	1	4.7		$\mu\text{F}$

## TPS65186

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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### Electrical Characteristics (continued)

$V_{IN} = 3.7 \text{ V}$ ,  $T_A = -10^\circ\text{C}$  to  $85^\circ\text{C}$ , Typical values are at  $T_A = 25^\circ\text{C}$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT	
<b>LD01 (POS) AND LDO2 (VNEG) TRACKING</b>						
$V_{DIFF}$	Difference between VPOS and VNEG $V_{SET} = \pm 15 \text{ V}$ , $I_{LOAD} = \pm 20 \text{ mA}$ , $0^\circ\text{C}$ to $60^\circ\text{C}$	-50	50	50	mV	
<b>VCOM DRIVER</b>						
$I_{VCOM}$	Drive current		15		mA	
$V_{COM}$	Allowed operating range	Outside this range VCOM is shut down and VCOMF interrupt is set	-5.5	1	V	
	Accuracy	$V_{COM}[8:0] = 0x07Dh$ (-1.25 V), $V_{IN} = 3.4 \text{ V}$ to $4.2 \text{ V}$ , no load	-0.8%	0.8%		
		$V_{COM}[8:0] = 0x07Dh$ (-1.25 V), $V_{IN} = 3 \text{ V}$ to $6 \text{ V}$ , no load	-1.5%	1.5%		
	Output voltage range		-5.11	0	V	
	Resolution	1LSB		10	mV	
<b>CP1 (VDDH) CHARGE PUMP</b>						
$V_{DDH\_IN}$	Input voltage range	15.2	16	16.8	V	
PG	Power good threshold	Fraction of nominal output voltage	90%			
	Power good time-out	Not tested in production	50		ms	
$V_{FB}$	Feedback voltage		0.998		V	
	Accuracy	$I_{LOAD} = 2 \text{ mA}$	-2%	2%		
$V_{DDH\_OUT}$	Output voltage range	$V_{SET} = 22 \text{ V}$ , $I_{LOAD} = 2 \text{ mA}$	21	22	23	V
$I_{LOAD}$	Load current range			10	mA	
$f_{SW}$	Switching frequency		560		kHz	
$C_D$	Driver capacitor		10		nF	
$C_O$	Output capacitor	1	2.2		$\mu\text{F}$	
<b>CP2 (VEE) NEGATIVE CHARGE PUMP</b>						
$V_{EE\_IN}$	Input voltage range	16.8	-16	-15.2	V	
PG	Power good threshold	Fraction of nominal output voltage	90%			
	Power good time-out	Not tested in production	50		ms	
$V_{FB}$	Feedback voltage		-0.994		V	
	Accuracy	$I_{LOAD} = 2 \text{ mA}$	-2%	2%		
$V_{EE\_OUT}$	Output voltage range	$V_{SET} = -20 \text{ V}$ , $I_{LOAD} = 3 \text{ mA}$	-21	-20	-19	V
$I_{LOAD}$	Load current range			12	mA	
$f_{SW}$	Switching frequency		560		kHz	
$C_D$	Driver capacitor		10		nF	
$C_O$	Nominal output capacitor	Capacitor tolerance $\pm 10\%$	1	2.2	$\mu\text{F}$	

## Electrical Characteristics (continued)

$V_{IN} = 3.7$  V,  $T_A = -10^\circ\text{C}$  to  $85^\circ\text{C}$ , Typical values are at  $T_A = 25^\circ\text{C}$  (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT			
<b>VIN3P3 TO V3P3 SWITCH</b>								
$R_{DS(ON)}$	MOSFET ON-resistance	$V_{IN3P3} = 3.3$ V, $I_D = 10$ mA Over full temperature range	10.5	Ω	Ω			
		$V_{IN3P3} = 2.7$ V, $I_D = 10$ mA Over full temperature range	12.3					
$R_{DIS}$	Discharge impedance to ground	$V_{3P3EN} = 0$	800	1000	1200			
<b>THERMISTOR MONITOR<sup>(2)</sup></b>								
$A_{TMS}$	Temperature to voltage ratio	Not tested in production	-0.0161	V/°C				
$Offset_{TMS}$	Offset	Temperature = $0^\circ\text{C}$	1.575	V				
$V_{TMS\_HOT}$	Temp hot trip voltage ( $T = 50^\circ\text{C}$ )	TEMP_HOT_SET = 0x8C	0.768	V				
$V_{TMS\_COOL}$	Temp hot escape voltage ( $T = 45^\circ\text{C}$ )	TEMP_COOL_SET = 0x82	0.845	V				
$V_{TMS\_MAX}$	Maximum input level		2.25	V				
$R_{NTC\_PU}$	Internal pullup resistor		7.307	kΩ				
$R_{LINEAR}$	External linearization resistor		43	kΩ				
$ADC_{RES}$	ADC resolution	Not tested in production, 1 bit	16.1	mV				
$ADC_{DEL}$	ADC conversion time	Not tested in production	19	μs				
$TMST_{TOL}$	Accuracy	Not tested in production	-1	1				
<b>LOGIC LEVELS AND TIMING CHARACTERISTICS (SCL, SDA, nINT, PWR_GOOD, PWRUP)</b>								
$V_{OL}$	Output low threshold level	$I_{O} = 3$ mA, sink current (SDA, nINT, PWR_GOOD)	0.4	V				
$V_{IL}$	Input low threshold level		0.4	V				
$V_{IH}$	Input high threshold level		1.2	V				
$I_{(bias)}$	Input bias current	$V_{IO} = 1.8$ V	1	μA				
$t_{deglitch}$	Deglitch time, WAKEUP pin	Not tested in production	500	μs				
	Deglitch time, PWRUP pin	Not tested in production	400					
$f_{SCL}$	SCL clock frequency		400	kHz				
	$I^2\text{C}$ slave address	7-bit address	$0 \times 48\text{h}^{(3)}$					
<b>OSCILLATOR</b>								
$f_{osc}$	Oscillator frequency		9	MHz				
	Frequency accuracy	$T_A = -40^\circ\text{C}$ to $85^\circ\text{C}$	-10%	10%				
<b>THERMAL SHUTDOWN</b>								
$T_{SHTDWN}$	Thermal trip point		150	°C				
	Thermal hysteresis		20	°C				

(2) 10-kΩ Murata NCP18XH103F03RB thermistor (1%) in parallel with a linearization resistor (43 kΩ, 1%) are used at TS pin for panel temperature measurement.

(3) Contact TI for alternate address of  $0 \times 68\text{h}$ .

**TPS65186**

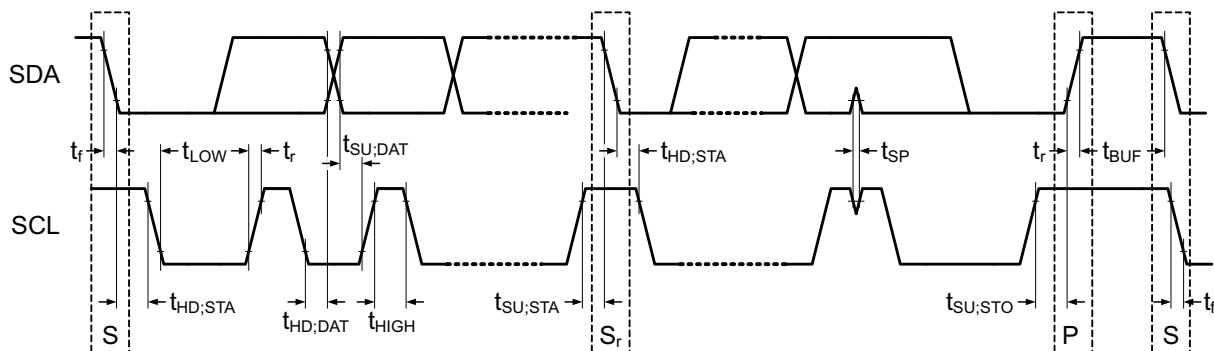
SLVSB04A –JULY 2011–REVISED AUGUST 2015

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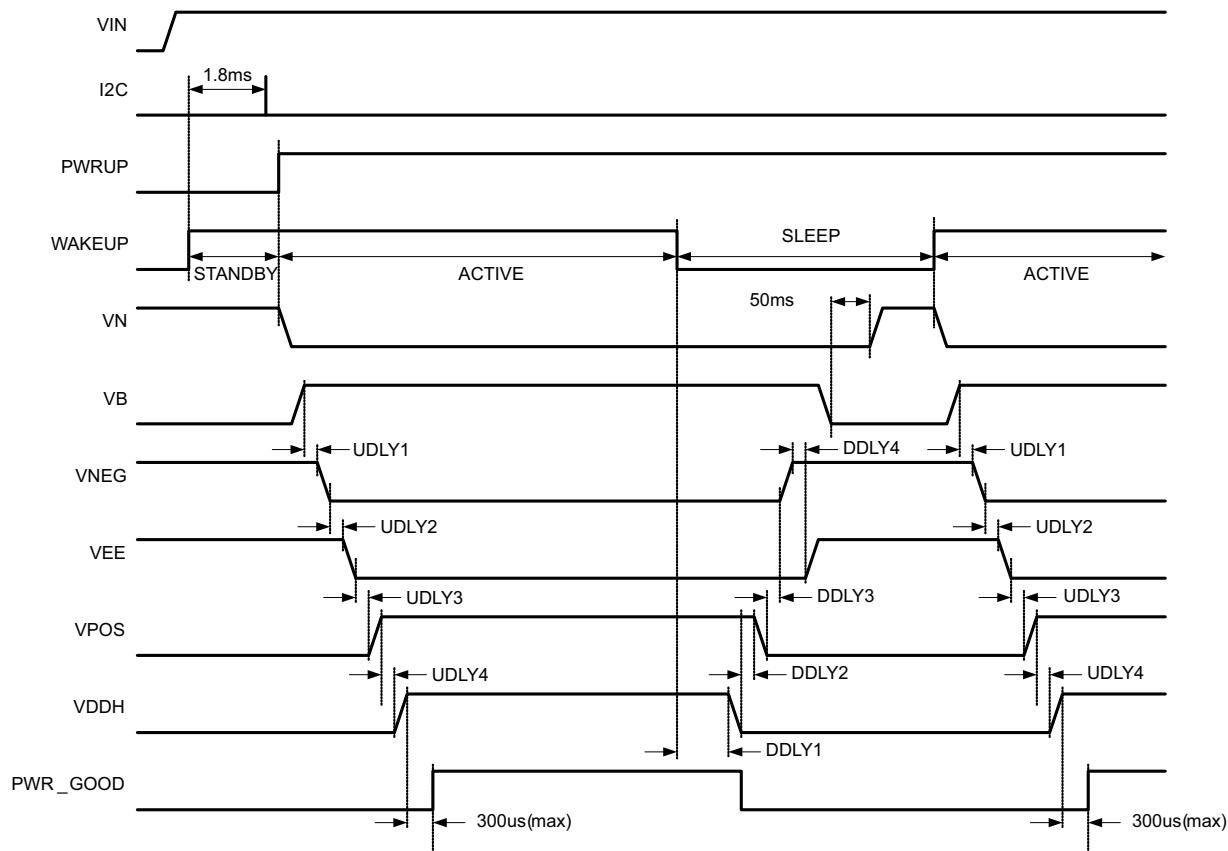
## 7.6 Timing Requirements: Data Transmission

$V_{BAT} = 3.6 \text{ V} \pm 5\%$ ,  $T_A = 25^\circ\text{C}$ ,  $C_L = 100 \text{ pF}$  (unless otherwise noted)

			MIN	NOM	MAX	UNIT
$f_{SCL}$	Serial clock frequency		100	400	kHz	
$t_{HD;STA}$	Hold time (repeated) START condition. After this period, the first clock pulse is generated.	SCL = 100 kHz	4			μs
		SCL = 400 kHz	600			ns
$t_{LOW}$	LOW period of the SCL clock	SCL = 100 kHz	4.7			μs
		SCL = 400 kHz	1.3			
$t_{HIGH}$	HIGH period of the SCL clock	SCL = 100 kHz	4			μs
		SCL = 400 kHz	600			ns
$t_{SU;STA}$	Setup time for a repeated START condition	SCL = 100 kHz	4.7			μs
		SCL = 400 kHz	600			ns
$t_{HD;DAT}$	Data hold time	SCL = 100 kHz	0	3.45		μs
		SCL = 400 kHz	0	900		ns
$t_{SU;DAT}$	Data setup time	SCL = 100 kHz	250			ns
		SCL = 400 kHz	100			
$t_r$	Rise time of both SDA and SCL signals	SCL = 100 kHz		1000		ns
		SCL = 400 kHz		300		
$t_f$	Fall time of both SDA and SCL signals	SCL = 100 kHz		300		ns
		SCL = 400 kHz		300		
$t_{SU;STO}$	Setup time for STOP condition	SCL = 100 kHz	4			μs
		SCL = 400 kHz	600			ns
$t_{BUF}$	Bus Free Time Between Stop and Start Condition	SCL = 100 kHz	4.7			μs
		SCL = 400 kHz	1.3			
$t_{SP}$	Pulse width of spikes that must be suppressed by the input filter	SCL = 100 kHz	n/a	n/a		ns
		SCL = 400 kHz	0	50		
$C_b$	Capacitive load for each bus line	SCL = 100 kHz		400		pF
		SCL = 400 kHz		400		



**Figure 1. I<sup>2</sup>C Data Transmission Timing**



Minimum delay time between WAKEUP rising edge and IC ready to accept I<sup>2</sup>C transaction.

In this example, the first power-up sequence is started by pulling the PWRUP pin high (rising edge). Power-down is initiated by pulling the WAKEUP pin low (device enters sleep mode). The second power-up sequence is initiated by pulling the WAKEUP pin high while the PWRUP pin is also high (power up from sleep to active).

**Figure 2. Power-Up and Power-Down Timing Diagram**

## TPS65186

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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### 7.7 Typical Characteristics

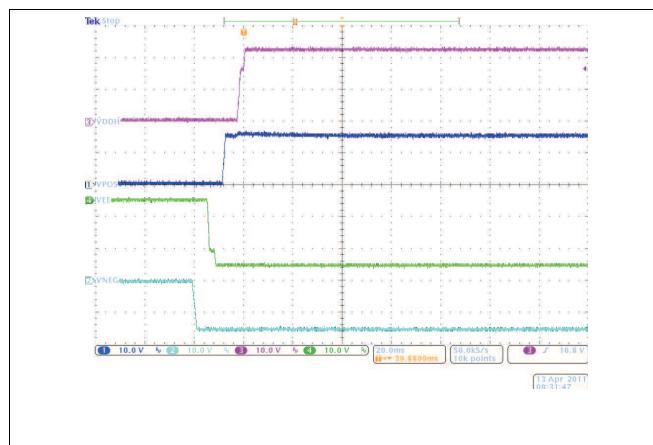


Figure 3. Default Power-Up Sequence

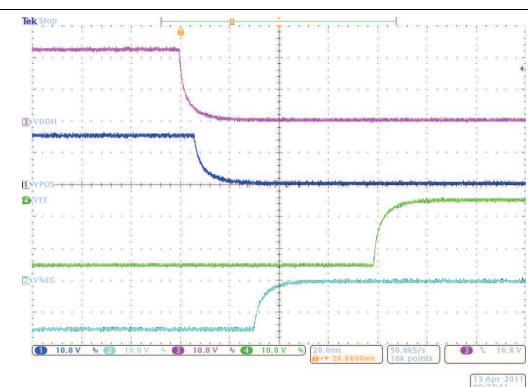


Figure 4. Default Power-Down Sequence



Figure 5. Inrush Current

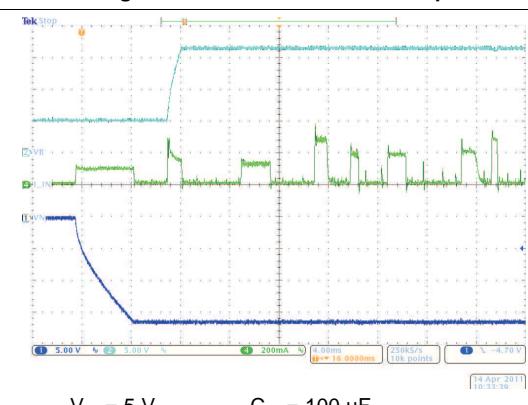


Figure 6. Inrush Current

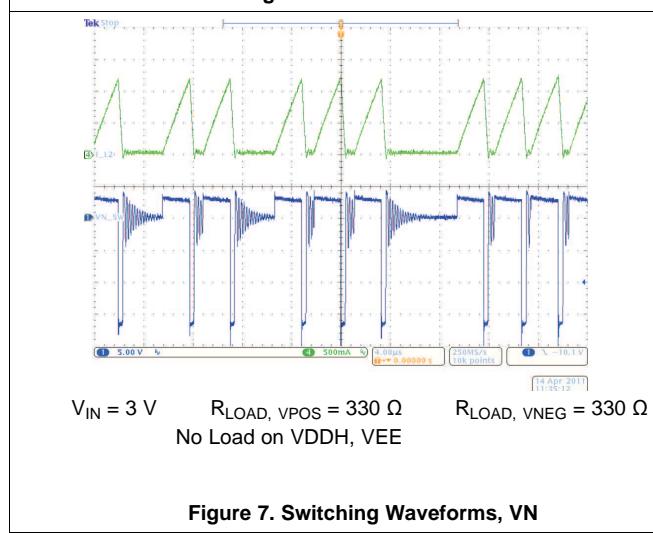


Figure 7. Switching Waveforms, VN

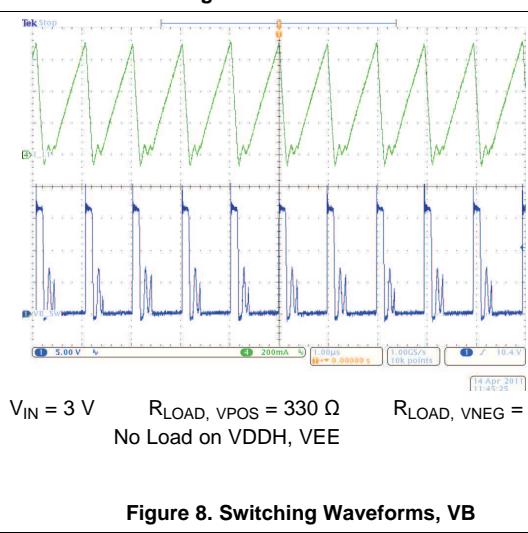
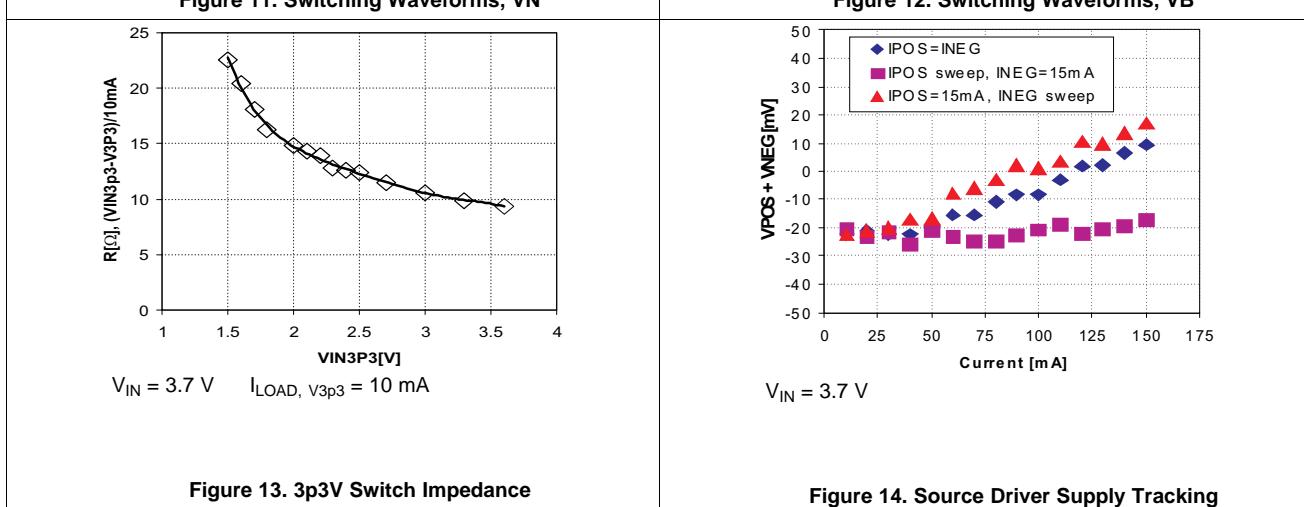
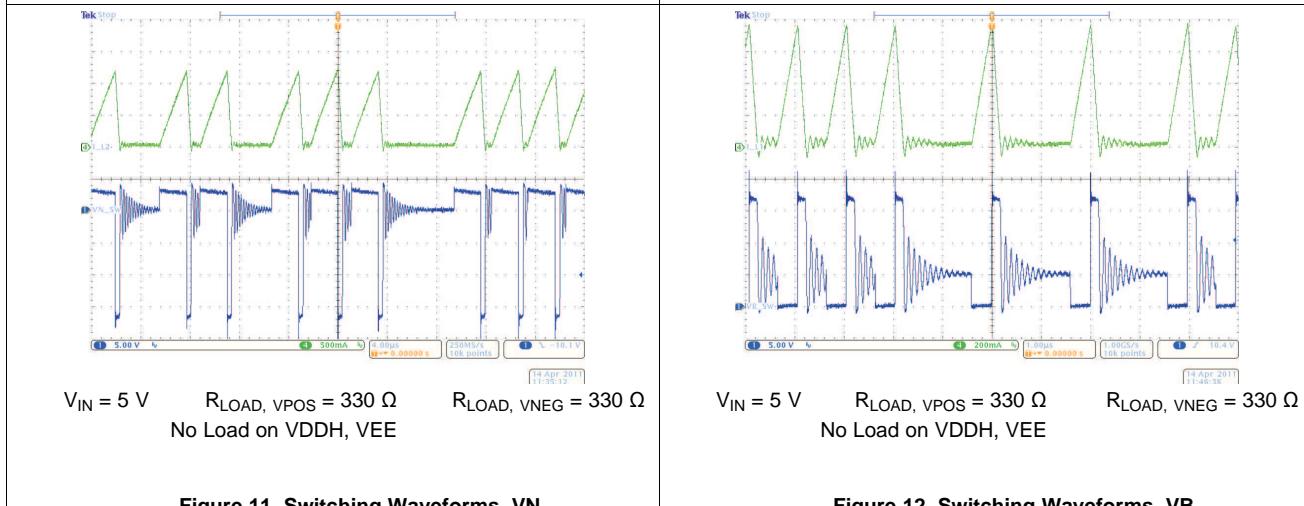
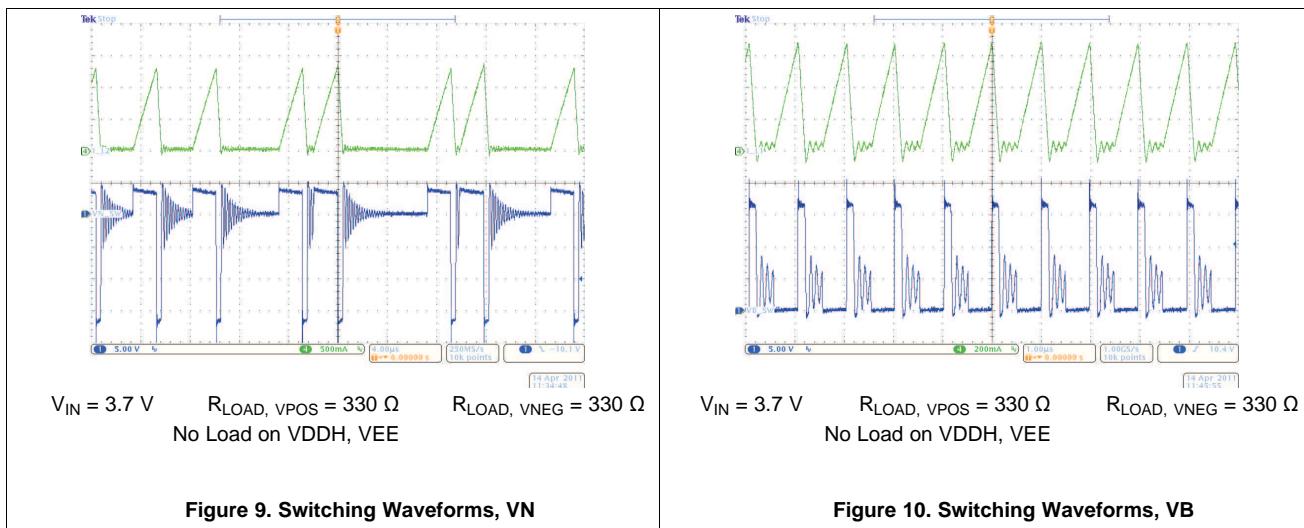


Figure 8. Switching Waveforms, VB

## Typical Characteristics (continued)

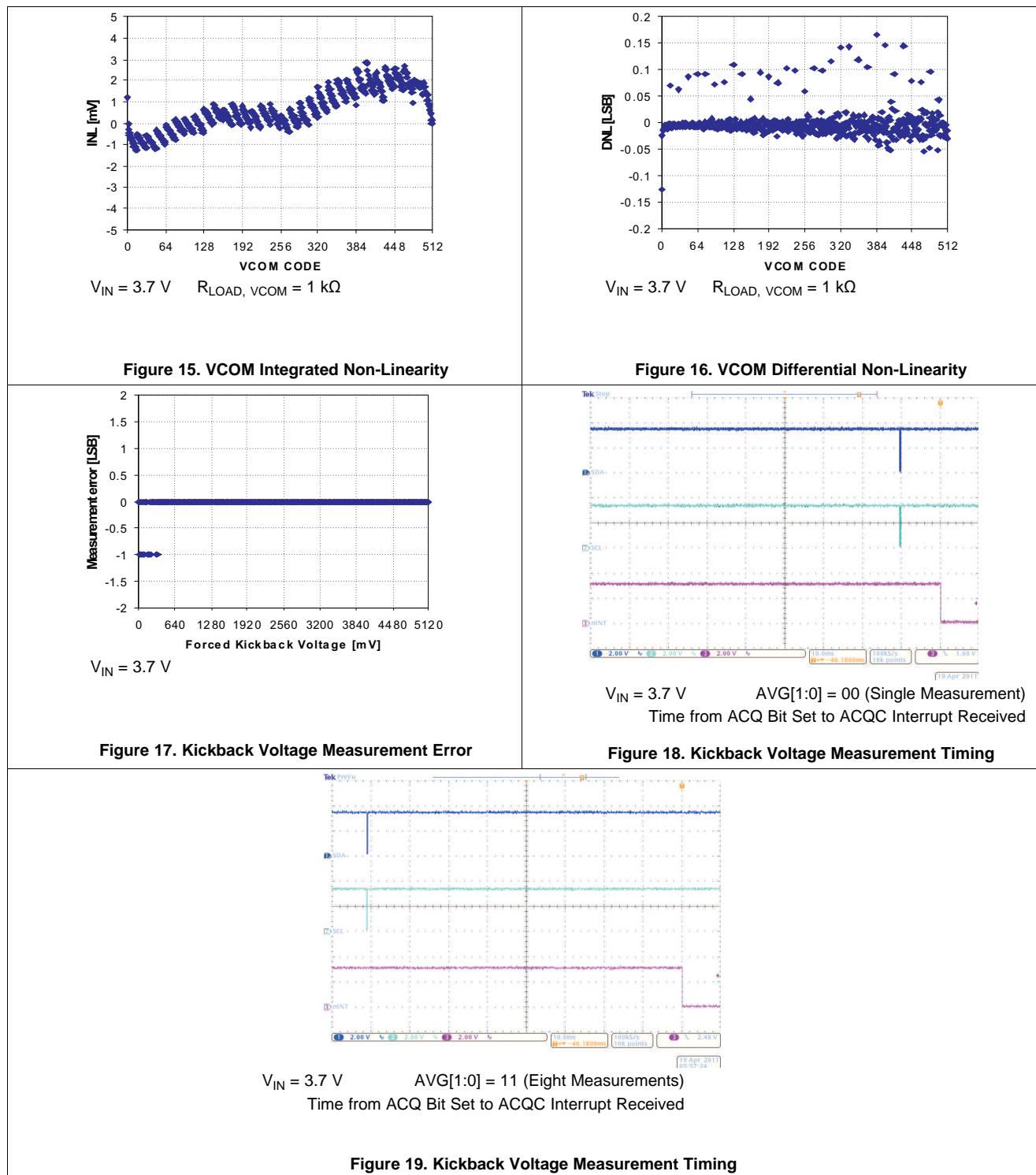


**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**Typical Characteristics (continued)**



## 8 Detailed Description

### 8.1 Overview

The TPS65186 device provides two adjustable LDOs, inverting buck-boost converter, boost converter, thermistor monitoring, and flexible power-up and power-down sequencing. The system can be supplied by a regulated input voltage ranging from 3 V to 6 V. The device is characterized across a  $-10^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  temperature range, best suited for personal electronic applications.

The I<sup>2</sup>C interface provides comprehensive features for using the TPS65186. All rails can be enabled or disabled. Power-up and power-down sequences can also be programmed through the I<sup>2</sup>C interface, as well as thermistor configuration and interrupt configuration. Voltage adjustment can also be controlled by the I<sup>2</sup>C interface.

The adjustable LDOs can supply up to 120 mA of current. The default output voltages for each LDO can be adjusted through the I<sup>2</sup>C interface. LDO1 (VPOS) and LDO2 (VNEG) track each other in a way that they are of opposite sign but same magnitude. The sum of VLDO1 and VLDO2 is guaranteed to be less than 50 mV.

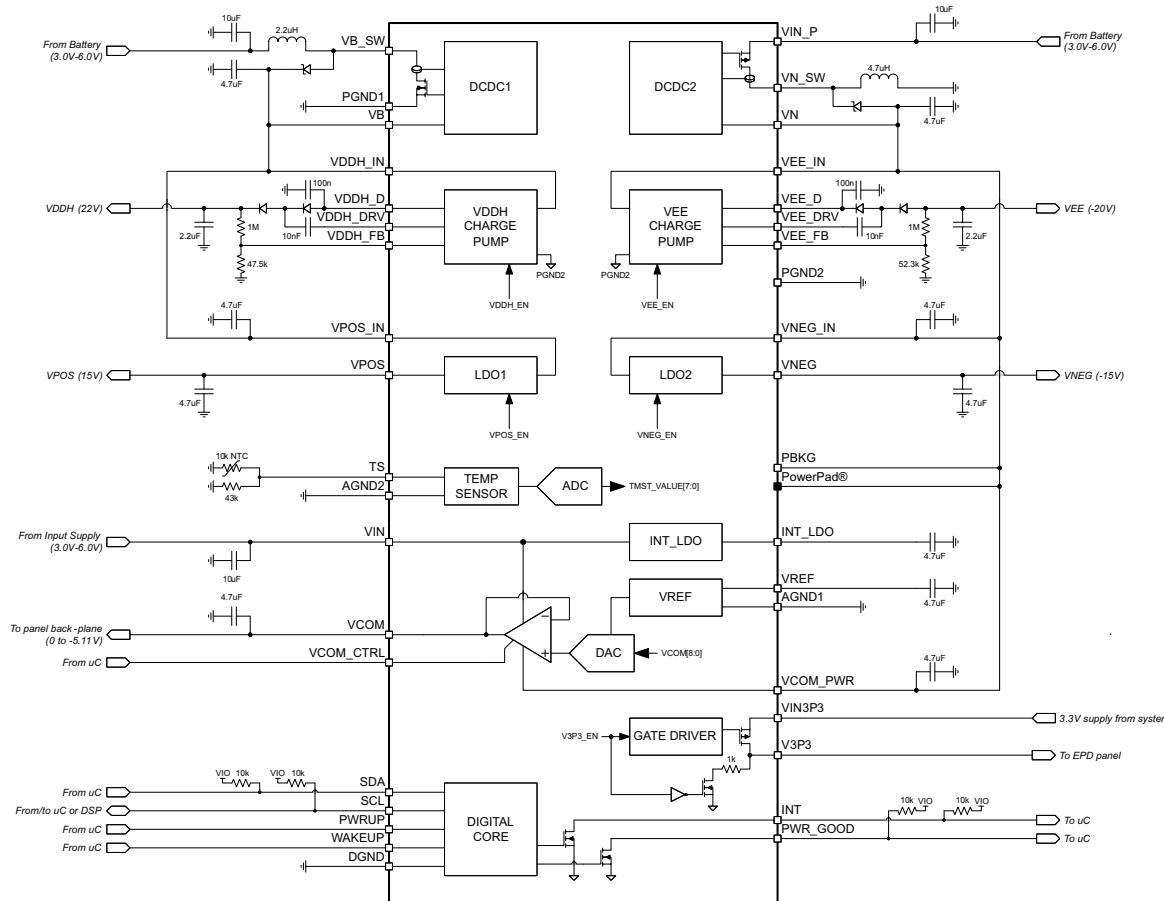
There are two charge pumps: VDDH and VEE 10 mA and 12 mA respectively. These charge pumps boost the DC-DC boost converters  $\pm 16\text{-V}$  rails to provide a gate channel supply.

The power good functionality is open-drain output, if any of the four power rails (CP1, CP2, LDO1, LDO2) are not in regulation, encounters a fault, or is disabled the pin is pulled low. PWR\_GOOD remains low if one of the rails is not enabled by the host and only after all rails are in regulation PWR\_GOOD is released to Hi-Z state (pulled up by external resistor).

The TPS65186 provides circuitry to bias and measure an external NTC to monitor the display panel temperature in a range from  $-10^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  with an accuracy of  $\pm 1^{\circ}\text{C}$  from  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$ . Temperature measurement are triggered by the controlling host and the last temperature reading is always stored in the TMST\_VALUE register. Interrupts are issued when the temperature exceeds the programmable HOT, or drops below the programmable COLD threshold, or when the temperature has changed by more than a user-defined threshold from the baseline value.

This device is offered in a 48-Pin, 0.5-mm Pitch, 7 mm  $\times$  7 mm  $\times$  0.9 mm (VQFN) RGZ package.

## 8.2 Functional Block Diagram



## 8.3 Feature Description

### 8.3.1 Wake-Up and Power-Up Sequencing

The power-up and power-down order and timing is defined by user register settings. The default settings support the E Ink Vizplex panel and typically do not need to be changed.

In SLEEP mode the TPS65186 is completely turned off, the I<sup>2</sup>C registers are reset, and the device does not accept any I<sup>2</sup>C transaction. Pull the WAKEUP pin high with the PWRUP pin low and the device enters STANDBY mode that enables the I<sup>2</sup>C interface. Write to the UPSEQ0 register to define the order in which the output rails are enabled at power-up and to the UPSEQ1 registers to define the power-up delays between rails. Finally, set the ACTIVE bit in the ENABLE register to 1 to execute the power-up sequence and bring up all power rails. Alternatively, pull the PWRUP pin high (rising edge).

After the ACTIVE bit has been set, the negative boost converter (VN) is powered up first, followed by the positive boost (VB). The positive boost enable is gated by the internal power-good signal of the negative boost. Once VB is in regulation, it issues an internal power-good signal and after delay time UDLY1 has expired, STROBE1 is issued. The rail assigned to STROBE1 will power up next and after its power-good signal has been asserted and delay time UDLY2 has expired, STROBE2 is issued. The sequence continues until STROBE4 has occurred and the last rail has been enabled.

To power down the device, set the STANDBY bit of the ENABLE register to 1 or pull the PWRUP pin low (falling edge) and the TPS65186 will power down in the order defined by DWNSEQx registers. The delay times DDLY2, DDLY3, and DDLY4 are weighted by a factor of DFCTR which allows the user to space out the power down of the rails to avoid crossing during discharge. DFCTR is located in register DWNSEQ1. The positive boost (VB) is shut down together with the last rail at STROBE4. However, the negative boost (VN) remains up and running for another 50 ms. Then VN is powered down and the device enters STANDBY or SLEEP mode, depending on the WAKEUP pin.

If either the ACTIVE bit is set or the PWRUP pin is pulled high while the device is powering down, the power-down sequence (STROBE1-4) is completed first, followed by a power-up sequence. VB and VN may or may not be powered down and depending on the relative timing of STROBE4 to the new power-up event.

During power-up, if the STANDBY bit is set or the PWRUP pin is pulled low, the power-up sequence is aborted and the power-down sequence starts immediately.

### 8.3.2 Dependencies Between Rails

Charge pumps, LDOs, and VCOM driver are dependent on the positive and inverting buck-boost converters and several dependencies exist that affect the power-up sequencing. These dependencies are the following:

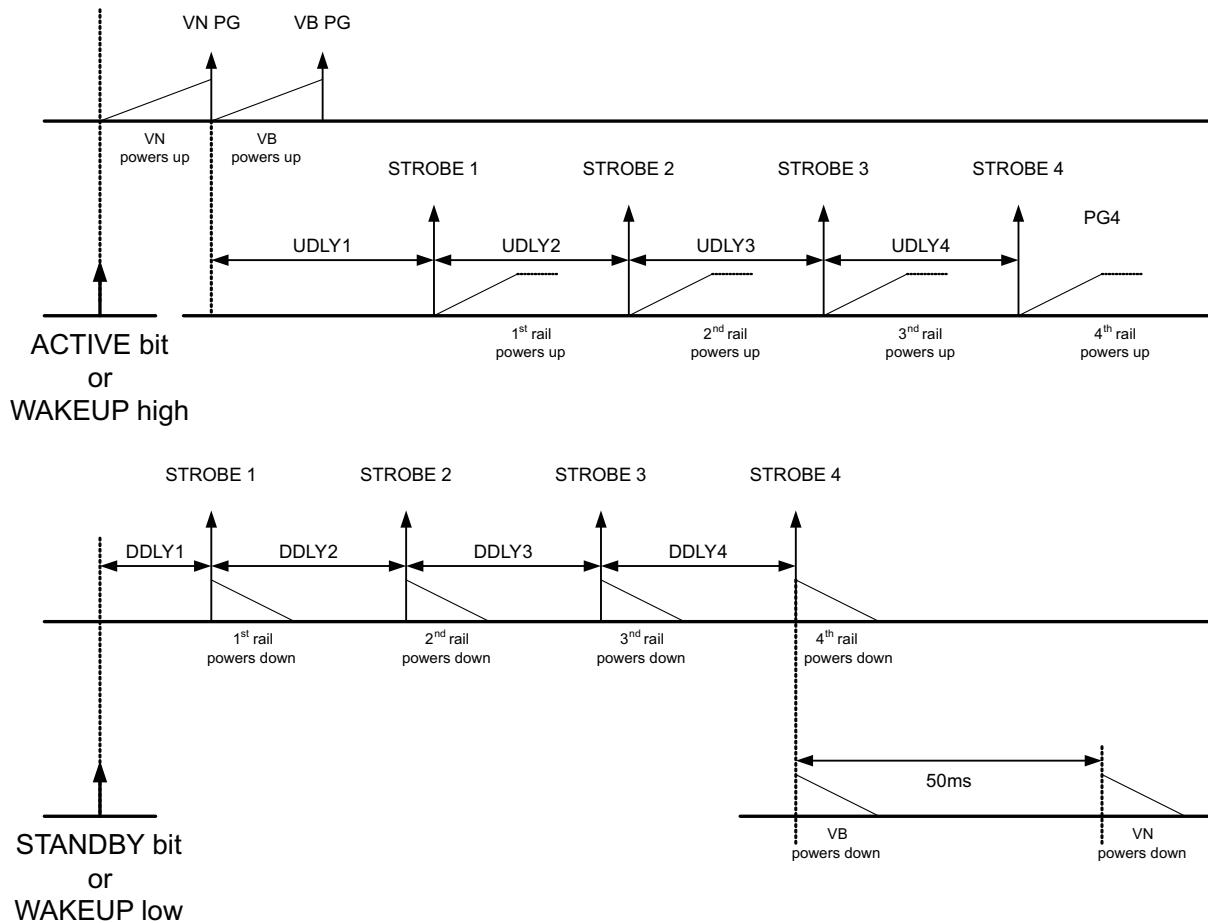
- Inverting buck-boost (DCDC2) must be in regulation before positive boost (DCDC1) can be enabled. Internally, DCDC1 enable is gated by DCDC2 power good.
- Positive boost (DCDC1) must be in regulation before LDO2 (VNEG) can be enabled. Internally LDO2 enable is gated DCDC1 power good.
- Positive boost (DCDC1) must be in regulation before VCOM can be enabled. Internally VCOM enable is gated by DCDC1 power good.
- Positive boost (DCDC1) must be in regulation before negative charge pump (CP2) can be enabled. Internally CP2 enable is gated by DCDC1 power good.
- Positive boost (DCDC1) must be in regulation before positive charge pump (CP1) can be enabled. Internally CP1 enable is gated by DCDC1 power good.
- LDO2 must be in regulation before LDO1 can be enabled. Internally LDO1 enable is gated by LDO2 power good.

## TPS65186

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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## Feature Description (continued)



**Figure 20. Power-Up and Power-Down Sequence**

### 8.3.3 Soft Start

TPS65186 supports soft start for all rails, that is, inrush current is limited during startup of DCDC1, DCDC2, LDO1, LDO2, CP1, and CP2. If DCDC1 or DCDC2 are unable to reach power-good status within 50 ms, the corresponding UV flag is set in the interrupt registers, the interrupt pin is pulled low, and the device enters STANDBY mode. LDO1, LDO2, positive and negative charge pumps also have a 50-ms power-good time-out limit. If either rail is unable to power up within 50 ms after it has been enabled, the corresponding UV flag is set and the interrupt pin is pulled low. However, the device will remain in ACTIVE mode in this case.

### 8.3.4 VPOS/VNEG Supply Tracking

LDO1 (VPOS) and LDO2 (VNEG) track each other in a way that they are of opposite sign but same magnitude. The sum of VLDO1 and VLDO2 is guaranteed to be less than 50 mV.

## Feature Description (continued)

### 8.3.5 V3P3 Power Switch

The integrated power switch is used to cut the 3.3-V supply to the EPD panel and is controlled through the V3P3\_EN pin of the ENABLE register. In SLEEP mode the switch is automatically turned off and its output is discharged to ground. The default power-up state is OFF. To turn the switch ON, set the V3P3\_ENbit to 1.

### 8.3.6 VCOM Adjustment

VCOM is the output of a power-amplifier with an output voltage range of 0 V to  $-5.11$  V, adjustable in 10-mV steps. In a typical application VCOM is connected to the VCOM terminal of the EPD panel and the amplifier is controlled through the VCOM\_CTRL pin. With VCOM\_CTRL high, the amplifier drives the VCOM pin to the voltage specified by the VCOM1 and VCOM2 register.

For ease of design, the VCOM\_CTRL pin may also be tied to the battery or IO supply. In this case, VCOM is enabled with STROBE4 during the power-up sequence and disabled on STROBE1 of the power-down sequence. Therefore VCOM is the last rail to be enabled and the first to be disabled.

#### 8.3.6.1 Kick-Back Voltage Measurement

TPS65186 can perform a voltage measurement on the VCOM pin to determine the kick-back voltage of the panel. This allows in-system calibration of VCOM. To perform a kick-back voltage measurement, follow these steps:

- Pull the WAKEUP pin and the PWRUP pin high to enable all output rails.
- Set the Hi-Z bit in the VCOM2 register. This puts the VCOM pin in a high-impedance state.
- Drive the panel with the Null waveform. Refer to E-Ink specification for detail.
- Set the ACQ bit in the VCOM2 register to 1. This starts the measurement routine.
- When the measurement is complete, the ACQC (Acquisition Complete) bit in the INT1 register is set and the nINT pin is pulled low.
- The measurement result is stored in the VCOM[8:0] bits of the VCOM1 and VCOM2 register.

The measurement result is not automatically programmed into nonvolatile memory. Changing the power-up default is described in [Storing the VCOM Power-Up Default Value in Memory](#).

#### 8.3.6.2 Storing the VCOM Power-Up Default Value in Memory

The power-up default value of VCOM can be user-set and programmed into nonvolatile memory. To do so, write the default value to the VCOM[8:0] bits of the VCOM1 and VCOM2 register, then set the PROG bit in VCOM2 register to 1. First, all power rails are shut down, then the VCOM[8:0] value is committed to nonvolatile memory such that it becomes the new power-up default. Once programming is complete, the PRGC bit in the INT1 register is set and the nINT pin is pulled low. To verify that the new value has been saved properly, first write the VCOM[8:0] bits to 0x000h, then pull the WAKEUP pin low. After the WAKEUP pin is pulled back high, read the VCOM[8:0] bits to verify that the new default value is correct.

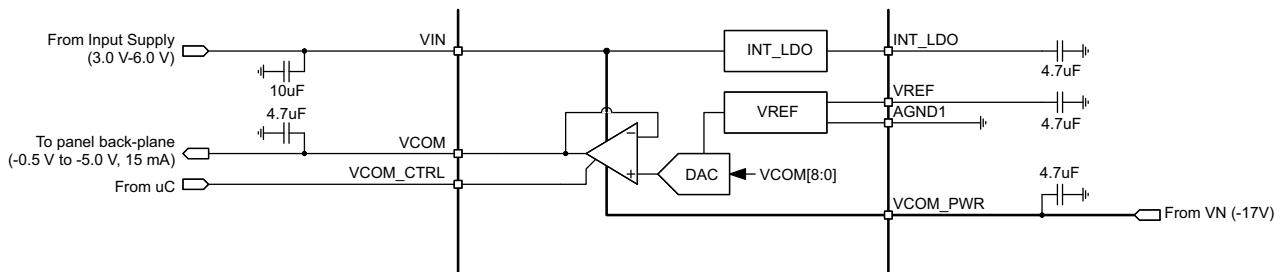


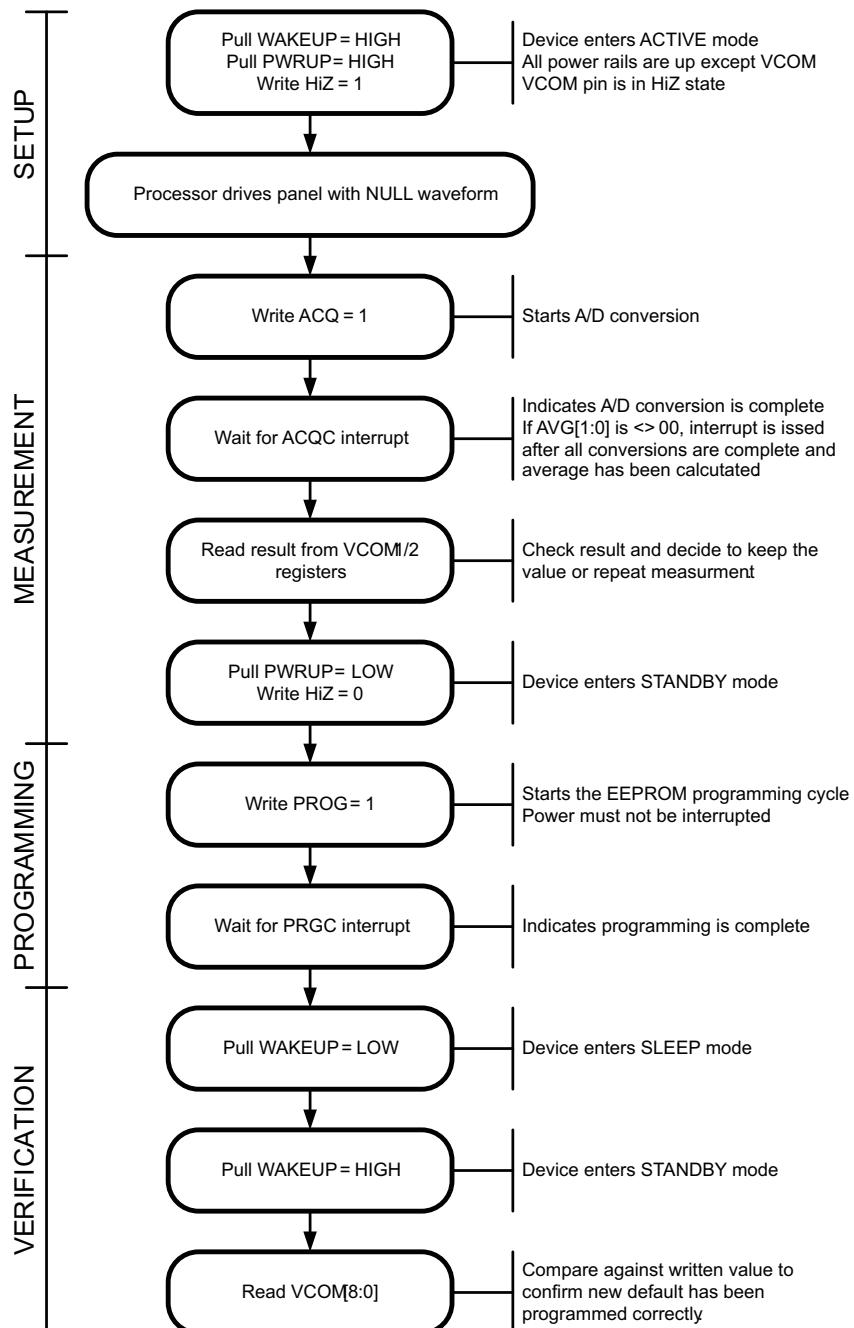
Figure 21. Block Diagram of VCOM Circuit

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**Feature Description (continued)**



**Figure 22. VCOM Calibration Flow**

## Feature Description (continued)

### 8.3.7 Fault Handling and Recovery

The TPS65186 monitors input/output voltages and die temperature; the device will take action if operating conditions are outside normal limits when the following are encountered:

- Thermal Shutdown (TSD)
- Positive Boost Undervoltage (VB\_UV)
- Inverting Buck-Boost Undervoltage (VN\_UV)
- Input Undervoltage Lockout (UVLO)

The TPS65186 shuts down all power rails and enters STANDBY mode. Shutdown follows the order defined by DWNSEQx registers. The exception is VCOM fault which leads to immediate shutdown of all rails. Once a fault is detected, the PWR\_GOOD and nINT pins are pulled low and the corresponding interrupt bit is set in the interrupt register. Power rails cannot be re-enabled unless the interrupt bits have been cleared by reading the INT1 and INT2 register. Alternatively, toggling the WAKEUP pin also resets the interrupt bits. As the PWRUP input is edge sensitive, the host must toggle the PWRUP pin to re-enable the rails through GPIO control, that is, it must bring the PWRUP pin low before asserting it again. Alternatively rails can be re-enabled through the I<sup>2</sup>C interface.

Whenever the TPS65186 encounters undervoltage on VNEG (VNEG\_UV), VPOS (VPOS\_UV), VEE (VEE\_UV), or VDDH (VDDH\_UV), rails are not shut down but the PWR\_GOOD and nINT is pulled low with the corresponding interrupt bit set. The device remains in ACTIVE mode and recovers automatically once the fault has been removed.

### 8.3.8 Power Good Pin

The power good pin (PWR\_GOOD) is an open-drain output that is pulled high (by an external pullup resistor) when all four power rails (CP1, CP2, LDO1, LDO2) are in regulation and is pulled low if any of the rails encounters a fault or is disabled. PWR\_GOOD remains low if one of the rails is not enabled by the host and only after all rails are in regulation PWR\_GOOD is released to Hi-Z state (pulled up by external resistor).

### 8.3.9 Interrupt Pin

The interrupt pin (nINT) is an open-drain output that is pulled low whenever one or more of the INT1 or INT2 bits are set. The nINT pin is released (returns to Hi-Z state) and fault bits are cleared once the register with the set bit has been read by the host. If the fault persists, the nINT pin will be pulled low again after a maximum of 32 µs.

Interrupt events can be masked by re-setting the corresponding enable bit in the INT\_EN1 and INT\_EN2 register, that is, the user can determine which events cause the nINT pin to be pulled low. The status of the enable bits affects the nINT pin only and has no effect on any of the protection and monitoring circuits or the INT1/INT2 bits themselves.

Persisting faults such as thermal shutdown can cause the nINT pin to be pulled low for an extended period of time which can keep the host in a loop trying to resolve the interrupt. If this behavior is not desired, set the corresponding mask bit after receiving the interrupt and keep polling the INT1/INT2 register to see when the fault condition has disappeared. After the fault is resolved, unmask the interrupt bit again.

### 8.3.10 Panel Temperature Monitoring

The TPS65186 provides circuitry to bias and measure an external Negative Temperature Coefficient Resistor (NTC) to monitor the display panel temperature in a range from  $-10^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  with an accuracy of  $\pm 1^{\circ}\text{C}$  from  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$ . Temperature measurement must be triggered by the controlling host and the last temperature reading is always stored in the TMST\_VALUE register. Interrupts are issued when the temperature exceeds the programmable HOT, or drops below the programmable COLD threshold, or when the temperature has changed by more than a user-defined threshold from the baseline value. Details are explained under [Hot, Cold, and Temperature-Change Interrupts](#).

**TPS65186**

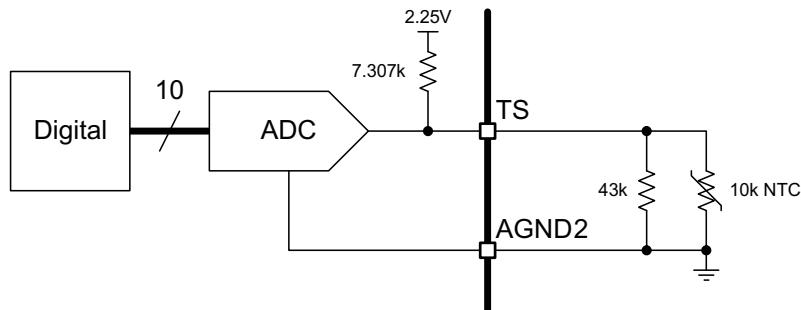
SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**Feature Description (continued)**
**8.3.10.1 NTC Bias Circuit**

Figure 23 shows the block diagram of the NTC bias and measurement circuit. The NTC is biased from an internally generated 2.25-V reference voltage through an integrated 7.307-k $\Omega$  bias resistor. A 43-k $\Omega$  resistor is connected parallel to the NTC to linearize the temperature response curve. The circuit is designed to work with a nominal 10-k $\Omega$  NTC and achieves accuracy of  $\pm 1^\circ\text{C}$  from  $0^\circ\text{C}$  to  $50^\circ\text{C}$ . The voltage drop across the NTC is digitized by a 10-bit SAR ADC and translated into an 8-bit two's complement by digital per Table 1.

**Table 1. ADC Output Value vs Temperature**

TEMPERATURE	TMST_VALUE[7:0]
< $-10^\circ\text{C}$	1111 0110
$-10^\circ\text{C}$	1111 0110
$-9^\circ\text{C}$	1111 0111
...	...
$-2^\circ\text{C}$	1111 1110
$-1^\circ\text{C}$	1111 1111
$0^\circ\text{C}$	0000 0000
$1^\circ\text{C}$	0000 0001
$2^\circ\text{C}$	0000 0010
...	...
$25^\circ\text{C}$	0001 1001
...	...
$85^\circ\text{C}$	0101 0101
> $85^\circ\text{C}$	0101 0101


**Figure 23. NTC Bias and Measurement Circuit**

A temperature measurement is triggered by setting the READ\_THERM bit of the TMST1 register to 1. During the A/D conversion the CONV\_END bit of the TMST1 register reads 0, otherwise it reads 1. At the end of the A/D conversion the EOC bit in the INT2 register is set and the temperature value is available in the TMST\_VALUE register.

### 8.3.10.2 Hot, Cold, and Temperature-Change Interrupts

Each temperature acquisition is compared against the programmable TMST\_HOT and TMST\_COLD thresholds and to the baseline temperature, to determine if the display is within allowed operating temperature range and if the temperature has changed by more than a user-defined threshold since the last update. The first temperature reading after the WAKEUP pin has been pulled high automatically becomes the baseline temperature. Any subsequent reading is compared against the baseline temperature. If the difference is equal or greater than the threshold value, an interrupt is issued (DTX bit in register INT1 is set to 1) and the latest value becomes the new baseline. If the difference is less than the threshold value, no action is taken. The threshold value is defined by DT[1:0] bits in the TMST1 register and has a default value of  $\pm 2^{\circ}\text{C}$ . In summary:

- When the temperature is equal or less than the TMST\_COLD[3:0] threshold, the TMST\_COLD interrupt bit of the INT1 register is set, and the nINT pin is pulled low.
- When the temperature is greater than TMST\_COLD but lower than TMST\_HOT, no action is taken.
- When the temperature is equal or greater than the TMST\_HOT[3:0] threshold, the TMST\_HOT interrupt bit of the INT1 register is set, and the nINT pin is pulled low.
- If the last temperature is different from the baseline temperature by  $\pm 2^{\circ}\text{C}$  (default) or more, the DTX interrupt bit of the INT1 register is set. The latest temperature becomes the new baseline temperature. By default the DTX interrupt is disabled, that is, the nINT pin is not pulled low unless the DTX\_EN bit was previously set high.
- If the last temperature change is less than  $\pm 2^{\circ}\text{C}$  (default), no action is taken.

### 8.3.10.3 Typical Application of the Temperature Monitor

In a typical application the temperature monitor and interrupts are used in the following manner:

- After the WAKEUP pin has been pulled high, the Application Processor (AP) writes 0x80h to the TMST1 register (address 0x0Dh). This starts the temperature measurement.
- The AP waits for the EOC interrupt. Alternatively the AP can poll the CONV\_END bit in register TMST1. This will notify the AP that the A/D conversion is complete and the new temperature reading is available in the TMST\_VALUE register (address 0x00h).
- The AP reads the temperature value from the TMST\_VALUE register (address 0x00h).
- If the temperature changes by  $\pm 2^{\circ}\text{C}$  (default) or more from the first reading, the processor is notified by the DTX interrupt. The A/P may or may not decide to select a different set of waveforms to drive the panel.
- If the temperature is outside the allowed operating range of the panel, the processor is notified by the THOT and TCOLD interrupts, respectively. The processor may or may not decide to continue with the page update.
- When an overtemperature or undertemperature has been detected, the AP must reset the TMST\_HOT\_EN or TMST\_COLD\_EN bits, respectively, to avoid the nINT pin to be continuously pulled low. The TMST\_HOT and TMST\_COLD interrupt bits then must be polled continuously, to determine when the panel temperature recovers to the normal operating range. Once the temperature has recovered, the TMST\_HOT\_EN or TMST\_COLD\_EN bits must be set to 1 again and normal operation can resume.

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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## 8.4 Device Functional Modes

The TPS65186 has three modes of operation, SLEEP, STANDBY, and ACTIVE. SLEEP mode is the lowest-power mode in which all internal circuitry is turned off. In STANDBY, all power rails are shut down but the device is ready to accept commands through the I<sup>2</sup>C interface. In ACTIVE mode one or more power rails are enabled.

### 8.4.1 SLEEP

This is the lowest power mode of operation. All internal circuitry is turned off, registers are reset to default values and the device does not respond to I<sup>2</sup>C communications. TPS65186 enters SLEEP mode whenever WAKEUP pin is pulled low.

### 8.4.2 STANDBY

In STANDBY all internal support circuitry is powered up and the device is ready to accept commands through the I<sup>2</sup>C interface but none of the power rails are enabled. The device enters STANDBY mode when the WAKEUP pin is pulled high and either the PWRUP pin is pulled low or the STANDBY bit is set. The device also enters STANDBY mode if input undervoltage lockout (UVLO), positive boost undervoltage (VB\_UV), or inverting buck-boost undervoltage (VN\_UV) is detected, thermal shutdown occurs, or the PROG bit is set (see [Figure 22](#))

### 8.4.3 ACTIVE

The device is in ACTIVE mode when any of the output rails are enabled and no fault condition is present. This is the normal mode of operation while the device is powered up.

### 8.4.4 Mode Transitions

#### 8.4.4.1 SLEEP → ACTIVE

WAKEUP pin is pulled high with PWRUP pin high. Rails come up in the order defined by the UPSEQx registers (OK to tie WAKEUP and PWRUP pin together).

#### 8.4.4.2 SLEEP → STANDBY

WAKEUP pin is pulled high with PWRUP pin low. Rails will remain powered down.

#### 8.4.4.3 STANDBY → ACTIVE

WAKEUP pin is high and PWRRUP pin is pulled high (rising edge) or the ACTIVE bit is set. Output rails will power up in the order defined by the UPSEQx registers.

#### 8.4.4.4 ACTIVE → STANDBY

WAKEUP pin is high and STANDBY bit is set or PWRUP pin is pulled low (falling edge). Rails are shut down in the order defined by DWNSEQx registers. Device also enters STANDBY in the event of thermal shutdown (TSD), undervoltage lockout (UVLO), positive boost or inverting buck-boost undervoltage (UV), VCOM fault (VCOMF), or when the PROG bit is set (see [Figure 22](#)).

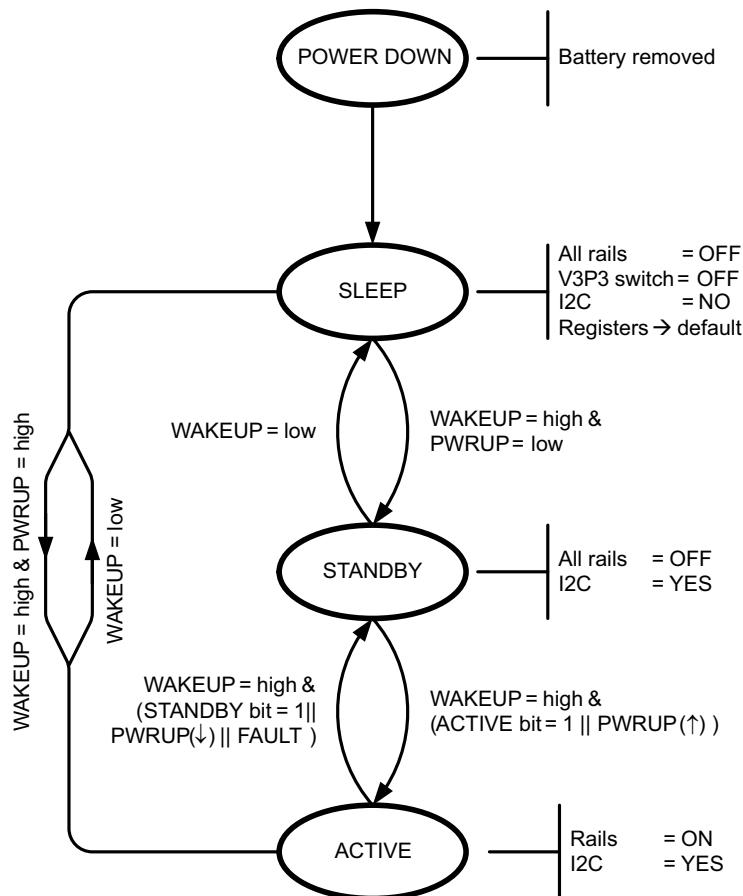
#### 8.4.4.5 STANDBY → SLEEP

WAKEUP pin is pulled low while none of the output rails are enabled.

#### 8.4.4.6 ACTIVE → SLEEP

WAKEUP pin is pulled low while at least one output rail is enabled. Rails are shut down in the order defined by DWNSEQx registers.

## Device Functional Modes (continued)



### NOTES:

||, & = logic OR, and AND.  
 $(\uparrow), (\downarrow)$  = rising edge, falling edge  
 UVLO = Undervoltage Lockout  
 TSD = Thermal Shutdown  
 UV = Undervoltage  
 FAULT = UVLO || TSD || BOOST UV || VCOM fault

**Figure 24. Global State Diagram**

# TPS65186

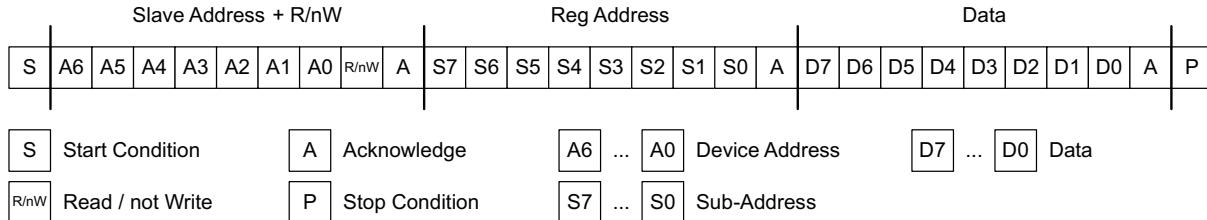
SLVSB04A –JULY 2011–REVISED AUGUST 2015

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## 8.5 Programming

### 8.5.1 I<sup>2</sup>C Bus Operation

The TPS65186 hosts a slave I<sup>2</sup>C interface that supports data rates up to 400 kbit/s and auto-increment addressing and is compliant to I<sup>2</sup>C standard 3.0.



**Figure 25. Subaddress in I<sup>2</sup>C Transmission**

The I<sup>2</sup>C Bus is a communications link between a controller and a series of slave terminals. The link is established using a two-wire bus consisting of a serial clock signal (SCL) and a serial data signal (SDA). The serial clock is sourced from the controller in all cases where the serial data line is bidirectional for data communication between the controller and the slave terminals. Each device has an open drain output to transmit data on the serial data line. An external pullup resistor must be placed on the serial data line to pull the drain output high during data transmission.

Data transmission is initiated with a start bit from the controller as shown in [Figure 27](#). The start condition is recognized when the SDA line transitions from high to low during the high portion of the SCL signal. Upon reception of a start bit, the device will receive serial data on the SDA input and check for valid address and control information. If the appropriate slave address bits are set for the device, then the device will issue an acknowledge pulse and prepare to receive the register address. Depending on the R/nW bit, the next byte received from the master is written to the addressed register ( $R/nW = 0$ ) or the device responds with 8-bit data from the register ( $R/nW = 1$ ). Data transmission is completed by either the reception of a stop condition or the reception of the data word sent to the device. A stop condition is recognized as a low to high transition of the SDA input during the high portion of the SCL signal. All other transitions of the SDA line must occur during the low portion of the SCL signal. An acknowledge is issued after the reception of valid address, sub-address and data words. The I<sup>2</sup>C interfaces will auto-sequence through register addresses, so that multiple data words can be sent for a given I<sup>2</sup>C transmission. See [Figure 26](#) and [Figure 27](#) for details.

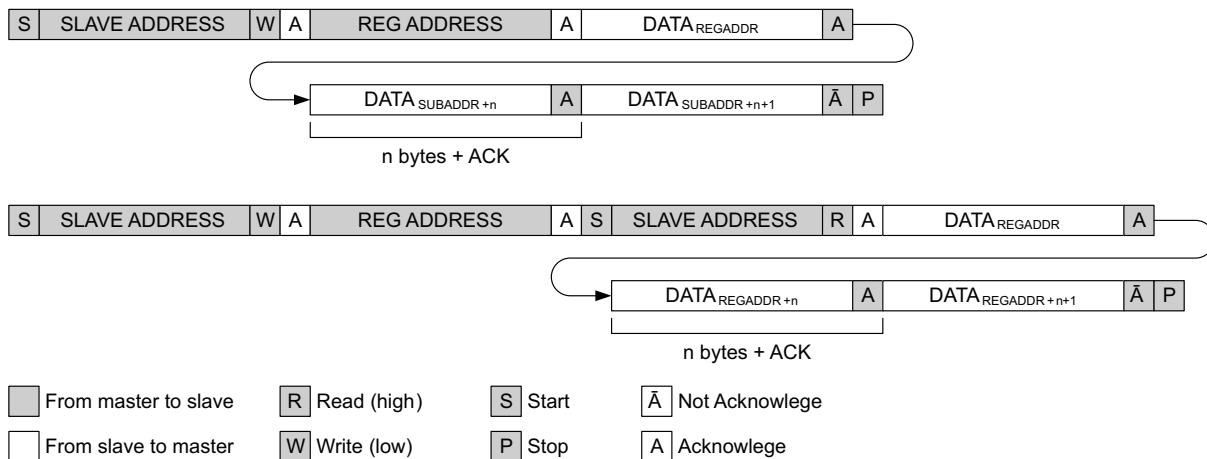
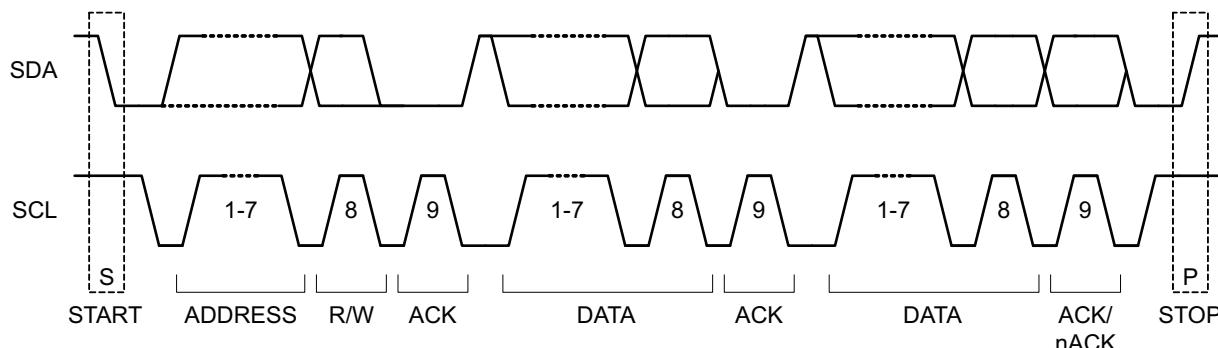


Figure 26. I<sup>2</sup>C Data Protocol

## Programming (continued)



**Figure 27. I<sup>2</sup>C Start/Stop/Acknowledge Protocol**

## 8.6 Register Maps

REGISTER	ADDRESS (HEX)	NAME	DESCRIPTION
0	0x00	TMST_VALUE	Thermistor value read by ADC
1	0x01	ENABLE	Enable/disable bits for regulators
2	0x02	VADJ	VPOS/VNEG voltage adjustment
3	0x03	VCOM1	Voltage settings for VCOM
4	0x04	VCOM2	Voltage settings for VCOM + control
5	0x05	INT_EN1	Interrupt enable group1
6	0x06	INT_EN2	Interrupt enable group2
7	0x07	INT1	Interrupt group1
8	0x08	INT2	Interrupt group2
9	0x09	UPSEQ0	Power-up strobe assignment
10	0x0A	UPSEQ1	Power-up sequence delay times
11	0x0B	DWNSEQ0	Power-down strobe assignment
12	0x0C	DWNSEQ1	Power-down sequence delay times
13	0x0D	TMST1	Thermistor configuration
14	0x0E	TMST2	Thermistor hot temp set
15	0x0F	PG	Power good status each rails
16	0x10	REVID	Device revision ID information

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.1 Thermistor Readout (TMST\_VALUE)**

Address – 0x00h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	TMST_VALUE[7:0]							
READ/WRITE	R	R	R	R	R	R	R	R
RESET VALUE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

FIELD NAME	BIT DEFINITION
TMST_VALUE[7:0]	Temperature read-out 1111 0110 – < -10°C 1111 0110 – -10°C 1111 0111 – -9°C ... 1111 1110 – -2°C 1111 1111 – -1 °C 0000 0000 – 0 °C 0000 0001 – 1°C 0000 0010 – 2°C ... 0001 1001 – 25°C ... 0101 0101 – 85°C 0101 0101 – > 85°C

### 8.6.2 Enable (ENABLE)

Address – 0x01h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	ACTIVE	STANDBY	V3P3_EN	VCOM_EN	VDDH_EN	VPOS_EN	VEE_EN	VNEG_EN
READ/WRITE	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
RESET VALUE	0	0	0	0	0	0	0	0

FIELD NAME	BIT DEFINITION <sup>(1)</sup>
ACTIVE	STANDBY to ACTIVE transition bit 1 – Transition from STANDBY to ACTIVE mode. Rails power up as defined by UPSEQx registers 0 – no effect NOTE: After transition bit is cleared automatically
STANDBY	STANDBY to ACTIVE transition bit 1 – Transition from STANDBY to ACTIVE mode. Rails power up as defined by DWNSEQx registers 0 – no effect NOTE: After transition bit is cleared automatically. STANDBY bit has priority over ACTIVE.
V3P3_EN	VIN3P3 to V3P3 switch enable 1 – switch is ON 0 – switch is OFF
VCOM_EN	VCOM buffer enable 1 – enabled 0 – disabled
VDDH_EN	VDDH charge pump enable 1 – enabled 0 – disabled
VPOS_EN	VPOS LDO regulator enable 1 – enabled 0 – disabled NOTE: VPOS cannot be enabled before VNEG is enabled.
VEE_EN	VEE charge pump enable 1 – enabled 0 – disabled
VNEG_EN	VNEG LDO regulator enable 1 – enabled 0 – disabled NOTE: When VNEG is disabled VPOS will also be disabled.

(1) Enable bits always reflect actual status of the corresponding rail.

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.3 Voltage Adjustment Register (VADJ)**

Address – 0x02h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	not used	VSET[2:0]						
READ/WRITE	R/W	R/W	R/W	R/W	R	R/W	R/W	R/W
RESET VALUE	0	0	1	0	0	$0^{E2}$	$1^{E2}$	$1^{E2}$

FIELD NAME	BIT DEFINITION
not used	N/A
VSET[2:0]	VPOS and VNEG voltage setting 000 - not valid 001 - not valid 010 - not valid 011 - $\pm 15.000$ V 100 - $\pm 14.750$ V 101 - $\pm 14.500$ V 110 - $\pm 14.250$ V 111 - reserved

**8.6.4 VCOM 1 (VCOM1)**

Address – 0x03h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	VCOM [7:0]							
READ/WRITE	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
RESET VALUE	$0^{E2}$	$1^{E2}$	$1^{E2}$	$1^{E2}$	1	1	0	1

FIELD NAME	BIT DEFINITION
VCOM[7:0]	VCOM voltage, least significant byte. See <a href="#">VCOM 2 (VCOM2)</a> for details.

### 8.6.5 VCOM 2 (VCOM2)

Address – 0x04h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
<b>FIELD NAME</b>	ACQ	PROG	HiZ	AVG[1:0]		not used	not used	VCOM[8]
<b>READ/WRITE</b>	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
<b>RESET VALUE</b>	0	0	0	0	0	1	0	0 <sup>E2</sup>

FIELD NAME	BIT DEFINITION
ACQ	<p>Kick-back voltage acquisition bit 1 – starts kick-back voltage measurement routine 0 – no effect NOTE: After measurement is complete bit is cleared automatically and measurement result is reflected in VCOM[8:0] bits.</p>
PROG	<p>VCOM programming bit 1 – VCOM[8:0] value is committed to nonvolatile memory and becomes new power-up default 0 – no effect NOTE: After programming bit is cleared automatically and TPS65186 will enter STANDBY mode.</p>
HiZ	<p>VCOM HiZ bit 1 – VCOM pin is placed into hi-impedance state to allow VCOM measurement 0 – VCOM amplifier is connected to VCOM pin</p>
AVG[1:0]	<p>Number of acquisitions that is averaged to a single kick-back voltage measurement 00 – 1x 01 – 2x 10 – 4x 11 – 8x NOTE: When the ACQ bit is set, the state machine repeat the A/D conversion of the kick-back voltage AVG[1:0] times and returns a single, averaged, value to VCOM[8:0]</p>
not used	N/A
not used	N/A
VCOM[8:0]	<p>VCOM voltage adjustment VCOM = VCOM[8:0] x -10 mV in the range from 0 mV to -5.110 V 0x000h – 0 0000 0000 – -0 mV 0x001h – 0 0000 0001 – -10 mV 0x002h – 0 0000 0010 – -20 mV ... 0x07Dh – 0 0111 1101 – -1250 mV ... 0x1FEh – 1 1111 1110 – -5100 mV 0x1FFh – 1 1111 1111 – -5110 mV</p>

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.6 Interrupt Enable 1 (INT\_EN1)**

Address – 0x05h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	DTX_EN	TSD_EN	HOT_EN	TMST_HOT_EN	TMST_COLD_EN	UVLO_EN	ACQC_EN	PRGC_EN
READ/WRITE	R	R/W	R/W	R/W	R/W	R/W	R	R
RESET VALUE	0	1	1	1	1	1	1	1

FIELD NAME	BIT DEFINITION <sup>(1)</sup>
DTX_EN	Panel temperature-change interrupt enable 1 – enabled 0 – disabled
TSD_EN	Thermal shutdown interrupt enable 1 – enabled 0 – disabled
HOT_EN	Thermal shutdown early warning enable 1 – enabled 0 – disabled
TMST_HOT_EN	Thermistor hot interrupt enable 1 – enabled 0 – disabled
TMST_COLD_EN	Thermistor cold interrupt enable 1 – enabled 0 – disabled
UVLO_EN	VIN undervoltage detect interrupt enable 1 – enabled 0 – disabled
ACQC_EN	VCOM acquisition complete interrupt enable 1 – enabled 0 – disabled
PRGC_EN	VCOM programming complete interrupt enable 1 – enabled 0 – disabled

(1) Enabled means nINT pin is pulled low when interrupt occurs.

Disabled means nINT pin is not pulled low when interrupt occurs.

### 8.6.7 Interrupt Enable 2 (INT\_EN2)

Address – 0x06h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	VBUVEN	VDDHUVEN	VNUV_EN	VPOSUVEN	VEEUVEN	VCOMFEN	VNEGUVEN	EOCEN
READ/WRITE	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
RESET VALUE	1	1	1	1	1	1	1	1

FIELD NAME	BIT DEFINITION <sup>(1)</sup>
VBUVEN	Positive boost converter undervoltage detect interrupt enable 1 – enabled 0 – disabled
VDDHUVEN	VDDH undervoltage detect interrupt enable 1 – enabled 0 – disabled
VNUV_EN	Inverting buck-boost converter undervoltage detect interrupt enable 1 – enabled 0 – disabled
VPOSUVEN	VPOS undervoltage detect interrupt enable 1 – enabled 0 – disabled
VEEUVEN	VEE undervoltage detect interrupt enable 1 – enabled 0 – disabled
VCOMFEN	VCOM FAULT interrupt enable 1 – enabled 0 – disabled
VNEGUVEN	VNEG undervoltage detect interrupt enable 1 – enabled 0 – disabled
EOCEN	Temperature ADC end of conversion interrupt enable 1 – enabled 0 – disabled

(1) Enabled means nINT pin is pulled low when interrupt occurs.  
Disabled means nINT pin is not pulled low when interrupt occurs.

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.8 Interrupt 1 (INT1)**

Address – 0x07h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	DTX	TSD	HOT	TMST_HOT	TMST_COLD	UVLO	ACQC	PRGC
READ/WRITE	R	R	R	R	R	R	R	R
RESET VALUE	0	N/A	N/A	N/A	N/A	N/A	0	0

FIELD NAME	BIT DEFINITION
DTX	Panel temperature-change interrupt 1 – temperature has changed by 3 deg or more over previous reading 0 – no significance
TSD	Thermal shutdown interrupt 1 – chip is in overtemperature shutdown 0 – no fault
HOT	Thermal shutdown early warning 1 – chip is approaching overtemperature shutdown 0 – no fault
TMST_HOT	Thermistor hot interrupt 1 – thermistor temperature is equal or greater than TMST_HOT threshold 0 – no fault
TMST_COLD	Thermistor cold interrupt 1 – thermistor temperature is equal or less than TMST_COLD threshold 0 – no fault
UVLO	VIN undervoltage detect interrupt 1 – input voltage is below UVLO threshold 0 – no fault
ACQC	VCOM acquisition complete 1 – VCOM measurement is complete 0 – no significance
PRGC	VCOM programming complete 1 – VCOM programming is complete 0 – no significance

### 8.6.9 Interrupt 2 (INT2)

Address – 0x08h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	VB_UV	VDDH_UV	VN_UV	VPOS_UV	VEE_UV	VCOMF	VNEG_UV	EOC
READ/WRITE	R	R	R	R	R	R	R	R
RESET VALUE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

FIELD NAME	BIT DEFINITION
VB_UV	Positive boost converter undervoltage detect interrupt 1 – under-voltage on DCDC1 detected 0 – no fault
VDDH_UV	VDDH undervoltage detect interrupt 1 – undervoltage on VDDH charge pump detected 0 – no fault
VN_UV	Inverting buck-boost converter undervoltage detect interrupt 1 – undervoltage on DCDC2 detected 0 – no fault
VPOS_UV	VPOS undervoltage detect interrupt 1 – undervoltage on LDO1(VPOS) detected 0 – no fault
VEE_UV	VEE undervoltage detect interrupt 1 – undervoltage on VEE charge pump detected 0 – no fault
VCOMF	VCOM fault detection 1 – fault on VCOM detected (VCOM is outside normal operating range) 0 – no fault
VNEG_UV	VNEG undervoltage detect interrupt 1 – undervoltage on LDO2(VNEG) detected 0 – no fault
EOC	ADC end of conversion interrupt 1 – ADC conversion is complete (temperature acquisition is complete) 0 – no significance

**TPS65186**

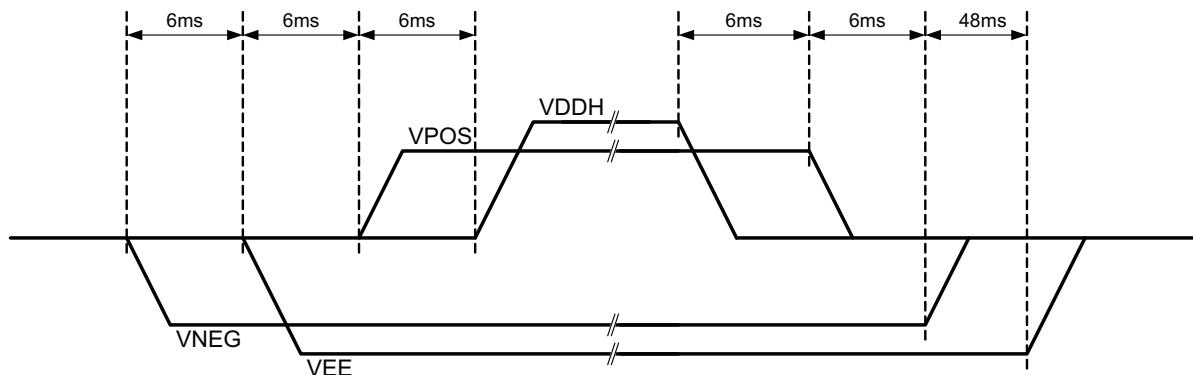
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**8.6.10 Power Up Sequence Register 0 (UPSEQ0)**

Address – 0x09h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	VDDH_UP[1:0]		VPOS_UP[1:0]		VEE_UP[1:0]		VNEG_UP[1:0]	
READ/WRITE	R/W							
RESET VALUE	1 <sup>E2</sup>	1 <sup>E2</sup>	1 <sup>E2</sup>	0 <sup>E2</sup>	0 <sup>E2</sup>	1 <sup>E2</sup>	0 <sup>E2</sup>	0 <sup>E2</sup>

FIELD NAME	BIT DEFINITION
VDDH_UP[1:0]	VDDH power-up order 00 – power up on STROBE1 01 – power up on STROBE2 10 – power up on STROBE3 11 – power up on STROBE4
VPOS_UP[1:0]	VPOS power-up order 00 – power up on STROBE1 01 – power up on STROBE2 10 – power up on STROBE3 11 – power up on STROBE4
VEE_UP[1:0]	VEE power-up order 00 – power up on STROBE1 01 – power up on STROBE2 10 – power up on STROBE3 11 – power up on STROBE4
VNEG_UP[1:0]	VNEG power-up order 00 – power up on STROBE1 01 – power up on STROBE2 10 – power up on STROBE3 11 – power up on STROBE4


**Figure 28. Default Power-Up/Power-Down Sequence**

### 8.6.11 Power Up Sequence Register 1 (UPSEQ1)

Address – 0x0Ah

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	UDLY4[1:0]		UDLY3[1:0]		UDLY2[1:0]		UDLY1[1:0]	
READ/WRITE	R/W							
RESET VALUE	0 <sup>E2</sup>	1 <sup>E2</sup>						

FIELD NAME	BIT DEFINITION
UDLY4[1:0]	DLY4 delay time set; defines the delay time from STROBE3 to STROBE4 during power up. 00 – 3 ms 01 – 6 ms 10 – 9 ms 11 – 12 ms
UDLY3[1:0]	DLY3 delay time set; defines the delay time from STROBE2 to STROBE3 during power up. 00 – 3 ms 01 – 6 ms 10 – 9 ms 11 – 12 ms
UDLY2[1:0]	DLY2 delay time set; defines the delay time from STROBE1 to STROBE2 during power up. 00 – 3 ms 01 – 6 ms 10 – 9 ms 11 – 12 ms
UDLY1[1:0]	DLY1 delay time set; defines the delay time from VN_PG high to STROBE1 during power up. 00 – 3 ms 01 – 6 ms 10 – 9 ms 11 – 12 ms

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.12 Power Down Sequence Register 0 (DWNSEQ0)**

Address – 0x0Bh

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	VDDH_DWN[1:0]		VPOS_DWN[1:0]		VEE_DWN[1:0]		VNEG_DWN[1:0]	
READ/WRITE	R/W							
RESET VALUE	0 <sup>E2</sup>	0 <sup>E2</sup>	0 <sup>E2</sup>	1 <sup>E2</sup>	1 <sup>E2</sup>	1 <sup>E2</sup>	1 <sup>E2</sup>	0 <sup>E2</sup>

FIELD NAME	BIT DEFINITION
VDDH_DWN[1:0]	VDDH power-down order 00 – power down on STROBE1 01 – power down on STROBE2 10 – power down on STROBE3 11 – power down on STROBE4
VPOS_DWN[1:0]	VPOS power-down order 00 – power down on STROBE1 01 – power down on STROBE2 10 – power down on STROBE3 11 – power down on STROBE4
VEE_DWN[1:0]	VEE power-down order 00 – power down on STROBE1 01 – power down on STROBE2 10 – power down on STROBE3 11 – power down on STROBE4
VNEG_DWN[1:0]	VNEG power-down order 00 – power down on STROBE1 01 – power down on STROBE2 10 – power down on STROBE3 11 – power down on STROBE4

### 8.6.13 Power Down Sequence Register 1 (DWNSEQ1)

Address – 0x0Ch

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	DDLY4[1:0]		DDLY3[1:0]		DDLY2[1:0]		DDLY1	DFCTR
READ/WRITE	R/W							
RESET VALUE	1 <sup>E2</sup>	1 <sup>E2</sup>	1 <sup>E2</sup>	0 <sup>E2</sup>				

FIELD NAME	BIT DEFINITION
DDLY4[1:0]	DLY4 delay time set; defines the delay time from STROBE3 to STROBE4 during power down. 00 – 6 ms 01 – 12 ms 10 – 24 ms 11 – 48 ms
DDLY3[1:0]	DLY3 delay time set; defines the delay time from STROBE2 to STROBE3 during power down. 00 – 6 ms 01 – 12 ms 10 – 24 ms 11 – 48 ms
DDLY2[1:0]	DLY2 delay time set; defines the delay time from STROBE1 to STROBE2 during power down. 00 – 6 ms 01 – 12 ms 10 – 24 ms 11 – 48 ms
DDLY1	DLY2 delay time set; defines the delay time from WAKEUP low to STROBE1 during power down. 0 – 3 ms 1 – 6 ms
DFCTR	At power-down delay time DLY2[1:0], DLY3[1:0], DLY4[1:0] are multiplied with DFCTR[1:0] 0 – 1x 1 – 16x

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.14 Thermistor Register 1 (TMST1)**

Address – 0x0Dh

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	READ_THERM	not used	CONV_END	not used	not used	not used	DT[1:0]	
READ/WRITE	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W
RESET VALUE	0	0	1	0	0	0	0	0

FIELD NAME	BIT DEFINITION
READ_THERM	Read thermistor value 1 – initiates temperature acquisition 0 – no effect NOTE: Bit is self-cleared after acquisition is completed
not used	N/A
CONV_END	ADC conversion done flag 1 – conversion is finished 0 – conversion is not finished
not used	N/A
not used	N/A
DT[1:0]	Panel temperature-change interrupt threshold 00 – 2°C 01 – 3°C 10 – 4°C 11 – 5°C DTX interrupt is issued when difference between most recent temperature reading and baseline temperature is equal to or greater than threshold value. See <a href="#">Hot, Cold, and Temperature-Change Interrupts</a> for details.

### 8.6.15 Thermistor Register 2 (TMST2)

Address – 0x0Eh

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	TMST_COLD[3:0]				TMST_HOT[3:0]			
READ/WRITE	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
RESET VALUE	0	1	1	1	1	0	0	0

FIELD NAME	BIT DEFINITION
TMST_COLD [3:0]	<p>Thermistor COLD threshold</p> <p>0000 – -7°C</p> <p>0001 – -6°C</p> <p>0010 – -5°C</p> <p>0011 – -4°C</p> <p>0100 – -3°C</p> <p>0101 – -2°C</p> <p>0110 – -1°C</p> <p>0111 – 0°C</p> <p>1000 – 1°C</p> <p>1001 – 2°C</p> <p>1010 – 3°C</p> <p>1011 – 4°C</p> <p>1100 – 5°C</p> <p>1101 – 6°C</p> <p>1110 – 7°C</p> <p>1111 – 8°C</p> <p>NOTE: An interrupt is issued when thermistor temperature is equal or less than COLD threshold</p>
TMST_HOT [3:0]	<p>Thermistor HOT threshold</p> <p>0000 – 42°C</p> <p>0001 – 43°C</p> <p>0010 – 44°C</p> <p>0011 – 45°C</p> <p>0100 – 46°C</p> <p>0101 – 47°C</p> <p>0110 – 48°C</p> <p>0111 – 49°C</p> <p>1000 – 50°C</p> <p>1001 – 51°C</p> <p>1010 – 52°C</p> <p>1011 – 53°C</p> <p>1100 – 54°C</p> <p>1101 – 55°C</p> <p>1110 – 56°C</p> <p>1111 – 57°C</p> <p>NOTE: An interrupt is issued when thermistor temperature is equal or greater than HOT threshold</p>

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

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**8.6.16 Power Good Status (PG)**

Address – 0x0Fh

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
FIELD NAME	VB_PG	VDDH_PG	VN_PG	VPOS_PG	VEE_PG	not used	VNEG_PG	not used
READ/WRITE	R	R	R	R	R	R	R	R
RESET VALUE	0	0	0	0	0	0	0	0

FIELD NAME	BIT DEFINITION <sup>(1)</sup>
VB_PG	Positive boost converter power good 1 – DCDC1 is in regulation 0 – DCDC1 is not in regulation or turned off
VDDH_PG	VDDH power good 1 – VDDH charge pump is in regulation 0 – VDDH charge pump is not in regulation or turned off
VN_PG	Inverting buck-boost power good 1 – DCDC2 is in regulation 0 – DCDC2 is not in regulation or turned off
VPOS_PG	VPOS power good 1 – LDO1(VPOS) is in regulation 0 – LDO1(VPOS) is not in regulation or turned off
VEE_PG	VEE power good 1 – VEE charge pump is in regulation 0 – VEE charge pump is not in regulation or turned off
not used	N/A
VNEG_PG	VNEG power good 1 – LDO2(VNEG) is in regulation 0 – LDO2(VNEG) is not in regulation or turned off
not used	N/A

(1) PG pin is pulled hi (Hi-Z state) when VDDH\_PG = VPOS\_PG = VEE\_PG = VNEG\_PG = 1

### 8.6.17 Revision and Version Control (REVID)

Address – 0x10h

DATA BIT	D7	D6	D5	D4	D3	D2	D1	D0
<b>FIELD NAME</b>	REVID[7:0]							
<b>READ/WRITE</b>	R	R	R	R	R	R	R	R
<b>RESET VALUE</b>	0	1	0	0	0 <sup>E2</sup>	1 <sup>E2</sup>	0 <sup>E2</sup>	1 <sup>E2</sup>

FIELD NAME	BIT DEFINITION
REVID[7:6]	MJREV
REVID[5:4]	MNREV
REVID[3:0]	VERSION
REVID [7:0]	0100 0101 - TPS65186 1p0 0101 0101 – TPS65186 1p1 0110 0101 – TPS65186 1p2

## 9 Application and Implementation

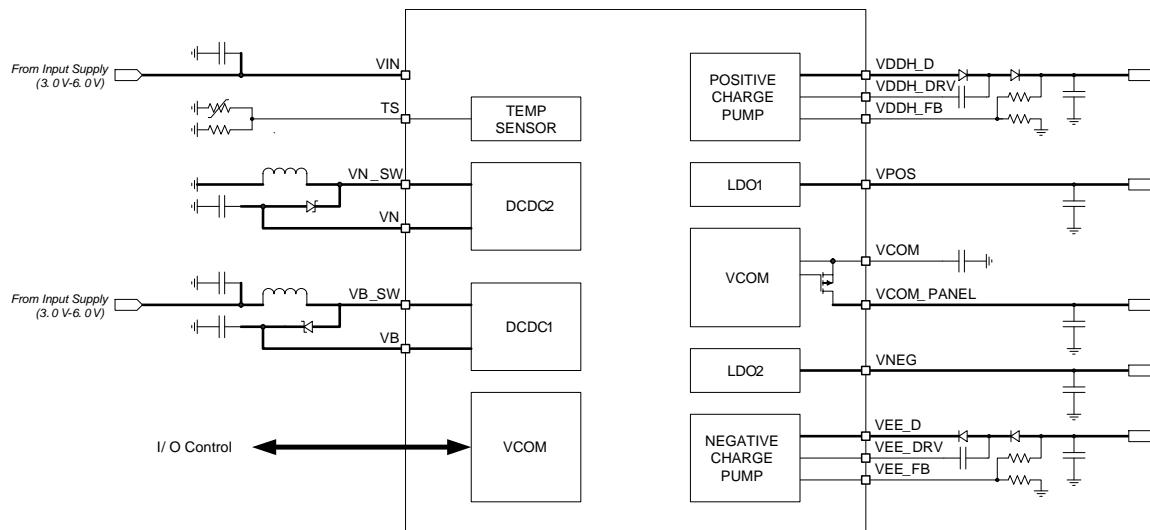
### NOTE

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.

### 9.1 Application Information

The TPS65186 is used to power display screens in E-book applications, specifically E-Ink Vizplex display, by connecting the screen to the positive and negative charge pump, LDOs 1 and 2, and VCOM rails. The display screens size that can be supported up to 9.7 inches.

### 9.2 Typical Application



#### 9.2.1 Design Requirements

For this design example, use the parameters listed in **Table 2** as the input parameters.

**Table 2. Design Parameters**

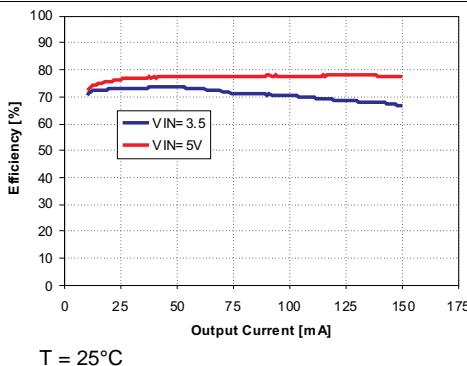
	VOLTAGE	SEQUENCE (STROBE)
VNEG (LDO2)	-15 V	1
VEE (Charge pump 2)	-20 V	2
VPOS (LDO1)	15 V	3
VDDH (Charge pump 1)	22 V	4

### 9.2.2 Detailed Design Procedure

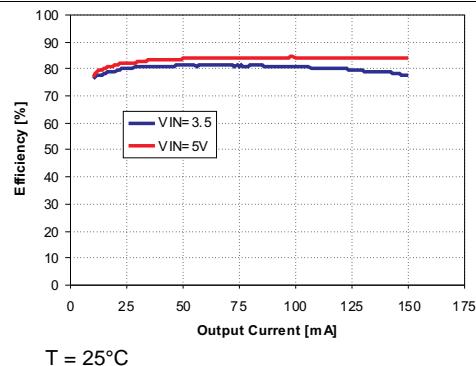
**Table 3. Recommended External Components**

PART NUMBER	VALUE	SIZE	MANUFACTURER
<b>INDUCTORS</b>			
LQH44PN4R7MP0	4.7 $\mu$ H	4 mm x 4 mm x 1.65 mm	Murata
NR4018T4R7M	4.7 $\mu$ H	4 mm x 4 mm x 1.8 mm	Taiyo Yuden
VLS252015ET-2R2M	2.2 $\mu$ H	2 mm x 2.5 mm x 1.5 mm	TDK
NR4012T2R2M	2.2 $\mu$ H	4 mm x 4 mm x 1.2 mm	Taiyo Yuden
<b>CAPACITORS</b>			
GRM21BC81E475KA12L	4.7 $\mu$ F, 25 V, X6S	805	Murata
GRM32ER71H475KA88L	4.7 $\mu$ F, 50 V, X7R	1210	Murata
All other capacitors	X5R or better	—	—
<b>DIODES</b>			
BAS3010	—	SOD-323	Infineon
MBR130T1	—	SOD-123	ON-Semi
BAV99	—	SOT-23	Fairchild
<b>THERMISTOR</b>			
NCP18XH103F03RB	10 k $\Omega$	603	Murata

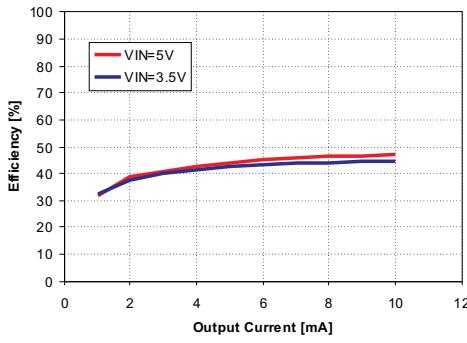
### 9.2.3 Application Curves



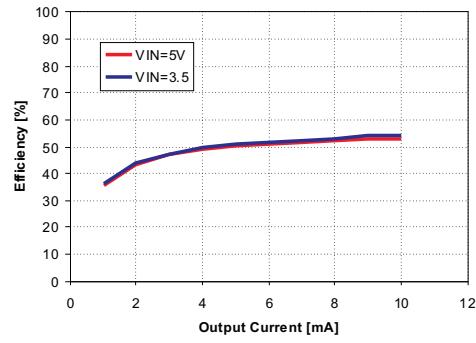
**Figure 29. VN DCDC Efficiency**



**Figure 30. VB DCDC Efficiency**



**Figure 31. VEE Charge Pump Efficiency**



**Figure 32. VDDH Charge Pump Efficiency**

**TPS65186**

SLVSB04A – JULY 2011 – REVISED AUGUST 2015

[www.ti.com](http://www.ti.com)

## 10 Power Supply Recommendations

The device is designed to operate with an input voltage supply range from 3 V to 6 V. This input supply can be from an externally regulated supply. If the input supply is located more than a few inches from the TPS65186, additional bulk capacitance may be required in addition to the ceramic bypass capacitors. An electrolytic capacitor with a value of 10  $\mu$ F is a typical choice.

## 11 Layout

### 11.1 Layout Guidelines

1. PBKG (Die substrate) must connect to VN (-16 V) with short, wide trace. Wide copper trace will improve heat dissipation.
2. PowerPad is internally connected to PBKG and must not be connected to ground, but connected to VN with a short wide copper trace.
3. Inductor traces must be kept on the PCB top layer free of any vias.
4. Feedback traces must be routed away from any potential noise source to avoid coupling.
5. Output caps must be placed immediately at output pin.
6. Vin pins must be bypassed to ground with low ESR ceramic bypass capacitors.

### 11.2 Layout Example

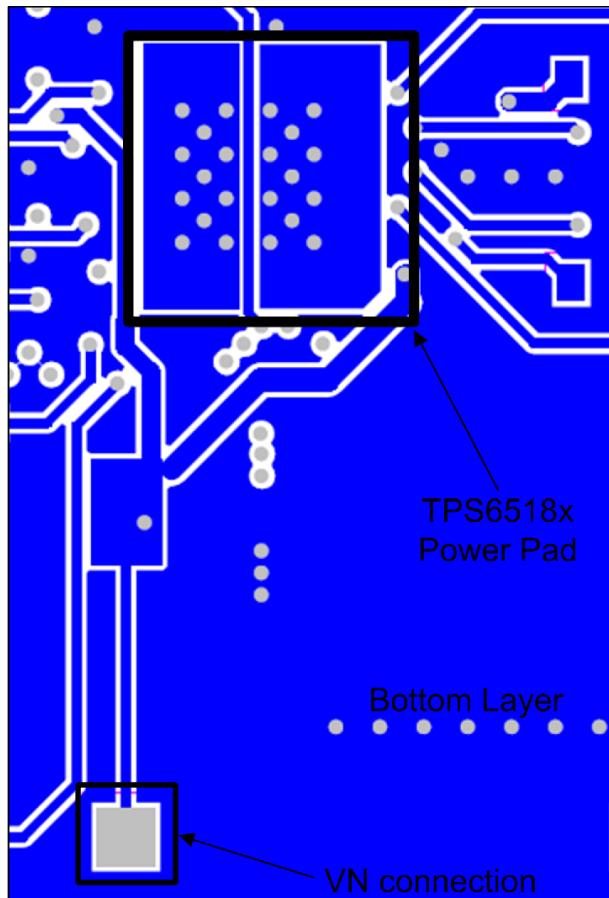


Figure 33. Layout Diagram

## 12 Device and Documentation Support

### 12.1 Device Support

#### 12.1.1 Third-Party Products Disclaimer

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### 12.2 Community Resources

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

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Vizplex is a trademark of E Ink Corporation.

E Ink is a registered trademark of E Ink Corporation.

EPSON is a registered trademark of Seiko Epson Corporation.

### 12.4 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.

### 12.5 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
TPS65186RGZR	ACTIVE	VQFN	RGZ	48	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	TPS65186	<span style="background-color: red; color: white;">Samples</span>
TPS65186RGZT	ACTIVE	VQFN	RGZ	48	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	TPS65186	<span style="background-color: red; color: white;">Samples</span>

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

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

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

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

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

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

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

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

(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.

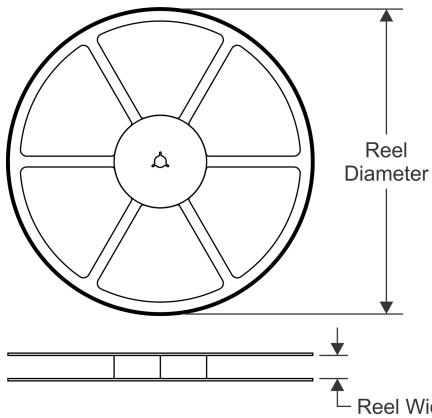
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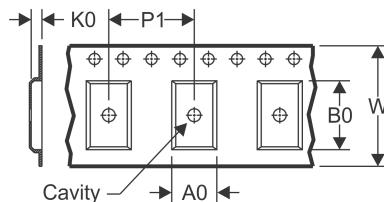
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**TAPE AND REEL INFORMATION**

**REEL DIMENSIONS**

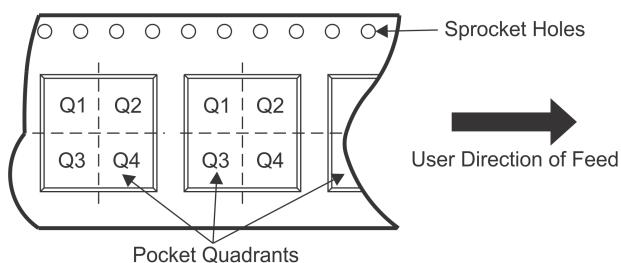


**TAPE DIMENSIONS**



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

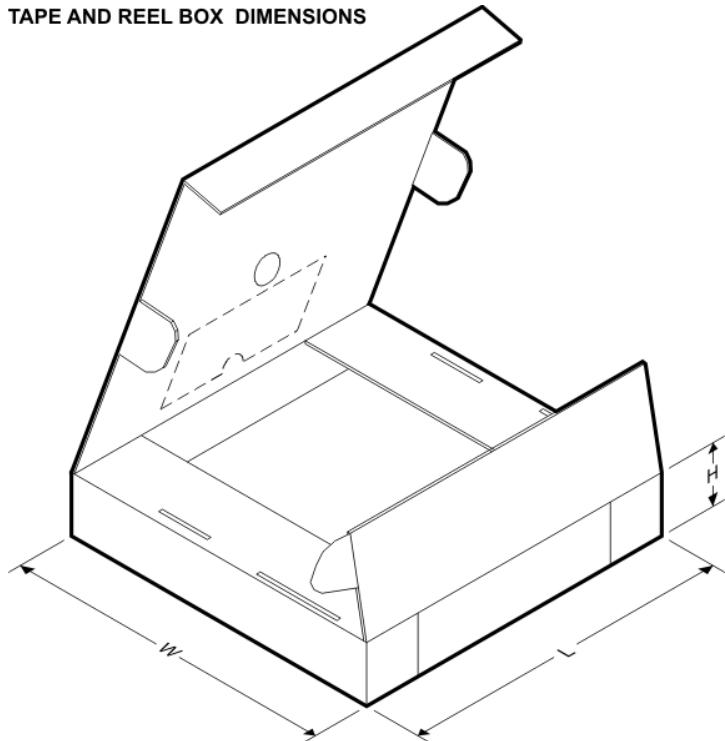
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS65186RGZR	VQFN	RGZ	48	2500	330.0	16.4	7.3	7.3	1.1	12.0	16.0	Q2
TPS65186RGZT	VQFN	RGZ	48	250	180.0	16.4	7.3	7.3	1.1	12.0	16.0	Q2

**TAPE AND REEL BOX DIMENSIONS**



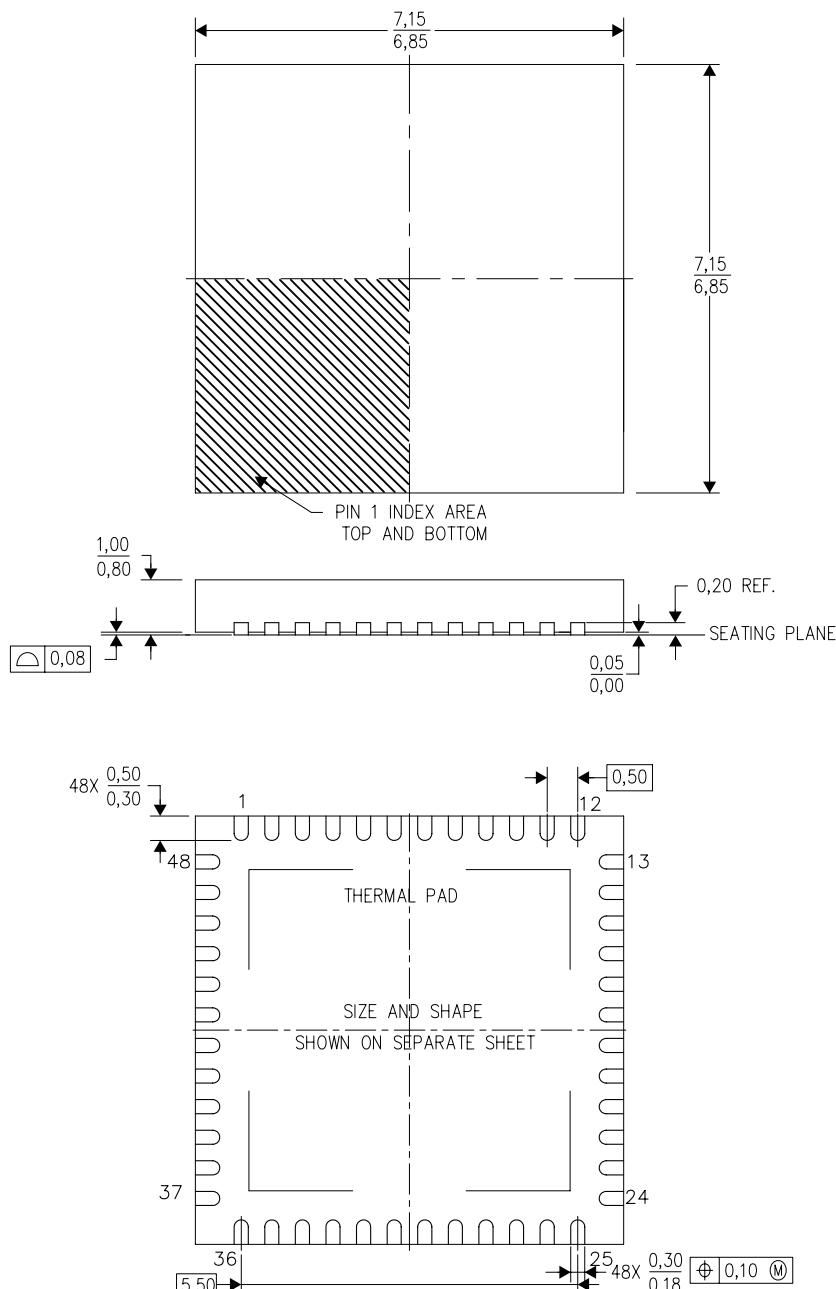
\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS65186RGZR	VQFN	RGZ	48	2500	367.0	367.0	38.0
TPS65186RGZT	VQFN	RGZ	48	250	210.0	185.0	35.0

## MECHANICAL DATA

RGZ (S-PVQFN-N48)

PLASTIC QUAD FLATPACK NO-LEAD



4204101/F 06/11

NOTES:

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

## THERMAL PAD MECHANICAL DATA

RGZ (S-PVQFN-N48)

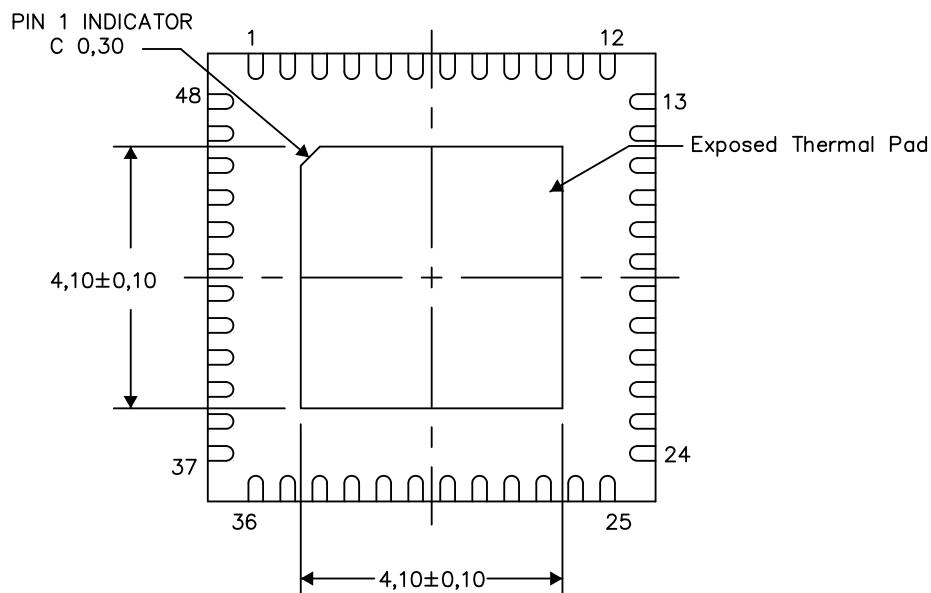
PLASTIC QUAD FLATPACK NO-LEAD

### 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

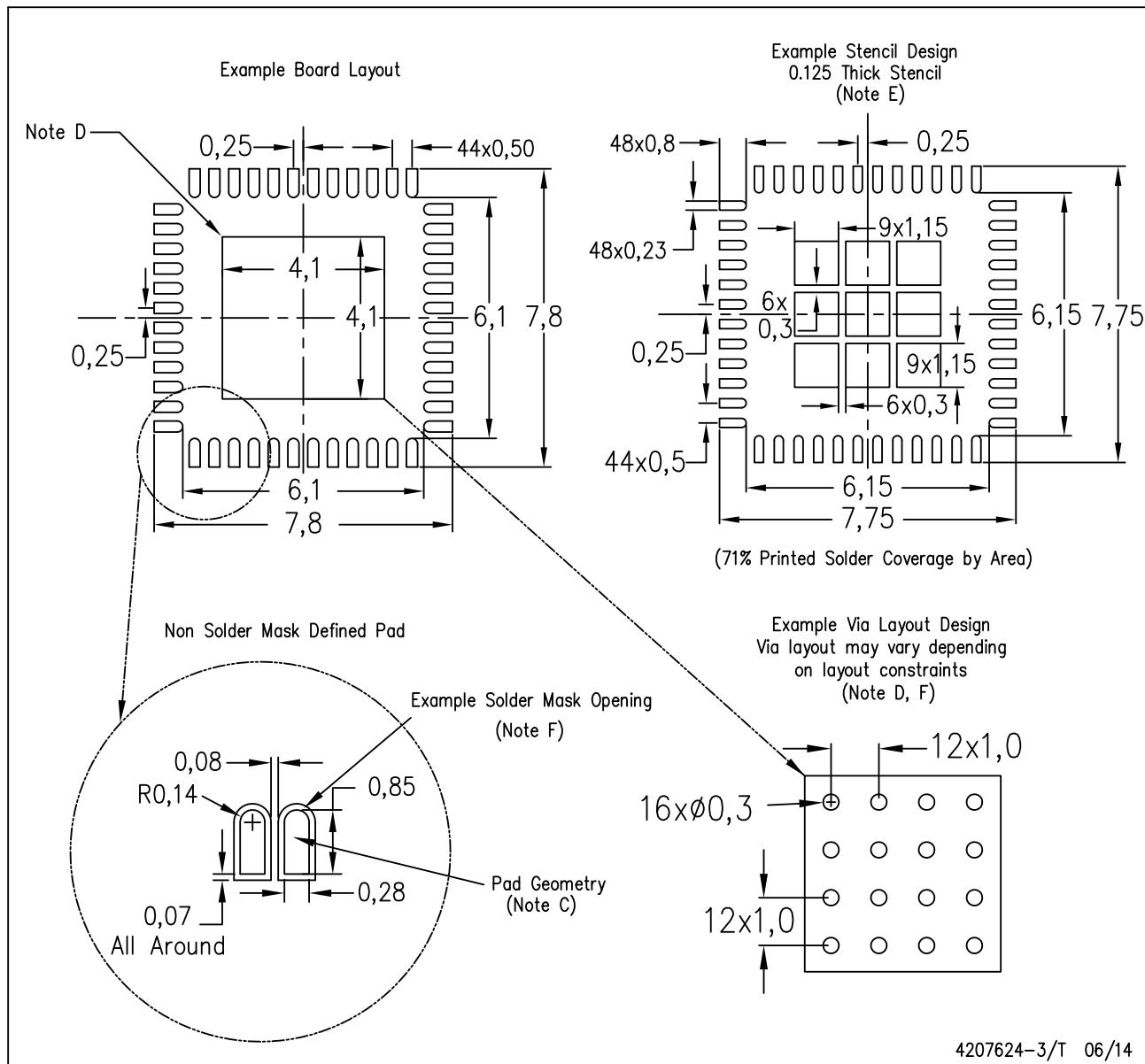
4206354-3/Z 03/15

NOTE: All linear dimensions are in millimeters

## LAND PATTERN DATA

RGZ (S-PVQFN-N48)

PLASTIC QUAD FLATPACK NO-LEAD



**NOTES:**

- All linear dimensions are in millimeters.
- This drawing is subject to change without notice.
- Publication IPC-7351 is recommended for alternate designs.
- This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat-Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at [www.ti.com](http://www.ti.com) <<http://www.ti.com>>.
- Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
- Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in the thermal pad.

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