TRIPLE-OUTPUT LCD SUPPLY WITH LINEAR REGULATOR AND VCOM BUFFER

Check for Samples: TPS65100-Q1

FEATURES

- **Qualified for Automotive Applications**
- **2.7-V to 5.8-V Input Voltage Range**
- **1.6-MHz Fixed Switching Frequency**
- **Three Independently Adjustable Outputs**
- **Main Output of up to 15 V With < 1% Output Voltage Accuracy**
- **Virtual Synchronous Converter Technology**
- **Negative Regulated Charge Pump Driver V_O2**
- **Positive Charge Pump Converter V_O3**
- **Integrated VCOM Buffer**
- **Auxiliary 3.3-V Linear Regulator Controller**
- **Internal Soft Start**
- **Internal Power-On Sequencing**
- **Fault Detection of all Outputs**
- **Thermal Shutdown**
- **Available in TSSOP-24 PowerPAD™ Package**

APPLICATIONS

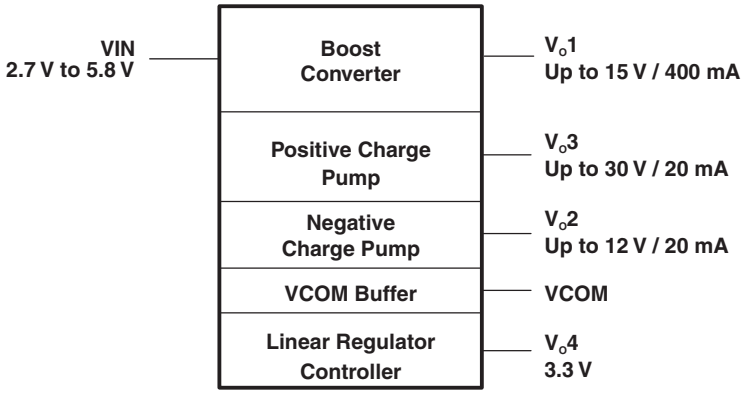
- **TFT LCD Displays for Notebooks**
- **TFT LCD Displays for Monitors**
- **Portable DVD Players**
- **Tablet PCs**
- **Car Navigation Systems**
- **Industrial Displays**

DESCRIPTION

The TPS65100 offers a compact and small power supply solution that provides all three voltages required by thin-film transistor (TFT) LCD displays. The auxiliary linear regulator controller can be used to generate a 3.3-V logic power rail for systems powered by a 5-V supply rail only.

The main output, V_O1, is a 1.6-MHz fixed-frequency PWM boost converter providing the source-drive voltage for the LCD display. The TPS65100 has a typical switch current limit of 2.3 A. A fully integrated adjustable charge pump doubler/tripler provides the positive LCD gate-drive voltage. An externally adjustable negative charge pump provides the negative gate-drive voltage. Due to the high 1.6-MHz switching frequency of the charge pumps, inexpensive and small 220-nF capacitors can be used.

The TPS65100 has an integrated VCOM buffer to power the LCD backplane. For LCD panels powered by 5 V only, the TPS65100 has a linear regulator controller using an external transistor to provide a regulated 3.3-V output for the digital circuits. For maximum safety, the TPS65100 goes into shutdown as soon as one of the outputs is out of regulation. The device can be enabled again by toggling the input or the enable (EN) pin to GND.

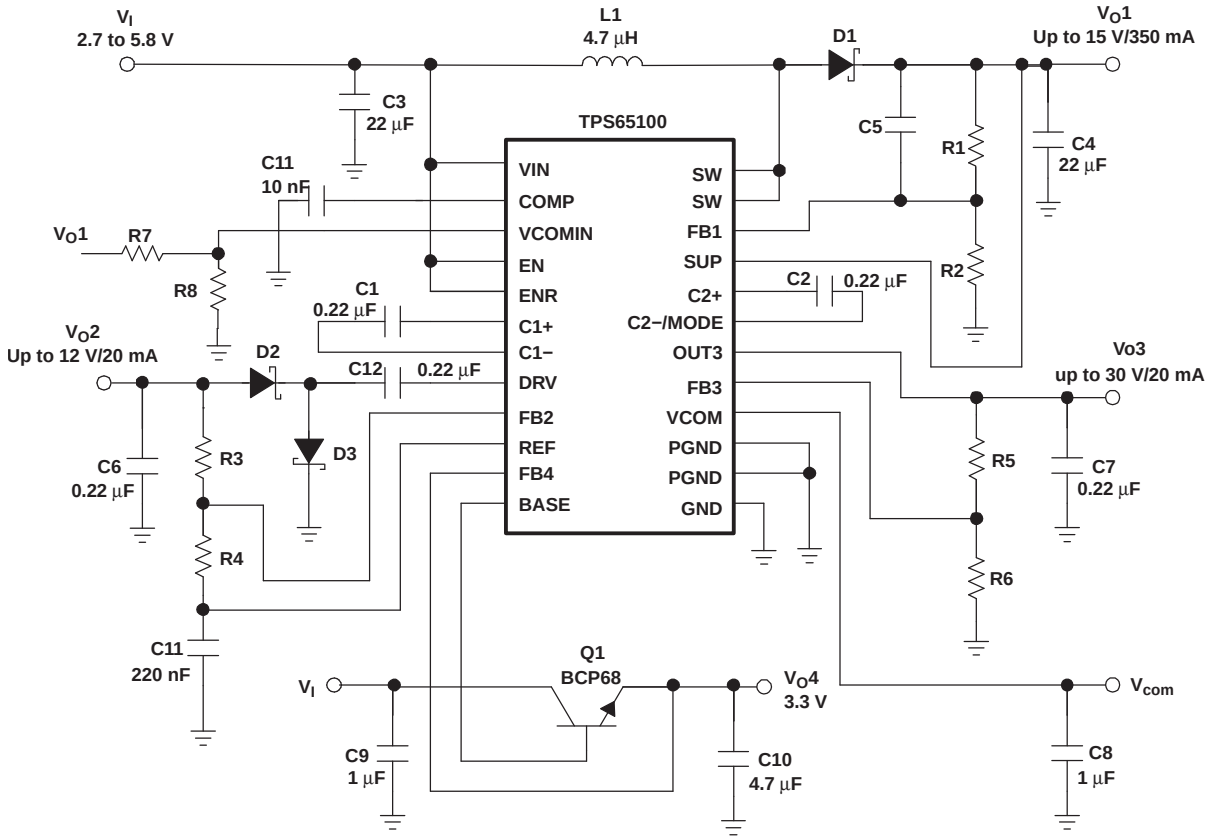


These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

TYPICAL APPLICATION CIRCUIT



ORDERING INFORMATION(1)

T_A	PACKAGE(2)		ORDERABLE PART NUMBER	TOP-SIDE MARKING
–40°C to 125°C	TSSOP – PWP	Reel of 2000	TPS65100QPWPRQ1	65100Q

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

(2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

ABSOLUTE MAXIMUM RATINGS(1)

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

Voltage range on pin VIN(2)		–0.3 V to 6 V
Voltage range on pins V_O1, SUP, PG (2)		–0.3 V to 15.5 V
Voltage range on pins EN, MODE, ENR(2)		–0.3 V to V_I + 0.3 V
Voltage on pin VCOMIN		14 V
Voltage on pin SW(2)		20 V
Continuous power dissipation		See Dissipation Ratings Table
Operating junction temperature range		–40°C to 150°C
Storage temperature range		–65°C to 150°C
Lead temperature (soldering, 10 seconds)		260°C
Electrostatic discharge (ESD) rating	Human-Body Model (HBM)	2000 V
	Machine Model (MM)	100 V
	Charged-Device Model (CDM)	1000 V

(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.

DISSIPATION RATINGS

PACKAGE	$R\theta_{JA}$	$T_A \leq 25°C$ POWER RATING	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING
24-pin TSSOP	30.13°C/W (PWP soldered)	3.3 W	1.83 W	1.32 W

THERMAL INFORMATION

THERMAL METRIC(1)		TPS65100-Q1 PWP (24 PINS)	UNIT
θ_{JA}	Junction-to-ambient thermal resistance	37.2	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	19.5	
θ_{JB}	Junction-to-board thermal resistance	16.7	
ψ_{JT}	Junction-to-top characterization parameter	0.4	
ψ_{JB}	Junction-to-board characterization parameter	16.6	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	2.1	

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

RECOMMENDED OPERATING CONDITIONS

		MIN	TYP	MAX	UNIT
VIN	Input voltage	2.7		5.8	V
L	Inductor(1)		4.7		µH
T_A	Operating free-air temperature	–40		125	°C
T_J	Operating virtual-junction temperature	–40		125	°C

(1) See the *Application Information* section for further information.

ELECTRICAL CHARACTERISTICS

V_{in} = 3.3 V, EN = VIN, V_O1 = 10 V, T_A = –40°C to 125°C, typical values are at T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY CURRENT						
V_i	Input voltage		2.7		5.8	V
I_Q	Quiescent current into VIN	ENR = VCOMIN = GND, $V_O3 = 2 \times V_O1$, Boost converter not switching		0.7	0.9	mA
$I_{QCharge}$	Charge pump quiescent current into SUP	V_O1 = SUP = 10 V, $V_O3 = 2 \times V_O1$		1.7	2.7	mA
		V_O1 = SUP = 10 V, $V_O3 = 3 \times V_O1$		3.9	6	
I_{QVCOM}	VCOM quiescent current into SUP	ENR = GND, V_O1 = SUP = 10 V		750	1300	µA
I_{QEN}	LDO controller quiescent current into VIN	ENR = VIN, EN = GND		300	800	µA
I_{SD}	Shutdown current into VIN	EN = ENR = GND		1	10	µA
V_{UVLO}	Undervoltage lockout threshold	VIN falling		2.2	2.4	V
	Thermal shutdown	Temperature rising		160		°C
LOGIC SIGNALS EN, ENR						
V_{IH}	High-level input voltage		1.5			V
V_{IL}	Low-level input voltage				0.4	V
I_{lleak}	Input leakage current	EN = GND or VIN		0.01	0.1	µA
MAIN BOOST CONVERTER						
V_O1	Output voltage range		5		15	V
$V_O1 – V_I$	Minimum input to output voltage difference		1			V
V_{REF}	Reference voltage		1.205	1.213	1.223	V
V_{FB}	Feedback regulation voltage		1.133	1.146	1.154	V
I_{FB}	Feedback input bias current			10	100	nA
$r_{DS(ON)}$	N-MOSFET on-resistance (Q1)	V_O1 = 10 V, I_{sw} = 500 mA		195	290	mΩ
		V_O1 = 5 V, I_{sw} = 500 mA		285	420	
I_{LIM}	N-MOSFET switch current limit (Q1)		1.6	2.3	2.7	A
$r_{DS(ON)}$	P-MOSFET on-resistance (Q2)	V_O1 = 10 V, I_{sw} = 100 mA		9	15	Ω
		V_O1 = 5 V, I_{sw} = 100 mA		14	22	
I_{MAX}	Maximum P-MOSFET peak switch current				1	A
I_{leak}	Switch leakage current	V_{sw} = 15 V		1	10	µA
f_{SW}	Oscillator frequency	0°C ≤ T_A ≤ 125°C	1.295	1.6	2.1	MHz
		–40°C ≤ T_A ≤ 125°C	1.191	1.6	2.1	
	Line regulation	2.7 V ≤ V_I ≤ 5.7 V, I_{load} = 100 mA		0.012		%/V
	Load regulation	0 mA ≤ I_O ≤ 300 mA		0.2		%/A
NEGATIVE CHARGE PUMP V_O2						
V_O2	Output voltage range		–2			V
V_{ref}	Reference voltage		1.205	1.213	1.219	V
V_{FB}	Feedback regulation voltage		–36	0	36	mV
I_{FB}	Feedback input bias current			10	100	nA
$r_{DS(ON)}$	Q8 P-channel switch $r_{DS(ON)}$	I_O = 20 mA		4.3	8	Ω
	Q9 N-channel switch $r_{DS(ON)}$			2.9	4.4	
I_O	Maximum output current		20			mA
	Line regulation	7 V ≤ V_O1 ≤ 15 V, I_{load} = 10 mA, V_O2 = –5 V		0.09		%/V
	Load regulation	1 mA ≤ I_O ≤ 20 mA, V_O2 = –5 V		0.126		%/mA

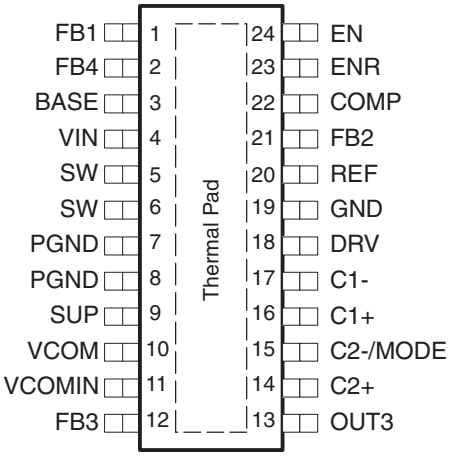
ELECTRICAL CHARACTERISTICS (continued)

V_{in} = 3.3 V, EN = VIN, V_O1 = 10 V, T_A = –40°C to 125°C, typical values are at T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
POSITIVE CHARGE PUMP V_O3						
V_O3	Output voltage range				30	V
V_{ref}	Reference voltage		1.205	1.213	1.219	V
V_{FB}	Feedback regulation voltage		1.187	1.214	1.238	V
I_{FB}	Feedback input bias current			10	100	nA
$r_{DS(ON)}$	Q3 P-channel switch $r_{DS(ON)}$	I_O = 20 mA		9.9	15.5	Ω
	Q4 N-channel switch $r_{DS(ON)}$			1.1	1.8	
	Q5 P-channel switch $r_{DS(ON)}$			4.6	8.5	
	Q6 N-channel switch $r_{DS(ON)}$			1.2	2.2	
V_d	D1–D4 Shottky diode forward voltage	$I_{D1–D4}$ = 40 mA		610	720	mV
I_O	Maximum output current		20			mA
	Line regulation	10 V ≤ V_O1 ≤ 15 V, I_{load} = 10 mA, V_O3 = 27 V		0.56		%/V
	Load regulation	1 mA ≤ I_O ≤ 20 mA, V_O3 = 27 V		0.05		%/mA
LINEAR REGULATOR CONTROLLER V_O4						
V_O4	Output voltage	4.5 V ≤ V_I ≤ 5.5 V, 10 mA ≤ I_O ≤ 500 mA	3.2	3.3	3.4	V
I_{BASE}	Maximum base drive current	$V_I – V_O4 – V_{BE}$ ≥ 0.5 V (1)	13.5	19		mA
		$V_I – V_O4 – V_{BE}$ ≥ 0.75 V (1)	20	27		
	Line regulation	4.75 V ≤ V_I ≤ 5.5 V, I_{load} = 500 mA		0.186		%/V
	Load regulation	1 mA ≤ I_O ≤ 500 mA, V_I = 5 V		0.064		%/A
	Start up current	V_O4 ≤ 0.8 V	11	20	25	mA
VCOM BUFFER						
V_{cm}	Common mode input range		2.25		(V_O1) – 2	V
V_{os}	Input offset voltage	I_O = 0 mA	–25		+25	mV
	DC Load regulation	I_O = ±25 mA	–30		37	mV
		I_O = ±50 mA	–45		55	
		I_O = ±100 mA	–72		85	
		I_O = ±150 mA	–97		110	
I_B	VCOMIN Input bias current		–300	–30	300	nA
I_{peak}	Peak output current	V_O1 = 15 V	1.2			A
		V_O1 = 10 V	0.65			A
		V_O1 = 5 V	0.15			A
FAULT PROTECTION THRESHOLDS						
$V_{(th,\ Vo1)}$	Shutdown threshold	V_O1 Rising	–12	–8.75% V_O1	–6	V
$V_{(th,\ Vo2)}$		V_O2 Rising	–13	–9% V_O2	–5	V
$V_{(th,\ Vo3)}$		V_O3 Rising	–11	–8% V_O3	–5	V

(1) With V_I = supply voltage of the TPS65100, V_O4 = output voltage of the regulator, V_{BE} = basis emitter voltage of external transistor

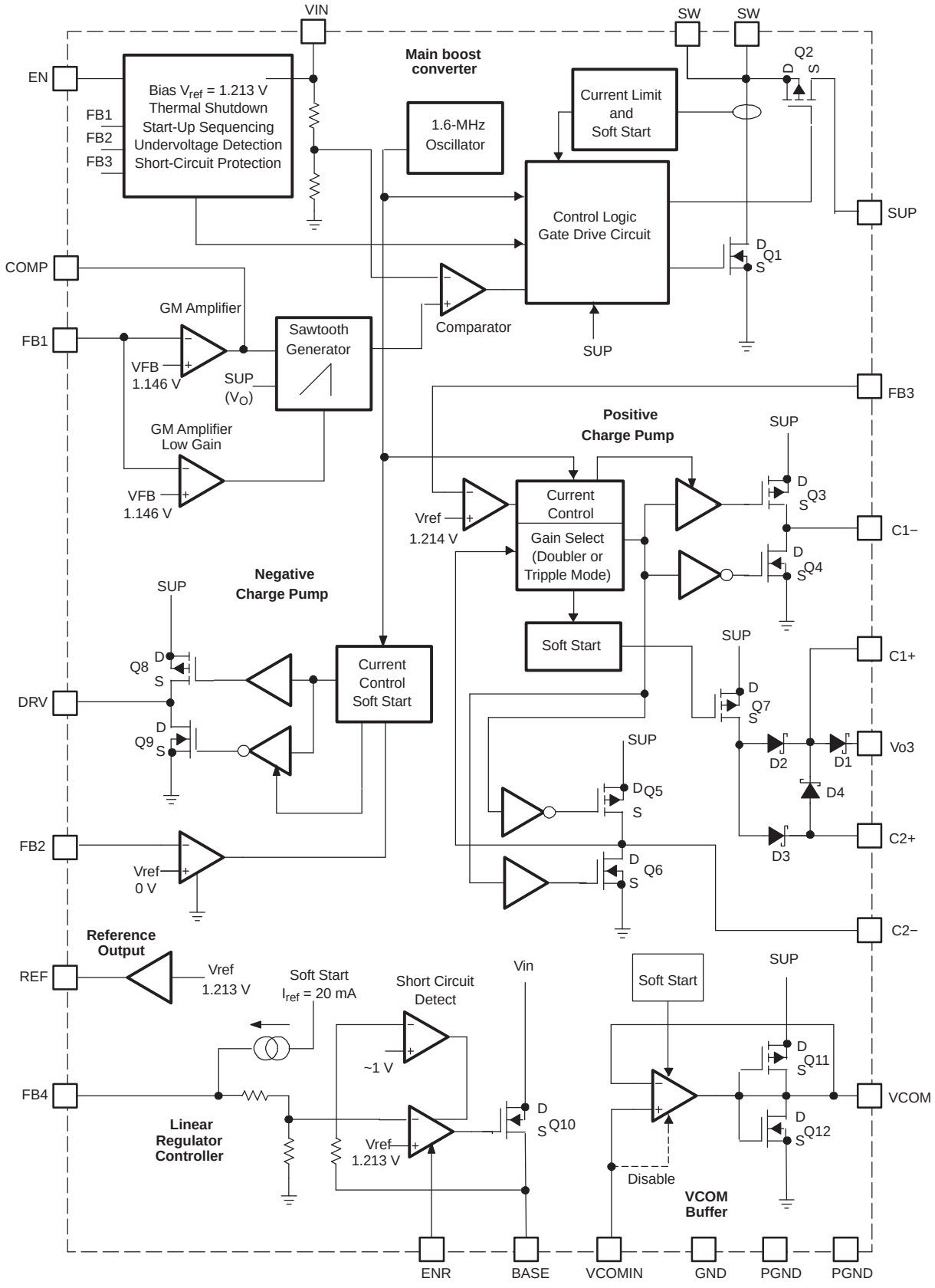
PWP PACKAGE
(TOP VIEW)



Terminal Functions

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
VIN	4	I	Input voltage pin of the device
EN	24	I	Enable pin of the device. This pin should be terminated and not be left floating. A logic high enables the device and a logic low shuts down the device.
COMP	22		Compensation pin for the main boost converter. A small capacitor is connected to this pin.
VCOMIN	11	I	Positive input terminal of the VCOM buffer. When the VCOM buffer is not used, this terminal can be connected to GND to reduce the overall quiescent current of the IC.
ENR	23	I	Enable pin of the linear regulator controller. This pin should be terminated and not be left floating. Logic high enables the regulator and a logic low puts the regulator in shutdown.
C1+	16		Positive terminal of the charge pump flying capacitor
C1–	17		Negative terminal of the charge pump flying capacitor
DRV	18	O	External charge pump driver
FB2	21	I	Feedback pin of negative charge pump
REF	20	O	Internal reference output typically 1.23 V
FB4	2	I	Feedback pin of the linear regulator controller. The linear regulator controller is set to a fixed output voltage of 3.3 V or 3 V depending on the version.
BASE	3	O	Base drive output for the external transistor
GND	19		Ground
PGND	7, 8		Power ground
VCOM	10	O	VCOM buffer output
FB3	12	I	Feedback pin of positive charge pump
OUT3	13	O	Positive charge pump output
C2–/MODE	15		Negative terminal of the charge pump flying capacitor and charge pump MODE pin. If the flying capacitor is connected to this pin, the converter operates in a voltage tripler mode. If the charge pump needs to operate in a voltage doubler mode, the flying capacitor is removed and the C2–/MODE pin should be connected to GND.
C2+	14		Positive terminal for the charge pump flying capacitor. If the device runs in voltage doubler mode, this pin should be left open.
SUP	9	I	Supply of the positive and negative charge pump, boost converter gate-drive circuit, and VCOM buffer. Should be connected to the output of the main boost converter and cannot be connected to any other voltage source. For performance reasons, do not connect a bypass capacitor directly to this pin.
FB1	1	I	Feedback pin of the boost converter
SW	5, 6	I	Switch pin of the boost converter
Thermal pad			The exposed thermal pad should be connected to the power ground (PGND).

FUNCTIONAL BLOCK DIAGRAM



TYPICAL CHARACTERISTICS

Table of Graphs

			FIGURE
Main Boost Converter			
η	Efficiency, main boost converter V_O1	vs Load current	1
	Efficiency, main boost converter V_O1	vs Load current	2
	Efficiency	vs Input voltage	3
f_{sw}	Switching frequency	vs Free-air temperature	4
$r_{DS(on)}$	$r_{DS(on)}$ N-channel main switch Q1	vs Free-air temperature	5
	PWM operation, continuous mode		6
	PWM operation at light load		7
	Load transient response, C_O = 22 µF		8
	Load transient response, C_O = 2 × 22 µF		9
	Power-up sequencing		10
	Soft start V_O1		11
Negative Charge Pump			
I_{max}	V_O2 Maximum load current	vs Output voltage V_O1	12
Positive Charge Pump			
I_{max}	V_O3 Maximum load current	vs Output voltage V_O1 (doubler mode)	13
I_{max}	V_O3 Maximum load current	vs Output voltage V_O1 (tripler mode)	14

EFFICIENCY vs LOAD CURRENT

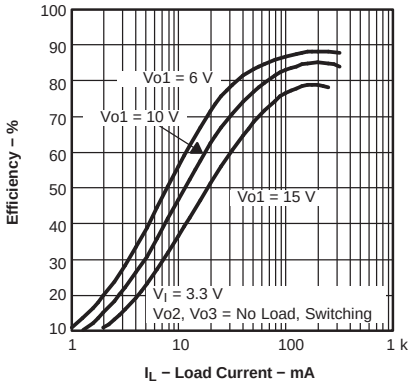


Figure 1.

EFFICIENCY vs LOAD CURRENT

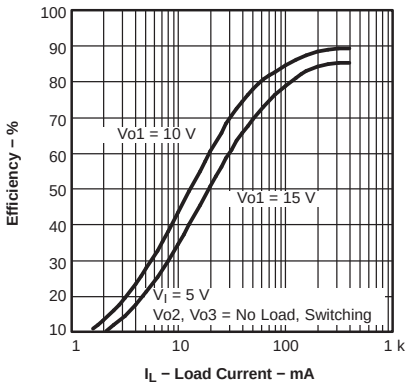


Figure 2.

EFFICIENCY vs INPUT VOLTAGE

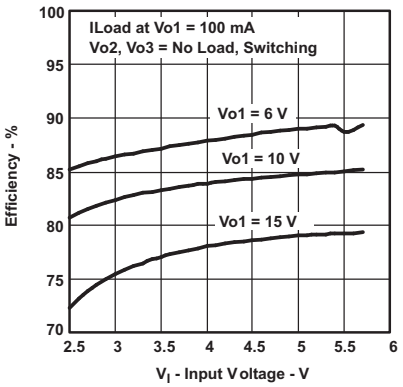


Figure 3.

SWITCHING FREQUENCY vs FREE-AIR TEMPERATURE

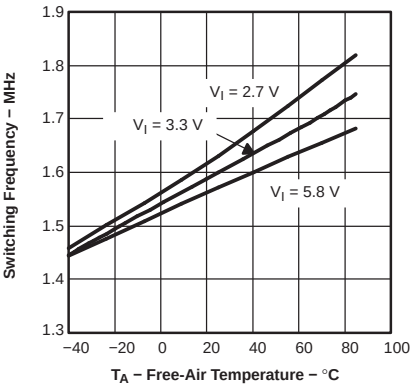


Figure 4.

$r_{DS(on)}$ N-CHANNEL MAIN SWITCH vs FREE-AIR TEMPERATURE

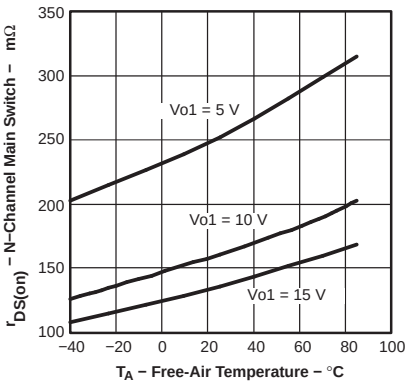


Figure 5.

PWM OPERATION CONTINUOUS MODE

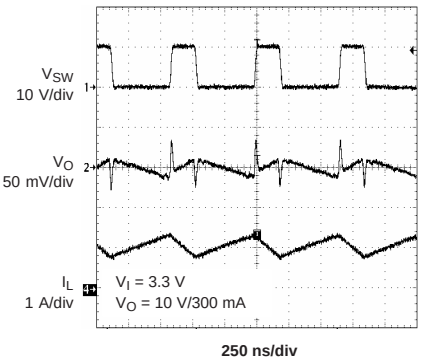


Figure 6.

PWM OPERATION AT LIGHT LOAD

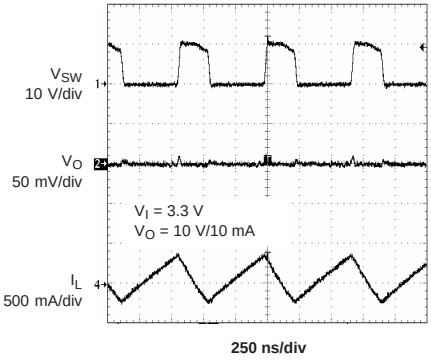


Figure 7.

LOAD TRANSIENT RESPONSE

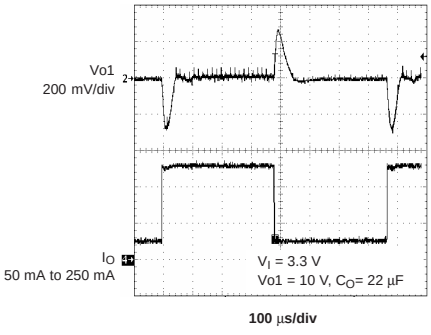


Figure 8.

LOAD TRANSIENT RESPONSE

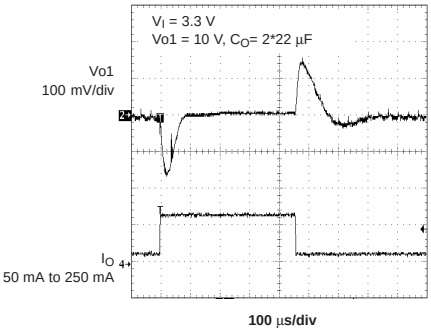


Figure 9.

POWER-UP SEQUENCING

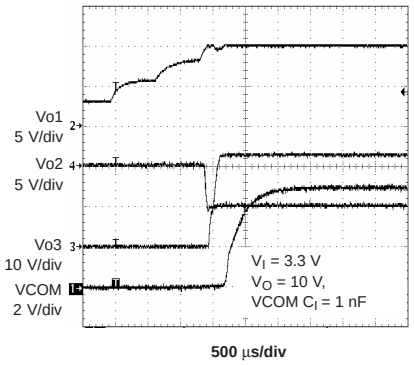


Figure 10.

SOFT START V_O1

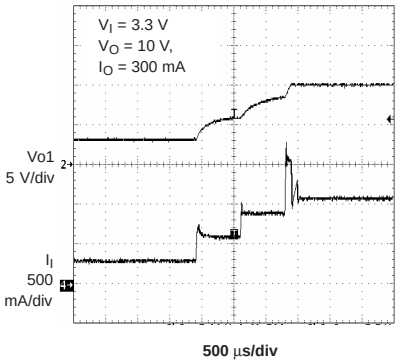


Figure 11.

V_O2 MAXIMUM LOAD CURRENT

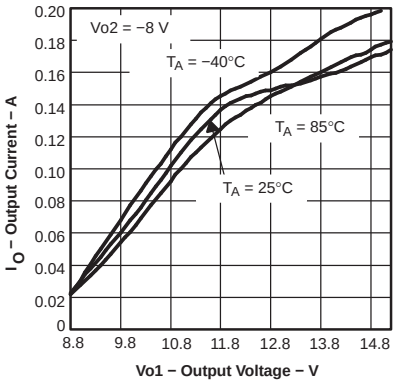


Figure 12.

V_O3 MAXIMUM LOAD CURRENT

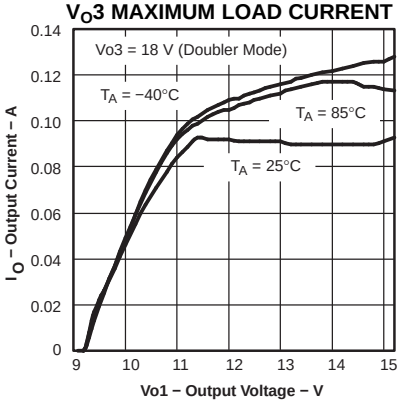


Figure 13.

V_O3 MAXIMUM LOAD CURRENT

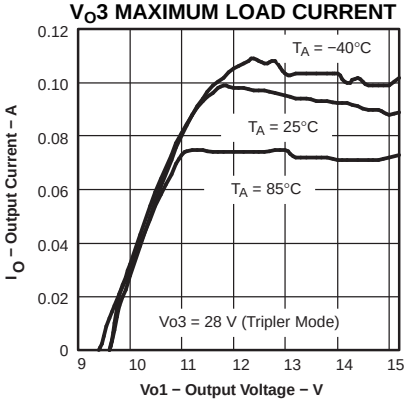


Figure 14.

DETAILED DESCRIPTION

The TPS65100 consists of a main boost converter operating with a fixed switching frequency of 1.6 MHz to allow for small external components. The boost converter output voltage V_O1 is also the input voltage, connected via the pin SUP, for the positive and negative charge pumps and the bias supply for the VCOM buffer. The linear regulator controller is independent from this system with its own enable pin. This design allows the linear regulator controller to continue to operate while the other supply rails are disabled or in shutdown due to a fault condition on one of their outputs. See the functional block diagram for more information.

Main Boost Converter

The main boost converter operates with PWM and a fixed switching frequency of 1.6 MHz. The converter uses a unique fast-response voltage-mode controller scheme with input voltage feedforward. This achieves excellent line and load regulation (0.2%/A load regulation typical) and allows the use of small external components. To add higher flexibility to the selection of external component values the device uses external loop compensation. Although the boost converter looks like a nonsynchronous boost converter topology operating in discontinuous mode at light load, the TPS65100 maintains continuous conduction even at light load currents. This is accomplished using the Virtual Synchronous Converter Technology for improved load transient response. This architecture uses an external Schottky diode and an integrated MOSFET in parallel connected between SW and SUP (see the functional block diagram). The integrated MOSFET Q2 allows the inductor current to become negative at light load conditions. For this purpose, a small integrated P-channel MOSFET with typically 10-Ω r_{DSon} is sufficient. When the inductor current is positive, the external Schottky diode with the lower forward voltage conducts the current. This causes the converter to operate with a fixed frequency in continuous conduction mode over the entire load current range. This avoids the ringing on the switch pin as seen with a standard nonsynchronous boost converter and allows a simpler compensation for the boost converter.

VCOM Buffer

VCOMIN is the input of the VCOM buffer. If the VCOM buffer is not required for certain applications, it is possible to shut down the VCOM buffer by connecting VCOMIN to ground, reducing the overall quiescent current. The VCOM buffer features soft start, avoiding a large voltage drop at V_O1 during start-up. The VCOMIN cannot be pulled dynamically to ground during operation.

Enable and Power On Sequencing (EN, ENR)

The device has two enable pins. These pins should be terminated and should not be left floating to prevent unpredictable operation. Pulling the enable pin (EN) high enables the device and starts the power-on sequencing with the main boost converter V_O1 coming up first, then the negative and positive charge pump and the VCOM buffer. If the VCOMIN pin is held low, the VCOM buffer remains disabled. The linear regulator has an independent enable pin (ENR). Pulling this pin low disables the regulator, and pulling this pin high enables this regulator.

If the enable pin EN is pulled high, the device starts its power on sequencing. The main boost converter starts up first with its soft start. If the output voltage has reached 91.25% of its output voltage, the negative charge pump comes up next. The negative charge pump starts with a soft start and when the output voltage has reached 91% of the nominal value, the positive charge pump comes up with a soft start. The VCOM buffer is enabled as soon as the positive charge pump has reached its nominal value and VCOMIN is greater than typically 1.0 V. Pulling the enable pin low shuts down the device. Depended on load current and output capacitance, each of the outputs goes down.

Positive Charge Pump

The TPS65100 has a fully regulated integrated positive charge pump generating V_O3. The input voltage for the charge pump is applied to the SUP pin that is equal to the output of the main boost converter V_O1. The charge pump is capable of supplying a minimum load current of 20 mA. Depending on the voltage difference between V_O1 and V_O3 higher load currents are possible (see Figure 13 and Figure 14).

Negative Charge Pump

The TPS65100 has a regulated negative charge pump using two external Schottky diodes. The input voltage for the charge pump is applied to the SUP pin that is connected to the output of the main boost converter V_O1. The charge pump inverts the main boost converter output voltage and is capable of supplying a minimum load current of 20 mA. Depending on the voltage difference between V_O1 and V_O2, higher load currents are possible (see Figure 12).

Linear Regulator Controller

The TPS65100 includes a linear regulator controller to generate a 3.3-V rail which is useful when the system is powered from a 5-V supply. The regulator is independent from the other voltage rails of the device and has its own enable (ENR). Since most of the systems require this voltage rail to come up first it is recommended to use a R-C delay on EN. This delays the start-up of the main boost converter which will reduce the inrush current as well.

Soft Start

The main boost converter as well as the charge pumps, linear regulator, and VCOM buffer have an internal soft start. This avoids heavy voltage drops at the input voltage rail or at the output of the main boost converter V_O1 during start-up caused by high inrush currents (see Figure 10 and Figure 11). During softstart of the main boost converter V_O1, the internal current limit threshold is increased in three steps. The device starts with the first step, where the current limit is set to 2/5 of the typical current limit (2/5 of 2.3 A) for 1024 clock cycles, then increased to 3/5 of the current limit for 1024 clock cycles, and finally raised to the full current limit.

Fault Protection

All the outputs of the TPS65100 have short-circuit detection that can force the device into shutdown. The main boost converter has overvoltage and undervoltage protection. If the output voltage V_O1 rises above the overvoltage protection threshold of 5% of V_O1 (typical), the device stops switching but remains operational. When the output voltage falls below this threshold again, the converter continues operation. When the output voltage falls below power good threshold of 8.75% of V_O1 (typical), in case of a short-circuit condition, then the TPS65100 goes into shutdown. Because there is a direct pass from the input to the output through the diode, the short-circuit condition remains. If this condition needs to be avoided, a fuse at the input or an output disconnect using a single transistor and resistor is required. The negative and positive charge pumps have an undervoltage lockout to protect the LCD panel from possible latchup conditions in the event of a short-circuit condition or faulty operation. When the negative output voltage is above 9.5% (typical) of its output voltage (closer to ground), the device enters shutdown. When the positive charge pump output voltage V_O3 is below 8% (typical) of its output voltage, the device goes into shutdown as well. See the electrical characteristics table under fault protection thresholds. The device can be enabled again by toggling the enable pin (EN) below 0.4 V or by cycling the input voltage below the UVLO of 1.7 V. The linear regulator reduces the output current to typical 20 mA under a short-circuit condition when the output voltage is < 1 V (typical). See the functional block diagram. The linear regulator does not go into shutdown under a short-circuit condition.

Thermal Shutdown

A thermal shutdown is implemented to prevent damage due to excessive heat and power dissipation. Typically, the thermal shutdown threshold is 160°C. If this temperature is reached, the device goes into shutdown. The device can be enabled by toggling the enable pin to low and back to high or by cycling the input voltage to GND and back to V_I again.

APPLICATION INFORMATION

BOOST CONVERTER DESIGN PROCEDURE

The first step in the design procedure is to calculate the maximum possible output current of the main boost converter under certain input and output voltage conditions. This example is for a 3.3-V to 10-V conversion: V_{in} = 3.3 V, V_{out} = 10 V, Switch voltage drop V_{sw} = 0.5 V, Schottky diode forward voltage V_D = 0.8 V

1. Duty cycle

$$D = \frac{V_{out} + V_D - V_{in}}{V_{out} + V_D - V_{sw}} = \frac{10\ V + 0.8\ V - 3.3\ V}{10\ V + 0.8\ V - 0.5\ V} = 0.73$$

2. Average inductor current

$$I_L = \frac{I_{out}}{1 - D} = \frac{300\ mA}{1 - 0.73} = 1.11\ A$$

3. Inductor peak-to-peak ripple current

$$\Delta i_L = \frac{\left[V_{in} - V_{sw}\right] \times D}{f_S \times L} = \frac{(3.3\ V - 0.5\ V) \times 0.73}{1.6\ MHz \times 4.2\ \mu H} = 304\ mA$$

4. Peak switch current

$$I_{swpeak} = I_L + \frac{\Delta i_L}{2} = 1.11\ A + \frac{304\ mA}{2} = 1.26\ A$$

The integrated switch, the inductor, and the external Schottky diode must be able to handle the peak switch current. The calculated peak switch current must be equal to or lower than the minimum N-MOSFET switch current limit specified in *electrical characteristics*. If the peak switch current is higher, the converter cannot support the required load current. This calculation must be done for the minimum input voltage, where the peak switch current is highest. The calculation includes conduction losses like switch r_{DSon} (0.5 V) and diode forward drop voltage losses (0.8 V). Additional switching losses, inductor core and winding losses, etc., require a slightly higher peak switch current in the actual application. This calculation still allows for good design and component selection.

Inductor Selection

Several inductors work with the TPS65100 and, particularly with the external compensation, performance can be adjusted to application requirements. The main parameter for inductor selection is the saturation current of the inductor, which should be higher than the peak switch current as previously calculated, with additional margin to allow for heavy load transients and extreme start-up conditions. Another method is to choose an inductor with a saturation current at least as high as the minimum switch current limit of 1.6 A. The different switch-current limits allow selection of a physically smaller inductor when less output current is required. Another important parameter is inductor dc resistance. Usually, the lower the dc resistance, the higher the efficiency. However, inductor dc resistance is not the only parameter determining the efficiency. Especially for a boost converter where the inductor is the energy storage element, the type and material of the inductor influences the efficiency as well. At the high switching frequency of 1.6 MHz, inductor core losses, proximity effects, and skin effects are more important. Usually, an inductor with a larger form factor yields higher efficiency. The efficiency difference between different inductors can vary between 2% to 10%. Inductor values between 3.3 µH and 6.8 µH are a good choice, but other values can be used. Possible inductors are shown in Table 1.

Table 1. Inductor Selection

INDUCTOR VALUE	COMPONENT SUPPLIER	DIMENSIONS (mm)	ISAT/DCR
4.7 µH	Coilcraft DO1813P-472HC	8,89 × 6,1 × 5	2.6 A/54 mΩ
4.2 µH	Sumida CDRH5D28 4R2	5,7 × 5,7 × 3	2.2 A/23 mΩ
4.7 µH	Sumida CDC5D23 4R7	6 × 6 × 2,5	1.6 A/48 mΩ
3.3 µH	Wuerth Elektronik 744042003	4,8 × 4,8 × 2	1.8 A/65 mΩ
4.2 µH	Sumida CDRH6D12 4R2	6,5 × 6,5 × 1,5	1.8 A/60 mΩ
3.3 µH	Sumida CDRH6D12 3R3	6,5 × 6,5 × 1,5	1.9 A/50 mΩ

Output Capacitor Selection

For the best output voltage filtering, a low ESR output capacitor is recommended. Ceramic capacitors have a low ESR value, but depending on the application, tantalum capacitors can be used as well. A 22-µF ceramic output capacitor works for most of the applications. Higher capacitor values can be used to improve the load transient regulation. See Table 2 for selection of the output capacitor. The output voltage ripple can be calculated as:

$$\Delta V_{out} = \frac{I_{out}}{C_{out}} \times \left[\frac{1}{f_s} - \frac{I_p \times L}{V_{out} + V_d - V_{in}} \right] + I_p \times ESR$$

with:

IP = Peak switch current as calculated in the previous section with $I_{SW(peak)}$.

L = Selected inductor value

I_{OUT} = Normal load current

f_s = Switching frequency

V_d = Rectifier diode forward voltage (typical 0.3 V)

C_{OUT} = Selected output capacitor

ESR = Output capacitor ESR value

Input Capacitor Selection

For good input voltage filtering, low ESR ceramic capacitors are recommended. A 22-µF ceramic input capacitor is sufficient for most of the applications. For better input voltage filtering, this value can be increased. See Table 2 and the typical applications for input capacitor recommendations.

Table 2. Input and Output Capacitors Selection

CAPACITOR	VOLTAGE RATING	COMPONENT SUPPLIER	COMMENTS
22 µF/1210	16 V	Taiyo Yuden EMK325BY226MM	C_{out}
22 µF/1206	6.3 V	Taiyo Yuden JMK316BJ226	C_{in}

Rectifier Diode Selection

To achieve high efficiency, a Schottky diode should be used. The voltage rating should be higher than the maximum output voltage of the converter. The average forward current should be equal to the average inductor current of the converter. The main parameter influencing the efficiency of the converter is the forward voltage and the reverse leakage current of the diode; both should be as low as possible. Possible diodes are: On Semiconductor MBRM120L, Microsemi UPS120E, and Fairchild Semiconductor MBRS130L.

Converter Loop Design and Stability

The TPS65100 converter loop can be externally compensated and allows access to the internal transconductance error amplifier output at the COMP pin. A small feedforward capacitor across the upper feedback resistor divider speeds up the circuit as well. To test the converter stability and load transient performance of the converter, a load step from 50 mA to 250 mA is applied, and the output voltage of the converter is monitored. Applying load steps to the converter output is a good tool to judge the stability of such a boost converter.

Design Procedure Quick Steps

1. Select the feedback resistor divider to set the output voltage.
2. Select the feedforward capacitor to place a zero at 50 kHz.
3. Select the compensation capacitor on pin COMP. The smaller the value, the higher the low frequency gain.
4. Use a 50-kΩ potentiometer in series to C_c and monitor V_{out} during load transients. Fine tune the load transient by adjusting the potentiometer. Select a resistor value that comes closest to the potentiometer resistor value. This needs to be done at the highest V_{in} and highest load current since the stability is most critical at these conditions.

Setting the Output Voltage and Selecting the Feedforward Capacitor

The output voltage is set by the external resistor divider and is calculated as:

$$V_{out} = 1.146\ V \times \left[1 + \frac{R1}{R2}\right]$$

Across the upper resistor a bypass capacitor is required to speed up the circuit during load transients as shown in Figure 15.

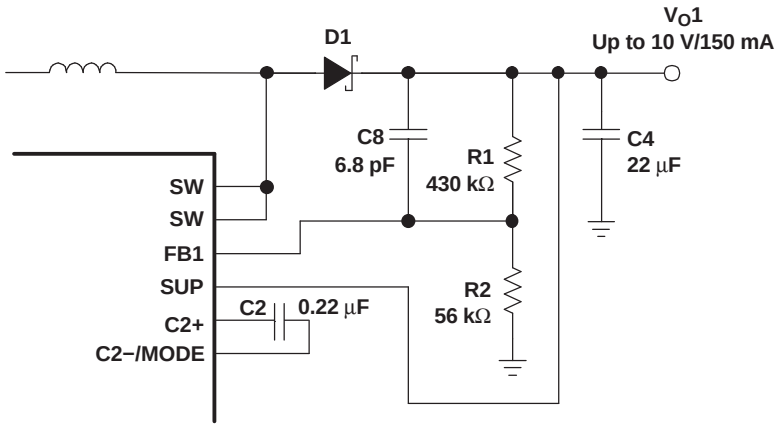


Figure 15. Feedforward Capacitor

Together with R1 the bypass capacitor C8 sets a zero in the control loop at approximately 50 kHz:

$$f_z = \frac{1}{2 \times \pi \times C8 \times R1}$$

A value closest to the calculated value should be used. Larger feedforward capacitor values reduce the load regulation of the converter and cause load steps as shown in Figure 16.

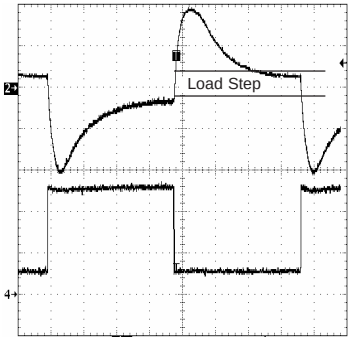


Figure 16. Load Step Caused By A Too Large Feedforward Capacitor Value

Compensation

The regulator loop can be compensated by adjusting the external components connected to the COMP pin. The COMP pin is connected to the output of the internal transconductance error amplifier. A typical compensation scheme is shown in Figure 17.

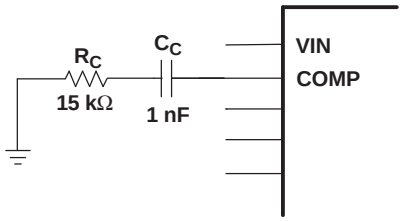


Figure 17. Compensation Network

The compensation capacitor C_C adjusts the low frequency gain and the resistor value adjusts the high frequency gain. The formula below calculates at what frequency the resistor increases the high frequency gain.

$$f_Z = \frac{1}{2 \times \pi \times Cc \times Rc}$$

Lower input voltages require a higher gain and therefore a lower compensation capacitor value. A good start is C_C = 1 nF for a 3.3-V input and C_C = 2.2 nF for a 5-V input. If the device operates over the entire input voltage range from 2.7 V to 5.8 V, a large compensation capacitor up to 10 nF is recommended. Figure 18 shows the load transient with a larger compensation capacitor, and Figure 19 shows a smaller compensation capacitor.

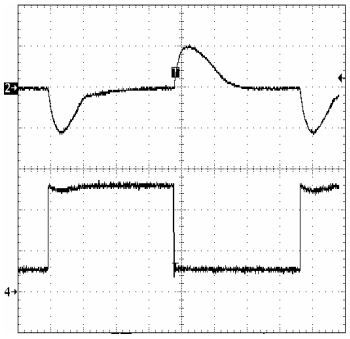


Figure 18. C_c = 4.7 nF

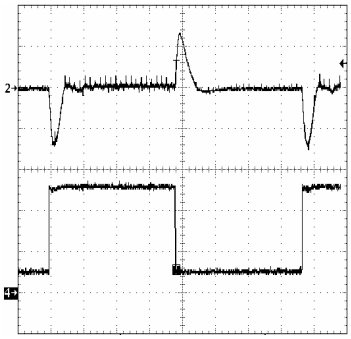


Figure 19. C_c = 1 nF

Finally, R_c needs to be selected. A good practice is to use a 50-kΩ potentiometer and adjust the potentiometer for best load transient where no oscillations should occur. These tests have to be done at the highest V_{in} and highest load current because converter stability is most critical under these conditions. Figure 20, Figure 21, and Figure 22 show the fine tuning of the loop with R_c.

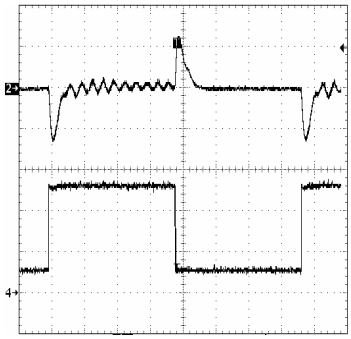


Figure 20. Overcompensated (Damped Oscillation), R_c Is Too Large

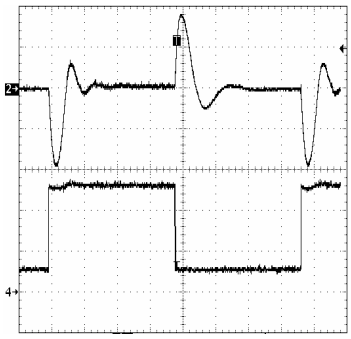


Figure 21. Undercompensated (Loop Is Too Slow), R_c Is Too Small

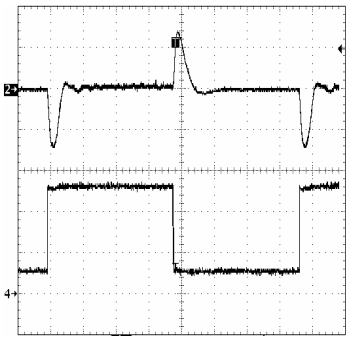


Figure 22. Optimum, R_c Is Ideal

Negative Charge Pump

The negative charge pump provides a regulated output voltage by inverting the main output voltage V_O1. The negative charge pump output voltage is set with external feedback resistors.

The maximum load current of the negative charge pump depends on the voltage drop across the external Schottky diodes, the internal on resistance of the charge pump MOSFETS Q8 and Q9, and the impedance of the flying capacitor C12. When the voltage drop across these components is larger than the voltage difference from V_O1 to V_O2, the charge pump is in dropout, providing the maximum possible output current. Therefore, the higher the voltage difference between V_O1 and V_O2, the higher the possible load current. See Figure 12 for the possible output current versus boost converter voltage V_O1.

$$V_{O\ (min)} = -(V_O - 2\ V_D - I_o\ (2 \times r_{DS(on)Q8} + 2 \times r_{DS(on)Q9} + X_{cfly}))$$

Setting the output voltage:

$$V_{OUT} = -V_{REF} \times \frac{R3}{R4} = -1.213\ V \times \frac{R3}{R4}$$

$$R3 = R4 \times \frac{|V_{OUT}|}{V_{REF}} = R4 \times \frac{|V_{OUT}|}{1.213}$$

The lower feedback resistor value R4 should be in a range between 40 kΩ to 120 kΩ or the overall feedback resistance should be within 500 kΩ to 1 MΩ. Smaller values load the reference too heavily and larger values may cause stability problems. The negative charge pump requires two external Schottky diodes. The peak current rating of the Schottky diode has to be twice the load current of the output. For a 20-mA output current, the dual Schottky diode BAT54 or similar is a good choice.

Positive Charge Pump

The positive charge pump can be operated in a voltage doubler mode or a voltage tripler mode depending on the configuration of the C2+ and C2-/MODE pins. Leaving the C2+ pin open and connecting C2-/MODE to GND forces the positive charge pump to operate in a voltage doubler mode. If higher output voltages are required, the positive charge pump can be operated as a voltage tripler. To operate the charge pump in the voltage tripler mode, a flying capacitor needs to be connected to C2+ and C2-/MODE.

The maximum load current of the positive charge pump depends on the voltage drop across the internal Schottky diodes, the internal on resistance of the charge pump MOSFETS, and the impedance of the flying capacitor. When the voltage drop across these components is larger than the voltage difference $V_O1 \times 2$ to V_O3 (doubler mode) or $V_O1 \times 3$ to V_O3 (tripler mode), then the charge pump is in dropout, providing the maximum possible output current. Therefore, the higher the voltage difference between $V_O1 \times 2$ (doubler) or $V_O1 \times 3$ (tripler) to V_O3, the higher the possible load current. See Figure 13 and Figure 14 for the output current versus boost converter voltage V_O1 and the following calculations.

Voltage doubler:

$$V_O3_{max} = 2 \times V_O1 - (2\ V_D + 2 \times Io \times (2 \times r_{DS(on)Q5} + r_{DS(on)Q3} + r_{DS(on)Q4} + X_{C1}))$$

Voltage tripler:

$$V_O3_{max} = 3 \times V_O1 - (3 \times V_D + 2 \times Io \times (3 \times r_{DS(on)Q5} + r_{DS(on)Q3} + r_{DS(on)Q4} + X_{C1} + X_{C2}))$$

The output voltage is set by the external resistor divider and is calculated as:

$$V_{out} = 1.214 \times \left[1 + \frac{R5}{R6}\right] \quad (1)$$

$$R5 = R6 \times \left[\frac{V_{out}}{V_{FB}} - 1\right] = R6 \times \left[\frac{V_{out}}{1.214} - 1\right]$$

VCOM Buffer

The VCOM buffer is typically used to drive the backplane of a TFT panel. The VCOM output voltage is typically set to half of the main output voltage V_O1 plus a small shift to implement the specific compensation voltage. The TFT video signal gets coupled through the TFT storage capacitor plus the LCD cell capacitance to the output of the VCOM buffer. Because of these, short current pulses in the positive and negative direction appear at the output of the VCOM buffer. To minimize the output voltage ripple caused by the current pulses, a transconductance amplifier having a current source output and an output capacitor is used. The output capacitor supports the high frequency part of the current pulses drawn from the LCD panel. The VCOM buffer only needs to handle the low frequency portion of the current pulses. A 1-µF ceramic output capacitor is sufficient for most of the applications. When using other output capacitor values it is important to keep in mind that the output capacitor is part of the VCOM buffer loop stabilization.

The VCOM buffer has an integrated soft start to avoid voltage drops on V_O1 during start-up. The soft start is implemented as such that the VCOMIN is held low until the VCOM buffer is fully biased and the common mode range is reached. Then the positive input is released and the VCOM buffer output slowly comes up. Usually a 1-nF capacitor on VCOMIN to GND is used to filter high frequency noise coupled in from V_O1. The size of this capacitor together with the upper feedback resistor value determines the start-up time. The larger the capacitor from VCOMIN to GND, the slower the soft start.

Linear Regulator Controller

The TPS65100 includes a linear regulator controller to generate a 3.3-V rail when the system is powered from a 5-V supply. Because an external npn transistor is required, the input voltage of the TPS65100 applied to VIN needs to be higher than the output voltage of the regulator. To provide a minimum base drive current of 13.5 mA, a minimum internal voltage drop of 500 mV from V_{in} to V_{base} is required. This can be translated into a minimum input voltage on VIN for a certain output voltage as the following calculation shows:

$$VIN_{min} = V_O4 + V_{BE} + 0.5\ V$$

The base drive current together with the h_{FE} of the external transistor determines the possible output current. Using a standard npn transistor like the BCP68 allows an output current of 1 A and using the BCP54 allows a load current of 337 mA for an input voltage of 5 V. Other transistors can be used as well depending on the required output current, power dissipation, and PCB space. The device is stable with a 4.7-µF ceramic output capacitor. Larger output capacitor values can be used to improve the load transient response when higher load currents are required.

Layout Considerations

For all switching power supplies, the layout is an important step in the design, especially at high-peak currents and switching frequencies. If the layout is not carefully designed, the regulator might show stability and EMI problems. Therefore, the traces carrying high-switching currents should be routed first using wide and short traces. The input filter capacitor should be placed as close as possible to the input pin VIN of the IC. See the evaluation module (EVM) for a layout example.

Thermal Information

An influential component of thermal performance of a package is board design. To take full advantage of the heat dissipation abilities of the PowerPAD package with exposed thermal die, a board that acts similar to a heat sink and allows the use of an exposed (and solderable) deep downset pad should be used. For further information, see the Texas Instruments application reports *PowerPAD Thermally Enhanced Package* (SLMA002) and *PowerPAD Made Easy* (SLMA004).

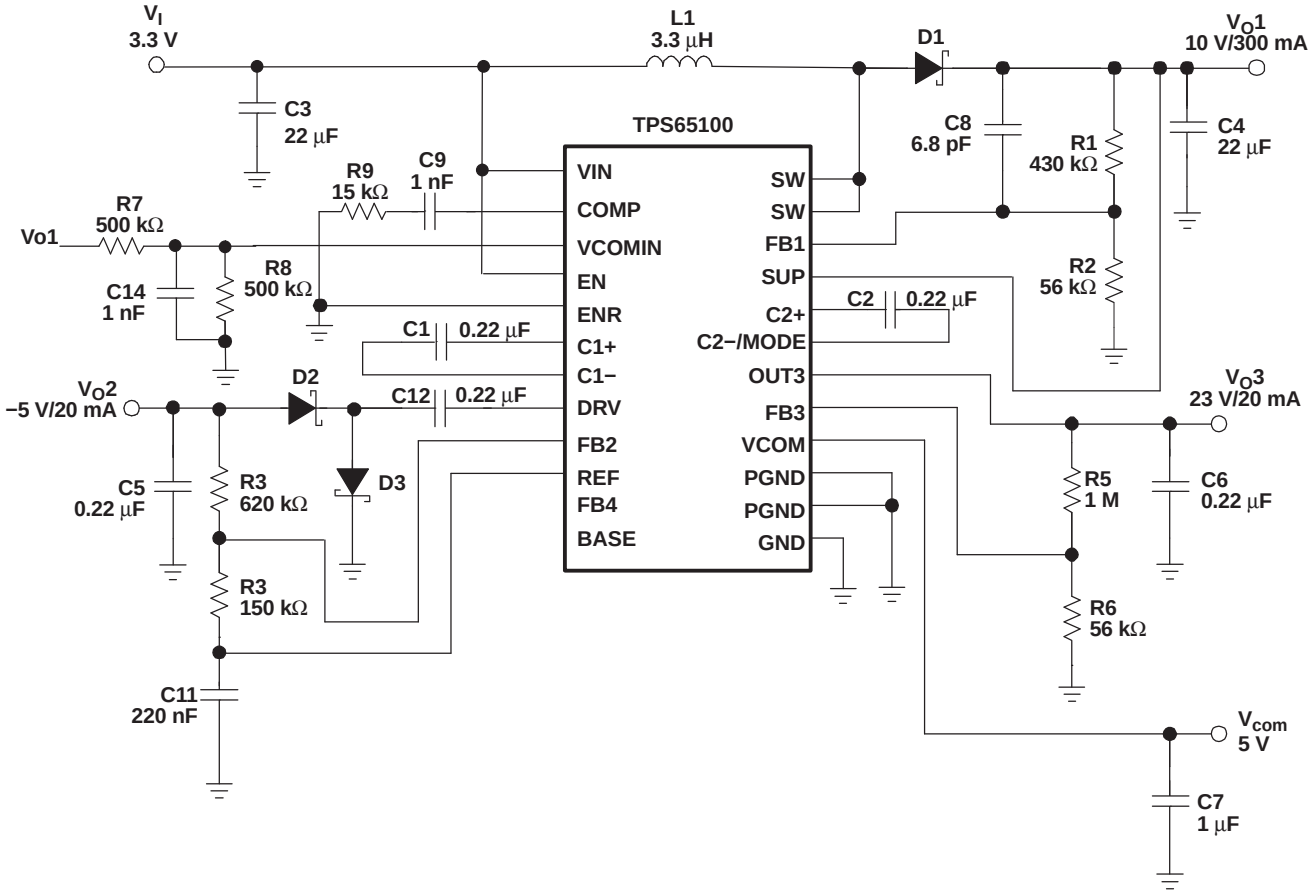


Figure 23. Typical Application, Notebook supply

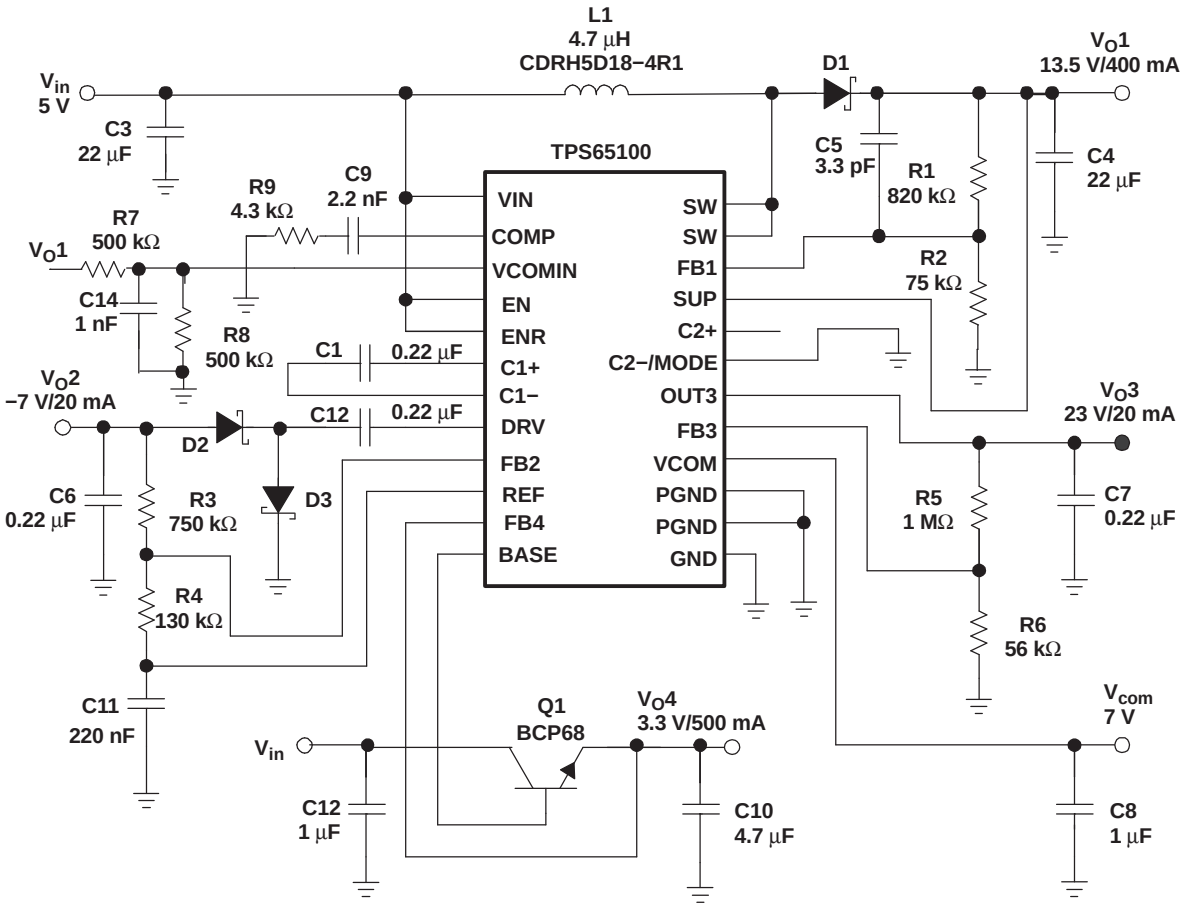


Figure 24. Typical Application, Monitor Supply

REVISION HISTORY

Changes from Original (July, 2008) to Revision A	Page
• Added thermal table for PWP package.	3

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
TPS65100QPWPRQ1	ACTIVE	HTSSOP	PWP	24	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 125	65100Q	Samples

(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) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side 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 Top-Side Marking for that device.

OTHER QUALIFIED VERSIONS OF TPS65100-Q1 :

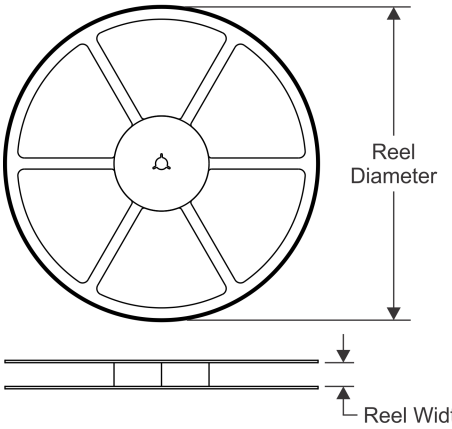
- Catalog: TPS65100

NOTE: Qualified Version Definitions:

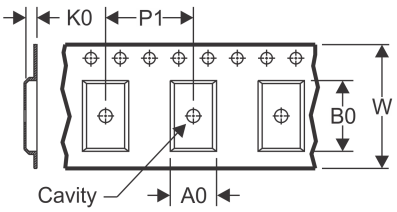
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

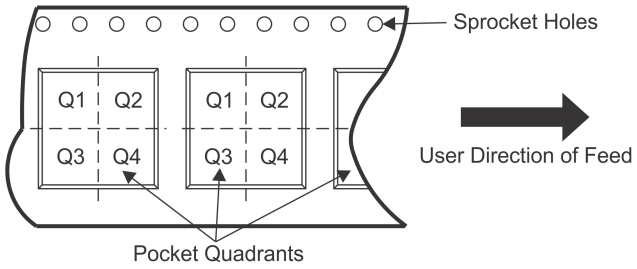


TAPE DIMENSIONS



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

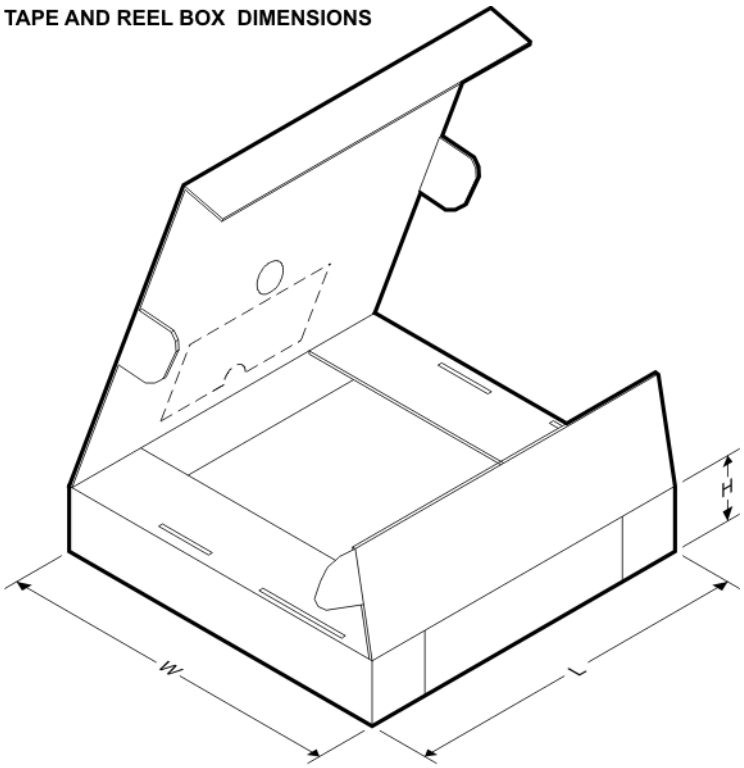
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TPS65100QPWPRQ1	HTSSOP	PWP	24	2000	330.0	16.4	6.95	8.3	1.6	8.0	16.0	Q1

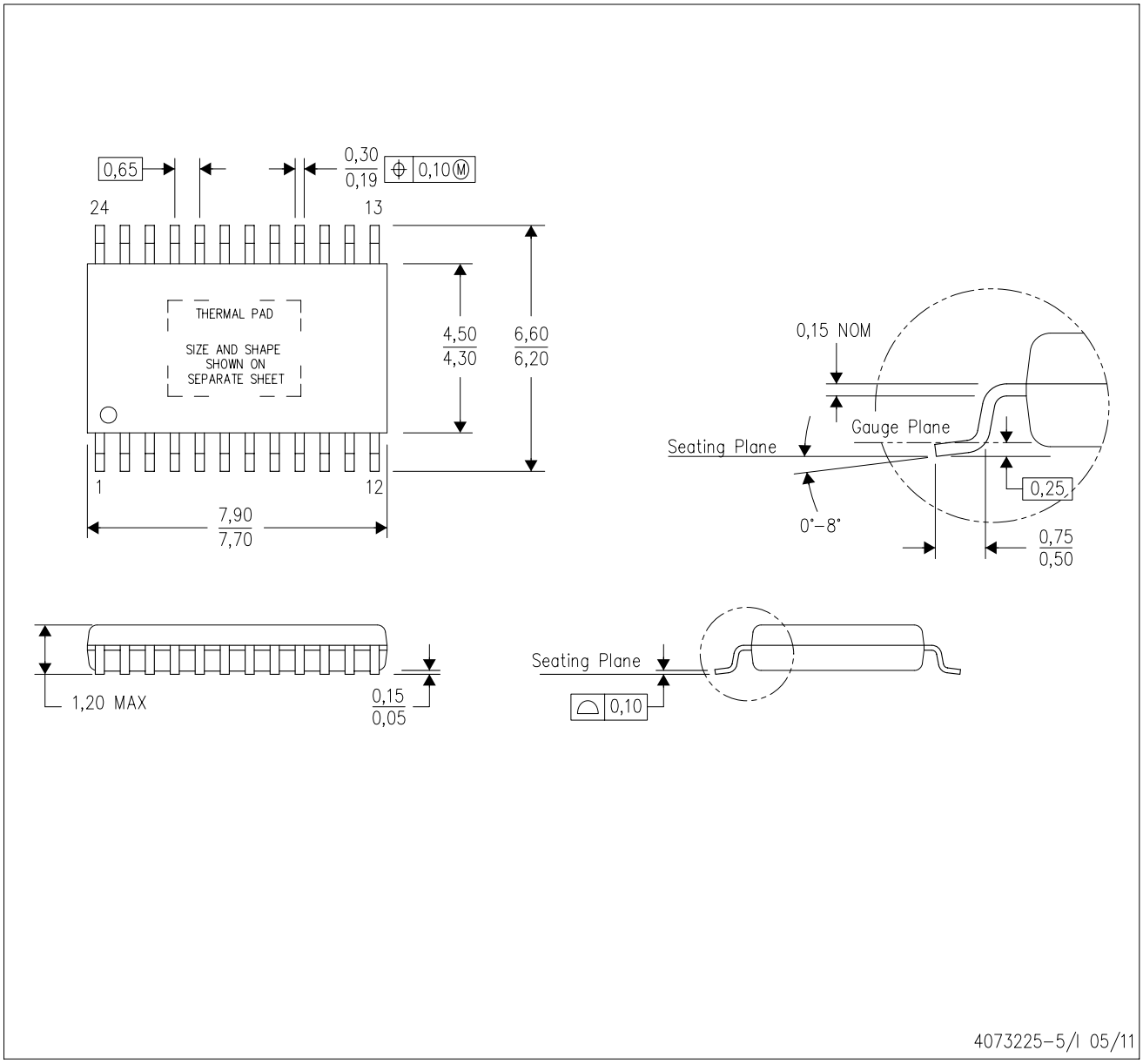
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS65100QPWPRQ1	HTSSOP	PWP	24	2000	367.0	367.0	38.0

PWP (R–PDSO–G24) PowerPAD™ PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusions. Mold flash and protrusion shall not exceed 0.15 per side.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <http://www.ti.com>.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
E. Falls within JEDEC MO–153

PowerPAD is a trademark of Texas Instruments.

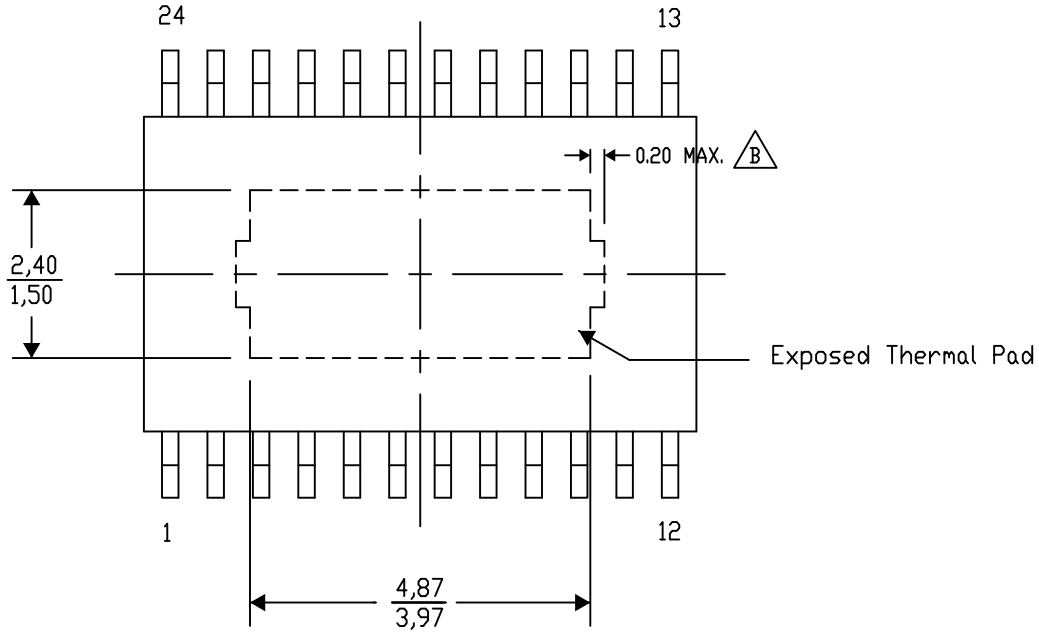
PWP (R–PDSO–G24) PowerPAD™ SMALL PLASTIC OUTLINE

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the 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 additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

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



Top View

Exposed Thermal Pad Dimensions

4206332–29/AJ 10/14

NOTE: A. All linear dimensions are in millimeters

B. Exposed tie strap features may not be present.

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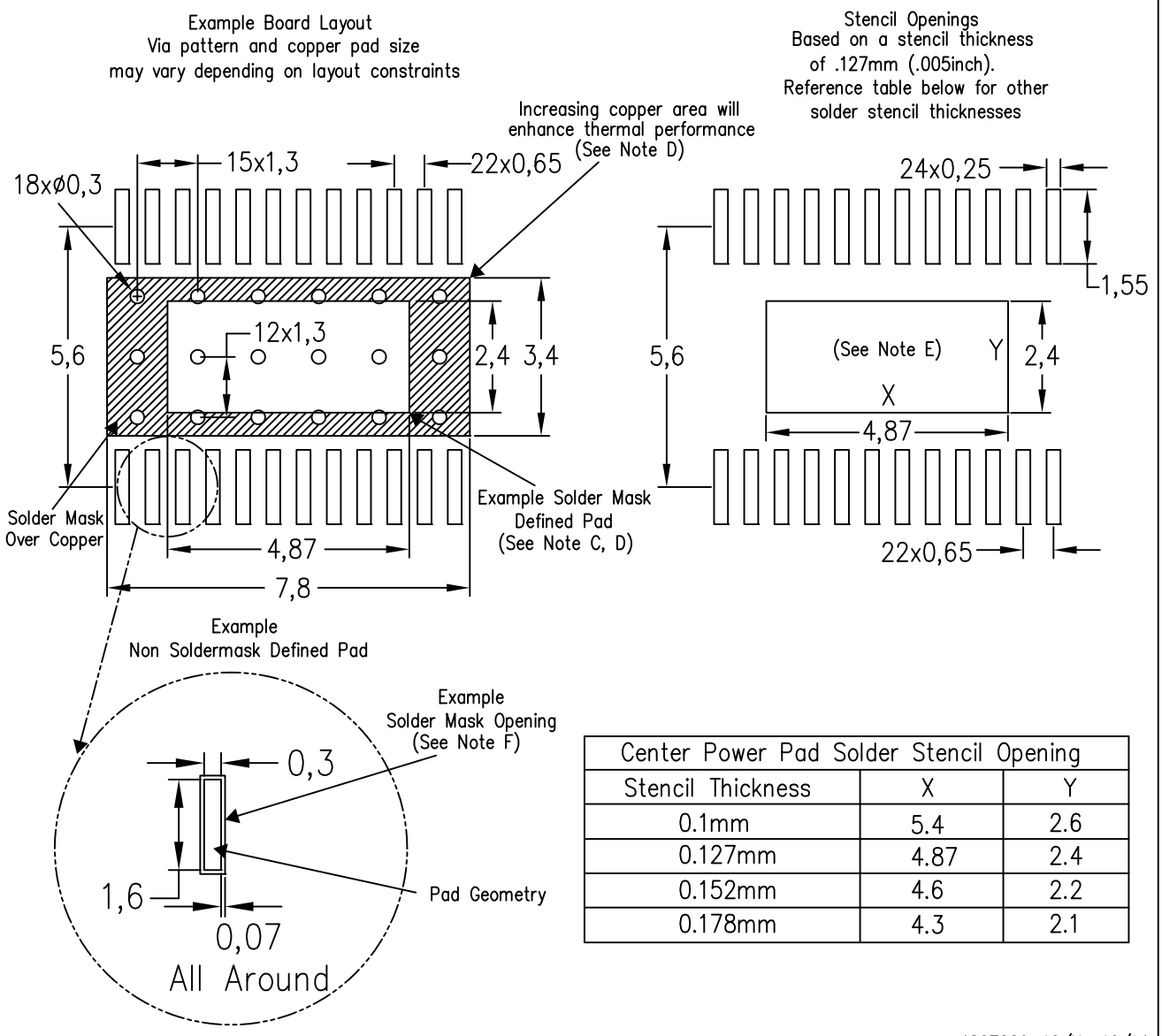
PWP (R–PDSO–G24) PowerPAD™ PLASTIC SMALL OUTLINE



Center Power Pad Solder Stencil Opening		
Stencil Thickness	X	Y
0.1mm	5.4	2.6
0.127mm	4.87	2.4
0.152mm	4.6	2.2
0.178mm	4.3	2.1

4207609–16/U 10/14

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002, SLMA004, 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>. Publication IPC–7351 is recommended for alternate designs.
E. 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. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.
F. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

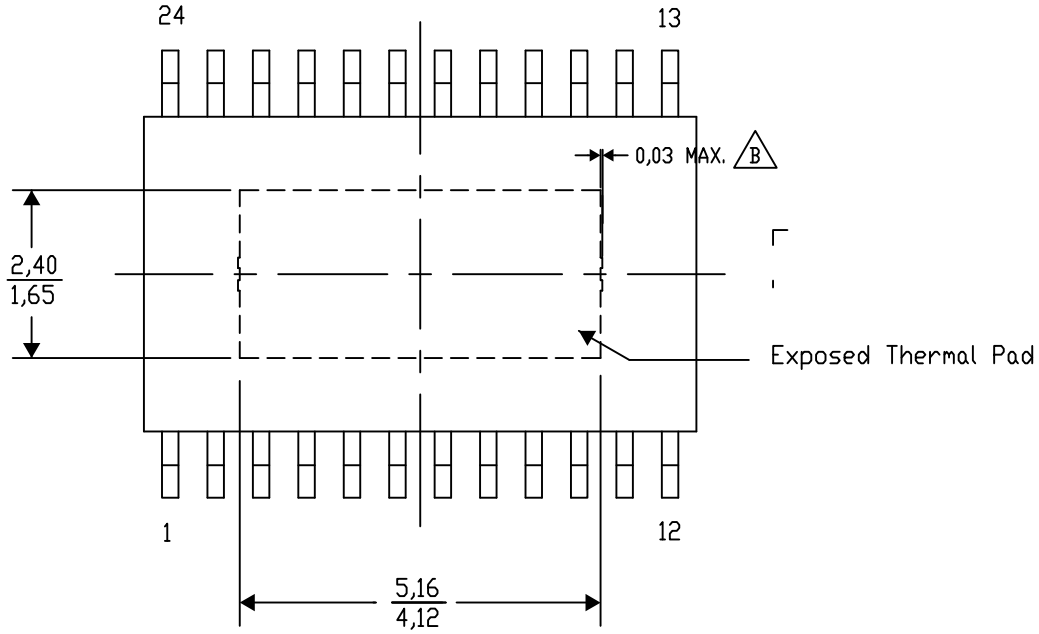
PWP (R–PDSO–G24) PowerPAD™ SMALL PLASTIC OUTLINE

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the 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 additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

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



Top View

Exposed Thermal Pad Dimensions

4206332–54/AJ 10/14

NOTE: A. All linear dimensions are in millimeters

B. Exposed tie strap features may not be present.

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