Synchronous Boost Converter with Ultra-Low Quiescent Current

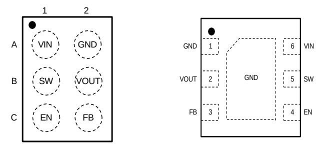
The HT26993 is an ultra-low quiescent current synchronous Boost converter. 0.9V to 5.2V operating input voltage is suitable for Li-Mn battery, NiMH and Li-Ion rech argeable batteries. The 0.6μA (TYP) quiescent current maximizes the light load efficiency and also increases the effective battery operation time. In addition, the high-side synchronous rectifier provides output disconnect feature which minimizes unnecessary current drawn from the battery during shutdown mode.The HT26993 is able to deliver 300mA output current from 3.3V to 5V conversion, and achieves up to 93% efficiency at 200mA load.The device offers down mode where the desired output voltage is regulated even when input voltage is higher than the output. In addition, when the input voltage is 300mV above the output voltage set point, the device enters pass-through mode.The device integrates various protection features such as over-voltage protection and thermal shutdown. In addition, the synchronous rectifier supports short circuit protection which further improves the robustness of the device.

FEATURES

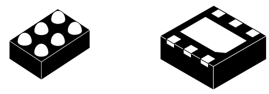
- **Operating Input Voltage Range: 0.9V to 5.2V**
- **Ultra-Low Quiescent Current**
  - **0.6μA (TYP) Ultra-Low I_Q into VOUT Pin**
  - **0.05μA (TYP) Ultra-Low I_Q into VIN Pin**
- **1.2MHz Fixed Frequency Operation**
- **Adjustable Output Voltage from 2.5V to 5.2V**
- **Fixed Output Voltage Versions Available**
- **Power-Save Mode for Improved Efficiency at Low Output Power**
- **Regulated Output Voltage in Down Mode**
- **True Disconnection During Shutdown**
- **Up to 75% Efficiency at 10μA Load with Fixed Output Voltage Version**
- **Up to 93% Efficiency from 10mA to 300mA Load**

PIN CONFIGURATION

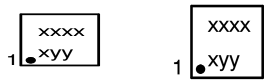
(TOP VIEW)



MARKING DIAGRAMS



WLCSP6 **DFN6（2x2）**



xxxxx = Specific Device Code
yy = Output Voltage

ORDERINGINFORMATION

HT26993C-xx SOT23-5
HT26993D-xx DFN6

T_A = -40° to 125° C for all packages

APPLICATIONS

LCD and LED Bias
Portable and Wearable Applications Low
Power Wireless Applications Battery
Powered Systems

TYPICAL APPLICATION

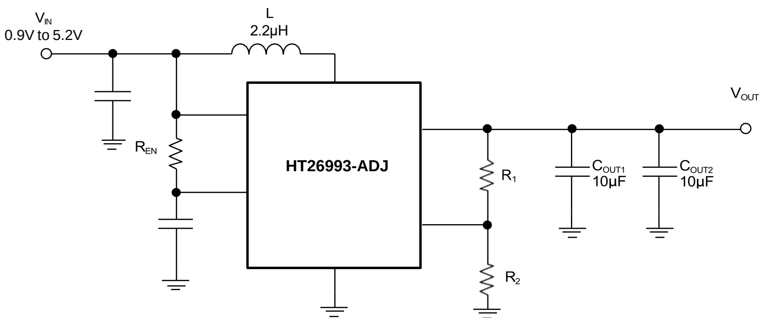


Figure 1. Typical Application Circuit

ABSOLUTE MAXIMUM RATINGS

VIN, SW, VOUT, FB, EN to GND............................ V to 6.0V
Package Thermal Resistance
WLCSP-1.22×0.83-6B, θ_{JA}........................143℃/W
TQFN-2×2-6AL, θ_{JA}........................105℃/W
Junction Temperature.. +150℃
Storage Temperature.................................. -65℃ to +150℃
Lead Temperature (Soldering, 10s)........................... +260℃
ESD Susceptibility
HBM.. 4000V
MM...V
CDM 1000V

RECOMMENDED OPERATING CONDITIONS

Input Voltage Range .... V (1) to 5.2V
Output Voltage Range .... V to 5.2V
Operating Ambient Temperature Range........ -40℃ to +85℃
Operating Junction Temperature Range...... -40℃ to +125℃

NOTE 1: Refer to the “Start-up and Low Supply Voltage Operation” for detailed description.

OVERSTRESS CAUTION

Stresses beyond those listed in Absolute Maximum Ratings may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect reliability. Functional operation of the device at any conditions beyond those indicated in the Recommended Operating Conditions section is not implied.

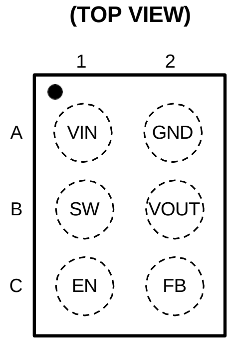
ESD SENSITIVITY CAUTION

This integrated circuit can be damaged by ESD if you don’t pay attention to ESD protection. Htcsemi 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.

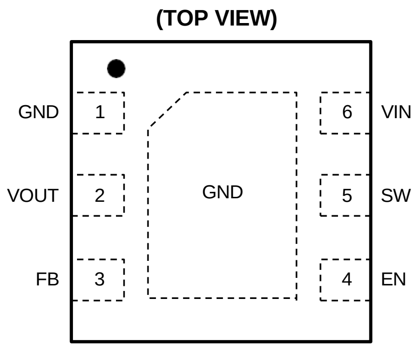
DISCLAIMER

SG Micro Corp reserves the right to make any change in circuit design, or specifications without prior notice.

PIN CONFIGURATIONS



WLCSP-1.22×0.83-6B



TDFN-2×2-6AL

PIN DESCRIPTION

PIN		NAME	TYPE	FUNCTION
WLCSP-1.22×0.83-6B	TDFN-2×2-6AL			
A1	6	VIN	P	Power Supply Input.
A2	1	GND	G	Ground.
B1	5	SW	O	Switch Node. Drain connection of low-side power MOSFET.
B2	2	VOUT	O	Boost Converter Output.
C1	4	EN	I	Device Enable Node. Pulling this pin logic high enables the device, logic low disables the device.
C2	3	FB	I	Voltage Feedback of Adjustable Output Voltage. Connect a resistive divider to program the desired output voltage.
—	Exposed Pad	GND	—	Connect to GND.

NOTE: I: input, O: output, G: ground, P: power for the circuit.

ELECTRICAL CHARACTERISTICS

(V_{IN} = 0.9V to 5.2V, C_{IN} = 10μF, C_{OUT} = 20μF, Full = -40℃ to +85℃, typical values are at V_{IN} = 3.7V, T_A = +25℃, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	TEMP	MIN	TYP	MAX	UNITS
Power Supply							
Input Voltage Range	V_{IN}		+25℃	0.9		5.2	V
Quiescent Current into VIN Pin	I_Q	No load, not switching	Full		0.05	0.2	μA
Quiescent Current into VOUT Pin		No load, not switching, boost or down mode	Full		0.6	1.1	μA
Shutdown Current into VIN Pin	I_{SD}	EN = GND, V_{IN} = 3.6V	Full		0.1	1	μA
Output							
Output Voltage Range	V_{OUT}		Full	2.5		5.2	V
Output Voltage		HT26993-5.0, $V_{IN} < V_{OUT}$, PWM mode	Full	4.85	5.00	5.09	V
		HT26993-5.0, $V_{IN} < V_{OUT}$, PFM mode	+25℃		5.08		V
		HT26993-4.5, $V_{IN} < V_{OUT}$, PWM mode	Full	4.37	4.50	4.58	V
		HT26993-4.5, $V_{IN} < V_{OUT}$, PFM mode	+25℃		4.57		V
		HT26993-3.6, $V_{IN} < V_{OUT}$, PWM mode	Full	3.50	3.60	3.67	V
		HT26993-3.6, $V_{IN} < V_{OUT}$, PFM mode	+25℃		3.65		V
		HT26993-3.3, $V_{IN} < V_{OUT}$, PWM mode	Full	3.21	3.30	3.35	V
		HT26993-3.3, $V_{IN} < V_{OUT}$, PFM mode	+25℃		3.35		V
		HT26993-3.0, $V_{IN} < V_{OUT}$, PWM mode	Full	2.92	3.00	3.05	V
		HT26993-3.0, $V_{IN} < V_{OUT}$, PFM mode	+25℃		3.04		V
		HT26993-2.5, $V_{IN} < V_{OUT}$, PWM mode	Full	2.44	2.50	2.54	V
		HT26993-2.5, $V_{IN} < V_{OUT}$, PFM mode	+25℃		2.54		V
Feedback Reference Voltage	V_{REF}	$V_{IN} < V_{OUT}$, PWM mode	Full	0.975	1.000	1.025	V
		$V_{IN} < V_{OUT}$, PFM mode	+25℃		1.020		V
Output Over-Voltage Protection Threshold	V_{OVP}	V_{OUT} rising	+25℃	5.50	5.8	5.95	V
OVP Hysteresis			+25℃		100		mV
Leakage Current into FB Pin	I_{FB_LKG}	V_{FB} = 1.1V	Full		10	50	nA
Switching							
Switching Frequency	f_{SW}	V_{IN} = 3.7V	Full	1	1.2	1.35	MHz
Power Switch							
Low-side Switch On-Resistance	$R_{DS(ON)\_LS}$	V_{OUT} = 5.0V (TDFN)	+25℃		280	400	mΩ
		V_{OUT} = 5.0V (WLCSP)	+25℃		220	310	mΩ
		V_{OUT} = 3.3V (TDFN)	+25℃		340	480	mΩ
		V_{OUT} = 3.3V (WLCSP)	+25℃		290	390	mΩ
Rectifier On-Resistance	$R_{DS(ON)\_HS}$	V_{OUT} = 5.0V (TDFN)	+25℃		270	350	mΩ
		V_{OUT} = 5.0V (WLCSP)	+25℃		250	350	mΩ
		V_{OUT} = 3.3V (TDFN)	+25℃		350		mΩ
		V_{OUT} = 3.3V (WLCSP)	+25℃		330		mΩ
Current Limit Threshold	I_{LIM}	V_{OUT} > 2.5V, boost operation	+25℃	0.89	1.3	1.62	A
		V_{OUT} = 2.5V, boost operation	+25℃	0.57	0.8	1.06	A

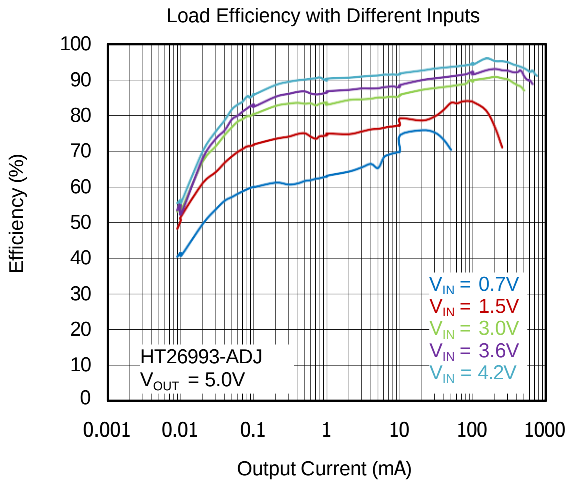
ELECTRICAL CHARACTERISTICS (continued)

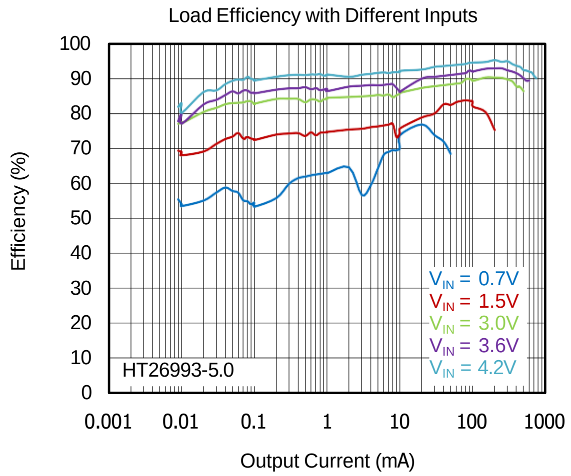
(V_{IN} = 0.9V to 5.2V, C_{IN} = 10μF, C_{OUT} = 20μF, Full = -40℃ to +85℃, typical values are at V_{IN} = 3.7V, T_A = +25℃, unless otherwise noted.)

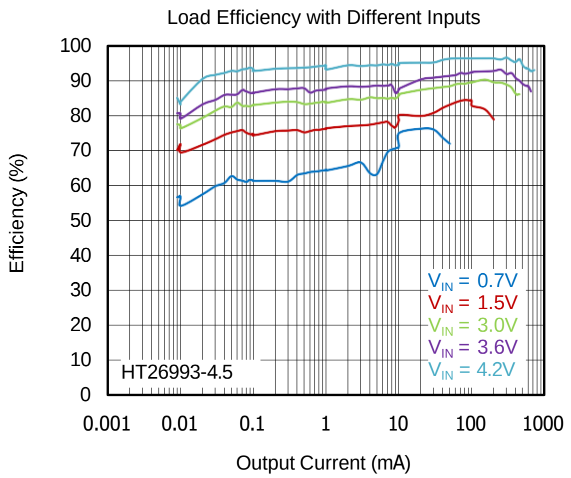
PARAMETER	SYMBOL	CONDITIONS	TEMP	MIN	TYP	MAX	UNITS
Control Logic							
EN Input Low Voltage Threshold	V_{IL}	V_{IN} ≤ 1.5V	Full			0.18 × V_{IN}	V
		V_{IN} > 1.5V	Full			0.4	V
EN Input High Voltage Threshold	V_{IH}	V_{IN} ≤ 1.5V	Full	0.8 × V_{IN}			V
		V_{IN} > 1.5V	Full	1.2			V
Leakage Current into EN Pin	I_{EN_LKG}	V_{EN} = 5.0V	+25℃			300	nA
Over-Temperature Protection					150		℃
Over-Temperature Hysteresis					25		℃

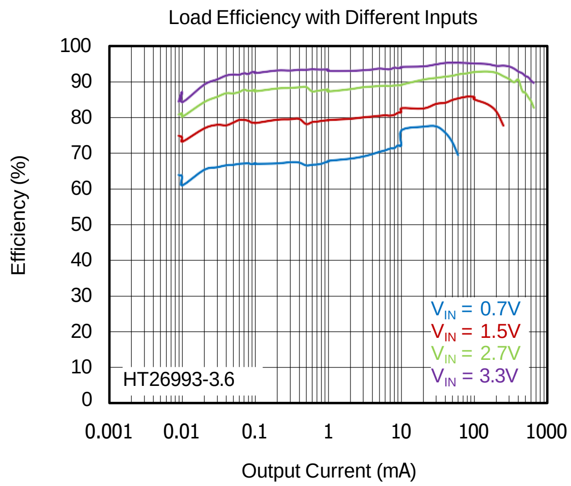
TYPICAL PERFORMANCE CHARACTERISTICS

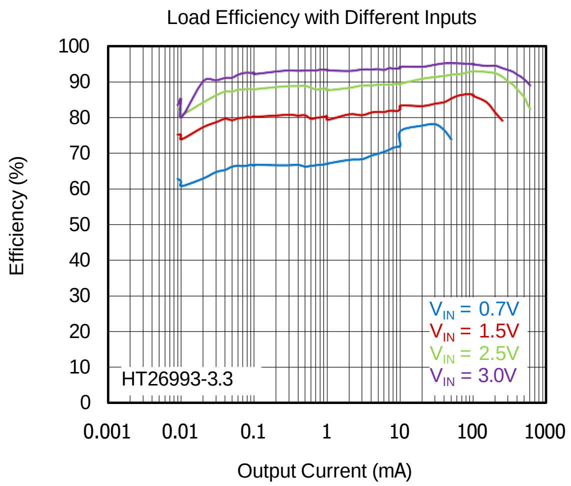
T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

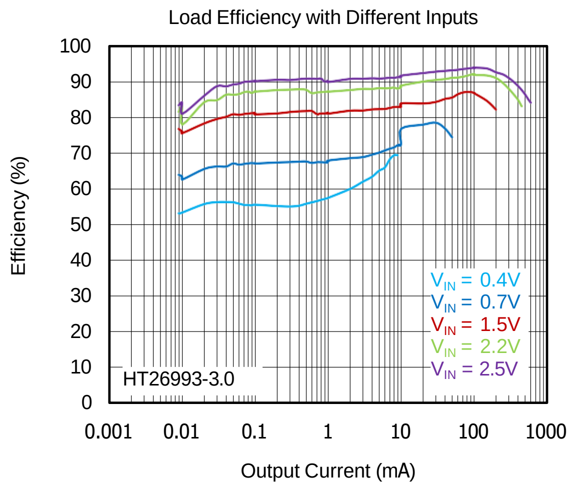








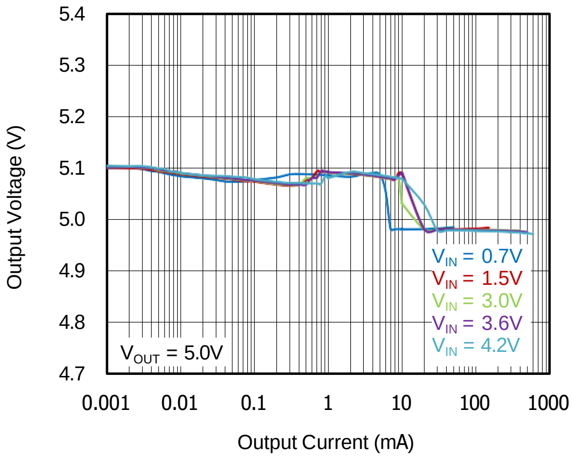




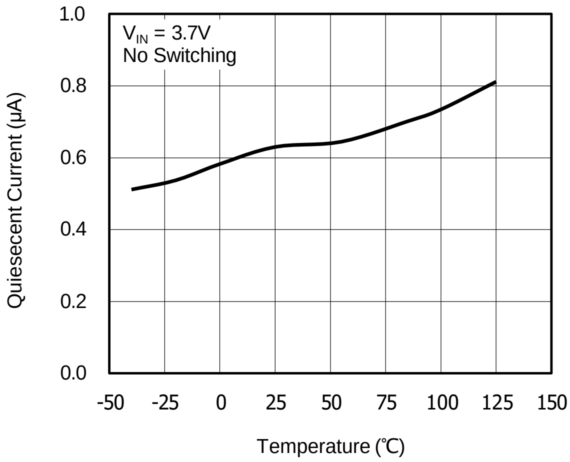
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

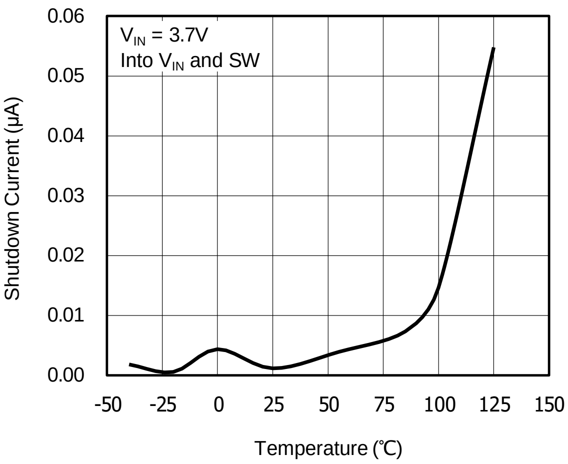
Load Regulation



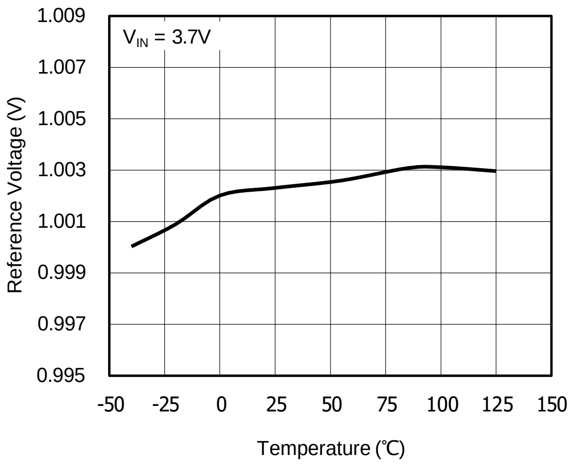
Quiescent Current into VOUT Pin vs. Temperature



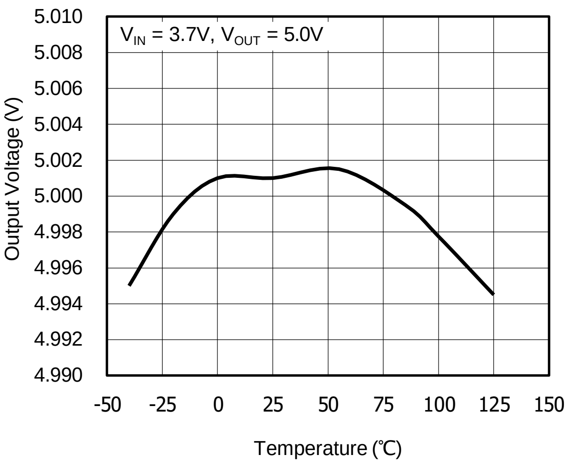
Shutdown Current vs. Temperature



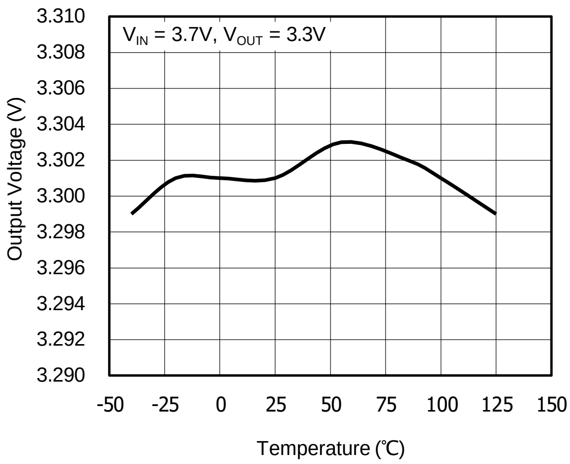
Reference Voltage vs. Temperature



Output Voltage vs. Temperature



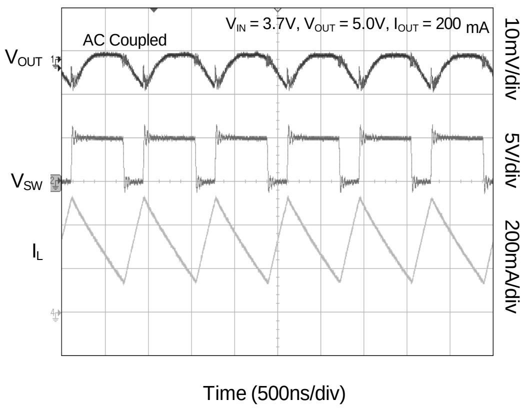
Output Voltage vs. Temperature



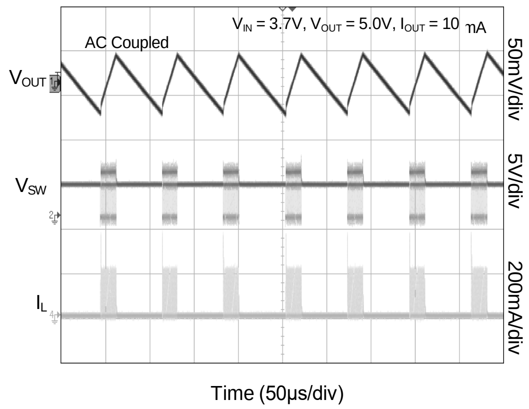
TYPICAL PERFORMANCE CHARACTERISTICS (continued)

T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.

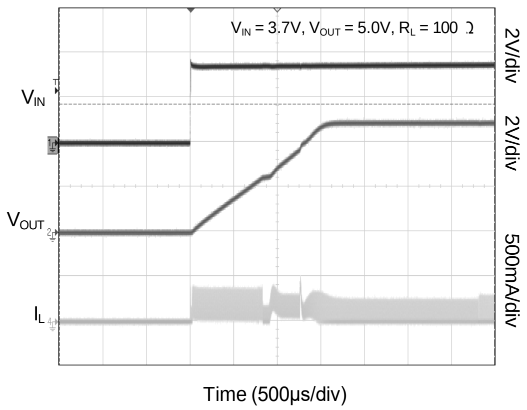
Switching Waveform at Heavy Load



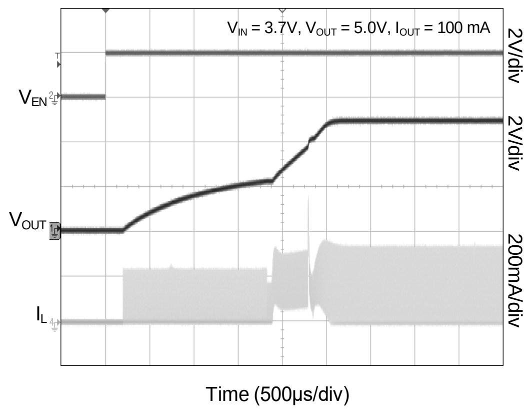
Switching Waveform at Light Load



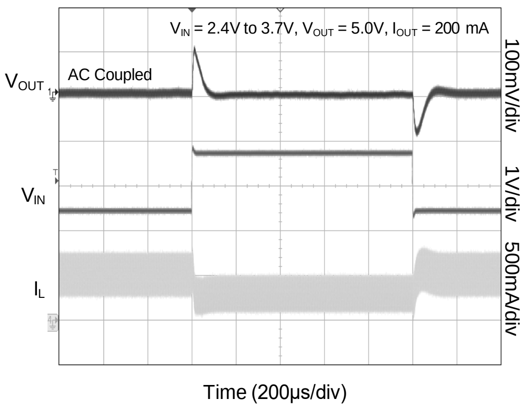
Start-up by VIN Pin



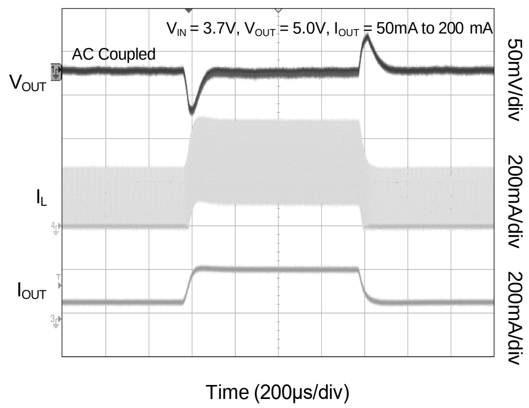
Start-up by EN Pin



Line Transient Response

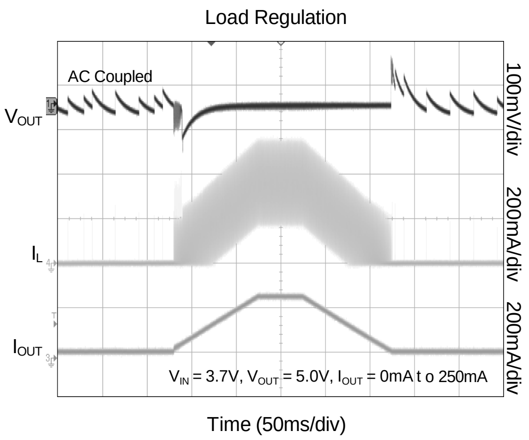


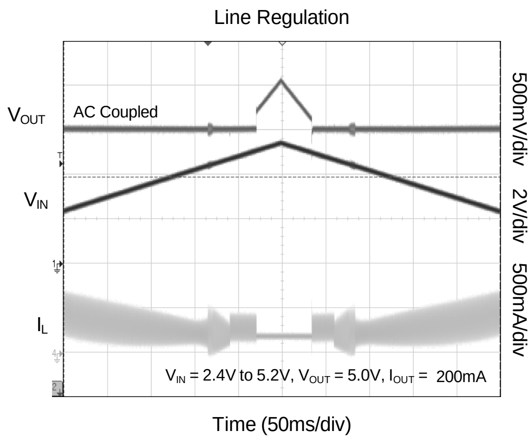
Load Transient Response

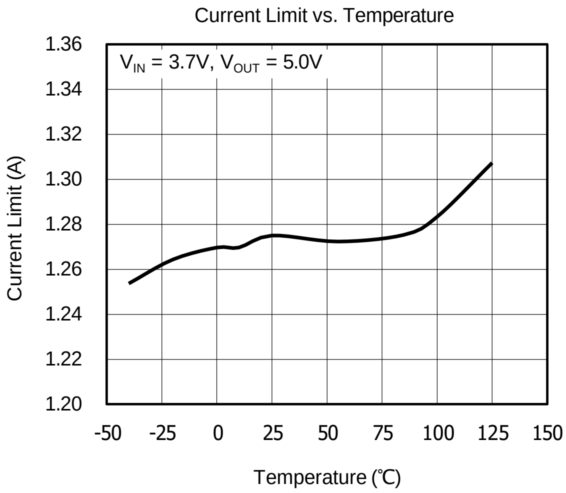


TYPICAL PERFORMANCE CHARACTERISTICS (continued)

T_A = +25℃, C_{IN} = 10μF, C_{OUT} = 20μF, unless otherwise noted.







FUNCTIONAL BLOCK DIAGRAM

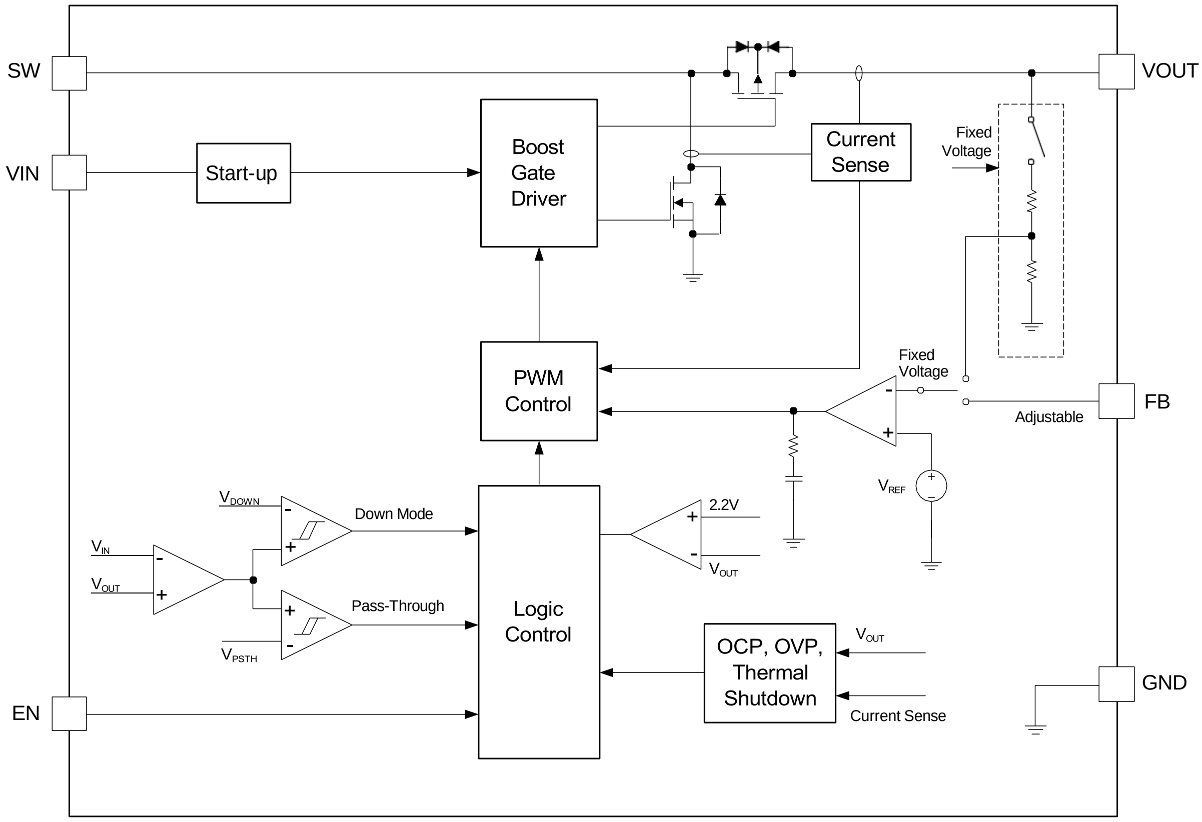


Figure 2. Block Diagram

DETAILED DESCRIPTION

The HT26993 synchronous Boost converter is designed for Li-Ion battery powered systems, where the compact solution size and battery operation time are key criterions. The device employs peak current mode control with 1.3A (TYP) peak switch current limit. The HT26993 is capable of disconnecting the output from input when the device is disabled to avoid unnecessary current consumption. The integrated down mode and pass-through mode ensure a smooth operation when input voltage is close to or higher than the set output voltage. The device is available in an adjustable output voltage version.

Start-up and Enable

Logic high on EN pin enables the HT26993, while a logic low disables the device. During logic low state, the device stops operation, and the output voltage is completely disconnected from the input voltage. During logic low state, the shutdown current is less than 1μA

The HT26993 is able to start up from 0.9V input voltage with larger than 3kΩ load. Before the output voltage reaches 2.2V during the start-up phase, the switch current is limited to about 200mA. Therefore, if the load during start-up is too heavy, the device will fail to charge the output voltage to above 2.2V after soft-start time expires, and it will not be able to start up successfully.

Over-Current and Short Circuit Protection

The HT26993 implements cycle-by-cycle current limit during an over-current event. When the current limit threshold (I_{LIM}) is reached, the low-side power MOSFET is turned off to prevent the inductor current from further increase. During over-current event, the output voltage will drop until a constant power state is reached between input and output. If the current limit causes the output to drop below the input voltage, the HT26993 enters down mode, where the peak current is still limited by I_{LIM} cycle-by-cycle. If the output continues dropping below 2.2V, the device enters start-up process again.

During the output short-to-ground case, as output voltage declines below 2.2V, the HT26993 reduces the current limit to about 200mA to reduce power dissipation within the device. As the short circuit condition is removed, the device resumes operation and goes through a soft-start sequence to regulate the set output voltage.

Over-Voltage Protection

HT26993 integrates over-voltage protection (OVP) to protect the device in the event of feedback resistor short-to-ground or incorrect feedback resistor value being populated. The HT26993 stops switching when the OVP threshold of 5.8V (TYP) is reached. The device implements 100mV OVP hysteresis. When the output voltage is 100mV lower than the OVP threshold, the device resumes switching.

Power-Save Mode under Light Load Condition

HT26993 enters power-save mode under light load condition.

Down Mode and Pass-Through Mode

HT26993 offers down mode feature where the device can still regulate the set output voltage even when the input voltage is higher than output voltage. If the input voltage continues increasing in down mode, the device automatically enters pass-through mode. Care should be taken in pass-through mode, where the input voltage should not exceed the recommended maximum input voltage.

In down mode, the control logic pulls the gate of PMOS to the input voltage rather than ground. This method allows effective control of inductor current when $V_{IN} > V_{OUT}$. Thermal consideration should be taken in down mode, where the voltage drop across the PMOS increases as the delta of V_{IN} and V_{OUT} increases.

In pass-through mode, the complimentary switching action stops. The gate of PMOS is pulled to ground for always-on and the low-side switch remains off. The output voltage is equal to the input voltage minus the voltage drop across the DC resistance (DCR) of the inductor and the on-resistance of the rectifying PMOS.

DETAILED DESCRIPTION (continued)

The HT26993 enters down mode when the input voltage is equal to or higher than V_{OUT} - 100mV. It remains in down mode until the V_{IN} is more than V_{OUT} + 0.3V and then automatically enters pass-through mode. In pass-through mode, the high-side PMOS is always turned on to pass the input voltage to the output. As V_{IN} drops below 1% above the target output voltage, the device exits pass-through mode and returns to down mode. The device exits down mode and returns to normal boost switching operation as V_{IN} drops 150mV below the target output voltage.

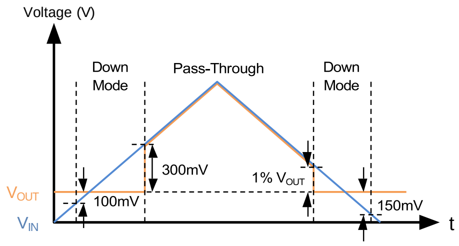


Figure 3. Down Mode and Pass-Through Mode

Thermal Shutdown

A thermal shutdown function is implemented to prevent damage caused by excessive heat and power dissipation. Once a junction temperature of +150℃ (TYP) is exceeded, the device is shut down. The device is released from shutdown automatically when the junction temperature decreases by 25℃.

APPLICATION INFORMATION

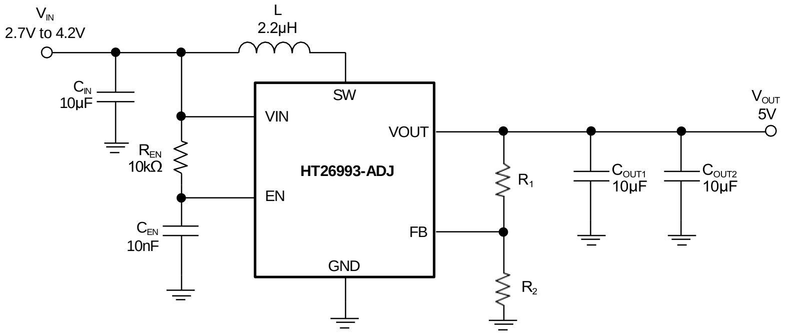


Figure 4. 5V Output Boost Converter

Design Requirements

5V output at 1mA load current is used to provide system bias power or LED bias voltage from a single cell Li-Ion battery as an example. The selection of external component values for the HT26993 can reference the following design procedure.

Table 1. Design Requirements

PARAMETERS	VALUES
Input Voltage	2.7V ~ 4.2V
Output Voltage	5V
Output Current	1mA
Output Voltage Ripple	±50mV

Programming the Output Voltage

External resistor dividers R_1 and R_2 (see Figure 4) can be used to set the output voltage. The typical voltage at the FB pin is V_{REF} of 1.0V.

$$V_{OUT} = V_{REF} \times \frac{R_1 + R_2}{R_2} \quad (1)$$

The leakage current into the FB pin affects the accuracy of output voltage. To minimize the leakage current effect, the current flowing through R_2 should be 100 times greater than FB pin leakage current. Small R_2 increases the noise immunity, while large R_2 reduces the leakage current flowing through feedback resistors, which improves the no load efficiency of the device. 1MΩ and 249kΩ resistors are selected for R_1 and R_2 respectively in this case. ±1% accuracy resistors are recommended for R_1 and R_2 to improve output voltage accuracy.

An external feed-forward capacitor (C_{FWD}) from 10pF to 22pF in parallel with R_1 is recommended to improve device's stability.

For fixed output voltage version, connect the FB pin to GND and do not leave FB pin floating. The HT26993 offers diverse fixed voltage versions.

Maximum Output Current

The maximum output load capability of HT26993 depends on the minimum desired operation input voltage and the current limit of the device. The maximum load current can be estimated by Equation 2,

$$I_{OUT(MAX)} = \frac{V_{IN} \cdot (I_{LIM} - \frac{I_{LH}}{2}) \cdot \eta}{V_{OUT}} \quad (2)$$

where η is the conversion efficiency, using 85% for estimation; I_{LH} is the inductor peak-to-peak ripple current and I_{LIM} is the switch current limit.

For worst-case condition analysis, the minimum input voltage, maximum Boost output voltage and minimum current limit (I_{LIM}) should be used.

Inductor Selection

Inductor selection is one of the most important criterions for switch mode power supply, because the inductor selection may affect the power supply's transient response, loop stability, efficiency and steady-state operation. Inductor parameters of DC resistance (DCR), inductance and saturation current are critical for a smooth and efficient power supply operation.

The internal compensation of the device is optimized with 1µH and 2.2µH. When V_{OUT} is higher than 3V, 2.2µH inductance should be selected. When V_{OUT} is less than 3V, 1.1µH inductance should be selected.

APPLICATION INFORMATION (continued)

Table 2. List of Inductors

V_{OUT} (V)	Inductance (µH)	Saturation Current (A)	DC Resistance (MΩ)	Size L × W × H (mm^3)	Part Number	Manufacturer
> 3.0	2.2	1.95	80	2.5 × 2.0 × 1.2	74404024022	Würth Elektronik
	2.2	1.7	92	2.5 × 2.0 × 1.1	LQH2HPN2R2MJR	muRata
	2.2	1.45	163	2.0 × 1.6 × 1.0	VLS201610CX-2R2M	TDK
≤ 3.0	1.0	2.6	37	2.5 × 2.0 × 1.2	74404024010	Würth Elektronik
	1.0	2.3	48	2.5 × 2.0 × 1.0	MLP2520W1R0MT0S1	TDK
	1.0	1.5	80	2.0 × 1.2 × 1.0	LQM21PN1R0MGH	muRata

Capacitor Selection

The input capacitor of boost converter not only minimizes input voltage ripple, but also reduces any voltage spike presenting on IC's VIN pin. A 10µF, low ESR and X5R or higher temperature coefficient ceramic capacitor is recommended to place as close to the VIN and GND pins as possible to improve transient response and EMI behavior.

Boost converter's output capacitor plays a significant role in ensuring good system performance. The location of output capacitor will have an effect on the switching spikes on the SW pin, which ultimately affects EMI performance and potentially damages the IC due to large switching spikes. The current loop formed by the output capacitor flowing from the VOUT pin and back to the GND pin should be as small as possible. Therefore, a ceramic cap should be placed as close to the VOUT and GND pins of the IC as possible.

Boost topology presents right-half-plane-zero which is dictated by inductance. In addition, the output capacitor sets the corner frequency of the converter for current mode controlled method. Consequently, with a larger inductor, a larger output capacitor must be used. The device's internal compensation is optimized to operate with inductance values between 1µH and 2.2µH, resulting in the minimum output capacitor value of 20µF (nominal value). Increasing the output capacitor can reduce output ripple in PWM mode.

Due to the nature of ceramic capacitors' DC bias effect, effective capacitance at the bias voltage should be verified. GRM188R60J106ME84D is used for V_{OUT} rail. It is a 10µF ceramic capacitor and has high effective capacitance value at DC biased condition.

In the case of load hot-plugging, the input capacitance of load device needs to be less than 1/10 of the output capacitance of HT26993.

Layout

In addition to component selection, layout is a critical step to ensure the performance of any switch mode power supplies. Poor layout could result in system instability, EMI failure, and device damage. Thus, place the inductor, input and output capacitors as close to the IC as possible, and use wide and short traces for current carrying traces to minimize PCB inductance.

For Boost converter, the current loop of the output capacitor from VOUT pin back to the GND pin of the device should be as small as possible.

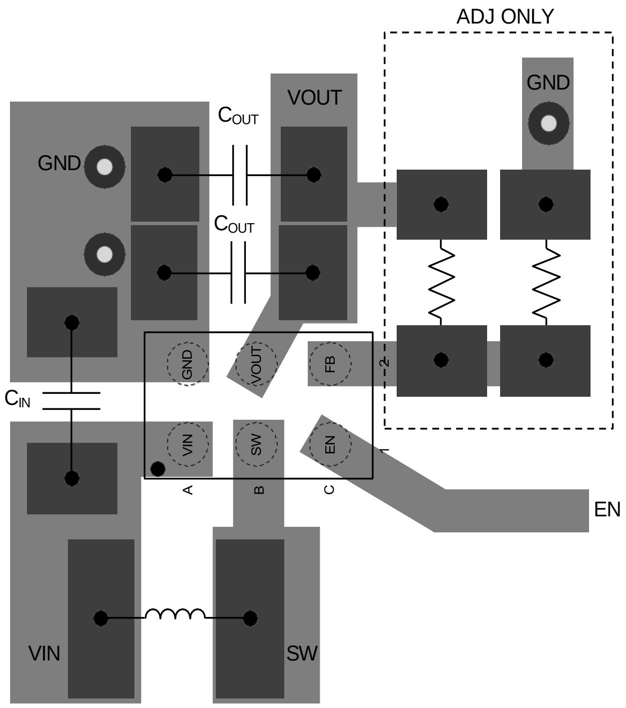
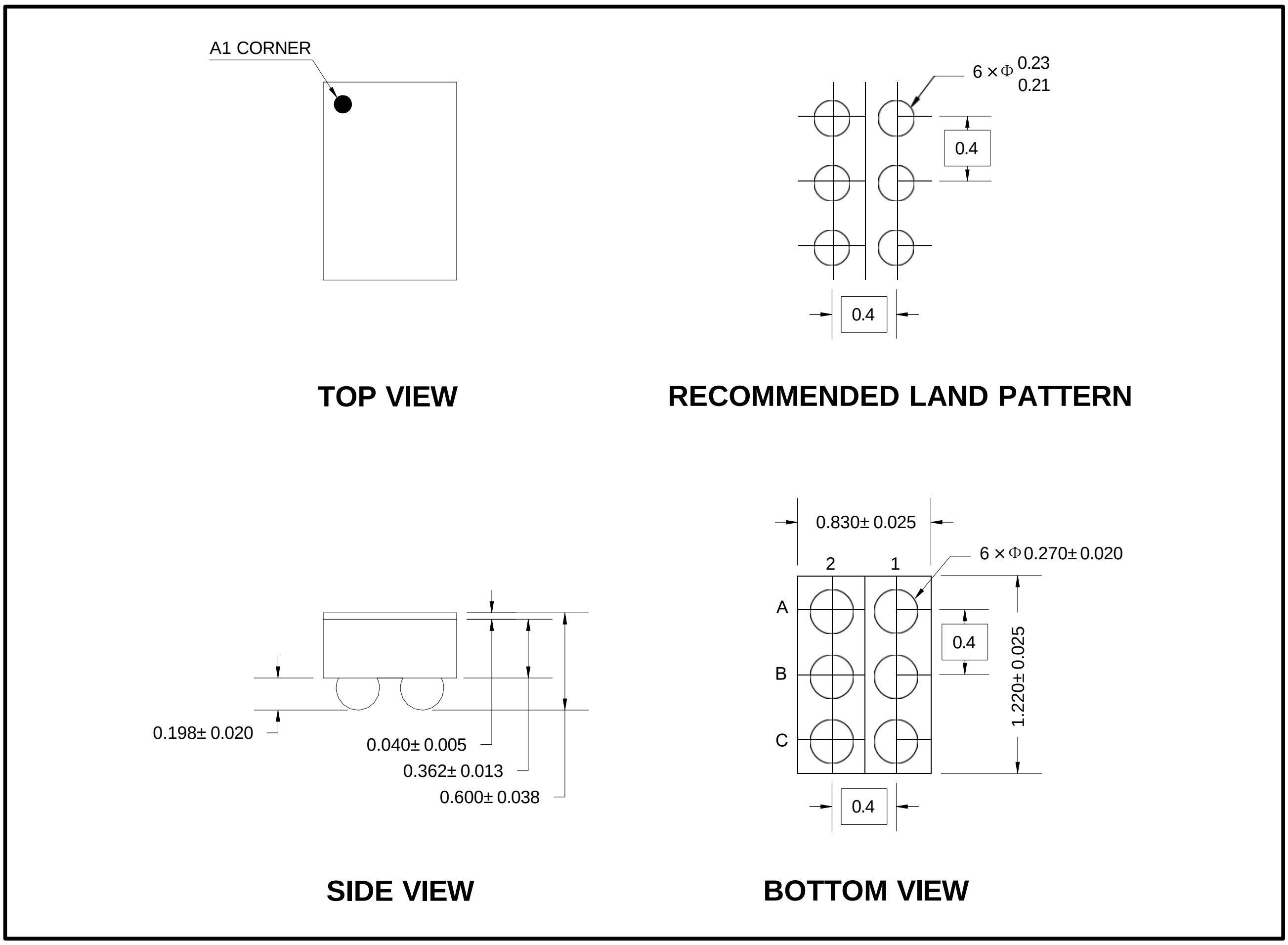


Figure 5. HT26993 PCB Layout

PACKAGE OUTLINE DIMENSIONS

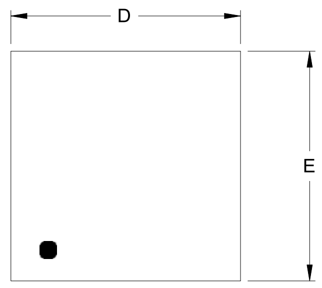
WLCSP-1.22×0.83-6B



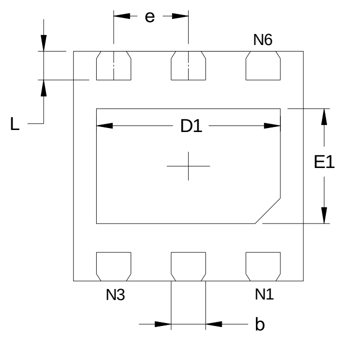
NOTE: All linear dimensions are in millimeters.

PACKAGE OUTLINE DIMENSIONS

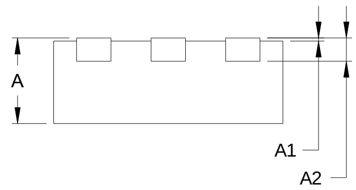
DFN-2×2-6AL



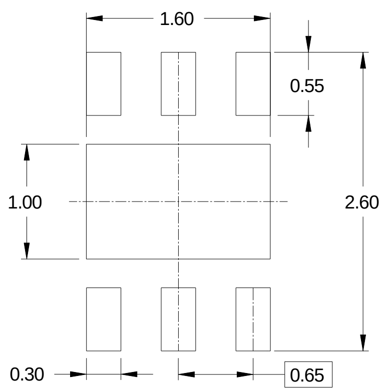
TOP VIEW



BOTTOM VIEW



SIDE VIEW

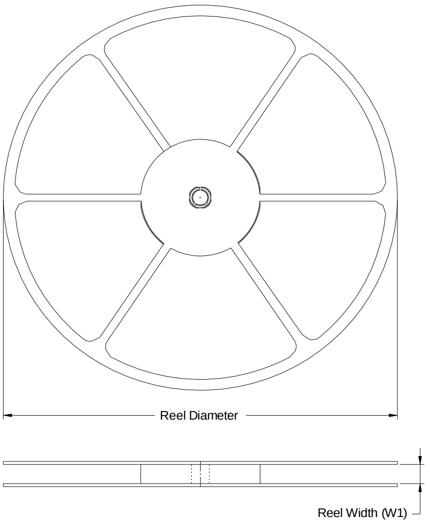


RECOMMENDED LAND PATTERN (Unit: mm)

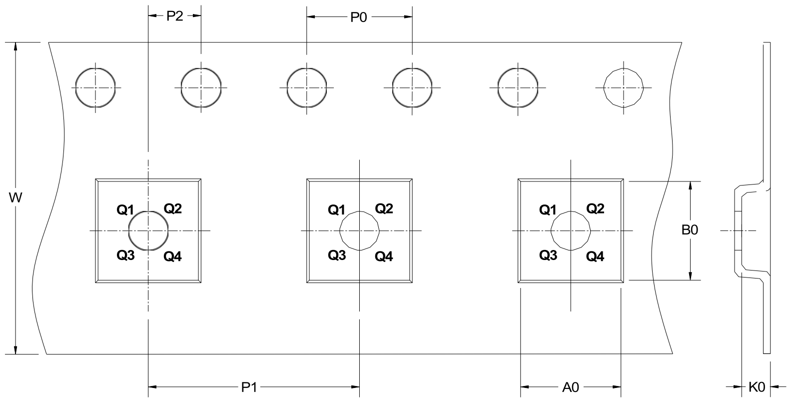
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A2	0.203 REF		0.008 REF	
D	1.900	2.100	0.075	0.083
D1	1.500	1.700	0.059	0.067
E	1.900	2.100	0.075	0.083
E1	0.900	1.100	0.035	0.043
b	0.250	0.350	0.010	0.014
e	0.650 BSC		0.026 BSC	
L	0.174	0.326	0.007	0.013

TAPE AND REEL INFORMATION

REEL DIMENSIONS



TAPE DIMENSIONS



DIRECTION OF FEED

NOTE: The picture is only for reference. Please make the object as the standard.

KEY PARAMETER LIST OF TAPE AND REEL

Package Type	Reel Diameter	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	P1 (mm)	P2 (mm)	W (mm)	Pin1 Quadrant
WLCSP-1.22×0.83-6B	7″	9.5	0.91	1.31	0.71	4.0	4.0	2.0	8.0	Q1
TDFN-2×2-6AL	7″	9.5	2.30	2.30	1.10	4.0	4.0	2.0	8.0	Q1

DD0001