High-Efficiency, 1-Cell and 2-Cell Boost Converter

Description

The FP6711 is a high efficiency, fixed frequency 500KHz, current mode PWM boost DC/DC converter which could operate from single/dual-cell NiCd, NiMH or alkaline battery such as input voltage below 1V. The converter output voltage can be adjusted from 1.8V to maximum 4V by an external resistor divider. Besides the converter includes a 0.35Ω N-channel MOSFET switch and 0.45Ω P-channel synchronous rectifier. So no external Schottky diode is required, and it could get better efficiency near 94%.

The converter is based on a fixed frequency, current mode, pulse-width-modulation PWM controller that goes automatically into PFM mode at light load which quiescent current is only 25μA in this mode operation.

The converter features a special function that the load is completely isolated from the battery during shutdown. Besides it also has auto-discharge function which could discharge the output capacitor immediately during shutdown.

When converter operates into discontinuous mode, the internal anti-ringing switch will reduce interference and radiated electromagnetic energy. The FP6711 is available in a space-saving 10-lead MSOP package for portable application.

Features

- Synchronous Rectification: 94% Efficiency
- Very Low Start-up Voltage at 0.85V
- Automatically Switch to PFM Mode for Improving Efficiency at Light Load
- Built-in True Shutdown: Isolation of Load from Battery during Shutdown
- Internal Anti-Ringing Switch across Inductor
- Low Battery Warning Display
- Fixed Frequency Operation at 500kHz
- Very Low Shutdown Current at 1μA
- Small 10-Pin MSOP Package
- RoHS Compliant

Applications

- Handheld Instrument
- Cordless Phone
- Wireless Handset
- GPS Receiver
- MP3

Pin Assignments

MS Package (MSOP-10)

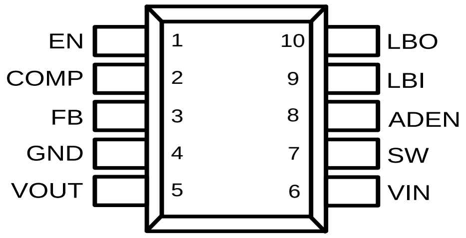
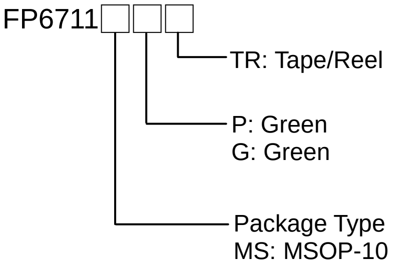


Figure 1. Pin Assignment of FP6711

Ordering Information



Typical Application Circuit

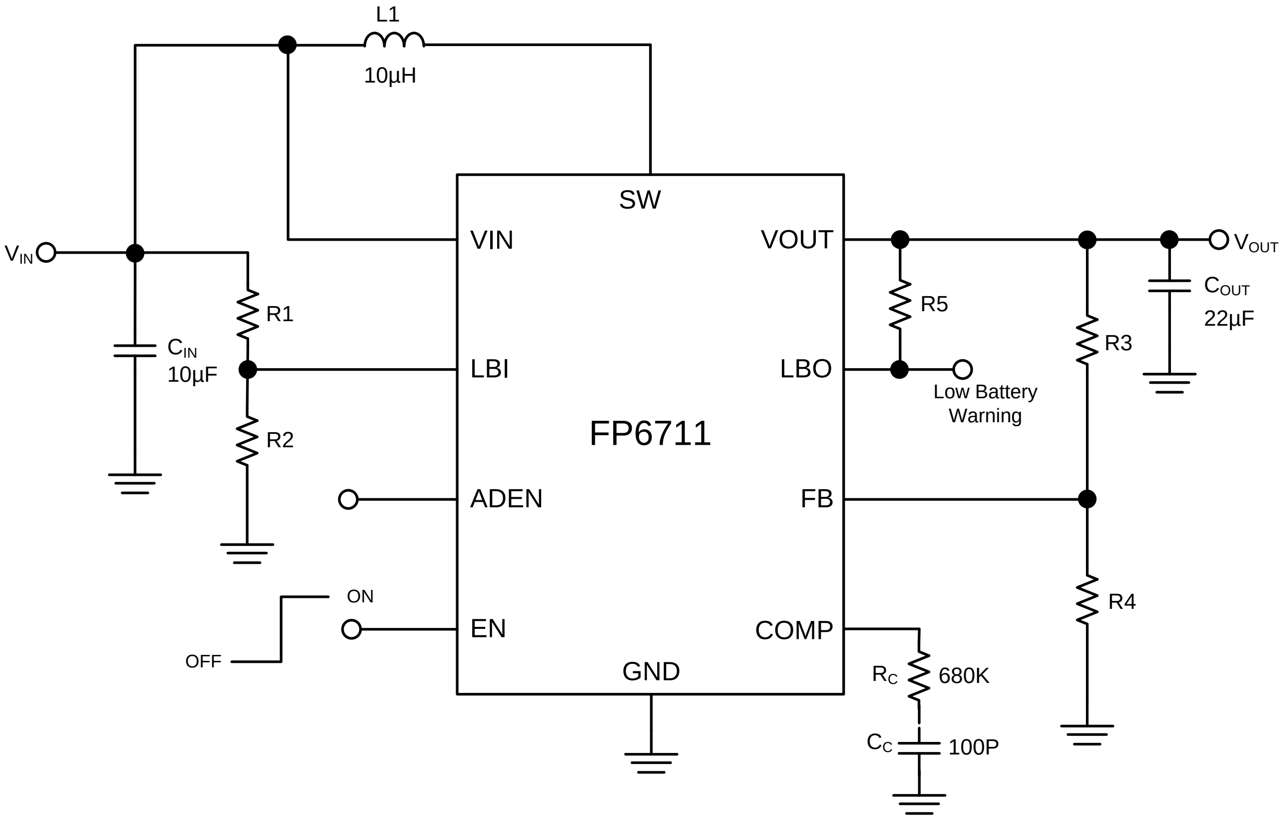


Figure 2. Typical Application Circuit of FP6711

Functional Pin Description

Pin Name	Pin Function
EN	Chip-enable input. Pull the pin high to enable IC. Pull the pin low to shutdown IC.
COMP	The gm error amplifier output. A frequency compensation network is connected from this pin to ground to compensate the loop.
FB	The feedback input for adjusting output voltage. This pin connects resistor divider that output voltage could be adjusted from 1.8V to 4V. The feedback voltage is typical at 0.5V.
GND	Ground pin
VOUT	Output voltage pin
VIN	Input voltage pin
SW	Switch input pin which is connected to inductor
ADEN	Auto-discharge enable input pin. The auto-discharge function will be enabled when this pin is connected to logic high. It will be disabled when this pin is connected to logic low.
LBI	Low battery detector input. A low battery warning signal is generated at LBO when the voltage on LBI drops below the threshold voltage of 500mV. Connect LBI to GND or VIN when low battery detector function is not used. Don't leave this pin floating.
LBO	Open drain low battery detector output. This Pin will be pulled low when the voltage on LBI drops below the threshold voltage of 500mV. An external pull-up resistor has to be connected between LBO and VOUT.

Block Diagram

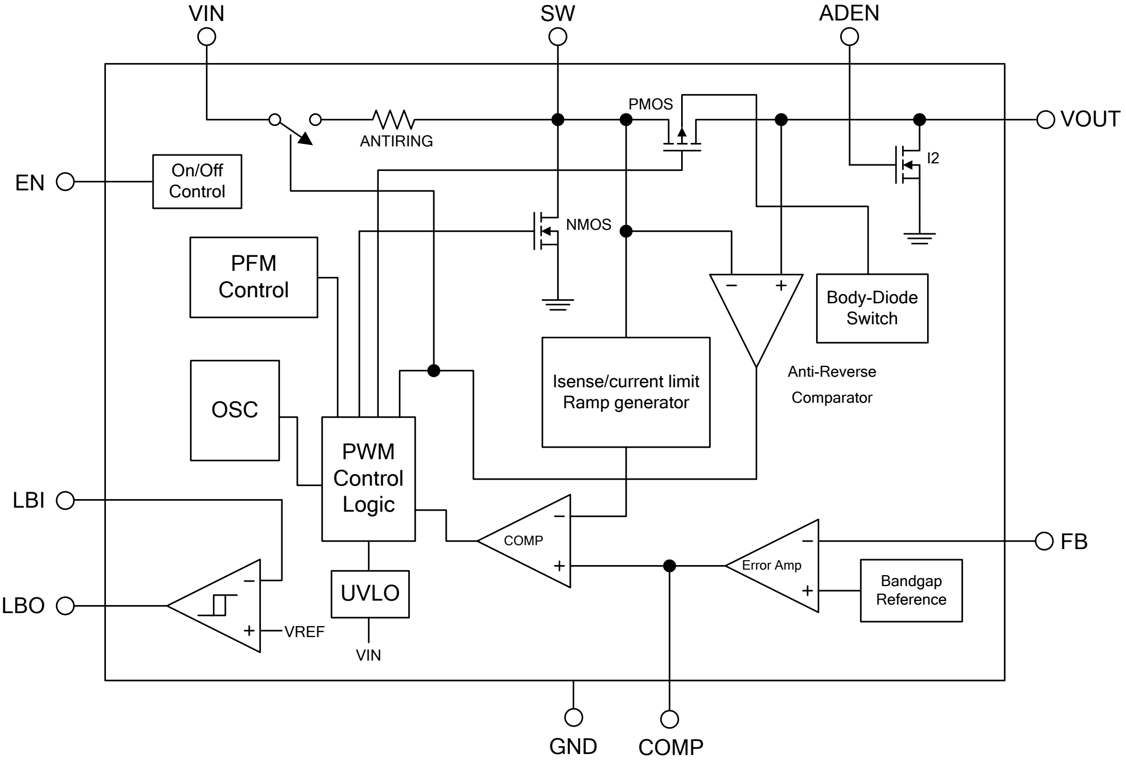


Figure 3. Block Diagram of FP6711

Absolute Maximum Ratings

- Supply Input Voltage (VIN ,VOUT, EN, LBI, COMP, FB, ADEN, LBO) ----------------------------- -0.3V to +4V
- SW Voltage (SW) --- -0.3V to +7V
- Power Dissipation @T_A=25°C, MSOP-10 (P_D) --- +630mW
- Package Thermal Resistance, MSOP-10 (θ_{JA}) -- +160°C/W
- Maximum Junction Temperature (T_J) -- +150°C
- Storage Temperature Range (T_S) -- -65°C to +150°C
- Lead Temperature (Soldering, 10 sec.) (T_{LEAD}) -- +260°C

Note 1：Stresses beyond those listed under “Absolute Maximum Ratings" may cause permanent damage to the device.

Recommended Operating Conditions

- Input Voltage (V_{IN}) -- +0.85V to V_{OUT}
- Operating Temperature Range (T_{OPR}) -- -40°C to +85°C

Electrical Characteristics

(V_{IN}=1.2V, EN=V_{IN}, T_A=25°C, unless otherwise specified)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Start-up Voltage	V_{ST}	I_{OUT} =1mA		0.85		V
Output Voltage Range	V_{OUT}	I_{OUT} =1mA	1.8		4	V
Quiescent Current (No Switching)	I_Q	V_{FB}>0.7V		25	40	µA
Switch Current Limit (Note2)	I_{LIM}	V_{OUT} =3.3V		1		A
Feedback Voltage	V_{FB}		490	500	510	mV
Oscillation Frequency	f_{OSC}		420	500	780	kHz
Maximum Duty Cycle	D_{MAX}			85		%
NMOS Switch ON Resistance (Note2)	$R_{DS(ON)}$	V_{OUT} =3.3V		0.35		Ω
PMOS Switch ON Resistance (Note2)	$R_{DS(ON)}$	V_{OUT} =3.3V		0.45		Ω
Line Regulation	Δ_{VLINE}	V_{IN} =2V to 2.4V Io =100mA		0.3		%
Load Regulation	Δ_{VLOAD}	V_{IN} =2V I_{OUT} =50 to 100mA		0.1		%
Auto-Discharge Switch Resistance (Note2)				300	400	Ω
Residual Output Voltage after Discharge		ADEB =V_{IN} EN =GND			0.4	V
LBI Voltage Threshold	V_{LBI}	V_{LBI} voltage decreasing	480	500	520	mV
LBI Input Hysteresis				10		mV
LBI Input Current				0.1	1	µA
LBO Output Low Voltage	V_{LBO}	V_{LBI} =0V, V_{OUT} =3.3V			0.2	V
LBO Output Leakage Current		V_{LBI} =650mV, V_{LBO} =V_O		0.1	1	µA
FB Input Bias Current	$I_{(FB)}$			0.1	1	µA
EN/ADEN Input Low Voltage	V_{IL}	0.8V<V_{IN}<5V			V_{IN}×0.1	V
EN/ADEN Input High Voltage	V_{IH}	0.8V<V_{IN}<5V	V_{IN}×0.9			V
EN/ADEN Input Current		EN/ADEN =GND or V_{IN}		0.1	1	µA
Shutdown Current from Power Source	I_{OFF}	EN =0V, ADEN= V_{IN}		1	5	µA
Over-Temperature Protection (Note2)	T_{SD}			150		°C
	$\Delta\ T_{SD}$	Hysteresis		20		°C

Note 2：The specification is guaranteed by design, not production tested.

Typical Performance Curves

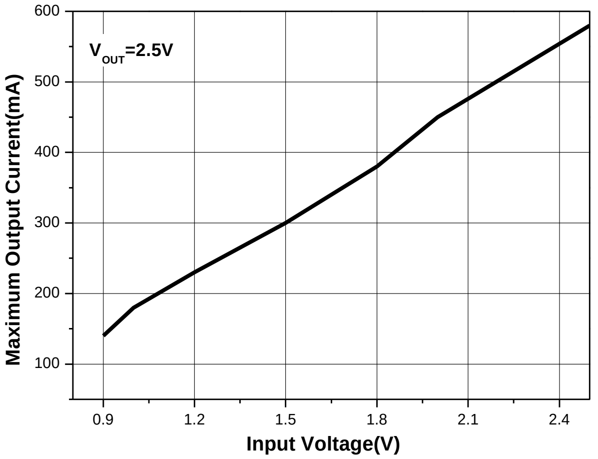


Figure 4. Maximum Output Current vs. Input Voltage

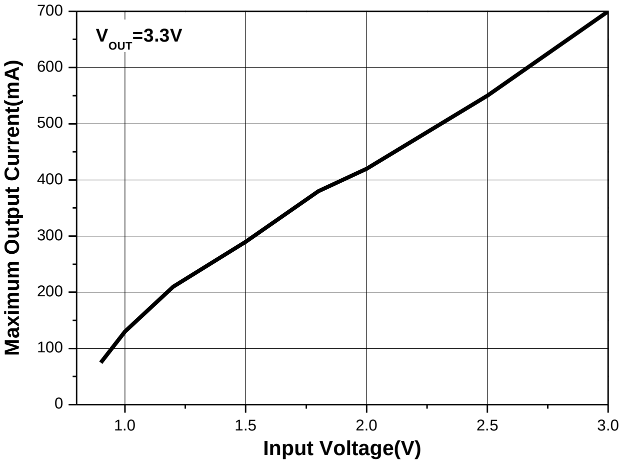


Figure 5. Maximum Output Current vs. Input Voltage

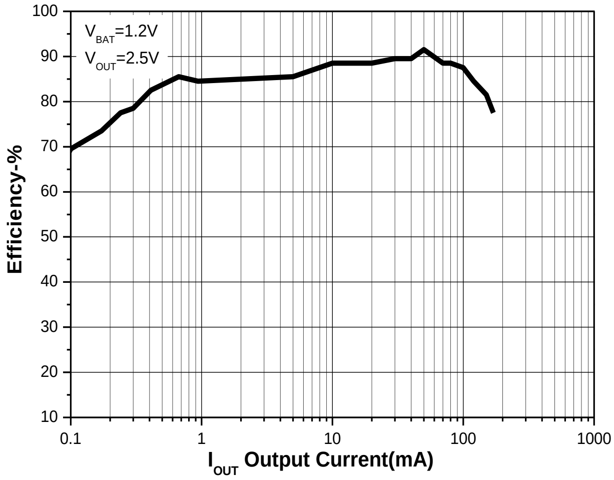


Figure 6. Efficiency vs. Output Current

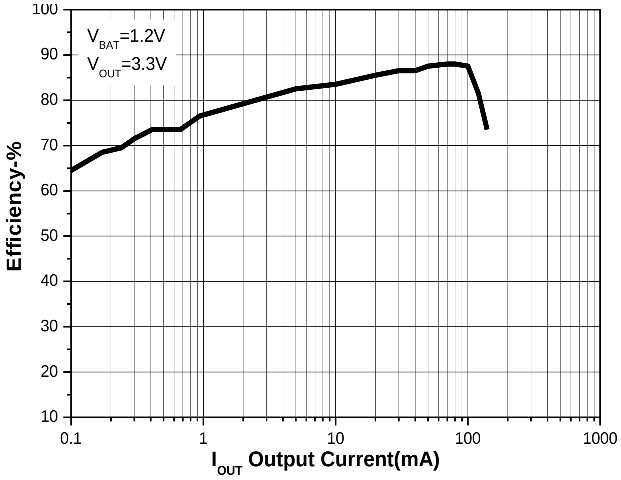


Figure 7. Efficiency vs. Output Current

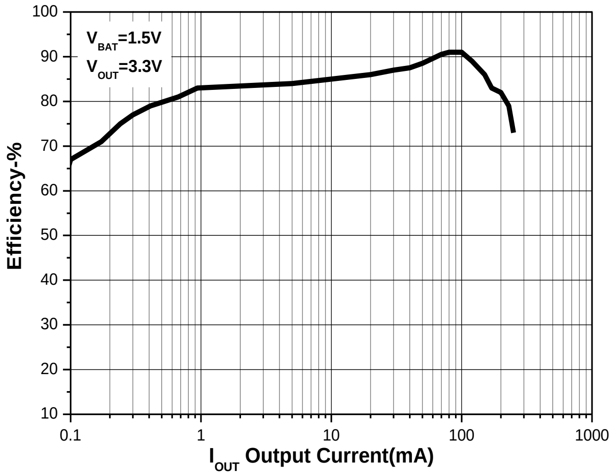


Figure 8. Efficiency vs. Output Current

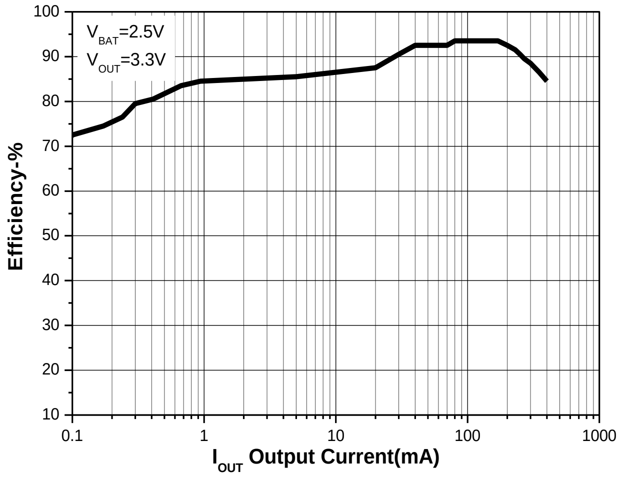


Figure 9. Efficiency vs. Output Current

Typical Performance Curves (Continued)

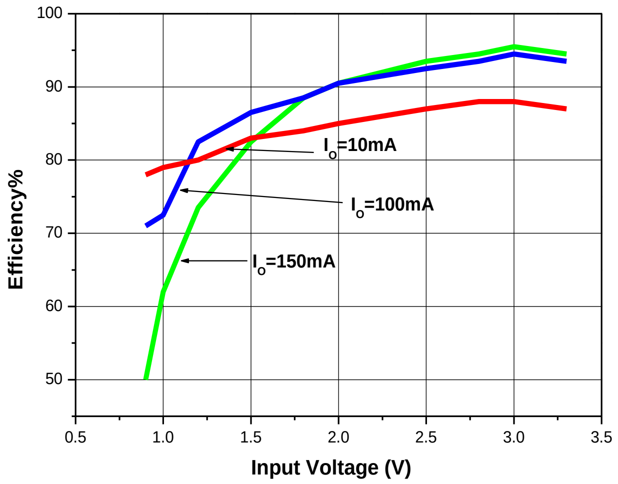


Figure 10. Efficiency vs. Input Voltage (V_{OUT}=3.3V)

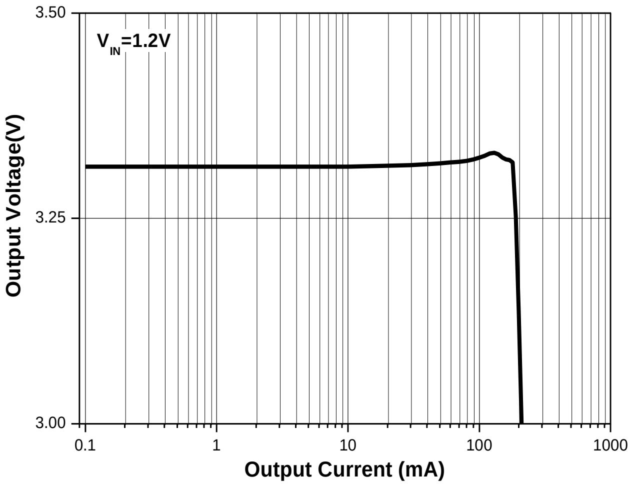


Figure 11. Output voltage vs. Output Current

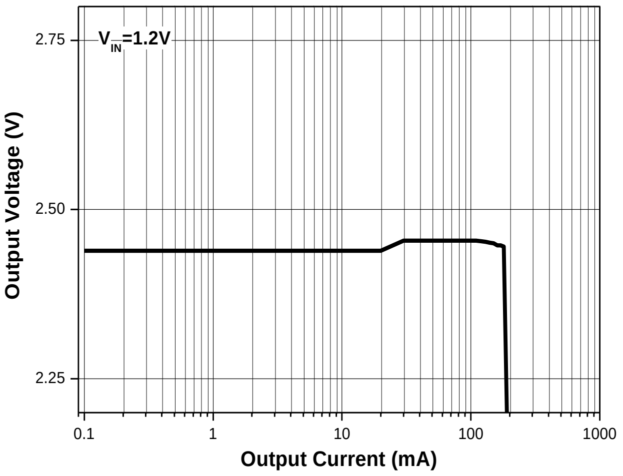


Figure 12. Output voltage vs. Output Current

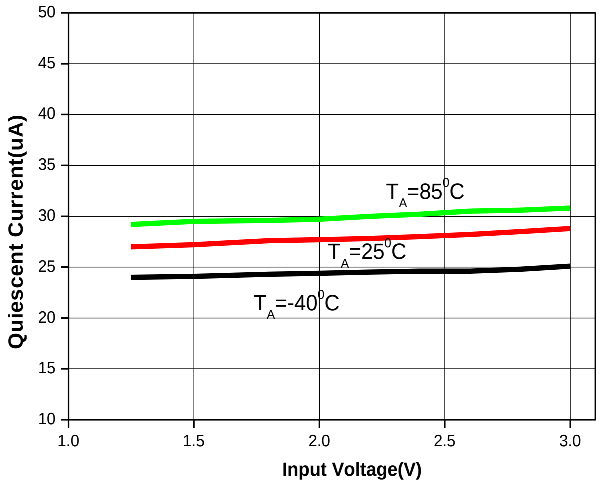


Figure 13. Quiescent Current vs. Input Voltage

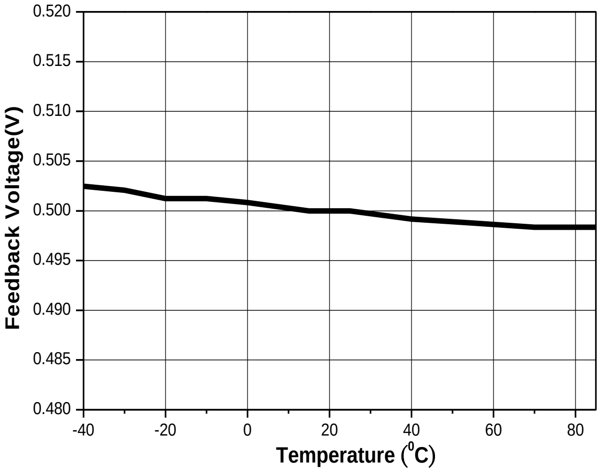


Figure 14. Feedback Voltage vs. Temperature

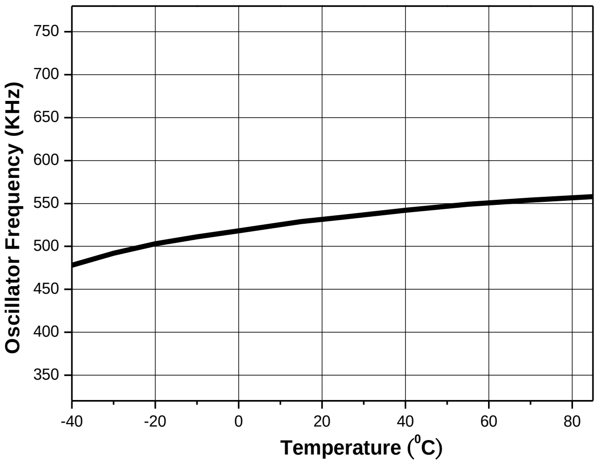


Figure 15. Oscillator Frequency vs. Temperature

Typical Performance Curves (Continued)

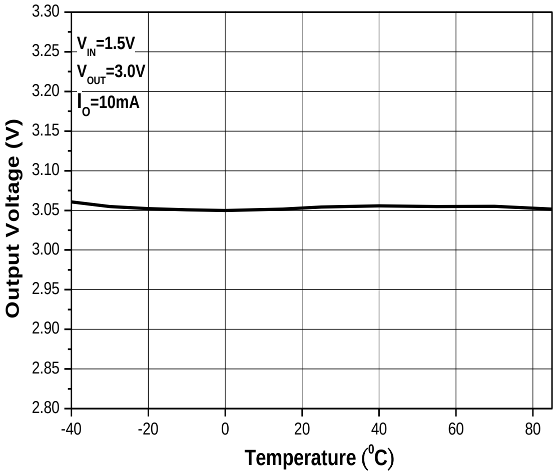


Figure 16. Output Voltage vs. Temperature

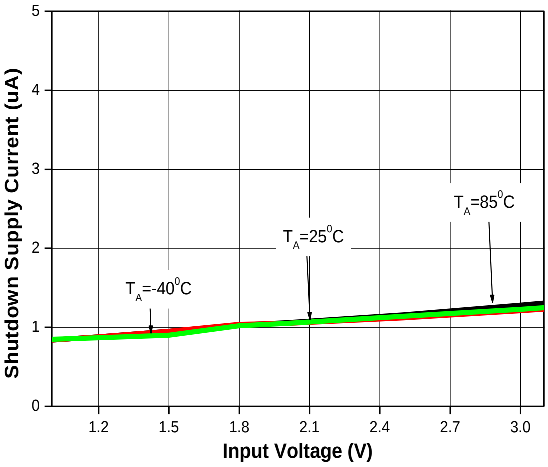
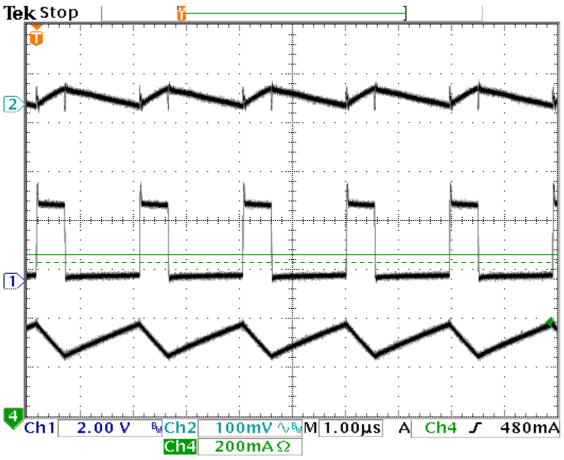
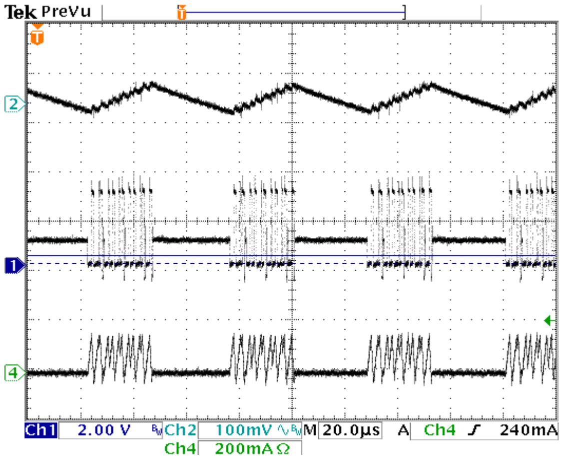


Figure 17.Shutdown Supply Current vs. Input Voltage



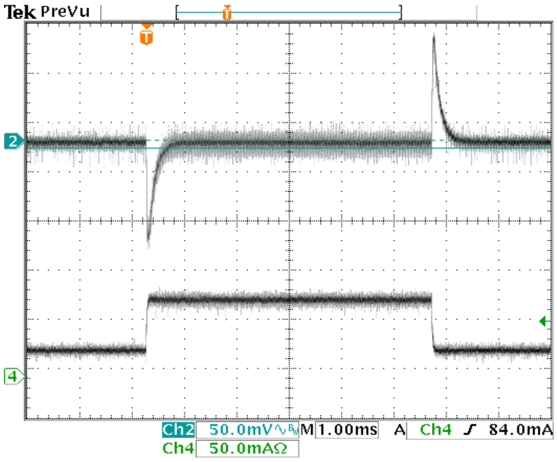
CH1: V_{SW} ,CH2: V_{OUT} ,CH4: I_L (V_{IN}=1.2V, V_{OUT}=3.3V, I_{OUT}=100mA)

Figure 18. Dynamic Test



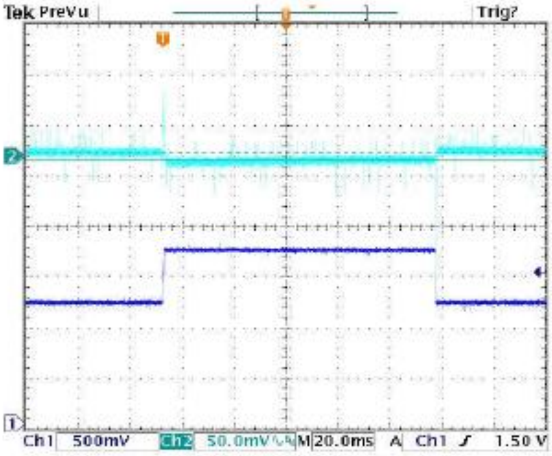
CH1: V_{SW} ,CH2: V_{OUT} ,CH4: I_L (V_{IN}=1.5V, V_{OUT}=3.3V, I_{OUT}=20mA)

Figure 19. Dynamic Test



CH2: V_{OUT} ,CH4: I_{OUT} (V_{IN}=2V, V_{OUT}=3V, I_{OUT}=50mA →100mA)

Figure 20. Load Transient Response



CH1: V_{IN} ,CH2: V_{OUT} (V_{IN}=1.2V~1.8V, V_{OUT}=3.3V, I_{OUT}=50mA)

Figure 21. Line Transient Response

Typical Performance Curves (Continued)

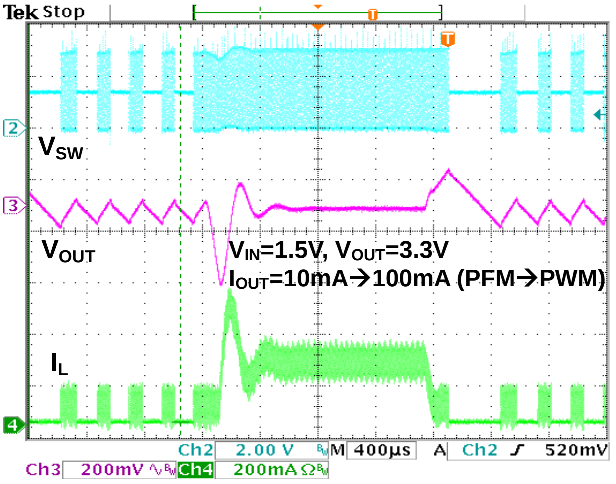


Figure 22. Load Transient Response

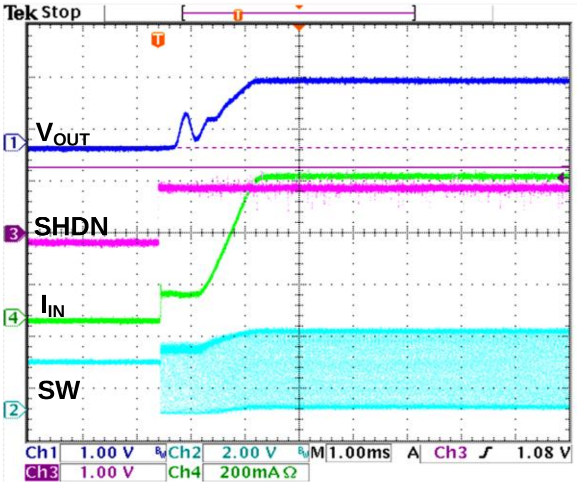


Figure 23. Converter Start-up Time after Enable

Application Information

Controller Circuit

The device is based on a current-mode control topology and uses a constant frequency pulse-width modulator to regulate the output voltage. The controller limits the current through the power switch on a pulse by pulse basis. The current sensing circuit is integrated in the device; therefore, no additional components are required. Due to the nature of the boost converter topology used here, the peak switch current is the same as the peak inductor current, which will be limited by the integrated current limiting circuits under normal operating conditions.

The control loop must be externally compensated with an R-C network connected to the COMP pin.

Synchronous Rectifier

The device integrates an N-channel and a P-channel MOSFET transistor to realize a synchronous rectifier. There is no additional Schottky diode required. Because the device uses a integrated low $R_{DS(ON)}$ PMOS switch for rectification, the power conversion efficiency reaches 94%.

A special circuit is applied to disconnect the load from the input during shutdown of the converter. In conventional synchronous rectifier circuits, the backgate diode of the high-side PMOS is forward biased in shutdown and allows current flowing from the battery to the output. This device, however, uses a special circuit to disconnect the backgate diode of the high-side PMOS and so, disconnects the output circuitry from the source when the regulator is not enabled (EN = low).

PFM Mode

The FP6711 is designed for high efficiency over a wide output current range. Even at light load, the efficiency stays high because the switching losses of the converter are minimized by effectively reducing the switching frequency. The controller will enter a power saving mode if certain conditions are met. In this mode, the controller only switches on the transistor if the output voltage trips below a set threshold voltage. It ramps up the output voltage with one or several pulses, and goes again into PFM mode once the output voltage exceeds a set threshold voltage.

Device Enable

The device will be shut down when EN is set to GND. In this mode, the regulator stops switching, all internal control circuitry including the low-battery comparator will be switched off, and the load is disconnected from the input (as described in above synchronous rectifier section). This also means that the output voltage may drop below the input voltage during shutdown.

The device is put into operation when EN is set high. During start-up of the converter, the duty cycle is limited in order to avoid high peak currents drawn from the battery. The limit is set internally by the current limit circuit and is proportional to the voltage on the COMP pin.

Under-Voltage Lockout

Under-voltage lockout function prevents the device from starting up if the supply voltage on VBAT is lower than approximately 0.7V. This under-voltage lockout function is implemented in order to prevent the malfunctioning of the converter. When the battery is being discharged, the device will automatically enter the shutdown mode if the voltage on VBAT drops below approximately 0.7V.

Application Information (Continued)

Auto-Discharge

The auto-discharge function is useful for applications where the supply voltage of a µC, µP, or memory has to be removed during shutdown in order to ensure a defined state of the system.

The auto-discharge function will be enabled when the ADEN is set high; and it will be disabled when the ADEN is set to GND. When the auto-discharge function is enabled, the output capacitor will be discharged after the device is shut down by setting EN to GND. The capacitors connected to the output are discharged by an integrated switch of 300Ω, hence the discharge time depends on the total output capacitance. The residual voltage on VOUT is less than 0.4V after auto-discharge.

The resistive divider scales down the battery voltage to a voltage level of 500mV, which is then compared to the LBI threshold voltage. The LBI pin has a built-in hysteresis of 10mV. See the application section for more details about the programming of the LBI threshold.

If the low-battery detection circuit is not used, the LBI pin should be connected to GND (or to VBAT) and the LBO pin can be left unconnected. Do not let the LBI pin float.

Low-Battery Detector Circuit (LBI and LBO)

The low-battery detector circuit is typically used to supervise the battery voltage and generate an error flag when the battery voltage drops below user-set threshold voltage. The function is active only when the device is enabled. When the device is disabled, the LBO pin will be high impedance. The LBO pin goes active low when the voltage on the LBI pin decreases below the set threshold voltage of 500 mV ±15 mV, which is equal to the internal reference voltage. The battery voltage, at the detection circuit switches, can be programmed with a resistive divider connected to the LBI pin.

Anti-Ringing Switch

The device integrates a circuit which removes the ringing that typically appears on the SW node when the converter enters the discontinuous current mode. In this case, the current through the inductor ramps to zero and the integrated PMOS switch turns off to prevent a reverse current from the output capacitors back to the battery. Due to remaining energy that is stored in parasitic components of the semiconductors and the inductor, a ringing on the SW pin is induced. The integrated anti-ringing switch clamps this voltage internally to V_{BAT}; therefore, dampens this ringing.

Adjustable Output Voltage

The accuracy of the output voltage is determined by the accuracy of the internal voltage reference, the controller topology, and the accuracy of the external resistor. The reference voltage has an accuracy of ± 4%. The controller switches between fixed frequency and PFM mode, depending on load current. The tolerance of the resistors in the feedback divider determines the total system accuracy.

Design Procedure

The FP6711 boost converter family is intended for systems that are powered by a single-cell NiCd or NiMH battery with a typical terminal voltage between 0.9V to 1.6V. It can also be used in systems that are powered by two-cell NiCd or NiMH batteries with a typical stack voltage between 1.8V to 3.2V. Additionally, single or dual-cell, primary and secondary alkaline battery cells can be the power source in systems where the FP6711 is used.

(1) Programming the Output Voltage

The output voltage of the FP6711 can be adjusted with an external resistor divider. The typical value of the voltage on the FB pin is 500mV in fixed frequency operation. The maximum allowed value for the output voltage is 3.3V. The current through the resistive divider should be about 100 times greater than the current into the FB pin. The typical current into the FB pin is 0.01µA, and the voltage across R4 is typically 500mV. Based on those two values, the recommended value for R4 is in the range of 500kΩ in order to set the divider current at 1µA. From that, the value of resistor R3, depending on the needed output voltage (V_O), can be calculated using Equation 1.

$$R3 = R4 \times \left(\frac{V_O}{V_{FB}} - 1 \right) = 500\text{k}\Omega \times \left(\frac{V_O}{500\,\text{mV}} - 1 \right) \quad .....(1)$$

Application Information (Continued)

(2) Programming the Low Battery Comparator Threshold Voltage

The current through the resistive divider should be about 100 times greater than the current into the LBI pin. The typical current into the LBI pin is 0.01µA; the voltage across R2 is equal to the reference voltage that is generated on-chip, which has a value of 500mV±15mV. The recommended value for R2 is therefore in the range of 500 kΩ. From that, the value of resistor R1, depending on the desired minimum battery voltage V_{BAT}, can be calculated using Equation 2.

$$R1 = R2 \times \left(\frac{V_{BAT}}{V_{REF}} - 1\right) = 500k\Omega \times \left(\frac{V_{BAT}}{500\,mV} - 1\right) \;.....(2)$$

For example, if the low-battery detection circuit should flag an error condition on the LBO output pin at a battery voltage of 1V, a resistor in the range of 500kΩ should be chosen for R1. The output of the low battery comparator is a simple open-drain output that goes active low if the battery voltage drops below the programmed threshold voltage on LBI. The output requires a pull-up resistor with a recommended value of 1MΩ, and should only be pulled up to the V_O. If not used, the LBO pin can be left floating or tied to GND.

(3) Inductor Selection

A boost converter normally requires two main passive components for storing energy during the conversion. A boost inductor is required and a storage capacitor at the output. To select the boost inductor, it is recommended to keep the possible peak inductor current below the current limit threshold of the power switch in the chosen configuration.

The second parameter for choosing the inductor is the desired current ripple in the inductor. Normally, it is advisable to work with a ripple of less than 20% of the average inductor current. A smaller ripple reduces the magnetic hysteresis losses in the inductor, as well as output voltage ripple and EMI. But in the same way, regulation time at load changes rises. In addition, a larger inductor increases the total system cost. With those parameters, it is possible to calculate the value for the inductor by using Equation 3.

$$L = \frac{V_{BAT} \times (V_{OUT} - V_{BAT})}{\Delta I_L \times f \times V_{OUT}} \;.....(3)$$

Parameter f is the switching frequency and ΔI_L is the ripple current in the inductor, i.e. 20% x I_L.

In this example, the desired inductor has the value of 12µH. With this calculated value and currents, it is possible to choose a suitable inductor. Care must be taken that load transients and losses in the circuit can lead to higher currents. Also, the losses in the inductor caused by magnetic hysteresis losses and copper losses are a major parameter for total circuit efficiency.

(4) Capacitor Selection

The major parameter necessary to define the output capacitor is the maximum allowed output voltage ripple of the converter. This ripple is determined by two parameters of the capacitor, the capacitance and the ESR. It is possible to calculate the minimum capacitance needed for the defined ripple, supposing that the ESR is zero, by using Equation 4.

$$C_{MIN} = \frac{I_{OUT} \times (V_{OUT} - V_{BAT})}{f \times \Delta V \times V_{OUT}} \;.....(4)$$

Parameter f is the switching frequency and △V is the maximum allowed ripple.

With a chosen ripple voltage of 15mV, a minimum capacitance of 10 µF is needed. The total ripple is larger due to the ESR of the output capacitor. This additional component of the ripple can be calculated using Equation 5.

$$\Delta V_{ESR} = I_{OUT} \times R_{ESR} \;.....(5)$$

An additional ripple of 30mV is the result of using a tantalum capacitor with a low ESR of 300mΩ. The total ripple is the sum of the ripple caused by the capacitance and the ripple caused by the ESR of the capacitor. In this example, the total ripple is 45mV. It is possible to improve the design by enlarging the capacitor or using smaller capacitors in parallel to reduce the ESR or by using better capacitors with lower ESR, like ceramics. For example, a 10µF ceramic capacitor with an ESR of 50mΩ is used on the evaluation module (EVM). Tradeoffs must be made between performance and costs of the converter circuit.

A 10µF input capacitor is recommended to improve transient behavior of the regulator. A ceramic or tantalum capacitor with a 100nF in parallel placed close to the IC is recommended.

Application Information (Continued)

(5) Compensation of the Control Loop

An R/C network must be connected to the COMP pin in order to stabilize the control loop of the converter. Both the pole generated by the inductor L1 and the zero caused by the ESR and capacitance of the output capacitor must be compensated. The network shown in Figure 24 satisfies these requirements.

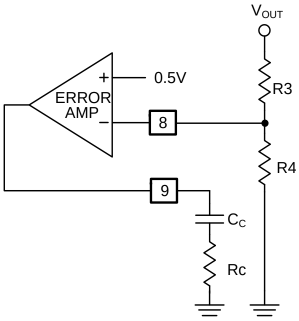


Figure 24. Compensation of Control Loop

Resistor R_C and capacitor C_C depend on the chosen inductance. The equation for the loop dynamics is shown as below :

$$f_{ZER01} = \frac{1}{2 \times \pi \times Rc \times C_C} \, H_Z$$

The FP6711 uses current mode control with internal adaptive slope compensation. Current mode control eliminates the 2nd order filter due to the inductor and output capacitor exhibited in voltage mode controllers and simplifies it to a single-pole filter response.

Thermal Information

The maximum junction temperature (T_J) of the FP6711 devices is recommended to 125°C. The thermal resistance of the 10-pin MSOP package is θ_{JA}=160°C/W. Specified regulator operations are assured to a maximum ambient temperature (T_A) of 70°C. Therefore, the maximum power dissipation is about 340mW. More power can be dissipated if the maximum ambient temperature of the application is lower.

$$P_{D(MAX)} = \frac{T_{J(MAX)} - T_A}{\theta_{JA}} = \frac{125°C - 70°C}{160°C/W} = 340mW$$

Layout Considerations

As for all switching power supplies, the layout is an important step in the design, especially at high peak currents and high switching frequencies. If the layout is not carefully done, the regulator could show stability problems as well as EMI problems. Therefore, use wide and short traces for the main current path as indicated in bold in Figure 25. The input capacitor, output capacitor and the inductor should be placed as close to the IC as possible. Use a common ground node as shown in Figure 25 to minimize the effects of ground noise. The compensation circuit and the feedback divider should be placed as close to the IC as possible. To layout the control ground, it is recommended to use short traces as well, separated from the power ground traces. Connect both grounds close to the ground pin of the IC as indicated in the layout diagram in Figure25. This avoids ground shift problems, which can occur due to superimposition of power ground current and control ground current.

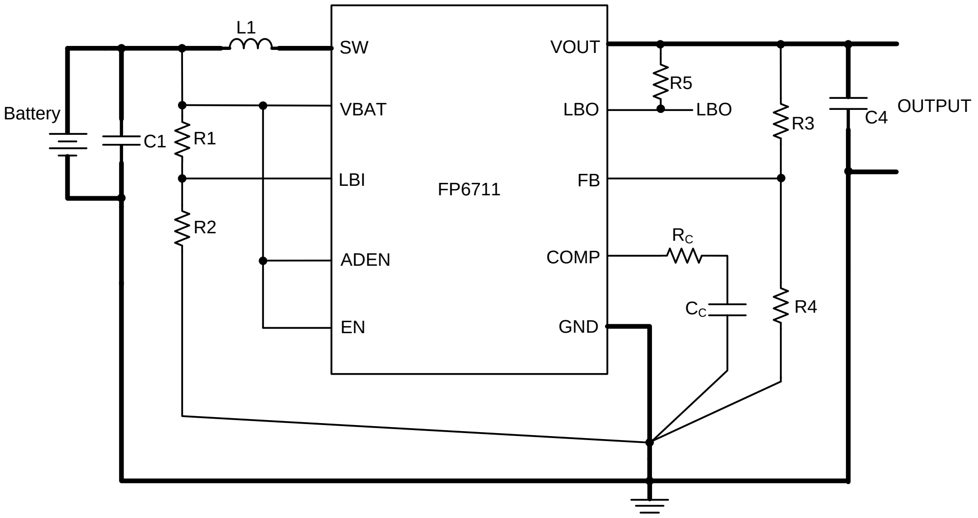
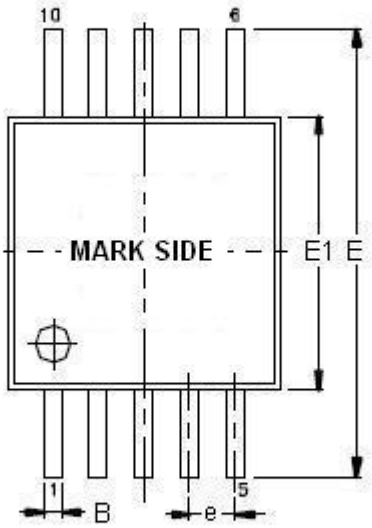
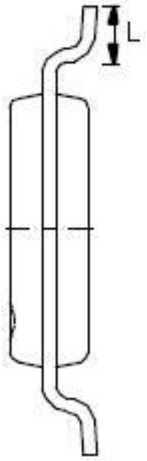


Figure 25. Layout Diagram

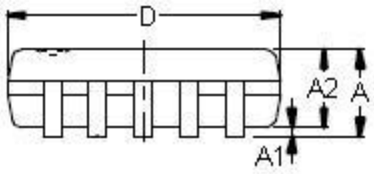
Outline Information

MSOP-10 Package (Unit: mm)

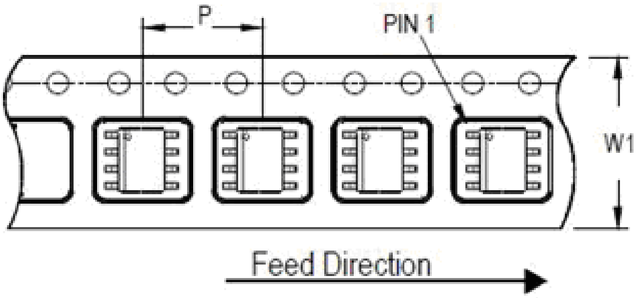


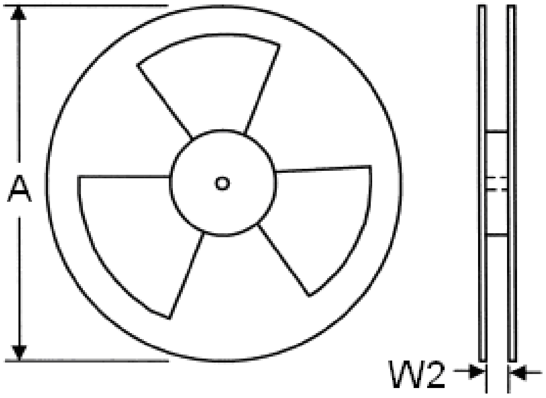


SYMBOLS UNIT	DIMENSION IN MILLIMETER	
	MIN	MAX
A	0.75	1.10
A1	0.00	0.15
A2	0.75	0.95
B	0.17	0.33
D	2.90	3.10
E	4.80	5.00
E1	2.90	3.10
e	0.40	0.60
L	0.40	0.80



Carrier dimensions





Tape Size (W1) mm	Pocket Pitch (P) mm	Reel Size (A)		Reel Width (W2) mm	Empty Cavity Length mm	Units per Reel
		in	mm			
12	8	13	330	12.4	400~1000	3,000