1.5MHz, 1A High Efficiency Buck Converter

Features

- Input voltage: 2.5V ~5.5V
- High efficiency (95%)
- No Schottky Diode Required
- 1A Output Current at 5V Input 3.3V Output
- 1.5MHz Switching Frequency
- Built-in ON/OFF Function
- Low Dropout Operation: 100% Duty Cycle
- Thermal Protection
- Tiny 6-Lead TDFN2X2 Package
- RoHS Compliant

Applications

- Mobile Phones
- Wireless and DSL modems
- Power Supply for Portable Devices

General Description

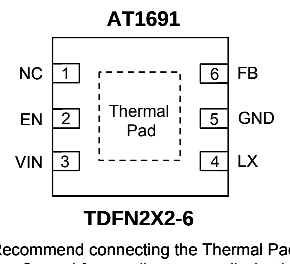
The AT1691 provides complete control for a DC/DC converter optimized for high-performance microprocessor applications. It is operated on current mode architecture for excellent line and load transient response. 1.5MHz operation frequency is allowing the use of small surface mount inductor and capacitor. The internal synchronous switch increases efficiency and eliminates the need for an external Schottky diode. The AT1691 is a family of low-noise synchronous step-down DC/DC converters that is ideally suited for systems powered from a 1-cell Li-ion battery or from a 3-cell to 4-cell NiCd, NiMH, or alkaline battery. It can also be used to USB-Based power system.

Ordering Information

ORDER NUMBER	MARKING	OUTPUT VOLTAGE (V)	TEMP. RANGE	PACKAGE (Green)
AT1691RB1U	A161	Adjustable	-40°C~ +85°C	TDFN2X2-6

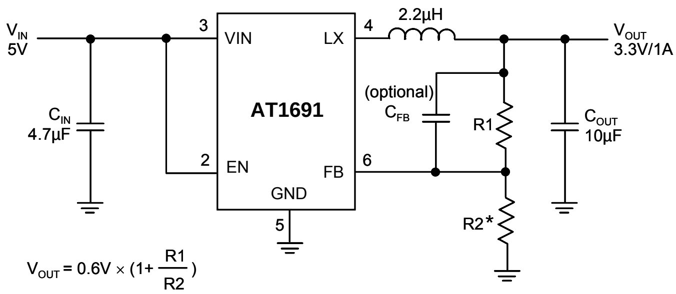
Note: RB: TDFN2X2-6
1: Bonding Code
U: Tape & Reel

Pin Configuration



Note: Recommend connecting the Thermal Pad to the Ground for excellent power dissipation.

Typical Application Circuit



$V_{OUT} = 0.6V \times (1+\frac{R1}{R2})$

*R2= 150K for stability consideration.

Absolute Maximum Ratings (Note1)

VIN to GND . . . . -0.3V to +6V
EN, VFB to GND. . . . . -0.3V to (VIN + 0.3V)
LX to GND . . . . -1V to (VIN + 1V)
Thermal Resistance Junction to Ambient, (θ_{JA})*
TDFN2X2-6 . . . . 165°C/W
Continuous Power Dissipation (T_A = +25°C)*
TDFN2X2-6 . . . . 0.6W
Thermal Resistance Junction to Case, (θ_{JC})
TDFN2X2-6 . . . . 63°C/W

Operating Temperature Range. . . . . -40°C to 85°C
Maximum Junction Temperature. . . . . .150°C
Storage Temperature Range. . . . .-65°C to 165°C
Reflow Temperature (soldeing,10 sec) . . . . .260°C
ESD Susceptibility (Note 2)
HBM (Human Body Mode) .2kV
MM (Machine Mode) 200V

* Please refer to Minimum Footprint PCB Layout Section.

Electrical Characteristics

V_{IN} = 3.6V, V_{OUT}=2.5V, V_{REF}=0.6V, T_A= 25°C.

The device is not guaranteed to function outside its operating conditions. Parameters with MIN and/or MAX limits are 100% tested at +25°C, unless otherwise specified.

PARAMETER	SYMBOL	CONDITION	MIN	TYP	MAX	UNIT
Input Supply Range	V_{IN}		2.5	---	5.5	V
Adjustable Output Voltage Range	V_{OUT}		0.6	---	V_{IN}-ΔV (Note3)	V
Voltage Dropout	ΔV	I_{OUT} =100mA	---	28	---	mV
Quiescent Current	I_S	FB=0.6V+5%, I_{LOAD}=0A	---	50	100	µA
Shutdown Current	I_{SD}	EN=0V, V_{IN}=5.5V	---	0.1	1	µA
Under Voltage Lockout	UVLO		---	1.8	---	V
Feedback Voltage	V_{FB}		0.588	0.600	0.612	V
Feedback Voltage Line-regulation	$V_{FB\text{-}Line}$	V_{IN}=2.5V to 5.5V	---	0.1	0.5	%
Output Voltage Accuracy	ΔV_{OUT}	V_{IN} =V_{OUT} +ΔV to 5.5V (Note3) 0A < I_{OUT} <1A	-3	---	+3	%
Feedback Current	I_{FB}		-50	---	50	nA
P-Channel Current Limit	I_{PK}	V_{IN}=5V,V_{OUT}=3.3V	1.3	1.5	---	A
EN Pin High Level	V_{EN_H}	V_{IN}=2.5V to 5.5V	1.5	---	V_{IN}	V
EN Pin Low Level	V_{EN_L}	V_{IN}=2.5V to 5.5V	0	---	0.6	V
Switching Frequency	fosc	I_{OUT}=100mA	1.2	1.5	1.8	MHz
$R_{DS(ON)}$ of P-Channel MOSFET	R_{PFET}	I_{LX}=1A	---	0.28	---	Ω
$R_{DS(ON)}$ of N-Channel MOSFET	R_{NFET}	I_{LX}=1A	---	0.25	---	Ω
Thermal Shutdown	T_S		---	160	---	°C
Thermal Shutdown Hysteresis	ΔT_S		---	45	---	°C
SW Leakage Current	I_{LSW}		---	±0.1	±1	µA
EN Pin Leakage Current	I_{EN}		---	±0.1	±1	µA

Note1: Stresses listed as above “Absolute Maximum Ratings” may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

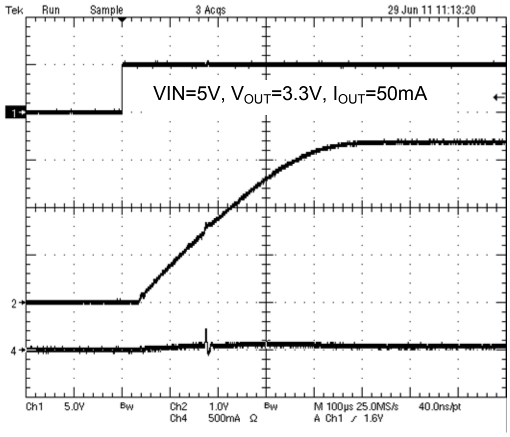
Note2: Devices are ESD sensitive. Handling precaution recommended.

Note3: $\Delta V = I_{OUT} \times R_{PFET}$

Typical Performance Characteristics

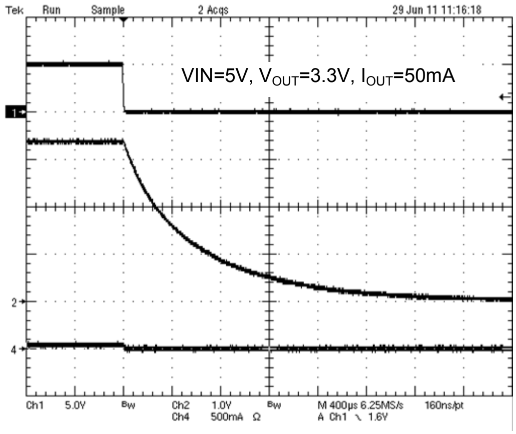
T_A=25°C, unless otherwise noted.

Power On



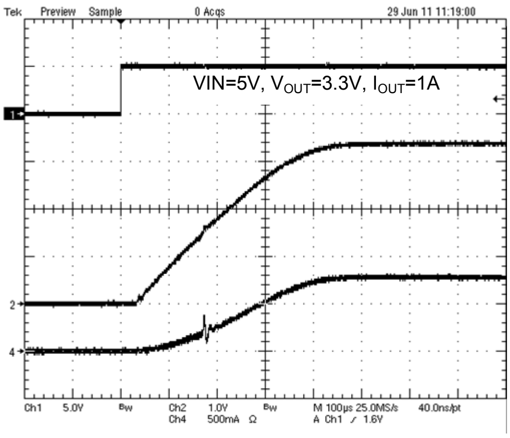
CH1：EN(5V/div), CH2：V_{OUT}(1V/div),
CH4：Iin(500mA/div)

Power Off



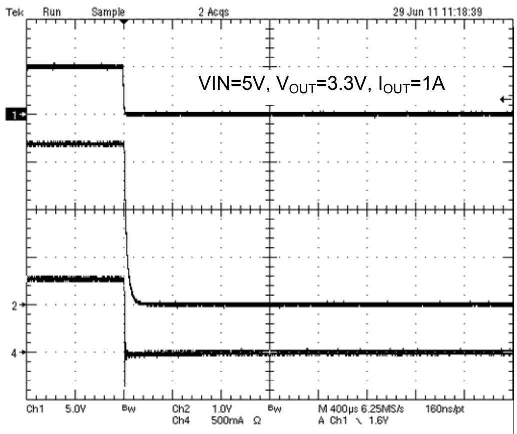
CH1：EN(5V/div), CH2：V_{OUT}(1V/div),
CH4：Iin(500mA/div)

Power On



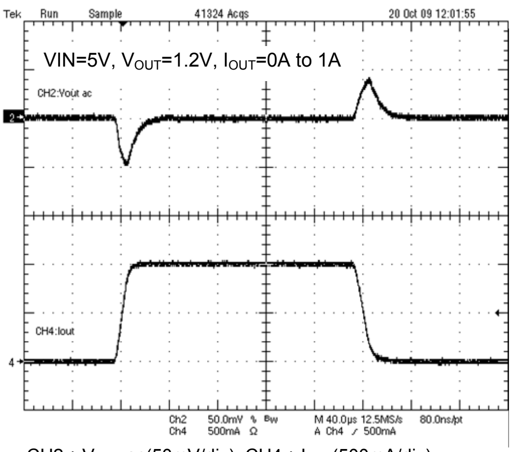
CH1：EN(5V/div), CH2：V_{OUT}(1V/div),
CH4：Iin(500mA/div)

Power Off



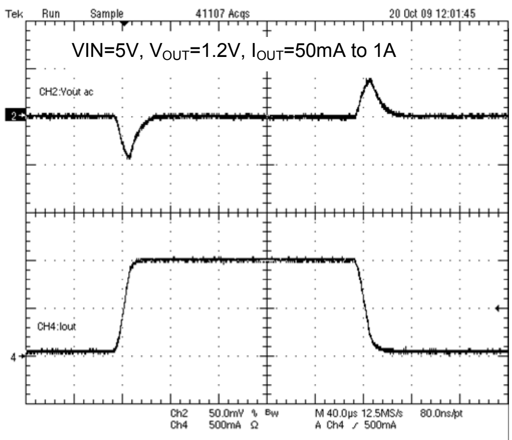
CH1：EN(5V/div), CH2：$V_{OUT(}$1V/div),
CH4：Iin(500mA/div)

Load Transient



CH2：V_{OUT} ac(50mV/div), CH4：I_{OUT}(500mA/div)

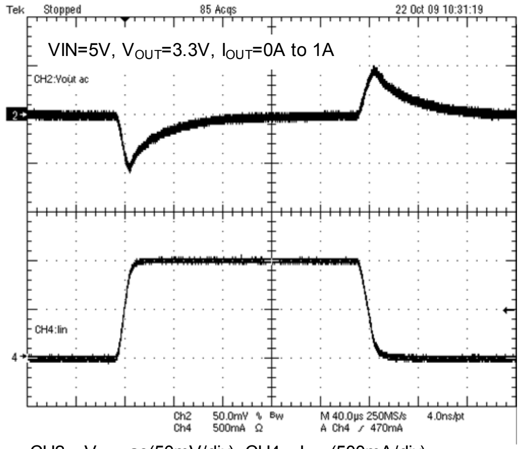
Load Transient



CH2：V_{OUT} ac(50mV/div), CH4：I_{OUT}(500mA/div)

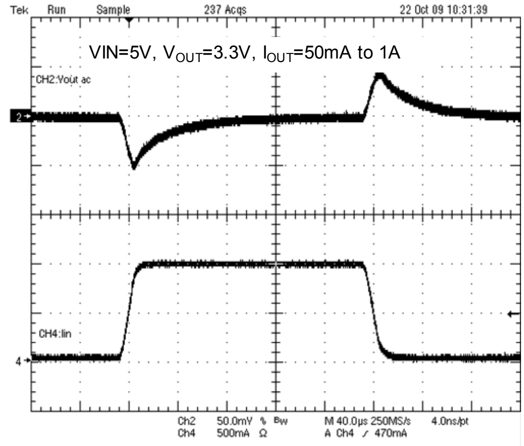
Typical Performance Characteristics (Continued)

Load Transient



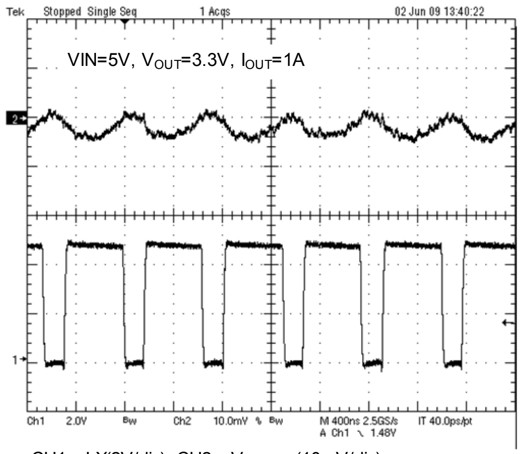
CH2 : V_{OUT} ac(50mV/div), CH4 : I_{OUT}(500mA/div)

Load Transient



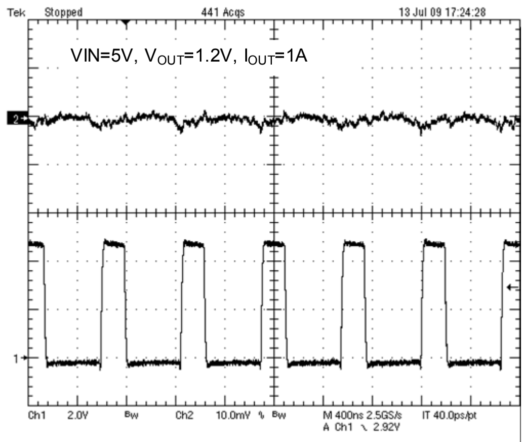
CH2 : V_{OUT} ac(50mV/div), CH4 : I_{OUT}(500mA/div)

Output Ripple Voltage



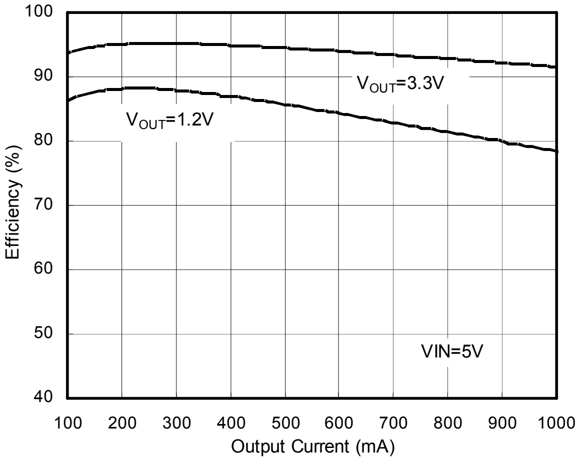
CH1 : LX(2V/div), CH2 : V_{OUT} ac(10mV/div)

Output Ripple Voltage

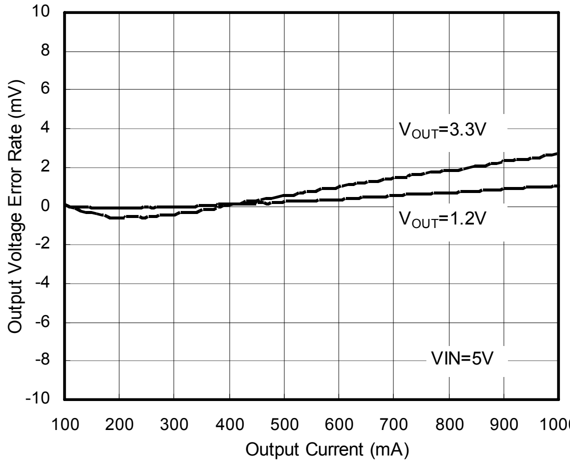


CH1 : LX(2V/div), CH2 : V_{OUT} ac(10mV/div)

Efficiency vs. Output Current

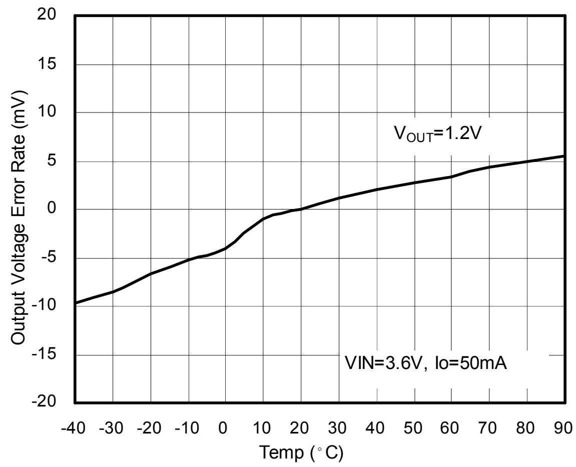


Output Voltage vs. Output Current

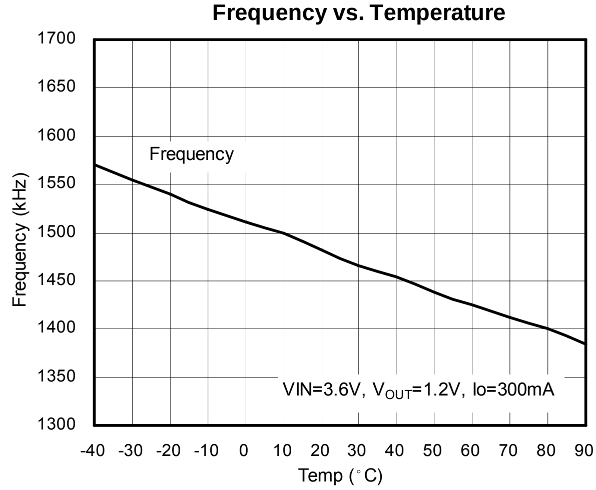


Typical Performance Characteristics (Continued)

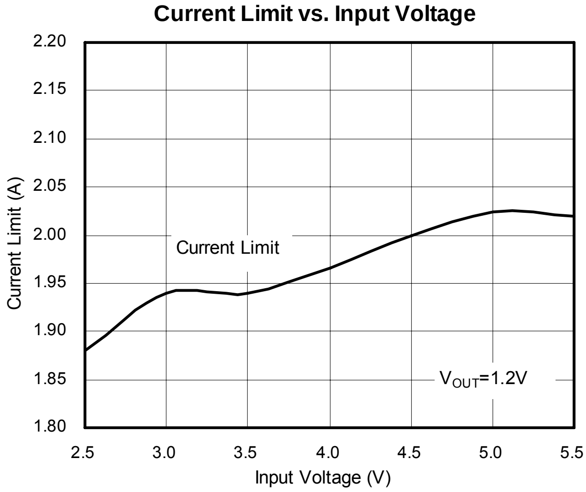
Output Voltage vs. Temerature



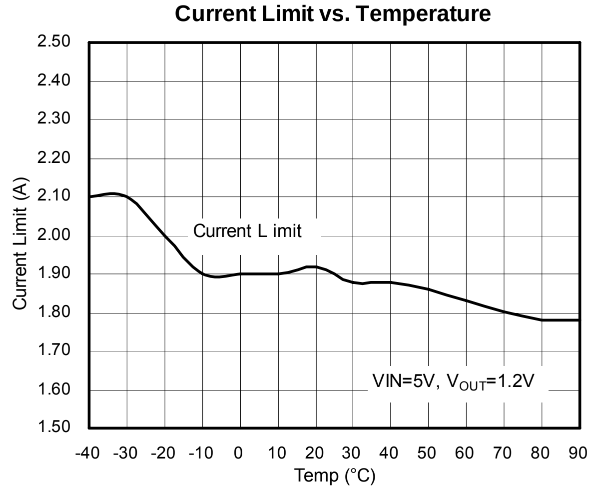
Frequency vs. Temperature



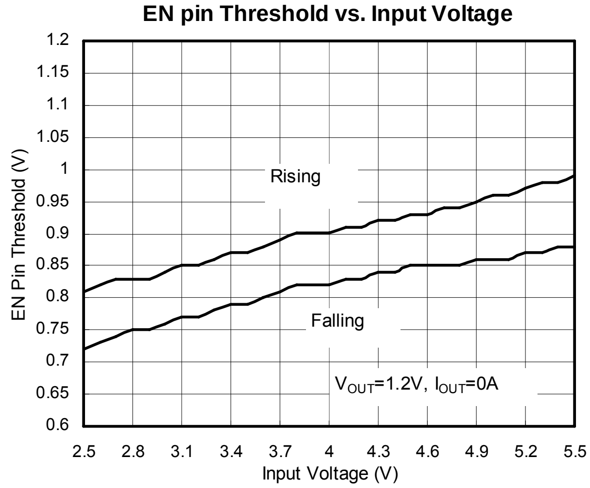
Current Limit vs. Input Voltage



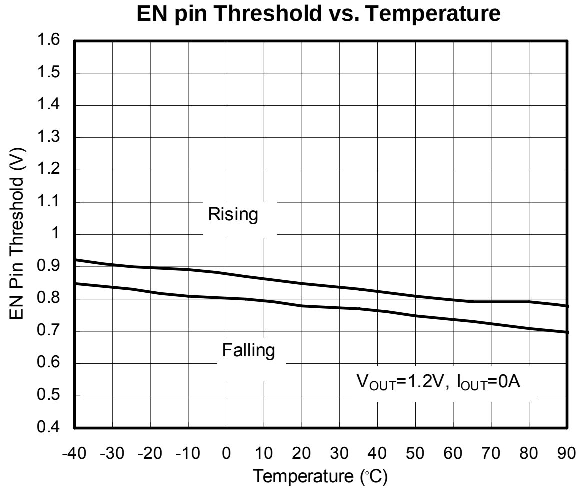
Current Limit vs. Temperature



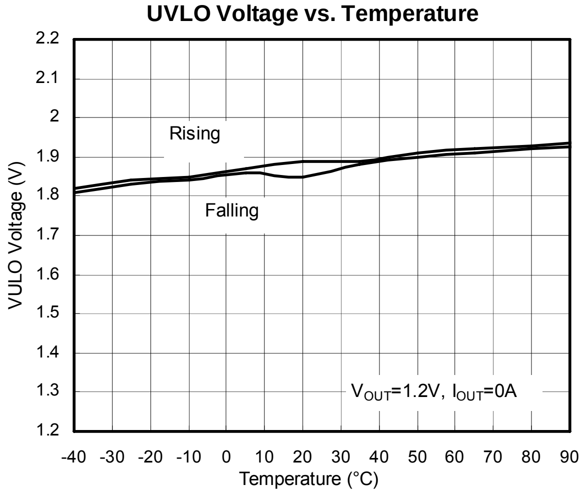
EN pin Threshold vs. Input Voltage



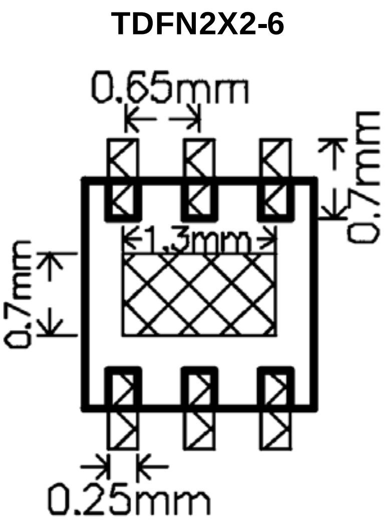
EN pin Threshold vs. Temperature



Typical Performance Characteristics (Continued)



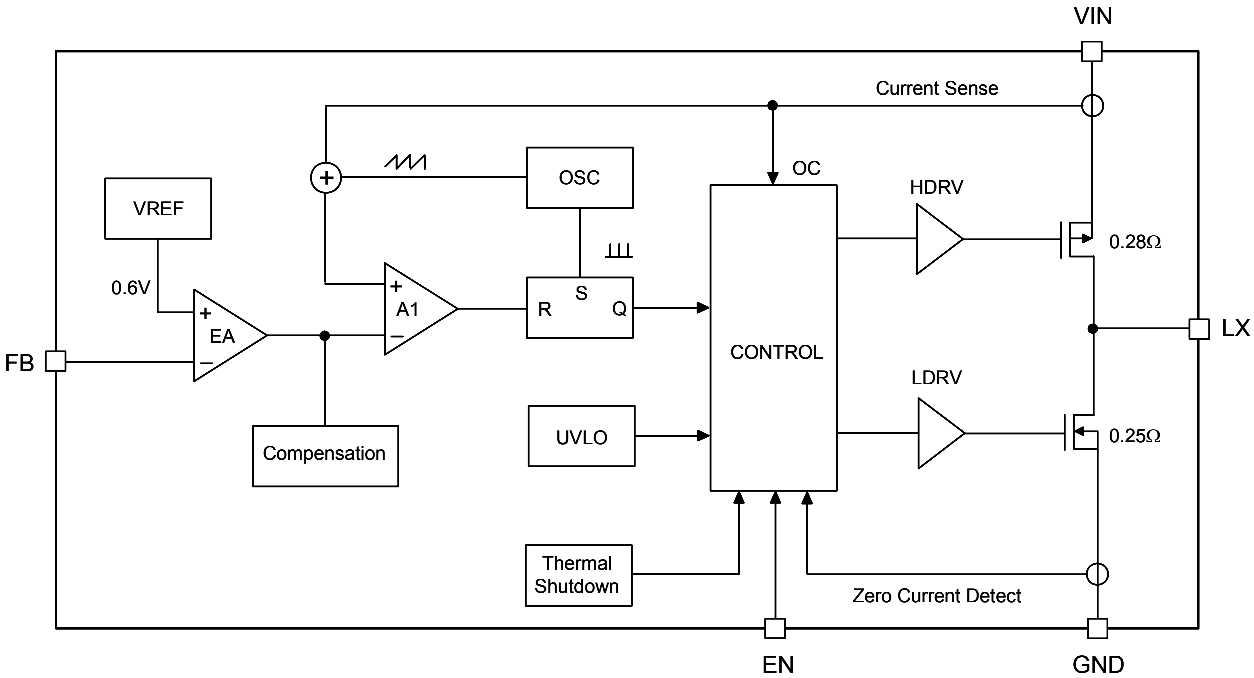
Minimum Footprint PCB Layout Section



Pin Descriptions

PIN	NAME	FUNCTION
1	NC	No Connect
2	EN	ON/OFF Control
3	VIN	Power Supply
4	LX	Switch Node Connection to Inductor
5	GND	Power Ground
6	FB	Output Feedback

Block Diagram



Function Description

The AT1691 uses a constant frequency, current mode step-down architecture. Both the high/low-side switches are internal. During normal operation, the internal high-side (PMOS) switch is turned on each cycle when the oscillator sets the SR latch, and turned off when the comparator (A1) resets the SR latch. The peak inductor current at which comparator (A1) resets the SR latch, is controlled by the output of error amplifier EA. While the high-side switch is off, the low-side switch is turned on until either the inductor current starts to reverse or the beginning of the next switching cycle.

Dropout Operation

As the input supply voltage decreases to a value approaching the output voltage, the duty cycle increases toward the maximum on-time. Further reduction of the supply voltage forces the high-side switch to remain on for more than one cycle until it reaches 100% duty cycle. The output voltage is dropped from the input supply for the voltage which across the high-side switch.

Soft-Start

The AT1691 employ soft-start circuitry to reduce supply inrush current during startup conditions. When the device exits under-voltage lockout (UVLO) or shutdown mode, the soft-start circuitry will slowly ramp up the output voltage to reduce the inrush current.

Over Temperature Protection

In most applications the AT1691 does not dissipate much heat due to high efficiency. But, in applications where the AT1691 is running at high ambient temperature with low supply voltage and high duty cycles, such as in dropout, the heat dissipated may exceed the maximum junction temperature of the part. If the junction temperature reaches approximately 150°C, both power switches will be turned off and the SW node will become high impedance.

Application Information

Inductor Selection

For most applications, the value of the inductor will fall in the range of 2.2μH to 10μH. Its value is chosen based on the desired ripple current. Large value inductors lower ripple current and small value inductors result in higher ripple currents. Higher V_{IN} or V_{OUT} also increase the ripple current ΔI_L:

$$\Delta I_L = \frac{1}{fL} V_{OUT}\left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

where f=switching frequency, L=inductance. A reasonable inductor current ripple is usually set as 1/2 to 1/5 of maximum out current.

The DC current rating of the inductor should be at least equal to the maximum load current plus half the ripple current to prevent core saturation. For better efficiency, choose a low DCR inductor.

Inductor Core Selection

Once the value for L is known, the type of inductor must be selected. High efficiency converters generally cannot afford the core loss found in low cost powdered iron cores, forcing the use of more expensive ferrite or molypermalloy cores. Actual core loss is independent of core size for a fixed inductor value but it is very dependent on the inductance selected. As the inductance increases, corelosses decrease. Unfortunately, increased inductance requires more turns of wire and therefore copper losses will increase.

Ferrite designs have very low core losses and are preferred at high switching frequencies, so design goals can concentrate on copper loss and preventing saturation. Ferrite core material saturates “hard”, which means that inductance collapses abruptly when the peak design current is exceeded. The “hard” saturation results in an abrupt increase in inductor ripple current and consequent output voltage ripple. Do not allow the core to saturate!

Different core materials and shapes will change the size/current and price/current relationship of an inductor.

Toroid or shielded pot cores in ferrite or permalloy materials are small and don't radiate energy but generally cost more than powdered iron core inductors with similar characteristics. The choice of which style inductor to use mainly depends on the price vs size requirements and any radiated field/EMI requirements.

Capacitor Selection
In continuous mode, the source current of the top MOSFET is a square wave of duty cycle V_{OUT}/V_{IN}. To prevent large voltage transients, a low ESR input capacitor sized for maximum RMS current must be used. The maximum RMS capacitor current is given by:

$$C_{IN} \text{ requires } I_{RMS} \cong I_{OMAX} \frac{\sqrt{V_{OUT}(V_{IN} - V_{OUT})}}{V_{IN}}$$

This formula has a maximum at $V_{IN}=2V_{OUT}$, where $I_{RMS}=I_{OUT}/2$. This simple worst case condition is commonly used for design because even significant deviations do not offer much relief.

The selection of C_{OUT} is driven by the required effective series resistance (ESR). Typically, once the ESR requirement for C_{OUT} has been met, the RMS current rating generally far exceeds the $I_{RIPPLE(P-P)}$ requirement. The output ripple ΔV_{OUT} is determined by:

$$\Delta V_{OUT} \cong \Delta I_L \left(ESR + \frac{1}{8fC_{OUT}} \right).$$

For a fixed output voltage, the output ripple is highest at maximum input voltage since ΔI_L increases with input voltage.

Nowadays, higher value, lower cost ceramic capacitors are becoming available in smaller case sizes. Their high ripple current, high voltage rating and low ESR make them ideal for switching regulator applications. Because the AT1691's control loop does not depend on the output capacitor's ESR for stable operation, ceramic capacitors can be used freely to achieve very low output ripple and small circuit size.

When choosing the input and output ceramic capacitors, choose the X5R or X7R dielectric formulations. These dielectrics have the best temperature and voltage characteristics of all the ceramics for given value and size.

Output Voltage Programming
In the adjustable version of AT1691, the output voltage is set by a resistive divider according to the following formula:

$$V_{OUT} = 0.6 \bullet \left(1 + \frac{R1}{R2} \right) \text{ Volt.}$$

Efficiency Considerations
Although all dissipative elements in the circuit produce losses, one major source usually account for most of the losses in AT1691 circuits: I^2R losses. The I^2R loss dominates the efficiency loss at medium to high load currents.

The I^2R losses are calculated from the resistances of the internal switches, R_{SW}, and external inductor R_L. In continuous mode, the average output current flowing through inductor L is "chopped" between the main switch and the synchronous switch. Thus the series resistance looking into the LX pin is a function of both top and bottom MOSFET $R_{DS(ON)}$ and the duty cycle (D) as follows:

$$R_{SW} = (R_{DS(ON)TOP})(D)+(R_{DS(ON)BOTTOM})(1-D)$$

The $R_{DS(ON)}$ for both the top and bottom MOSFETs can be obtained from Electrical Characteristics table. Thus, to obtained I^2R losses, simply add R_{SW} to R_L and multiply the result by the square of the average output current.

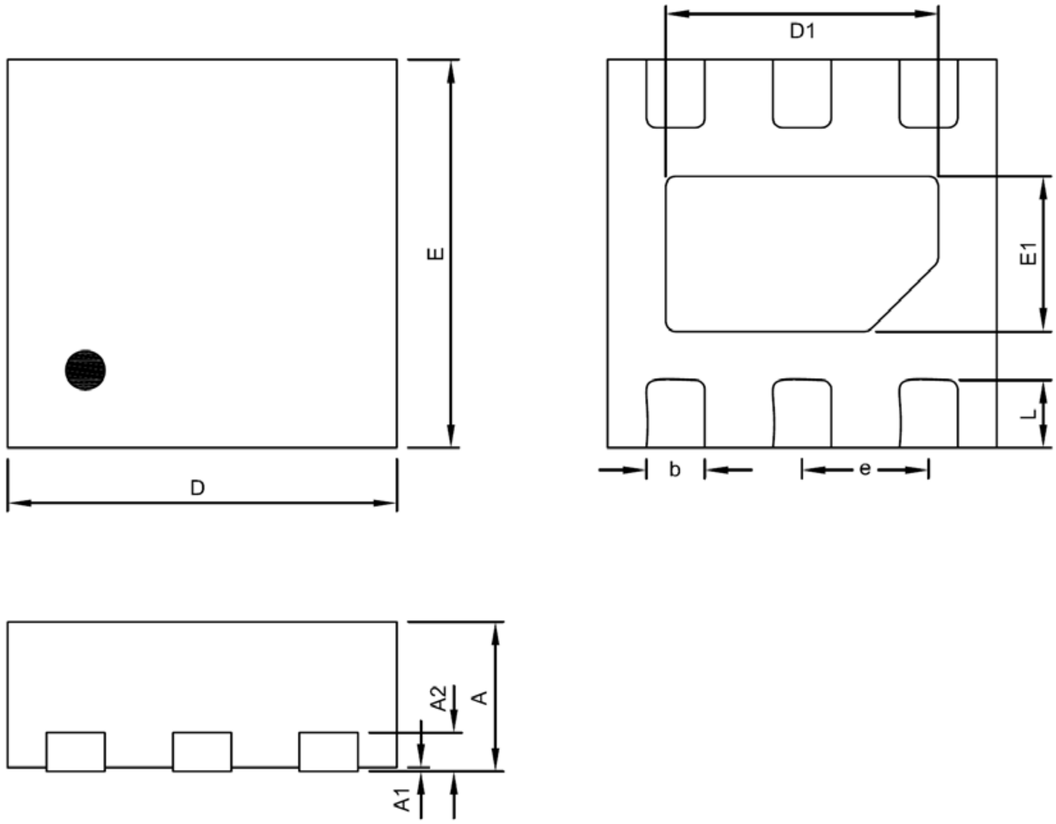
Other losses including C_{IN} and C_{OUT} ESR dissipative losses and inductor core losses generally account for less than 2% total additional loss.

Checking Transient Response
The regulator loop response can be checked by looking at the load transient response. Switching regulators take several cycles to respond to a step in load current. When a load step occurs, V_{OUT} immediately shifts by an amount equal to ($\Delta I_{LOAD} \bullet ESR$), where ESR is the effective series resistance of C_{OUT}. ΔI_{LOAD} also begins to charge or discharge C_{OUT}, which generates a feedback error signal. The regulator loop then acts to return V_{OUT} to its steady-state value. During this recovery time V_{OUT} can be monitored for overshoot or ringing that would indicate a stability problem.

Thermal considerations
In most application the AT1691 does not dissipate much heat due to its high efficiency. But, in applications where the AT1691 is running at high ambient temperature with low supply voltage and high duty cycles, such as in dropout, the heat dissipated may exceed the maximum junction temperature of the part. If the junction temperature reaches approximately 150°C, both power switches will be turned off and the LX node will become high impedance.

Assume power dissipation on AT1691 P_D=0.1W, ambient temperature T_A=70°C, thermal resistance of junction to ambient θ_{JA}=165°C/W, then temperature junction $T_J = T_A + \theta_{JA} * P_D$ = 86.5°C.

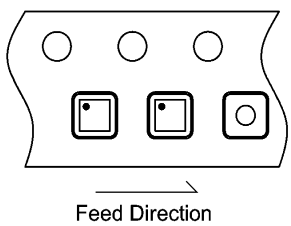
Package Information



TDFN2X2-6 Package

Symble	DIMENSION IN MM			DIMENSION IN INCH		
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.70	0.75	0.80	0.0276	0.0295	0.0315
A1	0.00	---	0.05	0.0000	---	0.0020
A2	0.19	0.20	0.21	0.0075	0.0079	0.0083
D	1.95	2.00	2.05	0.0768	0.0787	0.0807
E	1.95	2.00	2.05	0.0768	0.0787	0.0807
D1	1.15	1.30	1.45	0.0453	0.0512	0.0571
E1	0.55	0.70	0.85	0.0217	0.0276	0.0335
b	0.25	0.30	0.35	0.0098	0.0118	0.0138
e	0.65 BSC			0.0256 BSC		
L	0.30	0.35	0.40	0.0118	0.0138	0.0157

Taping Specification



PACKAGE	Q'TY/REEL
TDFN2X2-6	3,000 ea

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