24V 650KHz 2A Fast-PWM Synchronous Step-Down DC/DC Converter

❖ GENERAL DESCRIPTION

The AX3682 is a fully integrated high efficiency synchronous step-down converter which requires minimum number of external components. It offers very compact solution with up to 2A continuous output current over a wide input range.

The AX3682 employs proprietary Constant On-Time (COT) control scheme providing superior transient response and maintaining constant switching frequency under the continuous condition mode operation. The internal ramp compensation network allows stable operation with ultra-low equivalent series resistor (ESR) output ceramic capacitors without using external compensation network. An error amplifier in the control loop provides excellent line and load regulation.

The AX3682 integrates extensive protection functions include: UVLO, OCP, UVP and thermal shutdown. The converter is available in a small 6pin SOT23 package.

❖ FEATURES

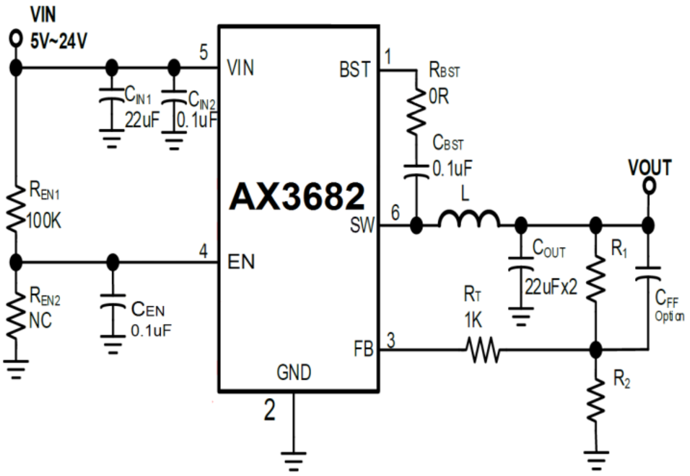
- Input Voltage Range from 4.3V to 24V
- 28V Input Transient Tolerance
- Output Voltage Adjustable from 0.6V to 24V
- 2A continuous output current
- Support 100% duty cycle Low Dropout Operation
- Stable operation with output low ESR ceramic capacitors
- Fast PWM COT control with superior transient performance
- 650KHz Switching frequency
- Internal 800us Soft-Start
- Integrated 110mΩ and 80mΩ HS/LS Switches
- Accurate EN UVLO threshold
- High Efficiency Operation at light load
- Thermal Shutdown with Auto recovery
- Hiccup mode at short circuit protection
- Available in a 6-pin SOT23 Package

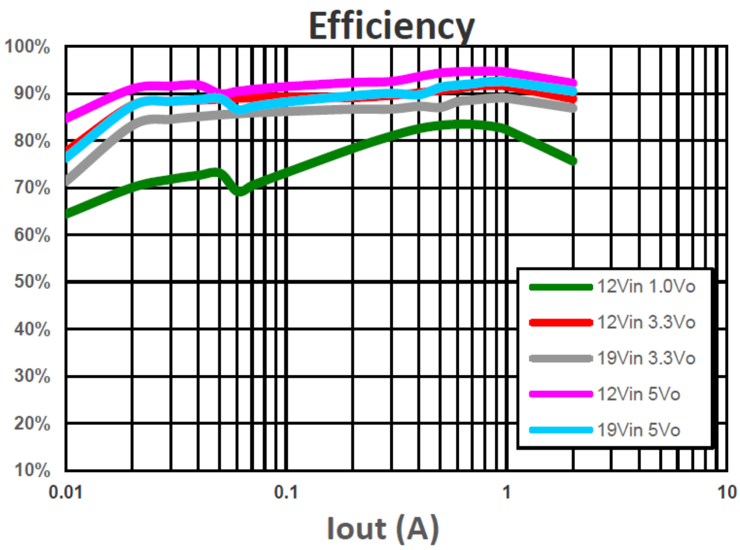
Rev.1.0 Jan.09, 2022

❖ APPLICATION

- Laptop Computer
- Tablet PC
- Networking Systems
- Personal Video Recorders
- Flat Panel Television and Monitors
- Distributed Power Systems

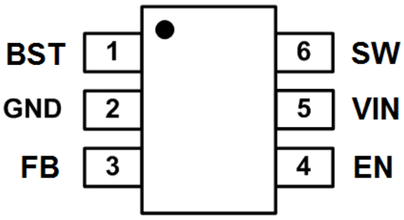
❖ TYPICAL APPLICATION





❖ PIN ASSIGNMENT

The package of AX3682, the pin assignment is given by:



Top View

Pin Description

Pin No.	Pin Name	Description
1	BST	Bootstrap. A 0.1uF ceramic capacitor connected between SW and BST pins is required to form a floating supply for the high-side switch driver.
2	GND	Power Ground
3	FB	Feedback. An external resistor divider from the output to GND, tapped to the FB pin, sets the output voltage.
4	EN	Enable pin. AX3682 is shut down when this pin is low and active when this pin is high. The hysteretic enable threshold voltage is 1.26V going up and 1.15V going down. Connect EN with VIN through a pull-up resistor or a resistive voltage divider for automatic startup. An external resistor divider from VIN can be used to program a VIN threshold below to stop the AX3682 operation. There is an internal 1000KΩ (typical) pull down resistor from EN to AGND.
5	VIN	Supply Voltage. The VIN pin supplies power for internal MOSFET and regulator. The AX3682 operates from a 4.3V to 24V input rail. An input capacitor is needed to decouple the input rail.
6	SW	Switch Output. Connect this pin to the inductor and bootstrap capacitor. SW node should be kept small on the PCB for good performance and low EMI.

❖ ORDER/MARKING INFORMATION

Order Information	Top Marking (SOT-23-6L)
AX3682 X X X Package Type C : SOT-23-6L Packing Blank : Bag A : Taping	3682 Y WW xx Manufacture Control Code Week Year

❖ ABSOLUTE MAXIMUM RATINGS

VIN Voltage……………………………….+30V

SW Voltage…..…………… -0.3V to V_{IN} +0.3V

Dynamic V_{SW} in 10ns Duration -3V to V_{IN} +3V

BS-SW Voltage……………………………+6V

EN, FB Voltage…………………………..…+6V

Junction Temperature Range…….. -40°C to +150°C

Storage Temperature Range……….-65°C to +150°C

Lead Temperature(Soldering 10s) ………..… +260°C

Recommend Operating Conditions (Note2)

Input Voltage (V_{IN}) ……………..…. +2.5V to 24V

Operating Temperature Range...…… -40°C to +85°C

Junction Temperature Range, T_J….. -40°C to +125°C

Thermal information (Note3, 4)

Maximum Power Dissipation(T_A=25°C) 1.25W

Thermal Resistance(θ_{JA}) …………………….100°C/W

Thermal Resistance(θ_{JC}) ………..……………. 55°C/W

Note (1): Stress exceeding those listed "Absolute Maximum Ratings" may damage the device.
Note (2): The device is not guaranteed to function outside of the recommended operating conditions.
Note (3): Measured on JESD51-7, 4-Layer PCB.
Note (4): The maximum allowable power dissipation is a function of the maximum junction temperature T_{J_MAX}, the junction to ambient thermal resistance θ_{JA}, and the ambient temperature T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by $P_{D\_MAX}= (T_{J\_MAX}-T_A)/\theta_{JA}$. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.

❖ ELECTRICAL CHARACTERISTICS

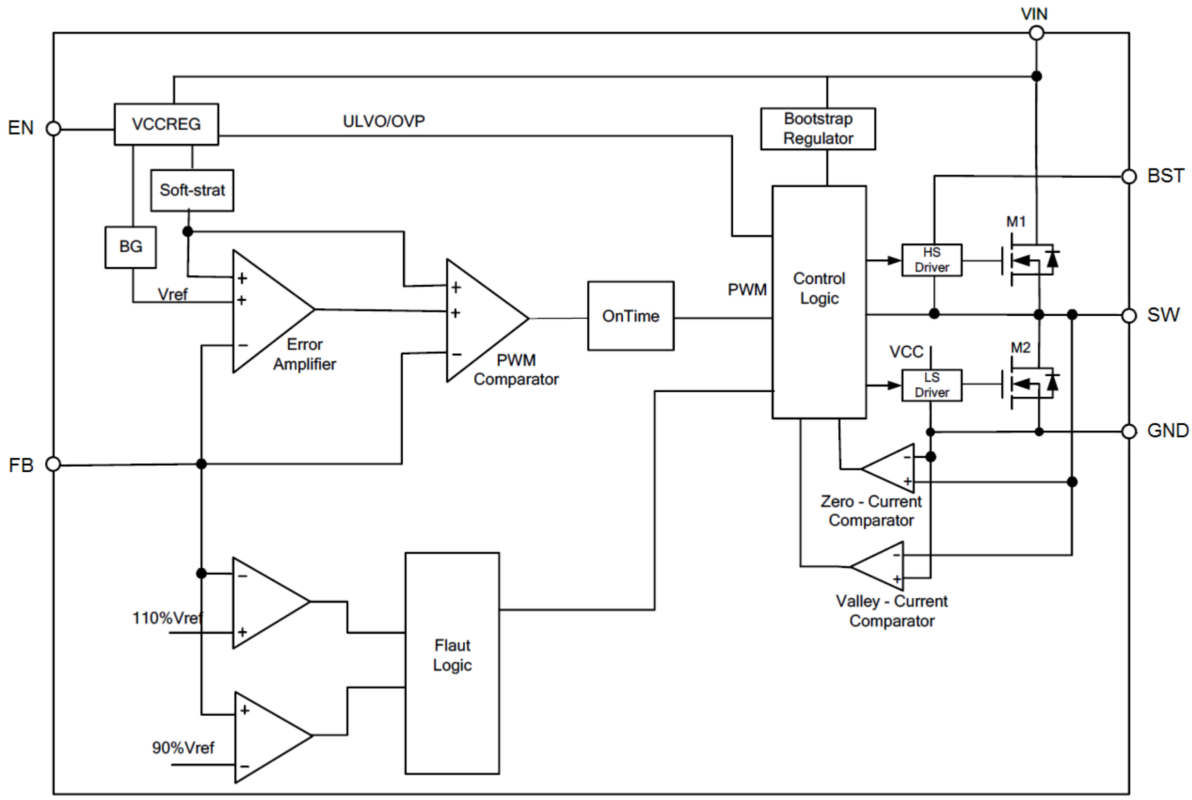
T_A = 25°C, V_{IN}=12V and V_{EN}=5V, unless otherwise noted. Typical values are at V_{IN} =12V, V_{EN} = 5V and V_{OUT}=5V.

Characteristics	Conditions	Min	Typ	Max	Units
Input Voltage Range V_{IN}		4.3		24	V
Shutdown Current	V_{EN} = 0V, V_{IN} = 5.5V		0.1	1	μA
Input Under Voltage Lockout Threshold	V_{IN} Increasing	3.6	3.7	4.25	V
Input Under Voltage Lockout Hysteresis			200		mV
Supply Current I_Q	V_{FB} = 0.7V		600	1000	μA
Feedback Regulation Voltage V_{FB}		588	600	612	mV
Feedback Current I_{FB}	V_{FB}=0.6V		10	50	nA
Internal Soft-Start Time T_{SS}			0.8		msec
Switching Frequency	I_{OUT}=1A		650		KHz
Minimum Off Time(5)			140		ns
Maximum Duty Cycle(6)			100		%
HS Main Switch-On Resistance RON_{HS}			110		mΩ
HS Switch Leakage Current	V_{IN} = 28V, V_{EN} = V_{SW} = 0V		0.1	10	μA
Low Side(LS) Switch Valley Current Limit			5.2		A
LS Switch Negative Current Limit I_{NEG}			-1.5		A
LS Switch-On Resistance RON_{LS}			80		mΩ
LS Switch Leakage Current	V_{IN} = V_{SW} = 28V, V_{EN} = 0V		0.1	10	μA
EN On Threshold	V_{EN} ramp up	1.11	1.26	1.31	V
EN Off Threshold	V_{EN} ramp down	1.01	1.15	1.21	V
EN Internal Pull-Down Resistor		700	1000	1300	kΩ
Thermal Shutdown			160		℃
Thermal Shutdown Hysteresis			30		℃

Note(5): Guaranteed by design, no production test.

Note(6): When the input voltage approaches the output voltage, the AX3682 will extend the on-time and force the main high side switch remaining on for multiple cycles (>10usec). High side switch is only turned off momentarily, and low side switch is forced on shortly (typical 120ns) to refresh the BST capacitor. High side switch will resume on after the BST refresh.

❖ Functional Block Diagram

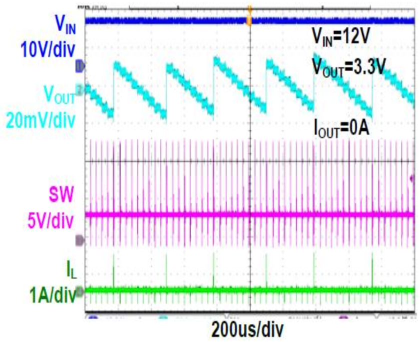


❖ TYPICAL PERFORMANCE CHARACTERISTICS

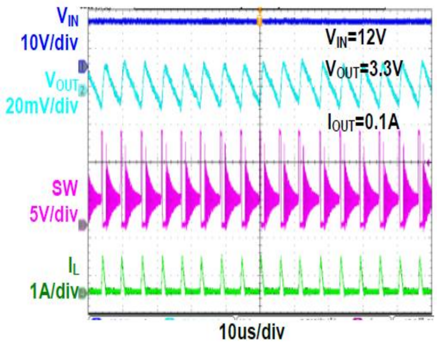
Performance waveforms are tested on the evaluation board of the Design Example section

VIN=12V, VOUT=3.3V, L=3.3uH, TJ=+25℃, unless otherwise noted.

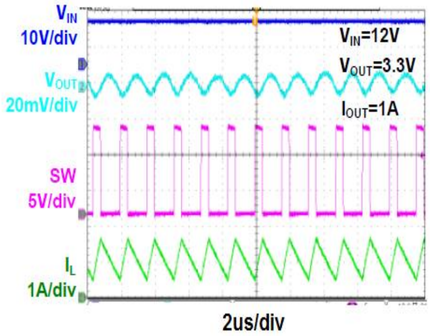
Steady State Test



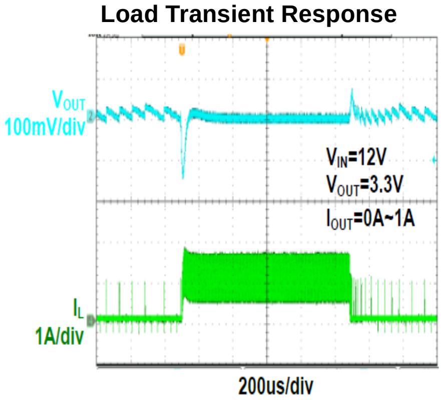
Steady State Test



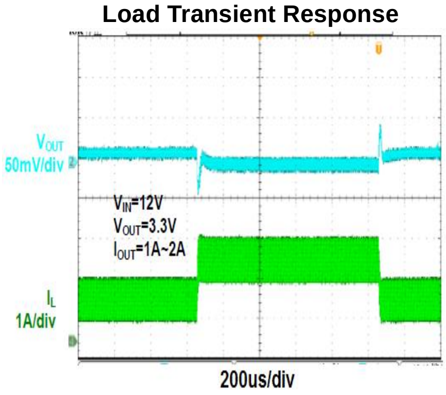
Steady State Test



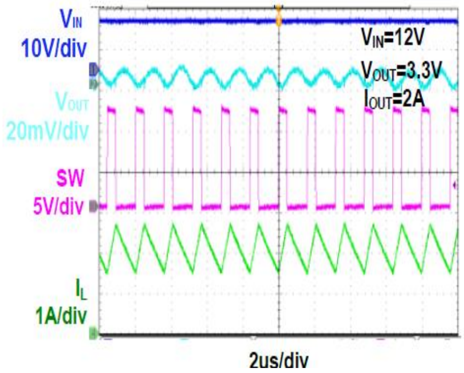
Load Transient Response



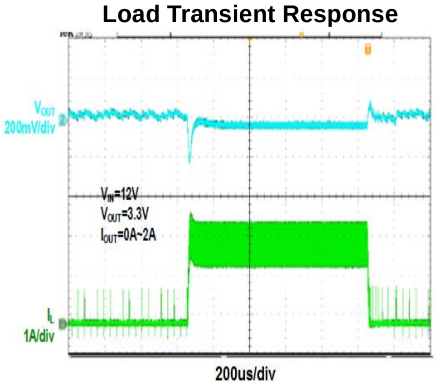
Load Transient Response



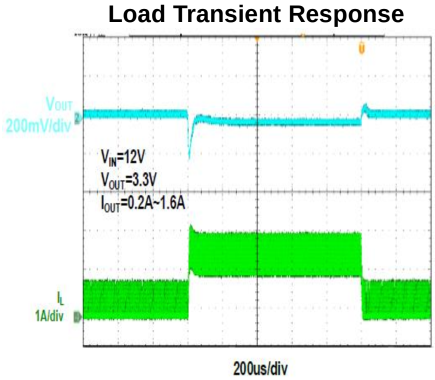
Steady State Test



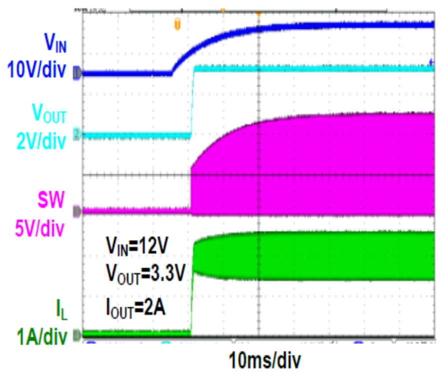
Load Transient Response



Load Transient Response



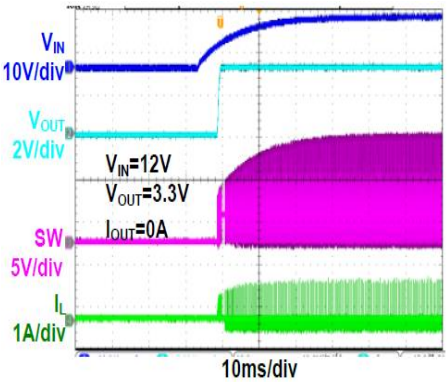
VIN Power On



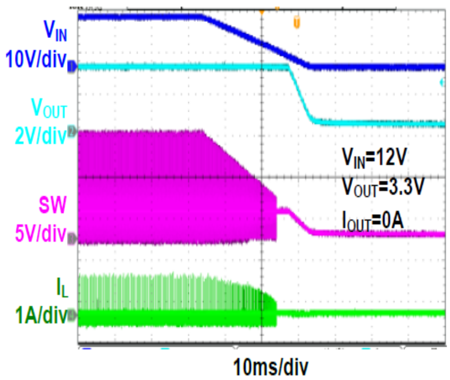
Performance waveforms are tested on the evaluation board of the Design Example section

VIN=12V, VOUT=3.3V, L=3.3uH, TJ=+25℃, unless otherwise noted.

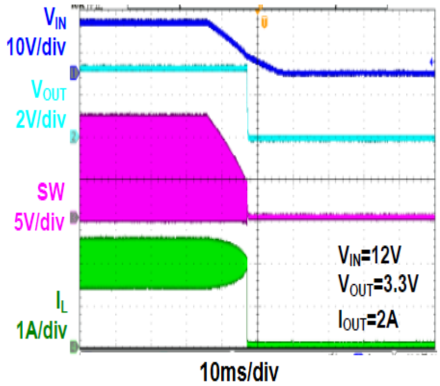
VIN Power On



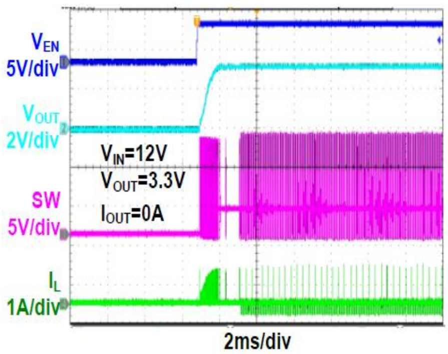
VIN Power Off



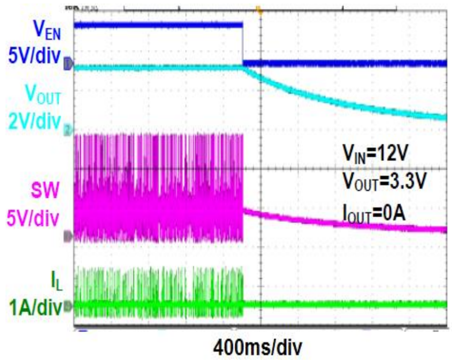
VIN Power Off



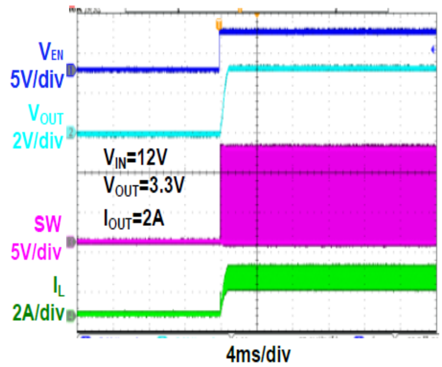
EN Power On



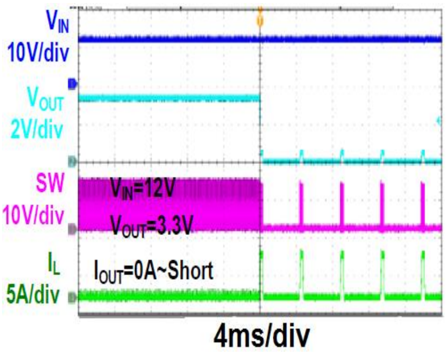
EN Power Off



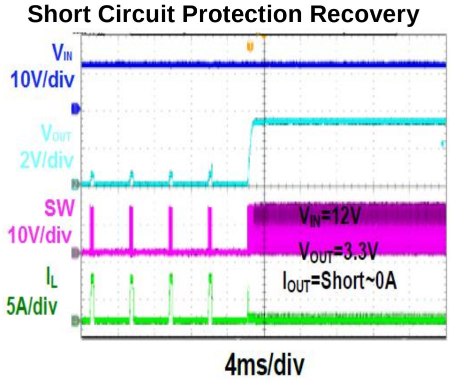
EN Power On



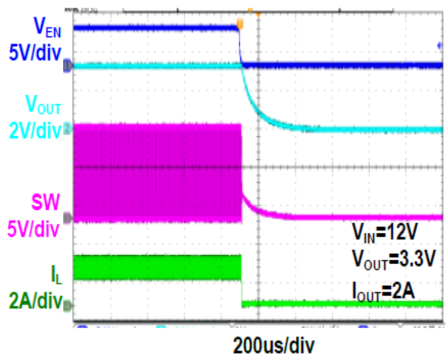
Short Circuit Protection



Short Circuit Protection Recovery



EN Power Off



Operation

The AX3682 is a fully integrated synchronous step-down converter employing constant on-time (COT) control scheme to achieve superior transient performance. Its proprietary internal ramp compensation offers stable operation with lower ESR ceramic output capacitors without using external complex compensation networks.

Constant On-Time Control

The constant on-time control (COT) operates by comparing the feedback voltage VFB with the reference voltage (V_{FBREG}). When FB drops below the reference, the control circuit turns on HS switch immediately for a pre-determined period of time (on-time) to ramp up the inductor current. When this on-time times out, the LS switch is then turned on to ramp down the inductor current. The LS switch is turned off when inductor current reaches zero I_{ZX} (or triggers negative current limit I_{NEG}) or HS switch is turned on again for the next cycle. This operation repeats itself if FB drops below reference again.

The AX3682 uses a proprietary algorithm to calculate the on-time based on input voltage, output voltage and load current to achieve nearly constant switch frequency over entire continuous conduction load current range. The on-time can be estimated as:

$$T_{ON} = \frac{V_{OUT}}{V_{IN}} \times \frac{1}{F_{SW}}$$

Due to its immediate response on FB voltage droop and simplified loop compensation, the AX3682 offers superior transient response compare to traditional fixed frequency PWM control converters.

Light Load Operation

In medium and heavy load condition, the AX3682 operates in PWM mode with typical switching frequency of 650KHz. When load current reduces, the AX3682 naturally transitions from PWM mode to PFM mode where the pulse width remains the calculated on-time but the switching frequency reduces to accommodate the low output current. The lower the output current, the lower the switching frequency. Once the switching frequency drops to low enough, the devices enter sleep mode to cut down its quiescent current to maintain high efficiency in light load.

The critical load current at the boundary of PWM mode and PFM mode is related to the inductor ripple current, which depends on the inductor value, input voltage and output voltage. Typically this critical load current level is estimated as:

$$I_{CRIT} = \frac{1}{2} \times \frac{(V_{IN}-V_{OUT}) \times V_{OUT}}{L \times F_{SW} \times V_{OUT}}$$

100% Duty Cycle Low Dropout Operation

When input voltage approaches the output voltage, the AX3682 will extend the on-time toward the maximum on-time to satisfy the duty cycle requirement to regulate the output voltage. If the input further drops to equal or lower than the output level, the AX3682 forces the main high side (HS) switch to remain on for more than one cycle, eventually reaching 100% duty cycle. The 100% duty cycle operation allows the converter to effectively pass through the input voltage directly to output with minimum voltage drops on the HS switch and inductor. In the low dropout operation mode, the AX3682 turns on HS switch for multiple switching cycles until it turns off HS switch momentarily and turn on low side (LS) switch (typical 120ns) to refresh the BST supply voltage. The LS switch is turned off after the BST refresh pulse, then the HS switch resumes on for multiple switching cycles which gives the effective 100% duty cycle. The refresh BST pulse is needed to charge the BST capacitor and ensure the HS switch driver circuits proper operation.

Enable

AX3682 offers an accurate enable threshold of EN pin, which typically 1.26V rise and 1.15V fall. The AX3682 is enabled by pulling up the EN pin above 1.26V and AX3682 is disabled by pulling down the EN pin above below 1.15V.

When using the EN pin threshold voltage to program the input startup voltage level, the following equation shall be used:

$$V_{IN\text{-}START} = 1.26V \times \frac{R_{UP} + R_{DOWN}//1M\Omega}{R_{DOWN}//1M\Omega}$$

Where the 1MΩ is the internal pull-down resistor on EN pin.

When EN is pulled high, AX3682 will start up if V_{IN} is higher than UVLO threshold. When EN pin is pulled low, AX3682 will go into shutdown. Tie EN pin to V_{IN} if the shutdown feature is not used.

Soft Start

AX3682 has built-in internal soft start of 800usec. During the soft start period, output voltage is ramped up linearly to the regulation level, independent of the load current and output capacitor value.

Current Limit and Hiccup Mode

AX3682 has built-in cycle-by-cycle current limit protection to prevent inductor current from running away in any fault conditions. The AX3682 continuously monitors the inductor valley current during its operation. Once the valley current exceeds the limit level, AX3682 will turn on LS and wait for inductor current to drop down to a pre-determined level before the HS can be turned on again. If this current limit condition is repeated for a sustained long period of time, AX3682 will enter hiccup mode, where it stop switching for a pre-determined period of time before automatically re-try to start up again. It always starts up with soft-start to limit inrush current and avoid output overshoot.

When AX3682 enters valley current limit mode, the peak current is also limit due to the fixed on-time of the HS, and this peak current can be estimated as:

$$I_{PEAK} = I_{VALLEY} + T_{ON} \times \frac{V_{IN} - V_{OUT}}{L}$$

Application Information

Setting the Output Voltage

External feedback resistors are used to set the output voltage. 1% resistors are recommended to maintain output voltage accuracy. Refer to typical application circuit on page2, the top feedback resistor R1 has some impact on the loop stability, the bottom feedback resistor R2 recommended 5KΩ~20KΩ, the top feedback resistor R1 can be calculated as:

$$R_1 = R_2 \times \left(\frac{V_{OUT}}{0.6} - 1 \right)$$

Inductor Selection

The inductor is necessary to supply constant current to the output load while being driven by the switched input voltage. A larger-value inductor will result in less ripple current that will result in lower output ripple voltage. However, a larger-value inductor will have a larger physical footprint, higher series resistance, and/or lower saturation current, a good rule for determining the inductance value is to design the peak-to-peak ripple current in the inductor to be in the range of 30% to 40% of the maximum output current, and that the peak inductor current is below the maximum switch current limit. The inductance value can be calculated by:

$$L = \frac{V_{OUT}}{F_{SW} \times \Delta I_L} \times \left(1 - \frac{V_{OUT}}{V_{IN}} \right)$$

Where ΔI_L is the peak-to-peak inductor ripple current.

To avoid overheating and poor efficiency, an inductor must be chosen with an RMS current rating that is greater than the maximum expected output load of the application. In addition, the saturation current (typically labeled ISAT) rating of the inductor must be higher than the maximum load current plus 1/2 of in inductor ripple current.

The peak inductor current can be calculated by:

$$I_{L\_PEAK} = I_{OUT} + \frac{V_{OUT}}{2F_{SW} \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Input Capacitor Selection

The input current to the step-down converter is discontinuous and therefore requires a capacitor to supply the AC current to the step-down converter while maintaining the DC input voltage. Ceramic capacitors are recommended for best performance and should be placed as close to the VIN pin as possible. Capacitors with X5R and X7R ceramic dielectrics are recommended because they are fairly stable with temperature fluctuations. The capacitors must also have a ripple current rating greater than the maximum input ripple current of the converter. The input ripple current can be estimated as follows:

$$I_{CIN} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The worst-case condition occurs at $V_{IN}=2V_{OUT}$, where:

$$I_{CIN} = \frac{I_{OUT}}{2}$$

For simplification, choose the input capacitor with an RMS current rating greater than half of the maximum load current. The input capacitance value determines the input voltage ripple of the converter. If there is an input voltage ripple requirement in the system, choose the input capacitor that meets the specification.

The input voltage ripple can be estimated as follows:

$$\Delta V_{IN} = \frac{I_{OUT}}{F_{SW} \times C_{IN}} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Under worst-case conditions where $V_{IN}=2*V_{OUT}$

$$\Delta V_{IN} = \frac{1}{4} \times \frac{I_{OUT}}{F_{SW} \times C_{IN}}$$

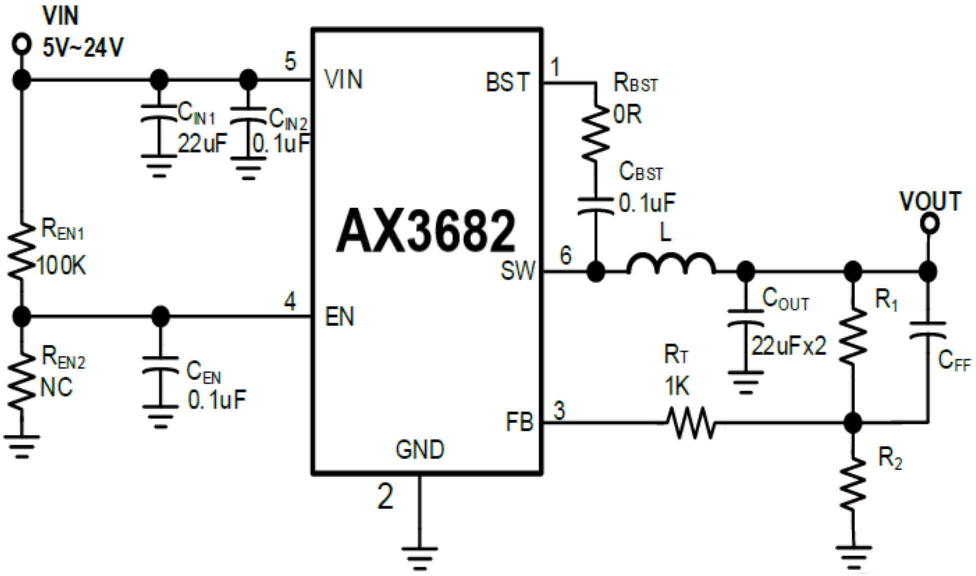
Output Capacitor Selection

The output capacitor has two essential functions. Along with the inductor, it filters the square wave generated by AX3682 to produce the DC output. In this role it determines the output ripple, thus low impedance at the switching frequency is important. The second function is to store energy in order to satisfy transient loads and stabilize the AX3682's control loop. S5R or X7R type ceramic capacitors have very low equivalent series resistance (ESR) and provide low output ripple and good transient response. Transient performance can be improved with a higher value output capacitor and the addition of a feed-forward capacitor placed between V_{OUT} and FB. Increasing the output capacitance will also decrease the output voltage ripple. A lower value of output capacitor can be used to save space and cost, but transient performance will suffer and may cause loop instability. When choosing a capacitor, special attention should be given to the data sheet to calculate the effective capacitance under the relevant operating conditions of voltage bias and temperature. A physically larger capacitor or one with a higher voltage rating may be required.

PCB Layout Instruction

(1) The high current paths (GND, IN, and SW) should be placed very close to the device with short, direct and wide traces.
(2) Put the input capacitor as close to IN and GND
(3) Put the decoupling capacitor as close to the VCC and GND pins as possible. Place the Cap close to AGND if the distance is long. And place > 3 vias if via is required to reduce the leakage inductance.
(4) Keep the switching node SW short and away from the feedback network.
(5) The external feedback resistors should be placed next to the FB pin. Make sure that there is no via on the FB trace.
(6) Keep the BST voltage path (BST, R_{BST}, C_{BST} and SW) as short as possible.
(7) Keep the IN and GND pads connected with large copper and use at least two layers for IN and GND trace to achieve better thermal performance. Also, add several Vias with 10mil_drill/18mil_copper_width close to the IN and GND pads to help on the thermal dissipation.
(8) Four-layer layout is strongly recommended to achieve better thermal performance.

❖ AX3682 Application Schematic

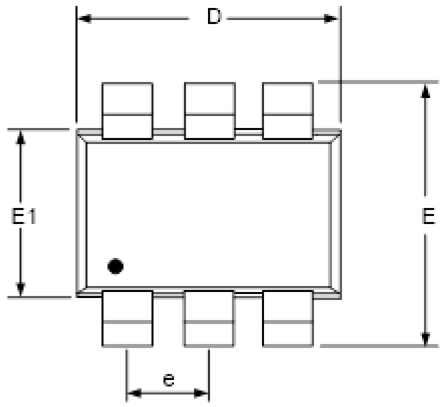


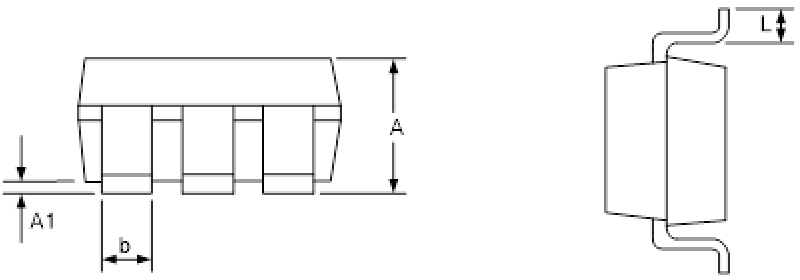
EVB BOM List

Qty	Ref	Value		Description	Package
1	C_{IN1}	22µF		Ceramic Capacitor, 50V, X5R	0805
2	C_{IN2}, C_{EN}	0.1µF		Ceramic Capacitor, 50V, X5R	0603
2	C_{OUT}	22µF		Ceramic Capacitor, 16V, X5R	0805
1	C_{BST}	0.1µF		Ceramic Capacitor, 10V, X5R	0603
1	L	V_{OUT}=5V	4.7µH	Inductor, Isat > 6A	SMD
		V_{OUT}=3.3V	3.3µH		
		V_{OUT}=1.0V	2.2µH		
1	R1	V_{OUT}=5V	80.6KΩ	Resistor, ±1%	0603
		V_{OUT}=3.3V	49.9KΩ		
		V_{OUT}=1.0V	7.32KΩ		
1	R2	V_{OUT}=5V	11KΩ	Resistor, ±1%	0603
		V_{OUT}=3.3V	11KΩ		
		V_{OUT}=1.0V	11KΩ		
1	C_{FF}	82pF		Ceramic Capacitor, 10V, X5R	0603
2	R_{EN1}	100KΩ		Resistor, ±5%	0603
1	R_{BST}	0Ω		Resistor, ±1%	0603
1	R_T	1KΩ		Resistor, ±1%	0603
1	Power IC	AX3682		Step-Down DC/DC Converter	SOT23_6L

❖ PACKAGE OUTLINES

SOT23_6L Outline Dimensions
Unit: inches/mm

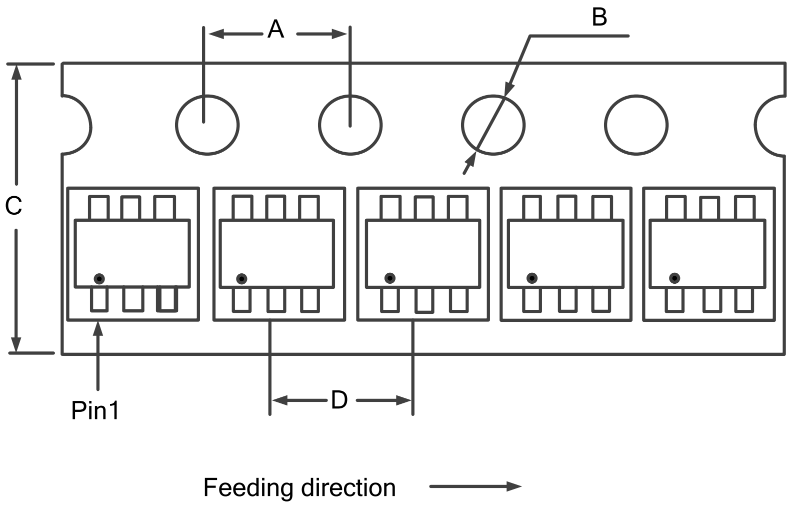




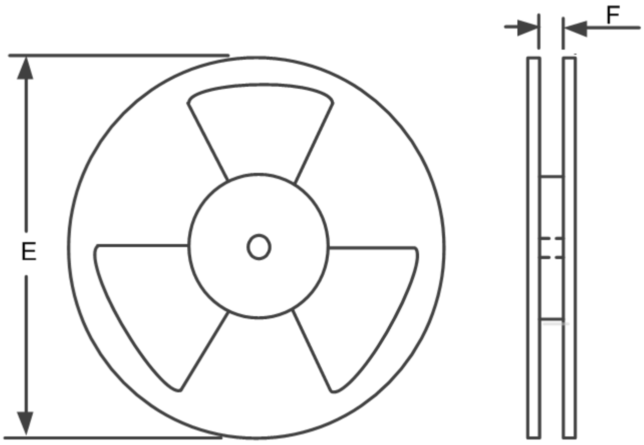
SYMBOLS	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.89	1.45	0.035	0.057
A1	0.00	0.15	0.000	0.006
b	0.30	0.50	0.012	0.020
D	2.70	3.10	0.106	0.122
E1	1.40	1.80	0.055	0.071
e	0.95 BSC		0.037 BSC	
E	2.60	3.00	0.102	0.118
L	0.30	0.60	0.012	0.024

❖ CARRIER TAPE DIMENSION

1. Orientation / Carrier Tape Information: SOT23_6L



1. Reel Information :



2. Dimension Details :

PKG Type	A	B	C	D	E	F	Q'ty/Reel
SOT23_6L	4.0 mm	1.5 mm	8.0 mm	4.0 mm	7 inches	9.0 mm	3,000