



Features

- Wide Input Voltage from 4.8V to 40V
- 3A Output Current
- Adjustable Output Voltage from 1V to 25V
- High Efficiency Up to 93%
- Fixed 350KHz Switching Frequency
- Current Mode Operation
- Adjustable Soft-Start
- Cycle-by-Cycle current limit
- Input Under Voltage Lockout
- Over-Temperature Protection
- Thermal Enhanced ESOP8 Package
- RoHS Compliant

Applications

- Set-Top-Box
- DVD, LCD Displays
- Datacom, XDSL
- Distributed Power System
- Pre-Regulator for Linear Regulators
- Automotive Industry

General Description

The TX9402 is a synchronous step-down DC/DC converter that provides wide 4.8V to 40V input voltage range and 3A continuous load current capability.

Fault protection includes cycle-by-cycle current limit, input UVLO, output over voltage protection and thermal shutdown. Besides, adjustable soft-start

function prevents inrush current at turn-on. This device uses current mode control scheme that provides fast transient response. In shutdown mode, the supply current is less than 1uA.

The TX9402 is available in an ESOP8 package, provides a very compact system solution and good thermal conductance.

Typical Application

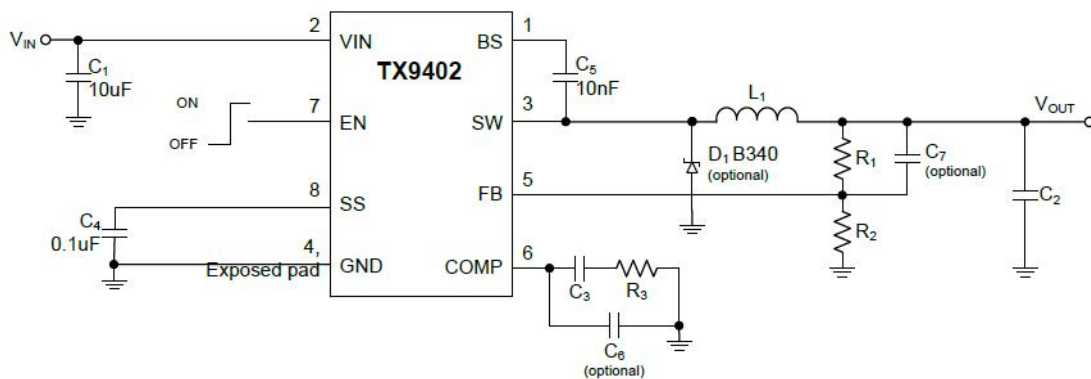


Figure 1. Typical Application Circuit

Vout	R1	R2	R3	C3	C6	L1	C2
5.0V	44.5K	10K	6.8K	3.3nF	150pF	10uH	22uF x 2
3.3V	25.3K	10K	4.7K	3.3nF	150pF	10uH	22uF x 2

Table 1. Recommended Component Selection



System Block Diagram

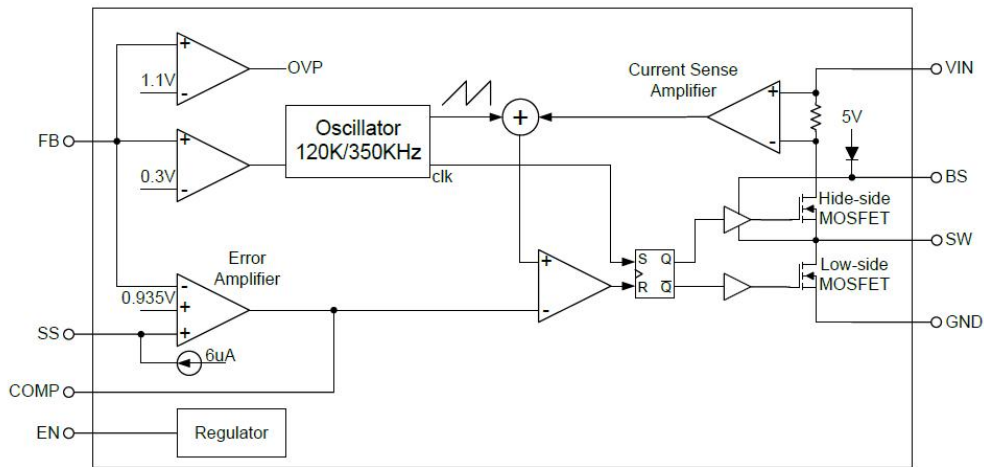


Figure 2. TX9402 Functional Block Diagram

Function Description

The TX9402 is a constant frequency current mode step-down synchronous DC/DC converter. It regulates input voltage from 4.8V to 40V, down to an output voltage as low as 1V, and can provide 3A of continuous load current.

Control Loop

During normal operation, the output voltage is sensed at FB pin through a resistive voltage divider and amplified through the error amplifier. The voltage of error amplifier output pin – COMP is compared to the switch current to controls the RS latch. At each cycle, the high side NMOS would be turned on when the oscillator sets the RS latch and would be turned off when current comparator resets the RS latch. When the load current increases, the FB pin voltage drops below 0.935V, it causes the COMP voltage increase until average inductor current arrive at new load current.

Enable

The TX9402 EN pin provides digital control to turn on/turn off the regulator. When the voltage of EN exceeds the threshold voltage, the regulator starts the soft start function. If the EN pin voltage is below than the threshold voltage, only the bandgap voltage is alive. If the EN pin voltage is below than the shutdown threshold voltage, the regulator will be disable and into the shutdown mode.

Maximum Load Current

The maximum load current decreases at lower input voltage because of large IR drop on the high side switch and low side switch. The slope compensation signal reduces the peak inductor current as a function of the duty cycle to prevent sub-harmonic oscillations at duty cycles greater than 50%.

Output Over Voltage Protection

When the FB pin voltage exceeds 20% of the regulation voltage, the output over voltage protection function will discharge the COMP pin and the SS pin to GND, turning the high side MOSFET off.

Input Under Voltage Lockout

When the TX9402 power on, the internal circuits are held inactive until VIN exceeds the input UVLO threshold voltage. And the regulator will be disabled when VIN below the input UVLO threshold voltage.



Short Circuit Protection

The TX9402 provides short circuit protection function to prevent the device damage from short condition. When the output short to ground, the oscillator frequency is reduced to prevent the inductor current increasing beyond the current limit. In the meantime, the current limit is also reduced to lower the short current. Once the short condition is removed, the frequency and current limit will return to normal.

Over Temperature Protection

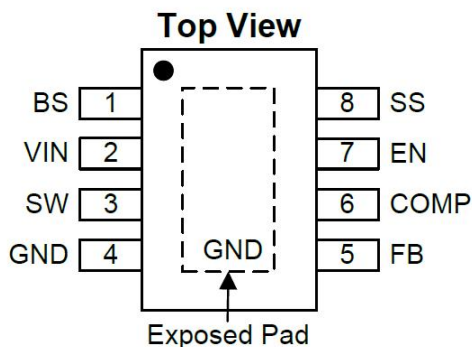
The TX9402 incorporates an over temperature protection circuit to protect itself from overheating. When the junction temperature exceeds the thermal shutdown threshold temperature, the regulator will be shutdown.

Compensation

The stability of the feedback circuit is controlled through COMP pin. The compensation value of the application circuit is optimized for particular requirements. If different conversions are requires some of the components may need to be changes to ensure stability.



Pin Configuration



Pin Function Description

Pin NO.	Pin Name	Pin Description
1	BS	High Side Gate Drive Boost Input. A 10nF or greater capacitor must be connected from this pin to SW. It can boost the gate drive to fully turn on the internal high side NMOS.
2	VIN	Power Supply Input Pin. Drive 4.8V to 40V voltage to this pin to power on this chip. Connecting a 10uF ceramic bypass capacitor between VIN and GND to eliminate noise .
3	SW	Power Switching Output. It is the output pin that internal high side NMOS switching to supply power.
4/EP	GND	Ground Pin. Connecting EP(exposed pad) to Pin 4. .
5	FB	Voltage Feedback Input Pin. Connecting FB and VOUT with a resistive voltage divider. This IC senses feedback voltage via FB and regulate it at 0.935V.
6	COMP	Compensation Pin. This pin is used to compensate the regulation control loop. Connect a series RC network from COMP pin to GND.
7	EN	Enable Input Pin. This pin provides a digital control to turn the converter on or off. Connect to VIN with a 100KΩ resistor for self-startup.
8	SS	Soft-Start Input Pin. This pin controls the soft-start period. Connect a capacitor from SS to GND to set the soft start period.

Order Information

Part Number	Package	Shipment
TX9402	ESOP8	Tape & Reel / 4000



Absolute Maximum Ratings⁽¹⁾

Input Supply Voltage V_{IN}	-0.3V ~ +41V	All Other Pins Voltage.....	-0.3V ~ 6V
EN Voltage V_{EN}	-0.3V ~ +41V	Maximum Junction Temperature.....	150°C
SW Voltage V_{SW}	0.3V(-5V for < 10ns)	Storage Temperature.....	-65°C ~ 150°C
~ 41V (43V for < 5ns)		Lead Temperature (Soldering 10 sec).....	260°C
Boost Voltage V_{BS}	($V_{SW} + 5V$)	ESD Classification (HBM).....	Class 2

Recommended Operating Conditions⁽²⁾

Input Supply Voltage V_{IN}	4.8V ~ 40V	Ambient Temperature T_A	-40°C~85°C
Output Voltage V_{OUT}	1V ~ 25V		

Thermal Characteristics

ESOP8(θ_{JA}).....	75°C/W	ESOP8(θ_{JC}).....	15°C/W
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Notes(1):Stresses exceed those ratings may damage the device.

Notes(2):If out of its operation conditions, the device is not guaranteed to function.



Electrical Characteristics

$V_{IN}=12V$, $T_A=25^{\circ}C$, unless otherwise specified.

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
V_{IN} Input Supply Voltage ⁽³⁾	---	---	4.8	---	40	V
V_{IN} Supply Current	---	$V_{EN} = V_{IN}$, $V_{FB} = 1V$	---	1.5	---	mA
V_{IN} Shutdown Supply Current	---	$V_{EN} = 0V$	---	0.3	3	uA
Feedback Voltage	V_{FB}	$4.8V \leq V_{IN} \leq 40V$	917	935	953	mV
		$-40^{\circ}C \leq T_A \leq 85^{\circ}C$	907	---	963	mV
Feedback OVP Threshold Voltage	---	---	1.05	1.1	1.15	V
High-Side MOSFET RDS(ON) ⁽⁴⁾	---	---	---	130	---	m Ω
Low-Side MOSFET RDS(ON) ⁽⁴⁾	---	---	---	100	---	m Ω
High-Side MOSFET Leakage Current	---	$V_{EN} = 0V$, $V_{SW} = 0V$	---	---	10	uA
High-Side MOSFET Current Limit ⁽⁴⁾	---	---	3.3	4.5	---	A
Low-Side MOSFET Current Limit ⁽⁴⁾	---	From drain to source	---	1.5	---	A
COMP to Current sense Transconductance	G_{CS}	---	---	7	---	A/V
Error Amplifier Transconductance	G_{EA}	$\Delta I_{COMP} = \pm 10\mu A$	---	820	---	$\mu A/V$
Error Amplifier Voltage Gain	A_{EA}	---	---	400	---	V/V
Oscillation frequency	F_{OSC}	---	280	350	420	KHz
Short Circuit Oscillation Frequency	F_{OSC}	$V_{FB} = 0V$	---	120	---	KHz
Maximum Duty Cycle	D_{MAX}	$V_{FB} = 0.7V$	80	90	---	%
Minimum On Time	T_{ON}	---	---	180	---	ns
Input UVLO Threshold	---	V_{IN} Rising	---	4.3	4.6	V
Under Voltage Lockout Threshold Hysteresis	---	---	---	200	---	mV
Soft-Start Current	---	$V_{COMP} = 0V$, $V_{SS} = 0V$	---	6	---	uA
Soft-Start Period	---	$C_{SS} = 0.1\mu F$	---	15	---	ms
EN Shutdown Threshold Voltage	---	---	---	1.5	2	V
Thermal Shutdown Threshold ⁽⁴⁾	---	---	---	160	---	$^{\circ}C$

Notes(3):When $V_{IN} = 4.8V$, $V_{OUT} = 3.3V$, only load 1.2A.

Notes(4):Guaranteed by design..

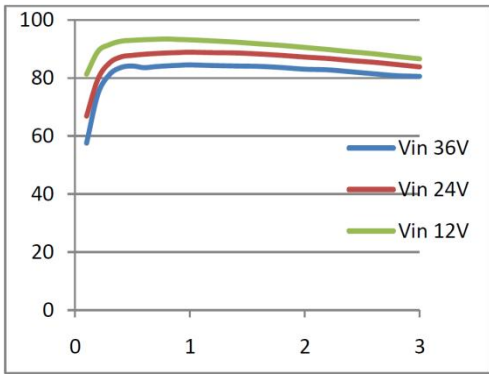


Typical Operating Characteristics:

C1 = 10uF , C2 = 22uF x 2, L1 = 10uH, C4 =NA, TA = +25°C , unless otherwise noted.

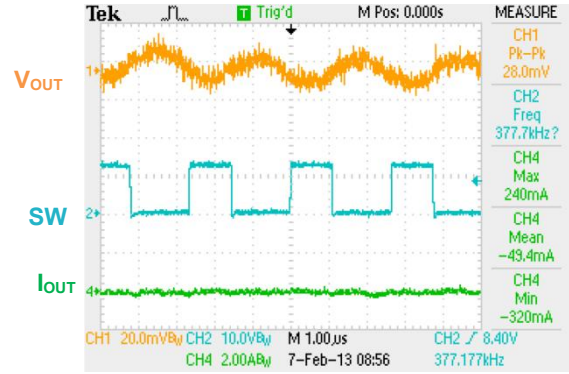
Efficiency Test

Vout=5V



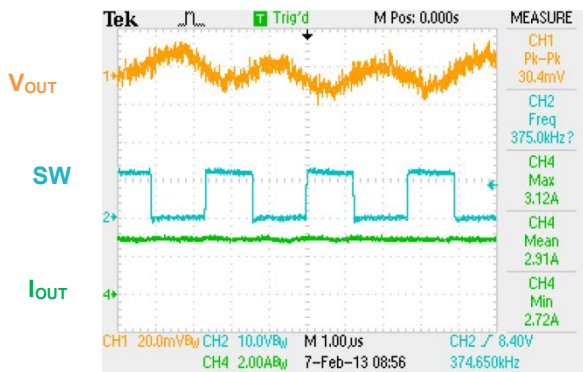
Steady State

Vin=12V, Vout=5V, Iout=0A



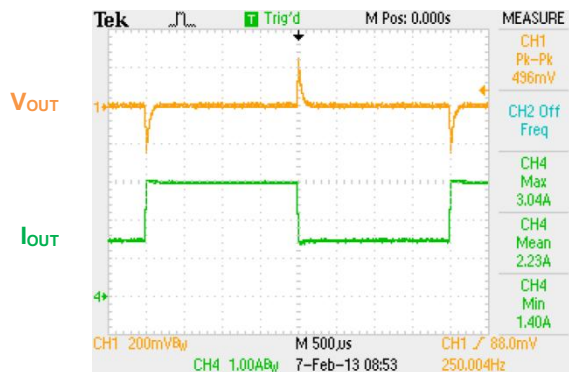
Steady State

Vin=12V, Vout=5V, Iout=3A



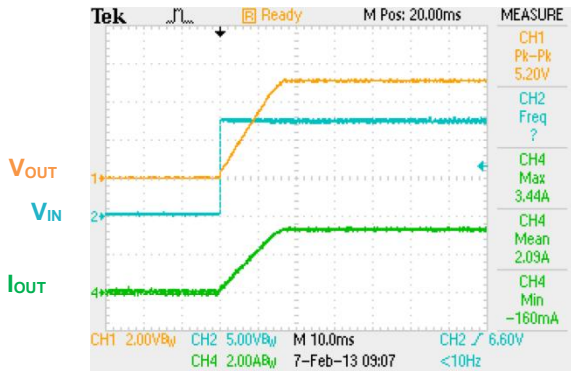
Dynamic Loading

Vin=12V, Vout=5V, Iout=1.5 to 3A



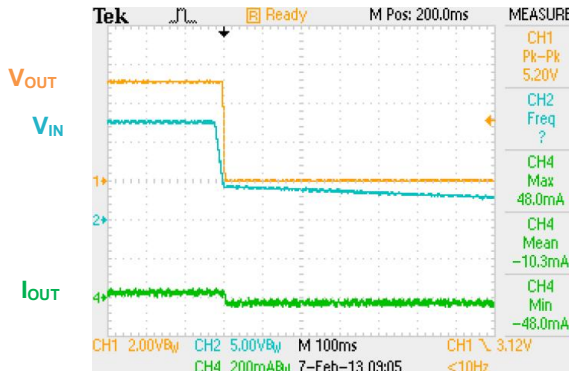
Power On

Vin=12V, Vout=5V, Iout=3A



Power Off

Vin=12V, Vout=5V, Iout=0.05A





Applications Information

Component Selection

Output Voltage Setting

The output voltage V_{out} is set using a resistive divider from the output to FB. The FB pin regulated voltage is 0.935V. Thus the output voltage is:

$$V_{out} = 0.935 * (1 + \frac{R1}{R2}) V$$

R2 recommended value is 10kΩ, so R1 is determined by:

$$R = 10.7 * (V_{out} - 0.935) K\Omega$$

Table1 lists recommended values of R1 and R2 for most used output voltage:

Vout	R1	R2
12V	46.2KΩ	3.9KΩ
5V	43.5K	10K
3.3V	40.5K	16K
2.5V	12.6K	7.5K
1.8V	11.1K	12K

Table1 Recommended Resistance Values

Place resistors R1 and R2 close to FB pin to prevent stray pickup.

Input Capacitor Selection

The use of the input capacitor is controlling the input voltage ripple and the MOSFETS switching spike voltage. Because the input current to the step-down converter is discontinuous, the input capacitor is required to supply the current to the converter to keep the DC input voltage. The capacitor voltage rating should be 1.25 times to 1.5 times greater than the maximum input voltage. The input capacitor ripple current RMS value is calculated as:

$$I_{IN(RMS)} = I_{out} * \sqrt{D * (1 - D)}$$

Where D is the duty cycle and the value is V_{OUT} / V_{IN} . A low ESR capacitor is required to keep the noise minimum. Ceramic capacitors are better, but tantalum or low ESR electrolytic capacitors may also suffice. When using tantalum or electrolytic capacitors, a 0.1uF ceramic capacitor should be placed as close to the IC as possible.

Output Capacitor Selection

The output capacitor is used to keep the DC output voltage

and supply the load transient current. Low ESR capacitors are preferred. Ceramic, tantalum or low ESR electrolytic capacitors can be used, depends on the output ripple requirement. Add a 100uF or 470uF low ESR electrolytic capacitor when operated in high input voltage range ($V_{IN} > 20V$). It can improve the device's stability. The output ripple voltage ΔV_{OUT} is described as:

$$\Delta V_{out} = \frac{V_{out}}{f_s * L} * (1 - \frac{V_{out}}{V_{in}}) * (R_{ESR} + \frac{1}{8 * f_s * C_2})$$

Where f_s is the switching frequency, L is the inductance value, V_{IN} is the input voltage, V_{OUT} is the output voltage, R_{ESR} is the equivalent series resistance value of the output capacitor, and the C_2 is the output capacitor. When using the ceramic capacitors, the R_{ESR} can be ignored and the output ripple voltage ΔV_{out} is shown as:

$$\Delta V_{out} = \frac{V_{out}}{8 * f_s^2 * L * C_2} * (1 - \frac{V_{out}}{V_{in}})$$

When using tantalum or electrolytic capacitors, typically 90% of the output voltage ripple is contributed by the ESR of output capacitors. the output ripple voltage ΔV_{out} can be estimated as

$$\Delta V_{out} = \frac{V_{out}}{f_s * L} * (1 - \frac{V_{out}}{V_{in}}) * R_{ESR}$$

The characteristics of the output capacitor also affect the stability of the regulation system. The TX9402 can be optimized for a wide range of capacitance and ESR values.

Inductor

The output inductor is used for store energy and filter output ripple current. A large value inductor will result in less ripple current and lower output ripple voltage. But the trade-off condition often happens between maximum energy storage and the physical size of the inductor. The first consideration for selecting the output inductor is to make sure that the inductance is large enough to keep the converter in the continuous current mode. That will lower ripple current and results in lower output ripple voltage. A good rule for determining the inductance is set the peak-to-peak inductor ripple current ΔI almost equal to 30% of the maximum load current. Then the minimum inductance can be calculated with the following equation:



$$L \geq \frac{V_{out}}{f_s \cdot \Delta I} * \left(1 - \frac{V_{out}}{V_{in}}\right)$$

$$\Delta I = 0.3 * I_{LOAD(MAX)}$$

Where V_{IN} is the input voltage, f_s is the switching frequency, ΔI is the peak-to-peak inductor ripple current and $I_{LOAD(MAX)}$ is the maximum load current.

Choose an inductor that will cause the peak inductor current satisfying the equation:

$$I_{LP} = I_{LOAD(MAX)} + \frac{V_{out}}{2 * f_s * L} * \left(1 - \frac{V_{out}}{V_{in}}\right) I_{LIMIT}$$

Where I_{LIMIT} is the high-side MOSFET current limit value.

Optional Schottky Diode

During the transition between switching MOSFETs, the body diode of the low-side MOSFET conducts the inductor current. The forward voltage of this body diode is large. An optional Schottky diode may be connected between SW pin and GND pin to improve overall efficiency.

Compensation Components

The system stability and transient response are controlled through the COMP pin. Selecting the appropriate compensation value by the following procedure:

1. Calculate the R3 value with the following equation:

$$R3 < \frac{2\pi * C2 * f_s * V_{out}}{10 * G_{EA} * G_{CS} * V_{FB}}$$

Where G_{EA} is the error amplifier transconductance, and G_{CS} is the current sense transconductance.

2. Calculate the C3 value with the following equation:

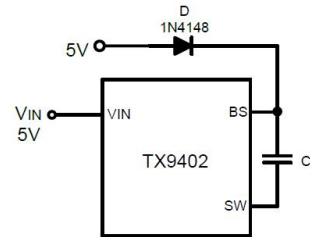
$$C3 > \frac{4 * 10}{2\pi * R3 * f_s}$$

3. If the C2 ESR zero is less than half of the switching frequency, use C6 to cancel the ESR zero:

$$C6 = \frac{C2 * RESR}{R3}$$

External Boost Diode Selection

For input voltage lower than 5.5V or duty cycle larger than 65% applications, it is recommended that an external boost diode be added. This helps improve the efficiency. The boost diode can be a low cost one such as 1N4148.



PCB Layout Recommendation

The device's performance and stability is dramatically affected by PCB layout. It is recommended to follow these general guidelines show bellow:

1. Place the input capacitors, output capacitors as close to the device as possible. Trace to these capacitors should be as short and wide as possible to minimize parasitic inductance and resistance.
2. Place V_{IN} bypass capacitors close to the V_{IN} pin.
3. Place feedback resistors close to the FB pin.
4. Place compensation components close to the COMP pin.
5. Keep the sensitive signal (FB, COMP) away from the switching signal (SW).
6. The exposed pad of the package should be soldered to an equivalent area of metal on the PCB. This area should connect to the GND plane and have multiple via connections to the back of the PCB as well as connections to intermediate PCB layers. The GND plane area connects to the exposed pad should be maximized to improve thermal performance.
7. Multi-layer PCB design is recommended.



Typical Application Circuit

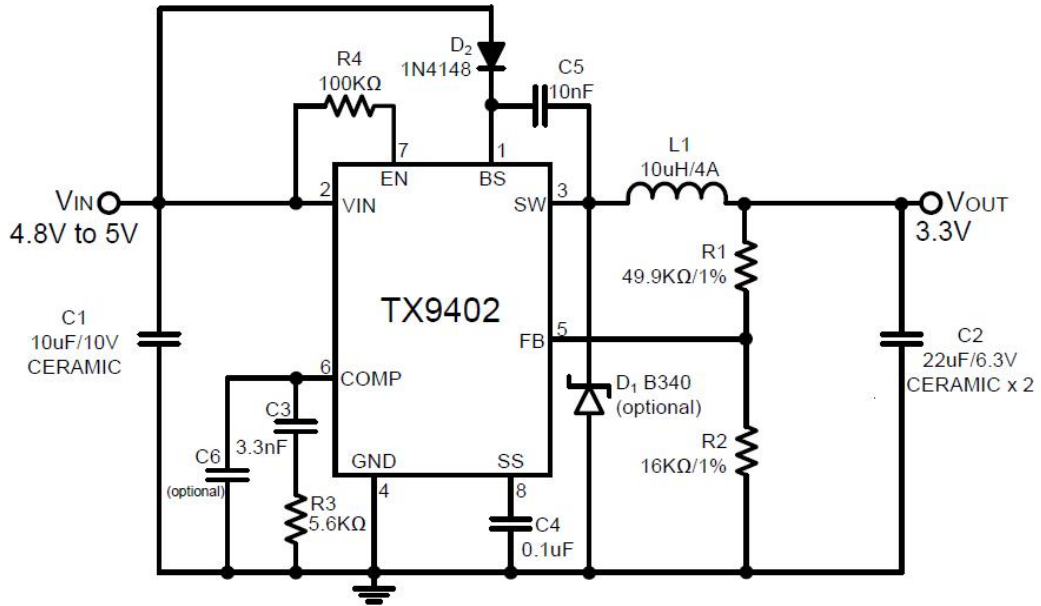
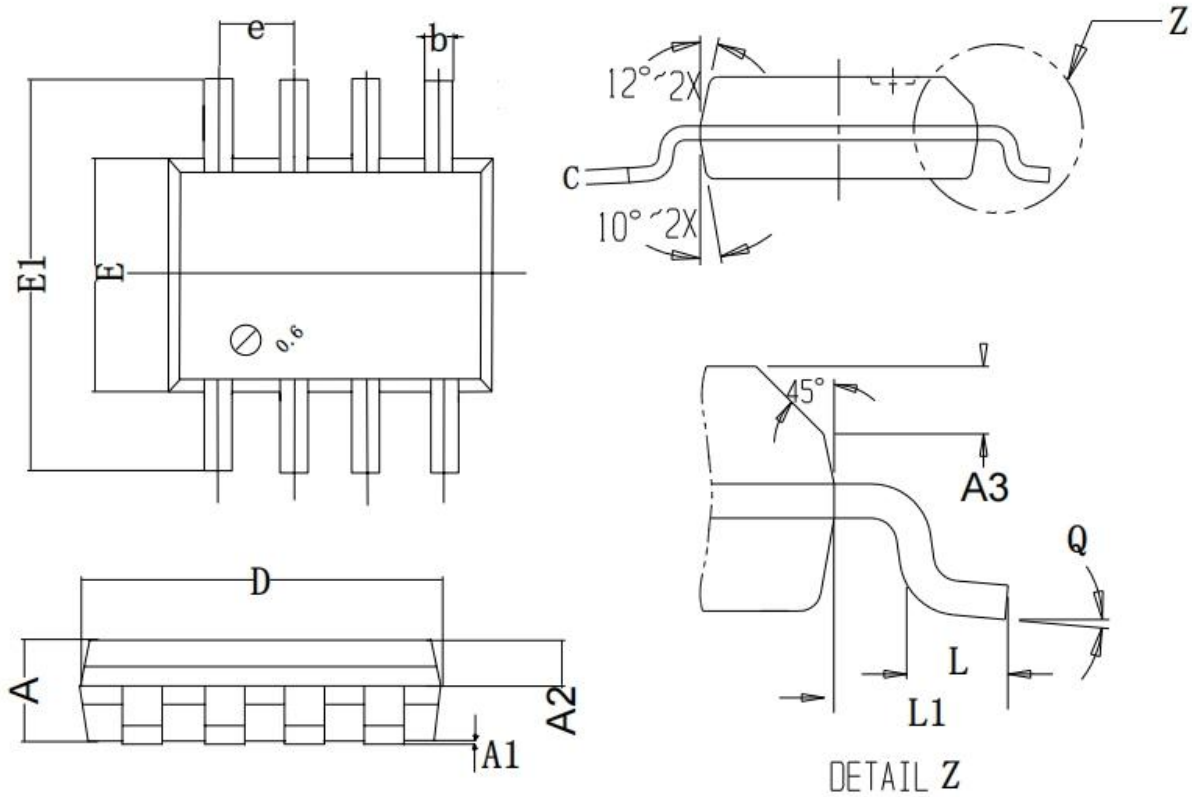


Figure 2 Low Input Voltage Application Circuit



ESOP8 PACKAGE INFORMATION



COMMON DIMENSIONS			
UNITS MEASURE=MILLIMETER			
SYMBOL	MIN	MID	MAX
A	1.35	1.45	1.55
A1	0.00	0.05	0.10
A2	0.65	0.70	0.75
A3	0.35	0.40	0.45
b	0.35	0.40	0.45
c	0.18	0.20	0.22
D	4.70	4.90	5.10
e	-	1.27TYP	-
E1	5.80	6.10	6.20
E	3.80	3.90	4.00
L	0.40	0.60	0.80
Q	0°	/	8°
M	3.10	3.20	3.30
N	2.20	2.30	2.40
L1	1.05REF		



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