

# 60V, 3A Asynchronous Step-Down DC/DC Converter

## Features

- Wide input voltage: 6V-60V
- Up to 3A Output Current
- Low Typical 7.5 $\mu$ A Shutdown Current
- Adjustable Soft-Start Time
- Adjustable Switching Frequency from 250 kHz to 2.3MHz
- Stable with Low ESR Ceramic Output
- Peak Current Mode with Internal Compensation
- PFM in Light Load Condition
- 0.8V Voltage Reference with  $\pm 1.5\%$  Accuracy
- Thermal Shutdown
- Cycle-by-cycle Current Limit Protection
- Over Current Protection with Hiccup Mode
- ESOP8 Package

## Application

- Smart Home Applications
- Power over Ethernet Applications
- Telecom and Datacom Systems
- General 12V, 24V and 48V Power Systems

## Description

TMI36030 and TMI36031 are wide input voltage of 6V to 60V, high efficiency current mode, asynchronous step-down DC/DC converter capable of delivering up to 3A current. TMI36030 and TMI36031 adopt peak current control mode and has internal compensation to simplify application design. This also could minimize the external components in application. A wide adjustable switching frequency range allows either efficiency or external component size to be optimized.

TMI36030 and TMI36031 integrate 95m $\Omega$  high-side MOSFET and achieve high efficiency over the wide input voltage range. TMI36030 and TMI36031 have advanced features include UVLO, Thermal Shutdown, Soft Start. TMI36030 has adjustable soft start time function and TMI36031 has power good indicator function for different application selection.

TMI36030 and TMI36031 are available ESOP8 package.

## Typical Application

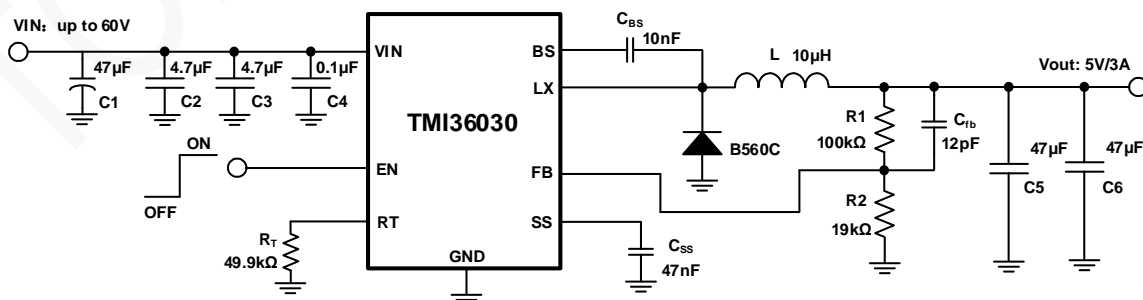
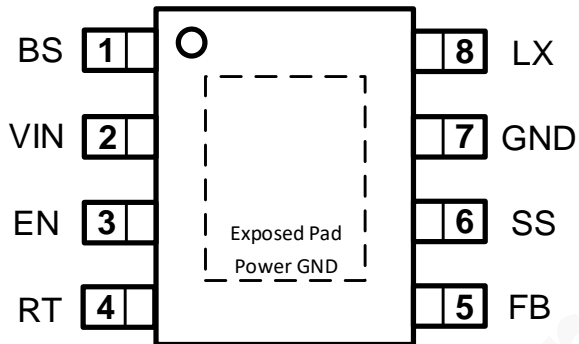


Figure 1. TMI36030 Typical Application Circuit

## Absolute Maximum Ratings (Note 1)

Parameter	Min	Max	Unit
Input Supply Voltage, EN	-0.3	65	V
BS to LX Voltage	-0.3	6	V
PG, SS, RT, FB Voltage	-0.3	6	V
LX Voltage	-0.6	65	V
LX Voltages (<10ns transient)	-3	70	V
Storage Temperature Range	-65	150	°C
Junction Temperature (Note2)	-40	150	°C
Power Dissipation	-	1.5	W
Lead Temperature (Soldering, 10s)	-	260	°C

## Package

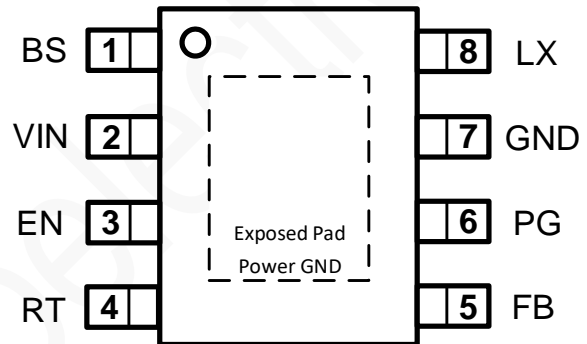


**TMI36030**

Top Mark: T36030/XXXXX

Device code: T36030

Inside code: XXXXX



**TMI36031**

Top Mark: T36031/XXXXX

Device code: T36031

Inside code: XXXXX

## Order Information

Part Number	Package	Top Marking	Quantity/Reel
TMI36030	ESOP8	T36030 XXXXX	3000
TMI36031	ESOP8	T36031 XXXXX	3000

TMI36030 and TMI36031 devices are Pb-free and RoHS compliant.

## Pin Functions

Pin	Name	Function
1	BS	Bootstrap capacitor connection for high-side MOSFET driver. Connect a high quality 0.1 $\mu$ F capacitor from BS to LX.
2	VIN	Connect to power supply and bypass capacitors C <sub>IN</sub> . Path from VIN pin to high frequency bypass C <sub>IN</sub> and GND must be as short as possible.
3	EN	Enable pin, with internal pull-up current source. Pull low to disable. Float or connect to VIN to enable.
4	RT	Resistor Timing input. An internal amplifier holds this pin at a fixed voltage when using an external resistor to ground to set the switching frequency.
5	FB	Feedback input pin, connect to the feedback divider to set VOUT.
6	SS (TMI36030)	SS pin for soft-start of TMI36030, connect to a capacitor to set soft-start time.
	PG (TMI36031)	Power Good indicator pin of TMI36031. Open drain output for power-good flag, use a 10k $\Omega$ to 100k $\Omega$ pull-up resistor to logic rail or other DC voltage no higher than 6V.
7	GND	System ground pin.
8	LX	Switching output of the regulator. Internally connected to high-side power MOSFET. Connect to power inductor.
9	Thermal Pad	Major heat dissipation path of the die. Must be connected to ground plane on PCB.

## ESD Rating (Note4)

Items	Description	Value	Unit
V <sub>ESD_HBM</sub>	Human Body Model for all pins	$\pm 2000$	V
V <sub>ESD_CDM</sub>	Charged Device Model for all pins	$\pm 500$	V

JEDEC specification JS-001

## Recommended Operating Conditions

Items	Description	Min	Max	Unit
Voltage Range	IN	6	60	V
T <sub>J</sub>	Operating Junction Temperature	-40	125	°C
T <sub>A</sub>	Operating Ambient Temperature	-40	85	°C

## Thermal Resistance (Note3)

Items	Description	Value	Unit
$\theta_{JA}$	Junction-to-ambient thermal resistance	45	°C/W
$\theta_{JC}$	Junction-to-case(top) thermal resistance	55	°C/W
$\psi_{JC}$	Junction-to-case(top) characterization parameter	10	°C/W

## Electrical Characteristics

**V<sub>IN</sub>=48V, V<sub>OUT</sub>=5V, T<sub>A</sub> = 25°C, unless otherwise noted.**

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Voltage Range	V <sub>IN</sub>		6		60	V
Under Voltage Lockout	V <sub>UVLO</sub>	V <sub>IN</sub> rising		5.7		V
UVLO Hysteresis	V <sub>UVLO_HY</sub>			0.18		V
Input Quiescent Current	I <sub>Q</sub>	V <sub>FB</sub> =1V, V <sub>EN</sub> =1.5V		380		μA
Shutdown Current	I <sub>SD</sub>	V <sub>EN</sub> = 0V		7.5		μA
Feedback Threshold Voltage	V <sub>FB</sub>	T <sub>J</sub> = 25 °C	0.784	0.8	0.816	V
FB Pin input current	I <sub>FB</sub>		-50		50	nA
EN Rising Threshold	V <sub>EN_R</sub>		1.05	1.2		V
EN Shutdown Threshold	V <sub>EN_SD</sub>			0.65		V
EN Pull-up Current Source	I <sub>EN</sub>			1.2		μA
EN Pull-up Hysteresis Current Source	I <sub>EN_Hys</sub>			3.5		μA
Soft start Time	t <sub>SS</sub>	TMI36031		0.8		ms
Soft start Current	I <sub>SS</sub>	TMI36030		3		μA
Current limit cycle-by-cycle	I <sub>LIM_MAX</sub>			6.5		A
LX leakage	I <sub>LX_LEAK</sub>				1	μA
Switch On-Resistance (high side)	R <sub>DSONH</sub>			95		mΩ
Power-good flag under voltage tripping threshold	V <sub>PG_UVLO</sub>	POWER GOOD (% of FB voltage)		94		%
		POWER BAD (% of FB voltage)		92		%
Power-good flag over voltage tripping threshold	V <sub>PG_OVP</sub>	POWER BAD (% of FB voltage)		109		%
		POWER GOOD (% of FB voltage)		107		%
Power-good flag recovery hysteresis	V <sub>PG_HYS</sub>	% of FB voltage		2		%
PG leakage current at high level output	I <sub>PG</sub>	V <sub>Pull-Up</sub> = 5 V		10		nA
PG low level output voltage	V <sub>PG_LOW</sub>	I <sub>Pull-Up</sub> = 1 mA		0.1		V
Switching Frequency	f <sub>SW1</sub>	RT=50kΩ		500		kHz
	f <sub>SW</sub>	Set by RT resistor	250		2300	kHz
Minimum Turn-on Time (Note 4)	t <sub>ON_MIN</sub>			120		ns
Thermal Shutdown Threshold (Note 4)	T <sub>SDN</sub>			160		°C
Thermal Shutdown Hysteresis (Note 4)	T <sub>SDN_HY</sub>			20		°C

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** T<sub>J</sub> is calculated from the ambient temperature T<sub>A</sub> and power dissipation P<sub>D</sub> according to the following formula: T<sub>J</sub> = T<sub>A</sub> + (P<sub>D</sub>) x θ<sub>JA</sub>.

**Note 3:** EN external resistor divide requirement is described in below Enable and Disable section.

**Note 4:** Guaranteed by design.

## Block Diagram

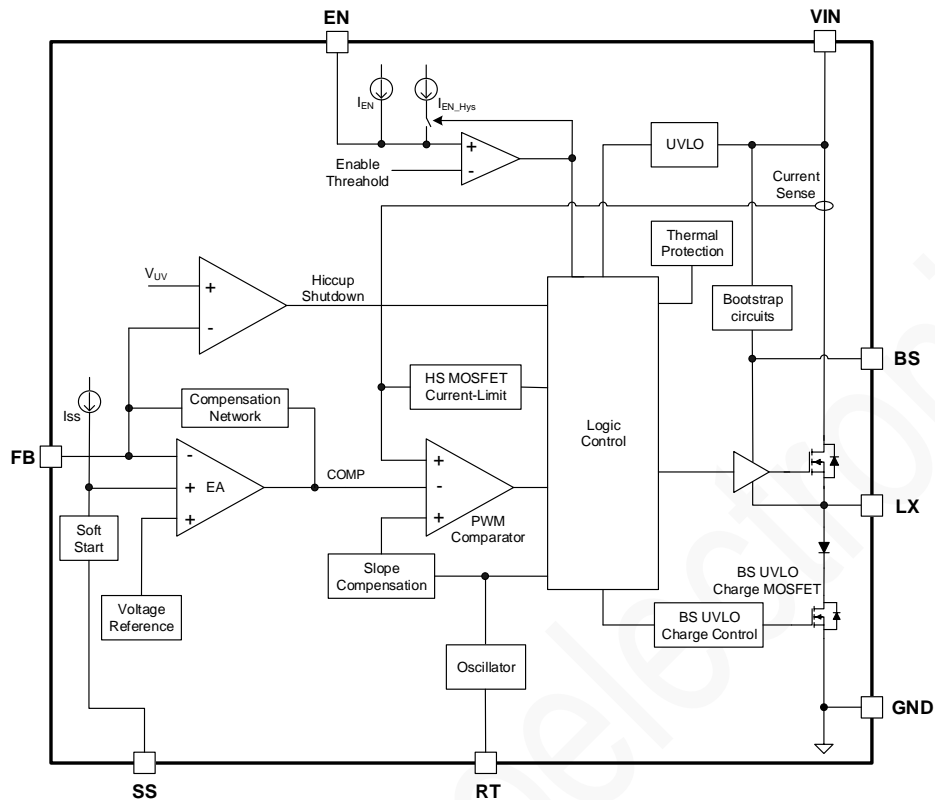


Figure 2. TMI36030 Block Diagram

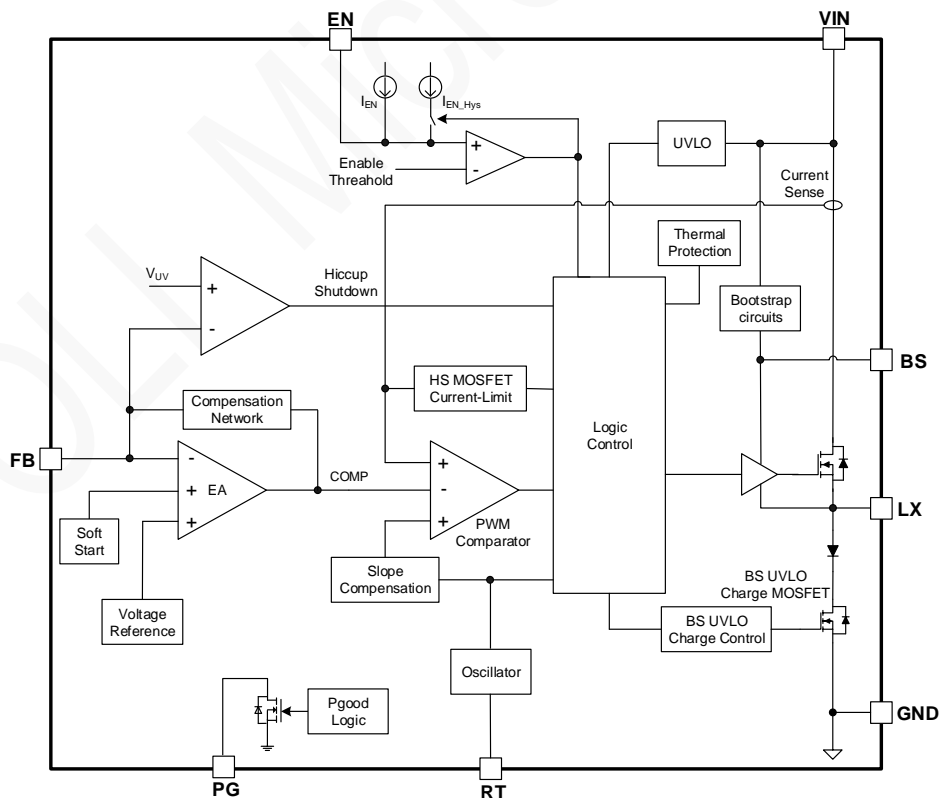


Figure 3. TMI36031 Block Diagram

## Operation Description

### Overview

As seen in Functional Block Diagram, the TMI36030 and TMI36031 are peak current mode pulse width modulation (PWM) non-synchronous converter with adjustable switching frequency from 250 kHz to 2.3MHz.

A switching cycle starts when the rising edge of the oscillator clock output causes the High-Side Power Switch to turn on. With the LX side of the inductor now connected to VIN, the inductor current ramps up to store energy in the magnetic field. The inductor current level is measured by the current sense amplifier and added to the oscillator ramp signal. If the resulting summation is higher than the COMP voltage, the output of the PWM comparator goes high. When this happens or when oscillator clock output goes low, the High-side power switch turns off.

At this point, the LX side of the inductor swings to a diode voltage below ground, causing the inductor current to decrease and magnetic energy to be transferred to output. This state continues until the cycle starts again. The high-side power switch is driven by logic using BS as the positive rail. This pin is charged to  $V_{LX} + 5V$  when the high-side power switch turns off. The COMP voltage is the integration of the error between FB input and the internal 0.8V reference. If  $V_{FB}$  is lower than the reference voltage, COMP tends to go higher to increase inductor current to the output side and try to increase output voltage.

In light or no load condition, TMI36030 and TMI36031 are operating in PFM mode for power saving. In PFM mode, the device ramps up its output voltage with one or several LX switching pulse, while the error amplifier output voltage  $V_{COMP}$  drops. The device stops switching when  $V_{COMP}$  voltage drops down the inner threshold, then the output voltage falls down and  $V_{COMP}$  voltage rises until  $V_{COMP}$  voltage is high enough to generate LX switching pulse.

### Input Under Voltage Lockout

TMI36030 and TMI36031 implement input under voltage lockout function to avoid mis-operation at low input voltages. When the input voltage is lower than input UVLO threshold with UVLO hysteresis, the device is shut down. The typical 180mV input UVLO hysteresis value of TMI36030 and TMI36031 are useful to prevent device from abnormal switching caused by input voltage oscillation around UVLO threshold during input voltage power-up and power-down with high load condition.

### Over-Current-Protection and Short Circuits Protection

The TMI36030 and TMI36031 have cycle-by-cycle peak current limit function. The periodic current limit of the high side MOSFET can protect this device in case of overload.

If the output is short to GND and the output voltage drop, the switching frequency is reduced according to feedback voltage VFB to reduce thermal consumption. The figure 4 shows the relationship of feedback voltage and switching frequency. If the feedback voltage is below the output under-voltage VUV threshold which is typically 50% of  $V_{REF}$ , TMI36030 and TMI36031 enter into hiccup mode to periodically disable and restart switching operation. The hiccup mode helps to reduce power dissipation and thermal rise during output short condition. The period of TMI36031 hiccup mode is typically 1.5ms.

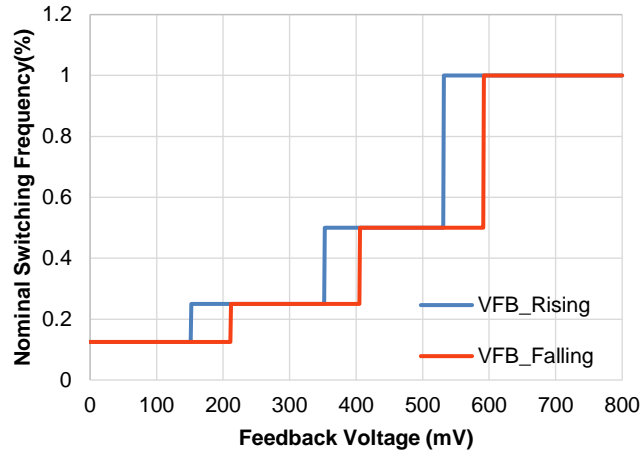


Figure 4. Feedback voltage vs. switching frequency

### Enable Control, Standby and Shutdown Mode

TMI36030 and TMI36031 have two EN threshold  $V_{EN\_R}$  and  $V_{EN\_R}$  internally. The TMI36030 and TMI36031 are enabled and in switching operation when the VIN pin voltage rises above 5.7V (typical) and the EN pin voltage exceeds the enable threshold  $V_{EN\_R}$  (typical 1.2V). The TMI36030 and TMI36031 are in standby mode and stops switching operation when the VIN pin voltage falls below 5.5V (typical) or when the EN pin voltage is below EN threshold. Two current source  $I_{EN}$  and  $I_{EN\_Hys}$  are used for EN hysteresis voltage setting with external EN divider resistors  $R_{EN1}$  and  $R_{EN2}$ . When EN terminal voltage exceeds  $V_{EN\_R}$ , an additional hysteresis current (typically  $I_{EN\_Hys} = 3.5\mu A$ ) is sourced out of EN terminal. When the EN terminal is pulled below  $V_{EN\_R}$ ,  $I_{EN\_Hys}$  current is removed. This additional current facilitates adjustable input voltage UVLO hysteresis.  $I_{EN} = 1.2\mu A$  and  $I_{EN\_Hys} = 3.5\mu A$  typically. We can refer to the following equation to set the expected  $V_{IN\_Open}$  and  $V_{IN\_Close}$  voltages by selecting the appropriate divider resistance in the EN Pin of  $R_{EN1}$  and  $R_{EN2}$ . In order to improve the anti-interference performance of the converter application, it is recommended to set the divider resistance of  $R_{EN1}$  to 1M $\Omega$  for enough control hysteresis.

In standby mode, the TMI36030 and TMI36031 stop switching operation and the internal regulators are active. When EN terminal voltage is down below  $V_{EN\_R}$  0.65V typically, the device is in shutdown mode where almost circuits of TMI36030 and TMI36031 are disabled.

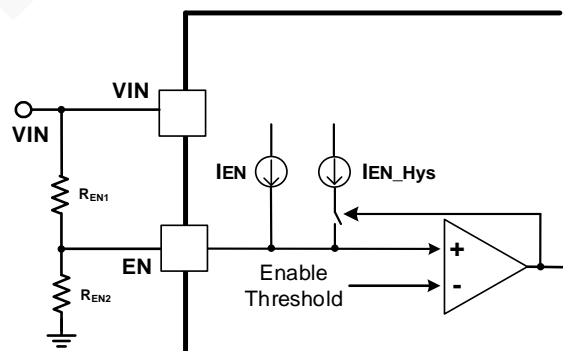


Figure 5. EN pin external connection

$$V_{IN\_Open} = V_{EN\_R} + \left( \frac{V_{EN\_R}}{R_{EN2}} - I_{EN} \right) \times R_{EN1}$$

$$V_{IN\_Close} = V_{IN\_Open} - I_{EN\_Hys} \times R_{EN1}$$



## Thermal Shutdown

The TMI36030 and TMI36031 disable switching when its junction temperature exceeds 160°C typically. Once the device junction temperature falls below the threshold with hysteresis, TMI36030 and TMI36031 returns to normal operation automatically.

## Power Good (PG) for TMI36031

The TMI36031 has a built-in power-good flag shown on PG pin to indicate whether the output voltage is within its regulation level. The PG signal can be used for start-up sequencing of multiple rails or fault protection. The PG pin is an open-drain output that requires a pull-up resistor to an appropriate DC voltage. Voltage seen by the PG pin should never exceed 6V. A resistor divider pair can be used to divide the voltage down from a higher potential. A typical range of pull-up resistor value is 10kΩ to 100kΩ.

Refer to Figure 6, when the FB voltage is within the power-good band, +7% above and -6% below the internal reference VREF typically, the PG switch will be turned off and the PG voltage will be pulled up to the voltage level defined by the pull-up resistor or divider. When the FB voltage is outside of the tolerance band, +9% above or -8% below VREF typically, the PG switch will be turned on and the PG pin voltage will be pulled low to indicate power bad.

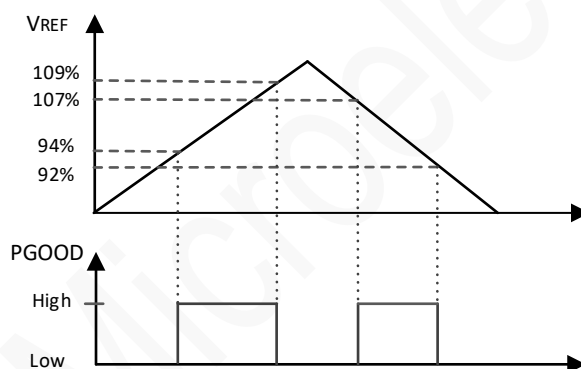


Figure 6. Power-Good Flag for TMI36031

## APPLICATION INFORMATION

### Output Voltage Setting

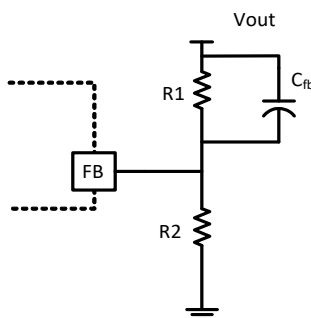


Figure 7. Output Voltage Setting

Figure 7 shows the connections for setting the output voltage. Select the proper ratio of the two feedback resistors R1 and R2 based on the output voltage. Adding a capacitor in parallel with R1 helps the system



stability. TMI36030 AND TMI36031 is peak current mode with OPA type error amplifier and upper feedback resistor affects control loop gain value. Typically, use  $R1=100k\Omega$  and determine  $R2$  from the following equation:

$$R2=R1 \times \left( \frac{V_{REF}}{V_{OUT} - V_{REF}} \right)$$

### Soft-Start Time Setting for TMI36030

The TMI36030 device use the SS pin voltage as the reference voltage and regulates the output accordingly. A capacitor on the SS pin to ground implements a soft-start time. The device has an internal pull-up current source of  $3\mu A$  that charges the external soft-start capacitor. Use following equation to calculate the soft time ( $t_{SS}$ , 10% to 90%) and soft capacitor ( $C_{SS}$ ).

$$t_{SS}(ms) = \frac{C_{SS}(nF) \times V_{REF}(V)}{I_{SS}}$$

Where:

$V_{REF}$  is the voltage reference (0.8V)

$I_{SS}$  is the soft-start charge current ( $3\mu A$ )

For TMI36031 device, the soft start time is fixed 0.8ms typically.

### Switching Frequency (RT)

The switching frequency of the TMI36030 and TMI36031 can be programmed by the resistor  $R_T$  from the  $R_T$  pin and GND pin. The  $R_T$  pin can't be left floating or shorted to ground. To determine the timing resistance for a given switching frequency, use Equation or the curve in Figure 8. Table 1 gives typical  $R_T$  values for a given  $f_{sw}$ .

$$R_T(k\Omega) = 42904 \times f_{sw}(kHz)^{-1.088}$$

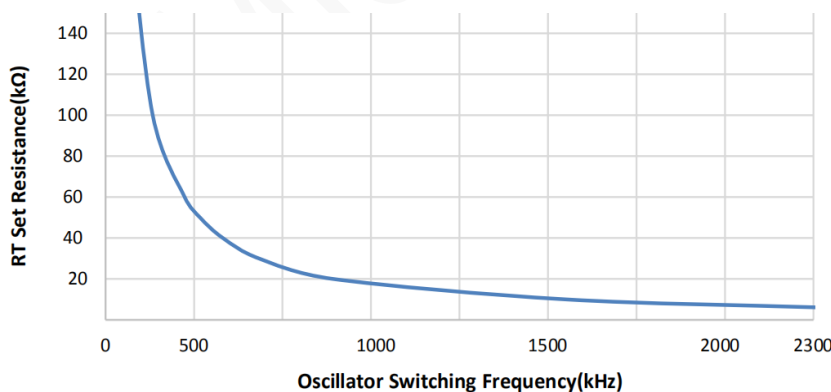


Figure 8.  $R_T$  vs. Frequency Curve

### Low Dropout Operation and Bootstrap Voltage (BS)

The TMI36030 and TMI36031 provides an integrated bootstrap voltage regulator. A small capacitor between the BS and LX pins provides the gate drive voltage for the high-side MOSFET. The BS capacitor is refreshed when the high-side MOSFET is off and the external low side diode conducts. TMI36030 and TMI36031 has BS under voltage protection. In light load condition or maximum duty operation, if the voltage between BS to LX drops down below 3V, the BS UV charge MOSFET is turned on during 100ns

to charge BS capacitor voltage. The BS capacitor value affects BS UV occurrence frequency. The recommended value of the BS capacitor is 10nF. A ceramic capacitor with an X7R or X5R grade dielectric with a voltage rating of 16 V or greater is recommended for stable performance over temperature and voltage.

### Inductor Selection

Inductance value is related to inductor ripple current value, input voltage, output voltage setting and switching frequency. The inductor value can be derived from the following equation:

$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times \Delta I_L \times f_{SW}}$$

Where  $\Delta I_L$  is inductor ripple current. Large value inductors result in lower ripple current and small value inductors result in high ripple current, so inductor value has effect on output voltage ripple value, however large value inductor have large size and is more expensive. DC resistance of inductor which has impact on efficiency of DC/DC converter should be taken into account when selecting the inductor.

The saturation current rating of the inductor should be considered. The saturation current must be larger than peak inductor current with maximum load conditions in all operation conditions, for example, maximum load transient condition. The peak inductor current value can be calculated according to the following equation. Meanwhile, if the system has output short condition, the saturation current of inductor should cover peak current limit value of the device.

$$I_{L\_peak} = I_{OUT\_MAX} + \frac{1}{2} \times \Delta I_L = I_{OUT\_MAX} + \frac{V_{OUT} \times (V_{IN\_MAX} - V_{OUT})}{2 \times V_{IN\_MAX} \times L \times f_{SW}}$$

### Input Capacitor Selection

Since the input current of the Buck converter is discontinuous, the input capacitor is needed to supply the AC current while maintaining the DC input voltage. The input capacitor impedance at the switching frequency should be less than input source impedance to prevent high frequency switching current passing to the input. A low ESR input capacitor sized for maximum RMS current must be used. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients. The voltage rating should be greater than the maximum input voltage plus input voltage ripple. A one 4.7μF to 10μF effective capacitance value ceramic capacitors for most applications is sufficient. A large value may be used for improved input voltage filtering. Additionally, a small 0.1μF ceramic capacitor located close on input pin and GND pad is help for high frequency filter.

### Output Capacitor Selection

The output capacitor is required to keep the output voltage ripple small in steady status and load transient condition, and to ensure regulation loop stability. The output ripple  $\Delta V_{OUT}$  is determined by:

$$\Delta V_{OUT} \approx \Delta I_L \times \left( ESR + \frac{1}{8 \times f_{SW} \times C_{OUT}} \right) = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{2 \times V_{IN} \times L \times f_{SW}} \times \left( R_{ESR} + \frac{1}{8 \times f_{SW} \times C_{OUT}} \right)$$

Where  $R_{ESR}$  is the equivalent series resistance value of output capacitor. As shown in above equation, the smaller ESR value and larger capacitance value of output capacitors, the smaller output voltage ripple. If ceramic capacitors are used as output capacitors, the output ripple is mainly depended on output capacitance value since the ceramic capacitors have low ESR value. If tantalum or electrolytic capacitors

are used as output capacitors,  $R_{ESR}$  dominates the output ripple value since the electrolytic capacitors have significantly higher ESR value. The TMI36030 and TMI36031 can be optimized for a wide range of output capacitance and ESR values.

### Schottky Diode Selection

The current rating of Schottky diode should be equal to the maximum output current for best reliability in most applications. The forward voltage of Schottky diode should be considered and the maximum forward voltage of Schottky diode should be smaller than 0.6V.

### PC Board Layout Guidance

When laying out the printed circuit board, the following checklist should be used to ensure proper operation of the IC.

- 1) Arrange the power components to reduce the AC loop size consisting of CIN, IN pin and LX pin.
- 2) Place input decoupling ceramic capacitor CIN as close to IN pin as possible. CIN is connected power GND with vias or short and wide path.
- 3) Return FB, SS and RT to signal GND pin, and connect the signal GND to power GND at a single point for best noise immunity. Connect exposed pad to power ground copper area with copper and vias.
- 4) Use copper plane for power GND for best heat dissipation and noise immunity.
- 5) Place feedback resistor close to FB pin.
- 6) Use short trace connecting BS- $C_{BS}$ -LX loop

## Typical Application Circuits

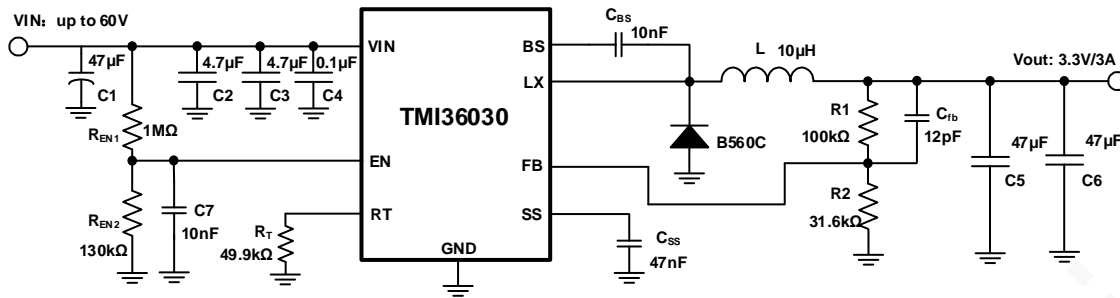


Figure 9. 3.3V Output ( $V_{FB}=0.8V$ )

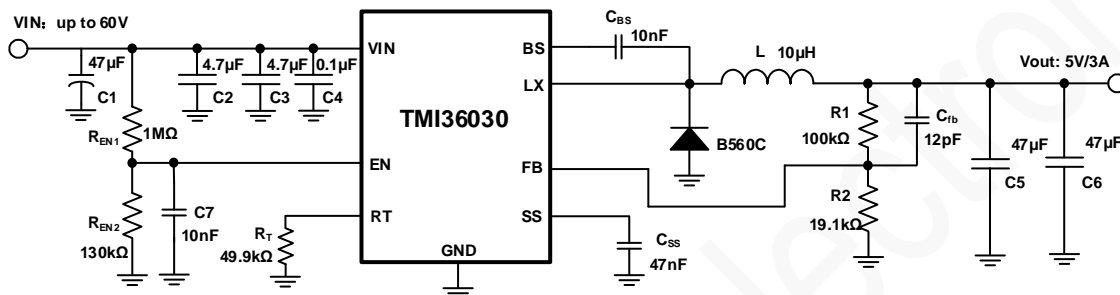


Figure 10. 5V Output ( $V_{FB}=0.8V$ )

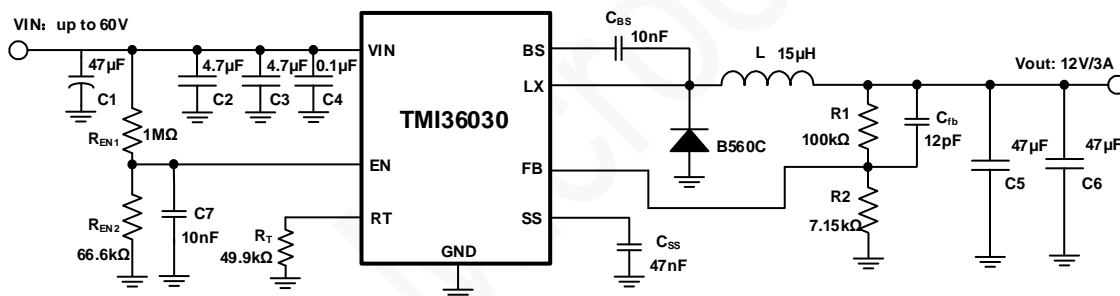
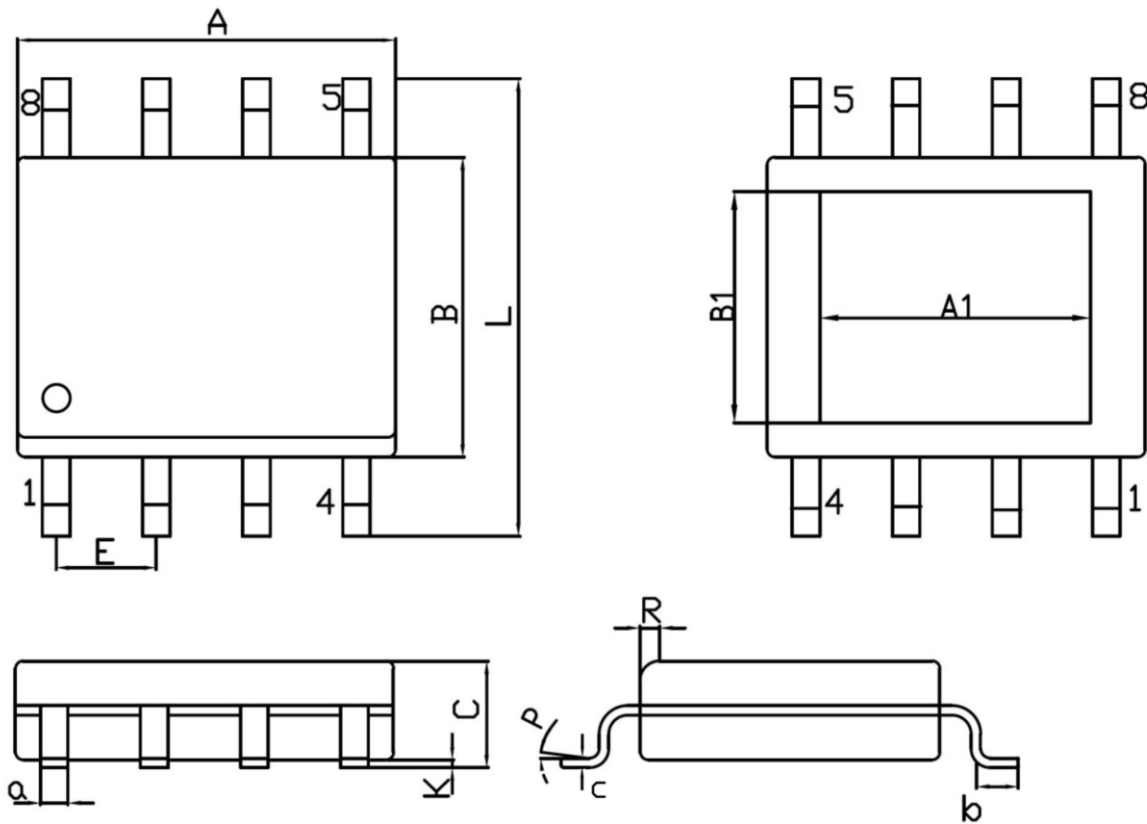


Figure 11. 12V Output ( $V_{FB}=0.8V$ )

## Package Information

### ESOP8



Unit: mm

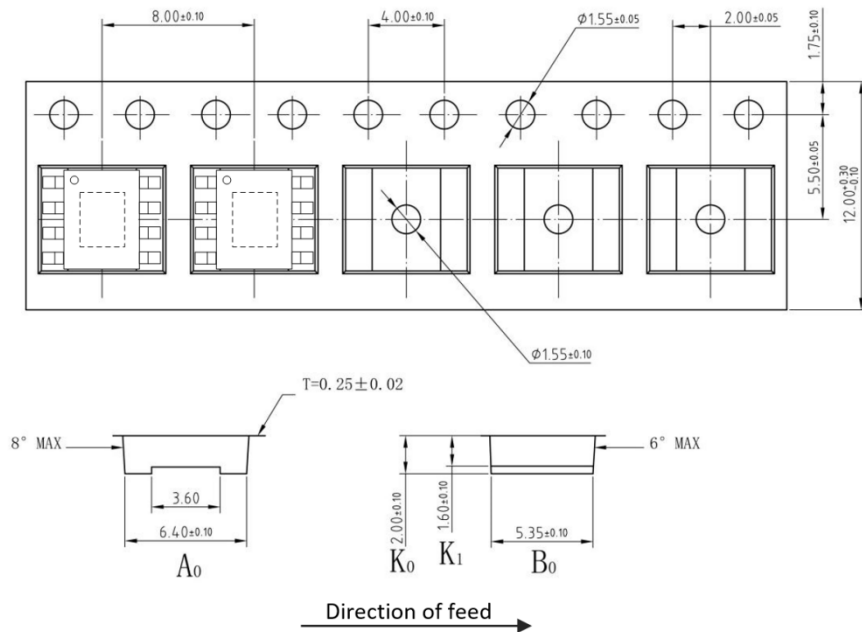
Symbol	Dimensions In Millimeters		Symbol	Dimensions In Millimeters	
	Min	Max		Min	Max
A	4.70	5.10	C	1.35	1.75
B	3.70	4.10	a	0.35	0.49
L	5.80	6.40	R	0.30	0.60
E	1.27 BSC		P	0°	7°
K	0.02	0.15	b	0.40	1.25
A1	3.1	3.5	B1	2.2	2.6
			c	0.203	0.243

#### Note:

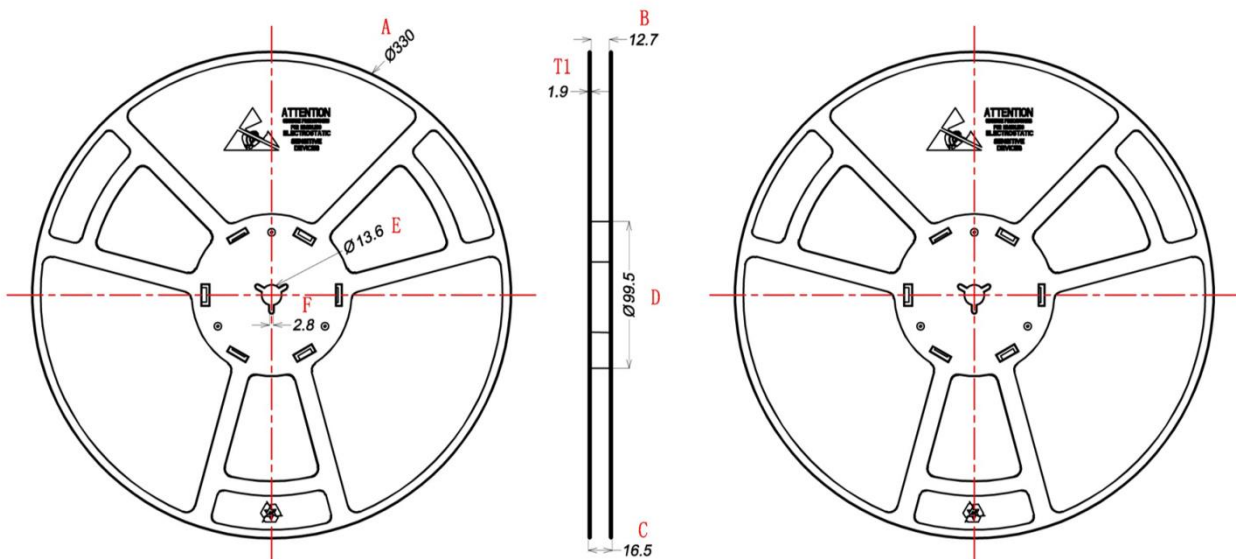
- 1) All dimensions are in millimeters.
- 2) Package length does not include mold flash, protrusion or gate burr.
- 3) Package width does not include inter lead flash or protrusion.
- 4) Lead popularity (bottom of leads after forming) shall be 0.10 millimeters max.
- 5) Pin 1 is lower left pin when reading top mark from left to right.

## Tape And Reel Information

### TAPE DIMENSIONS:



### REEL DIMENSIONS:



Unit: mm

A	B	C	D	E	F	T1
$\phi 330 \pm 1$	$12.7 \pm 0.5$	$16.5 \pm 0.3$	$\phi 99.5 \pm 0.5$	$\phi 13.6 \pm 0.2$	$2.8 \pm 0.2$	$1.9 \pm 0.2$

#### Note:

- 1) All Dimensions are in Millimeter
- 2) Quantity of Units per Reel is 3000
- 3) MSL level is level 3.

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