

36V, 3A Synchronous Step-Down Regulator

FEATURES

Wide Input Voltage Range: 3.0V to 36V
 410kHz Switching Frequency
3A Output Current Capability
 Low Operating Quiescent Current:
30 μ A (Typ.) From 12V_{IN} to 3.3V_{OUT}
 $\pm 1.5\%$ 1V Reference Over -40°C~125°C
 Peak Eff. **>95%** (Typ.) From 12V_{IN} to 5V_{OUT}
 Minimum On Time: **40ns** (Typ.)
 Internal Compensation
 Precision Enable
 Cycle by Cycle Current Limit and Hiccup When Overload or Short Circuit

APPLICATION

Automotive System: Cockpit, ADAS
 Consumer systems: Robotic Vacuum Cleaner, Drone.
 Battery Powered System: Power Tools, Home Appliance, GPS Tracker etc.
 Industrial and Medical Power Supplies

DESCRIPTION

The MP9943 is a high efficiency synchronous monolithic step-down switching regulator with integrated internal high-side and low-side MOSFETs. It provides up to 3A output current with peak current mode control for fast loop response. The MP9943 operates over a wide input voltage range from 3.0V to 36V with only 30 μ A low quiescent current.

Standard features include thermal shutdown, UVLO, enable (EN) control and power good (PG) indicator. During the overload or output short circuit, the cycle by cycle current limit and hiccup protection are provided. Thermal shutdown provides reliable and fault-tolerant operation.

Device Information

DEVICE	PACKAGE	BODY SIZE(NOM)
MP9943GQ	QFN-8	3.00mm × 3.00mm

Typical Application

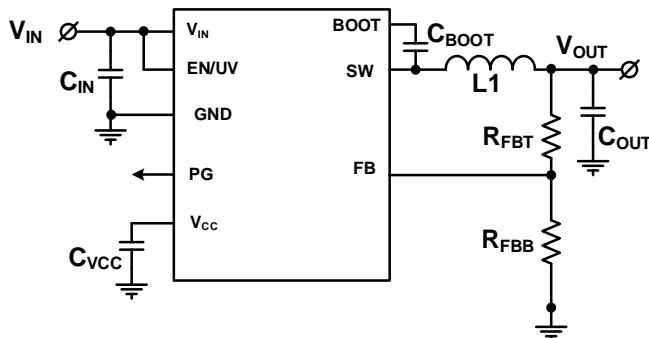


Fig.1 Schematic Diagram

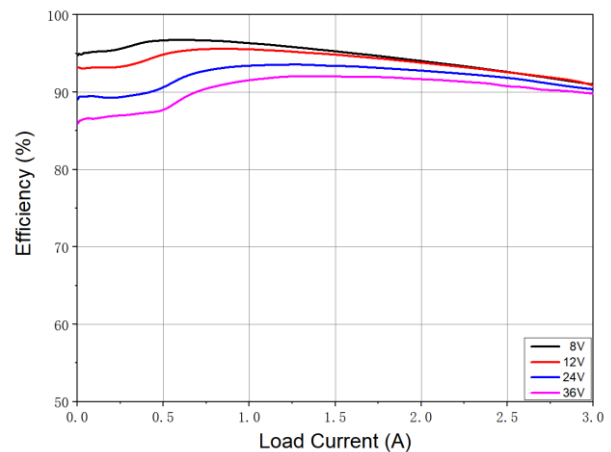
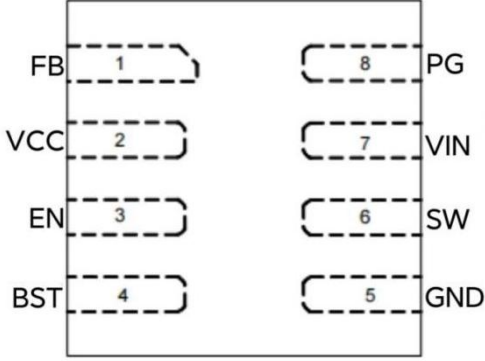


Fig.2 Efficiency vs. Output Current

PIN CONFIGURATION

Package	Pin Configuration (Top View)
QFN-8	

PIN DESCRIPTION

No.	Pin	Type ⁽¹⁾	Description
1	FB	I	Feedback Voltage
2	VCC	O	Internal Supply for Control Circuits
3	EN	I	Enable Input
4	BST	I/O	Bootstrap Supply Voltage
5	GND	G	Power Ground
6	SW	I/O	Switching Node Output
7	VIN	P	Input Voltage
8	PG	I/O	Power Good Signal

(1) G = Ground, I = Input, O = Output, P = Power

Table 1. MP9943 QFN-8 Pin Description

ABSOLUTE MAXIMUM RATINGS

		Min	Max	Units
Input	VIN, EN to GND	-0.3	42	V
	FB to GND	-0.3	5.5	
	PG to GND	-0.3	6	
	BST to SW	-0.3	5.5	
Output	VCC to GND	-0.3	6	V
	SW to GND	-0.3	42	
T _J	Junction temperature	-40	150	°C
T _S	Storage temperature	-55	150	

RECOMMENDED OPERATING CONDITIONS

		Min	Max	Units
Buck Regulator	V _{IN}	3.0	36	V
	SW		36	
	FB	0	5	
Control	EN	0	36	V
	PG	0	5	
Output	V _{OUT}	0	24	V
T _J	Junction temperature	-40	125	°C

ESD RATINGS

Symbol	Definition	Value	Units
V _{ESD}	HBM	±2000	V
	CDM	±2000	

ELECTRICAL CHARACTERISTICS

Limits apply over the recommended operating junction temperature -40°C to +125°C, unless otherwise stated. Minimum and Maximum limits are specified through test, design or statistical correlation. Typical values represent the most likely parametric norm at T_J = 25°C, and are provided for reference purposes only. Unless otherwise stated the following conditions apply: V_{IN} = 12 V. V_{OUT} is converter output voltage.

Symbol	Parameter	Condition	Min	Typ	Max	Units
I _{SD}	Shutdown Supply Current	V _{EN} =0V			8	μA
I _Q	Non-Switching Quiescent Current	V _{FB} =1.05V			20	μA
R _{DS(on)_H}	High Side MOSFET ON Resistance			105	190	mΩ
R _{DS(on)_L}	Low Side MOSFET ON Resistance			65	135	mΩ
I _{LKG_SW}	Switch Leakage	V _{EN} =0V, V _{SW} =12V			1	μA
I _{LIMIT_H}	High Side MOSFET Current Limit ⁽¹⁾		3.5	4.5	5.8	A
I _{LIMIT_L}	Low Side MOSFET Current Limit ^{(1) (2)}		2.8			A
f _{SW}	Switching Frequency		350	410	470	kHz
f _{FB}	Fold-Back Frequency	V _{FB} <700mV	210	280	350	kHz

D _{MAX}	Maximum Duty Cycle	V _{IN} =V _{OUT} =12V, I _{OUT} =1A	96	98.5		%
T _{ON_MIN}	Min. Turn On Time ⁽²⁾			40		ns
V _{FB}	Feedback voltage		0.985	1.00	1.015	V
I _{FB}	Current into FB pin	V _{FB} =1V	-100		100	nA
V _{EN_H}	Enable High Threshold		1.185	1.235	1.285	V
V _{EN_L}	Enable Low Threshold		0.95	1.03	1.09	V
V _{EN_HYS}	Enable Hysteresis Threshold			205		mV
V _{EN_LKG}	Enable Pin Leakage Current	V _{EN} =2V		-0.6		nA
V _{IN_UV}	Under Voltage Lockout Thresholds	Rising Threshold		2.85	3.2	V
		Falling Threshold	2.2	2.65		V
		Hysteresis		200		mV
V _{CC}	Internal Power Supply	4V≤V _{IN} , I _{LOAD} =0mA	3.32	3.5	3.68	V
	V _{CC} Load Regulation	4V≤V _{IN} , I _{LOAD} =5mA		1.5	3	%
T _{SS}	Internal Soft-Start Time		2	5	9	ms
T _{SD}	Thermal Shutdown			165		°C
T _{SD_HYS}				15		°C
V _{PG_R}	Power Good Threshold Rising	% of V _{FB}	91	94	97	%
V _{PG_F}	Power Good Threshold Falling	% of V _{FB}	89	92	95	%
PG _{Vth_HYS}	PG Threshold Hysteresis	% of V _{FB}		2		%
t _{PG}	Power Good Glitch Filter Delay		40	130	160	μs
R _{PG}	PG Pull-Down Resistance	V _{EN} =4V		95	250	Ω
		V _{EN} =0V		85	200	
I _{LKG_PG}	PG Leakage Current				100	nA

(1) The current limit values in this table are tested, open loop, in production. They may differ from those found in a closed loop application.

(2) Derived from bench characterization. Not tested in production.

FUNCTIONAL DIAGRAM

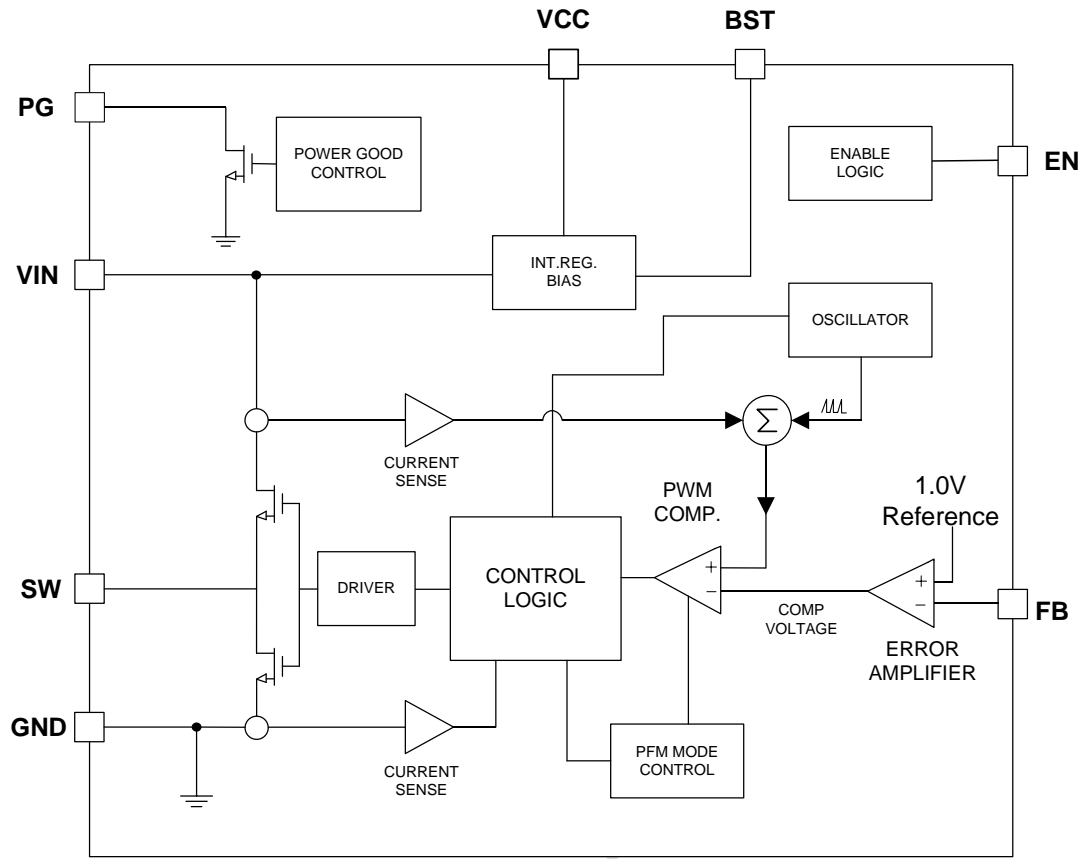


Fig.3 Functional Diagram

TYPICAL CHARACTERISTICS

Unless otherwise specified the following conditions apply: $V_{IN} = 12V$, $f_{SW} = 410kHz$, $L=10\mu H$, $C_{OUT} = 44\mu F$, $T_J = 25^\circ C$

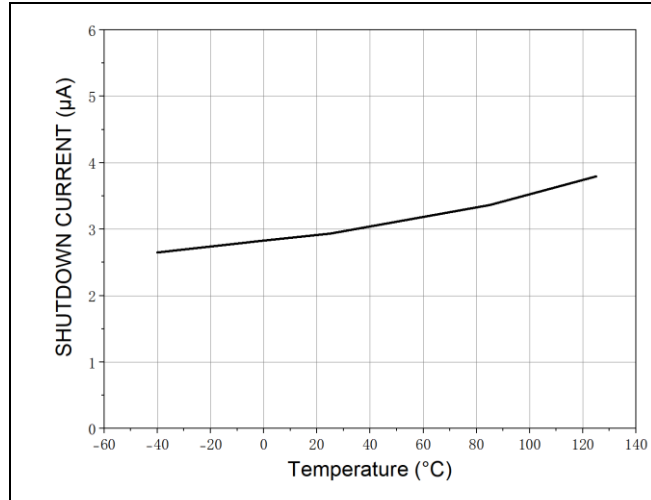


Fig.4 Shutdown Current VS. Junction Temperature

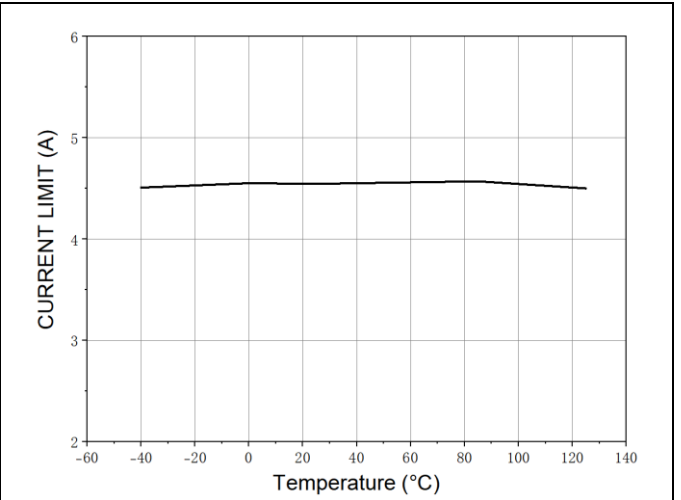


Fig.5 Current Limit VS. Junction Temperature
at Duty = 40%

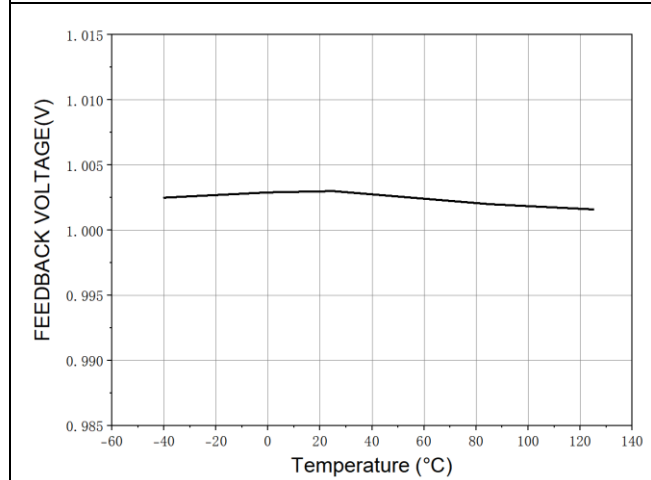


Fig.6 Feedback Voltage VS. Junction Temperature

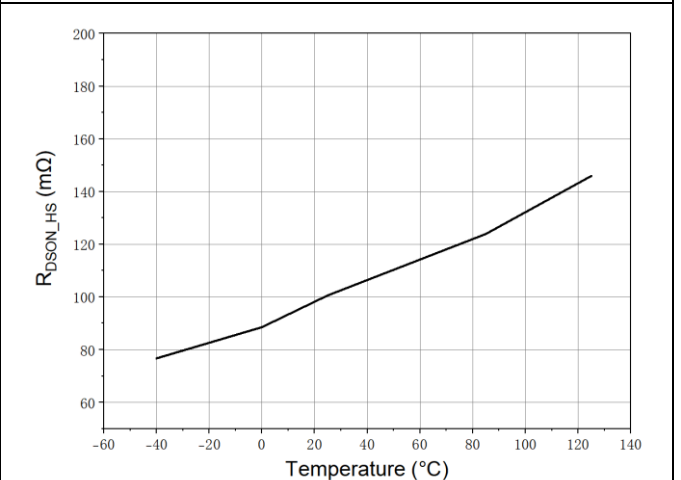


Fig.7 $R_{DS(on)_{HS}}$ VS. Junction Temperature

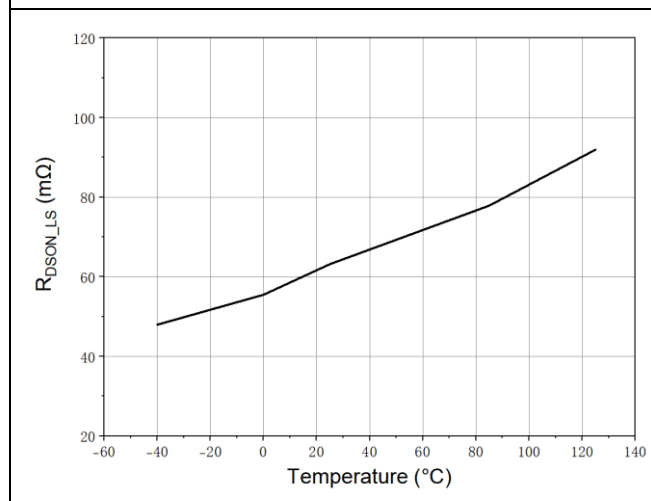


Fig.8 $R_{DS(on)_{LS}}$ VS. Junction Temperature

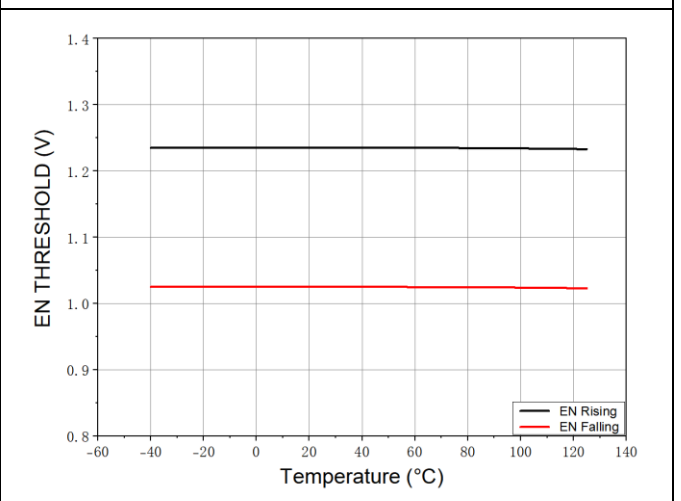


Fig.9 EN Threshold VS. Junction Temperature

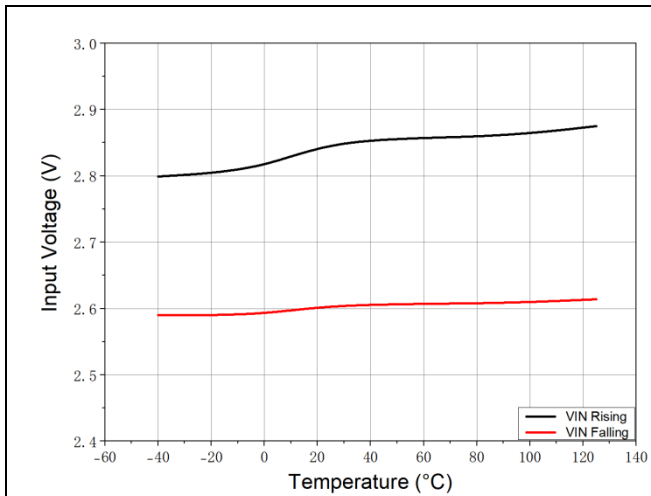
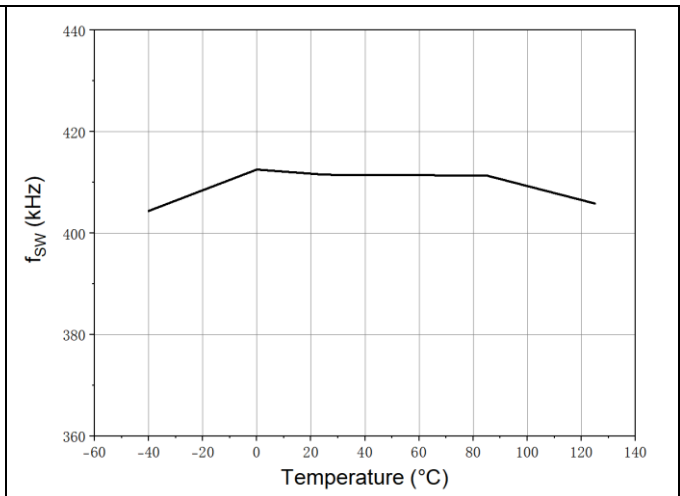

Fig.10 V_{IN} UVLO VS. Junction Temperature


Fig.11 Switching Frequency VS. Junction Temperature

PRODUCT OVERVIEW

The MP9943 is a synchronous, step-down, switching regulator with integrated high-side and low-side power MOSFETs. The MP9943 can provide 3A of output current with very high efficiency from light load to full load. The MP9943 features a wide input voltage from 3.0V to 36V, switching frequency 410 kHz. The internal soft start limits inrush current during power on. The MP9943 also integrated compensation circuit inside the chip to simplify the loop design. Another highlighted feature is its very low operational quiescent current which makes it suitable for battery powered applications.

FEATURE DESCRIPTION

Light Load Operation

The MP9943 utilizes advanced Pulse Frequency Modulation (PFM) control to improve efficiency in light load working condition. When the loading current decreases, the device approaches discontinuous conduction mode first and the COMP voltage decreases accordingly. The low-side power switch is turned off when the zero current detection is triggered to improve system efficiency. When the COMP voltage drops to the low clamped threshold voltage, the device will skip pulse and decrease switching frequency by extend the non-switching period. During this period, the output voltage decreases due to load current or capacitor discharge. The high-side power switch will resume to turn on once the COMP voltage is higher than the threshold. The device will try to obtain few switching pulses with minimum peak inductor current to reduce the output ripple and the COMP voltage will drop to the clamped value again and trigger another non-switching period.

Soft-Start with Pre-Biased Capability

The MP9943 implements a soft-start circuit to prevent the inrush current during start up. The soft start time is fixed internally. When the start-up period begins, the output voltage slowly ramps up. The MP9943 also supports a monotonic start-up with pre-biased loads. If output voltage is pre-biased to a certain value during start-up, the device disables switching for both high-side and low-side power switches until soft-start reference voltage exceeds the feedback voltage.

Over-Current Protection and Hiccup Mode

The MP9943 has cycle-by-cycle over current limit when the inductor current peak value exceeds the set current limit threshold. If, during current limit, the voltage on the FB input falls below about 0.5 V due to a short circuit, the device enters into hiccup mode. In this mode, the device stops switching for about 30 ms and then goes through a normal re-start with soft start. If the short-circuit condition remains, the device runs in current limit for about 5 ms (typical) and then shuts down again. This cycle repeats as long as the short circuit-condition persists. This mode of operation helps reduce the temperature rise of the device during a hard short on the output. The output current is greatly reduced during hiccup mode. Once the output short is removed and the hiccup delay is passed, the output voltage recovers normally.

Low Drop-out Mode

As the duty cycle is increasing, where the input voltage approaches the output voltage level, the required off time of high-side power switch will approach its minimum off time. When the minimum off time is reached, the MP9943 will automatically extend the high-side on time and reduce the switching frequency. The device can realize 98.5% max duty cycle in drop-out condition. In this condition, the dropout voltage difference between input and output is influenced by the on-resistance of power switch, the DCR of power inductor, and the maximum duty cycle achieved.

Minimum On Time

As the duty cycle is decreasing, where the conversion ratio is very low, the required on time of high-side power switch will approach its minimum on time. The MP9943 features typical 40ns ultra-low minimum on time and can support smaller duty cycle for high frequency power systems. Also, the device can automatically reduce the switching frequency, when the minimum on time is reached.

Power Good

The device employs an open-drain output PGOOD signal to check whether the output voltage is operating within the normal range. The external pull up voltage resource is recommended to be less than 5V (such as VCC) with a 100k Ω resistor. Once the feedback voltage is within the 92% and 107% of internal reference voltage, the PGOOD pull-down will be disabled and pulled up by the externally resistor. Once the feedback voltage is lower than 92% or greater than 107% of internal reference voltage, the PGOOD will be pulled low. To prevent glitching both the upper and lower thresholds include about 2% of hysteresis. Also, if UVLO, over temperature protection or EN pin is pulled low, the PGOOD will be pulled low accordingly.

APPLICATION

Fig.12 shows a typical application circuit for the MP9943. Thanks to the high integration in the MP9943, the application circuit based on MP9943 only need input capacitor, output capacitor, output inductor and feedback resistors which are needed to be selected based on applications specifications. Table 2 shows some typical external component values.

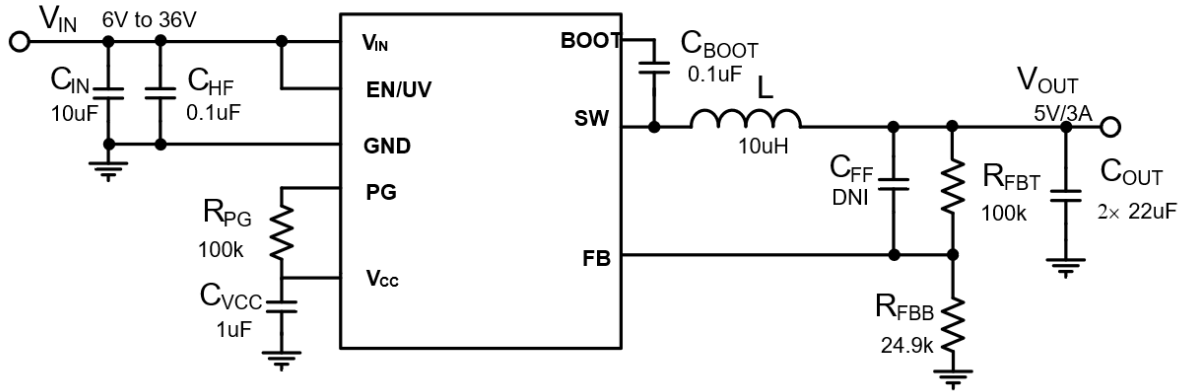


Fig.12 Typical Application Circuit (410kHz)

$f_{sw}(kHz)$	$V_{OUT}(V)$	$L(\mu H)$	$C_{OUT}(RATED\ CAPACITANCE)$	$R_{FBT}(k\Omega)$	$R_{FBB}(k\Omega)$	$C_{IN}+C_{HF}$	C_{BOOT}	C_{VCC}	C_{FF}
410	3.3	10	2*22 μF	100	43	10 μF +100nF	100nF	1uF	DNI
410	5	10	2*22 μF	100	24.9	10 μF +100nF	100nF	1uF	DNI

Table.2 Typical External Component Values

Setting Output Voltage

The external feedback resistors connected to FB sets the output voltage. The feedback resistors value can be calculated with the below equation.

$$R_{FBB} = \frac{V_{REF} R_{FBT}}{V_{OUT} - V_{REF}}$$

While $R_{FBT}=100k\Omega$, $V_{REF}=1V$, $V_{OUT}=5V$

Calculate $R_{FBB}=24.9k\Omega$

Inductor Selection

For higher efficiency, choose an inductor with a lower DC resistance. A larger-value inductor results in less ripple current and a lower output ripple voltage, but also has a larger physical size, higher series resistance, and lower saturation current. A good rule for determining the inductor value is to allow the inductor ripple current to be approximately 20% to 40% of the maximum load current. The minimum inductance value can be calculated with the below equation.

$$L_{MIN} = \frac{V_{OUT}(1 - D)}{f_{SW} \times \Delta I_L}$$

While $V_{OUT}=5V$, $f_{SW}=410kHz$, $\Delta I_L=30\% \times 3A=0.9A$, $D=5V/12V=0.417$
Calculate $L=10\mu H$.

Output Capacitor Selection

The output capacitor maintains the DC output voltage. Ceramic, tantalum, or low ESR electrolytic capacitors are recommended. For best results, use low ESR capacitors to keep the output voltage ripple low. The output voltage ripple can be estimated with equation. Generally, required the output voltage ripple is less than 1% of the output voltage.

$$\Delta V_{OUT} = \frac{V_{OUT} \times (1 - D)}{8 \times f_{SW}^2 \times L \times C_{OUT}}$$

Input Capacitor Selection

The input capacitor can be electrolytic, tantalum, or ceramic. When using electrolytic or tantalum capacitors, add a small, high-quality ceramic capacitor (like X7R, C0G etc.) as close to the IC as possible. When using ceramic capacitors, ensure that they have enough capacitance to provide a sufficient charge to prevent excessive voltage ripple at the input. From the below equation, can easily calculate the input voltage ripple. Generally, required the input voltage ripple is less than 10% of the input voltage.

$$\Delta V_{IN} = \frac{I_O \times D \times (1 - D)}{f_{SW} \times C_{IN}}$$

CFF Capacitor Selection

When some cases need improvement of load transient response or the margin of loop-phase, a feedforward capacitor can be used across R_{FBT} , especially when values of $R_{FBT} > 1000k\Omega$ are used. The minimum capacitance value can be calculated with the below equation

$$C_{FF} \leq \frac{C_{OUT} \times V_{OUT}}{110 \times R_{FBT} \times \sqrt{\frac{R_{FBB}}{R_{FBT} + R_{FBB}}}}$$

Bootstrap Capacitor Selection

A bootstrap capacitor connected between the BOOT pin and the SW pin. This capacitor stores energy that is used to supply the gate drivers for the internal MOSFETs. A ceramic capacitor of 0.1uF and 16V voltage rating is required.

VCC Capacitor Selection

The VCC pin is the output of the internal LDO used to supply the control circuits of the converter. This output requires a ceramic capacitor connected from VCC to GND for proper operation. It is highly recommended placing a ceramic capacitor of 1uF and 16V voltage rating. In general, avoid loading this output with any external circuitry. However, this output can be used to supply the pullup for the PGOOD function. The nominal output voltage on VCC is 3.5V. Do not short this output to ground or any other external voltage. Also, if over temperature protection or EN pin is pulled low, the VCC pin output will be low.

EN Resistor Selection

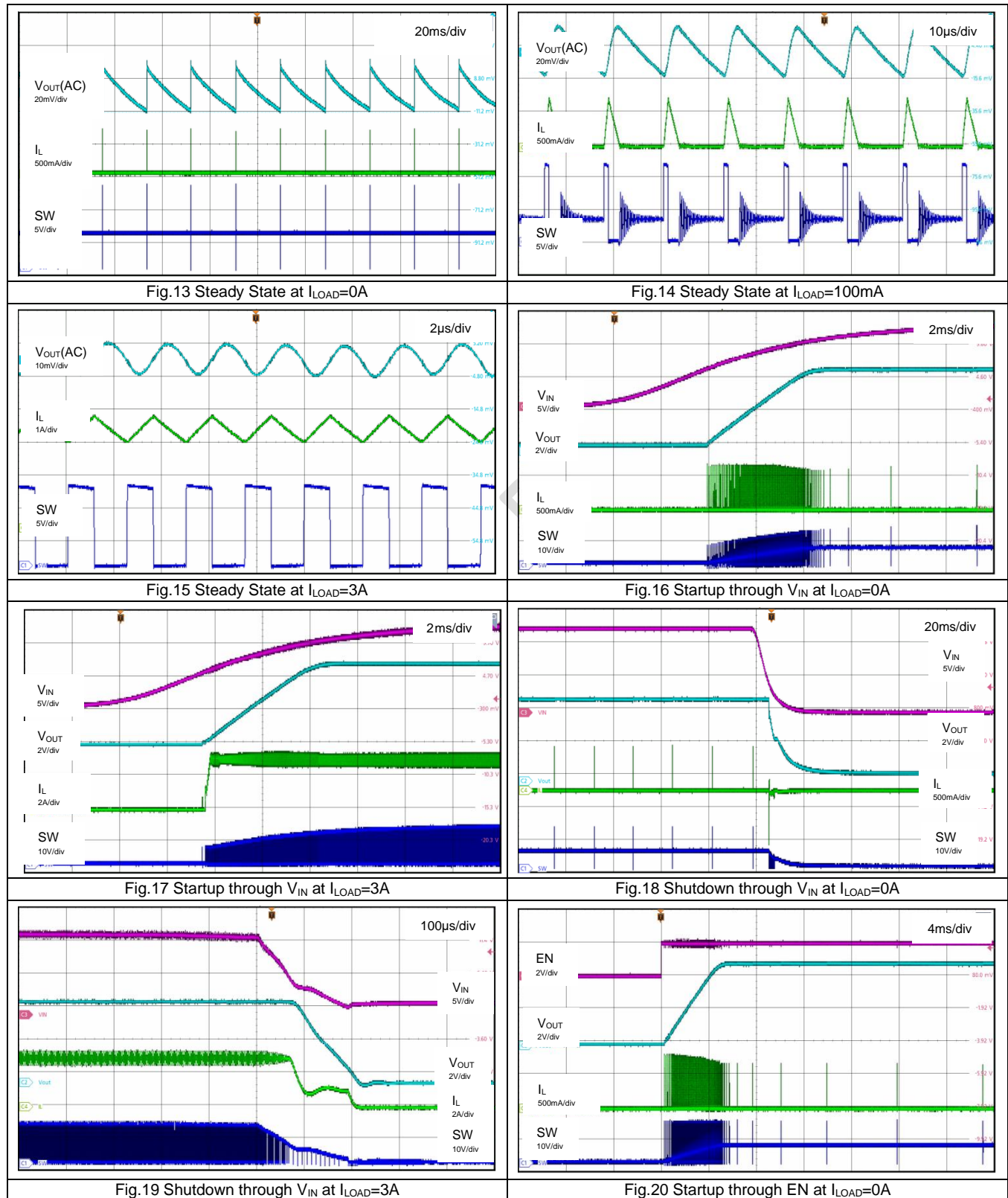
The MP9943 has undervoltage lockout feature with default rising threshold of 2.85 V. It can be adjusted by using EN pin with external resistor divider. The UVLO threshold integrates a 200mV hysteresis to make a desired hysteresis for input voltage.

V_{UVLO_R} is the desired system level undervoltage protection rising threshold voltage, V_{UVLO_F} is the desired system level undervoltage protection falling threshold voltage. The R_{ENT} and R_{ENB} value can be calculated with the below equation

$$V_{UVLO_R} = \left(\frac{R_{ENT}}{R_{ENT} + R_{ENB}} \right) \times V_{ENR}$$
$$V_{UVLO_F} = \left(\frac{R_{ENT}}{R_{ENT} + R_{ENB}} \right) \times (V_{ENR} - 0.2)$$

APPLICATION WAVEFORMS

Unless otherwise specified the following conditions apply: $V_{IN} = 12V$, $V_{OUT} = 5V$, $f_{SW} = 410kHz$, $L=10\mu H$, $C_{OUT} = 44\mu F$, $T_J = 25^\circ C$.



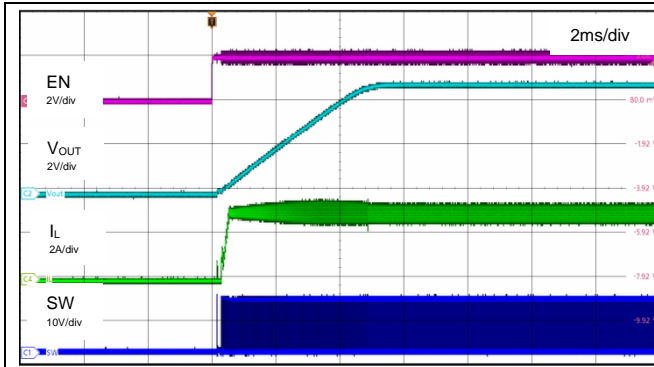
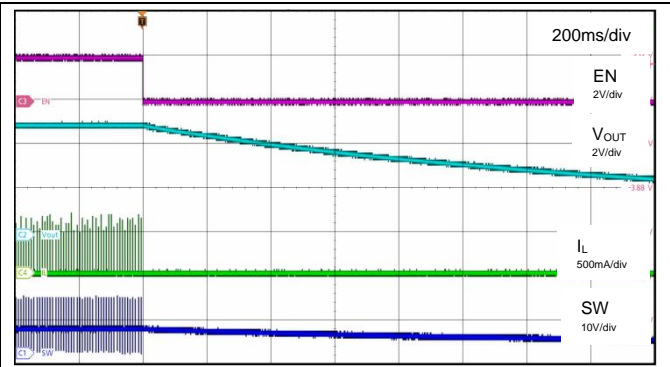
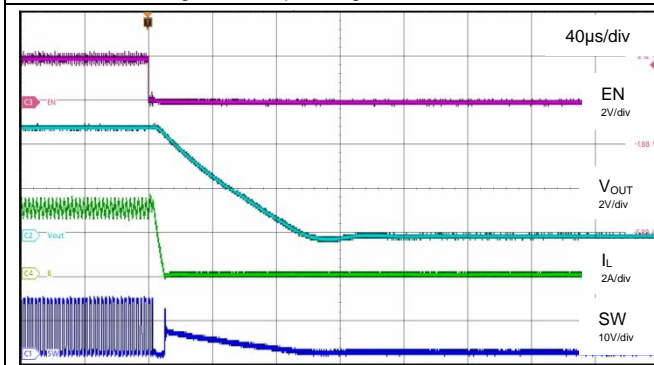
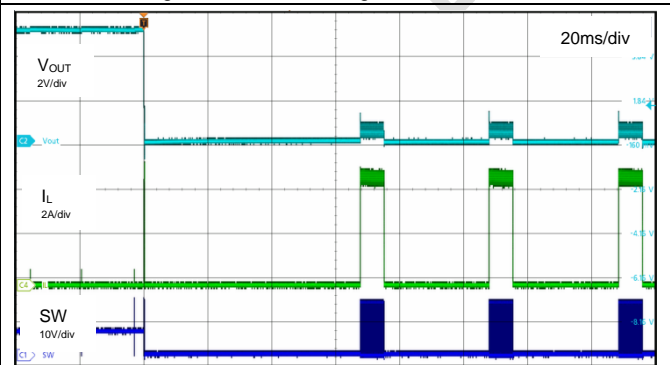
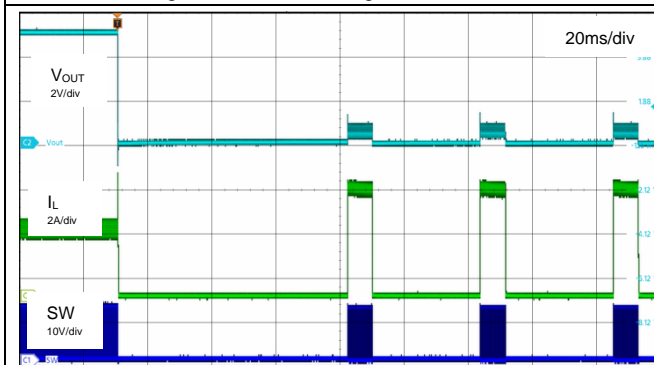
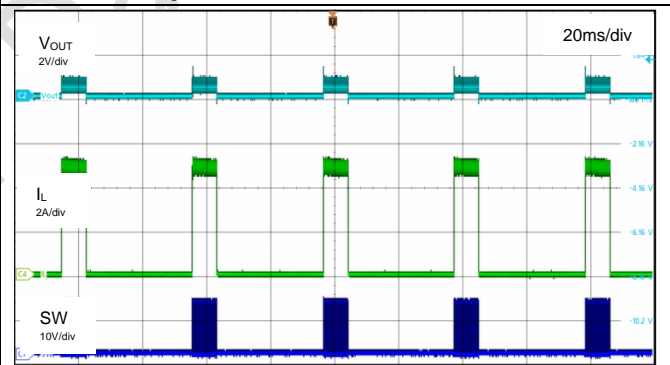
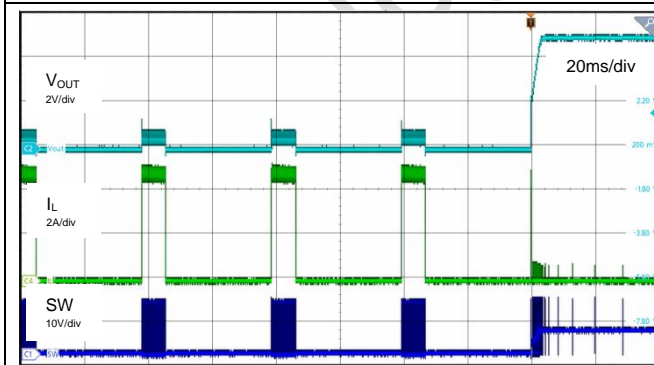
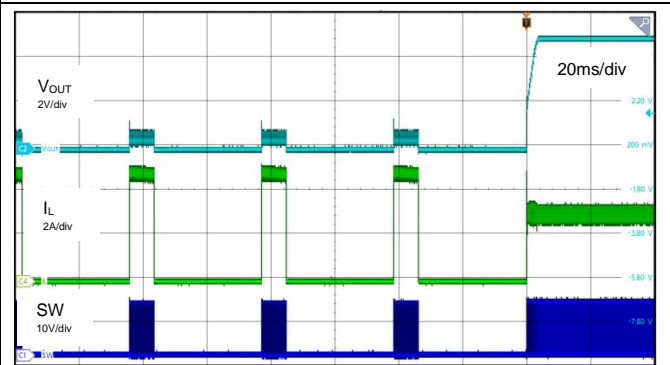
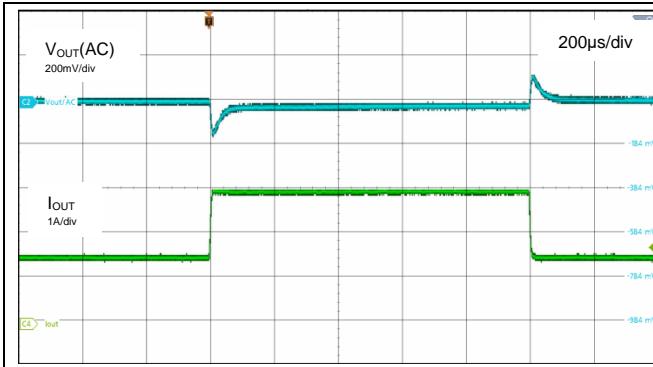
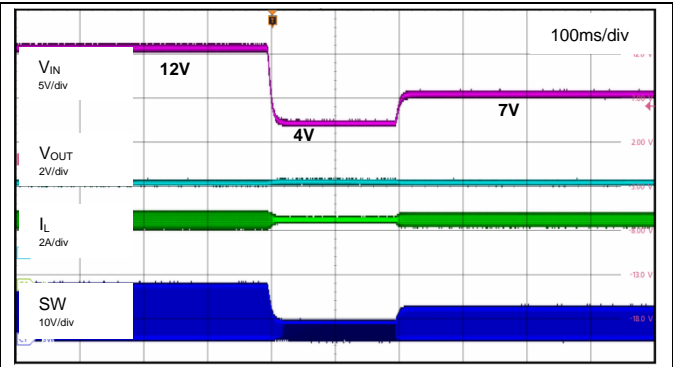
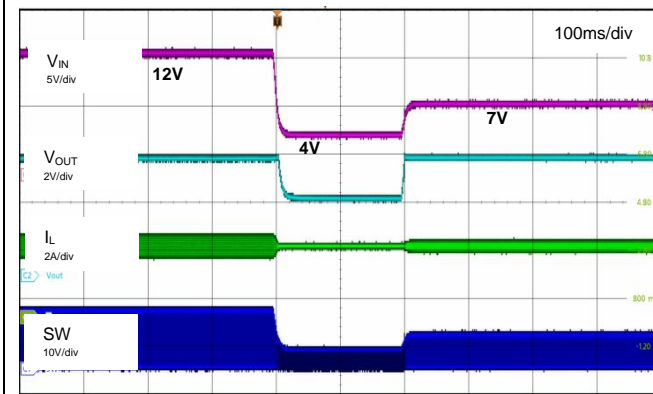
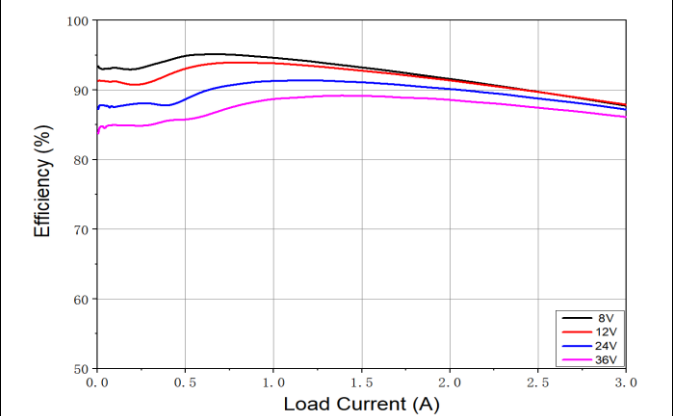
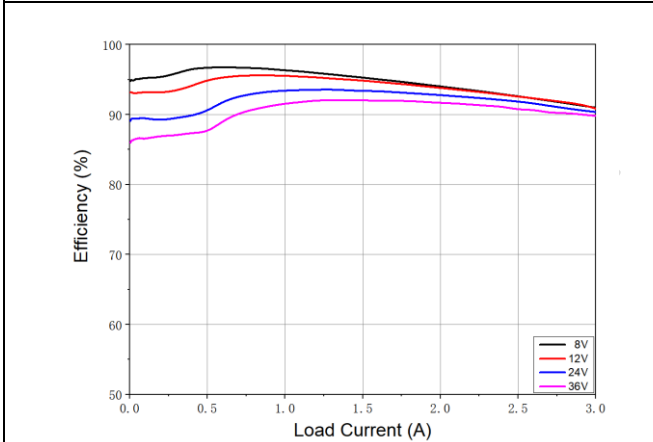
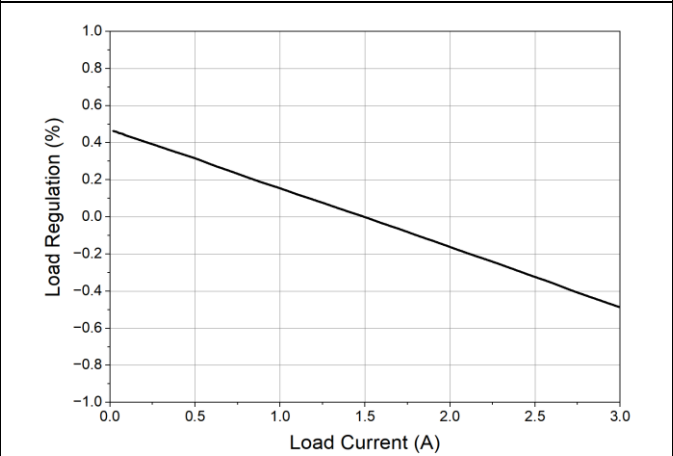
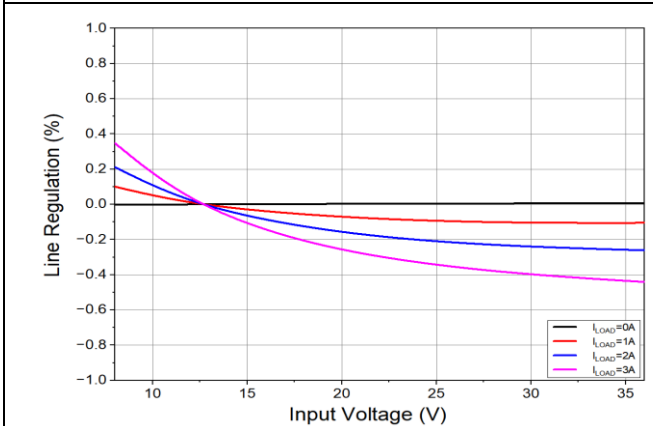

Fig.21 Startup through EN at $I_{LOAD}=3A$

Fig.22 Shutdown through EN at $I_{LOAD}=0A$

Fig.23 Shutdown through EN at $I_{LOAD}=3A$

Fig.24 Short Circuit Protection at $I_o=0A$

Fig.25 Short Circuit Protection at $I_o=3A$


Fig.26 Short Circuit Steady

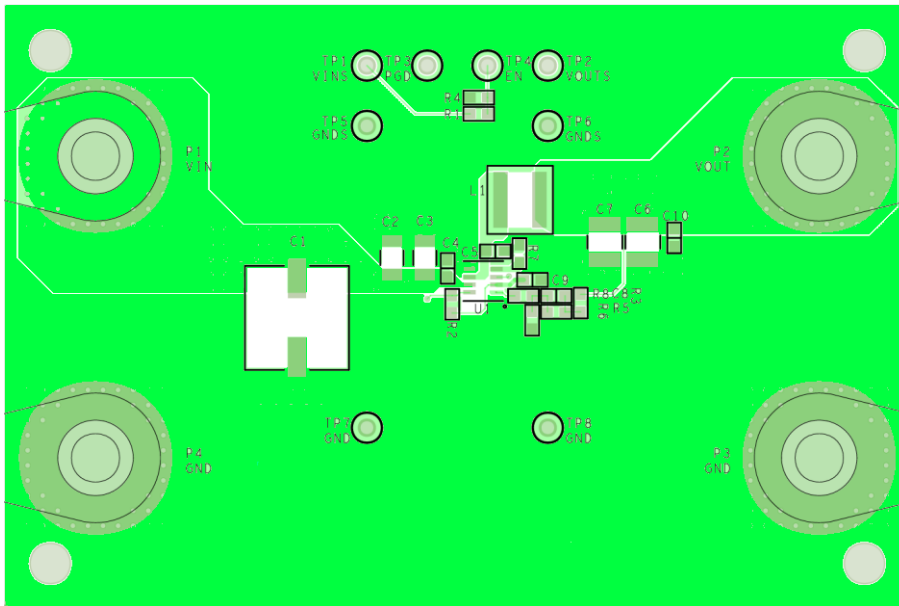

Fig.27 Short Circuit Recovery at $I_o=0A$

Fig.28 Short Circuit Recovery at $I_o=3A$


Fig.29 Load Transient at I_{LOAD} from 1.5A to 3A, 1.6A/μs

Fig.30 Cold-Crank at $V_{OUT}=3.3V$, $I_{OUT}=3A$

Fig.31 Cold-Crank at $V_{OUT}=5V$, $I_{OUT}=3A$

Fig.32 Efficiency VS. Load Current at $V_{OUT}=3.3V$

Fig.33 Efficiency VS. Load Current at $V_{OUT}=5V$

Fig.34 Load Regulation VS. Load Current at $V_{IN}=12V$

Fig.35 Line Regulation VS. Input Voltage at $V_{OUT}=5V$

PCB LAYOUT GUIDELINES

PCB layout is critical for stable operation of switching regulator MP9943, especially for thermal design and EMI design. For best results, please refer to Fig. 36 and follow the guidelines below.

1. Place a low ESR ceramic capacitor as close to VIN pin and the ground as possible.
2. Make sure top switching loop with power have lowest impedance of grounding.
3. Use a large ground plane to connect to GND directly. And add vias near GND.
4. Output inductor should be placed close to the SW pin to minimize the SW area.
5. The FB terminal is sensitive to noise so the feedback resistor should be located as close as possible to the IC.
6. Keep the connection of the input capacitor and VIN as short and wide as possible.



Tape and Reel Information

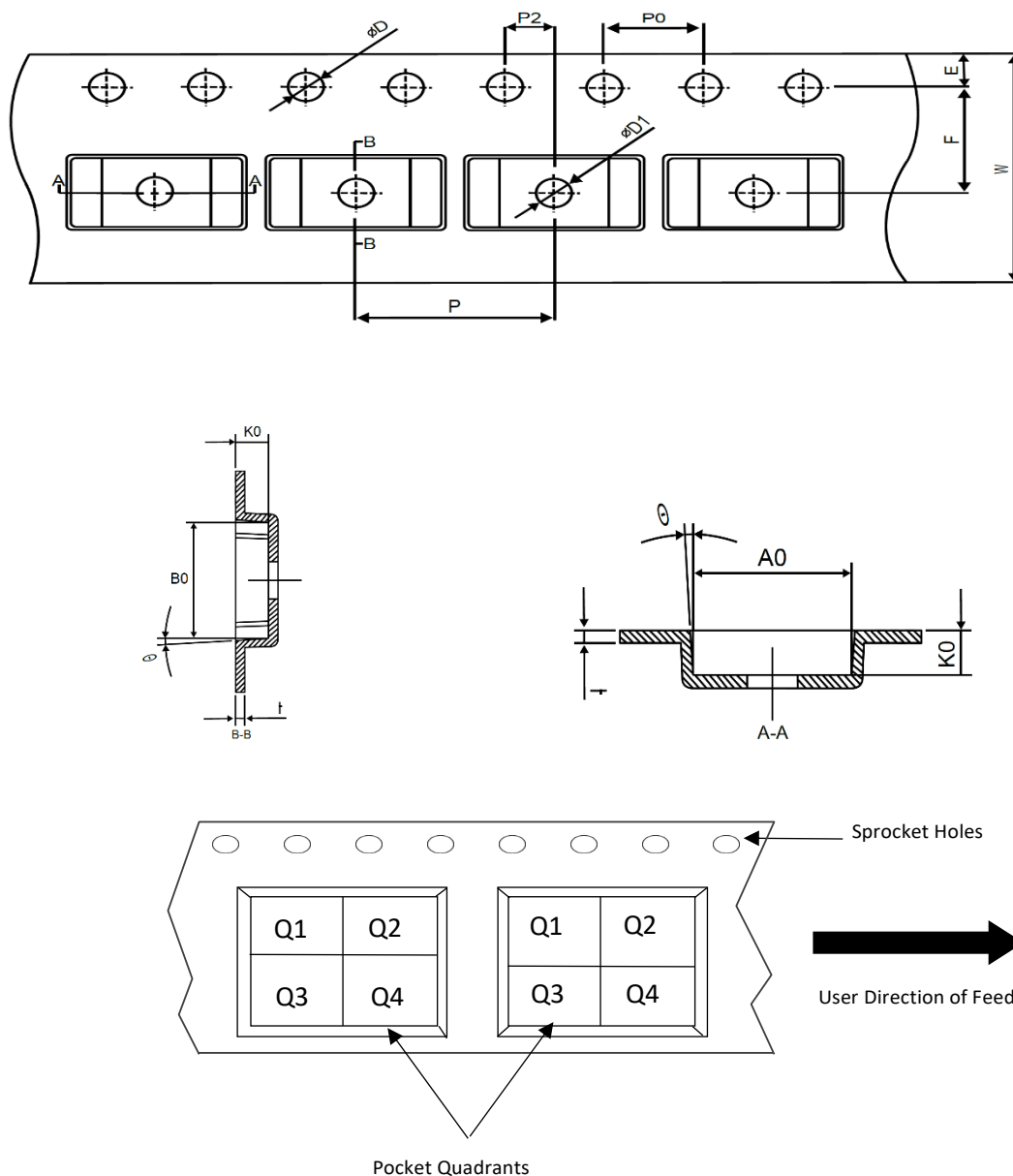


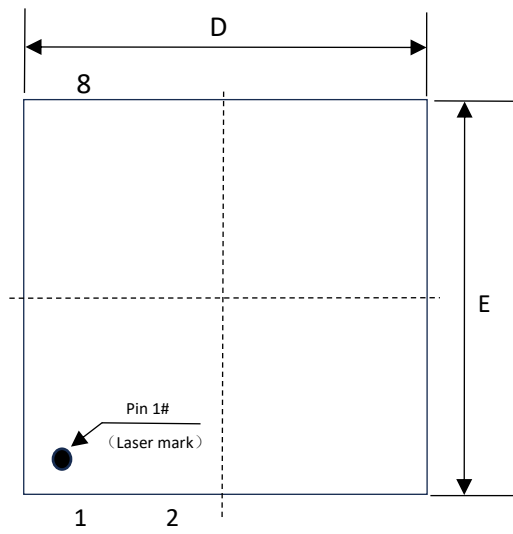
Fig.39 TAPE and Reel Information

DIMENSIONS AND PIN1 ORIENTATION

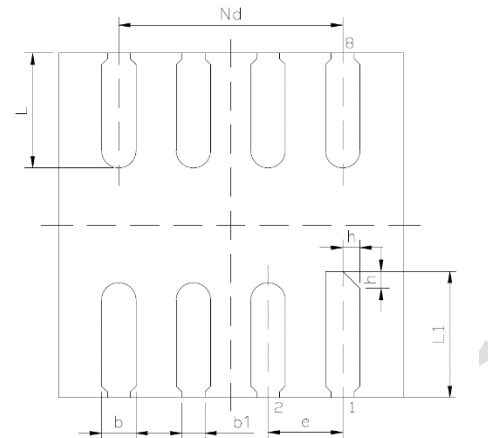
Device	Package Type	A0 (mm)	B0 (mm)	K0 (mm)	P (mm)	P0 (mm)	W (mm)	Pin1 Quadrant	Quantity
MP9943GQ	QFN-8	3.30	3.30	1.10	8.00	4.00	12.00	Q1	3000

All dimensions are nominal

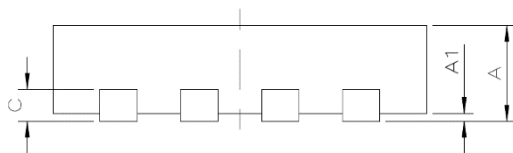
Package Outlines



Top VIEW



BOTTOM VIEW



SIDE VIEW

Fig.40 QFN-8 Package

SYMBOL	MILLIMETER		
	MIN	NOM	MAX
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
b	0.25	0.30	0.35
b1	0.20REF		
c	0.203REF		
D	2.90	3.00	3.10
e	0.65BSC		
Nd	1.95BSC		
E	2.90	3.00	3.10
e	0.65BSC		
L	0.90	1.00	1.10
L1	1.00	1.10	1.20
h	0.10	0.15	0.20



MP9943GQ

ORDERING INFORMATION

Device	Order Part No.	Frequency	Package	QTY
MP9943	MP9943GQ	410KHz	QFN-8 Pb-Free	3000/Reel