



Features

- Wide input voltage range: 4.5V – 36V
- Output voltage range: $V_{ref} - 13.2V$
- High efficiency operation
 - Integrated a 60-mΩ LS-MOSFET and an 80-mΩ HS-MOSFET
 - 90% efficiency at 3A load from 12V to 5V conversion
- Automatic PFM mode at light load (LP6433) and FPWM mode over all load range (LP6433F)
- $\pm 1\%$ V_{ref} accuracy
- Typical 500-kHz switching frequency
- COT control scheme with fast load transient response
- Hiccup protection
- Integrated UVLO, OVP, OCP, SCP, and OTP protections
- 1.6mm x 2.9mm SOT23-6 package
- RoHS Compliant and 100% Lead (Pb) Free

Applications

- Industrial PC
- Network/digital video recorder (NVR/DVR)
- TV and TV box
- 12V and 24V Industrial bus applications

General Description

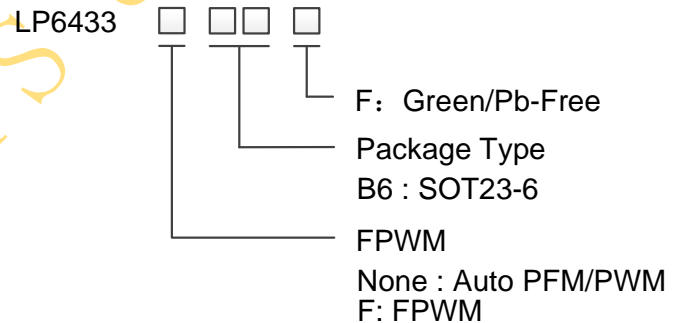
The LP6433X is a synchronous buck converter supporting up to 3A output current. The LP6433X employs an adaptive constant-on-time (COT) control scheme to achieve fast load transient response. The external components are minimized, requiring only one inductor, two resistors, and two capacitors.

The LP6433X supports both aluminum polymer capacitors and ceramic capacitors without extra compensation components.

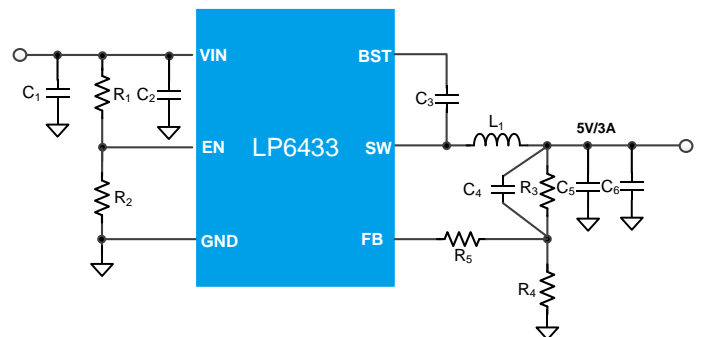
The LP6433X integrates PFM (Pulse Frequency Modulation) operation, which helps maintain the system efficiency at light load. The LP6433X also integrates multiple protection functions, i.e., over-current protection (OCP), over-temperature protection (OTP), under-voltage lockout (UVLO), output over-voltage protection (OVP), and short circuit protection (SCP).

The LP6433X is available in a small 6-pin 1.6mm x 2.9mm SOT23-6 package.

Order Information



Typical Application Circuit





Device Information

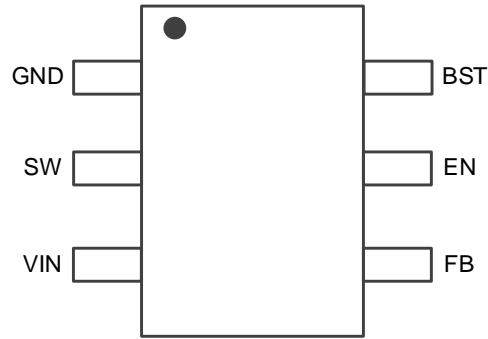
Part Number	Top Marking	Fsw	PFM/FPWM	MSL	Shipping
LP6433B6F	LPS K3 YWX	500kHz	PFM	LEVEL 3	3K/REEL
LP6433FB6F	LPS KR YWX	500kHz	FPWM	LEVEL 3	3K/REEL

Marking indication: Y: Year code. W: Week code. X: Batch numbers.
 MSL: Moisture Sensitivity Level according to JEDEC Standard.
 "****": Please contact LPS sales for Top Marking information.

Preliminary, LPS confidential



Pin Diagram



SOT23-6
(Top View)

LP6433 Pinout

Pin Description

Pin #	Name	Description
1	GND	Power ground of the IC.
2	SW	The switching node of the converter.
3	VIN	IC power supply input.
4	FB	Feedback pin. Use a resistor divider to set the desired output voltage.
5	EN	Enable input. This pin can be used to control the system power sequence as well.
6	BST	Bootstrap pin. Power supply for high-side MOSFET gate driver. A 0.1- μ F capacitor must be connected between this pin and SW pin.



Absolute Maximum Ratings (Note)

VIN to GND	-----	-0.3V to 36V
SW to GND	-----	-1V to 36V
SW to GND (5ns transient)	-----	-5.5V to 38V
EN to GND	-----	-0.3V to 30V
FB to GND	-----	-0.3V to 6.5V
BST to SW	-----	-0.3V to 5.5V
BST to GND (EN=Low)	-----	-0.3V to 38V
BST to GND (EN=High)	-----	-0.3V to 42V
Junction Temperature Range (T _J)	-----	-40°C to 150°C
Maximum Soldering Temperature (at leads, 10 sec)	-----	260°C

Note: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD Ratings

HBM (Human Body Model)	-----	2kV
CDM (Charged-device Model)	-----	500V

Thermal Information

θ _{JA} (Junction-to-Ambient Thermal Resistance)	-----	90°C/W
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Recommended Operating Conditions

SYMBOL	PARAMETER	MIN	TYP	MAX	UNIT
VIN	Input voltage	4.5		36	V
VOUT	Output voltage	V _{ref}		13.2	V
L	Inductor	0.7		13	μH
T _A	Ambient temperature range	-40		85	°C
C _{IN}	Input decoupling capacitor, 25V rating or higher	4.7		100	μF
C _{OUT}	Output capacitor, 10V rating or higher	10		100	μF



Electrical Characteristics

(The specifications are measured under conditions $V_{IN} = 12V$, $T_A = 25^\circ C$, unless otherwise specified.)

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT SECTION						
V_{ULVO_R}	Input voltage under lockout threshold	V_{IN} rising threshold		4.2	4.5	V
V_{ULVO_H}	UVLO hysteresis	V_{IN} falling threshold		0.2		V
I_{q_VIN}	Input quiescent current	No switching, $EN=3V$, $FB=1.0V$		300		μA
I_{SD}	Shutdown current	$EN=0V$, $V_{IN} = 12V$		4.5		μA
BUCK CONVERTER						
I_{LIM}	Low-side valley current limit	$T_A=25^\circ C$	3.0	4.0	5.0	A
I_{NOCL}	Low-side negative current limit	$T_A=25^\circ C$, LP6433F, LP6433HF		-1.2		A
V_{ref}	Reference voltage	$T_A=25^\circ C$,	0.594	0.6	0.606	V
R_{dson_HS}	High-side FET on resistance	$V_{IN}=12V$		80		m Ω
R_{dson_LS}	Low-side FET on resistance	$V_{IN}=12V$		60		m Ω
F_{sw}	Switching frequency			500		kHz
t_{on-min}	Minimum on-time ^[1]			50		ns
$t_{off-min}$	Minimum off-time ^[1]	$V_{FB}=V_{ref} - 0.2V$		100		ns
$t_{on-hiccup}$	Hiccup on time ^[1]		1	2	3.5	ms
$t_{off-hiccup}$	Hiccup waiting time ^[1]		6	12	21	ms
t_d	EN delay time ^[1]	From EN high to first switching		250		μs
t_{ss}	Soft-start time ^[1]	From first switching to 95% V_{ref}		600		μs
T_{jSD}	Thermal shutdown threshold	Rising threshold		160		$^\circ C$
	Thermal shutdown threshold	Falling threshold		135		$^\circ C$



SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
I _{leak_FB}	FB pin leakage current			0.01		μA
EN LOGIC						
V _H	EN pin logic high threshold	EN Rising threshold	1.14	1.2	1.26	V
V _{hys}	EN pin threshold hysteresis			0.1		V
	EN pin internal pull-down resistance			1000		kΩ
OUTPUT OVP						
V _{OVP_rise}	OVP threshold	VOUT rising edge, reference to Vref	108	110	112	%
V _{OVP_fall}	OVP hysteresis	VOUT falling edge, reference to Vref		105		%

[1]: Not production tested. Guaranteed by design.



Typical Characteristics

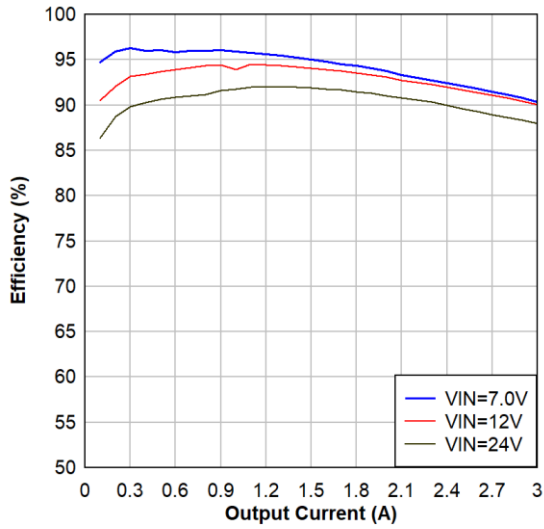


Figure 1. $V_{OUT}=5.0V$, Efficiency, $L=4.7-\mu H$

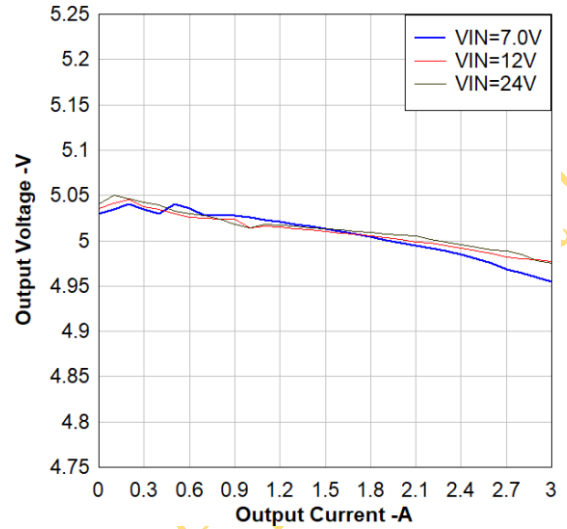


Figure 2. $V_{OUT}=5V$, Regulation, $L=4.7-\mu H$

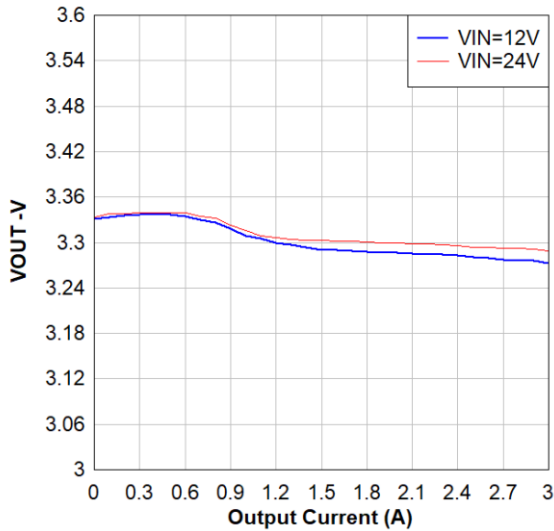


Figure 3. $V_{OUT}=3.3V$, Regulation, $L=4.7-\mu H$

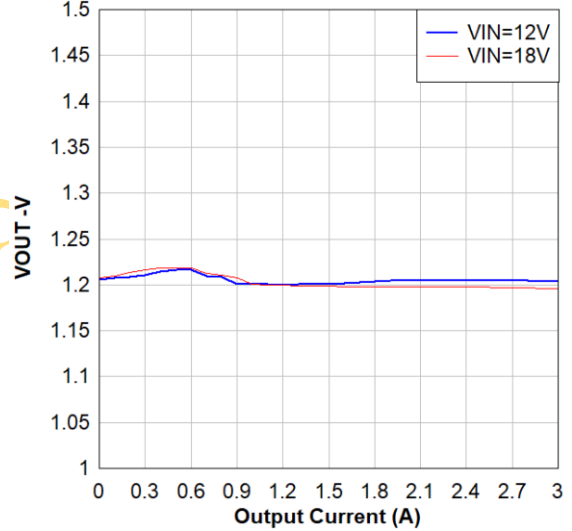


Figure 4. $V_{OUT}=1.2V$, Regulation, $L=2.2-\mu H$



Application Waveforms (Vin=12V, L=4.7μH, Cout=22μF*2)

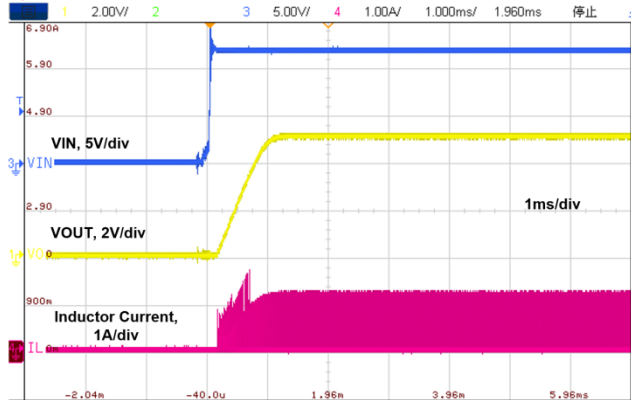


Figure 5. Startup by VIN, 50Ω load

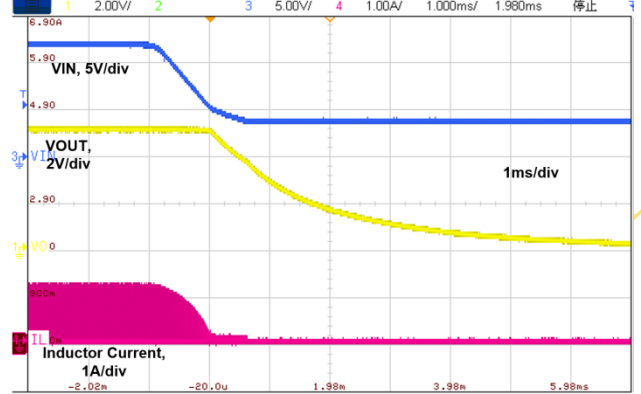


Figure 6. Shutdown by VIN, 50Ω load

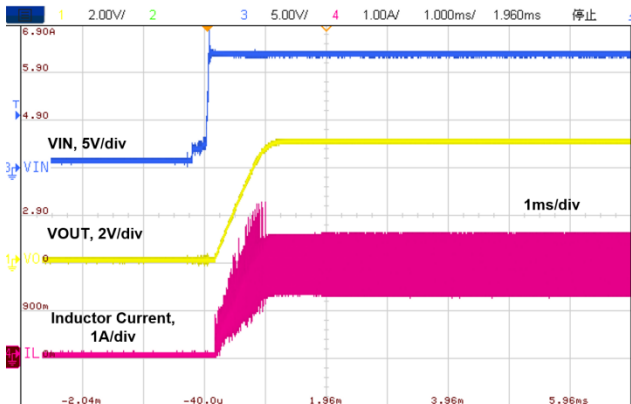


Figure 7. Startup by VIN, 2.5Ω load

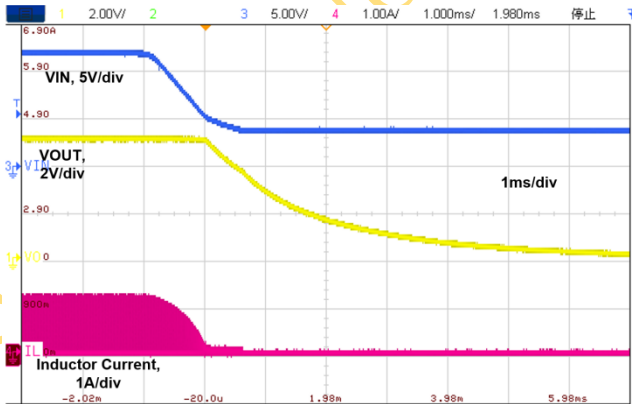


Figure 8. Shutdown by VIN, 2.5Ω load

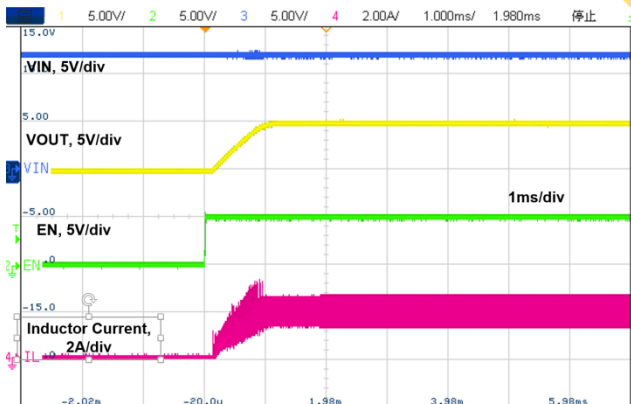


Figure 9. Startup by EN, 2.5Ω load

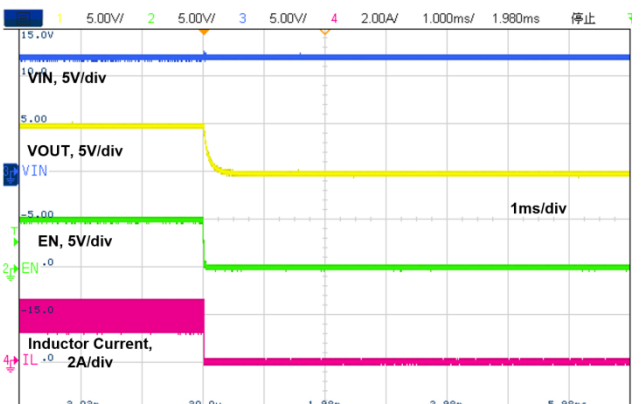


Figure 10. Shutdown by EN, 2.5Ω load

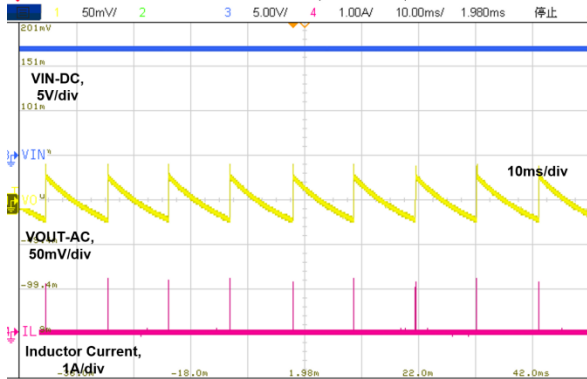


Figure 11. Switching Waveform, 0A load

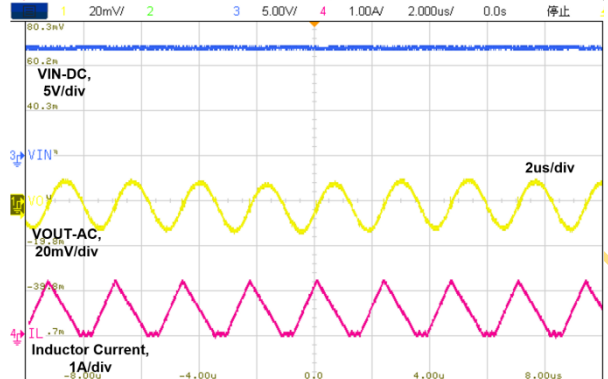


Figure 12. Switching Waveform, 500mA load

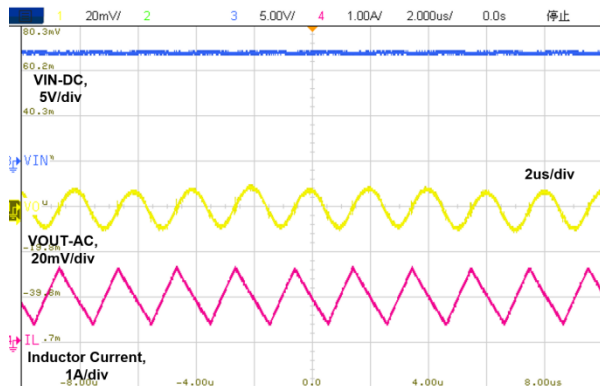


Figure 13. Switching Waveform, 1A load

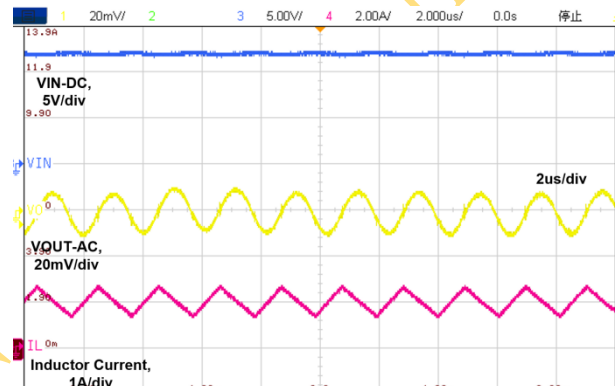


Figure 14. Switching Waveform, 2A load

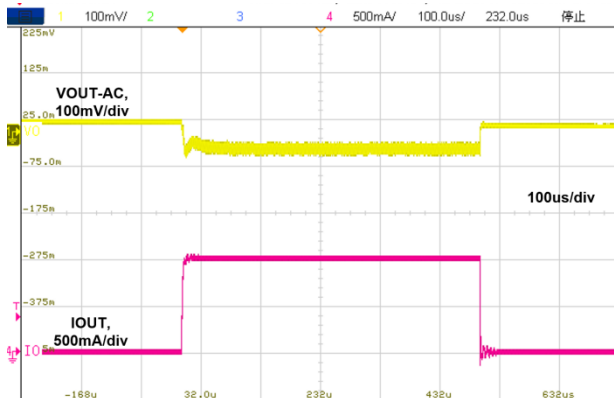


Figure 15. Load Transient, 0A-1A-0A

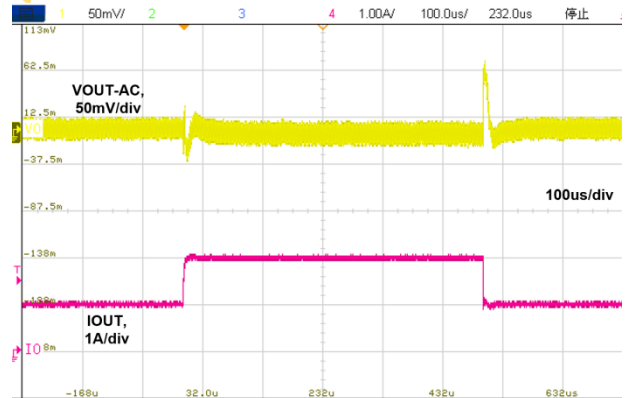


Figure 16. Load Transient, 1A-2A-1A

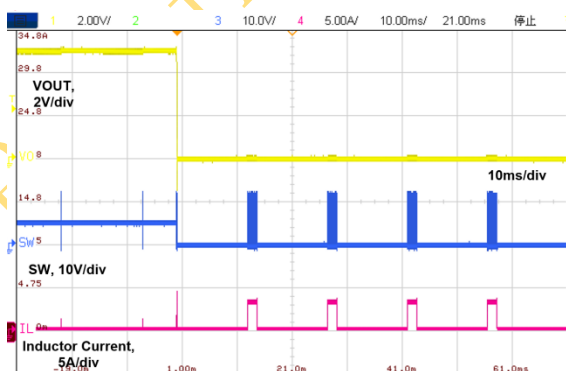


Figure 17. SCP Happen, Hiccup Operation

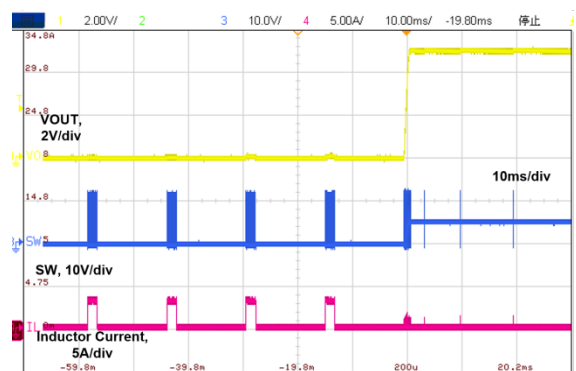
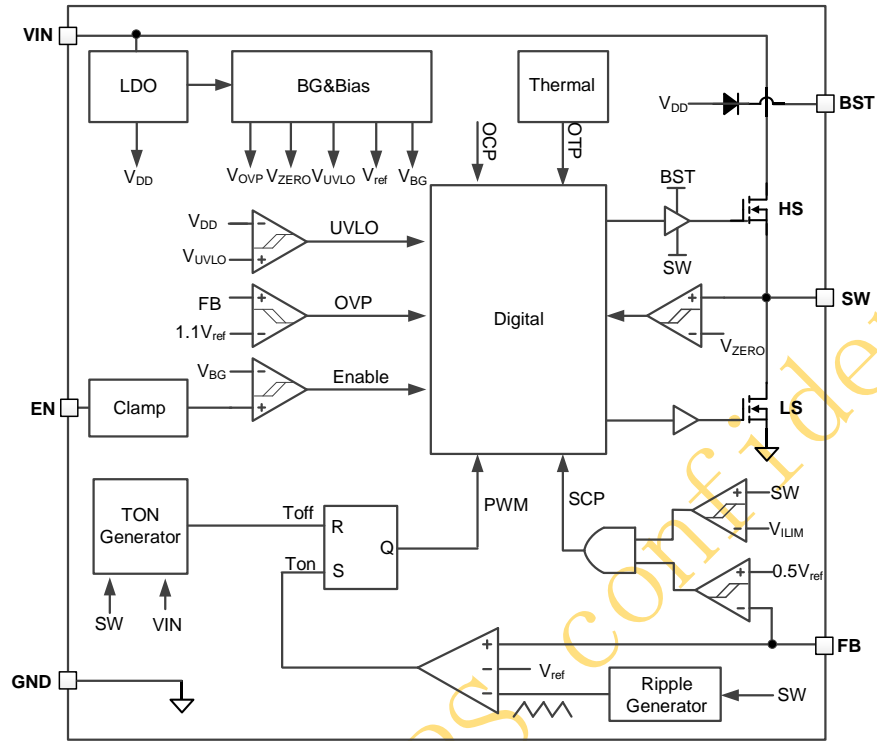


Figure 18. SCP Recovery



Functional Block Diagram





Detailed Description

Overview

The LP6433X is a 3A synchronous buck converter, supporting 4.5-36V input operating voltage range and withstand 38V input voltage. The adaptive COT control scheme enables fast transient respond and minimizes the output capacitance. The LP6433X supports both aluminum polymer capacitors and low-ESR ceramic capacitors without external compensation circuit. The LP6433X automatically transfers between PFM and PWM according to the output current while LP6433XF works in force PWM mode to minimize the output ripple over all the load range.

Under Voltage Lockout (UVLO)

When the input voltage V_{IN} is lower than the UVLO threshold, all functions are shut down. When the input voltage is higher than the UVLO rising threshold, the LP6433X can be enabled by the EN pin.

EN Control

The EN pin can be used to control the system power-up sequence. A precise voltage reference is used as the threshold. When the V_{IN} is above the UVLO threshold and EN voltage rises above the EN pin logic high threshold (1.2V typically), the LP6433X enables all the internal circuits, delays for 260 μ s, and begins the soft-start (refer to Soft-start section for more details).

The EN pin has an internal 1000k Ω pull-down resistor to ground.

Soft-start

The LP6433X integrates soft-start function with a typical time of 600 μ s (t_{ss}). After passing the UVLO threshold and enabled by the EN pin with the 250 μ s delay (t_d), the internal reference voltage ramps from zero to the V_{ref} in 600 μ s and the output voltage ramps up accordingly.

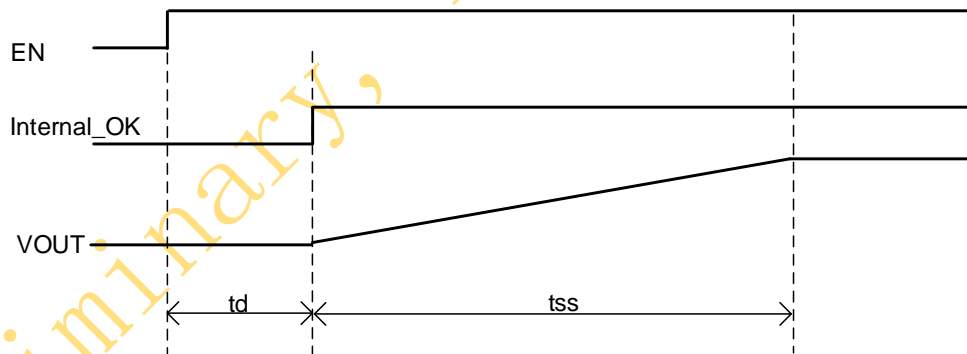


Figure 19. Soft Start Sequence

Constant-ON Time (COT) Control Scheme

The LP6433X integrates the COT control scheme for pseudo-fixed-frequency operation when operating in continuous conduction mode (CCM). Refer to the Functional Block Diagram for better understanding of the operation. The internal on-time (TON) generator block monitors the FB-pin voltage and turns on the high-side MOSFET to start a switching cycle, when the FB-pin voltage drops to an internal reference voltage V_{ref} . Then the internal circuits start to calculate the on-time of the high-side MOSFET, which is proportional to the input voltage and inversely proportional to the output voltage. Once the on-time is finished, the TOFF generator turns off the high-side MOSFET and turns on the low-side MOSFET.

PFM Operation



The LP6433 is designed to maintain high efficiency at light load by adopting pulse-frequency modulation (PFM). In the PFM, the switching cycle is still initiated by the TON generator monitoring the FB-pin voltage. The high-side MOSFET is turned on for TON time and then turned off, followed by turning on the low-side MOSFET. The inductor current falls when the low-side MOSFET is on. When the inductor current reaches zero, detected by the zero-current detection (ZCD) comparator, the low-side MOSFET is turned off, together with the high-side MOSFET. Both MOSFETs remain off until a new switching cycle begins, determined by TON generator. As the load current decreases, the duration for both MOSFETs to remain off increases, leading to a lower switching frequency and higher power efficiency.

FPWM Operation (LP6433F)

The LP6433F is designed to work at FPWM to maintain the good load regulation and transient performance. When the output decreases, the inductor is allowed to flow from the output to the ground plane. In this way, the switching frequency is kept the same even without load.

The FPWM operation mode reduced the output ripple under light load at the cost of lower light load efficiency.

Bootstrap Capacitor

The LP6433X integrates two N-MOSFET to achieve high efficiency. The high-side MOSFET is powered by the bootstrap capacitor C_{BST} , which is between the BST pin and SW pin. A $1\Omega\sim 100\Omega$ resistor is recommended in series with the bootstrap capacitor C_{BST} to reduce the switching noise and improve the system reliability.

Over Current Protection and Short Circuit Protection

The LP6433X protects an over current situation by limiting the inductor valley current. The current of low-side MOSFET is monitored all the time to sense the inductor valley current when the LP6433X is enabled. The high-side MOSFET cannot be turned on if the valley current is higher than the low-side valley current limit, protecting the inductor current from further increasing. The inductor current is limited to the valley current limit plus a half of the inductor ripple current.

The SCP is realized by monitoring the FB-pin voltage when the inductor current is limited. Once the output load draws more current than the current limit, the output voltage drops. When the FB voltage drops to 50% of the V_{ref} for 2-ms, the LP6433X shuts down. The LP6433X will restart after a typical 12-ms hiccup waiting time. If the SCP condition still holds after soft-start, the LP6433X shutdown again, repeating the hiccup operation.

When the over current condition is removed, the output voltage returns to normal operation.

Output Over-voltage Protection

The LP6433X stops switching immediately when the FB voltage rising above $110\%V_{ref}$ to protect the output capacitor voltage from further increasing. The LP6433X recovers switching when the FB voltage falls below $105\%V_{ref}$.

Thermal Protection

The LP6433X has a thermal protection function. The device will shut down when the internal temperature is higher than 160°C and will restart after the temperature drops below 135°C .



Application Information

Design Requirements

The table 1 shows the design parameters for a typical 5V output voltage in the IPC application.

Table 1 Design Parameters

Parameter	Target
Input voltage range	9~30V
Output voltage	5.0V
Transient ripple	±200mV
Operating frequency	500kHz

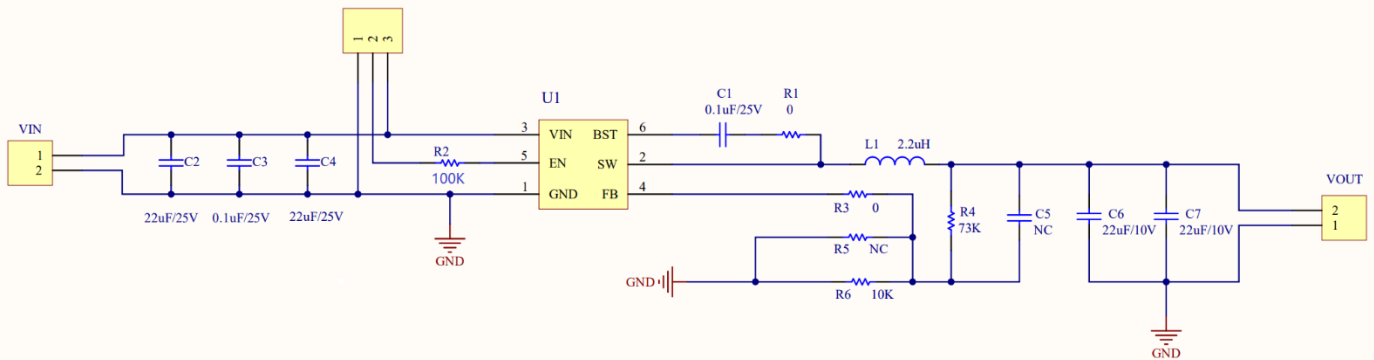


Figure 20. Typical schematic

Output Voltage Setting

The output voltage can be programmed by adjusting the external resistor divider R_{UP} and R_{DOWN} according to the equation below:

$$V_{OUT} = \left(\frac{R_{UP}}{R_{DOWN}} + 1 \right) * V_{ref}$$

When the output voltage is in regulation, the typical voltage at FB pin is 0.6V.

For better accuracy, the R_{DOWN} is recommended to be lower than 100kΩ to ensure the current flowing through R_{DOWN} is at least 100 times larger than the FB pin leakage current.

For a 5.0V-output application, a 10kΩ R_{DOWN} is selected and the R_{UP} is 73kΩ.

A resistor with higher than 1kΩ but lower than 100kΩ should be placed between the resistor divider and FB pin if a C_{ff} capacitor is soldered to reduce the switching noise influence.

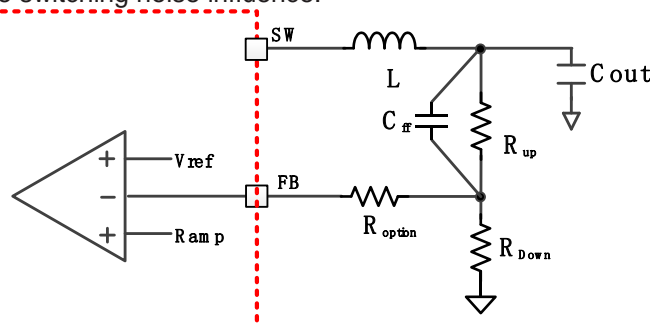


Figure 21. FB connection



EN Design

The LP6433XX allows the user to design a precise VIN voltage to enable the converter during power on. The startup sequence can be designed by adjusting the resistor divider of R_{UP_EN} and R_{DOWN_EN} with the equation below,

$$V_{EN} = \frac{1000k\Omega // R_{DOWN_EN}}{R_{UP_EN} + 1000k\Omega // R_{DOWN_EN}} * V_{IN}$$

where V_{EN} is the EN rising threshold voltage at which the converter is enabled, which is 1.2V typically. A 47pF-1nF capacitor is recommend to be soldered in parallel with the R_{EN_DOWN} to avoid the high-frequency noise influence from the switching node.

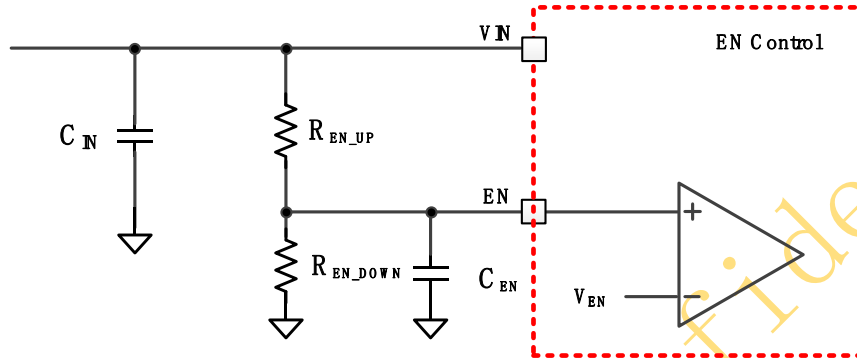


Figure 22. EN connection

Inductor and Output Capacitor Setting

The inductor ripple is calculated by the equation below:

$$I_{PP} = \left(\frac{V_{OUT}}{L * F_{SW}} * \frac{V_{IN} - V_{OUT}}{V_{IN}} \right)$$

To get a better efficiency, the inductor ripple is recommended to be controlled under 40% of the output current to minimize the AC loss of the inductor and power MOSFETs.

For a typical 12V input voltage and 5V output voltage, a low DCR value, 2.2-μH or 4.7-μH inductor is recommended.

The output capacitor not only impacts the output ripple but also the loop stability. Please follow the design rules in the table below. A feedforward capacitor C_{FF} can be selected to improve the transient behavior. The typical capacitance can be 10-100pF. For this design, 10V, X5R, 22μF capacitors (GRM21BR61A226ME51) from Murata are soldered at the V_{OUT} to GND. Multiple capacitors should be soldered to keep the system stable because of the voltage rating effect.

Table 2 Recommend R/L/C values

Vout	Inductor-L	Cout	R _{UP}	R _{DOWN}	R _{option}	C _{ff}
1.2V	1.5μH/3.3μH	22μF*1	10 kΩ	10 kΩ	0-10 kΩ	NA
3.3V	2.2μH~6.8μH	22μF*2	45 kΩ	10 kΩ	0-10 kΩ	22-100pF
5.0V	4.7μH ~10μH	22μF*2	73 kΩ	10 kΩ	0-10 kΩ	47-100pF

Bootstrap capacitor

Bootstrap capacitor is critical to drive the high-side MOSFET. A 0.1-μF ceramic capacitor is needed to supply power for the high-side driver. The capacitor should be at least 10V. The resistor R₁ is used to adjust the driver speed to optimize the EMI performance and reliability.

Input capacitor

A typical 22-μF ceramic capacitor is needed to serve as the bulk capacitor at the VIN pin. An additional 0.1-μF is strongly recommended to provide additional high frequency filtering and should be placed to the VIN pin and GND as close as possible.



PCB Layout Guidelines

Proper layout of the components to minimize high frequency current path loop is important to prevent electrical and magnetic field radiation and high frequency resonant problems. Follow this specific order carefully to achieve the proper layout.

- Place the input capacitors (C₂ and C₄, 0603 or 0402 size) as close as possible to VIN pin and GND pin and use shortest copper trace connection or GND plane, this is the most critical path and should have the highest priority when designing PCB floorplan. To minimize the switching noise, the SW pin is recommended to layout at the bottom layer by vias.
- Put output capacitor near to the inductor output terminal and the device. Ground connections need to be tied to the IC ground with a short copper trace or GND plane
- Place inductor input terminal to SW pin as close as possible and limit SW node copper area to lower electrical and magnetic field radiation. Do not use multiple layers in parallel for this connection. Minimize parasitic capacitance from this area to any other trace or plane.
- R₁ is reserved to slow down the switching speed for noise sensitive applications and R₃ with higher than 1k Ω resistor should be soldered if the feedforward capacitor is soldered at the same time.

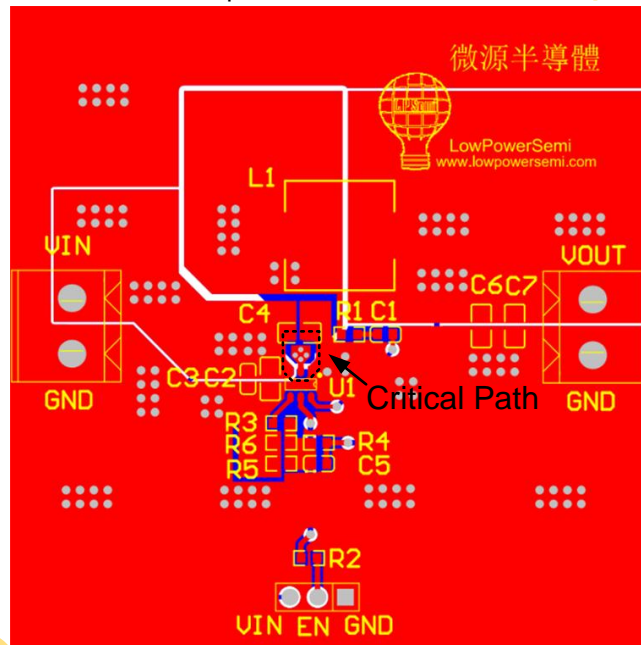
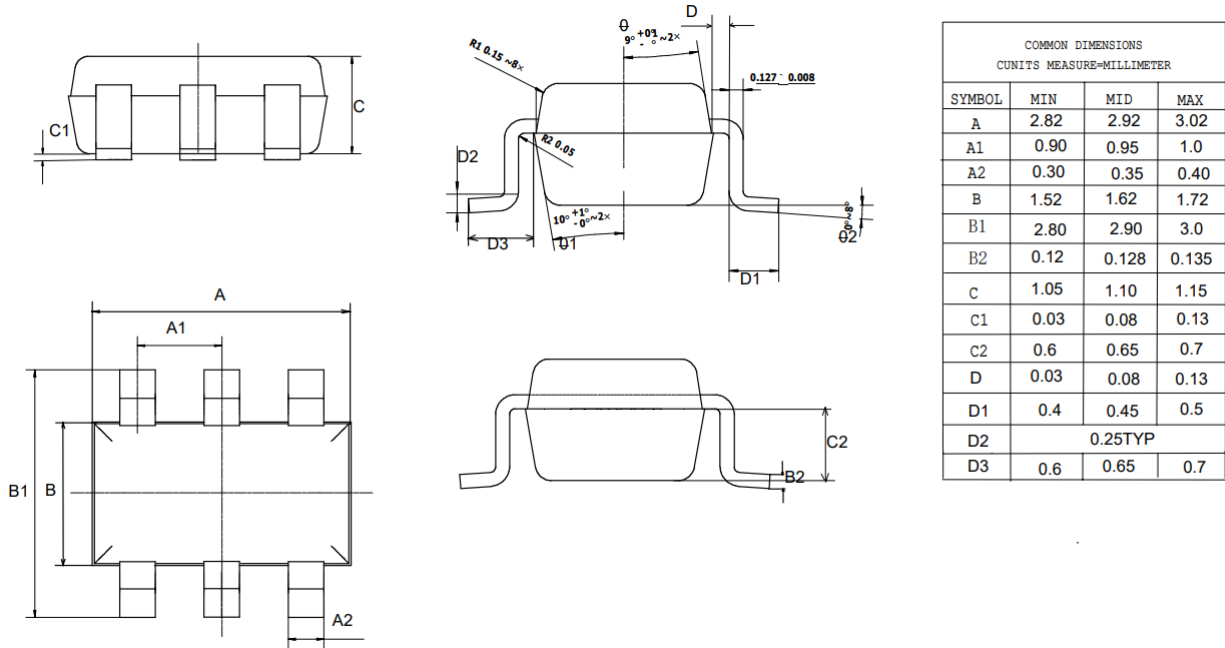


Figure 23. Layout example



Packaging Information

1.6mm×2.9mm SOT23-6 package

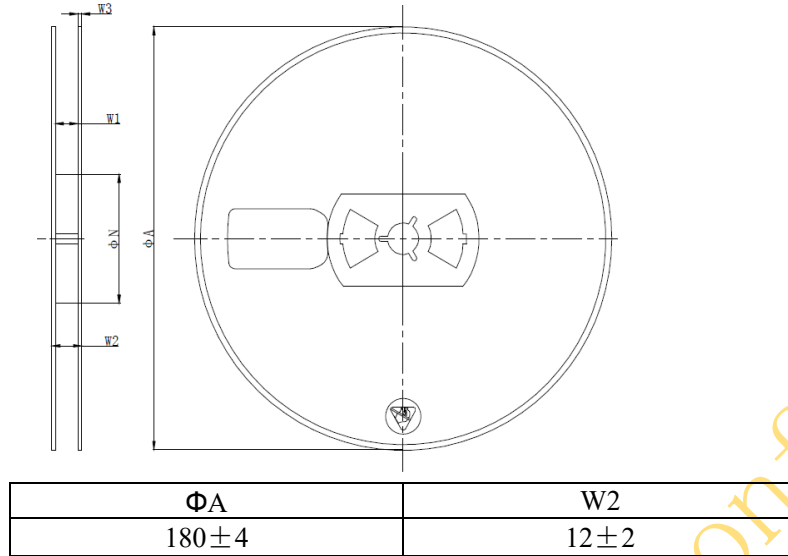


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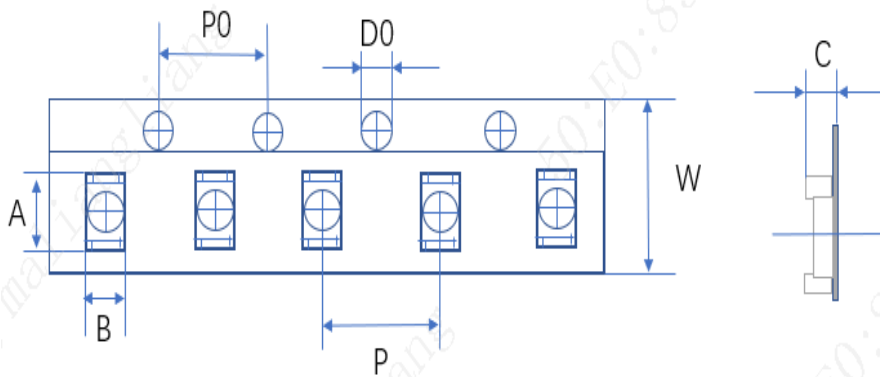


Tape and Reel Information

REEL DIMENSIONS (Unit: mm)



TAPE DIMENSIONS (Unit: mm)



Device	A	B	P0	P	D0	W	C
LP6433x	3.20 ± 0.20	3.26 ± 0.20	4.00 ± 0.10	4.00 ± 0.10	1.50 ± 0.10	8.00 ± 0.30	1.40 ± 0.20

PIN1 AND TAPE FEEDING DIRECTION

