TP6048BS6

600mA, 1.2MHz, 42V Synchronous Buck Converter

GENERAL DESCRIPTION

The TP6048BS6 is a high frequency, synchronous Buck converter with integrated switches. It can deliver up to 600mA to the output over a wide input voltage range of 5V to 42V. It is suitable for various industrial or automotive applications with high input voltage or for power conditioning from unregulated sources. Moreover, the low 14μA quiescent current and ultra-low shutdown current of only 0.6μA make it a suitable choice for battery-powered applications.

TP6048BS6 features high efficiency over a wide load range achieved by scaling down the switching frequency at light loads to reduce switching and gate driving losses. Other features include internal compensation, internal monotonic soft-start even with pre-biased output and fast loop response thanks to the peak- current mode controller. Switching at 1.2MHz, the TP6048BS6 can prevent EMI noise problems, such as the ones found in AM radio, ADSL and PLC applications.

Protection features include current limiting and short- circuit protection, thermal shutdown with auto recovery and output over-voltage protection. Frequency fold-back helps prevent inductor current runaway during startup.

TP6048BS6 is available in a Green SOT23-6 package.

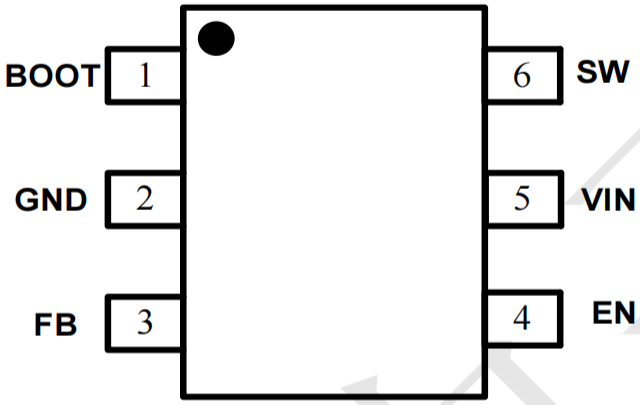
FEATURES

- Wide 5V~42V Operating Input Voltage Range
- 0.8V Internal Reference
- Low Quiescent Current: 14μA (TYP)
- Shutdown Current: 0.6μA (TYP)
- Current Output up to 600mA
- 1.2MHz Switching Frequency
- Internal Compensation and Soft-Start
- Simple Design and Minimal External Components
- Up to 95% Efficiency at 12V/400mA
- 0.8V to 24V Adjustable Output Voltage
- Current Limit and Short-Circuit Protection
- Output Over-Voltage Protection and Thermal Shutdown
- Power-Save Mode and PWM Mode Operation
- Monotonic Startup with Pre-biased Output
- 90% Maximum Duty Cycle
- Available in a Green SOT23-6 Package
- -40℃ to +85℃ Operating Temperature Range

APPLICATIONS

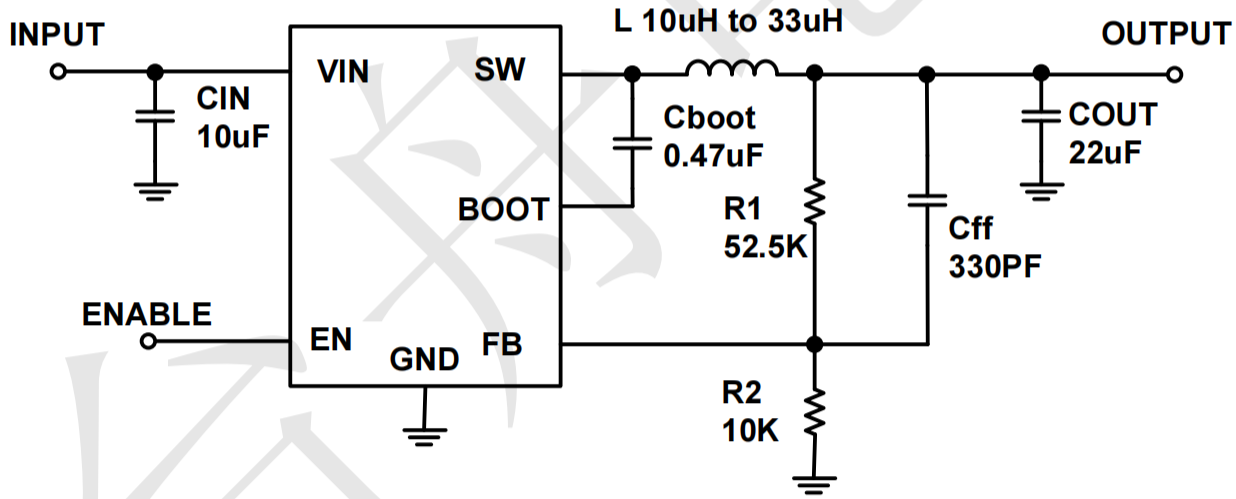
High Voltage Power Conversions
Automotive Systems
Industrial Power Systems
Distributed Power Systems
Battery Powered Systems
Power Meters

PIN CONFIGURATION（TOP VIEW）



SOT23-6

Typical Operating Circuit（VOUT=5.0V）



PIN DESCRIPTION

PIN SOT23-6	NAME	FUNCTION
1	BOOT	Bootstrap pin is used to provide a drive voltage, higher than the input voltage, to the topside power switch. Place a 0.47μF Boost capacitor (C_{BOOT}) as close as possible to the IC between this pin and SW pin. Do not place a resistor in series with this pin.
2	GND	Ground pin is the reference for input and the regulated output voltages. Special layout considerations are required.
3	FB	Feedback pin for programming the output voltage. The regulates the FB pin to 0.8V. Connect the feedback resistor divider tap to this pin. If the FB voltage exceeds 110% of 0.8V, over-voltage protection (OVP) will stop all PWM switching.
4	EN	Enable pin should not be left open and it should not be driven above VIN + 0.3V. Device will operate when the EN pin is high and shut down when the EN pin is low. EN can be tied to VIN pin via a resistor if the shutdown feature is not required or to a logic input for controlling shutdown.
5	VIN	VIN pin is connected to the input supply voltage and powers the internal control circuitry. This voltage is monitored by a UVLO lockout comparator. VIN is also connected to the drain of the converter top switch. Due to power switching, this pin has high di/dt transition edges and must be decoupled to the GND by input capacitors as close as possible to the GND pin to minimize the parasitic inductances.
6	SW	Switching node pin is the output of the internal power converter and should be connected to the output inductor. Bootstrap capacitor also connects to this pin. This node should be kept small on the PCB to minimize capacitive coupling, noise coupling and radiation.

ABSOLUTE MAXIMUM RATINGS

VIN to GND.....-0.3V to 45V
EN to GND.....-0.3V to VIN+0.3V
FB to GND.....-0.3V to 5.5V
SW to GND..... -0.3V to VIN+0.3V
BOOT to SW.....-0.3V to 5.5V
Storage Temperature Range.....-65℃ to +150℃
Junction Temperature.....150℃
Lead Temperature (Soldering, 10 sec).....260℃
Package Thermal Resistance(θ_{JA})
SOT23-6.....200℃/W
ESD Susceptibility
HBM.....2000V

RECOMMENDED OPERATING CONDITIONS

Input Voltage Range.....5V to 42V
Operating Temperature Range .....-40℃ to +85℃

OVERSTRESS CAUTION

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 SENSITIVITY CAUTION

This integrated circuit can be damaged by ESD if you don’t pay attention to ESD protection. Broadchip recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

DISCLAIMER

Broadchip reserves the right to make any change in circuit design, specification or other related things if necessary without notice at any time. Please contact Broadchip sales office to get the latest datasheet.

ELECTRICAL CHARACTERISTICS

(VIN= 18V, T_A = 25℃, unless otherwise specified.)

PARAMETER		SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Input Voltage		V_{IN}		5		42	V
Under-Voltage Lockout Threshold		V_{UVLO}		4.45	4.7	4.95	V
Under-Voltage Lockout Threshold Hysteresis		V_{UVLO_HYS}			370		mV
VIN Quiescent Current	Shutdown	I_Q	V_{EN} = 0V		0.6	1.2	μA
	Sleep Mode		V_{EN} = 2V, Not Switching, V_{IN} ≤ 36V		14	20	
Feedback Reference Voltage		V_{FB}	V_{IN} = 6V	0.777	0.800	0.823	V
Feedback Pin Input Current		I_{FB}	V_{FB} = 1V		0.1	1	μA
Minimum High-side Switch On-Time		t_{ON_MIN}	I_{LOAD} = 600mA		100		ns
Minimum High-side Switch Off-Time		t_{OFF_MIN}			100		ns
Switching Frequency		f_{SW}		0.85	1.2	1.5	MHz
Switch Leakage Current		I_{SW_H}	V_{SW} = 42V		0.1	1	μA
		I_{SW_L}	V_{SW} = 0V		0.1	1	μA
Top Power NMOS Current Limit		I_{LIM}		0.9	1.2	1.5	A
Top Power NMOS On-Resistance		R_{DSON}	I_{LOAD} = 0.1A		700		mΩ
Bottom Power NMOS On-Resistance			I_{LOAD} = 0.1A		300		mΩ
EN Input High Voltage		V_{IH}		1.2			V
EN Input Low Voltage		V_{IL}				0.5	V
EN Threshold, Hysteresis		V_{EN_HYS}			120		mV
Enable Leakage Current		I_{EN}	V_{EN} = 5V		0.1	1	μA
Output Over-Voltage Threshold		V_{OUT_OV}	OVP Rising	0.84	0.89	0.95	V
			OVP Falling	0.80	0.85	0.90	
Thermal Shutdown		T_{SHDN}			150		℃
Thermal Shutdown Hysteresis		T_{HYS}			20		℃

FUNCTIONAL DESCRIPTION

Overview

The TP6048BS6 is an internally compensated wide input range current mode controlled synchronous Buck converter. It is designed for high reliability and is particularly suitable for power conditioning from unregulated sources or battery-powered applications that need low sleep/ shutdown currents. It alsofeatures a power-save mode in which operating frequency is adaptively reduced under light loadconditions to reduce switching and gate losses and keep high efficiency. At no load and with switching stopped, the total operating current is approximately 14μA. If the device is disabled, the total consumption is typically0.6μA.

The two integrated MOSFET switches of the power stage are both over-current protected and can provide up to 600mA of continuous current for the load. Current limiting of the switches also prevents inductor current runaway. The converter switches are optimized for high efficiency at low duty cycle.

At the beginning of each switching cycle, the high-side switch is turned on. This is the time that feedback voltage (VFB) is below the reference voltage (VREF) and power must be delivered to the output. After the on-period, the high-side switch is turned off and the low-side switch is turned on until the end of switching cycle. For reliable operation and preventing shoot through, a short dead time is always inserted between gate pulses of the converter complimentary switches. During dead time, both switch gates are kept off.

The device is designed for safe monotonic start-up even if the output is pre-biased.

If the junction temperature exceeds a maximum threshold (TSHDN, typically +150℃), thermal shutdown. protection will happen and switching will stop. The device will automatically recover with soft-start when the junction temperature drops back well below the trip point. This hysteresis is typically 20℃.

The TP6048BS6 has current limit on both the high-side and low-side MOSFET switches. When current limit is activated, frequency fold-back is also activated. This occurs in the case of output overload or short circuit. Note that TP6048BS6 will continue to provide its maximum output current and will not shut down or hiccup. In such a case, the junction temperature may rise rapidly and trigger thermal shutdown.

During initial power-up of the device (soft-start), current limit and frequency fold-back are activated to prevent inductor current runaway while the output capacitor is charging to the desired VOUT.

Peak-Current Mode (PWM Control)

The TP6048BS6 employs fixed-frequency peak-current mode control in continuous conduction mode

FUNCTIONAL DESCRIPTION（Continued）

(when inductor minimum current is above zero). In light load conditions (when the inductor current reaches zero) the TP6048BS6 will enter discontinuous conduction mode and the control mode will change to shift frequency, peak-current mode to reduce the switching frequency and the associated switching and gate driving losses (power-save mode).

In continuous conduction mode, TP6048BS6 operates at fixed-frequency using peak-current mode control scheme. The controller has an outer voltage feedback loop to get accurate DC voltage regulation. The output of the outer loop is fed to an inner peak-current control loop as reference command that adjusts the peak- current of the inductor. The inductor peak-current is sensed from the high-side switch and is compared to the peak-current reference to control the duty cycle. In other words , as soon as the inductor current reaches the reference peak-current determined by voltage loop, the high-side switch is turned off and the low-side switch is turned on after dead time.

The internally compensated voltage feedback loop allows for simpler design, fewer external components, and stable operation with almost any combination of output capacitors.

Power-Save Mode

When the load is reduced, the inductor minimum (valley) current eventually reaches zero level (boundary condition). Synchronous rectifier (low-side switch) current is always sensed and when it reaches zero, the controller turns off the low-side switch and does not let the low-side switch sink current. This prevents inductor current from going below zero (negative). This results in discontinuous conduction mode (DCM) operation in which inductor current remains zero until next switching cycle. Both switches are off during this period and do not act as complementary switches. This off-time will extend (that means lower frequency) until output voltage falls below reference voltage again and triggers a new switching cycle. With a new cycle, the high-side switch is turned on again for almost the same t_{ON} time as CCM. Therefore, the output capacitors take almost the same charge in each cycle and with lighter loads it will take longer off-times until output capacitor voltage falls below the reference voltage. The extended off-times mean lower switching frequency that is called frequency fold-back and significantly reduces the switching losses, but usually increases the output ripple a little bit.

Note that the on-time of synchronous rectifier switch should always be long enough to fully charge the bootstrap capacitor and prevent bootstrap under-voltage lockout due to insufficient voltage for the high-side switch gate driver.

FUNCTIONAL DESCRIPTION（Continued）

Floating Driver and Bootstrap Charging UVLO Protection

The high-side MOSFET driver is powered by a floating supply provided by an external bootstrap capacitor. The bootstrap capacitor is charged and regulated to about 5V by the dedicated internal bootstrap regulator. When the voltage between BOOT and SW nodes is below regulation, a PMOS pass transistor turns on and connects VIN and BOOT pins internally, otherwise it will turn off. The power supply for the floating driver has its own UVLO protection. The rising UVLO threshold is about 4.7V and with 370mV hysteresis, the falling threshold is about 4.3V. In case of UVLO, the reference voltage of the controller is reset to zero and after recovery a new soft-start process will start.

Output Over-Voltage Protection (OVP)

The TP6048BS6 contains an over-voltage comparator that monitors the FB pin voltage. The over-voltage threshold is approximately 110% of nominal FB voltage. When the voltage at the FB pin exceeds the over-voltage threshold (VOUT_OV), PWM switching will be stopped and both high-side and low-side switches will be turned off. If the over-voltage fault is removed, the regulator will automatically recover.

The error amplifier is normally able to maintain regulation since the synchronous output stage has excellent sink and source capability. However it is not able to regulate output when the FB pin is disconnected or when the output is shorted to a higher supply like input supply. Also when VOUT is set to its minimum (0.8V) usually there is no voltage divider and VOUT is directly connected to FB through a resistor (R1 in the divider) and there is no resistor to ground (no R2). In such case and with no load, an internal current source of 5μA ~ 6μA from BOOT into the SW pin, which can slowly charge the output capacitor and pull VOUT up to VIN. Therefore a minimum load of at least 10μA must be always present on VOUT (for example an 80kΩ resistor: 0.8V/10μA = 80kΩ).

If the FB pin is disconnected, a tiny internal current source will force the voltage at the FB pin to rise above VOUT_OV that triggers over-voltage protection and disables the regulator to protect the loads from a significant over-voltage. Also, if by accident a higher external voltage is shorted to the output, VFB will rise above the over-voltage threshold and trigger an OVP event to protect the low-side switch.

FUNCTIONAL DESCRIPTION（Continued）

Minimum High-side On/Off-Time and Frequency Fold-Back

The shortest duration for the high-side switch on-time (t_{ON_MIN}) is 100ns (TYP). For the off-time (t_{OFF_MIN}) the minimum value is 100ns (TYP). The duty cycle (or equivalently the VOUT/VIN ratio) range in CCM operation is limited by t_{ON_MIN} and t_{OFF_MIN} depending on the switching frequency. Note that at 1.2MHz the total cycle time is t_{SW} = 833ns.

The minimum and maximum duty cycles without frequency fold-back are given by Equations：

$$D_{MIN} = t_{ON_MIN} \times f_{SW} \quad (1)$$

$$D_{MAX} = 1 - t_{OFF_MIN} \times f_{SW} \quad (2)$$

For any given output voltage, the highest and minimum input voltage without frequency fold-back can be calculated from:

$$V_{IN_MAX} = \frac{V_{OUT}}{f_{SW} \times t_{ON_MIN}} \quad (3)$$

$$V_{IN_MIN} = \frac{V_{OUT}}{1 - f_{SW} \times t_{OFF_MIN}} \quad (4)$$

Input Voltage

The TP6048BS6 can operate efficiently for inputs as high as 42V. For CCM operation (continuous conduction mode) keep duty cycle between 12% and 88%.

Output Voltage

The output voltage can be stepped down to as low as the 0.8V reference voltage (VREF). As explained before, when the output voltage is set to 0.8V and there is no voltage divider, a minimum small load will be needed. An 80kΩ resistor to ground will prevent the output voltage floating up.

Soft-Start

Soft-start is necessary to limits the input inrush current right after power-up or enabling the device.Soft-start is implemented by slowly ramping up the reference voltage that in turn slowly ramps up the output voltage to its target regulation value.

FUNCTIONAL DESCRIPTION（Continued）

Enable

EN pin turns the TP6048BS6 operation in on or off condition. If an applied voltage less than 0.5V, the device will shut down. If the voltage more than 1.2V, the device will start the regulator. The EN pin is an input and must not be left open. The simplest way to enable the device is to connect the EN pin to VIN pin via a resistor. This enables the TP6048BS6 to start up automatically when VIN is within the operating range An external logic signal can be used to drive the EN input for power savings, power supply sequencing and/or protection. If the EN pin is driven by an external logic signal, a 10kΩ resistor in series with the input is recommended.

Note: Voltage on the EN pin should never exceed VIN + 0.3V. Do not drive the EN pin with a logic level if VIN is not present. This can damage the EN pin and the device.

Thermal Shutdown

Thermal protection is designed to protect the die against overheating damage. If the junction temperature exceeds +150℃, the switching stops and the device shuts down. Automatic recovery with an internal soft-start will begin when the junction temperature drops below the +130℃ falling threshold.

APPLICATION INFORMATION

External Components

The following guidelines can be used to select external components.

f_{SW} (MHz)	V_{OUT} (V)	R_1 (kΩ)	R_2 (kΩ)	L (μH)	C_{BOOT} (μF)	C_{IN} (μF)	C_{OUT} (μF)
1.2	3.3	31.2	10	10	0.47	10	10
	5	52.5	10	22	0.47	10	22
	12	140	10	47	0.47	10	47

Setting the Output Voltage

The internal reference VREF is 0.8V (Typical).The output voltage is divided by a resistor, R1 and R2 to the FB pin. The output voltage is given by:

$$V_{OUT} = 0.8 \times (1 + \frac{R1}{R2}) \qquad (5)$$

To keep operating quiescent current small and prevent voltage errors due to leakage currents, it is recommended to choose R1 in the range of 10kΩ to 100kΩ.

If the output has no load other than the FB divider, make sure the divider draws at least 10μA from VOUT or an internal current source (5μA ~ 6μA) from BOOT to SW will slowly charge the output capacitor beyond the desired voltage.

Inductor Selection

Higher operating frequency allows the designer to choose smaller inductor and capacitor values; however, the switching and gate losses are increased. On the other hand, at lower frequencies the current ripple (ΔI_L) is higher, which results in higher light load losses. Use Equation 6 to calculate the required inductance (LMIN). K is the ratio of the inductor peak-to-peak ripple (ΔI_L) to the maximum operating DC current (IOUT). The recommended selection range for K is between 0.2 and 0.4. Choosing a higher K value reduces the selected inductance, but a too high K factor may result in insufficient slope compensation. The inductance is selected based on the desired peak-to-peak ripple current (ΔI_L) for CCM. Equation 7 shows that ΔIL is inversely proportional to f_{SW} × L and is increased at the maximum input voltage (VIN_MAX). Therefore by accepting larger ΔI_L values, smaller inductances can be chosen but the cost is higher output voltage ripple and increased core losses.

$$\Delta I_L = \frac{V_{OUT} \times (V_{IN_MAX} - V_{OUT})}{V_{IN_MAX} \times L \times f_{SW}} \qquad (6)$$

$$L_{MIN} = \frac{V_{IN_MAX} - V_{OUT}}{I_{OUT} \times K_{IND}} \times \frac{V_{OUT}}{V_{IN_MAX} \times f_{SW}} \qquad (7)$$

APPLICATION INFORMATION（Continued）

Inductor peak-current should never exceed the saturation even in transients to avoid over-current protection. Also inductor RMS rating should always be larger than operating RMS current even at maximum ambient temperature.

Note that it is generally desired to choose a smaller inductance value to have faster transient response, smaller size, and lower DCR. On the other hand, if the inductance is too small, current ripple will increase which can trigger over-current protection. Larger inductor current ripple also implies larger output voltage ripple with the same output capacitors. For peak-current mode control, it is recommended to choose large current ripple, because controller comparator performs better with higher signal to noise ratio. So, for this design example, K = 0.4 is chosen, and the minimum inductor value is calculated to be 15.3μH. The nearest standard value would be a 22μH ferrite inductor with a 1A RMS current rating and 1.5A saturation current that are well above the designed converter output current RMS and DC respectively.

Bootstrap Capacitor Selection

The TP6048BS6 requires a small external bootstrap capacitor, CBOOT, between the BOOT and SW pins to provide the gate drive supply voltage for the high-side MOSFET. The bootstrap capacitor is refreshed when the high-side MOSFET is off and the low-side switch conducts. An X7R or X5R 0.47μF ceramic capacitor with a voltage rating of 16V or higher is recommended for stable operating performance over temperature and voltage variations.

Input Capacitor Selection

The input capacitor also provides the high frequency switching transient currents. So, choosing a low-ESR and small size capacitor with high self-resonance frequency and sufficient RMS rating is necessary. The recommended high frequency decoupling capacitor value is 10μF X5R or X7R or higher. It is recommended to choose the voltage rating of the capacitor(s) at least twice the maximum input voltage to avoid derating of the ceramic capacitors with DC voltage. The value for the input capacitor is not critical but must be rated to handle the maximum input voltage including ripple. For this design, one 10μF, X7R, 50V is selected for the input decoupling capacitor. The ESR is approximately 10mΩ, and the current rating is 1A. To improve high frequency filtering, a small parallel 0.1μF capacitor may be placed as close as possible to the device pins.

APPLICATION INFORMATION（Continued）

Output Capacitor Selection

The output capacitor is required to keep the output voltage ripple small and to ensure regulation loop stability. The output capacitor must have low impedance at the switching frequency. Ceramic capacitors with X5R or X7R dielectrics are recommended due to their low ESR and high ripple current ratings.The output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \left(R_{ESR} + \frac{1}{8 \times f_S \times C_O}\right)$$

PCB Layout Recommendations

When laying out the printed circuit board, the following checking should be used to ensure proper operation of the TP6048BS6 Check the following in your layout:

The power traces, consisting of the GND trace, the SW trace and the VIN trace should be kept short, direct and wide

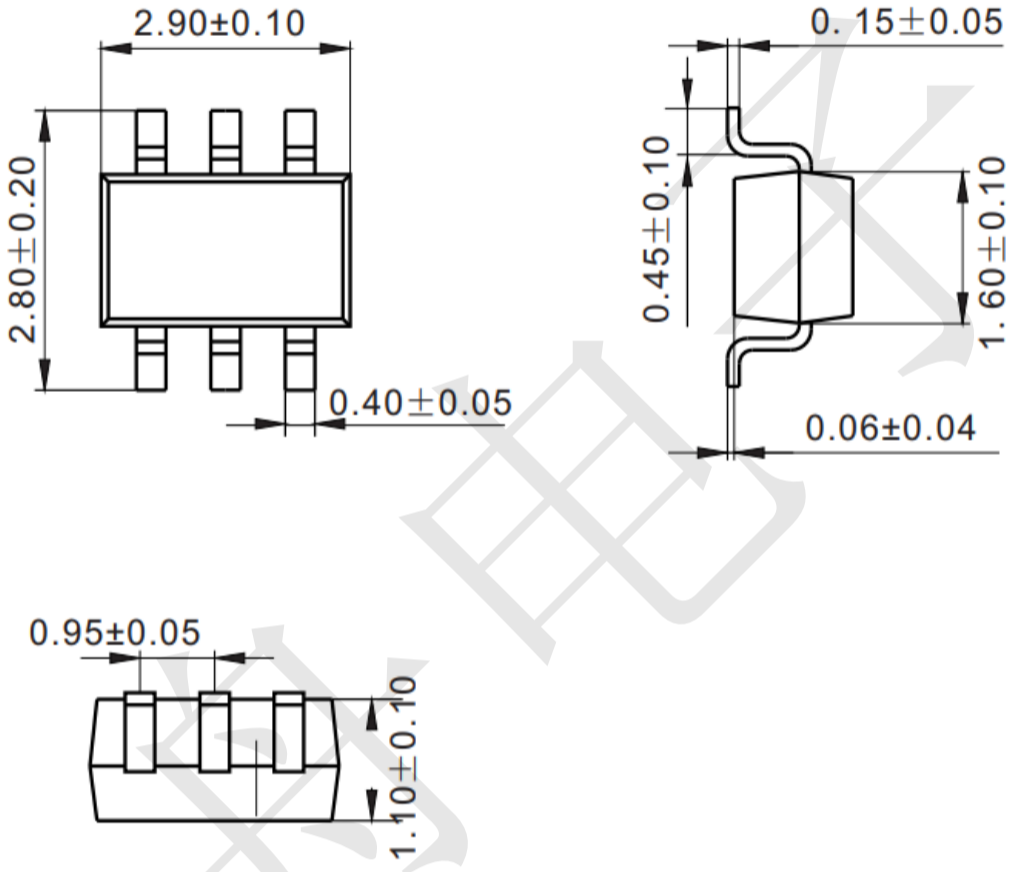
Does the (+) plates of CIN connect to VIN as closely as possible. This capacitor provides the AC current to the internal power MOSFETs.

Keep the switching node, SW, away from the sensitive VOUT node.

Keep the (-) plates of CIN and COUT as close as possible

Package information (Unit: mm)

SOT23-6



Mounting Pad Layout (Unit: mm)

