Automotive Grade 1-A Transformer Driver

Features

- Low-Side Center-Tapped Transformer Driver
- Automotive AEC-Q100 Grade-1 (TPM6501xQ only)
- Low-Noise, Low EMI with Spread Spectrum
  - Switching Frequency 420 kHz (TPM6501A)
  - Switching Frequency 2.2 MHz (TPM6501B)
- Support 2.25-V to 5.5-V Supply with 1-A Primary Side Current
- Soft-Start and Current Limit Protection
- Slew Rate and Switching Frequency Optimized for EMC
- Over-Temperature Protection
- SOT23-5 Package

Applications

- Isolated Power Supply for Battery Monitor Systems
- Isolated Power Supply for Interface Drivers
- Isolated Power Supply for Industrial Application
- Isolated Power Supply for Gate Drivers

Description

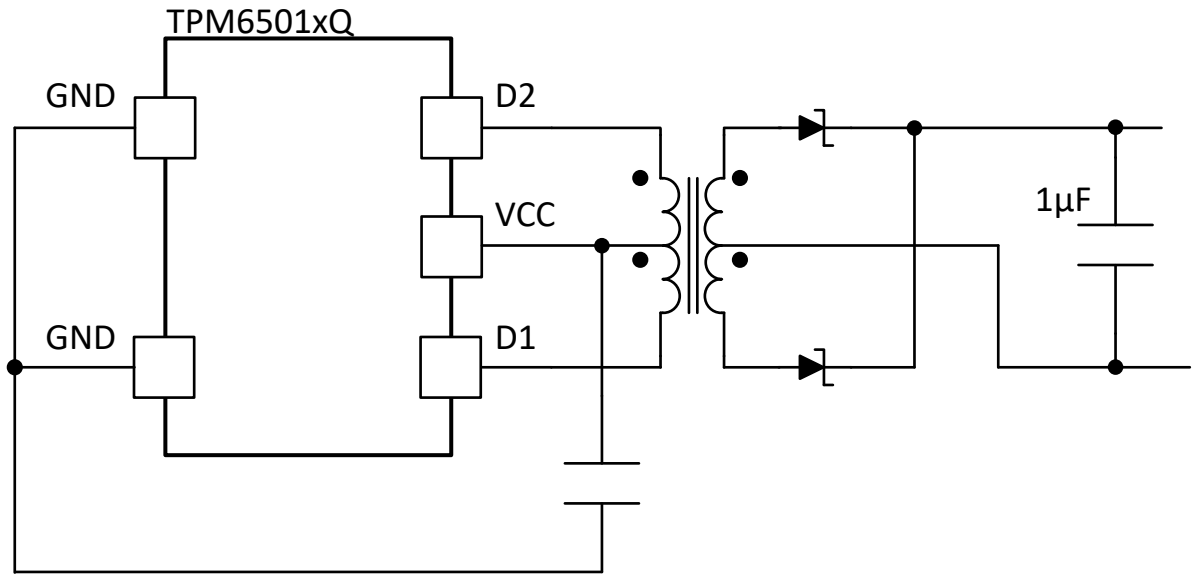
The TPM6501x/TPM6501xQ is a push-pull transformer driver family for isolated power supplies. The TPM6501xQ is qualified for automotive grade AEC-Q100 Grade 1. It is an open-loop center-tapped transformer driver with a voltage range from 2.25 V to 5.5 V. It is designed to optimize for EMC and noise performance.

The TPM6501x family is a simple solution for an isolated power supply. The device has an internal oscillator that generates a switching frequency with spread spectrum on the dual output channels. It supports both the 420-kHz option (TPM6501A) and the 2.2-MHz option (TPM6501B) for different EMC requirements. The interleaved dual-channel low-side outputs drives the transformer to generate an isolated power supply with a maximum 1-A switching current.

The TPM6501x device has high efficiency, low 0.25-Ω, and low on-resistance $R_{ds(ON)}$ output channels. The device has built-in 1.5-A current limit and over-temperature protection features to protect the system from hazardous scenarios.

The TPM6501x device is available in the SOT23-5 package, and supports a wide ambient temperature range from −40°C to 125°C.

Typical Application Circuit



Product Family Table

Order Number	Switching Frequency (kHz)	Package	Application
TPM6501AQ-S5TR-S	420	SOT23-5	Automotive
TPM6501BQ-S5TR-S	2200	SOT23-5	Automotive
TPM6501A-S5TR	420	SOT23-5	Industrial
TPM6501B-S5TR	2200	SOT23-5	Industrial

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Revision History

Date	Revision	Notes
2024-01-05	Rev.A.0	Initial release
2025-05-23	Rev.A.1	Added ESD ratings for automotive AECQ100 standards.

Pin Configuration and Functions

TPM6501xQ
SOT23-5 Package
Top View

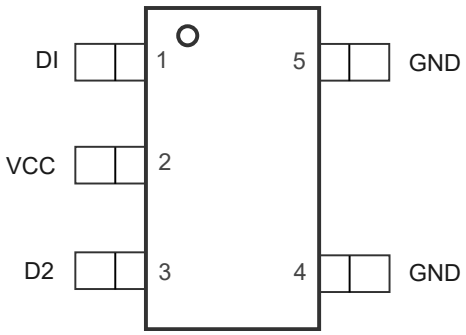


Table 1. Pin Functions: TPM6501

Pin	Name	I/O	Description
SOT23-5			
1	D1	Output	Open-drain output 1. Connect to transformer primary side 1
2	VCC	Power	Power supply. Connect a 0.1-uF and a 10-uF low ESR capacitor.
3	D2	Output	Open-drain output 2. Connect to transformer primary side 2
4	GND	Ground	Device ground.
5	GND	Ground	Device ground.

Specifications

Absolute Maximum Rating

Parameter		Min	Max	Unit
V_{CC}	Supply Voltage	−0.5	6	V
V_{OUT}	D1, D2 Output Voltage	−0.5	30	V
I_{OUT}	D1, D2 Output Current		2.4	A
I_{OUT}	D1, D2 Output Current, transient pulse width < 1 μs		4	A
T_J	Maximum Junction Temperature	−40	150	°C
T_{STG}	Storage Temperature Range	−65	150	°C
T_L	Lead Temperature (Soldering 10 sec)		260	°C

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime. This data was taken with the JEDEC low-effective thermal conductivity test board. This data was taken with the JEDEC standard multilayer test boards.

ESD, Electrostatic Discharge Protection

Table 2. TPM6501x

Symbol	Parameter	Condition	Minimum Level	Unit
HBM	Human Body Model ESD	ANSI/ESDA/JEDEC JS-001 (1)	±5000	V
CDM	Charged Device Model ESD	ANSI/ESDA/JEDEC JS-002 (2)	±1500	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

Table 3. TPM6501xQ

Symbol	Parameter	Condition	Minimum Level	Unit
HBM	Human Body Model ESD	AEC-Q100-002	±5000	V
CDM	Charged Device Model ESD	AEC-Q100-011	±1500	V

Recommended Operating Conditions

Parameter		Min	Typ	Max	Unit
V_{CC}		2.25		5.5	V
I_{D1} , I_{D2}	Output Current			1	A
T_A	Ambient Temperature	−40		125	℃

Thermal Information

Package Type	θ_{JA}	θ_{JC}	Unit
SOT23-5	159.6	11.5	°C/W

Electrical Characteristics

Over full-range of recommended operating conditions, T_A = −40°C to 125 °C unless otherwise noted. All typical values are at T_A = 25°C, V_{CC} = 5 V, and R_L = 50 Ω to V_{CC}.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Supply Voltage and Current						
I_Q	Quiescent Current	VCC = 5 V, no load, TPM6501A		1.9	4	mA
		VCC = 5 V, no load, TPM6501B		3.6		
$V_{(UVLO_rising)}$	Under Voltage Lockout, rising threshold			2.1	2.25	V
$V_{(UVLO_falling)}$	Under Voltage Lockout, falling threshold		1.65	1.78		V
$V_{(UVLO_hys)}$	Under Voltage Lockout, hysteresis			0.27		V
Output Drivers						
$f_{(SW)}$	D1, D2 Average Switching Frequency (TPM6501A)		340	440	515	kHz
	D1, D2 Average Switching Frequency (TPM6501B)			2200		
t_{mm}	Average on-time Mismatch between D1 and D2			0		μs
$R_{ds(ON)}$	Output on-resistance	VCC = 4.5 V		0.23		Ω
		VCC = 2.8 V		0.26		
		VCC = 2.25 V		0.3		
$V_{(SLEW)}$	Voltage Slew Rates on D1 and D2 for TPM6501A			48		V/μs
	Voltage Slew Rates on D1 and D2 for TPM6501B			152		
$I_{(SLEW)}$	Voltage Slew Rates on D1 and D2 for TPM6501A			11		A/μs
	Voltage Slew Rates on D1 and D2 for TPM6501B			42		
Protection						
I_{LIMIT}	Output Current Limit	Steady state current	1.1	1.5	2.4	A
T_{SD}	Thermal Shutdown Threshold		150	168	184	°C
T_{SD_HYS}	Thermal Shutdown Threshold Hysteresis			18		°C
Timing						
t_{DEAD}	Deadtime between D1 and D2	TPM6501A, 420 kHz		50		ns
t_{ss}	Soft-start Time, TPM6501A			4.2	7	ms

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
$t_{ssdelay}$	Softstart Time Delay, TPM6501A		4.7	8.3	13	ms
t_{UVLO_delay}	Power up Delay Time			60		μs

Typical Performance Characteristics

All test conditions: V_{IN} = 5 V, T_A = 25°C, unless otherwise noted.

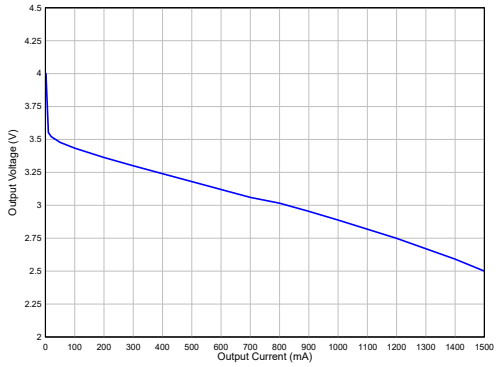


Figure 1. Output Voltage vs. Load Current

V_{OUT} = 3.3 V

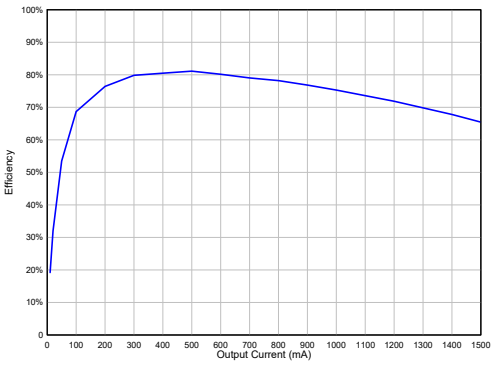


Figure 2. Efficiency vs. Load Current

V_{OUT} = 3.3 V

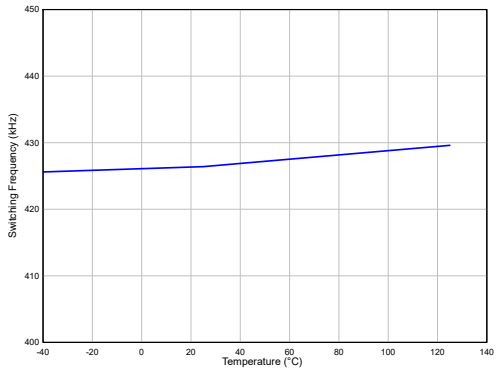


Figure 3. Switching Frequency vs. Temperature

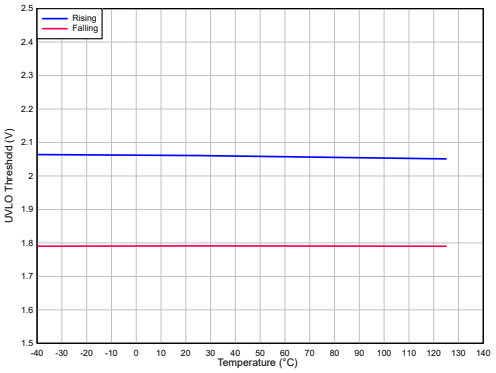


Figure 4. Under-Voltage Threshold vs. Temperature

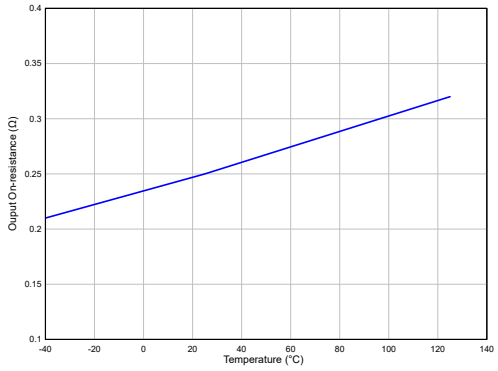


Figure 5. On-resistance vs. Temperature

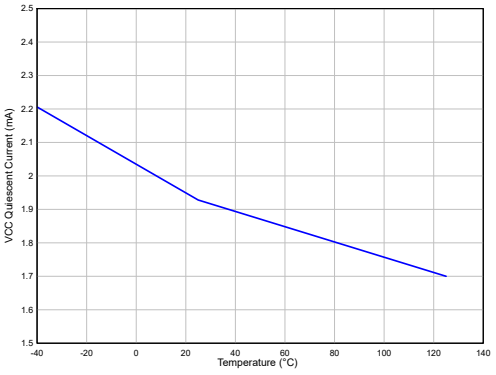


Figure 6. Quiescent Current vs. Temperature

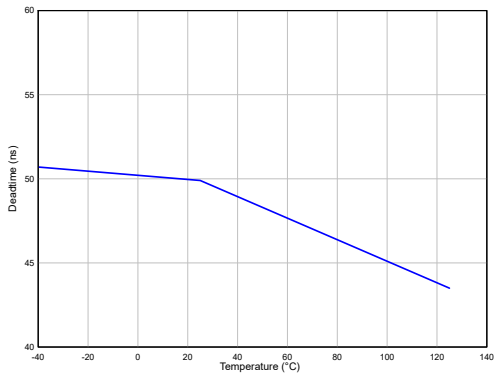


Figure 7. Deadtime vs. Temperature

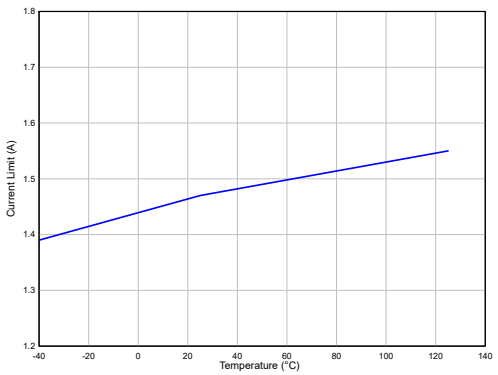


Figure 8. Current Limit Threshold vs. Temperature

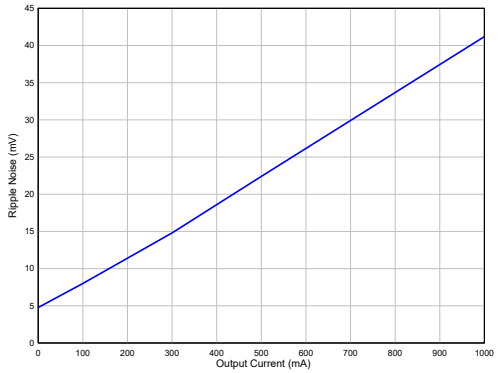


Figure 9. Output Ripple Noise vs. Temperature

Detailed Description

Overview

The TPM6501x is a push-pull transformer driver family designed for an isolated power supply. The TPM6501xQ is automotive-grade (AECQ100 Grade 1), and the TPM6501x is industrial-grade. The device has two complementary low-side MOSFETs to drive a center-tapped transformer to generate an isolated power supply.

The two output channels drive with a dead time in between to avoid shorting out both of the primary side inputs. On the secondary side, two rectification diodes are needed to rectify the output voltage. The device family supports both 420-kHz (TPM6501A) and 2200-kHz (TPM6501B) switching frequencies with spread spectrum to reduce electro-magnetic emissions.

The device has soft-start, current limit protection, and over-temperature protection features to protect the device from hazardous scenarios.

Functional Block Diagram

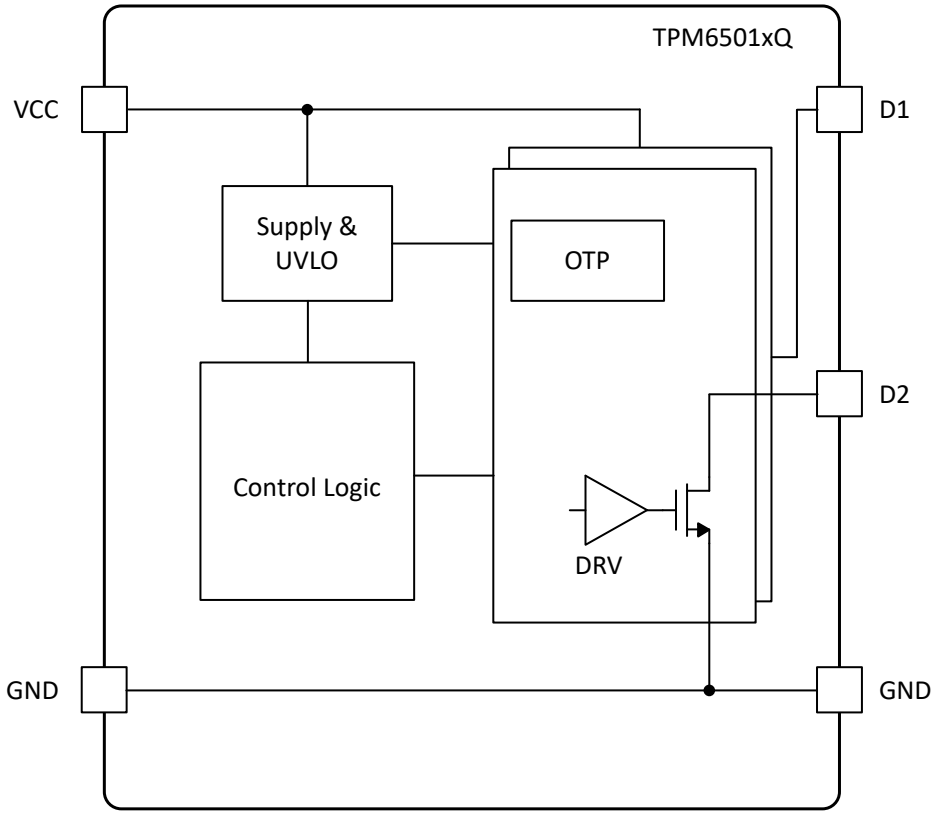


Figure 10. Functional Block Diagram

Feature Description

Push-pull Converter

The push-pull converter utilizes a center-tapped to transfer power from the primary side to the secondary side.

The dual low-side switches Q1 and Q2 are connected to inputs of the transformer's primary side. Q1 and Q2 drive half of the transformer coil complementarily. When Q1 is driving, current flows from the center tap to D1, through Q1 to GND. With the other half of the transformer floating, the device generates $2\times V_{IN}$ at the open end of D2. When Q2 is driving, current flows from the center-tap to D2, through Q2 to GND. With the other half of the transformer floating, the device generates $2\times V_{IN}$ at the open end of D1.

Switching Frequency Selection

Part Number	Frequency (kHz)
TPM6501A	420
TPM6501B	2200

The TPM6501x provides two options for different EMC performance and size considerations. In general, 420 kHz provides high-efficiency power conversion while 2200 kHz can help shrink board size. Both of them are designed for high electro-magnetic compliance performance.

Soft Start

The TPM6501x devices support the soft-start feature by limiting output current. When the device starts up, the output stops switching for 4 ms and then slowly ramps up the output current limit. The soft start feature can prevent in-rush current upon start-up and protect the transformer accordingly.

Current Limit

The TPM6501x devices support the current limit feature by clamping output current to I_{limit}. When the output current increases close to the threshold current, the output gate drive voltage is clamped and the output on-resistance increases accordingly. With a current limit, the device can help protect isolated power transformer from over current. However, the excessive thermal dissipation needs to be considered and can lead to over-temperature protection. It is also noted that during overload conditions, the current limit has an overshoot current higher than the expected clamp current. 3PEAK recommends limiting coil current below 1 A and using 1-μF output capacitance.

Over Temperature Protection

The TPM6501x devices support over-temperature protection. When the device junction temperature rises above the protection threshold, the device turns off outputs to protect the device from over-temperature damage. When the junction temperature falls below the falling threshold, the device resumes operation with a soft start.

Spread Spectrum

The TPM6501x has spread-spectrum clocks to enhance electro-magnetic performance by modulating its internal clock frequency. The emission energy is spread across a wider band of frequencies instead of a narrow band peak. The spread spectrum feature greatly improves EMC performances.

Application and Implementation

> Note
>
> Information in the following application sections is not part of the 3PEAK's component specification and 3PEAK does not warrant its accuracy or completeness. 3PEAK's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

Application Information

The TPM6501 is a transformer driver designed for low-cost, small form-factor, isolated DC-DC converters utilizing the push-pull topology. The device includes an oscillator that feeds a gate-drive circuit. The gate drive, comprising a frequency divider and a non-overlap logic, provides two complementary output signals that alternately turn the two output transistors on and off.

Typical Application

The recommendations below regarding component selection are aimed at designing an efficient push-pull converter with a high current drive capability.

The TPM6501 transformer driver is specifically designed for low-power push-pull converters operating within the input and output voltage range of 3 V to 5.5 V. Unlike the SN6501, the TPM6501 offers advanced features such as soft start, internal current limit, thermal shutdown (TSD), and spread spectrum for improved EMI performance.

The soft-start feature enables a gradual ramp-up of the output voltage, reducing stress on the components during power-up. The internal current limit ensures that the primary currents do not exceed the specified limits, providing protection and maintaining the device's operational integrity. Additionally, the thermal shutdown feature safeguards the TPM6501 against excessive temperature, preventing potential damage.

Furthermore, the TPM6501 incorporates spread spectrum functionality to mitigate electromagnetic interference (EMI) issues. This feature helps to distribute the energy of the switching frequency, reducing the peak emissions and improving overall system performance.

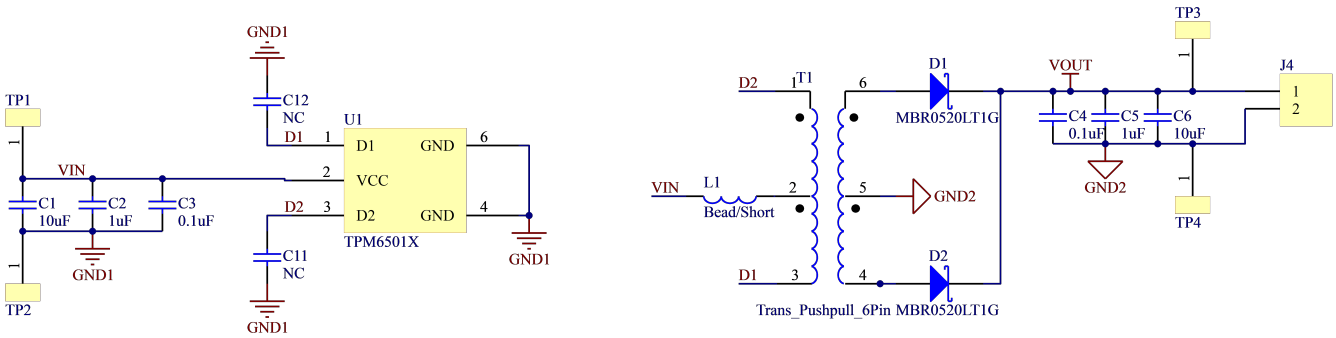


Figure 11. Typical Application Circuit

Isolated 5-V to 3.3-V Conversion

A rectifier diode used in high-frequency switching applications like the TPM6501 should have a low forward voltage and a short recovery time. Schottky diodes are recommended in push-pull converter designs as they meet these requirements.

For low-voltage applications with ambient temperatures up to 85°C, a cost-effective Schottky rectifier with a typical forward voltage of 275 mV at 100 mA forward current is suitable. In contrast, for higher output voltages such as ±10 V and above, a Schottky diode with a higher DC blocking voltage should be chosen.

It is important to consider that at temperatures above 100°C, the leakage currents of Schottky diodes increase significantly. This can result in thermal runaway and cause the collapse of the rectifier output voltage. To address this, it is recommended to use low-leakage Schottky diodes in environments with ambient temperatures higher than 85°C.

To avoid transformer saturation, it is crucial to ensure that the V-t product (product of voltage and time) of the transformer is greater than the maximum V-t product applied by the TPM6501. The maximum voltage delivered by the TPM6501 can be calculated by adding 10% to the nominal converter input voltage.

The maximum time duration for which this voltage is applied to the primary side of the transformer is half the period of the lowest frequency at the specified input voltage. This ensures that the transformer has sufficient time to recover and prevents saturation.

By carefully considering these factors and ensuring that the V-t product of the transformer is adequately higher than the maximum V-t product applied by the TPM6501, the risk of transformer saturation can be effectively minimized.

When selecting a transformer for use with the TPM6501, it is important to consider factors such as the V-t value, isolation voltage, transformer wattage, and turns ratio. While the V-t value can be met by a range of transformers, other considerations like isolation voltage ensure proper electrical isolation. Transformer wattage should match the power requirements, and the turns ratio affects voltage conversion and impedance matching. By evaluating these factors, an appropriate transformer can be chosen for the TPM6501 application.

Once the rectifier diodes and linear regulator have been selected, and the required V-t product for the transformer (at least 11 Vμs) has been determined, the next step is to determine the minimum turns ratio for the transformer. This turns ratio ensures the flawless operation of the push-pull converter within the specified current and temperature range.

The minimum turns ratio can be calculated by considering the ratio of the minimum secondary voltage (VS-min) to the minimum primary voltage, multiplied by a correction factor that takes the transformer's typical efficiency (97%) into account.

It is essential to ensure that the minimum secondary voltage (VS-min) is sufficiently large to allow for a maximum voltage drop (VF-max) across the rectifier diode. Additionally, it should provide enough input voltage for the regulator to remain in regulation.

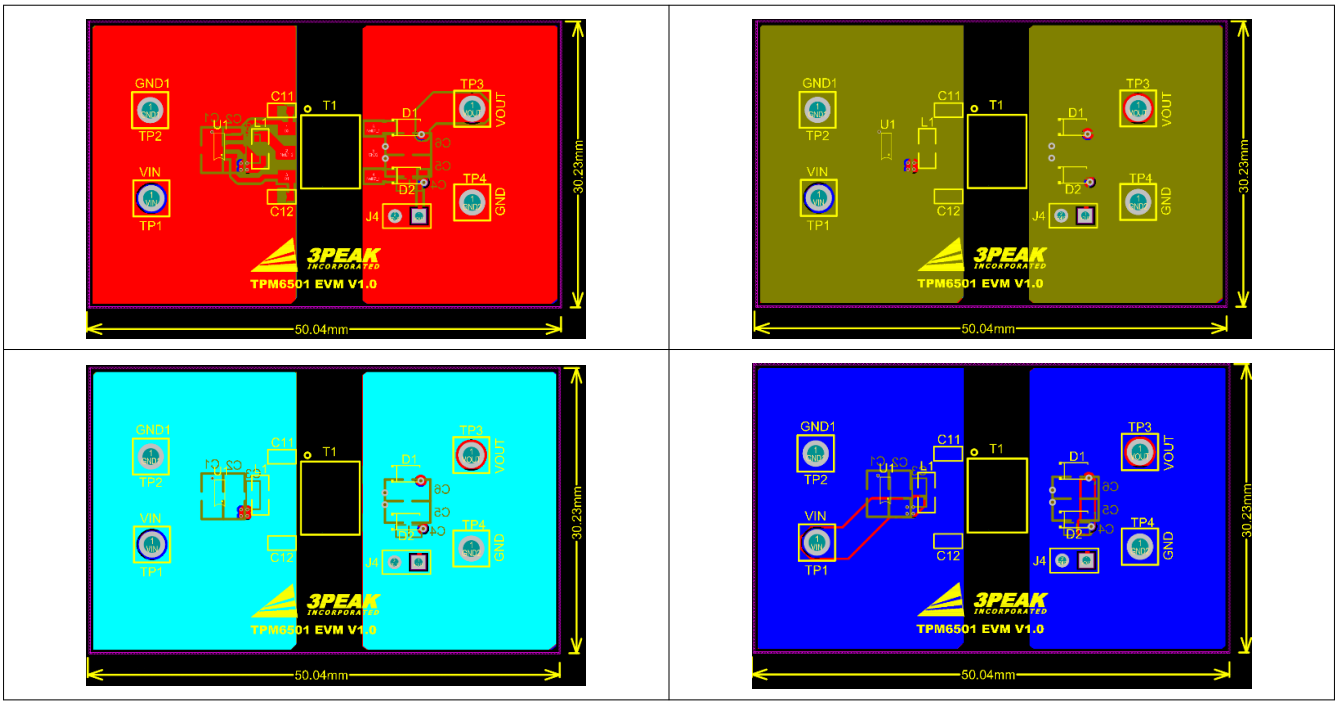
By calculating and evaluating these parameters, the minimum turns ratio required for the transformer can be determined, allowing for a proper selection of the transformer that meets the operational requirements of the push-pull converter system.

Layout

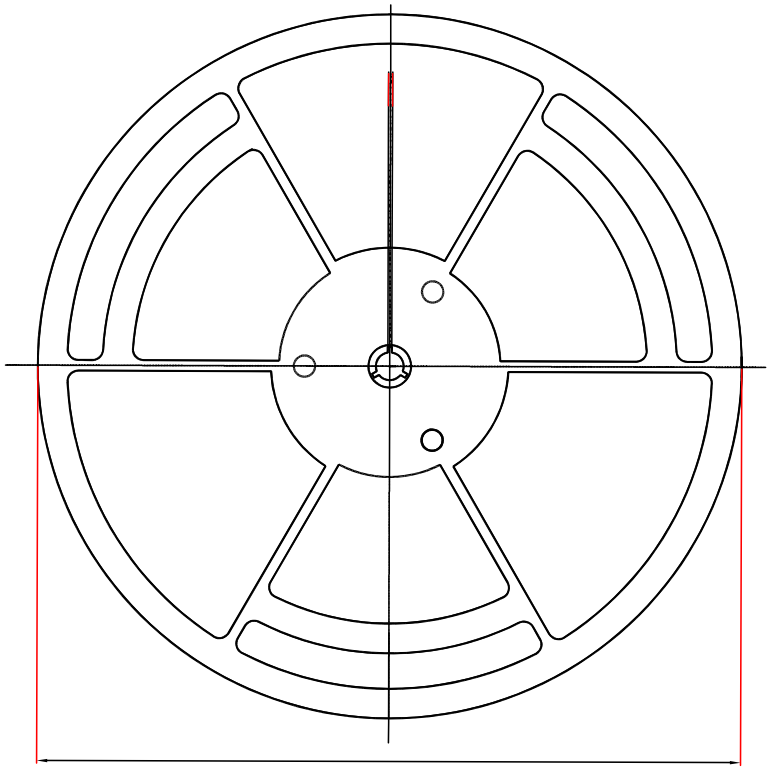
Layout Guideline

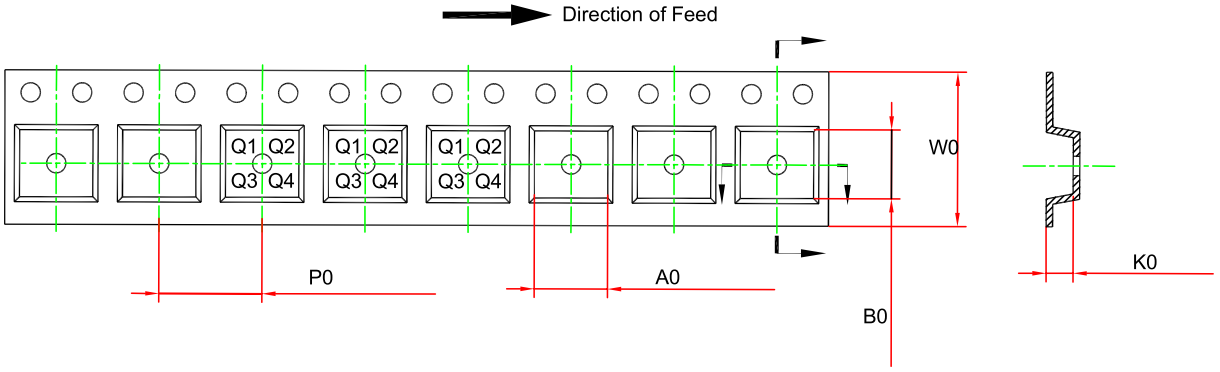
- Both input capacitors and output capacitors must be placed to the device pins as close as possible.
- It is recommended to bypass the input pin to ground with a 0.1 μF bypass capacitor.
- It is recommended to use wide and thick copper to minimize I×R drop and heat dissipation.
- The exposed pad must be connected to the PCB ground plane directly, and the copper area must be as large as possible.

Layout Example



Tape and Reel Information



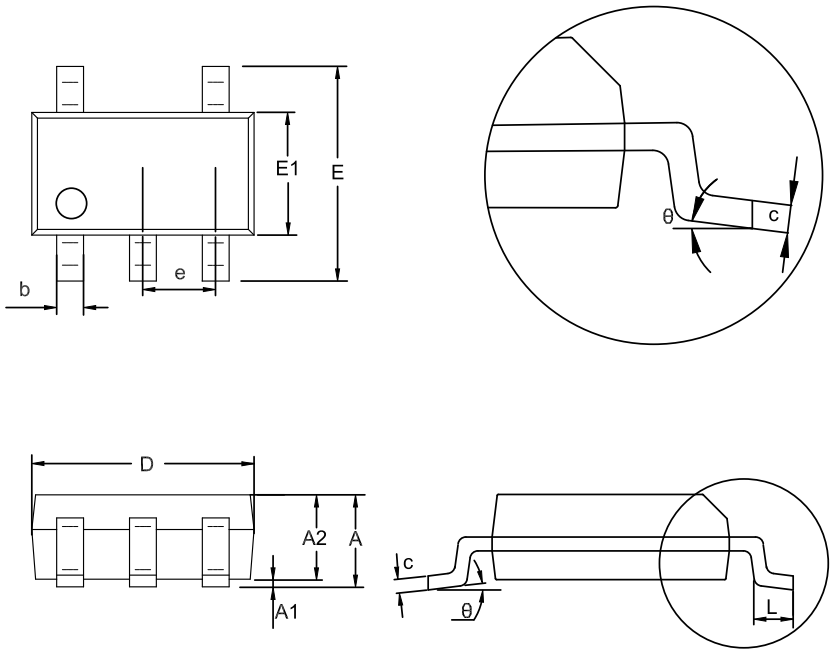


Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPM6501AQ-S5TR-S	SOT23-5	180	12	3.3	3.25	1.4	4.0	8.0	Q3
TPM6501A-S5TR	SOT23-5	180	12	3.3	3.25	1.4	4.0	8.0	Q3
TPM6501BQ-S5TR-S	SOT23-5	180	12	3.3	3.25	1.4	4.0	8.0	Q3
TPM6501B-S5TR	SOT23-5	180	12	3.3	3.25	1.4	4.0	8.0	Q3

Package Outline Dimension

SOT23-5

Package Outline Dimensions S5T(SOT23-5-A)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	1.050	1.250	0.041	0.049
A1	0.000	0.150	0.000	0.006
A2	1.000	1.200	0.039	0.047
b	0.280	0.500	0.011	0.020
c	0.100	0.230	0.004	0.009
D	2.820	3.020	0.111	0.119
E	2.600	3.000	0.102	0.118
E1	1.500	1.720	0.059	0.068
e	0.950 BSC		0.037 BSC	
L	0.300	0.600	0.012	0.024
θ	0	8°	0	8°

NOTES

1. Do not include mold flash or protrusion.
2. This drawing is subject to change without notice.

Order Information

Order Number	Operating Temperature Range	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TPM6501AQ-S5TR-S	−40 to 125°C	SOT23-5	51A	1	Tape and Reel, 3000	Green
TPM6501A-S5TR	−40 to 125°C	SOT23-5	51A	1	Tape and Reel, 3000	Green
TPM6501BQ-S5TR-S (1)	−40 to 125°C	SOT23-5	51B	1	Tape and Reel, 3000	Green
TPM6501B-S5TR (1)	−40 to 125°C	SOT23-5	51B	1	Tape and Reel, 3000	Green

(1) For future products, contact the 3PEAK factory for more information and samples.

Green: 3PEAK defines "Green" to mean RoHS compatible and free of halogen substances.

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