Automotive 65-V Reverse Protection Ideal Diode Controller

Features

- Qualified for Automotive Applications
  - AEC-Q100 Grade 1, T_A: −40°C to +125°C
  - Junction Temperature, T_J: −40°C to +150°C
- Wide Input Voltage Range
  - 3.2 V to 60 V, with 65 V Maximum Rating
  - −60 V Reverse Polarity Input Voltage, with −65 V Maximum Rating
- External NMOS Driver
  - Charge Pump with External Capacitor
  - Gate Driver for External N-Channel MOSFET
  - 20-mV V_{AK} for Regulated Conduction Mode
  - −11-mV V_{AK} for Reverse Current Blocking
  - 2.3-A Peak Sink Current to Turn-off NMOS
- Low Quiescent Current
  - 0.4-uA Low Shutdown Current (EN = LOW)
  - 60-uA Operating Current (EN = HIGH)
- Protection
  - Input Reverse Polarity Protection
  - Fast Reverse Current Blocking: 700 ns Maximum
- Meets Automotive ISO 7637 Transient Requirements with a Suitable TVS Diode
- SOT23-6 Package

Applications

- Automotive Infotainment, Navigation, Telematics
- Automotive ADAS, Surround-View Cameras
- Automotive Cluster, Head Unit, HUD
- Industry Control, Factory Automation
- Enterprise Power Supply

Description

The TPS65R01Q is an ideal diode controller that operates with an external N-channel MOSFET for reverse protection in automotive. The forward voltage drop is controlled at as low as 20 mV, which could significantly reduce power loss compared to an ordinary Schottky Diode.

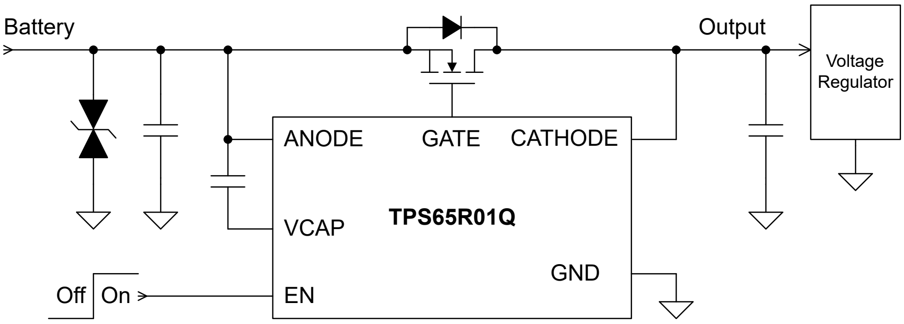
The TPS65R01Q supports a wide operating voltage range from 3.2 V to 60 V, with an absolute maximum rating of 65 V. The support for a 3.2-V input voltage is particularly suitable to meet the severe cold crank requirement in automotive systems. Moreover, this device can withstand a −60 V reverse voltage, with an absolute maximum rating of −65 V.

The TPS65R01Q integrates a charge pump to drive the external N-channel MOSFET. The device provides a precise gate control to regulate the voltage drop between the source and drain at 20 mV. When it detects a reverse voltage of −11 mV from ANODE (A) to CATHODE (K), the TPS65R01Q turns off the external MOSFET within 700 ns maximum to ensure no reverse current flows.

The above features make the TPS65R01Q suitable for different conditions in various automotive applications.

The TPS65R01Q provides a small SOT23-6 package, and it is qualified with AEC-Q100 Grade 1 to operate within the ambient temperature range from −40°C to +125°C.

Typical Application Circuit



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Product Family Table

Order Number	Maximum Voltage Range (V)	Operating Voltage Range (V)	Package
TPS65R01Q-S6TR-S	−65 to 65	3.2 to 60	SOT23-6

Revision History

Date	Revision	Notes
2023-09-30	Rev.Pre.0	Preliminary datasheet.
2024-03-31	Rev.Pre.1	Added Typical Performance Characteristics, Functional Block Diagram, and Feature Description.
2024-05-31	Rev.A.0	Initial Released.
2025-08-23	Rev.A.1	Added description to POD information required by packaging reference standards, and the actual product remains unchanged.

Pin Configuration and Functions

TPS65R01Q
SOT23-6 Package
Top View

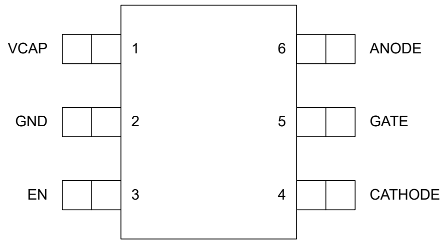


Table 1. Pin Functions: TPS65R01Q

Pin No.	Pin Name	I/O	Description
6	ANODE	I	Anode pin of the diode. Connect this pin to the source of the external N-channel MOSFET.
4	CATHODE	I	Cathode pin of the diode. Connect this pin to the drain of the external N-channel MOSFET.
3	EN	I	Enable pin. Connect this pin to HIGH for normal operation, and connect this pin to LOW to enter the standby mode.
5	GATE	O	Gate drive output pin. Connect this pin to the gate of the external N-channel MOSFET.
2	GND	-	Ground reference pin.
1	VCAP	O	Charge pump output pin. Connect this pin to the ANODE pin through an external capacitor.

Specifications

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
ANODE to GND		−65	65	V
EN to GND, VANODE > 0 V		−0.3	65	V
EN to GND, VANODE ≤ 0 V		V_{ANODE}	65 + V_{ANODE}	V
GATE to ANODE		−0.3	15	V
VCAP to ANODE		−0.3	15	V
CATHODE to ANODE		−5	75	V
T_J	Junction Temperature Range	−40	150	°C
T_A	Ambient Temperature Range	−40	125	°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.
(2) All voltage values are with respect to GND.
(3) Not subject to production test, specified by design.

ESD, Electrostatic Discharge Protection

Parameter		Condition	Minimum Level	Unit
HBM	Human Body Model ESD	AEC Q100-002	±2	kV
CDM	Charged Device Model ESD	AEC Q100-011	±2	kV

Recommended Operating Conditions

Parameter		Min	Max	Unit
V_{ANODE}	ANODE to GND	−60	60	V
$V_{CATHODE}$	CATHODE to GND		60	V
V_{EN}	EN to GND	−60	60	V
V_{AK}	ANODE (A) to CATHODE (K)	−70		V
V_{GA}	GATE to ANODE	15		V
C_{ANODE}	ANODE Input Capacitor	22		nF
$C_{CATHODE}$	CATHODE Output Capacitor	0.1		μF
C_{VA}	VCAP to ANODE Capacitor	0.1		μF
T_J	Junction Temperature Range	−40	150	°C

Thermal Information

Package Type	θ_{JA}	θ_{JB}	$\theta_{JC,TOP}$	Unit
SOT23-6	153.7	47.8	81	°C/W

Electrical Characteristics

All test conditions: T_A = −40°C to +125°C; typical values at T_A = 25°C, V_{ANODE} = 12 V, C_{VCAP} = 0.1 µF, V_{EN} = 3.3 V, over operating free-air temperature range (unless otherwise noted)

Parameter		Conditions	Min	Typ	Max	Unit
Supply Voltage and Current						
V_{ANODE}	Operating Input Voltage		4		60	V
V_{ANODE_UVLO}	ANODE Under-Voltage Lockout Threshold	V_{ANODE} rising			3.9	V
		V_{ANODE} falling	2.2	2.4	3.0	V
	ANODE Under-Voltage Lockout Hysteresis		0.44		1.08	V
I_{SD}	Shutdown Current	V_{EN} = 0 V, T_A = −40°C to +85°C		0.4	1.9	µA
		V_{EN} = 0 V, T_A = −40°C to +125°C			6	µA
I_Q	Quiescent Current			60	100	µA
Enable Input						
V_{IL_EN}	Enable Input Low Threshold		0.5	0.8	1.1	V
V_{IH_EN}	Enable Input High Threshold		1.1	1.6	2.2	V
V_{HYST_EN}	Enable Hysteresis		0.52		1.35	V
I_{EN}	Enable Pin Sink Current	V_{EN} = 12 V		1	2	µA
ANODE (A) to CATHODE (K) Voltage						
V_{AK_REG}	Regulated Forward Threshold		13	20	29	mV
V_{AK}	V_{AK} Threshold for Full Conduction Mode (1)		34	50	57	mV
V_{AK_REV}	V_{AK} Threshold for Reverse Current Blocking		–17	–11	–2	mV
GM	Regulation Error AMP Transconductance (1)		1200	1800	3100	µA/V
Gate Drive						
I_{GATE}	Peak Source Current	V_{ANODE} – $V_{CATHODE}$ = 100 mV, V_{GATE} – V_{ANODE} = 5 V	3	13		mA
	Peak Sink Current (1)	V_{ANODE} – $V_{CATHODE}$ = –20 mV, V_{GATE} – V_{ANODE} = 5 V		2370		mA
	Regulation Max Sink Current	V_{ANODE} – $V_{CATHODE}$ = 0 V, V_{GATE} – V_{ANODE} = 5 V	6	26		µA
R_{DIS}	Discharge Switch Resistance	V_{ANODE} – $V_{CATHODE}$ = –20 mV, V_{GATE} – V_{ANODE} = 100 mV	0.4		2	Ω
Charge Pump						
I_{VCAP}	Charge Pump Source Current (Charge Pump On)	V_{VCAP} – V_{ANODE} = 7 V	162	285	600	µA

Parameter		Conditions	Min	Typ	Max	Unit
	Charge Pump Sink Current (Charge Pump Off)	$V_{VCAP} – V_{ANODE}$ = 14 V		4	10	μA
$V_{VCAP} – V_{ANODE}$	Charge Pump Voltage at V_{ANODE} = 3.2 V	I_{VCAP} ≤ 30 μA	8			V
	Charge Pump Turn ON Voltage		9.8	11.1	12.5	V
	Charge Pump Turn OFF Voltage		10.7	12.1	13.5	V
	Charge Pump Enable Comparator Hysteresis		0.6	0.97	1.2	V
V_{VCAP_UVLO}	$V_{VCAP} – V_{ANODE}$ UV Release at Rising Edge	$V_{ANODE} – V_{CATHODE}$ = 100 mV	5.4	6.2	7	V
	$V_{VCAP} – V_{ANODE}$ UV Threshold at Falling Edge	$V_{ANODE} – V_{CATHODE}$ = 100 mV	4.4	5.2	5.9	V
CATHODE						
$I_{CATHODE}$	CATHODE Sink Current	V_{ANODE} = 12 V, $V_{ANODE} – V_{CATHODE}$ = –100 mV		1.7	2.5	μA
		$V_{ANODE} – V_{CATHODE}$ = 100 mV		0.57	1.5	μA
		V_{ANODE} = –12 V, $V_{CATHODE}$ = 12 V			1	μA
Switching Characteristics						
t_{EN_DLY}	Delay Time from Enable (LOW to HIGH) to Gate Turn On	$V_{VCAP} > V_{VCAP\_UVLO}$		75	110	μs
t_{REV_DLY}	Delay Time from Reverse Voltage Detection to Gate Turn OFF	$V_{ANODE} – V_{CATHODE}$ = 100 mV to –100 mV		0.39	0.70	μs
t_{FAW_DLY}	Delay Time from Forward Voltage Detection to Gate Turn ON	$V_{ANODE} – V_{CATHODE}$ = –100 mV to 700 mV		1.5	2.5	μs

(1) Not subject to production test, specified by design.

Typical Performance Characteristics

All test conditions: T_A = 25°C, V_{ANODE} = 12 V, C_{VCAP} = 0.1 μF, V_{EN} = 3.3 V, over operating free-air temperature range (unless otherwise noted).

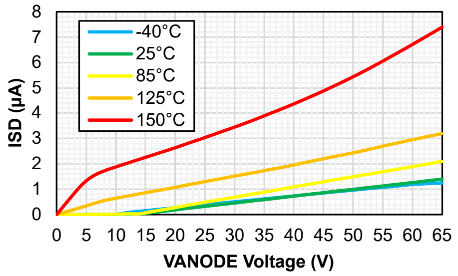


Figure 1. Shutdown Supply Current vs. Supply Voltage

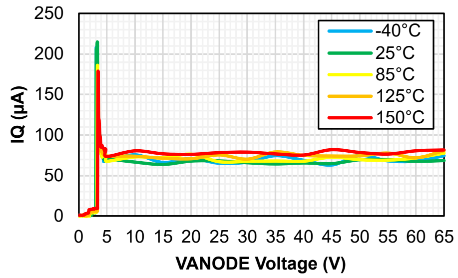


Figure 2. Operating Quiescent Current vs. Supply Voltage

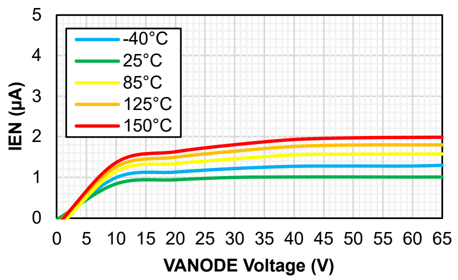


Figure 3. Enable Sink Current vs. Supply Voltage

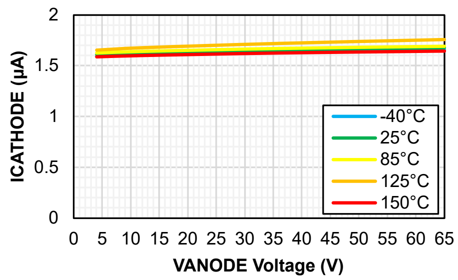


Figure 4. CATHODE Sink Current vs. Supply Voltage

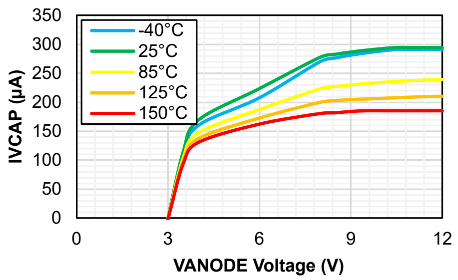


Figure 5. Charge Pump Current vs. Supply Voltage at V_{VCAP} = 6 V

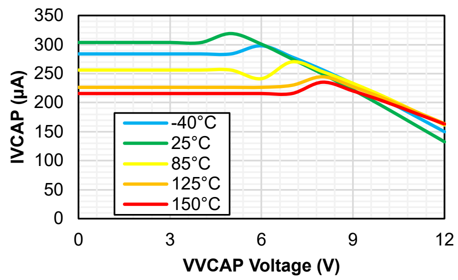


Figure 6. Charge Pump V-I Characteristics at V_{ANODE} = 12 V

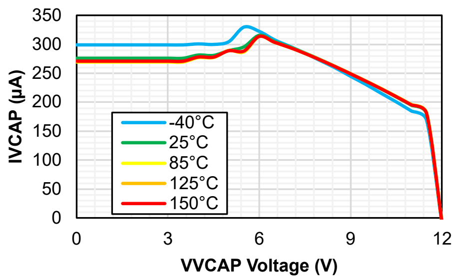


Figure 7. Charge Pump V-I Characteristics at V_{ANODE} = 65 V

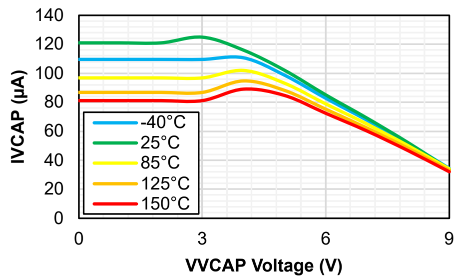


Figure 8. Charge Pump V-I Characteristics at V_{ANODE} = 3.2 V

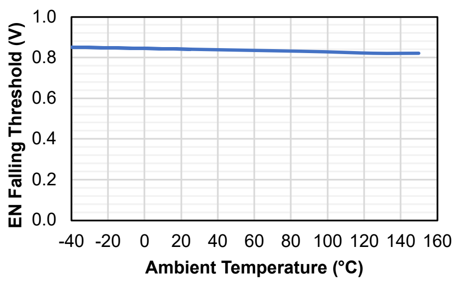


Figure 9. Enable Falling Threshold vs. Temperature

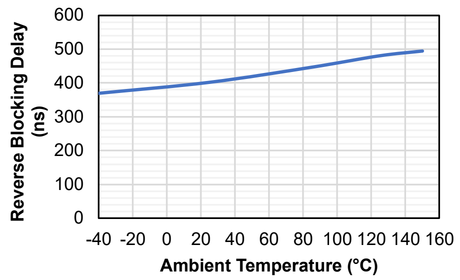


Figure 10. Reverse Current Blocking Delay vs. Temperature

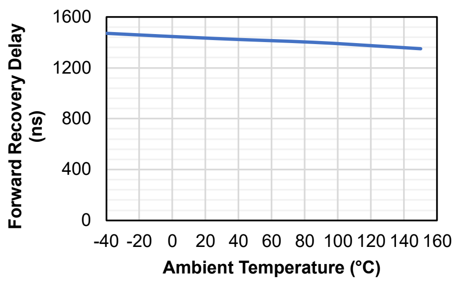


Figure 11. Forward Recovery Delay vs. Temperature

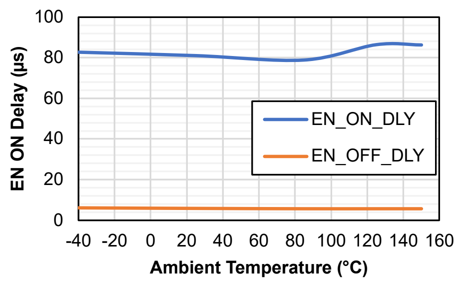


Figure 12. Enable to Gate Delay vs. Temperature

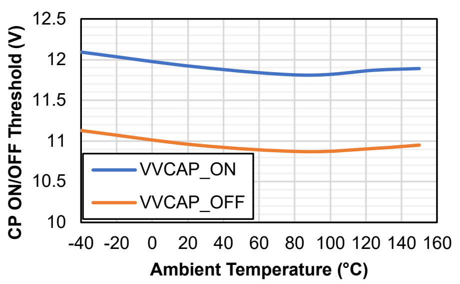


Figure 13. Charge Pump ON/OFF Threshold vs. Temperature

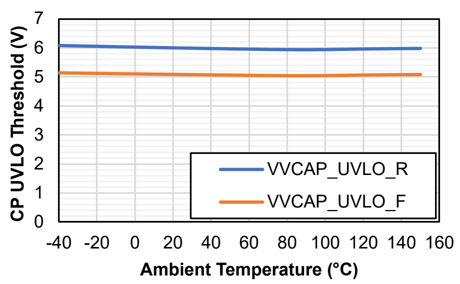


Figure 14. Charge Pump UVLO Threshold vs. Temperature

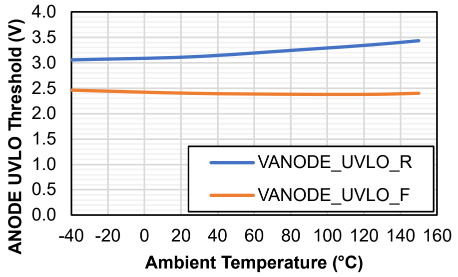


Figure 15. ANODE UVLO Threshold vs. Temperature

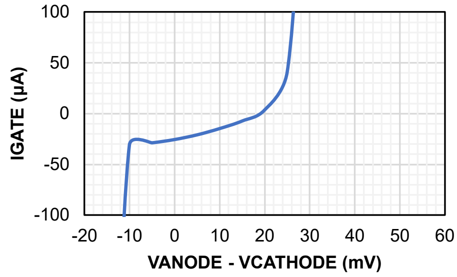


Figure 16. Gate Current vs. Forward Voltage Drop

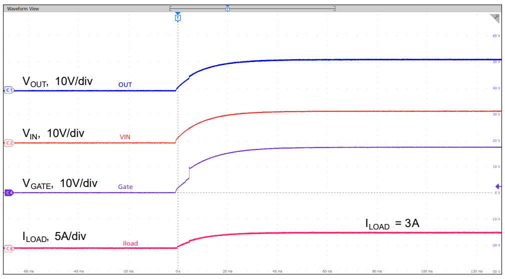


Figure 17. Startup with 3-A Load

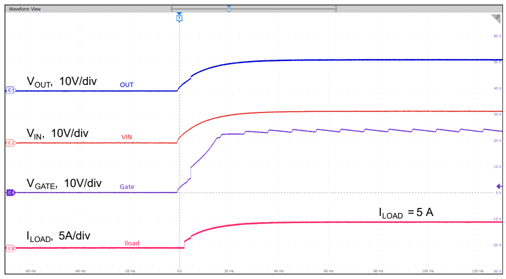


Figure 18. Startup with 5-A Load

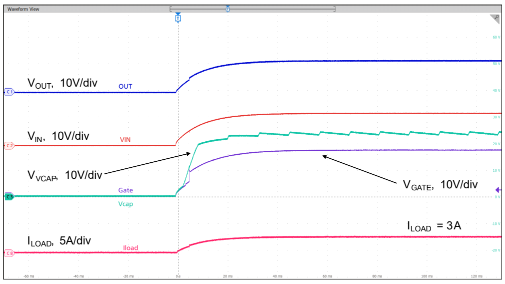


Figure 19. VCAP During Startup with 3-A Load

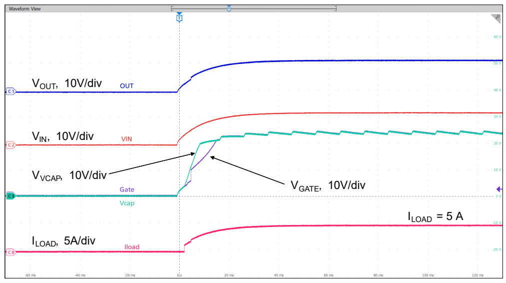


Figure 20. VCAP During Startup with 5-A Load

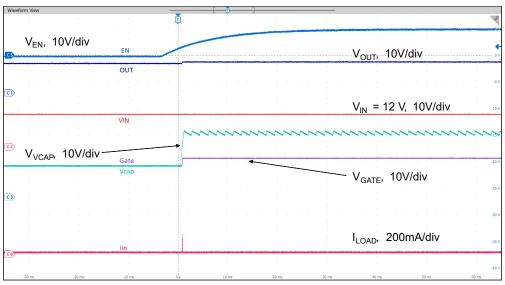


Figure 21. Enable Threshold

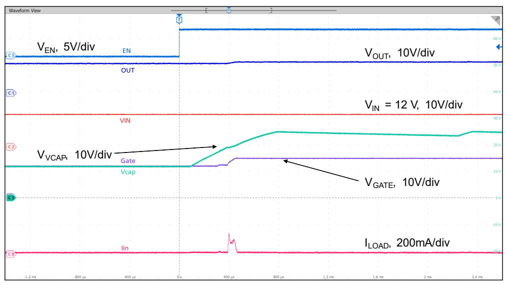


Figure 22. Enable Turn-On Delay

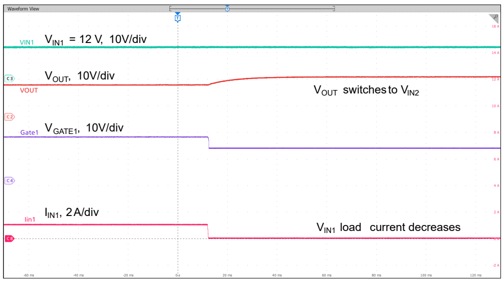


Figure 23. ORing: V_{IN1} Switches to V_{IN2}

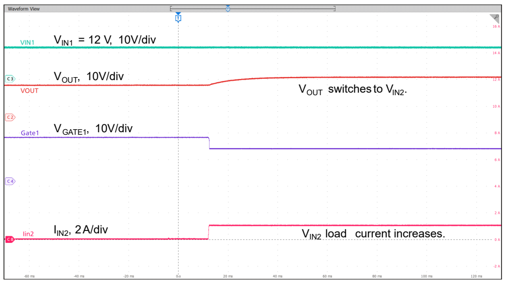


Figure 24. ORing: V_{IN1} Switches to V_{IN2}

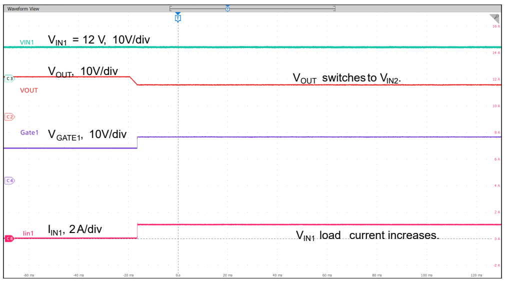


Figure 25. ORing: V_{IN2} Switches to V_{IN1}

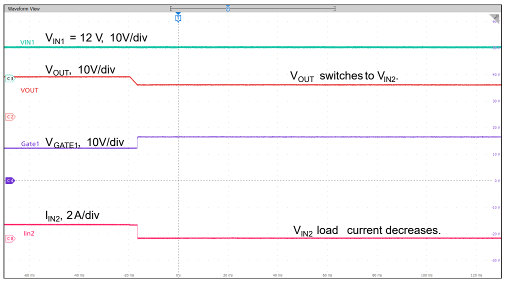


Figure 26. ORing: V_{IN2} Switches to V_{IN1}

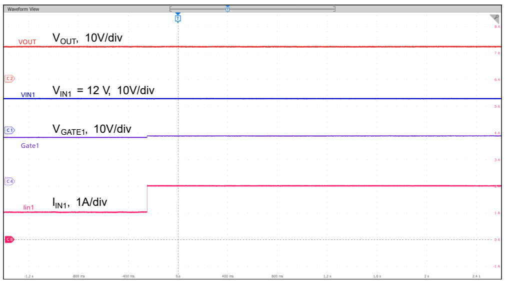


Figure 27. ORing: V_{IN2} Fails and Switches to V_{IN1}

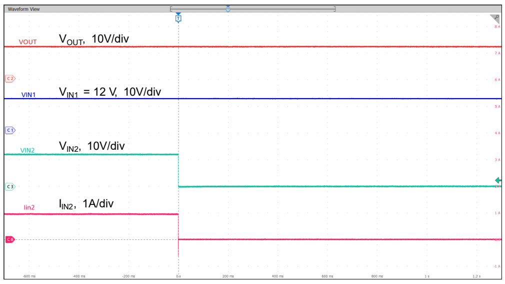


Figure 28. ORing: V_{IN2} Fails and Switches to V_{IN1}

Detailed Description

Overview

The TPS65R01Q is an ideal diode controller that operates with an external N-channel MOSFET for reverse protection in automotive. The forward voltage drop is controlled at as low as 20 mV, which could significantly reduce power loss compared to an ordinary Schottky Diode.

The TPS65R01Q supports a wide operating voltage range from 3.2 V to 60 V, with an absolute maximum rating of 65 V. The support for a 3.2-V input voltage is particularly suitable to meet the severe cold crank requirement in automotive systems. Moreover, this device can withstand a −60 V reverse voltage, with an absolute maximum rating of −65 V.

The TPS65R01Q integrates a charge pump to drive the external N-channel MOSFET. The device provides a precise gate control to regulate the voltage drop between the source and drain at 20 mV. When it detects a reverse voltage of −11 mV from ANODE (A) to CATHODE (K), the TPS65R01Q turns off the external MOSFET within 700 ns maximum to ensure no reverse current flows.

Functional Block Diagram

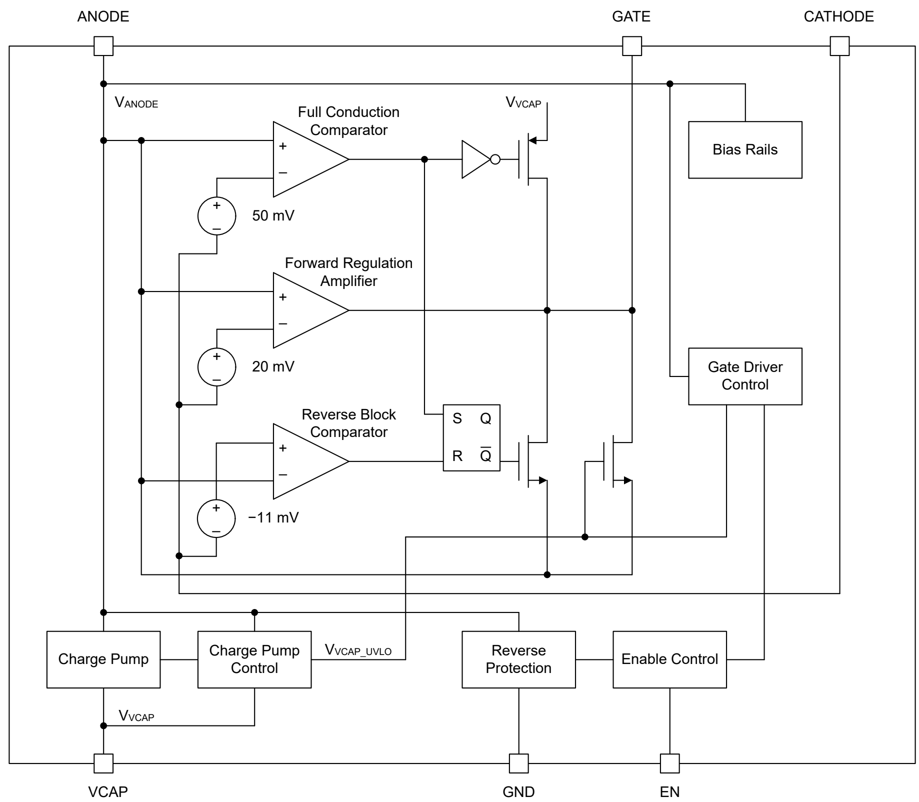


Figure 29. Functional Block Diagram

Feature Description

Input Power Supply Voltage (ANODE)

The TPS65R01Q uses the ANODE pin to power up the internal circuitry with a supply voltage ranging from 3.2 V to 60 V. The maximum voltage range from ANODE to GND is between 65 V and −65 V, allowing the device to withstand negative voltage transients.

When the ANODE pin voltage is lower than the V_{ANODE_UVLO} falling threshold, the TPS65R01Q enters shutdown mode with a low shutdown current. When the ANODE pin voltage is greater than the V_{ANODE_UVLO} rising threshold and EN is high, the TPS65R01Q enters conduction mode with low quiescent current.

Enable (EN)

The TPS65R01Q uses the EN pin to control the gate driver, enabling it to turn on or off. The maximum voltage from EN to GND is 65 V, allowing the EN pin to be connected directly to the ANODE pin if the enable functionality is not required.

When the EN pin voltage is lower than V_{IL_EN}, the device enters shutdown mode, disabling the gate driver and the charge pump. When the EN pin voltage exceeds V_{IH_EN}, the device enters conduction mode, enabling the gate driver and the charge pump. By default, the EN pin is pulled low when floating.

Charge Pump (VCAP)

The TPS65R01Q integrates a charge pump for the external N-channel MOSFET gate driver power supply by connecting a capacitor between the VCAP pin and the ANODE pin. When V_{EN} is greater than V_{IH_EN}, the charge pump typically sources a 285-μA current to turn on the external MOSFET. When V_{EN} is lower than V_{IL_EN}, the charge pump remains disabled.

To ensure the external MOSFET is well operated, the VCAP to ANODE voltage must exceed V_{VCAP_UVLO} before the internal gate driver is enabled. When the VCAP to ANODE voltage ramps above 12.1 V, the charge pump is disabled and starts discharging; when the VCAP to ANODE voltage falls below 11.1 V, the charge pump is re-enabled and starts charging again. The charge pump continues to operate with the VCAP to ANODE voltage charging and discharging between 11.1 V and 12.1 V.

Gate Driver (GATE) and Conduction Mode

The TPS65R01Q uses the gate driver to control the conduction mode of the external N-channel MOSFET. The gate driver function is enabled when $V_{ANODE} \geq V_{ANODE\_UVLO}$, $V_{EN} \geq V_{IH\_EN}$, and $V_{VCAP} – V_{ANODE} \geq V_{VCAP\_UVLO}$.

While the gate driver is active, there are three different condition modes based on the ANODE to CATHODE voltage: forward regulation mode, full conduction mode, and reverse current protection mode.

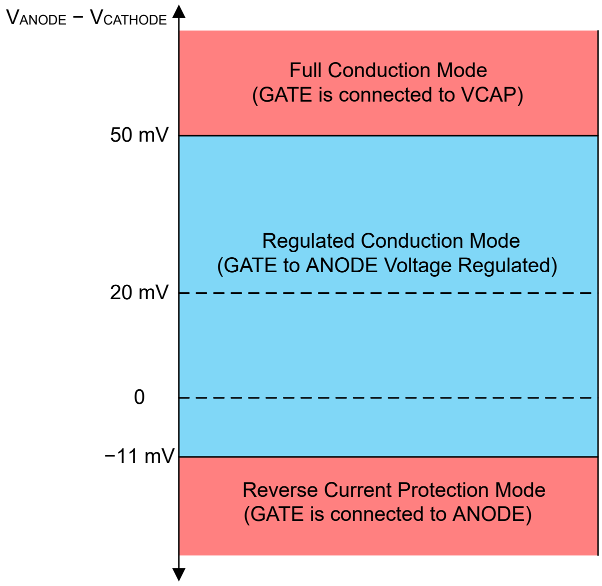


Figure 30. Conduction Mode

Forward Regulation Mode

When the gate driver is enabled, and the current flows through the external MOSFET keeping the ANODE to CATHODE voltage within the range of –11 mV to 50 mV typically, the TPS65R01Q operates in the forward regulation mode. In this mode, the TPS65R01Q regulates the ANODE to CATHODE voltage to 20 mV by fine-tuning the GATE to ANODE voltage. This closed-loop regulatory approach allows for a smooth deactivation of the MOSFET under light load conditions and ensures that there is no reverse DC current flow.

Full Conduction Mode

When the gate driver is enabled, and a large current flows through the external MOSFET resulting in the ANODE to CATHODE voltage greater than 50 mV typically, the TPS65R01Q operates in the full conduction mode. In this mode, the GATE pin is connected to the VCAP pin internally and the GATE to ANODE voltage is close to the VCAP to ANODE voltage. With the VCAP and GATE connected internally, the turn-on resistance of the external MOSFET is minimized, and the power dissipation of the external MOSFET is reduced under large forward current conditions.

Reverse Current Protection Mode

When the gate driver is enabled, and the current flows through the external MOSFET resulting in a reverse voltage of less than –11 mV typically from CATHODE to ANODE, the TPS65R01Q operates in reverse current protection mode. When the TPS65R01Q enters reverse protection mode, the GATE pin is discharged to the ANODE pin internally with a current of 2.37 A typically. With the GATE pin discharged, the external MOSFET is disabled, preventing any reverse current flow.

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 TPS65R01Q is an ideal diode controller operating with an external N-channel MOSFET for reverse protection in various automotive applications. The following Typical Application section shows a typical usage of the TPS65R01Q.

Typical Application

Reverse-Protection Application

Figure 31 shows the typical protection application schematic of the TPS65R01Q.

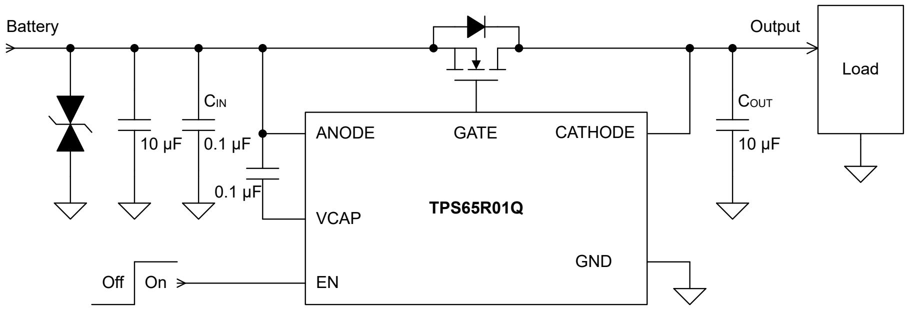


Figure 31. Reverse Protection Application Circuit

Design Example of Reverse Protection Application

Before beginning a new design, the following two points need to be considered first:

1. Supply voltage range, especially the cold crank and load dump in the automotive environment
2. Load current range during normal operation and the maximum load current.

Table 2 shows a design example with system parameters listed.

Table 2. Design Example Parameters

Design Parameter	Example value
Supply Voltage	Automotive 12-V battery, 9-V to 16-V nominal with 3.2-V cold crank and 35-V load dump
Output Voltage	Follow Supply Voltage
Output Current	3 A nominal, 5 A maximum
Output Capacitance	1-μF minimum, 47-μF typical hold-up capacitance
Automotive EMC Compliance	ISO 7637-2 and ISO 16750-2

After the design parameters are confirmed, the next considerations should be the MOSFET, input and output capacitors, and the charge pump-up capacitor.

1. External N-channel MOSFET.
   Key electrical specifications to consider for a MOSFET include the maximum continuous drain current I_D, the maximum drain-to-source voltage V_{DS_MAX}, the maximum gate-to-source voltage V_{GS_MAX}, the maximum source current through the body diode, and the drain-to-source on-state resistance R_{DS_ON}.
   The maximum continuous drain current I_D should be greater than the maximum load current required. The maximum drain-to-source voltage V_{DS_MAX} must be sufficient to handle the peak differential voltage encountered in the application. The maximum gate-to-source voltage V_{GS_MAX} should be higher than the maximum charge pump voltage, otherwise a Zener diode is required to clamp the V_{GS} voltage. The maximum source current rating of the body diode must be greater than the startup inrush current expected in the application.
   Using a MOSFET with R_{DS_ON} as low as possible is a good practice to reduce the conduction power loss. However, a very low R_{DS_ON} makes it difficult to implement reverse current detection. It is recommended to operate the MOSFET in regulated conduction mode during nominal load conditions and it is suggested to choose R_{DS_ON} between $20\ mV/I_{OUT\_NORMAL}$ and $50\ mV/I_{OUT\_NORMAL}$
   The thermal resistance of the MOSFET must be taken into account to ensure the maximum junction temperature remains within the safe area under the maximum power dissipation condition.
2. It is recommended to add a minimum 22 nF input capacitor at the ANODE pin and a minimum 100 nF output capacitor at the CATHODE pin. Both the input capacitor and the output capacitor should be placed as close to the device pins as possible.
3. It is required to add a minimum 100 nF capacitor from the VCAP pin to the ANODE pin. It is a good practice to add a VCAP capacitor with value of $10 \times C_{ISS\_MOSFET}$.

Figure 17 to Figure 22 show the typical performance characteristics of the reverse protection application.

Redundant Power Supplies Application

In a redundant power architecture, usually two or more power supplies are connecting together to drive the same load. To against power fault conditions, Schottky diodes are commonly used to prevent reverse current flowing from higher-voltage power to lower-voltage power. However, the forward voltage of each Schottky diode would cause much more additional power dissipation compared with an ideal diode solution.

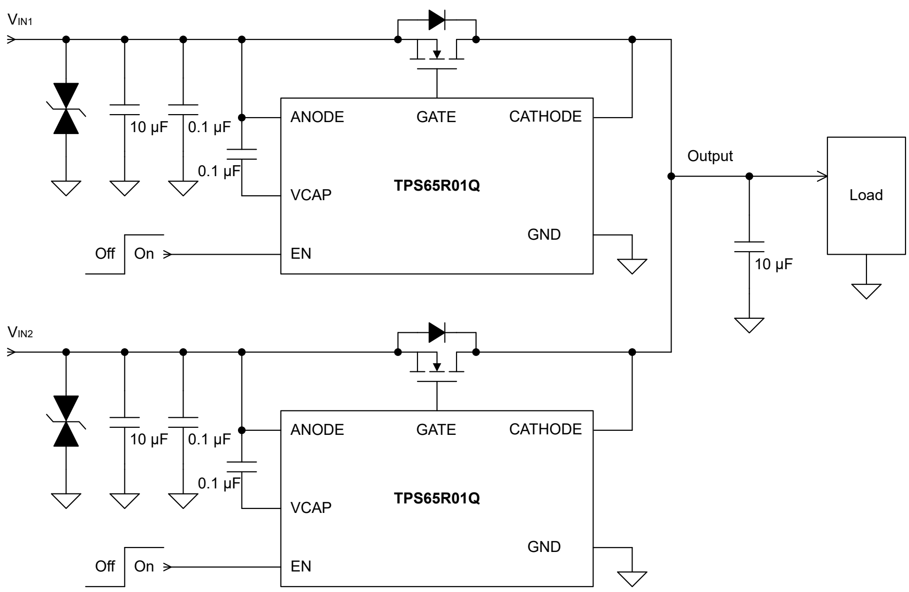


Figure 32. Redundant Power Supplies Application

Figure 32 shows the redundant power supplies application schematic with the TPS65R01Q devices. The TPS65R01Q continuous monitoring the voltage difference between the ANODE pin and the CATHODE pin. During forward operation mode, the voltage drop remains at 20 mV typically. When reverse voltage below –11 mV is detected, the TPS65R01Q turns off the gate of the MOSFET quickly and blocks reverse current in 390 ns typically.

Figure 23 to Figure 28 show the typical performance characteristics of the redundant power supplies application.

Layout

Layout Guideline

- Connect the ANODE, GATE, and CATHODE pins of TPS65R01Q close to the source, gate, and drain pins of the external N-channel MOSFET.
- Connect the GATE pin of TPS65R01Q to the gate pin of the external N-channel MOSFET with short and wide trace to avoid turn-off delay due to the trace resistance.
- The charge pump capacitor connected across the VCAP and ANODE pins must be kept away from the external N-channel MOSFET to minimize the thermal effects on the capacitance value.
- For the high current path through the external N-channel MOSFET, it is recommended to use wide trace lengths or thick copper weight to minimize I×R drop and heat dissipation.

Layout Example

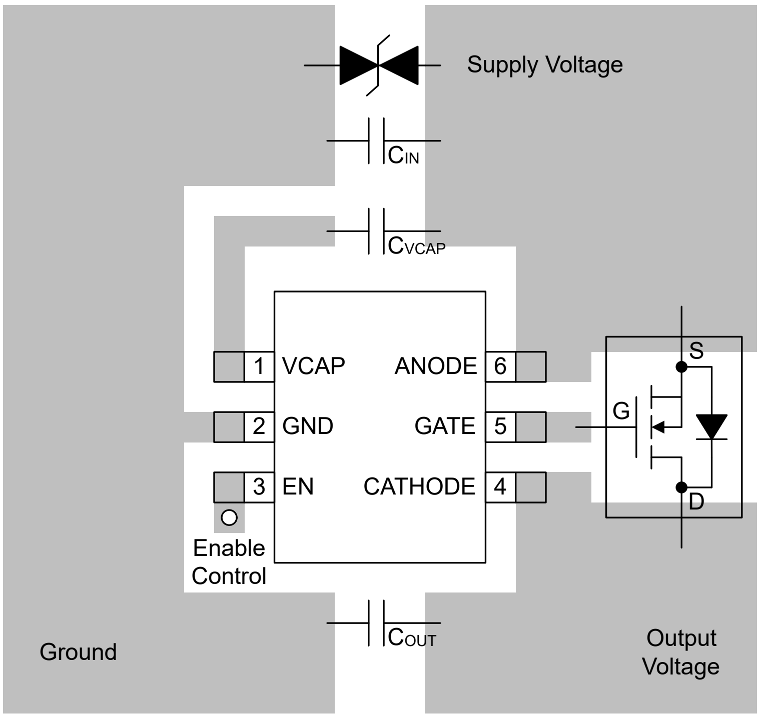
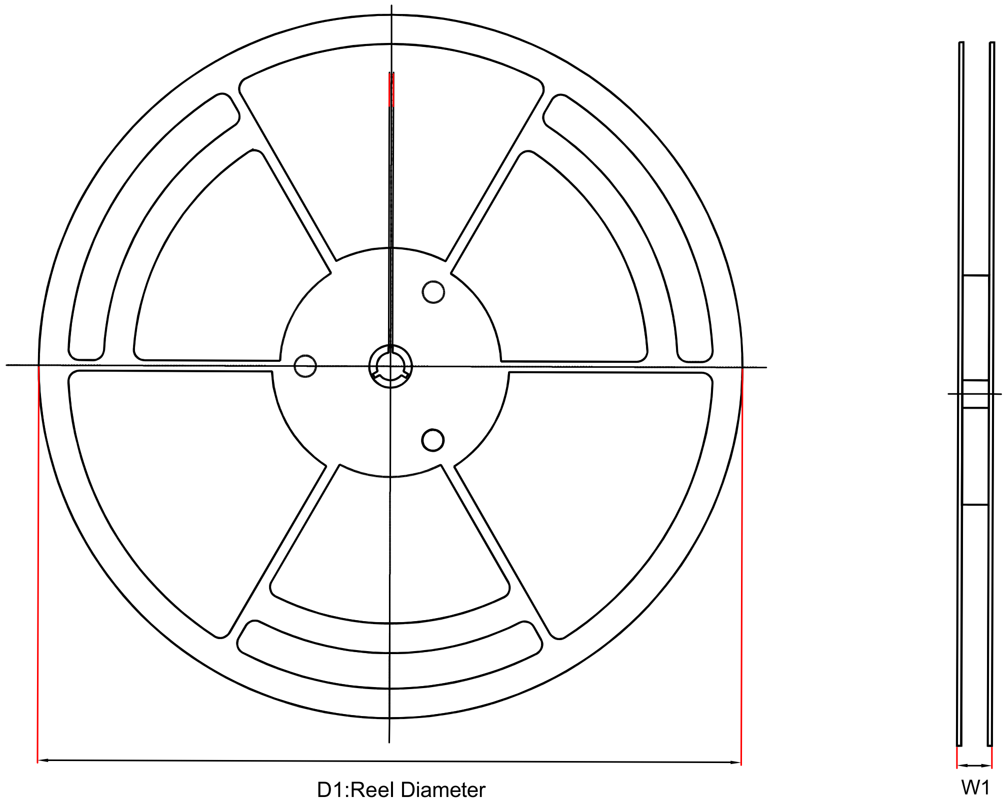
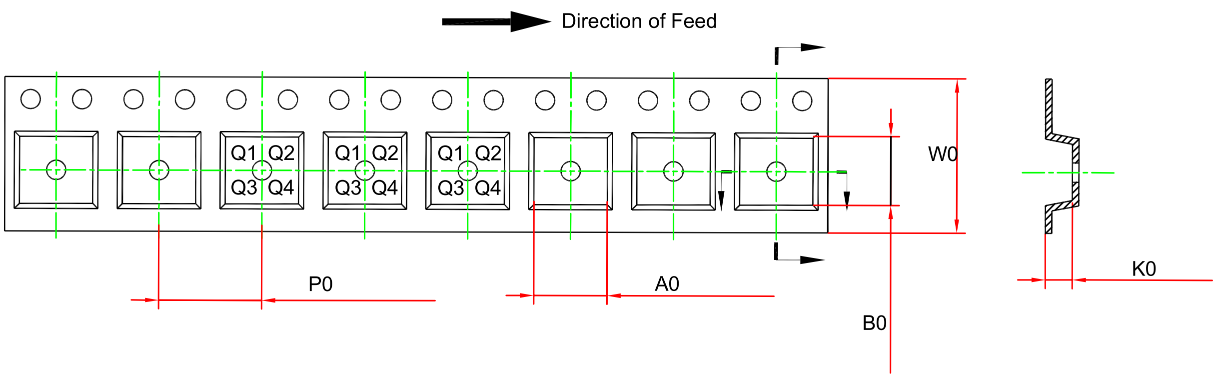


Figure 33. Layout Example

Tape and Reel Information



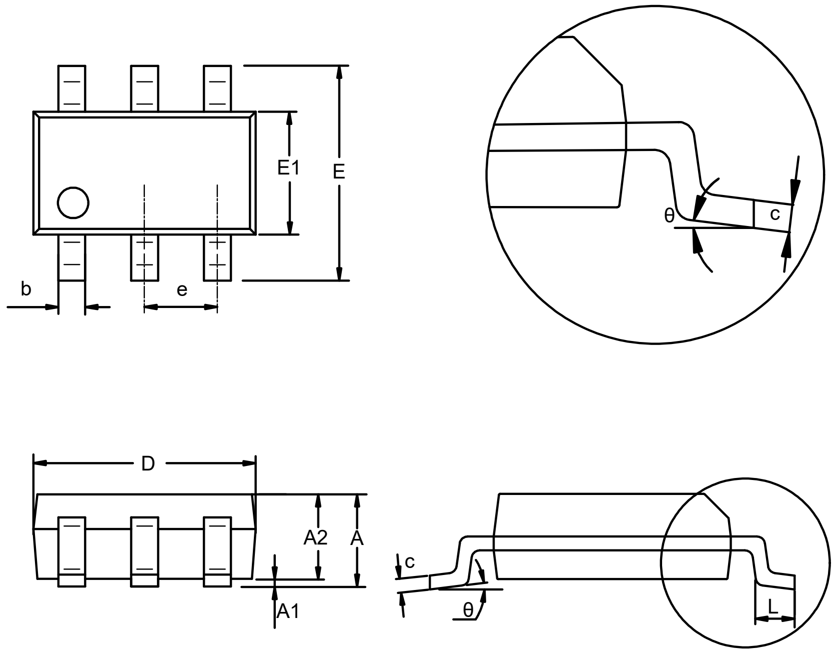


Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPS65R01Q-S6TR-S	SOT23-6	180	12	3.3	3.2	1.4	4	8	Q3

Package Outline Dimensions

SOT23-6

Package Outline Dimensions S6T(SOT23-6-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.
3. Reference JEDEC MO-178.

Order Information

Order Number	Operating Temperature Range	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TPS65R01Q-S6TR-S	−40 to 125°C	SOT23-6	65R	MSL2	Tape and Reel, 3000	Green

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

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