Precision Adjustable Current-Limited Power-Distribution Switches

General Description

The RTQ9728W is a cost effective, low voltage, P-MOSFET power switch IC with an adjustable current-limit feature. Low on-resistance (120mΩ typ.) and low supply current (120μA typ.) are designed in this IC.

The RTQ9728W can offer an adjustable current-limit threshold between 0.1A and 2.5A (typ.) via an external resistor. The ±10% current-limit accuracy can be realized for all current-limit settings.

The RTQ9728W is an ideal solution for power supply applications since it is functional for various current-limit requirements. It is available in WDFN-6SL 2x2 and SOT-23-6 packages.

Ordering Information

RTQ9728W□□□

- Pin 1 Orientation***
  (2) : Quadrant 2, Follow EIA-481-D
- Package Type
  QW : WDFN-6SL 2x2 (W-Type)
  E : SOT-23-6
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

Note :

***Empty means Pin1 orientation is Quadrant 1

Richtek products are :

- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.

Features

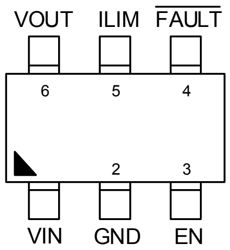
- **Adjustable Current Limit : 0.1A to 2.5A (typ.)**
- **±10% Current-Limit Accuracy @2A Over Temperature**
- **150mΩ (max) P-MOSFET**
- **Low Supply Current : 120μA**
- **Input Operating Voltage Range : 2.5V to 6V**
- **Reverse Input-Output Voltage Protection**
- **Built-in Soft-Start**
- **15-kV ESD Protection per IEC 61000-4-2 (With External Capacitance)**
- **Nemko Approved IEC62368-1**
- **RoHS Compliant and Halogen Free**

Applications

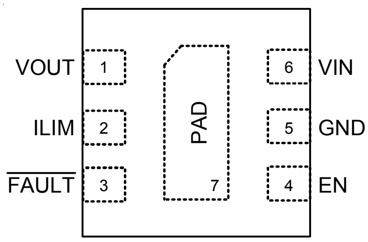
- Digital TVs
- Set Top Boxes
- VOIP Phones

Pin Configuration

(TOP VIEW)



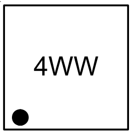
SOT-23-6



WDFN-6SL 2x2

Marking Information

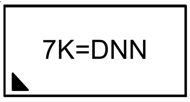
RTQ9728WGQW



4W : Product Code

W : Date Code

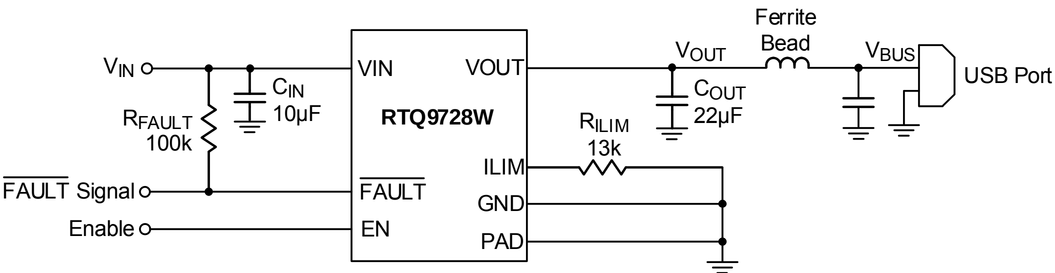
RTQ9728WGE



7K= : Product Code

DNN : Date Code

Typical Application Circuit

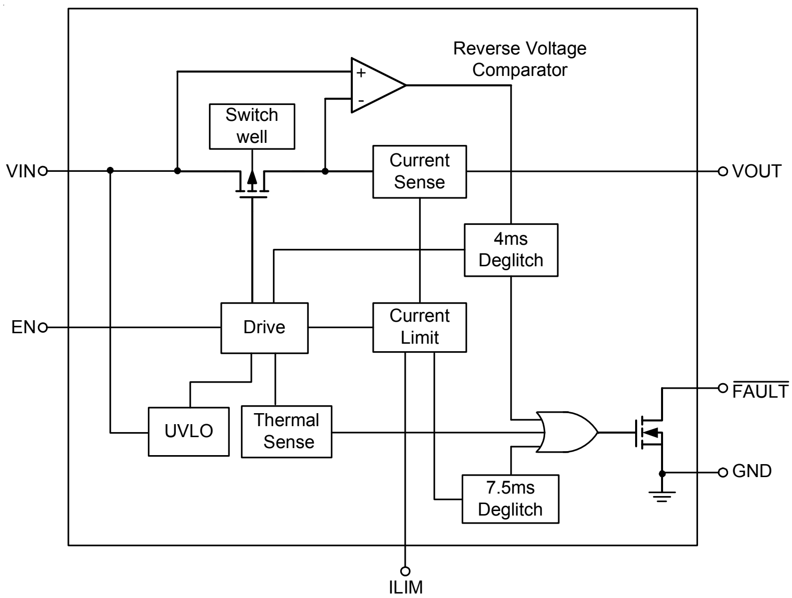


Note : R_{ILIM} = 13kΩ for 2A Power Switch Operation

Functional Pin Description

Pin No.		Pin Name	Pin Function
SOT-23-6	WDFN-6SL 2x2		
1	6	VIN	Power input. Connect a 10μF or greater ceramic capacitor from the VIN to GND as close to the IC as possible.
2	5	GND	Ground.
3	4	EN	Enable control input. Logic high turns on the power switch.
4	3	$\overline{\text{FAULT}}$	Active-low open-drain output. Asserted during over-current, over-temperature, or reverse-voltage conditions.
5	2	ILIM	Current limit setting. Connect an external resistor to set current-limit threshold. The recommended resistance range is $10k\Omega \leq R_{ILIM} \leq 226k\Omega$.
6	1	VOUT	Output.
--	7 (Exposed Pad)	PAD	Exposed pad. The exposed pad is internally unconnected and must be soldered to a large GND plane. Connect this GND plane to other layers with thermal vias to help dissipate heat from the device.

Functional Block Diagram



Operation

The RTQ9728W is a current-limited power switch using P-MOSFETs for applications where short-circuit or heavy capacitive loads will be encountered. These devices allow users to adjust the current-limit threshold between 100mA and 2.5A (typ.) via an external resistor. Additional device shutdown features include over-temperature protection and reverse-voltage protection.

The RTQ9728W provides built-in soft-start function. The driver controls the gate voltage of the power switch. The driver incorporates circuitry that controls the rising time and falling time of the output voltage to limit large inrush current and voltage surges. The RTQ9728W enters constant-current mode when the load exceeds the current-limit threshold.

Absolute Maximum Ratings (Note 1)

- Voltage Range On VIN, VOUT, EN, $\overline{\text{FAULT}}$, ILIM ---------- –0.3V to 6.5V
  <10ms ---------- –0.3V to 7V
- Power Dissipation, P_D @ T_A = 25°C
  SOT-23-6 ---------- 0.48W
  WDFN-6SL 2x2 ---------- 2.98W
- Package Thermal Resistance (Note 2)
  SOT-23-6, θ_{JA} ---------- 208.2°C/W
  WDFN-6SL 2x2, θ_{JA} ---------- 33.5°C/W
  WDFN-6SL 2x2, θ_{JC} ---------- 8.5°C/W
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Junction Temperature ---------- 150°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 3)
  HBM (Human Body Model) ---------- 2kV
  CDM (Charged Device Model) ---------- 500V
  IEC 61000-4-2 Contact Discharge (Note 7) ---------- 8kV
  IEC 61000-4-2 Air-Gap Discharge (Note 7) ---------- 15kV

Recommended Operating Conditions (Note 4)

- Supply Input Voltage, VIN ---------- 2.5V to 6V
- Temperature Range Junction ---------- –40°C to 125°C

Electrical Characteristics

(V_{IN} = 5V, T_A = T_J = –40°C to 125°C, unless otherwise specified)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Shutdown Current		I_{SHDN}	V_{EN} = 0V, I_{OUT} = 0A	--	1	10	μA
Quiescent Current		I_Q	I_{OUT} = 0A	--	120	300	μA
EN Input Voltage	Logic-High	V_{IH}		1.2	--	--	V
	Logic-Low	V_{IL}		--	--	0.4	
EN Input Current		I_{EN}	V_{IN} = 5.5V V_{EN} = 0V or 5.5V	--	0.02	0.5	μA
Reverse Leakage Current		I_{REV}	V_{OUT} = 5V, V_{IN} = 0V	--	1	10	μA
Under-Voltage Lockout Threshold		UVLO	VIN rising, 0°C ≤ T_J ≤ 125°C	--	2.3	2.5	V
			VIN rising, –40°C ≤ T_J ≤ 125°C	--	2.3	2.6	
			VIN falling	--	2.1	--	
$\overline{\text{FAULT}}$ Output Low Voltage		V_{OL}	$I_{\overline{FAULT}}$ = 1mA	--	--	180	mV
$\overline{\text{FAULT}}$ Off State Leakage			$V_{\overline{FAULT}}$ = 5.5V	--	--	1	μA
$\overline{\text{FAULT}}$ Deglitch			$\overline{\text{FAULT}}$ assertion or de-assertion due to reverse voltage condition	2	4	6	ms
			$\overline{\text{FAULT}}$ assertion or de-assertion due to over-current condition	2	7.5	20	

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
$\overline{FAULT}$ Flag Assertion Offset	$V_{\overline{FAULT}\_OFS}$	Offset between fault flag assertion level versus ILIM trigger level (Note 5)	–100	--	0	mA
Turn On Time	T_{ON}	C_O = 1μF, R_L = 100Ω (Note 6)	--	--	0.3	ms
Turn Off Time	T_{OFF}		--	--	0.45	
Static Drain-Source On-State Resistance	$R_{DS(ON)}$	I_{OUT} = 0.2A	--	120	150	mΩ
Reverse Voltage Comparator Trip Point	I_{REV_HYS}	V_{OUT} – V_{IN}	100	135	300	mV
Current Limit	I_{LIM}	R_{ILIM} = 13kΩ	1800	2000	2200	mA
		R_{ILIM} = 13kΩ, T_A = 25°C	1840	2000	2160	
		R_{ILIM} = 49.9kΩ	460	520	572	
Response Time to Short Circuit	t_{IOS}	V_{IN} = 5V (Note 5)	--	2	--	μs
Thermal Shutdown Temperature	T_{SD}	(Note 5)	--	160	--	°C
Thermal Shutdown Hysteresis	ΔT_{SD}	(Note 5)	--	20	--	°C

Note 1. 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 may affect device reliability.

Note 2. θ_{JA} is measured under natural convection (still air) at T_A = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. θ_{JC} is measured at the exposed pad of the package. The PCB copper area with exposed pad is $70mm^2$.

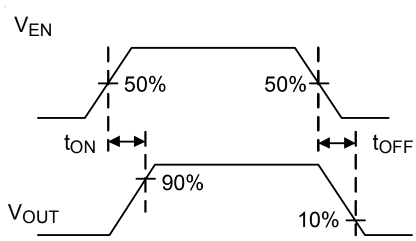
Note 3. Devices are ESD sensitive. Handling precautions are recommended.

Note 4. The device is not guaranteed to function outside its operating conditions.

Note 5. Guarantee by design.

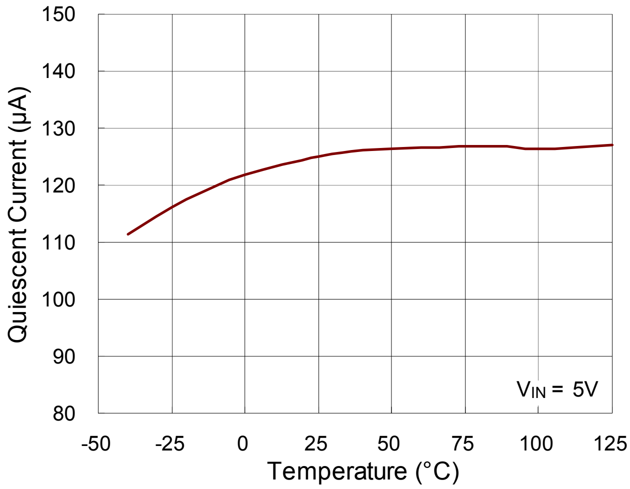
Note 6. Test Circuit and Voltage Waveforms

Note 7. Surges per EN61000-4-2. 1999 applied to output terminals of EVM. These are passing test levels, not failure threshold.

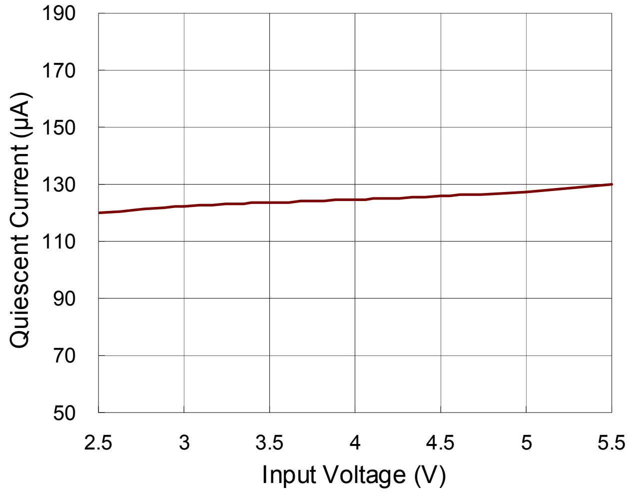


Typical Operating Characteristics

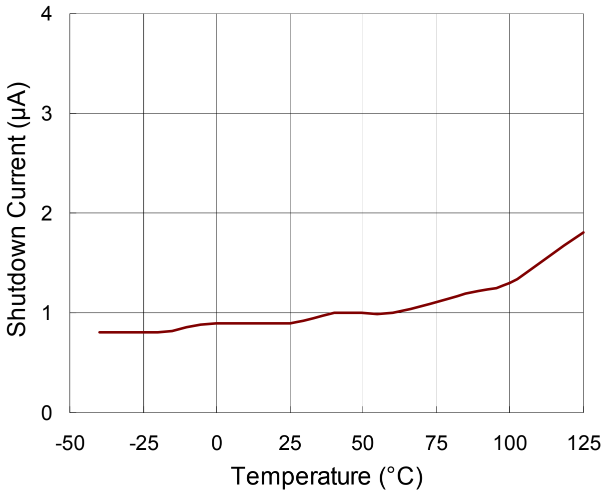
Quiescent Current vs. Temperature



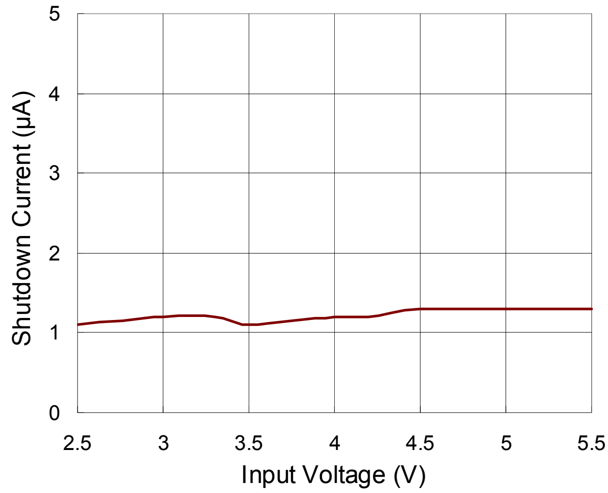
Quiescent Current vs. Input Voltage



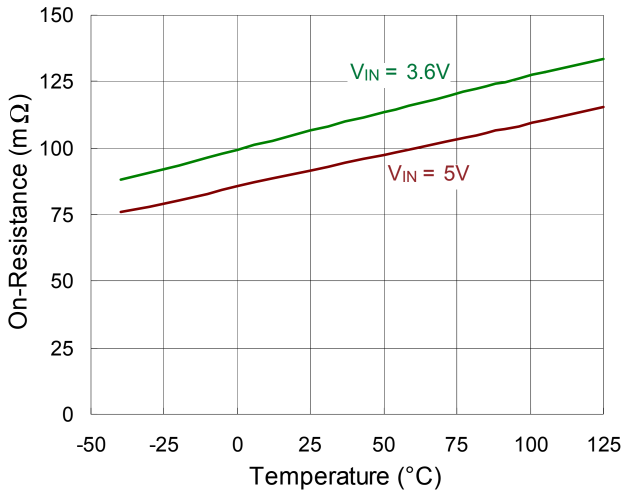
Shutdown Current vs. Temperature



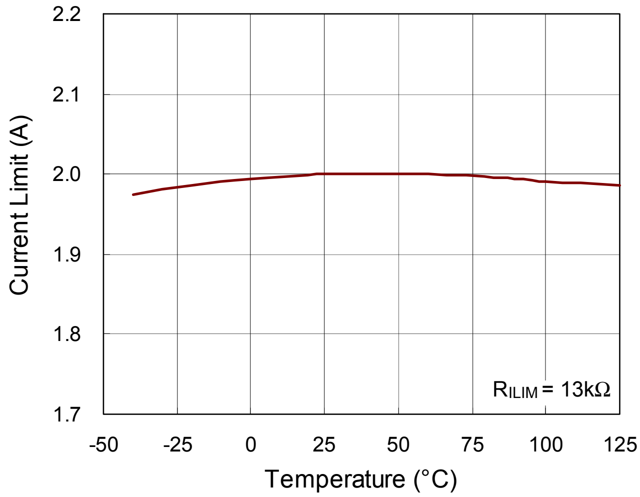
Shutdown Current vs. Input Voltage



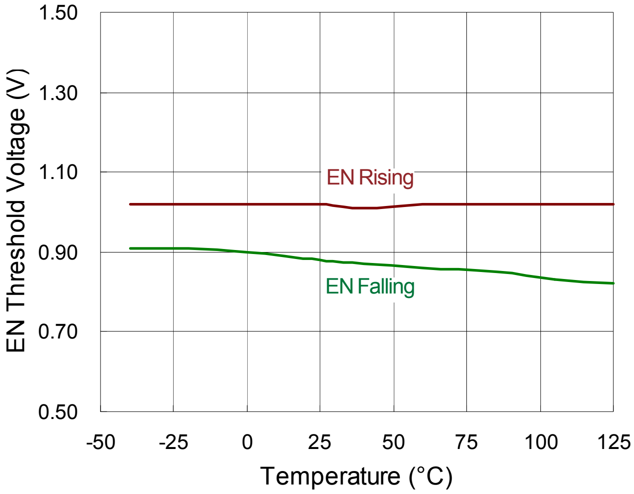
On-Resistance vs. Temperature



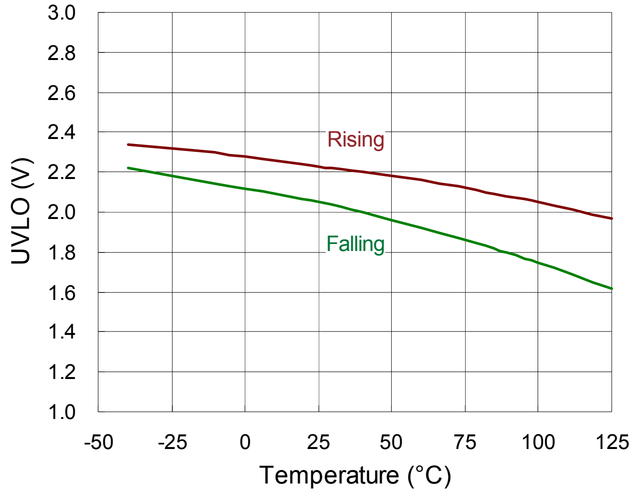
Current Limit vs. Temperature



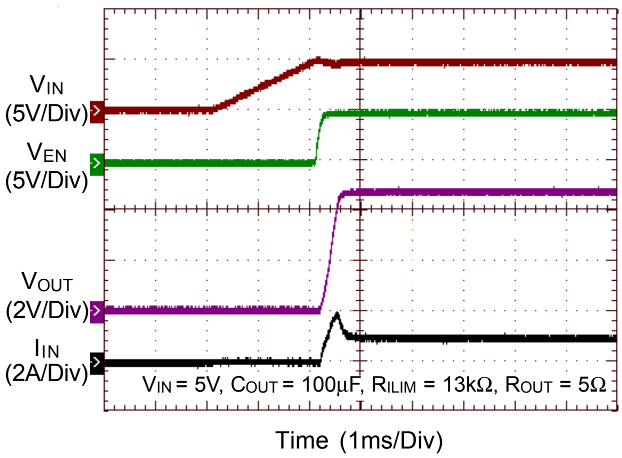
EN Threshold vs. Temperature



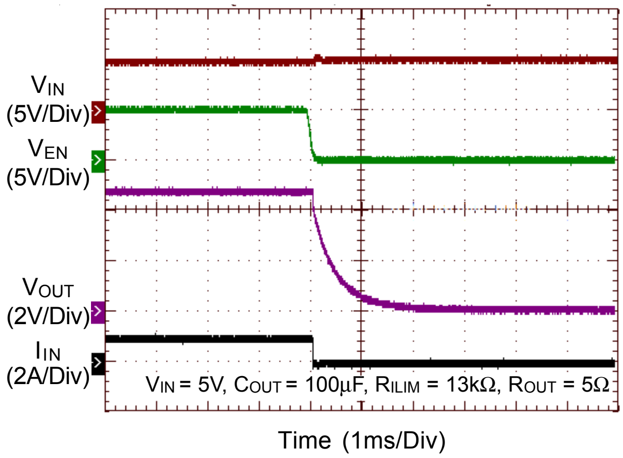
UVLO vs. Temperature



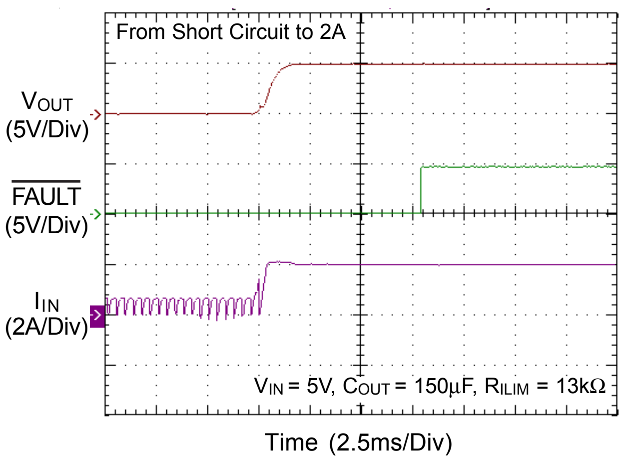
Power On from EN



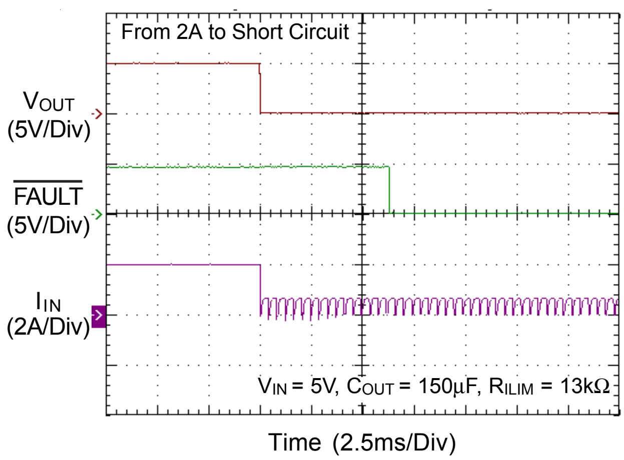
Power Off from EN

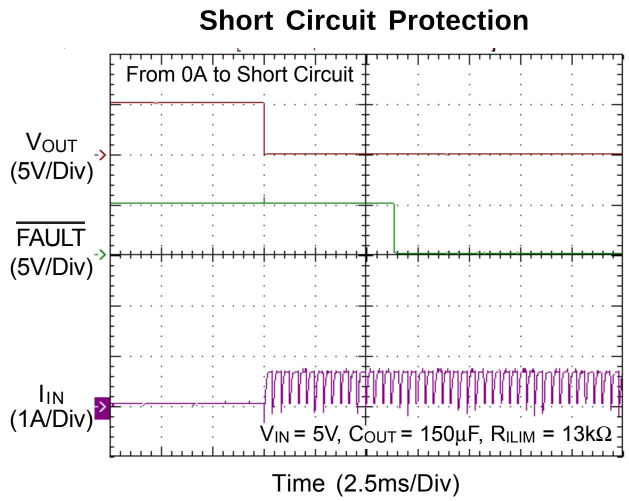


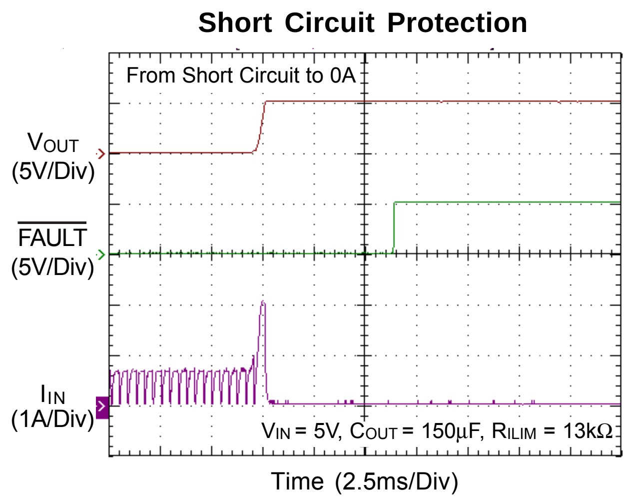
Short Circuit Protection

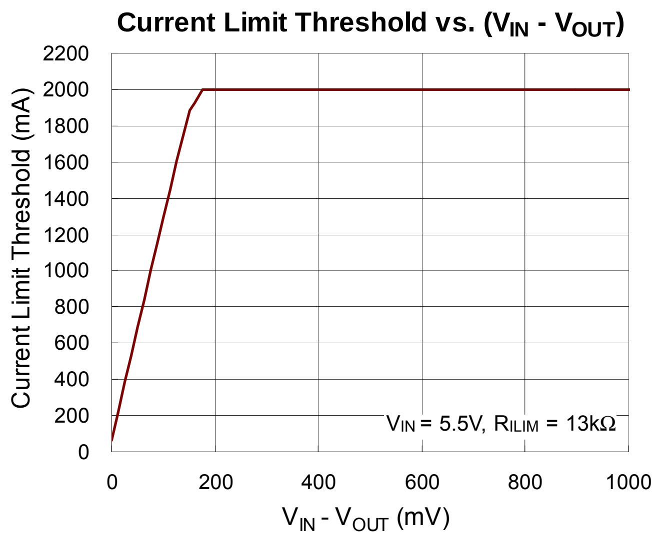


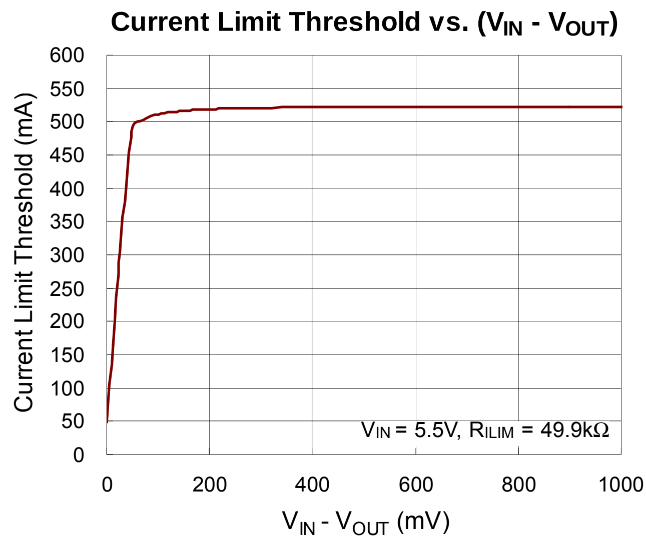
Short Circuit Protection

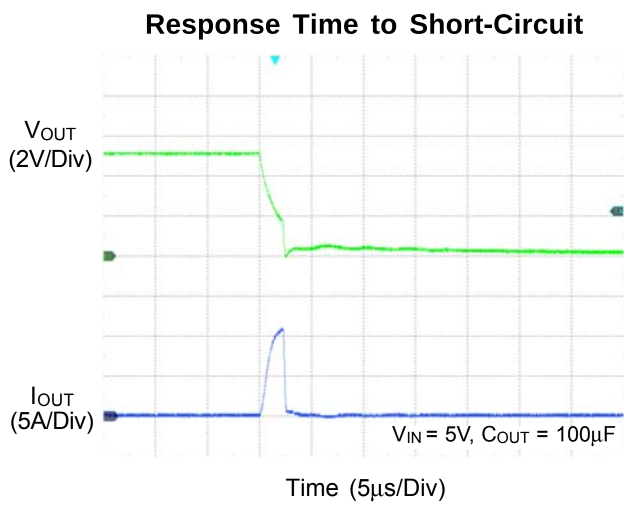


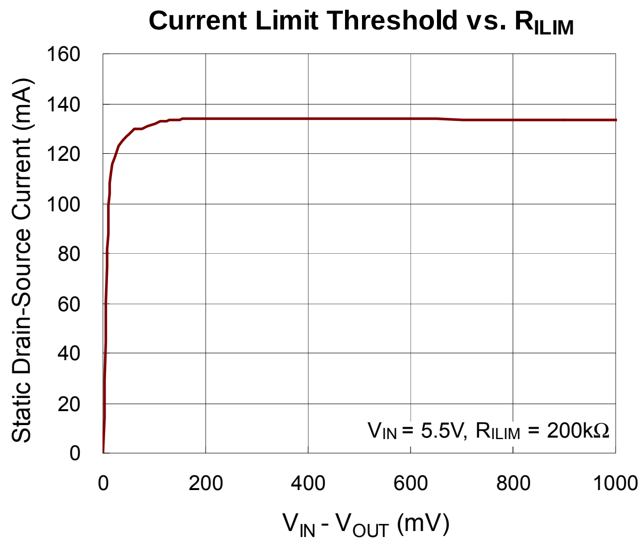

Short Circuit Protection
From 0A to Short Circuit
VOUT (5V/Div)
FAULT (5V/Div)
IIN (1A/Div)
VIN = 5V, COUT = 150μF, RILIM = 13kΩ
Time (2.5ms/Div)


Short Circuit Protection
From Short Circuit to 0A
VOUT (5V/Div)
FAULT (5V/Div)
IIN (1A/Div)
VIN = 5V, COUT = 150μF, RILIM = 13kΩ
Time (2.5ms/Div)


Current Limit Threshold vs. (VIN - VOUT)
Current Limit Threshold (mA)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
VIN - VOUT (mV)
VIN = 5.5V, RILIM = 13kΩ


Current Limit Threshold vs. (VIN - VOUT)
Current Limit Threshold (mA)
600
550
500
450
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
VIN - VOUT (mV)
VIN = 5.5V, RILIM = 49.9kΩ


Response Time to Short-Circuit
VOUT (2V/Div)
IOUT (5A/Div)
VIN = 5V, COUT = 100μF
Time (5μs/Div)


Current Limit Threshold vs. RILIM
Static Drain-Source Current (mA)
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
VIN - VOUT (mV)
VIN = 5.5V, RILIM = 200kΩ

Application Information

Richtek's component specification does not include the following information in the Application Information section. Thereby no warranty is given regarding its validity and accuracy. Customers should take responsibility to verify their own designs and to ensure the functional suitability of their components and systems.

The RTQ9728W is a single P-MOSFET high side power switch with active high enable input, optimized for self-powered and bus-powered Universal Serial Bus (USB) applications. The switch's low $R_{DS(ON)}$ meets USB voltage drop requirements and a flag output is available to indicate fault conditions to the local USB controller.

Current Limiting and Short Circuit Protection

When a heavy load or short circuit situation occurs while the switch is enabled, large transient current may flow through the device. The RTQ9728W includes a current-limit circuitry to prevent these large currents from damaging the MOSFET switch and the hub downstream ports. The RTQ9728W provides an adjustable current-limit threshold between 0.1A and 2.5A (typ.) via an external resistor, R_{ILIM}, between 10kΩ and 226kΩ. The maximum −100mA fault flag assertion offset needs cautions, especially for very low ILIM applications. Taking the application of ILIM = 250mA as an example, the minimum fault flag assertion level might be 150mA (40% error versus its target).Once the current-limit threshold is exceeded, and output voltage does not drop over 1/2 input voltage, the device enters constant current mode.

If output voltage drops under around 1/2 input voltage, the device enters re-soft start current fold-back mode until either thermal shutdown occurs or the fault is removed. Table1 shows a recommended current-limit value vs. R_{ILIM} resistor.

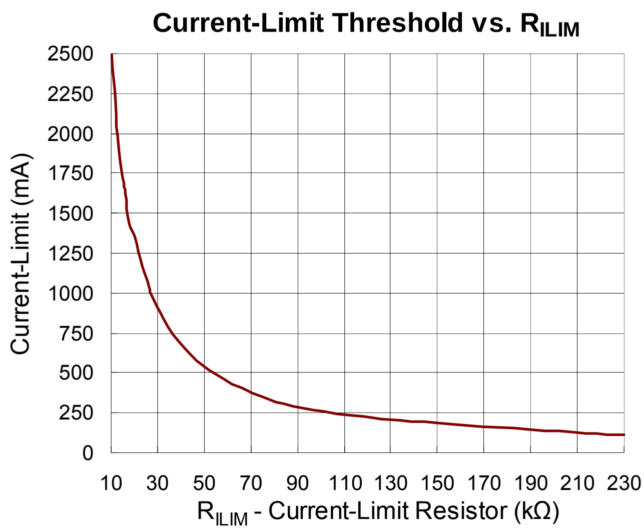


Figure 1. Current-Limit Threshold vs. R_{ILIM}

Table 1. Recommended R_{ILIM} Resistor Selections

Desired Nominal Current Limit (mA)	Ideal Resistor (kΩ)	Closet 1% Resistor (kΩ)	Actual Limits (Include R Tolerance)		
			IOS min (mA)	IOS nom (mA)	IOS max (mA)
120	226.1	226.0	101.3	120.0	142.1
200	134.0	133.0	173.7	201.5	233.9
300	88.5	88.7	262.1	299.4	342.3
400	65.9	66.5	351.1	396.7	448.7
500	52.5	52.3	443.9	501.6	562.4
600	43.5	43.2	535.1	604.6	674.1
700	37.2	37.4	616.0	696.0	776.0
800	32.4	32.4	708.7	800.8	892.9
900	28.7	28.7	797.8	901.5	1005.2
1000	25.8	26.1	875.4	989.1	1102.8
1100	23.4	23.2	982.1	1109.7	1237.3
1200	21.4	21.5	1057.9	1195.4	1332.9
1300	19.7	19.6	1158.0	1308.5	1459.0
1400	18.5	18.7	1225.7	1385.0	1544.3
1500	17.3	17.4	1317.3	1488.5	1659.7
1600	16.2	16.2	1414.8	1598.7	1782.6
1700	15.2	15.0	1528.1	1726.7	1925.3
1800	14.4	14.3	1602.9	1811.2	2019.5
1900	13.6	13.7	1673.1	1890.5	2107.9
2000	12.9	13.0	1763.2	1992.3	2221.4
2100	12.3	12.4	1848.5	2088.7	2328.9
2200	11.8	11.8	1942.6	2195.0	2447.4
2300	11.3	11.3	2028.4	2292.0	2555.6
2400	10.8	10.7	2141.7	2420.0	2698.3
2500	10.3	10.0	2292.2	2590.0	2887.9

Fault Flag

The RTQ9728W provides a $\overline{FAULT}$ signal pin which is an N-Channel open-drain MOSFET output. This open-drain output goes low when current exceeds current-limit threshold. The $\overline{FAULT}$ output is capable of sinking a 1mA load to typically 180mV above ground. The $\overline{FAULT}$ pin requires a pull-up resistor ; this resistor should be large in value to reduce energy drain. A 100kΩ pull-up resistor works well for most applications. In case of an over-current condition, $\overline{FAULT}$ will be asserted only after the flag response delay time, t_D, has elapsed. This ensures that $\overline{FAULT}$ is asserted upon valid over-current conditions and that erroneous error reporting is eliminated. For example, false over-current conditions may occur during hot-plug events when extremely large capacitive loads are connected, which induces a high transient inrush current that exceeds the current limit threshold. The $\overline{FAULT}$ response delay time, t_D, is typically 7.5ms.

Supply Filter/Bypass Capacitor

A 10μF low-ESR ceramic capacitor connected from VIN to GND and located close to the device is strongly recommended to prevent input voltage drooping during hot plug events. However, higher capacitor values may be used to further reduce the voltage droop on the input. Without this bypass capacitor, an output short may cause sufficient ringing on the input (from source lead inductance) to destroy the internal control circuitry. Note that the input transient voltage must never exceed 6V as stated in the Absolute Maximum Ratings.

Output Filter Capacitor

Standard bypass methods should be used to minimize inductance and resistance between the bypass capacitor and the downstream connector to reduce EMI and decouple voltage droop caused by hot-insertion transients in downstream cables. Ferrite beads in series with VBUS, the ground line and the bypass capacitors at the power connector pins are recommended for EMI and ESD protection. The bypass capacitor itself should have a low dissipation factor to allow decoupling at higher frequencies.

For commercial applications where the ambient temperature is 0°C to 70°C (such as a PC or USB hub), RTQ9728W supports an output capacitor range of up to 120μF. For industrial applications with an ambient temperature of −40°C~125°C, please limit the output capacitance to less than 50uF to ensure normal startup.

Chip Enable Input

The RTQ9728W do not have auto discharge function. During shutdown condition, the supply current is 1μA, typically. The maximum guaranteed voltage for a logic-low at the EN pin is 0.4V. A minimum guaranteed voltage of 1.2V at the EN pin will turn on the RTQ9728W. Floating the input may cause unpredictable operation.

Under-Voltage Lockout

Under-Voltage Lockout (UVLO) prevents the MOSFET switch from turning on until input voltage exceeds approximately 2.3V (typ.). If input voltage drops below approximately 2.1V (typ.), UVLO turns off the MOSFET switch.

Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature $T_{J(MAX)}$, listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using the following formula :

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$$

where $T_{J(MAX)}$ is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance.

For continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, θ_{JA}, is highly package dependent. For a SOT-23-6 package, the thermal resistance, θ_{JA}, is 208.2°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. For a WDFN-6SL 2x2 package, the thermal resistance, θ_{JA}, is 33.5°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at

T_A = 25°C can be calculated as below :

$P_{D(MAX)}$ = (125°C − 25°C) / (208.2°C/W) = 0.48W for a SOT-23-6 package.

$P_{D(MAX)}$ = (125°C − 25°C) / (33.5°C/W) = 2.98W for a WDFN-6SL 2x2 package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J(MAX)}$ and the thermal resistance, θ_{JA}. The derating curves in Figure 2 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

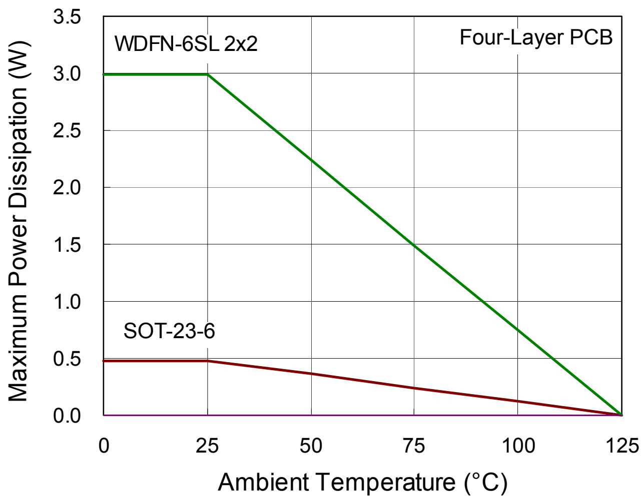


Figure 2. Derating Curve of Maximum Power Dissipation

Layout Consideration

Follow the PCB layout guidelines for optimal performance of the device.

- Place the R_{ILIM} resistor as close to the device as possible to reduce parasitic effects on the current limit accuracy.
- For better thermal performance, design a wide and thick plane for PCB ground or add sufficient vias to GND plane.

An example of PCB layout guide is shown in Figure 3 and Figure 4.

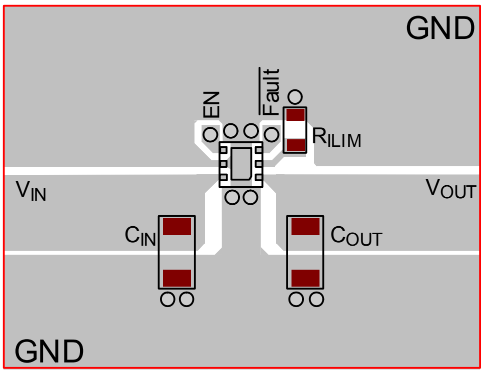


Figure 3. PCB Layout Guide for WDFN-6SL 2x2

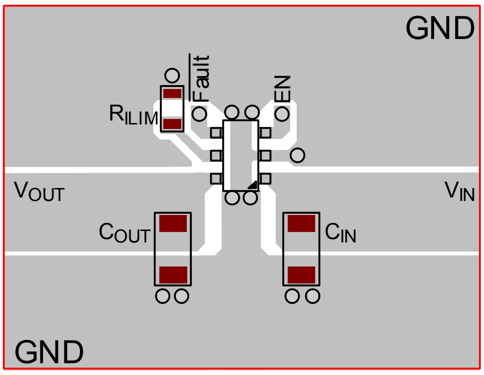
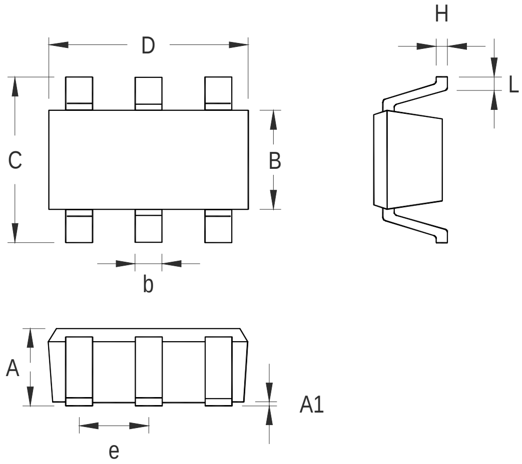


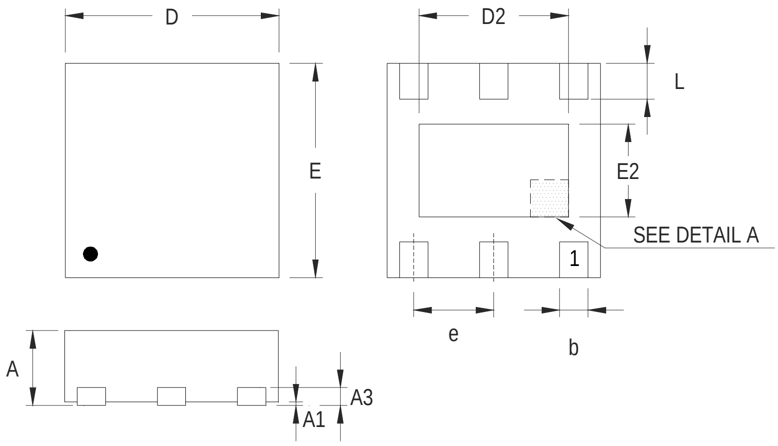
Figure 4. PCB Layout Guide for SOT-23-6

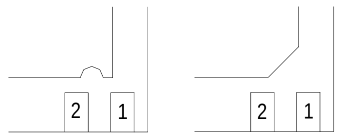
Outline Dimension



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.889	1.295	0.031	0.051
A1	0.000	0.152	0.000	0.006
B	1.397	1.803	0.055	0.071
b	0.250	0.560	0.010	0.022
C	2.591	2.997	0.102	0.118
D	2.692	3.099	0.106	0.122
e	0.838	1.041	0.033	0.041
H	0.080	0.254	0.003	0.010
L	0.300	0.610	0.012	0.024

SOT-23-6 Surface Mount Package





DETAIL A

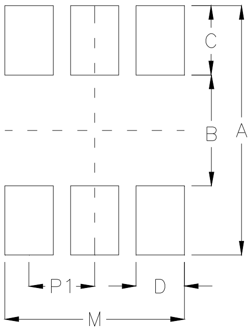
Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

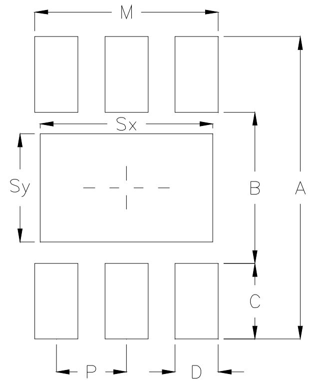
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.200	0.350	0.008	0.014
D	1.900	2.100	0.075	0.083
D2	1.550	1.650	0.061	0.065
E	1.900	2.100	0.075	0.083
E2	0.950	1.050	0.037	0.041
e	0.650		0.026	
L	0.200	0.300	0.008	0.012

W-Type 6SL DFN 2x2 Package

Footprint Information



Package	Number of Pin	Footprint Dimension (mm)						Tolerance
		P1	A	B	C	D	M	
TSOT-26/TSOT-26(FC)/SOT-26/SOT-26(COL)	6	0.95	3.60	1.60	1.00	0.70	2.60	±0.10



Package	Number of Pin	Footprint Dimension (mm)								Tolerance
		P	A	B	C	D	Sx	Sy	M	
V/W/U/XDFN2x2-6S	6	0.65	2.80	1.40	0.70	0.40	1.60	1.00	1.70	±0.05

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Datasheet Revision History

Version	Date	Description	Item
07	2023/2/1	Modify	General Description on P1 Features on P1 Electrical Characteristics on P6