

## General Description

AOZ1377DI is a current-limiting protection switch targeting applications that require comprehensive protections. Both VIN and VOUT terminals are rated at 28V absolute maximum.

The AOZ1377DI is a USB-C protection switch with a 5A/20VIN rating, capable of operating as either a sink or a source switch. There is a programmable soft-start feature that controls the inrush current for highly capacitive loads. The supply current reduces to 3μA in shut-down. It also has Input Under-Voltage Lock Out (UVLO), Input Over-Voltage Protection (OVP), and Thermal Shut Down Protection (TSD).

AOZ1377DI has True Reverse Current Blocking (TRCB) protection to avoid undesired reverse-current from VOUT to VIN. It also features an internal current-limiting circuit that protects the supply from large load current. The current limit threshold can be set externally with a resistor.

AOZ1377DI-01 will auto-restart when the fault conditions are cleared. AOZ1377DI-02 will latch the power switch off and EN must be reset to restart the device.

AOZ1377DI is available in small 3mm x 3mm 10-pin DFN package.

## Features

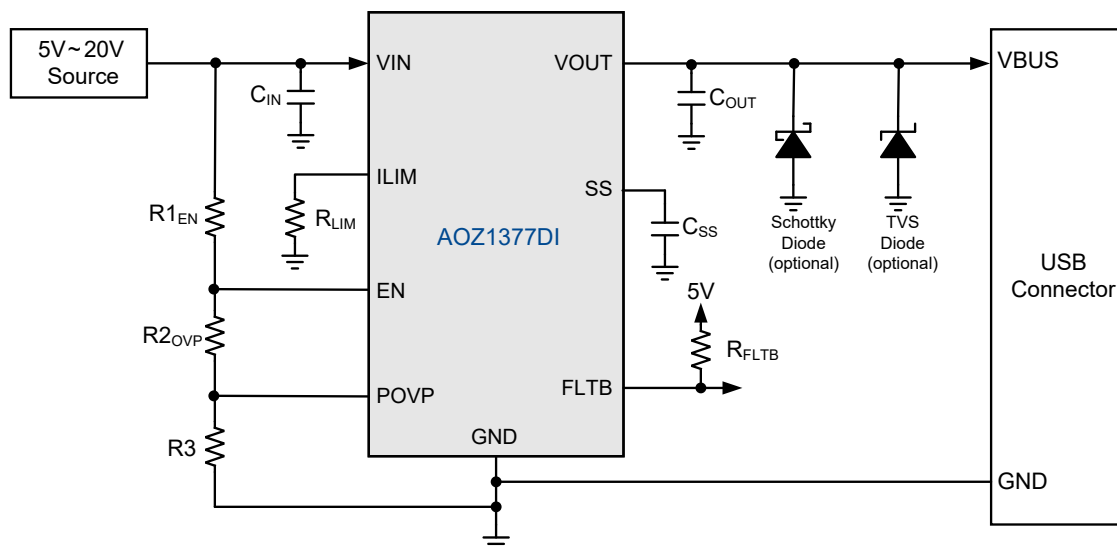
- 28V abs max voltage rating on VIN and VOUT pin
- Typical R<sub>ON</sub>: 19mΩ
- Support up to 7A at operating max 23V
- Programmable current limit
- True Reverse-Current Blocking (TRCB)
- Input Over-Voltage Protection (OVP)
- Short-Circuit Protection (SCP)
- Input Under-Voltage Lock Out (UVLO)
- Thermal Shut Down Protection (TSD)
- HBM ESD rating: ±4kV on all pins
- CDM ESD rating: ±1kV
- IEC 61000-4-2: ±8kV on VOUT and VIN
- IEC 61000-4-5: ±40V on VOUT, No cap
- IEC 62368-1:2018 (3rd Edition)
- UL2367 recognition

## Applications

- USB PD power source switch
- Smartphones and tablets
- Notebooks, ultra-books and desktops
- Portable devices



## Typical Application



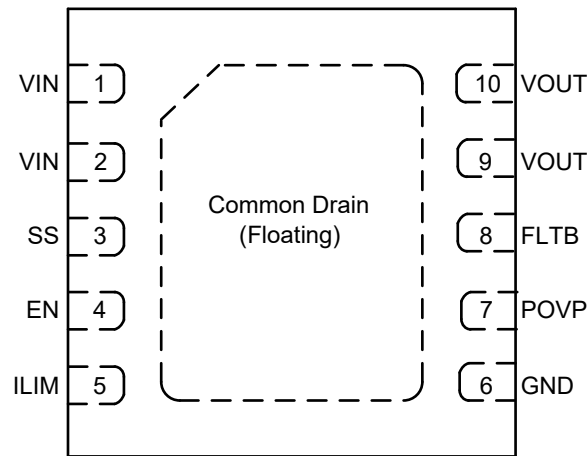
## Ordering Information

Part Number	Fault Recovery	Operating Voltage Range	Package	Environmental
AOZ1377DI-01	Auto-Restart	3.4V - 23V	DFN3x3-10L	RoHS
AOZ1377DI-02	Latch Off	3.4V - 23V	DFN3x3-10L	RoHS



AOS products are offered in packages with Pb-free plating and compliant to RoHS standards. Please visit <https://aosmd.com/sites/default/files/media/AOSGreenPolicy.pdf> for additional information.

## Pin Configuration



DFN3x3-10L  
(Top Transparent View)

## Pin Description

Pin Number	Pin Name	Pin Function
1, 2	VIN	Supply input. Connected to internal power regulator. They are internally connected together.
3	SS	Soft Start control. Connect a capacitor CSS from SS to GND to set the soft start time.
4	EN	Enable input. Active high.
5	ILIM	Current limit set pin. Connect a 1% resistor RLIM from ILIM to GND to set the current limit threshold.
6	GND	Ground
7	POVP	Programmable Over Voltage Protection. Use resistor divider from VIN to GND to set the OVP threshold.
8	FLT B	Open-drain Fault indicator.
9, 10	VOUT	Power output. Connect to Type C port. They are internally connected together.
EXP	EXP	Exposed Thermal Pad. It is the common drain node for the power switches and it must be electrically isolated. Solder to a metal surface directly underneath the EXP and connect to floating copper thermal pads on multiple PCB layers through many VIAs. For best thermal performance, make the floating copper pads as large as possible.

## Absolute Maximum Ratings

Exceeding the Absolute Maximum ratings may damage the device.

Parameter	Rating
VIN, VOUT to GND	-0.3V to +28V
EN, ILIM, SS, FLT, POVP to GND	-0.3V to +6V
Junction Temperature (T <sub>J</sub> )	+150°C
Storage Temperature (T <sub>S</sub> )	-65°C to +150°C
ESD Rating HBM All Pins	±4kV
IEC 61000-4-2: VOUT and VIN	±8kV

## Recommended Operating Conditions

The device is not guaranteed to operate beyond the Maximum Recommended Operating Conditions.

Parameter	Rating
VIN, VOUT to GND	3.4V to 23V
EN, ILIM, SS, FLT to GND	0V to 5.5V
POVP to GND	0V to 3V
Switch DC Current (I <sub>SW</sub> )	0A to 7A
Ambient Temperature (T <sub>A</sub> )	-40°C to +85°C
Package Thermal Resistance (Θ <sub>JA</sub> )	50°C/W

## Electrical Characteristics

T<sub>A</sub> = 25°C, VIN = 12V, EN = 5V, unless otherwise specified.

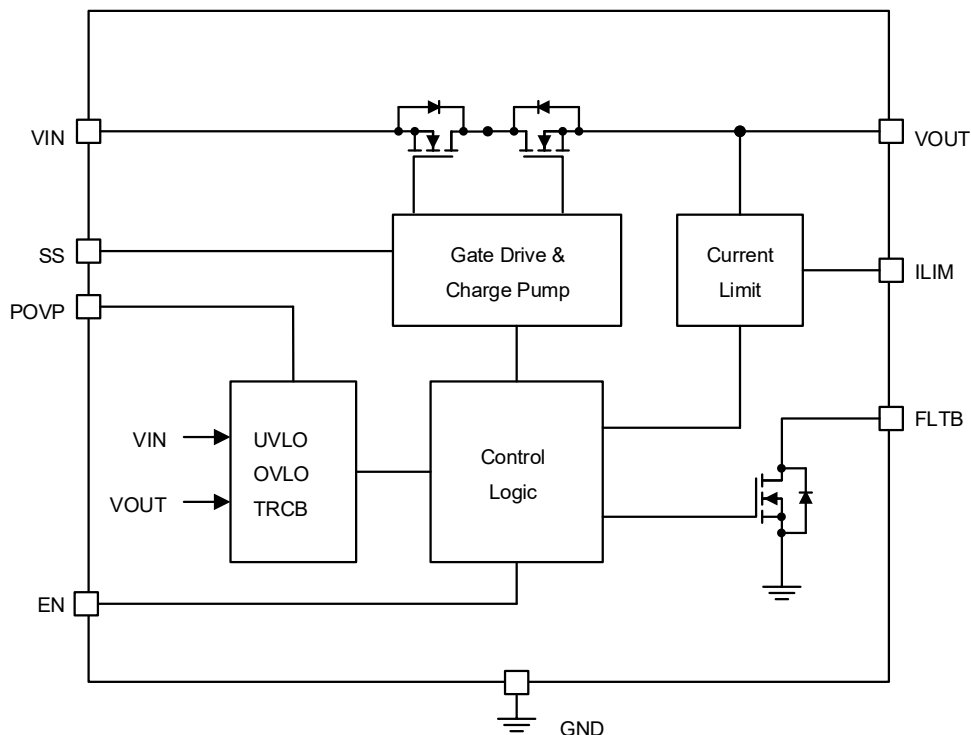
Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>General</b>						
V <sub>VIN</sub>	Input Supply Voltage		3.4		23	V
V <sub>UVLO_R</sub>	Under-voltage Lockout Threshold	VIN rising	2.9		3.35	V
V <sub>UVLO_HYS</sub>	Under-voltage Lockout Hysteresis	VIN falling		250		mV
I <sub>VIN_ON</sub>	Input Quiescent Current	I <sub>OUT</sub> = 0 A		900		uA
I <sub>VIN_OFF</sub>	Input Shutdown Current	EN = 0 V		3		μA
R <sub>ON_20V</sub>	Switch ON-Resistance	VIN = 20V, I <sub>OUT</sub> = 1 A		19		mΩ
R <sub>ON_5V</sub>		VIN = 5V, I <sub>OUT</sub> = 1 A		19		mΩ
V <sub>EN_H</sub>	Enable Input Logic High Threshold	EN rising	1.05	1.20	1.35	V
V <sub>EN_L</sub>	Enable Input Logic Low Threshold	EN falling	0.85	1.00	1.15	V
I <sub>EN_BIAS</sub>	Enable Input Bias Current	EN = 1.8V		20		nA
V <sub>FLT_LO</sub>	FLT Pull-down Voltage	I <sub>SINK</sub> = 3mA			0.3	V
<b>Dynamic Characteristics</b>						
t <sub>D_ON</sub>	Turn-On Delay Time (From EN 50% to VOUT=0.5V)	VIN = 12V, C <sub>SS</sub> = 22nF R <sub>LIM</sub> = 3.92kΩ		1		ms
t <sub>ON</sub>	Turn-On Time (VOUT from 10% to 90% of 12V VIN)	VIN = 12V, C <sub>SS</sub> = 22nF R <sub>LIM</sub> = 3.92kΩ		3.2		ms
t <sub>REC</sub>	FLT Recovery Time	Fault is removed (AOZ1377DI-01 Only)		130		ms
<b>True Reverse-Current Blocking (TRCB)</b>						
V <sub>T_TRCB</sub>	TRCB Protection Trip Point	VOUT-VIN, VOUT rising		30		mV
t <sub>TRCB</sub>	TRCB Response Time	VOUT-VIN > V <sub>T_TRCB</sub> + 500mV		1		μs

### Electrical Characteristics

T<sub>A</sub> = 25°C, VIN = 12V, EN = 5V, unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>Input Over-Voltage Protection (OVP)</b>						
V <sub>POVP</sub>	Over-voltage Lockout Threshold	VPOVP rising		1.2		V
V <sub>POVP_HYS</sub>	Over-voltage Lockout Hysteresis	AOZ1377DI-01 only		100		mV
I <sub>POVP_BIAS</sub>	POVP Input Bias Current	POVP = 1.8V		20		nA
t <sub>DELAY_OVP</sub>	OVP Turn-Off Delay			1		µs
<b>Over Current Protection (OCP)</b>						
I <sub>LIM</sub>	Current Limit Threshold	R <sub>LIM</sub> = 2.74kΩ (1% Tolerance)	6.4	7.1	7.8	A
		R <sub>LIM</sub> = 3.92kΩ (1% Tolerance)	4.5	5.0	5.5	
		R <sub>LIM</sub> = 6.65kΩ (1% Tolerance)	2.55	3.0	3.45	
t <sub>OCP</sub>	Over-Current Duration before Switch Off	From I <sub>OUT</sub> ≥ I <sub>LIM</sub> to Switch Off		1		ms
t <sub>OCP_FLTB</sub>	Over-Current Flag Delay	From I <sub>OUT</sub> ≥ I <sub>LIM</sub> to FLTB pulled low		1		ms
<b>Short-Circuit Protection (SCP)</b>						
t <sub>SC_RESPONSE</sub>	Response time to open the switch after a VOUT short circuit condition is detected	VIN - VOUT > 500mV		1		µs
<b>Thermal Shutdown (TSD)</b>						
T <sub>SD</sub>	Thermal Shutdown Threshold	Temperature rising		140		°C
T <sub>SD_HYS</sub>	Thermal Shutdown Hysteresis	Temperature falling (AOZ1377DI-01 only)		30		°C

### Functional Block Diagram



## Timing Diagrams

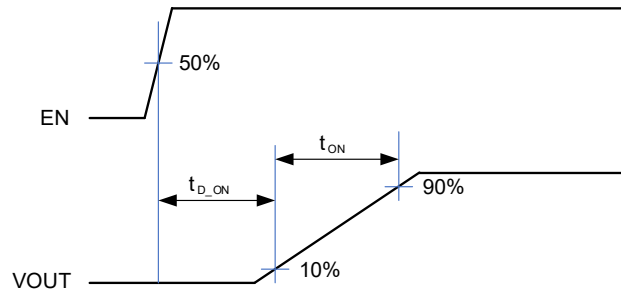


Figure 1. Power On Delay and Soft Start Time

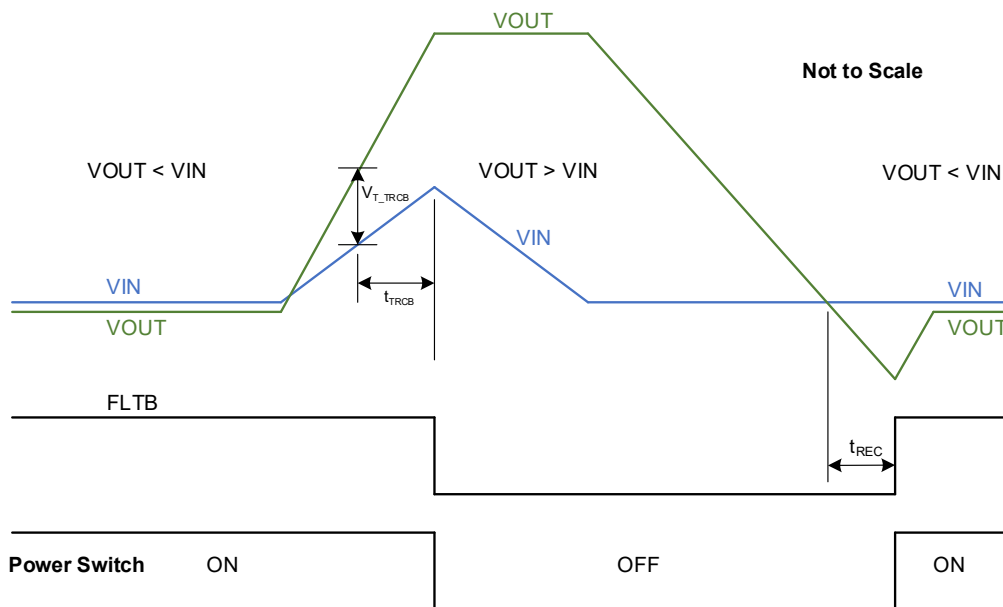


Figure 2. True Reverse Current Blocking (TRCB) Operation (AOZ1377DI-01)

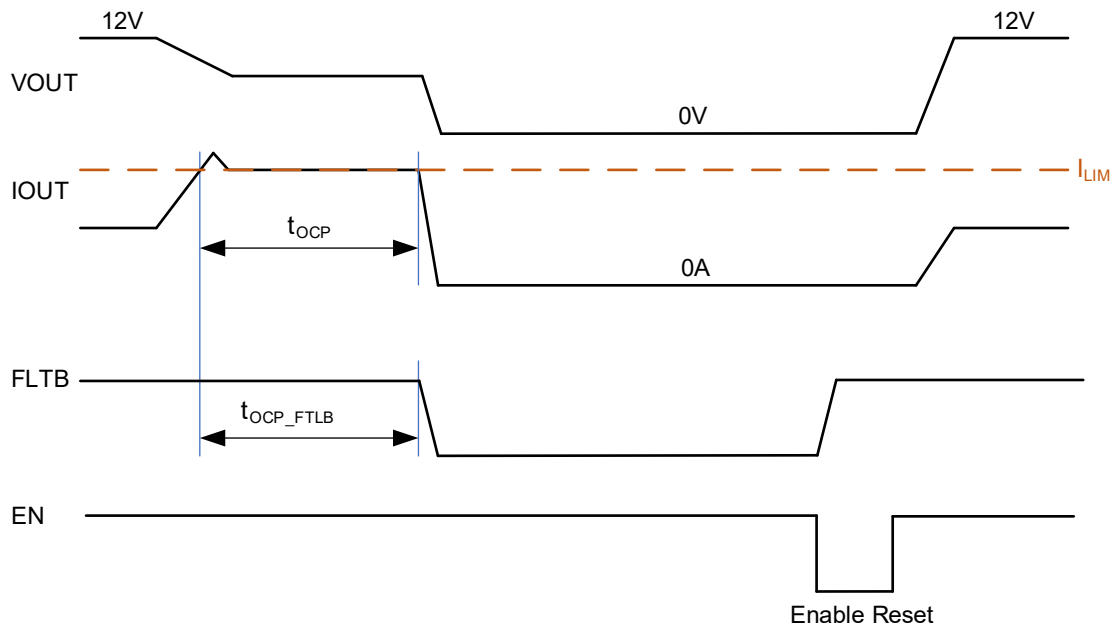
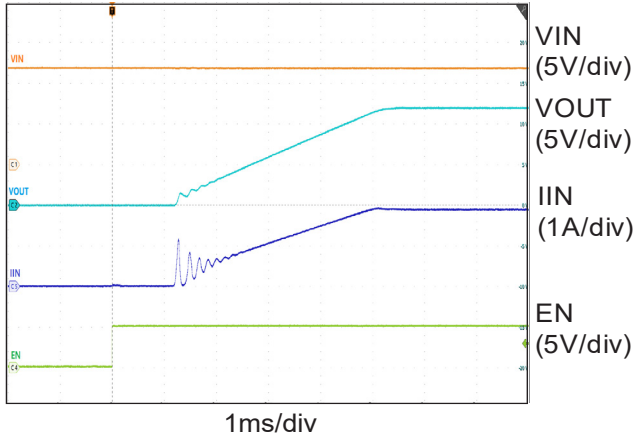


Figure 3. Over Current Protection (OCP) Operation for Latch Off Version. AOZ1377DI-02. VIN = 12V.

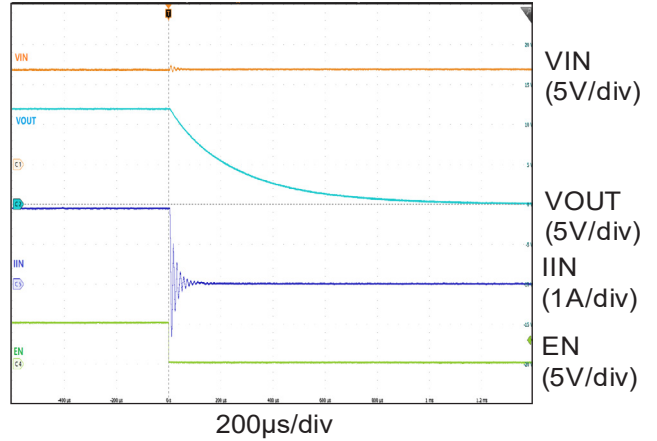
### Typical Characteristics

$T_A = 25^\circ\text{C}$ ,  $V_{IN} = 12\text{V}$ ,  $C_{IN} = 10\mu\text{F}$ ,  $C_{OUT} = 40\mu\text{F}$ ,  $C_{SS} = 22\text{nF}$ ,  $C_{CAP} = 1\text{nF}$ ,  $R_{LIM} = 3.92\text{k}\Omega$  unless otherwise specified.

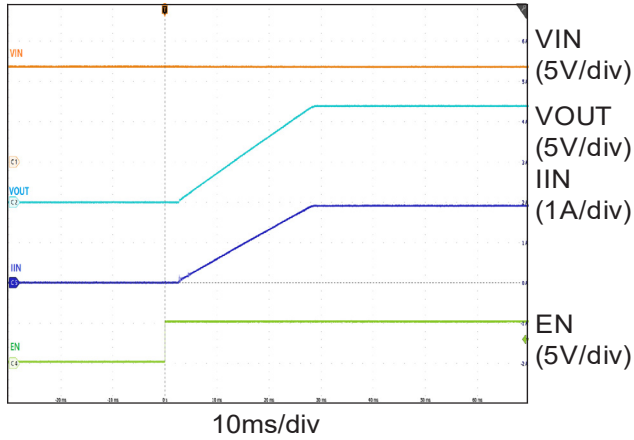
**Soft Start by EN  
(LOAD = 6.5Ω)**



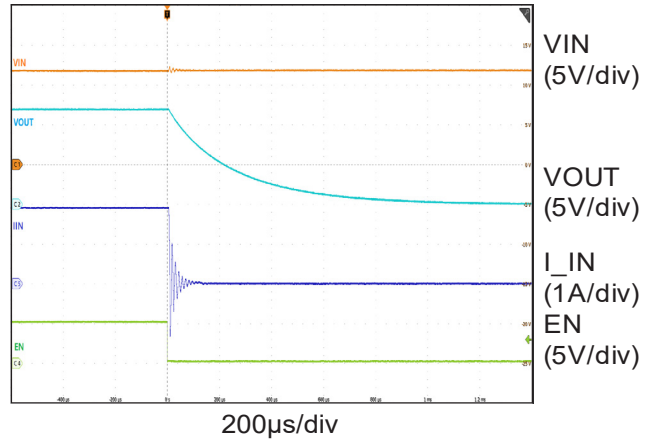
**Shutdown by EN  
(LOAD = 6.5Ω)**



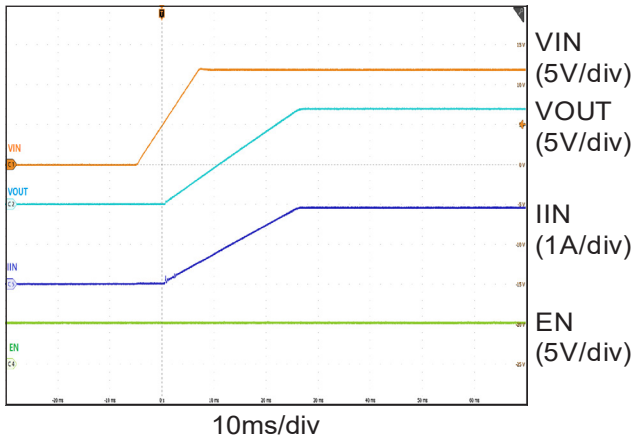
**Soft Start by EN  
(LOAD = 6.5Ω,  $C_{SS} = 134\text{nF}$ )**



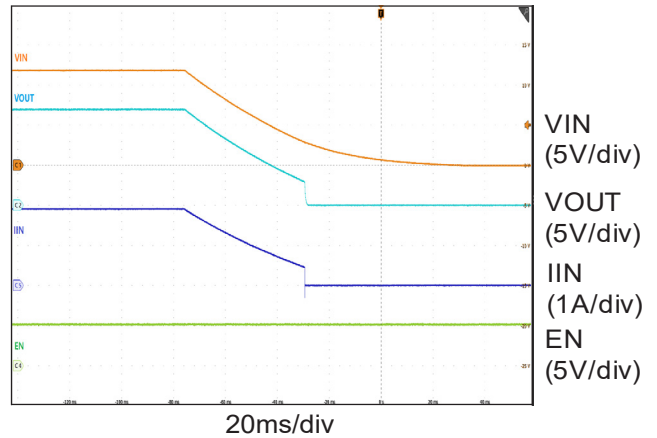
**Shutdown by EN  
(LOAD = 6.5Ω,  $C_{SS} = 134\text{nF}$ )**



**Soft Start by VIN  
(LOAD = 6.5Ω,  $C_{SS} = 134\text{nF}$ )**



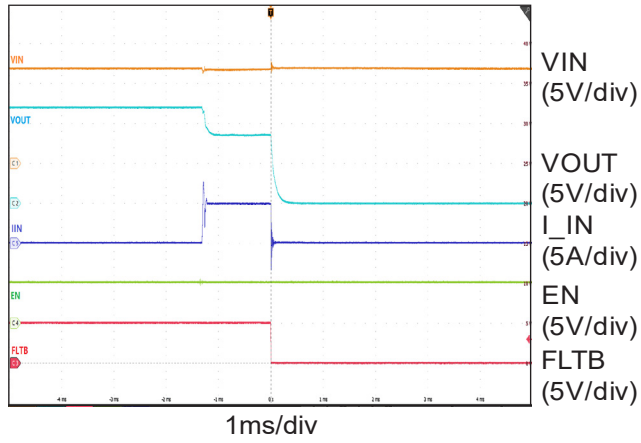
**Shut Down by VIN  
(LOAD = 6.5Ω,  $C_{SS} = 134\text{nF}$ )**



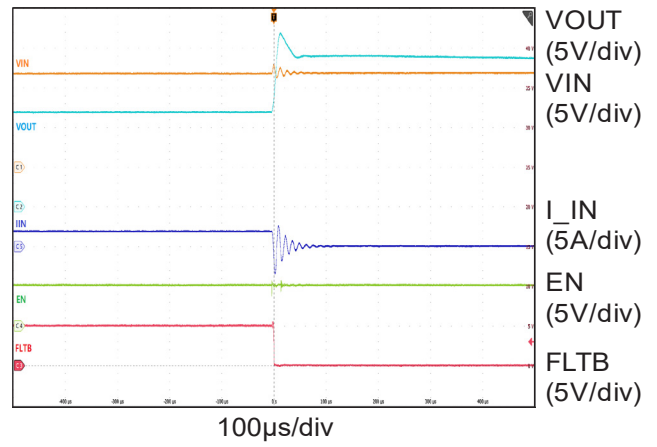
## Typical Characteristics

$T_A = 25\text{ }^\circ\text{C}$ ,  $V_{IN} = 12\text{V}$ ,  $C_{IN} = 10\text{ }\mu\text{F}$ ,  $C_{OUT} = 40\text{ }\mu\text{F}$ ,  $C_{SS} = 22\text{ nF}$ ,  $C_{CAP} = 1\text{ nF}$ ,  $R_{LIM} = 3.92\text{ k}\Omega$  unless otherwise specified.

**Over Current Protection  
(LOAD = 2 $\Omega$  Plugged In)**



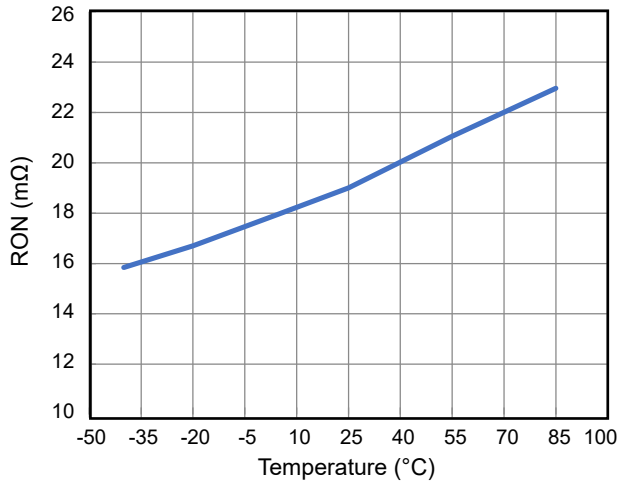
**Reverse Current Blocking  
(LOAD = 6.5 $\Omega$ , VOUT pulled up to 20V)**



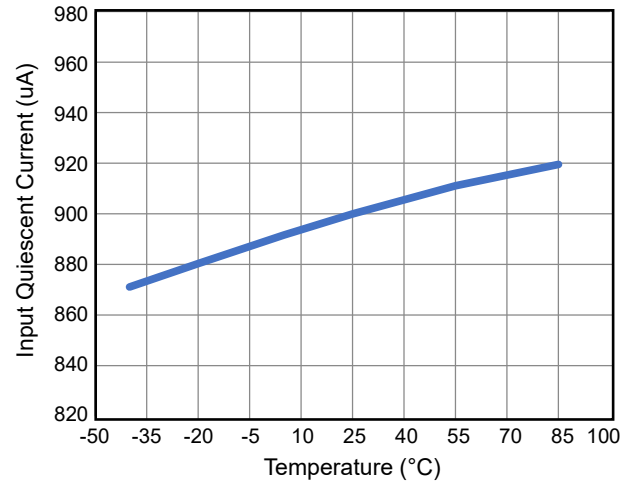


## Typical Characteristics

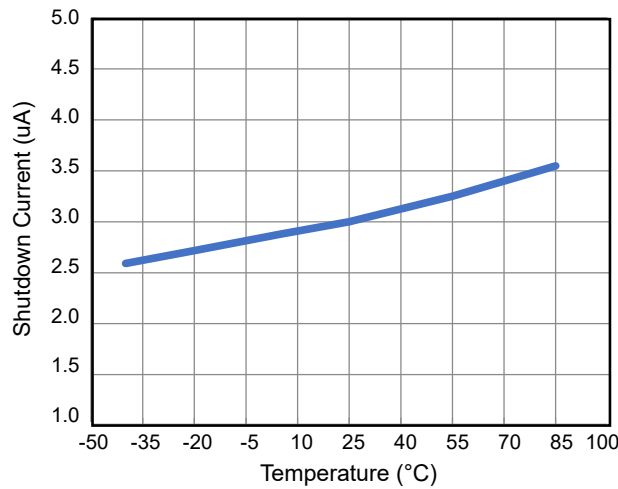
$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.



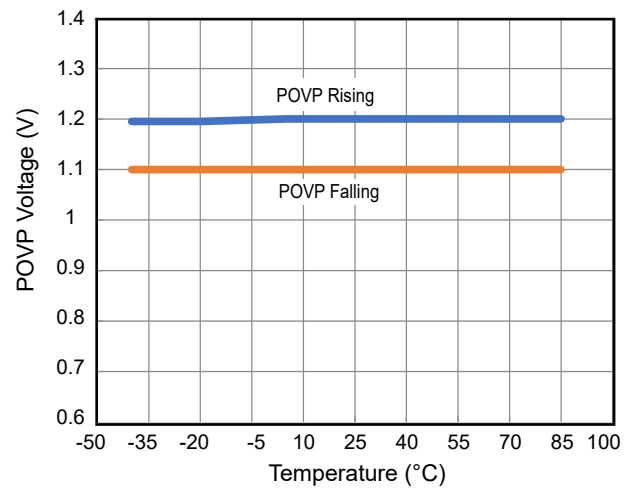
**On Resistance vs. Temperature**  
(VIN = 20V)



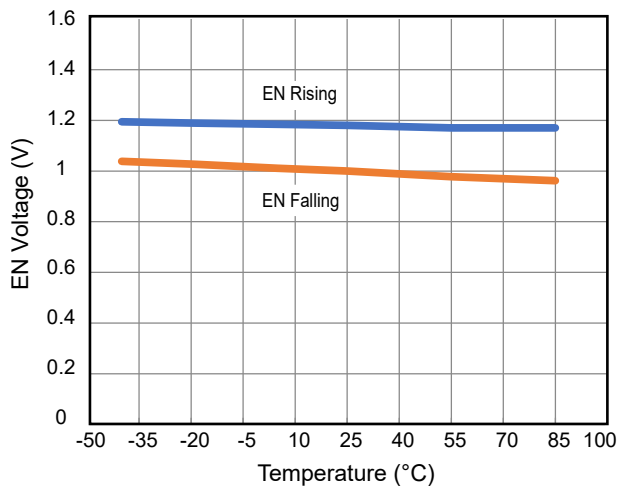
**Quiescent Current vs. Temperature**  
(VIN = 20V)



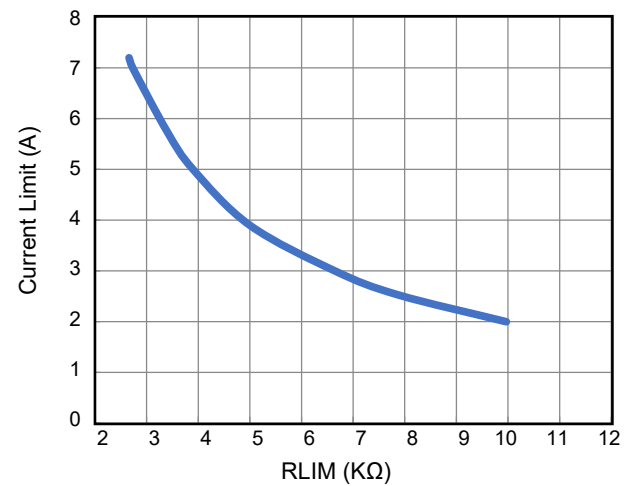
**Shutdown Current vs. Temperature**  
(VIN = 20V)



**POVP Pin Threshold vs. Temperature**



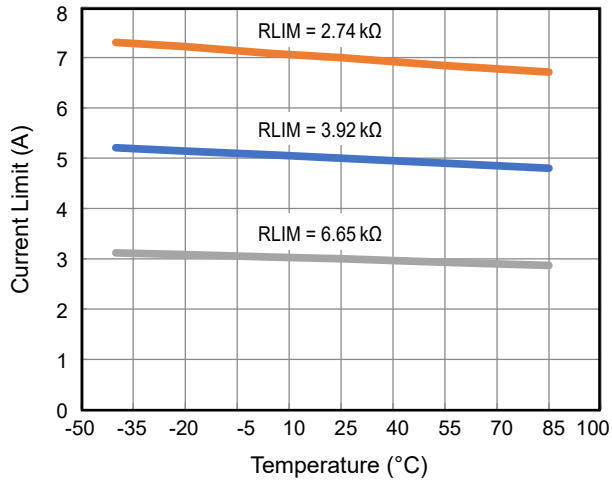
**EN Threshold vs. Temperature**



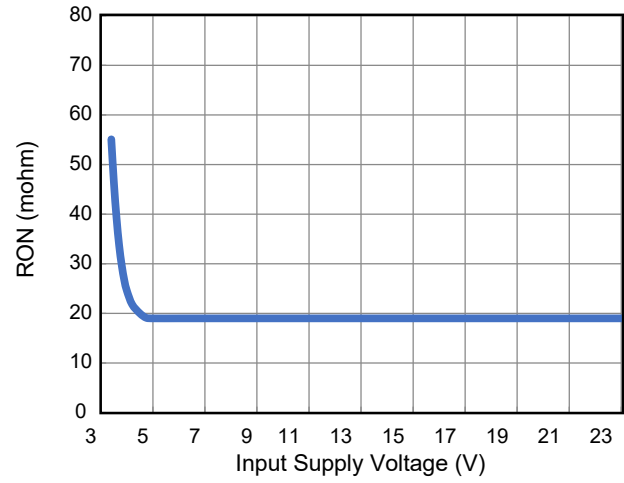
**Current Limit vs. RLIM**

## Typical Characteristics

$T_A = 25\text{ }^\circ\text{C}$ , unless otherwise specified.



Current Limit vs. Temperature



ON Resistance vs. VIN

## Functional Description

The AOZ1377 is a power switch with current limiting, offering over-voltage, over-current, SCP, reverse-current, and thermal shutdown protections.

The device has true reverse-current blocking (TRCB) features that will prevent undesired current flow from output to its input in either enabled or disabled state. The AOZ1377 can operate as either a sink or a source switch.

### Enable

The EN pin is the ON/OFF control for the power switch. The device is enabled when EN pin is high and not in under-voltage lockout state. The EN pin must be driven to a logic high or logic low state to guarantee operation.

Alternatively, EN pin can be biased with resistor divider network from VIN so that device enable will be tracking the input voltage. While disabled, the AOZ1377DI draws 3µA from supply.

### Input Under-Voltage Lockout (UVLO)

The under-voltage lockout (UVLO) circuit monitors the input voltage. The power switch is only allowed to turn on when input voltage is higher than UVLO threshold. Otherwise the switch is off.

### Over-Voltage Protection (OVP)

The voltage at VIN pin is constantly monitored once the device is enabled. The over-voltage protection threshold can be programmed externally through POVP pin. In case input voltage exceeds the over-voltage protection threshold ( $V_{OVP}$ ) of 1.2V at POVP pin, the power switch is either turned off immediately or kept off, depending on its initial state. FLTb will be pulled low to indicate a fault condition.

AOZ1377DI-01 can be restarted when voltage at POVP pin drops below the hysteresis voltage of  $V_{OVP\_HYS}$ . Once the device detects that the OVP condition no longer exists, it will turn back on the switch after FLTb recovery time blanking ( $t_{REC}$ ) (AOZ1377DI-01 only).

### Programmable Current Limit and Over-Current Protection (OCP)

The AOZ1377DI implements current limit to ensure that the current through the switch does not exceed current limit threshold set by the external resistor  $R_{LIM}$ .

The current limit threshold can be estimated using the equations below:

$$I_{LIM} = \frac{1.24}{R_{LIM}} \times 5000 \times 3.14$$

where  $R_{LIM}$  unit is in ohm and  $I_{LIM}$  unit is in Ampere.

For example, a 3.92kΩ  $R_{LIM}$  resistor should be selected for 5A current limit threshold. Resistor with 1% tolerance is recommended for  $R_{LIM}$ .

AOZ1377DI continuously limits the output current when output is overloaded. The output current will be under regulation for 1ms ( $t_{OCP}$ ). If the overloaded output condition still exists after this 1ms blanking time, the power switch will shut down. FLTb is also pulled low after a 1ms delay ( $t_{OCP\_FLTb}$ ) from over-current condition is detected.

For AOZ1377DI-01 Auto-Restart version, the power switch will be turn on again to restart after FLTb recovery time of 130ms ( $t_{REC}$ ).

For AOZ1377DI-02 Latch Off version, the power switch will only be turned on after toggling the EN input logic to reset the device.

Severe overload causes power dissipation and die temperature to increase and may trigger thermal shutdown.

### Short Circuit Protection (SCP)

When VOUT drops significantly lower than VIN, the system interprets that as a VOUT shorted to GND condition. From that point it takes 1µs ( $t_{SC\_RESPONSE}$ ) to respond and open the switch which will isolate VIN from VOUT.

For AOZ1377DI-01 Auto-Restart version, the power switch will be turn on again to restart after the recovery time of 130ms ( $t_{REC}$ ).

For AOZ1377DI-02 Latch Off version, the power switch will only be turned on after toggling the EN input logic to reset the device.

### Programming Soft Start

The AOZ1377DI start up delay and soft start time are programmable externally through SS pin. The turn-on time (0% to 100% of Vout) and turn-on delay time can be estimated using the equations below:

$$t_{ON} = \frac{C_{SS}}{2} \times \frac{VIN}{32}$$

$$t_{D\_ON} = 0.35 + \frac{C_{SS}}{32}$$

where  $C_{SS}$  is in nF, VIN is in V,  $t_{ON}$  and  $t_{D\_ON}$  are in ms.

For example, a 12V VIN and a 22nF soft start capacitor will generate soft start time ( $t_{ON}$ ) of 4.125ms after start up delay ( $t_{D\_ON}$ ) of 1ms. The calculated turn-on time is for 0% to 100% of Vout rising.

For prebias condition, part of the soft start time is incorporated in the delay time. The following equations can be used to estimate the soft start delay and ramp time for pre-bias condition:

$$t_{ON} = C_{SS} \times \frac{VIN - VOUT_{PREBIAS}}{32}$$

$$t_{D\_ON} = 0.35 + \frac{C_{SS}}{32} + \frac{C_{SS} \times VOUT_{PREBIAS}}{32}$$

where  $C_{SS}$  is in nF,  $VOUT_{PREBIAS}$  is the Output PreBias voltage in V,  $t_{ON}$  and  $t_{D\_ON}$  are in ms.

The actual soft start time may not be equal to the estimated value from the above equation if the operating condition exceeds the SOA of the power switch.

### True Reverse Current Blocking (TRCB)

True reverse-current blocking prevents undesired current flow from output to input when power switch is in either on or off state. When device is enabled, power switch is quickly turned off whenever output voltage is higher than input voltage by 30mV ( $V_{T\_TRCB}$ ). Once the device detects the TRCB condition it will quickly turn off the switch in 1 $\mu$ s ( $t_{TRCB}$ ). FLTb will be pulled low to indicate a TRCB condition.

For AOZ1377DI-01 Auto-Restart version, the power switch can be turned on again when  $VOUT < VIN$ . Once the device detects that the TRCB condition no longer exists, it will turn back on the switch after FLTb recovery time blanking ( $t_{REC}$ ).

### Thermal Shut Down Protection (TSD)

Thermal shutdown protects device from excessive temperature. The power switch is turned off when the die temperature reaches thermal shutdown threshold of 140°C. There is a 30°C hysteresis. When thermal shutdown is activated, FLTb is pulled low immediately to report fault condition to host.

For AOZ1377DI-01 Auto-Restart version, the power switch will be turn on again after the temperature decreases by hysteresis of 30°C.

For AOZ1377DI-02 Latch Off version, the power switch stays off after thermal shutdown and can only turn on by either toggling EN or cycling the input power supply.

### Startup

The device is enabled when  $EN \geq V_{EN\_H}$  and input voltage VIN is higher than UVLO threshold. The device first checks if any fault condition exists. If no fault exists, the power switch will turn on and the output starts to ramp up. Power switch is kept off if fault condition is detected.

### Fault Reporting

AOZ1377DI protects itself and load from the following fault condition: over-voltage, over-current, short-circuit, reverse-current, and thermal shutdown.

The FLTb pin is an open drain output. It is asserted low when over-current, short-circuit, over-voltage, reverse current, or over-temperature condition occurs. The FLTb pin becomes high impedance when the fault conditions are removed. A pull-up resistor ( $R_{FLTb}$ ) must be connected between FLTb to 5V to provide a logic signal.

When thermal shutdown is activated, FLTb is pulled low immediately to report fault condition to host.

For output current overload condition, FLTb pin is pulled low 1ms ( $t_{OCP\_FLTb}$ ) after device is in current limiting.

The power switch will be turned off and FLTb pin will be pulled low for a fault condition to indicate fault status of the device. The device will continuously monitor the fault conditions. See the Table 1 and 2 as a summary of the fault responses.

**Table 1. AOZ1377DI-01 Fault flag response to all protection functions**

Protection	Fault Response	FLTb Status
TRCB	Auto-restart	Low
SCP	Auto-restart	Low
Current Limit	Auto-restart	Low
TSD	Auto-restart	Low
OVP	Auto-restart	Low

**Table 2. AOZ1377DI-02 Fault flag response to all protection functions**

Protection	Fault Response	FLTb Status
TRCB	Latch-off	Low
SCP	Latch-off	Low
Current Limit	Latch-off	Low
TSD	Latch-off	Low
OVP	Latch-off	Low

For AOZ1377DI-01 (Auto-Restart version), the power switch is turned off under fault condition. The device will try to restart indefinitely for every  $t_{REC}$  of 130ms until it is disabled.

For AOZ1377DI-02 (Latch-Off version), the device will latch off under fault condition and can only turn on by either toggling EN or cycling the input power supply.

### Input Capacitor Selection

The input capacitor prevents large voltage transients from appearing at the input, and provides the instantaneous

current needed each time the switch turns on to charge output capacitors and to limit input voltage drop. It also prevents high-frequency noise on the power line from passing through to the output. The input capacitor should be located as close to the pin as possible. A minimum of 10µF ceramic capacitor should be used. A higher capacitor value is strongly recommended to further reduce the transient voltage drop at the input.

**Output Capacitor Selection**

The output capacitor acts in a similar way. Also, the output capacitor has to supply enough current for a large load that it may encounter during system transient. This bulk capacitor must be large enough to supply fast transient load in order to prevent the output from dropping.

**Power Dissipation Calculation**

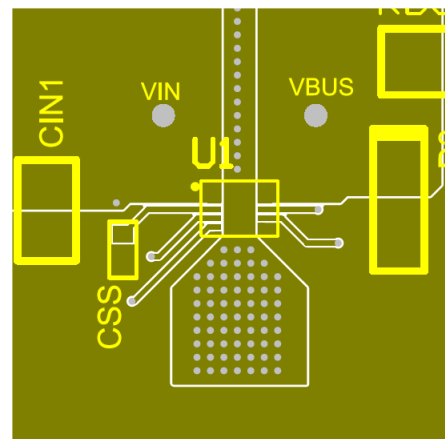
Calculate the power dissipation for normal load condition using the following equation:

$$Power\ Dissipation = R_{ON} \times (I_{OUT})^2$$

**Layout Guidelines**

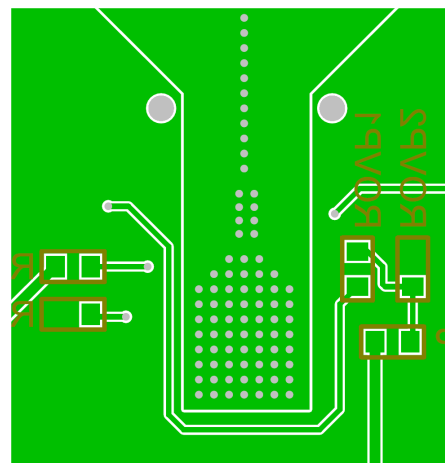
Good PCB layout is important for improving the thermal and overall performance. To optimize the switch response time to output short-circuit conditions, keep all traces as short as possible to reduce the effect of unwanted parasitic inductance. Place the input and output bypass capacitors as close as possible to the VIN and VOUT pins. The input and output PCB traces should be as wide as possible for the given PCB space. Use a ground plane to enhance the power dissipation capability of the device.

For the most efficient heat sinking, connect as much copper as possible to the exposed pad. The exposed pad is the common drain of the power switch which must be electrically isolated.



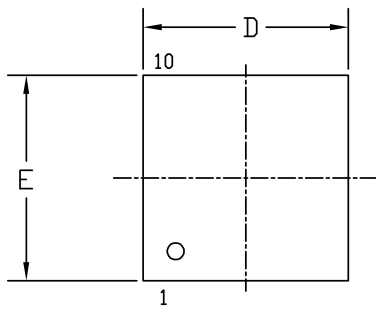
**Figure 4. Top Layer**

In addition to the top plane, if available, connect to the bottom layer plane for best thermal performance.

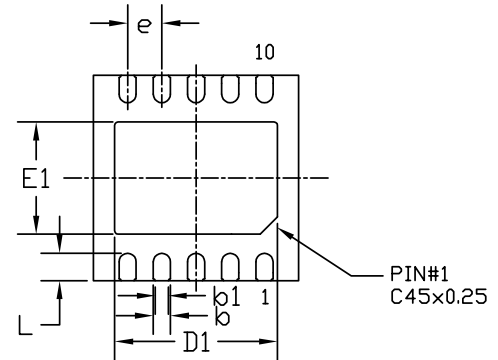


**Figure 5. Bottom Layer**

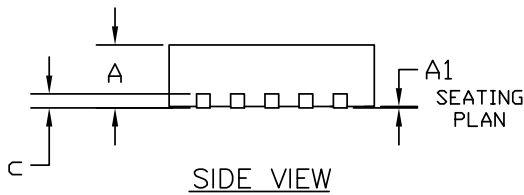
Package Dimensions, DFN3x3-10L



TOP VIEW

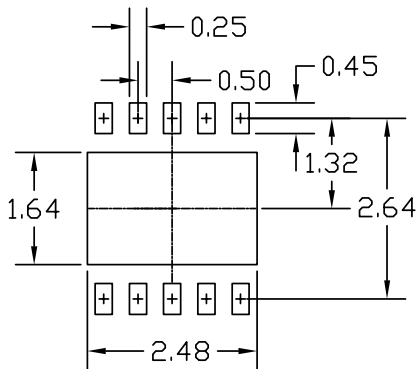


BOTTOM VIEW



SIDE VIEW

RECOMMENDED LAND PATTERN



UNIT: mm

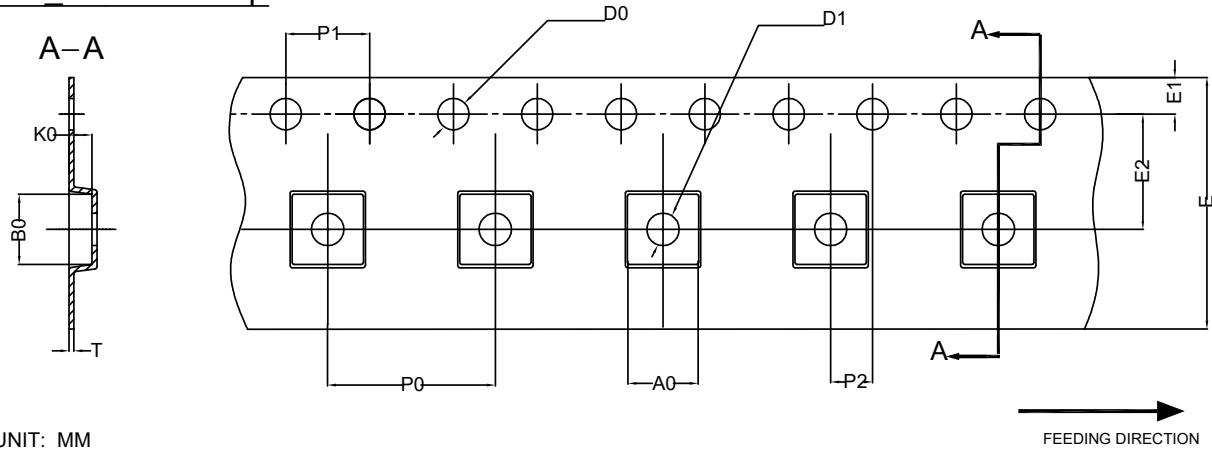
SYMBOLS	DIMENSION IN MM			DIMENSION IN INCHES		
	MIN	NOM	MAX	MIN	NOM	MAX
A	0.80	0.90	1.00	0.031	0.035	0.039
A1	0.00	0.02	0.05	0.000	0.001	0.002
b	0.20	0.25	0.30	0.008	0.010	0.012
b1	0.09	0.19	0.29	0.004	0.007	0.011
c	0.195	0.203	0.211	0.008	0.008	0.008
D	2.90	3.00	3.10	0.114	0.118	0.122
D1	2.28	2.38	2.48	0.090	0.094	0.098
E	2.90	3.00	3.10	0.114	0.118	0.122
E1	1.54	1.64	1.74	0.061	0.065	0.069
L	0.30	0.40	0.50	0.012	0.016	0.020
e	0.50BSC			0.020BSC		

NOTE

1. DIMENSIONING AND TOLERANCING CONFORM TO ASME Y14.5M-1994.
2. CONTROLLING DIMENSION IS MILLIMETER.  
CONVERTED INCH DIMENSIONS ARE NOT NECESSARILY EXACT.

**Tape and Reel Dimensions, DFN3x3-10L**

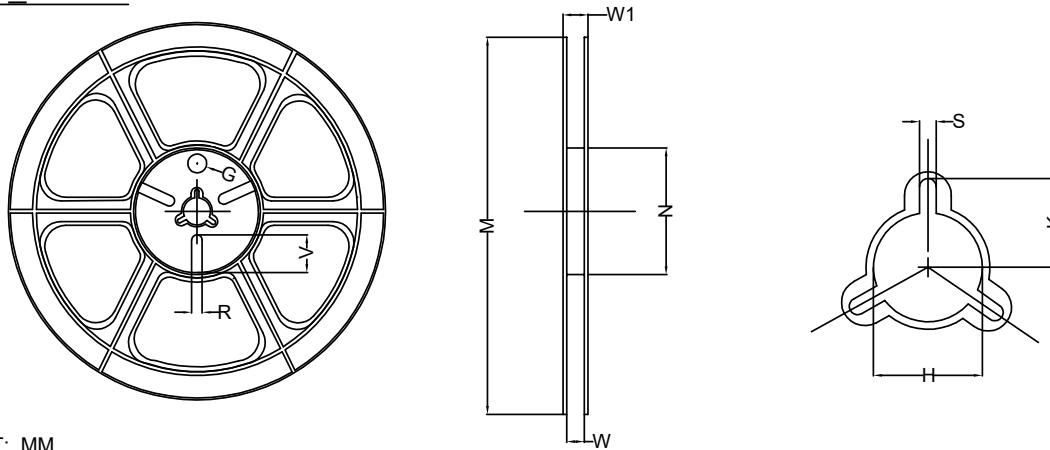
**DFN3x3 EPCarrier Tape**



UNIT: MM

PACKAGE	A0	B0	K0	D0	D1	E	E1	E2	F0	P1	P2	T
DFN3x3_EP	3.40 ±0.10	3.35 ±0.10	1.10 ±0.10	1.50 +0.10 -0	1.50 +0.10 -0	12.00 ±0.30	1.75 ±0.10	5.50 ±0.05	8.00 ±0.10	4.00 ±0.10	2.00 ±0.05	0.30 ±0.05

**DFN3x3 EP Reel**

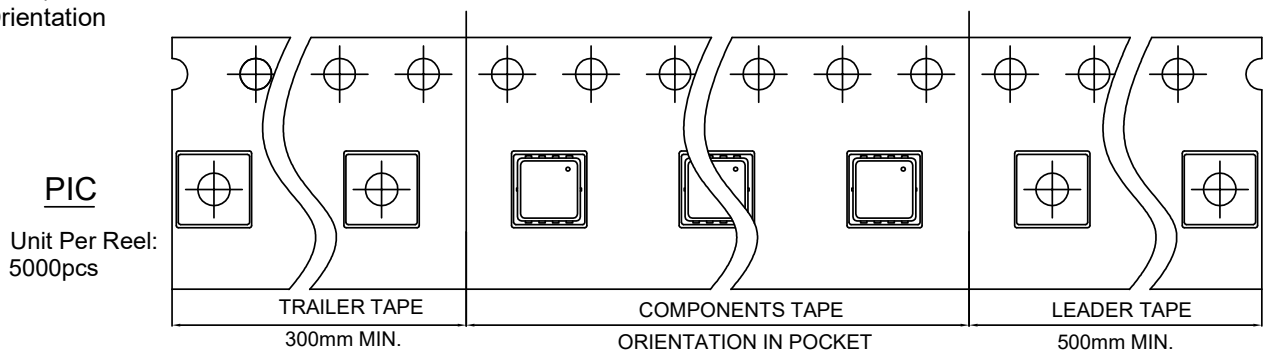


UNIT: MM

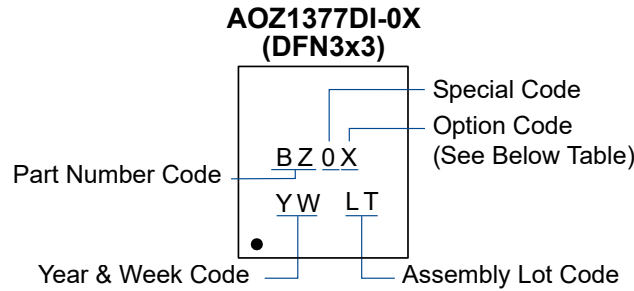
TAPESIZE	REEL SIZE	M	N	W	W1	H	K	S	G	R	V
12 mm	Ø330	Ø330.00 ±0.50	Ø97.00 ±0.10	13.00 ±0.30	17.40 ±1.00	Ø13.00 +0.50 -0.20	10.60	2.00 ±0.50	---	---	---

**DFN3x3 EPTape**

Leader / Trailer  
& Orientation



**Part Marking**



Part Number	Fault Recovery	Code
AOZ1377DI-01	Auto-Restart	BZ01
AOZ1377DI-02	Latch-Off	BZ02

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2. A critical component in any component of a life support, device, or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.