AOZ1351DI-01

ECPower™ 5V 38mΩ Protection Switch
True Reverse Current Blocking with Fast Recovery

General Description

AOZ1351DI-01 is a current-limiting protection switch targeting applications that require comprehensive protections. The output terminal VOUT is rated at 28V absolute maximum. The internal current-limiting circuit protects the supply from large load current. The current limit threshold can be set externally with a resistor. Internal 2ms soft-start feature controls the inrush current due to highly capacitive loads. The supply current reduces to 6µA in shut-down. It also has Input Under-Voltage LockOut (UVLO), Input Over-Voltage LockOut (OVLO), and Over-Temperature Protection (OTP).

AOZ1351DI-01 has True Reverse Current Blocking (TRCB) protection to avoid undesired reverse-current from VOUT to VIN. It also features fast recovery in 1µs to turn on power switch once reverse current blocking protection is released. It will auto-restart after the fault conditions are released.

AOZ1351DI-01 is available in small 3mm x 3mm 12-pin DFN package.

Features

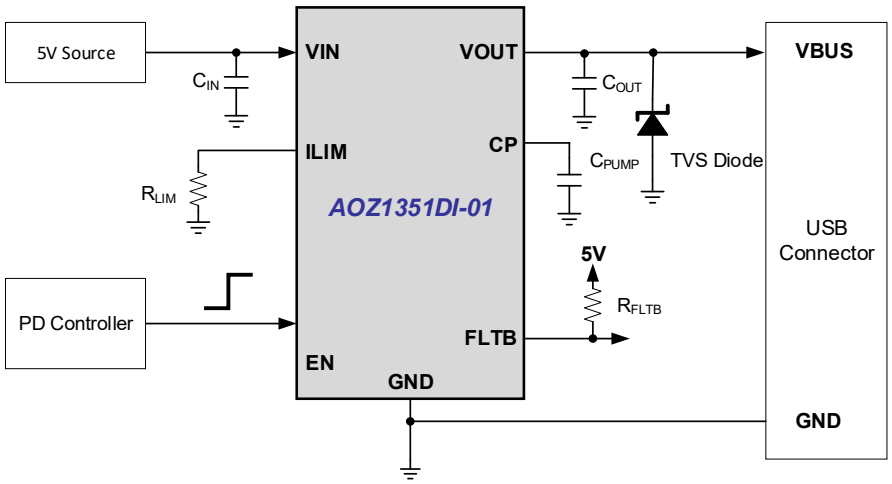
- 28V voltage rating on VOUT pin
- Typical R_{ON}: 38mΩ
- Programmable current limit
- True Reverse Current Blocking (TRCB)
- 1µs fast recovery from TRCB
- 220µA quiescent current
- Internal soft start control
- Input Over-Voltage Protection (OVLO)
- Short-Circuit Protection (SCP)
- Input Under-Voltage LockOut (UVLO)
- Over-Temperature Protection (OTP)
- ±2kV HBM rating
- ±1kV CDM rating
- IEC 61000-4-2: 8kV on VOUT
- IEC 62368-1:2014 E326264-A60004-CB-1

Applications

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

Green Product

Typical Application

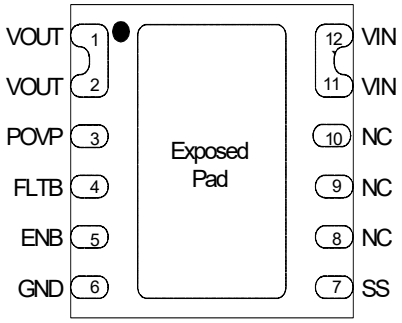


Ordering Information

Part Number	Fault Recovery	Temperature Range	Package	Environmental
AOZ1351DI-01	Auto-Restart	-40°C to +85°C	DFN3x3-12L	RoHS

All AOS products are offered in packages with Pb-free plating and compliant to RoHS standards. Please visit www.aosmd.com/media/AOSGreenPolicy.pdf for additional information.

Pin Configuration



DFN3x3-12L
(Top Transparent View)

Pin Description

Pin Number	Pin Name	Pin Function
1, 2, 3	VOUT	Power output. Connect to Type C port. They are internally connected together.
4	FLTB	Open-drain Fault indicator. Active-low when over current or over temperature fault conditions occur.
5	CP	Charge pump reservoir capacitor. Connect a 47nF capacitor to GND. No external load allowed.
6	NC	No connect.
7	GND	Ground.
8	ILIM	Current limit set pin. Connect a 1% resistor R_{LIM} from ILIM to GND to set the current limit threshold.
9	EN	Enable input. Active high. Internally pulled down with a 1.8MΩ resistor.
10, 11, 12	VIN	Connect to adapter or power input. They are internally connected together.
EXP	EXP	Exposed Thermal Pad. Connect to GND. Solder to a metal surface directly underneath the EXP and connect to PCB ground on multiple layers through VIAs. For best thermal performance make the ground copper pads as large as possible and connect to EXP with multiple VIAs.

Absolute Maximum Ratings

Exceeding the Absolute Maximum ratings may damage the device.

Parameter	Rating
VOUT to GND	-0.3V to +28V
VIN, EN, ILIM, FLTB, CP to GND	-0.3V to +6V
Junction Temperature (T_J)	+150°C
Storage Temperature (T_S)	-65°C to +150°C
ESD Rating HBM/CDM	±2kV / ±1kV

Recommend Operating Ratings

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

Parameter	Rating
VIN to GND	3.4V to 5.5V
VOUT to GND	0V to 23V
EN, FLTB, CP to GND	0V to 5.5V
Switch DC Current (I_{SW})	0A to 4.5A
ILIM to GND	0V to 2V
Ambient Temperature (T_A)	-40°C to +85°C
Package Thermal Resistance (Θ_{JA})	50°C/W

Electrical Characteristics

T_A = 25°C, VIN = 5V, EN = 5V, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Units
General						
V_{VIN}	Input Supply Voltage		3.4		5.5	V
V_{UVLO}	Under-voltage Lockout Threshold	VIN rising	3.0	3.25	3.35	V
V_{UVLO_HYS}	Under-voltage Lockout Hysteresis	VIN falling	175	250	325	mV
I_{IN_ON}	Input Quiescent Current	I_{OUT} = 0A		220	350	V
I_{IN_OFF}	Input Shutdown Current	EN = 0V		5.8	10	µA
R_{ON}	Switch On Resistance	I_{OUT} = 1A		38	49	mΩ
		I_{OUT} = 1A, T_A: -40°C to +85°C			59	
V_{EN_H}	Enable Input Logic Low Threshold	EN rising	1.4			V
V_{EN_L}	Enable Input Logic Low Threshold	EN falling			0.4	V
I_{EN_BIAS}	Enable Input Bias Current	EN = 1.8V		1	1.5	µA
V_{FLTB_LO}	FLTB Pull-down Voltage	I_{SINK} = 3mA			0.3	V
Dynamic Characteristics						
t_{D_ON}	Turn-On Delay Time (From EN 50% to VOUT=0.5V)	C_{OUT} = 1µF, R_{LIM} = 14.7kΩ		1	1.4	ms
t_{ON}	Turn-On Time (VOUT from 0.5V to 4.5V)			2	2.6	ms
$t_{TRCB\_RCV\_SETUP}$	TRCB Fast Recovery Setup Time after (t_{D_ON} + t_{ON})			1.3	1.7	ms
True Reverse-Current Blocking (TRCB)						
V_{T_TRCB}	TRCB Protection Trip Point	VOUT-VIN, VOUT rising	10	25	40	mV
V_{R_TRCB}	TRCB Protection Release Trip Point	VOUT-VIN, VOUT falling	-15	10	35	mV
V_{TRCB_HYS}	TRCB Hysteresis	V_{T_TRCB} -V_{R_TRCB}	5	15	25	mV
t_{TRCB}	TRCB Response Time	VOUT-VIN > 500mV		600		ns
t_{TRCB_RCV}	TRCB Fast Recovery	No C_{OUT}, I_{OUT} =50mA, after startup and setup time is complete		1	1.3	µs
I_{TRCB}	TRCB Reverse Current				1	A

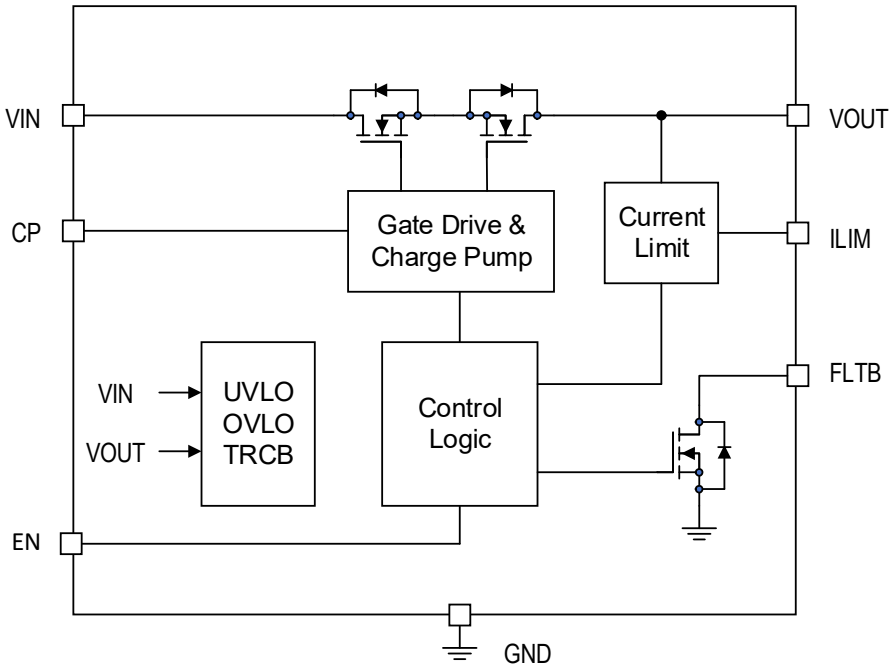
Electrical Characteristics

T_A = 25°C, VIN = 5V, EN = 5V, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Units
Input Over-Voltage Lockout Protection (OVLO)						
V_{OVLO_R}	Over-voltage Lockout Threshold	VIN rising	5.6	5.8	6	V
V_{OVLO_HYS}	Over-voltage Lockout Hysteresis		180	280	380	mV
t_{DELAY_OVP}	OVP Turn-Off Delay	VIN-VOUT > 500mV		2		µA
Over Current Protection (OCP)						
I_{LIM}	Current Limit Threshold	R_{LIM} = 3.52kΩ	3.52	4.0	4.48	A
		R_{LIM} = 4.02kΩ	3.08	3.5	3.92	
		R_{LIM} = 4.65kΩ	2.64	3.0	3.36	
		R_{LIM} = 14.7kΩ	0.88	1.0	1.12	
$I_{LIM\_FOLDBACK}$	Current Limit Foldback	R_{LIM} = 3.52kΩ		8 (1)		% of I_{LIM}
t_{OCP_FLTB}	Over-Current Flag Delay	From $I_{OUT} \geq I_{LIM}$ to FLTB pulled low		10		ms
Short Circuit Protection (SCP)						
V_{SC_DETECT}	VIN-VOUT difference at which a VOUT short circuit condition is detected			390		mv
$t_{SC\_RESPONSE}$	Response time to open the switch after a VOUT short circuit condition is detected	VIN - VOUT > 390mV		1		µs
t_{SCP_FLTB}	Short Circuit Flag Delay			13		ms
Thermal Shutdown (OTP)						
T_{SD}	Thermal Shutdown Threshold	Temperature rising		140		°C
T_{SD_HYS}	Thermal Shutdown Hysteresis	Temperature falling		20		

Note:
1. Guaranteed by characterization and design

Functional Block Diagram



Timing Diagrams

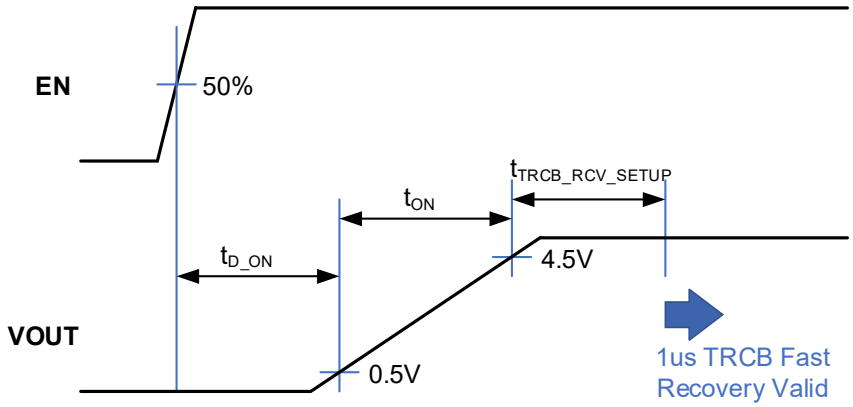


Figure 1. Turn-on Delay and Turn-on Time (VIN = 5V)

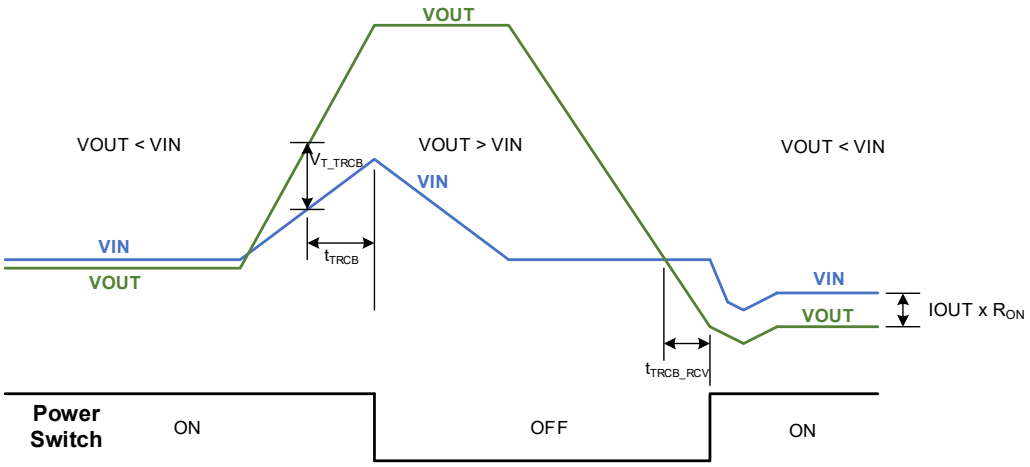


Figure 2. True Reverse Current Blocking (TRCB) Operation

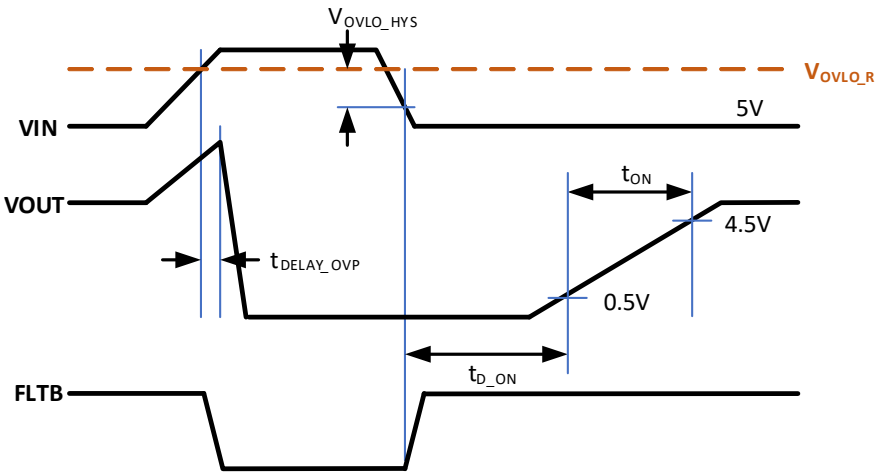


Figure 3. Input Over-Voltage LockOut (OVLO) Operation (VIN=5V)

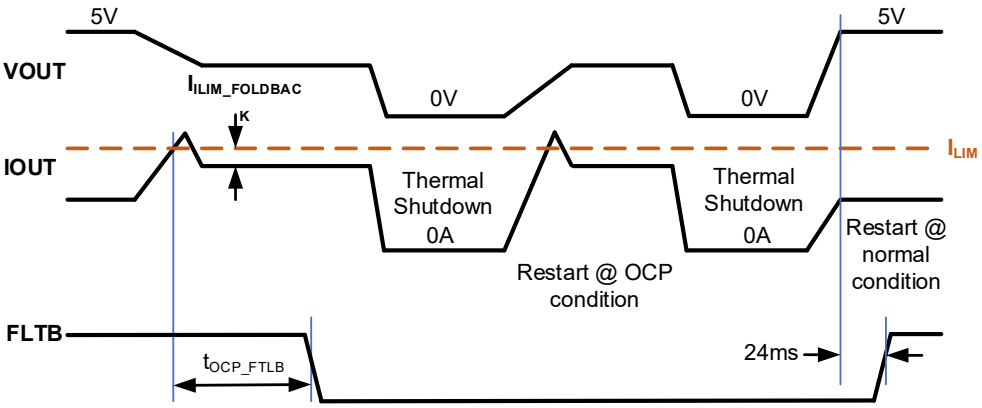


Figure 4. Current Limit (OCP) Operation

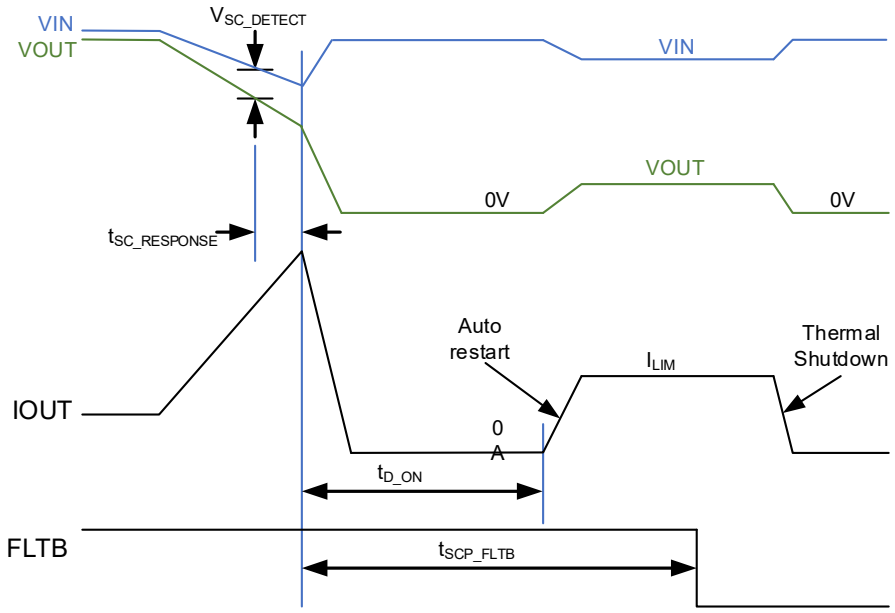


Figure 5. Short Circuit Protection (SCP) Operation

Typical Characteristics

T_A=25°C, V_{IN}=5V, C_{IN}=47µF, C_{OUT}=3x47µF, C_{PUMP}=47nF, R_{LIM}=3.52kΩ, unless otherwise noted.

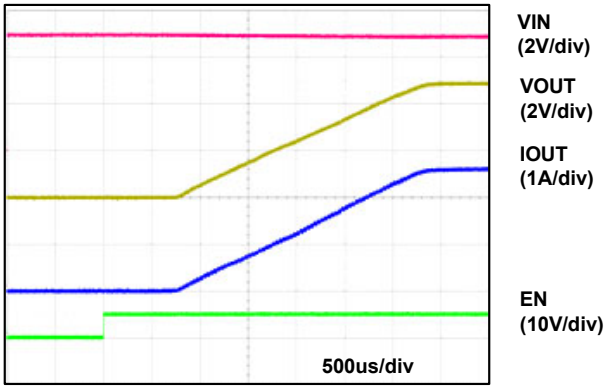


Figure 6. Soft Start (R_{LOAD} = 1.9Ω)

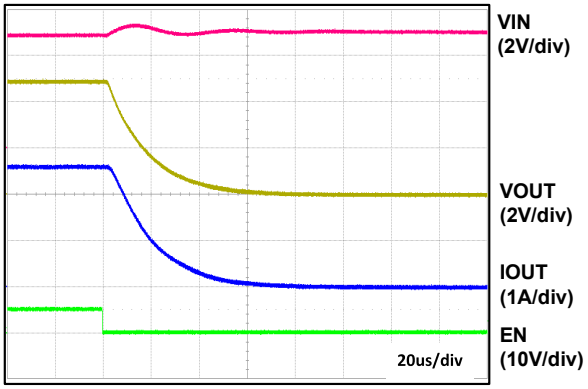


Figure 7. Shutdown by EN (R_{LOAD} = 1.9Ω)

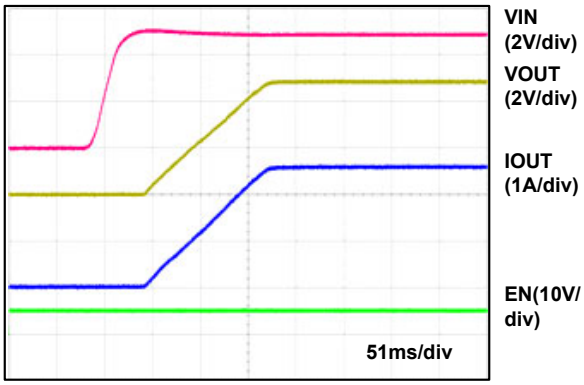


Figure 8. Soft Start by Toggling VIN (R_{LOAD} = 1.9Ω)

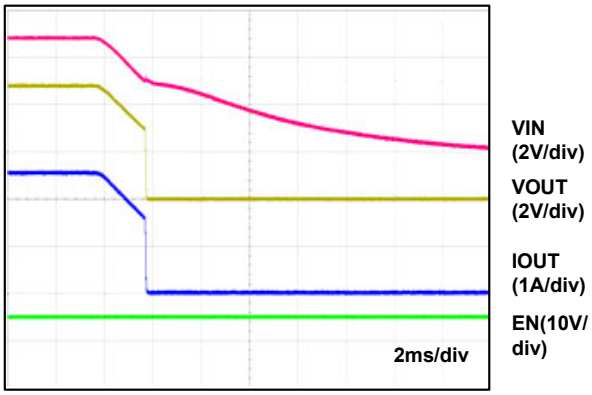


Figure 9. Shutdown by Toggling VIN (R_{LOAD} = 1.9Ω)

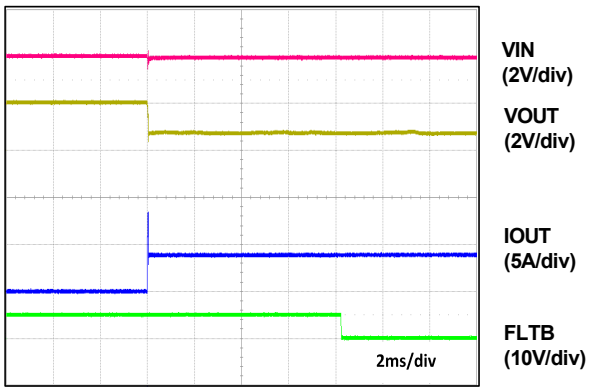


Figure 10. Over Current Protection (R_{LOAD} = 1.2Ω Plugged In)

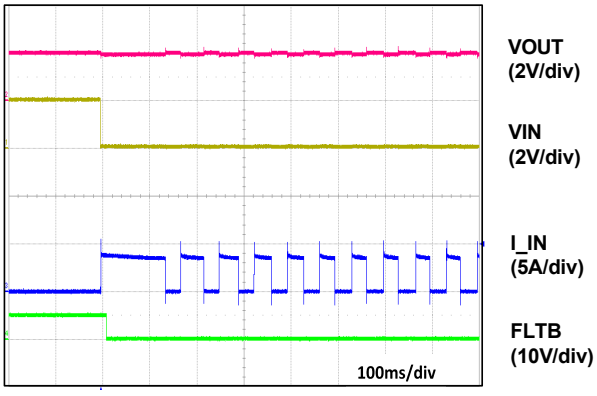


Figure 11. Over Current Limit, Thermal Shutdown, and Restart

Typical Characteristics *(Continued)*

T_A=25°C, V_{IN}=5V, C_{IN}=47µF, C_{OUT}=3x47µF, C_{PUMP}=47nF, R_{LIM}=3.52kΩ, unless otherwise noted.

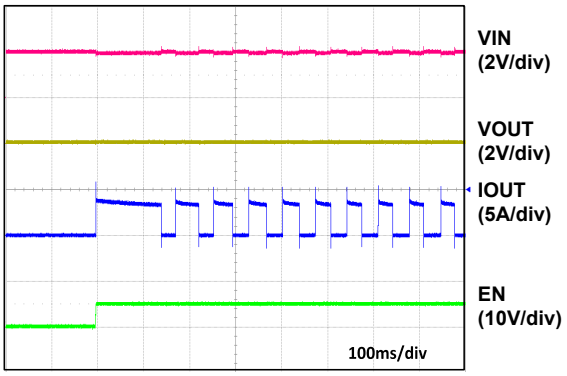


Figure 12. Starting Up into Shorted Output

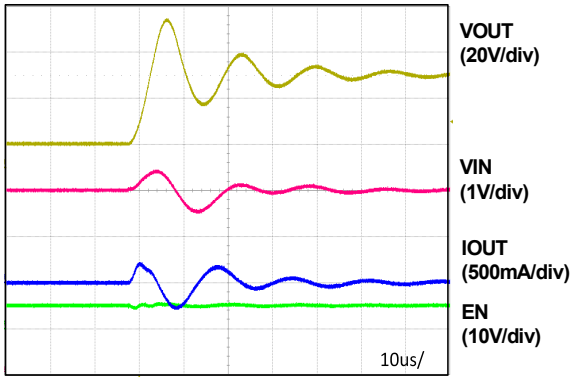


Figure 13. Reverse Current Blocking (VOUT shorted to 20V)

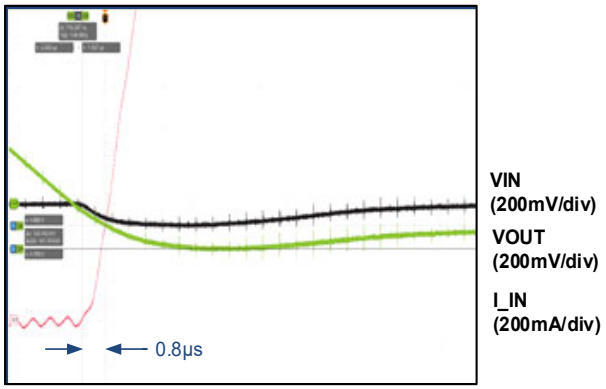


Figure 14. Recovery from Reverse Current Blocking

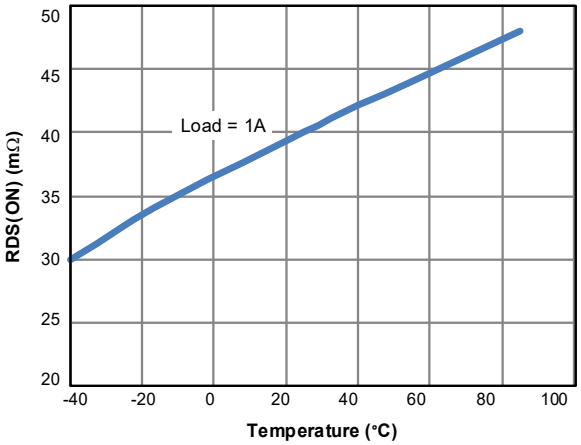


Figure 15. RON vs. Temperature

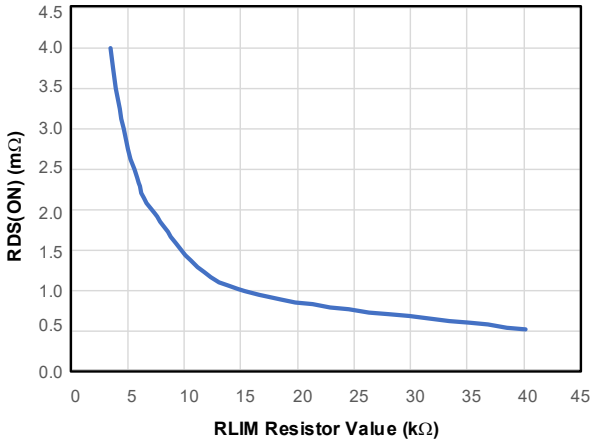


Figure 16. RON vs. Input Voltage

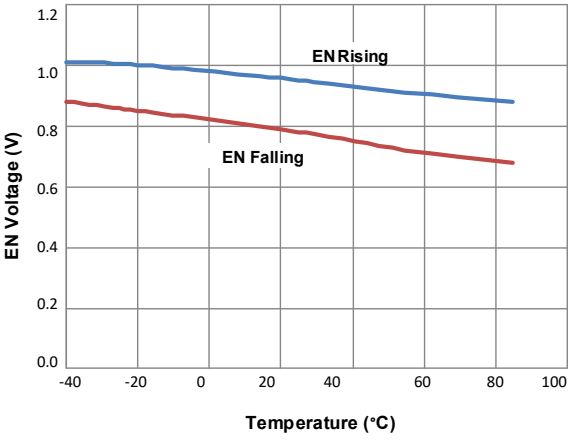


Figure 17. Enable Threshold vs. Temperature

Typical Characteristics *(Continued)*

T_A = 25°C, unless otherwise specified.

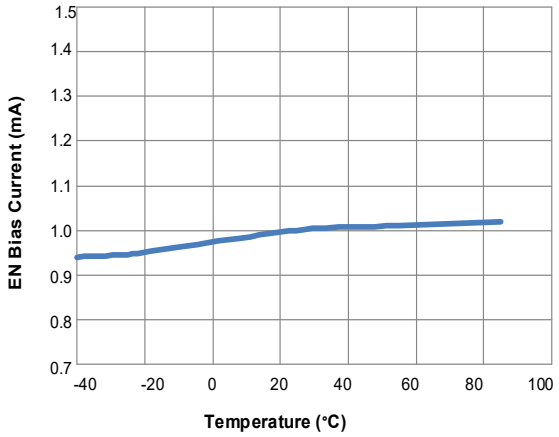


Figure 18. EN Bias Current vs. Temperature (EN = 1.8V)

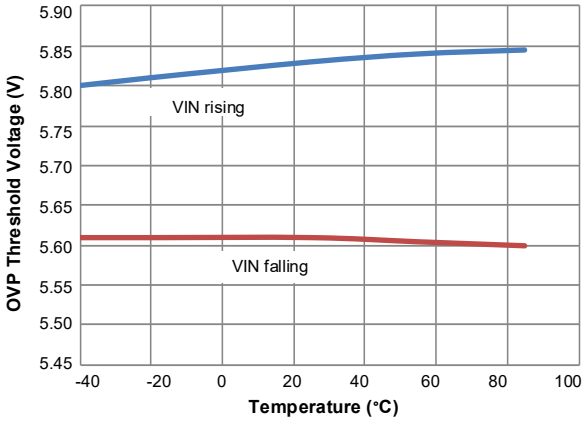


Figure 19. OVP Threshold vs. Temperature

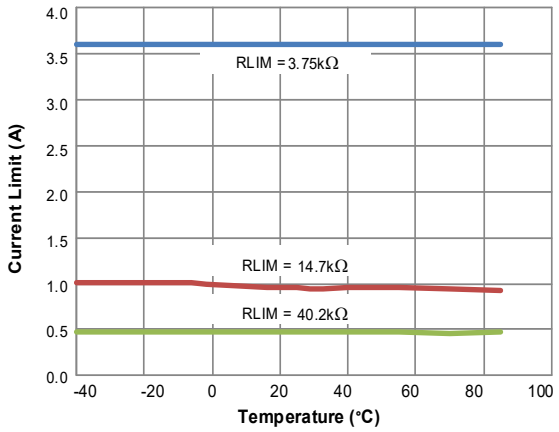


Figure 20. Current Limit Threshold vs. Temperature

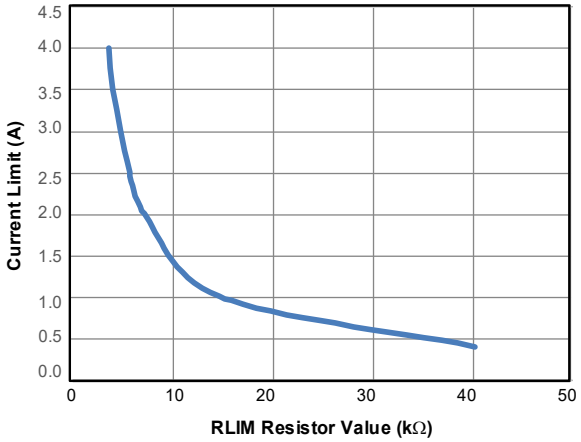


Figure 21. Current Limit vs RLIM

Functional Description

The AOZ1351DI-01 is a current limited power switch with over-voltage, over-current, reverse-current and thermal shutdown protections. The VOUT pin is rated 28V.

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.

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. While disabled, the AOZ1351DI-01 draws 6µA 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 (OVLO)

The voltages at VIN pin is constantly monitored once the device is enabled. In case input voltage exceeds the over-voltage lockout threshold (V_{OVLO_R}), the power switch is either turned off immediately or kept off, depending on its initial state. AOZ1351DI-01 can restart when VIN drops below the hysteresis voltage of V_{OVLO_HYS}.

Programmable Current Limit and Over-Current Protection (OCP)

The AOZ1351DI-01 has current limit feature that ensures the current passing through the switch does not exceed the current limit threshold set by the external resistor R_{LIM}.

The current limit threshold can be estimated using the equations below for the range from 2.5A to 4A:

$$I_{LIM,max} = 16997 \times R_{LIM}{}^{-1.0085}$$

$$I_{LIM,typ} = 20141 \times R_{LIM}{}^{-1.043}$$

$$I_{LIM,min} = 25488 \times R_{LIM}{}^{-1.0876}$$

where R_{LIM} unit is in ohms and I_{LIM} unit is in Amperes. For example, a 3.52kΩ R_{LIM} resistor should be selected for 4A current limit threshold. Resistor with 1% tolerance is recommended for R_{LIM}. Figure 22 show the linearity within this current limit range.

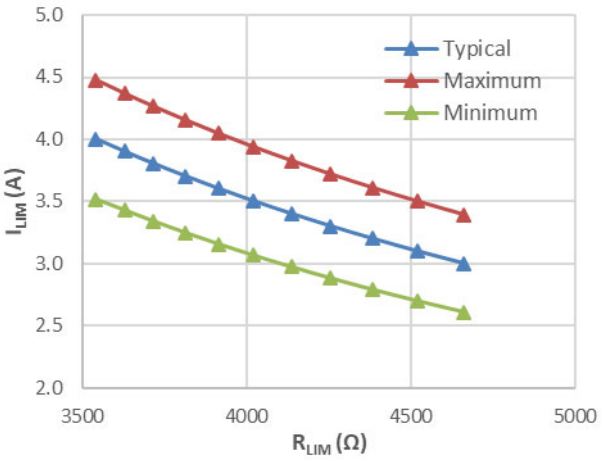


Figure 22. I_{LIM} in Amperes vs R_{LIM} in Ohms

For current less than 2.5A, we recommend to use Table 1 value due to second order non-linearity effects:

Table 1. R_{LIM} Resistor Value vs Current Limit Threshold

Typical Current Limit (A)	Resistor Value ±1% (kΩ)
4.0	3.52
3.5	4.02
3.0	4.65
2.5	5.62
2.0	7.15
1.0	14.7
0.5	40.2

AOZ1351DI-01 continuously limits the output current when output is overloaded. Under current-limiting condition, FLTB is pulled low after a 10ms delay (t_{OCP_FLTB}). Severe overload causes power dissipation and die temperature to increase and may trigger thermal shutdown

Current Limit Foldback

Once the system detects an over current condition, the controlled current is reduced (folded back) by 8% from the RLIM set point. For example, if the I_{LIM} = 3A, then after detecting current limit the current is regulated to 8% lower or 2.76A.

Current Limit Blanking

The AOZ1351DI-01 has a blank out time for over-current pulses to avoid reporting false fault conditions. During plug in or when the output capacitor has been discharged, the system may experience momentary large currents greater than the programmed current limit. The device will ignore these events if they are less than 10ms (t_{OCP_FLTB}).

Short-Circuit Protection (SCP)

When VOUT drops 390mV (V_{SC_DETECT}) below 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.

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 25mV (V_{T_TRCB}). Once the device detects the TRCB condition it will quickly turn off the switch in 600ns (t_{TRCB}).

The power switch is turned on again when the output to input difference is less than the release voltage difference of 10mV (V_{R_TRCB}). Once the device detects that the TRCB condition no longer exists, it will turn back on the switch in 1µs (t_{TRCB_RCV}).

A setup time is required from the part is enabled to the fast recovery from TRCB condition. The TRCB Fast Recovery Setup Time ($t_{RCB\_RCV\_SETUP}$) starts after the initial Turn-On Delay Time (t_{D_ON}) and Turn-On Time (t_{ON}). Typical setup time is 1.3ms. If TRCB recovery happens before this setup time, the power switch will still be turned on but in a slower response. Figure 1 shows the timing from part enable to TRCB fast recovery.

Soft Start

The AOZ1351DI-01 has a fixed internal soft-start control to limit in-rush current due to large capacitive load. The soft start time is 2ms (t_{ON}).

Thermal Shutdown Protection (OTP)

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 20°C hysteresis. The power switch is allowed to turn on again if die temperature drops below approximately 120°C.

Startup

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

Fault Reporting

AOZ1351DI-01 protects itself and load from the following fault condition: over-voltage, over-current, reverse-current, and over-temperature.

The FLTB pin is an open drain output. It is asserted low only when either an over-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. In case of output overload, FLTB pin is pulled low 10ms (t_{OCP_FLTB}) after device is in current limiting.

There is no fault reporting for UVLO, OVP, or TRCB events.

Auto-Restart

The device will try to restart after the power switch is turned off and when OVP or thermal shutdown fault is removed.

Power switch is turned on immediately after a TRCB event is removed.

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 47µF ceramic capacitor should be used. A higher capacitor value is strongly recommended to further reduce the transient voltage drop at the input.

C_{PUMP} Capacitor Selection

The C_{PUMP} capacitor of 47nF should be connected between CP (Pin 5) and GND (Pin 7). It is required to insure the gate voltage for effective turning on and off of the power switch. C_{PUMP} must be within the range of 47nF (minimum) to 100nF (maximum).

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.

There is an upper limit for output capacitor for AOZ1351DI-01 to ensure the output capacitor can be charged fully during start-up. This upper limit is set by the current limit level and soft-start time.

$$C_{OUT} = I_{LIM} \times \frac{t_{ON}}{VIN}$$

Power Dissipation Calculation

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

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

The worst case power dissipation occurs when the load current hits the current limit due to over-current. The power dissipation can be calculated using the following equation:

$$Power\ Dissipated\ = (V_{IN} - V_{OUT}) \times I_{LIM}$$

Layout Guidelines

AOZ1351DI-01 is a protection switch designed deliver high current. Layout is critical to remove the heat generated by this current. For the most efficient heat sinking, connect as much copper as possible to the exposed pad and then connect the exposed pad to ground potential.

On the top layer expand the exposed pad island as much as possible for optimal thermal performance. The exposed pad copper plane must be connected to ground. See example in Figure 23.

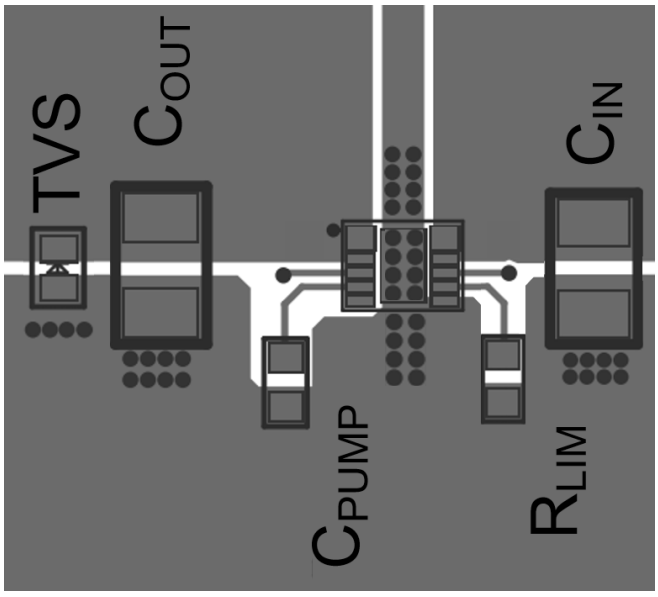


Figure 23. Top layer.

In addition to the top plane, if available, connect to the bottom layer ground plane for best thermal performance. See example in Figure 24.

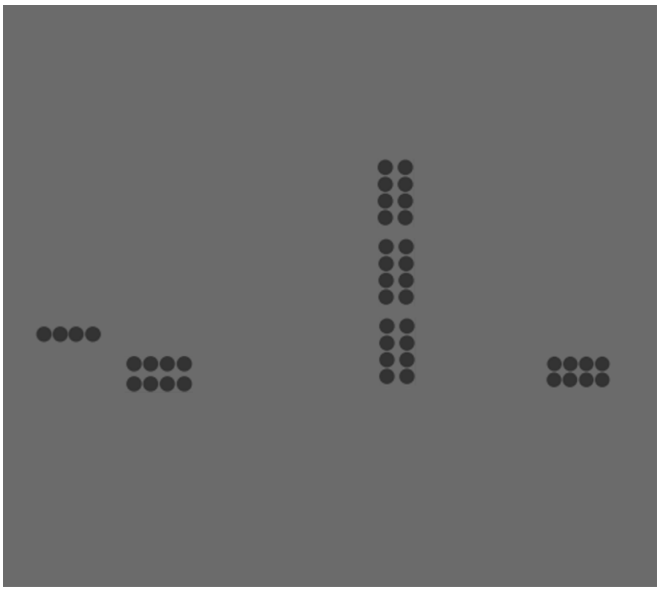
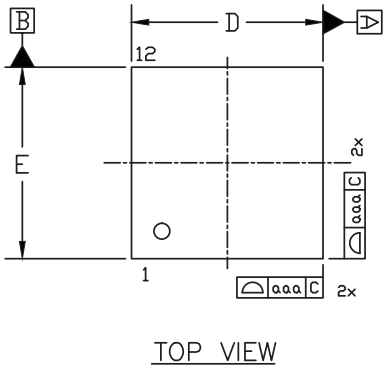


Figure 24. Bottom layer.

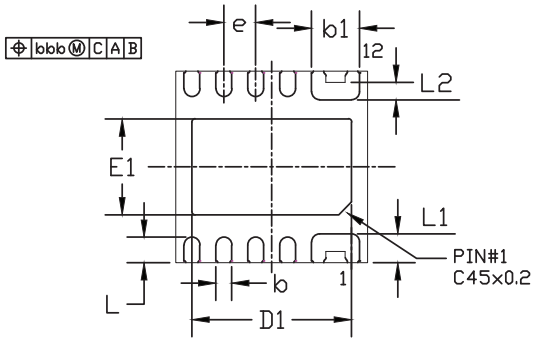
Component Placement

Component placement is crucial to proper performance. The current limit resistor R_{LIM} is the current programming voltage and must be placed close to the IC as. The C_{PUMP} is the charge reservoir. It supplies power to the internal circuitry. As such it must be placed close to the IC to avoid power loss through the PCB traces. After these two components the C_{IN} and C_{OUT} must be placed as close to the IC as possible. C_{IN} and C_{OUT} handle large currents and voltages. Place close and connect with short wide traces to avoid transient noise and power loss due to plug/unplug events and fast load transients. Next to C_{OUT} place the transient voltage suppressor (TVS). The TVS eliminates over voltage by clamping the voltage seen by the VOUT pins. The R_{FLTB} pull up resistor, which is noise insensitive, can be placed last but still as close as possible given the higher priority of the aforementioned components.

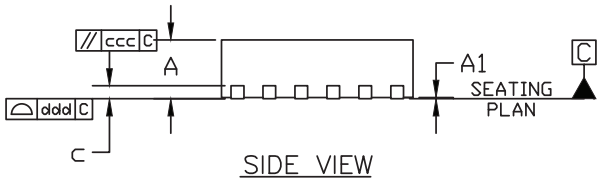
Package Dimensions, DFN3x3B-12L, EP1_S



TOP VIEW

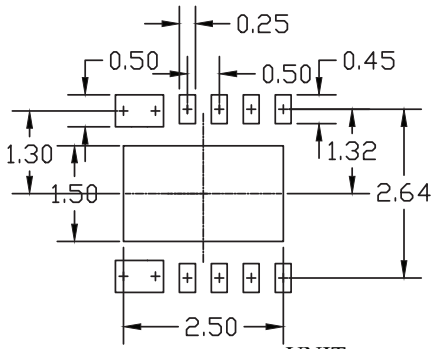


BOTTOM VIEW



SIDE VIEW

RECOMMENDED LAND PATTERN



UNIT: mm

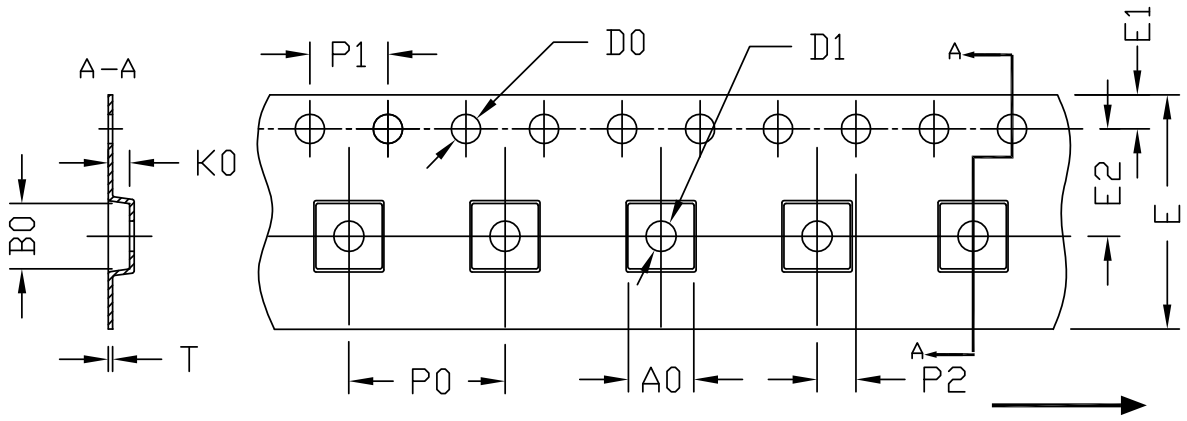
SYMBOLS	DIMENSIONS IN MILLIMETERS			DIMENSIONS IN INCHES		
	MIN	NOM	MAX	MIN	NOM	MAX
A	0.80	0.90	1.00	0.031	0.035	0.039
A1	0.00	0.02	0.05	0.000	0.001	0.002
b	0.20	0.25	0.30	0.008	0.010	0.012
b1	0.70	0.75	0.80	0.028	0.030	0.032
c	0.195	0.203	0.211	0.008	0.008	0.008
D	2.90	3.00	3.10	0.114	0.118	0.122
D1	2.40	2.50	2.60	0.094	0.098	0.102
E	2.90	3.00	3.10	0.114	0.118	0.122
E1	1.40	1.50	1.60	0.055	0.059	0.063
e	0.50BSC			0.020BSC		
L	0.30	0.40	0.50	0.012	0.016	0.020
L1	0.35	0.45	0.55	0.014	0.018	0.022
L2	0.22	0.27	0.32	0.009	0.011	0.013
aaa	0.15			0.006		
bbb	0.10			0.004		
ccc	0.10			0.004		
ddd	0.08			0.003		

NOTE

1. DIMENSIONING AND TOLERANCING CONFORM TO ASME Y14.5M-1994.
2. CONTROLLING DIMENSION IS MILLIMETER.
   CONVERTED INCH DIMENSIONS ARE NOT NECESSARILY EXACT.
3. DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.15mm. AND 0.30mm FROM THE TERMINAL TIP. IF THE TERMINAL HAS THE OPTIONAL RADIUS ON THE OTHER END OF THE TERMINAL, THE DIMENSION b SHOULD NOT BE MEASURED IN THAT RADIUS AREA.
4. COPLANARITY ddd APPLIERS TO THE TERMINALS AND ALL OTHER BOTTOM SURFACE METALLIZATION.

Tape and Reel Dimensions, DFN3x3B-12L, EP1_S

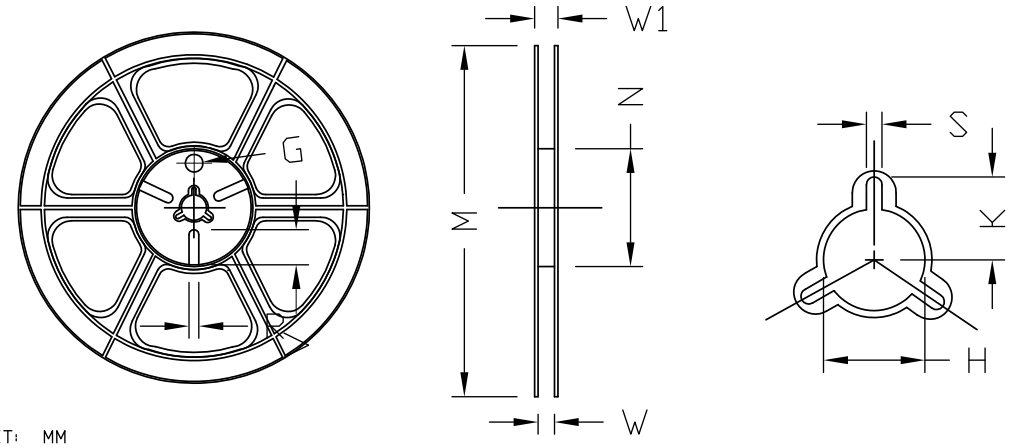
Carrier Tape



UNIT: MM

PACKAGE	A0	B0	K0	D0	D1	E	E1	E2	P0	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

Reel

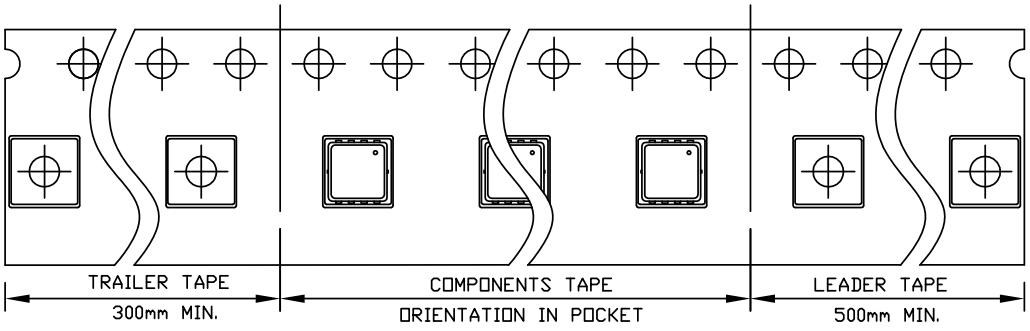


UNIT: MM

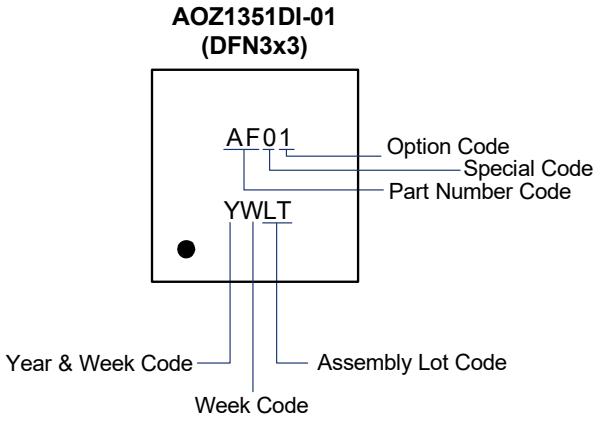
TAPE SIZE	REEL SIZE	M	N	W	W1	H	K	S	G	R	V
12 mm	ø330	ø330.00 ±0.50	ø97.00 ±0.10	13.00 ±0.30	17.40 ±1.00	ø13.00 +0.50 −0.20	10.60	2.00 ±0.50	---	---	---

DFN3x3 EP TAPE
Leader / Trailer & Orientation

Unit Per Reel:
5000pcs



Part Marking



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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.