2.0A SINGLE CHANNEL CURRENT-LIMITED POWER SWITCH WITH LATCH-OFF

Description

The AP2401 and AP2411 are single channel current-limited integrated high-side power switches optimized for Universal Serial Bus (USB) and other hot-swap applications. The family of devices complies with USB standards and is available with both polarities of enable input.

The devices have fast short-circuit response time for improved overall system robustness, and have integrated output discharge function to ensure completely controlled discharging of the output voltage capacitor. They provide a complete protection solution for applications subject to heavy capacitive loads and the prospect of short circuit, and offer reverse current blocking, over-current, over-temperature and short-circuit protection, as well as controlled rise time and under-voltage lockout functionality. A 7ms deglitch capability on the open-drain Flag output prevents false over-current reporting and does not require any external components. AP2401 and AP2411 will be latched off after 7ms deglitch.

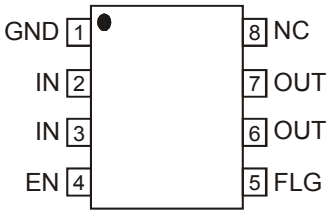
All devices are available in SO-8, MSOP-8, MSOP-8EP, U-DFN3030-8 and U-DFN2020-6 packages.

Features

- Single Channel Current-Limited Power Switch
- Output Discharge Function
- Output Current Latch-Off when OCP Triggered
- Fast Short-Circuit Response Time: 2µs
- 2.5A Accurate Current Limiting
- Reverse Current Blocking
- 70mΩ On-Resistance
- Input Voltage Range: 2.7V - 5.5V
- Built-In Soft-Start with 0.6ms Typical Rise Time
- Over-Current and Thermal Protection
- Fault Report (FLG) with Blanking Time (7ms typ)
- ESD Protection: 2kV HBM, 200V MM
- Active Low (AP2401) or Active High (AP2411) Enable
- Ambient Temperature Range: -40°C to +85°C
- SO-8, MSOP-8, MSOP-8EP, U-DFN3030-8 and U-DFN2020-6: Available in "Green" Molding Compound (No Br, Sb)
  - **Lead-Free Finish; RoHS Compliant (Notes 1 & 2)**
  - **Halogen and Antimony Free. "Green" Device (Note 3)**
- UL Recognized, File Number E322375
- IEC60950-1 CB Scheme Certified

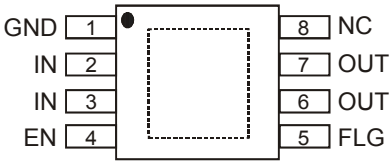
Pin Assignments

(Top View)



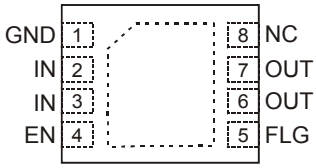
SO-8

(Top View)

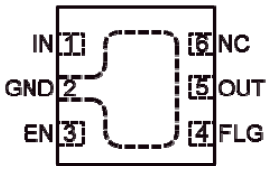


MSOP-8/MSOP-8EP
Note: Latter with exposed pad (dotted line)

(Top View)



U-DFN3030-8



U-DFN2020-6

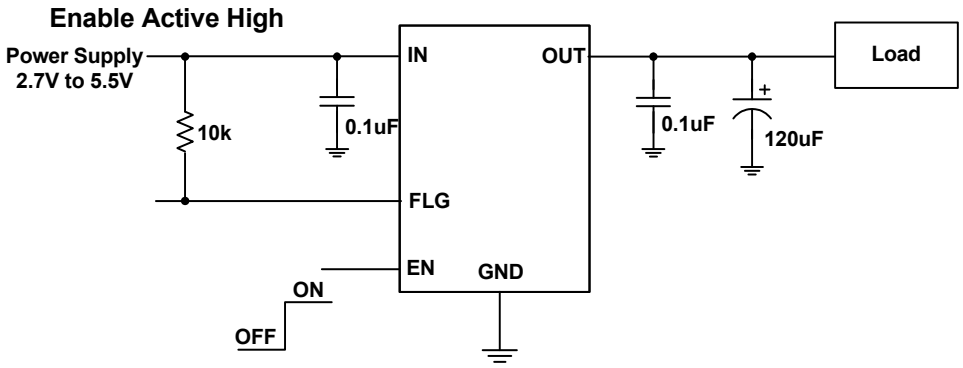
Applications

- LCD TVs & Monitors
- Set-Top-Boxes, Residential Gateways
- Laptops, Desktops, Servers, e-Readers
- Printers, Docking Stations, HUBs

Notes:
1. EU Directive 2002/95/EC (RoHS) & 2011/65/EU (RoHS 2) compliant. All applicable RoHS exemptions applied.
2. See http://www.diodes.com/quality/lead_free.html for more information about Diodes Incorporated's definitions of Halogen- and Antimony-free, "Green" and Lead-free.
3. Halogen- and Antimony-free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.

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Typical Applications Circuit



Available Options

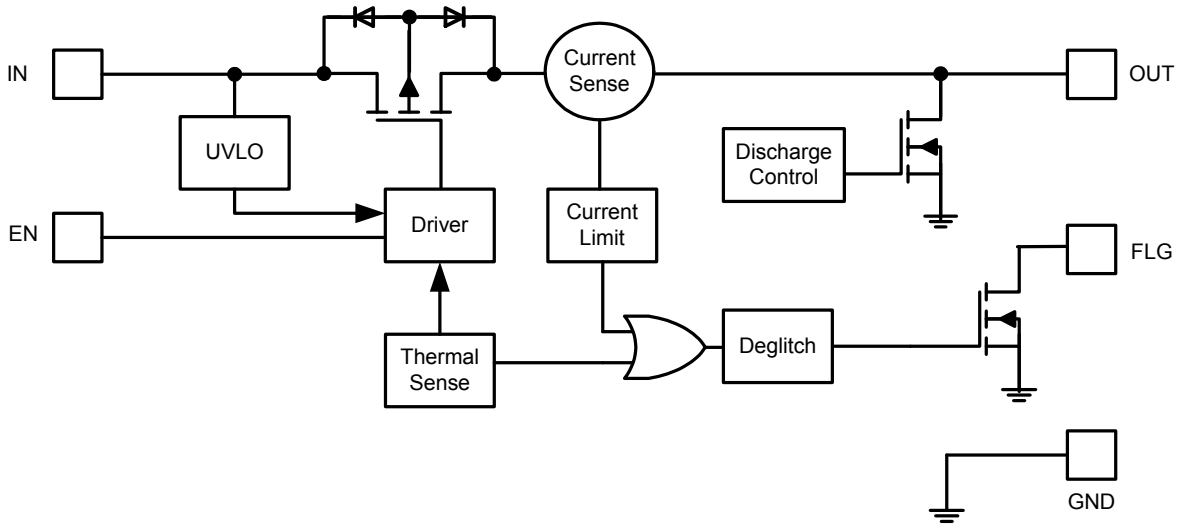
Part Number	Channel	Enable Pin (EN)	Recommended Maximum Continuous Load Current (A)	Typical Output Latch-Off Current Limit (A)	Package
AP2401	1	Active Low	2	2.5	SO-8 MSOP-8 MSOP-8EP U-DFN3030-8 U-DFN2020-6
AP2411	1	Active High			

Pin Descriptions

Pin Name	Pin Number			Function
	SO-8, MSOP-8	MSOP-8EP, U-DFN3030-8	U-DFN2020-6	
GND	1	1	2	Ground
IN	2, 3	2, 3	1	Voltage Input Pin. Connect a 0.1µF or larger ceramic capacitor from IN to GND as close as possible. (all IN pins must be tied together externally)
EN	4	4	3	Enable Input. Active low (AP2401) or active high (AP2411).
FLG	5	5	4	Over-temperature and over-current fault reporting with 7ms deglitch; active low open-drain output. FLG is disabled for 7ms after turn-on.
OUT	6, 7	6, 7	5	Voltage Output Pin (all OUT pins must be tied together externally)
NC	8	8	6	No Internal Connection. Recommend tie to OUT pins.
Exposed Pad	—	Exposed Pad	Exposed Pad	Exposed pad. **It should be externally connected to GND plane and thermal mass for enhanced thermal impedance.** Exposed pad should not be used as electrical ground conduction path.

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Functional Block Diagram



Absolute Maximum Ratings (@T_A = +25°C, unless otherwise specified.)

Symbol	Parameter	Ratings	Unit
ESD HBM	Human Body Model ESD Protection	4	kV
ESD MM	Machine Model ESD Protection	300	V
V_{IN}	Input Voltage (Note 4)	-0.3 to 6.5	V
V_{OUT}	Output Voltage (Note 4)	-0.3 to V_{IN} +0.3 or 6.5	V
V_{EN}, V_{FLG}	Enable Voltage (Note 4)	-0.3 to V_{IN} +0.3 or 6.5	V
I_{LOAD}	Maximum Continuous Load Current	Internal Limited	A
$T_{J(MAX)}$	Maximum Junction Temperature	150	°C
T_{ST}	Storage Temperature Range (Note 4)	-65 to +150	°C

Notes: 4. All voltages referred to GND pin. Maximums are the lower of V_{IN} + 0.3 and 6.5V

5. UL Recognized Rating from -30°C to +70°C (Diodes qualified T_{ST} from -65°C to +150°C).

Caution: Stresses greater than the 'Absolute Maximum Ratings' specified above, may cause permanent damage to the device. These are stress ratings only; functional operation of the device at these or any other conditions exceeding those indicated in this specification is not implied. Device reliability may be affected by exposure to absolute maximum rating conditions for extended periods of time.

Semiconductor devices are ESD sensitive and may be damaged by exposure to ESD events. Suitable ESD precautions should be taken when handling and transporting these devices

Recommended Operating Conditions (@T_A = +25°C, unless otherwise specified.)

Symbol	Parameter	Min	Max	Unit
V_{IN}	Input voltage	2.7	5.5	V
I_{OUT}	Output Current	0	2	A
V_{IL}	EN Input Logic Low Voltage	0	0.8	V
V_{IH}	EN Input Logic High Voltage	2	V_{IN}	V
T_A	Operating Ambient Temperature	-40	+85	°C

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Electrical Characteristics (@T_A = +25°C, V_{IN} = +5.0V, C_{IN} = 0.1µF, C_L= 1µF, unless otherwise specified.)

Symbol	Parameter	Test Conditions (Note 5)		Min	Typ	Max	Unit
V_{UVLO}	Input UVLO	V_{IN} rising		1.6	2.0	2.4	V
ΔV_{UVLO}	Input UVLO Hysteresis	V_{IN} decreasing			50		mV
I_{SHDN}	Input Shutdown Current	Disabled, OUT = open			0.1	1	µA
I_Q	Input Quiescent Current	Enabled, OUT = open			60	100	µA
I_{LEAK}	Input Leakage Current	Disabled, OUT grounded			0.1	1	µA
I_{REV}	Reverse Leakage Current	Disabled, V_{IN} = 0V, V_{OUT} = 5V, I_{REV} at V_{IN}			0.01	1	µA
$R_{DS(ON)}$	Switch on-resistance	V_{IN} = 5V, I_{OUT}= 2.0A	T_A = +25°C		70	84	mΩ
			-40°C ≤ T_A ≤ +85°C			105	
		V_{IN} = 3.3V, I_{OUT}= 2.0A	T_A = +25°C		90	108	
			-40°C ≤ T_A ≤ +85°C			135	
I_{LIMIT}	Over-Load Current Limit (Note 6)	V_{IN}= 5V, V_{OUT}= 4.5V	-40°C ≤ T_A ≤+85°C	2.05	2.5	2.85	A
I_{Trig}	Current limiting trigger threshold	Output Current Slew rate (< 100A/s)			2.5		A
I_{SHORT}	Short-Circuit Current Limit	Enabled into short circuit		2.1	2.75	3.3	A
T_{SHORT}	Short-circuit Response Time	V_{OUT} = 0V to I_{OUT} = I_{LIMIT} (OUT shorted to ground)			2		µs
V_{IL}	EN Input Logic Low Voltage	V_{IN} = 2.7V to 5.5V				0.8	V
V_{IH}	EN Input Logic High Voltage	V_{IN} = 2.7V to 5.5V		2			V
$I_{LEAK-EN}$	EN Input leakage	V_{IN} = 5V, V_{EN} = 0V and 5.5V			0.01	1	µA
I_{LEAK-O}	Output leakage current	Disabled, V_{OUT} = 0V			0.5	1	µA
$T_{D(ON)}$	Output turn-on delay time	C_L = 1µF, R_{LOAD} = 5Ω			0.1		ms
T_R	Output turn-on rise time	C_L = 1µF, R_{LOAD} = 5Ω			0.6	1.5	ms
$T_{D(OFF)}$	Output turn-off delay time	C_L = 1µF, R_{LOAD} = 5Ω			0.1		ms
T_F	Output turn-off fall time	C_L = 1µF, R_{LOAD} = 5Ω			0.05	0.1	ms
R_{FLG}	FLG output FET on-resistance	I_{FLG} = 10mA			20	40	Ω
I_{FOH}	FLG Off Current	V_{FLG} = 5V			0.01	1	µA
T_{BLANK}	FLG blanking and latch off time	Assertion or deassertion due to overcurrent and over-temperature condition		4	7	15	ms
T_{DIS}	Discharge time	C_L= 1µF, V_{IN} = 5V, disabled to V_{OUT} < 0.5V			0.6		ms
R_{DIS}	Discharge resistance (Note 7)	V_{IN} = 5V, disabled, I_{OUT} = 1mA			100		Ω
T_{SHDN}	Thermal Shutdown Threshold	Enabled			140		°C
T_{HYS}	Thermal Shutdown Hysteresis				20		°C
θ_{JA}	Thermal Resistance Junction-to-Ambient	SO-8 (Note 8)			96		°C/W
		MSOP-8 (Note 8)			130		°C/W
		MSOP-8EP (Note 9)			92		°C/W
		U-DFN3030-8 (Note 9)			84		°C/W
		U-DFN2020-6 (Note 10)			90		°C/W

Notes:
6. Pulse-testing techniques maintain junction temperature close to ambient temperature; thermal effects must be taken into account separately.
7. The discharge function is active when the device is disabled (when enable is de-asserted or during power-up power-down when V_{IN} < V_{UVLO}. The discharge function offers a resistive discharge path for the external storage capacitor for limited time.
8. Device mounted on 2” x 2” FR-4 substrate PCB, 2oz copper, with minimum recommended pad layout.
9. Device mounted on 2” x 2” FR-4 substrate PCB, 2oz copper, with minimum recommended pad on top layer and thermal vias to bottom layer ground plane.
10. Device mounted on 1"x1" FR-4 substrate PCB, 2oz copper, with minimum recommended padon top layer and thermal vias to bottom layer ground.

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Typical Performance Characteristics

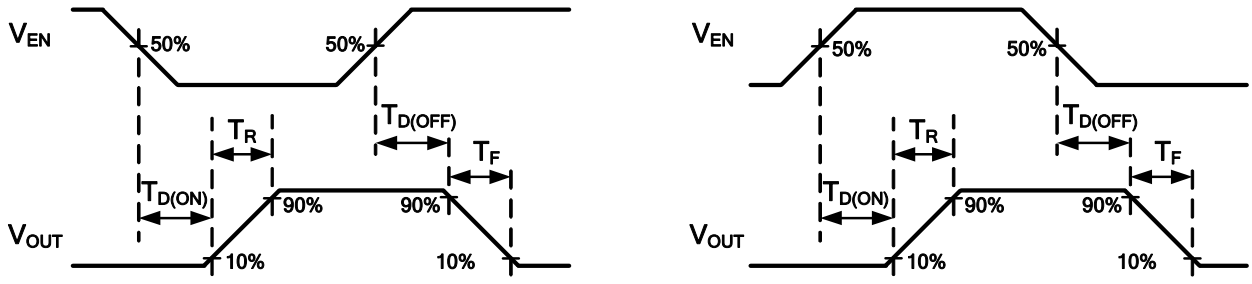
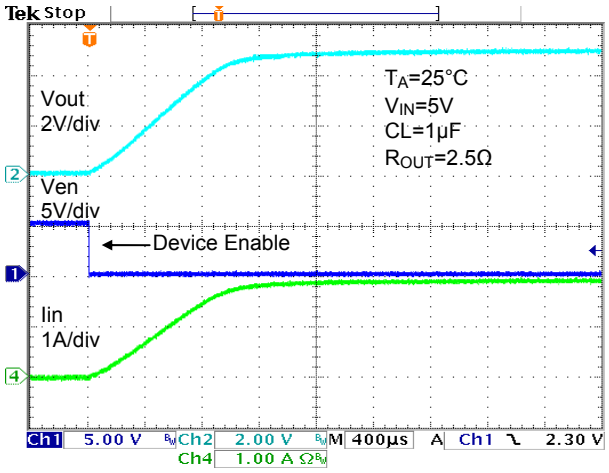


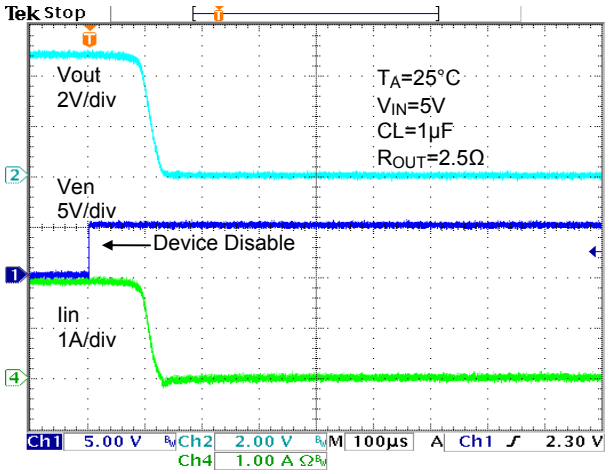
Figure 1 Voltage Waveforms: AP2401 (left), AP2411 (right)

All Enable Plots are for Enable Active Low

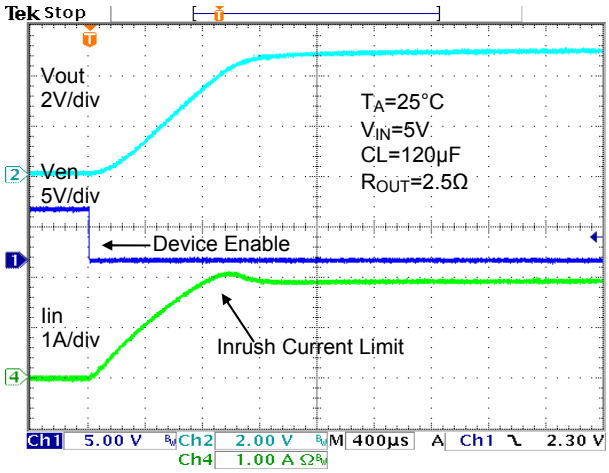
Turn-On Delay and Rise Time



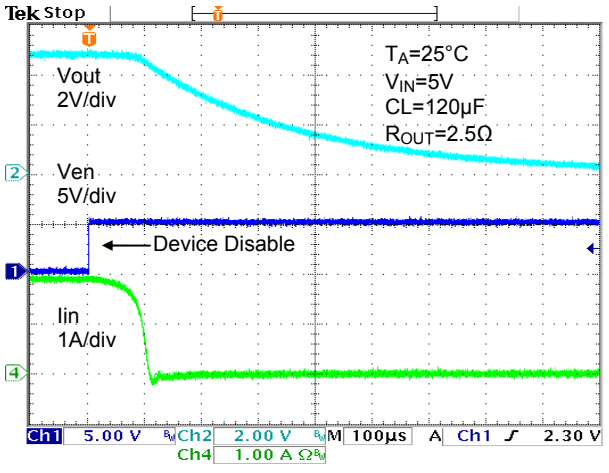
Turn-Off Delay and Fall Time



Turn-On Delay and Rise Time



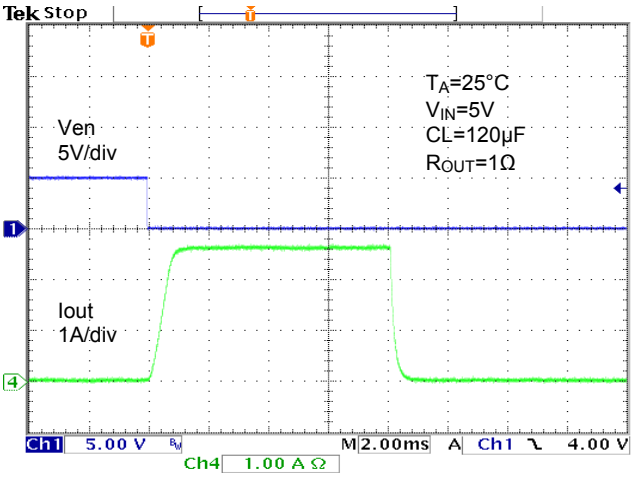
Turn-Off Delay and Fall Time



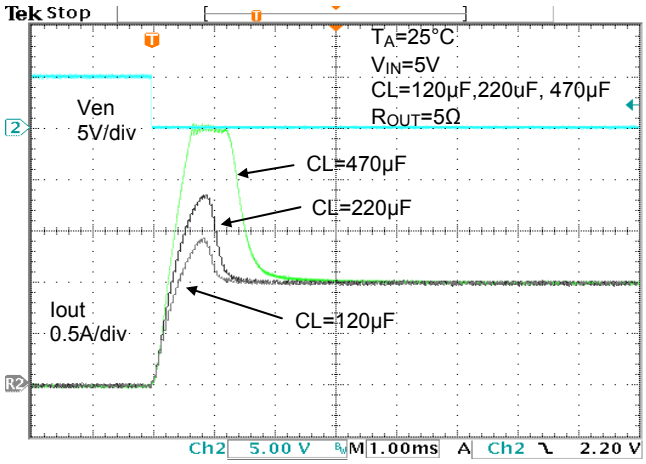
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Typical Performance Characteristics (cont.)

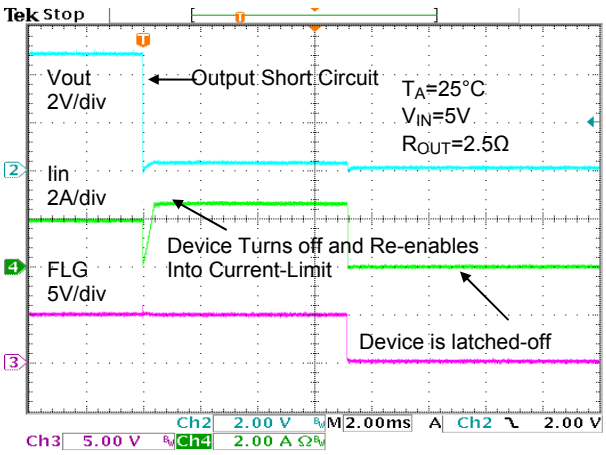
Device Enabled Into Short-Circuit



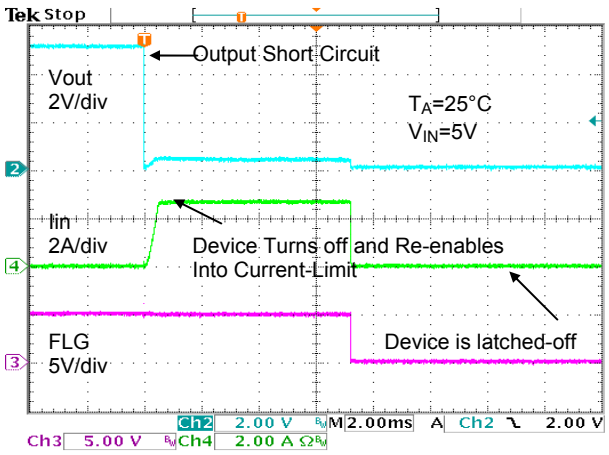
Inrush Current



Full-Load to Short-Circuit Transient Response



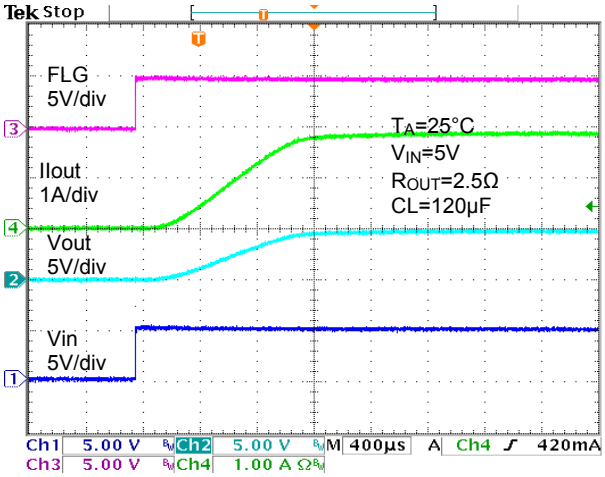
No-Load to Short-Circuit Transient Response



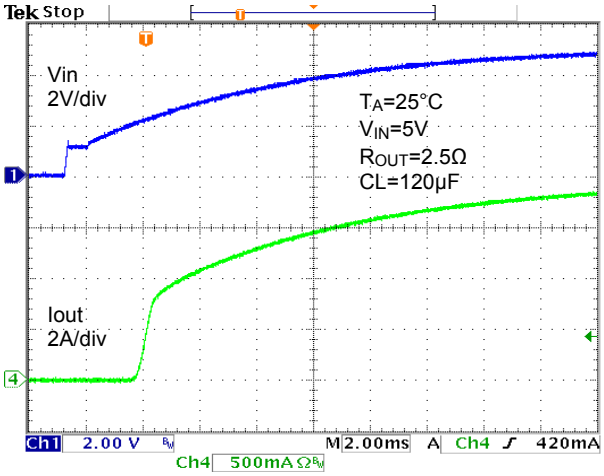
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Typical Performance Characteristics (cont.)

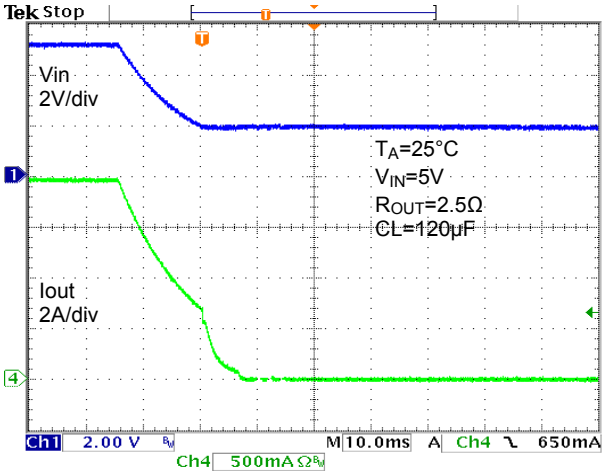
Power ON



UVLO Increasing

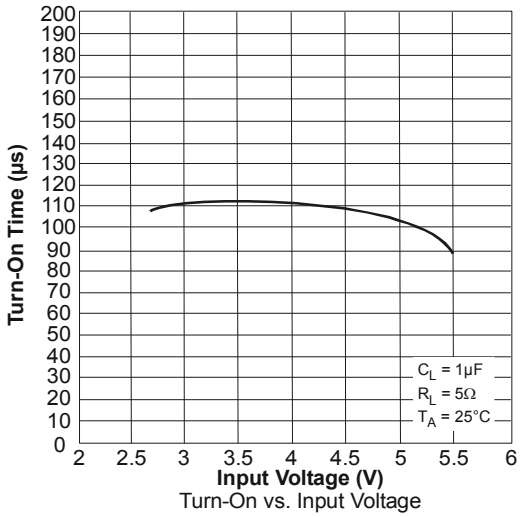


UVLO Decreasing

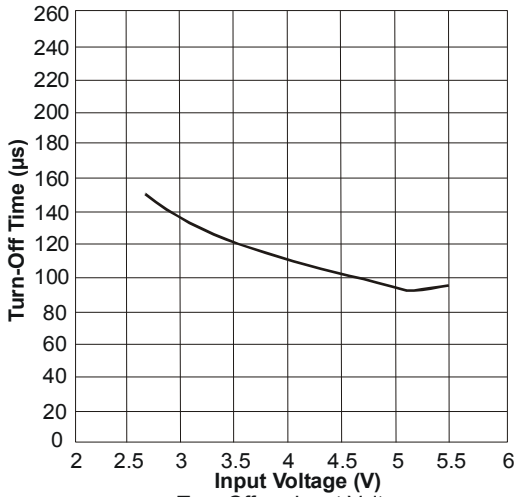


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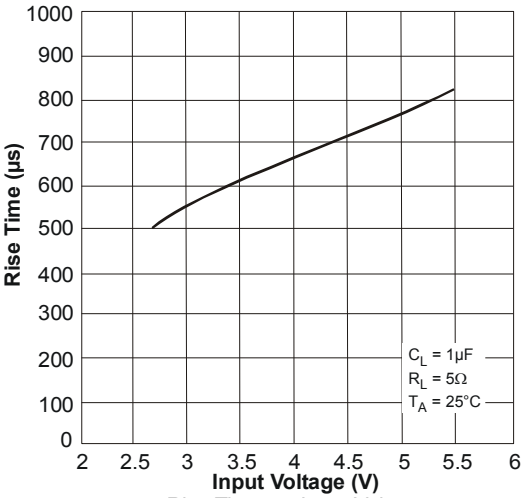
Typical Performance Characteristics (cont.)



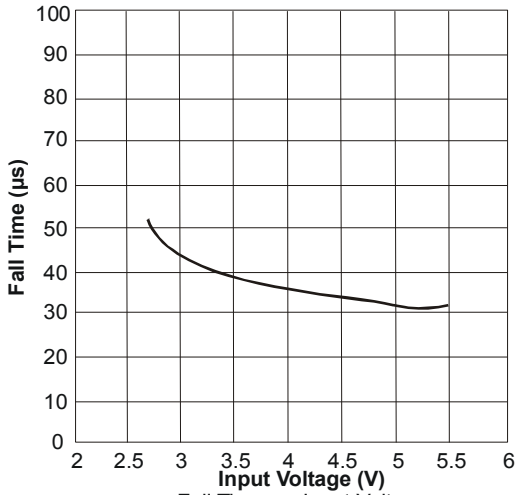
Turn-On vs. Input Voltage



Turn-Off vs. Input Voltage



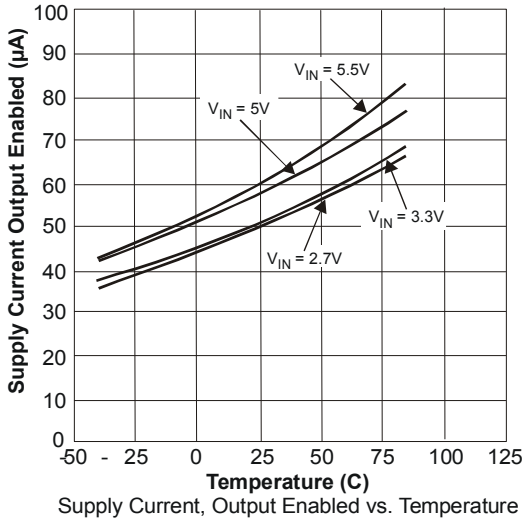
Rise Time vs. Input Voltage



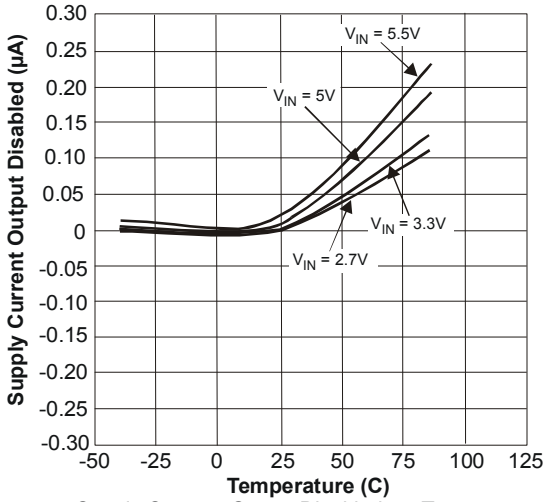
Fall Time vs. Input Voltage

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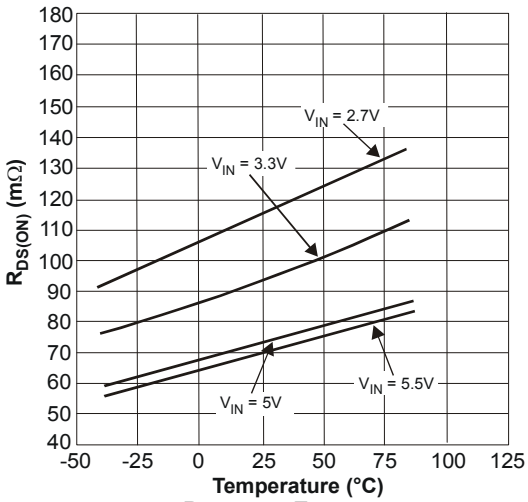
Typical Performance Characteristics (cont.)



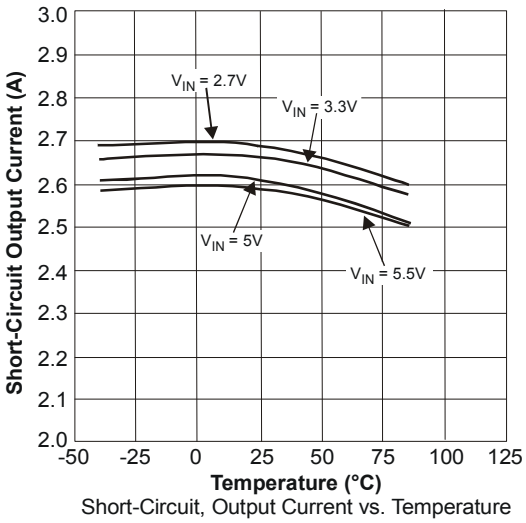
Supply Current, Output Enabled vs. Temperature



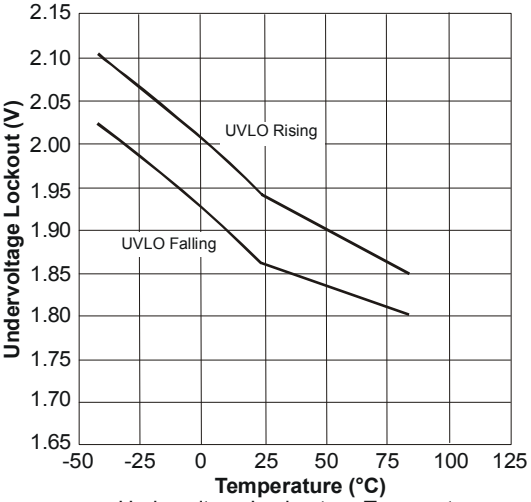
Supply Current, Output Disabled vs. Temperature



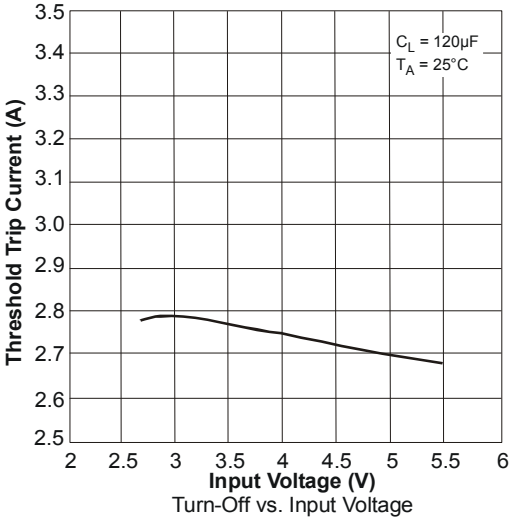
$R_{DS(ON)}$ vs. Temperature



Short-Circuit, Output Current vs. Temperature



Undervoltage Lockout vs. Temperature



Turn-Off vs. Input Voltage

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Application Information

Power Supply Considerations

A 0.1µF to 2.2µF X7R or X5R ceramic bypass capacitor placed between IN and GND, close to the device, is recommended. When an external power supply is used, or an additional ferrite bead is added to the input, high inrush current may cause voltage spikes higher than the device maximum input rating during short circuit condition. In this case a 2.2µF or bigger capacitor is recommended. Placing a high-value electrolytic capacitor on the input and output pin(s) is recommended when the output load is heavy. This precaution reduces power-supply transients that may cause ringing on the input. Additionally, bypassing the output with a 0.1µF to 1.0µF ceramic capacitor improves the immunity of the device to short circuit transients.

Over-Current and Short Circuit Protection

An internal sensing FET is employed to check for over-current conditions. Unlike current-sense resistors, sense FETs do not increase the series resistance of the current path. When an overcurrent condition is detected, the devices will limit the current until the overload condition is removed or the internal deglitch time (7-ms typical) is reached and the device is turned off. The device will remain latched off even overload condition is removed until power is cycled or the device enable is toggled.

Three possible overload conditions can occur. In the first condition, the output has been shorted to GND before the device is enabled or before VIN has been applied. The AP2401/AP2411 senses the short circuit and immediately clamps output current to a certain safe level namely I_{LIMIT}, and turns off after deglitch time(7-ms typical).

In the second condition, an output short or an overload occurs while the device is enabled. At the instance the overload occurs, higher current may flow for a very short period of time before the current limit function can react. After the current limit function has tripped (reached the over-current trip threshold), the device switches into current limiting mode and the current is clamped at I_{LIMIT} current for deglitch time period (7-ms typical), and then turned off.

In the third condition, the load has been gradually increased beyond the recommended operating current. The current is permitted to rise until the current-limit threshold (I_{TRIG}) is reached or until the thermal limit of the device is exceeded. The AP2401/AP2411 is capable of delivering current up to the current-limit threshold without damaging the device. Once the threshold has been reached, the device switches into its current limiting mode and output current is clamped at I_{LIMIT} for deglitch time period (7-ms typical), and then turned off.

FLG Response

When an over-current or over-temperature shutdown condition is encountered, the FLG open-drain output goes active low after a nominal 7-ms deglitch timeout.

When that happens, the FLG will remain low and the switch will be latched off until the fault condition is removed. Connecting a heavy capacitive load to the output of the device can cause a momentary over-current condition, which does not trigger the FLG due to the 7-ms deglitch timeout. The AP2401/AP2411 is designed to eliminate false over-current reporting without the need of external components to remove unwanted pulses.

Power Dissipation and Junction Temperature

The low on-resistance of the internal MOSFET allows the small surface-mount packages to pass large current. Using the maximum operating ambient temperature (TA) and $R_{DS(ON)}$, the power dissipation can be calculated by:

$$P_D = R_{DS(ON)} \times I^2$$

Finally, calculate the junction temperature:

$$T_J = P_D \times R_{\theta JA} + T_A$$

Where:

T_A= Ambient temperature°C

$R_{\theta JA}$ = Thermal resistance

P_D = Total power dissipation

Thermal Protection

Thermal protection prevents the IC from damage when heavy-overload or short-circuit faults are present for extended periods of time. The AP2401/AP2411 implements a thermal sensing to monitor the operating junction temperature of the power distribution switch. Once the die temperature rises to approximately +140°C due to excessive power dissipation in an over-current condition, the internal thermal sense circuitry turns the power switch off, thus preventing the power switch from damage. Hysteresis is built into the thermal sense circuit allowing the device to cool down approximately +25°C before the switch turns back on. The switch continues to cycle in this manner until the load fault or input power is removed. The FLG open-drain output is asserted when an over-temperature shutdown occurs with 7-ms deglitch.

When the FLG is asserted, the switch will be latched off until the temperature drops to 20°C below the thermal shutdown threshold and the power or EN pin is cycled.

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Application Information (cont.)

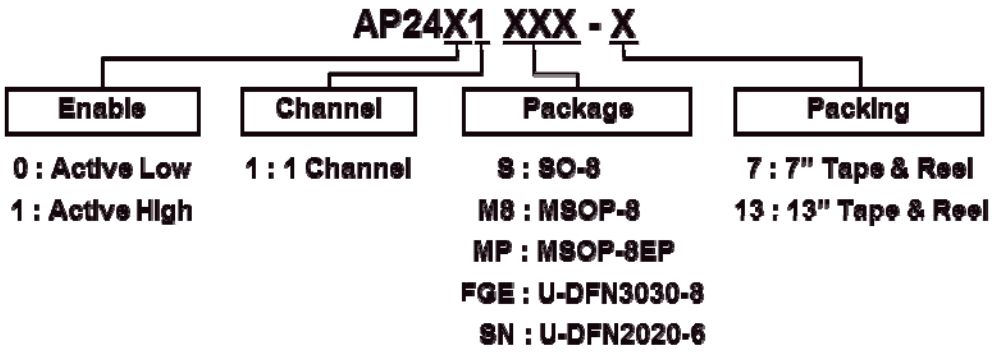
Under-Voltage Lockout (UVLO)

Under-voltage lockout function (UVLO) keeps the internal power switch from being turned on until the power supply has reached at least 2V, even if the switch is enabled. Whenever the input voltage falls below approximately 2V, the power switch is quickly turned off. This facilitates the design of hot-insertion systems where it is not possible to turn off the power switch before input power is removed.

Discharge Function

The discharge function of the device is active when enable is disabled or de-asserted. The discharge function with the N-MOS power switch implementation is activated and offers a resistive discharge path for the external storage capacitor. This is designed for discharging any residue of the output voltage when either no external output resistance or load resistance is present at the output.

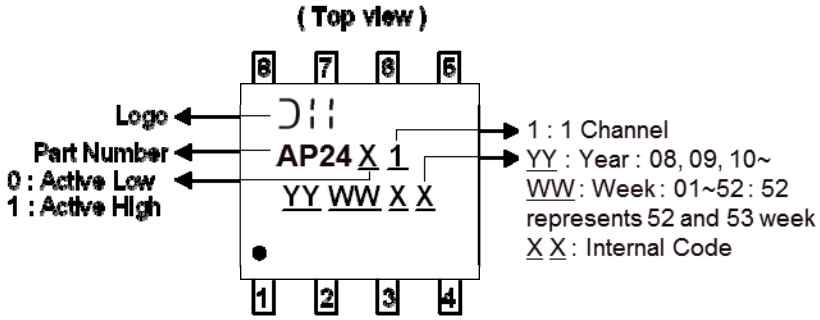
Ordering Information



Part Number	Status	Package Code	Packaging	7"/13" Tape and Reel	
				Quantity	Part Number Suffix
AP24X1S-13	New Product	S	SO-8	2500/Tape & Reel	-13
AP24X1M8-13	New Product	M8	MSOP-8	2500/Tape & Reel	-13
AP24X1MP-13	New Product	MP	MSOP-8EP	2500/Tape & Reel	-13
AP24X1FGE-7	New Product	FGE	U-DFN3030-8	3000/Tape & Reel	-7
AP24X1SN-7	Preview	SN	U-DFN2020-6	3000/Tape & Reel	-7

Marking Information

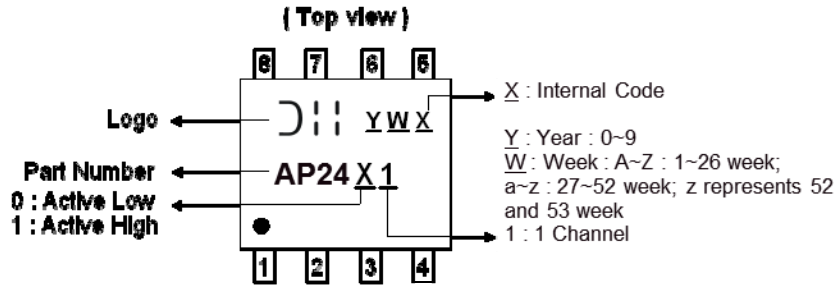
(1) SO-8



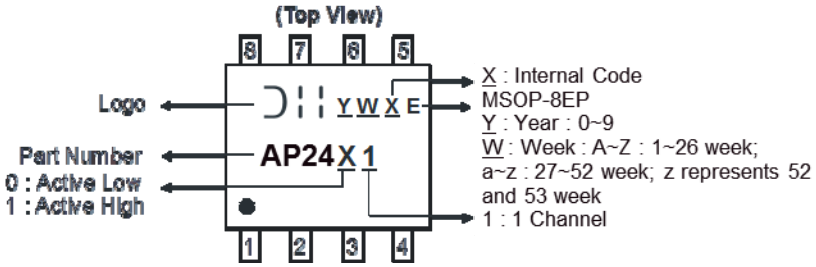
© Diodes Incorporated

Marking Information (cont.)

(2) MSOP-8

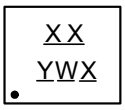


(3) MSOP-8EP



(4) U-DFN3030-8

(Top View)

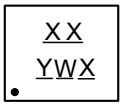


XX : Identification Code
Y : Year : 0~9
W : Week : A~Z : 1~26 week;
a~z : 27~52 week; z represents 52 and 53 week
X : A~Z : Internal Code

Part Number	Package	Identification Code
AP2401FGE-7	U-DFN3030-8	BD
AP2411FGE-7	U-DFN3030-8	BF

(5) U-DFN2020-6

(Top View)



XX : Identification Code
Y : Year : 0~9
W : Week : A~Z : 1~26 week;
a~z : 27~52 week; z represents 52 and 53 week
X : A~Z : Internal Code

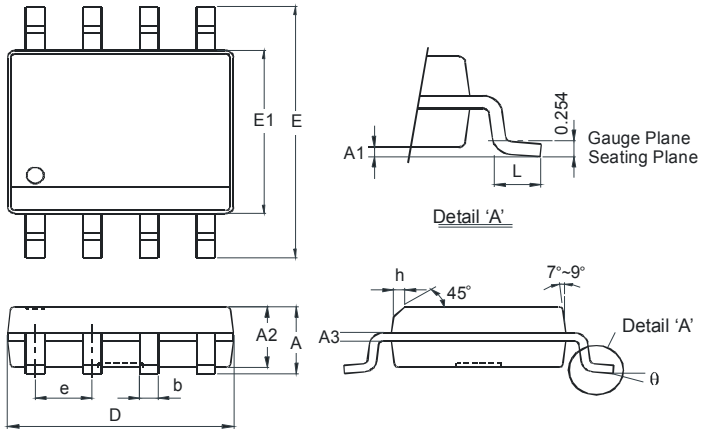
Part Number	Package	Identification Code
AP2401SN-7	U-DFN2020-6	DD
AP2411SN-7	U-DFN2020-6	DF

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Package Outline Dimensions (All dimensions in mm.)

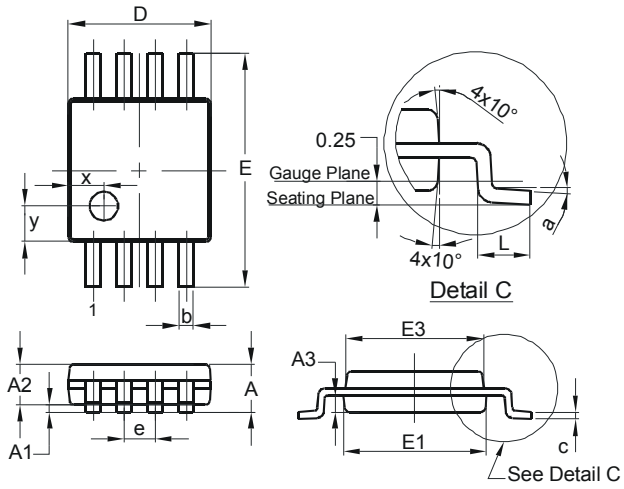
Please see AP02002 at http://www.diodes.com/datasheets/ap02002.pdf for latest version.

1. Package type: SO-8



SO-8		
Dim	**Min**	**Max**
A	-	1.75
A1	0.10	0.20
A2	1.30	1.50
A3	0.15	0.25
b	0.3	0.5
D	4.85	4.95
E	5.90	6.10
E1	3.85	3.95
e	1.27 Typ	
h	-	0.35
L	0.62	0.82
θ	0°	8°
All Dimensions in mm		

2. Package type: MSOP-8



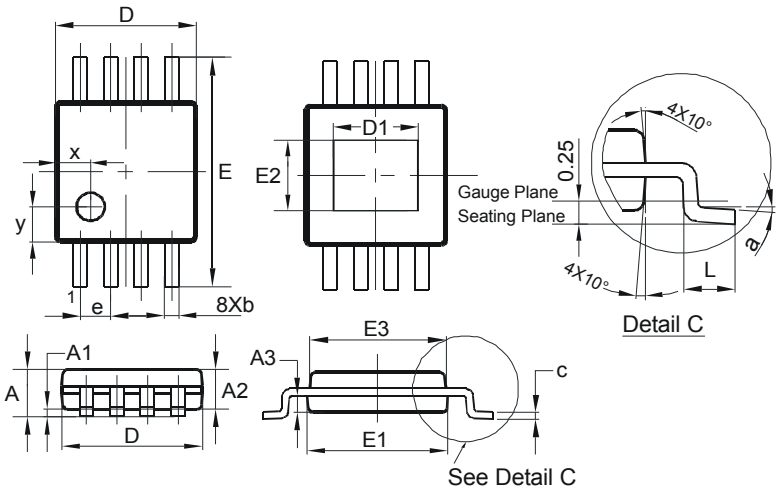
MSOP-8			
Dim	**Min**	**Max**	**Typ**
A	-	1.10	-
A1	0.05	0.15	0.10
A2	0.75	0.95	0.86
A3	0.29	0.49	0.39
b	0.22	0.38	0.30
c	0.08	0.23	0.15
D	2.90	3.10	3.00
E	4.70	5.10	4.90
E1	2.90	3.10	3.00
E3	2.85	3.05	2.95
e	-	-	0.65
L	0.40	0.80	0.60
a	0°	8°	4°
x	-	-	0.750
y	-	-	0.750
All Dimensions in mm			

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Package Outline Dimensions (cont.) (All dimensions in mm.)

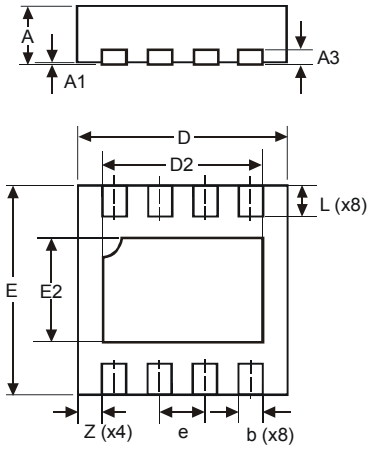
Please see AP02002 at http://www.diodes.com/datasheets/ap02002.pdf for latest version.

3. Package type: MSOP-8EP



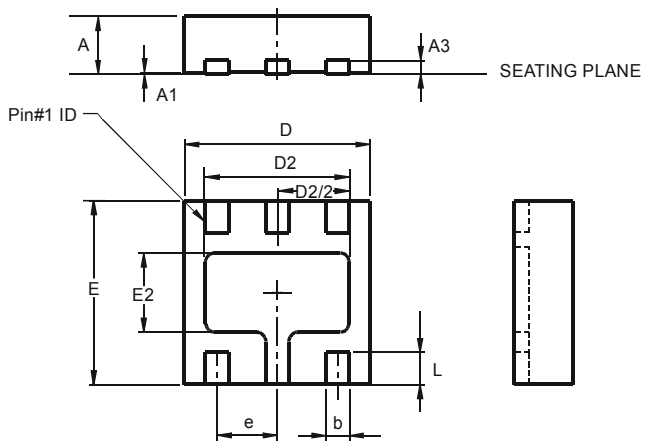
MSOP-8EP			
Dim	**Min**	**Max**	**Typ**
A	-	1.10	-
A1	0.05	0.15	0.10
A2	0.75	0.95	0.86
A3	0.29	0.49	0.39
b	0.22	0.38	0.30
c	0.08	0.23	0.15
D	2.90	3.10	3.00
D1	1.60	2.00	1.80
E	4.70	5.10	4.90
E1	2.90	3.10	3.00
E2	1.30	1.70	1.50
E3	2.85	3.05	2.95
e	-	-	0.65
L	0.40	0.80	0.60
a	0°	8°	4°
x	-	-	0.750
y	-	-	0.750
All Dimensions in mm			

4. Package type: U-DFN3030-8 Type E



U-DFN3030-8 Type E			
Dim	**Min**	**Max**	**Typ**
A	0.57	0.63	0.60
A1	0	0.05	0.02
A3	–	–	0.15
b	0.20	0.30	0.25
D	2.95	3.05	3.00
D2	2.15	2.35	2.25
E	2.95	3.05	3.00
e	–	–	0.65
E2	1.40	1.60	1.50
L	0.30	0.60	0.45
Z	–	–	0.40
All Dimensions in mm			

5. Package type: U-DFN2020-6



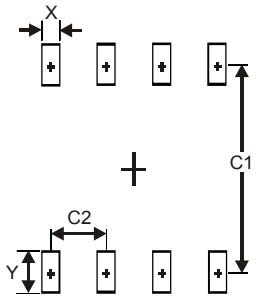
U-DFN2020-6			
Dim	**Min**	**Max**	**Typ**
A	0.57	0.63	0.60
A1	0	0.05	0.03
A3	—	—	0.15
b	0.20	0.30	0.25
D	1.95	2.075	2.00
D2	1.45	1.65	1.55
e	—	—	0.65
E	1.95	2.075	2.00
E2	0.76	0.96	0.86
L	0.30	0.40	0.35
All Dimensions in mm			

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Suggested Pad Layout

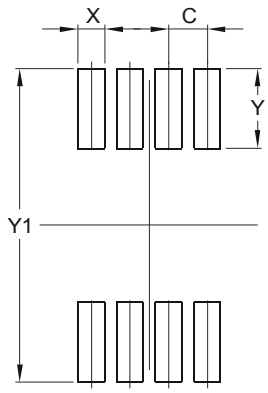
Please see AP02001 at http://www.diodes.com/datasheets/ap02001.pdf for the latest version.

(1) Package type: SO-8



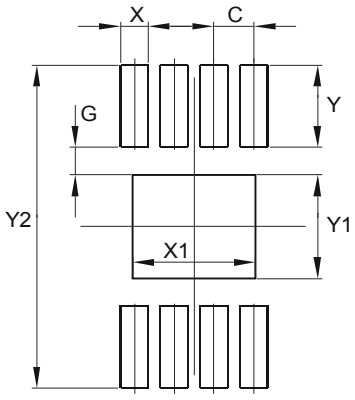
Dimensions	Value (in mm)
X	0.60
Y	1.55
C1	5.4
C2	1.27

(2) Package type: MSOP-8



Dimensions	Value (in mm)
C	0.650
X	0.450
Y	1.350
Y1	5.300

(3) Package type: MSOP-8EP



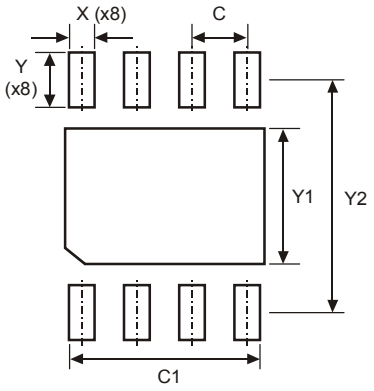
Dimensions	Value (in mm)
C	0.650
G	0.450
X	0.450
X1	2.000
Y	1.350
Y1	1.700
Y2	5.300

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Suggested Pad Layout (cont.)

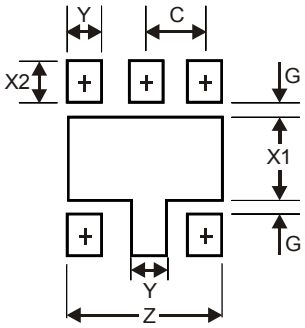
Please see AP02001 at http://www.diodes.com/datasheets/ap02001.pdf for the latest version.

(4) Package type: U-DFN3030-8 Type E



Dimensions	Value (in mm)
C	0.65
C1	2.35
X	0.30
Y	0.65
Y1	1.60
Y2	2.75

(5) Package type: U-DFN2020-6

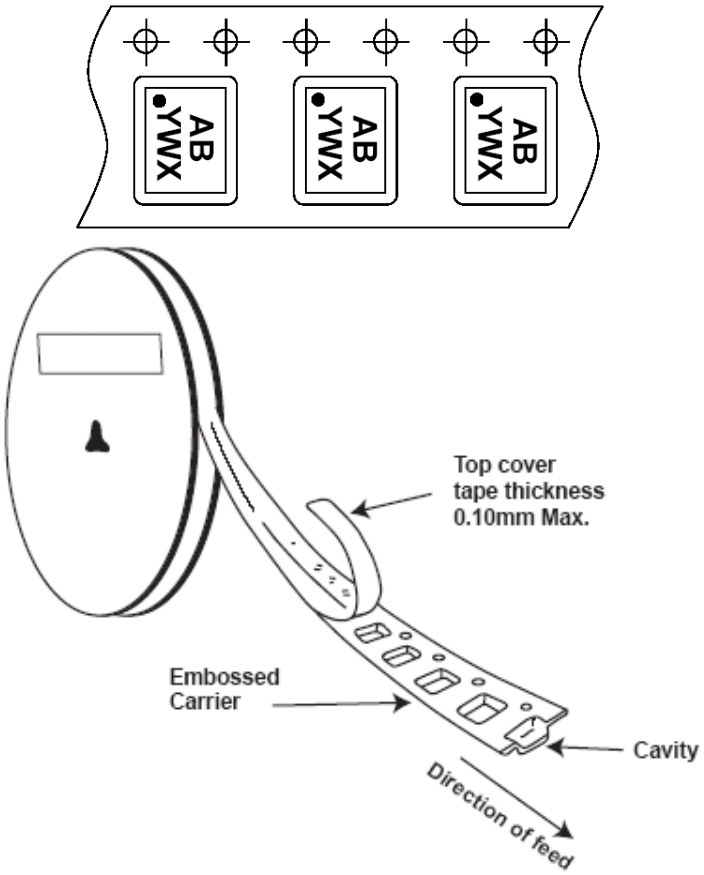


Dimensions	Value (in mm)
Z	1.67
G	0.15
X1	0.90
X2	0.45
Y	0.37
C	0.65

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Taping Orientation (Note 11)

For U-DFN2020-6 and U-DFN3030-8 Type E



Note: 11. The taping orientation of the other package type can be found on our website at http://www.diodes.com/datasheets/ap02007.pdf

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