UNIVERSAL AC VOLTAGE STEP DOWN POWER SWITCHER

Description

The AP3928 is a universal AC voltage step-down power switcher, specially designed for home appliances and IoT applications with non-isolated buck solution.

The device integrates a 700V high performance power MOSFET. Coordinating with a single-winding inductor, it uses fewer external components and provides a low bill of materials (BOM) cost solution.

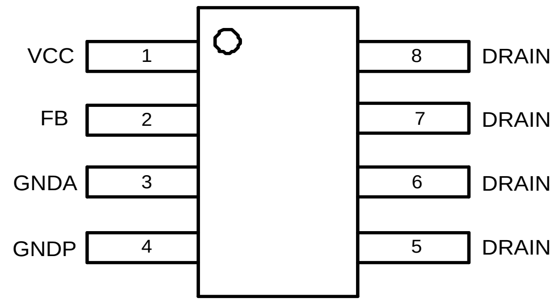
The AP3928 can achieve high output current, excellent constant voltage regulation, and high conversion efficiency. The peak current and switching frequency continuously reduces as the load decreases, so the device can achieve excellent efficiency performance at light load and improve overall system efficiency.

The AP3928 has multiple protection features to enhance the system safety and reliability. The device has overtemperature protection, under-voltage lock function, output short protection, overload protection, and open-loop protection.

The AP3928 is available in the SO-8 (Standard) package.

Pin Assignments

(Top View)



SO-8 (Standard)

Features

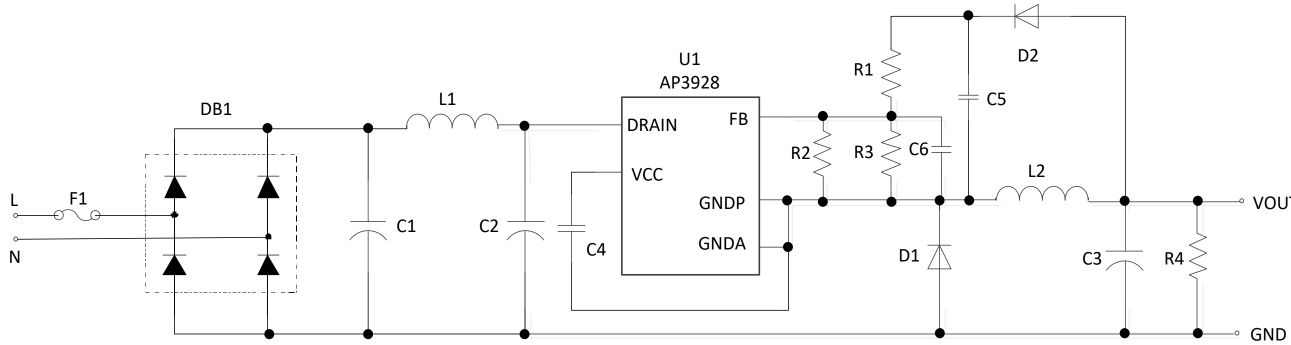
- Universal $85V_{AC}$ to $300V_{AC}$ Input Range
- Internal MOSFET of 700V
- Maximal Peak Current: 1.1A Typical.
- Maximum 600mA Rated Output Current
- Up to 10W Output Power
- No Load Power Consumption: < 30mW with External Bias
- Frequency Modulation to Suppress EMI
- Various Protections: OTP (Overtemperature Protection), OLP (Overload Protection), SCP (Short-Circuit Protection)
- Fewer Components
- Low Audible Noise Solution
- SO-8 (Standard) Package
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**
- **For automotive applications requiring specific change control (i.e. parts qualified to AEC-Q100/101/200, PPAP capable, and manufactured in IATF 16949 certified facilities), please contact us or your local Diodes representative.**
  https://www.diodes.com/quality/product-definitions/

Applications

- Home Appliances
- IoT Applications
- Industrial Controls
- Standby Power and Auxiliary Power

Notes:
1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS), 2011/65/EU (RoHS 2) & 2015/863/EU (RoHS 3) compliant.
2. See https://www.diodes.com/quality/lead-free/ 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.

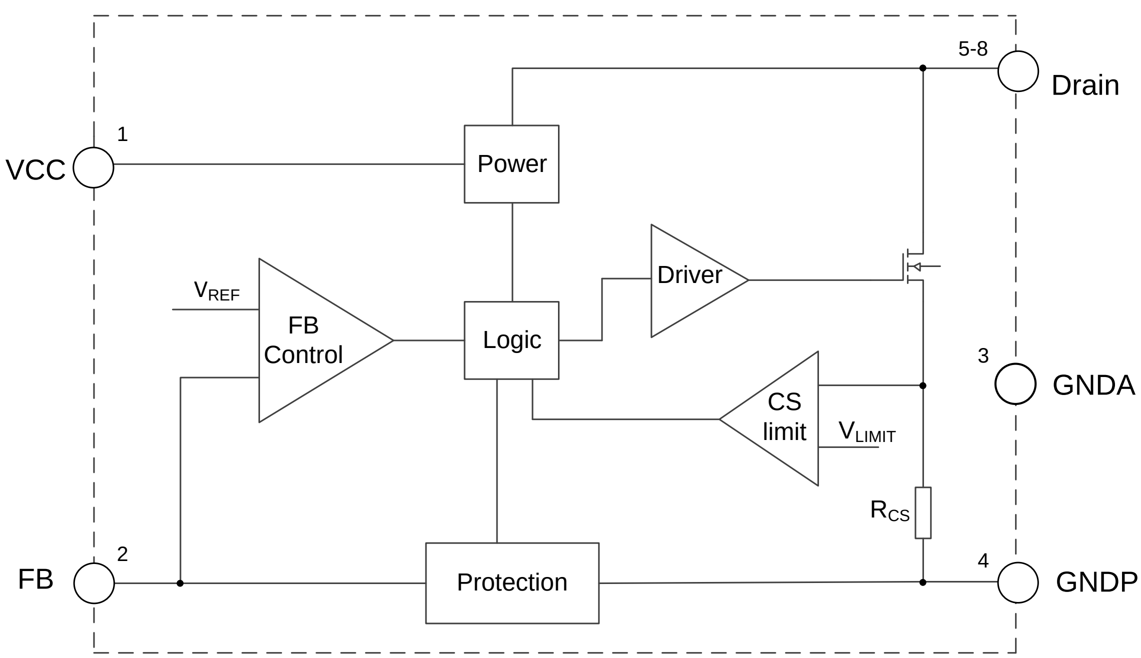
Typical Applications Circuit



Pin Descriptions

Pin Number	Pin Name	Function
1	VCC	Connection Point of External Bypass Capacitor for Internally Generated Control Circuit Power Supply.
2	FB	Regulator Feedback.
3	GNDA	Ground Reference for VCC and FB Pins. Short to GNDP Pin in the application.
4	GNDP	IC Power Ground.
5, 6, 7, 8	DRAIN	Internal Power MOSFET Drain. High-Voltage Current Source Input.

Functional Block Diagram



Absolute Maximum Ratings (Note 4)

Symbol	Parameter	Rating	Unit
V_{DSS}	Drain Pin Voltage	-0.3 to 700	V
VCC	Internally Generated Control Circuit Power Supply	-0.3 to 20	V
V_{FB}, GNDA, GNDP	FB, GNDA and GNDP Pin Voltage	-0.3 to 6.5	V
P_D	Continuous Power Dissipation (T_A = +25°C)	2	W
T_J	Operating Junction Temperature	+150	°C
T_{STG}	Storage Temperature	-65 to +150	°C
T_{LEAD}	Lead Temperature (Soldering, 10s)	+300	°C
θ_{JA}	Thermal Resistance (Junction to Ambient) (Note 5)	76	°C/W
θ_{JC}	Thermal Resistance (Junction to Case)	23	°C/W
—	ESD (Human Body Model)	4000	V
—	ESD (Charge Device Model)	1000	V

Notes: 4. Stresses greater than those listed under *Absolute Maximum Ratings* can 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 under *Recommended Operating Conditions* is not implied. Exposure to *Absolute Maximum Ratings* for extended periods can affect device reliability.
5. Test condition: Device mounted on FR-4 substrate PC board, 2oz copper, with 1inch^2 cooling area.

Recommended Operating Conditions

Symbol	Parameter	Min	Max	Unit
VCC	Supply Voltage	7.9	19	V
V_{DSS}	Drain-Source Voltage (Note 6)	—	560	V
T_A	Ambient Temperature	-40	+125	°C

Note: 6. The drain-source voltage is 80% of V_{DSS} in the aging condition.

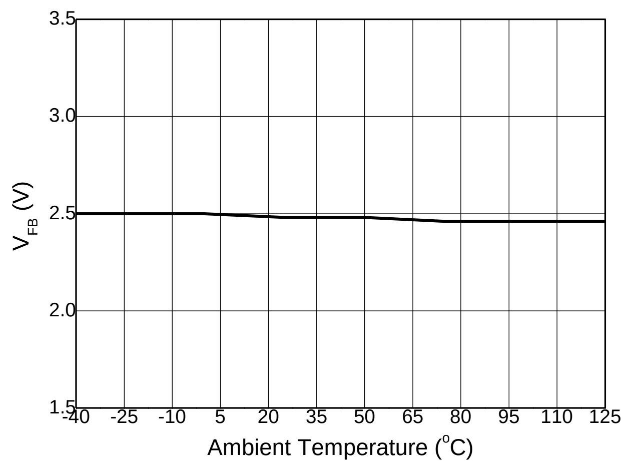
Electrical Characteristics (VCC = 8.8V, -40°C <T_A<+125°C, unless otherwise specified.)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
HV Startup Current Source						
I_{HV}	HV Supply Current	VCC = 7V, V_{DRAIN} = 100V	1	3.5	10	mA
I_{LEAK}	Leakage Current of Drain	VCC= 9.5V; V_{DRAIN} = 400V, T_A = +25°C	—	10	12	µA
VCC Voltage Management						
$VCC_{\_HVOFF}$	VCC Increasing Level at which HV Supply is OFF	—	8.4	9	9.6	V
$VCC_{\_HVON}$	VCC Decreasing Level at which HV Supply is ON	—	7.9	8.5	9.1	V
$VCC_{\_HYS}$	VCC Hysteresis ($VCC_{\_HVOFF}$ -$VCC_{\_HVON}$)	—	200	—	—	mV
$VCC_{\_UVLO}$	VCC Minimum Operating Voltage	T_A = +25°C	7.3	7.9	8.5	V
$VCC_{\_RESTART}$	VCC Restart Voltage	—	3	4.5	5.5	V
I_{CC1}	VCC Operating Current with MOSFET Switching	VCC = 9.5V, f = 58kHz, T_A = +25°C	450	850	1150	µA
I_{CC2}	VCC Quiescent Current with No Switching	T_A = +25°C	80	136	300	µA
I_{CC_LATCH}	VCC Latch Off-Current	VCC = 9.5V, T_A = +25°C	—	26	50	µA
Internal MOSFET						
V_{DSS}	Breakdown Voltage	(Note 7) T_A = +25°C	700	—	—	V
$R_{DS(ON)}$	ON Resistance	T_A = +25°C	—	5.2	6.5	Ω
Internal Current Sense						
I_{PK_MAX}	Maximum Peak Current	T_A = +25°C	980	1100	1220	mA
t_{LEB1}	Leading-Edge Blanking	T_A = +25°C	—	350	470	ns
I_{SCP}	Current Set Point for Short-Circuit Protection	T_A = +25°C (Note 8)	1500	1925	2200	mA
t_{LEB2}	Leading-Edge Blanking for Short-Circuit Protection	T_A = +25°C (Note 8)	—	200	—	ns
Feedback Input (FB Pin)						
t_{MINOFF}	Minimum OFF-Time	T_A = +25°C	11	13	15	µs
t_{MAXON}	Maximal ON-Time	T_A = +25°C	29	35	41	µs
V_{FB}	Feedback Voltage for MOSFET Switch-On Threshold	—	2.4	2.5	2.6	V
OLP_Counting	The Counting Cycle for OLP	—	—	8192	—	cycle
V_{OLD}	Open-Loop Detection Voltage	T_A = +25°C	0.2	0.3	0.4	V
Overtemperature Protection						
T_{OTP}	Thermal Shutdown Threshold	(Note 8)	+135	+150	+165	°C
	Thermal Shutdown Hysteresis	(Note 8)	—	30	—	°C

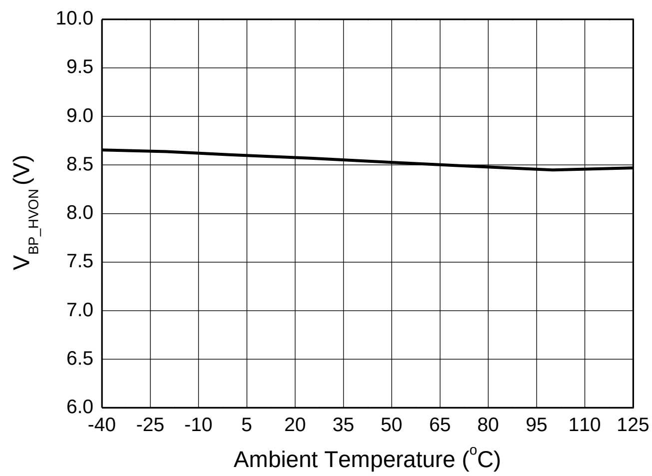
Notes: 7. The drain-source voltage is 80% of V_{DSS} in the aging condition.
8. Guaranteed by design.

Performance Characteristics

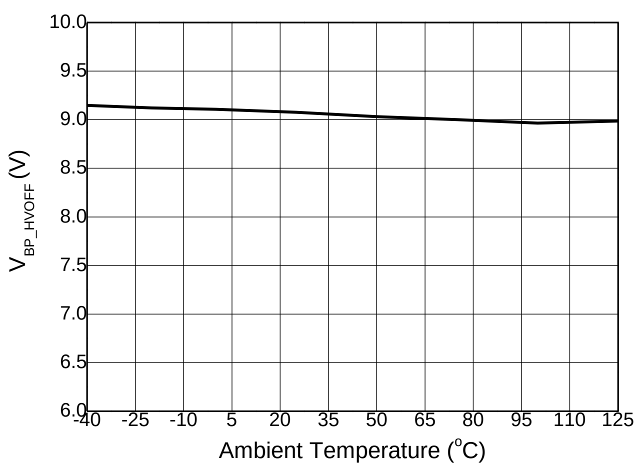
FB Voltage vs. Ambient Temperature



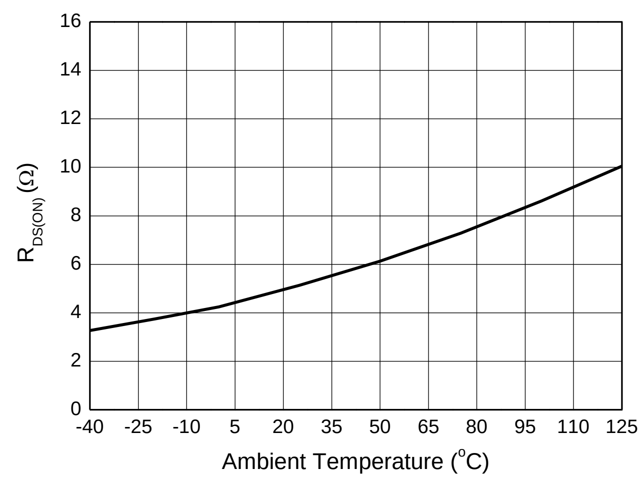
V_{BP_HVON} Voltage vs. Ambient Temperature



V_{BP_HVOFF} Voltage vs. Ambient Temperature



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



Performance Characteristics

Overall Introduction

The AP3928 is a universal AC input step-down power switcher. Peak current and switching frequency reduce as load decreases, so the device achieves excellent efficiency performance at light load and improves overall system efficiency. Coordinating with an external single-winding inductor can achieve a low BOM cost solution.

VCC Waveform and ON/OFF Control

The AP3928 control-circuit power-supply voltage V_{CC} is charged by the internal high-voltage regulator. When the VCC voltage is charged to $VCC_{\_HVOFF}$ (9V), the IC starts up, and the internal high-voltage regulator is turned off. When the VCC voltage drops below $VCC_{\_HVON}$ (8.5V), the internal high-voltage regulator turns on again to charge the external VCC capacitor.

When fault conditions occur, such as overload faults, short-circuit faults, overtemperature faults, and open-loop faults, the AP3928 stops switching. Afterwards, an internal current source I_{CC_LATCH} discharges the external VCC capacitor. The internal high-voltage regulator will not turn on again until the voltage on VCC capacitor drops below $VCC_{\_RESTART}$ (4.5V). The restart time interval is proportional to the capacitance of external VCC capacitor: the larger capacitance of the external VCC capacitor, the longer restart time.

The restart time after a fault is about;

$$t_{RESTART} = C_{VCC} \times \left(\frac{VCC_{\_FAULT} - VCC_{\_RESTART}}{I_{CC\_LATCH}} + \frac{VCC_{\_HVOFF} - VCC_{\_RESTART}}{I_{HV}}\right)$$

Where;

- $VCC_{\_FAULT}$ is the actual voltage value of the VCC pin at the time of the fault, which is between $VCC_{\_HVON}$ and $VCC_{\_HVOFF}$

Figure 1 shows the typical waveform of VCC.

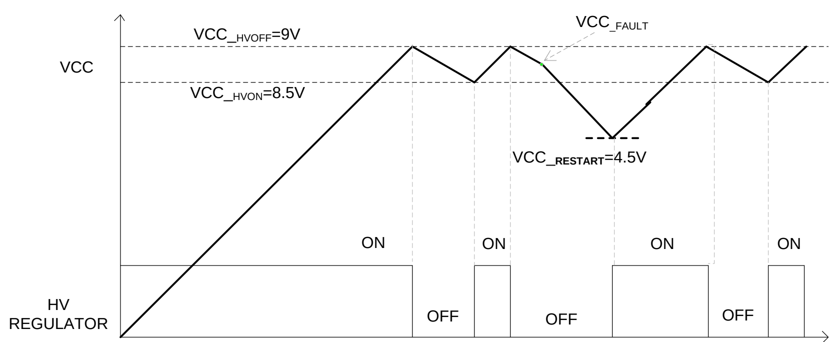


Figure 1. VCC Waveform and HV Regulator ON/OFF Status

Auxiliary VCC Supply

If the output voltage is higher than the voltage of $VCC_{\_HVON}$, an auxiliary VCC supply can be implemented to reduce overall power consumption by connecting a resistor (R5) between C4 and C5. Standby power of less than 30mW can be achieved especially in no-load condition.

Figure 2 shows the low standby power circuit with the auxiliary VCC supply.

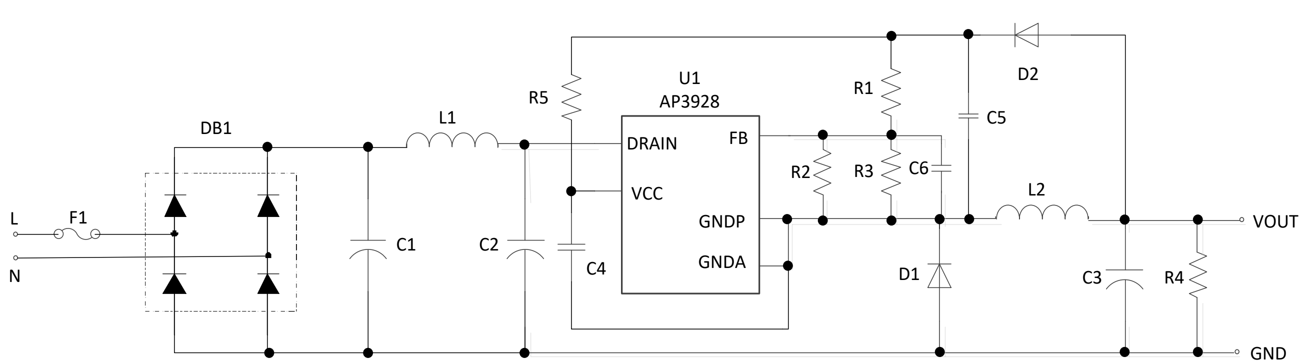


Figure 2. Low Standby Power Circuit with Auxiliary VCC Supply

Performance Characteristics (continued)

The value of R5 can be determined by the following equation:

$$R5 = \frac{V_O - VCC_{\_HVON}}{I_{CC2}}$$

Constant Voltage Operation

The AP3928 can be used in a buck circuit as shown in the typical application circuit. In the beginning of each cycle, the internal integrated MOSFET turns ON when the FB voltages fall below the reference voltage V_{FB} (2.5V). The FB voltage is derived from the sampling capacitor voltage, which can reflect output voltage.

The ON period time is determined by the inductor current variable value ΔI_L, (ΔI_L is the gap of the peak-current limitation value I_{PK} and the initial inductor current value I_{INI}), the inductance value, and the input voltage. The ON time calculation is as follows:

$$t_{ON} = L \cdot \frac{\Delta I_L}{V_{IN\_DC}} = L \cdot \frac{I_{PK} - I_{INI}}{V_{IN\_DC}}$$

Where I_{INI} is zero in DCM status.

When the inductor current reaches peak-current limitation, the internal MOSFET will turn off. The inductor current charges the sampling capacitor (C5) and the output capacitor (C3) via the freewheeling diodes D2 and D1 respectively. In this stage, the sampling capacitor voltage reflects the output voltage.

The output voltage can be regulated by sampling the FB voltage. In the MOSFET OFF time, the inductor current decreases linearly from peak current. When the inductor current falls below the output current, the FB voltage begins to decrease with the sampling capacitor voltage decreasing. Once the FB voltage is detected below the reference voltage of primary MOSFET turn-on threshold, a new switching cycle starts.
The regulated output voltage can be described as the following equation:

$$V_O = V_{FB} \times \left(\frac{R_{UP} + R_{DOWN}}{R_{DOWN}}\right)$$

Where, $R_{UP} = R1$ and $R_{DOWN} = \frac{R2 \bullet R3}{R2 + R3}$.

Figures 3(a) and 3(b) show the operation diagram under DCM and CCM.

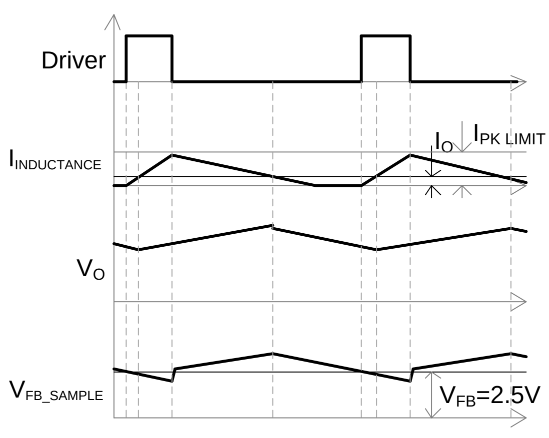


Figure 3(a). DCM

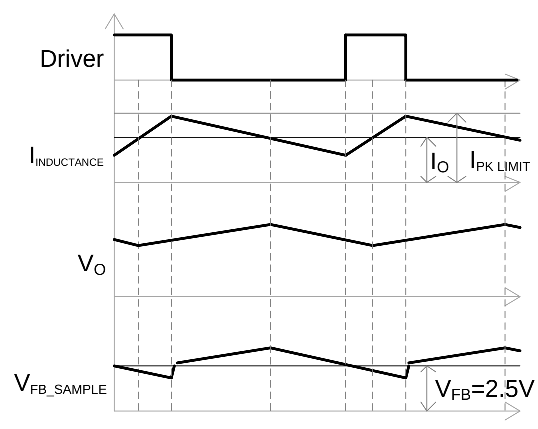


Figure 3(b). CCM

Performance Characteristics (continued)

Start-up Control

An eight-stage control method is designed for soft-start function. During start-up period, the minimum OFF time limit is reduced from 52.4µs to 13µs in stages. Every stage has different numbers of switching cycles (see Table 1).

Figure 4 describes the driver time sequence.

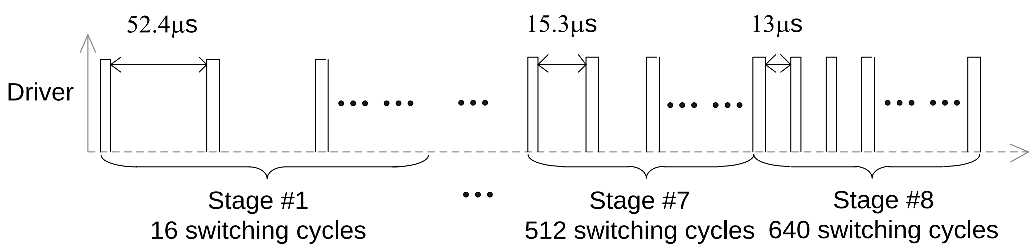


Figure 4. Driver Time Sequence in Start-up Process

Stage	Minimum OFF Time (uS)	Cycles
#1	52.4	16
#2	38.9	32
#3	25.6	64
#4	22.4	128
#5	19.5	256
#6	17.1	384
#7	15.3	512
#8	13	640

Table 1. The number of cycles in every stage

Operation Frequency and Peak Current Characteristics

In order to achieve excellent efficiency performance at light load and improve overall system efficiency, the AP3928 utilizes an optimized frequency curve, as shown in Figure 5. By means of increasing MOSFET off-time, switching frequency continuously decreases as the load decreases, which is optimized for better light load efficiency. The peak current also decreases with load decreases, which can avoid audio noise when the frequency enters into audio frequency range.

The switching-frequency equation is as follows:

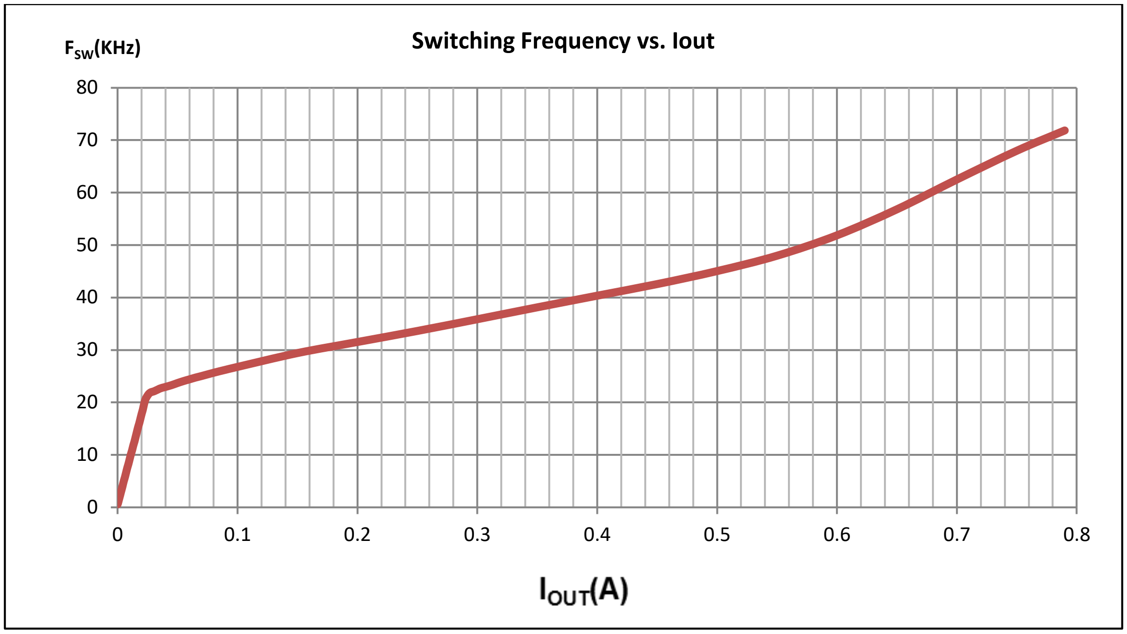
$$f_s = \left(\frac{V_{IN} - V_O}{V_{IN}}\right) \cdot \frac{V_O}{2 \cdot L \cdot (I_{PK} - I_O)}, \quad for \quad CCM$$

$$f_s = \left(\frac{V_{IN} - V_O}{V_{IN}}\right) \cdot \frac{2 \cdot V_O \cdot I_O}{L \cdot I_{PK}^{2}}, \quad for \quad DCM$$

The switching frequency and the peak current limit adjust as shown in the following equation:

$$I_{PK} = I_{PK\_MAX} - (40mA / us) \bullet (t_{OFF} - t_{MINOFF})$$

The minimal value of I_{PK} is limited internally.



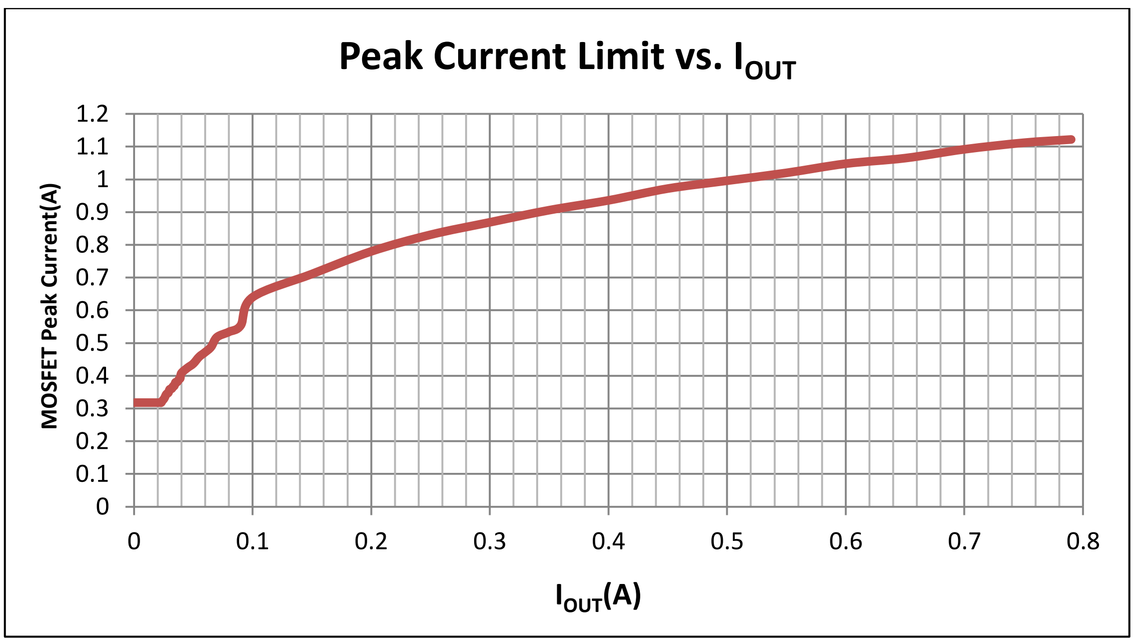


Figure 5. Frequency and Peak Current Limit Characteristic (Vo = 18V, L1 = 0.47mH)

Performance Characteristics (continued)

Overload Protection (OLP)

With the increase of load, the peak current and the switching frequency also increase. When the peak current reaches the maximum limitation, and the OFF time is the minimum OFF time, the internal OLP timer begins to count. For avoiding false triggering during startup and other load transition condition, OLP activates only when the switching pulses reach to the OLP_counting cycles requirement.

Short-Circuit Protection (SCP)

The AP3928 shuts down when the peak current exceeds short-circuit threshold, and the AP3928 resumes operation when the fault is removed.

Note that the inductor saturation current should be higher than I_{SCP} to avoid SCP being triggered during startup. Otherwise, the device may not turn on normally.

Overtemperature Protection (OTP)

The AP3928 integrates an internal overtemperature protection function. The AP3928 shuts down when the inner junction temperature exceeds thermal shutdown threshold T_{OTP} (+150°C). After exceeding the threshold, the VCC voltage begins to drop, and when VCC voltage drops to $VCC_{\_RESTART}$ (4.5V), the internal high-voltage regulator turns on to charge the external VCC capacitor.

Open-Loop Detection (OLD)

When the FB voltage drops below the open-loop detection threshold voltage V_{OLD}, the AP3928 stops working and begins a restart cycle. The open-loop detection is blanked for 64 switching cycles during startup process. Moreover, if FB pin was floating, output voltage will be fixed to 12V typically.

Overshoot Improvement

In general, there is no capacitor between FB pin and GNDA (GNDP) pin. But in some cases where strict overshoot is required, we recommend a ceramic capacitor C6 (390pF to 2.2nF) in Figure 6. In addition，adding a C6 can improve output voltage ripple as well.

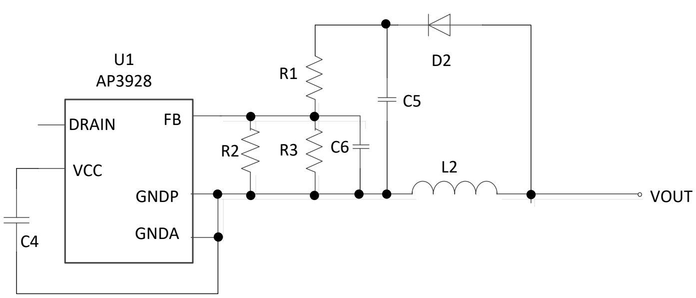
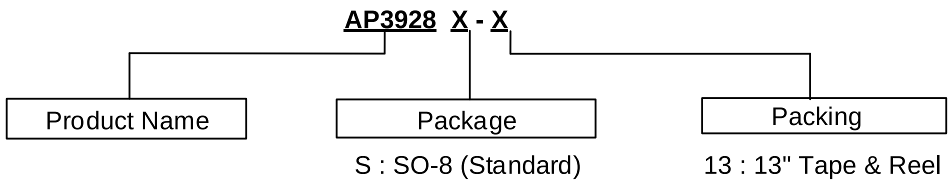


Figure 6. Overshoot Improvement

Leading-Edge Blanking (LEB)

A narrow spike on the leading edge of the current waveform can usually be observed when the power MOSFET is turned on. Normally, the leading-edge blanking time t_{LEB1} is built in to prevent false-triggering caused by the turn-on spike. But in the case of a short circuit, the leading-edge blanking time is t_{LEB2}. During this period, the current limit comparator is disabled, and the gate driver cannot be switched off.

Ordering Information

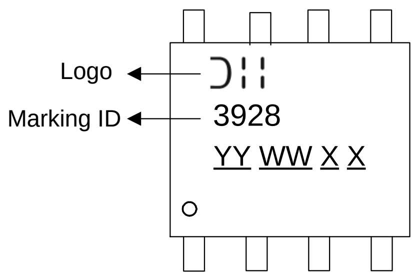


Package	Part Number	Marking ID	13''Tape and Reel	
			Quantity	Part Number Suffix
SO-8 (Standard)	AP3928S-13	3928	4000/Tape and Reel	-13

Marking Information

Package Type: SO-8 (Standard)

(Top View)

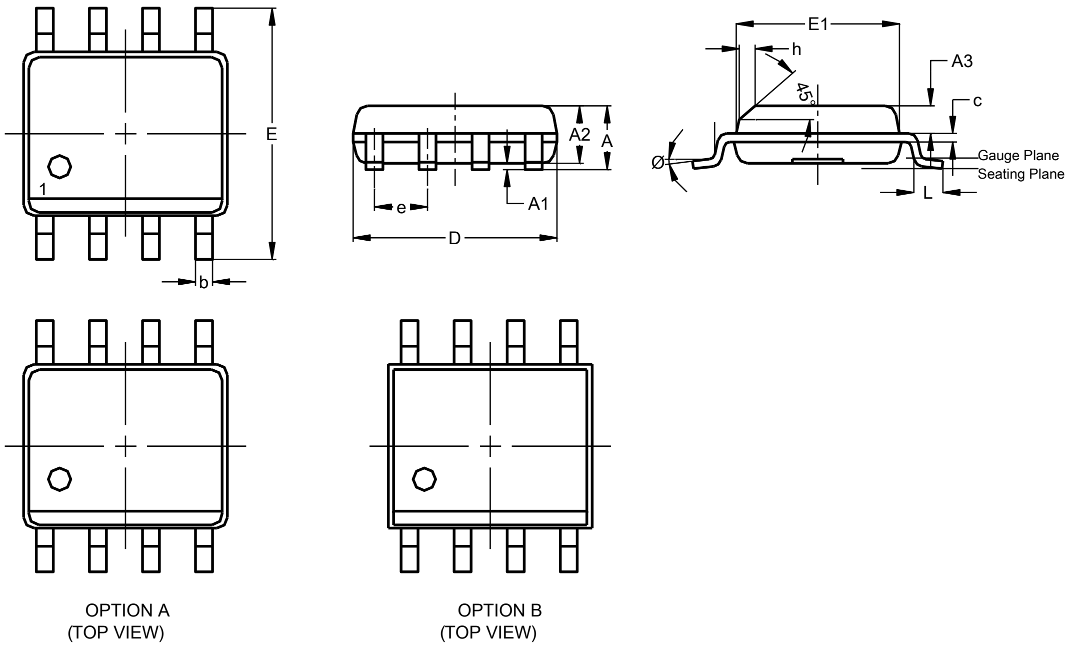


YY : Year : 19, 20, 21 ~
WW : Week : 01~52; 52 represents 52 and 53 week
X X : Internal Code

Package Outline Dimensions

Please see http://www.diodes.com/package-outlines.html for the latest version.

SO-8 (Standard)

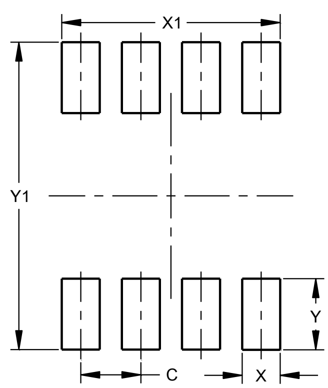


SO-8 (Standard)			
Dim	**Min**	**Max**	**Typ**
A	--	1.75	--
A1	0.10	0.25	--
A2	1.25	1.65	--
A3	0.50	0.70	--
b	0.30	0.51	--
c	0.15	0.25	--
D	4.80	5.00	--
E	5.80	6.20	6.00
E1	3.80	4.00	--
e	--	--	1.27
h	0.25	0.50	--
L	0.45	0.82	--
Ø	0°	8°	--
All Dimensions in mm			

Suggested Pad Layout

Please see http://www.diodes.com/package-outlines.html for the latest version.

SO-8 (Standard)



Dimensions	Value (in mm)
C	1.27
X	0.802
X1	4.612
Y	1.505
Y1	6.50

Mechanical Data

- Moisture Sensitivity: MSL Level 3 per JESD22-A113
- Terminals: Finish – Matte Tin Plated Leads, Solderable per JESD22-B102 e3
- Weight: 0.076 grams (Approximate)

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