

## 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, undervoltage lock function, output short protection, overload protection, and open-loop protection.

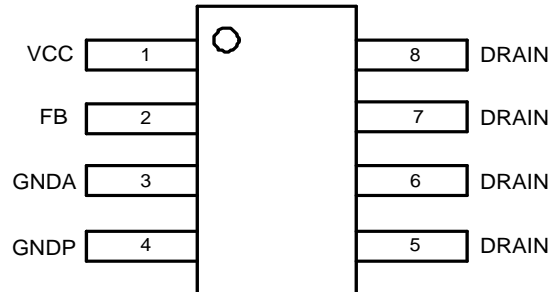
The AP3928 is available in the SO-8 (Standard) package.

## Features

- Universal 85V<sub>AC</sub> to 300V<sub>AC</sub> 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-Q100/101/104/200, PPAP capable, and manufactured in IATF 16949 certified facilities), please [contact us](https://www.diodes.com/contact-us) or your local Diodes representative. <https://www.diodes.com/quality/product-definitions/>**

## Pin Assignments

(Top View)



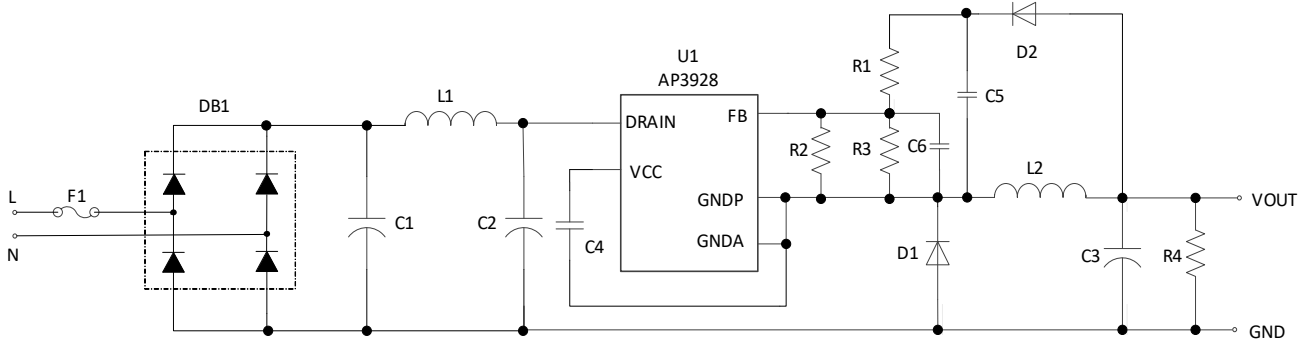
SO-8 (Standard)

## 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.

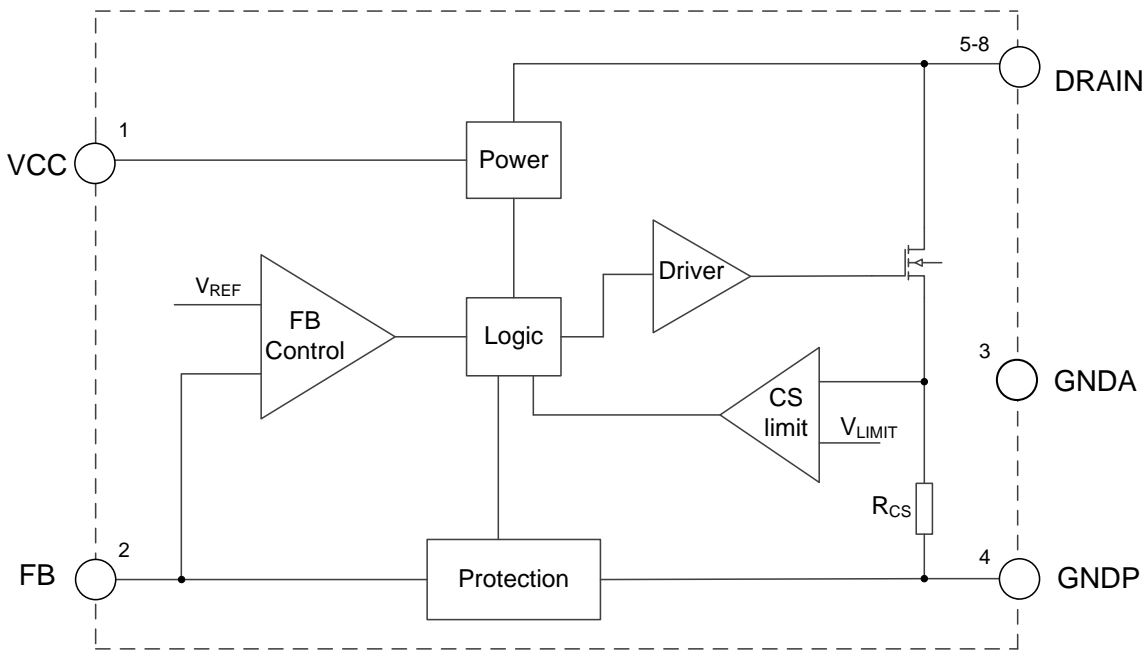
**Typical Applications Circuit**



**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 <sub>DSS</sub>                                      | Drain Pin Voltage                                     | -0.3 to 700 | V    |
| VCC   | Internally Generated Control Circuit Power Supply     | -0.3 to 20  | V    |
| V <sub>FB</sub> , G <sub>NDA</sub> , G <sub>NDP</sub> | FB, GNDA and GNDP Pin Voltage                         | -0.3 to 6.5 | V    |
| P <sub>D</sub>  | Continuous Power Dissipation (T <sub>A</sub> = +25°C) | 2           | W    |
| T <sub>J</sub>  | Operating Junction Temperature                        | +150        | °C   |
| T <sub>STG</sub>                                      | Storage Temperature                                   | -65 to +150 | °C   |
| T <sub>LEAD</sub>                                     | Lead Temperature (Soldering, 10s)                     | +300        | °C   |
| θ <sub>JA</sub>                                       | Thermal Resistance (Junction to Ambient) (Note 5)     | 76          | °C/W |
| θ <sub>JC</sub>                                       | Thermal Resistance (Junction to Case)                 | 23          | °C/W |
| —   | ESD (Human Body Model)                                | 4000        | V    |
| —   | ESD (Charge Device Model)                             | 1000        | V    |

- Notes:
- 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.
  - Test condition: device mounted on FR-4 substrate PC board, 2oz copper, with 1inch<sup>2</sup> cooling area.

## Recommended Operating Conditions

| Symbol           | Parameter                     | Min | Max  | Unit |
|------------------|-------------------------------|-----|------|------|
| VCC              | Supply Voltage                | 7.9 | 19   | V    |
| V <sub>DSS</sub> | Drain-Source Voltage (Note 6) | —   | 560  | V    |
| T <sub>A</sub>   | Ambient Temperature           | -40 | +125 | °C   |

- Note:
- The drain-source voltage is 80% of V<sub>DSS</sub> in the aging condition.

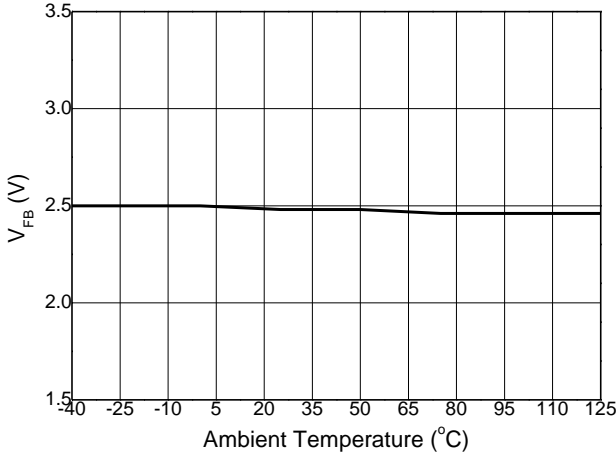
**Electrical Characteristics** (VCC = 8.8V, -40°C < TA < +125°C, unless otherwise specified.)

| Symbol                            | Parameter  | Condition   | Min  | Typ  | Max  | Unit  |
|-----------------------------------|--|---|------|------|------|-------|
| <b>HV Startup Current Source</b>  |  |   |      |      |      |       |
| I <sub>HV</sub>                   | HV Supply Current                                  | VCC = 7V<br>V <sub>DRAIN</sub> = 100V                             | 1    | 3.5  | 10   | mA    |
| I <sub>LEAK</sub>                 | Leakage Current of Drain                           | VCC = 9.5V<br>V <sub>DRAIN</sub> = 400V<br>T <sub>A</sub> = +25°C | —    | 10   | 12   | μA    |
| <b>VCC Voltage Management</b>     |  |   |      |      |      |       |
| 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 <sub>A</sub> = +25°C  | 7.3  | 7.9  | 8.5  | V     |
| VCC_RESTART                       | VCC Restart Voltage                                | —   | 3    | 4.5  | 5.5  | V     |
| I <sub>CC1</sub>                  | VCC Operating Current with MOSFET Switching        | VCC = 9.5V, f = 58kHz<br>T <sub>A</sub> = +25°C                   | 450  | 850  | 1150 | μA    |
| I <sub>CC2</sub>                  | VCC Quiescent Current with No Switching            | T <sub>A</sub> = +25°C  | 80   | 136  | 300  | μA    |
| I <sub>CC_LATCH</sub>             | VCC Latch Off-Current                              | VCC = 9.5V, T <sub>A</sub> = +25°C                                | —    | 26   | 50   | μA    |
| <b>Internal MOSFET</b>            |  |   |      |      |      |       |
| V <sub>DSS</sub>                  | Breakdown Voltage                                  | T <sub>A</sub> = +25°C (Note 7)                                   | 700  | —    | —    | V     |
| R <sub>DS(ON)</sub>               | ON Resistance                                      | T <sub>A</sub> = +25°C  | —    | 5.2  | 6.5  | Ω     |
| <b>Internal Current Sense</b>     |  |   |      |      |      |       |
| I <sub>PK_MAX</sub>               | Maximum Peak Current                               | T <sub>A</sub> = +25°C  | 980  | 1100 | 1220 | mA    |
| t <sub>LEB1</sub>                 | Leading-Edge Blanking                              | T <sub>A</sub> = +25°C  | —    | 350  | 470  | ns    |
| I <sub>SCP</sub>                  | Current Set Point for Short-Circuit Protection     | T <sub>A</sub> = +25°C (Note 8)                                   | 1500 | 1925 | 2200 | mA    |
| t <sub>LEB2</sub>                 | Leading-Edge Blanking for Short-Circuit Protection | T <sub>A</sub> = +25°C (Note 8)                                   | —    | 200  | —    | ns    |
| <b>Feedback Input (FB Pin)</b>    |  |   |      |      |      |       |
| t <sub>MINOFF</sub>               | Minimum OFF-Time                                   | T <sub>A</sub> = +25°C  | 11   | 13   | 15   | μs    |
| t <sub>MAXON</sub>                | Maximal ON-Time                                    | T <sub>A</sub> = +25°C  | 29   | 35   | 41   | μs    |
| V <sub>FB</sub>                   | Feedback Voltage for MOSFET Switch-On Threshold    | —   | 2.4  | 2.5  | 2.6  | V     |
| OLP_Counting                      | The Counting Cycle for OLP                         | —   | —    | 8192 | —    | cycle |
| V <sub>OLD</sub>                  | Open-Loop Detection Voltage                        | T <sub>A</sub> = +25°C  | 0.2  | 0.3  | 0.4  | V     |
| <b>Overtemperature Protection</b> |  |   |      |      |      |       |
| T <sub>OTP</sub>                  | Thermal Shutdown Threshold                         | (Note 8)  | +135 | +150 | +165 | °C    |
|                                   | Thermal Shutdown Hysteresis                        | (Note 8)  | —    | +30  | —    | °C    |

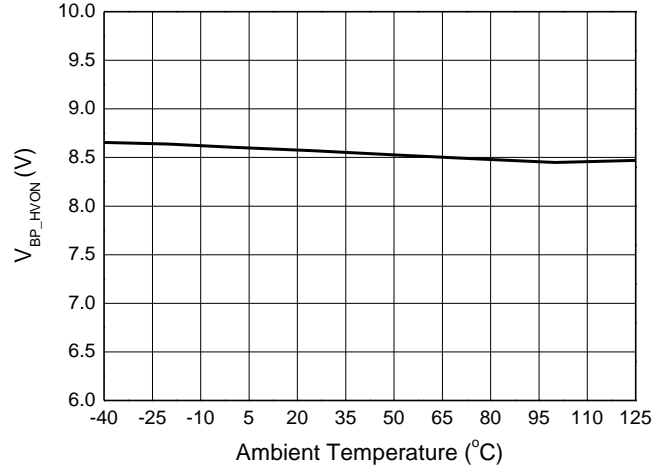
Notes: 7. The drain-source voltage is 80% of V<sub>DSS</sub> in the aging condition.  
8. Guaranteed by design.

**Performance Characteristics**

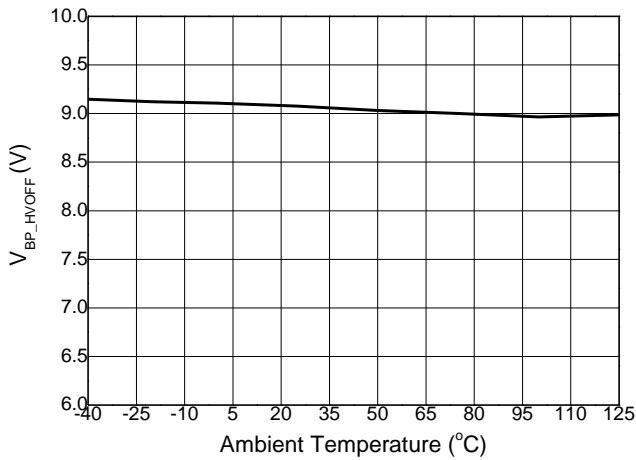
**FB Voltage vs. Ambient Temperature**



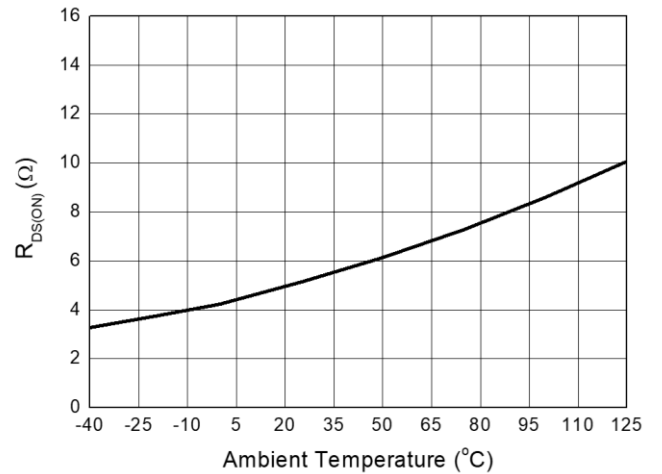
**V<sub>BP\_HVON</sub> Voltage vs. Ambient Temperature**



**V<sub>BP\_HVOFF</sub> Voltage vs. Ambient Temperature**



**R<sub>DS(ON)</sub> vs. Ambient Temperature**



**Performance Characteristics** (continued)

**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 VCC is charged by the internal high-voltage regulator. When the VCC voltage is charged to VCC\_HV<sub>OFF</sub> (9V), the IC starts up, and the internal high-voltage regulator is turned off. When the VCC voltage drops below VCC\_HV<sub>ON</sub> (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<sub>CC\_LATCH</sub> 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:

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

Where,

- VCC\_FAULT is the actual voltage value of the VCC pin at the time of the fault, which is between VCC\_HV<sub>ON</sub> and VCC\_HV<sub>OFF</sub>

Figure 1 shows the typical waveform of VCC.

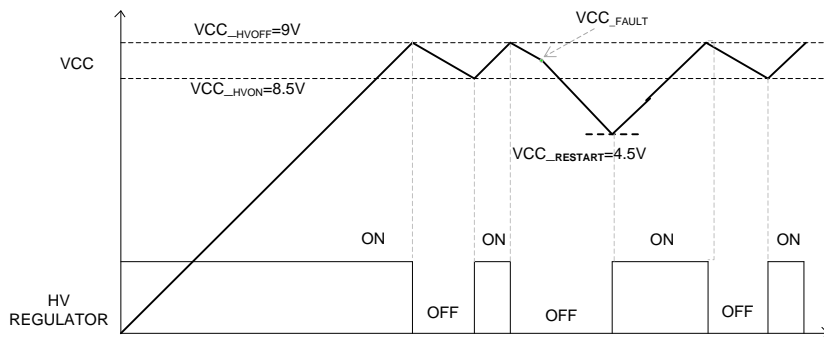


Figure 1. VCC Waveform and HV Regulator ON/OFF Status

**Auxiliary VCC Supply**

If the output voltage is higher than the voltage of VCC\_HV<sub>ON</sub>, 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.

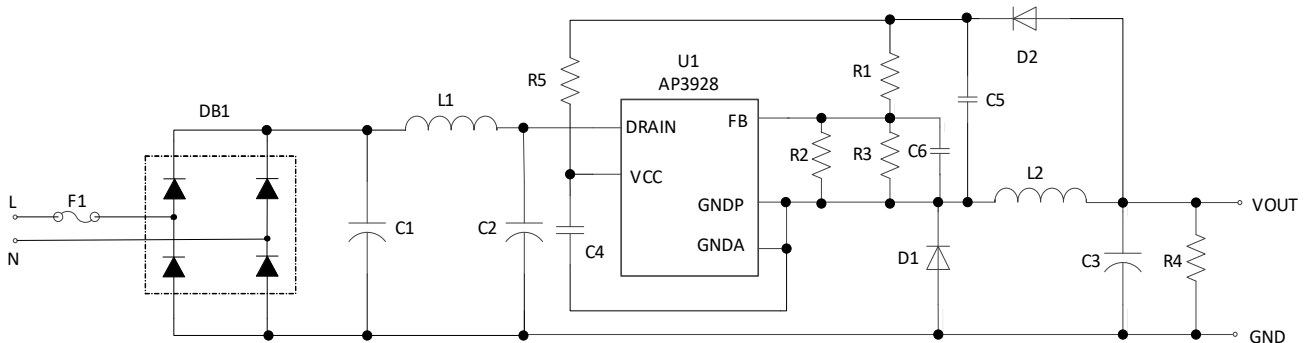


Figure 2. Low Standby Power Circuit with Auxiliary VCC Supply

**Performance Characteristics** (continued)

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

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

**Constant Voltage Operation**

The AP3928 can be used in a buck circuit as shown in the *Typical Applications Circuit*. In the beginning of each cycle, the internal integrated MOSFET turns ON when the FB voltages fall below the reference voltage V<sub>FB</sub> (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<sub>L</sub>, (ΔI<sub>L</sub> is the gap of the peak-current limitation value I<sub>PK</sub> and the initial inductor current value I<sub>INI</sub>), 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<sub>INI</sub> 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<sub>UP</sub> = R1 and R<sub>DOWN</sub> =  $\frac{R2 \cdot R3}{R2 + R3}$ .

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

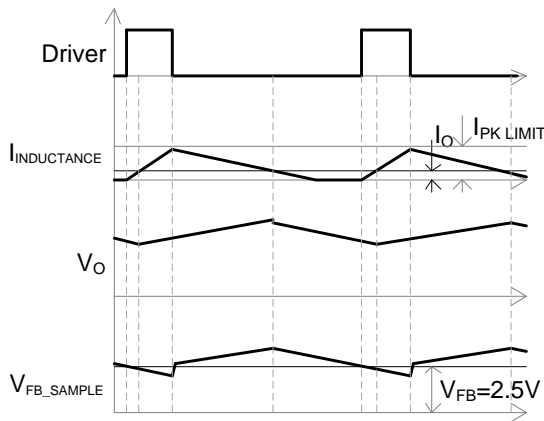


Figure 3(a). DCM

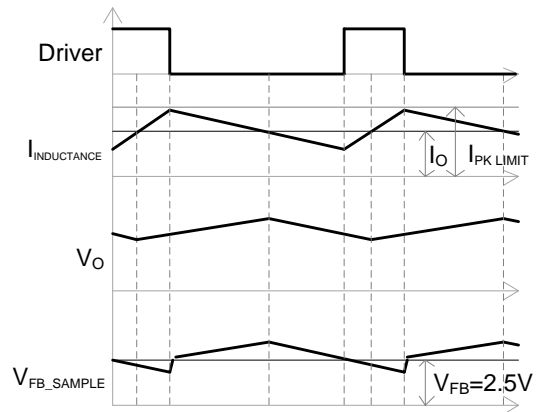


Figure 3(b). CCM

**Performance Characteristics** (continued)

**Startup Control**

An eight-stage control method is designed for soft-start function. During startup 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.

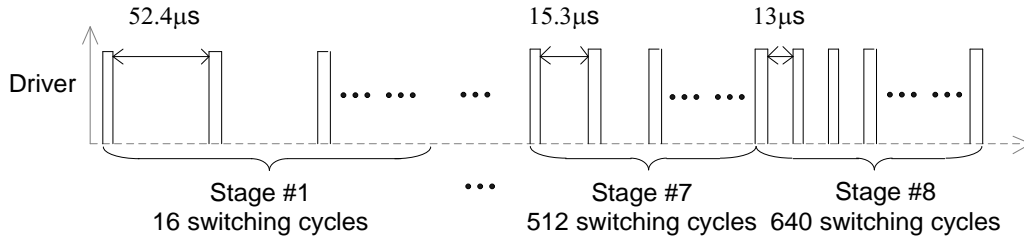


Figure 4. Driver Time Sequence in Startup Process

| Stage | Minimum OFF Time (µs) | 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:

$$f_s = \left(\frac{V_{IN} - V_o}{V_{IN}}\right) \cdot \frac{V_o}{2 \cdot L \cdot (I_{PK} - I_o)}, \text{ for CCM}$$

$$f_s = \left(\frac{V_{IN} - V_o}{V_{IN}}\right) \cdot \frac{2 \cdot V_o \cdot I_o}{L \cdot I_{PK}^2}, \text{ for DCM}$$

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

$$I_{PK} = I_{PK\_MAX} - (40mA / \mu s) \cdot (t_{OFF} - t_{MINOFF})$$

The minimal value of I<sub>PK</sub> is limited internally.



**Performance Characteristics** (continued)

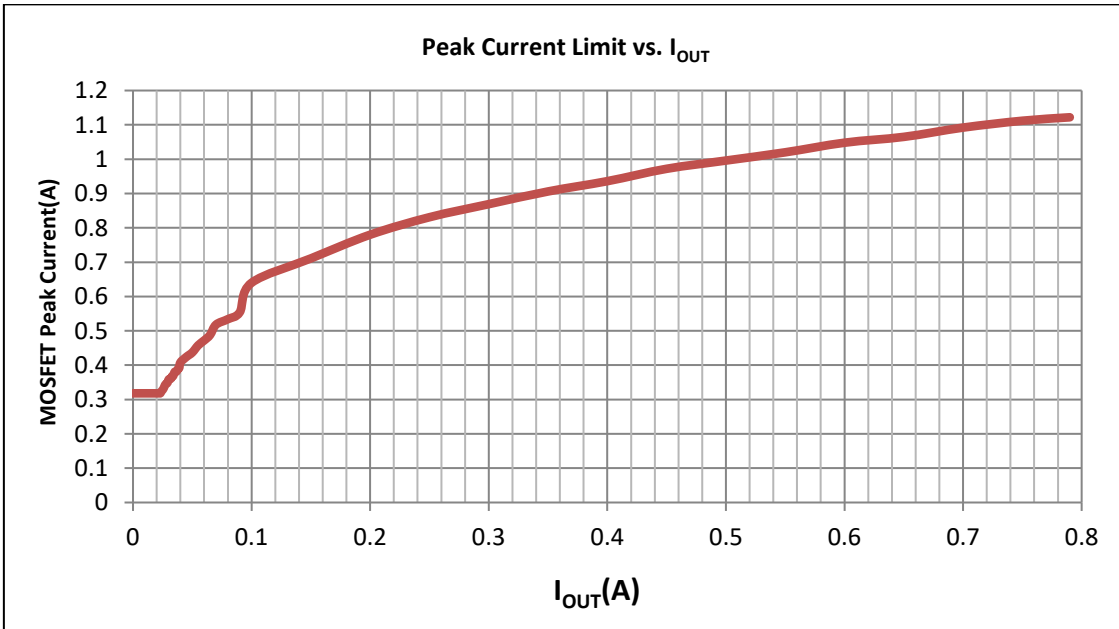
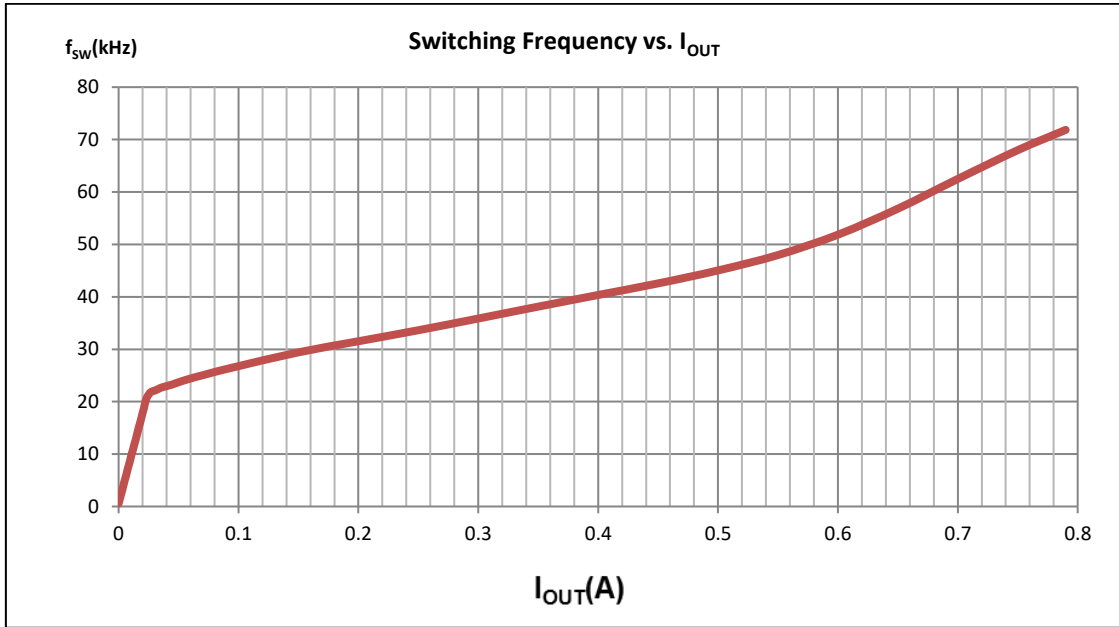


Figure 5. Frequency and Peak Current Limit Characteristic ( $V_o = 18V$ ,  $L1 = 0.47mH$ )

## 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 is activated 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 GNDP (GNDA) 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.

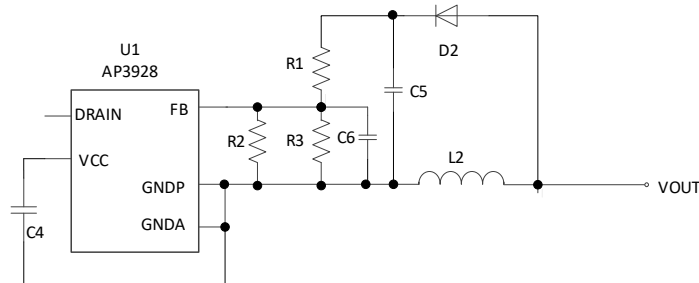
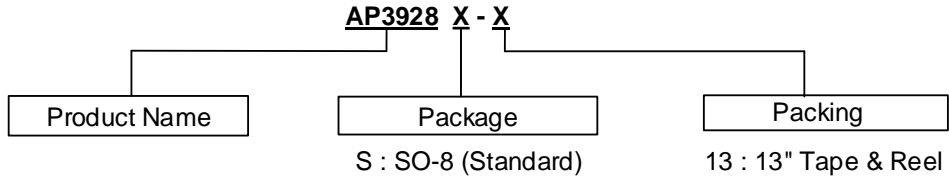


Figure 6. Overshoot Improvement

### 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.

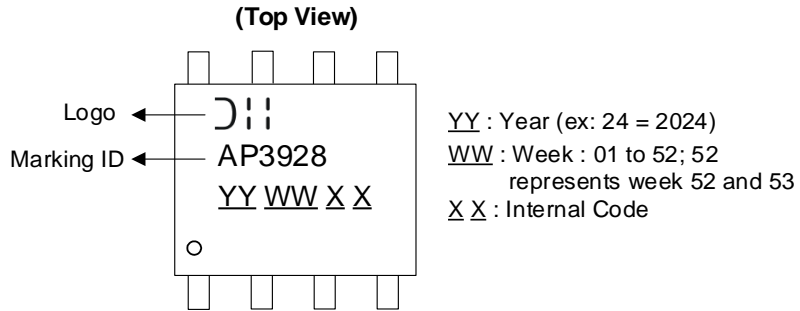
**Ordering Information**



| Orderable Part Number | Part Number Suffix | Package         | Marking ID | Packing |               |
|-----------------------|--------------------|-----------------|------------|---------|---------------|
|                       |                    |                 |            | Qty.    | Carrier       |
| AP3928S-13            | -13                | SO-8 (Standard) | AP3928     | 4000    | Tape and Reel |

**Marking Information**

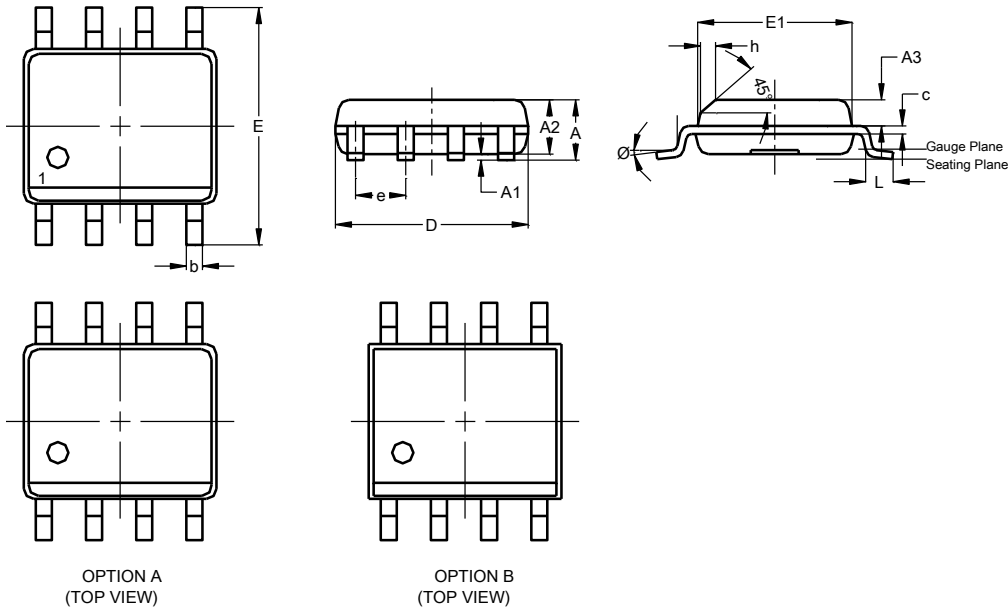
Package Type: SO-8 (Standard)



**Package Outline Dimensions**

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

**SO-8 (Standard)**

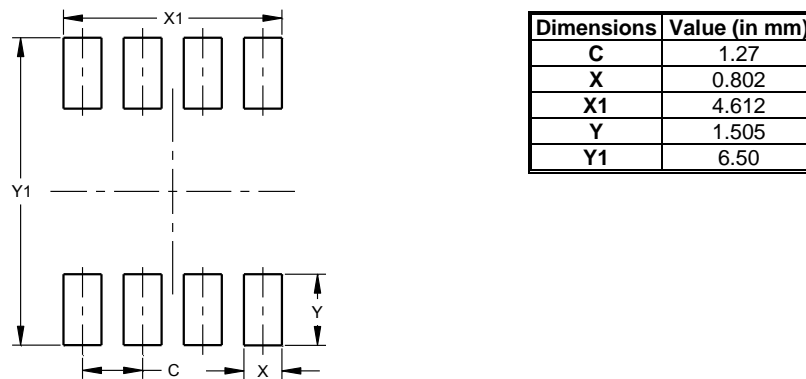


| SO-8 (Standard)      |      |      |      |
|----------------------|------|------|------|
| Dim                  | Min  | Max  | Typ  |
| A                    | --   | 1.75 | --   |
| A1                   | 0.10 | 0.25 | --   |
| A2                   | 1.25 | 1.65 | --   |
| A3                   | 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: 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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