

# FSAR001 AC-DC Linear Regulator

## Features

- High Output Voltage Accuracy: 2%
- Output Voltage: 5V
- Low Ground Current: < 2.0mA
- Ultra-Fast Line and Load Transient Response
- Hysteretic Thermal and Current-Limit Protections
- Over-Voltage and Under-Voltage Protections
- Ultra-Low Power Dissipation with No Load
- Universal Input Range: 80~265V<sub>RMS</sub>
- No Inductor Required
- Low Components and Cost

## Applications

- Non-Isolation AC/DC Converter
- Home Appliance

## Description

FSAR001 is designed to replace capacitor-fed ("cap dropper") non-isolated power supplies, offering better high-power conversion performance and high-energy efficiency than a cap dropper solution. The appliance needs no inductor, uses few components, and offers lower cost.

FSAR001 integrates a 600V high-power device, startup controller, voltage control circuit, synchronous circuit, low dropout regulator, over-temperature protector, over-voltage protector, under-voltage protector, and current-limit circuit onto a monolithic IC.

## Ordering Information

| Part Number | Operating Ambient Temperature Range | Output Voltage | Maximum Load | Package | Packing Method |
|-------------|-------------------------------------|----------------|--------------|---------|----------------|
| FSAR001BNY  | -40°C to +105°C                     | 5V             | 35mA         | DIP-8   | Tube           |

## Application Diagram

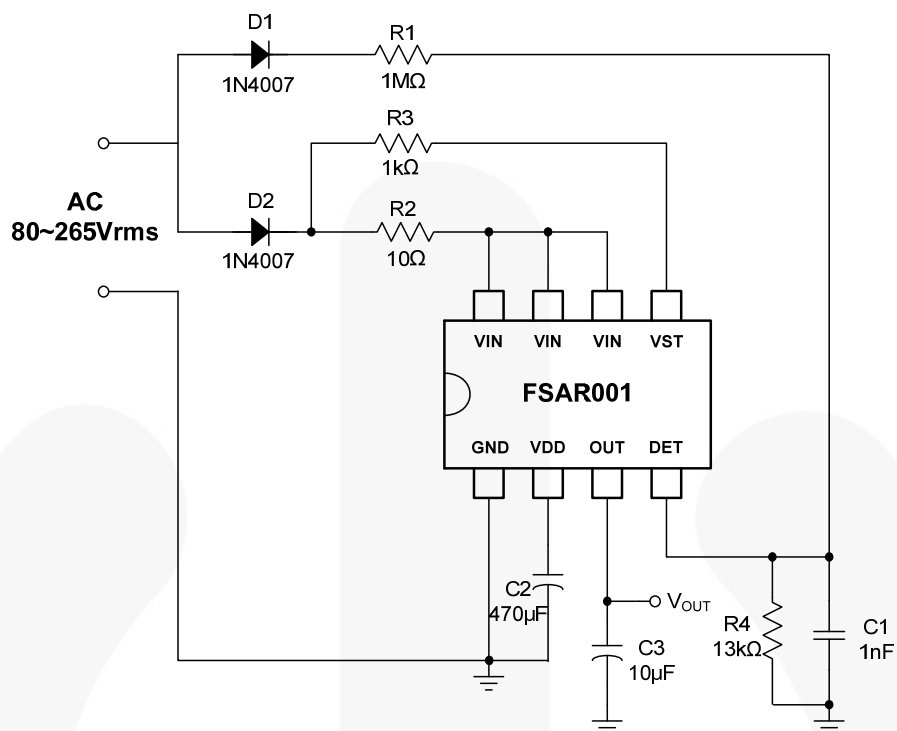


Figure 1. Typical Application

## Internal Block Diagram

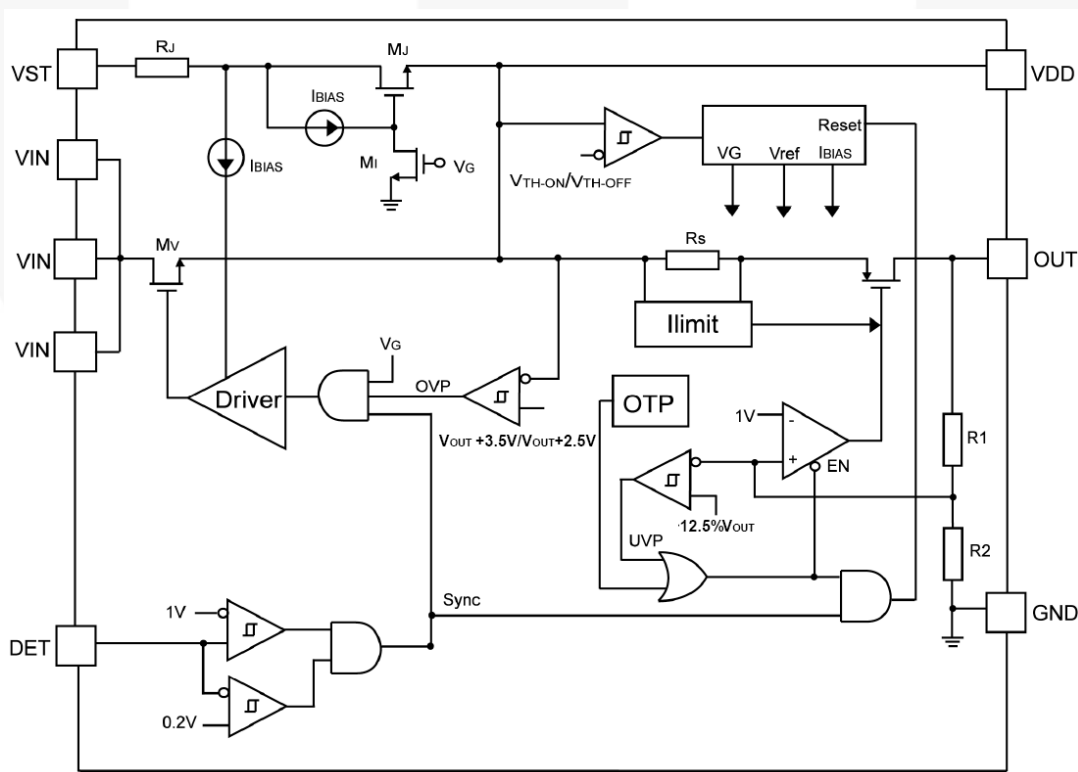
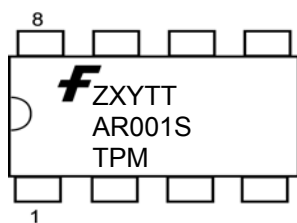


Figure 2. Functional Block Diagram

## Marking Information



F - Fairchild Logo  
 Z - Plant Code  
 X - 1-Digit Year Code  
 Y - 1-Digit Week Code  
 TT - 2-Digit Die Run Code  
 S: B: 5V  $V_{OUT}$   
 T: Package Type (N=DIP)  
 P - Y: Green Package  
 M - Manufacture Flow Code

Figure 3. Top Mark

## Pin Configuration

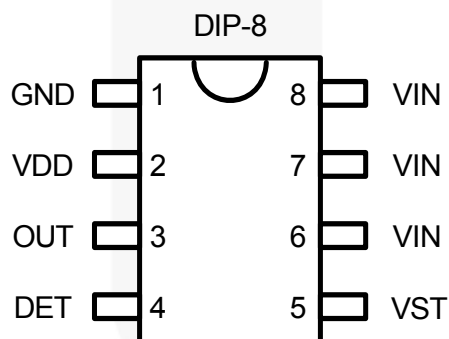


Figure 4. DIP-8 Pin Configuration

## Pin Definitions

| Name | Pin # | Type         | Description                                                                                                       |
|------|-------|--------------|-------------------------------------------------------------------------------------------------------------------|
| VDD  | 2     | Power Supply | Connect a 470 $\mu$ F external capacitor to ground for generated $V_{OUT}+2.5V \sim V_{OUT}+3.5V$ supply voltage. |
| GND  | 1     | Ground       | Ground                                                                                                            |
| OUT  | 3     | Output       | Regulator output; fixed 5V output voltage                                                                         |
| DET  | 4     | Detect       | Sin waveforms input connection. Connects to full-bridge output and provides synchronous signal.                   |
| VST  | 5     | HV Start     | 500V power device startup connection.                                                                             |
| VIN  | 6     | 600V Input   | 600V power device input connection                                                                                |
|      | 7     |              |                                                                                                                   |
|      | 8     |              |                                                                                                                   |

## Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

| Symbol           | Parameter                                           |                                       | Min. | Max. | Unit |
|------------------|-----------------------------------------------------|---------------------------------------|------|------|------|
| V <sub>IN</sub>  | Input Voltage of VIN Pin                            |                                       |      | 600  | V    |
| V <sub>ST</sub>  | Input Voltage of VST Pin                            |                                       |      | 500  | V    |
| V <sub>DET</sub> | Input Voltage of DET Pin                            |                                       |      | 7    | V    |
| V <sub>DD</sub>  | Input Voltage of VDD Pin                            |                                       |      | 30   | V    |
| V <sub>OUT</sub> | Input Voltage of OUT Pin                            |                                       |      | 30   | V    |
| P <sub>D</sub>   | Power Dissipation (T <sub>A</sub> ≤ 50°C)           |                                       |      | 1.15 | W    |
| Θ <sub>JA</sub>  | Thermal Resistance (Junction to Air)                |                                       |      | 95   | °C/W |
| T <sub>J</sub>   | Operating Junction Temperature                      |                                       | -40  | +125 | °C   |
| T <sub>STG</sub> | Storage Temperature Range                           |                                       | -55  | +150 | °C   |
| T <sub>L</sub>   | Lead Temperature (Wave Soldering or IR, 10 Seconds) |                                       |      | 260  | °C   |
| ESD              | Human Body Model, JEDEC:JESD22-A114                 | All Pins Except HV Pin <sup>(3)</sup> |      | 6    | KV   |
|                  | Charged Device Model, JEDEC:JESD22-C101             | All Pins Except HV Pin <sup>(3)</sup> |      | 2    |      |

### Notes:

1. All voltage values, except differential voltages, are given with respect to the network ground terminal.
2. Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device.
3. ESD with HV pin CDM=1000V and HBM=500V.

## Recommended Operating Conditions

| Symbol   | Parameter                     | Min. | Max. | Unit             |
|----------|-------------------------------|------|------|------------------|
| $V_{IN}$ | 600V High-Voltage Input       |      | 600  | V                |
| $V_{ST}$ | 500V High-Voltage Startup     |      | 500  | V                |
| $T_A$    | Operating Ambient Temperature | -40  | +105 | $^\circ\text{C}$ |

### Note:

4. For proper operation.

## Electrical Characteristics

$V_{IN}$ =open,  $V_{DD}=V_{OUT}+1$  V,  $C_{VDD}=470$   $\mu$ F/ 25 V,  $C_{OUT}=10$   $\mu$ F/ 16 V,  $I_{OUT}=1$  mA,  $T_A=25^\circ\text{C}$ , unless otherwise noted.

| Symbol                | Parameter                                                          | Conditions                                                                                                  | Min.          | Typ.          | Max.          | Unit             |
|-----------------------|--------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|---------------|---------------|---------------|------------------|
| <b>VDD Section</b>    |                                                                    |                                                                                                             |               |               |               |                  |
| $V_{TH-ON}$           | Turn-On Threshold Voltage ( $V_{OUT}=5$ V)                         | VDD Pin                                                                                                     | 9             | 10            | 11            | V                |
| $V_{TH-OFF}$          | Turn-off Voltage ( $V_{OUT}=5$ V)                                  | VDD Pin                                                                                                     | 3             | 4             | 5             | V                |
| $I_{DD-ST}$           | Startup Current of VDD Pin                                         | VDD Pin                                                                                                     |               | 10            | 30            | $\mu$ A          |
| $I_{DD-OP}$           | Operating Supply Current                                           | $I_{OUT}=1$ mA                                                                                              | 1.0           | 1.5           | 2.0           | mA               |
| $V_{DD-OVP}$          | Threshold of $V_{DD}$ OVP                                          |                                                                                                             | $V_{OUT}+3.0$ | $V_{OUT}+3.5$ | $V_{OUT}+4.0$ | V                |
| $V_{DD-OVPHYS}$       | Threshold of $V_{DD}$ OVP Hysteresis                               |                                                                                                             | 0.8           | 1.0           | 1.2           | V                |
| $t_{VDD-OVP}$         | Time Delay of $V_{DD}$ OVP                                         |                                                                                                             |               | 1.5           |               | $\mu$ s          |
| <b>VIN Section</b>    |                                                                    |                                                                                                             |               |               |               |                  |
| $V_{VIN}$             | Supply Voltage                                                     |                                                                                                             |               |               | 600           | V                |
| <b>VST Section</b>    |                                                                    |                                                                                                             |               |               |               |                  |
| $I_{ST}$              | Supply Current from VST Pin                                        | $V_{AC}=90$ V ( $V_{DC}=120$ V),<br>$V_{DD}=10$ $\mu$ F                                                     | 2.50          | 3.75          | 5.00          | mA               |
| $I_{ST-LC}$           | Supply Current After Startup                                       | HV=500V, $V_{DD}=V_{DD-OFF}+1$ V                                                                            |               | 1             | 20            | $\mu$ A          |
| <b>DET Section</b>    |                                                                    |                                                                                                             |               |               |               |                  |
| $V_{DET\_MAX}$        | Turn-Off Synchronous Voltage                                       |                                                                                                             | 0.90          | 0.95          | 1.00          | V                |
| $V_{DET\_MAXHYS}$     | Turn-Off Synchronous Voltage Hysteresis                            |                                                                                                             | 0.08          | 0.10          | 0.12          | V                |
| $V_{DET\_MIN}$        | Turn-On Synchronous Voltage                                        |                                                                                                             | 0.08          | 0.14          | 0.20          | V                |
| $V_{DET\_MINHYS}$     | Turn-Off Synchronous Voltage Hysteresis                            |                                                                                                             | 0.08          | 0.14          | 0.20          | V                |
| $I_{DET}$             | DET Current                                                        |                                                                                                             |               | 0.1           |               | $\mu$ A          |
| <b>VOOUT Section</b>  |                                                                    |                                                                                                             |               |               |               |                  |
| $UVP_{Vout}$          | Output Pin Under-Voltage Protection                                |                                                                                                             | -10.0         | -12.5         | -15.0         | %                |
| $V_{ACC}$             | Output Voltage Accuracy                                            |                                                                                                             | -2            |               | 2             | %                |
| LR                    | Load Regulation                                                    | $I_{OUT}=1$ mA to Maximum                                                                                   | -2            |               | 2             | %                |
| $\Delta V_{OUT(VIN)}$ | Line Regulation $dV_{OUT}/dV_{IN}$                                 |                                                                                                             | -0.2          |               | 0.2           | %/V              |
| ILIM                  | Current Limit                                                      | $V_{DD}=V_{OUT}+3$ V                                                                                        | 110           | 140           | 170           | mA               |
| $V_{Drop}$            | Dropout Voltage ( $V_{OUT}=5$ V)                                   | $I_{OUT}=35$ mA                                                                                             | 0.3           | 0.4           | 0.5           | V                |
| $I_G$                 | Ground Pin Current <sup>(5)</sup>                                  | Output Current = Maximum Load                                                                               |               | 1.5           | 2.0           | mA               |
| $t_{DOUT-ST}$         | Output Voltage Rising Time ( $V_{OUT}=12$ V) $V_{DD}$ to $V_{OUT}$ | $V_{OUT}=0\%\sim 90\%$<br>$C_{OUT}=1$ $\mu$ F                                                               | 40            | 50            | 60            | $\mu$ s          |
| PSRR                  | Ripple Rejection <sup>(6)</sup>                                    | $f=50$ Hz, $C_{OUT}=10$ $\mu$ F,<br>$I_{OUT}=35$ mA<br>$f=100$ Hz, $C_{OUT}=10$ $\mu$ F,<br>$I_{OUT}=35$ mA |               | 60            |               | dB               |
| $T_{OTP}$             | Protection Junction Temperature <sup>(6)</sup>                     |                                                                                                             |               | 150           |               | $^\circ\text{C}$ |
| $T_{HYS}$             | Restart Junction Temperature <sup>(6)</sup>                        |                                                                                                             |               | $T_{OTP}-40$  |               | $^\circ\text{C}$ |

### Notes:

- For  $V_{Drop}=1$ V of  $V_{OUT}=3.3$ V version, the test condition is modified to  $V_{DD}=V_{OUT}+1.5$ V.
- Guaranteed by design.

## Typical Performance Characteristics

$V_{AC} = 264V/50Hz$ ,  $V_{OUT} = 5V$ ,  $I_{OUT} = 35mA \sim 40mA$ ,  $C_{VDD} = 470\mu F$ ,  $C_{OUT} = 10\mu F$ ,  $T_A = 25^\circ C$ , unless otherwise noted.

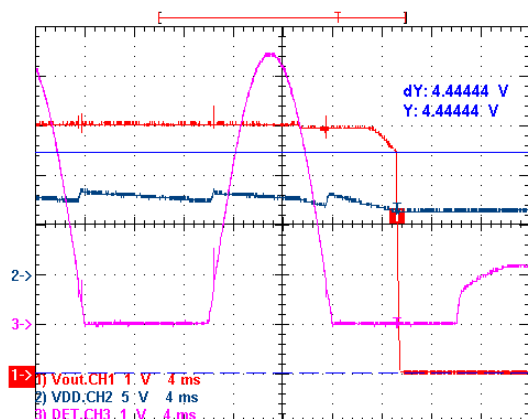


Figure 5.  $V_{OUT}$  Pin Under-Voltage Protection

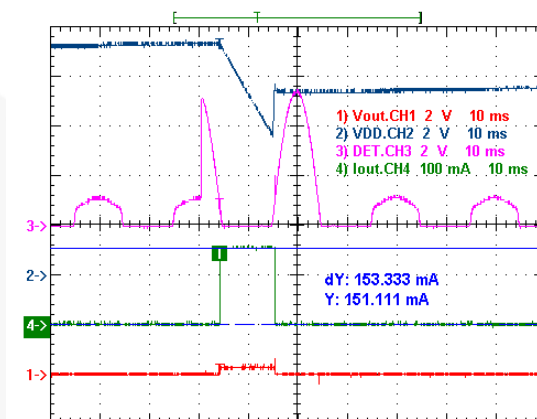


Figure 6. Current Limit

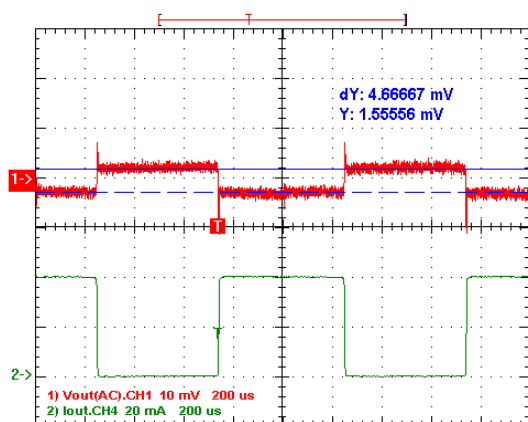


Figure 7. Load Transient

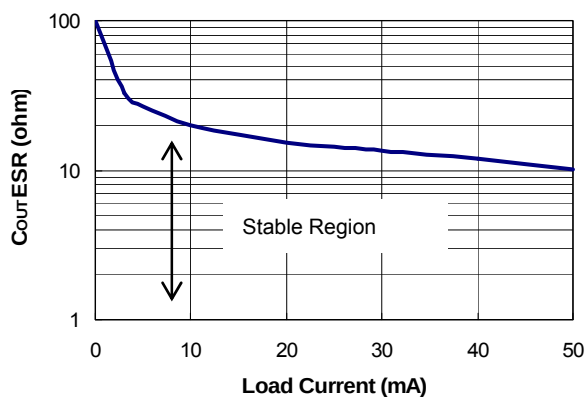


Figure 8. Region of Stable  $C_{OUT}$  ESR vs. Load Current

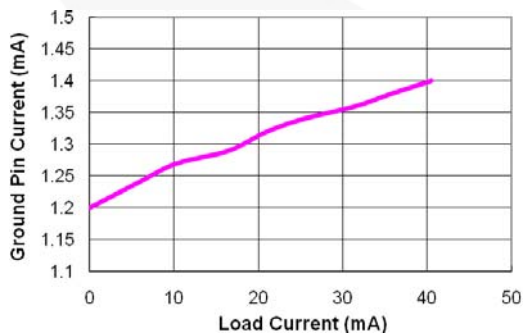


Figure 9. Ground Pin Current vs. Load Current

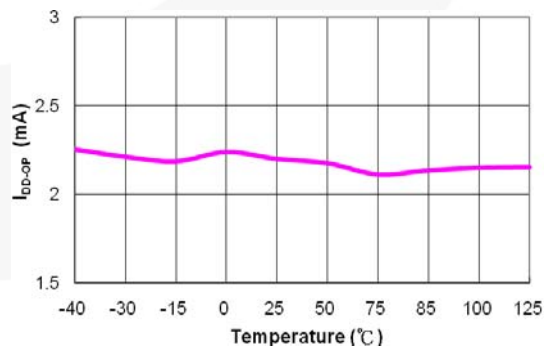


Figure 10. Operating Supply Current vs. Temperature

# Typical Performance Characteristics (Continued)

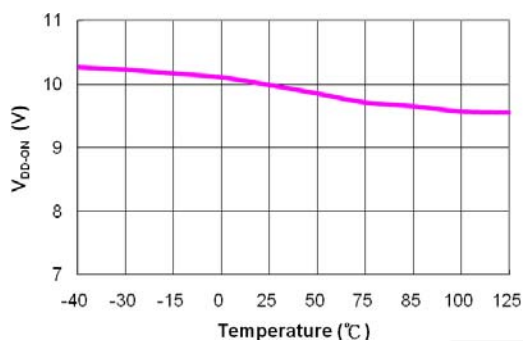


Figure 11. Turn-On Threshold Voltage vs. Temperature

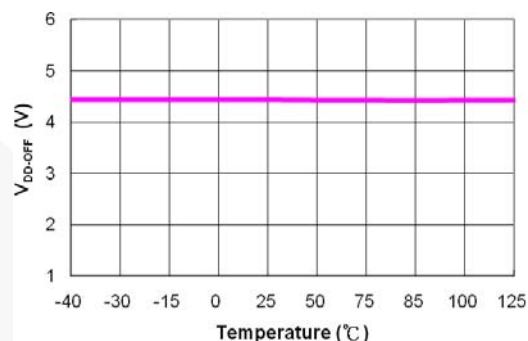


Figure 12. Turn-Off Threshold Voltage vs. Temperature

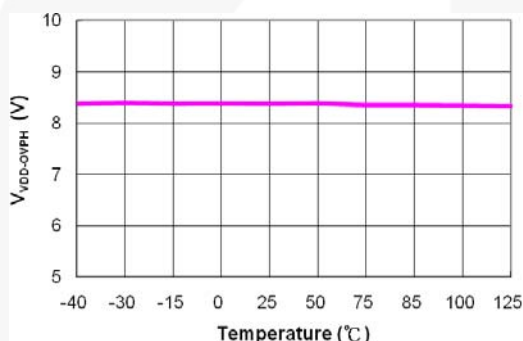


Figure 13. Threshold of V<sub>DD</sub> OVP HIGH vs. Temperature

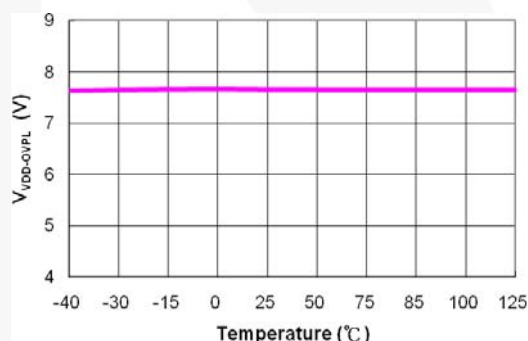


Figure 14. Threshold of V<sub>DD</sub> OVP LOW vs. Temperature

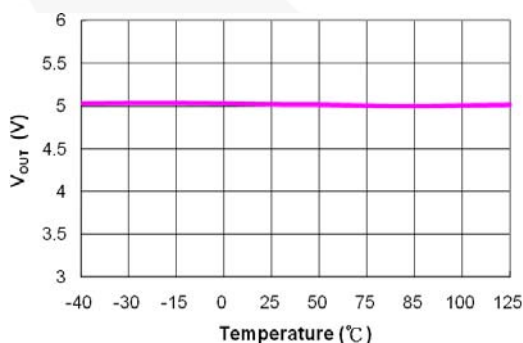


Figure 15. Output Voltage vs. Temperature

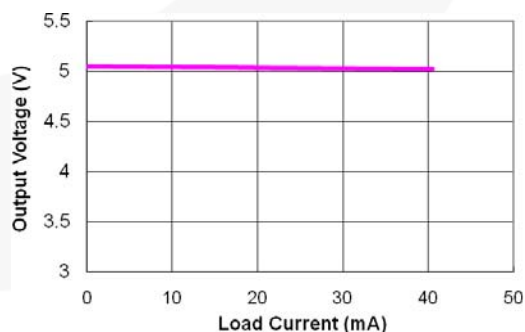


Figure 16. Output Voltage vs. Output Load

## Functional Description

The FSAR001 is a compact, inductor-free, and highly monolithic AC/DC linear converter housed in 8-lead DIP packages and designed for non-isolated AC/DC converter and home appliances. The FSAR001 provides universal AC voltage input from  $80V_{RMS}$  to  $265V_{RMS}$  and fixed-DC output voltage with current limiter for the non-isolated AC/DC converter operating safety and stability. The FSAR001 integrates many protection functions, including output current limiter ( $I_{LIMIT}$ ), output under-voltage protection (UVP), over-temperature protector (OTP),  $V_{DD}$  over-voltage protection (OVP), and AC synchronous signal detect function ( $V_{DET}$ ).

As the FSAR001 operates in a typical application, the startup current flows through the startup pin ( $V_{ST}$ ) and charges  $V_{DD}$  capacitor. When the voltage of  $V_{DD}$  is larger than  $V_{TH\_ON}$ , the FSAR001 is turned on. After one AC synchronous signal, the LDO is turned on and creates output voltage ( $V_{OUT}$ ). At steady state, the energy of  $V_{DD}$  capacitor decreases because of the chip operation and load power dissipation. The behavior is shown in Figure 17 and the energy is recharged during conduction angle interval (settled by R3 and R4) and under OVP function limitation ( $V_{DD-OVPH}$ ). With a view to increasing LDO efficiency and system stability, FSAR001 sets the  $V_{DD}$  OVP voltage at 8.5V for 5V LDO regulator. The  $V_{DD}$  capacitor recovery angle controls below  $50V_{RMS}$  settled by AC synchronous signal (DET sense voltage), detailed in the following sections.

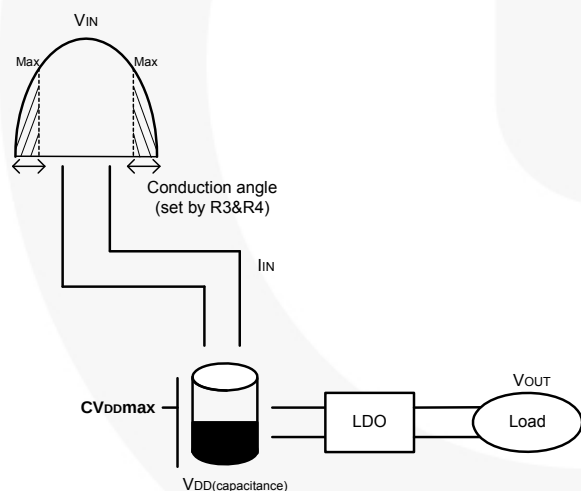


Figure 17. Operating Principle

### Startup Current

During FSAR001 startup, the startup current through the rectifier and  $V_{ST}$  pin charges the  $V_{DD}$  capacitor with maximum start current of  $V_{ST}$  pin of 3.75mA and the synchronous current controlled by R3 (1M $\Omega$ ) and R4 (13k $\Omega$ ), shown in Figure 1. The FSAR001 remains off until the  $V_{DD}$  voltage is larger than  $V_{TH\_ON}$  and the output voltage is created at the same time. After the FSAR001 turns on, the  $V_{ST}$  function is disabled by the control loop. The major energy path changes from  $V_{ST}$  pin from the inner power MOSFET MV ( $V_{IN}$ ).

### OUT Pin Under-Voltage Protection

When the output power is larger than the maximum handling power of FSAR001, the condition causes the output voltage to drop. Until the output voltage is less than output nominal voltage -12% ( $5V - 0.625V = 4.375V$ ), the UVP function disables the LDO stage and waits until the next AC synchronous signal to restart the FSAR001 automatically.

### Current Limit

The FSAR001 includes a current limiter ( $I_{LIMIT}$ ) for safe LDO operation. The limiter monitors the loading current and directly controls the output delivery current of LDO. The typical limited current set is 140mA to avoid the output shorted to ground for an indefinite amount of time without damaging the part. At over-current operation, the  $I_{LIMIT}$  function limits the maximum output current and causes the unregulated output voltage to drop until the UVP function occurs.

### Over-Temperature Protection

The FSAR001 operates in highly converting ratio. The thermal energy of FSAR001 is generated by the inner converting power of the MOSFET. When the junction temperature ( $T_J$ ) exceeds 150°C, the OTP function disables LDO stage and waits for the next AC synchronous signal to restart. The over-temperature hysteresis range is 40°C. After startup, the OTP function monitors the junction temperature. When junction temperature decreases to the ( $T_{OTP-THYS}$ ), the OTP function enables the signal and allows LDO turn on. If not, OTP function keeps the output function disabled and continuously monitors the junction temperature. The OTP function is designed to protect against abnormal conditions and over-power operation.

### DET Pin Selection

The DET pin connects to the commutated AC bus. It sinks commutated AC voltage waveform used to provide the AC synchronous signal and to set the  $V_{DD}$  capacitor recovery conduction angle. For synchronous signal function, the AC synchronous signal used to enable output voltage of the LDO and to trigger the output stage protection with UVP and OTP. To limit the recovery-conduction angle of the  $V_{DD}$  capacitor, the DET pin sense voltage ( $V_{DET}$ ) is set between 0.14V ~0.95V. During the sense-voltage range of the DET pin, the  $V_{DD}$  capacitor can be charged by the power MOSFET until the OVP function is operating in every synchronous cycle. As shown in Figure 18, the DET pin sense voltage limits the charge time of  $t_0 \sim t_1$  and  $t_2 \sim t_3/2$  settled by R3 and R4. The maximum commutated input voltage of FSAR001 can be determined by the following equation with the maximum DET sense voltage defined:



## Functional Description (Continued)

$$V_{DET,max} = \frac{R4}{R3+R4} \times V_{ac}$$

$$V_{DET,min} = \frac{R4}{R3+R4} \times V_{ac}$$

EQ 1

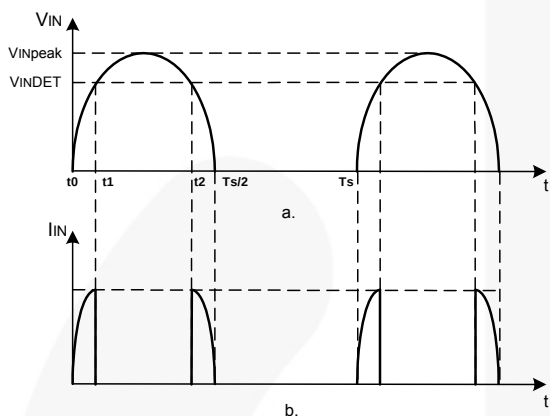


Figure 18. Typical Waveforms

## VDD Pin Over-Voltage Protection

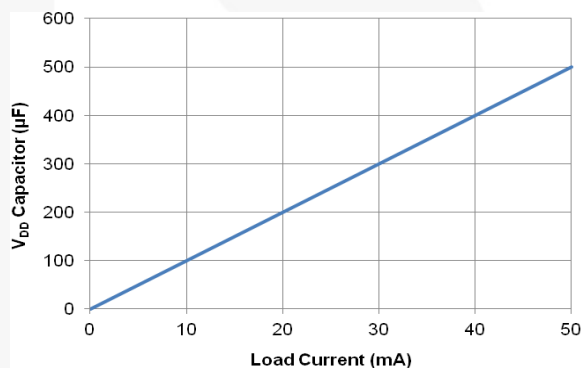
After startup, FSAR001 turns on the OVP function. During conduction angle interval, the  $V_{DD}$  voltage has two kinds of behavior. One is that if the  $V_{DD}$  capacitor recharges to OVP trigger point (8.5V for 5V version), the FSAR001 turns off the power MOSFET to limit the maximum  $V_{DD}$  voltage. The other is that if the voltage of  $V_{DD}$  cannot recharge to the OVP level during the conduction interval, the power MOSFET is turned off by AC synchronous signal and continuously recharges  $V_{DD}$  capacitor at next duration. Using this technique, energy is drawn from the AC mains only during the low-voltage portions of each positive half cycle, reducing the

dissipation in the first stage. During the power MOSFET turn-on, the current provided by the commutated AC voltage is used to supply the loads and to charge the  $V_{DD}$  capacitor. In this way, when the power MOSFET switches off, the loads receive the required currents by the capacitor discharge. For this reason, it is important to properly set the conduction angle.

For the  $V_{DD}$  capacitor selection, during conduction angle interval; the energy is drawn from commutated AC bus, which not only provides the output requirement but also recharges the  $V_{DD}$  capacitor to OVP level. Outside of conduction angle, the  $V_{DD}$  capacitor supplies the whole system requirement. The  $V_{DD}$  capacitor can be reduced by maximum loading power. The capacitor is evaluated by Equation 2; the selection chart is shown in Figure 19.

$$C_{VDD} = \frac{I_{LOAD} \times 10m}{1}, (unit = F)$$

EQ 2

Figure 19.  $V_{DD}$  Capacitor vs. Output Current

## Applications Information

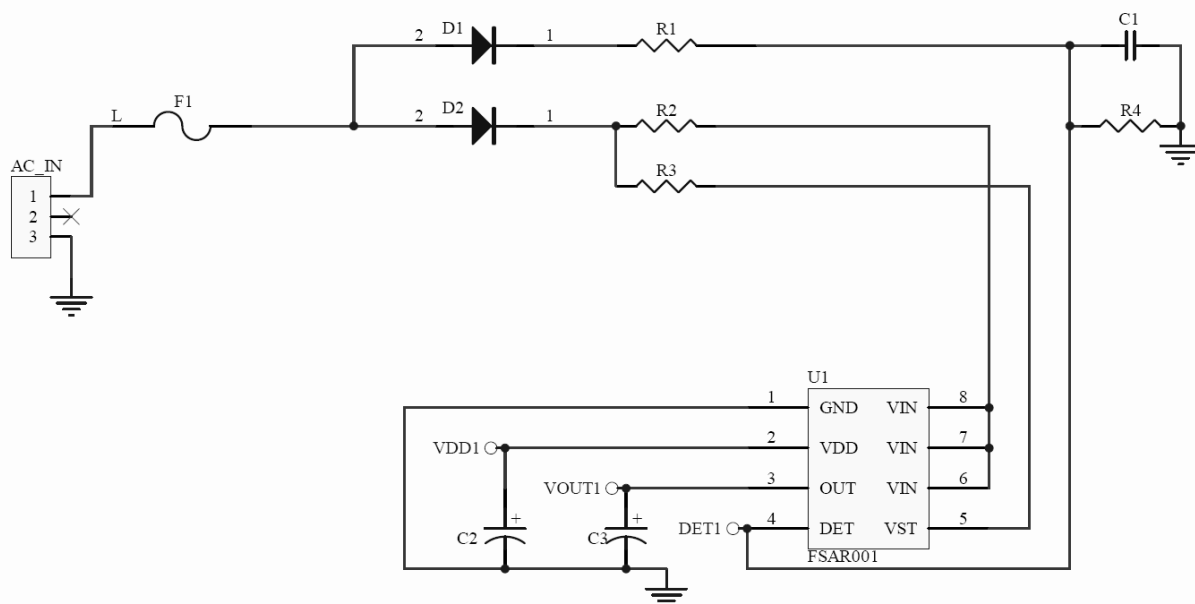


Figure 20. Application Circuit

## Bill of Materials (BOM)

| Designator | Part Type       | Designator | Part Type         |
|------------|-----------------|------------|-------------------|
| F1         | FUSE 3A/250V    | D2         | 1N4007            |
| C1         | 1nF/50V         | R1         | 1M $\Omega$ 1/4W  |
| C2         | 470 $\mu$ F/25V | R2         | 10 $\Omega$ 2W    |
| C3         | 10 $\mu$ F/50V  | R3         | 1K $\Omega$ 1/2W  |
| D1         | 1N4007          | R4         | 13K $\Omega$ 1/4W |

## Physical Dimensions

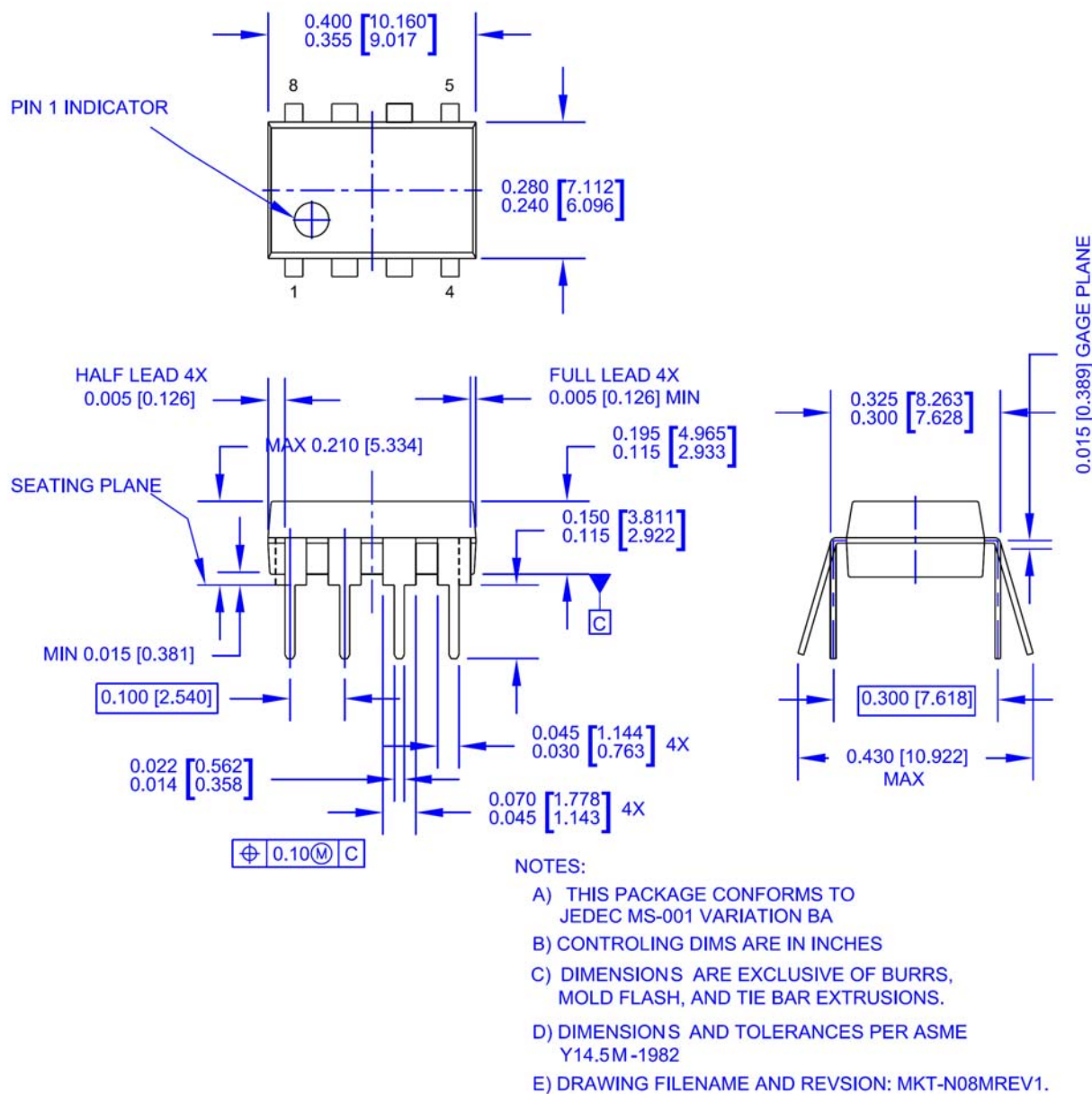


Figure 21. 8-Pin, DIP-8 Package

Package drawings are provided as a service to customers considering Fairchild components. Drawings may change in any manner without notice. Please note the revision and/or date on the drawing and contact a Fairchild Semiconductor representative to verify or obtain the most recent revision. Package specifications do not expand the terms of Fairchild's worldwide terms and conditions, specifically the warranty therein, which covers Fairchild products.

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|-----------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| 2Cool™                                                                            | F-PFS™                                         | PowerTrench®                                                                      | The Power Franchise®                                                                |
| AccuPower™                                                                        | FRFET®                                         | PowerXS™                                                                          | the power franchise                                                                 |
| AX-CAP™*                                                                          | Global Power Resource™                         | Programmable Active Droop™                                                        | TinyBoost™                                                                          |
| BitSiC™                                                                           | GreenBridge™                                   | QFET®                                                                             | TinyBuck™                                                                           |
| Build it Now™                                                                     | Green FPS™                                     | QS™                                                                               | TinyCalc™                                                                           |
| CorePLUS™                                                                         | Green FPS™ e-Series™                           | Quiet Series™                                                                     | TinyLogic®                                                                          |
| CorePOWER™                                                                        | Gmax™                                          | RapidConfigure™                                                                   | TINYOPTO™                                                                           |
| CROSSVOLT™                                                                        | GTO™                                           |  | TinyPower™                                                                          |
| CTL™                                                                              | IntelliMAX™                                    | Saving our world, 1mW/W at a time™                                                | TinyPWM™                                                                            |
| Current Transfer Logic™                                                           | ISOPLANAR™                                     | SignalWise™                                                                       | TinyWire™                                                                           |
| DEUXPEED®                                                                         | Making Small Speakers Sound Louder and Better™ | SmartMax™                                                                         | TranSiC™                                                                            |
| Dual Cool™                                                                        | MegaBuck™                                      | SMART START™                                                                      | TriFault Detect™                                                                    |
| EcoSPARK®                                                                         | MICROCOUPLER™                                  | Solutions for Your Success™                                                       | TRUECURRENT®*                                                                       |
| EfficientMax™                                                                     | MicroFET™                                      | SPM®                                                                              | µSerDes™                                                                            |
| ESBC™                                                                             | MicroPak™                                      | STEALTH™                                                                          |  |
|  | MicroPak2™                                     | SuperFET®                                                                         | UHC®                                                                                |
| Fairchild®                                                                        | MillerDrive™                                   | SuperSOT™-3                                                                       | Ultra FRFET™                                                                        |
| Fairchild Semiconductor®                                                          | MotionMax™                                     | SuperSOT™-6                                                                       | UniFET™                                                                             |
| FACT Quiet Series™                                                                | Motion-SPM™                                    | SuperSOT™-8                                                                       | VCX™                                                                                |
| FACT®                                                                             | mWSaver™                                       | SupreMOS®                                                                         | VisualMax™                                                                          |
| FAST®                                                                             | OptoHiT™                                       | SyncFET™                                                                          | VoltagePlus™                                                                        |
| FastvCore™                                                                        | OPTOLOGIC®                                     | Sync-Lock™                                                                        | XS™                                                                                 |
| FETBench™                                                                         | OPTOPLANAR®                                    |  |                                                                                     |
| FlashWriter®*                                                                     |                                                |                                                                                   |                                                                                     |
| FPS™                                                                              |                                                |                                                                                   |                                                                                     |

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## PRODUCT STATUS DEFINITIONS

### Definition of Terms

| Datasheet Identification | Product Status        | Definition                                                                                                                                                                                          |
|--------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Advance Information      | Formative / In Design | Datasheet contains the design specifications for product development. Specifications may change in any manner without notice.                                                                       |
| Preliminary              | First Production      | Datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design. |
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