

# FAN6961

## Boundary Mode PFC Controller

### Features

- Boundary Mode PFC Controller
- Low Input Current THD
- Controlled On-Time PWM
- Zero-Current Detection
- Cycle-by-Cycle Current Limiting
- Leading-Edge Blanking instead of RC Filtering
- Low Start-up Current: 10µA Typical
- Low Operating Current: 4.5mA Typical
- Feedback Open-Loop Protection
- Programmable Maximum On-Time (MOT)
- Output Over-Voltage Clamping Protection
- Clamped Gate Output Voltage 16.5V


### Applications


- Electric Lamp Ballasts
- AC-DC Switching Mode Power Converter
- Open Frame Power Supplies and Power Adapters
- Flyback Power Converters with ZCS / ZVS

### Description

The FAN6961 is an 8-pin, boundary-mode, PFC controller IC intended for controlling PFC pre-regulators. The FAN6961 provides a controlled on-time to regulate the output DC voltage and achieve natural power factor correction. The maximum on-time of the external switch is programmable to ensure safe operation during AC brownouts. An innovative multi-vector error amplifier is built in to provide rapid transient response and precise output voltage clamping. A built-in circuit disables the controller if the output feedback loop is opened. The start-up current is lower than 20µA and the operating current has been reduced to under 6mA. The supply voltage can be up to 25V, maximizing application flexibility.

### Ordering Information

| Part Number | Operating Temperature Range | Package                            |  Eco Status | Packing Method |
|-------------|-----------------------------|------------------------------------|--|----------------|
| FAN6961SZ   | -40°C to +125°C             | 8-Pin, Small Outline Package (SOP) | RoHS   | Tape & Reel    |
| FAN6961DZ   | -40°C to +125°C             | 8-Pin, Dual In-line Package (DIP)  | RoHS   | Tube           |
| FAN6961SY   | -40°C to +125°C             | 8-Pin, Small Outline Package (SOP) | Green  | Tape & Reel    |

 For Fairchild's definition of "green" Eco Status, please visit: [http://www.fairchildsemi.com/company/green/rohs\\_green.html](http://www.fairchildsemi.com/company/green/rohs_green.html).

### Application Diagram

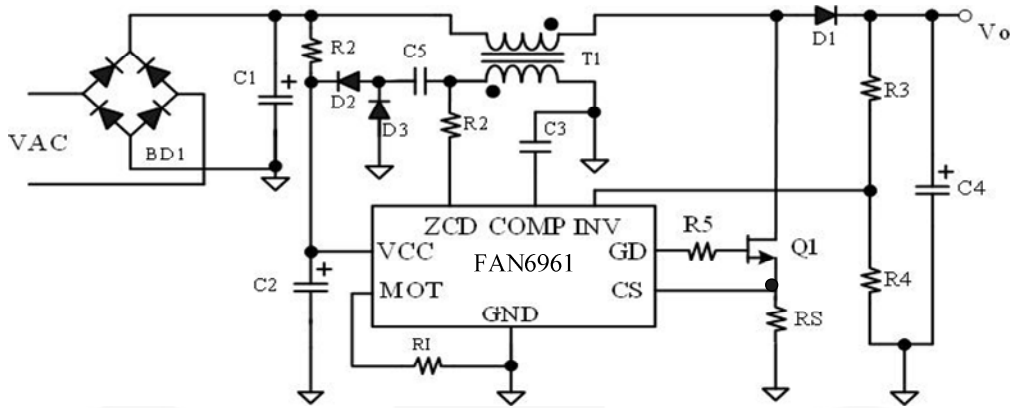


Figure 1. Typical Application

### Block Diagram

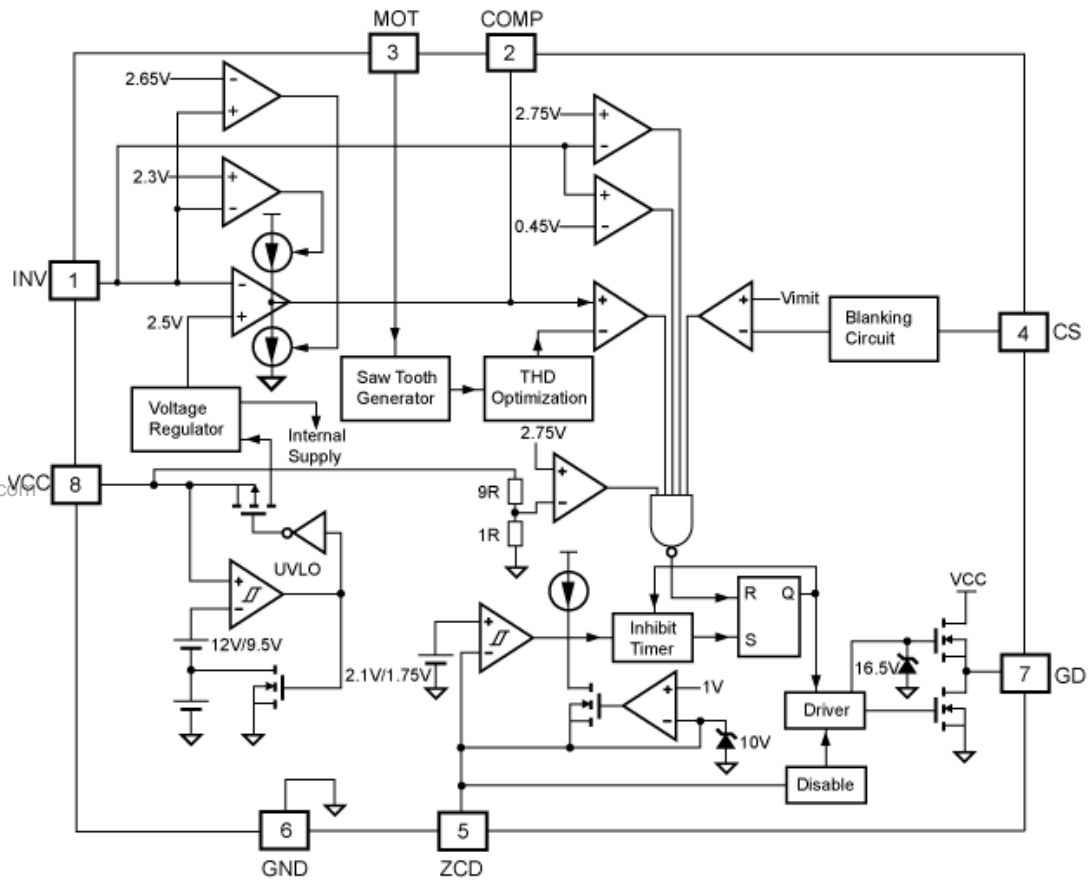
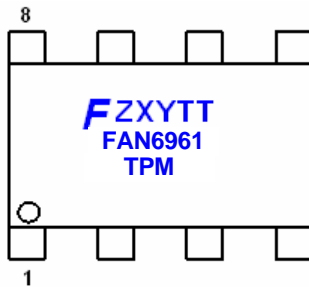


Figure 2. Function Block Diagram

## Marking Information



F- Fairchild Logo  
 Z- Plant Code  
 X- Year Code  
 Y- Week Code  
 TT: Die Run Code  
 T: Package type (S=SOP, D=DIP)  
 P: Z: Pb Free      Y: Green Compound  
 M: Manufacture Flow Code

Figure 3. Marking Information

## Pin Configuration

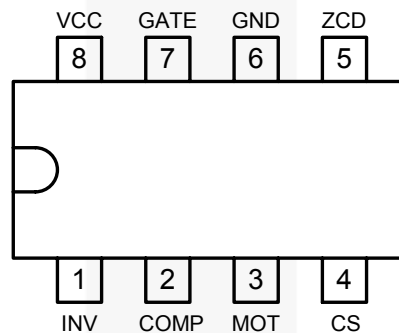


Figure 4. DIP and SOP Pin Configuration (Top View)

## Pin Definitions

| Pin # | Name | Description   |
|-------|------|---|
| 1     | INV  | <b>Inverting input of the error amplifier.</b> INV is connected to the converter output via a resistive divider. This pin is also used for over-voltage clamping and open-loop feedback protection.   |
| 2     | COMP | <b>The output of the error amplifier.</b> To create a precise clamping protection, a compensation network between this pin and GND is suggested.  |
| 3     | MOT  | <b>Maximum On Time</b> A resistor from MOT to GND is used to determine the maximum on-time of the external power MOSFET. The maximum output power of the converter is a function of the maximum on time.  |
| 4     | CS   | <b>Current Sense.</b> Input to the over-current protection comparator. When the sensed voltage across the sense resistor reaches the internal threshold (0.8V), the switch is turned off to activate cycle-by-cycle current limiting.                                   |
| 5     | ZCD  | <b>Zero Current Detection.</b> This pin is connected to an auxiliary winding via a resistor to detect the zero crossing of the switch current. When the zero crossing is detected, a new switching cycle is started. If it is connected to GND, the device is disabled. |
| 6     | GND  | <b>Ground.</b> The power ground and signal ground. Placing a 0.1µF decoupling capacitor between VCC and GND is recommended.   |
| 7     | GATE | <b>Driver output.</b> Totem-pole driver output to drive the external power MOSFET. The clamped gate output voltage is 16.5V.  |
| 8     | VCC  | <b>Power supply.</b> Driver and control circuit supply voltage.   |

## 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. All voltage values, except differential voltage, are given with respect to GND pin.

| Symbol            | Parameter   | Min. | Max. | Unit |
|-------------------|---|------|------|------|
| V <sub>VCC</sub>  | DC Supply Voltage                                   |      | 30   | V    |
| V <sub>HIGH</sub> | Gate Driver   | -0.3 | 30.0 | V    |
| V <sub>LOW</sub>  | Others (INV, COMP, MOT, CS)                         | -0.3 | 7.0  | V    |
| V <sub>ZCD</sub>  | Input Voltage to ZCD Pin                            | -0.3 | 12.0 | V    |
| P <sub>D</sub>    | Power Dissipation                                   | SOP  | 400  | mW   |
|                   |   | DIP  | 800  |      |
| T <sub>J</sub>    | Operating Junction Temperature                      | -40  | +125 | °C   |
| θ <sub>JA</sub>   | Thermal Resistance (Junction-to-Air)                | SOP  | 150  | °C/W |
|                   |   | DIP  | 113  |      |
| T <sub>STG</sub>  | Storage Temperature Range                           | -65  | +150 | °C   |
| T <sub>L</sub>    | Lead Temperature (Wave Soldering or IR, 10 Seconds) | SOP  | +230 | °C   |
|                   |   | DIP  | +260 |      |
| ESD               | Human Body Model: JESD22-A114                       |      | 2.5  | KV   |
|                   | Machine Model: JESD22-A115                          |      | 200  | V    |

## Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance to the datasheet specifications. Fairchild does not recommend exceeding them or designing to Absolute Maximum Ratings.

| Symbol         | Parameter                     | Min. | Typ. | Max. | Unit |
|----------------|-------------------------------|------|------|------|------|
| T <sub>A</sub> | Operating Ambient Temperature | -40  |      | +125 | °C   |

## Electrical Characteristics

$V_{CC}=15V$  and  $T_A=25^{\circ}C$  unless otherwise noted.

| Symbol                         | Parameter   | Conditions                                     | Min.  | Typ.  | Max.  | Units |
|--------------------------------|---|--|-------|-------|-------|-------|
| <b>V<sub>CC</sub> Section</b>  |   |  |       |       |       |       |
| V <sub>CC-OP</sub>             | Continuous Operation Voltage                                  |  |       |       | 24.5  | V     |
| V <sub>CC-ON</sub>             | Turn-on Threshold Voltage                                     |  | 11    | 12    | 13    | V     |
| V <sub>CC-OFF</sub>            | Turn-off Threshold Voltage                                    |  | 8.5   | 9.5   | 10.5  | V     |
| I <sub>CC-ST</sub>             | Start-up Current  | $V_{CC}=V_{CC-ON} - 0.16V$                     |       | 10    | 20    | μA    |
| I <sub>CC-OP</sub>             | Operating Supply Current                                      | $V_{CC}=12V, V_{CS}=0V, C_L=3nF, f_{SW}=60KHz$ |       | 4.5   | 6     | mA    |
| V <sub>CC-OVP</sub>            | V <sub>DD</sub> Over-Voltage Protection Level                 |  | 26.5  | 27.5  | 28.5  | V     |
| t <sub>D-VCCOVP</sub>          | V <sub>DD</sub> Over-Voltage Protection Debounce              |  |       | 30    |       | μs    |
| <b>Error Amplifier Section</b> |   |  |       |       |       |       |
| V <sub>REF</sub>               | Reference Voltage   |  | 2.475 | 2.500 | 2.525 | V     |
| G <sub>m</sub>                 | Transconductance  |  |       | 125   |       | μmho  |
| V <sub>INVH</sub>              | Clamp High Feedback Voltage                                   |  |       | 2.65  | 2.70  | V     |
| V <sub>INVL</sub>              | Clamp Low Feedback Voltage                                    |  | 2.25  | 2.30  |       | V     |
| V <sub>OUT HIGH</sub>          | Output High Voltage   |  | 4.8   |       |       | V     |
| V <sub>oZ</sub>                | Zero Duty Cycle Output Voltage                                |  | 1.15  | 1.25  | 1.35  | V     |
| V <sub>INV-OVP</sub>           | Over Voltage Protection for INV Input                         |  | 2.70  | 2.75  | 2.80  | V     |
| V <sub>INV-UVP</sub>           | Under Voltage Protection for INV Input                        |  | 0.40  | 0.45  | 0.50  | V     |
| I <sub>COMP</sub>              | Source Current  | $V_{INV}=2.35V, V_{COMP}=1.5V$                 | 10    | 20    |       | μA    |
|                                |   | $V_{INV}=1.5V,$                                | 550   | 800   |       |       |
|                                | Sink Current  | $V_{INV}=2.65V, V_{COMP}=5V$                   | 10    | 20    |       |       |
| <b>Current-Sense Section</b>   |   |  |       |       |       |       |
| V <sub>PK</sub>                | Threshold Voltage for Peak Current Limit Cycle-by-Cycle Limit |  | 0.77  | 0.82  | 0.87  | V     |
| t <sub>PD</sub>                | Propagation Delay   |  |       |       | 200   | ns    |
| t <sub>LEB</sub>               | Leading-Edge Blanking Time                                    | $R_{MOT}=24k\Omega, V_{COMP}=5V$               |       | 400   | 500   | ns    |
|                                |   | $R_{MOT}=24k\Omega, V_{COMP}=V_{oZ}+50mV$      |       | 270   | 350   |       |
| <b>Gate Section</b>            |   |  |       |       |       |       |
| V <sub>Z-OUT</sub>             | Output Voltage Maximum (Clamp)                                | $V_{CC}=25V$                                   | 15.0  | 16.5  | 18.0  | V     |
| V <sub>OL</sub>                | Output Voltage Low  | $V_{CC}=15V, I_O=100mA$                        |       |       | 1.4   | V     |
| V <sub>OH</sub>                | Output Voltage High   | $V_{CC}=14V, I_O=100mA$                        | 8     |       |       | V     |
| t <sub>R</sub>                 | Rising Time   | $V_{CC}=12V, C_L=3nF, 20\sim 80\%$             |       | 80    |       | ns    |
| t <sub>F</sub>                 | Falling Time  | $V_{CC}=12V, C_L=3nF, 80\sim 20\%$             |       | 40    |       | ns    |

Continued on the following page...

## Electrical Characteristics

$V_{CC}=15V$  and  $T_A=25^{\circ}C$  unless otherwise noted.

| Symbol                                | Parameter  | Conditions   | Min. | Typ. | Max. | Units   |
|---------------------------------------|--|--|------|------|------|---------|
| <b>Zero Current Detection Section</b> |  |  |      |      |      |         |
| $V_{ZCD}$                             | Input Threshold Voltage Rising Edge              | $V_{ZCD}$ Increasing                                 | 1.9  | 2.1  | 2.3  | V       |
| $H_{YS}$ of $V_{ZCD}$                 | Threshold Voltage Hysteresis                     | $V_{ZCD}$ Decreasing                                 |      | 0.35 |      | V       |
| $V_{ZCD-HIGH}$                        | Upper Clamp Voltage                              | $I_{ZCD}=3mA$  |      |      | 12   | V       |
| $V_{ZCD-LOW}$                         | Lower Clamp Voltage                              | $I_{ZCD}=-1.5mA$                                     | 0.3  |      |      | V       |
| $t_{DEAD}$                            | Maximum Delay, ZCD to Output Turn-On             | $V_{COMP}=5V$ ,<br>$f_{SW}=60KHz$                    | 100  |      | 400  | ns      |
| $t_{RESTART}$                         | Restart Time                                     | Output Turned Off by ZCD                             | 300  | 500  | 700  | $\mu s$ |
| $t_{INHIB}$                           | Inhibit Time (Maximum Switching Frequency Limit) | $R_{MOT}=24k\Omega$                                  |      | 2.8  |      | $\mu s$ |
| $V_{DIS}$                             | Disable Threshold Voltage                        |  | 150  | 200  | 250  | mV      |
| $t_{ZCD-DIS}$                         | Disable Function Debounce Time                   | $R_{MOT}=24k\Omega$ ,<br>$V_{ZCD}=100mV$             | 800  |      |      | $\mu s$ |
| <b>Maximum On Time Section</b>        |  |  |      |      |      |         |
| $V_{MOT}$                             | Maximum On Time Voltage                          |  | 1.25 | 1.30 | 1.35 | V       |
| $t_{ON-MAX}$                          | Maximum On Time Programming (Resistor Based)     | $R_{MOT}=24k\Omega$ , $V_{CS}=0V$ ,<br>$V_{COMP}=5V$ |      | 25   |      | $\mu s$ |

### Typical Performance Characteristics

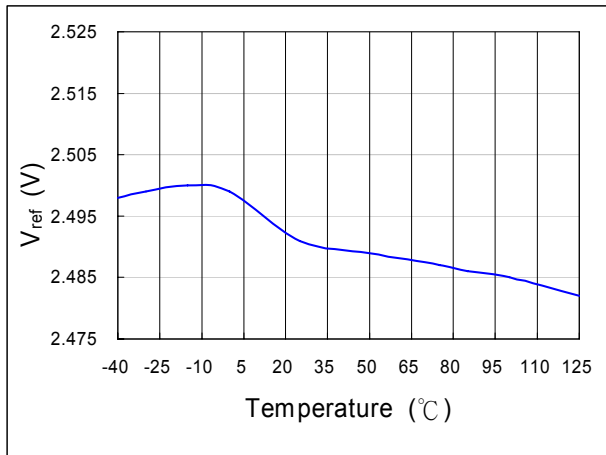


Figure 5.  $V_{REF}$  vs.  $T_A$

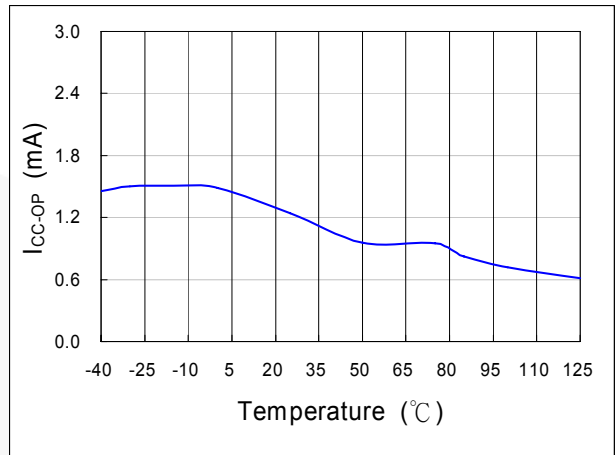


Figure 6.  $I_{CC-OP}$  vs.  $T_A$

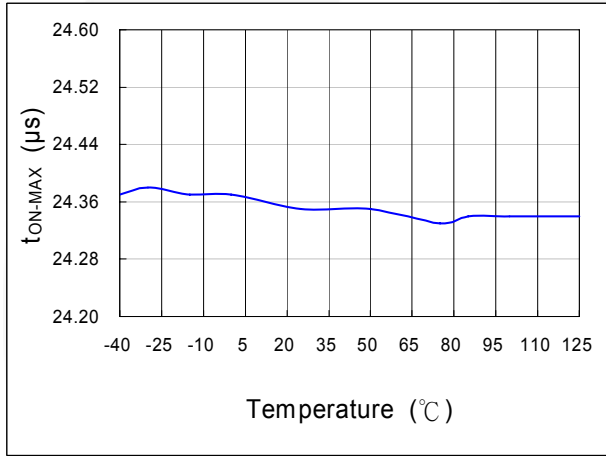


Figure 7.  $t_{ON-MAX}$  vs.  $T_A$

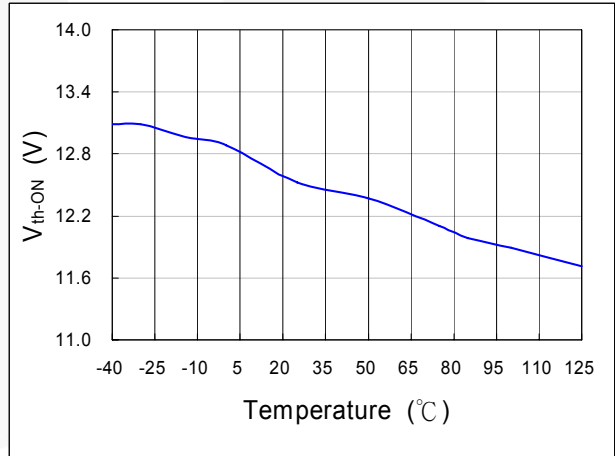


Figure 8.  $V_{th-ON}$  vs.  $T_A$

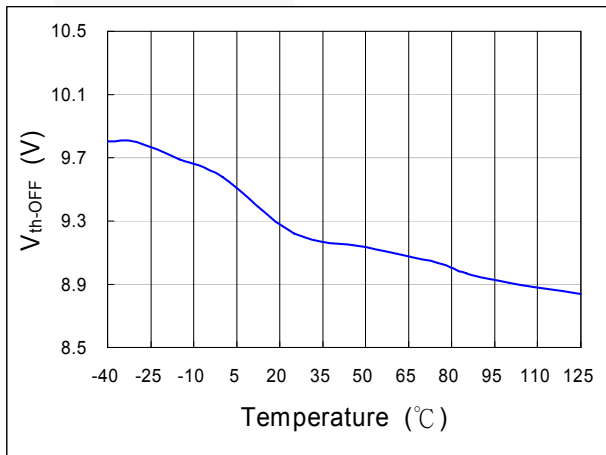


Figure 9.  $V_{th-OFF}$  vs.  $T_A$

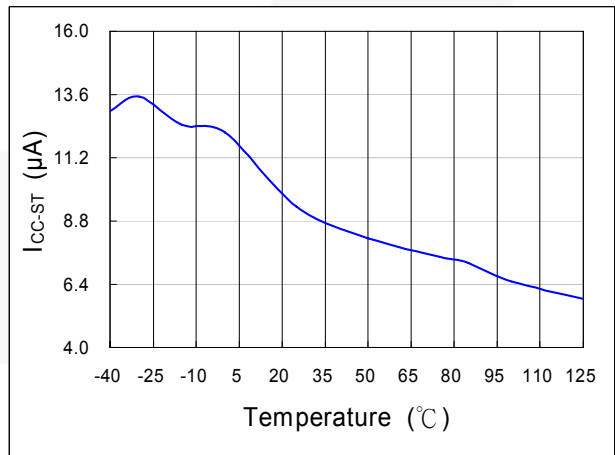


Figure 10.  $I_{CC-ST}$  vs.  $T_A$

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Typical Performance Characteristics (Continued)

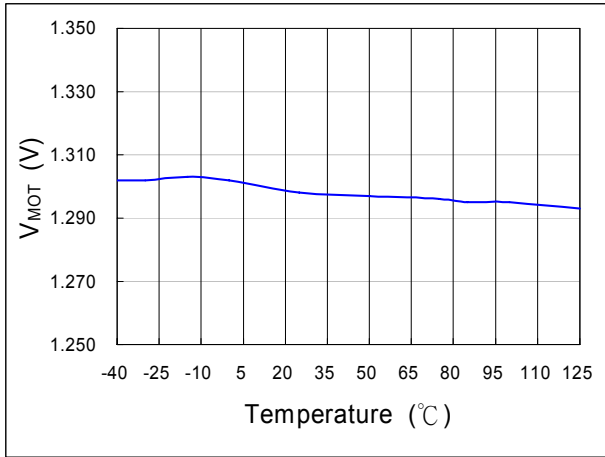


Figure 11.  $V_{MOT}$  vs.  $T_A$

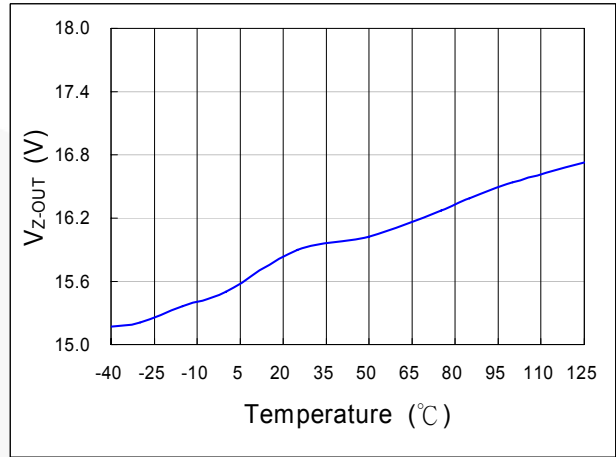


Figure 12.  $V_{Z-OUT}$  vs.  $T_A$

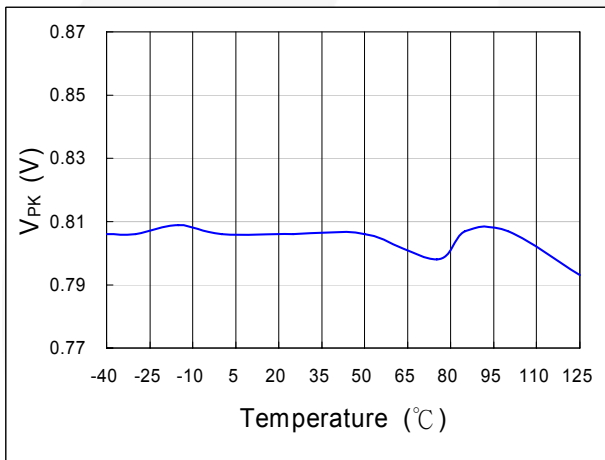


Figure 13.  $V_{PK}$  vs.  $T_A$

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## Functional Description

### Error Amplifier

The inverting input of the error amplifier is referenced to INV. The output of the error amplifier is referenced to COMP. The non-inverting input is internally connected to a fixed  $2.5V \pm 2\%$  voltage. The output of the error amplifier is used to determine the on-time of the PWM output and regulate the output voltage. To achieve a low input current THD, the variation of the on time within one input AC cycle should be very small. A multi-vector error amplifier is built in to provide fast transient response and precise output voltage clamping.

For FAN6961, connecting a capacitance, such as  $1\mu F$ , between COMP and GND is suggested. The error amplifier is a trans-conductance amplifier that converts voltage to current with a  $125\mu mho$ .

### Startup Current

Typical startup current is less than  $20\mu A$ . This ultra-low startup current allows the usage of high resistance, low-wattage start-up resistor. For example,  $1M\Omega/0.25W$  startup resistor and a  $10\mu F/25V$  ( $V_{CC}$  hold-up) capacitor are recommended for an AC-to-DC power adaptor with a wide input range  $85-265V_{AC}$ .

### Operating Current

Operating current is typically  $4.5mA$ . The low operating current enables a better efficiency and reduces the requirement of  $V_{CC}$  hold-up capacitance.

### Maximum On-Time Operation

Given a fixed inductor value and maximum output power, the relationship between on-time and line voltage is:

$$t_{on} = \frac{2 \cdot L \cdot P_o}{V_{rms}^2 \cdot \eta} \quad (1)$$

If the line voltage is too low or the inductor value is too high,  $t_{ON}$  is too long. To avoid extra low operating frequency and achieve brownout protection, the maximum value of  $t_{ON}$  is programmable by one resistor,  $R_I$ , connected between MOT and GND. A  $24k\Omega$  resistor  $R_I$  generates corresponds to  $25\mu s$  maximum on time:

$$t_{on(max)} = R_I(k\Omega) \cdot \frac{25}{24}(\mu s) \quad (2)$$

The range of the maximum on-time is designed as  $10 \sim 50\mu s$ .

### Peak Current Limiting

The switch current is sensed by one resistor. The signal is feed into CS pin and an input terminal of a comparator. A high voltage in CS pin terminates a switching cycle immediately and cycle-by-cycle current limit is achieved. The designed threshold of the protection point is  $0.82V$ .

### Leading-Edge Blanking (LEB)

A turn-on spike on CS pin appears when the power MOSFET is switched on. At the beginning of each switching pulse, the current-limit comparator is disabled for around  $400ns$  to avoid premature termination. The gate drive output cannot be switched off during the blanking period. Conventional RC filtering is not necessary, so the propagation delay of current limit protection can be minimized.

### Under-Voltage Lockout (UVLO)

The turn-on and turn-off threshold voltage is fixed internally at  $12V/9.5V$ . This hysteresis behavior guarantees a one-shot start-up with proper start-up resistor and hold-up capacitor. With an ultra-low start-up current of  $20\mu A$ , one  $1M\Omega R_{IN}$  is sufficient for start-up under low input line voltage,  $85V_{rms}$ . Power dissipation on  $R_{IN}$  would be less than  $0.1W$  even under high line ( $V_{AC}=265V_{rms}$ ) condition.

### Output Driver

With low on resistance and high current driving capability, the output driver can drive an external capacitive load larger than  $3000pF$ . Cross conduction current has been avoided to minimize heat dissipation, improving efficiency and reliability. This output driver is internally clamped by a  $16.5V$  Zener diode.

### Zero-Current Detection (ZCD)

The zero-current detection of the inductor is achieved using its auxiliary winding. When the stored energy of the inductor is fully released to output, the voltage on ZCD goes down and a new switching cycle is enabled after a ZCD trigger. The power MOSFET is always turned on with zero inductor current such that turn-on loss and noise can be minimized. The converter works in boundary mode and peak inductor current is always exactly twice of the average current. A natural power factor correction function is achieved with the low-bandwidth, on-time modulation. An inherent maximum off time is built in to ensure proper start-up operation. This ZCD pin can be used as a synchronous input.

### Noise Immunity

Noise on the current sense or control signal can cause significant pulse-width jitter, particularly in the boundary-mode operation. Slope compensation and built-in debounce circuit can alleviate this problem. Because the FAN6961 has a single ground pin, high sink current at the output cannot be returned separately. Good high-frequency or RF layout practices should be followed. Avoiding long PCB traces and component leads, locating compensation and filter components near to the FAN6961, and increasing the power MOSFET gate resistance improve performance.

Reference Circuit

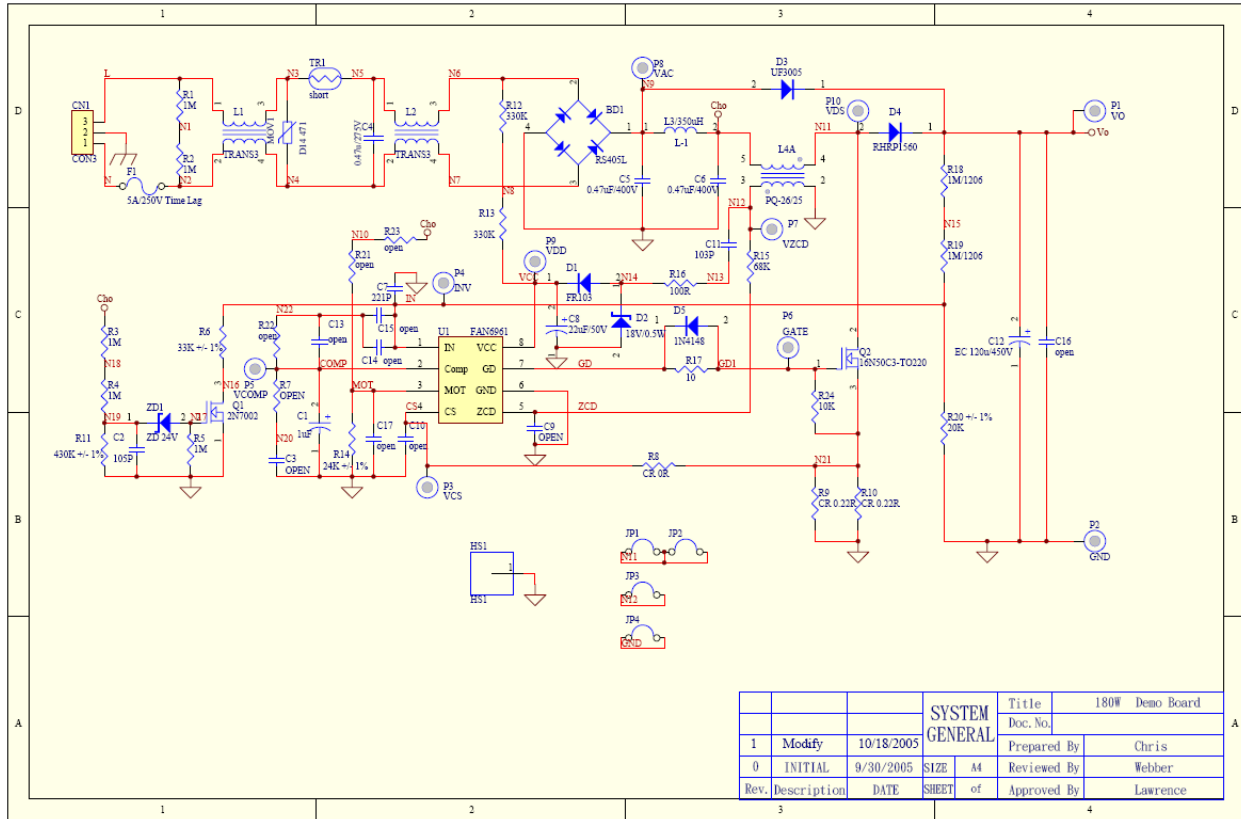
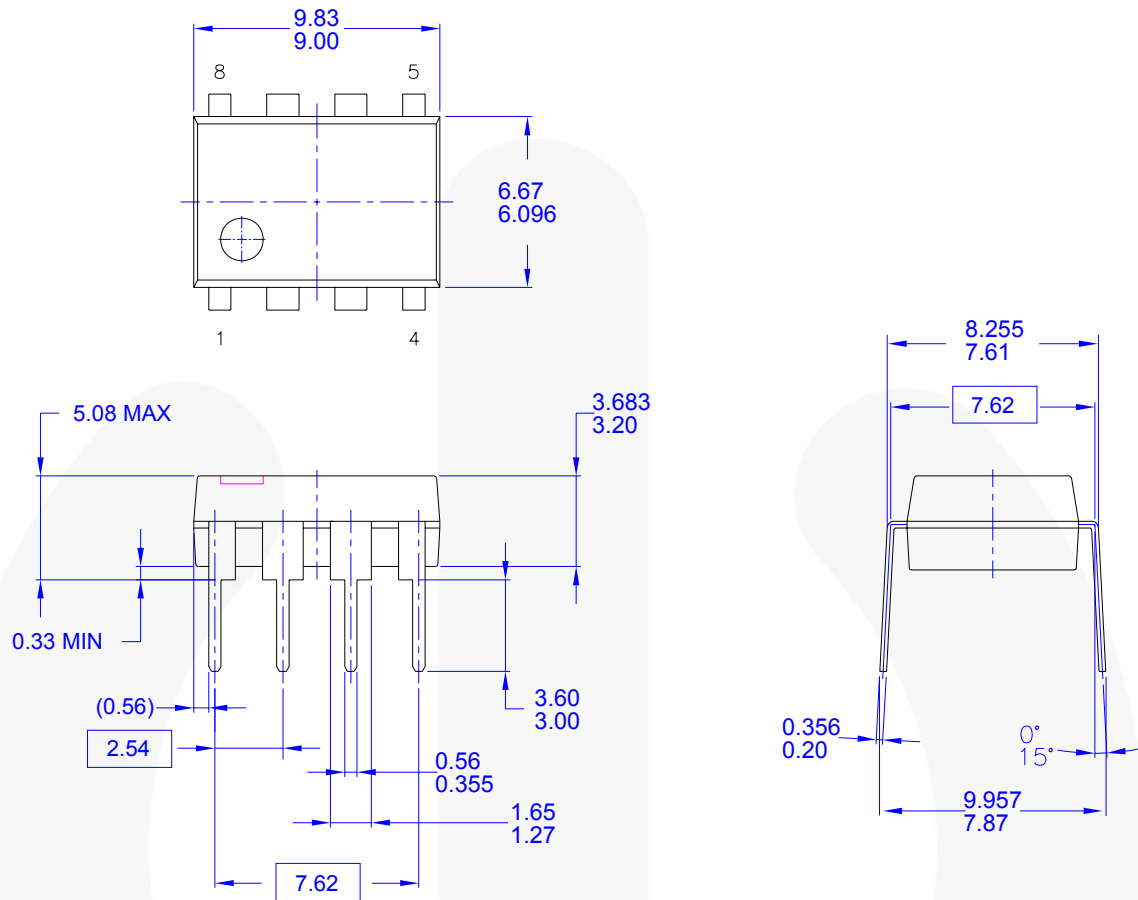


Figure 14. Reference Circuit

## Physical Dimensions



## NOTES: UNLESS OTHERWISE SPECIFIED

A) THIS PACKAGE CONFORMS TO JEDEC MS-001 VARIATION BA

B) ALL DIMENSIONS ARE IN MILLIMETERS.

C) DIMENSIONS ARE EXCLUSIVE OF BURRS, MOLD FLASH, AND TIE BAR EXTRUSIONS.

D) DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994

E) DRAWING FILENAME AND REVISION: MKT-N08FREV2.

Figure 15. 8-Lead, PDIP, JEDEC MS-001, .300 Inch Wide

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Physical Dimensions (Continued)

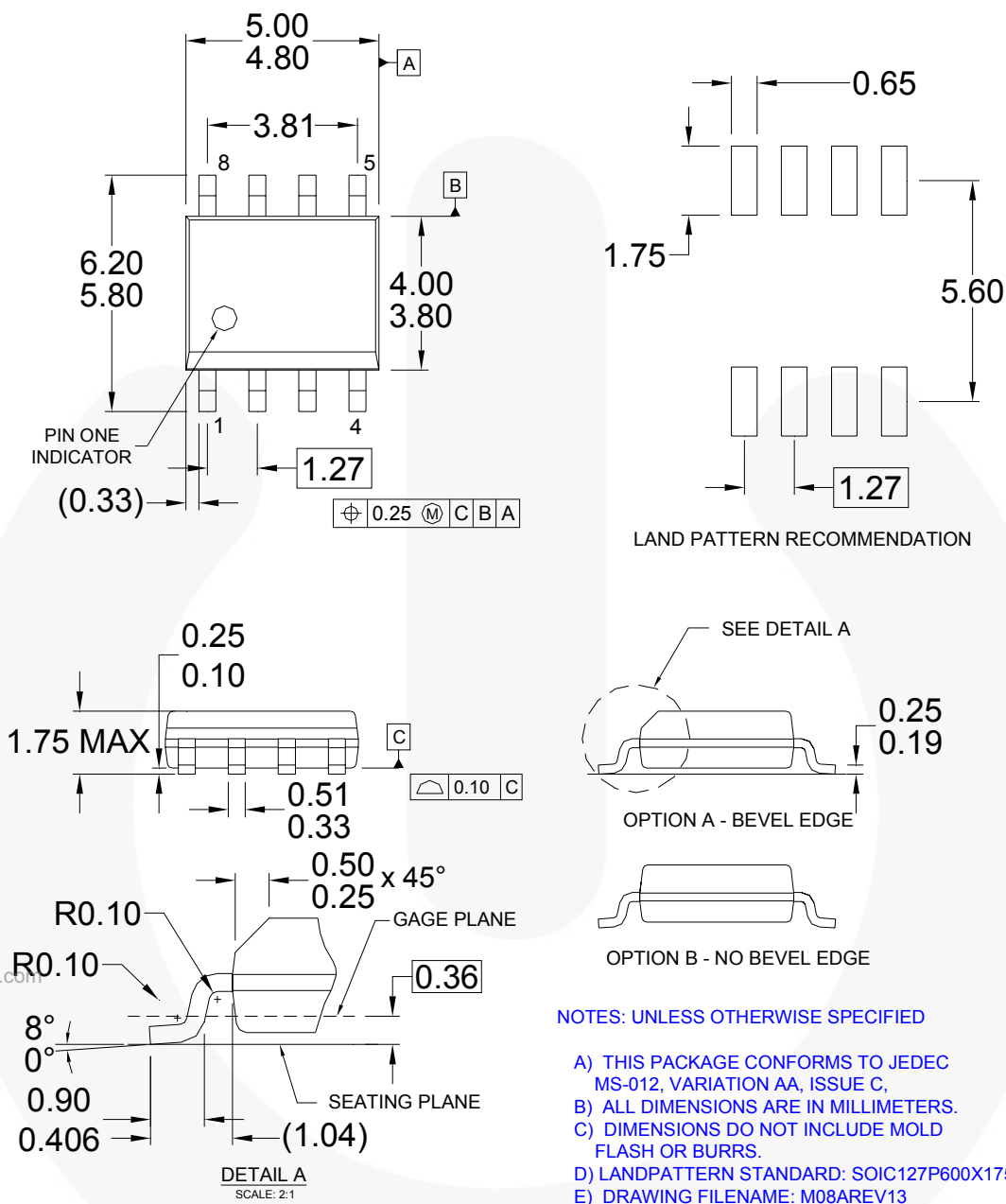


Figure 16. 8-Lead, SOIC, JEDEC MS-012, .150 Inch Narrow Body

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| CorePOWER™               | Green FPS™                          | QS™                                   |  |
| CROSSVOLT™               | Green FPS™ e-Series™                | Quiet Series™                         |  |
| CTL™                     | GTOTM                               | RapidConfigure™                       |  |
| Current Transfer Logic™  | IntelliMAX™                         | ™                                     |  |
| EcoSPARK®                | ISOPLANAR™                          | Saving our world, 1mW/Wk/W at a time™ |  |
| EfficientMax™            | MegaBuck™                           | SmartMax™                             |  |
| EZSWITCH™*               | MICROCOUPLER™                       | SMART START™                          |  |
| ™                        | MicroFET™                           | SPM®                                  |  |
| ™                        | MicroPak™                           | STEALTH™                              |  |
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| FACT®                    | OPTOLOGIC®                          | SuperSOT™.8                           |  |
| FAST®                    | OPTOPLANAR®                         | SupreMOS™                             |  |
| FastvCore™               | ™                                   | SyncFET™                              |  |
| FlashWriter®*            | PDP SPM™                            | ™                                     |  |
| FPS™                     | Power-SPM™                          | The Power Franchise®                  |  |
| F-PFS™                   | PowerTrench®                        |                                       |  |
|                          | PowerXS™                            |                                       |  |

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As used herein:

- Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body or (b) support or sustain life, and (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury of the user.
- A critical component in any component of a life support device, or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

## ANTI-COUNTERFEITING POLICY

Fairchild Semiconductor Corporation's Anti-Counterfeiting Policy. Fairchild's Anti-Counterfeiting Policy is also stated on our external website, [www.fairchildsemi.com](http://www.fairchildsemi.com), under Sales Support.

Counterfeiting of semiconductor parts is a growing problem in the industry. All manufacturers of semiconductor products are experiencing counterfeiting of their parts. Customers who inadvertently purchase counterfeit parts experience many problems such as loss of brand reputation, substandard performance, failed applications, and increased cost of production and manufacturing delays. Fairchild is taking strong measures to protect ourselves and our customers from the proliferation of counterfeit parts. Fairchild strongly encourages customers to purchase Fairchild parts either directly from Fairchild or from Authorized Fairchild Distributors who are listed by country on our web page cited above. Products customers buy either from Fairchild directly or from Authorized Fairchild Distributors are genuine parts, have full traceability, meet Fairchild's quality standards for handling and storage and provide access to Fairchild's full range of up-to-date technical and product information. Fairchild and our Authorized Distributors will stand behind all warranties and will appropriately address any warranty issues that may arise. Fairchild will not provide any warranty coverage or other assistance for parts bought from Unauthorized Sources. Fairchild is committed to combat this global problem and encourage our customers to do their part in stopping this practice by buying direct or from authorized distributors.

## 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. |
| No Identification Needed | Full Production       | Datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve the design.   |
| Obsolete                 | Not In Production     | Datasheet contains specifications on a product that is discontinued by Fairchild Semiconductor. The datasheet is for reference information only.  |

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