

# FL6961 Single-Stage Flyback and Boundary Mode PFC Controller for Lighting

Description

The FL6961 is a general lighting power controller for low- to high-power lumens applications requiring power

factor correction. It is designed for flyback or boost

The FL6961 provides a controlled on-time to regulate

the output DC voltage and achieves natural power factor

correction (PFC). The maximum on-time of the external switch is programmable to ensure safe operation during

AC brownouts. An innovative multi-vector error amplifier

provides rapid transient response and precise output voltage clamping. A built-in circuit disables the controller

if the output feedback loop is opened. The startup

current is lower than  $20\mu$ A and the operating current is less than 6mA. The supply voltage can be up to 25V.

converter operating in Boundary Mode.

maximizing application flexibility.

#### 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 Startup 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

- General LED Lighting
- Industrial, Commercial and Residential Fixtures
- Outdoor Lighting: Street, Roadway, Parking, Construction, and Ornamental LED Lighting

### **Ordering Information**

Part Number	Operating Temperature Range	Package	Packing Method	
FL6961MY	-40°C to +125°C	8-Pin, Small Outline Package (SOP)	Tape & Reel	



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## **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
$V_{\text{LOW}}$	Others (INV, COMP, MOT, CS)	-0.3	7.0	V
$V_{ZCD}$	Input Voltage to ZCD Pin	-0.3	12.0	V
PD	Power Dissipation		660	mW
$T_{J}$	Operating Junction Temperature	-40	+150	°C
θ <sub>JA</sub>	Thermal Resistance (Junction-to-Air)		150	°C/W
θ <sub>JC</sub>	Thermal Resistance (Junction-to-Case)		39	°C/W
T <sub>STG</sub>	Storage Temperature Range	-65	+150	°C
TL	Lead Temperature (Wave Soldering or IR, 10 Seconds)		+230	°C
ESD	Human Body Model: JESD22-A114		2.5	KV
ESD	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.	Тур.	Max.	Unit
T <sub>A</sub>	Operating Ambient Temperature	-40		+125	°C

## **Electrical Characteristics**

Unless otherwise noted,  $V_{CC}$ =15V and  $T_J$ =-40°C to 150°C. Current is defined as positive into the device and negative out of the device.

Symbol	Parameter	Conditions	Min.	Тур.	Max.	Units	
V <sub>CC</sub> Section	on						
V <sub>CC-OP</sub>	Continuous Operation Voltage				24.5	V	
V <sub>CC-ON</sub>	Turn-On Threshold Voltage		11.5	12.5	13.5	V	
$V_{\text{CC-OFF}}$	Turn-Off Threshold Voltage		8.5	9.5	10.5	V	
I <sub>CC-ST</sub>	Startup Current	V <sub>CC</sub> =V <sub>CC-ON</sub> - 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		26.8	27.8	28.8	V	
t <sub>D-VCCOVP</sub>	V <sub>DD</sub> Over-Voltage Protection Debounce			30		μs	
Error Am	plifier Section						
V <sub>REF</sub>	Reference Voltage		2.475	2.500	2.525	V	
Gm	Transconductance			125		µmho	
V <sub>INVH</sub>	Clamp High Feedback Voltage			2.65	2.70	V	
VINVL	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	
VINV-UVP	Under-Voltage Protection for INV Input		0.40	0.45	0.50	V	
		V <sub>INV</sub> =2.35V, V <sub>COMP</sub> =1.5V	10	20			
I <sub>COMP</sub>	Source Current	V <sub>INV</sub> =1.5V	550	800		μA	
	Sink Current	V <sub>INV</sub> =2.65V, V <sub>COMP</sub> =5V	10	20		1	
Current-S	Sense Section		7			/	
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	
		R <sub>MOT</sub> =24kΩ, V <sub>COMP</sub> =5V		400	500		
t <sub>LEB</sub>	Leading-Edge Blanking Time	$\begin{array}{l} R_{MOT} = 24k\Omega, \\ V_{COMP} = V_{OZ} + 50mV \end{array}$		270	350	ns	
Gate Sect	tion					< )	
V <sub>Z</sub> -OUT	Output Voltage Maximum (Clamp)	V <sub>CC</sub> =25V	14.5	16.0	17.5	V	
V <sub>OL</sub>	Output Voltage Low	V <sub>CC</sub> =15V, I <sub>O</sub> =100mA			1.4	V	
V <sub>OH</sub>	Output Voltage High	V <sub>CC</sub> =14V, I <sub>O</sub> =100mA	8			V	
t <sub>R</sub>	Rising Time         V <sub>CC</sub> =12V, C <sub>L</sub> =3nF, 20~80%			80		ns	
t <sub>F</sub>	Falling Time	V <sub>CC</sub> =12V, C <sub>L</sub> =3nF, 80~20%		40		ns	

## **Electrical Characteristics**

Unless otherwise noted,  $V_{CC}$ =15V and  $T_J$ =-40°C to 150°C. Current is defined as positive into the device and negative out of the device.

Symbol	Parameter	Conditions	Min.	Тур.	Max.	Units
Zero-Curi	rent Detection Section					
V <sub>ZCD</sub>	Input Threshold Voltage Rising Edge	V <sub>ZCD</sub> Increasing	1.9	2.1	2.3	V
$\begin{array}{c} H_{YS} \text{ of } \\ V_{ZCD} \end{array}$	Threshold Voltage Hysteresis	V <sub>ZCD</sub> Decreasing		0.35		V
V <sub>ZCD-HIGH</sub>	Upper Clamp Voltage	I <sub>ZCD</sub> =3mA			12	V
V <sub>ZCD-LOW</sub>	Lower Clamp Voltage	I <sub>ZCD</sub> =-1.5mA	0.3			V
t <sub>DEAD</sub>	Maximum Delay, ZCD to Output Turn-On	V <sub>COMP</sub> =5V, f <sub>SW</sub> =60KHz	100		400	ns
trestart	Restart Time	Output Turned Off by ZCD	300	500	700	μs
t <sub>inhib</sub>	Inhibit Time (Maximum Switching Frequency Limit)	R <sub>MOT</sub> =24kΩ		2.8		μs
V <sub>DIS</sub>	Disable Threshold Voltage		130	200	250	mV
t <sub>zcd-DIS</sub>	Disable Function Debounce Time	$R_{MOT}$ =24k $\Omega$ , V <sub>ZCD</sub> =100mV	800			μs
Maximum	On Time Section					
V <sub>MOT</sub>	Maximum On Time Voltage		1.25	1.30	1.35	V
t <sub>on-max</sub>	Maximum On Time Programming (Resistor Based)	$\begin{array}{c} R_{\text{MOT}} = 24 k\Omega,  V_{\text{CS}} = 0V, \\ V_{\text{COMP}} = 5V \end{array}$		25		μs





### **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 multivector error amplifier is built in to provide fast transient response and precise output voltage clamping.

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

#### **Operating Current**

Operating current is typically 4.5mA. The low operating current enables 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:

$$t_{on} = \frac{2 \bullet L \bullet P_o}{V_{rms}^2 \bullet \eta} \tag{1}$$

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 25µs maximum on time:

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

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

#### **Peak Current Limiting**

The switch current is sensed by one resistor. The signal is fed into the CS pin and an input terminal of a comparator. A high voltage on the CS pin terminates the 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 the 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 voltages are fixed internally at 12V and 9.5V, respectively. This hysteresis behavior guarantees a one-shot startup with proper startup resistor and hold-up capacitor. With an ultra-low startup current of 20 $\mu$ A, one 1M $\Omega$  R<sub>IN</sub> is sufficient for startup under low input line voltage, 85V<sub>rms</sub>. Power dissipation on R<sub>IN</sub> would be less than 0.1W even under high line (V<sub>AC</sub>=265V<sub>rms</sub>) 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 lowbandwidth, on-time modulation. An inherent maximum off time is built in to ensure proper startup 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 Boundary Mode. Slope compensation and a built-in debounce circuit can alleviate this problem. Because the FL6961 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 FL6961, and increasing the power MOSFET gate resistance all improve performance.



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