1. Introduction

The FAN7527 is an active power factor correction (PFC) controller for boost PFC application which operates in the critical conduction mode. It turns on MOSFET when the inductor current reaches zero and turns off MOSFET when the inductor current meets the desired input current reference voltage as shown in Fig. 1. In this way, the input current waveform follows that of the input voltage, therefore a good power factor is obtained.

1-1. Internal Block Diagram

It contains following blocks.
- Error amplifier (E/A)
- Zero current detection (Idet)
- Switch current sensing (CS)
- Input voltage sensing (MULT)
- Switch drive (OUT)
2. Device Block Description

2-1. Error Amplifier and Over Voltage Protection Block

The sensed and divided output voltage is feedback to the error amplifier inverting input (INV) to regulate the output voltage. The non-inverting input is internally biased at 2.5V. The error amp output (EA_OUT) is internally connected to the multiplier and is pinned out for the loop compensation. Generally, the control loop bandwidth of PFC converter is set below 20Hz to get a good power factor. In this application, a capacitor is connected between INV and EA_OUT. However, in case of over voltage condition, the E/A must be saturated low as soon as possible, but the narrow E/A bandwidth slows down the response. To make the over voltage protection fast, the soft OVP and dynamic OVP is added. The FAN7527 monitors the current flowing into the EA_OUT pin. If the monitored current reaches about 30uA, the output of multiplier is forced to be decreased, thus reducing the input current drawn from the mains (soft OVP). If the monitored current exceeds 40uA, the OVP protection is triggered (dynamic OVP), then the external power transistor is switched off until the current falls below about 10uA. In this case, it disables some internal blocks reducing the quiescent current of the chip to 2mA. However, if the over voltage lasts so long that the output of E/A goes below 2.25V, then the protection is activated (static OVP) keeping the output stage and the external power switch turned off. The operation of the device is re-enabled as the E/A output goes back into its linear region.

![Error Amplifier and OVP Block Diagram](image)

2-2. Multiplier

A single quadrant, two input multiplier is the critical element that enables this device to get power factor correction. One input of multiplier (Pin 3) is connected to an external resistor divider which monitors the rectified ac line voltage. The other input is internally driven by a DC voltage which is the difference between error amplifier output (Pin 2) and reference voltage, Vref. The multiplier is designed to have an extremely linear transfer curve over a wide dynamic range, 0V to 3.8V for Pin 3, and 2.25V to 6V for error amplifier output under all line and load conditions.

The multiplier output controls the current sense comparator threshold voltage as the ac voltage traverses sinusoidally from zero to peak line. This allows the inductor peak current to follow the ac line thus forcing the average input current to be sinusoidal. In other words, this has the effect of forcing the MOSFET on-time to track the input line voltage, resulting in a fixed drive output on-time, thus making the pre-converter load appear to be resistive to the ac line.

The equation below describes the relationship between multiplier output and its inputs.

\[ V_{mo} = K \times V_{m1} \times (V_{m2} - V_{ref}) \]

- **K**: Multiplier gain
- **V_{m1}**: Voltage at Pin 3
- **V_{m2}**: Error amp output voltage
- **V_{mo}**: Multiplier output voltage
2-3. Current Sense Comparator

The current sense comparator adopts the RS latch configuration to ensure that only a single pulse appears at the drive output during a given cycle. MOSFET drain current is sensed using an external sense resistor in series with the external MOSFET. When the sensed voltage exceeds the threshold set by the multiplier output, the current sense comparator turns off the MOSFET and resets the PWM latch. The latch insures that the output remains in a low state after the MOSFET drain current falls back to zero. The peak inductor current under the normal operating condition is controlled by the multiplier output, Vmo. The abnormal operating condition occurs during pre-converter start-up at extremely high line or as output voltage sensing is lost. Under these conditions, the multiplier output and current sense threshold will be internally clamped to 1.8V. Therefore, the maximum peak switch current is limited to:

\[ I_{pk(max)} = \frac{1.8V}{R_{sense}} \]

In the FAN7527, an internal R/C filter has been included to attenuate any high frequency noise that may be present on the current waveform. This circuit block eliminates the need for an external R/C filter otherwise required for proper operation of the circuit.

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**Figure 4. Multiplier block**

**Figure 5. Current Sense Circuit**
2-4. Zero Current Detector

FAN7527 operates as a critical conduction current mode controller. The zero current detector switches on the external MOSFET as the voltage across the boost inductor reverses, just after the current through the boost inductor has gone to zero. The slope of the inductor current is indirectly detected by monitoring the voltage across an auxiliary winding and connecting it to the zero current detector Pin 5. Once the inductor current reaches ground level, the polarity of the voltage across the winding is reversed. When the Idet input falls below 1.5V, the comparator output is triggered to the low state. To prevent false tripping, 0.5V hysteresis is provided. The zero current detector input is protected internally by two clamps. The upper 6.5V clamp prevents input over voltage breakdown while the lower 0.75V clamp prevents substrate injection. An internal current limit resistor protects the lower clamp transistor in case the Idet pin is shorted to ground accidentally. A watchdog timer function is added to the IC to eliminate the need for an external oscillator when used in stand-alone applications. The timer provides a means to start or restart the pre-converter automatically if the drive output has been off for more than 500us after the inductor current reached zero.

![Zero Current Detector Block](image)

2-5. Output Drive

The FAN7527 contains a single totem-pole output stage designed specifically for a direct drive of power MOSFET. The drive output is capable of up to 500mA peak current with a typical rise and fall time of 130ns, 50ns respectively with a 1.0nF load. Additional circuitry has been added to keep the drive output in a sinking mode whenever the UVLO is active. This characteristic eliminates the need for an external gate pull-down resistor. Internal voltage clamping ensures that the output driver is always lower than 14V when supply voltage exceeds the rated Vgs of the external MOSFET. This eliminates an external zener diode and extra power dissipation associated with it that otherwise is required for the reliable circuit operation.

3. Circuit Components Design

3-1. Power stage design

1) Boost inductor design

The boost inductor value is determined by the minimum switching frequency limitation. The minimum switching frequency has to be above the audio frequency.

The switching period is maximum when the input voltage is highest at maximum load condition. \( T_{S(max)} \) is a function of \( V_{in(peak)} \) and \( V_O \). It can have maximum value at highest line or at lowest line according to \( V_O \). Check \( T_{S(max)} \) at \( V_{in(peak\_min)} \) and \( V_{in(peak\_max)} \), then take the higher value for the maximum switching period. The boost inductor value can be obtained by (5)

\[
t_{on} = L \frac{1}{V} \frac{1}{V_{in(peak)\sin(\omega t)}} = L \frac{2I_{in(peak)\sin(\omega t)}}{V_{in(peak)\sin(\omega t)}} = L \frac{2I_{in(peak)}}{V_{in(peak)}}
\]
2) Auxiliary winding design

The auxiliary winding voltage is lowest at the highest line. So the number of auxiliary winding can be obtained by (7). A small resistor is connected to the auxiliary winding to suppress the high frequency ringing voltage.

\[ N_{aux} = \frac{V_{CC} \cdot N_P}{\left( V_O - \frac{2V}{\pi V_{in(HL)}} \right)} \]  
(7)

3) Input capacitor design

The voltage ripple of the input capacitor is maximum when the line is lowest and the load is heaviest. If \( f_{sw(min)} \gg f_{ac} \), the input current can be assumed to be constant during a switching period.

\[ I_{in(peak)} = \frac{2V_O I_O}{\eta \cdot V_{in(peak)}} \]  
(3)

\[ T_S = t_{on} + t_{off} \]  
(4)

\[ L = \frac{4L V_O I_{O(max)}^2}{\eta^2 \cdot V_{in(peak)}^2 (V_O - V_{in(peak)})^2} \]  
(6)

\[ C_{in} \geq \frac{2}{\Delta V_{in(max)}} \int_0^{t_{on}} \frac{I_{in(peak)}(t) \sin(\omega t)}{V_{in(HL)}} dt \]  
(8)

\[ C_{in(max)} = \frac{I_a}{\omega^2 V_{in(peak)}} \tan^{-1}(\text{IDF}) \]  
(12)

The input capacitor must be larger than the value calculated by (8). And the maximum input capacitance is limited by the input displacement factor(IDF), defined as \( \text{IDF} = \cos \theta \). Therefore the input capacitor must be smaller than \( C_{in(max)} \) calculated by (12).
4) Output capacitor design

The output capacitor is determined by the relation between the input power and the output power. As shown in Fig. 10, the minimum output capacitance is determined by (14).

\[ C_{O\text{(min)}} = \frac{I_{Q\text{(max)}}}{2\pi f_{ac} \cdot V_{O\text{(max)}}} \] (14)

5) MOSFET and diode selection

Maximum MOSFET rms current is obtained by (15) and the conduction loss of the MOSFET is calculated by (16). When MOSFET turns on the MOSFET current rises slowly so the turn on loss is negligible. MOSFET turn off loss and MOSFET discharge loss are obtained by (17) and (18) respectively. The switching frequency of the critical conduction mode boost PFC converter varies according to the line condition and load condition. Therefore the switching frequency is the average value during a line period. The total MOSFET loss can be calculate by (19) and then a MOSFET can be selected considering MOSFET thermal characteristic.

\[ I_{Q\text{rms}} = I_{L\text{(peak,max)}} \frac{1}{\sqrt{2}} \frac{4\sqrt{2}V_{\text{in(LL)}}}{9\pi V_{O}} \] (15)

\[ P_{\text{on}} = I_{Q\text{rms}}^2 \cdot R_{DS\text{on}} \] (16)

\[ P_{\text{turn-off}} = \frac{1}{6}V_{O}I_{L\text{(peak,max)}} \cdot t_{f} \cdot f_{sw} \] (17)

\[ P_{\text{discharge}} = \frac{4}{3}C_{oss}V_{O} \cdot V_{O} \cdot f_{sw} \] (18)

\[ P_{\text{MOSFET}} = P_{\text{on}} + P_{\text{turn-off}} + P_{\text{discharge}} \] (19)

And the MOSFET gate drive resistor is determined by (20).

\[ R_{g} > \frac{V_{O\text{max}}}{I_{O\text{max}}} = \frac{16V}{500mA} = 32\Omega \] (20)
Diode average current can be calculated by (21). The total diode loss can be calculated by (22) and then a diode can be selected considering diode thermal characteristic.

\[ I_{\text{Davg}} = I_{O(\text{max})} \]  
\[ P_{\text{Diode}} = V_i I_{\text{Davg}} \]  

3-2. Control circuit design

1) Output voltage sensing resistor and feedback loop design 

\[ R_1 = \frac{V_o - 2.5}{2.5} \]  
\[ R_2 = \frac{2.5 R_1}{V_o - 2.5} \]  

The feedback loop bandwidth must be narrower than 20Hz for the PFC application. Therefore a capacitor is connected between INV and EA_OUT to eliminate the 120Hz ripple voltage by 40dB. The error amp compensation capacitor can be calculated by (24). To improve the power factor, \( C_{\text{comp}} \) must be increased than the calculated value. And to improve the system response, \( C_{\text{comp}} \) must be lowered than the calculated value.

\[ C_{\text{comp}} = \frac{1}{0.01 \cdot 2 \pi \cdot 120 \text{Hz} \cdot R_1} \]  

2) Zero current detection resistor design

\( R_{\text{det}} \) should be less than 3mA, therefore zero current detection resistor is determined by (25).

\[ R_{\text{det}} > \frac{N_{\text{aux}} \cdot V_o}{N_p \cdot 3 \text{mA}} \]  

3) Start-up circuit design

To start up the FAN7527, the start-up current must be supplied through a start-up resistor. The resistor value is calculated by (26) and (27). The start-up capacitor must supply IC operating current before the auxiliary winding supplies IC operating current maintaining Vcc voltage higher than the UVLO voltage. Therefore the start up capacitor is designed by (28).

\[ R_{\text{ST}} \leq \frac{V_{\text{in(peak min)}} - V_{\text{th(st) max}}}{I_{\text{ST max}}} \]  
\[ P_{\text{ST}} = \frac{V_{\text{in(max)}}^2}{R_{\text{ST}}} \leq 0.5 \text{W} \]  
\[ C_{\text{ST}} \geq \frac{I_{\text{dc}}}{2 \pi \cdot f_{\text{nuc}} \cdot H_{\text{HY(ST) min}}} \]  

4) Line voltage sense resistor and current sense resistor design

The maximum line voltage sensing gain is determined by (29) at the highest line.

\[ V_{\text{PIN3}} = \frac{V_{\text{in(peak max)}} \cdot R_{\text{in2}}}{R_{\text{in1}} + R_{\text{in2}}} \]  
\[ = V_{\text{in(peak max)}} \cdot G_{\text{in(max)}} < 3.8 \text{V} \]  

Calculate the pin 3 voltage at the lowest line using \( G_{\text{in(max)}} \) by (30). Then the current sense resistor is determined by (31), (32) and (34). Once the current sense resistor is determined, then the minimum line voltage sensing gain, \( G_{\text{in(max)}} \) is determined by (31).

\( R_{\text{sense}} \leq \frac{V_{\text{O(m)}}}{L_{\text{in}}} = K \cdot \frac{V_{\text{in(peak min)}} \cdot R_{\text{in2}}}{R_{\text{in1}} + R_{\text{in2}}} \)  
\[ \cdot 2.5 \cdot \frac{\eta \cdot V_{\text{in(peak min)}}}{4 \cdot V_{\text{O(m)}}} \]  

4. Design Example

A 100W converter is designed to illustrate the design procedure. The system parameters are as follows.

- Maximum output power : 100W
- Input voltage range : 85Vrms~265Vrms
- Output voltage : 400V
- AC line frequency : 60Hz
- PFC efficiency : 90%
- Minimum switching frequency : 34kHz
- Input displacement factor(IDF) : 0.98
- Input capacitor ripple voltage : 24V
- Output voltage ripple : 8V
- OVP set voltage : 450V

4-1. Inductor design

The boost inductor is determined by (6). Calculate it at both the lowest line and the highest line and choose the lower value. The calculated value is 586uH. To get the calculate inductor value, EI3026 core is used and the primary winding is 62 turns. The air gap is 0.586mm at both legs of the EI core. The auxiliary winding is determined by (7) and the auxiliary winding is 5 turns.

4-2. Input capacitor design

The minimum input capacitance is determined by the input voltage ripple specification. The calculated minimum input
capacitor value is 0.56\(\mu\)F. And the maximum input capacitance is restricted by IDF. The calculated value is 0.76\(\mu\)F. The selected value is 0.67\(\mu\)F for the input capacitor (sum of all capacitors connected to the input).

4-3. Output capacitor design
The minimum output capacitor is determined by (14) and the calculated value is 83\(\mu\)F. The selected value is 100\(\mu\)F capacitor.

4-4. MOSFET and diode selection
By (15)–(19), 500V/6A MOSFET FQP6N50 is selected and by (21)–(23), and 1000V/1A diode BYV26E is selected by (21)–(22).

4-5. Output voltage sense resistor and feedback loop design
The upper output voltage sense resistor is 1.2M\(\Omega\) and the bottom output voltage sense resistor is 7k\(\Omega\) plus 10k\(\Omega\) variable resistor. A variable resistor is used to adjust the output voltage. The error amp compensation capacitance must be larger than 0.11\(\mu\)F by (24). Therefore 0.33\(\mu\)F capacitor is used.

4-6. Zero current detection resistor design
The calculate value is 430\(\Omega\) and the selected value is 22k\(\Omega\).

4-7. Start-up circuit design
The maximum start-up resistor is 1 M\(\Omega\) and the minimum is 140k\(\Omega\) by (26)–(27). Our selection is 150k\(\Omega\). And the start-up capacitance must be larger than 10.6\(\mu\)F by (28). The selected value is 47\(\mu\)F.

4-8. Line voltage sense resistor and current sense resistor design
The maximum input voltage sensing gain is determined by (29). Using the calculated value, the current sense resistance is determined by (31), (32) and (34). The maximum current sense resistance is 0.48\(\Omega\) and the selected value is 0.2\(\Omega\). Then the minimum input voltage sensing gain is determined by (30). If we choose the input voltage sense bottom resistor to be 18\(\Omega\) then the maximum input voltage sense upper resistance and the minimum input voltage sense upper resistance can be obtained from \(G_{\text{in(min)}}\) and \(G_{\text{in(max)}}\). The selected value is 2.7M\(\Omega\).

Fig. 11 shows the designed application circuit diagram and table 1 shows the 100W demo board components list.
Table 1: 100W demo board part list

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Table 2: 150W demo board part list

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**Line Filter**

**Inductor**

**MOSFET**
Table 3: 200W demo board part list

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<td>0.68nF</td>
<td>630V</td>
</tr>
<tr>
<td>RT1</td>
<td>10D-9</td>
<td></td>
<td>C6</td>
<td>47nF</td>
<td>35V</td>
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<td></td>
<td>C7</td>
<td>1nF</td>
<td>MLCC</td>
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<tr>
<td>R1</td>
<td>2.2MΩ</td>
<td>1/4W</td>
<td>C8</td>
<td>220nF</td>
<td>450V</td>
</tr>
<tr>
<td>R2</td>
<td>22kΩ</td>
<td>1/4W</td>
<td>C9</td>
<td>102</td>
<td>Ceramic</td>
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<td>R3</td>
<td>150kΩ</td>
<td>1W</td>
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<tr>
<td>R4</td>
<td>100Ω</td>
<td>1/4W</td>
<td>BD1</td>
<td>660(600V/6A)</td>
<td>Bridge Diode</td>
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<td>R5</td>
<td>22kΩ</td>
<td>1/4W</td>
<td>D1</td>
<td>1N4148</td>
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</tr>
<tr>
<td>R6</td>
<td>47Ω</td>
<td>1/4W</td>
<td>D2</td>
<td>SUF15J</td>
<td>600V/1.5A</td>
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<tr>
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<td>0.1Ω</td>
<td>1W</td>
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<tr>
<td>R8</td>
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<td>1/4W</td>
<td>LF1</td>
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<td>T1</td>
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<td>VR1</td>
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**Nomenclature**

- $I_{L(peak)}(t)$: inductor current peak value during one switching cycle
- $I_{L(peak)}$: inductor current peak value during one AC line cycle
- $I_{L(peak\_max)}$: maximum inductor current peak value
- $I_L(t)$: inductor current
- $I_D$: boost diode current
- $I_{in}(t)$: input current
- $I_{in}(peak)$: input current peak value
- $I_{in}(peak\_max)$: maximum of the input current peak value
- $I_{in}(rms)$: input current RMS value
- $I_{Qrms}$: MOSFET rms current
- $I_{Drms}$: diode rms current
- $I_{Davg}$: diode average current
- $I_O$: output current
- $I_O(max)$: maximum output current
- $V_{in}(t)$: input voltage
- $\Delta V_{in}(max)$: maximum input voltage ripple
- $V_{in}(peak)$: input voltage peak value
- $V_{in}(peak\_max)$: maximum input voltage peak value
- $V_{in}(peak\_min)$: minimum input voltage peak value
- $V_{in}(rms)$: input voltage RMS value
- $V_{in}(rms\_max)$: maximum input voltage RMS value
- $V_{in}(rms\_min)$: minimum input voltage RMS value
- $V_{in}(LL)$: low line rms input voltage
- $V_{in}(HL)$: high line rms input voltage
- $V_O$: output voltage
- $\Delta V_{O(max)}$: maximum output voltage ripple
- $\Delta V_{OVP}$: maximum output over voltage
- $P_O$: output power
- $P_{O(max)}$: maximum output power
- $P_{in}$: input power
- $\eta$: converter efficiency
- $t_{on}$: switch on time
- $t_{off}$: switch off time
- $t_I$: MOSFET current falling time
- $T_S$: switching period
- $f_{ac}$: AC line frequency
- $\omega$: AC line angular frequency
- $f_{SW}$: switching frequency
- $f_{SW(max)}$: maximum switching frequency
- $f_{SW(min)}$: minimum switching frequency
- $L$: boost inductance
- $C_O$: output capacitance
- $C_{in}$: input capacitance
- $\eta$: converter efficiency
- $N_{aux}$: auxiliary winding turn number
- $N_P$: boost inductor turn number
- $C_{comp}$: compensation capacitance
- $R_{det}$: zero current detection resistance
- $R_{ST}$: start up resistance
- $R_1$: output voltage divider top resistance
- $R_2$: output voltage divider bottom resistance
- $R_{in1}$: input voltage divider top resistance
- $R_{in2}$: input voltage divider bottom resistance
- $R_{sense}$: current sense resistance
- $I_{ST\_max}$: maximum start up supply current
- $C_{ST}$: start up capacitance
- $HY_{ST\_min}$: minimum UVLO hysteresis
- $K$: multiplier gain
- $G_{in\_min}$: minimum input voltage sense gain
- $G_{in\_max}$: maximum input voltage sense gain