Application Guide Of Primary-side Feedback LED Driver Chip FT8260/1x With Active PFC

ABSTRACT:

FT8260/1x is a primary-side feedback LED driver chip with Power Factor Correction (PFC) function. By its unique primary-side current detection control method, the precise constant-current output can be achieved without any secondary-side feedback, which greatly simplifies the system design. By fixing conducting time control, the high Power Factor (PF) and low THD characteristics can be realized synchronously. FT8260/1x has several protective functions, such as adjustable output over-voltage protection, OSCP, switching period current-limiting protection and chip over-temperature protection, which make the LED system may work in a more reliable and safer way.

FEATURES:

- High PF > 0.9
- Ultra-low start-up current(≤30μA)
- High constant current precision±3%
- No dimming function (FT8260x), switching dimming (FT8261x)
- External adjustable output over-voltage protection
- IC over-temperature protection
- Current-limiting protection
- Output short-circuit protection
- Low primary-side feed back peripheral component costs

APPLICATION FIELD:

- Isolated AC/DC LED illuminating drive application
- Commercial and industrial illumination
- Displaceable lamp source, like E27,GU10, T8, etc..

PRODUCT DEFINITION:

Part No.	Dimming Method	Integrated MOS	Power	Package
FT8260	N/A	N/A	30W	SOT23-6
FT8260B	N/A	650V, 2A	7W	SOP8
FT8260DD	N/A	650V, 4A	18W	DIP8
FT8261	3-level On-Off Dimming	N/A	30W	SOT23-6
FT8261B	3-level On-Off Dimming	650V, 2A	7W	SOP8
FT8261DD	3-level On-Off Dimming	650V, 4A	18W	DIP8

PIN CONFIGURATION:

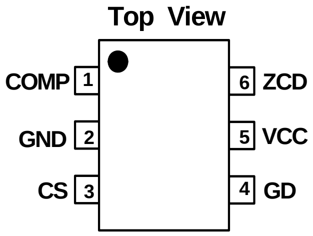


Fig.1a FT8260/1

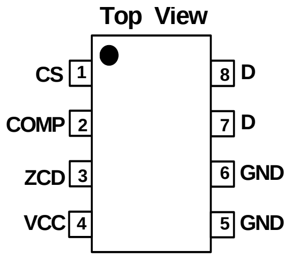


Fig.1b FT8260/1B/DD

INNER MODULE BLOCK DIAGRAM:

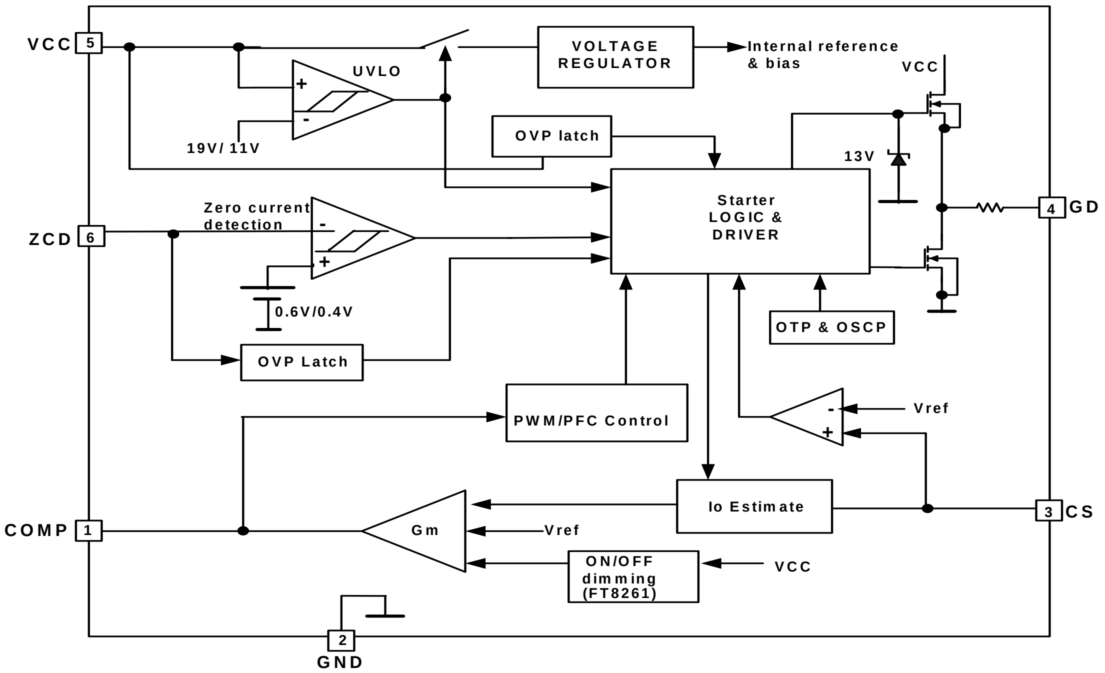


Fig.2a FT8260/1 block diagram

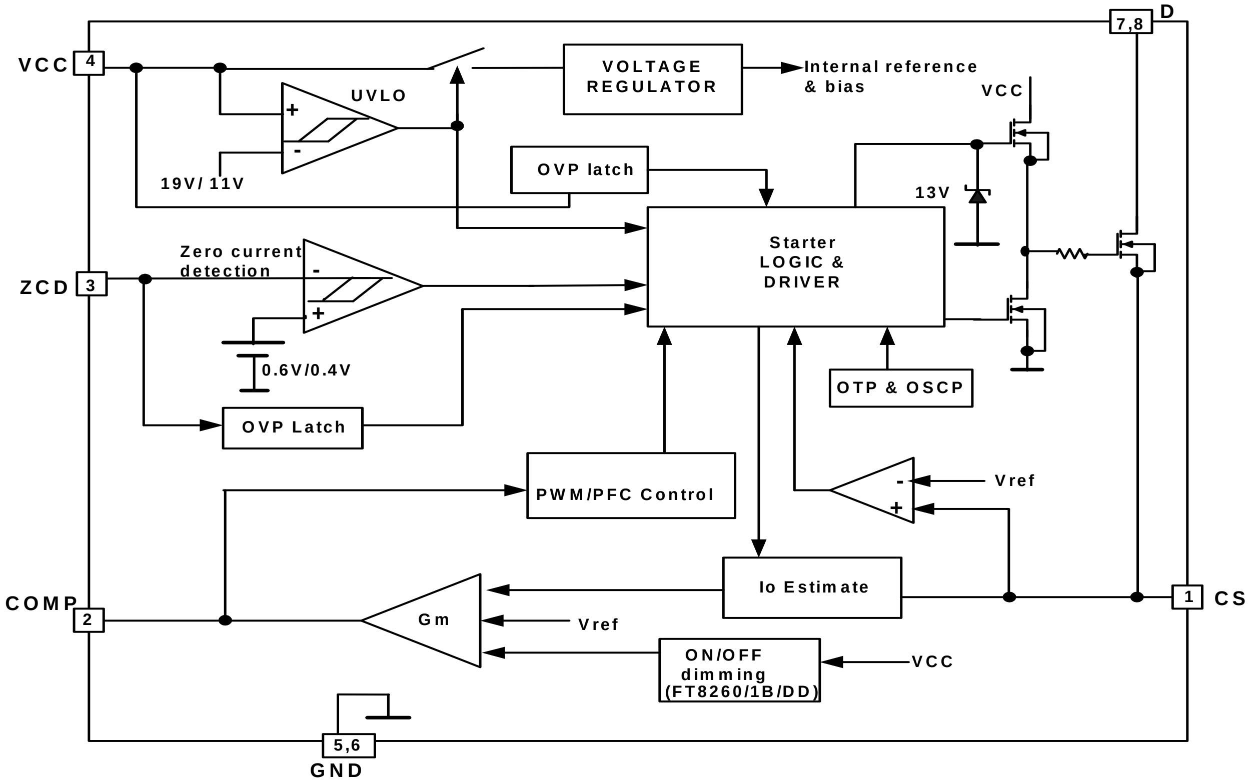


Fig.2b FT8260/1B/DD block diagram

TYPICAL APPLICATION CIRCUIT：

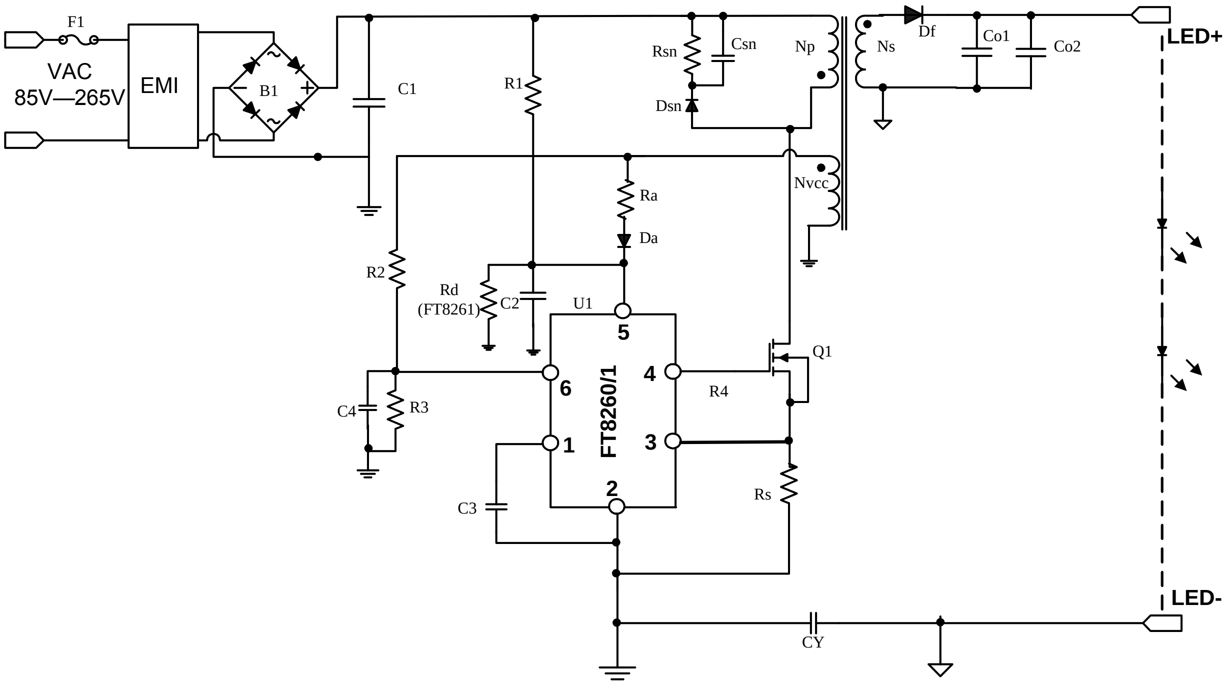


Fig.3a FT8260/1 typical application diagram

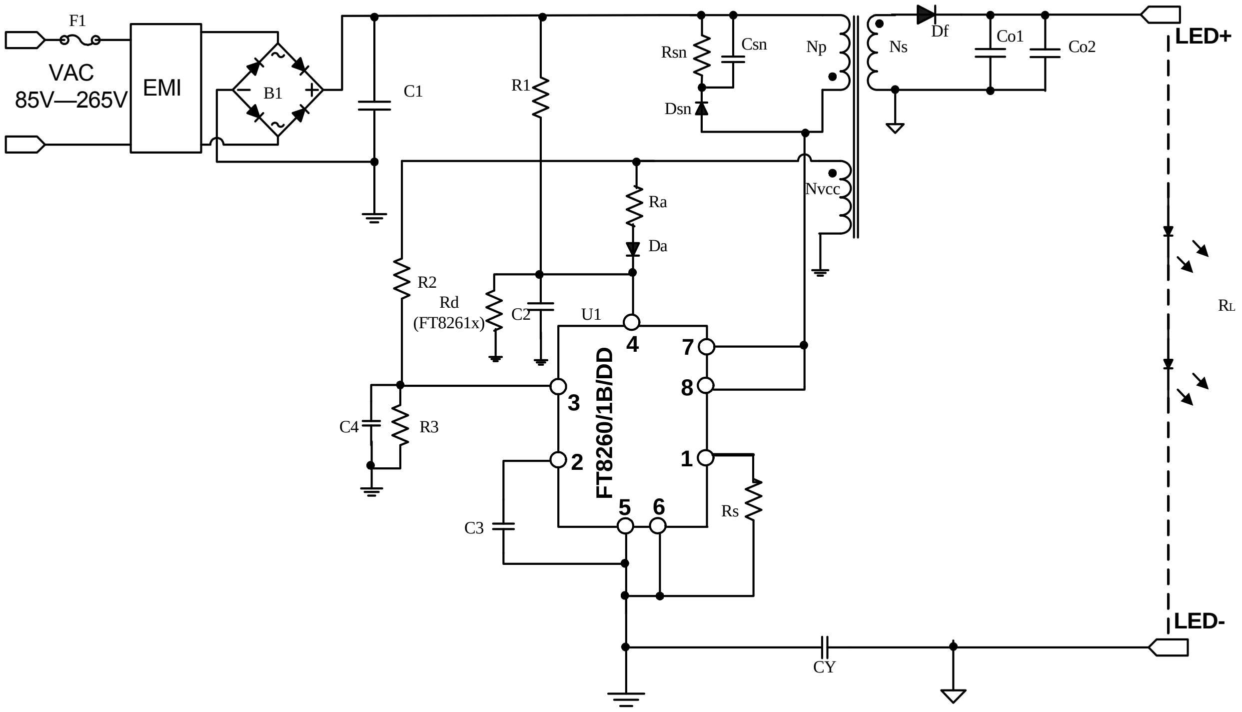


Fig. 3b FT8260/1B/DD typical application diagram

PRODUCT INTRODUCTION:

The typical application of FT8260/1x is the primary-side fly-back topology, as shown in Fig.3. When the MOSFET is on, the inductor is charged by input voltage after the rectifier, and also the output capacitor discharges for the loads, where the inductor current is increased from zero to the peak current; When the MOSFET is off, the energy stored in the inductor may force the secondary-side rectifier to conduct, and the secondary inductor discharges for the loads and charges for the output capacitor, where the inductor current is reduced from peak current to zero linearly.

By its unique primary-side current detection control method, the precise constant-current output can be achieved without any secondary-side feedback. The average output current can be expressed as:

$$I_o \approx \frac{N * V_{FB}}{2 * R_s} * \eta 2$$

Wherein, N—Turn ratio of primary side to secondary side;

VFB—Inner feedback voltage reference, typical value is 0.4V;

Rs—Primary side current detection resistor, connected between the MOS tube end and ground

η2—Conversion efficiency of the transformer

By fixing conducting time control, the input current can track the input voltage in consistent phase, synchronously achieving the high PF and low THD.

1. System application introduction

Start-up and shut-down process:

During the power start-up process, the input voltage charges for VCC capacitor C2 through R1. The internal voltage begins to charge for COMP pin capacitor when the voltage of C2 reaches the chip start-up voltage V_{CC-ON}, and the chip begins to switch when the COMP voltage is higher than the COMP low clamping voltage.

Considering that power is still consumed inside the chip, the VCC will be reduced until the transformer auxiliary winding can provide power for the VCC. In order to achieve one-time start-up, VCC C2 should be ensured that it can provide enough energy for chip power consumption before the transformer auxiliary starts to supply the power. The start-up resistor R1 should be selected by meeting the charging current is higher that the chip start-up current and lower than chip clamping current.

When the system is off, the capacitor begins to discharge after the rectifier bridge. The VCC begins to reduce when the auxiliary winding is not large enough to supply power for the VCC. The chip stops on-off when the VCC is lower than V_{CC-OFF}, therefore the COMP voltage are reduced.

In order to achieve the high PF and low THD, The 2.2uF X7R/NPO capacitor is recommended for COMP use.

Over-voltage protection

As shown in Fig.4a, during the normal operation, the output voltage is reflected by the auxiliary winding through transformer-coupling, then a feedback of output voltage signal on chip ZCD pin is made through R2 and R3.

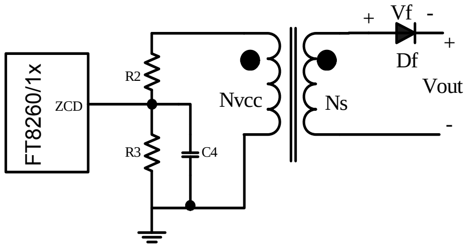


Fig.4a ZCD over-voltage protection

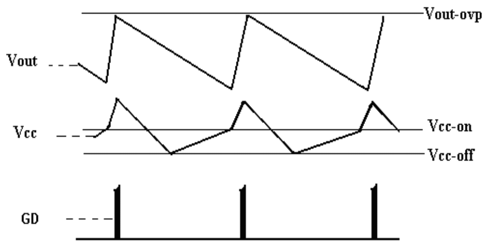


Fig.4b ZCD over-voltage waveform

During the normal operation, FT8260/1x will control the MOSFET to conduct when a falling-edge signal from over 0.6V to less than 0.4V is detected on the ZCD pin after the minimum chip turn-off time. Therefore, we can conclude: $V_{ZCD} = \frac{(V_{out} + V_f)}{N_s} * N_{vcc} * \frac{R3}{R2 + R3} > 0.6$

When the output circuit is open, the output voltage will be increased. After the MOSFET is off for about 1us, if the detection voltage V_{ZCD} is higher that the chip internal OVP triggering voltage, assuming the typical value is 3.2V, the triggering chip will output the over-voltage protection and control the MOSFET to turn-off until the VCC is lower than $V_{CC\text{-}OFF}$. The chip begins to control the MOSFET on-off when the voltage is higher than $V_{CC\text{-}ON}$. If the output over-voltage is not released, then the process mentioned above should be repeated, as shown is Fig.4b. The chip can work in normal sate only if the output voltage back to normal. Therefore, the over-voltage point $V_{out\text{-}ovp}$ of the output voltage can be designated according to the transformer turn ratio and resistance divider.

$$V_{out-ovp} = 3.2 * \frac{R2 + R3}{R3} * \frac{N_s}{N_{vcc}} - V_f$$

The resistance of R2 and R3 is determined by line voltage compensation. C4 is used for filtering high-frequency ripple and leakage inductance and random signal. The typical value is dozens of pF.

Meanwhile, the VCC pin also has the over-voltage function. When the VCC is higher than Vcc-ovp for about 6us, the VCC over-voltage protection is triggered, and the chip will stop on-off until the VCC re-start up.

Line voltage compensation

Given the on-off delay of the driver tube and several errors inside the chip, the output voltage of the system will be increased with the various input voltages. By adding compensating voltage on CS pin when the chip is on, the compensation can be achieved by FT8260/1x. The compensating voltage is related to the external R2 of ZCD pin, the turn ratio of transformer auxiliary winding to the primary side winding. When the turn ratio is fixed, the compensating voltage is in inverse proportion to the R2. When the output current of the system is increased with the input voltage, the R2 should be reduced to compensate, and vice visa. The R2 is usually selected between the 20K and 100K.

Outputs short-circuit protection (OSCP):

If the output short-circuit is detected, the frequency of FT8260/1x will be reduced to 7 KHz and the VCC will be constantly reduced as well due to the lack of power supply. Meanwhile, the COMP voltage will be increased. When the COMP voltage is higher than the protective voltage for about 2.8V, the chip will stop on-off until the VCC re-UVLO.

Over-temperature protection (OTP):

When the junction temperature of the chip is over 150℃, the built-in over-temperature detection circuit will control the MOSFET to turn off and maintain this state for a while. When the chip temperature is lower than about 130℃, the MOSFET begins to restore the on-off. If the VCC is completed power down, the internal state of the chip can not be maintained.

Dimming design:

FT8261x has the on-off dimming function without extra circuits, which is more environmentally friendly. By the on-off of the power, the LED light can be controlled to transfer its brightness among 100%, 50% and 25%. As shown in Fig.5, The brightness of the LED light at the first on-state is 100%, and then the switch is disconnected. After that, the switch is on at the time of T_{ONOFF}, and the brightness of LED light now is 50%. Repeatedly, the brightness of the LED light is 25%, and then circulating among 100%, 50% and 25%. If the switch turn-off time is longer than T_{RESET}, the light is considered to be turned off indeed, and the brightness of the LED will be 100% when the light is turned on at the next time. The T_{RESET} and T_{ONOFF} can be regulated by R_d between the VCC and GND , as shown in Fig.3b.

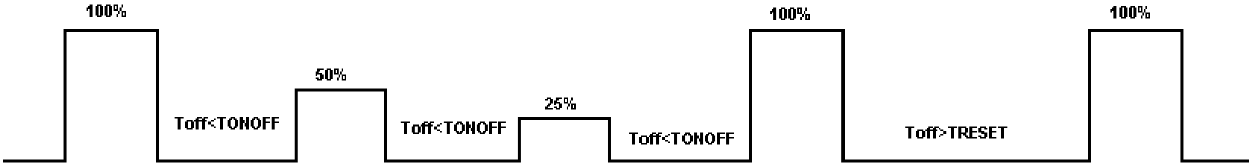


Fig.5 Schematic diagram of on-off dimming

2. System power component design:

In order to achieve the high power factor, the FT8260/1x operates in the fixed conducting time mode, wherein the conducting time is determined by the effective vale of input voltage and output loads. When the effective value of the input voltage is the minimum and the load is the maximum, the conducting time is the longest. Besides, the secondary-side discharging time is longest when the input voltage is its peak value. Therefore, the system minimum switching frequency occurs in the minimum of the effective value of the input voltage, maximum load and peak value of the input voltage. The system switching frequency is a variable and can be expressed as:

$$f_{sw}=\frac{1}{T}=\frac{1}{T_{ON}+T_{OFF}}=\frac{V_{PK}}{L_p * I_{PKp}}*\frac{1}{1+\frac{V_{PK}}{N*(V_{out}+V_f)}*\left|\sin(\theta)\right|}$$

Wherein, **T**

T_{ON} –conducting time

T_{OFF}—off time

V_{PK}—Peak value of input voltage

L_P—Primary side inductance

I_{PKP}-- Peak current of input voltage

Vout—Output voltage

V_f-- Secondary side rectifier conducting voltage

N-- Turn ratio of the primary side to the secondary side

$\theta=2*\pi*f_L*t$,

f_L—Power frequency period of input voltage

(a) Determine the system target parameter

At first, determine system target parameter according to the practical use, Such as minimum AC input voltage V_{inmin}

Maximum AC input voltage V_{inmax}

AC input voltage frequency f_L

Output voltage V_{out}

Output current I_{out}

Then, pre-design the system parameter in view of target parameter. Estimate the conversion efficiency η of the whole machine in advance to calculate the system maximum input power; the maximum input power P_{in} can be expressed as:

$$P_{in} = \frac{P_{out}}{\eta} = \frac{V_{out} * I_{out}}{\eta}$$

After that, determine the transformer reflected voltage V_R, which can be defined as:

$$V_R = N * \left(V_{out} + V_f\right)$$

The value of V_R has an effect of the selection of MOSFET and the secondary side rectifier and the design of absorption circuit as well.

(b) Calculation of system operation condition

Calculate the system operation condition according to the target parameter and system parameter for pre-designing, and make basis for the peripheral component selection.

In order to facilitate the calculation, ignore the effect of the minimum turn-off time and define the K_V as the ratio of input voltage peak value to the reflected voltage, which can be expressed as: $K_V = \frac{V_{PK}}{V_R}$. Generally, the larger the K_V value i, the lower the PF will be and the higher the THD will be as well.

The maximum primary-side inductance current peak value I_{Pkp} is:

$$I_{PKp} = \frac{2 * P_{in}}{V_{PK} * \overline{\frac{\sin^2(\theta)}{1 + K_V * \sin(\theta)}}} \approx \frac{2 * P_{in}}{V_{PK} * \frac{0.5 + 1.4 * 10^{-3} * K_V}{1 + 0.815 * K_V}}$$

The effective value of the primary current is:

$$I_{RMSp} = \sqrt{\frac{1}{3} * \overline{I_{pkp}^2(\theta) * D}} = I_{PKp} * \sqrt{\frac{1}{3} * \overline{\frac{\sin^2(\theta)}{1 + K_V * \sin(\theta)}}} \approx I_{PKp} * \sqrt{\frac{1}{3} * \frac{0.5 + 1.4 * 10^{-3} * K_V}{1 + 0.815 * K_V}}$$

Wherein, D is duty cycle, defined as the ratio of conducting time to the switching period,

$$D=\frac{T_{ON}}{T}=\frac{T_{ON}}{T_{ON}+T_{OFF}}=\frac{1}{1+K_V*\left|\sin(\theta)\right|}$$

The maximum secondary-side inductance current peak value I_{Pkp} is:

$$I_{PKs}=\frac{2*I_{out}}{K_V*\dfrac{\sin^2(\theta)}{1+K_V\sin(\theta)}}\approx\frac{2*I_{out}}{K_V*\dfrac{0.5+1.4*10^{-3}*K_V}{1+0.815*K_V}}$$

The effective value of the secondary-side current I_{RMSs} is:

$$I_{RMSs}=\sqrt{\frac{1}{3}*\overline{I_{pks}^2(\theta)*(1-D)}}=I_{PKs}*\sqrt{\frac{K_V}{3}*\overline{\frac{\sin^3(\theta)}{1+K_V*\sin(\theta)}}}\approx I_{PKs}*\sqrt{\frac{1}{3}*K_V*\frac{0.424+5.7*10^{-4}*K_V}{1+0.862*K_V}}$$

(C) Transformer parameter design

At first, determine the primary-side inductance of the transformer, wherein the value of the inductance is related to the minimum switching frequency. The minimum switching frequency $f_{sw\text{-}min}$ in the system design should be higher than the inner starter frequency of FT8260/1x. In the practice uses, in order to reduce the size of transformer, the minimum switching frequency will be far higher than the inner starter frequency, like 40 kHz or higher. The equation is as follows:

$$L_P=\frac{V_{PK\min}}{(1+K_V)*f_{sw-\min}*I_{PKp}},$$

After the primary-side inductance L_P is determined, select the magnetic material of the transformer. If there are no appropriate references, the following equation can be used for the estimation:

$$AP=A_e*A_w=\left[\frac{L_p*I_{PKp}*I_{RMSp}*10^4}{B_m*K_F*450}\right]^{1.143}\ (\text{cm}^4)$$

Wherein, A_e is the sectional area of the magnetic material and A_w is the window area of the magnetic material. B_m is the magnetic flux density under normal operating state and the unit is T. For most of the power ferrite magnetic materials, the B_m is generally between 0.28T and 0.3T. K_F is the filling coefficient from 0.2 and 0.3. Then, according to the selected magnetic material, determine the minimum primary-side coil number to avoid the transformer saturation. The formula is as follows:

$$N_P^{\min}=\frac{L_P*I_{PKp}}{B_{sat}*A_e}*10^6,$$

B_{sat} is the saturation flux density of the selected magnetic material, and the unit is T. The reference B_{sat} is usually between 0.32T and 0.35T. With the increase of the temperature, the value of B_{sat} is reduced.

After that, determine the coil number of the secondary-side winding, and the turn ratio of the primary-side winding to the secondary-side winding is determined by the reflected voltage V_R:

$$N = \frac{V_R}{(V_{out} + V_f)},$$

Therefore, the coil number N_s of the secondary-side winding can be expressed as: $N_s = \frac{N_P}{N}$。

Determine the coil number N_{vcc} of the chip VCC power supply winding, which can be expressed as follows:

$$N_{vcc} = \frac{(V_{CC}^{*} + V_{fa}) * N_s}{V_{out} + V_f},$$

Wherein, VCC is the VCC voltage, as shown in Fig.6, V_{fa} is the forward voltage drop of the VCC winding-side diode D_a. With the increase of output voltage V_{out}, VCC will be increased as well. In order to ensure that the VCC has its allowances, the chip power consumption is reduced under any possible conditions and the phenomenon that the chip VCC over-voltage protection function is triggered in a wrong way is avoided, the normal operation voltage of the VCC is 18V.

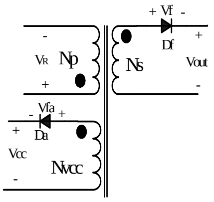


Fig.6

After the primary-side inductance and the secondary-side winding coil number are determined, the length of the air gap G of the magnetic core can be estimated by the formula below (the unit is mm):

$$G = 40\pi * A_e * (\frac{N_p^2}{1000 * L_p} - \frac{1}{A_L})$$

Wherein, the A_L is the A_L value of the magnetic core without air gap, and the unit is nH/turns^2.

Then, design the diameter of the winding. When the length of the winding is larger than 1m, the typical current density is 5A/mm^2. When the winding is relatively short and the coil number of the winding is small, the current density can be given by 6-10A/mm^2. In order to facilitate the winding operation and reduce the eddy current consumption, the diameter of the winding should be smaller than 1mm. If the output current is large, the wire with smaller diameter can be used in the double-wire and parallel-winding mode to reduce the skin effect.

Detect whether the winding window of the magnetic material can wind all the windings or not. The needed equation of the window area is:

$$A_w = \frac{A_c}{K_F}$$

Wherein, A_C is the real winding area, and K_F is the filling coefficient.

If the magnetic material cannot wind all the windings, bigger magnetic material should be used. However, considering the cost and space size limitation, if the bigger magnetic material is not available, we can increase Kv or minimum operation frequency to reduce L_p so as to decrease the coil number of the minimum primary-side winding and other winding coil number and meet the size of winding window. However, to increase the operation frequency may increase the switching frequency as well.

(d) Key component selection

After the design of the transformer is completed, then select the peripheral key components.

The selection of MOSFET:

For the external MOSFET Q1, the N-channel MOSFET is usually adopted. The maximum drain current $_{dmax}$ of MOSFET should be larger than the maximum peak current I_{PKpmax} across the MOSFET. Considering the issues of allowances, the current of MOSFET can be selected according to the standard that the current should be larger than the 1.5 times of the maximum current across the MOSFET:

$$I_{d\max} \geq 1.5 * I_{PKp\max}$$

The 90% of the drain-source break-down voltage BV_{dss} of MOSFET should be higher than the sum of maximum input voltage peak value, reflected voltage and leakage inductance voltage:

$$BV_{dss} * 0.9 > V_{PK\max} + V_{sn-\max} = V_{PK\max} + V_R + \Delta V$$ 。

The selection of secondary-side rectifier D_f:

Considering the issue of allowances, the maximum reverse voltage V_{RRM} of the secondary-side rectifier D_f should meet the following formula:

$$V_{RRM} > 1.3 * (\frac{V_{PK\max}}{N} + V_{out})$$,

The average forward current I_f should meet the following formula: $I_f > 1.5 * I_{RMSs}$.

In order to reduce the conduction consumption of the rectifier, the FRD with smaller forward voltage drop can be selected.

The selection of the output capacitor:

The output capacitor is determined by the output current ripple, and can be expressed as:

$$C_O = \frac{\sqrt{\left(\frac{2I_O}{\Delta I_O}\right)^2 - 1}}{4\pi f_L R_{LED}}$$

△I_O is the output ripple current and R_{LED} is the output LED equivalent series resistor.

The selection of CS current detection resistor:

The CS current detection resistor R_S is connected between the source end of MOSFET and the ground to detect the instantaneous current of the primary-side inductor. The secondary-side constant-current output is achieved by FT8260/1x through primary-side current detection and control. The selection of the CS current detection resistor R_S is determined by the average output current, and can be expressed as:

$$R_S \approx \frac{N * V_{FB}}{2 * I_o} * \eta 2$$

η2 is the transformer efficiency

Meanwhile, the R_S should meet the following formula： $R_s < \frac{1.8}{I_{PKp\max}}$

Otherwise, the turn ratio of the primary side to the secondary side should be re-designed.

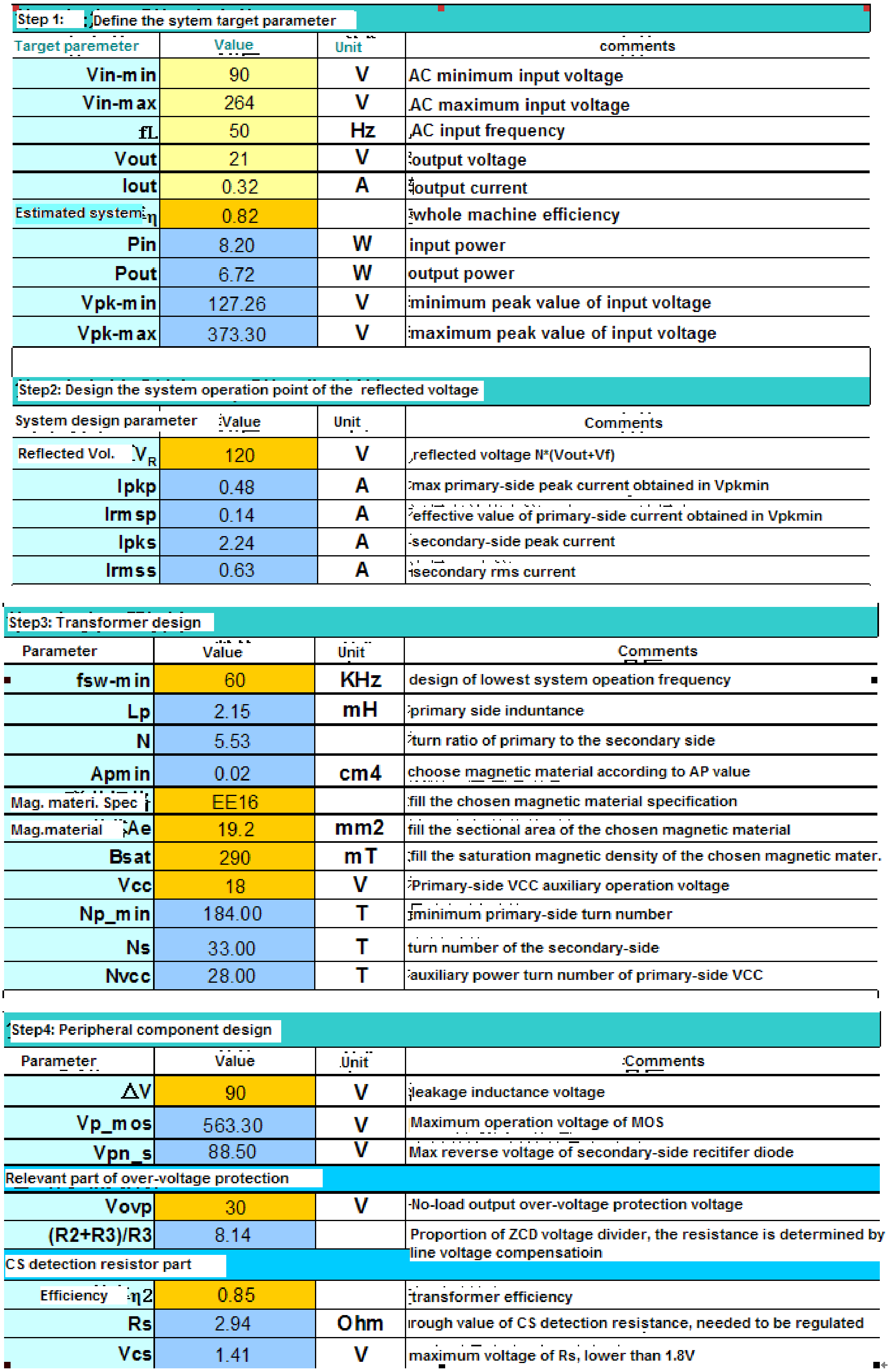
In order to avoid the over-current, FT8260/1x has the cycle-by-cycle current-limiting protective function. The maximum of the V_{CS} cannot exceed the current-limiting voltage.

3. Design example

In order to facilitate the design, an EXCEL is made for the FT8260/1x primary-side feedback and fly-back system design flow.

During the design, fill the system target parameter in the light yellow part and the system design parameter in the golden part. The EXCEL can automatically calculate partial parameters to be the references, which is shown in the light blue part.

21V-0P32A is chosen as an example to demonstrate, as shown in Fig.7.



Step 1: Define the sytem target parameter

Target paremeter	Value	Unit	comments
Vin-min	90	V	AC minimum input voltage
Vin-max	264	V	AC maximum input voltage
fL	50	Hz	AC input frequency
Vout	21	V	output voltage
Iout	0.32	A	output current
Estimated system η	0.82		whole machine efficiency
Pin	8.20	W	input power
Pout	6.72	W	output power
Vpk-min	127.26	V	minimum peak value of input voltage
Vpk-max	373.30	V	maximum peak value of input voltage

Step2: Design the system operation point of the reflected voltage

System design parameter	Value	Unit	Comments
Reflected Vol. V_R	120	V	reflected voltage N*(Vout+Vf)
Ipkp	0.48	A	max primary-side peak current obtained in Vpkmin
Irmsp	0.14	A	effective value of primary-side current obtained in Vpkmin
Ipks	2.24	A	secondary-side peak current
Irmss	0.63	A	secondary rms current

Step3: Transformer design

Parameter	Value	Unit	Comments
fsw-min	60	KHz	design of lowest system opeation frequency
Lp	2.15	mH	primary side induntance
N	5.53		turn ratio of primary to the secondary side
Apmin	0.02	cm4	choose magnetic material according to AP value
Mag. materi. Spec	EE16		fill the chosen magnetic material specification
Mag.material Ae	19.2	mm2	fill the sectional area of the chosen magnetic material
Bsat	290	mT	fill the saturation magnetic density of the chosen magnetic mater.
Vcc	18	V	Primary-side VCC auxiliary operation voltage
Np_min	184.00	T	minimum primary-side turn number
Ns	33.00	T	turn number of the secondary-side
Nvcc	28.00	T	auxiliary power turn number of primary-side VCC

Step4: Peripheral component design

Parameter	Value	Unit	Comments
ΔV	90	V	leakage inductance voltage
Vp_mos	563.30	V	Maximum operation voltage of MOS
Vpn_s	88.50	V	Max reverse voltage of secondary-side recitifer diode
Relevant part of over-voltage protection			
Vovp	30	V	No-load output over-voltage protection voltage
(R2+R3)/R3	8.14		Proportion of ZCD voltage divider, the resistance is determined by line voltage compensatioin
CS detection resistor part			
Efficiency η2	0.85		transformer efficiency
Rs	2.94	Ohm	rough value of CS detection resistance, needed to be regulated
Vcs	1.41	V	maximum voltage of Rs, lower than 1.8V

Fig.7

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