Introduction

AP3706/08N uses Pulse Frequency Modulation (PFM) method to realize Discontinuous Conduction Mode (DCM) operation for flyback power supplies; uses Primary Side Regulation (PSR) to provide Constant Voltage (CV) and Constant Current (CC) regulation. The principle of PFM is different from that of Pulse Width Modulation (PWM), so the design steps of the transformer for PFM operation is also different from that for PWM operation. In the other side, AP3706/08N uses PSR to provide CV/CC regulation without requiring opto-coupler and loop compensation, which makes the design of transformer more critical than that with PWM. The following design steps focus on the transformer design. Some design guides to select diodes and transistor are also included.

Figure 1 is a simplified flyback converter controlled by AP3706 with a 3-winding transformer: Primary winding (N_p), Secondary winding (N_s) and Auxiliary winding (N_AUX). The AP3706 senses the Auxiliary winding feedback voltage at FB pin and obtains power supply at VCC pin. In the circuit:

- \( V_{dri} \) is a simplified driving signal of primary transistor.
- \( I_p \) is the primary side current.
- \( I_s \) is the secondary side current.
- \( V_s \) is the voltage of secondary side.

Figure 2 shows the relatively ideal operation waveforms to illustrate some parameters used in the following design steps. The nomenclature of the parameters in Figure 2 are listed as below:

- \( T_{SW} \) is the period of switching frequency
- \( T_{onp} \) is the time of primary side “ON”
- \( T_{ons} \) is the time of secondary side “ON”
- \( T_{off} \) is the discontinuous time
- \( I_{pk} \) is the peak current of primary side
- \( I_{pks} \) is the peak current of secondary side
- \( V_s \) equals the sum of \( V_o \) and forward voltage of rectification diode

The only difference between AP3706 and AP3708N is cable compensation. AP3708N has built-in it, while AP3706 has not. Their design steps are quite similar.
Basic Design Step

Step 1: Select a Reasonable Ipk of Flyback Converter Using AP3706/08N

1-1. Calculate the Maximum Turn Ratio of the Transformer

The maximum turn ration of the transformer should be calculated first to ensure the system working in DCM under all working conditions, especially at the minimum input voltage and full load.

If the system meets equation (1) at minimum input voltage and full load, the circuit can work in DCM in all working conditions.

\[ T_{sw} \geq T_{onp} + T_{ons} \]  \hspace{1cm} \text{(1)}

For the primary side current,

\[ T_{onp} = Ipk \times \frac{L_M}{V_g} \]

where

- \( L_M \) is the inductance of primary winding.
- \( V_g \) is the rectified DC voltage of input.

When \( V_g \) is at the minimum value, the maximum \( T_{onp} \) can be obtained. So,

\[ T_{onp\_max} = Ipk \times \frac{L_M}{V_g\_min} \]  \hspace{1cm} \text{(2)}

For the secondary side current,

\[ T_{ons} = Ipks \times \frac{L_S}{V_s} \]  \hspace{1cm} \text{(3)}

where
L_S is the inductance of secondary winding.

\[ V_S = V_O + V_d \]  
Vd is the forward voltage of secondary diode.

For (3), in CV regulation, the \( V_S \) is a constant voltage, so \( T_{on} \) is a constant value with different input voltage.

In Flyback converter, the energy stored in the magnetizing inductance \( L_M \) when the primary transistor turns ON. So the power transferring from the input to the output is given by:

\[ P_{IN} = \frac{1}{2} L_M \times I_{pk}^2 \times f_{SW} \]  

......(4)

then,

\[ T_{SW} = \frac{1}{f_{SW}} \times \frac{L_M \times I_{pk}^2}{2 \times P_{IN}} \]

Substitute \( T_{SW}, T_{onp} \) and \( T_{ons} \) in equation (1) with (4), (2) and (3):

\[ \frac{L_M \times I_{pk}^2}{2 \times P_{IN}} \geq I_{PKS} \times \frac{L_M}{V_S} + I_{PK} \times \frac{L_M}{V_g \_\_min} \]

......(5)

Because the peak current and inductance of primary side and secondary side have the following relationship:

\[ I_{PKS} = N_{PS} \times I_P \]

......(6)

here, \( N_{PS} = N_P / N_S \) is the turn ratio of primary to secondary sides, then

\[ L_S = \frac{L_M}{N_{PS}^2} \]

......(7)

From (5), (6) and (7):

\[ I_P \geq \frac{1}{2 \times P_{IN}} \times \frac{1}{V_S \times N_{PS}} + \frac{1}{V_g} \]

......(8)

Because \( P_{IN} = \frac{V_O \times I_O}{\eta} \)

......(9)

where \( \eta \) is the system efficiency.

At the full load, the system will work in the boundary of CC regulation. \( I_O \) is determined by:

\[ I_O = \frac{1}{2} \times \frac{T_{ons}}{T_{SW}} \times I_{PKS} \]

Then, \( I_{PKS} \) can be defined as:

\[ I_{PKS} = k \times I_O \]

......(10)

In the design of AP3706/08N,

\[ k = \frac{2 \times T_{SW}}{T_{SW}} = 3.5 \]

With (8), (9) and (10), it can be obtained:

\[ N_{PS} \_\_min \leq V_g \_\_min \times \left( \frac{k \times \eta - \frac{1}{V_S}}{2 \times V_O} \right) \]

......(11)

So, the maximum turn ration of primary and secondary side can be obtained:

\[ N_{PS} \_\_MAX = V_g \_\_min \times \left( \frac{k \times \eta - \frac{1}{V_O + V_d}}{2 \times V_O} \right) \]

\( (k \approx 4) \)

......(12)

Because above calculations are all based on ideal conditions without considering power loss, k is given an approximately value 4 instead of the real value 3.5.

1-2. Calculate the Peak Current of Primary Side and Current Sense Resistor

\( I_{pk} \) can be calculated by the output current:

\[ I_{pk} = \frac{I_{PKS}}{N_{PS} \_\_MAX} = \frac{k \times I_O}{N_{PS} \_\_MAX} \]

......(13)

here, \( k = 4 \).

In AP3706/08N, 0.5V is an internal reference voltage. If the sensed voltage \( V_{CS} \) reaches to 0.5V, the
power transistor (APT13003 for this application) will be shut down and Tonp will be ended. So, R_CS can be calculated as:

$$R_{CS} = \frac{0.5V}{I_{pk}}$$  \hspace{1cm} \ldots (14)$$

Then, select R_CS with a real value from the standard resistor series. After R_CS determined, Ipk should be modified according to the selected R_CS.

**Step 2: Design Transformer**

2-1. Calculate the Inductance of Primary Side\textsuperscript{--}L_M

The primary side inductance L_M is relative with the stored energy. L_M should be big enough to store enough energy, so that P_O_max can be obtained from this system.

From equation (9), the output power can be obtained from:

$$P_O = \frac{1}{2} \times L_m \times I_{pk}^2 \times f_{SW} \times \eta$$  \hspace{1cm} \ldots (15)$$

Then, L_M is:

$$L_m = \frac{2 \times P_o}{I_{pk}^2 \times f_{SW} \times \eta}$$  \hspace{1cm} \ldots (16)$$

To achieve good overall system performance, the optimum switching frequency f_{SW} is recommended to be 50 to 60kHz under full load.

2-2. Re-calculate the Turn Ratio of Primary to Secondary Side--N_{PS}

From formula (13), the turn ratio of primary and secondary side N_{PS} should be re-calculated.

$$N_{PS} = \frac{k \times I_P}{I_{pk}} \hspace{1cm} (k = 4)$$  \hspace{1cm} \ldots (17)$$

2-3. Calculate the Turns of Primary, Secondary and Auxiliary Windings

First, select the reasonable core-type and \Delta B . Then, decide the turns of 3-winding transformer respectively.

The turns of primary winding is:

$$N_p = \frac{L_m \times I_{pk} \times 10^8}{Ae \times \Delta B}$$  \hspace{1cm} \ldots (18)$$

The turns of secondary winding is:

$$N_s = \frac{N_p}{N_{PS}}$$  \hspace{1cm} \ldots (19)$$

The turns of Auxiliary winding is:

$$N_{aux} = \frac{N_s \times V_{aux}}{V_s}$$  \hspace{1cm} \ldots (20)$$

here, V_{aux} can be set to its typical value 15V. V_s is equal to V_O + V_d. Ae can be obtained automatically after core-type is selected.

**Step 3: Select Diode and Primary Transistor**

3-1. Select Diodes of Secondary and Auxiliary Sides

Maximum reverse voltage of secondary side is:

$$V_{dr} = V_O + \frac{V_g \_\text{max} \times N_s}{N_p}$$  \hspace{1cm} \ldots (21)$$

Maximum reverse voltage of Auxiliary side is:

$$V_{dar} = V_{aux} + \frac{V_g \_\text{max} \times N_{aux}}{N_p}$$  \hspace{1cm} \ldots (22)$$

$$V_{dc \_\text{max}} = V_{dc \_\text{spike}} + V_g \_\text{max} + \frac{V_s \times N_p}{N_s}$$  \hspace{1cm} \ldots (23)$$

In (21) and (22), the maximum DC input voltage should be used.

3-2. Select the Primary Side Transistor

It should be noted that the value of V_{dc \_\text{spike}} will be different in circuits with different snubber.
Design Example

Design Specification

<table>
<thead>
<tr>
<th>Input Voltage</th>
<th>85 to 265 VAC</th>
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<tbody>
<tr>
<td>Output Voltage</td>
<td>VO=5.5V</td>
</tr>
<tr>
<td>Output Current</td>
<td>IO=0.5A</td>
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<tr>
<td>Efficiency</td>
<td>75%</td>
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Settings Selected by Users

<table>
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<tr>
<th>Frequency</th>
<th>fSW=55kHz</th>
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<tr>
<td>Forward Voltage</td>
<td>Vd=0.4V</td>
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<tr>
<td>Forward Voltage</td>
<td>Vda=1V</td>
</tr>
<tr>
<td>Feedback Voltage</td>
<td>VAUX=15V</td>
</tr>
<tr>
<td>Core type</td>
<td>EE16 (Ae=19.2mm²)</td>
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<tr>
<td>Core type</td>
<td>∆B=2850GS</td>
</tr>
<tr>
<td>Vdc_spike</td>
<td>200V</td>
</tr>
</tbody>
</table>

Design Step

Step 1: Select a Reasonable Ipk for the Flyback Converter Using AP3706

1-1. Calculate the Maximum Turn Ratio of the Transformer

\[ N_{PS, MAX} = \frac{V_g \cdot \text{min} \times \left( \frac{k \times \eta}{2 \times V_o} - \frac{1}{V_o + V_d} \right)}{V_o + V_d} \]  \( (k \approx 4) \)  \( \ldots (12) \)

\[ V_g \cdot \text{min} = V_{in, \text{min}} \times \sqrt{2} - 40 \]

\[ N_{PS, MAX} = 8.259 \]

1-2. Calculate the Peak Current of Primary Side and Current Sense Resistor

\[ Ipk = \frac{I_{PKS}}{N_{PS, MAX}} = \frac{k \times I_o}{N_{PS, MAX}} \]  \( \ldots (13) \)

\[ Ipk = 242mA \]

\[ R_{CS} = \frac{0.5V}{Ipk} \]  \( \ldots (14) \)

\[ R_{CS} \approx 2.1\Omega \]

Re-calculate peak current of primary side,

\[ Ipk = 238mA \]

Step 2: Design Transformer

2-1. Calculate the Inductance of Primary Side--\( L_M \)

\[ L_M = \frac{2 \times P_o}{Ipk^2 \times f_{SW} \times \eta} \]  \( \ldots (16) \)

\[ L_M = 2.35mH \]

2-2. Re-calculate the Turn Ratio of Primary to Secondary Side--\( N_{PS} \)

\[ N_{PS} = \frac{k \times I_o}{Ipk} \]  \( (k \approx 4) \)  \( \ldots (17) \)

\[ N_{PS} = 8.4 \]

2-3. Calculate the Turns of Primary, Secondary and Auxiliary Windings

\[ N_p = \frac{L_M \times Ipk \times 10^8}{Ae \times \Delta B} \]  \( \ldots (18) \)

\[ N_p = 102T \]

\[ N_s = \frac{N_p}{N_{PS}} \]  \( \ldots (19) \)

\[ N_s = 12T \]

\[ N_{AUX} = \frac{N_s \times V_{AUX}}{V_s} \]  \( \ldots (20) \)

\[ N_{AUX} = 31T \]
Step 3: Select Diode and Primary Transistor

3-1. Select Diodes of Secondary and Auxiliary Sides

Maximum reverse voltage of secondary side.

\[ V_{dr} = V_o + \frac{V_{g_{max}} \times N_S}{N_P} \] ......(21)

\[ V_{g_{max}} = V_{iS_{max}} \times \sqrt{2} \]

\[ V_{dr} = 50V \]

3-2. Select the Primary Side Transistor

Maximum reverse voltage of auxiliary side.

\[ V_{dar} = V_{acx} + \frac{V_{g_{max}} \times N_{aux}}{N_P} \] ......(22)

\[ V_{dar} = 129V \]

\[ V_{dc_{max}} = V_{dc_{spike}} + V_{g_{max}} \times \frac{V_S \times N_P}{N_S} \] ......(23)

\[ V_{dc_{max}} = 625V \]

Design Results Summary

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<td>Turns of Auxiliary Side</td>
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<tr>
<td>Maximum Reverse Voltage of Auxiliary Diode</td>
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<td>Voltage Stress of Primary Transistor</td>
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