Basic Steps to Design a PSR Flyback Converter Using AP3706/08N

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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:

Vdri 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
Tonp is the time of primary side "ON"
Tons is the time of secondary side "ON"
Toff is the discontinuous time
Ipk is the peak current of primary side
Ipks 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.

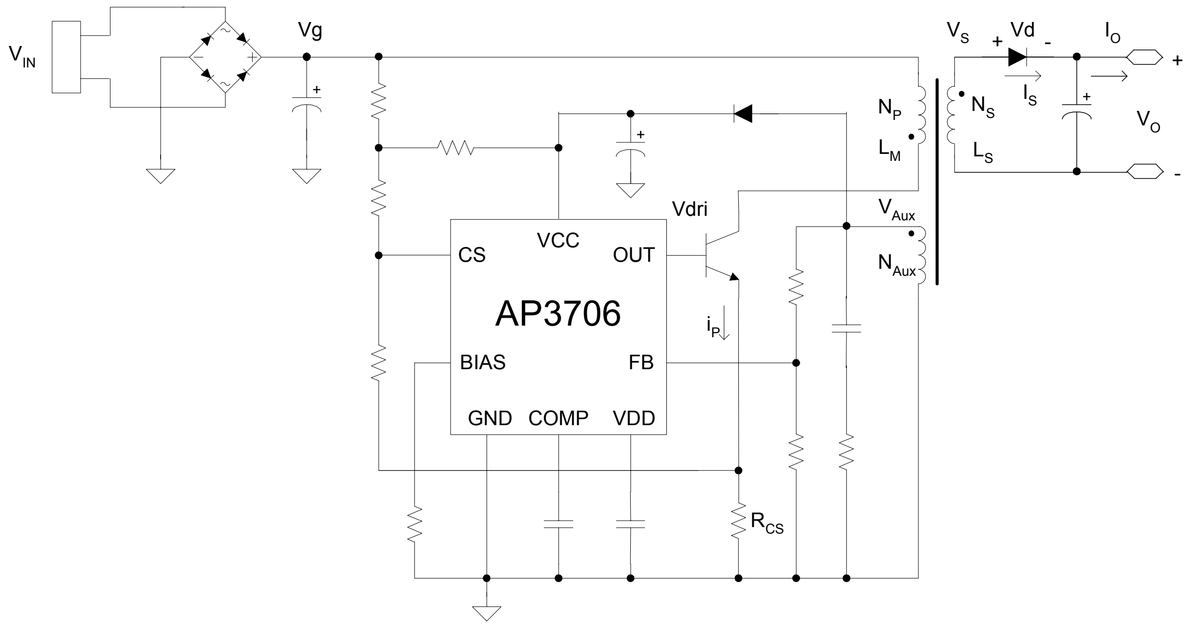

Figure 1. Simplified Flyback Converter Using AP3706

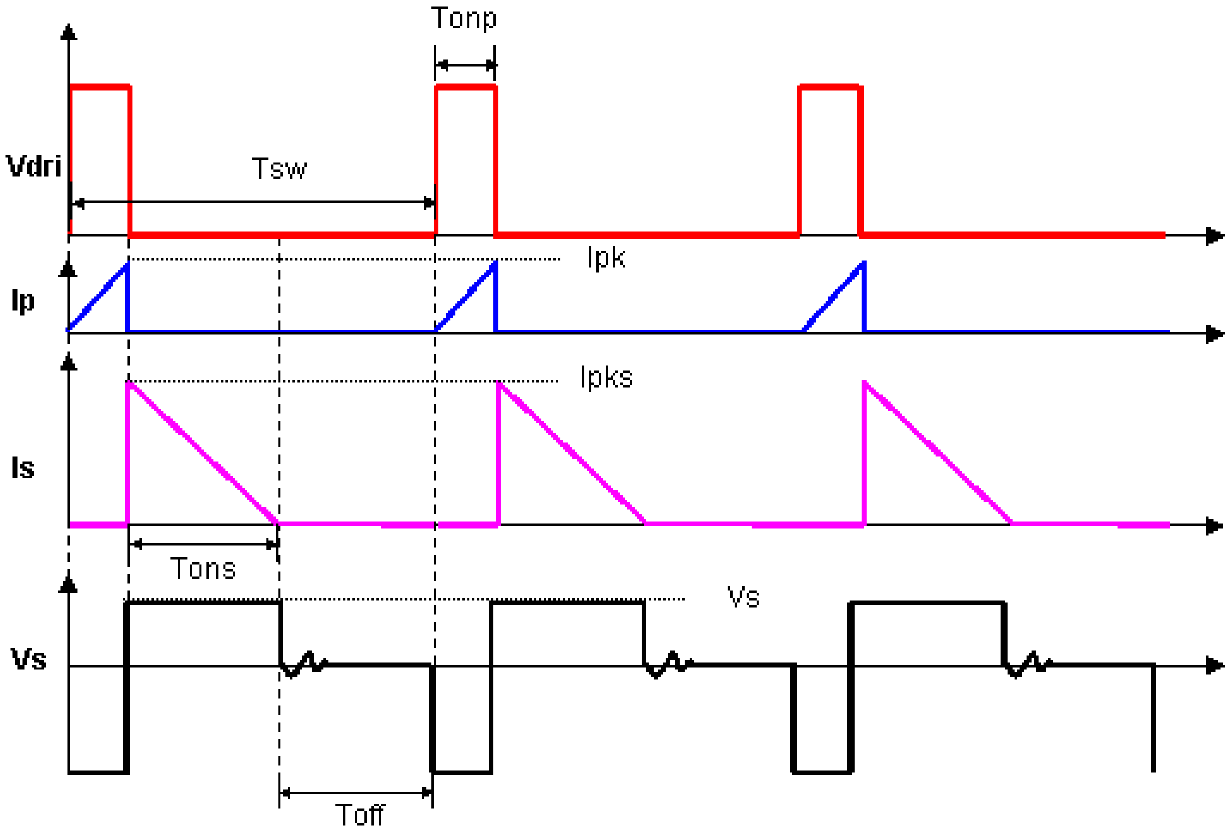

Figure 2. Ideal Operation Waveforms for a Simplified Flyback Converter

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.

$$T_{SW} \geqslant Tonp + Tons \qquad \text{......(1)}$$

For the primary side current,

$$Tonp = Ipk \times \frac{L_M}{Vg}$$

where

L_M is the inductance of primary winding.

Vg is the rectified DC voltage of input.

When Vg is at the minimum value, the maximum Tonp can be obtained. So,

$$Tonp\_\max = Ipk \times \frac{L_M}{Vg\_\min} \qquad \text{......(2)}$$

For the secondary side current,

$$Tons = Ipks \times \frac{L_S}{V_S} \qquad \text{......(3)}$$

where

L_S is the inductance of secondary winding.

$V_S=V_O+Vd$, Vd is the forward voltage of secondary diode.

For (3), in CV regulation, the V_S is a constant voltage, so Tons 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:

$$P_{IN}=\frac{1}{2}\times L_M\times Ipk^2\times f_{SW} \qquad ......(4)$$

then,

$$T_{SW}=\frac{1}{f_{SW}}=\frac{L_M\times Ipk^2}{2\times P_{IN}}$$

Substitute T_{SW}, Tonp and Tons in equation (1) with (4), (2) and (3):

$$\frac{L_M\times Ipk^2}{2\times P_{IN}}\geqslant Ipks\times\frac{L_S}{Vs}+Ipk\times\frac{L_M}{Vg\_min}$$

......(5)

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

$$Ipks=N_{PS}\times Ipk \qquad ......(6)$$

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

$$L_S=\frac{L_M}{N_{PS}^2} \qquad ......(7)$$

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

$$\frac{Ipk}{2\times P_{IN}}\geqslant\frac{1}{V_S\times N_{PS}}+\frac{1}{Vg} \qquad ......(8)$$

Because

$$P_{IN}=\frac{V_O\times I_O}{\eta} \qquad ......(9)$$

where η is the system efficiency.

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

$$I_O=\frac{1}{2}\times\frac{Tons}{T_{SW}}\times Ipks$$

Then, Ipks can be defined as:

$$Ipks=k\times I_O \qquad ......(10)$$

In the design of AP3706/08N,

$$k=\frac{2\times T_{SW}}{Tons}=3.5$$

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

$$N_{PS}\leqslant Vg\_\min\times(\frac{k\times\eta}{2\times V_O}-\frac{1}{V_S}) \qquad ......(11)$$

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

$$N_{PS\_MAX}=Vg\_\min\times(\frac{k\times\eta}{2\times V_O}-\frac{1}{V_O+Vd})$$

$$(k\approx 4)$$

......(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

Ipk can be calculated by the output current:

$$Ipk=\frac{Ipks}{N_{PS\_MAX}}=\frac{k\times I_O}{N_{PS\_MAX}} \qquad ......(13)$$

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:

$$R_{CS} = \frac{0.5V}{Ipk} \quad ......(14)$$

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---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:

$$P_O = \frac{1}{2} \times L_M \times Ipk^2 \times f_{SW} \times \eta \quad ......(15)$$

Then, L_M is:

$$L_M = \frac{2 \times P_O}{Ipk^2 \times f_{SW} \times \eta} \quad ......(16)$$

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.

$$N_{PS} = \frac{k \times I_O}{Ipk} \quad (k \approx 4) \quad ......(17)$$

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

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

The turns of primary winding is:

$$N_P = \frac{L_M \times Ipk \times 10^8}{Ae \times \Delta B} \quad ......(18)$$

The turns of secondary winding is:

$$N_S = \frac{N_P}{N_{PS}} \quad ......(19)$$

The turns of Auxiliary winding is:

$$N_{AUX} = \frac{N_S \times V_{AUX}}{V_S} \quad ......(20)$$

here,
V_{AUX} can be set to its typical value 15V.
Vs is equal to V_O+Vd.
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:

$$Vdr = V_O + \frac{Vg\_\max \times N_S}{N_P} \quad ......(21)$$

Maximum reverse voltage of Auxiliary side is:

$$Vdar = V_{AUX} + \frac{Vg\_\max \times N_{AUX}}{N_P} \quad ......(22)$$

$$Vdc\_\max = Vdc\_spike + Vg\_\max + \frac{V_S \times N_P}{N_S} \quad ......(23)$$

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 Vdc_spike will be different in circuits with different snubber.

Design Example

Design Specification

Input Voltage	85 to 265 VAC
Output Voltage	V_O=5.5V
Output Current	I_O=0.5A
Efficiency	75%

Settings Selected by Users

Switching Frequency	f_{SW}=55kHz
Forward Voltage of Secondary Diode	Vd=0.4V
Forward Voltage of Auxiliary Diode	Vda=1V
Feedback Voltage of Auxiliary Winding	V_{AUX}=15V
Core_type	EE16 (Ae=19.2mm^2)
ΔB	ΔB=2850GS
Vdc_spike	200V

Design Step

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

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

$$N_{PS\_MAX} = Vg\_\min \times \left(\frac{k\times\eta}{2\times Vo} - \frac{1}{Vo+Vd}\right) \quad \text{......(12)}$$

$(k \approx 4)$

$$Vg\_\min = V_{IN}\_\min \times \sqrt{2} - 40$$

$$N_{PS\_MAX} = 8.259$$

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

$$Ipk = \frac{Ipks}{N_{PS\_MAX}} = \frac{k\times I_O}{N_{PS\_MAX}} \quad \text{......(13)}$$

$$Ipk = 242mA$$

$$R_{CS} = \frac{0.5V}{Ipk} \quad \text{......(14)}$$

$$R_{CS} \approx 2.1\Omega$$

Re-calculate peak current of primary side,

$$Ipk = 238mA$$

Step 2: Design Transformer

2-1. Calculate the Inductance of Primary Side---L_M

$$L_M = \frac{2\times P_O}{Ipk^2 \times f_{SW} \times \eta} \quad \text{......(16)}$$

$$L_M = 2.35mH$$

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

$$N_{PS} = \frac{k\times I_O}{Ipk} \ (k \approx 4) \quad \text{......(17)}$$

$$N_{PS} = 8.4$$

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

$$N_P = \frac{L_M \times Ipk \times 10^8}{Ae \times \Delta B} \quad \text{......(18)}$$

$$N_P = 102T$$

$$N_S = \frac{N_P}{N_{PS}} \quad \text{......(19)}$$

$$N_S = 12T$$

$$N_{AUX} = \frac{N_S \times V_{AUX}}{V_S} \quad \text{......(20)}$$

$$N_{AUX} = 31T$$

Step 3: Select Diode and Primary Transistor

3-1. Select Diodes of Secondary and Auxiliary Sides

Maximum reverse voltage of secondary side.

$$Vdr = V_O + \frac{Vg\_max \times N_S}{N_P} \quad \text{......(21)}$$

$$Vg\_max = V_{IN}\_max \times \sqrt{2}$$

$$Vdr = 50V$$

Maximum reverse voltage of secondary side.

$$Vdar = V_{AUX} + \frac{Vg\_max \times N_{AUX}}{N_P} \quad \text{......(22)}$$

$$Vdar = 129V$$

3-2. Select the Primary Side Transistor

$$Vdc\_max = Vdc\_spike + Vg\_max + \frac{V_S \times N_P}{N_S} \quad \text{......(23)}$$

$$Vdc\_max = 625V$$

Design Results Summary

1. Calculate the Maximum Peak Current of Primary Side and R_{CS}	
Peak Current of Primary Side	Ipk=238mA
Current Sense Resistor	R_{CS}=2.1Ω
2. Design Transformer	
Inductance of Primary Side	L_M=2.35mH(+/-8%)
Turn Ratio of Primary to Secondary Windings	N_{PS}=8.4
Turns of Primary Side	N_P=102T
Turns of Secondary Side	N_S=12T
Turns of Auxiliary Side	N_{AUX}=31T
3. Select Diode and Primary Transistor	
Maximum Reverse Voltage of Secondary Diode	Vdr=50V
Maximum Reverse Voltage of Auxiliary Diode	Vdar=129V
Voltage Stress of Primary Transistor	Vdc_max=625V