

## Design and Application Notes for AP3768 System Solution

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### 1. Introduction

The AP3768 is the generation II Primary Side Regulation (PSR) controller, which uses Pulse Frequency Modulation (PFM) method to realize Discontinuous Conduction Mode (DCM) operation for flyback power supplies.

The AP3768 can provide accurate constant voltage, constant current (CV/CC) regulation. In order to achieve the excellent voltage regulation, AP3768 has a programmable cable voltage drop compensation function to accommodate various cables with different gauges and lengths.

The AP3768 can also achieve ultra-low standby power due to its PFM operation and an innovative ultra-low startup current technique. Less than 30mW standby power can be obtained to meet five-star charger criteria with AP3768 system solution.

A typical AP3768 application circuit is shown in Figure 1. And the design guidelines can be classified to the following sections.

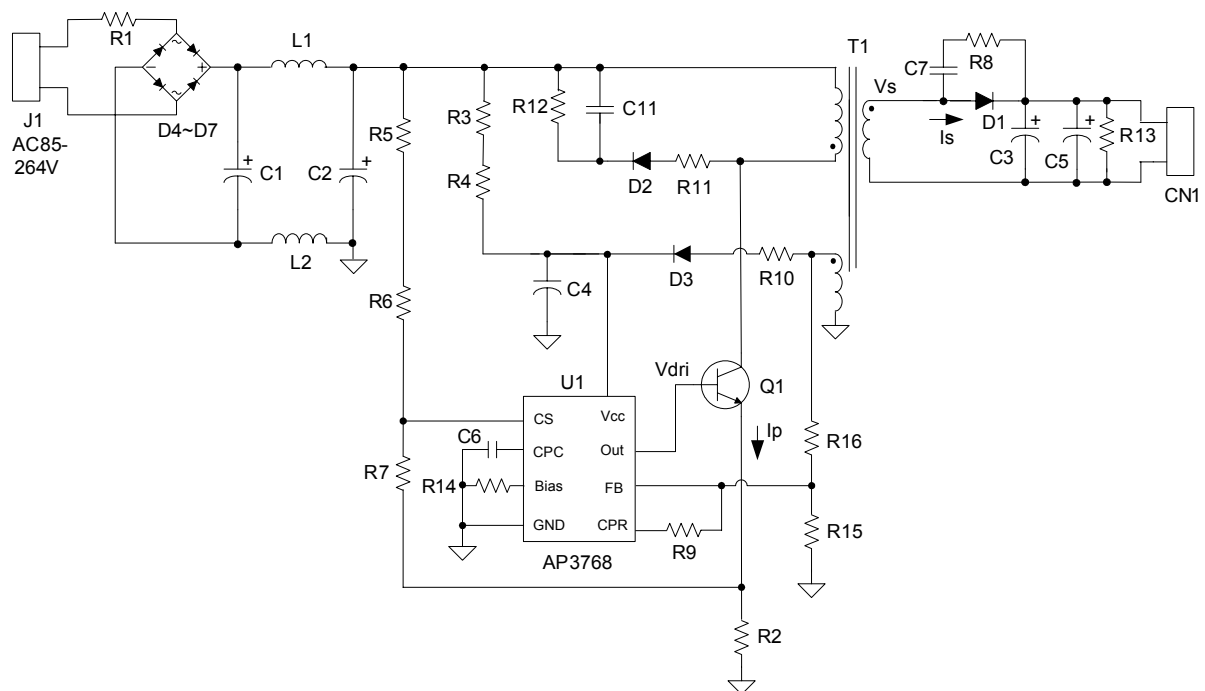


Figure 1. Typical Schematic of AP3768 Solution

### 1.1 Low Standby Power Design

The tradeoff between the low standby power and the output overshoot at no load should be considered during the selection of the dummy resistor R13. In order to achieve less than 30mW standby power while having an acceptable output voltage rise at no load, 5.1k to 10k is recommended for R13. The power consumed in the startup resistors (R3+R4) and the resistors (R5+R6) for CC line compensation also becomes considerable in no load or light load conditions. So 10M to 13M resistance is recommended for the sum of R3 and R4 considering the target of less than 30mW standby power and less than 3S turn-on delay time. And the bias capacitor C4 is recommended as 1 $\mu$ F to 1.5 $\mu$ F accordingly. Meanwhile, normally 30M resistance is suggested for the sum of R5 plus R6. After that, R7 can be adjusted to achieve an optimal CC line compensation.

### 1.2 Transformer Design

Figure 1 describes a flyback converter controlled by AP3768 with a 3-winding transformer---primary winding ( $N_p$ ), secondary winding ( $N_s$ ) and auxiliary

winding ( $N_a$ ) for bias power and output voltage detecting. The AP3768 senses the auxiliary winding feedback voltage at FB pin and obtains power supply at VCC pin. In Figure 2, a series of relative ideal operation waveforms are given to illustrate some parameters used in following design steps. And the nomenclature of the parameters in Figure 2 is as the following:

$V_{dri}$ ---a simplified driving signal of primary transistor  
 $I_p$ ---the primary side current  
 $I_s$ ---the secondary side current  
 $V_s$ ---the secondary side voltage  
 $T_{sw}$ ---the switching period of frequency  
 $F_{sw}$ ---the switching frequency  
 $t_{onp}$ ---the time of primary side "ON"  
 $t_{ons}$ ---the time of secondary side "ON"  
 $t_{off}$ ---the discontinuous time  
 $I_{pk}$ ---peak current of primary side  
 $I_{pks}$ ---peak current of secondary side  
 $V_{ds}$ ---the sum of  $V_o$  and the forward voltage drop of rectification diode

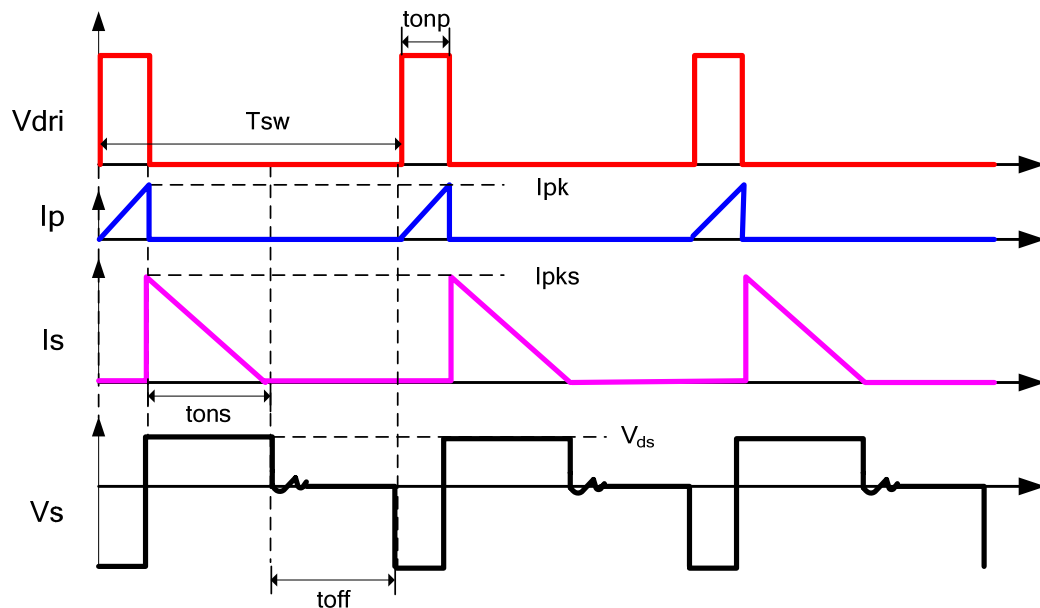


Figure 2. Operation Waveforms

**Design Steps:**
**Step 1. Select a Reasonable  $I_{pk}$  for the Flyback Converter with AP3768**
**1-1. Calculate the Maximum Turn Ratio of XFMR**

The maximum turn ratio of transformer should be designed first, which is to ensure that the system should work in DCM in all working conditions, especially at the minimum input voltage and full load.

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

$$T_{SW} \geq t_{onp} + t_{ons} \quad (1)$$

For the primary side current,

$$t_{onp} = I_{pk} \frac{L_p}{V_{indc}} \quad (2)$$

Where  $L_p$  is the inductance of primary winding.  
 $V_{indc}$  is the rectified DC voltage of input.

When  $V_{indc}$  is the minimum value, the maximum  $t_{onp}$  can be obtained. So,

$$t_{onp\_max} = I_{pk} \frac{L_p}{V_{indc\_min}} \quad (3)$$

For the secondary side current,

$$t_{ons} = I_{pks} \frac{L_s}{V_s} \quad (4)$$

In (4),  $L_s$  is the inductance of secondary winding.

$V_s = V_O + V_d$ ,  $V_d$  is the forward voltage drop of the secondary diode.

For (3), in CV regulation, the  $V_s$  is a constant voltage, so  $t_{ons}$  is a constant value with different input voltage.

In the flyback converter, when the primary transistor turns ON, the energy is stored in the magnetizing inductance  $L_p$ . So the power transferring from the input to the output is given by,

$$P_{in} = \frac{1}{2} L_p I_{pk}^2 f_{SW}$$

Then,

$$T_{SW} = \frac{L_p I_{pk}^2}{2P_{in}} \quad (5)$$

$T_{SW}$ ,  $t_{onp}$  and  $t_{ons}$  in (1) are replaced with (5), (3) and (4),

$$\frac{L_p I_{pk}^2}{2P_{in}} \geq I_{pks} \frac{L_s}{V_s} + I_{pk} \frac{L_p}{V_{indc\_min}} \quad (6)$$

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

$$I_{pks} = n_{ps} \times I_{pk} \quad (7)$$

$$L_s = \frac{L_p}{n_{ps}^2} \quad (8)$$

Where  $n_{ps}$  is the turn ratio of primary winding to the secondary winding.

With (6), (7) and (8), then,

$$\frac{I_{pk}}{2P_{in}} \geq \frac{I}{V_s n_{ps}} + \frac{I}{V_{in}} \quad (9)$$

Because,

$$P_{in} = \frac{V_O I_O}{\eta} \quad (10)$$

Where  $\eta$  is the system efficiency.

At maximum load, the system will work in the boundary between CV and CC stages.  $I_O$  can be given by,

$$I_O = \frac{I}{2} \times \frac{t_{ons}}{T_{SW}} - I_{pks}$$

Then,  $I_{pks}$  can be defined,

$$I_{pks} = k I_O \quad (11)$$

In the design of AP3768,

$$k = \frac{2T_{SW}}{t_{ons}} = 3.5$$

So it can be obtained,

$$n \leq V_{indc\_min} \left( \frac{k \times \eta}{2V_O} - \frac{I}{V_S} \right) \quad (12)$$

Therefore, the maximum turn ratio of primary and secondary side can be obtained.

$$N \leq V_{indc\_min} \left( \frac{k \times \eta}{2V_O} - \frac{I}{V_O + V_d} \right) \quad (13)$$

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

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

$I_{pk}$  can be calculated by the output current.

$$I_{pk} = \frac{I_{pks}}{n_{ps}} = \frac{k \times I_O}{n_{ps}} \quad (14)$$

Here,  $k=4$

$n_{ps}$  is the calculated value of  $n_{max}$ .

In AP3768, 0.5V is an internal reference voltage. If the sensed voltage  $V_{CS}$  reaches 0.5V, the power transistor APT13003E will be shut down and  $t_{onp}$  will be ended.

$$R_{CS} = \frac{0.5V}{I_{pk}} \quad (15)$$

So  $R_{CS}$  can be obtained from equation (15) and selected with a real value from the standard resistor series. After  $R_{CS}$  is selected,  $I_{pk}$  should be modified based on the selected  $R_{CS}$ .

From now on,  $I_{pk}$  and  $R_{CS}$  have been designed.

## Step 2. Design Transformer

### 2-1. Calculation of the Primary Side Inductance --- $L_P$

The primary side inductance  $L_P$  is relative with the stored energy.  $L_P$  should be big enough to store enough energy, so that  $P_{o\_Max}$  can be obtained from this system.

From formula (10), the output power can be given by,

$$P_O = \frac{I}{2} L_P I_{pk}^2 f_{SW} \eta \quad (16)$$

Then,  $L_P$  can be got by,

$$L_P = \frac{2P_O}{I_{pk}^2 f_{SW} \eta} \quad (17)$$

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

### 2-2. Re-calculate the Turn Ratio of Primary and Secondary Sides--- $n_{ps}$

From formula (14), the turn ratio of primary and secondary side n can be re-calculated.

$$n_{ps} = \frac{k \cdot I_O}{I_{pk}} (k = 4) \quad (18)$$

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

First, the reasonable core-type and  $\Delta B$  should be selected. Then, the turns of 3-winding transformer can be obtained respectively.

The turn of primary winding,

$$N_P = \frac{L_P I_{pk} 10^8}{Ae \times \Delta B} \quad (19)$$

The turn of secondary winding,

$$N_S = \frac{N_P}{n_{ps}} \quad (20)$$

The turn of auxiliary winding,

$$N_A = \frac{N_S V_A}{V_S} \quad (21)$$

Here,  $V_A$  can be set a typical value of 20V.

$V_S$  is equal to  $V_O + V_d$ .

$Ae$  can be gotten automatically after core-type is selected.

## Step 3. Select Diode and Primary Transistor

### 3-1. Select Diodes of Secondary and Auxiliary Sides

Max. reverse voltage of secondary side

$$V_{dr} = V_O + \frac{V_{indc\_max} N_S}{N_P} \quad (22)$$

Max. reverse voltage of auxiliary side,

$$V_{dar} = V_A + \frac{V_{indc\_max} N_A}{N_P} \quad (23)$$

In (22) and (23), the maximum DC input voltage should be used.

### 3-2. Select the Primary Side Transistor

$$V_{dc\_max} = V_{dc\_spike} + V_{indc\_max} + \frac{V_S N_P}{N_S} \quad (24)$$

Be careful that the value of  $V_{dc\_spike}$  will be varied with different snubber circuit.

### 1.3 Output Cable Voltage Drop Compensation

The AP3768 has a programmable cable compensation function which can precisely offset the voltage drop on different cables with various gauges and lengths, and thus ensure good output voltage regulation.

The external output cable voltage drop compensation circuitry of AP3768 is shown in Figure 3. The AP3768 senses the auxiliary winding feedback voltage at FB pin and operates in constant-voltage (CV) mode to regulate the output voltage. In CV mode, FB pin voltage  $V_{FB}$  is a constant of 4.0V.

The CPR pin voltage  $V_{CPR}$  is generated by the internal circuit of AP3768. It linearly decreases with the rise of the output load directly. Then  $V_{CPR}$  is shown as below:

$$V_{CPR} = 3.08 - 2.75 \times D_{ons} \quad (25)$$

Where  $D_{ons}$  is the duty cycle of secondary diode, and is equal to  $T_{ons}/T_{sw}$ , which is directly proportional to the output loading. The maximum  $D_{ons}$  is 4/7 and the minimal  $D_{ons}$  is close to zero in CV mode of AP3768, so the minimum of  $V_{CPR}$  is about 1.5V and the maximal  $D_{ons}$  is about 3V.

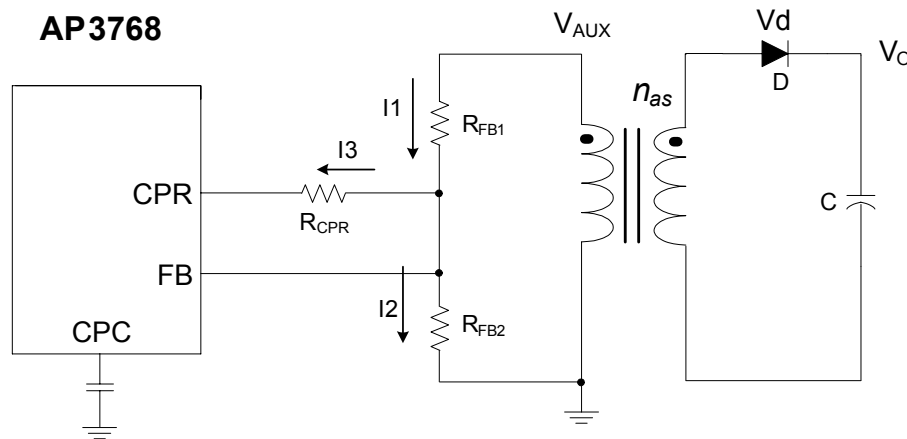


Figure 3. Output Cable Compensation Circuit

From the resistor network shown in figure 3, the current through  $R_{FB1}$  is equal to the sum of current through  $R_{FB2}$  and  $R_{CPR}$ :

$$I_1 = I_2 + I_3 \quad (26)$$

So equation (27) can be obtained:

$$\frac{V_{FB} - V_{CPR}}{R_{CPR}} + \frac{V_{FB}}{R_{FB2}} = \frac{V_{AUX} - V_{FB}}{R_{FB1}} \quad (27)$$

Then  $V_{AUX}$  can be calculated as:

$$V_{AUX} = \left(1 + \frac{R_{FB1}}{R_{FB2}} + \frac{R_{FB1}}{R_{CPR}}\right) \times V_{FB} - \frac{R_{FB1}}{R_{CPR}} \times V_{CPR} \quad (28)$$

Because of the relation between  $V_O$  and  $V_{AUX}$  shown in figure 3, the output voltage can be given by:

$$V_o = \left(1 + \frac{R_{FB1}}{R_{FB2}} + \frac{R_{FB1}}{R_{CPR}}\right) \times \frac{V_{FB}}{n_{AS}} - V_d - \frac{R_{FB1}}{R_{CPR} \times n_{AS}} \times V_{CPR} \quad (29)$$

In equation (29),  $n_{AS}$  is the turn ratio of auxiliary winding to the secondary winding. It is obvious that  $V_O$  linearly increases with the decrease of  $V_{CPR}$ . Since  $V_{CPR}$  linearly decreases with the rise of output load,  $V_O$  will linearly increase with the rise of the output load, which is just what the output cable voltage drop compensation requires.

From equation (26) and (29), the cable voltage drop compensation is got:

$$\Delta V_O = 2.75 \times \frac{R_{FB1}}{R_{CPR}} \times \Delta D_{ons} \times \frac{1}{n_{AS}} \quad (30)$$

Generally it is recommended that  $n_{AS}$  is designed to make sure  $T_{ons}/T_{sw}$  is about 4/7 at full load condition. Thus the maximum compensation voltage  $\Delta V_O$  will occur at the full load and equation (30) can be simplified as:

$$\Delta V_O = 1.57 \times \frac{R_{FB1}}{R_{CPR}} \times \frac{I}{n_{AS}} \quad (31)$$

$R_{CPR}$  can be calculated as equation (32).

$$R_{CPR} = 1.57 * \frac{R_{FB1}}{n_{AS} \times \Delta V_O} \quad (32)$$

From equation (32), for the fixed transformer turn ratio  $n_{AS}$ , the compensation voltage can be easily adjusted to accommodate different cables with various gauges and lengths by changing the value of  $R_{CPR}$ . Meanwhile, the upper feedback resistor  $R_{FB1}$  may also need a slight adjustment to keep the same output voltage precisely.

Considering the limitation of sinking current of the pin CPR, 10k $\Omega$  or above is recommended for  $R_{CPR}$ .  $R_{FB1}$  and  $R_{FB2}$  should be chosen correspondingly based on this restriction. And the recommended value of  $R_{FB2}$  is above 5k $\Omega$ .

#### 1.4 Design Example

Specification:

Input voltage: 85V<sub>AC</sub>-265V<sub>AC</sub>

Output voltage:  $V_O=5.5V$

Output current:  $I_O=0.5A$

Efficiency: 75%

Switching frequency:  $f_{sw}=60kHz$

Forward voltage of secondary diode:  $V_d=0.4V$

Forward voltage of auxiliary diode:  $V_{da}=1V$

Feedback voltage of auxiliary winding:  $V_a=15V$

Core\_type: EE16 ( $A_e=19.2mm^2$ )

$\Delta B: \Delta B=2450GS$

$V_{dc\_spike}=100V$  (with snubber circuit)

Output cable: 28AWG, 1.5m long, 0.214 $\Omega/m$

Secondary diode turns on duty cycle:  $D_{ons} = 4/7$

Feedback resistor:  $R_{FB1} = 33K$

#### Design Steps:

#### Step 1. A Reasonable $I_{pk}$ of Flyback with AP3768 Should be Designed

##### 1-1. Calculate the Max. Turn Ratio of XFMR

$$N_{MAX} = V_{indc\_min} \left( \frac{k \times \eta}{2V_O} - \frac{1}{V_O + V_d} \right) (k \approx 4)$$

$$V_{indc\_min} = V_{inac\_min} \times \sqrt{2} - 40$$

$$N_{MAX} = 8.259$$

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

$$I_{pk} = \frac{I_{pks}}{N} = \frac{k \times I_O}{N}$$

$$I_{pk\_max} = 242mA$$

Sensed current resistor,

$$R_{CS} = \frac{0.5V}{I_{pk}}$$

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

Re-calculate peak current of primary side,

$$I_{pk\_max} = 238mA$$

#### Step 2. Design Transformer

##### 2-1. Calculation of the Inductance of Primary Side--- $L_p$

$$L_p = \frac{2P_O}{I_{PK}^2 f_{sw} \eta}$$

$$L_p = 2.16mH$$

##### 2-2. Re-calculate the Turn Ratio of Primary and Secondary Side--- $N$

$$N = \frac{k \cdot I_O}{I_{pk}} (k \approx 4)$$

$$N = 8.4$$

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

The turns of primary winding,

$$N_p = \frac{L_p I_{pk} 10^8}{Ae \times \Delta B}$$

$$N_p = 109N$$

The turns of secondary winding,

$$N_s = \frac{N_p}{N}$$

$$N_s = 13T$$

The turns of auxiliary winding,

$$N_A = \frac{N_s V_A}{V_S}$$

$$N_A = 35T$$

### Step 3. Select Diode and Primary Transistor

#### 3-1. Select Diodes of Secondary and Auxiliary Sides

Maximum reverse voltage of secondary side

$$V_{dr} = V_O + \frac{V_{indc\_max} N_s}{N_p}$$

$$V_{dr} = 50V$$

Max. reverse voltage of auxiliary side

$$V_{dar} = V_A + \frac{V_{indc\_max} N_A}{N_p}$$

$$V_{dar} = 135V$$

#### 3-2. Select Primary Side Transistor

$$V_{dc\_max} = V_{dc\_spike} + V_{indc\_max} + \frac{V_S N_p}{N_s}$$

$$V_{dc\_max} = 448V$$

### Step 4. Select Reasonable Cable Compensation Resistor R<sub>CPR</sub>

#### 4-1. Calculation of Voltage Drop on Cable

Resistor of 1.5m 28AWG cable:

$$R_{cab} = 0.214 \times 2 \times 1.5 = 0.642\Omega$$

Voltage drop on cable:

$$\Delta V = R_{cab} * I_O = 0.642 \times 0.5 = 0.32V$$

#### 4-2. Calculation of R<sub>CPR</sub>

The turns ratio of auxiliary winding to secondary winding:

$$n_{AS} = \frac{N_A}{N_s} \approx 2.7$$

Because transformer is designed to make sure that on full load condition, T<sub>ONS</sub>/T<sub>SW</sub> is 4/7, the R<sub>CPR</sub> can be calculated by equation (32)

$$R_{CPR} = \frac{1.57 \times 33k}{2.7 \times 0.32} = 60k$$

### Design Results Summary:

1. Calculate the Maximum Peak Current of Primary Side and Rcs			
Ipk=	238	mA	Peak current of primary side
Rcs=	2.1	Ω	Current sensed resistor
2. Design Transformer			
Lp=	2.16	mH (±8%)	Inductance of primary side
N=	8.4		Turn ratio of primary and secondary
Np=	109	T	Turns of primary side
Ns=	13	T	Turns of secondary side
Na=	35	T	Turns of auxiliary side
3. Select Diode and Primary Transistor			
Vdr=	50	V	Maximum reverse voltage of secondary diode
Vdar=	135	V	Maximum reverse voltage of auxiliary diode
Vdc_max=	448	V	Voltage stress of primary transistor
4. Select			
R <sub>CPR</sub> =	60	kΩ	Cable compensation resistor