Designing an off-line power supply involves many aspects of electrical engineering: analog and digital circuits, bipolar and MOS power device characteristics, magnetics, thermal considerations, safety requirements, control loop stability, etc. This represents an enormous challenge involving complex trade-offs with a large number of design variables. As a result, new off-line power supply development has always been tedious and time consuming even for the experts in the field. This application note introduces a simple, yet highly efficient methodology for the design of TOPSwitch-GX family based off-line power supplies. For TOPSwitch-GX Flyback designs, Power Integrations recommends the use of PI Expert which implements this design methodology and also includes a knowledge base and optimization feature for making key design choices, further reducing design time.

**Introduction**

The design of a switching power supply, by nature, is an iterative process with many variables requiring adjustment to optimize the design. The design method described in this document consists of two major sections: A design flow chart and a step-by-step design procedure. The flow chart shows the design sequence at a conceptual level for TOPSwitch-GX flyback power supply design. The step-by-step procedure gives details within each step of the design flow chart, including empirical design guidelines and look-up tables. All key equations and guidelines are provided wherever possible to assist the readers in better understanding and/or further optimization.

**Basic Circuit Configuration**

Because of the high level integration of TOPSwitch-GX, many power supply design issues are resolved in the chip. Far fewer issues are left to be addressed externally, resulting in one common circuit configuration for all applications. Different output power levels may require different values for some circuit components, but the circuit configuration stays unchanged. TOPSwitch-GX is a feature-rich product family. Advanced features like under-voltage, overvoltage, external \( I_{\text{LIMIT}} \), line feed forward, and remote ON/OFF are easily implemented with a minimal number of external components, but do involve additional design considerations. Please refer to the TOPSwitch-GX data sheet for details. Other application

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Figure 1. Typical TOPSwitch-GX Flyback Power Supply.
specific issues such as constant current, constant power outputs, etc. are beyond the scope of this application note. However, such requirements may be satisfied by adding additional circuitry to the basic converter configuration. The only part of the circuit configuration that may change from application to application is the feedback circuitry. Depending on the power supply output specifications, one of the four feedback circuits, shown in Figures 3, 4, 5 and 6, will be chosen for the application.

The basic circuit configuration used in TOPSwitch-GX flyback power supplies is shown in Figure 1, which also serves as the reference circuit for component identifications used in the description throughout this application note.

**Design Flow**

Figures 2A, 2B and 2C present a design flow chart showing the complete design procedure in 37 steps. With the basic circuit configuration shown in Figure 1 as its foundation, the logic behind this design approach can be summarized as follows:

1. Determine system requirements and decide on feedback circuit accordingly.
2. Choose the smallest TOPSwitch-GX capable of the required output power.
3. Design the smallest transformer for the TOPSwitch-GX chosen.
4. Select all other components in Figure 1 to complete the design.
Figure 2B. TOPSwitch-GX Design Flow Chart. Step 12 to 28.

12. Determine \( L_p \)

13. Choose Core & Bobbin
   Determine \( A_e, L_p, A_L, BW \)

14. Set \( N_p, L \)

15. Calculate \( N_p, N_B \)

16. Calculate \( OD, DIA, AWG \)

17. Calculate \( B_M \)

18. \( B_M \leq 3000 \)

19. Calculate \( L_{sp}, CMA \)

20. \( L_{sp} \geq 0.10 \) mm

21. \( 200 \leq CMA \leq 500 \)

22. \( N_p, L \) Iterated

23. \( B_p \leq 4200 \)

24. Calculate \( I_{SP} \)

25. Calculate \( I_{RMS} \)

26. Calculate \( OD_{sp}, DIA_{sp}, AWG_{sp} \)

27. Calculate \( I_{RIPPLE} \)

28. Calculate \( PIV_{sp}, PIV_B \)

To Step 10

Step 12-28
Design the Smallest Transformer to work with the TOPSwitch-GX Chosen

From Step 11

22. \( N_p, L \) Iterated

To Step 29
Figure 2C. TOPSwitch-GX Design Flow Chart. Step 29 to 37.

The overriding objective of this procedure is “design for cost effectiveness.” Using smaller components usually leads to a less expensive power supply. However, for applications with stringent size or weight limitations, the designer may need to strike a compromise between cost and specific design requirements in order to achieve the optimum cost effectiveness for the end product.
Step-by-Step Design Procedure

This design procedure uses the PI Expert design software (available from Power Integrations), which contains all the important equations required for a TOPSwitch-GX flyback power supply design, and automates most calculations. Designers are, therefore, relieved from the tedious calculations involved in the complicated and highly iterative design process. Look-up tables and empirical design guidelines are provided in this procedure where appropriate to facilitate the design task.

Step 1. Determine system requirements: \( V_{ACMAX}, V_{ACMIN}, f_L, V_o, P_o, \eta, Z \)

- Minimum AC input voltage, \( V_{ACMIN} \): in volts.
- Maximum AC input voltage, \( V_{ACMAX} \): in volts.
- Recommended AC input ranges:

<table>
<thead>
<tr>
<th>Input (VAC)</th>
<th>( V_{ACMIN} ) (VAC)</th>
<th>( V_{ACMAX} ) (VAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal</td>
<td>85</td>
<td>265</td>
</tr>
<tr>
<td>230 or 115 with doubler</td>
<td>195</td>
<td>265</td>
</tr>
</tbody>
</table>

*Over 10% to 100% Load Range.

Table 1.

- Line frequency, \( f_L \): 50 Hz or 60 Hz.
- Output voltage, \( V_o \): in Volts.
- Output power: \( P_o \): in Watts.

- Power supply efficiency, \( \eta \): 0.8 if no better reference data available. (Refer to AN-29)
- Loss allocation factor, \( Z \): If \( Z = 1 \), all losses are on the secondary side. If \( Z = 0 \), all losses are on the primary side. Set \( Z = 0.5 \) if no better reference data is available.

Step 2. Choose feedback circuit and bias voltage \( V_B \) based on output requirements

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pri./Basic</td>
<td>5.8</td>
<td>±10%</td>
<td>±5%</td>
<td>±0.1%</td>
<td>±16.5%</td>
</tr>
<tr>
<td>Pri./Enh.</td>
<td>27.8</td>
<td>±2.5%</td>
<td>±1.5%</td>
<td>±0.5%</td>
<td>±9%</td>
</tr>
<tr>
<td>Opto/Zener</td>
<td>12</td>
<td>±2.5%</td>
<td>±1.5%</td>
<td>±0.5%</td>
<td>±6.5%</td>
</tr>
<tr>
<td>Opto/TL431</td>
<td>12</td>
<td>±1%</td>
<td>±0.5%</td>
<td>±0.2%</td>
<td>±1.4%</td>
</tr>
</tbody>
</table>

*Over 10% to 100% Load Range.
Table 2.

- Use primary feedback for lowest cost (for low power applications only).
- Use Opto/Zener for low cost, good output accuracy.
- Use Opto/TL431 for best output accuracy.
- Set bias voltage \( V_B \) according to Table 2.
- Choose optocoupler from Table 3.
Figure 4. Primary/Enhanced Feedback Circuit.

Figure 5. Opto/Zener Feedback Circuit.

*47 Ω is suitable for $V_O$ up to 7.5V. For $V_O > 7.5V$, a higher value may be required for optimum transient response.

**470 Ω is good for Zeners with $I_{ZT} = 5$ mA. Lower values are needed for Zeners with higher $I_{ZT}$. (E.g. 150 Ω for $I_{ZT} = 20$ mA).
Step 3. Determine minimum and maximum DC input voltages $V_{\text{MIN}}$, $V_{\text{MAX}}$ and input storage capacitance $C_{\text{IN}}$, based on AC input voltage and $P_O$ (Figure 7)

- Choose input storage capacitor, $C_{\text{IN}}$ per Table 4.

<table>
<thead>
<tr>
<th>Input (VAC)</th>
<th>$C_{\text{IN}}$ ($\mu$F/Watt of $P_O$)</th>
<th>$V_{\text{MIN}}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal</td>
<td>2 ~ 3</td>
<td>≥ 90</td>
</tr>
<tr>
<td>230 or 115 with doubler</td>
<td>1</td>
<td>≥ 240</td>
</tr>
</tbody>
</table>

*Table 4*

- Set bridge rectifier conduction time, $t_C = 3 \text{ ms}$.
- Derive minimum DC input voltage $V_{\text{MIN}}$:

$$V_{\text{MIN}} = \sqrt{\frac{2 \times P_O \times \left(\frac{1}{2 \times f_L} - t_C\right)}{\eta \times C_{\text{IN}}}}$$

where units are volts, watts, Hz, seconds and farads

- Calculate maximum DC input voltage $V_{\text{MAX}}$:

$$V_{\text{MAX}} = \sqrt{2} \times V_{AC_{\text{MAX}}}$$

---

Figure 6. Opto/TL431 Feedback Circuit.

<table>
<thead>
<tr>
<th>P/N</th>
<th>CTR(%)</th>
<th>BVCEO</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Pin DIP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC123Y6</td>
<td>80-160</td>
<td>70 V</td>
<td>Sharp</td>
</tr>
<tr>
<td>PC817X1</td>
<td>80-160</td>
<td>70 V</td>
<td>Sharp</td>
</tr>
<tr>
<td>SFH615A-2</td>
<td>63-125</td>
<td>70 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>SFH617A-2</td>
<td>63-125</td>
<td>70 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>SFH618A-2</td>
<td>63-125</td>
<td>55 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>ISP817A</td>
<td>80-160</td>
<td>35 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>LTV817A</td>
<td>80-160</td>
<td>35 V</td>
<td>Litech</td>
</tr>
<tr>
<td>LTV816A</td>
<td>80-160</td>
<td>80 V</td>
<td>Litech</td>
</tr>
<tr>
<td>LTV123A</td>
<td>80-160</td>
<td>70 V</td>
<td>Litech</td>
</tr>
<tr>
<td>K1010A</td>
<td>60-160</td>
<td>60 V</td>
<td>Cosmo</td>
</tr>
<tr>
<td>6 Pin DIP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTV702FB</td>
<td>63-125</td>
<td>70 V</td>
<td>Litech</td>
</tr>
<tr>
<td>LTV703FB</td>
<td>63-125</td>
<td>70 V</td>
<td>Litech</td>
</tr>
<tr>
<td>LTV713FA</td>
<td>80-160</td>
<td>35 V</td>
<td>Litech</td>
</tr>
<tr>
<td>K2010</td>
<td>60-160</td>
<td>60 V</td>
<td>Cosmo</td>
</tr>
<tr>
<td>PC702V2NSZX</td>
<td>63-125</td>
<td>70 V</td>
<td>Sharp</td>
</tr>
<tr>
<td>PC703V2NSZX</td>
<td>63-125</td>
<td>70 V</td>
<td>Sharp</td>
</tr>
<tr>
<td>PC713V1NSZX</td>
<td>80-160</td>
<td>35 V</td>
<td>Sharp</td>
</tr>
<tr>
<td>PC714V1NSZX</td>
<td>80-160</td>
<td>35 V</td>
<td>Sharp</td>
</tr>
<tr>
<td>MOC8102</td>
<td>73-117</td>
<td>30 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>MOC8103</td>
<td>108-173</td>
<td>30 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>MOC8105</td>
<td>63-133</td>
<td>30 V</td>
<td>Vishay, Isocom</td>
</tr>
<tr>
<td>CNY17F-2</td>
<td>63-125</td>
<td>70 V</td>
<td>Vishay, Isocom, Litech</td>
</tr>
</tbody>
</table>
Step 4. Determine reflected output voltage $V_{OR}$ and clamp Zener voltage $V_{CLO}$ (Figure 8)

- Set reflected output voltage, $V_{OR} = 100$ V for multiple output, 120 V for single output. These values optimize cross-regulation and efficiency. To obtain the maximum output power from a given TOPSwitch-GX device, set $V_{OR} = 135$ V.
- RCD (Resistor/Capacitor/Diode) clamp may be used with TOPSwitch-GX when and only when current limit is set externally with current limit reduction as a function of line voltage. Compared to Zener clamps, designs using RCD clamps usually have lower efficiency at light load. In addition, great care must be taken in RCD clamp design. Because of its inherent variation in clamp voltage across load range, if not designed properly, an RCD clamp may fail to protect TOPSwitch-GX, especially under startup or output overload conditions.

![Figure 7. Input Voltage Waveform.](PI-2585-012500)

![Figure 8. Reflected Voltage $V_{OR}$ and Clamp Zener Voltage $V_{CLO}$.](PI-3336-091402)
Step 5. Set current waveform parameter $K_P$ for desired mode of operation and current waveform: $K_P = K_{RP}$ for $K_P \leq 1.0$ and $K_P = K_{DP}$ for $K_P \geq 1.0$ (Figures 9 and 10)

- For $K_P \leq 1.0$, $K_P = K_{RP}$, continuous mode (see Figure 9)

$$K_P = K_{RP} = \frac{I_R}{I_p}$$

where $I_R$ is primary ripple current and $I_p$ is primary peak current.

- For $K_P \geq 1.0$, $K_P = K_{DP}$, discontinuous mode (see Figure 10)

$$K_P = K_{DP} = \frac{V_{OR} \times (1 - D_{MAX})}{(V_{MIN} - V_{DS}) \times D_{MAX}}$$

- For continuous mode design, set $K_P = 0.4$ for universal input 0.6 for 230 VAC or 115 VAC with doubler.

- For discontinuous mode design, set $K_P = 1.0$.

- $K_P$ must be kept within the range specified in Table 5.
Step 6. Determine $D_{\text{MAX}}$ based on $V_{\text{MIN}}$ and $V_{OR}$

- Continuous mode

$$D_{\text{MAX}} = \frac{V_{OR}}{(V_{\text{MIN}} - V_{DS}) + V_{OR}}$$

- Discontinuous mode

$$D_{\text{MAX}} = \frac{V_{OR}}{K_p \times (V_{\text{MIN}} - V_{DS}) + V_{OR}}$$

- Set TOPSwitch-GX Drain to Source voltage, $V_{DS} = 10$ V.

Step 7. Calculate primary peak current $I_p$

- Continuous mode ($K_p \leq 1.0$)

$$I_p = \frac{I_{AVG}}{(1 - \frac{K_p}{2}) \times D_{\text{MAX}}}$$

- Discontinuous mode ($K_p \geq 1.0$)

$$I_p = \frac{2 \times I_{AVG}}{D_{\text{MAX}}}$$

- Input average current $I_{AVG} = \frac{P_o}{\eta \times V_{\text{MIN}}}$

Step 8. Calculate primary RMS current $I_{\text{RMS}}$

- Continuous mode

$$I_{\text{RMS}} = I_p \times \sqrt{D_{\text{MAX}} \times \left(\frac{K_p^2}{3} - K_p + 1\right)}$$

- Discontinuous mode

$$I_{\text{RMS}} = \sqrt{D_{\text{MAX}} \times \frac{I_p^2}{3}}$$

Step 9. Choose TOPSwitch-GX based on AC input voltage, $V_o$, $P_o$ and $\eta$ using AN-29 selection curves

- Choose the smallest TOPSwitch-GX using TOPSwitch-GX Selection Curves in AN-29.
- Identify appropriate selection curves according to AC input voltage and output voltage, $V_o$.
- Continuous mode: Use selection curves as is.
- Discontinuous mode: Use selection curves with the output power derated by 33%. This effectively makes a 10 W discontinuous design equivalent to a 15 W continuous design in TOPSwitch-GX selection.
- Switching Frequency $f_s$: For DIP and SMP packages, set $f_s = 132$ kHz. For TO-220 package, choose between 66 kHz and 132 kHz.

Step 10. Set $I_{\text{LIMIT}}$ reduction factor $K_i$ for External $I_{\text{LIMIT}}$

- $K_i = \frac{\text{external } I_{\text{LIMIT}}}{\text{default } I_{\text{LIMIT}}}$ where $0.3 \leq K_i \leq 1.0$
- $K_i$ is set by the value of the resistor connected between M pin and SOURCE pin (Refer to TOPSwitch-GX data sheet).
- For applications demanding very high efficiency, a TOPSwitch-GX bigger than necessary may be used by lowering $I_{\text{LIMIT}}$ externally to take advantage of the lower $R_{DS(ON)}$.
- If no special requirement, set $K_i = 1.0$.
- Calculate $I_{\text{LIMIT}}(\text{min})$ and $I_{\text{LIMIT}}(\text{max})$.

$$I_{\text{LIMIT}}(\text{min}) = \text{default } I_{\text{LIMIT}}(\text{min}) \times K_i$$

$$I_{\text{LIMIT}}(\text{max}) = \text{default } I_{\text{LIMIT}}(\text{max}) \times K_i$$

Step 11. Validate TOPSwitch-GX selection by checking $I_p$ against $I_{\text{LIMIT}}(\text{min})$

- For $K_i = 1.0$, check $I_p \leq 0.96 \times I_{\text{LIMIT}}(\text{min})$.
- For $K_i < 1.0$, check $I_p \leq 0.94 \times I_{\text{LIMIT}}(\text{min})$.
- Choose larger TOPSwitch-GX if necessary.

Step 12. Calculate primary inductance $L_p$

- Continuous mode

$$L_p = \frac{10^6 \times P_o}{I_p^2 \times K_p \times \left(1 - \frac{K_p}{2}\right) \times f_s (\text{min})} \times \frac{Z \times (1 - \eta) + \eta}{\eta}$$

where units are $\mu$H, watts, amps and Hz

- Discontinuous mode

$$L_p = \frac{10^6 \times P_o}{I_p^2 \times \frac{1}{2} \times f_s (\text{min})} \times \frac{Z \times (1 - \eta) + \eta}{\eta}$$

where units are $\mu$H, watts, amps and Hz

<table>
<thead>
<tr>
<th>Input (VAC)</th>
<th>$K_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal</td>
<td>0.4–1.0</td>
</tr>
<tr>
<td>230</td>
<td>0.6–1.0</td>
</tr>
</tbody>
</table>

Table 5
Step 13. Choose core and bobbin based on \( f_s \) and \( P_o \) using Table 6 and determine \( A_e, L_e, A_L \) and \( BW \) from core and bobbin catalog

- Core effective cross-sectional area, \( A_e \): in cm\(^2\).
- Core effective path length, \( L_e \): in cm.
- Core ungapped effective inductance, \( A_L \): in nH/turn\(^2\).
- Bobbin width, \( BW \): in mm.
- Choose core and bobbin based on \( f_s \), \( P_o \), and construction type.

<table>
<thead>
<tr>
<th>Output Power</th>
<th>66 kHz</th>
<th>132 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Triple Insulated Wire</strong></td>
<td><strong>Margin Wound</strong></td>
<td><strong>Triple Insulated Wire</strong></td>
</tr>
<tr>
<td>0-10 W</td>
<td>EF12.6 EE13 EE16 EE19 EI22 EI22/19/6 EE19 EF20 EI25 EE19</td>
<td>EI22 EE19 EI22/19/6 EE16 EE16</td>
</tr>
<tr>
<td>10 W-20 W</td>
<td>EF20 EE19 EI22 EE19 EE19</td>
<td>EE19 EI22 EI22/19/6 EE19</td>
</tr>
<tr>
<td>20 W-30 W</td>
<td>EF25 E30 EI30 E30/15/7 EER28</td>
<td>EI30 E30/15/7 EER28</td>
</tr>
<tr>
<td>30 W-50 W</td>
<td>EI28 EI30 EI35 E30/15/7 EER28</td>
<td>EI30 E30/15/7 EER28</td>
</tr>
<tr>
<td>50 W-70 W</td>
<td>ETD29 EI35 EI35 EI35</td>
<td>EI35 E30/15/7 EER28</td>
</tr>
<tr>
<td>70 W-100 W</td>
<td>ETD34 EI40 EI40 EI40</td>
<td>EI40 E36/18/11 EER35</td>
</tr>
<tr>
<td>100 W-150 W</td>
<td>ETD39 EER40 E21/15</td>
<td>E21/15 EER40 EER40</td>
</tr>
</tbody>
</table>

Table 6. Transformer Core.

Step 14. Set value for number of primary layers \( L \) and number of secondary turns \( N_s \) (may need iteration)

- Starting with \( L = 2 \) (Keep \( 1.0 \leq L \leq 2.0 \) throughout iteration).
- Starting with \( N_s = 0.6 \) turn/volt.
- Both \( L \) and \( N_s \) may need iteration.

Step 15. Calculate number of primary turns \( N_P \) and number of bias turns \( N_B \)

- Diode forward voltages: 0.7 V for ultra-fast P/N diode and 0.5 V for Schottky diode.
- Set output rectifier forward voltage, \( V_D \).
- Set bias rectifier forward voltage, \( V_{DB} \).
- Calculate number of primary turns.

\[
N_P = N_s \times \frac{V_{OR}}{V_O + V_D}
\]

- Calculate number of bias turns \( N_B \).

\[
N_B = N_s \times \frac{V_B + V_{DB}}{V_O + V_D}
\]

Step 16. Determine primary winding wire parameters \( OD, DIA, AWG \)

- Primary wire outside diameter in mm.

\[
OD = \frac{L \times (BW - 2 \times M)}{N_P}
\]

where \( L \) is number of primary layers,
\( BW \) is bobbin width in mm,
\( M \) is safety margin in mm.

- Determine primary wire bare conductor diameter \( DIA \) and primary wire gauge \( AWG \).

Step 17 to Step 22. Check \( B_m \), \( CMA \) and \( L_g \). Iterate if necessary by changing \( L, N_s \) or core/bobbin until within specified range

- Set safety margin, \( M \). Use 3 mm (118 mils) for margin wound and zero for triple insulated secondary.
- Maximum flux density: \( 3000 \geq B_m \geq 2000 \), in gauss or \( 0.3 \geq B_m \geq 0.2 \), in tesla.

\[
B_m = \frac{100 \times I_p \times L_p}{N_p \times A_e}
\]

where units are gauss, amps, \( \mu \)H and cm\(^2\).
• Gap length in mm: \( L_g \geq 0.1 \)

\[
L_g = 40 \times \pi \times A_e \times \left( \frac{N_p^2}{1000 \times L_p} - \frac{1}{A_L} \right)
\]

where \( L_g \) in mm, \( A_e \) in cm\(^2\), \( A_L \) in nH/turn\(^2\) and \( L_p \) in \( \mu \)H

• Primary winding current capacity in circular mils per amp:

\[
500 \geq CMA \geq 200
\]

\[
CMA = \frac{1.27 \times DIA^2 \times \frac{\pi}{4} \times 1000}{25.4^2}
\]

where \( DIA \) is the bare conductor diameter in mm

• Iterate by changing \( L \), \( N_S \), core/bobbin according to Table 7.

<table>
<thead>
<tr>
<th>( B_M )</th>
<th>( L_g )</th>
<th>CMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

Table 7.

Step 23. Check \( B_P \leq 4200 \). If necessary, reduce current limit by lowering \( I_{\text{LIMIT}} \), reduction factor \( K_I \)

- \( B_P = \frac{I_{\text{LIMIT}}(\text{max})}{I_P} \times B_M \)
- Check \( B_P \leq 4200 \) gauss (0.42 tesla) to avoid transformer saturation at startup and output over load.
- Decrease \( K_I \), if necessary, until \( B_P \leq 4200 \).

Step 24. Calculate secondary peak current \( I_{\text{SP}} \)

\[
I_{\text{SP}} = I_P \times \frac{N_p}{N_S}
\]

Step 25. Calculate secondary RMS current \( I_{\text{SRMS}} \)

- Continuous mode

\[
I_{\text{SRMS}} = I_{\text{SP}} \times \sqrt{(1 - D_{\text{MAX}}) \times \left( \frac{K_p^2}{3} - K_p + 1 \right)}
\]

- Discontinuous mode

\[
I_{\text{SRMS}} = I_{\text{SP}} \times \sqrt{\frac{1 - D_{\text{MAX}}}{3 \times K_p}}
\]

Step 26. Determine secondary winding wire parameters \( OD_s \), \( DIA_s \), \( AWG_s \)

- Secondary wire outside diameter in mm

\[
OD_s = \frac{BW - (2 \times M)}{N_S}
\]

- Secondary wire bare conductor diameter in mm

\[
DIA_s = \sqrt{\frac{4 \times CMA_s \times I_{\text{SRMS}}}{1.27 \times \pi}} \times \frac{25.4}{1000}
\]

where \( CMA_s \) is secondary winding current capacity in circular mils per amp. Minimum wire diameter is calculated by using a \( CMA_s \) of 200.

- Determine secondary winding wire gauge \( AWG_s \) based on \( DIA_s \). If the bare conductor diameter of the wire is larger than that of the 27 AWG for 132 kHz or 25 AWG for 66 kHz, a parallel winding using multiple strands of thinner wire should be used to minimize skin effect.

Step 27. Determine output capacitor ripple current \( I_{\text{RIPPLE}} \)

- Output capacitor ripple current

\[
I_{\text{RIPPLE}} = \sqrt{I_{\text{SRMS}}^2 - I_O^2}
\]

where \( I_O \) is the output DC current

Step 28. Determine maximum peak inverse voltages \( PIV_s \), \( PIV_b \) for secondary and bias windings

- Secondary winding maximum peak inverse voltage.

\[
PIV_s = V_O + (V_{MAX} \times \frac{N_g}{N_p})
\]

- Bias winding maximum peak inverse voltage.

\[
PIV_b = V_B + (V_{MAX} \times \frac{N_g}{N_p})
\]

Step 29. Select clamp Zener and blocking diode per Table 8 for primary clamping based on \( V_{\text{OR}} \) and the type of output

<table>
<thead>
<tr>
<th>PS Output</th>
<th>( V_{\text{OR}} )</th>
<th>Blocking Diode</th>
<th>Clamp Zener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Output</td>
<td>100 V</td>
<td>BYV26C MUR160 UF4005</td>
<td>P6KE150</td>
</tr>
<tr>
<td>Single Output</td>
<td>120 V</td>
<td>BYV26C MUR160 UF4005</td>
<td>P6KE180</td>
</tr>
</tbody>
</table>

Table 8.
Step 30. Select output rectifier per Table 9

- \( V_r \geq 1.25 \times PIV_s \); where \( PIV_s \) is from Step 28 and \( V_r \) is the rated reverse voltage of the rectifier diode.
- \( I_D \geq 3 \times I_O \); where \( I_D \) is the diode rated DC current and \( I_O = \frac{P_o}{V_o} \).

<table>
<thead>
<tr>
<th>Rec. Diode</th>
<th>( V_r ) (V)</th>
<th>( I_r ) (A)</th>
<th>Package</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schottky</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1N5819</td>
<td>40</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>SB140</td>
<td>40</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>SB160</td>
<td>60</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>MBR160</td>
<td>60</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>11DQ06</td>
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<td>1.1</td>
<td>Axial</td>
<td>IR</td>
</tr>
<tr>
<td>1N5822</td>
<td>40</td>
<td>3</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>SB340</td>
<td>40</td>
<td>3</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>MBR340</td>
<td>40</td>
<td>3</td>
<td>Axial</td>
<td>IR</td>
</tr>
<tr>
<td>SB360</td>
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<td>3</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>MBR360</td>
<td>60</td>
<td>3</td>
<td>Axial</td>
<td>IR</td>
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<tr>
<td>SB540</td>
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<td>Axial</td>
<td>General Semi</td>
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<td>SB560</td>
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<td>5</td>
<td>Axial</td>
<td>General Semi</td>
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<tr>
<td>MBR745</td>
<td>45</td>
<td>7.5</td>
<td>TO-220</td>
<td>General Semi</td>
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<tr>
<td>MBR760</td>
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<td>7.5</td>
<td>TO-220</td>
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</tr>
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<td>MBR2045CT</td>
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<td>20(2x10)</td>
<td>TO-220</td>
<td>General Semi</td>
</tr>
<tr>
<td>MBR2060CT</td>
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<td>20(2x10)</td>
<td>TO-220</td>
<td>General Semi</td>
</tr>
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<td>20(2x10)</td>
<td>TO-220</td>
<td>General Semi</td>
</tr>
<tr>
<td>UFR</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UF4002</td>
<td>100</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>UF4003</td>
<td>200</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>MUR120</td>
<td>200</td>
<td>1</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>EGP20D</td>
<td>200</td>
<td>2</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>BYV27-200</td>
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<td>2</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>UF5401</td>
<td>100</td>
<td>3</td>
<td>Axial</td>
<td>General Semi</td>
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<tr>
<td>UF5402</td>
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<td>3</td>
<td>Axial</td>
<td>General Semi</td>
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<tr>
<td>EGP30D</td>
<td>200</td>
<td>3</td>
<td>Axial</td>
<td>General Semi</td>
</tr>
<tr>
<td>BYV28-200</td>
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<td>Axial</td>
<td>General Semi</td>
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<tr>
<td>MUR420</td>
<td>200</td>
<td>4</td>
<td>TO-220</td>
<td>General Semi</td>
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<tr>
<td>BYW29-200</td>
<td>200</td>
<td>8</td>
<td>TO-220</td>
<td>General Semi</td>
</tr>
<tr>
<td>BYV32-200</td>
<td>200</td>
<td>18</td>
<td>TO-220</td>
<td>General Semi</td>
</tr>
</tbody>
</table>

Table 9.

Step 31. Select output capacitor

- Ripple current specification at 105 °C, 100 kHz: Must be equal to or larger than \( I_{RIPPLE} \), where \( I_{RIPPLE} \) is from Step 27.
- ESR specification: Use low ESR, electrolytic capacitor. Output switching ripple voltage is \( I_{SP} \times ESR \), where \( I_{SP} \) is from Step 24.
- Examples:

<table>
<thead>
<tr>
<th>Output</th>
<th>Output Capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 V to 24 V, 1 A</td>
<td>330 µF, 35 V, low ESR, electrolytic</td>
</tr>
<tr>
<td></td>
<td>United Chemicon LXZ35VB331M10X16LL</td>
</tr>
<tr>
<td></td>
<td>Rubycon 35YXG330M10x16</td>
</tr>
<tr>
<td></td>
<td>Panasonic EEUFC1V331</td>
</tr>
<tr>
<td>5 V to 24 V, 2 A</td>
<td>1000 µF, 35 V, low ESR, electrolytic</td>
</tr>
<tr>
<td></td>
<td>United Chemicon LXZ35VB102M12X25LL</td>
</tr>
<tr>
<td></td>
<td>Rubycon 35YXG1000M12.5x25</td>
</tr>
<tr>
<td></td>
<td>Panasonic EEUFC1V102</td>
</tr>
</tbody>
</table>

Step 32. Select output post filter \( L, C \)

- Inductor \( L \): 2.2 µH to 4.7 µH. Use ferrite bead for low current (≤1A) output and standard off-the-shelf choke for higher current output. Increase choke current rating or wire size, if necessary, to avoid significant DC voltage drop.
- Capacitor \( C \): 100 µF to 330 µF, 35 V, electrolytic

Examples for 100 µF, 35 V, electrolytic:

- United Chemicon KMG35VB101M6X11LL
- Rubycon 35YXA100M6.3x11
- Panasonic ECA1VHG101

Step 33. Select bias rectifier from Table 10

- \( V_r \geq 1.25 \times PIV_b \); where \( PIV_b \) is from Step 28 and \( V_r \) is the rated reverse voltage of the rectifier diode.

<table>
<thead>
<tr>
<th>Rectifier</th>
<th>( V_r ) (V)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAV21</td>
<td>200</td>
<td>Philips</td>
</tr>
<tr>
<td>UF4003</td>
<td>200</td>
<td>General Semi</td>
</tr>
<tr>
<td>1N4148</td>
<td>75</td>
<td>Motorola</td>
</tr>
</tbody>
</table>

Table 10.

Step 34. Select bias capacitor

- Use 0.1 µF, 50 V, ceramic.

Step 35. Select CONTROL pin capacitor and series resistor

- CONTROL pin capacitor: 47 µF, 10 V, low cost electrolytic (Do not use low ESR capacitor).
• Series resistor: 6.8 Ω, 1/4 W (Not needed if $K_p \geq 1$, i.e. discontinuous mode).

Step 36. Select feedback circuit components according to applicable reference feedback circuits shown in Figures 3, 4, 5 and 6

• Applicable reference circuit: Identified in Step 2.

Step 37. Select input bridge rectifier

• $V_r \geq 1.25 \times \sqrt{2} \times V_{ACMAX}$; where $V_{ACMAX}$ is from Step 1.
• $I_D \geq 2 \times I_{AVE}$; where $I_D$ is the bridge rectifier rated current and $I_{AVE}$ is average input current.

Note: $I_{AVE} = \frac{P_{OUT}}{V_{MIN} \times \eta}$;

where $V_{MIN}$ is from Step 3 and $\eta$ from Step 1.
Appendix A

Multiple Output Flyback Power Supply Design

The only difference between a multiple output flyback power supply and a single output flyback power supply of the same total output power is in the secondary side design. Instead of delivering all power to one output as in the single output case, a multiple output flyback distributes its output power among several outputs. Therefore, the design procedure for the primary side stays the same, while that for the secondary side demands further considerations.

Design with lumped output power

One simple way of doing multiple output flyback design is described in detail in AN-22, “Designing Multiple Output Flyback Power Supplies with TOPSwitch”. The design method starts with a single output equivalent by lumping output power of all outputs to one main output. Secondary peak current \( I_{sp} \) and RMS current \( I_{SRMS} \) are derived. Output average current \( I_o \) corresponding to the lumped power is also calculated.

Assumption for simplification

The current waveforms in the individual output windings are determined by the impedance in each circuit, which is a function of leakage inductance, rectifier characteristics, capacitor value and most importantly, output load. Although this current waveform may not be exactly the same from output to output, it is reasonable to assume that, to the first order, all output currents have the same shape as for the single output equivalent of lumped power.

Output RMS current vs. average current

The output average current is always equal to the DC load current, while the RMS value is determined by current wave shape. Since the current wave shapes are assumed to be the same for all outputs, their ratio of RMS to average currents must also be identical. Therefore, with the output average current known, the RMS current for each output winding can be calculated as

\[
I_{SRMS}(n) = I_o(n) \times \frac{I_{SRMS}}{I_o}
\]

where \( I_{SRMS}(n) \) and \( I_o(n) \) are the secondary RMS current and output average current of the \( n \)th output and \( I_{SRMS} \) and \( I_o \) are the secondary RMS current and output average current for the lumped single output equivalent design.

Customization of secondary designs for each output

The turns for each secondary winding are calculated based on the respective output voltage \( V_o(n) \):

\[
N_{S}(n) = \frac{V_{o}(n) + V_D(n)}{V + V_D}
\]

Output rectifier maximum inverse voltage is

\[
PIV_S(n) = \frac{N_{S}(n)}{N_P} + V_o(n)
\]

With output RMS current \( I_{SRMS}(n) \), secondary number of turns \( N_S(n) \) and output rectifier maximum inverse voltage \( PIV_S(n) \) known, the secondary side design for each output can now be carried out exactly the same way as for the single output design.

Secondary winding wire size

The TOPSwitch-GX design spreadsheet assumes a CMA of 200 when calculating secondary winding wire diameters. This gives the minimum wire sizes required for the RMS currents of each output using separate windings. Designers may wish to use larger size wire for better thermal performance. Other considerations such as skin effect and bobbin coverage may suggest the use of a smaller wire by using multiple strands wound in parallel. In addition, practical considerations in transformer manufacturing may also dictate the wire size.
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<table>
<thead>
<tr>
<th>Revision</th>
<th>Notes</th>
<th>Date</th>
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<td>A</td>
<td>1) Final release.</td>
<td>9/02</td>
</tr>
<tr>
<td>B</td>
<td>1) Minor revision.</td>
<td>12/02</td>
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<tr>
<td>C</td>
<td>1) Minor revision: Corrected $V_{\text{MAX}}$ equation.</td>
<td>7/04</td>
</tr>
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</table>

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