Fly-Back Converter
CCM Vs DCM
(Continuous Conduction Mode Vs Discontinuous Conduction Mode)

Giridharan Shanmugavel
giri.shanmugavel@maxim-ic.com
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Fly-back Converter

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q Comprehensive MAXIM Solutions
Objectives and Audience

q **Desired Objective for this session:**

This presentation aims to outlay the Flyback converter, and its operation in Continuous and Discontinuous modes. Steady state design performance metrics are discussed, with an application example. Dynamic performance differences in the two modes are highlighted. Comprehensive Maxim Power Management solutions are proposed.

q **Target Audience:**

Power Converter Designers and Application Engineers focused on Isolated / Non-isolated flyback converter, and Magnetic component designers
Fly-back Converter

Salient Points

- Suitable for low power (<50W) applications
- Very high voltage transfer ratio possible ("Transformer")
- Can provide galvanic isolation
- Tolerate wide range of input voltage
- Least component count among isolated power converters
Power Conversion Steps

**Step#1:** MOSFET is in ON State. Energy is transferred from source to primary winding of inductor. *Output Capacitor continues to deliver the load*

**Step#2:** MOSFET is in OFF State. Energy is delivered from the secondary winding of inductor to output capacitor. *Output Capacitor continues to deliver the load*

(The “Transformer” is actually a Two-Winding Inductor)
Energy in the Inductor (CCM)

Inductor has Residual Energy at the beginning and end of “$T_s$”

† Continuous Conduction Mode (CCM)
Inductor has Zero Energy at the beginning and end of “T_s”

† Discontinuous Conduction Mode (DCM)
“In CCM, $D_2$ extends to $(1-D)$”
Typical Application

Offline Power Supply
- Universal Input Voltage (85~265Vac, 50/60Hz)
- Typical in Smart Meters
- Neutral referenced (non-isolated) output voltage
- 12V~15V, 1A output
Typical Design Example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CCM</th>
<th>DCM</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_P$</td>
<td>490</td>
<td>143</td>
<td>uH</td>
</tr>
<tr>
<td>$L_S$</td>
<td>19.5</td>
<td>5.7</td>
<td>uH</td>
</tr>
<tr>
<td>$I_{Peak,Primary}$</td>
<td>0.67</td>
<td>1.22</td>
<td>Amp</td>
</tr>
<tr>
<td>$I_{Peak,Secondary}$</td>
<td>3.6</td>
<td>6.5</td>
<td>Amp</td>
</tr>
<tr>
<td>$I_{RMS,Primary}$</td>
<td>0.34</td>
<td>0.47</td>
<td>Amp</td>
</tr>
<tr>
<td>$I_{RMS,Secondary}$</td>
<td>1.8</td>
<td>2.5</td>
<td>Amp</td>
</tr>
</tbody>
</table>

For the same Duty Cycle, $V_o$ is greater in DCM!!

For the same requirements, Transformer is smaller in DCM!!

**NOTES:**
- $C_{IN}$ is chosen based on holding time requirement
- $C_{OUT}$ is chosen based on output ripple requirement
Design Performance
(Steady State)

Applying Volt-Second balance, the Input output relationships are derived

**CCM:**
\[
\frac{V_o}{V_{IN}} = \frac{D}{N \cdot (1 - D)}
\]

**DCM:**
\[
\frac{V_o}{V_{IN}} = \frac{D}{N \cdot \frac{D}{D_2}}
\]

Resolving for D₂ (writing D₂ in terms of circuit parameters)

**CCM:**
\[
\frac{V_o}{V_{IN}} = \frac{D}{N \cdot (1 - D)}
\]

**DCM:**
\[
\frac{V_o}{V_{IN}} = \frac{D}{\sqrt{K}}
\]

Where, the “K” parameter relates to circuit parameters as:

\[
K = \frac{2 \cdot L_S}{R \cdot T_S}
\]

- \(L_S\) is the Secondary Inductance
- \(R\) is the Load Resistance
- \(T_S\) is the Switching Time Period

**CCM:**
- \(V_o\) is related to:
  - Circuit parameters (N) and
  - Operating point \(V_{IN}, D\)

**DCM:**
- \(V_o\) is related to:
  - Circuit parameters (N, \(L_S, T_S\)) and
  - Operating point \(V_{IN}, D, R_{LOAD}\)

Operating Duty Cycle (D) is different for CCM & DCM
(for the same input-output conditions, and N)
Design Performance
(Steady State)

- Peak current and voltage stress in Power devices

<table>
<thead>
<tr>
<th>Stress Variable</th>
<th>CCM</th>
<th>DCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak MOSFET (Q) Voltage</td>
<td>Same (assume same N)</td>
<td></td>
</tr>
<tr>
<td>Peak MOSFET (Q) Current</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Peak Diode (D) Voltage</td>
<td>Same (assume same N)</td>
<td></td>
</tr>
<tr>
<td>Peak Diode (D) Current</td>
<td>Lower</td>
<td>Higher</td>
</tr>
</tbody>
</table>

- RMS current in circuit – and indicator of losses
  - Higher RMS currents due to peaky nature of currents in DCM (for the same input voltage and output load conditions)
  - Higher losses in DCM operation than in CCM

- Larger current excursions in DCM
  - Larger flux excursions in the magnetic circuit
  - Higher losses in magnetic coupling media in DCM

Typically Higher losses in DCM than in CCM (for the same input-output conditions)
Design Performance
(Dynamic conditions)

q Control transfer functions, for Voltage Mode Control (simplified and expressed for N=1)

<table>
<thead>
<tr>
<th>Transfer Function</th>
<th>CCM</th>
<th>DCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control to Output Voltage</td>
<td>[ \frac{\ddot{v}<em>o(s)}{d(s)} = \frac{V</em>{IN}}{(1-D)^2} \cdot \left(1 - s \frac{L_P}{R} \frac{D}{(1-D)^2} \right) ]</td>
<td>[ \frac{\ddot{v}<em>o(s)}{d(s)} = \frac{V</em>{IN}}{\sqrt{K}} \cdot \frac{1}{\left(1 + s \frac{RC}{2}\right)} ]</td>
</tr>
</tbody>
</table>

- Control Transfer Functions simpler in DCM
- Inductor current is no longer a “State” in DCM
  (Initial and Final Energy levels are zero)
- Right Half Plane Zero present in CCM
  (Limits the maximum achievable Closed Loop Bandwidth)
For a Duty Cycle Step:
- The energy gained by inductor is not available for transfer “immediately”
- Due to discontinuous nature of diode current, the energy transfer is “reduced”
- The output voltage reduces (for a given load) momentarily...
- Eventually, the inductor energy build is sufficiently large to build output voltage

Quick Duty Cycle changes = “Momentary” reduction in output voltage!
- Indirectly limits the rate of control
- Limits the closed loop bandwidth
MAXIM Solutions

MAX17499/MAX17500

Features

- Current-Mode Control
- Programmable Switching Frequency Up to 625kHz
- Accurate UVLO Threshold (1%)
- Open-Drain UVLO Flag Output with Internal Delay
- 36V to 72V Telecom Voltage Range
- Universal Offline Input Voltage Range
  Rectified 85V AC to 265V AC (MAX17500)
- 9.5V to 24V Input (MAX17499)
- Digital Soft-Start
- Internal Bootstrap UVLO with Large Hysteresis (MAX17500)
- Internal Error Amplifier with 1.5% Accurate Reference
- 50µA (typ) Startup Supply Current
- 50% Maximum Duty-Cycle Limit (MAX17499A/MAX17500A)
- 75% Maximum Duty-Cycle Limit (MAX17499B/MAX17500B)
- 60ns Cycle-by-Cycle Current-Limit Propagation Delay
- Available in Tiny 10-Pin µMAX Packages

Current-Mode PWM Controllers with Programmable Switching Frequency

General Description

The MAX17499/MAX17500 current-mode PWM controllers contain all the circuitry required for the design of wide-input-voltage isolated and nonisolated power supplies. The MAX17499 is well suited for low input voltage (3.6V DC to 24V DC) power supplies. The MAX17500 is well suited for universal input (rectified 60V AC to 265V AC) or telecom (-36V DC to 72V DC) power supplies.

The MAX17499/MAX17500 contain an internal error amplifier that regulates the tertiary winding output voltage that is used in primary-side-regulated isolated power supplies. Primary-side regulation eliminates the need for an optocoupler. An input undervoltage lockout (UVLO) is provided for programming the input-supply start-up voltage and to ensure proper operation during brownout conditions. An open-drain UVLO flag output, with 27µs internal delay, allows the sequencing of a secondary-side controller. The input-supply start-up is externally programmable with a voltage-divider UVLOuden is used to shut down the MAX17490/MAX17500. Internal digital soft-start eliminates output voltage overshoot.

The MAX17500 has an internal bootstrap UVLO with large hysteresis that requires a minimum 2.5V start-up. The MAX17499 does not have the internal bootstrap UVLO and can be biased directly from a minimum voltage of 5.5V.

The switching frequency for the MAX17499/MAX17500 is programmable with an internal resistor. The MAX17499A/MAX17500A provide a 50% maximum duty-cycle limit, while the MAX17499B/MAX17500B provide a 75% maximum duty-cycle limit. These devices are available in 10-pin µMAX packages and are rated for operation over the -40°C to +85°C temperature range.

Applications

- 12V, 14V, and 18V Brick Power Modules
- High-Efficiency, Isolated Telecom Power Supplies
- Networking Server
- Isolated Kiosk/UPS Power Supplies
- HD Video and DC/DC Converters
- Isolated and Nonisolated High-Brightness LED Power Supplies
- Industrial Power Conversion

Ordering Information

<table>
<thead>
<tr>
<th>PART</th>
<th>TEMP RANGE</th>
<th>PIN/PACKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX17499</td>
<td>-40°C to +85°C</td>
<td>10 µMAX</td>
</tr>
<tr>
<td>MAX17499DUL</td>
<td>-40°C to +85°C</td>
<td>10 µMAX</td>
</tr>
<tr>
<td>MAX17499EL</td>
<td>-40°C to +85°C</td>
<td>10 µMAX</td>
</tr>
<tr>
<td>MAX17500</td>
<td>-40°C to +85°C</td>
<td>10 µMAX</td>
</tr>
<tr>
<td>MAX17500DUL</td>
<td>-40°C to +85°C</td>
<td>10 µMAX</td>
</tr>
<tr>
<td>MAX17500EL</td>
<td>-40°C to +85°C</td>
<td>10 µMAX</td>
</tr>
</tbody>
</table>

Warning: The MAX17499/MAX17500 are designed to work with high voltages. Exercise caution.

(Drawing may not be 100% accurate.)

MAXIM Integrated Products

(continued on next page)
Secondary-side Regulated, Isolated Power Supply
Summary

Key highlights:

- An overview of basic operation of the Flyback converter
- Operation in Continuous and Discontinuous modes
- Steady state design performance metrics (application example)
  - Operating point for a given input-output conditions
  - Stress in circuit elements
- Dynamic performance differences in the two modes
- Physical insight into the Right Half Plane Zero
- Comprehensive Maxim Power Management solutions
Thank You