Fly-Back Converter

CCM Vs DCM

(Continuous Conduction Mode Vs Discontinuous Conduction Mode)

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Objectives and Audience

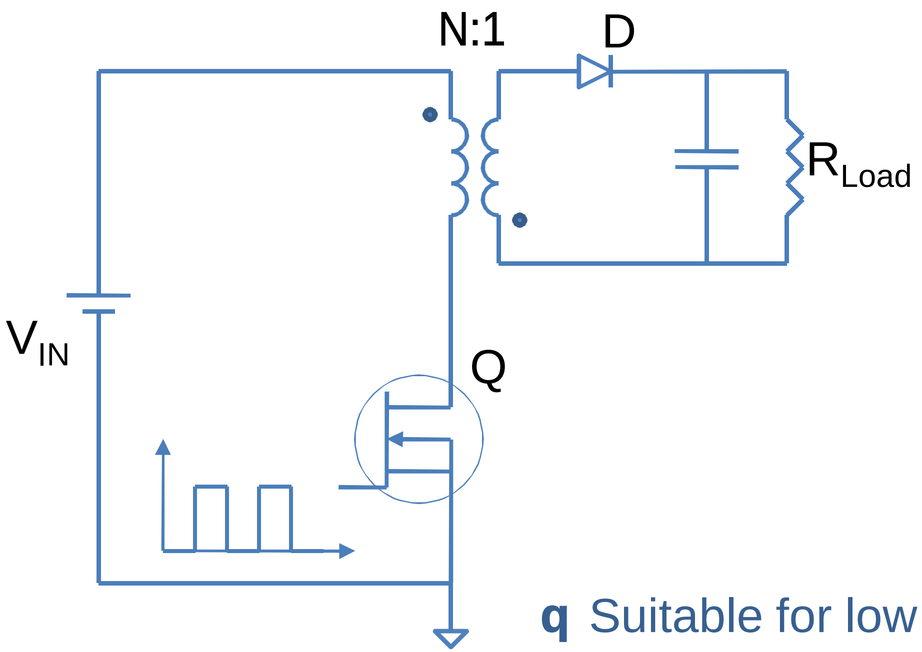
- **Desired Objective for this session**:

  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.

- **Target Audience**:

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

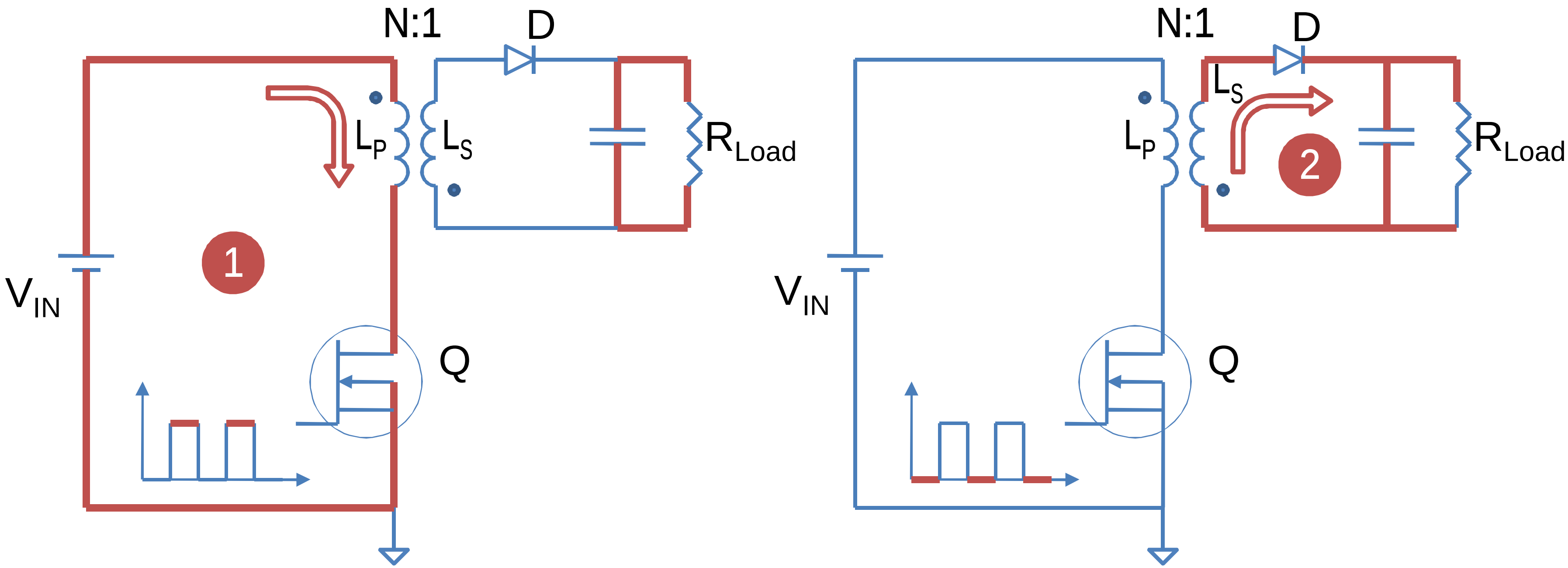
Fly-back Converter



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

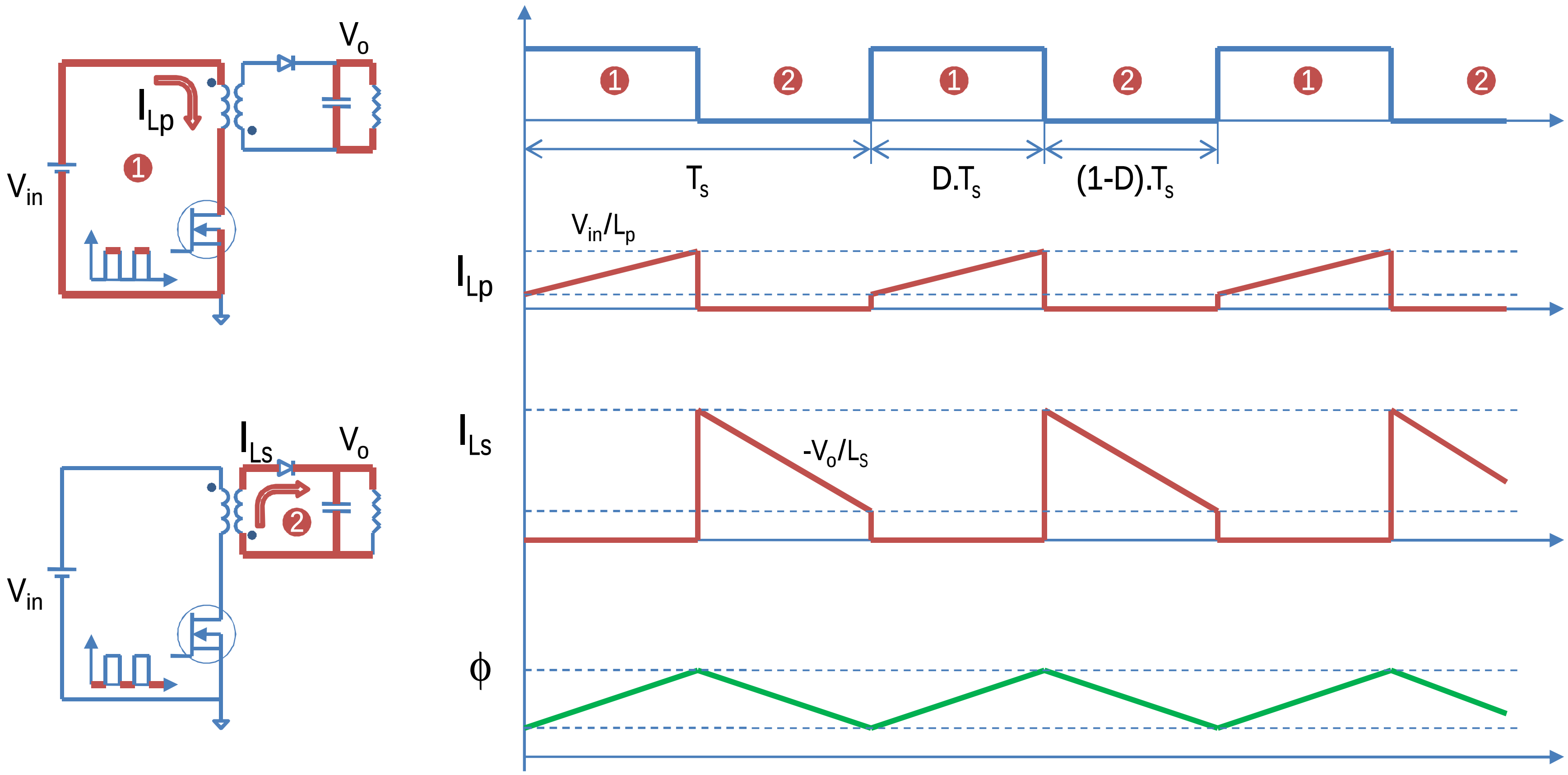


Step#1: MOSFET is in ON State. Energy is transferred from source to primary winding of inductor [*Output Capacitor continues to deliver the load*]

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)

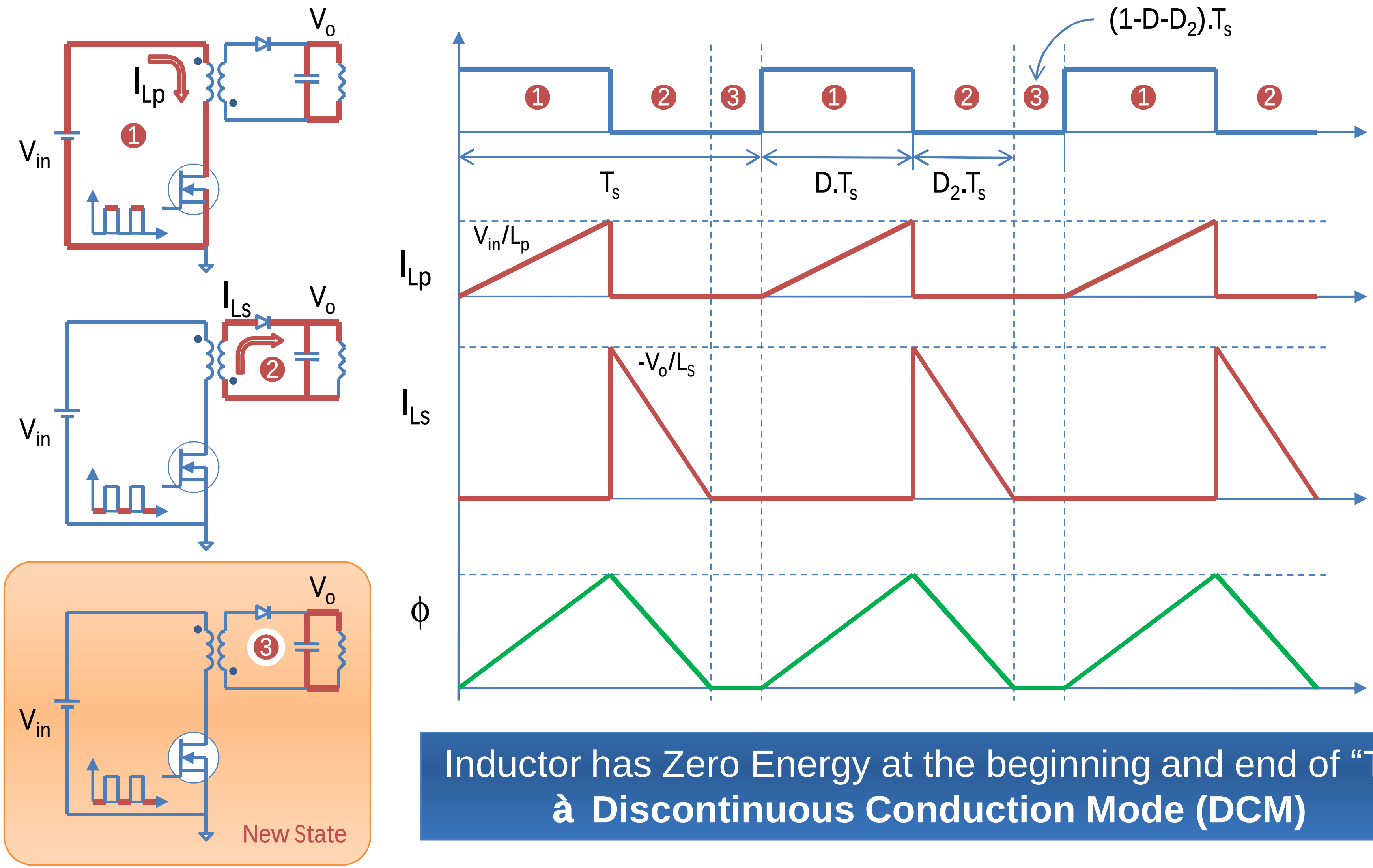
Energy in the Inductor (CCM)



Inductor has Residual Energy at the beginning and end of "T_s"

à Continuous Conduction Mode (CCM)

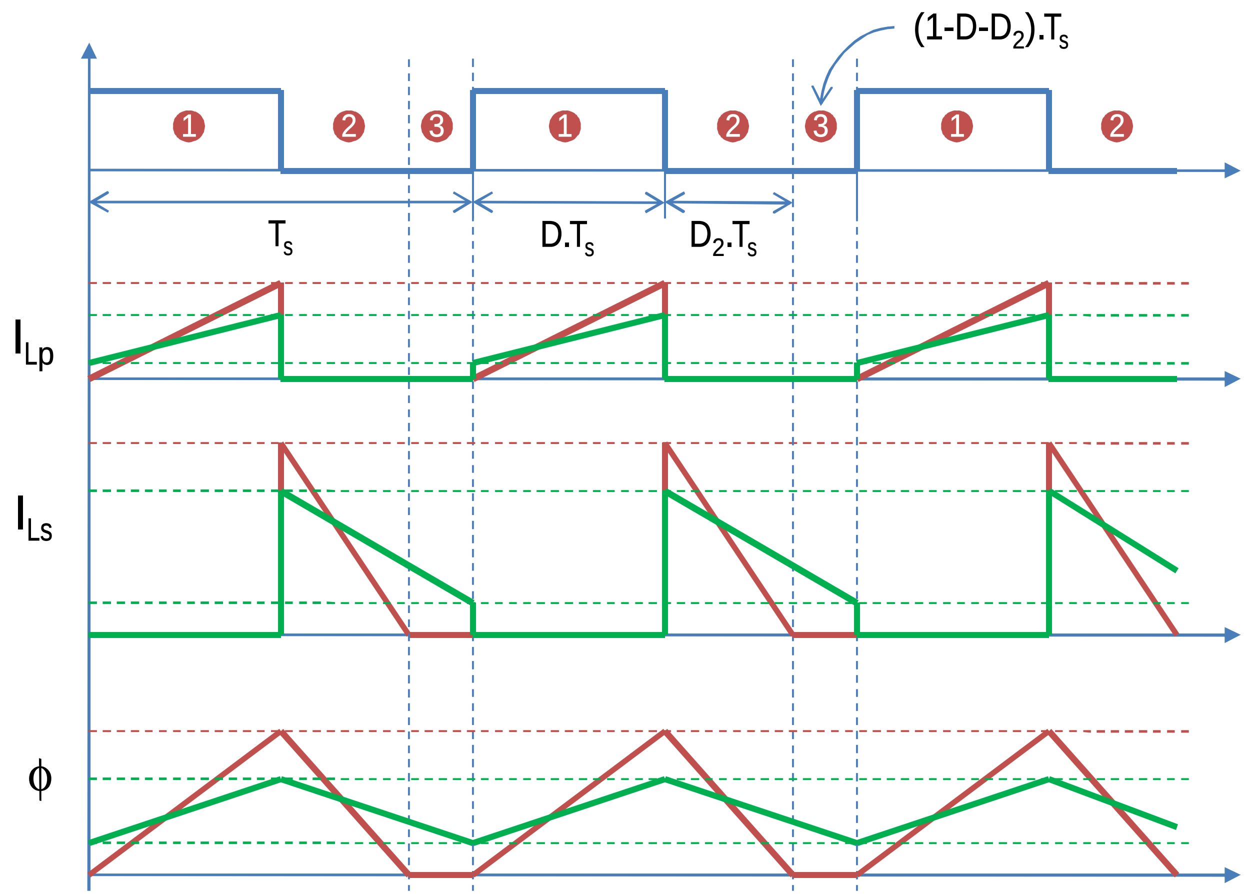
Energy in the Inductor (DCM)



Inductor has Zero Energy at the beginning and end of "T_S"

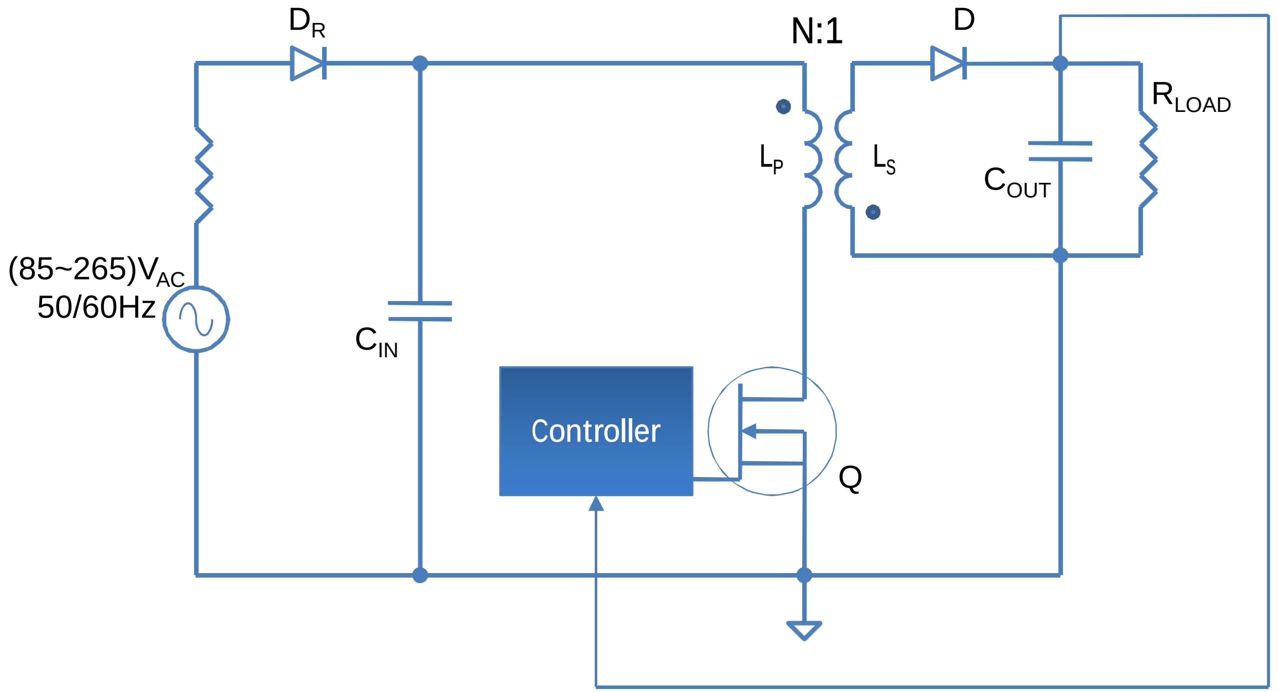
à Discontinuous Conduction Mode (DCM)

CCM Vs DCM



"In CCM, D_2 extends to (1-D)"

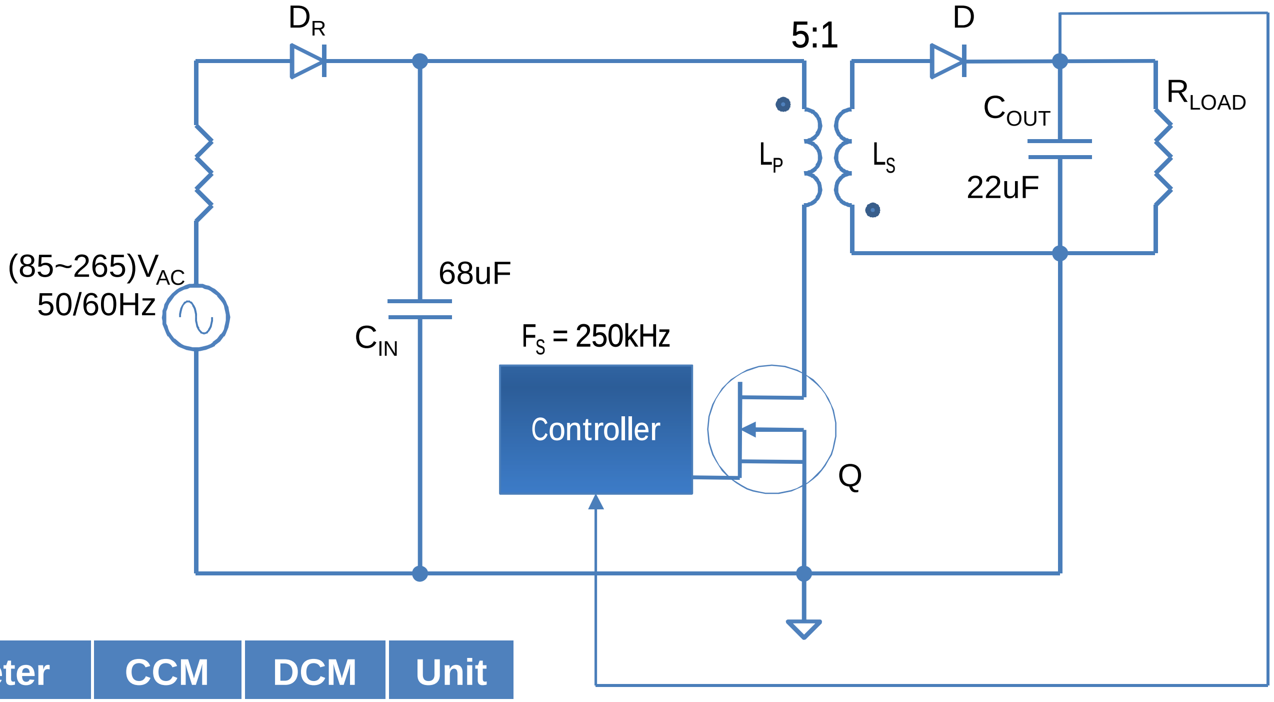
Typical Application



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



Parameter	CCM	DCM	Unit
L_P	490	143	uH
L_S	19.5	5.7	uH
$I_{Peak,Primary}$	0.67	1.22	Amp
$I_{Peak,Secondary}$	3.6	6.5	Amp
$I_{RMS,Primary}$	0.34	0.47	Amp
$I_{RMS,Secondary}$	1.8	2.5	Amp

For the same Duty Cycle, Vo 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)

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

CCM: $$\frac{V_O}{V_{IN}} = \frac{1}{N} \cdot \frac{D}{(1-D)}$$

DCM: $$\frac{V_O}{V_{IN}} = \frac{1}{N} \cdot \frac{D}{D_2}$$

q Resolving for D_2 (writing D_2 in terms of circuit parameters)

CCM: $$\frac{V_O}{V_{IN}} = \frac{1}{N} \cdot \frac{D}{(1-D)}$$

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)

q Peak current and voltage stress in Power devices

Stress Variable	CCM	DCM
Peak MOSFET (Q) Voltage	Same (assume same N)	
Peak MOSFET (Q) Current	Lower	Higher
Peak Diode (D) Voltage	Same (assume same N)	
Peak Diode (D) Current	Lower	Higher

q 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)

à Higher losses in DCM operation than in CCM

q Larger current excursions in DCM

à Larger flux excursions in the magnetic circuit

à Higher losses in magnetic coupling media in DCM

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

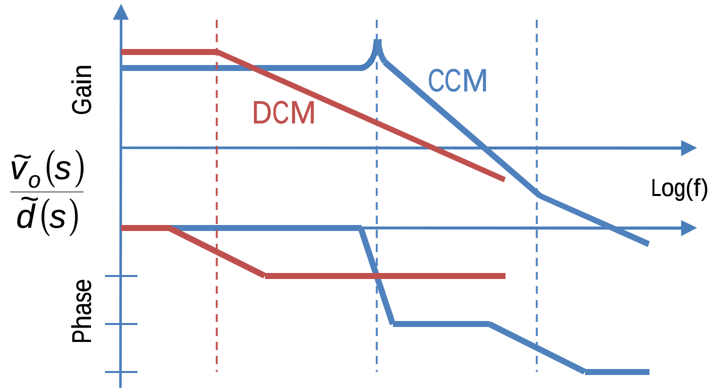
Design Performance

(Dynamic conditions)

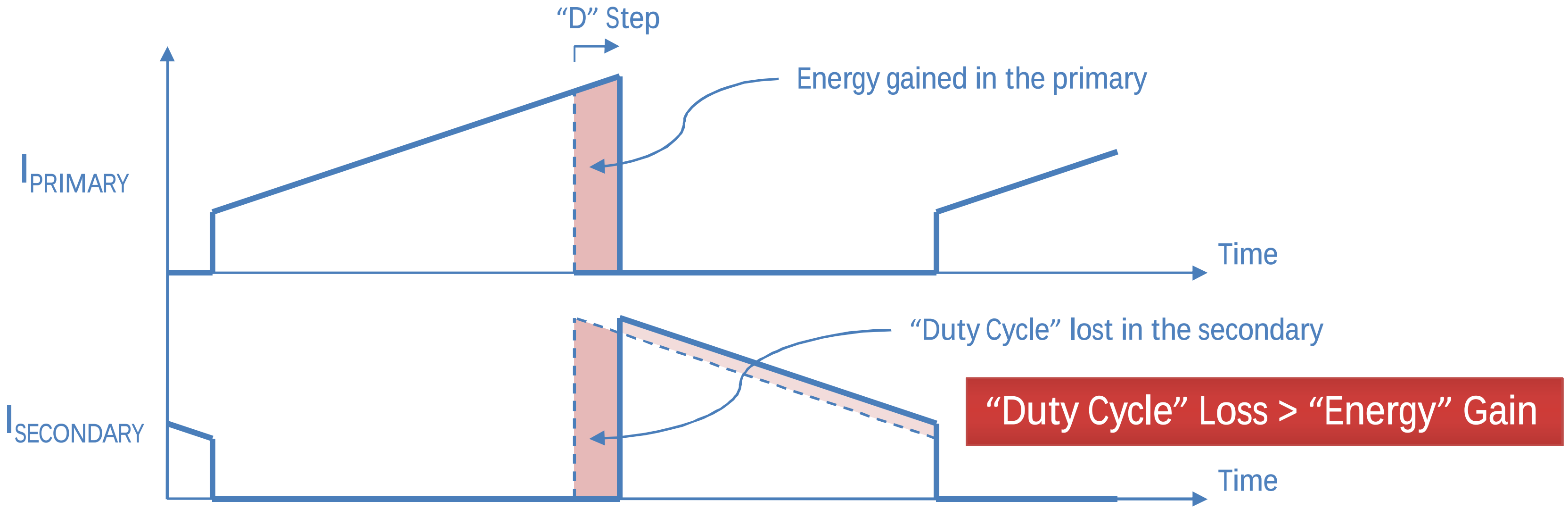
q Control transfer functions, for Voltage Mode Control (simplified and expressed for N=1)

Transfer Function	CCM	DCM
Control to Output Voltage	$\frac{\tilde{v}_o(s)}{\tilde{d}(s)} = \frac{V_{IN}}{(1-D)^2} \cdot \frac{\left(1 - s\frac{L_P}{R}\frac{D}{(1-D)^2}\right)}{\left(1 + s\frac{L_P}{R}\frac{1}{(1-D)^2} + s^2\frac{L_P C}{(1-D)^2}\right)}$	$\frac{\tilde{v}_o(s)}{\tilde{d}(s)} = \frac{V_{IN}}{\sqrt{K}} \cdot \frac{1}{\left(1 + s\frac{RC}{2}\right)}$

- 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)



RHP Zero



- 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

XX-XXXX; Rev 0; 8/10

EVALUATION KIT AVAILABLE

MAXIM

Current-Mode PWM Controllers with Programmable Switching Frequency

MAX17499/MAX17500

General Description

The MAX17499/MAX17500 current-mode PWM controllers contain all the control circuitry required for the design of wide-input-voltage isolated and nonisolated power supplies. The MAX17499 is well suited for low input voltage (9.5V DC to 24V DC) power supplies. The MAX17500 is well suited for universal input (rectified 85V 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 voltage and to ensure proper operation during brownout conditions. An open-drain UVLO flag output, with 210µs internal delay, allows the sequencing of a secondary-side controller. The input-supply start voltage is externally programmable with a voltage-divider. A UVLO/EN input is used to shut down the MAX17499/MAX17500. Internal digital soft-start eliminates output voltage overshoot.

The MAX17500 has an internal bootstrap UVLO with large hysteresis that requires a minimum 23.6V for startup. The MAX17499 does not have the internal bootstrap UVLO and can be biased directly from a minimum voltage of 9.5V.

The switching frequency for the MAX17499/MAX17500 is programmable with an external 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

1/2, 1/4, and 1/8 Brick Power Modules

High-Efficiency, Isolated Telecom Power Supplies

Networking/Servers

Isolated Keep-Alive Power Supplies

12V Boost and SEPIC Regulators

Isolated and Nonisolated High-Brightness LED Power Supplies

Industrial Power Conversion

Selector Guide appears at end of data sheet.

Features

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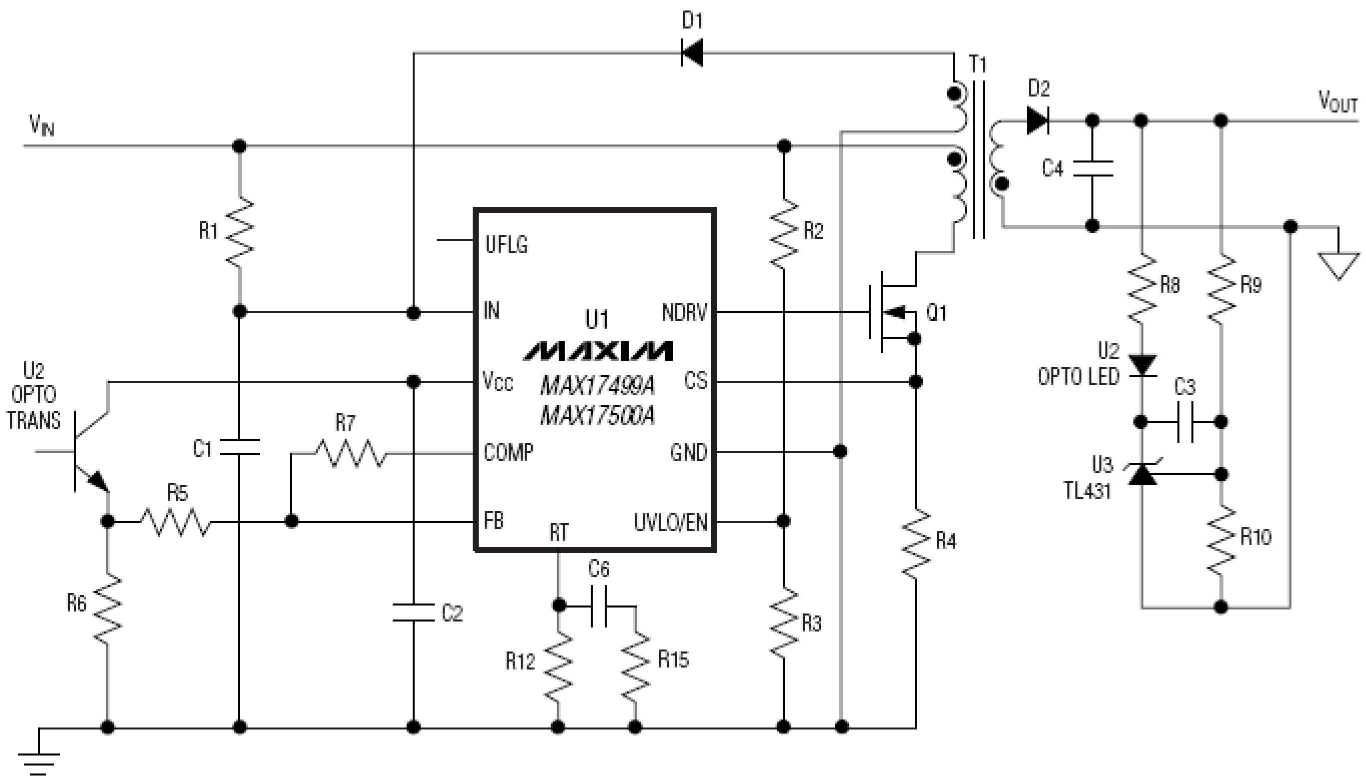
- 60ns Cycle-by-Cycle Current-Limit Propagation Delay
- Available in Tiny 10-Pin µMAX Packages

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX17499AEUB+	-40°C to +85°C	10 µMAX
MAX17499BEUB+	-40°C to +85°C	10 µMAX
MAX17500AEUB+	-40°C to +85°C	10 µMAX
MAX17500BEUB+	-40°C to +85°C	10 µMAX

***Warning:** The MAX17499/MAX17500 are designed to work with high voltages. Exercise caution.*
+Denotes lead-free package.

MAXIM Solutions



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