Active Clamp Flyback Converter
主動鉗位式返馳轉換器

Power Delivery Webinar
Speaker : Adam Lin
Soft-Switching Passive Clamp Flyback

Valley Switching (QR)

PCF-SR

PCF-Aux

PWM

PWML

PWMH

driver

controller

V_{bulk}

V_{sw}

i_{m}

i_{sec}

i_{clamp}

EMI

V_{bulk}

i_{clamp}

i_{m}

i_{sec}

PWMH

I. Confidential – Selective Disclosure

2

Texas Instruments
Active Clamp Flyback

Eliminates switching losses and reduces EMI with proper control of the clamp which allows zero voltage switching (ZVS) to be achieved.

Improves efficiency over traditional Flyback converters by recirculating the leakage energy and delivering it to the output instead of dissipating it.

Enables greater power density Lower switching losses enables higher switching frequencies, which allows for smaller passive components. Lower temperature rise allows tighter packaging.
TI Active Clamp Flyback vs Existing Solutions

TI Solution:
1. Over 2x Greater Power Density
2. Efficiency exceeding 94%

* Open frame power density
TI Active Clamp Flyback Chipset

More power in less space

**UCC28780 Active Clamp Flyback**
High frequency without a heatsink
- 1 MHz GaN or Si FET support
- Best in class efficiency from innovative ZVS algorithm
- Advanced protection features
- 3 patents filed

**UCC24612 Advanced Sync Rectifier**
High performance, simplified design
- Up to 1 MHz support with Si FET
- Wide voltage range operation
- Intelligent control provides near ideal diode emulation
UCC28780 Design Support Tools

Datasheet
TI Sales Support
Application Notes
Training Videos
E2E Forums
SIMPLIS Simulation Model
Evaluation Modules
Reference Designs
Mathcad Design Calculator

Plethora of design support tools starting at
www.ti.com/product/UCC28780
Why Galium Nitride (GaN) FET?

Advantages of active clamp flyback are further increased with GaN power devices.

**UCC28780 is optimized to interface with GaN FETs**

- **Interaction**: Direct interface with driver + FET integrated solutions
- **Size**: Operation up to 1 MHz enables further size reduction
- **Performance**: Control law optimized to work with GaN and Si parameters

<table>
<thead>
<tr>
<th></th>
<th>Si FET 680mΩ</th>
<th>Si FET 180mΩ</th>
<th>GaN FET 500mΩ</th>
<th>GaN FET 150mΩ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vds (V)</td>
<td>10000</td>
<td>1000</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Coss (pF)</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>Vds (V)</td>
<td>1000</td>
<td>100</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Coss (pF)</td>
<td>1000</td>
<td>1000</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

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TI Confidential – Selective Disclosure
UCC28780 | High Frequency Active Clamp Flyback

Features
- Externally programmable for optimization with either Silicon (Si) and Gallium Nitride (GaN) power FETs
- Zero voltage switching (ZVS) over wide operating range
  - Advanced auto-tuning and adaptive dead-time optimization
- Switching frequency up to 1 MHz
- Secondary side regulation for CV/CC operation
- Multimode Control enables high efficiency while mitigating audible noise
  - Adaptive burst mode, adaptive amplitude modulation, low power mode, standby power mode
- Accurate Programmable Over-Power Protection (OPP) enables high power density and reduction in component size
- Fault Protections
  - Over temperature, output over voltage, over current limit, short circuit, pin fault

Benefits
- DoE Level VI and CoC V5 Tier-2 EPS standards compliant
- Flexible to work with both Si FET driver or GaN power stages
- ZVS reduces switching losses for higher switching frequency
  - Reduced transformer size and generated EMI
- External HV startup FET enables standby power below 75 mW
- Multimode Control maximizes performance
  - Maintain ZVS over line, load and component tolerances
  - Highest average efficiency for entire load range
  - Reduces output voltage ripple
  - Mitigates audible noise

Applications
- High-Density AC-to-DC Adapters for Notebook, Tablet, TV, Set-Top Box and Printer
- USB Power Delivery, Direct and Fast Mobile Chargers
- AC-to-DC or DC-to-DC Auxiliary Power Supply

www.ti.com/product/UCC28780
UCC28780
Adaptive ZVS Active Clamp Flyback Controller

Features

High Power Density
Efficient operation up to 1 MHz can reduce solution sizes by up to 50% when compared to existing 25-100 W flyback

High Efficiency
Adaptive ZVS algorithm achieves high efficiency and performance that exceeds DoE Level VI and CoC Tier-2 EPS standards

Accurate Fault Protection
Fast and accurate over power protection reduces passive component size and enables high power density

Flexible Implementation
Externally programmable for optimization with either GaN or Si FET
UCC28780
Adaptive ZVS Active Clamp Flyback Controller

Features

Discovery questions

Pricing, availability, resources

Are you looking to reduce the size of your AC/DC converter?
UCC28780 can reduce the size of an AC/DC adapter by 50%

Are you looking to increase the efficiency of your AC/DC converter?
UCC28780 can enable efficiencies that exceed 94%

Do you need a highly efficient AC/DC converter?
UCC28780 works with controllers such as UCC24612 and can exceed stringent efficiency standards such as DoE Level VI and CoC Tier 2
UCC28780
Adaptive ZVS Active Clamp Flyback Controller

Pricing 1Ku: $0.60

Availability:
• Silicon Samples: http://www.ti.com/product/UCC28780/samplebuy
• GaN Based Evaluation Board: http://www.ti.com/tool/ucc28780evm-002
• GaN SIMPLIS Model: http://www.ti.com/lit/zip/slum626
• Si SIMPLIS Model: http://www.ti.com/lit/zip/slum643
• Mathcad Design Calculator: http://www.ti.com/lit/zip/sluc644

Additional resources:
• Support (E2E): http://e2e.ti.com/support/power_management/isolated_controllers/
# UCC28780 Customer Collateral

<table>
<thead>
<tr>
<th>Content type</th>
<th>Content title</th>
<th>Link to content or more details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training Video</td>
<td>What is an Active Clamp Flyback?</td>
<td><a href="https://training.ti.com/what-active-clamp-flyback">https://training.ti.com/what-active-clamp-flyback</a></td>
</tr>
<tr>
<td>Training Video</td>
<td>Making power supplies smaller: An overview of the active clamp flyback chipset</td>
<td><a href="https://training.ti.com/making-power-supplies-smaller-overview-active-clamp-flyback-chipset">https://training.ti.com/making-power-supplies-smaller-overview-active-clamp-flyback-chipset</a></td>
</tr>
<tr>
<td>Si SIMPLIS Model</td>
<td>Si based UCC28780 and UCC24612 SIMPLIS simulation model</td>
<td><a href="http://www.ti.com/lit/zip/slum643">http://www.ti.com/lit/zip/slum643</a></td>
</tr>
</tbody>
</table>
Operation Details
UCC28780 Simplified Schematic

Half-bridge Driver

VO
RUN PWMH PWML
VDD
FB
SWS
VSW
HVG
CS
VS
GND
NTC
RDM
RTZ
BUR
REF

CC/CV Regulator

VAC
~
~
+

Half-bridge Driver

UCC28780

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Zero Voltage Switching

- High voltage sensing network measures voltage on the switch node and modulates PWMH (high side clamp FET) on time and dead time to achieve ZVS
  - Adjustment of PWMH and PWML effectively optimizes demagnetization time $t_{DM}$
  - Achieves ZVS with least amount of circulating current necessary
- Allows for auto detection and tuning to guarantee ZVS, regardless of component tolerance and parameter shift
Zero Voltage Switching

Measured results of UCC28780 adaptively achieving ZVS
Purple: Switch Node Voltage
Green: Transformer Primary Current
Blue: PWMH
Brown: PWML

Adaptive, auto tuning control enables zero voltage switching with least amount of circulating current
Difference Between Si and GaN

- Optimal way to drive GaN and Si FET in ACF is slightly different
  - GaN has smaller and less non-linear output capacitance ($C_{OSS}$) when compared to Si FET, especially super junction
- Connecting SET pin to REF (5V) enables Si FET timing control
- Connecting SET pin to GND (0V) enables GaN FET timing control
Benefit of GaN FET + Si SR for ACF

P. Liu, “Design Consideration of Active Clamp Flyback Converter with Highly Nonlinear Junction Capacitance,” APEC’18

Condition: $V_{\text{bulk}}=325\text{V}$, $V_o=20\text{V}/30\text{W}$, primary-resonance ACF

<table>
<thead>
<tr>
<th>Primary Switch</th>
<th>Secondary Rectifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schottky diode</td>
<td>Sync. Rectifier (SR)</td>
</tr>
</tbody>
</table>

- **Silicon FET (650mΩ)**
  - $i_{\text{clamp(RMS)}}=686\text{mA}$
  - $i_{\text{clamp}}=0.5\text{A}$
  - $i_{\text{clamp}}=0.55\text{A}$

- **GaN FET (500mΩ)**
  - $i_{\text{clamp(RMS)}}=530\text{mA}$
  - $i_{\text{clamp}}=0.3\text{A}$
  - $i_{\text{clamp}}=0.35\text{A}$

Less $C_{\text{oss}}$ on primary (GaN) + Higher $C_{\text{oss}}$ on secondary (SR)

Significantly less Primary RMS current

Primary GaN + Secondary Si further reduces the winding loss and $Q_L$ conduction loss
Modes of Operation

UCC28780 has 4 different modes of operation based on power level

Full Load: Adaptive Amplitude Modulation (AAM)
Medium Load: Adaptive Burst Mode (ABM)
Light Load: Low Power Mode (LPM)
No Load: Standby Power Mode (SBP)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Operation</th>
<th>PWMH</th>
<th>ZVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAM</td>
<td>Adaptive Amplitude Modulation</td>
<td>Enabled</td>
<td>Yes</td>
</tr>
<tr>
<td>ABM</td>
<td>Adaptive Burst Mode</td>
<td>Enabled</td>
<td>Yes</td>
</tr>
<tr>
<td>LPM</td>
<td>Low Power Mode</td>
<td>Disabled</td>
<td>No</td>
</tr>
<tr>
<td>SBP</td>
<td>Standby Power</td>
<td>Disabled</td>
<td>No</td>
</tr>
</tbody>
</table>
Full Load
Adaptive Amplitude Modulation (AAM)

- PWML and PWMH complementary switched
- $i_{m(-)}$ constant to achieve ZVS
- $i_{m(+)}$ adjusted to regulate output voltage
  - Decreases as power level is reduced
  - Decreases as input voltage is increased
- As power level decreased or input voltage increased switching frequency is increased
**Medium Load**

Adaptive Burst Mode (ABM)

- Occurs when $V_{CS}$ decreases below $V_{CST(BUR)}$
- UCC28780 enters burst mode
  - First pulse in burst does not have ZVS, but all subsequent pulses do
  - Number of pulses in burst ($N_{SW}$) reduced as power decreases
- Lower burst frequency $f_{BUR}$ always above 20kHz audible range
- Threshold to enter ABM set by BUR pin

**Diagram:**
- $i_m$
- $f_{SW}$
- $f_{BUR}$
- $t_{D(RUN-PWML)}$
- $V_{CST(BUR)}/R_{CS}$
- $ZVS$
- $ZCD$ through $V_{aux}$
- $t_{LEB}$
- $2.2\mu s$
- $0A$
Light Load
Low Power Mode (LPM)

- Occurs when number of pulses in burst ($N_{SW}$) is 2 and burst frequency is less than $f_{BUR(LR)}$
- PWMH is disabled
  - ZVS replaced with DCM valley switching

\[
t_{on(min)} = \frac{V_{CST(BUR)}}{R_{CS}} / \frac{V_{CST(MIN)}}{R_{CS}} - ZCD \text{ though AUX}
\]
No Load
Standby Power Mode (SPM)

- Occurs when $V_{CST}$ reaches $V_{CST(min)}$
- PWMH is disabled
  - ZVS replaced with DCM valley switching
- $f_{BUR}$ reduced to achieve low standby power consumption
Fault Protection

- UCC28780 has extensive integrated fault protection
- Accurate and fast response allows for reduced component oversizing
- Additionally includes device pin open/short protection
Why 16 pins?

<table>
<thead>
<tr>
<th>Function</th>
<th>Pin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias</td>
<td>VDD</td>
<td>Bias from aux winding</td>
</tr>
<tr>
<td></td>
<td>REF</td>
<td>5V reference; +Bypass cap 0.1uF</td>
</tr>
<tr>
<td></td>
<td>HVG</td>
<td>Bias D-FET; +Bypass cap 2nF</td>
</tr>
<tr>
<td></td>
<td>GND</td>
<td>Ground return</td>
</tr>
<tr>
<td>Sense</td>
<td>SWS</td>
<td>HV startup; switch node monitoring</td>
</tr>
<tr>
<td></td>
<td>VS</td>
<td>Resistor divider for line and NVo sensing; zero-crossing detect (ZCD)</td>
</tr>
<tr>
<td></td>
<td>CS</td>
<td>current sensing; program OPP by a line comp resistor</td>
</tr>
<tr>
<td></td>
<td>FB</td>
<td>Sense optocoupler current for output regulation</td>
</tr>
<tr>
<td></td>
<td>NTC</td>
<td>OTP; disable PWM if short</td>
</tr>
<tr>
<td>Output</td>
<td>PWML</td>
<td>Control high-side switch driver</td>
</tr>
<tr>
<td></td>
<td>PWMH</td>
<td>Control low-side switch driver</td>
</tr>
<tr>
<td></td>
<td>RUN</td>
<td>Enable driver; PWML/H active after RUN goes high</td>
</tr>
<tr>
<td>Program</td>
<td>RDM</td>
<td>Set synthesized DeMagnetization time for ZVS tuning</td>
</tr>
<tr>
<td></td>
<td>RTZ</td>
<td>Set transition time to zero delay at high line</td>
</tr>
<tr>
<td></td>
<td>BUR</td>
<td>Set peak current level at high line entering into adaptive burst mode</td>
</tr>
<tr>
<td></td>
<td>SET</td>
<td>SET primary switch type (Si FET to REF; GaN FET to GND)</td>
</tr>
</tbody>
</table>

4 pins used to program UCC28780 to compensate for parasitic impact and optimization for unique implementation.
Experimental Results
## Reference Designs

<table>
<thead>
<tr>
<th>Power Level</th>
<th>Output Voltage</th>
<th>FET</th>
<th>Reference Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>45W</td>
<td>20V</td>
<td>GaN</td>
<td>UCC28780EVM-002</td>
</tr>
<tr>
<td>45W</td>
<td>20V</td>
<td>Si</td>
<td>UCC28780EVM-021</td>
</tr>
<tr>
<td>65W</td>
<td>USB PD (5, 9, 15, 20V)</td>
<td>GaN</td>
<td>TIDA-01622</td>
</tr>
<tr>
<td>65W</td>
<td>USB PD (5, 9, 15, 20V)</td>
<td>Si</td>
<td>PMP21479</td>
</tr>
</tbody>
</table>
UCC28780EVM-002 Overview

GaN Based Design

Input: 85-265VAC RMS, 47-63Hz  Output: 20V, 45W

Board Dimensions: 2.32in x 1.32in x 0.68in

Open Frame Power Density: **21.5W/in³**

**UCC28780EVM-002 Specification Details**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT CHARACTERISTICS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{in}$</td>
<td>Input line voltage (RMS)</td>
<td>90</td>
<td>115 / 230</td>
<td>284</td>
<td>V</td>
</tr>
<tr>
<td>$f_{LINE}$</td>
<td>Input line frequency</td>
<td>47</td>
<td>50 / 60</td>
<td>63</td>
<td>Hz</td>
</tr>
<tr>
<td>$P_{IN}$</td>
<td>Input power at no-load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{IN}$</td>
<td>Input power at no-load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{SW}$</td>
<td>Input power at 0.25W load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{SW}$</td>
<td>Input power at 0.25W load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OUTPUT CHARACTERISTICS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{OUT}$</td>
<td>Output voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{OUT}$</td>
<td>Output voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{OUT}$</td>
<td>Full load rated output current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{Ripple,vpp}$</td>
<td>Output ripple voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{Ripple,vpp}$</td>
<td>Output ripple voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{OUT}$</td>
<td>Over-power protection power limit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t_{SP}$</td>
<td>Over-power protection duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{OUT}$</td>
<td>Output voltage deviation due to load step up</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SYSTEMS CHARACTERISTICS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>Full-load efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>4-point average efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>Efficiency at 10% Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_{AMB}$</td>
<td>Ambient operating temperature range</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) The performance listed in this table is achieved using secondary resonance and based on the test results from a single board.

www.ti.com/tool/UCC28780EVM-002
UCC28780EVM-002 Schematic
High efficiency over entire load and line range exceeds standards DoE Level VI and CoC Tier 2

www.ti.com/tool/UCC28780EVM-002
Adaptive Amplitude Modulation (AAM)

Sensing with auto-tuning guarantees ZVS during operation

www.ti.com/tool/UCC28780EVM-002
Adaptive Burst Mode (ABM)

ZVS achieved during bursts of transition mode (TM) operation followed by discontinuous conduction mode (DCM), except for first cycle of burst packet
UCC28780EVM-002 Accurate OPP

Over power protection threshold varies by less than 3W over input voltage range.

www.ti.com/tool/UCC28780EVM-002
UCC28780EVM-002 Thermal Measurement
# Modification for Si FET

<table>
<thead>
<tr>
<th></th>
<th>Resonance Approach</th>
<th>Pri FET</th>
<th>High-side Driving</th>
<th>$C_{\text{clamp}}$</th>
<th>$R_{\text{RTZ}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaN ACF</td>
<td>Sec. resonance</td>
<td>NV6117($Q_L$)</td>
<td>ISO7710F</td>
<td>0.44μF</td>
<td>240kΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NV6115 ($Q_H$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si ACF</td>
<td>Sec. resonance</td>
<td>CP 350mΩ</td>
<td>UCC27712</td>
<td>0.88μF</td>
<td>348kΩ</td>
</tr>
</tbody>
</table>

Use same EMI filter, input/output filter, and transformer for a fair comparison.
**45W Full-Load Efficiency Comparison**

Condition: (1) same RM8LP XFMR; (2) same EMI filter; (3) same output filter; (4) similar $f_{sw}$ range

<table>
<thead>
<tr>
<th></th>
<th>90Vac</th>
<th>265Vac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si QR</td>
<td>92.12% ($f_{sw}$=237kHz)</td>
<td>89.93% ($f_{sw}$=413kHz)</td>
</tr>
<tr>
<td>Si ACF</td>
<td>93.12% ($f_{sw}$=206kHz)</td>
<td>93.51% ($f_{sw}$=285kHz)</td>
</tr>
<tr>
<td>GaN ACF</td>
<td>94.14% ($f_{sw}$=227kHz)</td>
<td>94.63% ($f_{sw}$=295kHz)</td>
</tr>
</tbody>
</table>

- Si ACF provides 3.6% improvement over Si QR at 265Vac.
- With same EMI filter, Si ACF is 1% lower than GaN ACF at 90Vac.
31W/in³, 94% Efficiency, 65W USB-PD AC/DC Adapter Reference Design / TI Design: TIDA-01622

**Features**

- Active-clamp Flyback + SR topology (UCC28780+UCC24612)
- Wide AC input range: 85 – 265 VAC, Output ripple voltage <=200mV@20V
- 94% Peak efficiency
- Robust OCP/SCP/OPP with Auto Recovery, OVP latch
- No load power <=75mW (60mW), 20Vout@0.25W Pin<=0.5W
- Meets Norms: EN–55032 class B (CE)

**Benefits**

- Solution is based on the both-ended type-C cable
- Enable UCB PD 2.0 fully compatible AC/DC adapter design.
- **Leading power density** with active-clamp flyback topology in high switching frequency
- Meet DoE level VI & CoC Tier2 regulation
- Robust protection built-in

**Target Applications**

- Notebook PC power adapter
- Smartphone wall charger
- Other 60W AC/DC converter

**Tools & Resources**

- TIDA-01622 and Tools Folder
- Design Guide
- Design Files: Schematics, BOM, Gerbers
- Device Datasheets:
  - UCC28780RTE, UCC24612-1, TPS25740B, ATL431, ISO7710F

64mm*28.6mm*18.4mm
65W Efficiency Data 115V/60Hz

GaN
TIDA-01622

Si
PMP21479

Efficiency

Load

5V 9V 15V 20V

115VAC/60Hz

Si design NOT final

Texas Instruments
65W Efficiency Data 230V/60Hz

GaN
TIDA-01622

Si
PMP21479

Si design NOT final