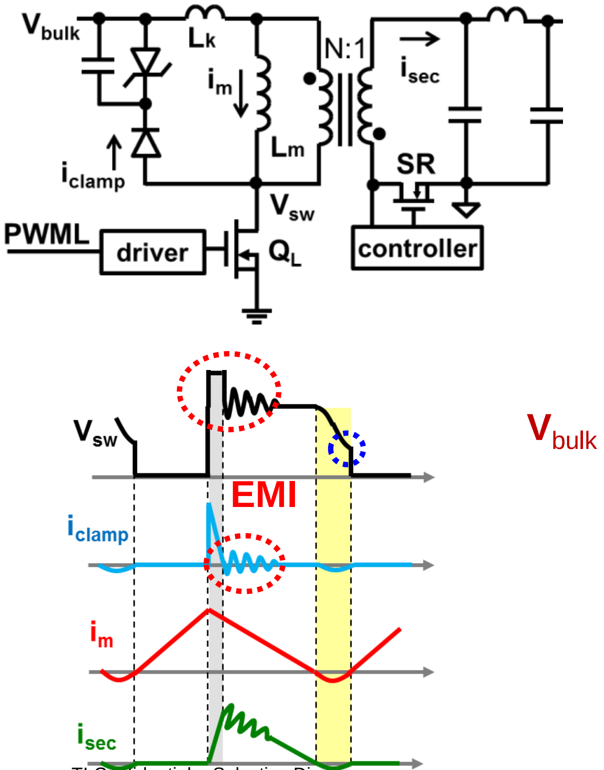
Active Clamp Flyback Converter
主動鉗位式返馳轉換器

Power Delivery Webinar

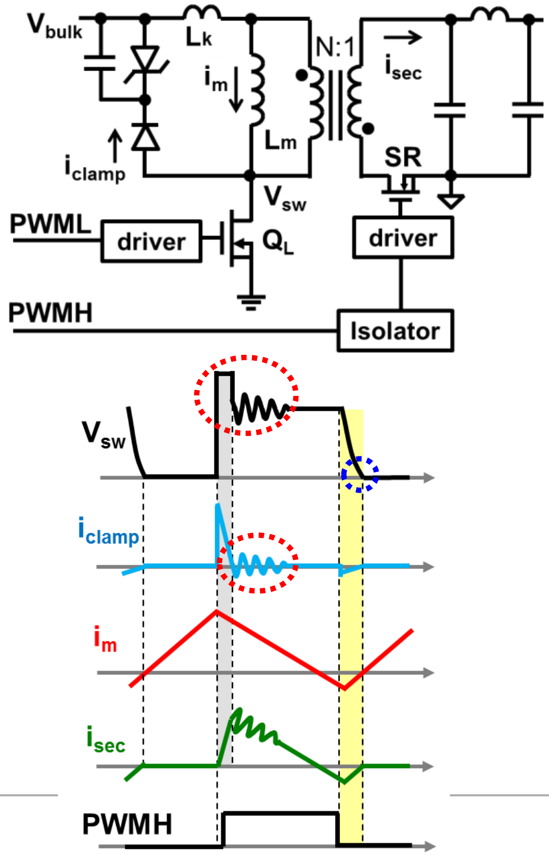
Speaker : Adam Lin

Soft-Switching Passive Clamp Flyback

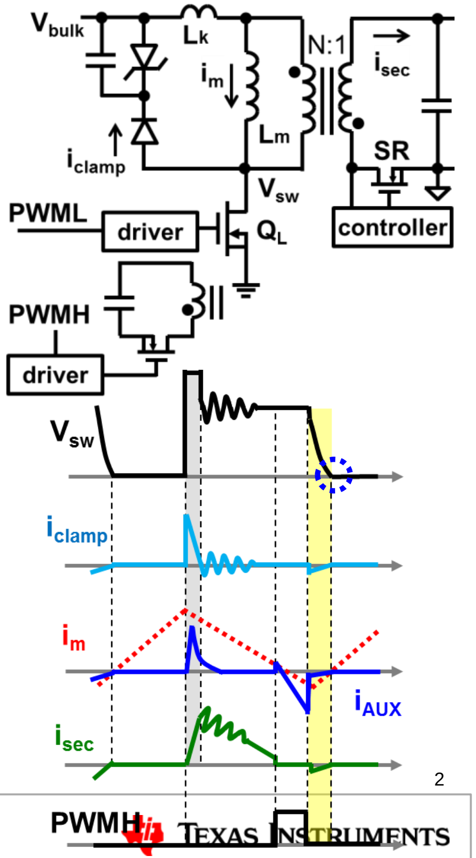
Valley Switching (QR)



PCF-SR



PCF-Aux

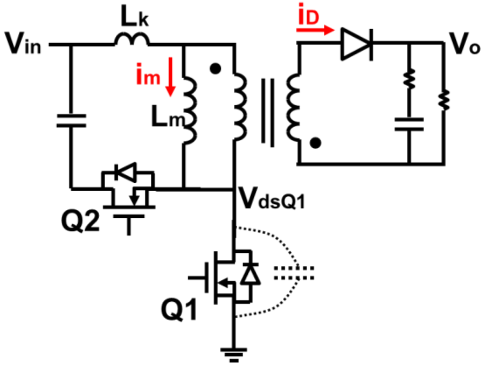


Active Clamp Flyback

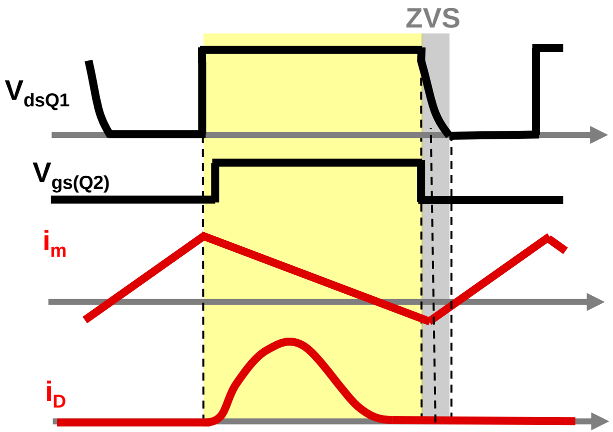
Eliminates switching losses and reduces EMI with proper control of the clamp which allows **zero voltage switching (ZVS) to be achieved**.

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

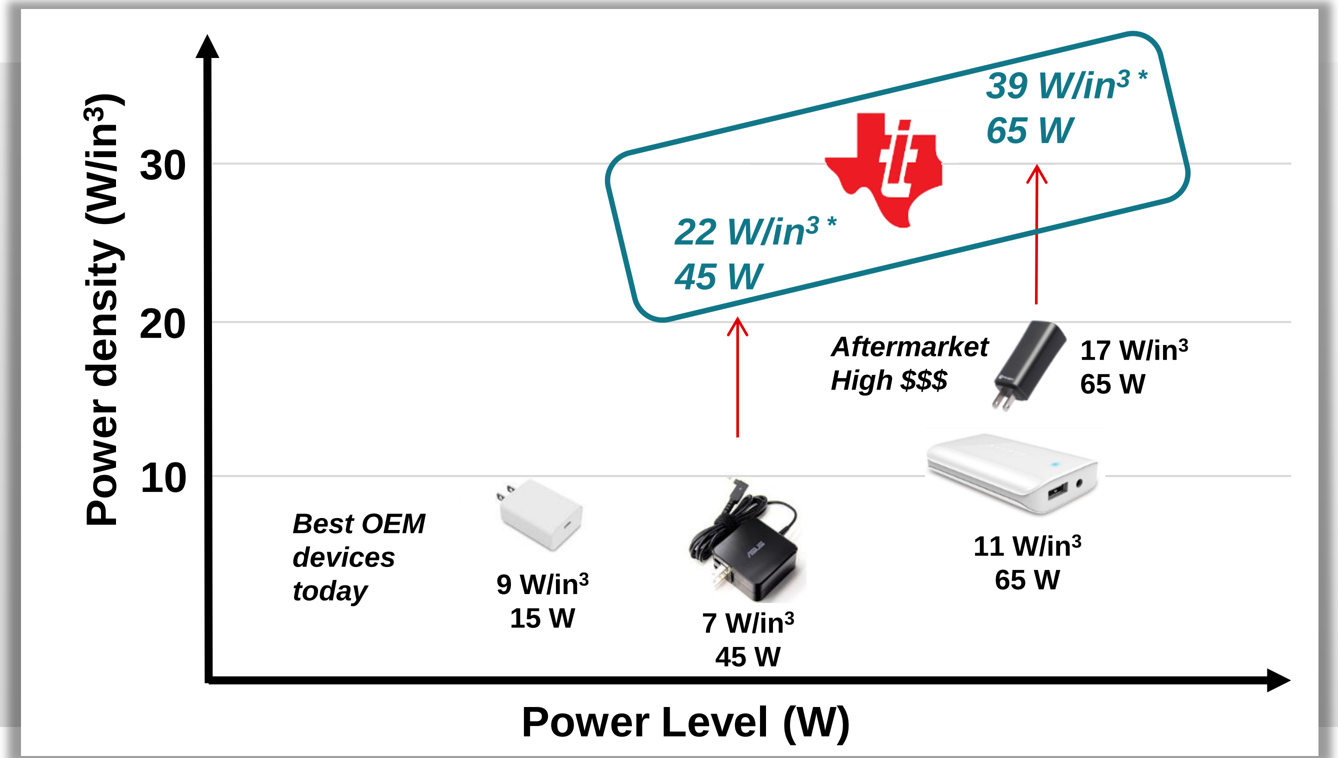
Enables greater power density Lower switching losses enables higher switching frequencies, which allows for smaller passive components.
Lower temperature rise allows tighter packaging.



ACF Topology



TI Active Clamp Flyback vs Existing Solutions



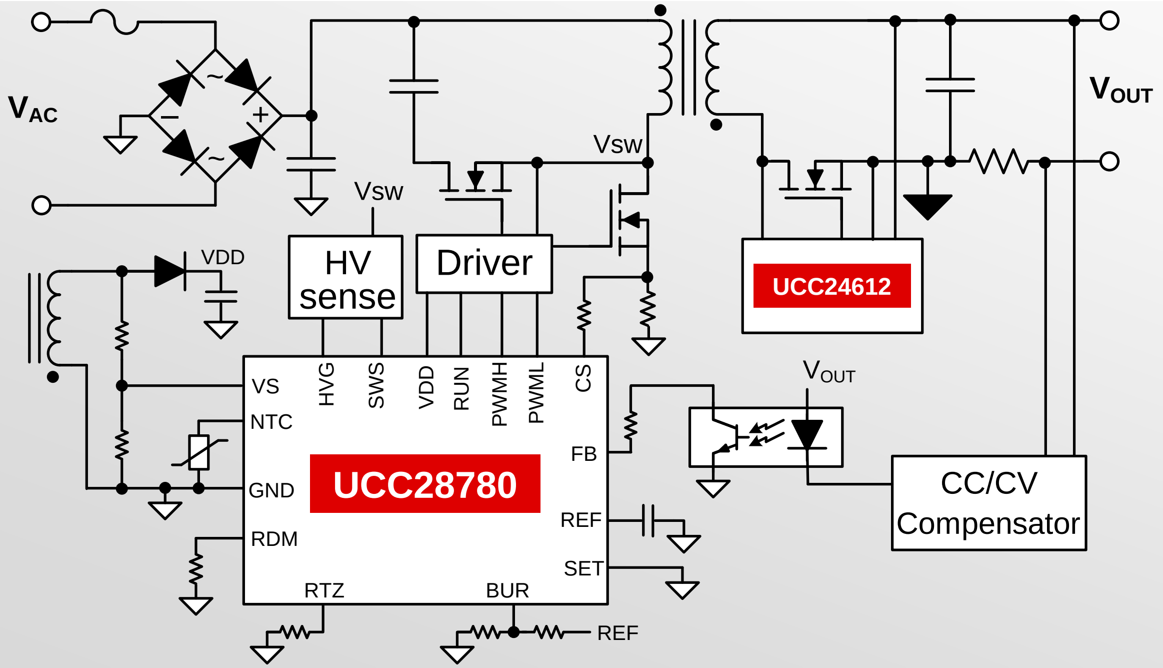
* Open frame power density

TI Solution:

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

TI Active Clamp Flyback Chipset

More power in less space



UCC28780 Active Clamp Flyback

High frequency without a heatsink

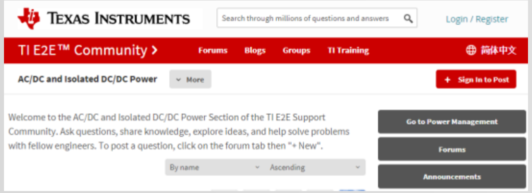
- 1 MHz GaN or Si FET support
- Best in class efficiency from innovative ZVS algorithm
- Advanced protection features
- 3 patents filed

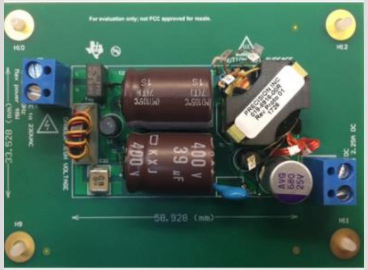
UCC24612 Advanced Sync Rectifier

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

Application Notes

TI Sales Support

E2E Forums

Training Videos

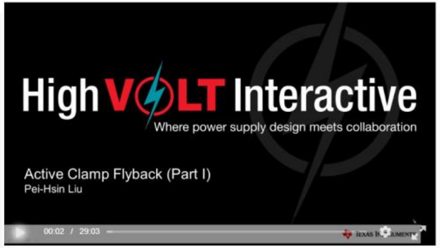
Plethora of design support tools starting at www.ti.com/product/UCC28780

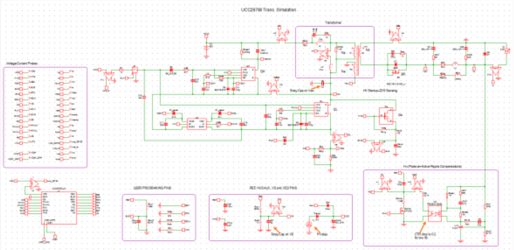
Evaluation Modules

SIMPLIS Simulation Model

Reference Designs

Mathcad Design Calculator



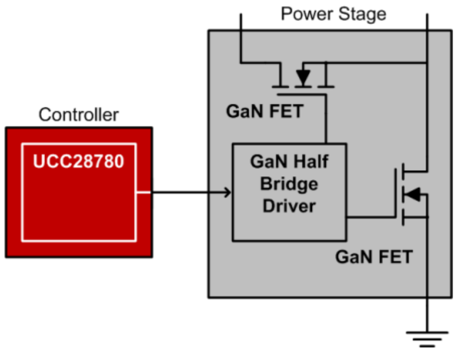


Why Galium Nitride (GaN) FET ?

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

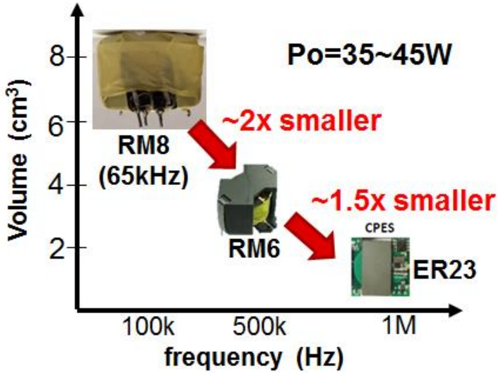
UCC28780 is optimized to interface with GaN FETs

Interaction



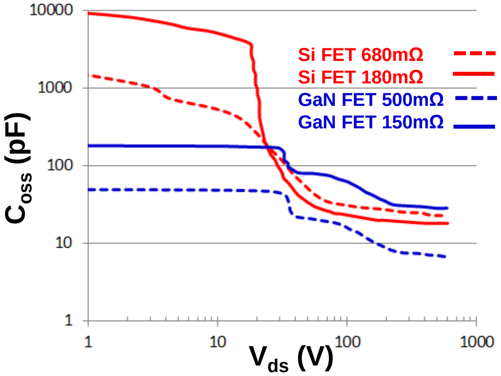
Direct interface with driver + FET integrated solutions

Size



Operation up to 1 MHz enables further size reduction

Performance



Control law optimized to work with GaN and Si parameters

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

Applications

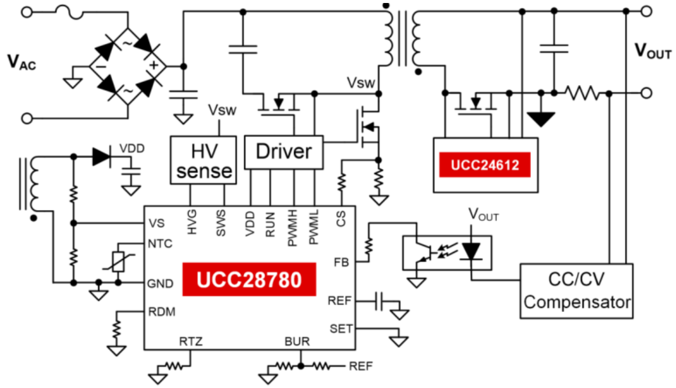
- High-Density AC-to-DC Adapters for Notebook, Tablet, TV, Set-Top Box and Printer
- USB Power Delivery, Direct and Fast Mobile Chargers
- AC-to-DC or DC-to-DC Auxiliary Power Supply

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

QFN-16

SOIC-16



www.ti.com/product/UCC28780

UCC28780

Adaptive ZVS Active Clamp Flyback Controller

Features

Discovery questions

Pricing, availability, resources

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

Features

Discovery questions

Pricing, availability, resources

Product Info: http://www.ti.com/product/UCC28780

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
- Datasheet: http://www.ti.com/lit/ds/symlink/ucc28780.pdf
- 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:

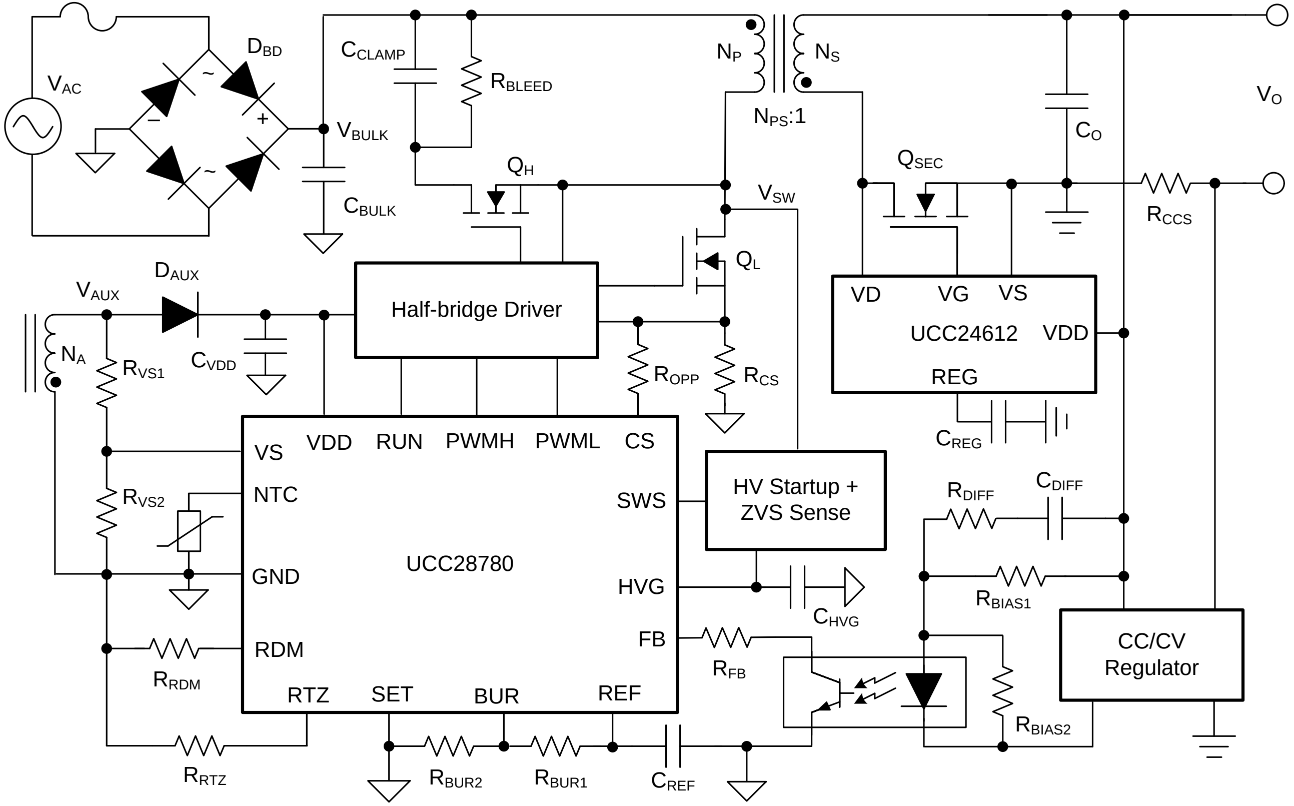
- Support (E2E): http://e2e.ti.com/support/power_management/isolated_controllers/

UCC28780 Customer Collateral

Content type	Content title	Link to content or more details
Training Video	What is an Active Clamp Flyback?	https://training.ti.com/what-active-clamp-flyback
Technical Note	Increasing Power Density With the Active Clamp Flyback Controller (UCC28780)	http://www.ti.com/lit/an/slua871/slua871.pdf
Training Video	Making power supplies smaller: An overview of the active clamp flyback chipset	https://training.ti.com/making-power-supplies-smaller-overview-active-clamp-flyback-chipset
GaN Reference Design	30-W/in^3, 94% Efficiency, 65-W USB Type-C PD AC/DC Adapter Reference Design	http://www.ti.com/tool/TIDA-01622
Si Reference Design	High Efficiency, High Power Density Active Clamp Flyback Adapter with SJ FET Reference Design	http://www.ti.com/tool/PMP40328
Evaluation Module (EVM)	45-W High-Density Active-Clamp Flyback AC-DC Converter Evaluation Module Using GaN MOSFETs	http://www.ti.com/tool/ucc28780evm-002
Datasheet	UCC28780 Datasheet	http://www.ti.com/lit/ds/symlink/ucc28780.pdf
Design Calculator	UCC28780 Mathcad Design Calculator	http://www.ti.com/lit/zip/sluc644
GaN SIMPLIS Model	GaN based UCC28780 and UCC24612 SIMPLIS simulation model	http://www.ti.com/lit/zip/slum626
Si SIMPLIS Model	Si based UCC28780 and UCC24612 SIMPLIS simulation model	http://www.ti.com/lit/zip/slum643
High Voltage Interactive Technical Training Video	Active Clamp Flyback (Part 1 and 2)	Part 1: https://training.ti.com/active-clamp-flyback-part-1?cu=1134585 Part 2: https://training.ti.com/active-clamp-flyback-part-2?cu=1134585
	Hysteresis loss in high voltage MOSFETs: Findings and effects for high frequency AC-DC converters	https://training.ti.com/hysteresis-loss-high-voltage-mosfets-findings-and-effects-high-frequency-ac-dc-converters
Power Supply Design Seminar	Comparison of GaN and Silicon FET-Based Active Clamp Flyback Converters	Part 1: https://training.ti.com/gan-and-silicon-fet-based-acf-1?cu=1135482 Part 2: https://training.ti.com/gan-and-silicon-fet-based-acf-2?cu=1135482 Part 3: https://training.ti.com/gan-and-silicon-fet-based-acf-3?cu=1135482

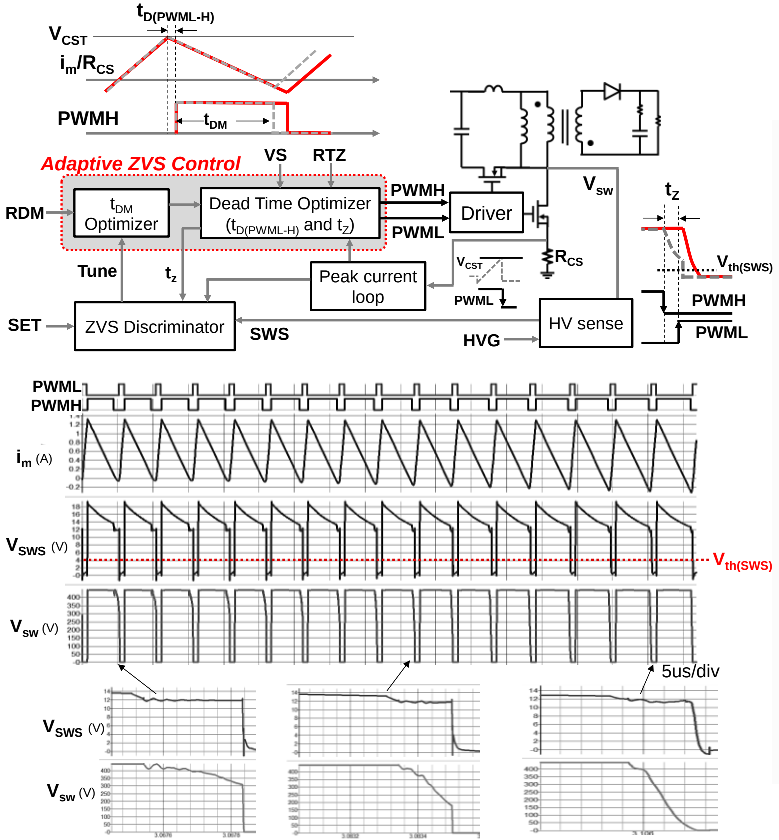
Operation Details

UCC28780 Simplified Schematic

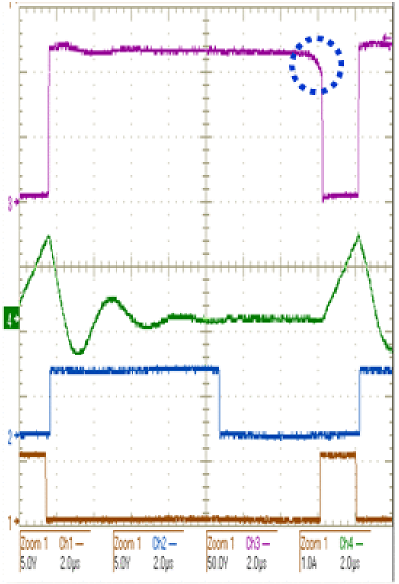


Zero Voltage Switching

- 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

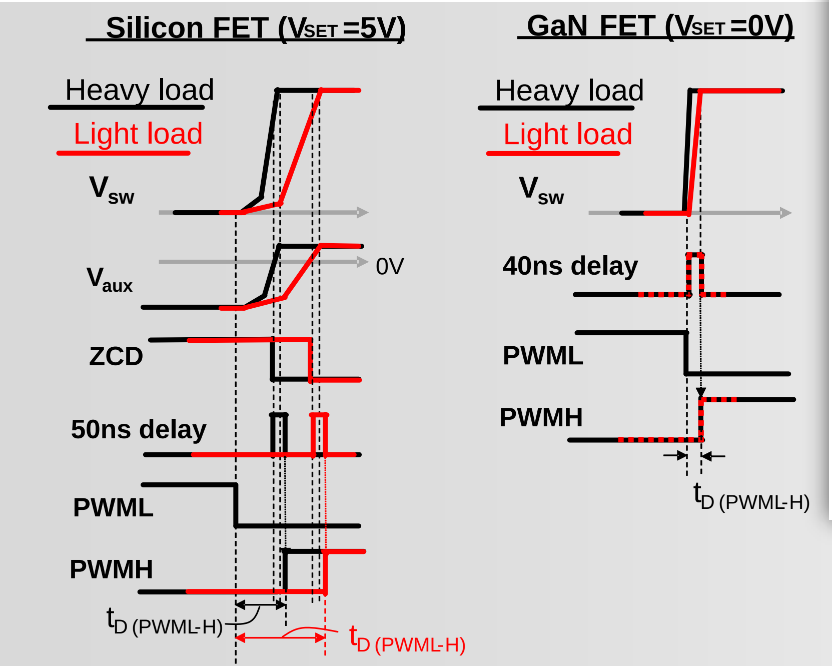
Green: Transformer Primary Current

Blue: PWMH

Brown: PWML

Adaptive, auto tuning control enables zero voltage switching with least amount of circulating current

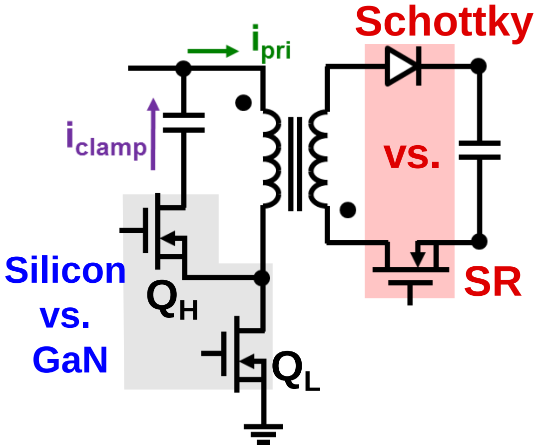
Difference Between Si and GaN



- 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

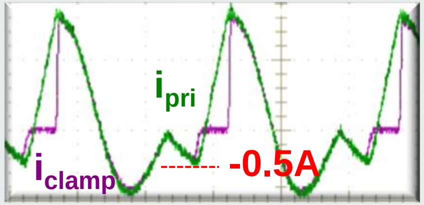
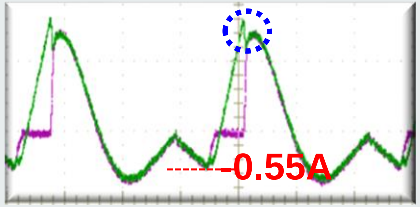
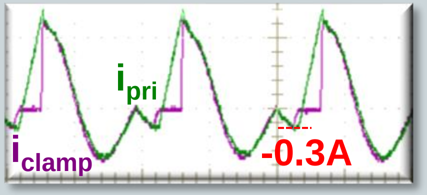
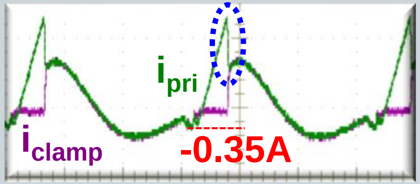
P. Liu, “Design Consideration of Active Clamp Flyback Converter with Highly Nonlinear Junction Capacitance,” *APEC‘18*



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

Significantly less Primary RMS current

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

Primary Switch	Secondary Rectifier	
	Schottky diode	Sync. Rectifier (SR)
Silicon FET (650mΩ)	 $i_{clamp(RMS)}$=686mA	 $i_{clamp(RMS)}$=600mA
GaN FET (500mΩ)	 $i_{clamp(RMS)}$=530mA	 $i_{clamp(RMS)}$=349mA

Primary GaN + Secondary Si further reduces the winding loss and Q_H conduction loss

Modes of Operation

UCC28780 has 4 different modes of operation based on power level

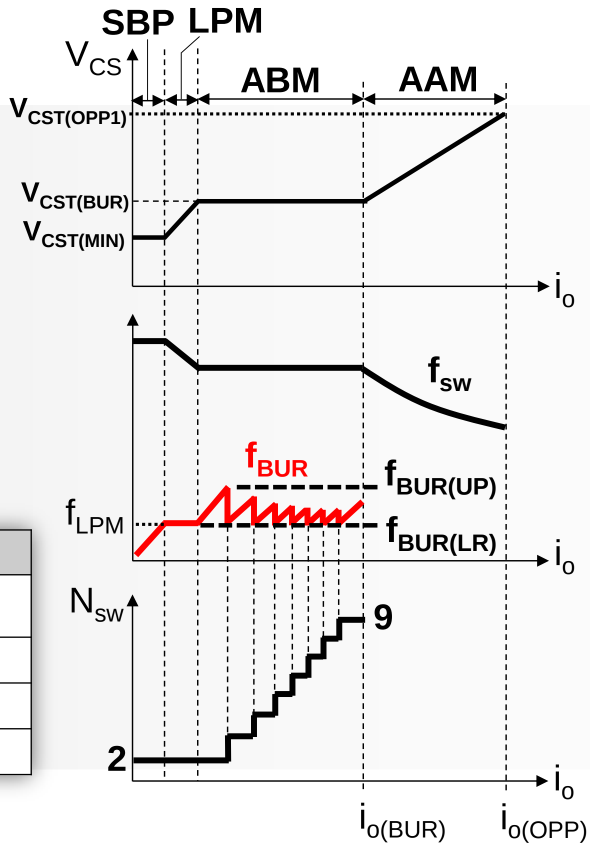
Full Load: Adaptive Amplitude Modulation (AAM)

Medium Load: Adaptive Burst Mode (ABM)

Light Load: Low Power Mode (LPM)

No Load: Standby Power Mode (SBP)

Mode		Operation	PWMH	ZVS
AAM	Adaptive Amplitude Modulation	Complementary ACF	Enabled	Yes
ABM	Adaptive Burst Mode	Variable f_{BUR}>20kHz, Complementary ACF	Enabled	Yes
LPM	Low Power Mode	Fix f_{BUR}≈25kHz, Valley Switching	Disabled	No
SBP	Standby Power	Variable f_{BUR}<25kHz, Valley Switching	Disabled	No

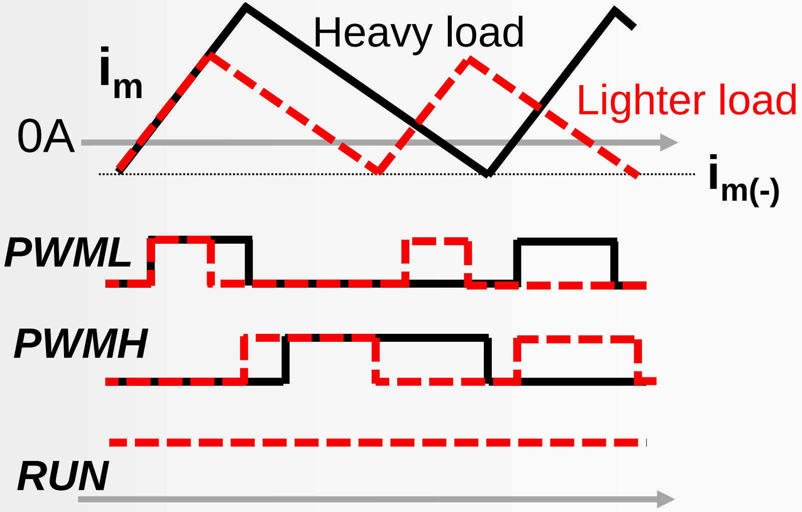


Texas Instruments

Full Load

Adaptive Amplitude Modulation (AAM)

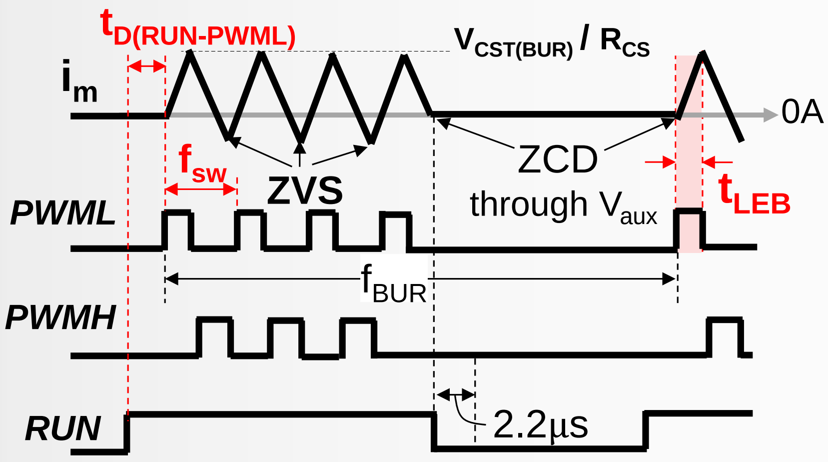
- PWML and PWMH complementary switched
- $i_{m(-)}$ constant to achieve ZVS
- $i_{m(+)}$ adjusted to regulate output voltage
  - Decreases as power level is reduced
  - Decreases as input voltage is increased
- As power level decreased or input voltage increased switching frequency is increased



Medium Load

Adaptive Burst Mode (ABM)

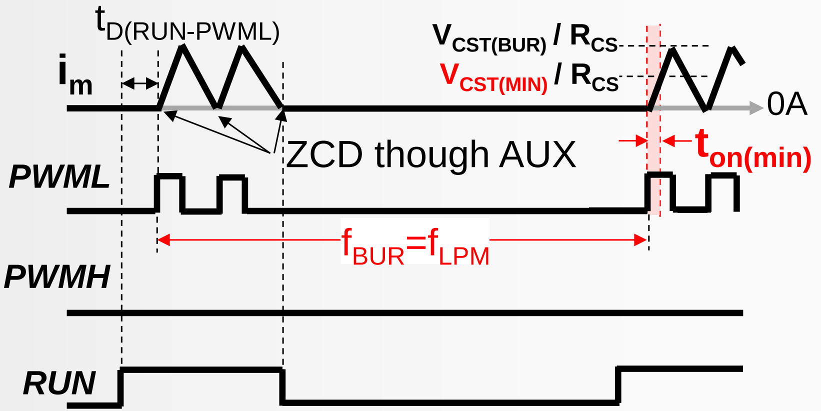
- Occurs when V_{CS} decreases below $V_{CST(BUR)}$
- UCC28780 enters burst mode
  - First pulse in burst does not have ZVS, but all subsequent pulses do
  - Number of pulses in burst (N_{SW}) reduced as power decreases
- Lower burst frequency f_{BUR} always above 20kHz audible range
- Threshold to enter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



Light Load

Low Power Mode (LPM)

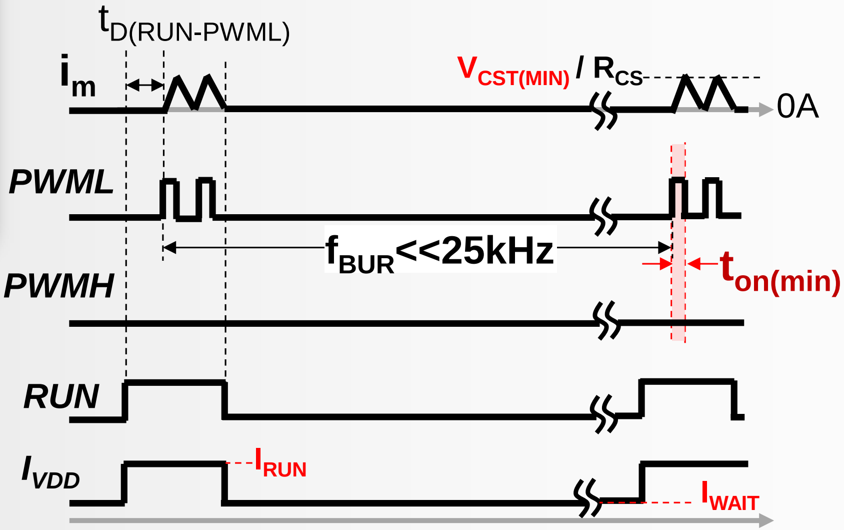
- Occurs when number of pulses in burst (N_{SW}) is 2 and burst frequency is less than $f_{BUR(LR)}$
- PWMH is disabled
  - ZVS replaced with DCM valley switching



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



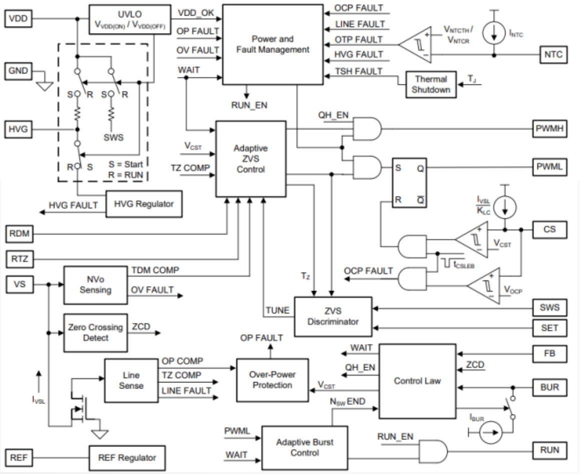
Fault Protection

PROTECTION	SENSING	THRESHOLD	DELAY TO ACTION	ACTION
VDD UVLO	VDD voltage	$V_{VDD(OFF)} \leq V_{VDD} \leq V_{VDD(ON)}$	None	UVLO reset
Over-power protection (OPP)	CS voltage	$V_{CST(OPP)} \leq V_{CST} \leq V_{CST(MAX)}$	t_{OPP} (160 ms)	t_{FDR} restart (1.5s)
Peak current limit (PCL)	CS voltage	$V_{CST} \leq V_{CST(MAX)}$		
Over-current protection (OCP)	CS voltage	$V_{CS} \geq V_{OCP}$	3 PWML pulses	t_{FDR} restart
Output short-circuit protection (SCP)	CS, VS, and VDD voltages	(1) $V_{VDD} = V_{VDD(OFF)}$ & $V_{CST} \geq V_{CST(OPP)}$; (2) $V_{VDD} = V_{VDD(OFF)}$ & $V_{VS} \leq 0.6$ V	$\leq t_{OPP}$	t_{FDR} restart
Output over-voltage protection (OVP)	VS voltage	$V_{VS} \geq V_{OVP}$	3 PWML pulses	t_{FDR} restart
Brown-in detection	VS current	$I_{VSL} \leq I_{VSL(RUN)}$	4 PWML pulses	UVLO reset
Brown-out detection	VS current	$I_{VSL} \leq I_{VSL(STOP)}$	t_{BO} (60ms)	UVLO reset
Over-temperature protection (OTP)	NTC voltage	$R_{NTC} \leq R_{NTCTH}$	3 PWML pulses	UVLO reset until $R_{NTC} \geq R_{NTCR}$
Thermal shutdown	Junction temperature	$T_J \geq T_{J(STOP)}$	3 PWML pulses	UVLO reset

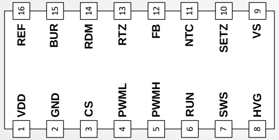
- UCC28780 has extensive integrated fault protection
- Accurate and fast response allows for reduced component oversizing
- **Additionally includes device pin open/short protection**

Why 16 pins?

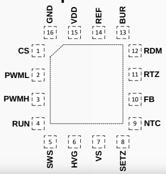
Function	Pin	Description
Bias	VDD	Bias from aux winding
	REF	5V reference; +Bypass cap 0.1uF
	HVG	Bias D-FET; +Bypass cap 2nF
	GND	Ground return
Sense	SWS	HV startup; switch node monitoring
	VS	Resistor divider for line and NVo sensing; zero-crossing detect (ZCD)
	CS	current sensing; program OPP by a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



UCC28780
D PKG, SOIC-16
Top View



RTE Package
16 Pin VQFN
Top View



4 pins used to program UCC28780 to compensate for parasitic impact and optimization for unique implementation

Experimental Results

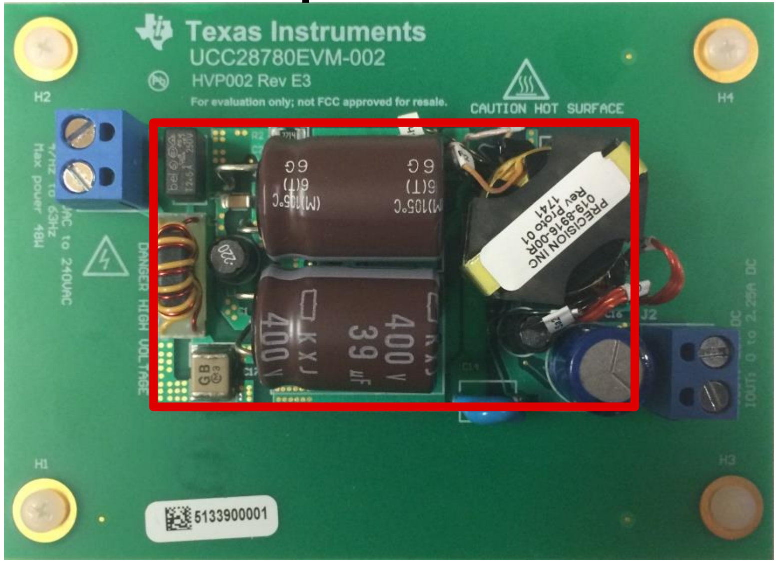
Reference Designs

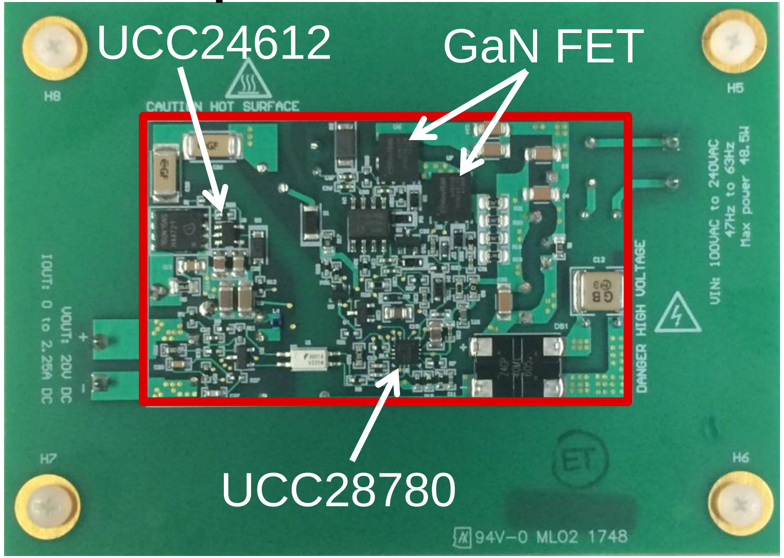
Power Level	Output Voltage	FET	Reference Number
45W	20V	GaN	UCC28780EVM-002
45W	20V	Si	UCC28780EVM-021
65W	USB PD (5, 9, 15, 20V)	GaN	TIDA-01622
65W	USB PD (5, 9, 15, 20V)	Si	PMP21479

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/in^3**

www.ti.com/tool/**UCC28780EVM-002**

UCC28780EVM-002 Specification Details

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
INPUT CHARACTERISTICS						
V_{IN}	Input line voltage (RMS)		90	115 / 230	264	V
f_{LINE}	Input line frequency		47	50 / 60	63	Hz
P_{STBY}	Input power at no-load	V_{IN} = 115 V_{RMS}, I_{OUT} = 0 A		41.1		mW
P_{STBY}	Input power at no-load	V_{IN} = 230 V_{RMS}, I_{OUT} = 0 A		52.8		mW
$P_{0.25W}$	Input power at 0.25W load	V_{IN} = 115 V_{RMS}, P_{OUT} = 250.6 mW		383.8		mW
$P_{0.25W}$	Input power at 0.25W load	V_{IN} = 230 V_{RMS}, P_{OUT} = 250.6 mW		435.0		mW
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage	V_{IN} = 115 V_{RMS}, I_{OUT} = 2.249 A		19.853		V
		V_{IN} = 230V_{RMS}, I_{OUT} = 2.249 A		19.852		
V_{OUT}	Output voltage	V_{IN} = 115 V_{RMS}, I_{OUT} = 0 A		19.943		V
		V_{IN} = 230V_{RMS}, I_{OUT} = 0 A		19.948		
I_{OUT}	Full load rated output current	V_{IN} = 90 to 264 V_{RMS}		2.25		A
V_{OUT_pp}	Output ripple voltage	V_{IN} = 115 V / 230 V_{RMS}, I_{OUT} = 0 to 2.25		80		mVpp
V_{OUT_pp}	Output ripple voltage	V_{IN} = 115 V / 230 V_{RMS}, I_{OUT} = 2.25 A		45		mVpp
V_{OUT_pp}	Output ripple voltage	V_{IN} = 115 V / 230 V_{RMS}, I_{OUT} = 0 A		50		mVpp
P_{OUT_opp}	Over-power protection power limit	V_{IN} = 90 to 264 V_{RMS}		55		W
t_{OPP}	Over-power protection duration	V_{IN} = 90 to 264 V_{RMS}, P_{OUT} = P_{OUT_opp}		160		ms
V_{OUT_Δ}	Output voltage deviation due to load step up	I_{OUT} step between 0 A and 2.25A		< 5		%
SYSTEMS CHARACTERISTICS						
η	Full-load efficiency	V_{IN} = 115 V_{RMS}, I_{OUT} = 2.25A		94.59		%
		V_{IN} = 230 V_{RMS}, I_{OUT} = 2.25A		94.74		%
		V_{IN} = 90V RMS, I_{OUT} = 2.25A		93.98		%
η	4-point average efficiency[2]	V_{IN} = 115 V_{RMS}		93.88		%
		V_{IN} = 230 V_{RMS}		92.47		%
η	Efficiency at 10% Load	V_{IN} = 115 V_{RMS}, I_{OUT} = 10% rated current		88.69		%
		V_{IN} = 230 V_{RMS}, I_{OUT} = 10% rated current		85.86		%
T_{AMB}	Ambient operating temperature range	V_{IN} = 90 to 264 V_{RMS}, I_{OUT} = 0 to 2.25A		25		°C

(1) The performance listed in this table is achieved using secondary resonance and based on the test results from a single board.
(2) Average efficiency of four load points, I_{OUT} = 25%, 50%, 75% and 100% nom.

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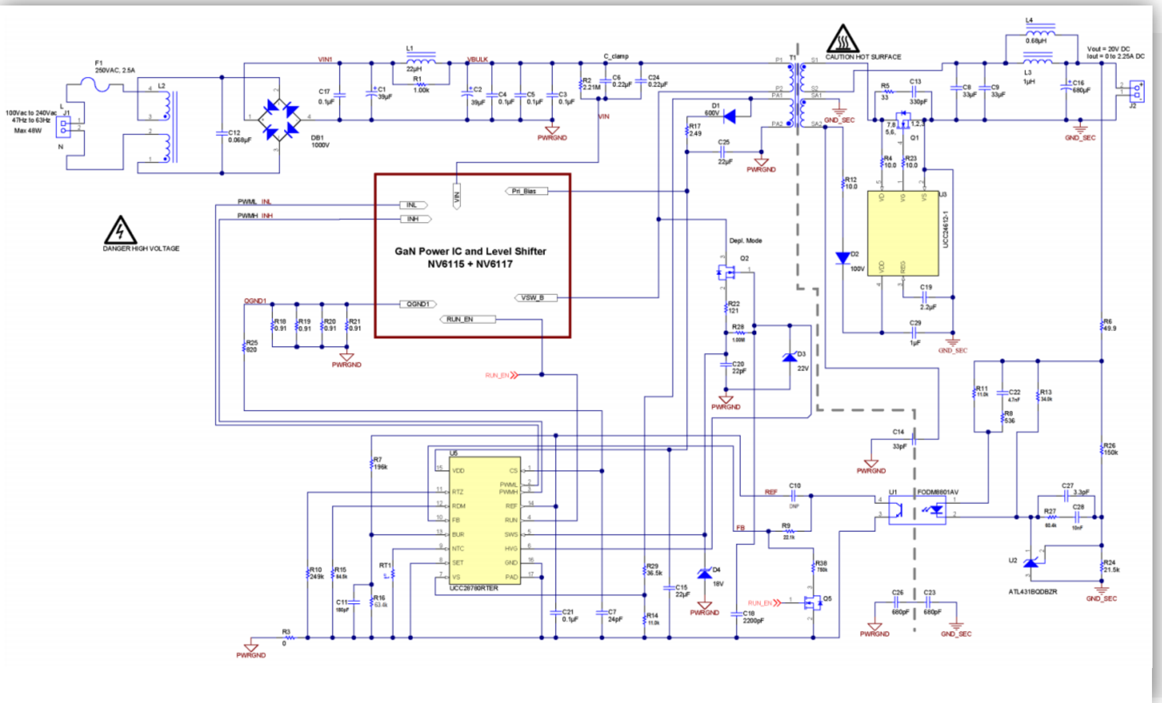
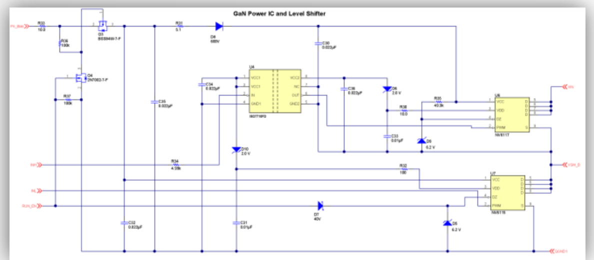
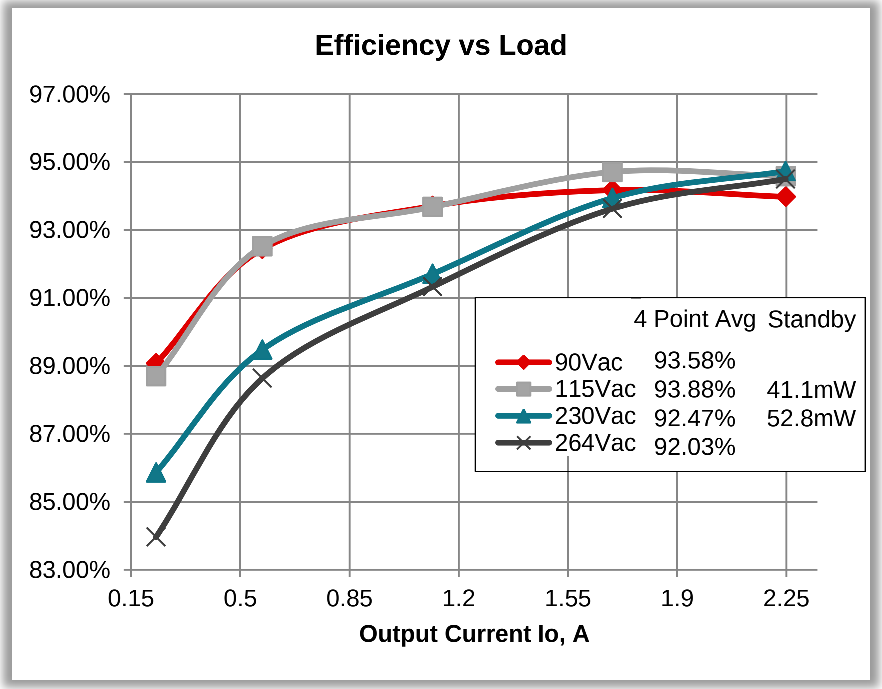
UCC28780EVM-002 Schematic

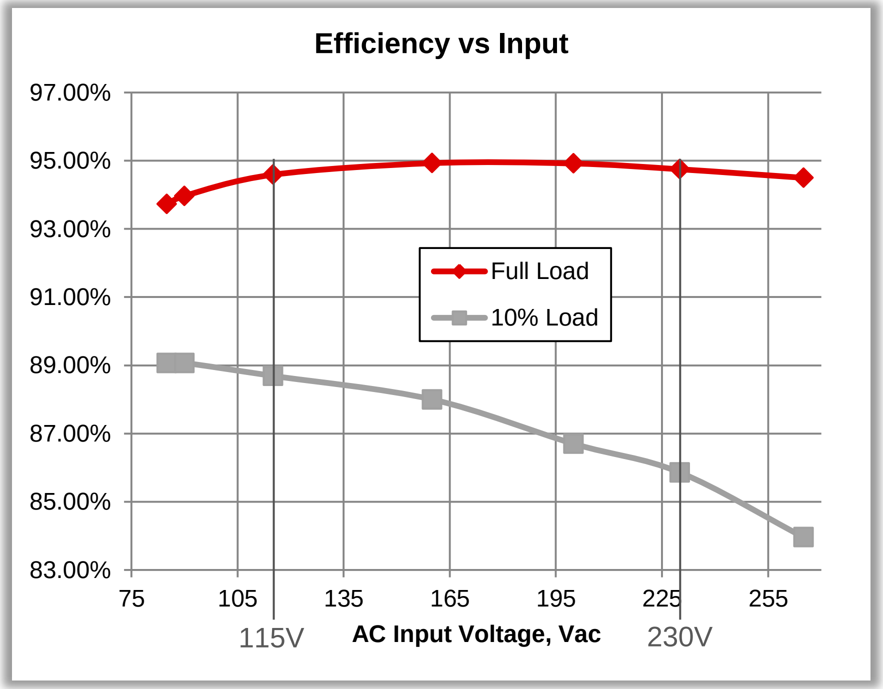




Texas Instruments

UCC28780EVM-002 Measured Efficiency





High efficiency over entire load and line range

exceeds standards DoE Level VI and CoC Tier 2

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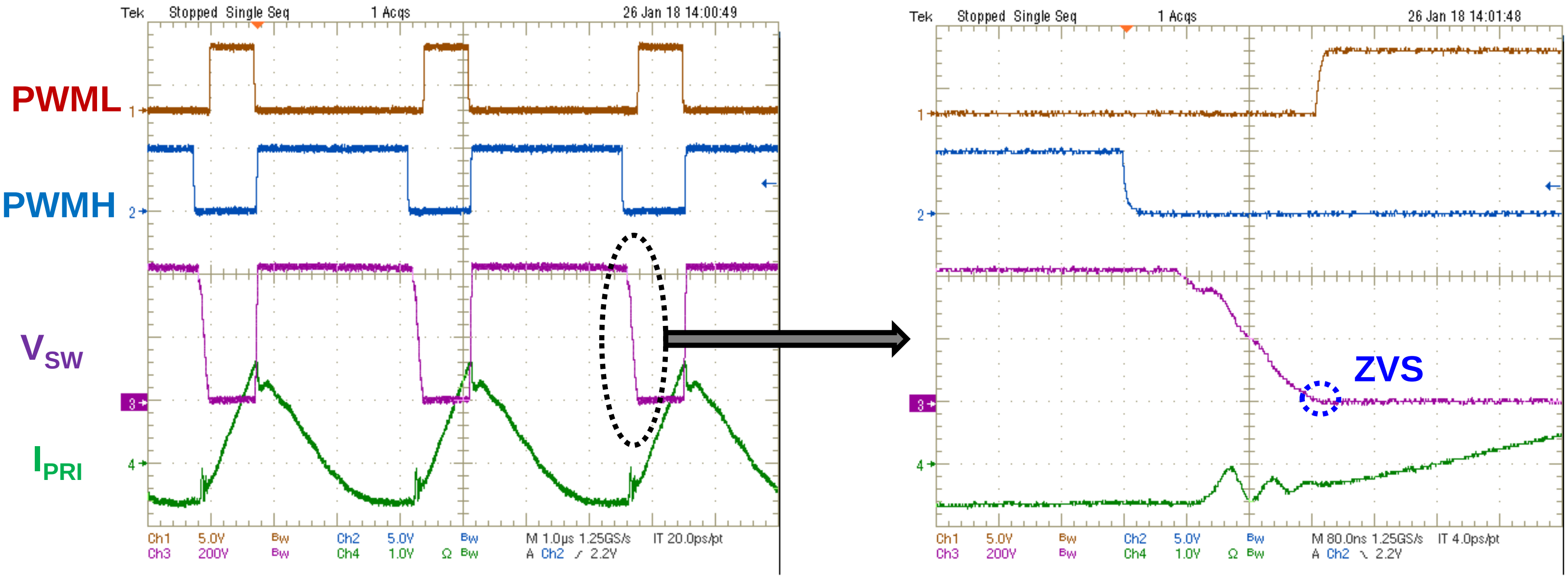
Adaptive Amplitude Modulation (AAM)



Sensing with auto-tuning guarantees ZVS during operation

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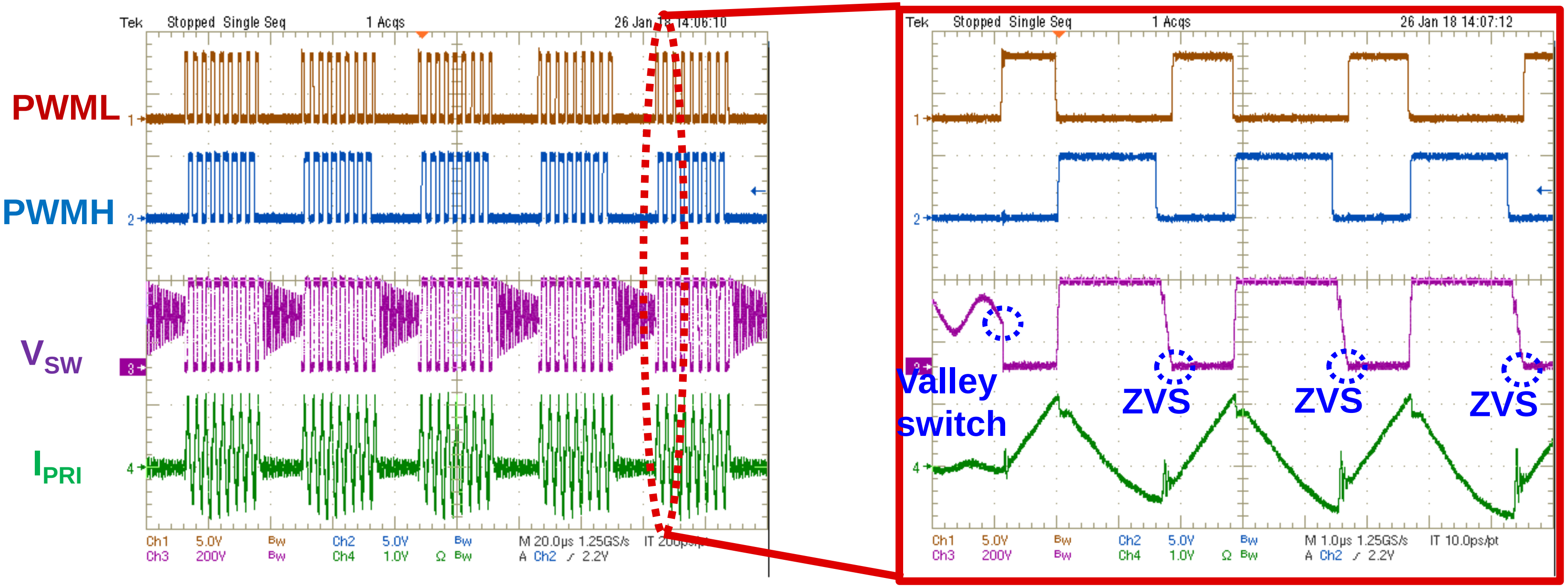
Adaptive Burst Mode (ABM)



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

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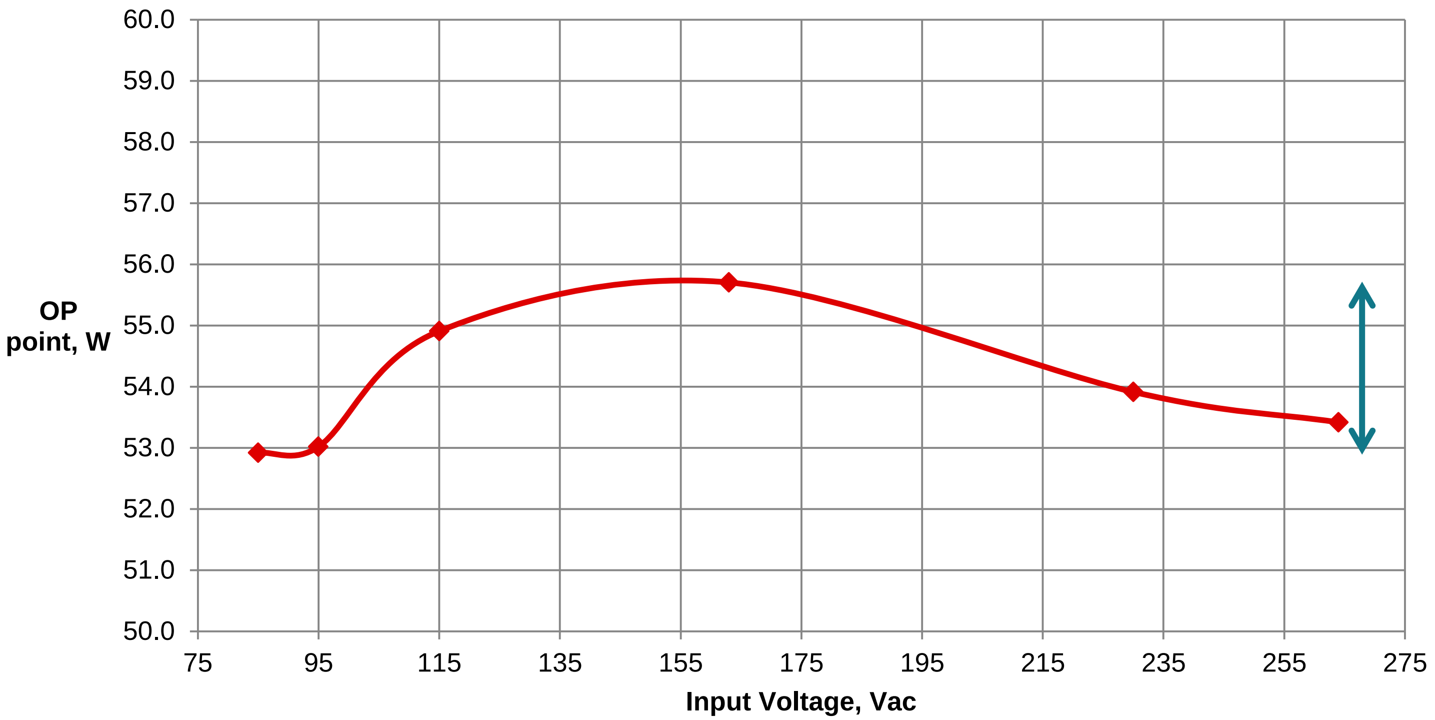
UCC28780EVM-002 Accurate OPP



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

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UCC28780EVM-002 Thermal Measurement

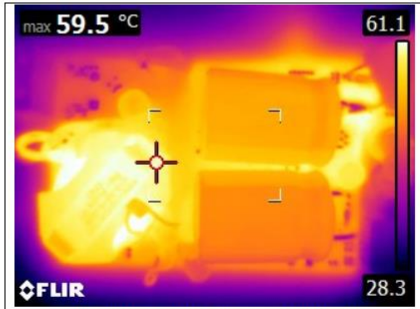

Figure 36. V_{IN} = 90 V_{AC}, Top Side (Transformer: 60 °C)

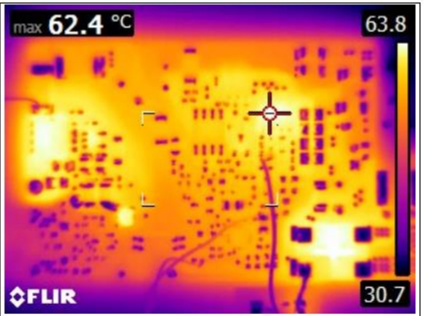

Figure 37. V_{IN} = 90 V_{AC}, Bottom Side (Q1: 64 °C; U7: 63 °C; DB1: 64 °C)

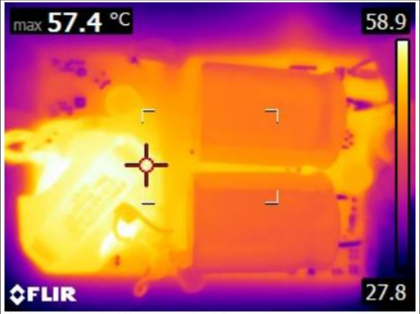

Figure 38. V_{IN} = 115 V_{AC}, Top Side (Transformer: 59 °C)

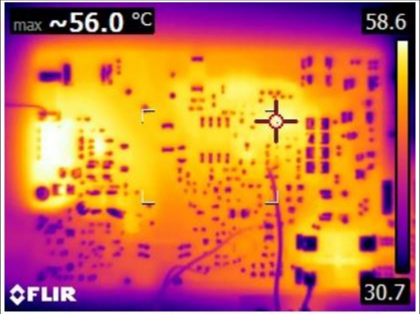

Figure 39. V_{IN} = 115 V_{AC}, Bottom Side (Q1: 59 °C; U7: 56 °C)

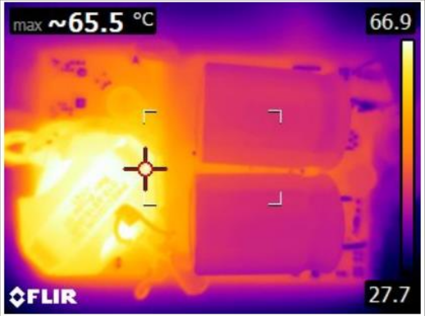

Figure 40. V_{IN} = 230 V_{AC}, Top Side (Transformer: 66 °C)

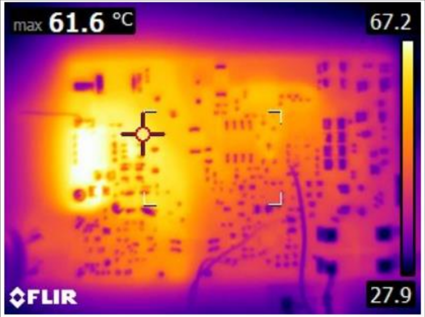

Figure 41. V_{IN} = 230 V_{AC}, Bottom Side (Q1: 76 °C)

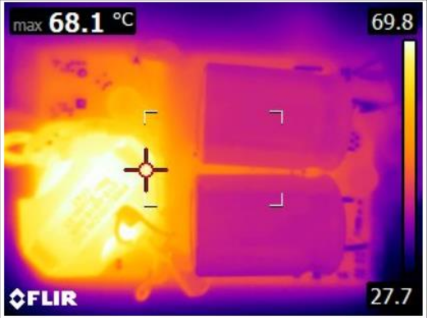

Figure 42. V_{IN} = 265 V_{AC}, Top Side (Transformer: 69 °C)

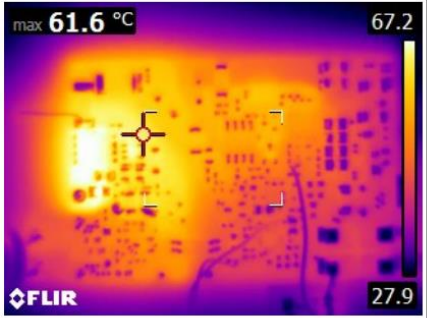

Figure 43. V_{IN} = 265 V_{AC}, Bottom Side (Q1: 79 °C)

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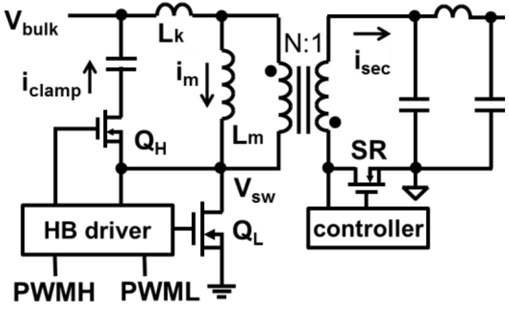
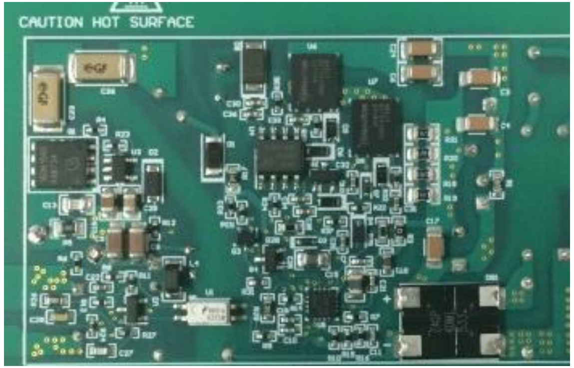
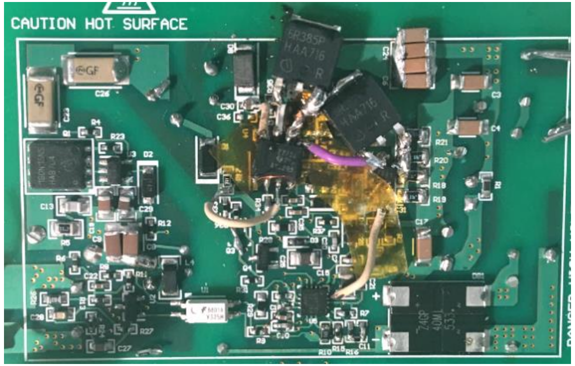
Modification for Si FET



GaN ACF
UCC28780EVM-002



Si ACF
UCC28780EVM-021



	Resonance Approach	Pri FET	High-side Driving	C_{clamp}	R_{RTZ}
GaN ACF	Sec. resonance	NV6117(Q_L) NV6115 (Q_H)	ISO7710F	0.44µF	240kΩ
Si ACF	Sec. resonance	CP 350mΩ	UCC27712	0.88µF	348kΩ

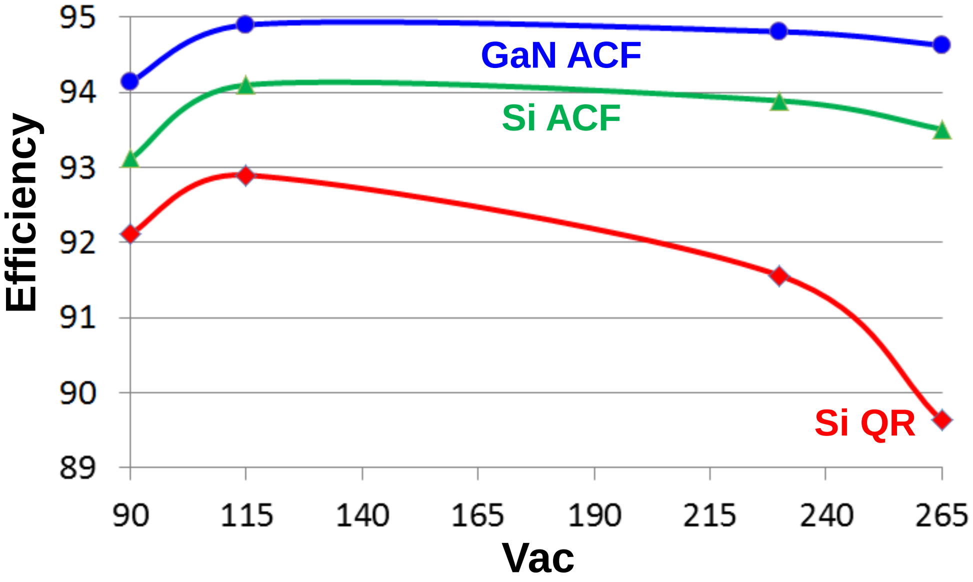
Use same EMI filter, input/output filter, and transformer for a fair comparison.

45W Full-Load Efficiency Comparison

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

	90Vac	265Vac
Si QR	92.12% (f_{sw}=237kHz)	**89.93%** (f_{sw}=413kHz)
Si ACF	**93.12%** (f_{sw}=206kHz)	93.51% (f_{sw}=285kHz)
GaN ACF	**94.14%** (f_{sw}=227kHz)	94.63% (f_{sw}=295kHz)

- **20V/45W Efficiency:**



- **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/in^3, 94% Efficiency, 65W USB-PD AC/DC Adapter Reference Design /*TI Design: TIDA-01622*

UDPATED

TIDesigns

Features

- Active-clamp Flyback + SR topology (UCC28780+UCC24612)
- Wide AC input range: 85 – 265 VAC, Output ripple voltage <=200mV@20V
- **Fully compatible with USB PD 2.0 standard , with 5V/3A, 9V/3A, 15V/3A, 20V/3.25A output.**
- **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)

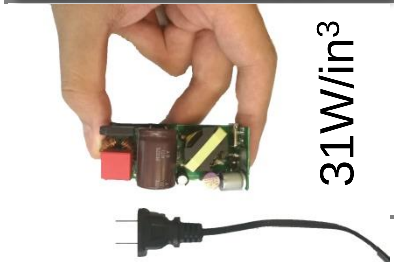
Benefits

- 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

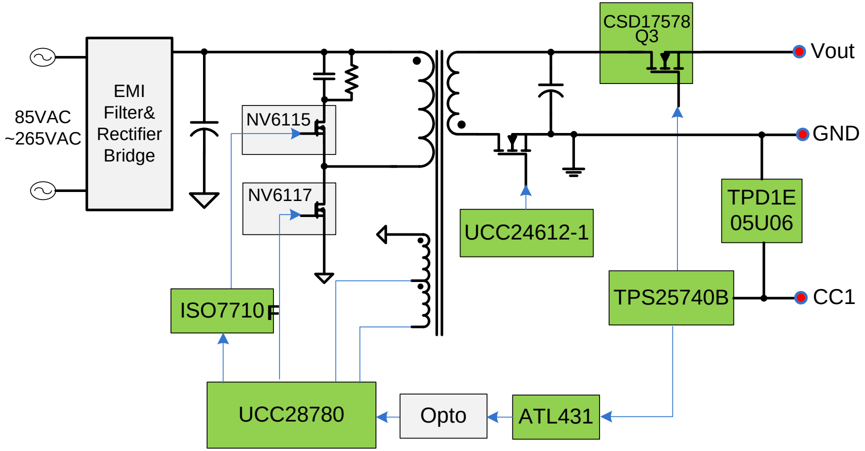
Tools & Resources



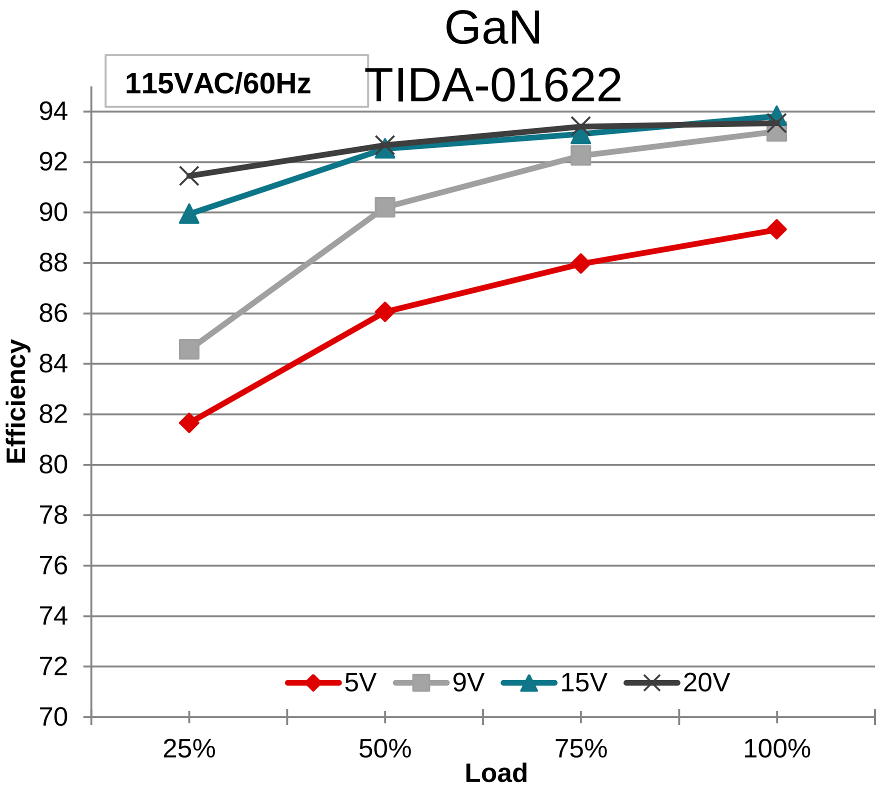
31W/in^3

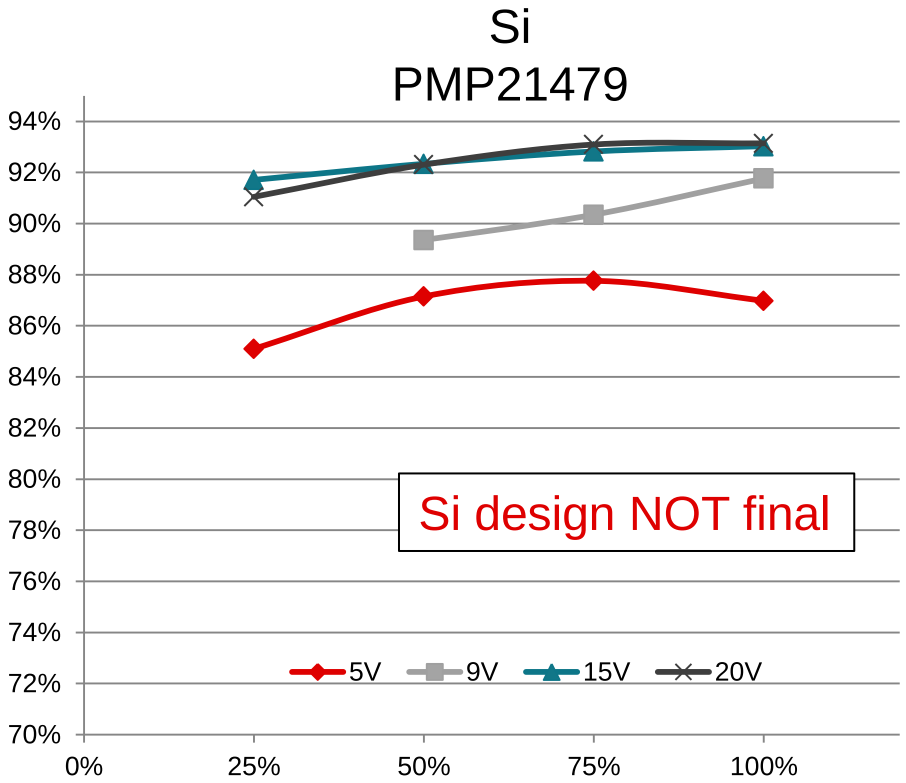
- **TIDA-01622 and Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers
- **Device Datasheets:**
  - UCC28780RTE, UCC24612-1, TPS25740B, ATL431, ISO7710F

64mm*28.6mm*18.4mm



65W Efficiency Data 115V/60Hz





65W Efficiency Data 230V/60Hz