Texas Instruments System Power Solutions -High efficiency LLC resonant controller and synchronous rectifier

Texas Instruments

Power Management

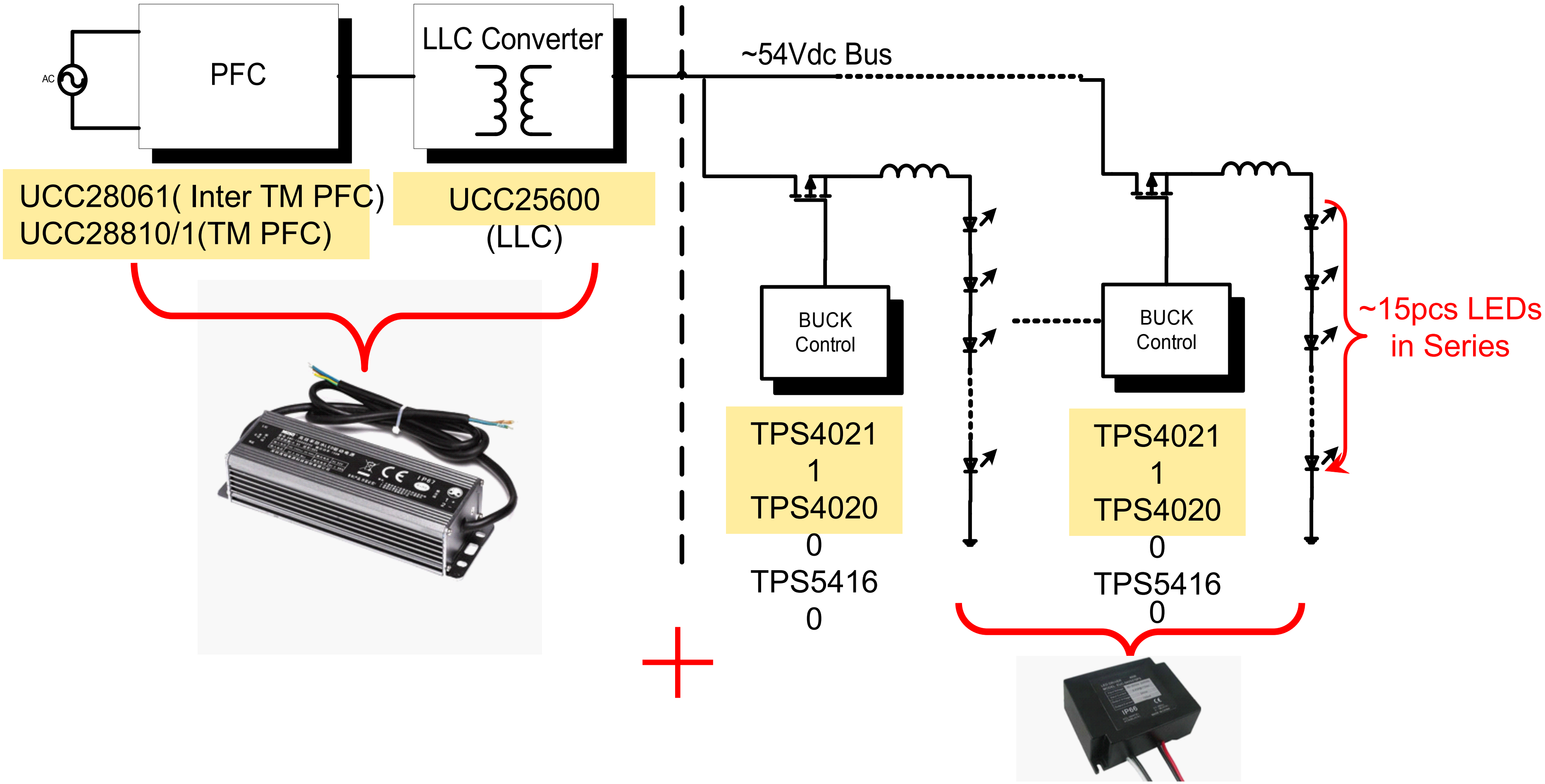
AGENDA

1. UCC25710 Multi-strings LLC LED driver
   1. Features and Application
   2. Block Diagram
   3. Operating descriptions and evaluation results:
2. UCC25600 LLC controller
   1. LLC operating descriptions
   2. Block diagram and features:
3. UCC24610 Synchronous driver:
   1. Features and Application
   2. EVM and test results:

Typical High Watt (>100W) LED Lighting Driver Topology

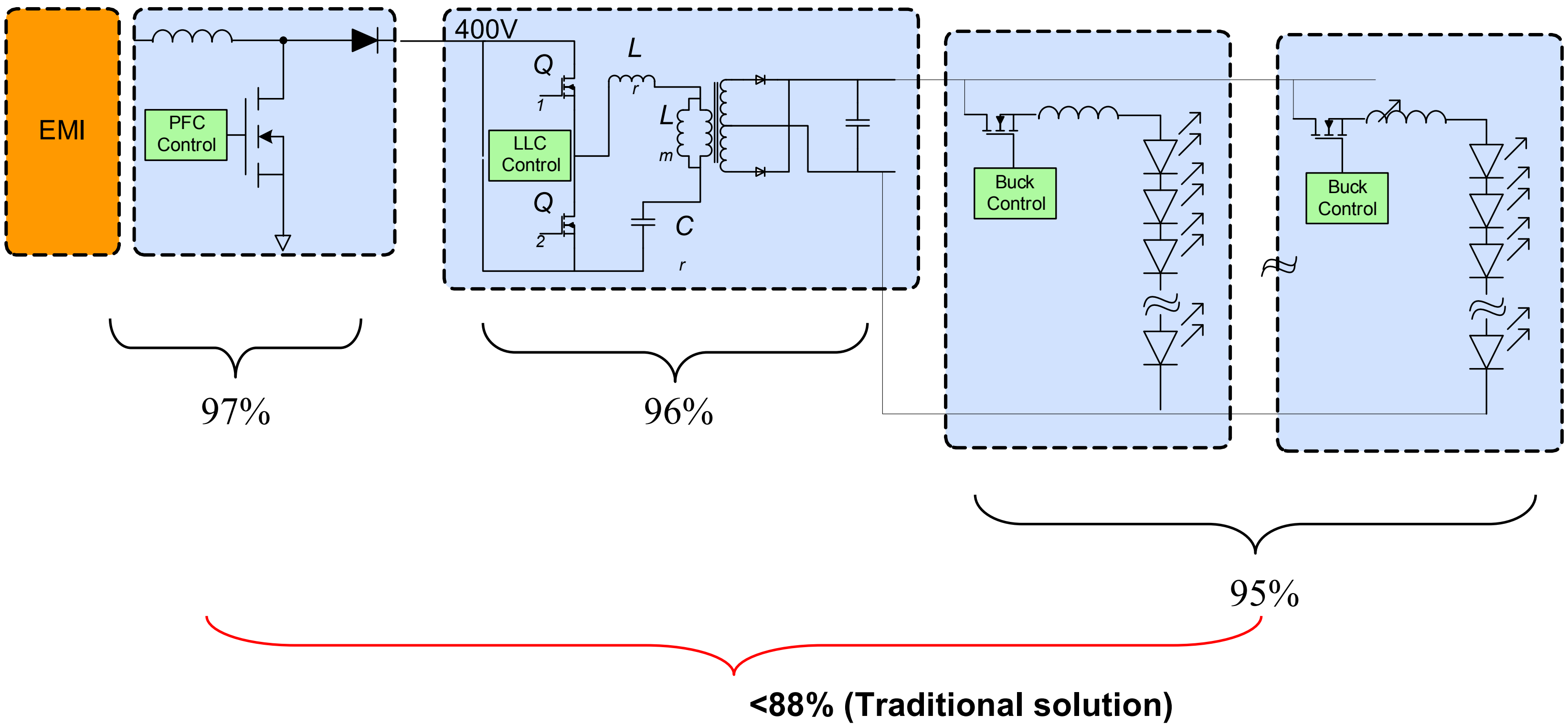
1. AC/DC Power Stage

2. Constant Current Driver Stage



High Watt (>100W) LED Lighting Efficiency Budget

Outdoor and Industrial >100W



Conventional Topology Issues:

☹ High cost: PFC+LLC+CC BUCK (multi-chips!!)
☹ Low efficiency (<~88%)
☹ Low reliability (many components' counts)
☹ EMI issues

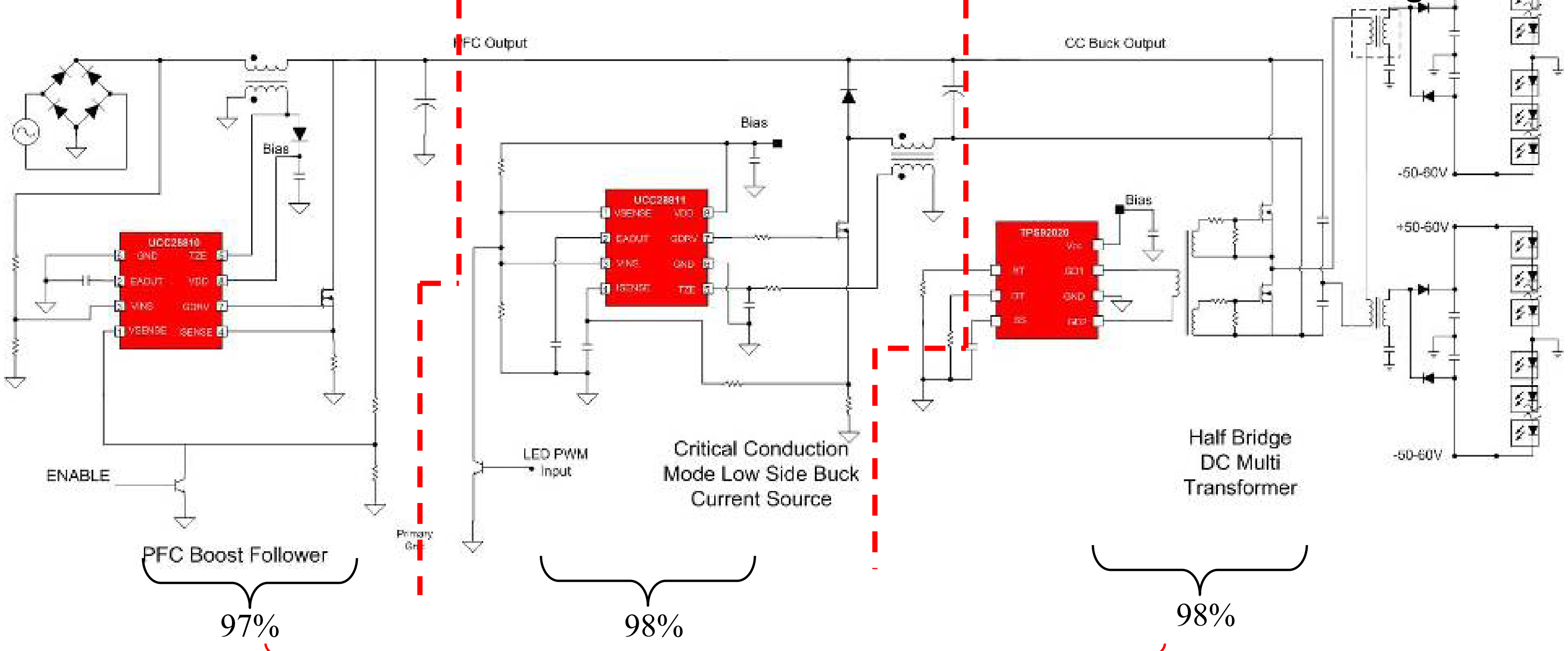
TI UCC28810EVM-003 - SIMPLEDrive™

Series Input, Multiple Parallel Equivalent LED Drive (SIMP*LED*rive)

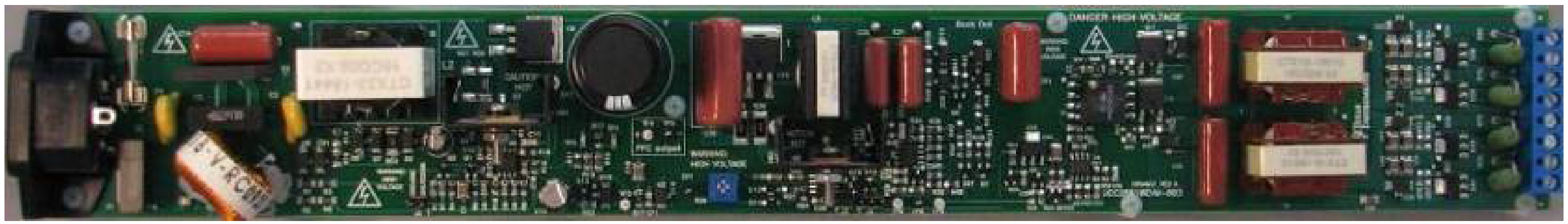
1st stage: **TM Boost for PFC**

2nd stage: **TM Buck for LED current**

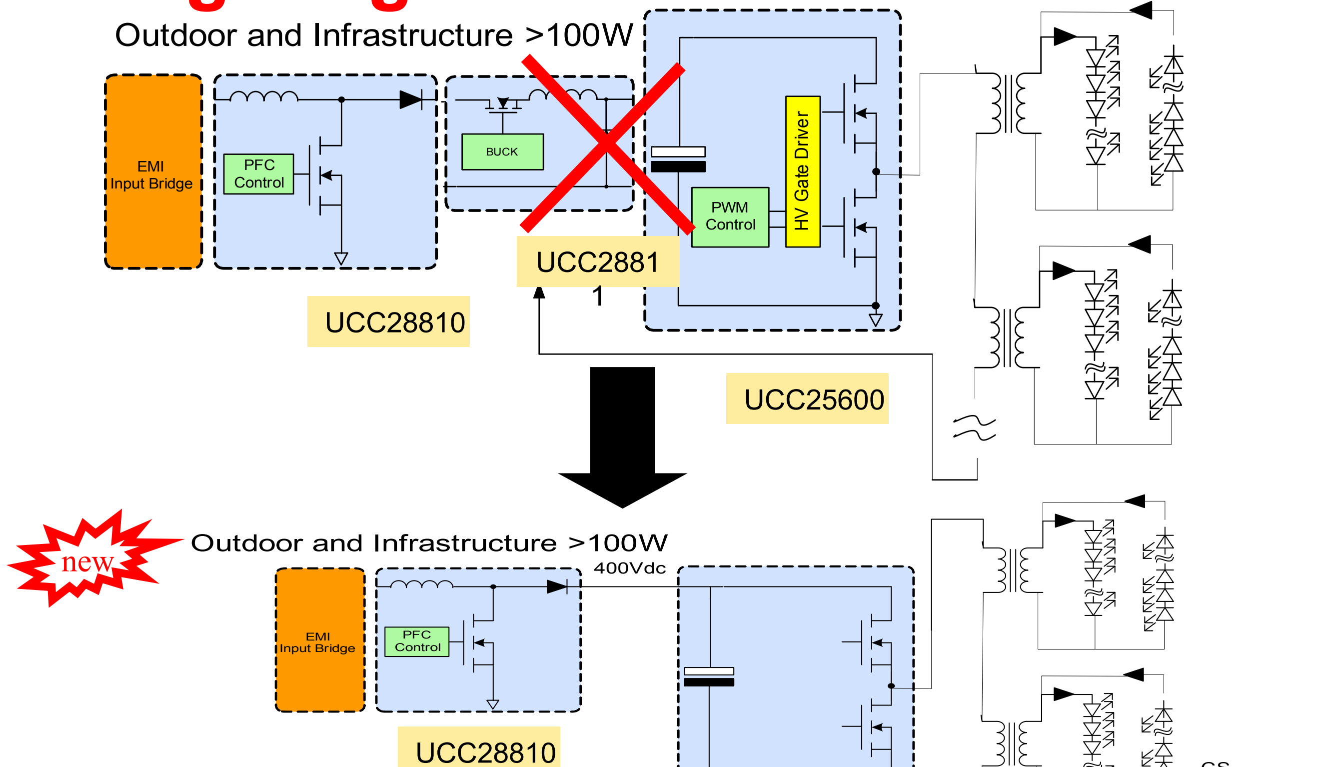
3rd stage: **Resonant Current Half Bridge**



>93% (Three stages multi-string transformer solution)

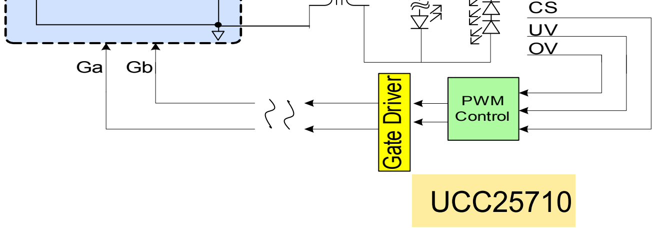


Innovative two stages multi-string LLC topology for LED lighting

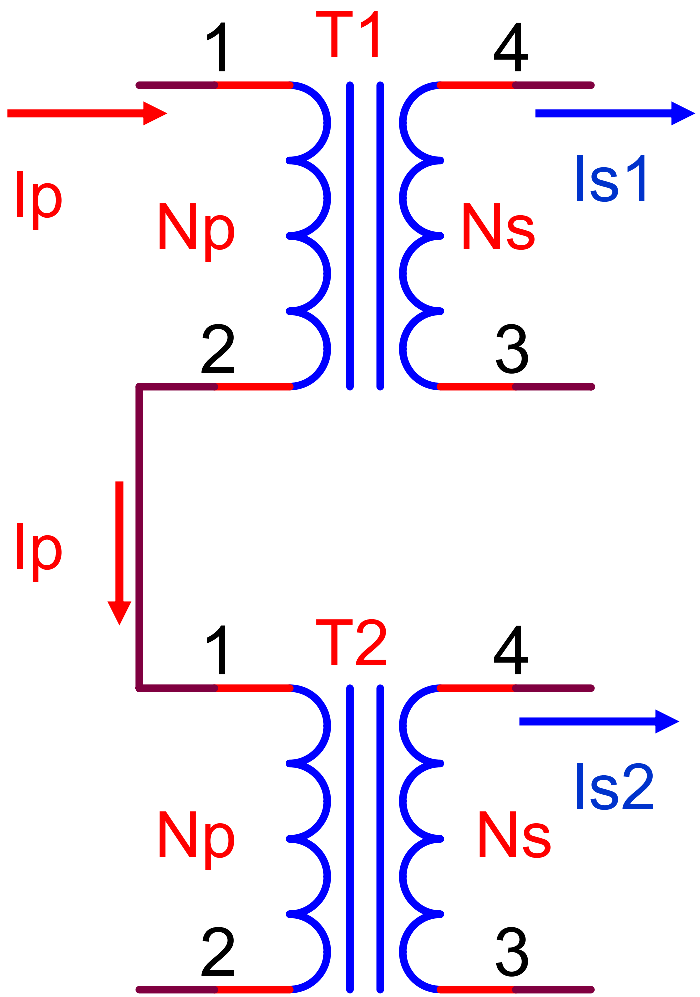


Benefits for the proposed topology:

- ☺ High efficiency ~92%
- ☺ Low cost (no need CC DC/DC driver)
- ☺ High reliability
- ☺ Easy EMI
- ☺ PWM or analog dimming compatible

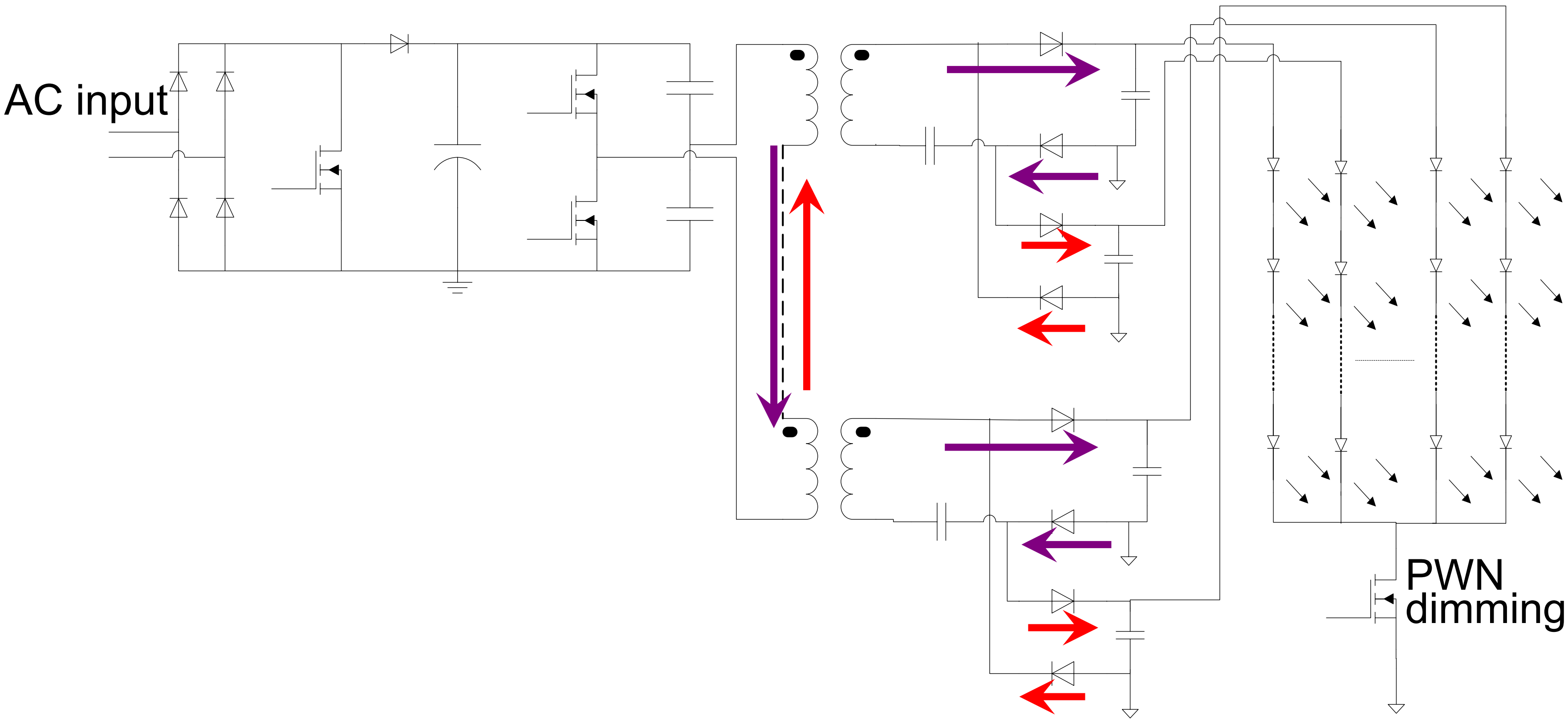


Why Transformer Can Balance Current



- Transformer current is in reverse proportion to turn ratio
- Ip/Np = Is/Ns; Is=Ns*Ip/Np
- When transformer primary is connected together, their primary current must be the same
- When T1 is the same as T2 because of transformer operation principle their secondary current is the same
- Is1=Ns*Ip/Np=Is2

Multi-Transformer Architecture (TI Patented)



One transformer control two LED strings!

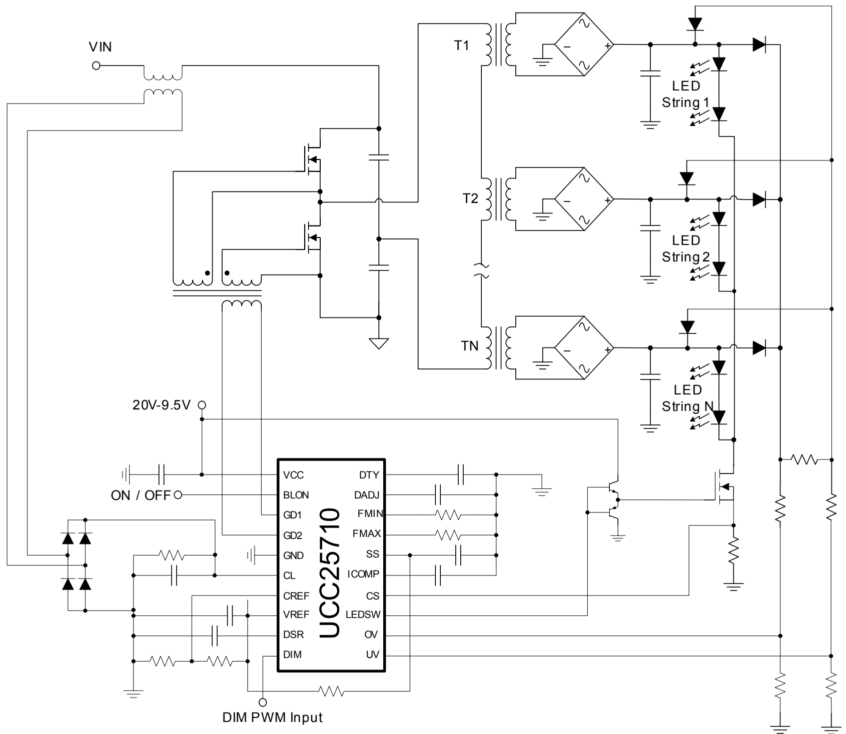
UCC25710: LED driver Controller IC

Features

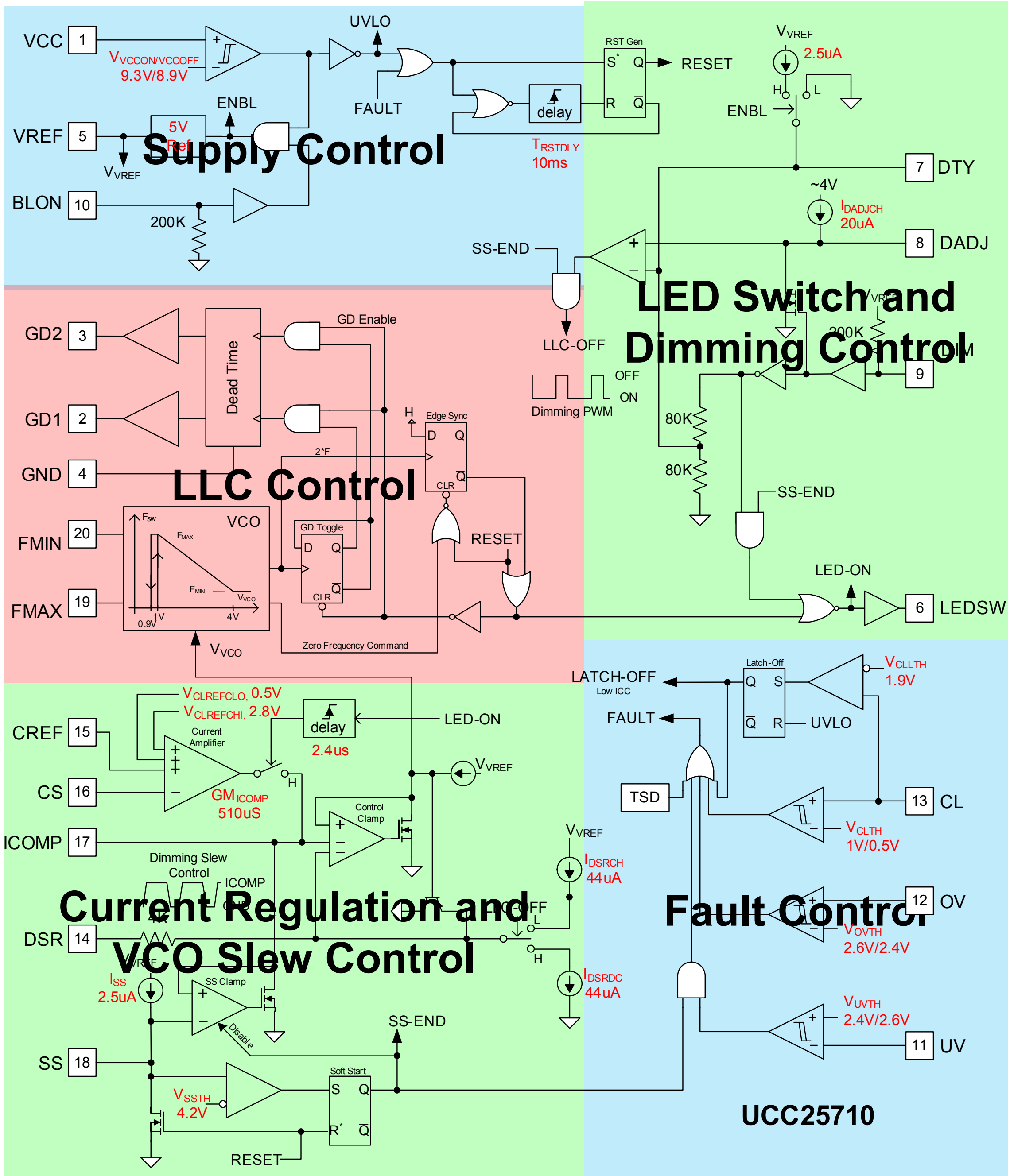
- Industry first single chip LLC controller for driving multiple LED strings directly from PFC output
- Adjustable Fmin (3% accuracy), and Fmax 6% (accuracy)
- Closed Loop LED String Current Control
- PWM Dimming Input
- LLC and Series LED Switch Control for Dimming
- Programmable Dimming LLC ON/OFF Ramp for Elimination of Audible Noise
- Closed Loop Current Control at Low Dimming Duty-Cycles
- Programmable Soft Start
- Accurate VREF for Tight Output Regulation
- Over-voltage and Under-voltage and Input Over-current Protection with Auto-restart Response
- Second Over-current threshold with Latch-off Response
- +400-mA/-800mA Gate Drive Current
- Low Start-Up and Operating Currents
- 20 pin SO Lead (Pb)-Free Package

Applications

- General LED Lighting
- LED TV Backlighting

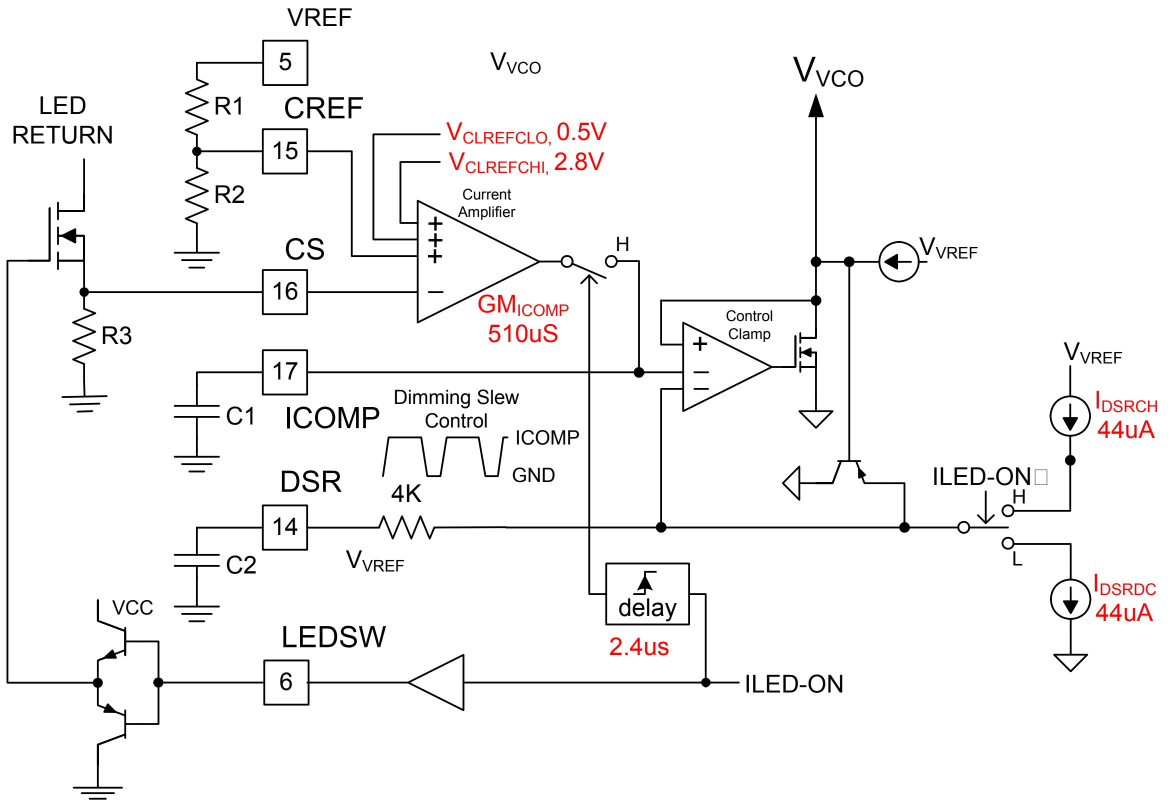


UCC25710 Block Diagram



UCC25710: DIMMING – LLC ON/OFF TRANSITION & CURRENT CONTROL

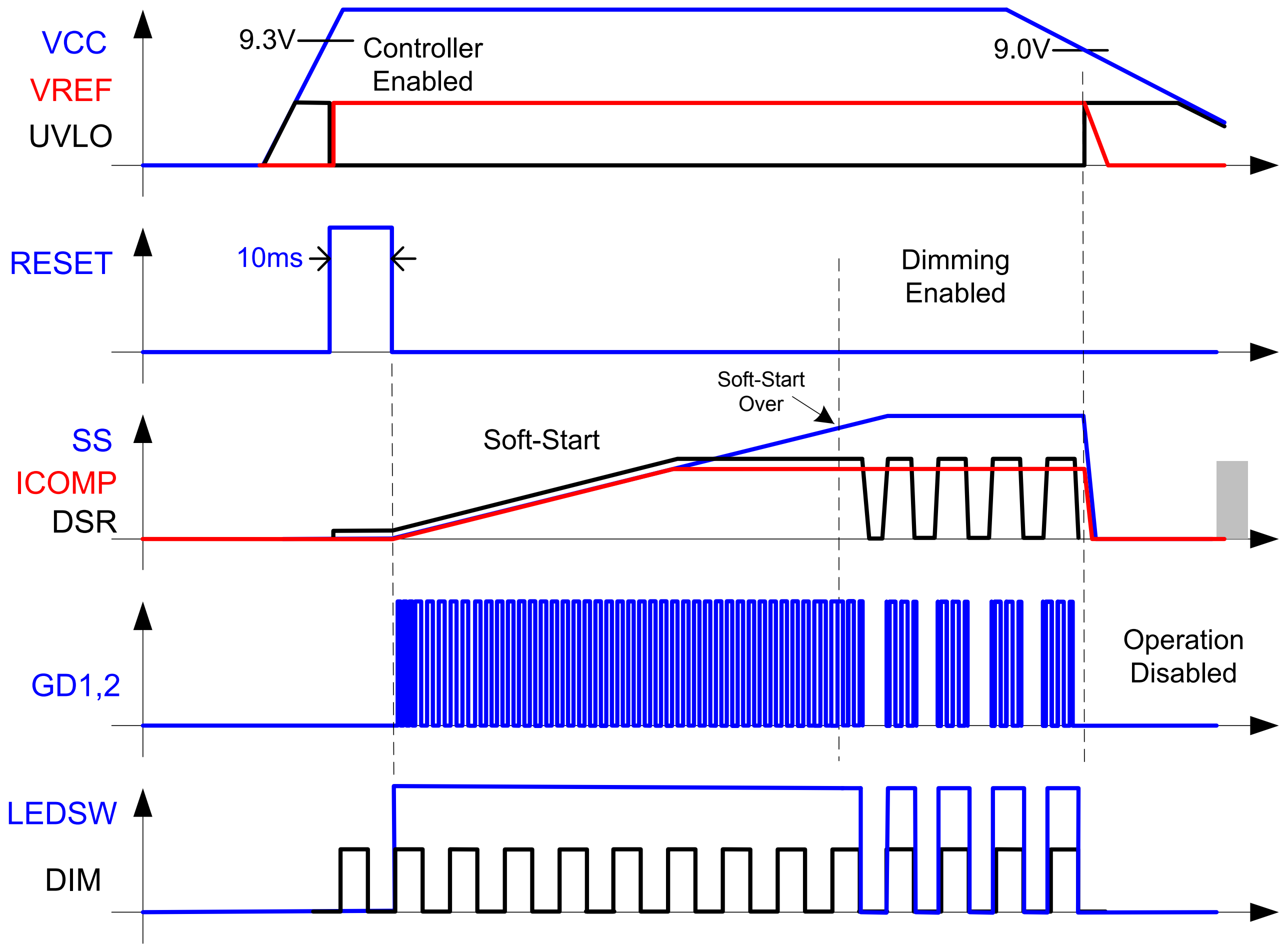
- The DIM input controls the ILED-ON an ILED-ON` signals.
- DSR capacitor C2 and internal 44uA currents control the slew rate of V_{VCO} during dimming off and on transitions.
  - Turn-off: DSR is discharged to GND by 44uA
  - Turn-on: DSR is charged to ICOMP by 44uA. Charge level is clamped to 1Vbe above ICOMP
- Control Clamp output, V_{VCO}, tracks the lower of ICOMP and DSR
- ICOMP is only driven by GM amp during LED-ON times.
- During LED-OFF times the ICOMP voltage is held by C1



UCC25710: START-UP & DIM WAVEFORMS

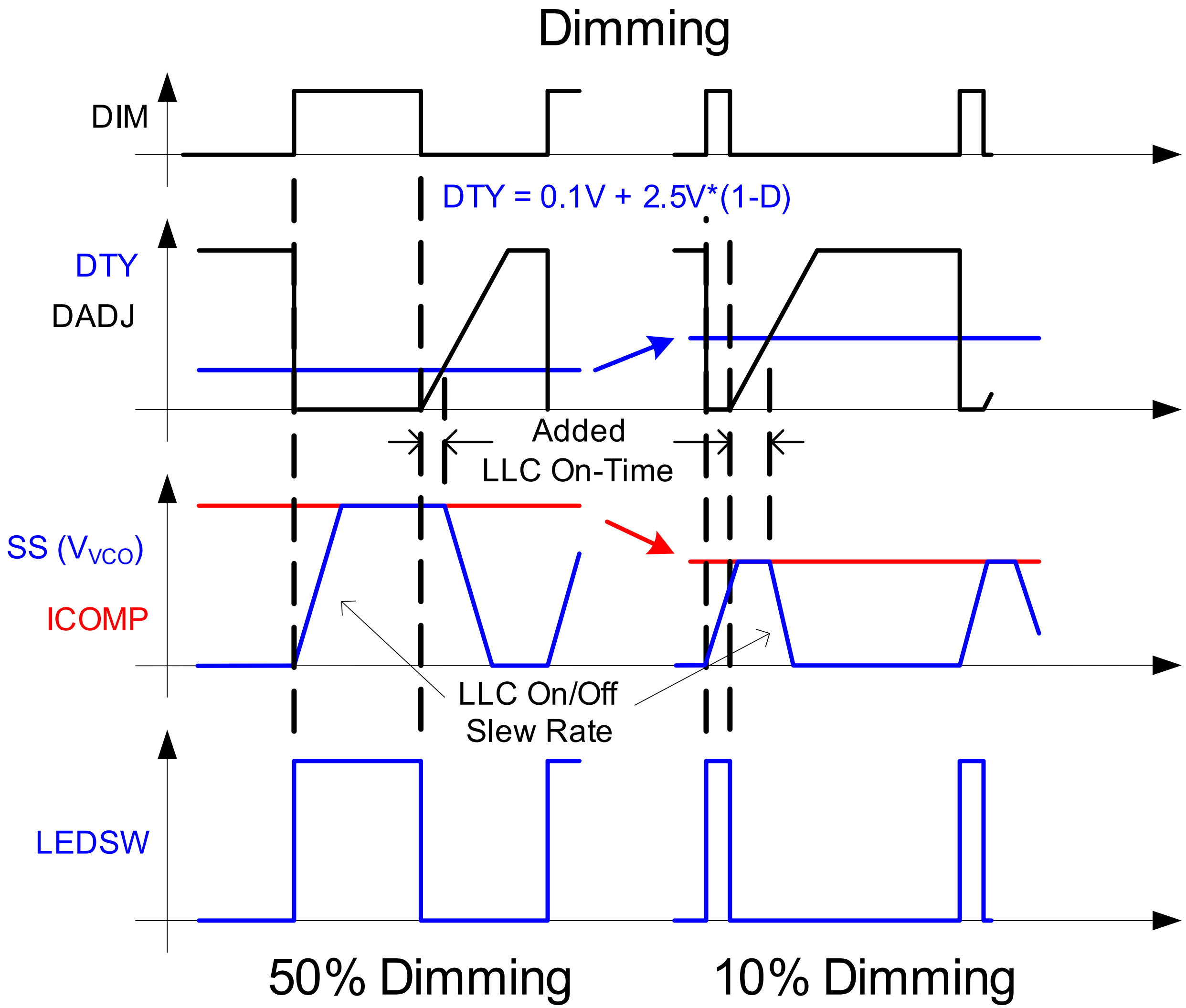
- 10ms RESET initiates Soft-Start (SS)
- LLC Soft-Start, VCO control is clamped to SS until SS > ICOMP
- Dimming is disabled during SS
- DSR cap is used to limit LLC control slew rate during dimming
- ICOMP voltage is maintained during dimming

Start-up and UVLO Shutdown



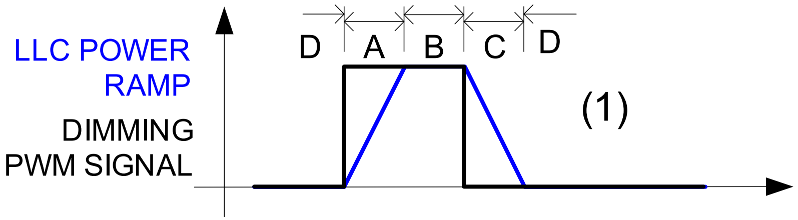
UCC25710: DIMMING – WAVEFORMS

- DIM input controls LEDSW
- DIM input triggers soft turn-on and turn-off of LLC converter
- LLC on-time is extended
- On-time extension is proportional to 1-D, D is dimming duty-cycle
- Extended on-time allows ICOMP to maintain current regulation at low D

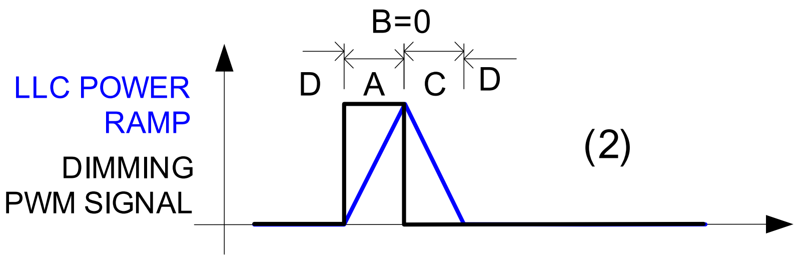


UCC25710: LOW DUTY-CYLE ILLUSTRATION

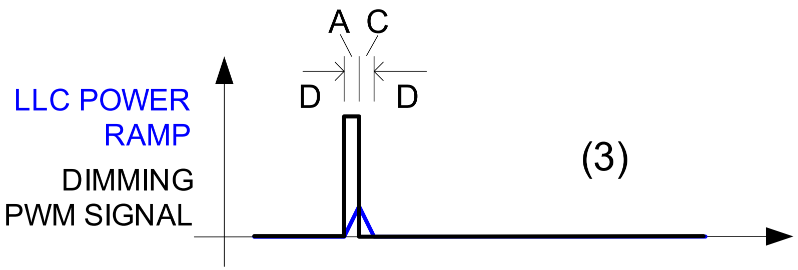
1. LLC reaches power level equal to pedestal LED current in region B. Power is under delivered in region A, but is compensated for in region C



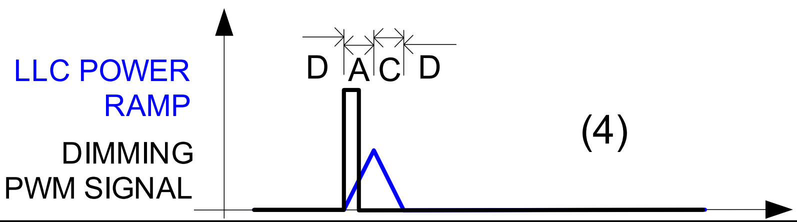
2. Region B is zero, but sum of A+C still deliveries correct energy.



3. Energy delivered in region A + C is too low, loop is open and realized peak LED current will drop



4. On-time is extended. A + C energy/pulse is correct to maintain same peak LED current

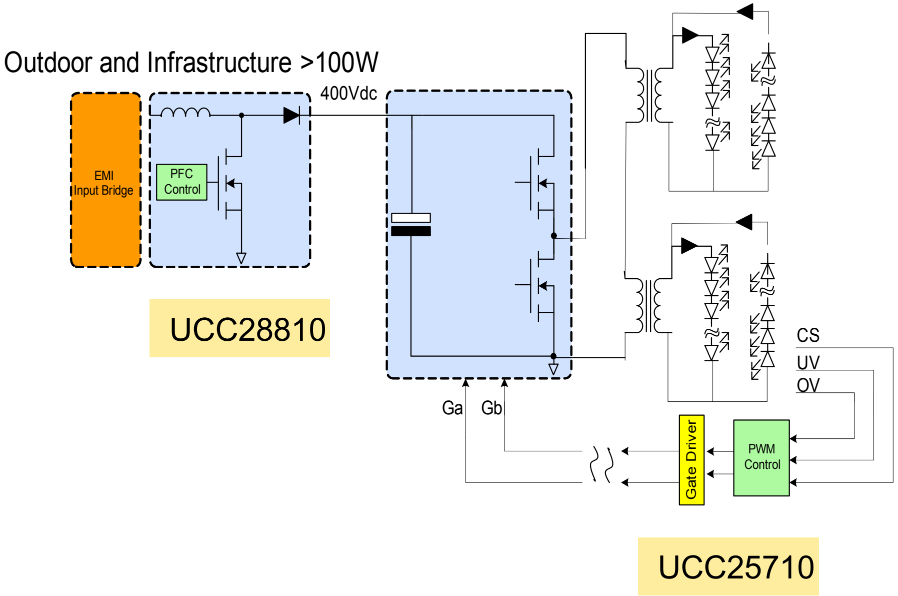


UCC25710: FAULT MANAGEMENT

- Faults
  - OV – highest LED string voltage
  - UV – lowest LED string voltage
  - CL(1V) – input current signal over-current
  - CL(2V) – input current signal latch-off
  - TSD – Chip thermal shutdown
- Response
  - OV, CL(1V) & TSD: The LLC converter and LEDSW are turned off. When the fault clears a RESET and SS are initiated.
  - UV: The LLC converter and LEDSW are turned off. A RESET and SS are immediately initiated, repeatedly, until fault clears.
  - CL(2V): The LLC and LEDSW are latched off until UVLO recycles.
  - During RESET the LLC converter and LEDSW are OFF
  - During SS the LLC converter and LEDSW are ON, i.e. no DIMMING

PMP4302: Multi-string LLC AC/DC Driver for general LED lighting

Reference Design	TI Parts	V_{in}	Output	Topology	Eff.	Dimming
PMP4302: **AC input Multi-string LLC converter for general LED lighting**	UCC28810 *(TM PFC)* UCC25710 *(Multi-string LLC)* UCC28610 *(Aux Flyback)*	90V~264V	54V@500mA with 4 string	TM PFC+Multi-string LLC converter	92%	PWM dimming

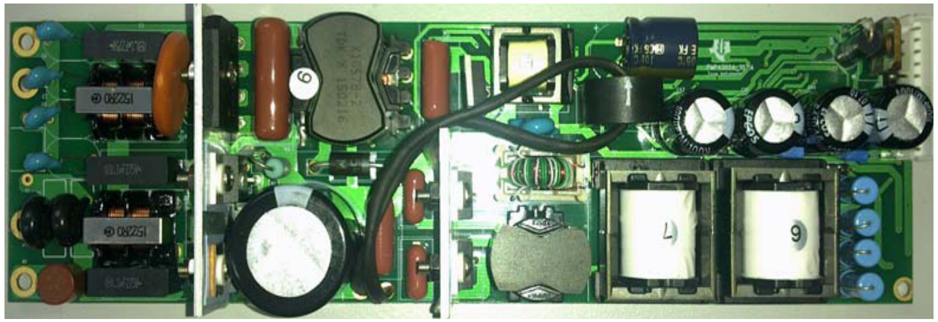


Features

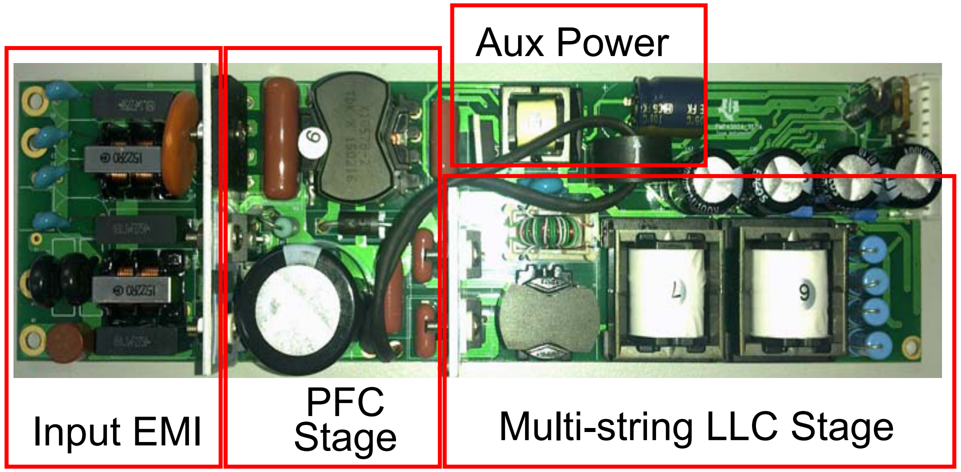
- Lowest cost than AC/DC + DC/DC
- Highest efficiency to 92%
- PWM dimming compatible
- Integrate LED open/short protection and over current protection

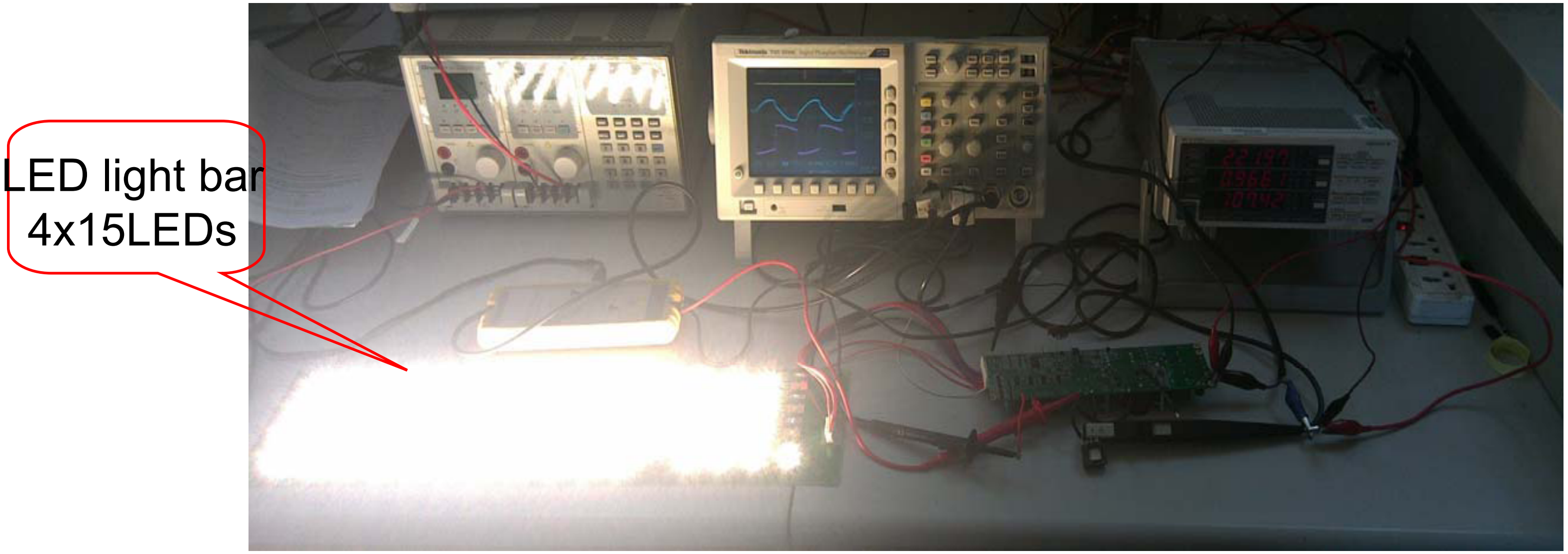
Applications

- General LED lighting and LED backlight TV



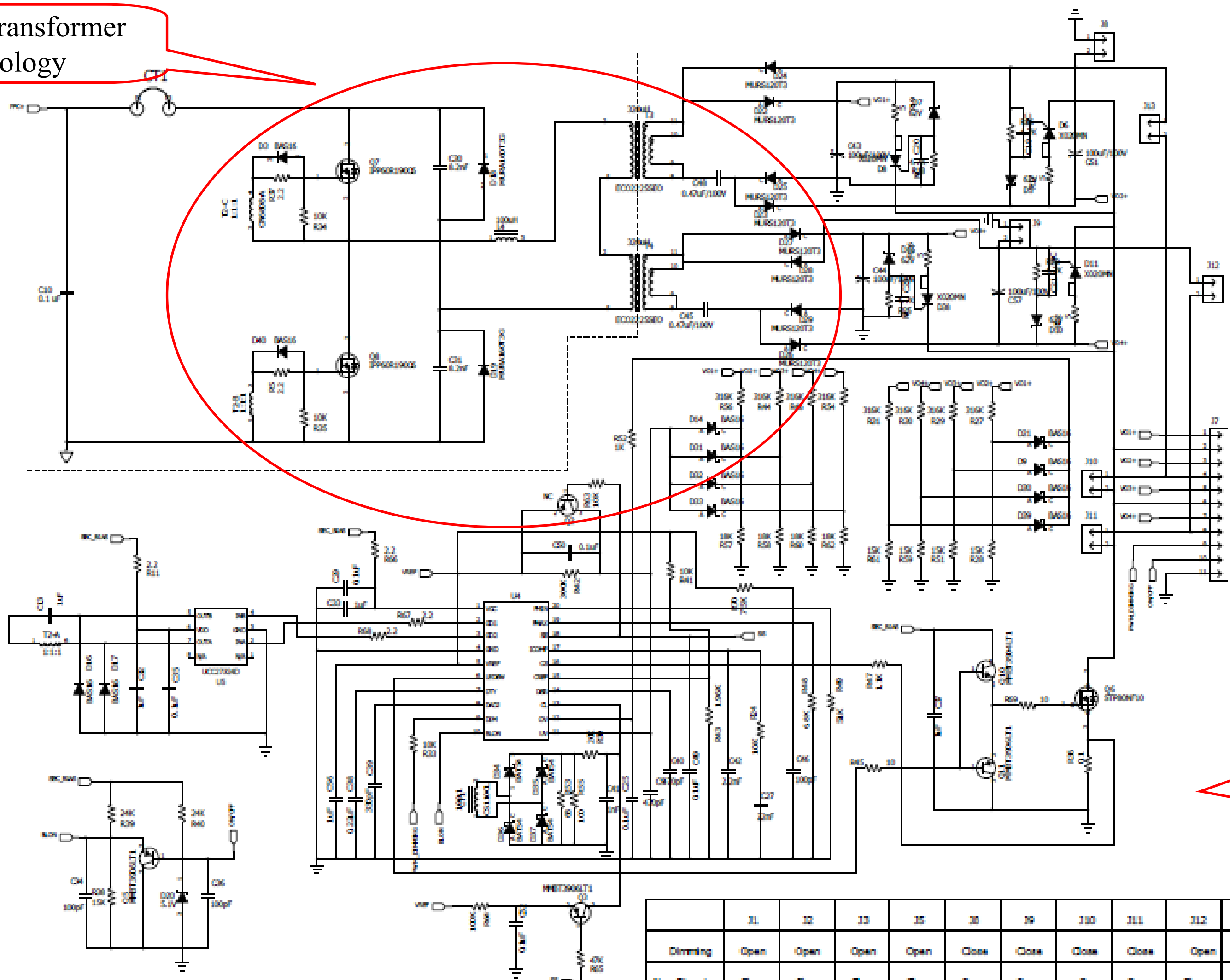
PMP4302 demo board





PMP4302: Schematics for UCC25710 after PFC stage

Multi-string transformer LLC topology



PWM dimming & Total current sensing feedback

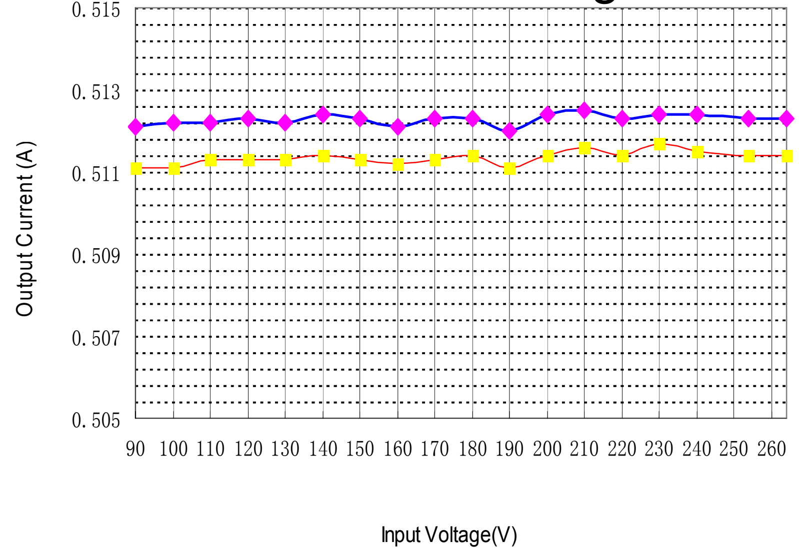
	J1	J2	J3	J5	J8	J9	J10	J11	J12	J13		R44 R54 R58 R62
Dimming	Open	Open	Open	Open	Close	Close	Close	Close	Open	Open		
Non-Dimming	Close	Close	Close	Close	Open	Open	Open	Open	Close	Close		Open

PMP4302: LED current output tolerance

230V ac input

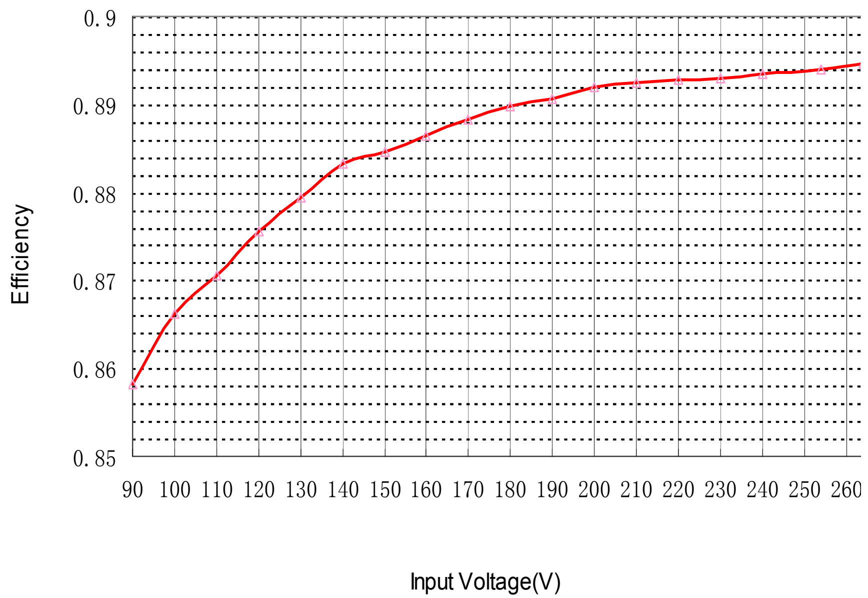
PWM Dimming	Io1	Io2	Io3	Io4	%
1%	4.9	4.8	5	5.1	3.030
2%	10	9.8	10.4	10.3	2.962
5%	25.2	24.1	25.2	25.1	2.208
10%	50.4	49.7	51.5	51.3	1.774
20%	100.9	100.1	102.7	102.5	1.280
30%	151.4	150.4	154.1	153.6	1.214
40%	201.9	200.9	205.1	204.9	1.033
50%	252.4	251.1	256.4	255.8	1.043
60%	302.9	301.4	307.7	307	1.033
70%	353.5	351.8	358.6	357.8	0.956
80%	403.9	402.2	409.7	408.8	0.923
90%	454.3	452.2	461.1	460.1	0.973
99%	499.3	496.7	507.2	506.2	1.045
100%	503.9	501.4	512.4	511.7	1.084

LED output current Vs Input voltage
w/ 100% dimming

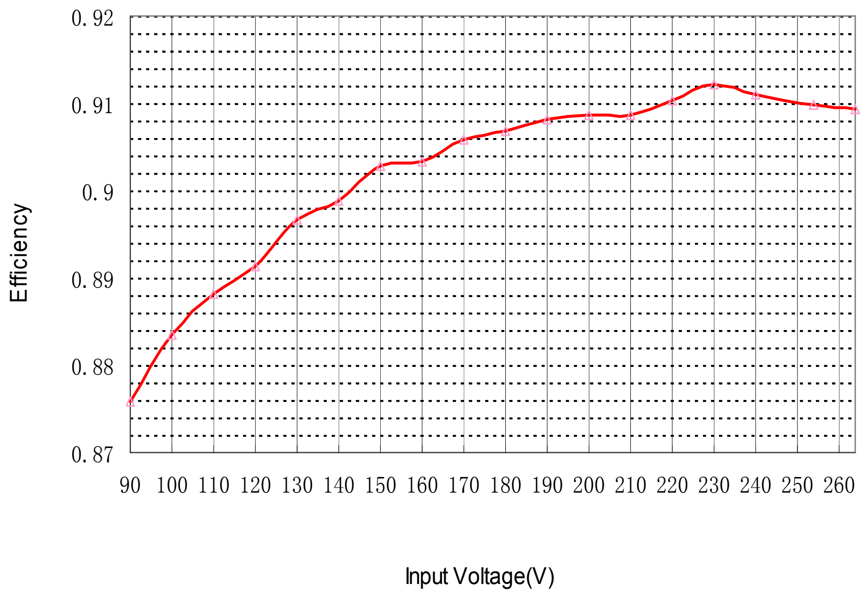


Current tolerance can achieve <+-3% with dimming range from 1% to 100%

PMP4302: Efficiency
(TM PFC + Multi-string LLC + Aux power)

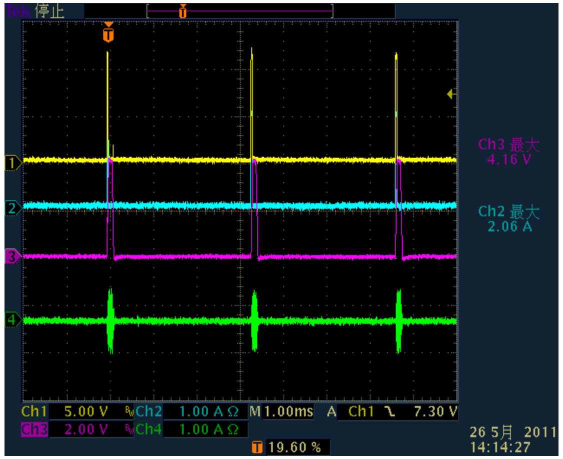


Dimming version

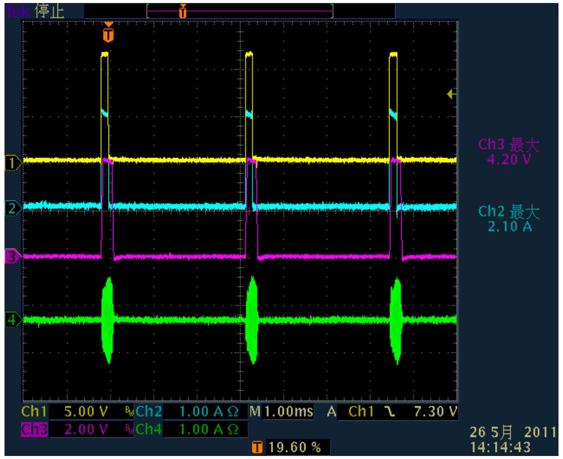


Non-Dimming version

PMP4302: waveforms



1% dimming



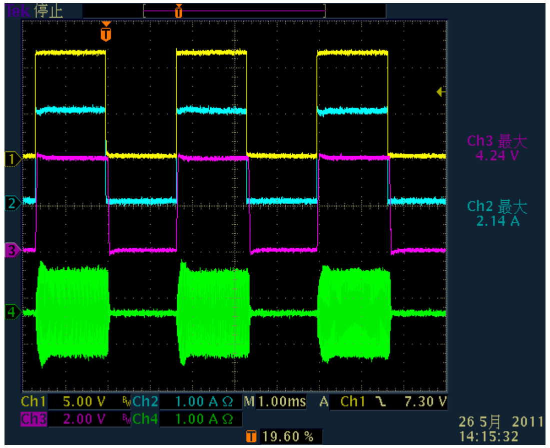
5% dimming

CH1: LEDSW MOSFET Vgs 5V/Div

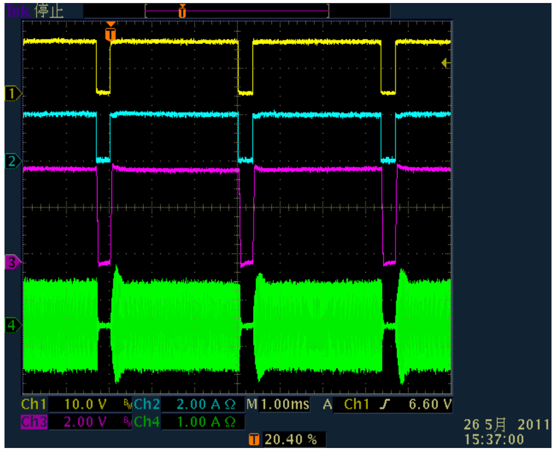
CH2: LED Output Current 1A/Div

CH3: DSR 2V/Div

CH4: Primary Current 1A/Div

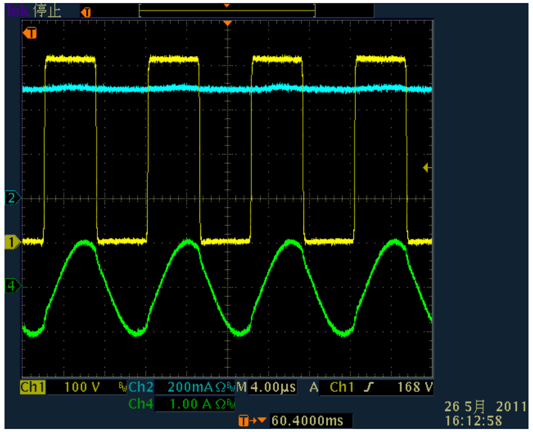


50% dimming

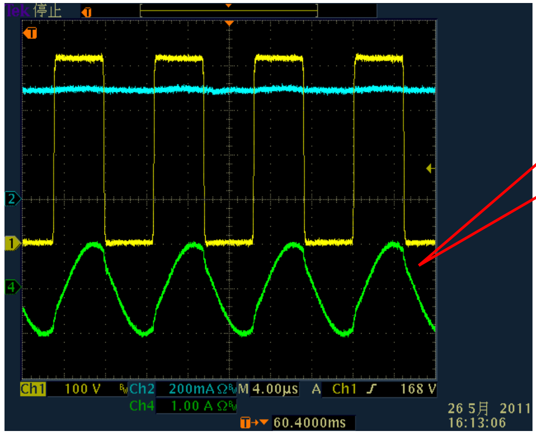


90% dimming

PMP4302: waveforms

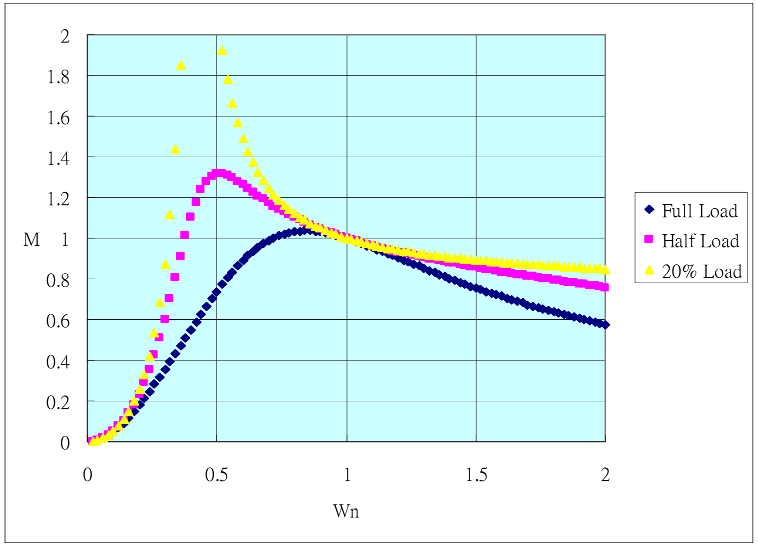


90Vac input



230Vac input

CCM to get better current tolerance



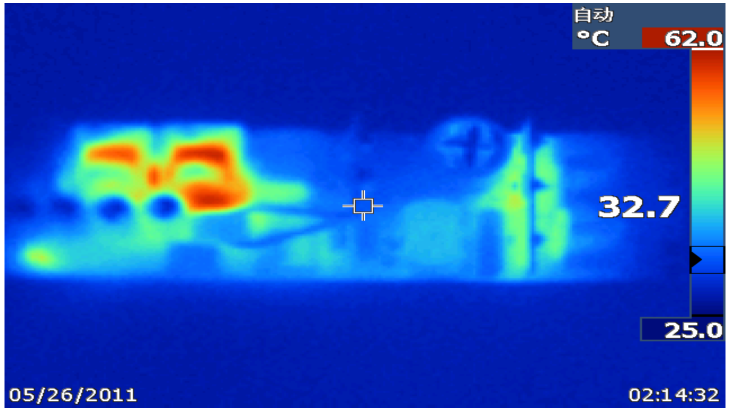
Lm/Lk=6
Fs=100KHz
Q=0.7

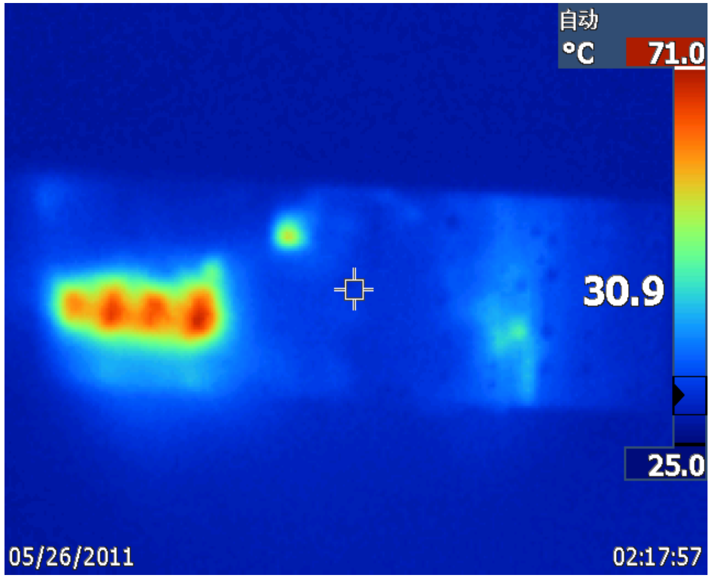
⇨

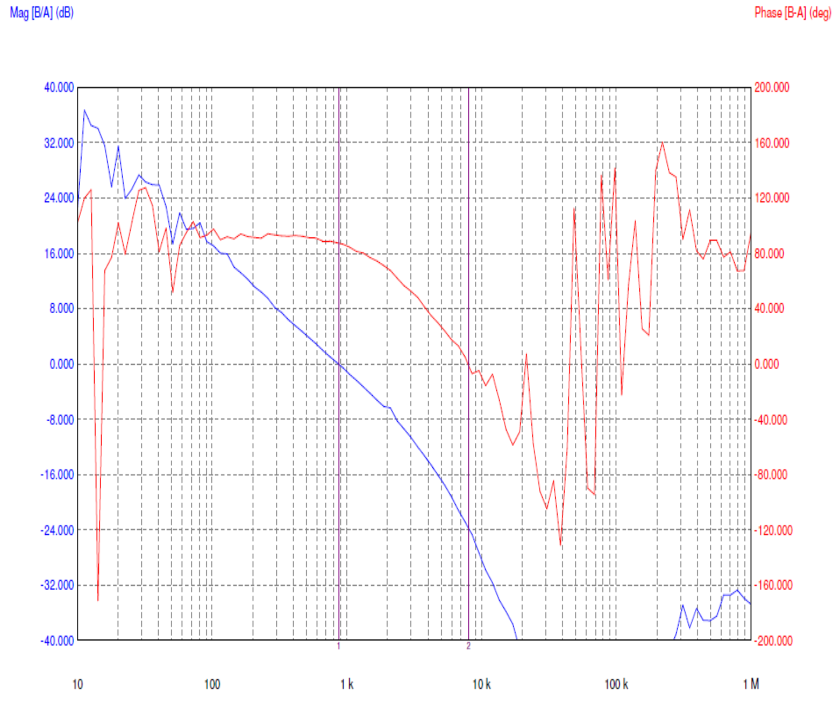
Lm1+Lm2=640uH
Lr=100uH
Cr=30nF

CH1: Primary MOSFET Vds 100V/Div
CH2: LED Output Current 200mA/Div
CH4: Primary Current 1A/Div

PMP4302: Thermal and Bode Plot





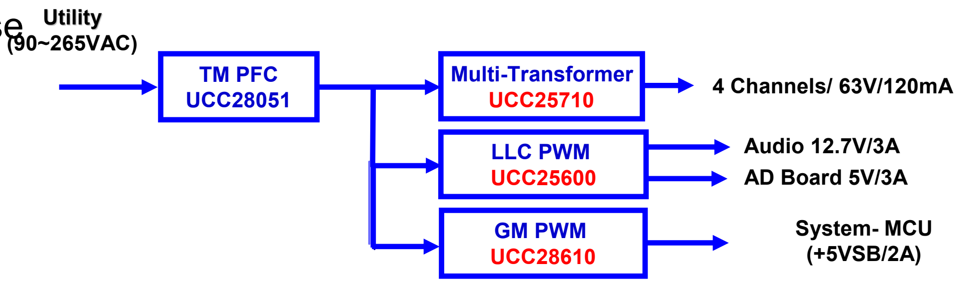


	M1	M2	M2 - M1
Frequency	871.72 Hz	7.99 kHz	7.12 kHz
Magnitude	-0.048 dB	-23.740 dB	-23.693 dB
Phase	87.264 deg	-0.838 deg	-88.102 deg

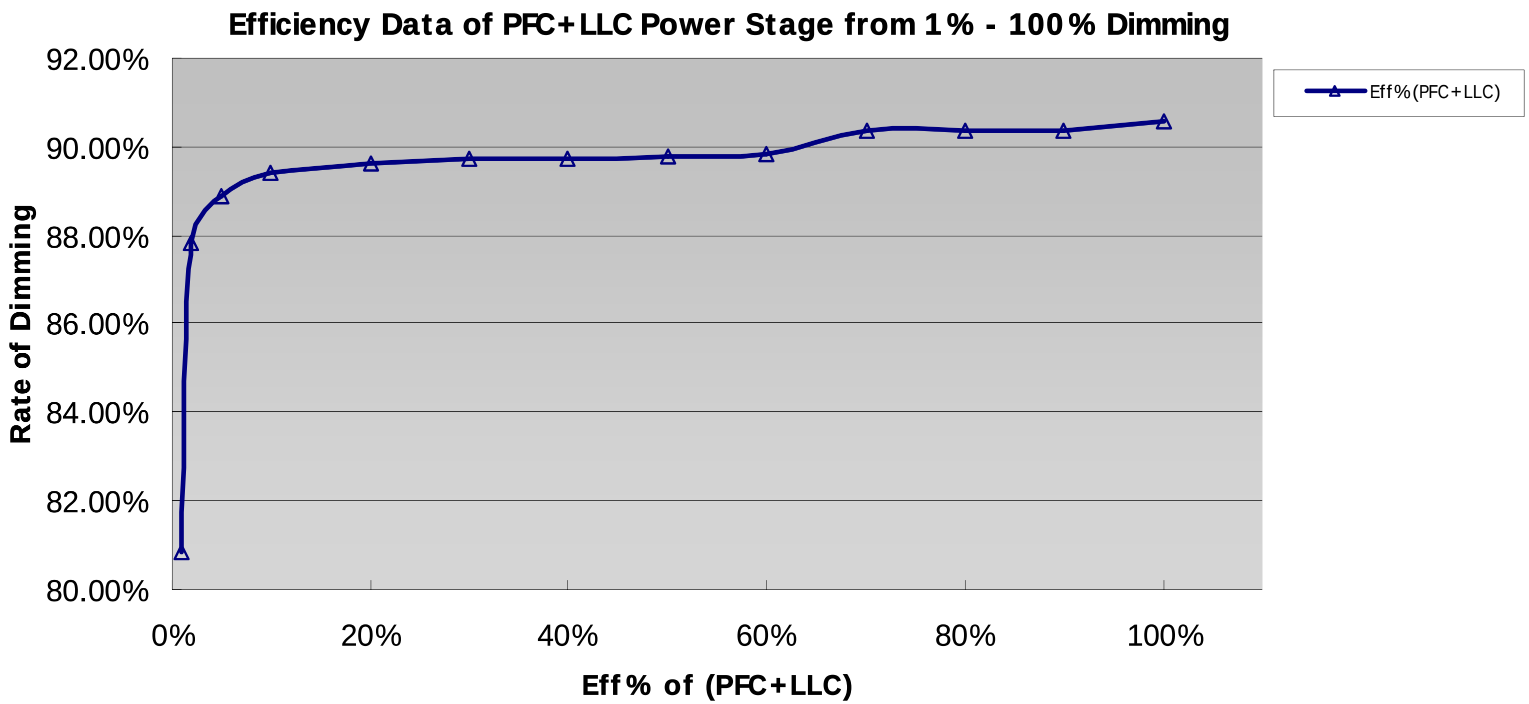
PMP6251: LED Backlighting for Edge-Lite/ Group Dimming Digital TV Application

Reference design Features

- Support to universal 90~264Vac range
- LED 4 outputs @120mA, 63V, 5Vsb@1A, 5V@3A, 13V@3A
- Eff 83.7%@110Vac, 85.2%@240Vac
- Secondary side 120Hz blanking control for dimming
- 8mm height and 6mmheight for LED magnetic component
- Board dimension 300mm(L) * 200mm(W) * 8mm(H)
- LED output common + and LED OVP and UVP
- Integrated the protection ckt to reduce the solution part count.
- Dedicated controller for edge-lit/ group dimming base on the LLC topology – **UCC25710**
- Providing design package – Schematic, Gerbo file, PCB file, Magnetic components…



PMP6251: PFC+ Multi-string LLC Efficiency



Efficiency exclude standby Power Converter at full load condition ~ 90%

Summary

- *UCC25710 with multi-transformer LLC topology can achieve:*

☺ High efficiency

☺ Low total BOM cost with high reliability

☺ PWM or analog dimming compatible

☺ Output LED strings open/short protection

☺ Input over current protection

☺ Support 1%~100% dimming range

☺ Easy EMI

Summary

- LED backlight becomes a trend for flat screen TVs
- TI proposed multi-transformer backlight solution
  – Simple current matching method
  – Single stage power processing
  – Fault tolerant capability
- UCC25710 provides the IC solution for multi-transformer architecture
- Multi-Transformer LLC + LED switch control
- Precision LED current control
- Soft ramping of LLC for audible noise reduction
- Extended PWM dimming dynamic range
- Complete protection features

TI UCC25600
8 Pin Resonant Half Bridge Controller

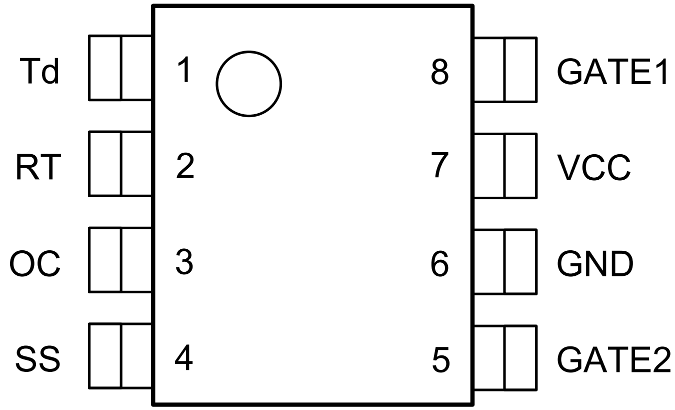
Features

- Adjustable Soft start (1ms to 500ms)
- Adjustable dead time
- Adjustable F_{swmax} & F_{swmin} (3% accuracy)
- Io = +1A /-1.5A
- Enable (ON/OFF control)

Protection functions

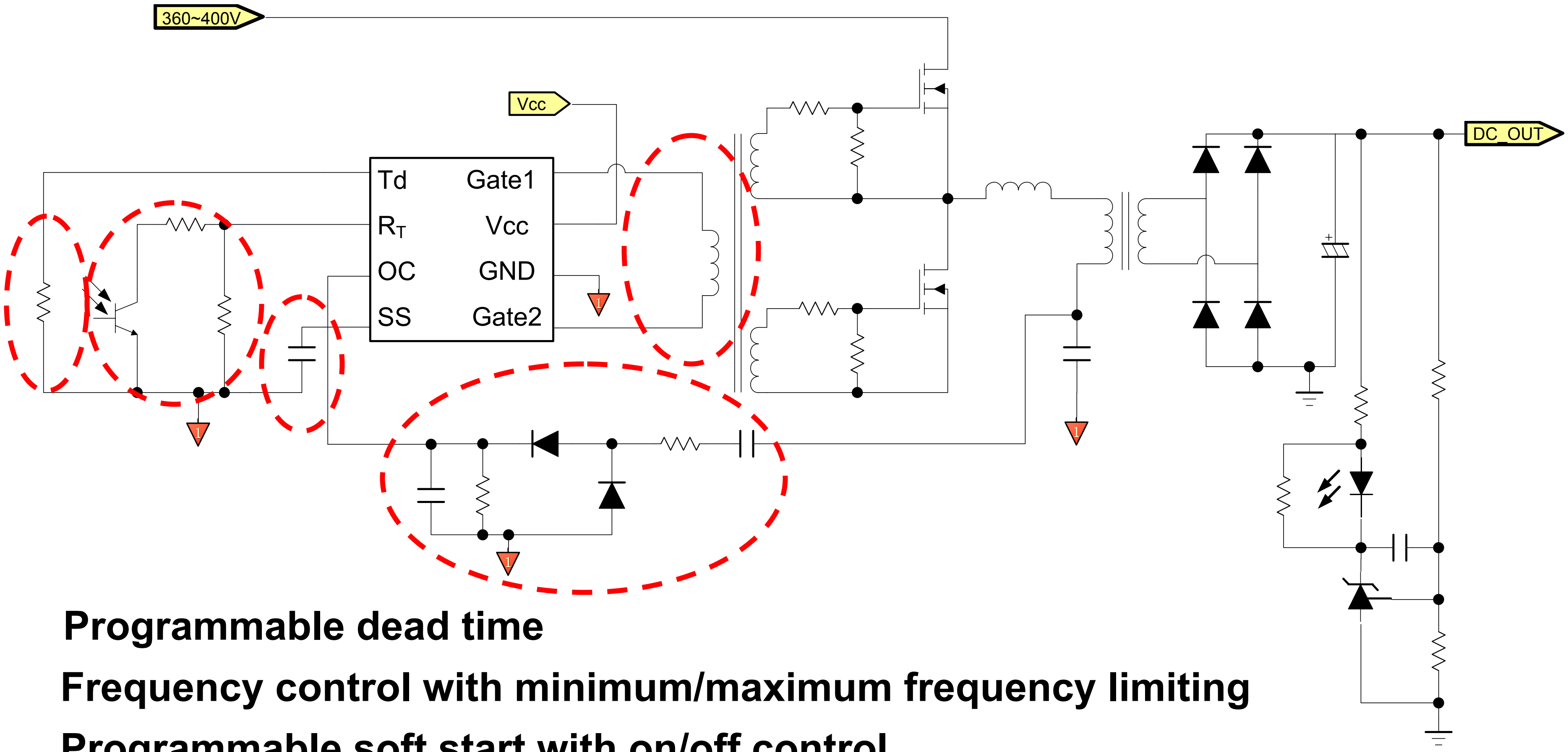
- Two levels over current protection
  - auto recovery
  - latch
- Bias voltage UV and OV protection
- Over temperature protection
- Soft start after all fault conditions

SOT 8 pin package= Easy design and layout



Ready to Order

Application Circuit



Programmable dead time

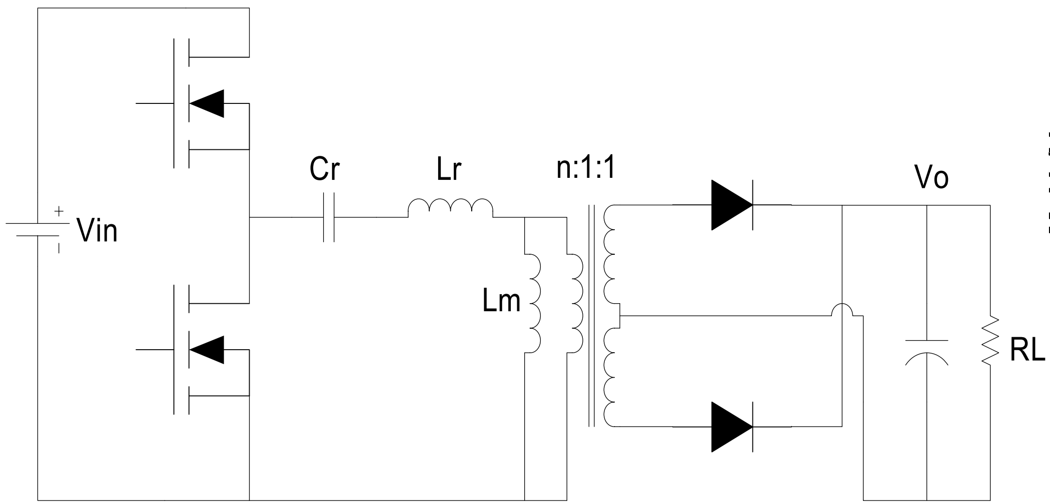
Frequency control with minimum/maximum frequency limiting

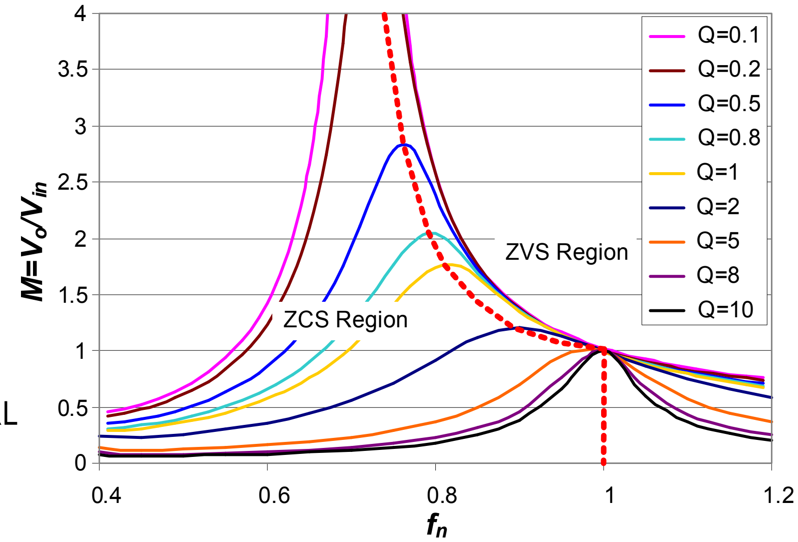
Programmable soft start with on/off control

Two level over current protection, auto-recovery and latch up

Matching output with 50ns tolerance

LLC Resonant Converter with Wide Operation Range



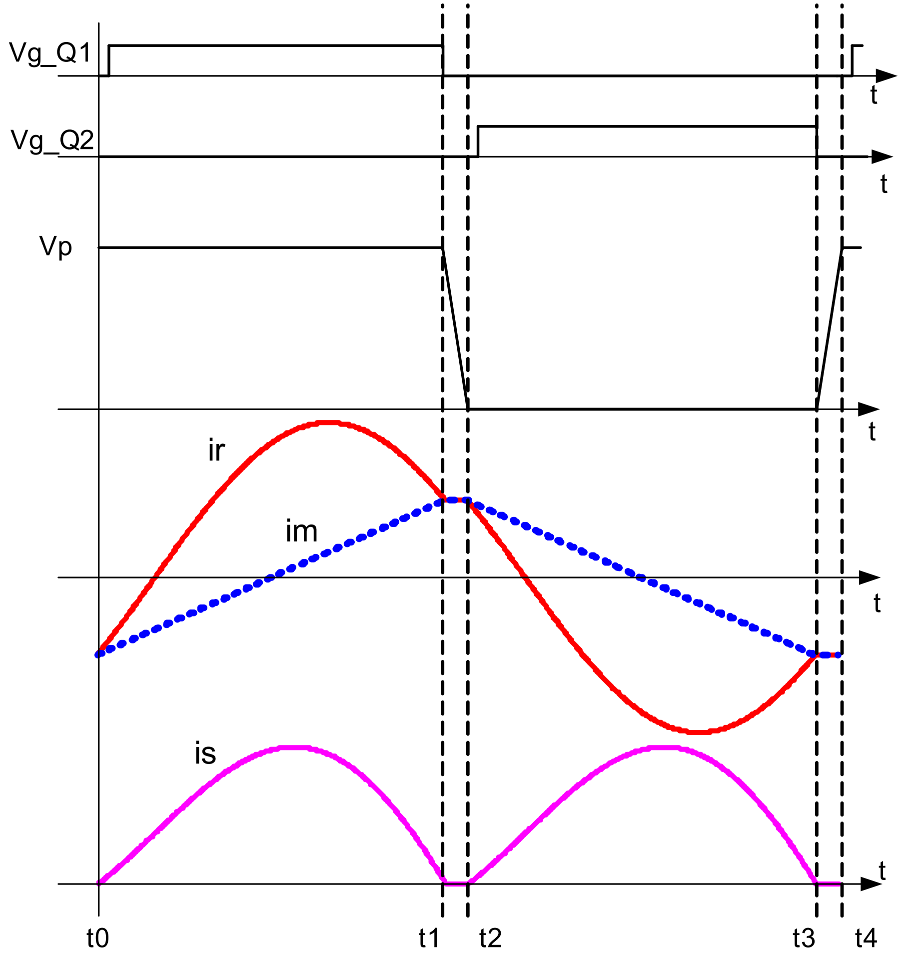


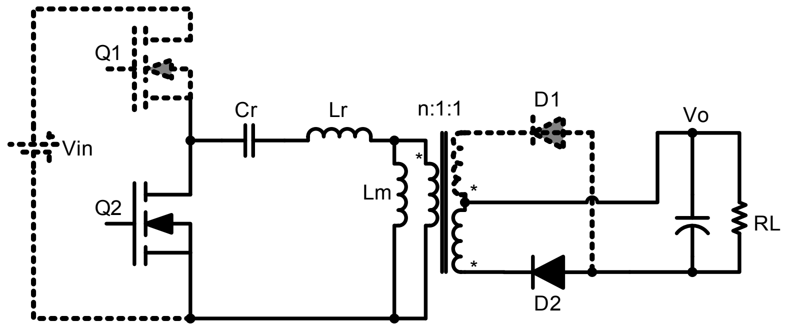
Resonant frequency $f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$

Transformer turns-ratio $n = \frac{V_{in}/2}{V_o}$

- **At 400V input, switching frequency is resonant frequency**
- **During holdup time, switching frequency is reduced**

Operation Principles
At Resonant Frequency

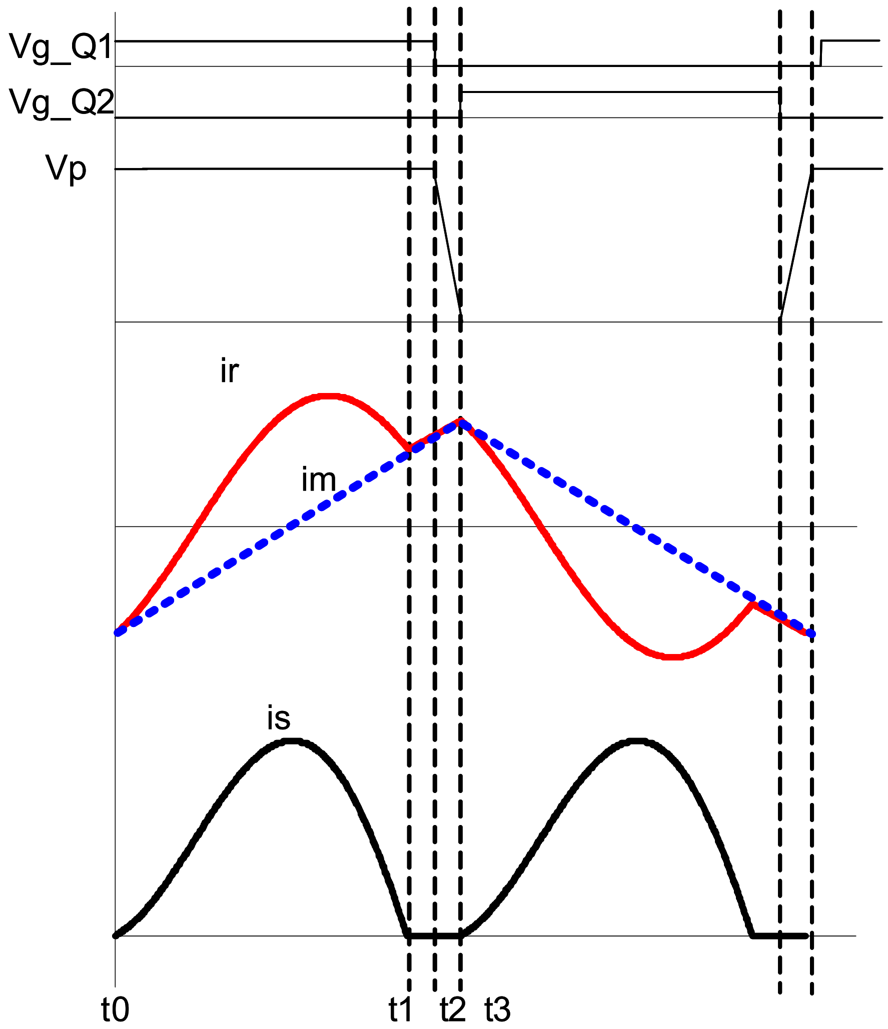


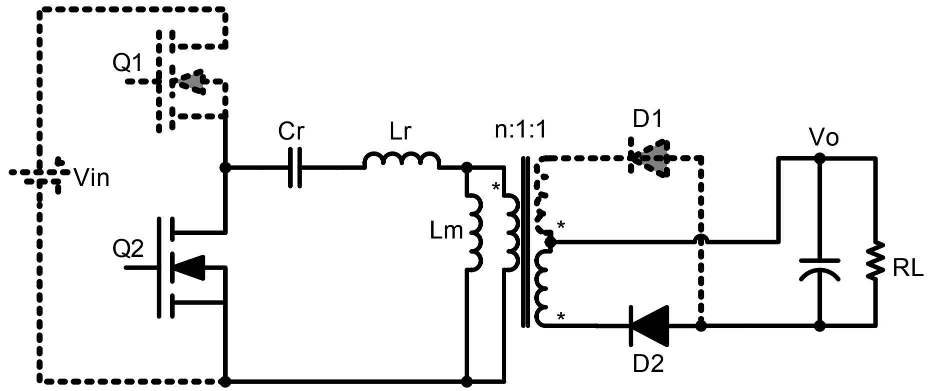


➢At resonant frequency, maximum efficiency is expected

Operation Principle

Below Resonant Frequency

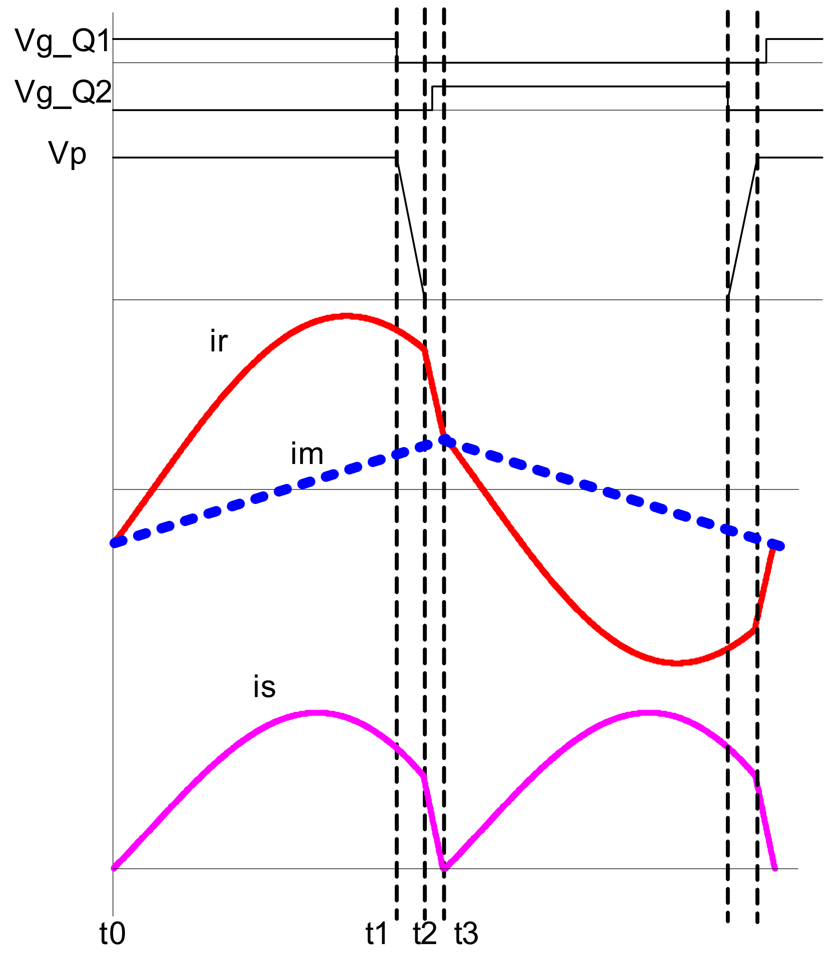


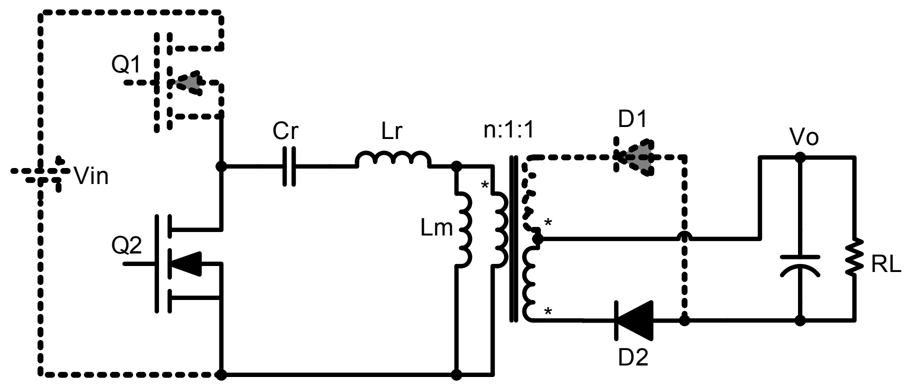


- When switching frequency is below resonant frequency, magnetizing inductor begins to participate in resonant and increase voltage gain
- Secondary diode becomes discontinuous

Operation Principle

Above Resonant Frequency

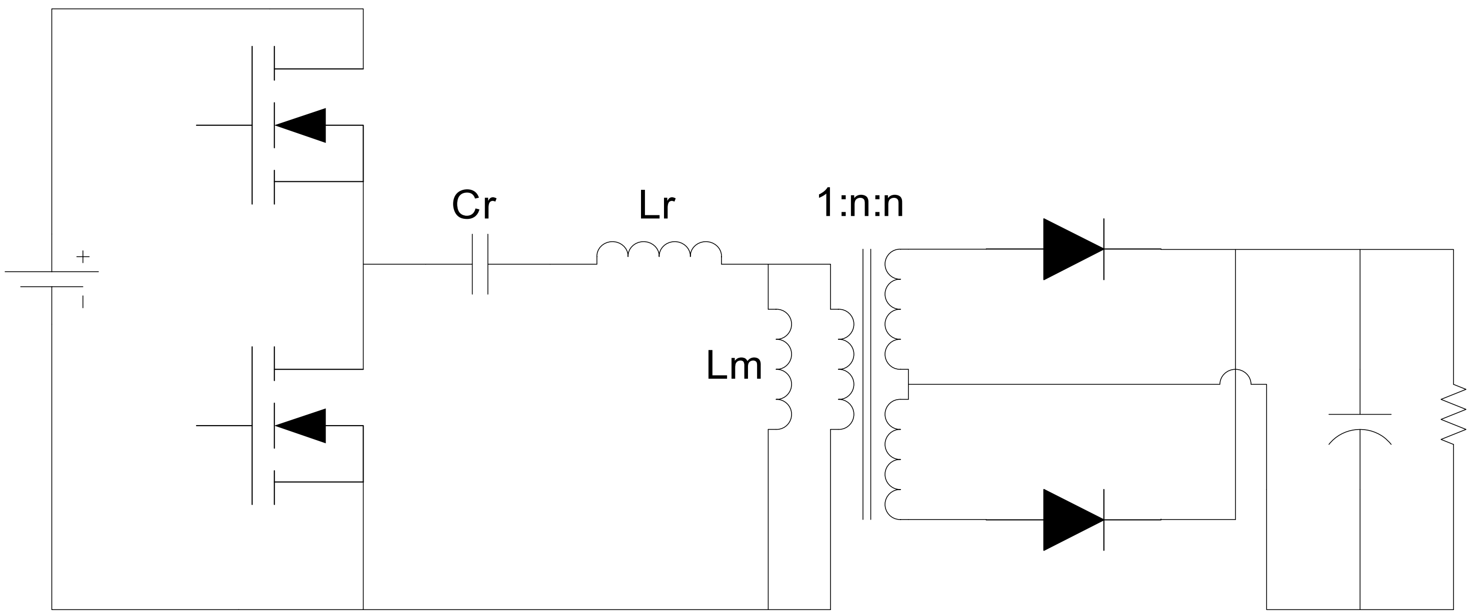




➢When switching frequency is above resonant frequency, circuit behaves as SRC

➢Secondary current becomes CCM, reverse recovery loss increases

Benefits of LLC Resonant Converter



- ZVS can be achieved by utilizing transformer magnetizing inductor
- Capacitor filter, less voltage stress on rectifiers
- Smaller switching loss due to small turn off current
- Variable switching frequency control, not sensitive to load change
- Wide operation range without reducing normal operation efficiency

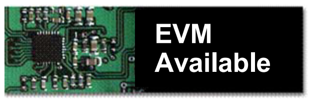
UCC24610
Green Rectifier Controller

Features

- Secondary Side Synchronous Rectifier Controller for Flyback and LLC Converters
- Operates in Continuous and Discontinuous Mode Flybacks and LLC Resonant
- Automatic Light Load Management
- Highly Integrated Control
- Micro Power Sleep Current at light/No load

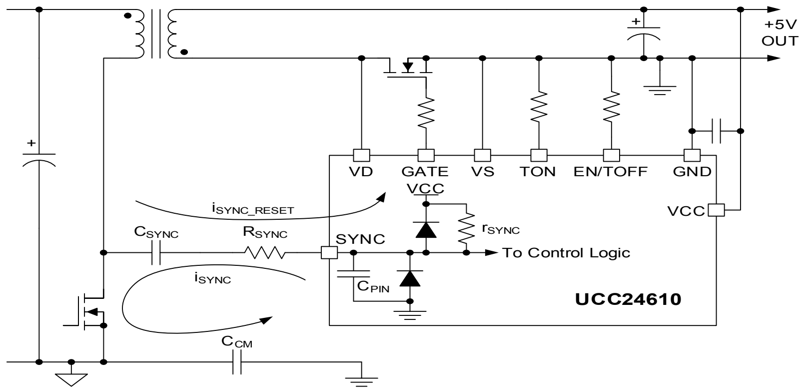
Applications

- AC/DC Adaptors
- Mobile Chargers – Cell Phone, IPod
- Set Top Box
- Appliance Power Supplies
- Bias Supplies

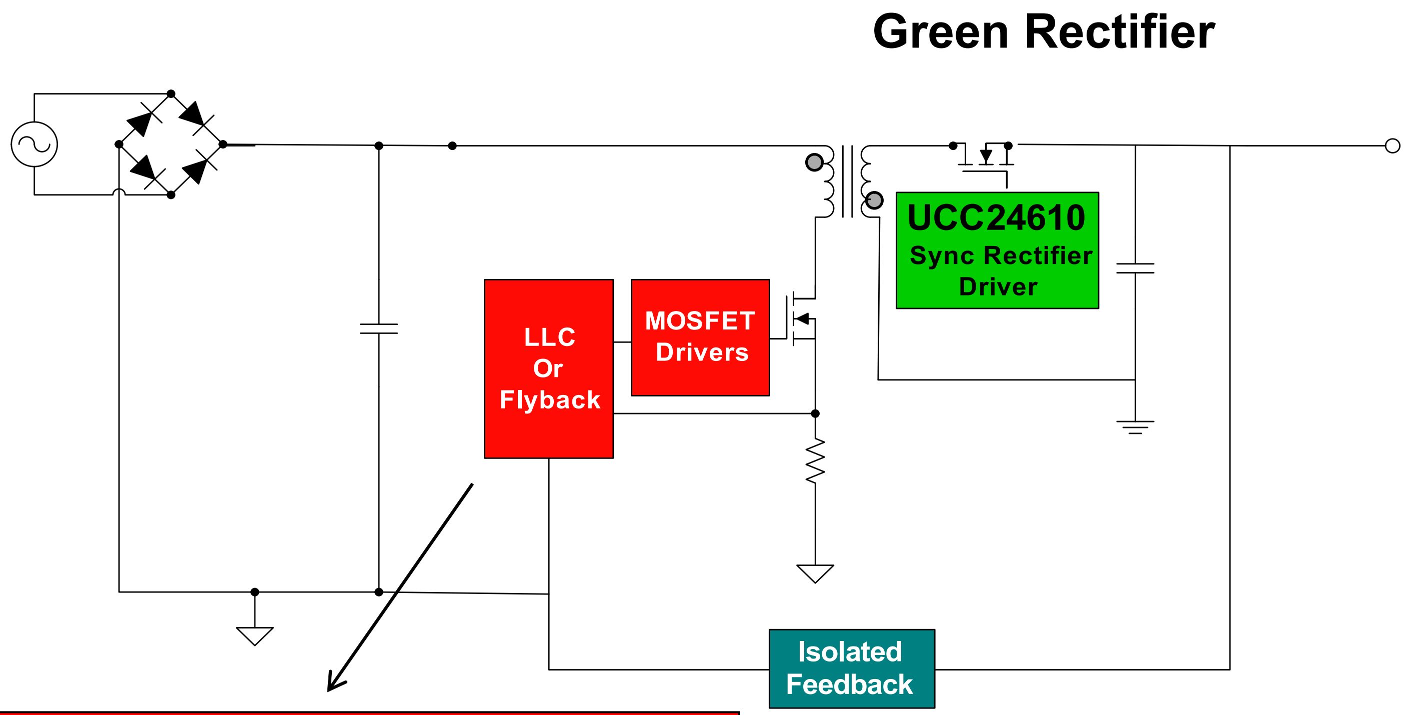


Benefits

- Enables 90%+ efficiency at full load and Optimized Efficiency Over Entire Load Range
- Zero Glitch Transition between CCM and DCM Operation for varying Line or Load Changes
- Turns MOSFETS Off to Maximize Light Load Efficiency
- Reduces External Components with up to 5% Reduction in Power Supply Costs
- Dissipates less than 1mW in Sleep Mode Making Energy Star Goals easily Achievable



Adding Green Solutions to the Portfolio



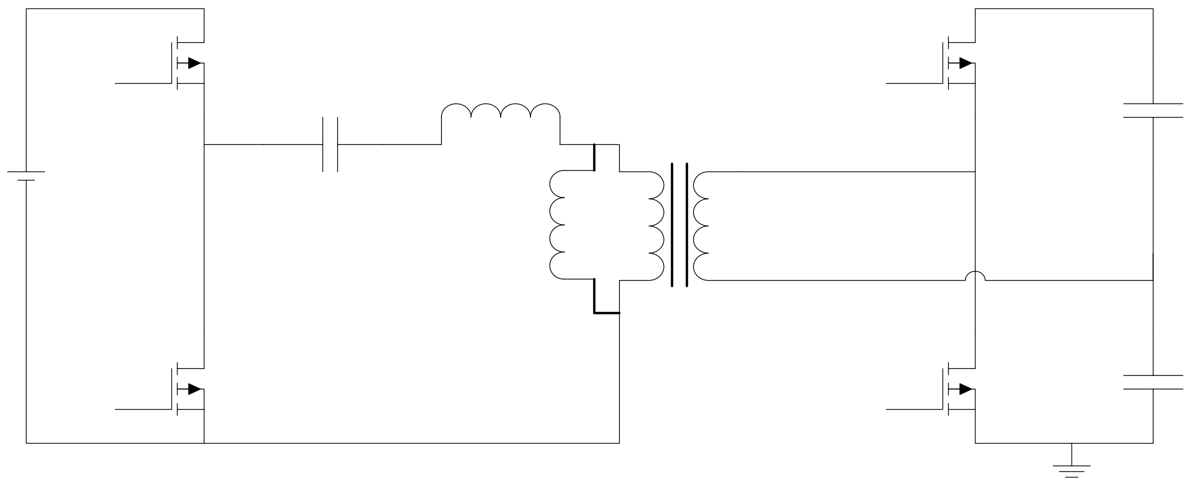
Green PWM Controllers

UCC28610 Green Mode PWM

UCC28600 Green Mode QR PWM

UCC25600 Green Mode Resonant LLC

Expand the Operation Range of UCC24610



- With 50V maximum rating, UCC24610 has trouble to use in 19V output LLC
- LLC converter with voltage doubler can be used to extend the operation range of UCC24610
  - No center tap, simpler transformer structure
  - Less voltage drop on the SR, better devices can be used
- UCC24610 can be powered up using on aux power source with boots trap diode

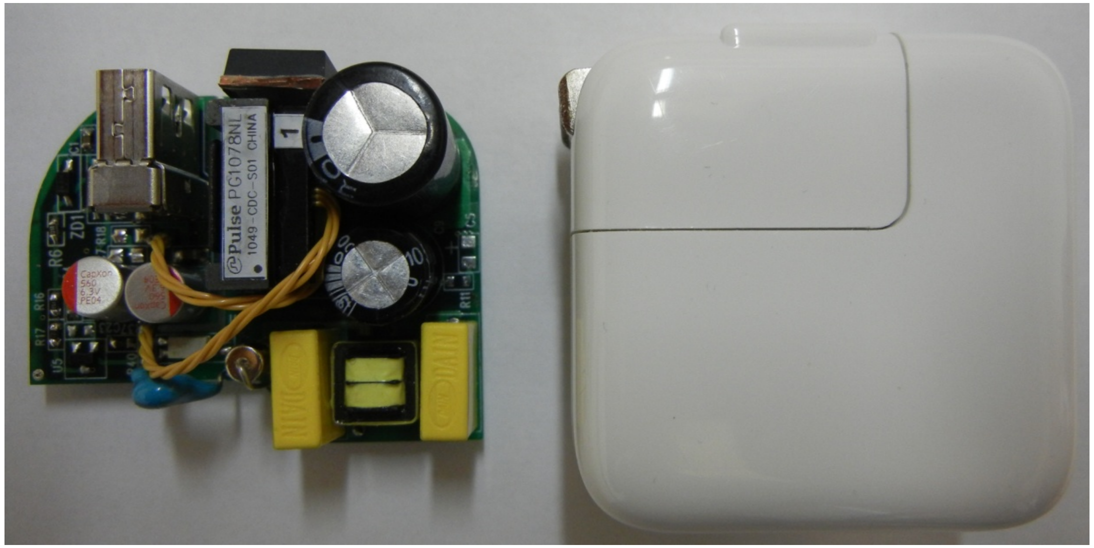
UCC24610 Competitive Analysis

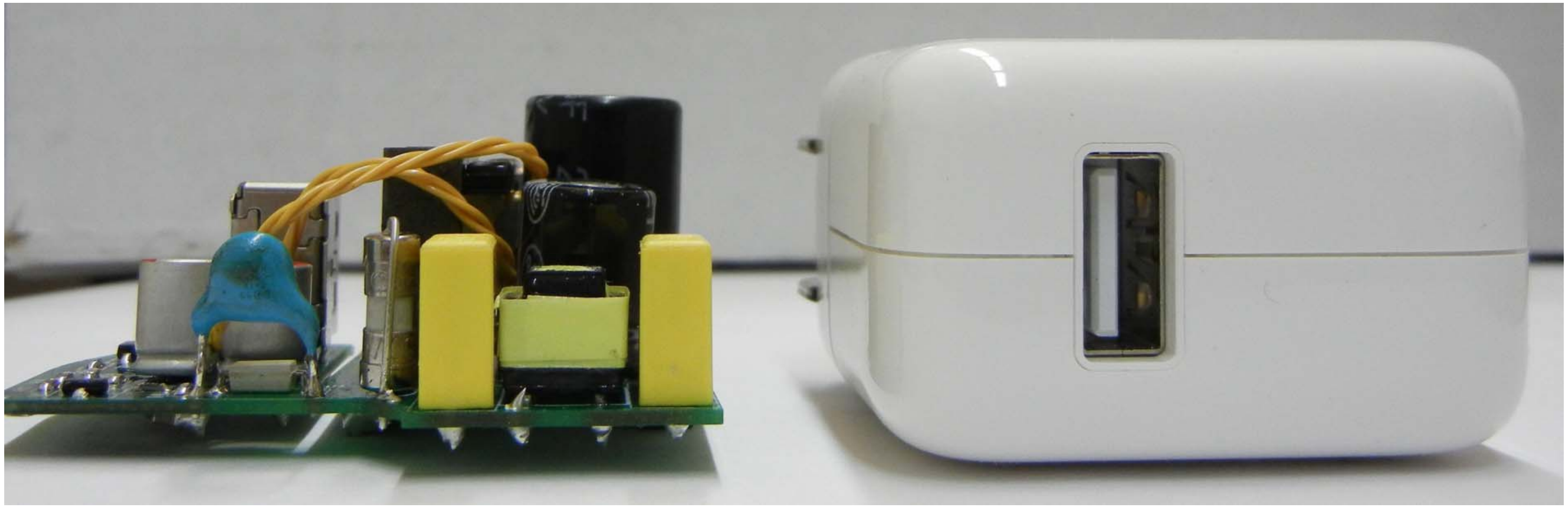
	TI	IR	NXP	NXP	ST	ON	ON	Gren	Zerex
Parameter/Device:	UCC24610	IR1166S[8]	TEA1761T	TEA1791T	STSR30	NCP4302	NCP4303B[9]	GR8387	ZXGD3101T8
Vdrain (V)	50	200	120	120	(ext. clamp)	95	200	200	180
Conduction Modes	DCM, QR, CCM	DCM, QR, CCM	DCM, QR	DCM, QR	DCM, QR, CCM	DCM, QR, CCM	DCM, QR, CCM	DCM, QR, CCM	DCM, QR, CCM
GATE Ion (Apk)	-3	-1	-0.25	-0.25	-1.5	2.5	2.5	1	2.5
GATE Ioff (Apk)	3	4	2.7	2.7	1.5	-2.5	-5	-4	-2.5
Max Freq (kHz)	600	500	?	?	500	250	500	500	n/a
Packages	PwrQFN-8, SO-8	SO-8	SO-8	SO-8	SO-8	SO-8	SO-8	SO-8	SO-8
Rthja (C/W)	67, 147	128	150	150	160	178	180	128	250
Tj Range (C)	-40 to +125	-25 to +125	-20 to +128	-20 to +128	-40 to +125	-40 to +125	-40 to +125	Unknown [5]	Unknown [5]
Special Features:									
Enable function	Yes	Yes	No	No	Yes	No	Yes	Yes	No
Auto Light-Load Mode	Yes	No	Yes	Yes	No	No	No	No	No
Inductance Compensation	No	No	No	No	No	No	Yes	No	No
Open/Short Protections	Yes	None Indicated	None Indicated	None Indicated	None Indicated	None Indicated	None Indicated	None Indicated	None Indicated
Regulated Opto-drive	No	No	Yes	No	No	Yes	No	No	No
Gate Voltage Reduction	No	No	Yes	Yes	No	No	Yes	No	Yes
Over-temp Protection	No	No	Yes	No	No	No	No	No	No

Key Differentiators

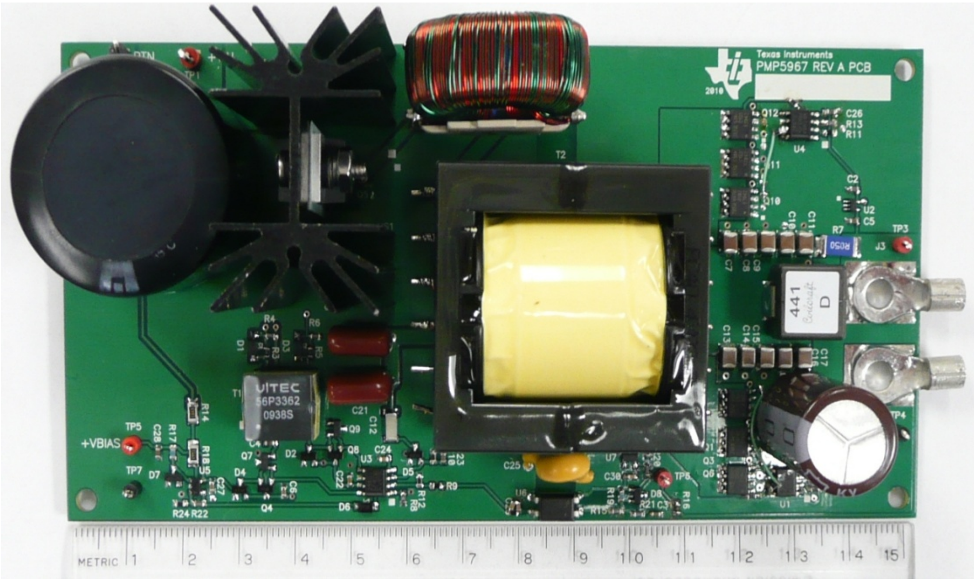
- High Gate Drive current
- Auto Light Load Mode
- Open/Short Protection

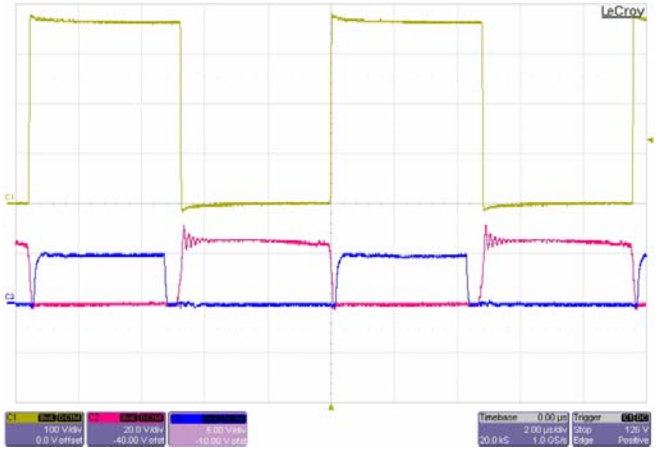
5.6V/3A AC Adapter:

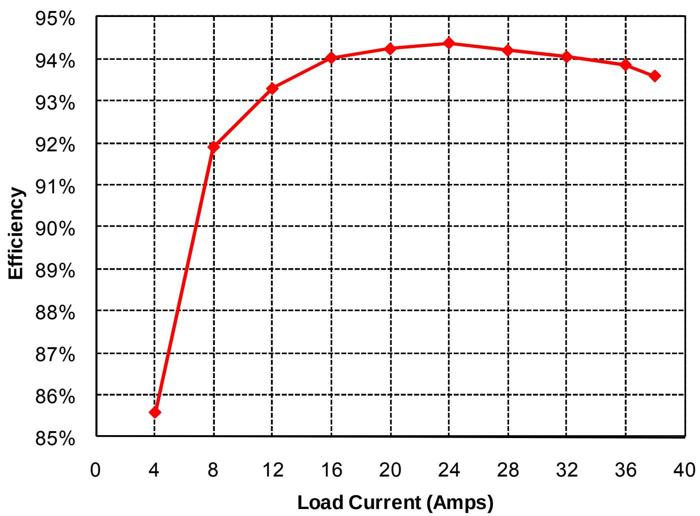




12V/40A Server Application:

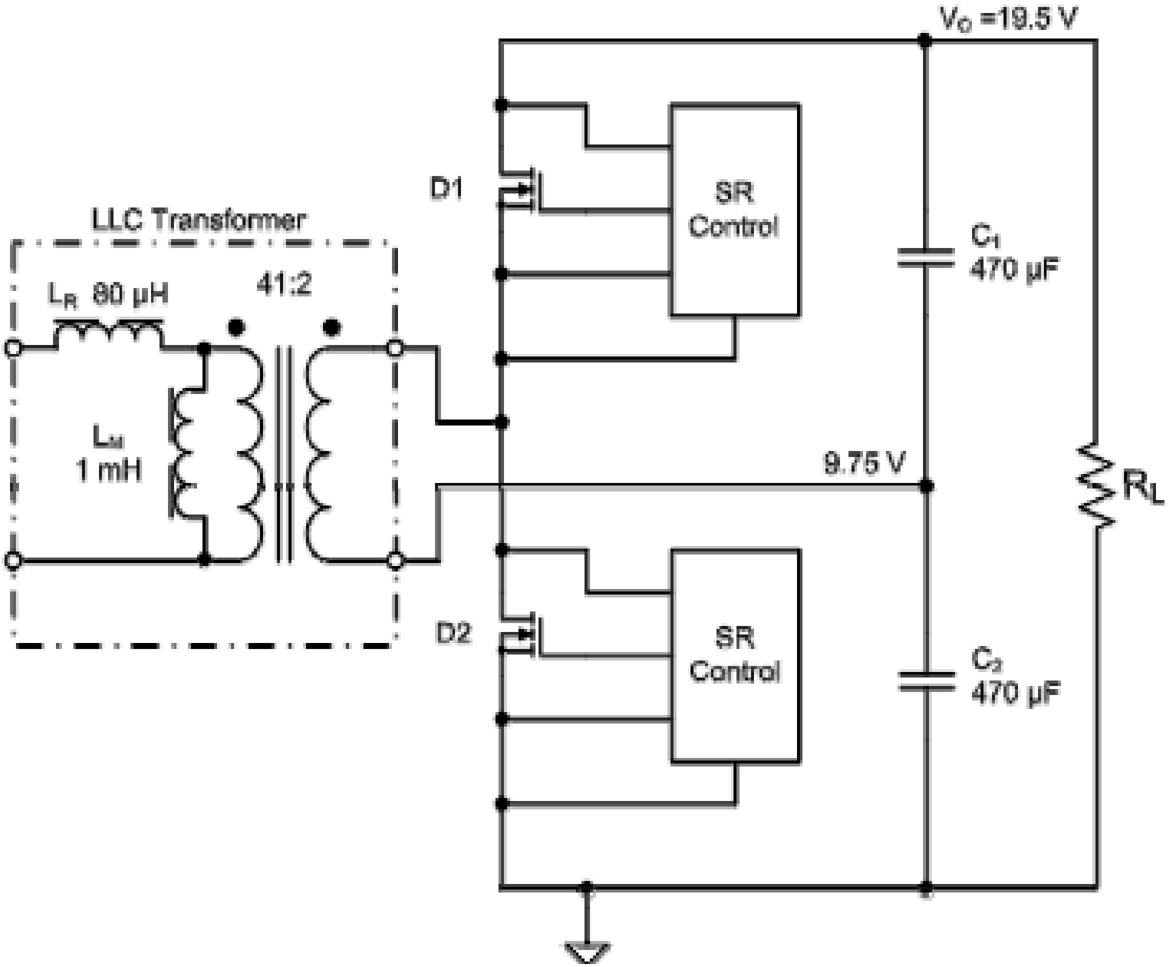




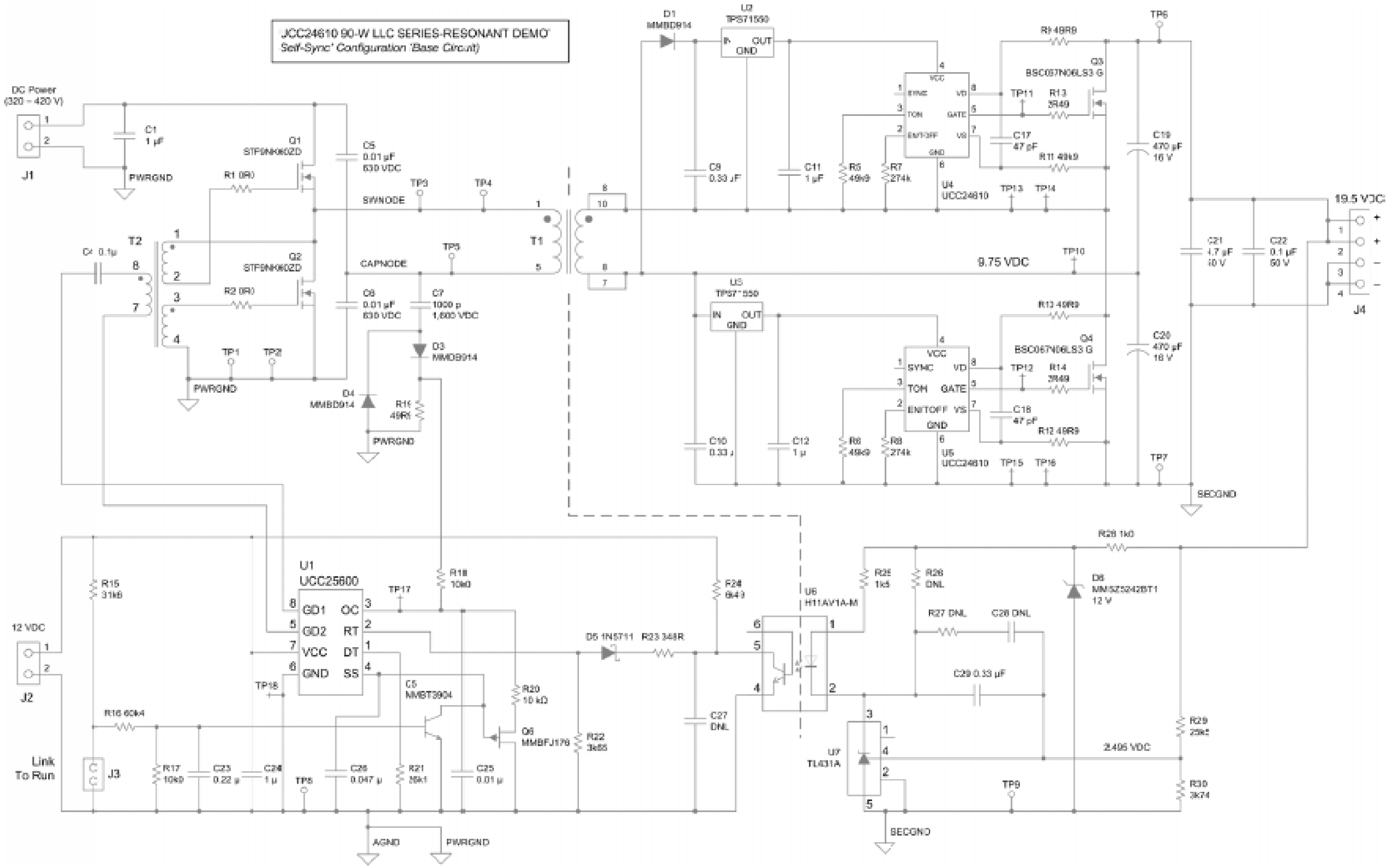


UCC24610 in 19.5V LLC AC Adapter Application

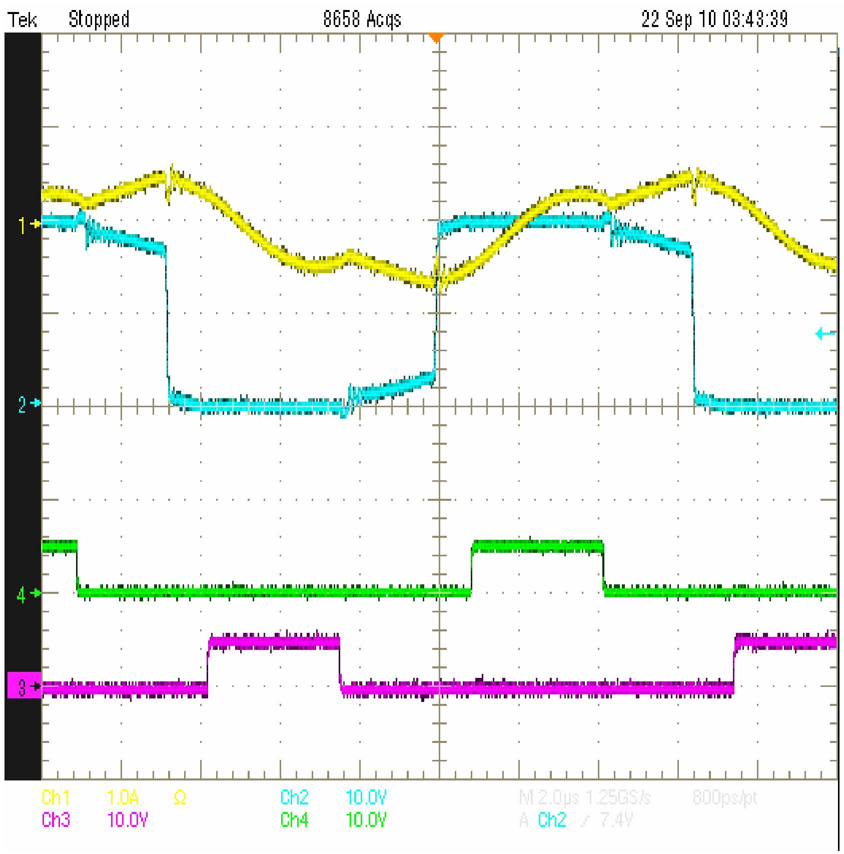
Synchronous rectifier in LLC converter



System implementation

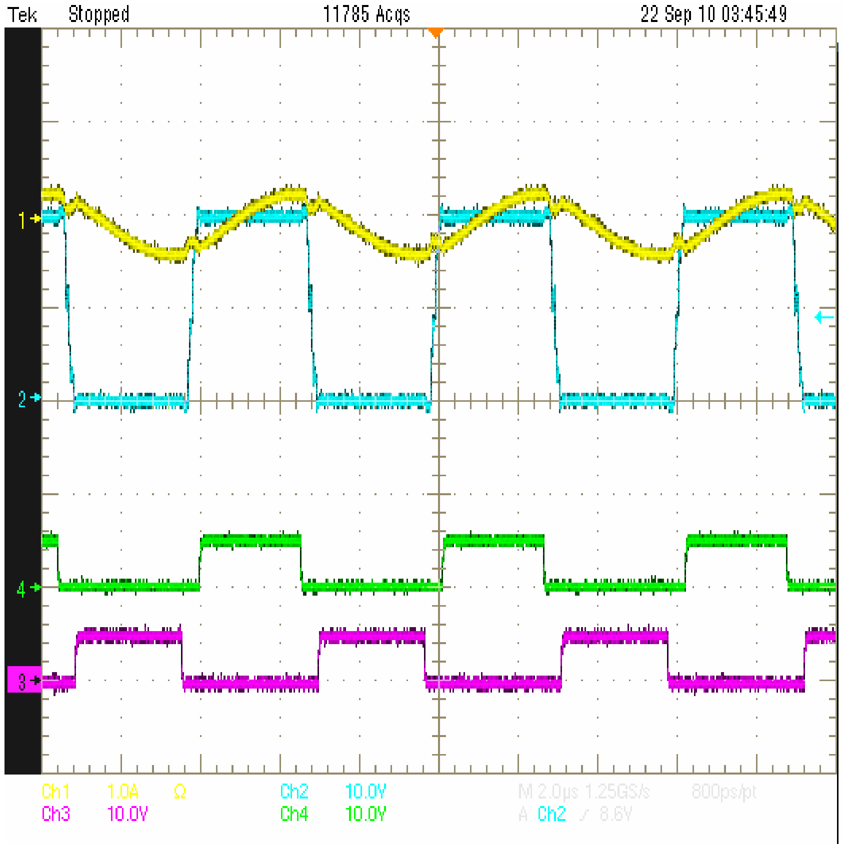


Test Results



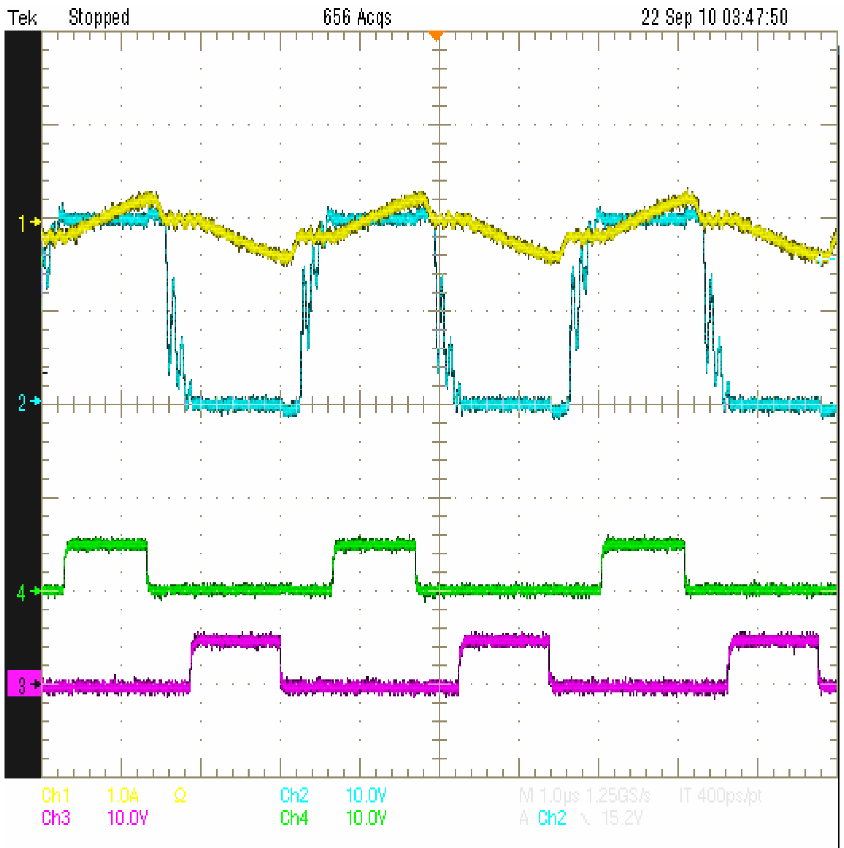
- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 2 μs/Div
- Operating conditions
  - V_I =320 V
  - I_O =1.0 Adc (20 W)
  - f_{SW} below resonance

Test Results



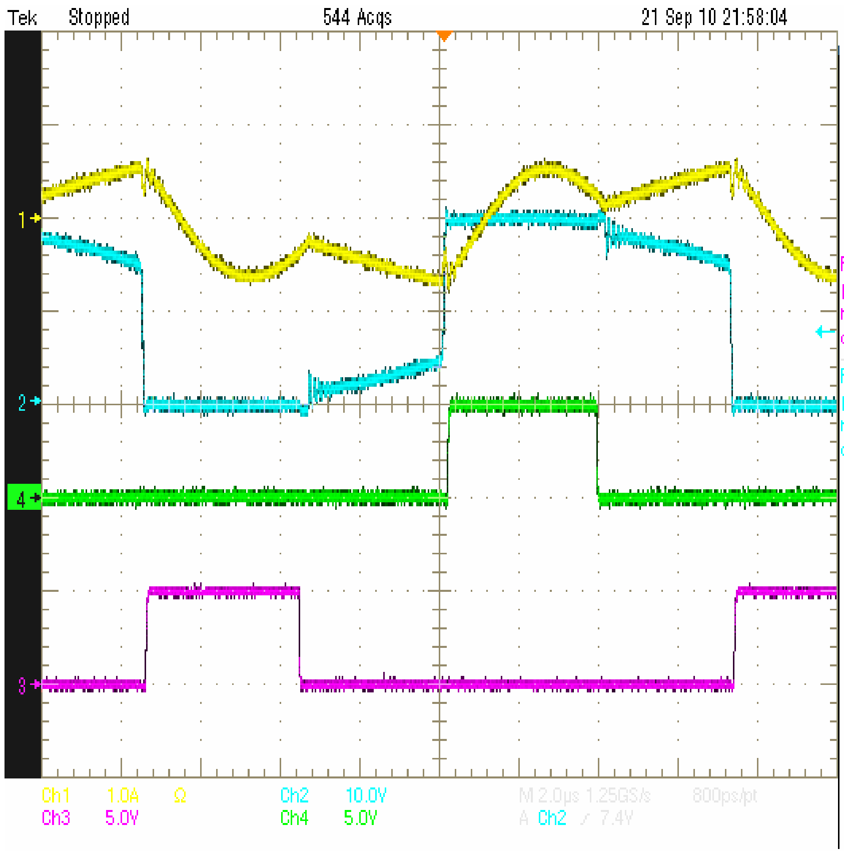
- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - V_I =390 V
  - I_O =1.0 Adc (20 W)
  - f_{SW} close to resonance

Test Results



- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 1 µs/Div
- Operating conditions
  - V_I =420 V
  - I_O =1.0 Adc (20 W)
  - f_{SW} above resonance

Test Results



- Waveforms
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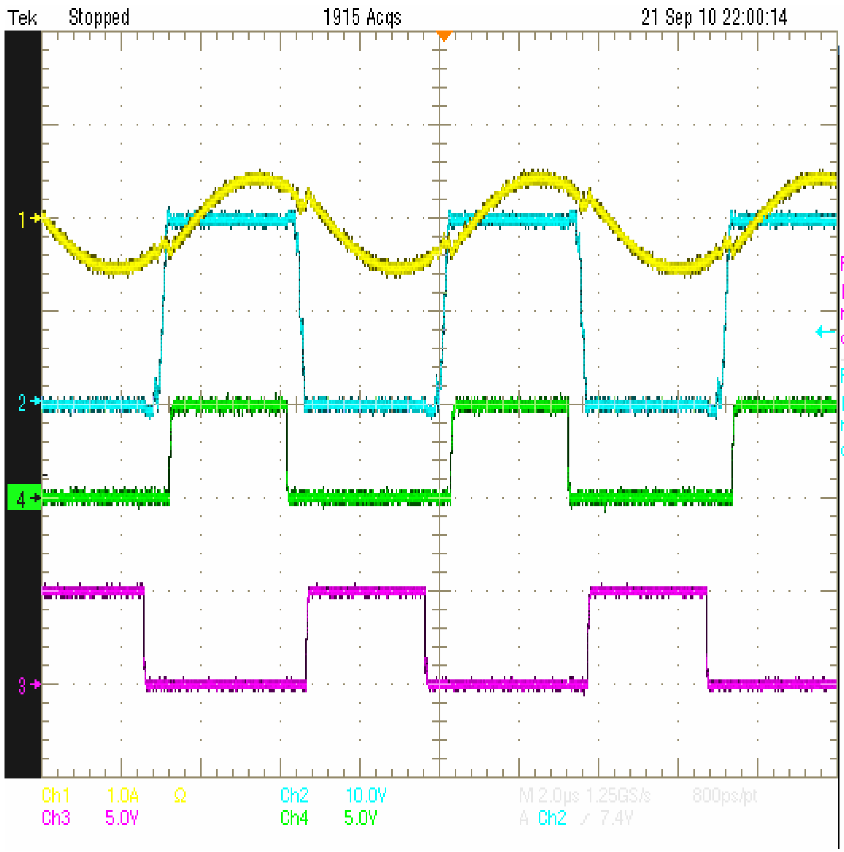
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 2 μs/Div
- Operating conditions
  - V_I =320 V
  - I_O =2.3 Adc (45 W)
  - f_{SW} below resonance

Test Results



- Waveforms
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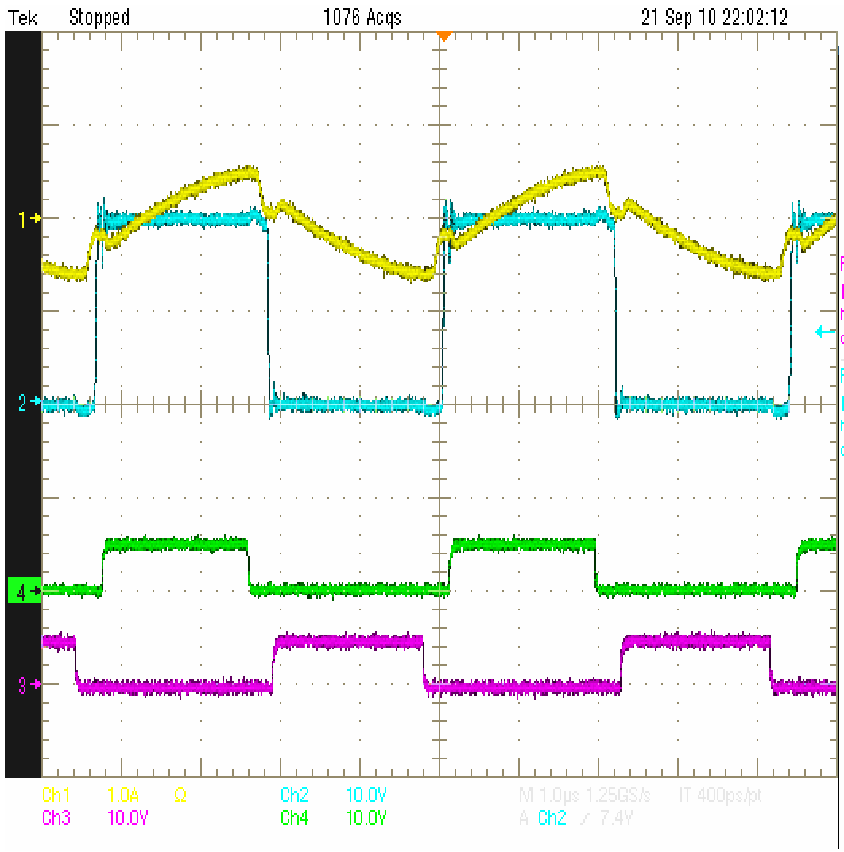
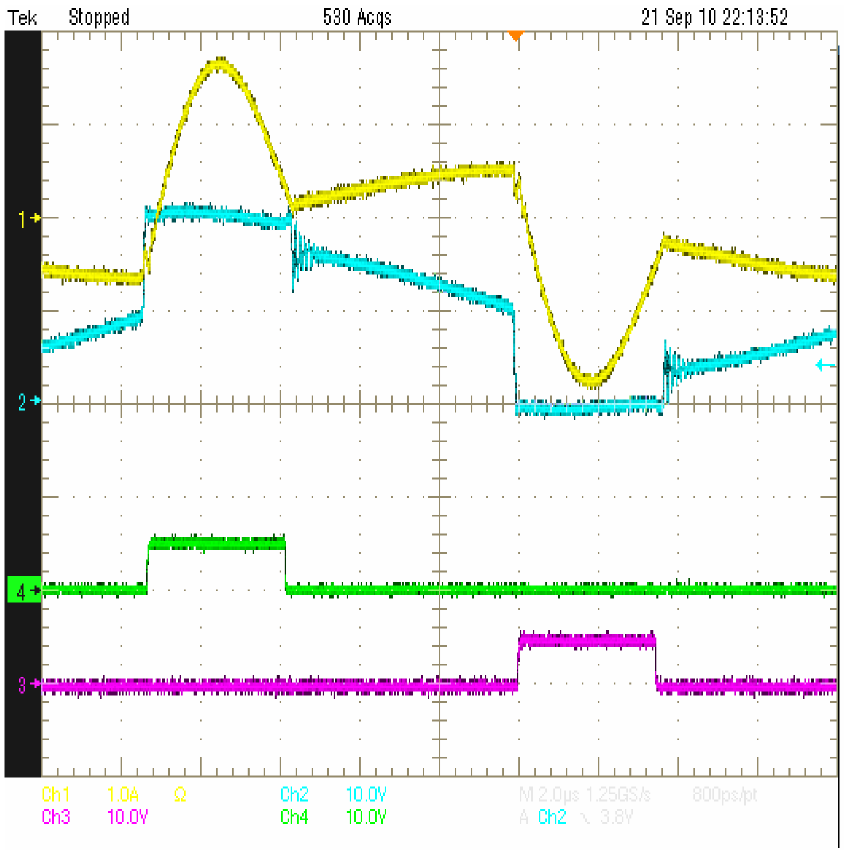
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - V_I =390 V
  - I_O =2.3 Adc (45 W)
  - f_{SW} close to resonance

Test Results



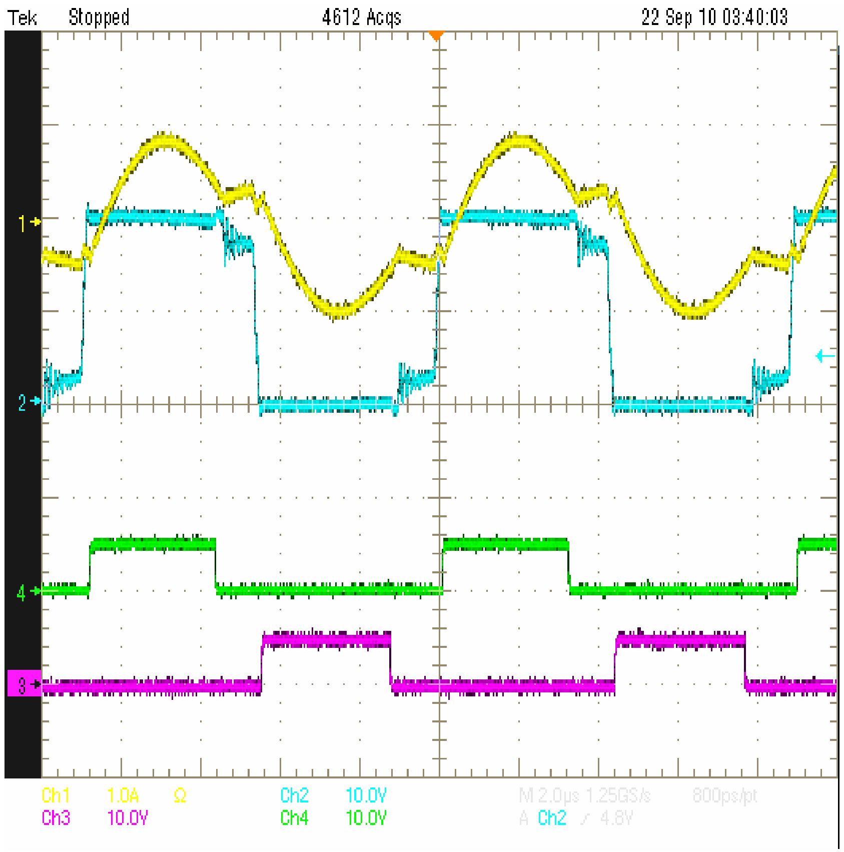
- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 1 μs/Div
- Operating conditions
  - V_I =420 V
  - I_O =2.3 Adc (45 W)
  - f_{SW} above resonance

Test Results



- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - V_I =320 V
  - I_O =4.6 Adc (90 W)
  - f_{SW} below resonance

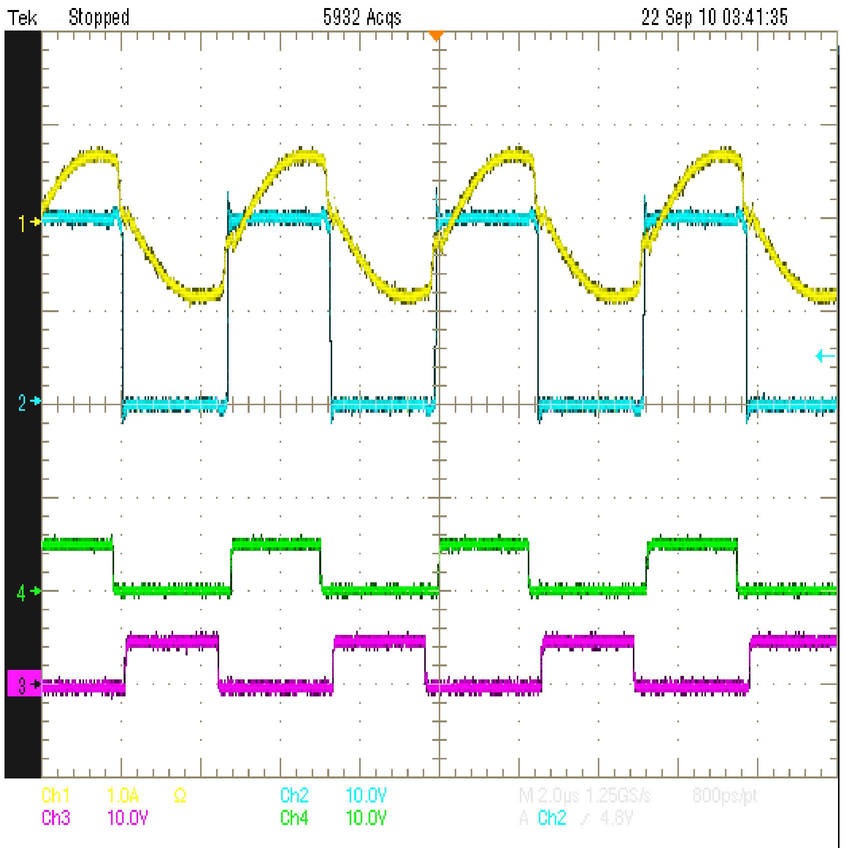
Test Results



- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10 V/Div
  - RED (Lower SR V_{GS}) 10 V/Div
- Horizontal scale
  - 2 µs/Div
- Operating conditions
  - V_I =390 V
  - I_O =4.6 Adc (90 W)
  - f_{SW} close to resonance

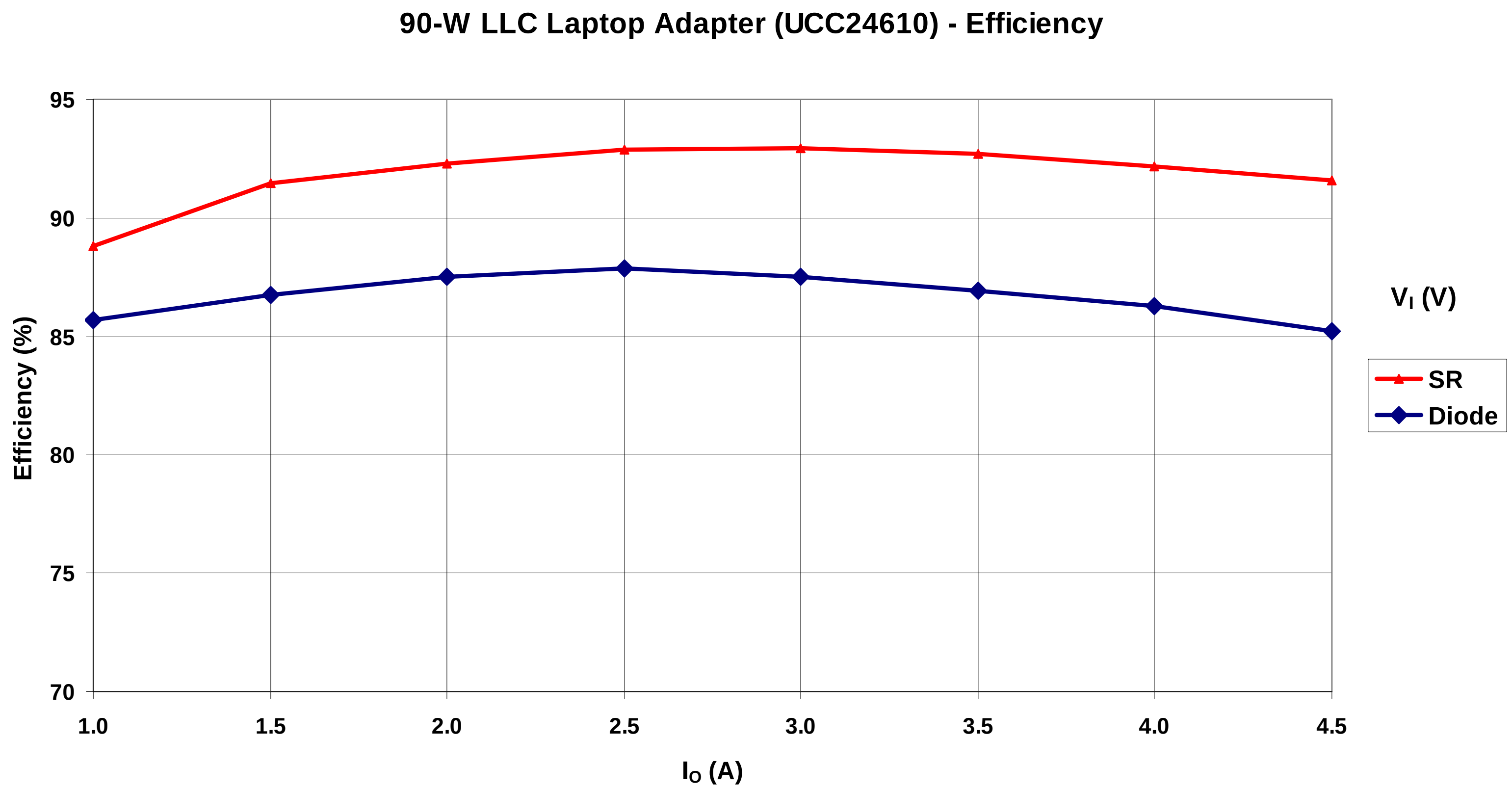
Texas Instruments

Test Results



- Waveforms
  - YEL (Primary current) 1 A/Div
  - BLU (Lower SR V_{DS}) 10 V/Div
  - GRN (Upper SR V_{GS}) 10V/Div
  - RED (Lower SR V_{GS}) 10V/Div
- Horizontal scale: 2 µs/Div
- Operating conditions
  - V_I =420 V
  - I_O =4.6 Adc (90 W)
  - f_{SW} above resonance

Operating Efficiency with UCC24610



More than 6% efficiency improvement is achieved by using UCC24610 with Synchronous rectifier

Thank You!