PDS Tips and Tricks

On Industrial Power Designs

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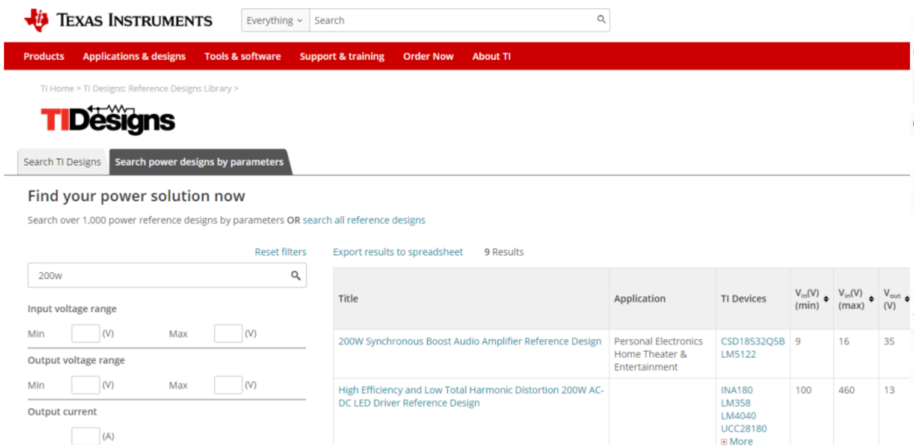
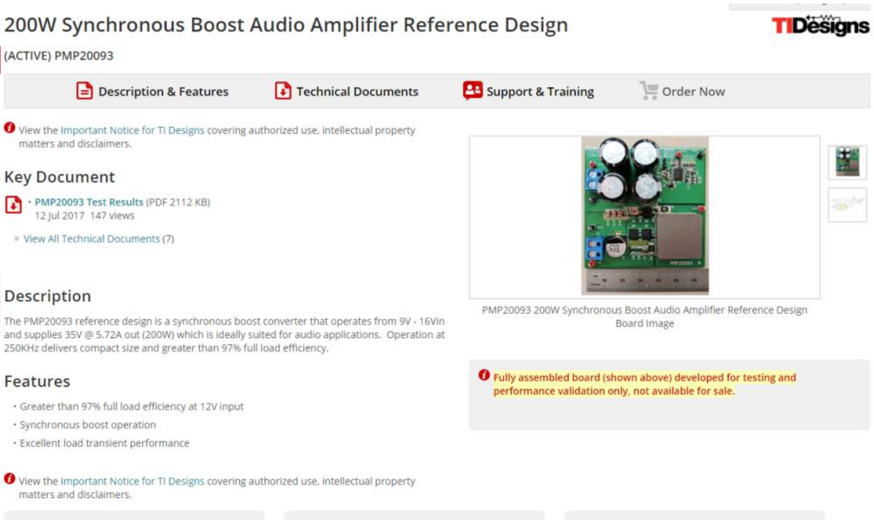
Agenda

1. Where to find tested PDS designs
2. Review of 5 different Industrial Designs
   a) 24V Isolated DC-DC **PMP20676**
   b) Universal Input AC-DC **PMP40347**
   c) Battery Charging AC-DC **PMP30047**
   d) USB Type-C/PD design AC-DC **PMP11451** (power conversion) + **PMP11455** (USB interface)
   e) HV AC-DC for Lighting **PMP20612**

Searching Existing Designs

- PDS uploads customer-ready designs to TIDesigns, always search here first.
- If a solution cannot be found on TIDesigns, work with local TI FAE.





24Vin Isolated DC-DC Design
EE: Industrial Gateway PMP20676

48W Isolated Flyback off 18V-30VDC input

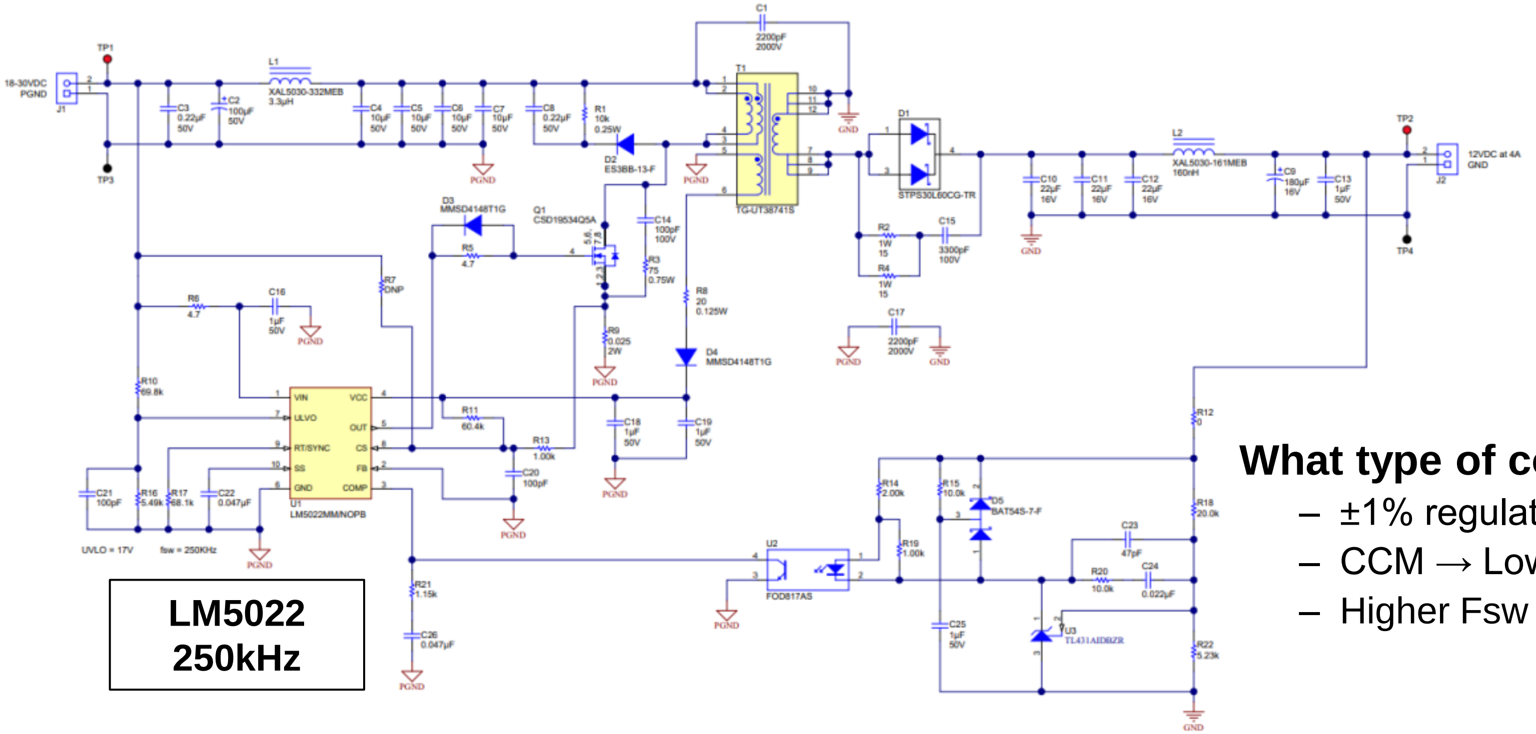
Design Specifications

- 12Vout @ 4A
- 18V to 30V input range
- 12Vout @ 4A
- ±1% output voltage regulation
- Total efficiency > 85% at Max Load
- Cost #1, Efficiency #2, Size #3

Design Considerations

- Selecting a control method
- Minimizing noise
- Managing power loss
- Output filter design

48W Isolated Flyback Design Considerations

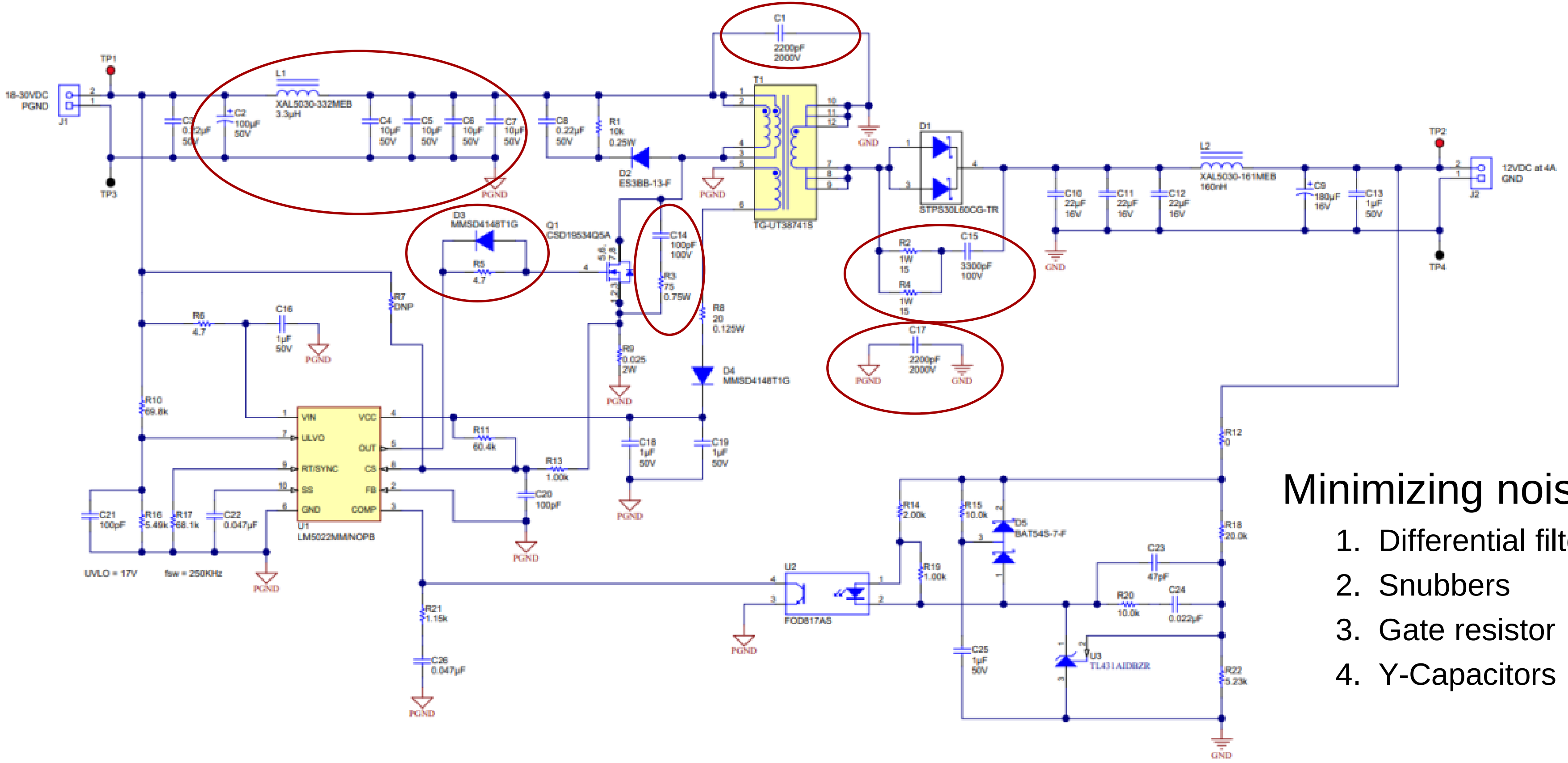


LM5022
250kHz

What type of control method?

- ±1% regulation → SSR
- CCM → Lower winding I_{pk}, I_{rms}
- Higher Fsw → Smaller size

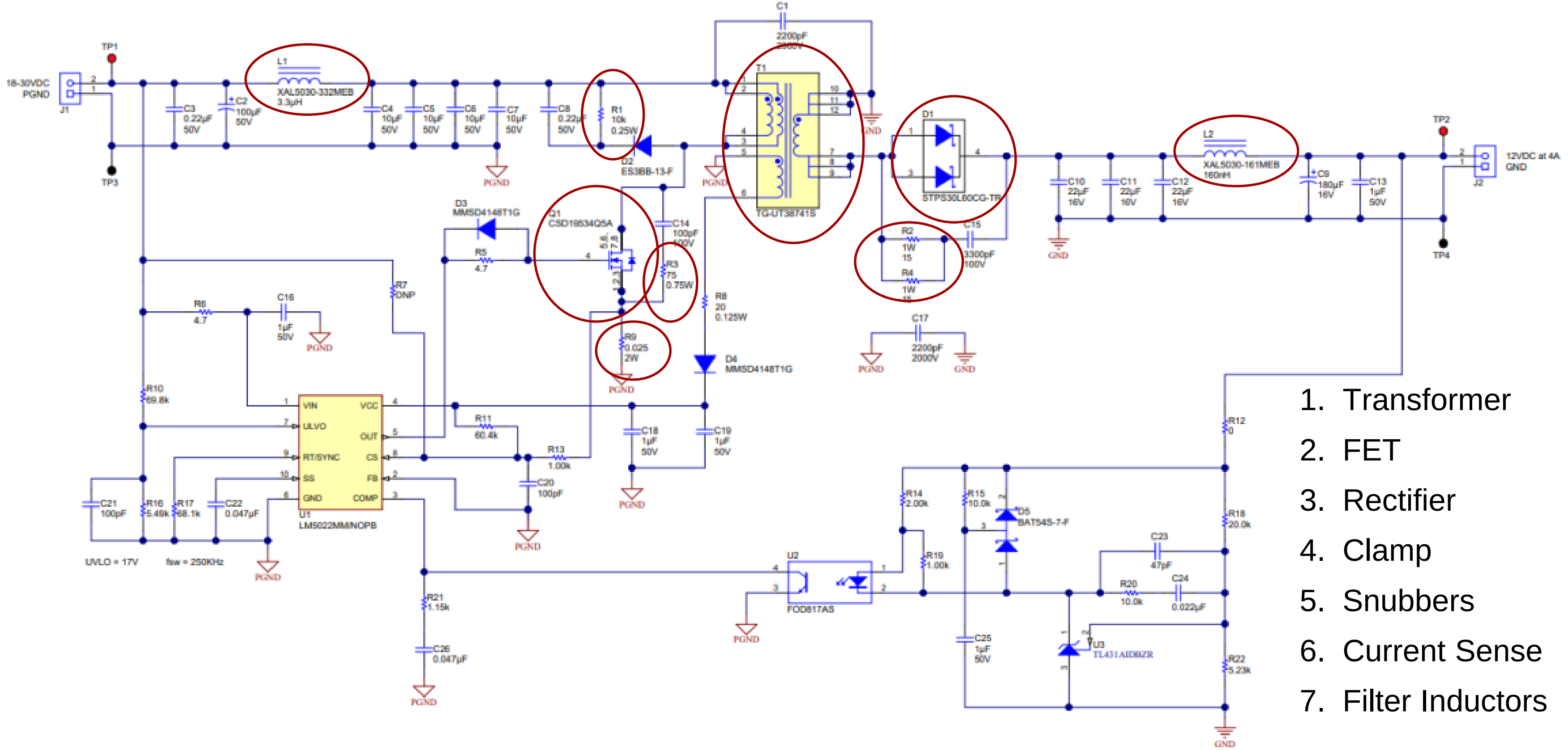
48W Isolated Flyback Design Considerations



Minimizing noise:

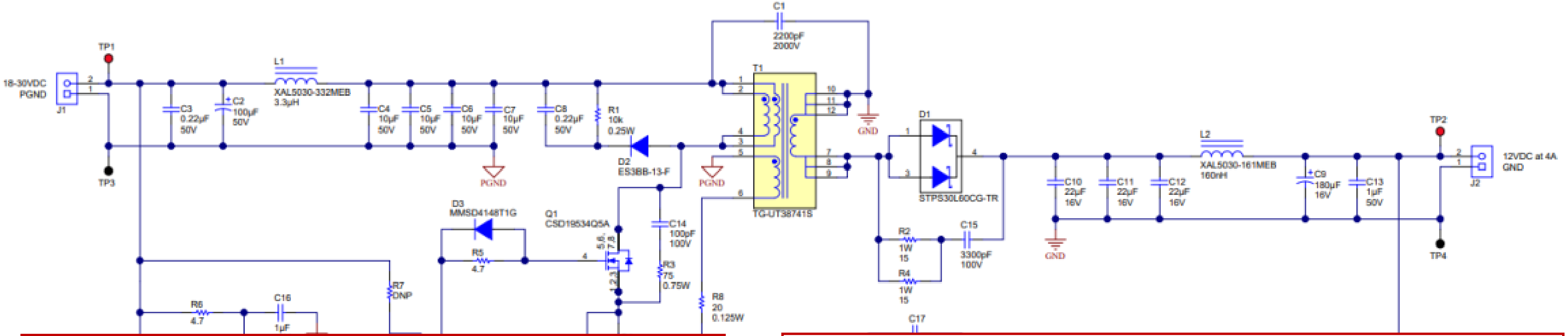
1. Differential filter
2. Snubbers
3. Gate resistor
4. Y-Capacitors

48W Isolated Flyback Major Loss Sources



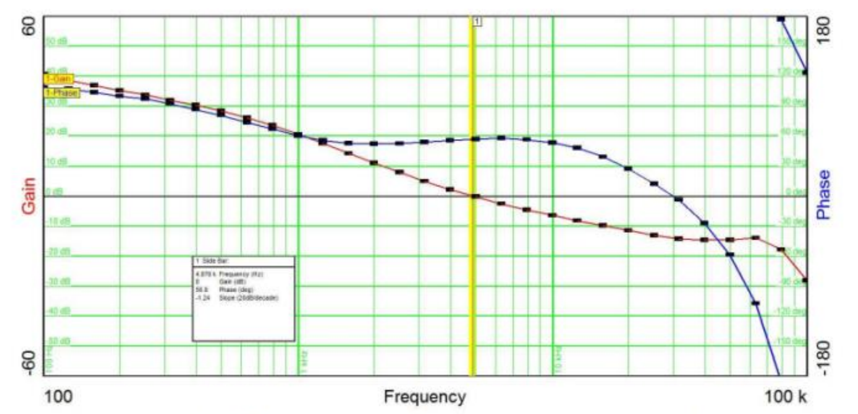
1. Transformer
2. FET
3. Rectifier
4. Clamp
5. Snubbers
6. Current Sense
7. Filter Inductors

48W Isolated Flyback Output Filtering



Two Stage Filter Considerations

- 1st stage → High RMS Current (Ceramic)
- 2nd state → Hold Up for Transients (Al)
- Resonance of L2 and 1st stage C
  - May cause large ringing
  - ESR of 2nd stage C damps resonance
  - Can damp L2 with parallel R, but burns W
- Reduced I_{rms} in 2nd stage C increases life

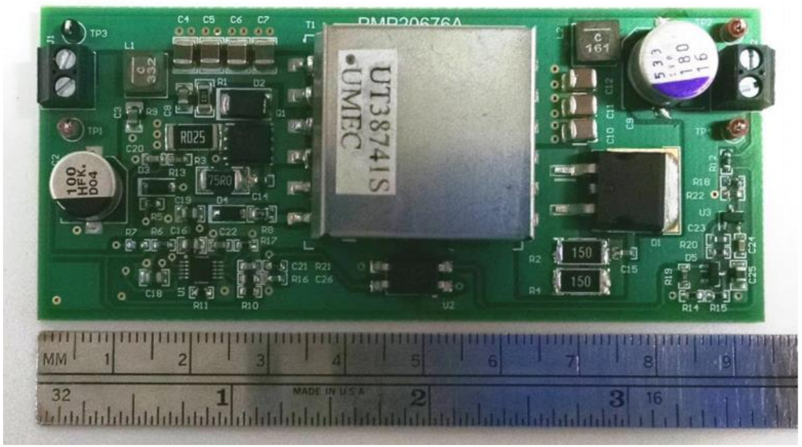


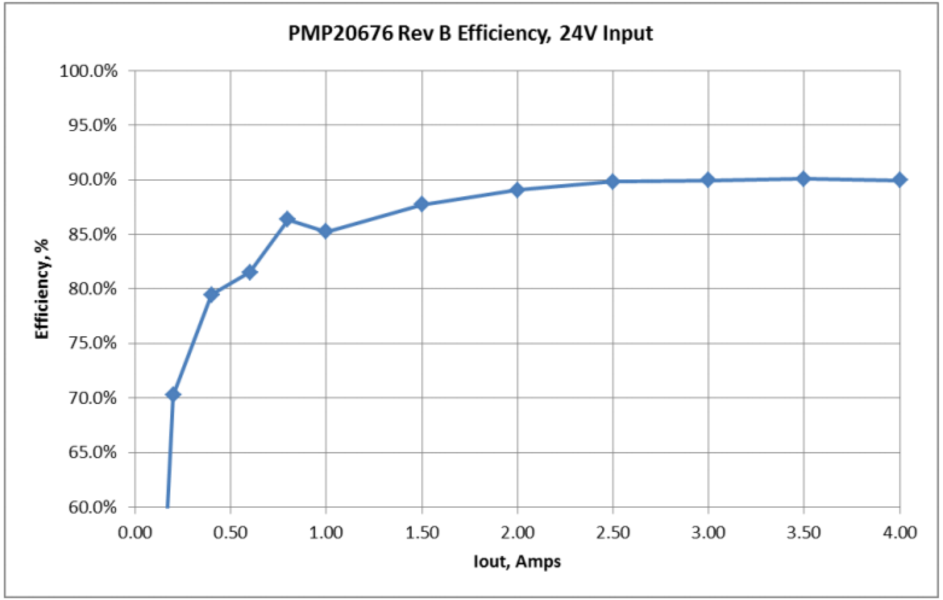
Bandwidth= 4.8 kHz Phase Margin=56 degrees Gain Margin=14dB

48W Isolated Flyback Design Results

Results

- 90% efficiency at full load
- Small form factor
- Won due to low cost
- Available online
  - http://www.ti.com/tool/PMP20676





Universal Input AC-DC Design
EE: E-Meter PMP40347

12W Supply from 3-Phase 110VAC-420VAC Input

Design Specifications

- 3 separate 3kV isolated outputs: 12V@0.7A, 12V@0.2A, 5V@0.2A
- 110VAC-420VAC 3-Phase Input
- Input OVP, independent output OCP and SCP for each rail
- 0.1% output ripple on 12V@0.7A rail
- Total efficiency > 70% at 6W output power, over entire input voltage range
- Cost #1, Efficiency #2, Size #3

Design Considerations

- Dealing with multiple outputs
- Architecture and device choices
- Dealing with high input voltage

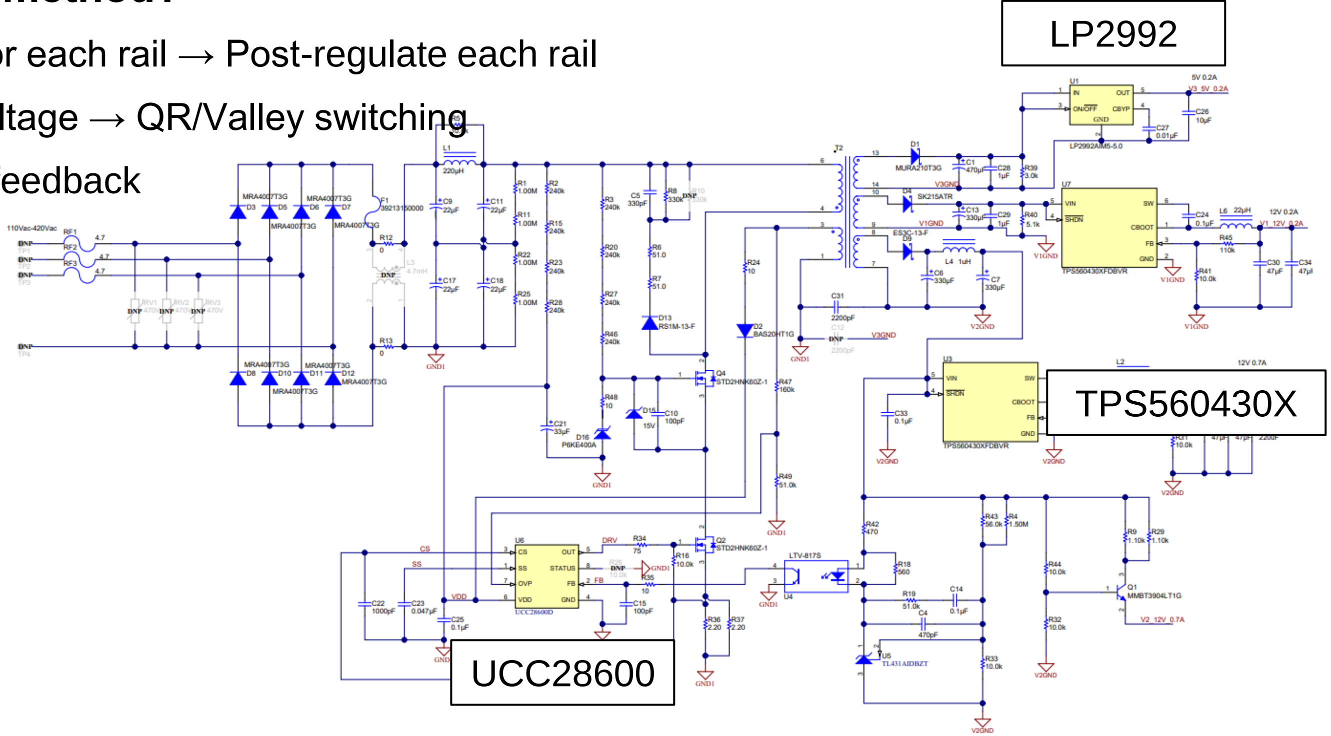
12W Supply from 3-Phase 110VAC-420VAC Input

What type of control method?

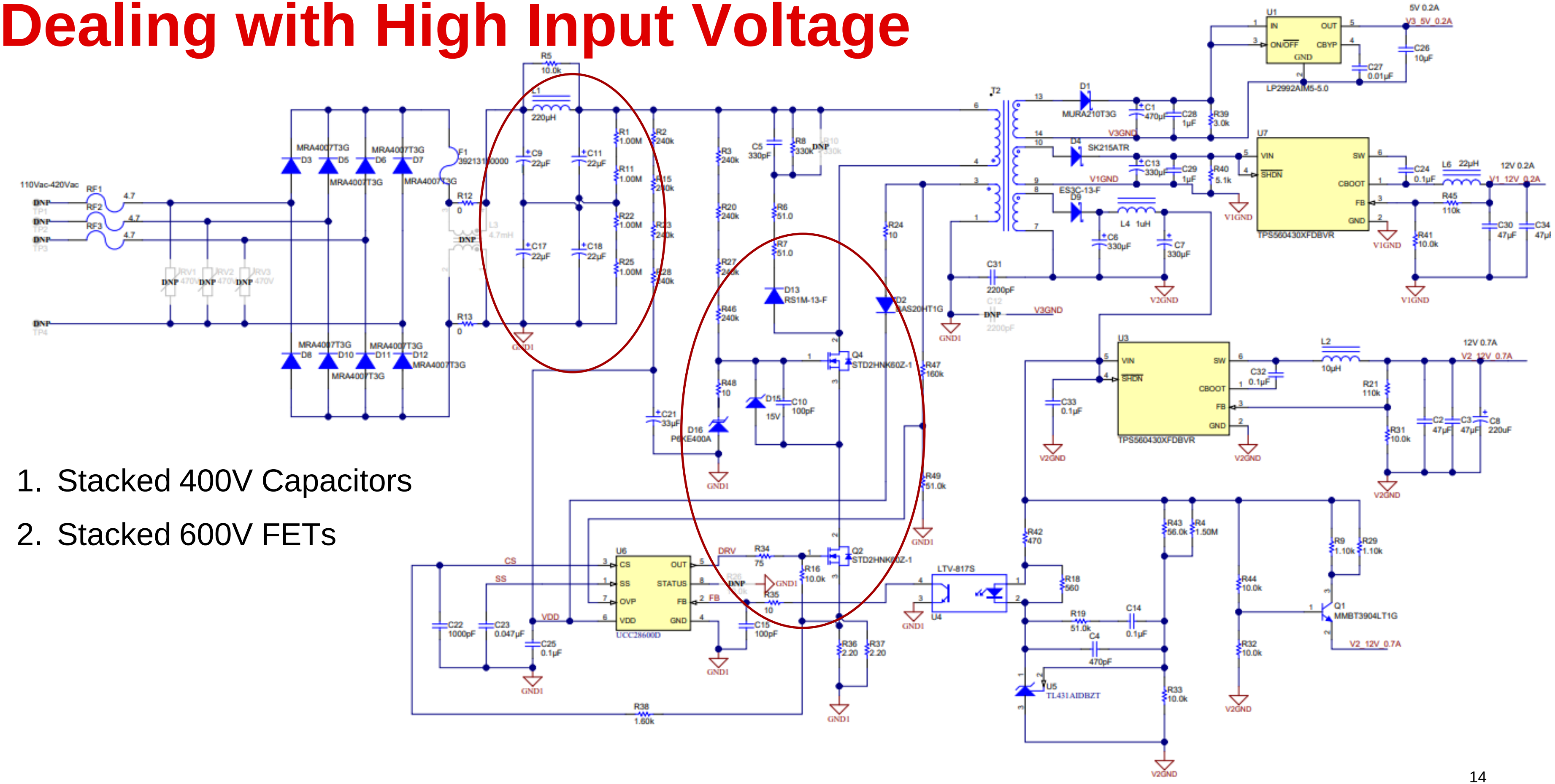
Independent OCP/SCP for each rail → Post-regulate each rail

Low Power/High Input Voltage → QR/Valley switching

Multiple outputs → Opto-feedback



Dealing with High Input Voltage

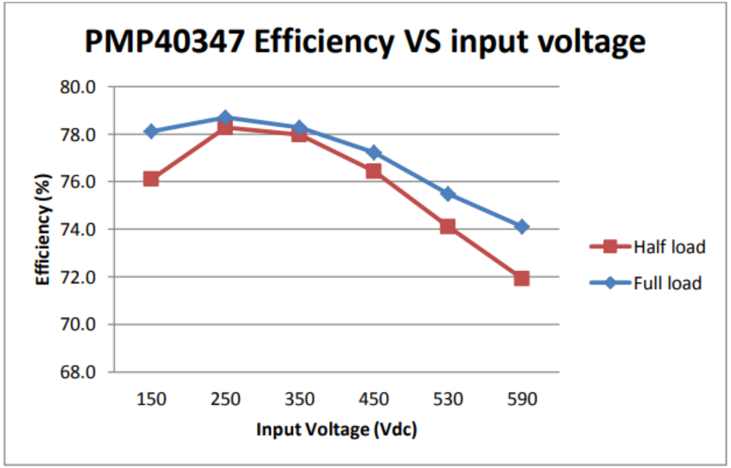


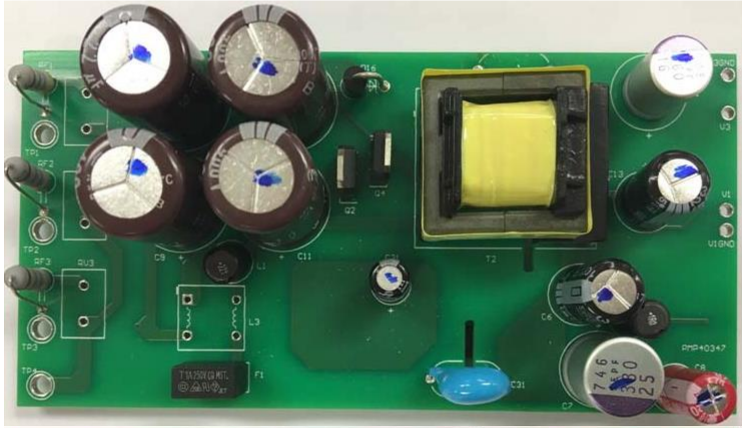
1. Stacked 400V Capacitors
2. Stacked 600V FETs

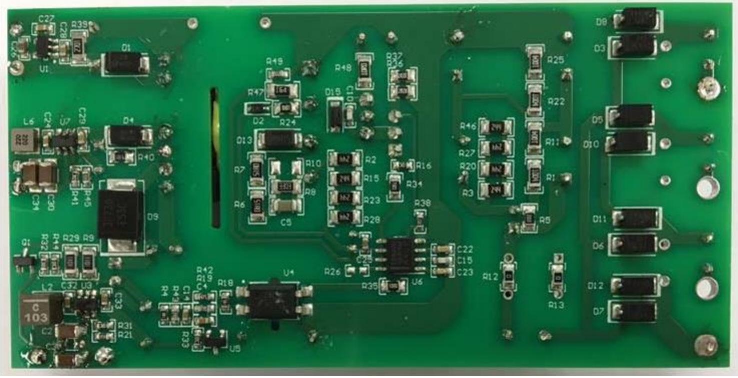
12W Supply from 3-Phase 110VAC-420VAC input

Results

- >72% efficiency across input range
- Small form factor (50mmx100mm)
- Won due to low cost/performance
- Available online
  - http://www.ti.com/tool/PMP40347







Offline Battery Charging Design
EE: Lead Acid Battery Charging PMP30047

230VAC, 64W Lead Acid Charger

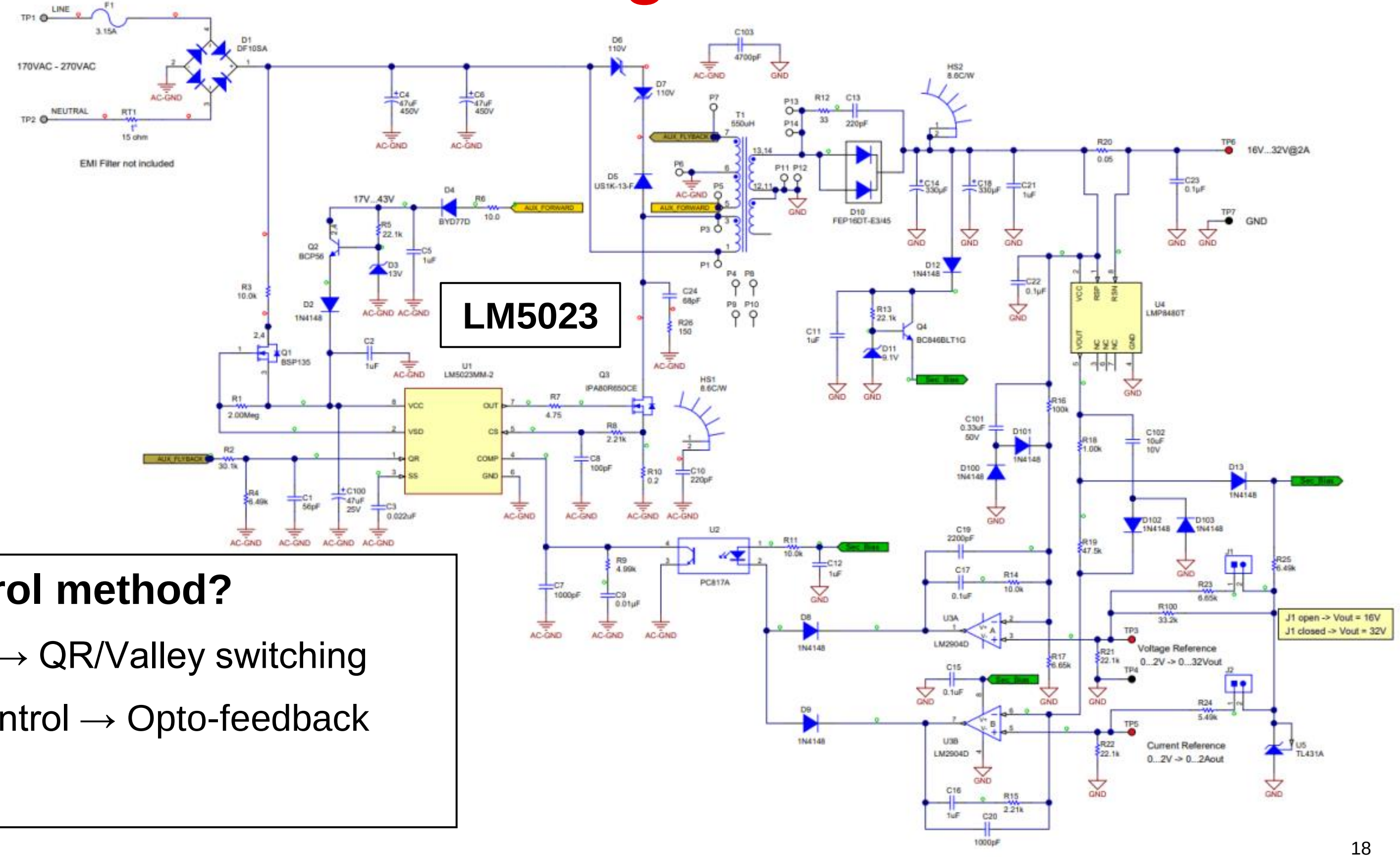
Design Specifications

- Selectable output voltage 16V or 32V @ 2A for single or dual lead acid battery load
- 170VAC to 270VAC Input
- Efficiency > 85% at 64W output power
- Dimensions 60mm x 60mm
- Cost #1, Efficiency #2

Design Considerations

- Topology/control method
- Voltage and current control
- Providing bias power

230VAC, 64W Lead Acid Charger

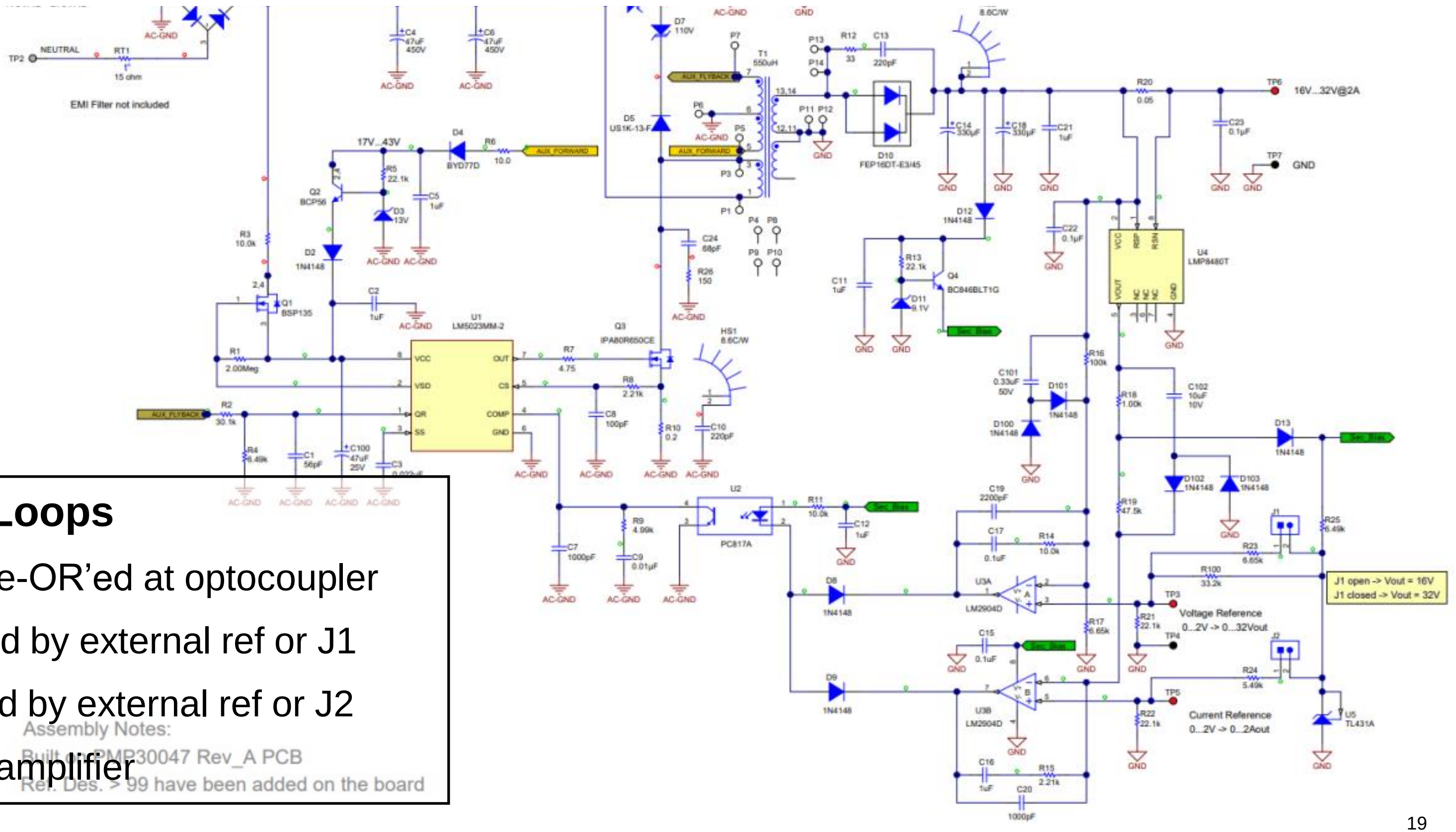


What type of control method?

85% Efficiency target → QR/Valley switching

Complex V/I output control → Opto-feedback

Voltage/Current Control

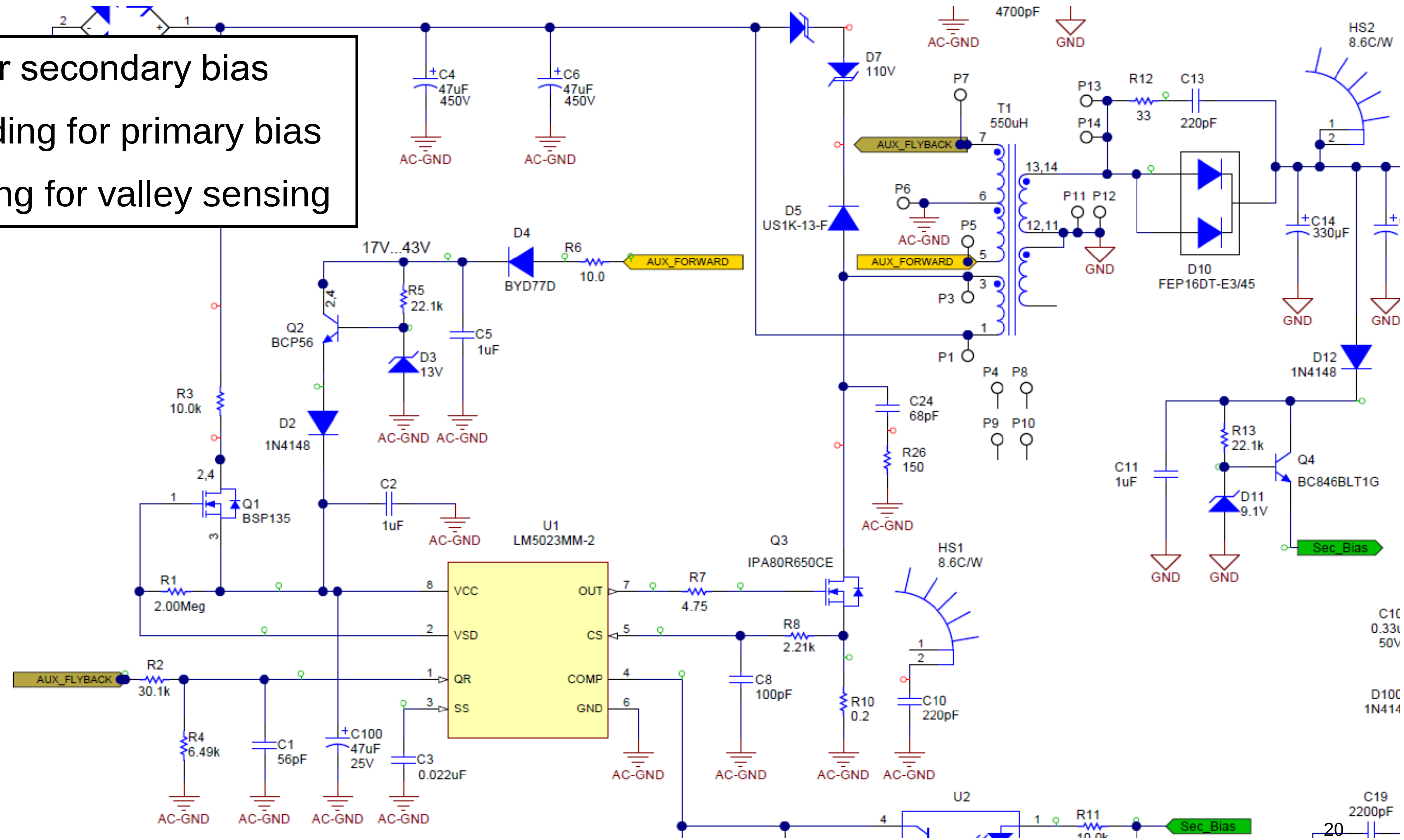


Two Feedback Loops

- E/A outputs diode-OR'ed at optocoupler
- Voltage controlled by external ref or J1
- Current controlled by external ref or J2
- Current sensing amplifier

Biasing Primary and Secondary

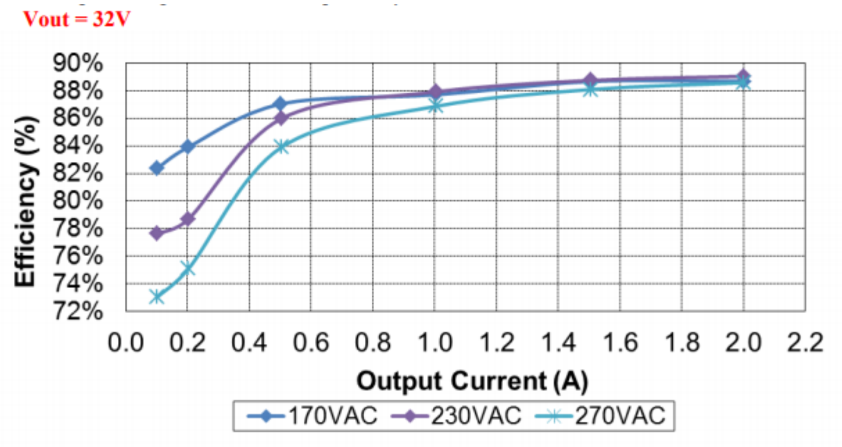
- “Poor Man’s Linear” for secondary bias
- AUX_FORWARD winding for primary bias
- AUX_FLYBACK winding for valley sensing

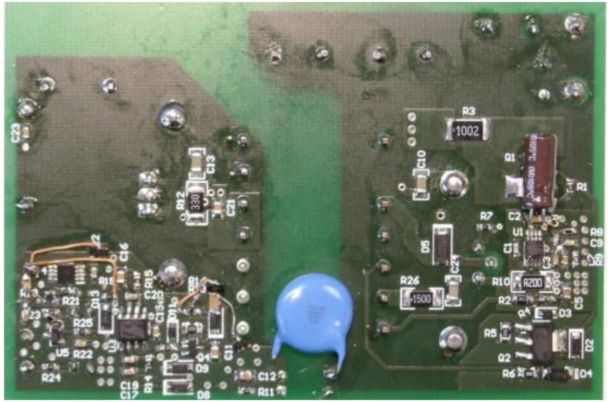


64W Supply from 170VAC to 270VAC input

Results

- 89% peak efficiency
- Small form factor (60mm x 60mm)
- Won due to low cost/good efficiency
- Available online
  - http://www.ti.com/tool/PMP30047





USB Type-C/PD design
EE: PD Adapters (Industrial power delivery) PMP11451 (power conversion) + PMP11455 (small plug-in daughter board for USB interface)

85-265VAC USB-C/PD 60W Design

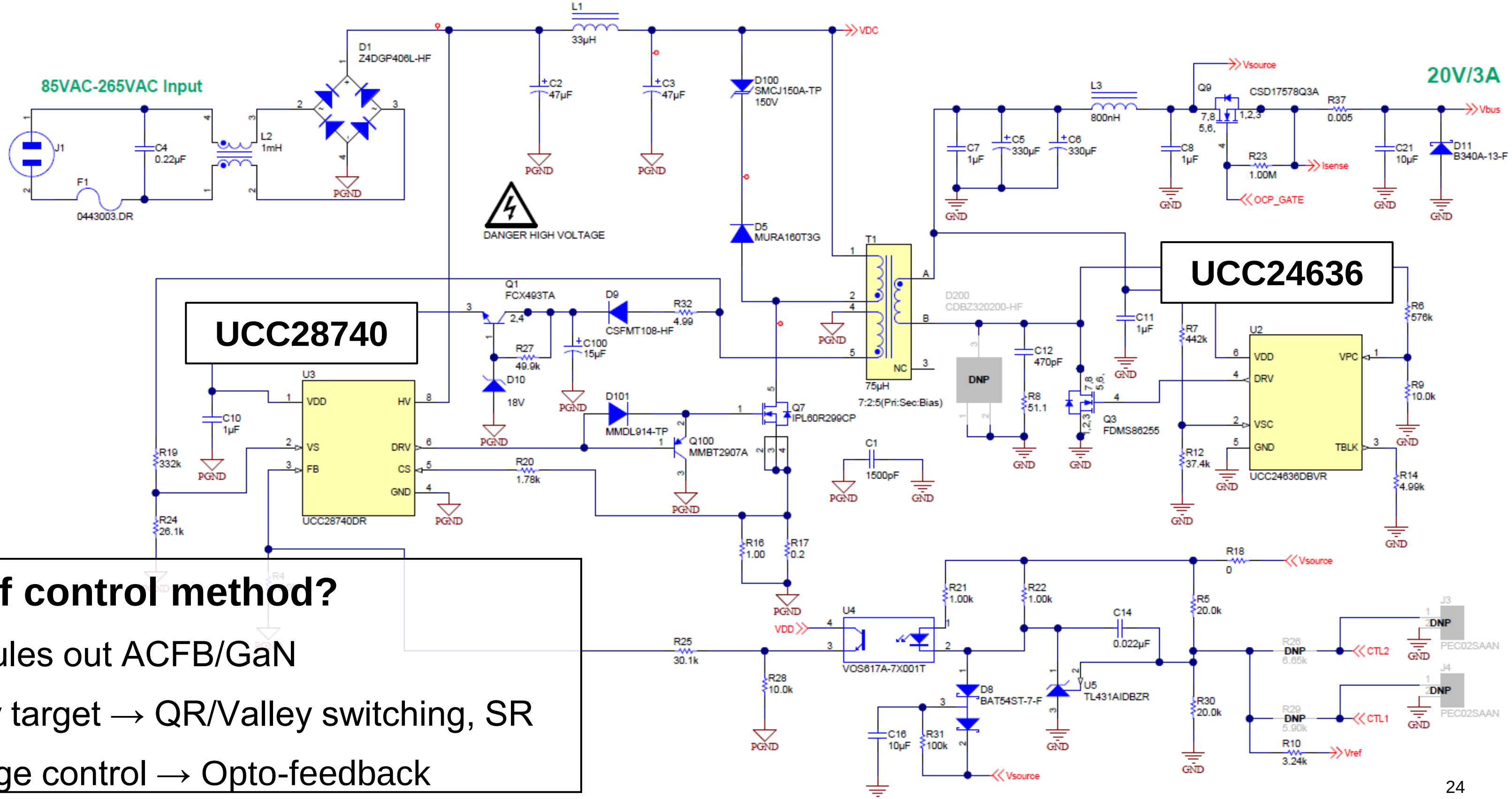
Design Specifications

- 60W load capability; selectable output voltage 20V @ 3A, 12V @ 3A, or 5V @ 3A
- 85VAC to 265VAC input range
- >91% at max load
- Less than 50mW standby power consumption
- Cost #1, Efficiency/Size #2

Design Considerations

- Controller selection
- Providing bias power
- USB-C control
- What's next?

85-265VAC USB-C/PD 60W Design



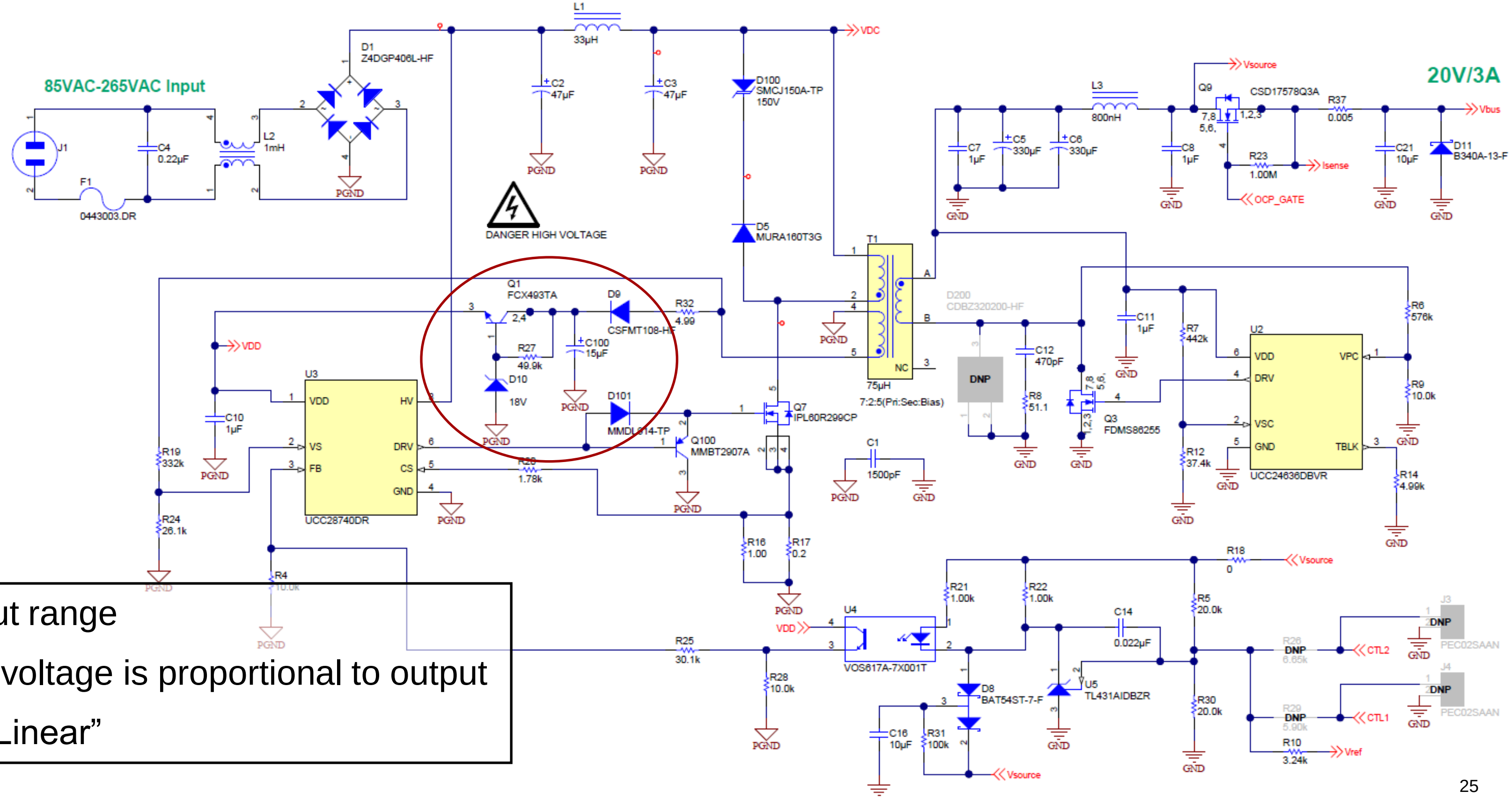
What type of control method?

Low cost → Rules out ACFB/GaN

91% Efficiency target → QR/Valley switching, SR

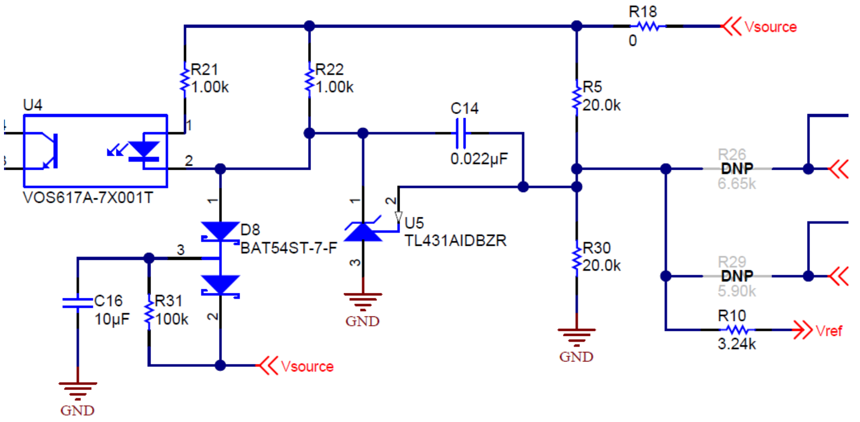
Complex voltage control → Opto-feedback

85-265VAC USB-C/PD 60W Design

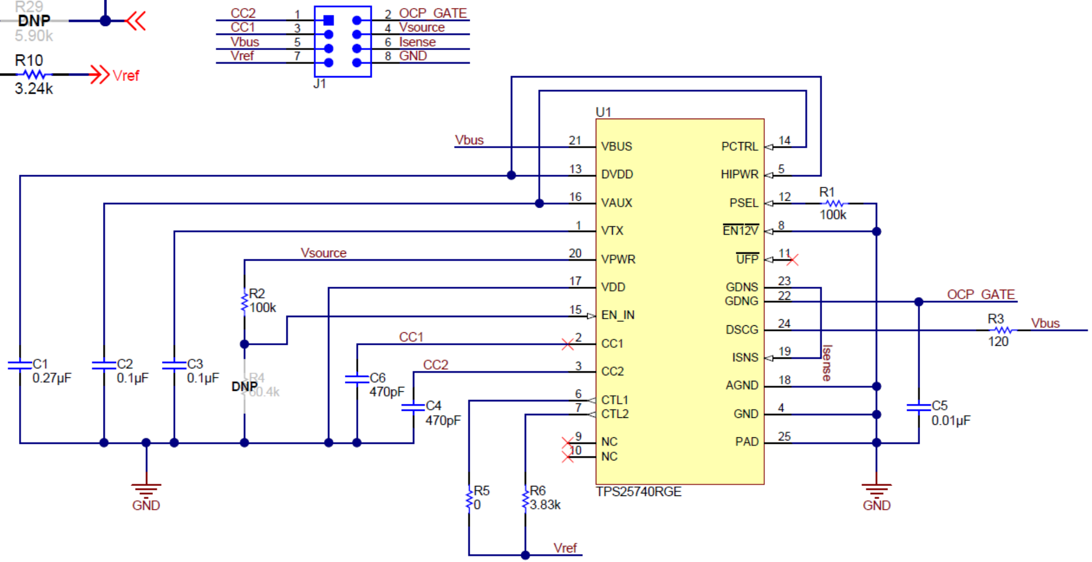


- 5V-20V output range
- Bias winding voltage is proportional to output
- “Poor Man’s Linear”

85-265VAC USB-C/PD 60W Design



Output	CTL1	CTL2
5V	HI Z	HI Z
12V	LOW	HI Z
20V	HI Z	LOW



- PD Controlled by PMP11455
  - TPS25740 daughter card
- CTL1/CTL2 open drain signals
  - Switch resistors into feedback divider

85-265VAC USB-C/PD 60W Design

PMP11451 + PMP11455

35mW Standby

5V Output

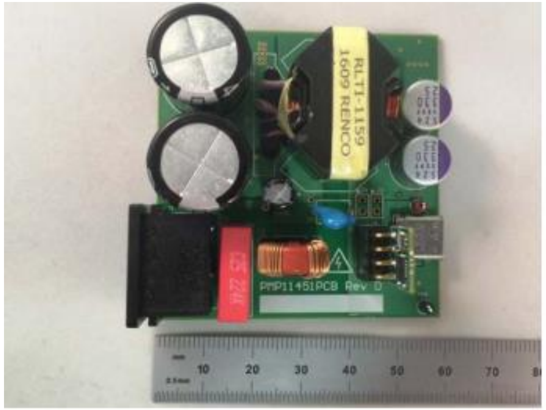
Vin	Pin	Vout	Iout	Load	Efficiency	Avg. Eff.
120VAC/60Hz	1.83	5.00	0.299	10%	81.67%	
	4.29	4.99	0.750	25%	87.14%	**88.22%**
	8.41	4.97	1.500	50%	88.67%	
	12.60	4.96	2.250	75%	88.58%	
	16.77	4.95	2.999	100%	88.47%	
230VAC/50Hz	2.04	5.00	0.299	10%	73.28%	
	4.59	4.99	0.750	25%	81.49%	**85.26%**
	8.69	4.97	1.500	50%	85.88%	
	12.86	4.96	2.250	75%	86.78%	
	17.08	4.95	3.000	100%	86.89%	

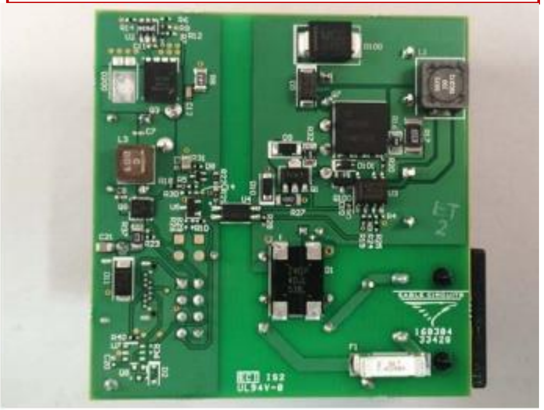
12V Output

Vin	Pin	Vout	Iout	Load	Efficiency	Avg. Eff.
120VAC/60Hz	4.26	11.98	0.301	10%	84.67%	
	9.98	11.97	0.749	25%	89.88%	**90.73%**
	19.71	11.95	1.501	50%	91.01%	
	29.49	11.94	2.249	75%	91.06%	
	39.32	11.92	3.001	100%	90.98%	
230VAC/50Hz	4.52	11.98	0.301	10%	79.73%	
	10.22	11.97	0.751	25%	87.98%	**90.10%**
	19.80	11.95	1.498	50%	90.42%	
	29.52	11.94	2.250	75%	91.01%	
	39.32	11.92	3.002	100%	91.01%	

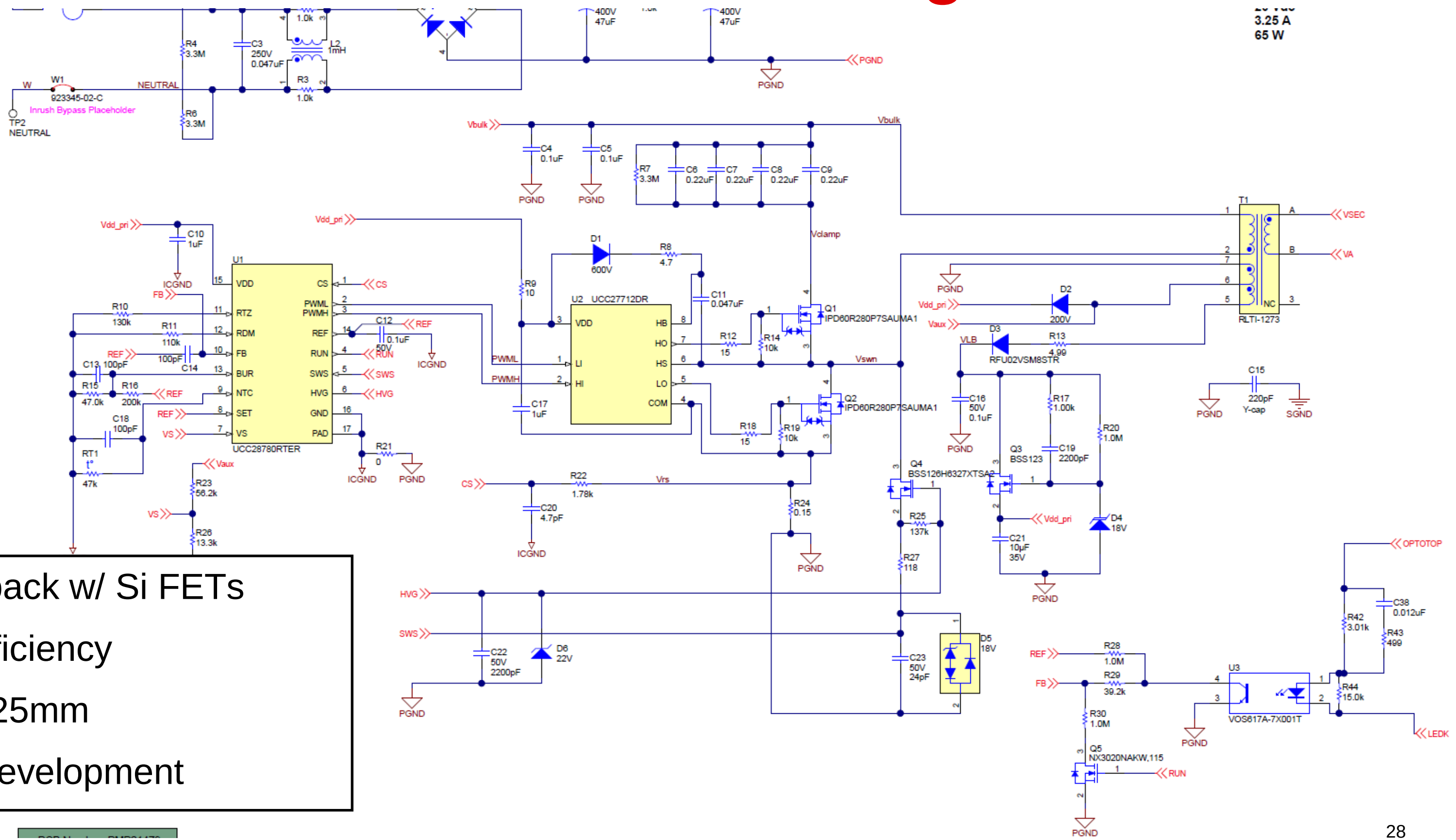
20V Output

Vin	Pin	Vout	Iout	Load	Efficiency	Avg. Eff.
120VAC/60Hz	7.07	20.08	0.300	10%	85.22%	
	16.69	20.07	0.749	25%	90.07%	**91.04%**
	33.01	20.06	1.502	50%	91.28%	
	49.35	20.04	2.251	75%	91.41%	
	65.67	20.02	2.999	100%	91.43%	
230VAC/50Hz	7.30	20.08	0.298	10%	81.97%	
	16.85	20.07	0.750	25%	89.32%	**91.02%**
	32.92	20.06	1.499	50%	91.34%	
	49.23	20.04	2.251	75%	91.63%	
	65.42	20.02	2.999	100%	91.78%	





Next Generation USB-C/PD 65W Design



- Active Clamp Flyback w/ Si FETs
- Targeting 93% Efficiency
- 50mm x 50mm x 25mm
- PMP21479 – In Development

High Voltage Application EE: LED Lighting PMP5509; PMP5112; PMP5242; PMP6023; PMP11155; PMP20612

Common Lighting Power Specifications

- Power Level: from 15W to 1000W.
- Input Range: 120VAC to 277VAC (+/-10%)
- **Power Factor and THD:**
  - **P.F. > 0.9 and THD <20% on power supply with >25W rated power.**

Table 1: Equipment classification

Class A	• Balanced three-phase equipment • Household appliances, excluding equipment identified by Class D • Tools excluding portable tools • Dimmers for incandescent lamps Audio equipment Everything else that is not classified as B, C or D
Class B	• Portable tools • Arc welding equipment which is not professional equipment
Class C	• Lighting equipment over 25 W including dimming devices
Class D	• Equipment having an active power of less than or equal to 600W and is either a PC or PC monitor, or a television.

Table 2: Harmonic limits for class C equipment

Harmonic order (n)	Maximum value expressed as a percentage of the fundamental input current of luminaires
3	30*λ
5	10
7	7
9	5
11< n <39	3

IEC61000-3-2

Common Lighting Power Specifications

- Power Level: from 15W to 1000W.
- Input Range: 120VAC to 277VAC (+/-10%)
- Power Factor and THD: P.F. > 0.9 and THD <20% on power supply with >10W rated power.
- **Dimming: Flicker-free. 0.1%-100% or 10%-100%.**
  - Flicker-free => <u>output ripple needs to be low during dimming</u>.

<u>For use with 120V or 277V</u>

DIML2	0-10V dim, 10% (provided standard)
DIML3	Lutron Hi-Lume 1% 2-wire, 120V only
DIML4	Lutron Hi-Lume 1% 3-wire/ECO
DIML6A	EldoLED 0-10V, 0.1%, logarithmic / Lutron controls
DIML6B	EldoLED 0-10V 0.1%, linear controls
DIML6E	EldoLED 0-10V, 1%, logarithmic/Lutron controls
DIML6F	EldoLED 0-10V, 1%, linear controls
DIML7	EldoLED DALI, 0.1%
DIML8	EldoLED DMX, 0.1% [3]

<u>Common Dimmers</u>

Common Lighting Power Specifications

- Power Level: from 15W to 1000W.
- Input Range: 120VAC to 277VAC (+/-10%)
- Power Factor and THD:
  - P.F. > 0.9 and THD <20% on power supply with >10W rated power.
- Dimming: Flicker-free. 0.1%-100% or 10%-100%.
- **Standby Power Consumptions: <0.5W (current), <0.2W (2019).**
- **Isolation: Mechanical or Electrical.**

7. State-regulated LED lamps that have an ANSI standard lamp shape of B, BA, C, CA, F, or G shall meet the decorative light distribution requirements of ENERGY STAR's Product Specification for Lamps Version 1.1 (August 2014).

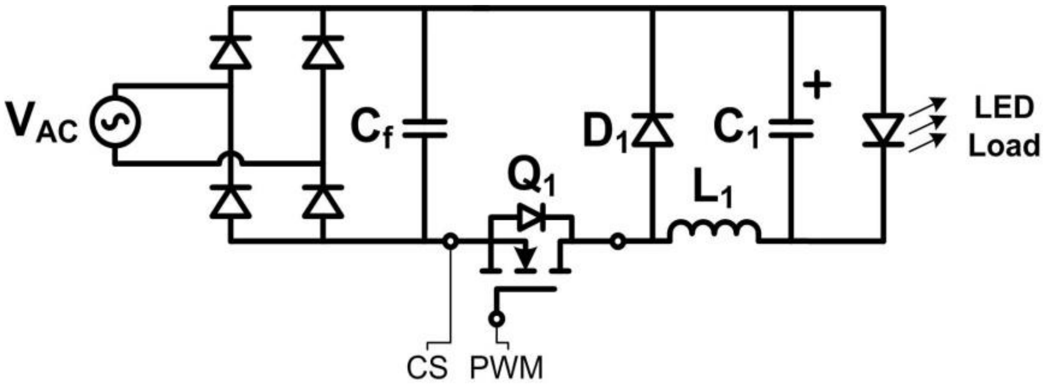
(D) In addition to the requirements in section 1605.3(k)(2)(C), state-regulated LED lamps manufactured on or after July 1, 2019 shall have a standby mode power of 0.2 watts or less.

CEC requirements.

Topology choice with mechanical isolation

Choice #1:

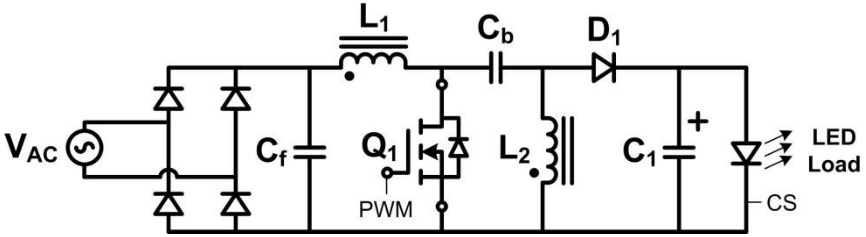
- **PFC Buck. Reference design example: PMP5509.**
  - **Minimum input Cap to achieve high power factor.**
  - **Large 2 x F_{AC} ripple at output.**
  - **Device to be used:**
    - **Regular PWM controller:**
      - **TPS92001/2, UCC3809…**



Topology choice with mechanical isolation

Choice #2:

- **PFC SEPIC.** Reference design examples: PMP5112, PMP5242.
  - Same minimum input Cap and large 2 x F_{AC} output ripple.
  - Common input/output GND.
    - Lower common mode noise.
  - Device to be used:
    - PFC controller:
      - UCC28810/1, UCC28056, Flintstone…
  - Better power factor than PFC Buck with regular PWM controller.



Topology choice with electrical isolation

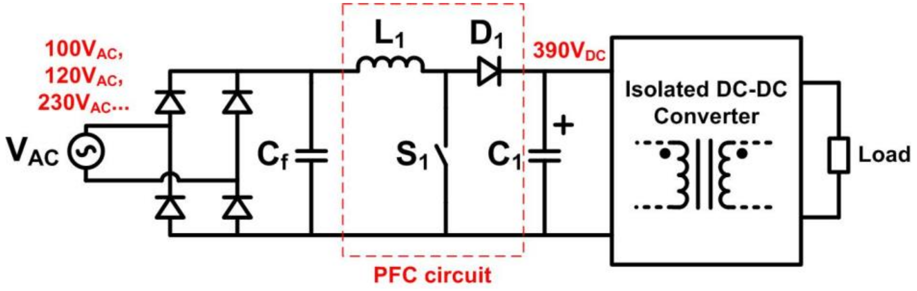
Low power (<100W) choice:

- **PFC Flyback. Reference design examples: PMP6023, PMP11155.**
  - **Good for <100W LED driver.**
  - **Same minimum input Cap and large 2 x F_{AC} output ripple.**
  - **Safety isolated.**
  - **Device to be used:**
    - **PFC controller:**
      - **TPS92210, UCC28810/1, Flintstone…**
  - **Better power factor than PFC Buck with regular PWM controller.**

Topology choice with electrical isolation

High power (>100W) choices:

- **Boost PFC + Isolated DC/DC.**
  - **High bandwidth of isolated DC/DC converter allow small output ripple.**
  - **Isolated DC/DC selection varies according to output power.**
  - **Device to be used:**
    - **PFC controller:**
      - **(CRM PFC) TPS92210, UCC28810/1, UCC28064, Flintstone…**
      - **(CCM PFC) UCC28180, UCC28070.**
    - **DC/DC controller:**
      - **(Flyback) UCC28740, UCC28780…**
      - **(Resonant) UCC25630.**

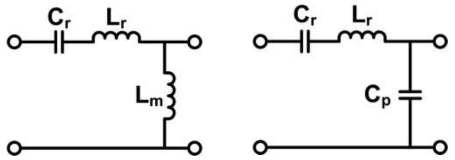


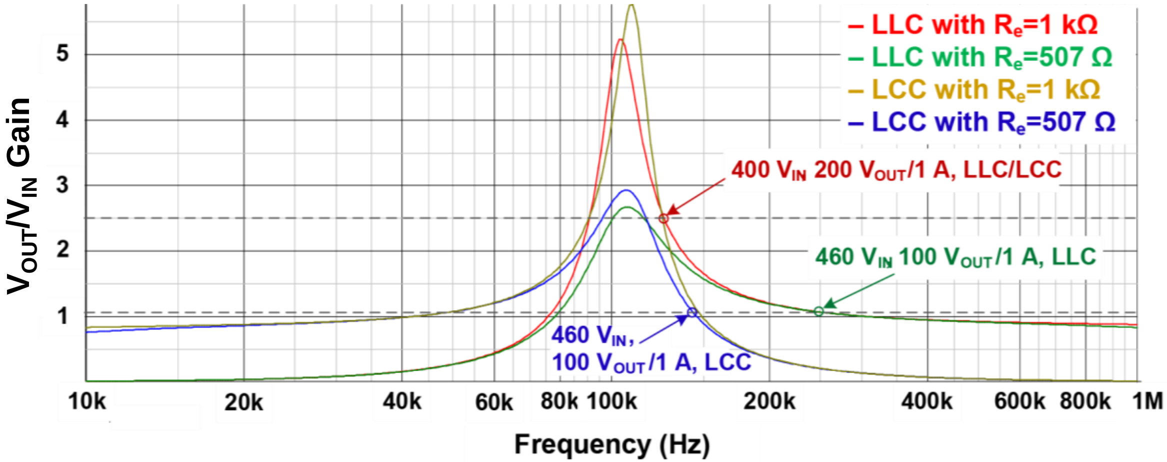
Resonant Converter Designs for Lighting

- LLC resonant tank parameters: L_r=40 µH, L_m=300 µH, C_r=7 nF
- LCC resonant tank parameters: L_r=300 µH, C_r=0.047 µF, C_p=8.2 nF

Target spec:

- V_{IN} range: 400-460 V
- V_{OUT} range: 100-200 V
- I_{OUT}: 1 A, P_{OUT} = 200 W

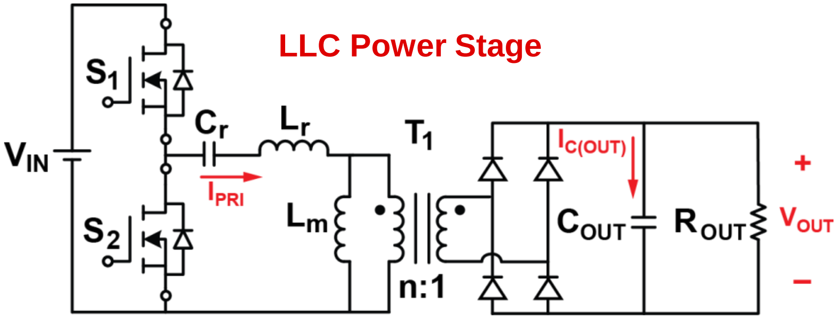


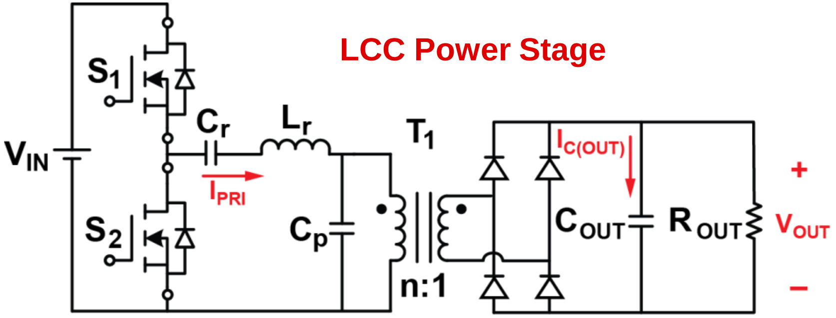


Simulation Results (LLC & LCC for Lighting)

V_{IN} (V)	V_{OUT} (V)	I_{OUT} (A)	LLC I_{PRI} (A_{RMS})	LCC I_{PRI} (A_{RMS})	LLC f_{SW} (kHz)	LCC f_{SW} (kHz)	LLC $I_{C(OUT)}$ (A_{RMS})	LCC $I_{C(OUT)}$ (A_{RMS})
400	200	1	1.73	2.69	131	122	1.37	1.97
460	200	1	1.69	2.76	138	125	1.32	1.98
400	100	1	0.775	1.65	196	130	0.904	1.66
460	100	1	0.709	1.7	245	135	0.722	1.67

$\Delta F_{LLC} > \Delta F_{LCC}$





LLC has lower RMS current than LCC

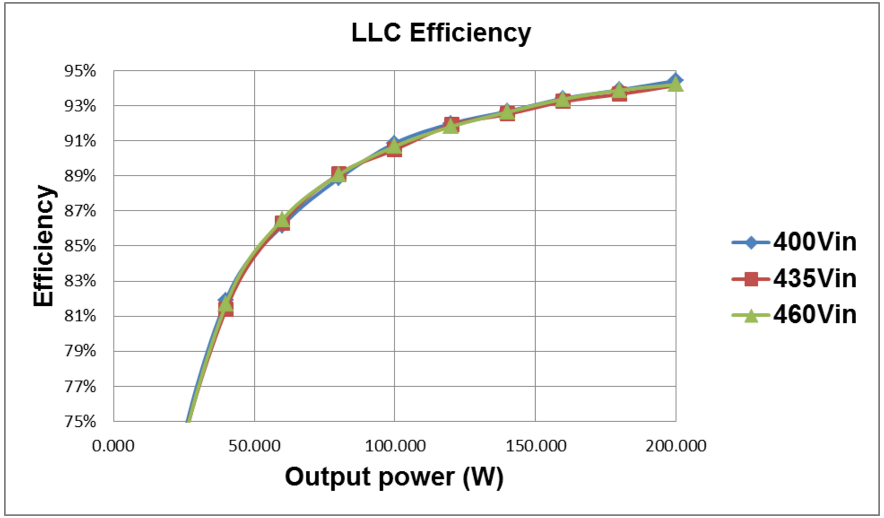
– Implies better efficiency on LLC

LCC has narrower frequency variation

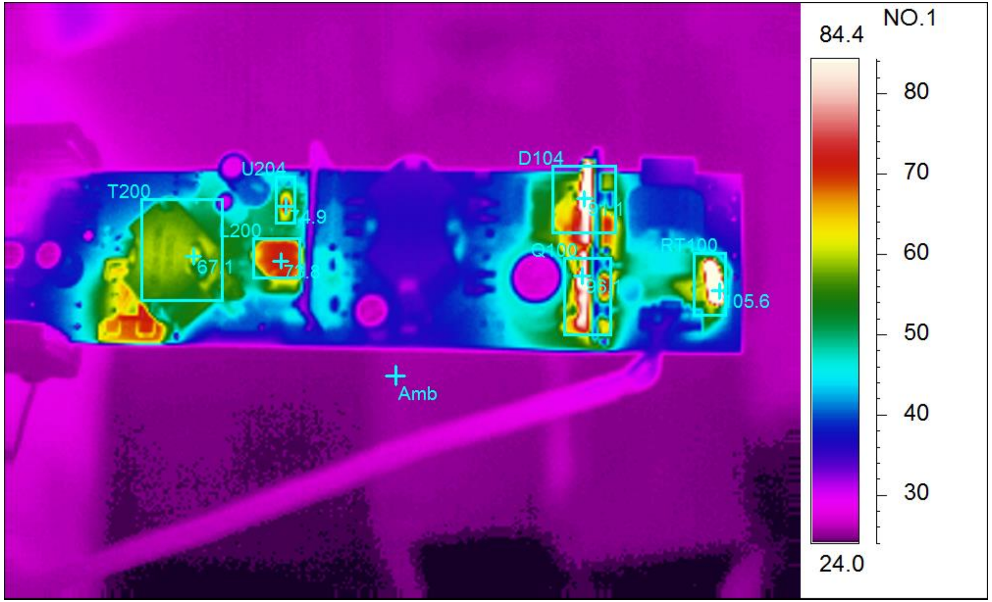
– May not need bursting at light load

Expermental Results (LLC & LCC for Lighting)

200W Lighting LLC Design: L_r=40 µH, L_m=300 µH, C_r=8.2 nF



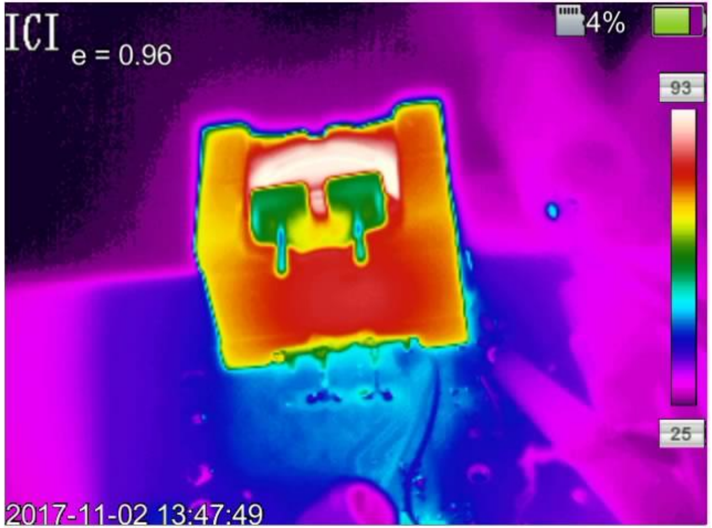
At 200V_{out}

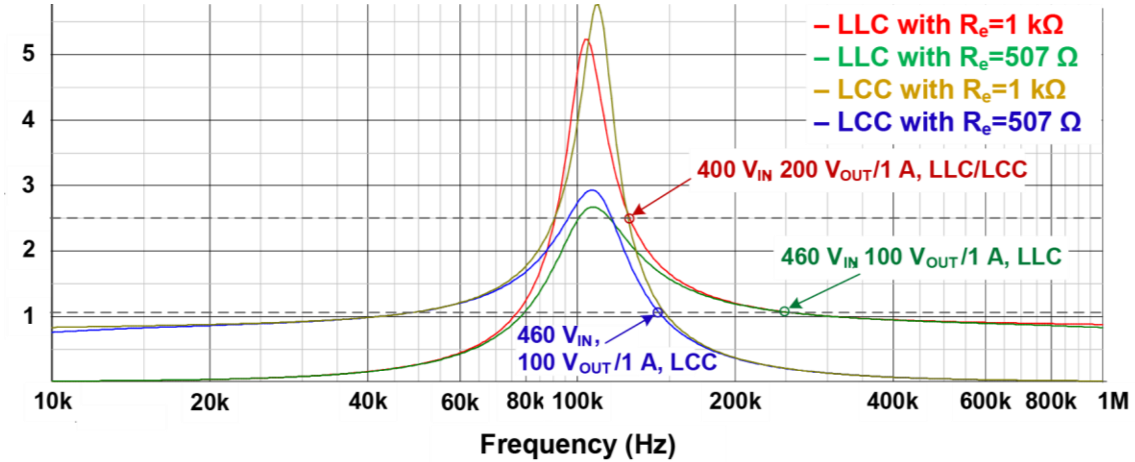


Experimental Results (LLC & LCC for Lighting)

200W Lighting LCC Design 1st attempt: L_r=300 µH, C_r=0.044 µF, C_p=8.2 nF

- **At 30% load, resonant inductor temperature rise >70degC with 81% efficiency. (5% less than LLC under the same condition.)**

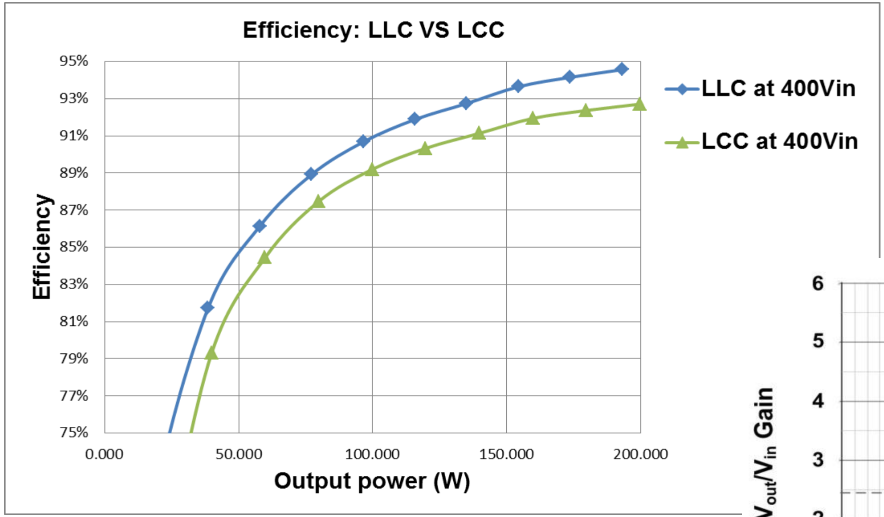


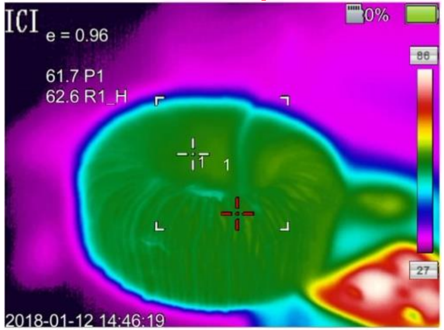


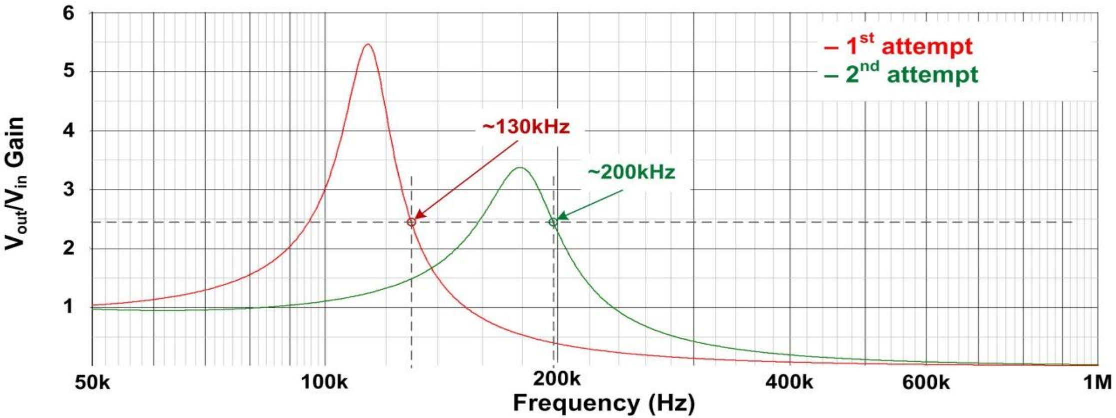
Expermental Results (LLC & LCC for Lighting)

200W Lighting LCC Design 2nd attempt: L_r=280 µH, C_r=0.044 µF, C_p=3.7 nF

- **Efficiency about 2% lower than LLC (as expected.)**



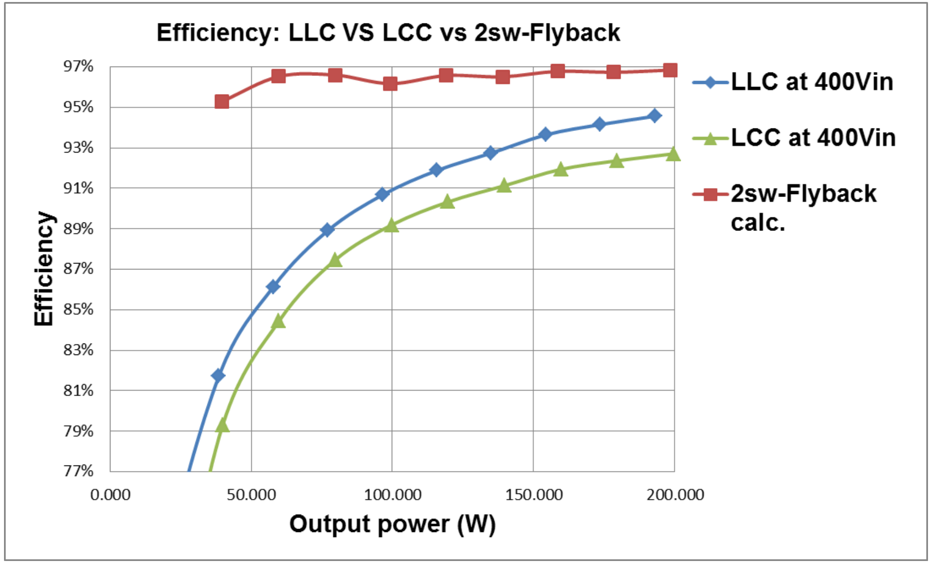




Expermental Results (LLC & LCC & 2-Sw Flyback)

The same 200W Lighting power supply designed with 3 different topologies

- **Efficiency: 2-Switch Flyback > LLC > LCC**
- **Power stage area: 2-Switch Flyback < LLC < LCC**



2-Switch Flyback : PMP20612 (On-line)
LLC : PMP20947 (Done, upload pending)
LCC : PMP20946 (In development)

Summary

- Lighting power supply concerns THD, dimming, and power saving performance.
- PFC Buck and SEPIC are common choices for non-isolated lighting power supply.
- PFC Flyback for low power isolated lighting power supply.
- PFC + DC/DC for high power isolated lighting power supply.
  - Flyback derived topolgies (ex: 2sw-Flyback) for <200W DC-DC.
  - LLC for 200W~400W DC-DC.
  - LCC for >400W DC-DC.

  http://www.ti.com/tool/PMP20612

References

Stacked FETs blogs:

- https://e2e.ti.com/blogs_/b/powerhouse/archive/2015/10/07/power-tips-power-converter-topology-component-high-input-voltage-applications

- https://e2e.ti.com/blogs_/b/powerhouse/archive/2015/11/03/design-considerations-of-high-voltage-converters-in-a-cascode-mosfet

PMP Designs Covered:

- http://www.ti.com/tool/PMP20676 - 24Vin to 48W Isolated DC-DC
- http://www.ti.com/tool/PMP40347 - 3 Phase 110-420VAC input to 12W Multiple Isolated output design
- http://www.ti.com/tool/PMP30047 - 170-270VAC input 64W Battery Charger
- http://www.ti.com/tool/PMP11451 - 85-265VAC input 60W USBSupply
- http://www.ti.com/tool/PMP20612 - 108-305VAC input 200W LED Supply
- PMP21479 - Active Clamp Flyback to be released online soon.

Questions?