High VOLT Interactive

Where power supply design meets collaboration

Multiple Output Flybacks: How to Improve Cross Regulation

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What will I get out of this session?

- Purpose:

1. Causes of poor cross regulation in multi-output Flybacks

2. Design techniques for improving cross regulation

- Part numbers mentioned

1. TL431, UCC28630, LM5023, UCC24630/6

- Reference designs mentioned:

1. PMP20001, PMP4444

- Relevant end equipment (<150W):

1. Bias or auxiliary embedded supplies
2. Appliances
3. HEV/EV

Agenda

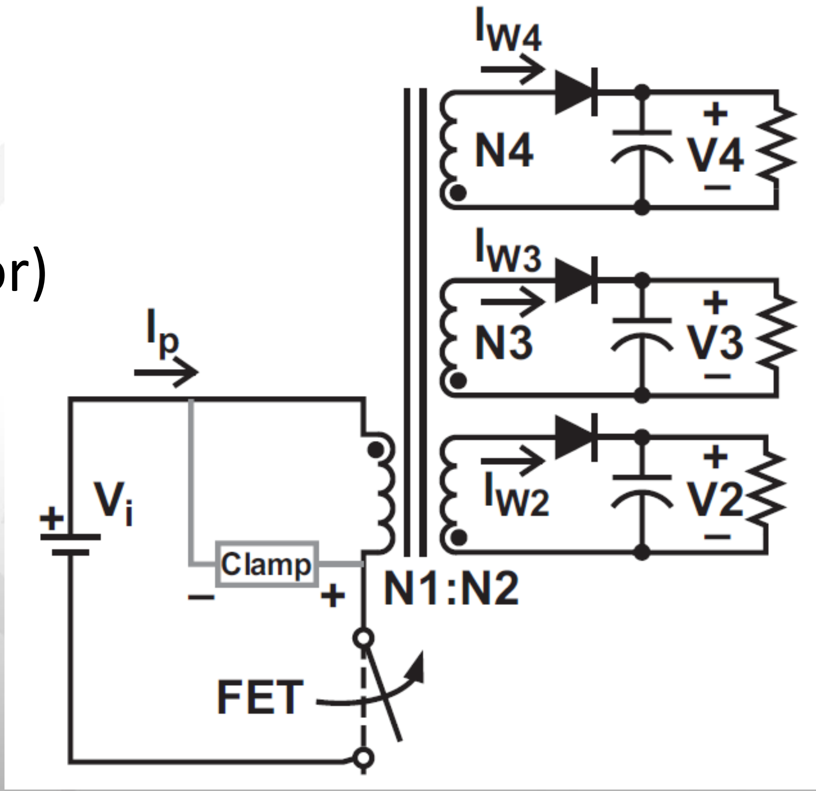
- Review multiple output flyback converter
- Causes of poor cross regulation
- Techniques to improve cross regulation
  1. Transformer design recommendations
  2. Preload the outputs
  3. Zener clamps
  4. LDO series pass regulators
  5. Stacking output windings to improve cross regulation
  6. Multiple feedback TL431/opto Isolation
  7. Use of SR's (synchronous rectifiers)

Reference Material

- “Under the Hood of Flyback SMPS Designs”
  - ✓ https://www.ti.com/seclit/ml/slup261/slup261.pdf
    Jean Picard
- “The Effects of Leakage inductance on Multi-Output Flyback Circuits”
  - ✓ http://www.ti.com/lit/ml/slup081/slup081.pdf
    Lloyd Dixon
- Effects of Leakage Inductance on Cross Regulation, EDN, Power Tips #78: “Synchronous rectifiers improve cross-regulation in flyback power supplies”
  - ✓ http://www.edn.com/electronics-blogs/power-tips-ti/4458559/Power-Tips--78--Synchronous-rectifiers-improve-cross-regulation-in-flyback-power-supplies
    Brian King

Multiple output Flyback converter

- Economical, fewer components
  - ✓ One transformer (coupled inductor)
  - ✓ Multiple windings
  - ✓ One switch
  - ✓ No output filter inductors
- Cross-regulation can be challenging



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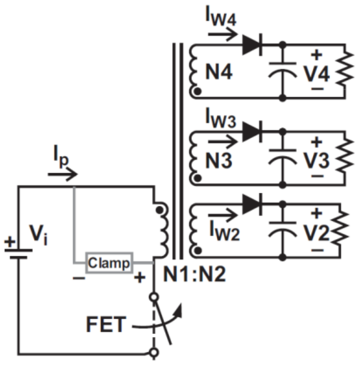
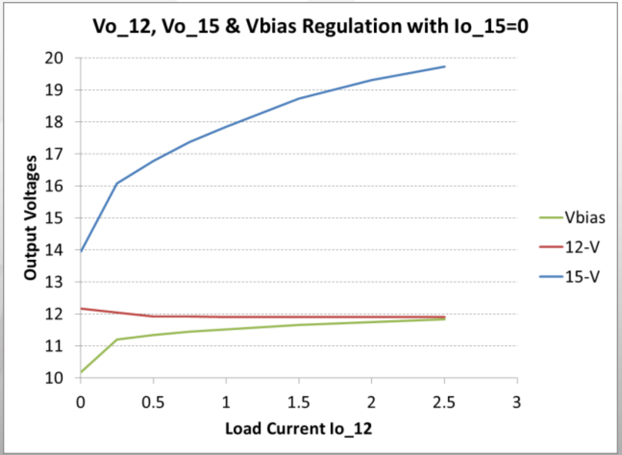
What is cross regulation?

- How well do outputs (V2, V3, V4) regulate with varying loads?
- Worst case
  - One or more outputs at minimum or zero load
  - Another output at heavy or maximum load
- Example of three-output design, 15-V, 12-V and separate Vbias (also 12 V)
- No-load on 15-V rail, fixed load on Vbias
  - As 12-V load increases, 15-V -> 20 V!
  - As 12-V load -> zero, Vbias drops





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Question #1: Which techniques have you used to improve cross regulation?

A. Transformer Winding Techniques to Reduce Leakage Inductance

B. Pre-Load Outputs

C. Zener Clamps

D. LDO and Series Pass Regulator

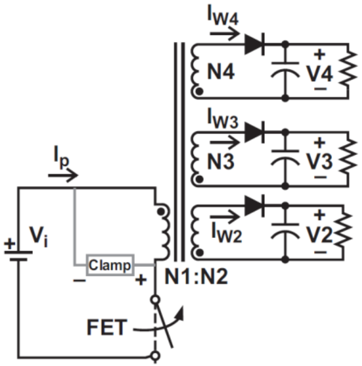
E. AC-Stacking Output Windings

F. DC-Stacking Output Windings

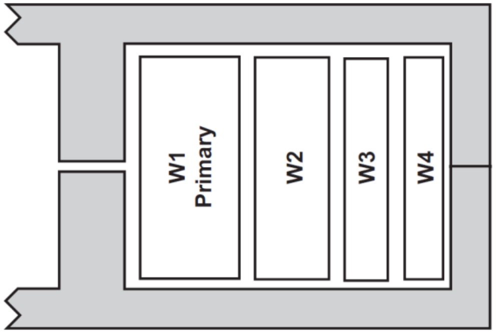
G. Weighted Feedback TL431/Opto

Cross regulation causes

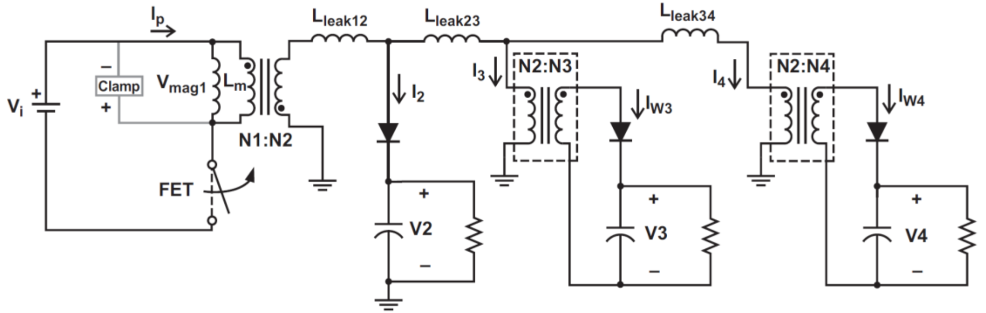
- Non-ideal transformer – leakage inductance to primary and from secondary-to-secondary
- Circuit impendences & voltage drop mismatch
- Variation in rectifier diode V_F
- Equivalent circuit – normalised turns ratios with ideal transformer
- Equal voltage imposed, lightly loaded output has less drop across leakage, resistance, diode => higher cap voltage



Basic Flyback circuit



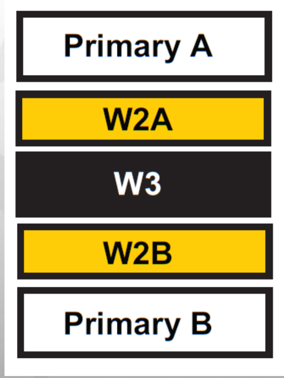
Possible Transformer Construction



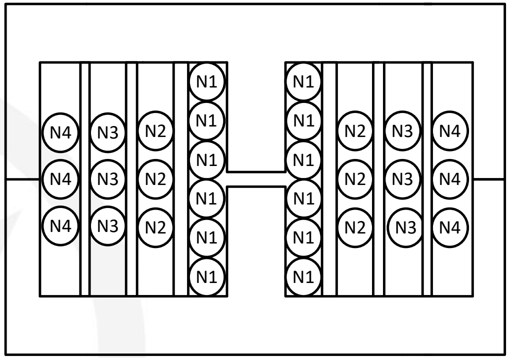
Transformer Equivalent Circuit Model

Transformer winding recommendations

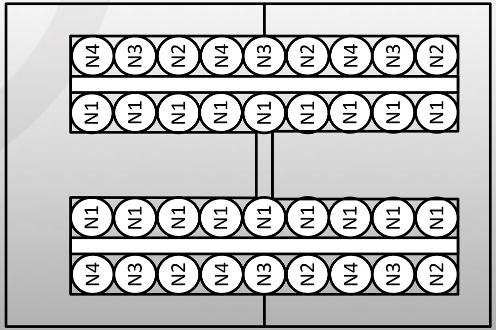
- Minimise leakage inductance – primary-to-secondary, and secondary-to-secondary
  - High leakage inductance causes lightly-loaded outputs to “pump up”
- Interleave primary (or winding with highest number turns)
  - Reduces leakage inductance by half
- Wind full layers for best layer-layer coupling
  - Fill layer with multi-strands
- Wind secondaries bifilar or multifilar same layer
- Sandwich (shield) low power secondary windings between layers of high power secondaries



Stacked



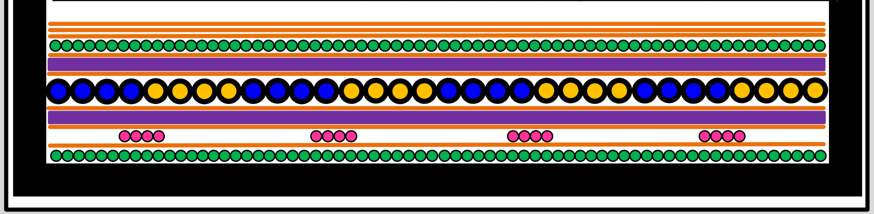
Multi-filar



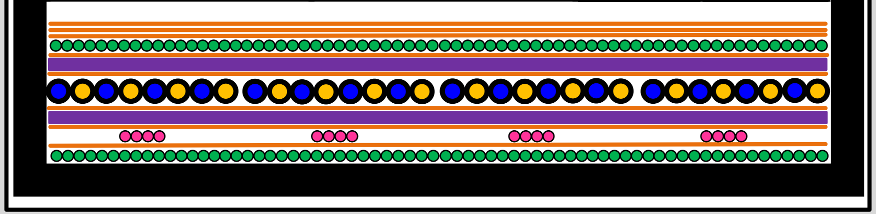
Cross-regulation effect of secondary winding structure

- Customer request for dual 12-V outputs (isolated GNDs) @ 90 W using ER35
- Require +/-5% cross-regulation (11.4 – 12.6 V) with min loading
- Passes with 12VB @ 0.25 A min – RHS winding achieves ~40 nH leakage inductance sec-sec

I SPEC		Measure data		Nom	12.00
12VA	12VB	12VA	12VB	12VA	12VB
4.0A	0.15A	11.53V	13.13V	-3.92%	9.42%
0.5A	3.5A	12.24V	11.22V	2.00%	-6.50%
4.0A	3.5A	11.81V	11.80V	-1.58%	-1.67%
0.5A	0.15A	11.63V	11.88V	-3.08%	-1.00%



I SPEC		Measure data		Nom	12.00
12VA	12VB	12VA	12VB	12VA	12VB
4.0A	0.15A	11.55V	12.85V	-3.75%	7.08%
0.5A	3.5A	12.17V	11.24V	1.42%	-6.33%
4.0A	3.5A	11.81V	11.78V	-1.58%	-1.83%
0.5A	0.15A	11.63V	11.84V	-3.08%	-1.33%

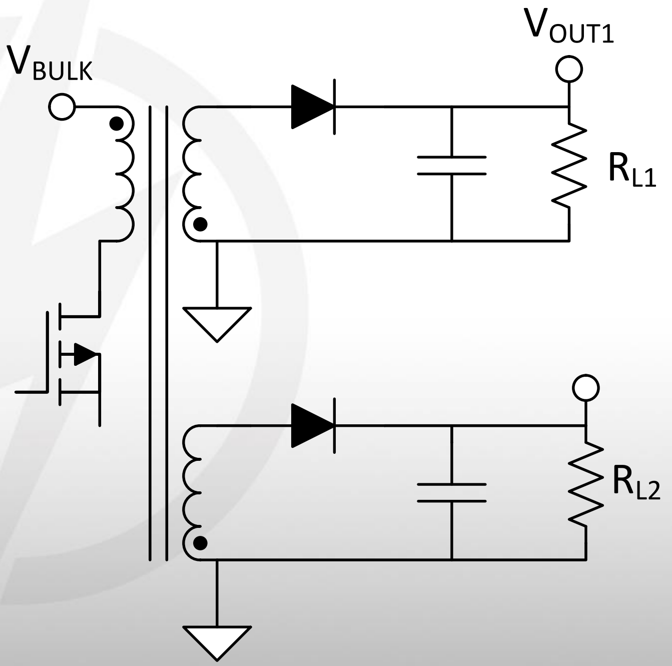


Add pre-load to outputs (R_{L1} and R_{L2})

- Improve no/light load regulation
  - Add preload resistors

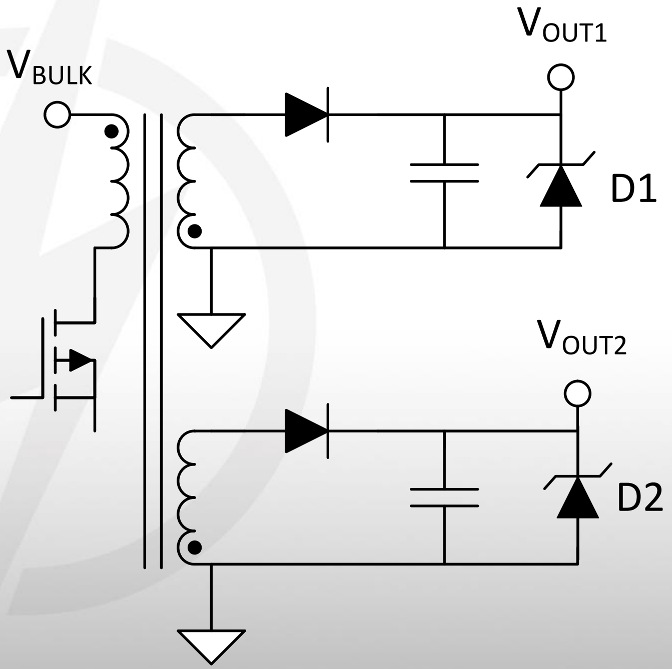
  ✓ This will help discharge transformer leakage energy and keep the output in regulation.

  ✓ Effectively adding some minimum output loading
- Disadvantage:
  - Increase standby power, reduces light-load efficiency
  - May require excessive pre-load for tight regulation



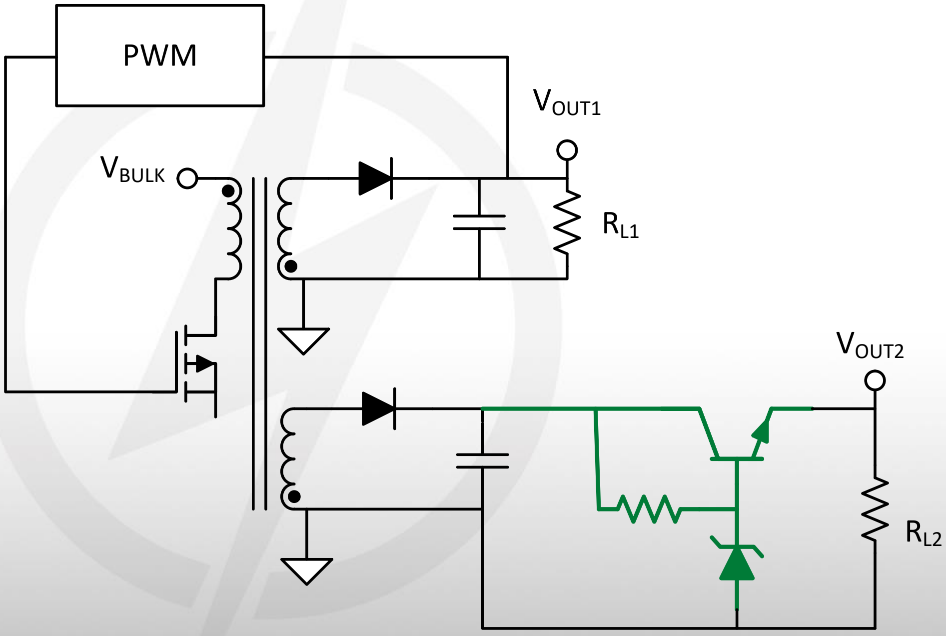
Zener clamps (D1 and D2)

- Can improve light-load cross regulation
  - ✓ Will only dissipate leakage energy
    - When secondary voltage is above Zener voltage
  - ✓ Improves overall system efficiency compared to pre-load resistors
- Disadvantage:
  - Will still impact standby power & light-load efficiency to some extent
  - Higher Zener voltage => less dissipation, but worse cross-regulation



LDO/series pass regulators

- Regulate main output with feedback
- Second/other output(s)
  - Use series pass regulator or secondary side regulator
- Disadvantages:
  - Need headroom for LDO dropout
  - LDO P_{diss} – impact on efficiency
- Higher power applications may require switching regulator (efficiency)



Question #2: What mix of multi-outputs do you usually require?

A. Shared common GND or isolated from each other

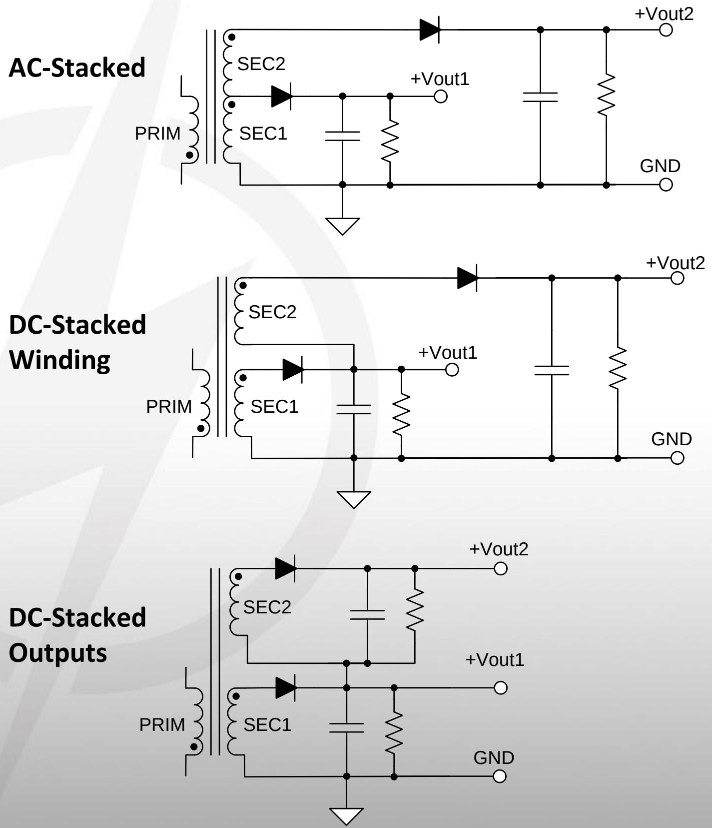
B. Bipolar outputs e.g. +/- 12V, +/- 15V, etc.

C. Paired low & high voltage outputs, e.g. +5V/+12V, +5V/+24V, +3V3/+15 V, etc.

D. Multiple similar-voltage rails

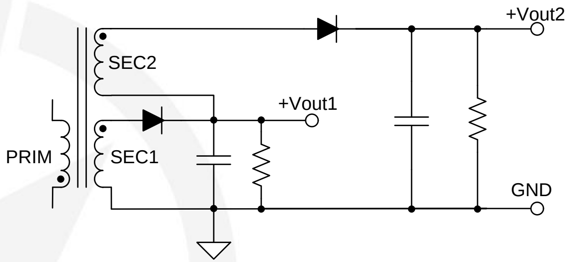
Stacked transformer windings

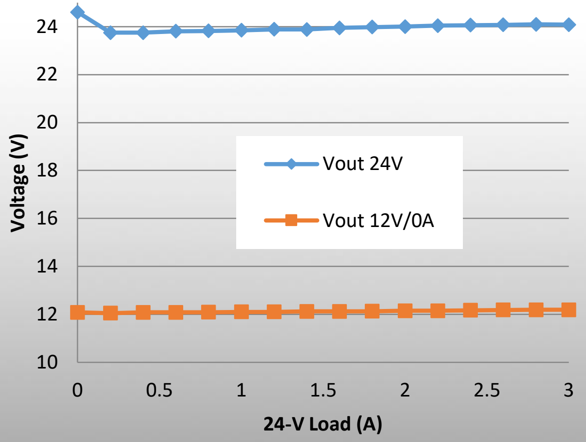
- Improves cross regulation for lower output
  - I_{out2} always flows through lower winding
  - Leakage energy of lower winding flows to V_{out2}
- AC-stacking very commonly used
- DC-stacking less common
  - Gives superior performance
  - Excellent regulation for lower V_{out1}
  - V_{out1} never at no load
- Requires common-GND & $V_{out2} > V_{out1}$

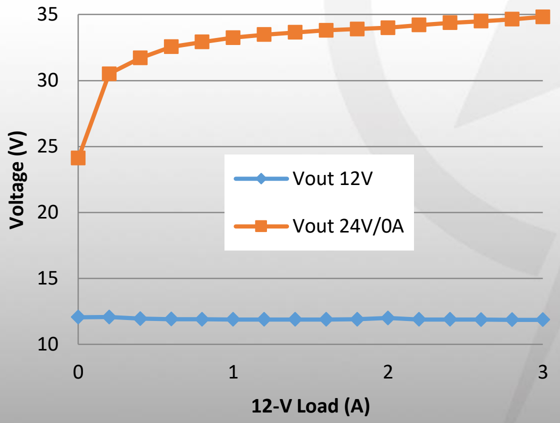


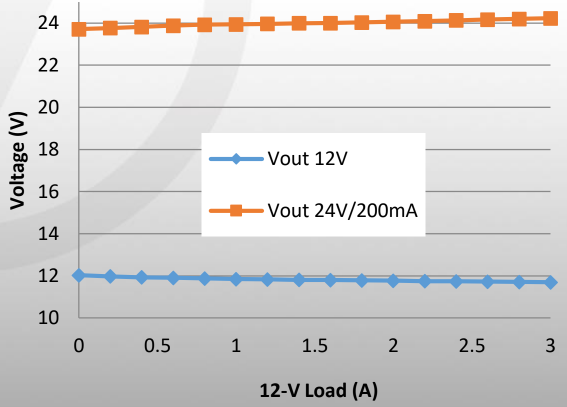
Cross regulation performance with DC-stacked outputs

- Design for V_{out2} = 24 V @ 1.3 A, V_{out1} = 12 V @ 3A
- Secondaries wound trifilar in 1 layer (2+1 strands)
- PSR (primary-side-regulated) UCC28630 – no opto



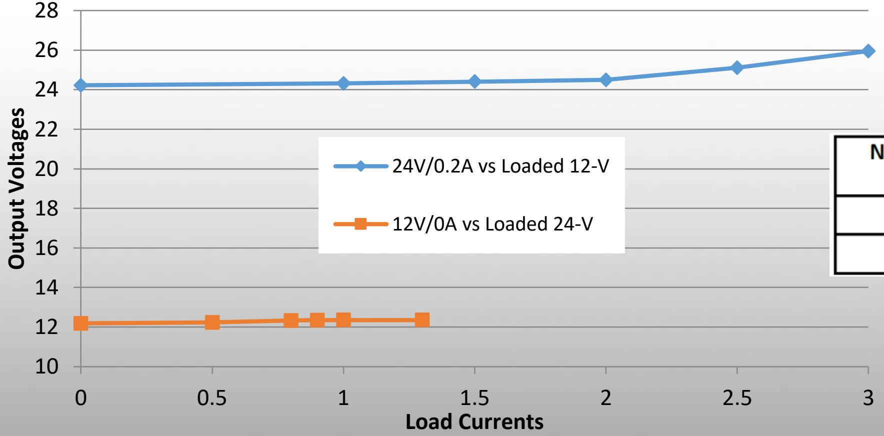




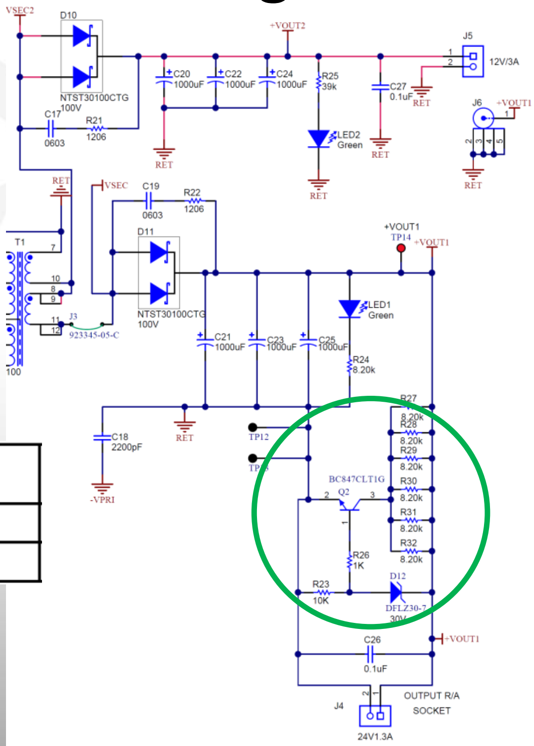


Reference design with AC-stacked transformer windings

- UCC28630-based PMP4444, http://www.ti.com/tool/PMP4444
- Employs zener/npn based active bleed on 24-V rail
  - Only pre-loads the 24-V rail when it gets too high
  - No impact on standby power

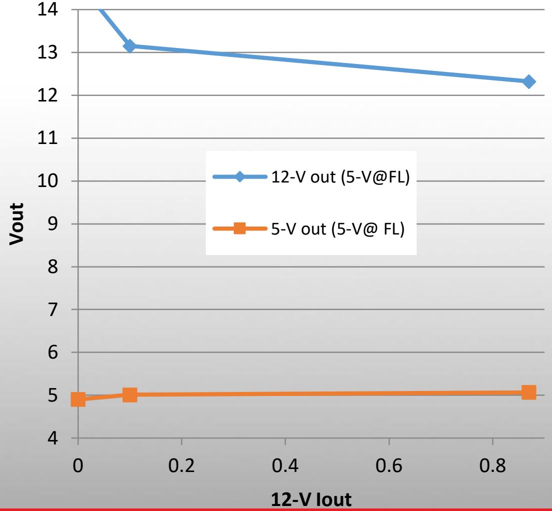


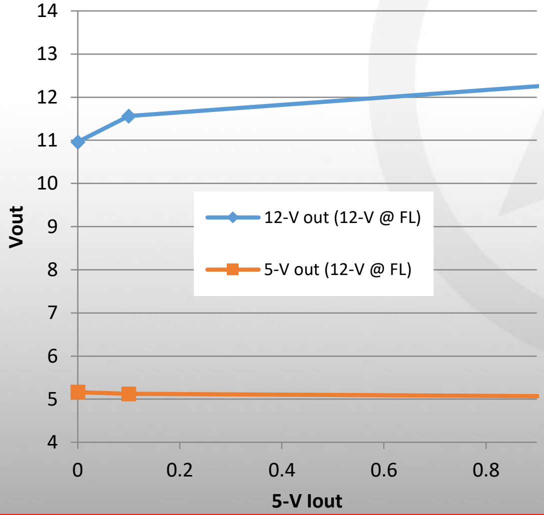
No-Load Power Loss	P1
Vin	0W
240VAC	73mW

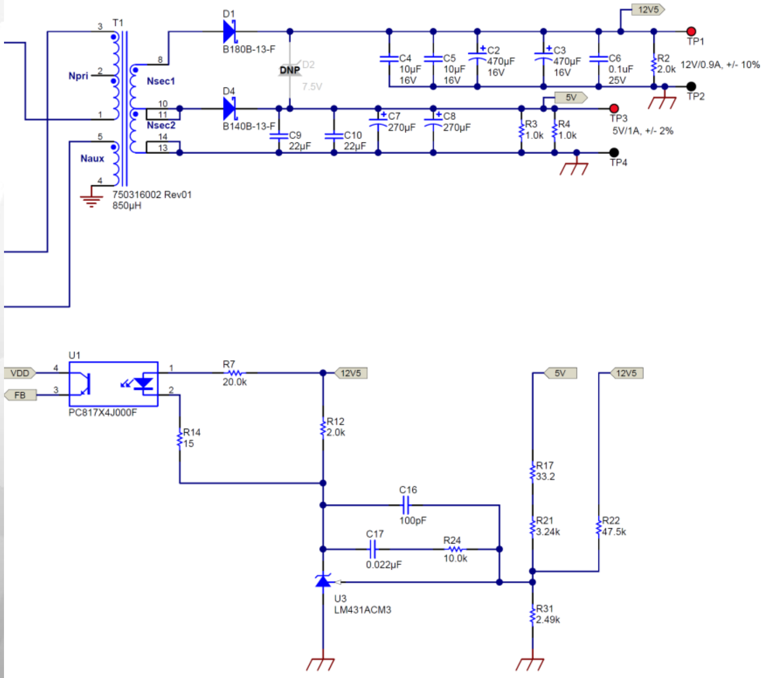


Multiple/weighted feedback TL431/opto PMP20001

- UCC28740 primary controller with weigthed opto feedback
- Degrades regulation of each output slightly
- Helps improve cross regulation

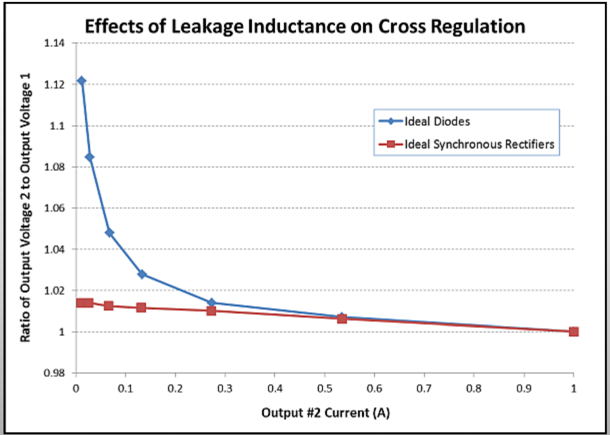


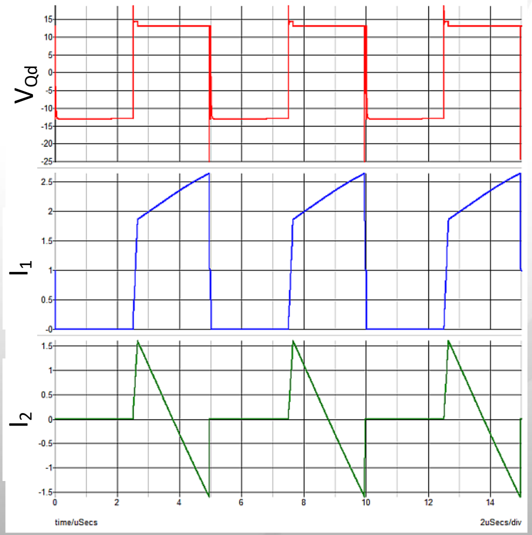


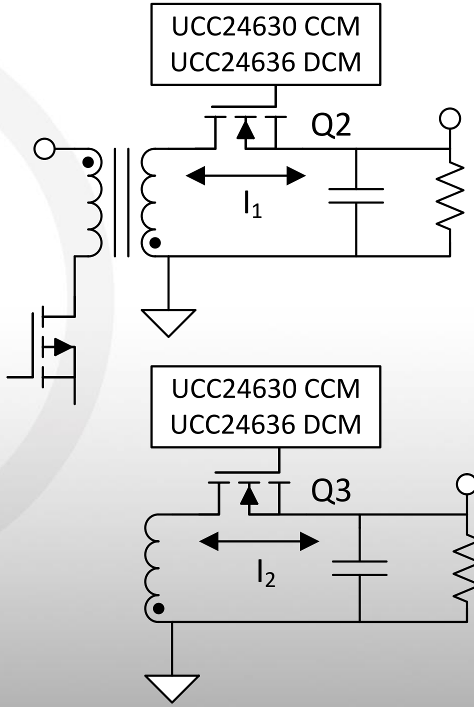


Secondary side synchronous rectification

- Bidirectional current through SR
- SRs (Q2,Q3) allow current flow in reverse direction under lighter loads
  - Helps dissipate energy from lighter loads, improves cross regulation
  - Waveform example (I_1 full load, I_2 no load)

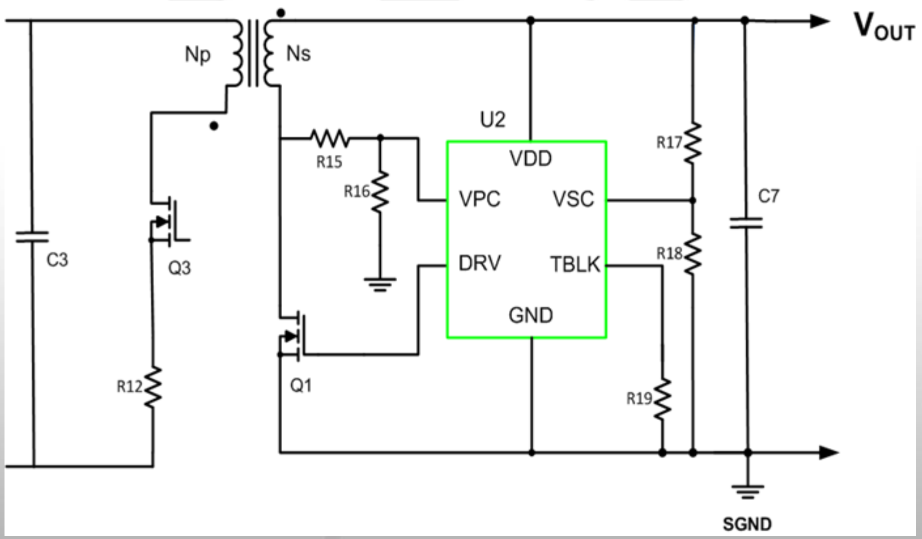






UCC24630/6 synchronous rectifier (SR) controllers

- Use Volt-Second balance to control SR gate drive
- Wide VDD range 3.6 to 28V
- 5V to 24V outputs
- UCC24630 200 kHz f_{max}
- UCC24636 130 kHz f_{max}
- 0.9-A source/1.1-A sink
  - ✓ Self Limited



Summary – cross-regulation improvement & mitigation

- Main causes of cross-regulation have been outlined
- Several different techniques discussed to help improve cross-reg:
  - Transformer construction – minimise leakage inductance
  - Minimise secondary wiring resistance & inductance (flying leads)
  - Minimise rectifier on-state drop, especially for low voltage outputs
  - Add pre-load or minimum loads, Zener-clamps, or linear regulators to outputs
  - AC or DC-stack the outputs (if they share the same GND)
  - Weighted multi-feedback to TL431
  - Use SR (synchronous rectification)
- However, there is no free lunch – not easy to get great cross-regulation at low cost
  - It's all about compromise and managing trade-offs
- Pay close attention to detailed internal transformer construction – good design goes a long way to achieving good cross-regulation

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