How to Design Multi-kW Converters for Electric Vehicles

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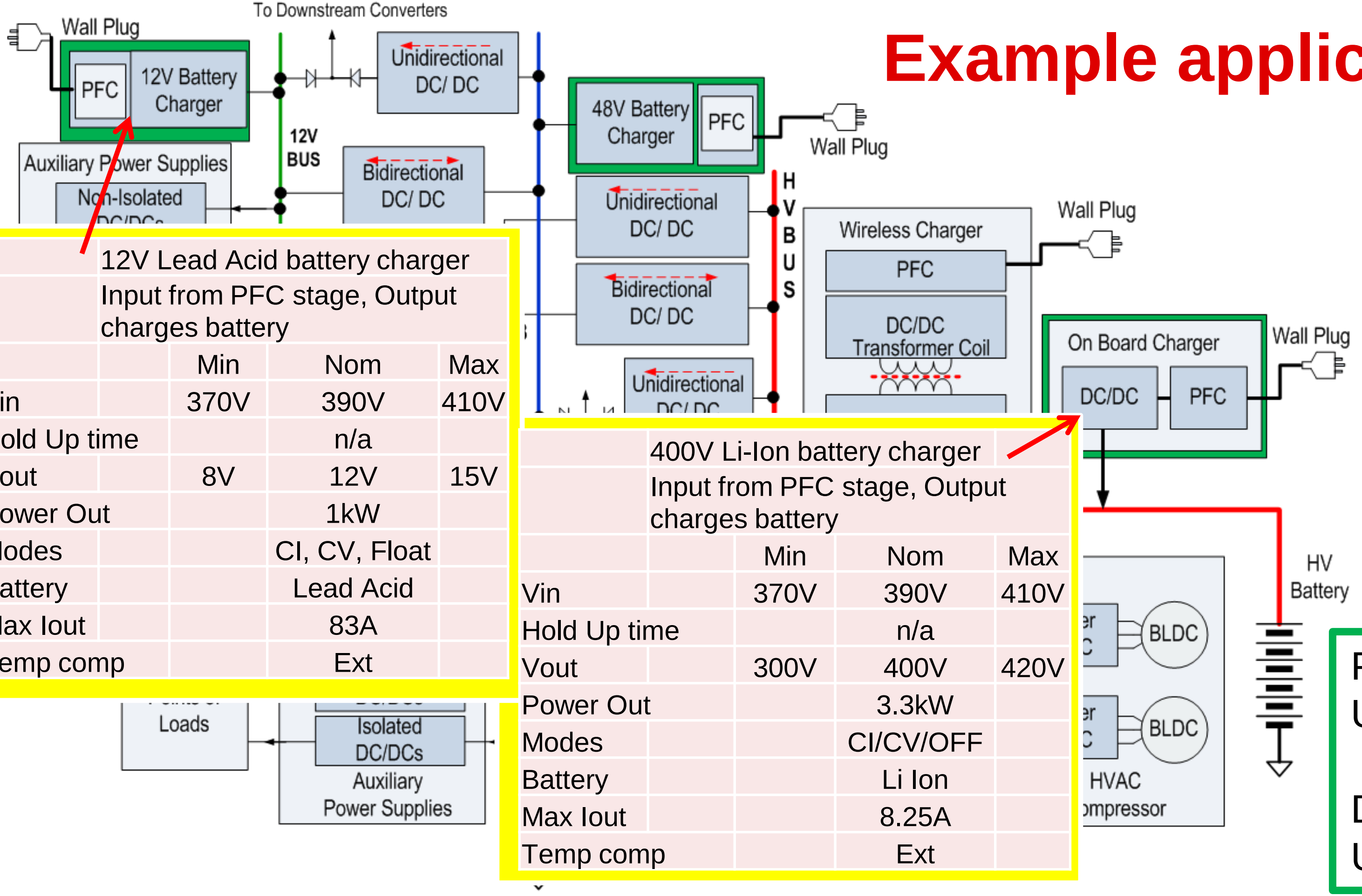
Systems Overview

- **Problem:** Electric vehicles need systems to convert AC power into DC for storage in high (HV) and low voltage (LV) batteries and to convert the stored energy back to AC to drive the Motors. We've seen the overall system block diagram and outlined how the PFC and PSFB stages operate. Now we will examine how to design the PFC and DC/DC stages.
- **Solution:** We use the UCC28070-Q1 and UCC28951-Q1 to control the PFC and PSFB power stages respectively.
- **Key components:** Texas Instruments offers a wide variety of devices for use in OBC applications in H/EV. A few examples:
- The UCC28070-Q1 interleaved PFC controller
- The UCC28951-Q1 PSFB controller. (UCC2895-Q1 if diode rectification, no SR Drives)
- The UCC27524A1-Q1 gate driver.
- The multi channel UCC21520 8kV isolated gate driver.
- The UCC28C4x-Q1 and UCC28700-Q1 Flyback controllers – for bias power applications

Example applications



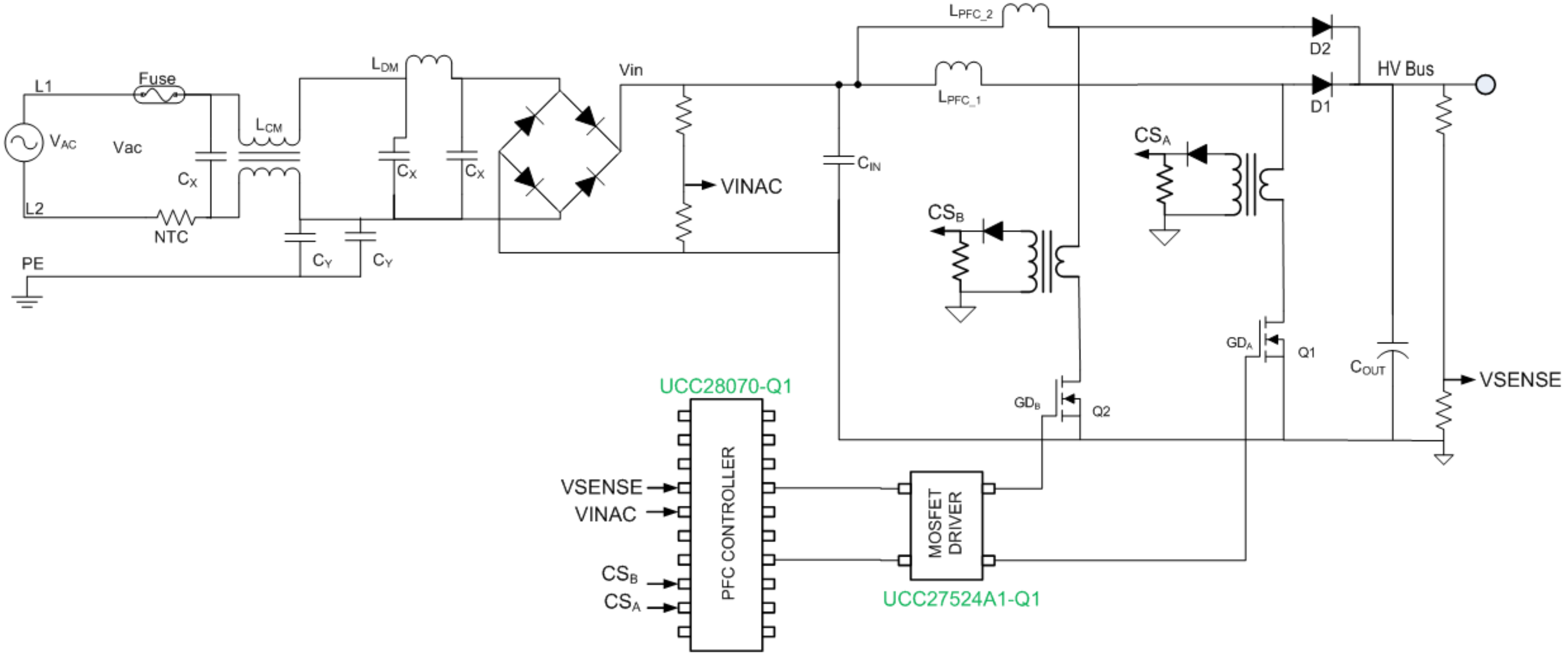
	12V Lead Acid battery charger			
	Input from PFC stage, Output charges battery			
		Min	Nom	Max
Vin		370V	390V	410V
Hold Up time			n/a	
Vout		8V	12V	15V
Power Out			1kW	
Modes			CI, CV, Float	
Battery			Lead Acid	
Max Iout			83A	
Temp comp			Ext	

	400V Li-Ion battery charger			
	Input from PFC stage, Output charges battery			
		Min	Nom	Max
Vin		370V	390V	410V
Hold Up time			n/a	
Vout		300V	400V	420V
Power Out			3.3kW	
Modes			CI/CV/OFF	
Battery			Li Ion	
Max Iout			8.25A	
Temp comp			Ext	

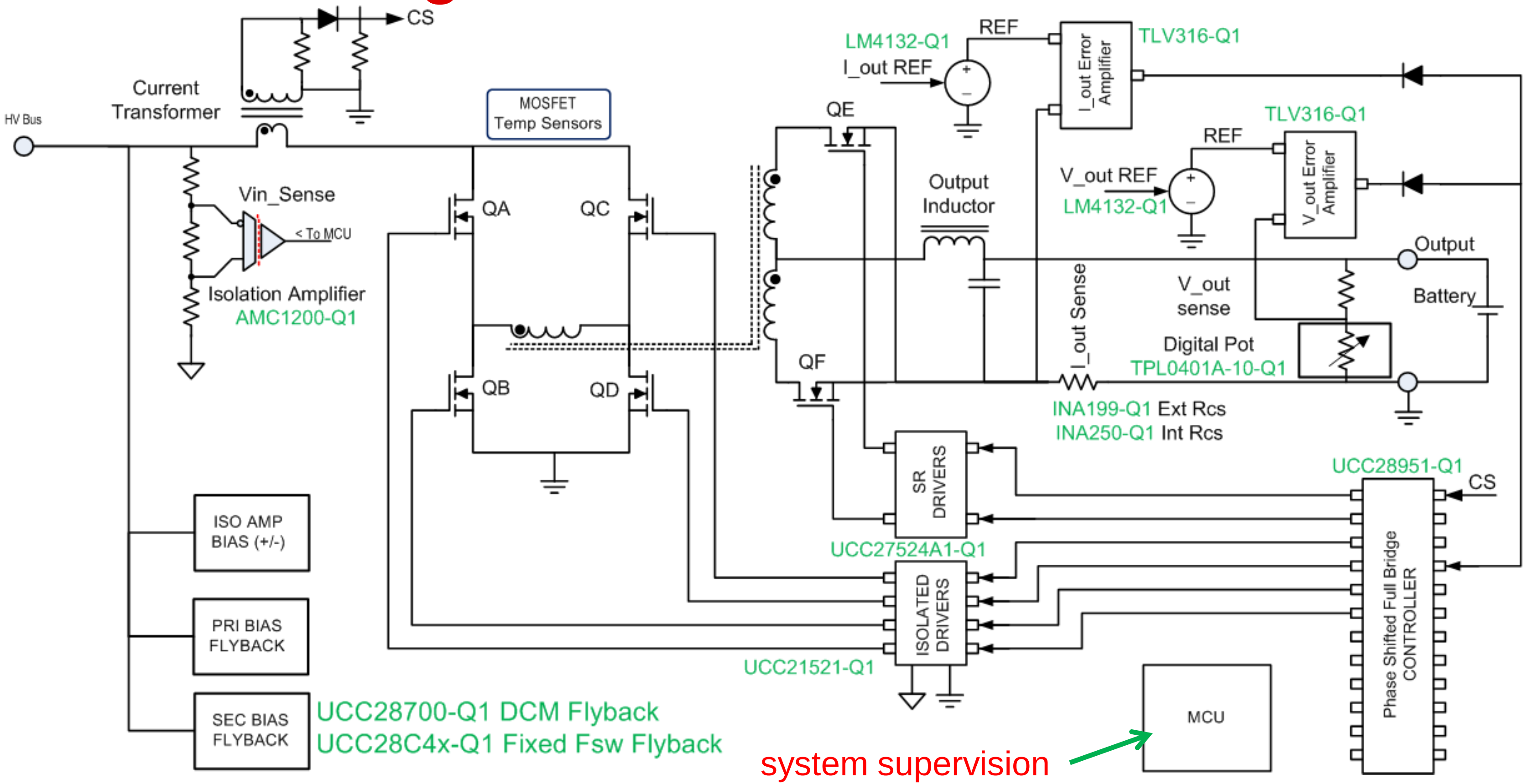
PFC
UCC28070-Q1

DC/DC
UCC28951-Q1

On Board Charger < 3.3kW PFC

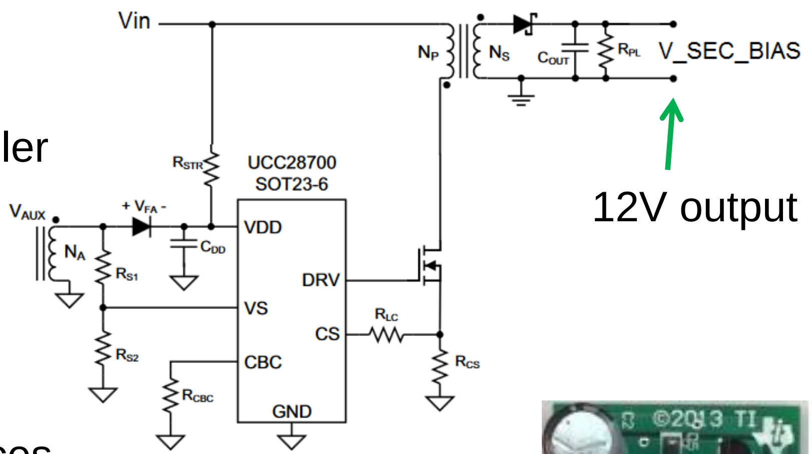


On Board Charger < 3.3kW DC-DC



On Board Charger: Sec Bias Flyback

- Small Flyback PSU for Secondary side power
- UCC28700-Q1 for example
- Primary side regulation – no need for an optocoupler
- Simple, low cost transformer
- Small size, 6 pin SOT23
- Efficiency probably about 75%
  - – power level is low – estimate 5W
- Variable frequency – as with all DCM flyback devices
- Cable compensation (CBC) probably not needed – tie CBC pin to GND
- Design tools available http://www.ti.com/product/UCC28700/toolssoftware
  - – Webench
  - – Reference designs
  - – Evaluation Modules



28mm x 33mm

PMP8787

On Board Charger: Pri Bias Flyback

- Small Flyback PSU for Primary side power
- UCC28700-Q1 for example
- Primary side regulation – no need for an optocoupler
- Simple, low cost transformer
- Small size, 6 pin SOT23
- Efficiency probably about 75%
  - power level is low – estimate 5W
- Variable frequency – as with all DCM flyback devices
- Cable compensation (CBC) probably not needed – tie CBC pin to GND
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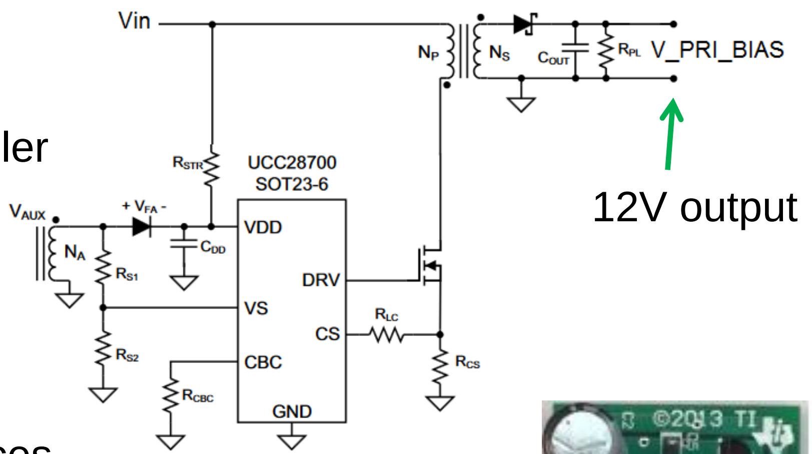
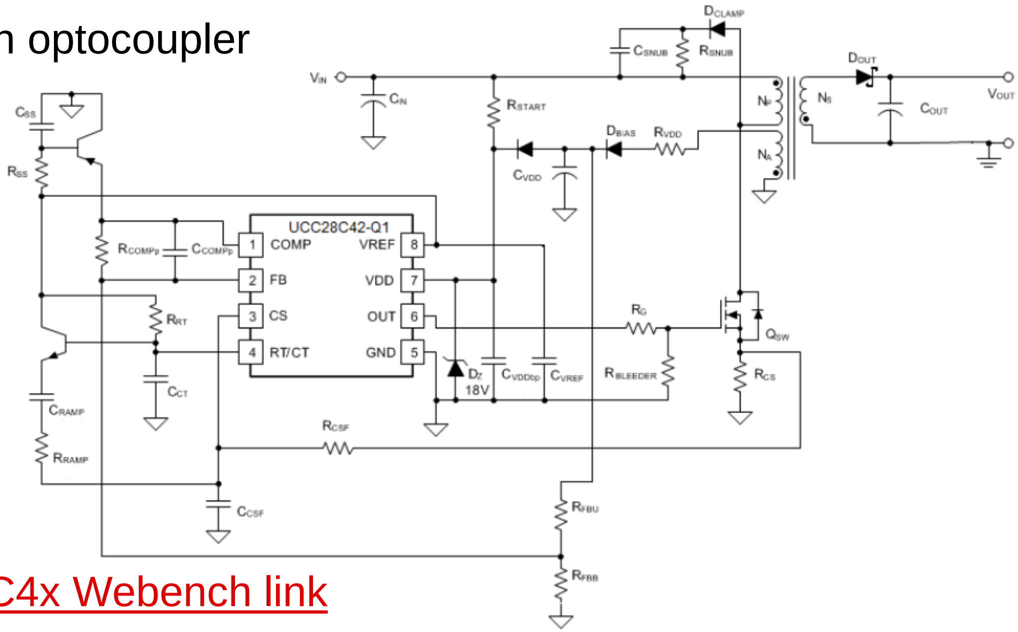


28mm x 33mm

PMP8787

On Board Charger: Pri Bias Flyback

- Small Flyback PSU for Primary side power
- UCC28C4x-Q1 for example
- Primary side regulation – no need for an optocoupler
- Simple, low cost transformer
- Small size, SOIC8
- Fixed Frequency operation



- Webench design tool available UCC28C4x Webench link
- Typical example at http://www.ti.com/lit/an/slua274a/slua274a.pdf

On Board Charger: Rectification – General

- Choice of secondary rectification depends on -
  - Output Voltage
  - Output Current

400Vout:

Diodes – Simple solution, a good choice for 400V

Full Wave or Bridge options

Reverse recovery losses makes SiC a good choice

12Vout:

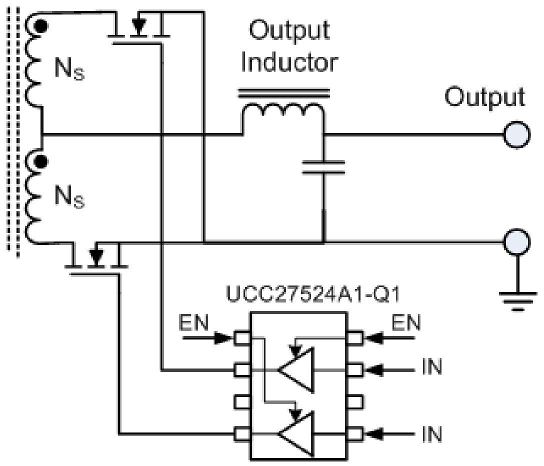
SR – Good option at 12V out, body diode reverse recovery losses can be significant

Full wave with centre tap or Bridge with single secondary winding options

SRs require a MOSFET driver

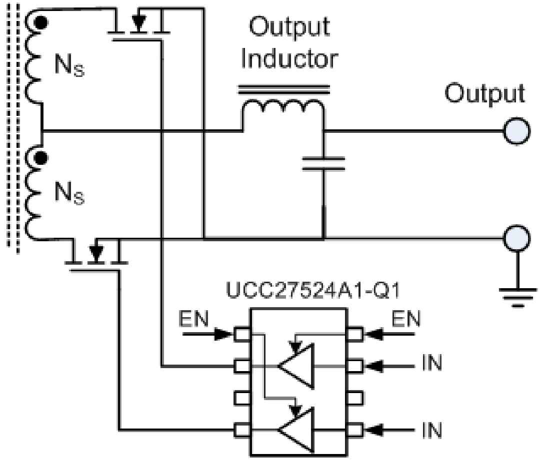
Consider Schottky diodes, higher losses but easier drive, no reverse recovery

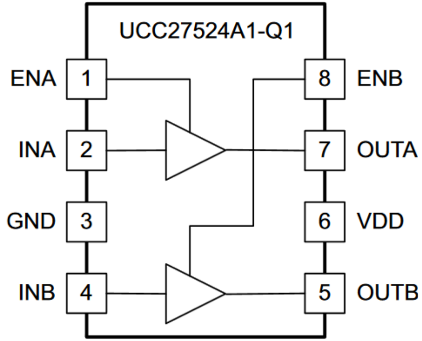
Current doubler with SR is a good option – single sec. winding



On Board Charger: Rectification – 12V output

- SRs are large rectifier MOSFETs.
- UCC27524A1-Q1 is a dual non-inverting MOSFET driver.
- MOSFETs see 2 x Vin_max Ns/Np + margin
  - Use 30V devices for 12V output
  - Reverse recovery losses in SR can be significant
- Centre tapped secondary
- Half of sec winding ‘idle’ at a given time
- ‘Idle’ half may cause proximity losses

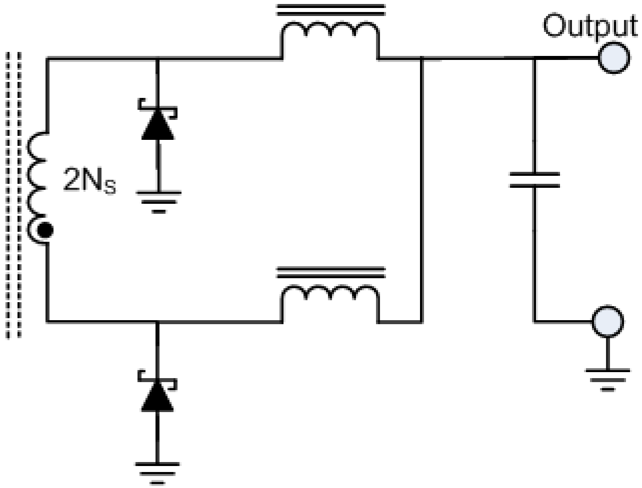




On Board Charger: Rectification – 12V output

- Current Doubler output with Schottky Rectifiers
  - Current Doubler – suited to high current outputs
  - Requires Current Mode Control
  - Ripple current cancellation in Cout
- Single winding on transformer secondary
  - best use of transformer winding window
- Two output inductors needed
  - Each inductor carries half the output current
- Vf losses are significant – depends on diode
  - Heatsinking requirements significant

- Electrically – this is the simplest option
- Significant losses in Diodes.

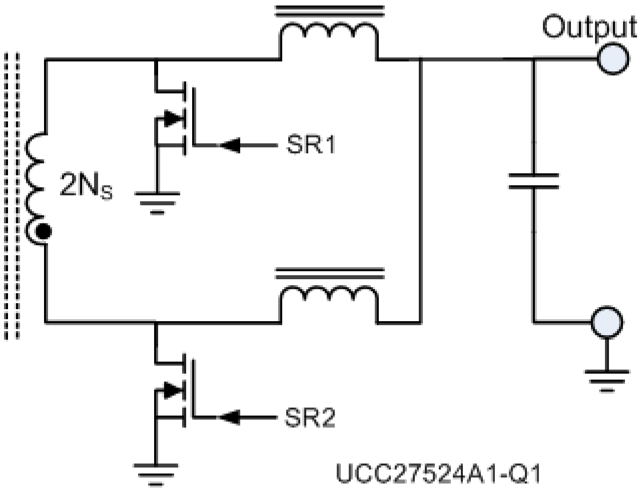


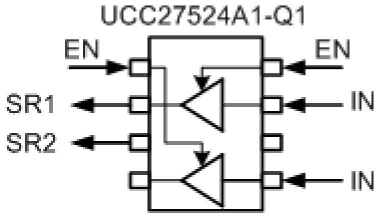
Secondary	Centre Tapped	Current Doubler
Ind Current	I_out	I_out/2
Ind Freq	2 f_{SW}	f_{SW}
Inductance	L_out	<Lout*

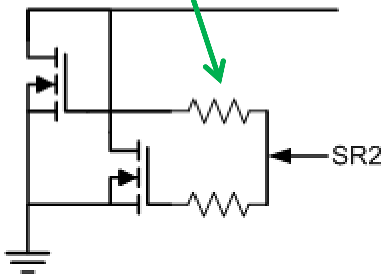
* Depends on Duty Cycle

On Board Charger: Rectification – 12V output

- Current Doubler output with Synchronous Rectifiers
  - http://www.ti.com/lit/an/slua121/slua121.pdf
- MOSFETs see 2 x Vin_max Ns/Np + margin
- Reverse recovery losses in SR can be significant
- SRs are ground referenced – simple driver
- UCC28951-Q1 OUTE and OUTF signals are driver inputs
- May need to parallel several MOSFETs
  - Use separate gate drives
  - or separate gate drive resistors
  - Needs careful layout to avoid HF oscillations

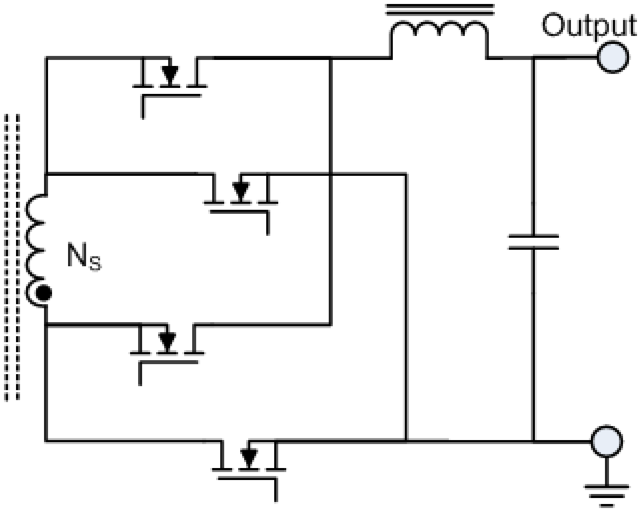






On Board Charger: Rectification – 12V output

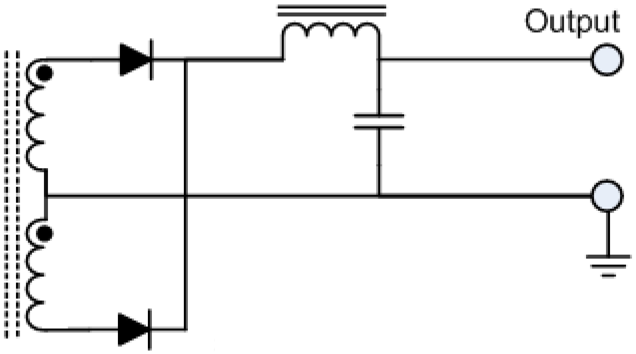
- Full wave rectification with SR
- Simplest transformer
  - Single secondary winding
- Single output inductor
- Two SR voltage drops in current path
- SRs see Vin_max Ns/Np + margin
- Reverse recovery effects in SR diodes
- SR drive complexity
- 2 low side drives, 2 high side drives



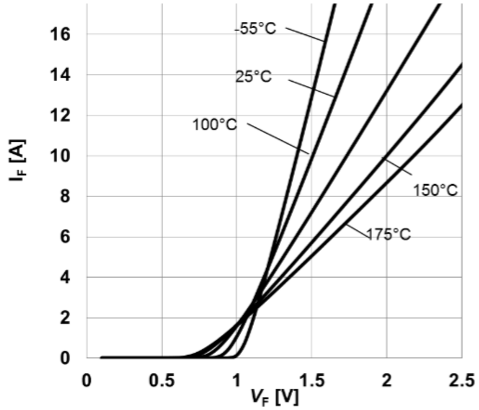
On Board Charger: Rectification – 400V output

- SiC diodes are simplest solution
- Positive temp coefficient of Vf
- Relatively low currents allow use of centre tapped secondary
- V stresses on diodes are 2 x Vin_max Ns/Np + margin
- Use 1200V rated SiC diodes
- UCC2895-Q1 is an alternative PSFB controller

    No SR drives

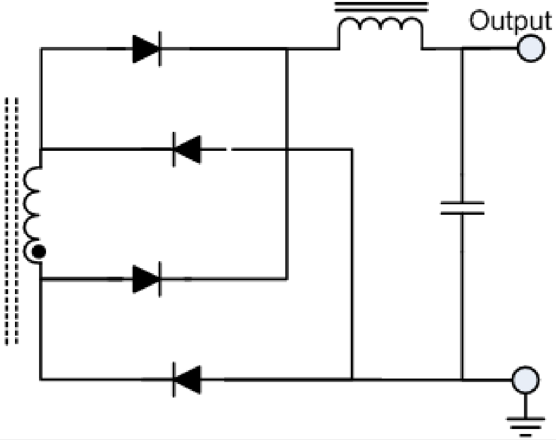


Infineon IDH10G120C5



Typical forward characteristics,

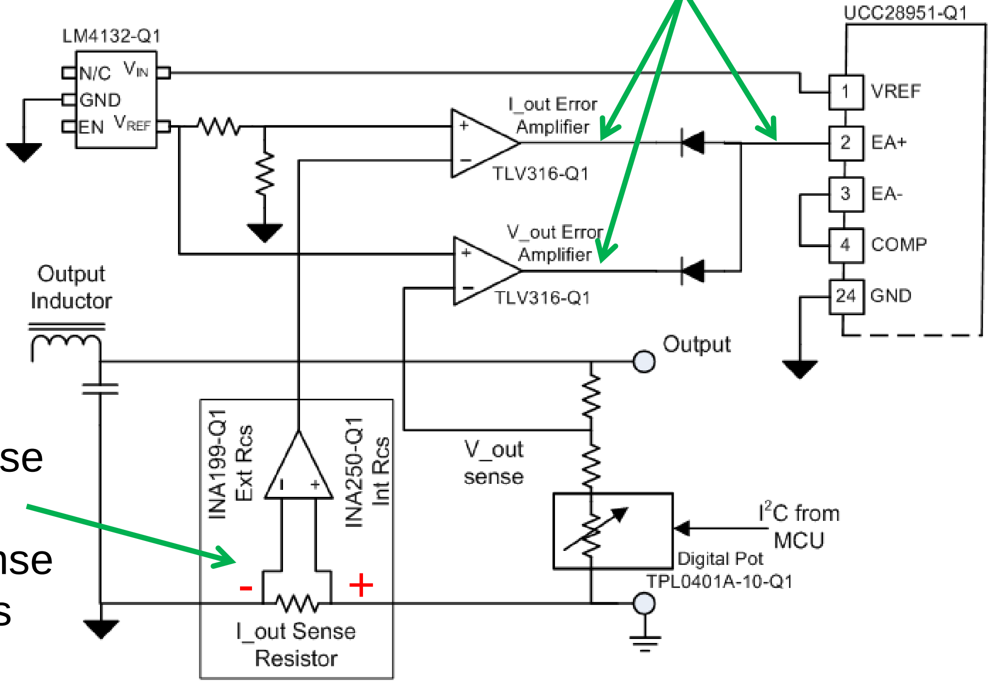
- Full Bridge rectification
    - Halves V stresses
    - Simplifies secondary
    - Increases rectifier losses

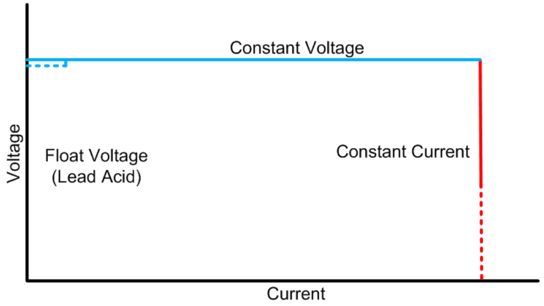


On Board Charger: Error Amplifiers (I and V)

- Measure output current
- Compare to reference
- Output error signal (power demand)
- Measure output voltage
- Compare to reference
- Output error signal (power demand)
- Diode ‘or’ errors – lowest error ‘wins’
  - Automatic CV / CI transition
  - This is the usual technique

Lowest error ‘wins’ and controls the output



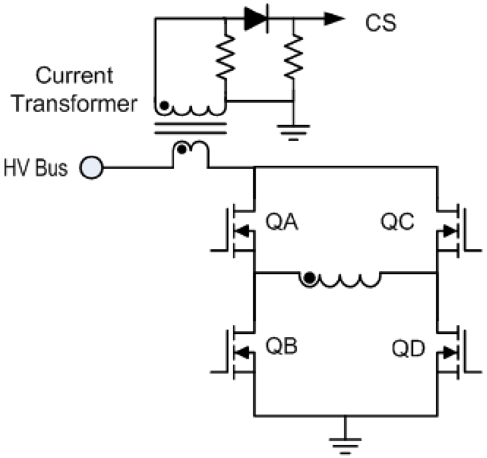


Low side sense at 400Vout
High side sense at 12Vout is possible

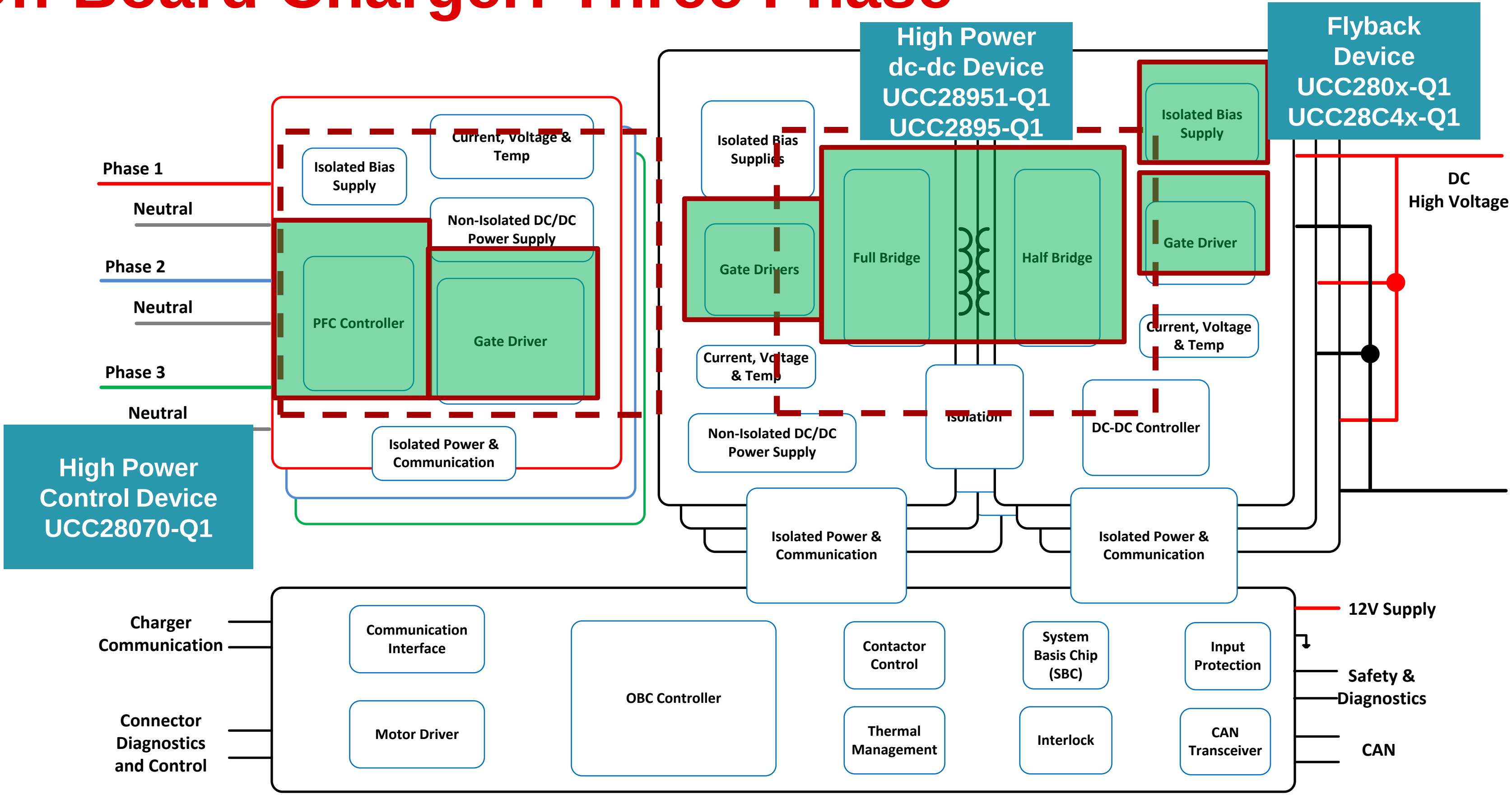
On Board Charger: Input current sensing

- Current Transformer in the input power rail senses input current
- In this position, it senses the full bridge current
- Senses any ‘shoot through’ events
  - QA and QB or QC and QD ON simultaneously
- CS signal used for Peak Current Mode (PCM) control of PSFB
- PCM gives cycle-by-cycle control of peak current in primary
- Protection against transformer saturation

- CS signal is used for regulation in both CV and CI modes
- Regulation setpoint depends on whether the CV or CI error amplifier is in control



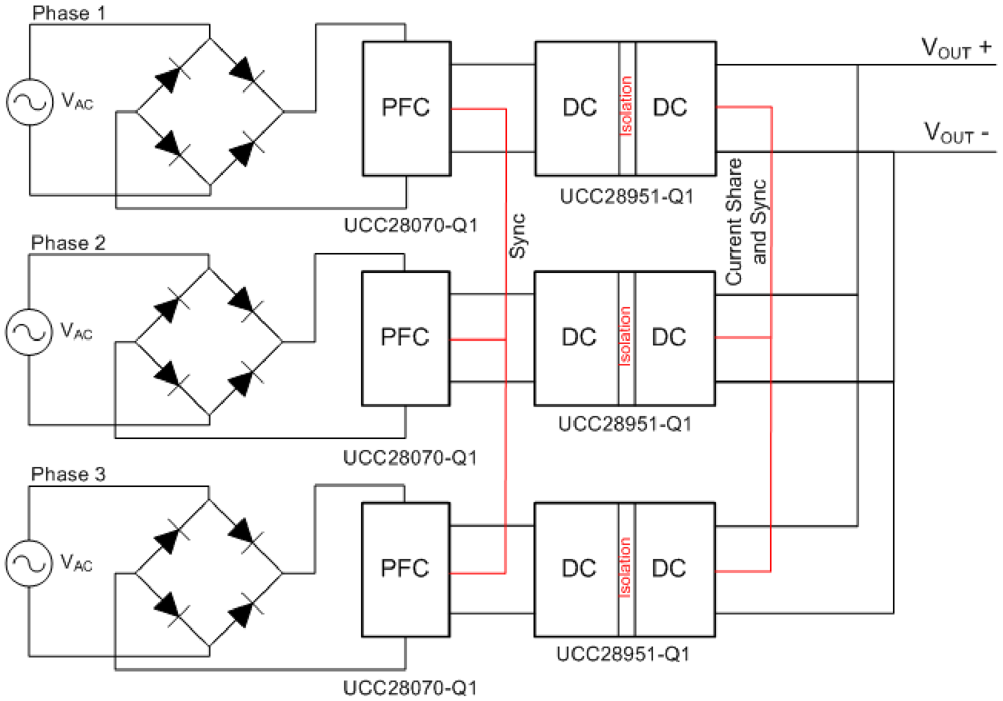
On-Board Charger: Three Phase



Three Phase System

Separate PFC stages for each phase
- UCC28070-Q1 controllers
- Synchronised to each other

Separate DC/DC stages
- No common PFC output ground
- UCC28951-Q1 controllers
- Current Share
- Synchronisation



Paralleling, Current Sharing and Synch: PSFB

Paralleling is used to increase system level power in manageable steps. A 15kW system may be built from three 5kW systems in parallel.

We also want the three sub-systems to share the load equally. This is required to force current balancing three line phases

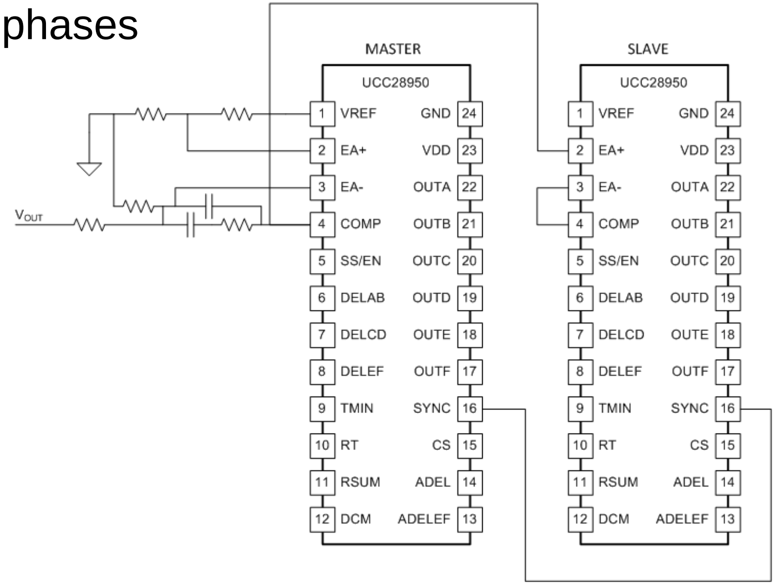
Redundancy, n+1

Synchronisation is optional but desirable

- Ripple current reduction in the output capacitors
- System noise reduction
- Fewer noise induced control problems
- Less acoustic noise from beat frequency

Expansion to meet future expected load growth

Current Sharing PSFB
With (optional) SYNC

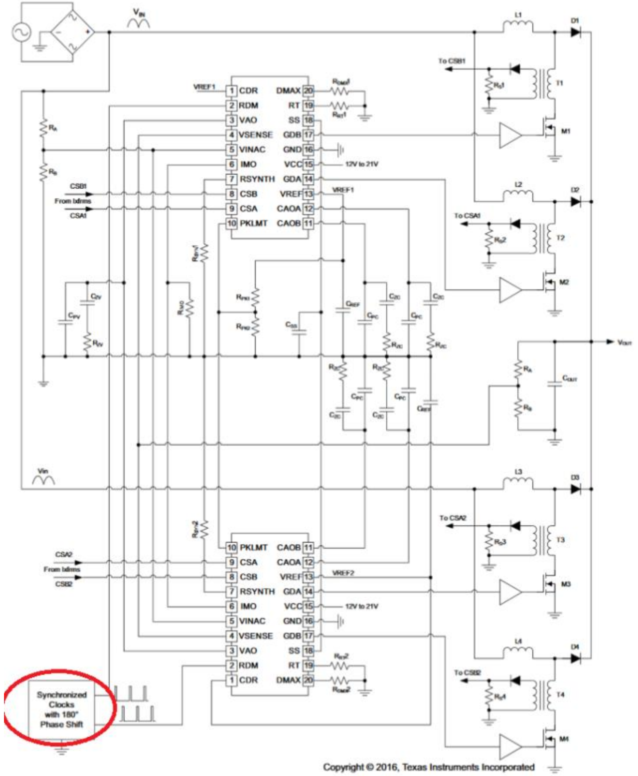


Paralleling, Current Sharing and Synch: PFC

UCC28070A-Q1 device inherently shares current across two PFC stages.

Multiple stages can be paralleled too – note sync source

This arrangement is on a single line phase



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Thank You

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Texas Instruments