Analog AC/DC and Isolated DC/DC solutions for Automotive HEV/EV Applications

High Voltage Controllers (HVC)

Michael O’Loughlin, Colin Gillmore

How to Design Multi-kW Converters for Electric Vehicles

Topics:

1. Electric Vehicle (EV) Power Systems
2. On Board Charger (OBC) Overview
3. Power Factor Correction (PFC)
4. The Phase Shifted Full Bridge (PSFB), 500 W to 3.3 kW +
5. Auxiliary Power, 5 to 150W
6. Gate driver considerations
7. Introduction to Battery Chargers
8. HEV/EV Powertrain Solutions
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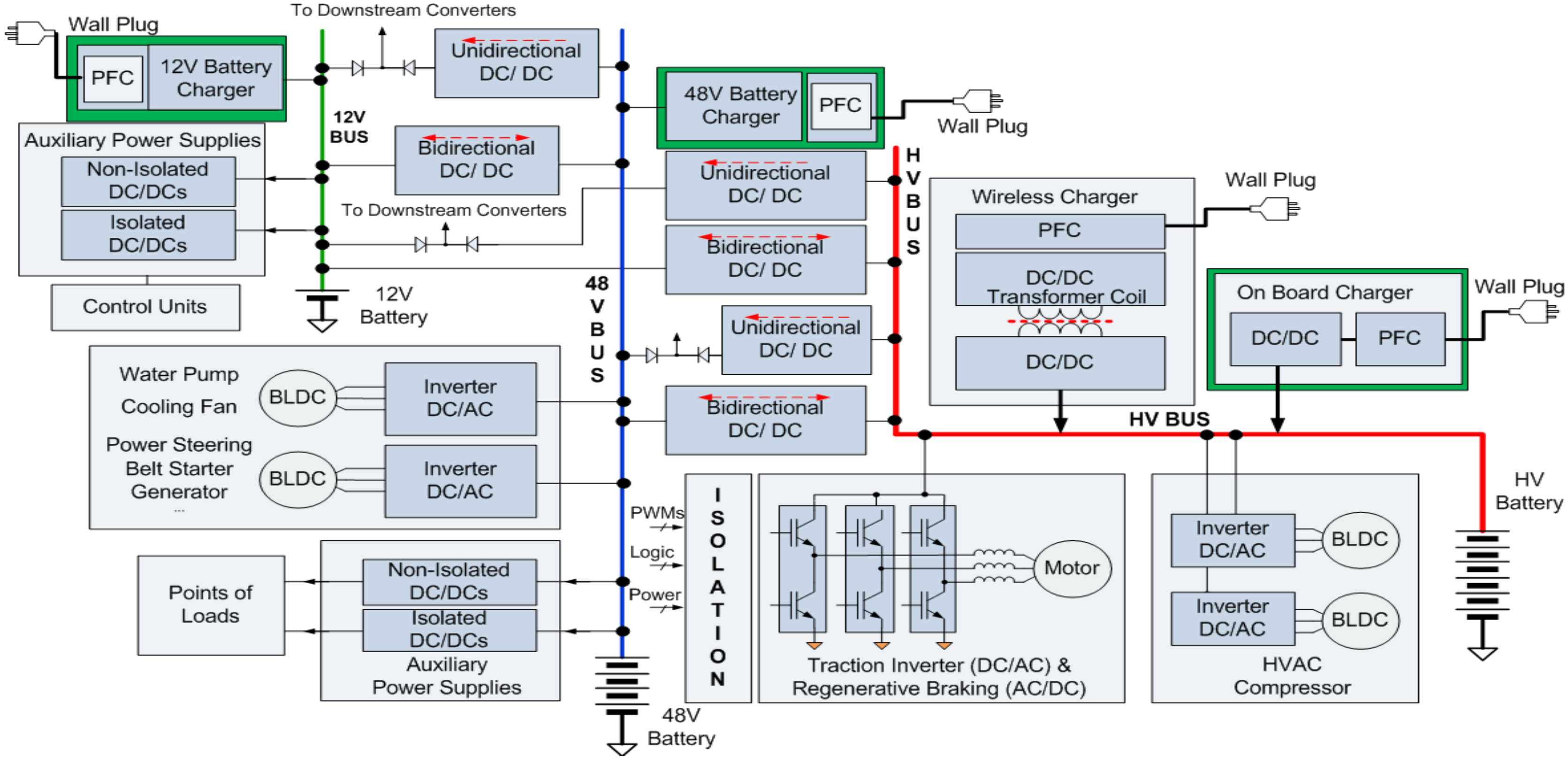
EV System Block Diagram



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On-Board Charger (OBC)

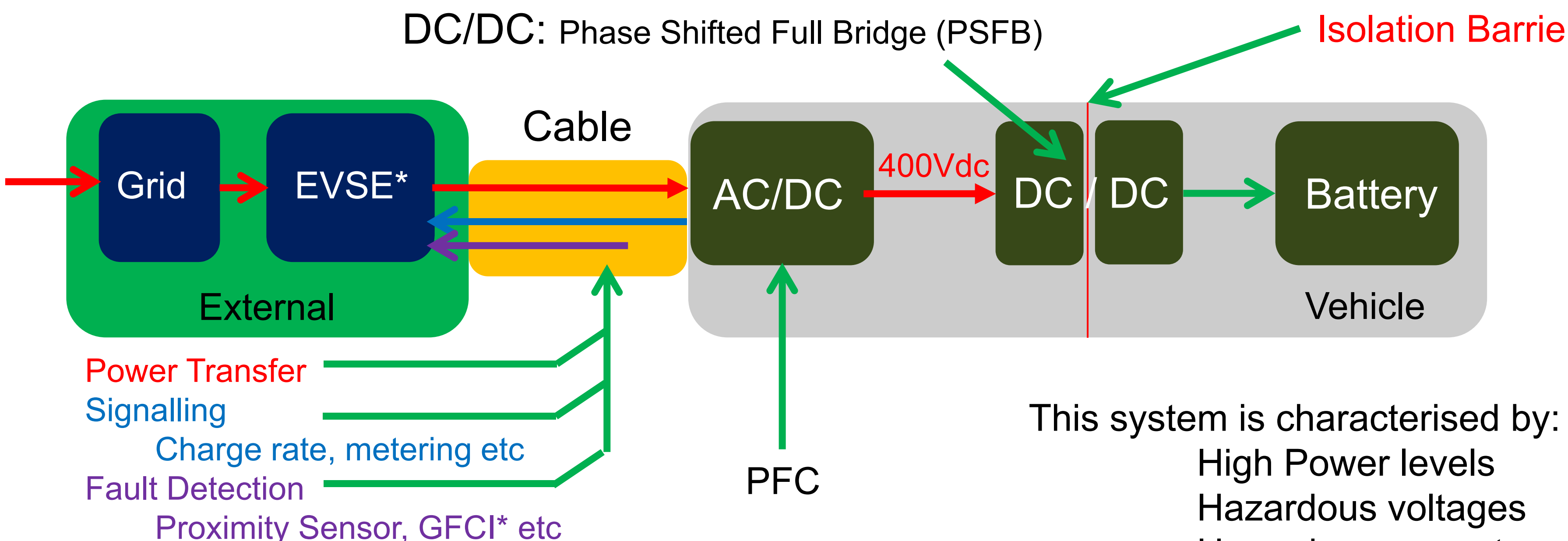
What is the On-board Charger?

- An On Board Charger is used in an electric vehicle (EV) or hybrid electric vehicle (HEV) to charge the traction battery (48V or HV usually ~400V)
- This includes:
    - Converts 50/60Hz AC into DC
    - Adjusts the DC level to the levels required by the battery and provides the galvanic isolation
    - Includes a Power Factor corrector (PFC)

What does this EE consist of?

- **PFC Controller and Rectification**
    - High Efficiency rectification with lowest harmonic impact to the grid
- **Controller**
    - Analog or Digital Control (<2kW to >100kW)
    - Adjusts the DC level to the levels required by the battery
- **Galvanic Isolation**
    - Galvanic Isolation Grid to Battery
    - Bias Supply
- **Diagnostics**
    - Temperature Sensing
    - Current & Voltage Sensing
    - Iso Barrier

Typical high power system: EV charger



This system is characterised by:
- High Power levels
- Hazardous voltages
- Hazardous currents
- Harsh environment

Charger power levels, Society of Automotive Engineers (SAE)
Level 1: Single phase: AC power, 1.92kW
Level 2: Split phase: AC power, 19.2 kW
Level 3: DC power, 240kW

*EVSE – Electric Vehicle Service Equipment
*GFCI – Ground Fault Current Interruptor
(EVSE) Reference Design, tidub87

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PFC Needed to Utilize Full Line Power for OBC

- In Europe to Meet EN61000-3-2 harmonics requirements generally PFC is used in applications > 75W
- To charge batteries with 1.92 kW to 19.2 kW offline requires PFC.
  - Can easily be seen studying 120 V RMS, Pout(max), for 1.92 kW OBC.
    - With and Without PFC pre-regulator

PF= $\frac{\frac{P_{OUT}}{\eta}}{V_{IN(RMS)} \times I_{IN(RMS)}}$

Pout(max)= $\times\ V_{IN(RMS)} \times I_{IN(RMS)} \times \eta$

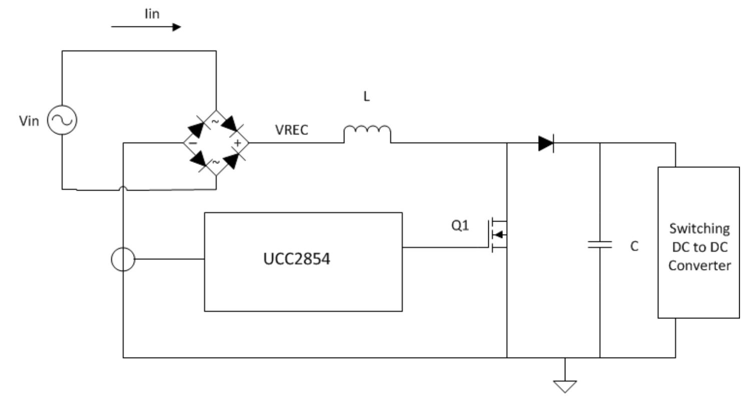
PF = 0.45 without PFC, Pout(max) = 0.45*120V*20A*0.85=918 W

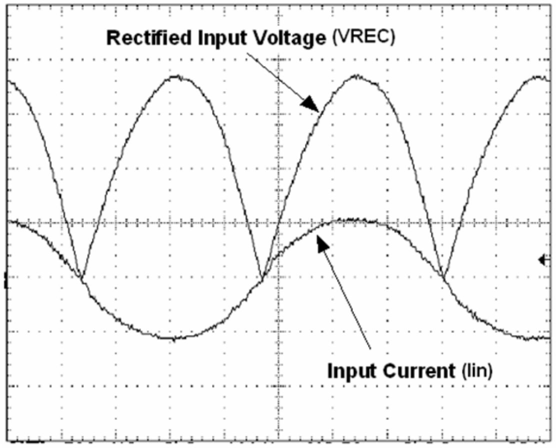
PF = 0.98 with PFC, Pout(max) = 0.98*120V*20A*0.85≈2 kW

PFC Pre-regulator

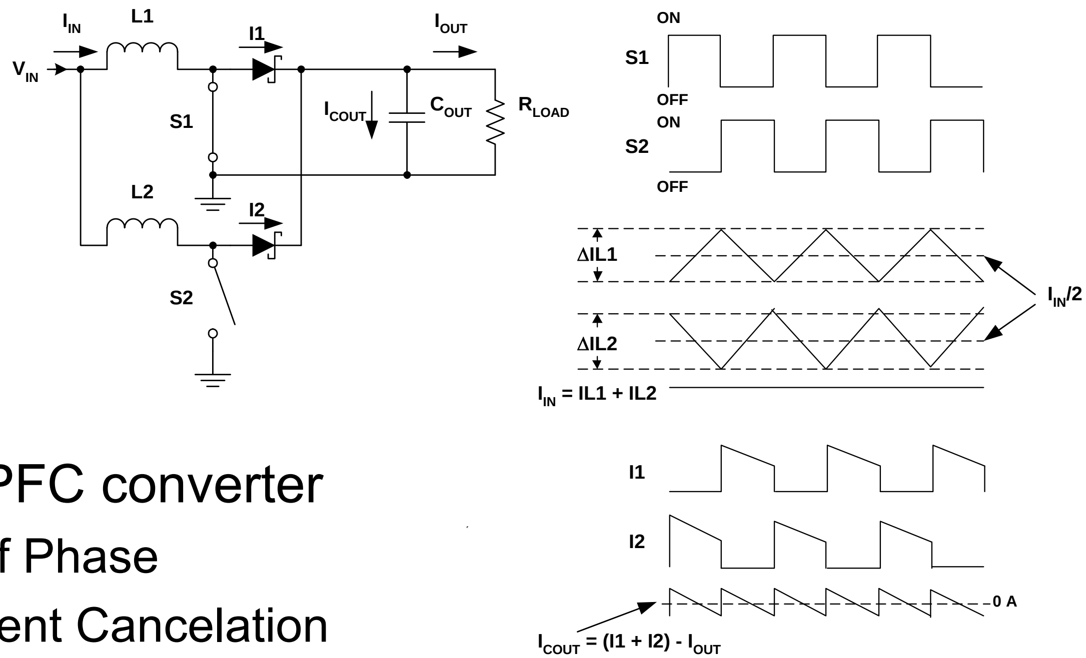
- Boost Pre-regulator
- Average/Peak Current Mode Control
  - Used to force Iin to track Vin.
    - Near unity PF can be achieved
    - It all started with the UCC2854
      - ➢ Now High Power UCC28070-Q1 -Interleaved PFC

$$PF=\frac{\frac{P_{OUT}}{\eta}}{V_{IN(RMS)} \times I_{IN(RMS)}} \approx 1$$





UCC28070-Q1 Interleaving PFC (600 W >)



- 2-phase Interleaved PFC converter
  - Operates 180° out of Phase
  - Inductor Ripple Current Cancelation
    - Reduces filtering requirements on the input capacitor
  - Reduces output capacitor RMS current

Interleaving Reduces Total Inductor Energy by 50%

- This can lead to a 32% reduction total inductor volume.

$$E_{Total\_Single\_Phase\_Inductor\_Energy} = \frac{1}{2} L I^2$$

$$E_{Total\_Interleaved\_Inductor\_Energy} = \frac{1}{2} L \left(\frac{I}{2}\right)^2 + \frac{1}{2} L \left(\frac{I}{2}\right)^2 = \frac{1}{4} L I^2$$

$$\frac{E_{Total\_Single\_Phase\_Inductor\_Energy}}{E_{Total\_Interleaved\_Inductor\_Energy}} \times 100 = 50\%$$

Interleaving PFC Pre-regulators

- Cuts conduction losses by 50%
  - Low rated components can be used
  - The design is more efficient than single stage

$P_{Single} = I^2 R$, single stage conduction losses

$P_{Two\_phase} = \left(\frac{I}{2}\right)^2 R + \left(\frac{I}{2}\right)^2 R = \frac{I^2}{2} R$, two phase conduction losses

$\frac{P_{Single}}{P_{Two\_phase}} \times 100 = 50\%$, 50% reduction in conduction losses

Interleaved PFC Results

- Smaller Total Inductor Volume (< 32%)
  - Increases power density
- Greater Efficiency
  - Easier thermal management
    - Less heat sinking is required
      - Should reduce raw material cost
  - Reduces cost of use for the end user

UCC28070-Q1

Automotive Two-Phase Interleaved CCM Current Mode PFC Controller

Features

- Qualified for Automotive Applications
- Interleaved Average Current-Mode PWM Control with Inherent Current Matching
- Advanced Current Synthesizer Current Sensing for Superior Efficiency
- Highly-Linear Multiplier Output with Internal Quantized Voltage Feed-Forward Correction for Near-Unity PF
- Programmable Frequency (30 kHz to 300 kHz)
- Programmable Frequency Dithering Rate and Magnitude for Enhanced EMI Reduction
    - Magnitude: 3 kHz to 30 kHz
    - Rate: Up to 30 kHz
- External Clock Synchronization Capability
- Programmable Peak Current Limiting
- Programmable Soft Start

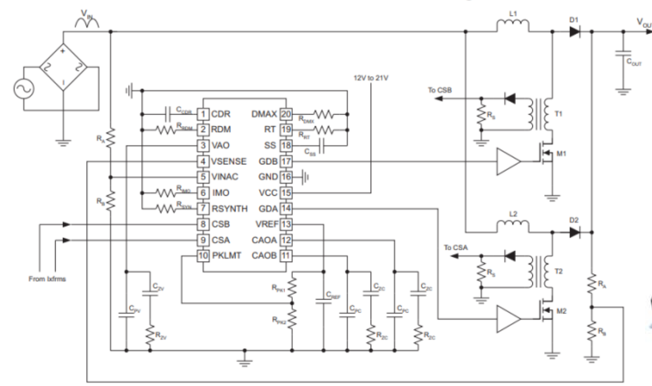
Applications

- **On Board or Charging Station Chargers for PFC AC-DC conversion**

Benefits

- Two-Phase Interleaved for greater than several kilo-watt applications
- External Clock Synchronization Capability to parallel for higher power charging systems
- External PFC-Disable Interface to save power when in standby mode
- Various protection features including: UVLO, Over-Voltage Protection, Open-Loop Detection, PFC Enable, and Open-Circuit protection on VSENSE and VINAC pins

Simplified Application Diagram



20-pin TSSOP

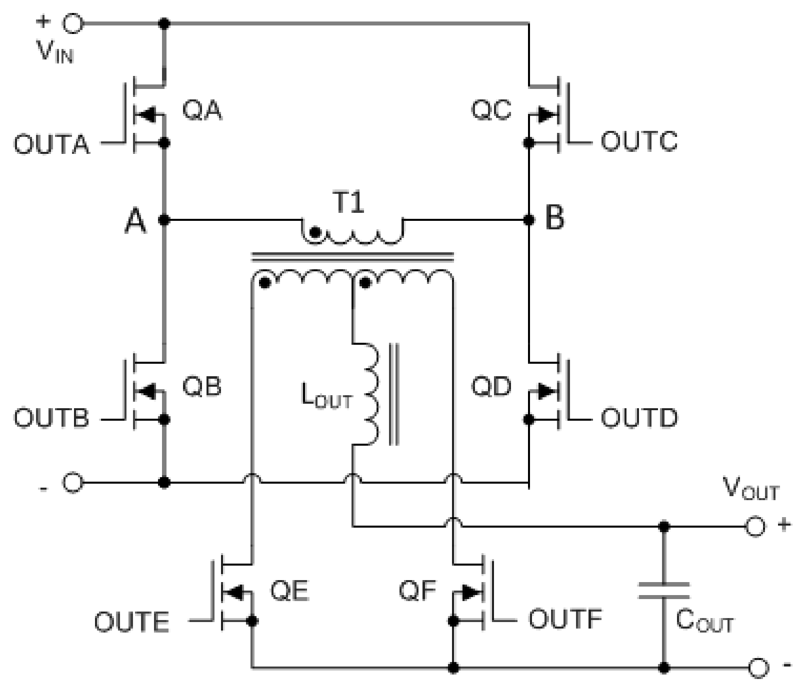
How to Design Multi-kW Converters for Electric Vehicles

Topics:

Phase Shifted Full Bridge (PSFB) Multi kW Designs

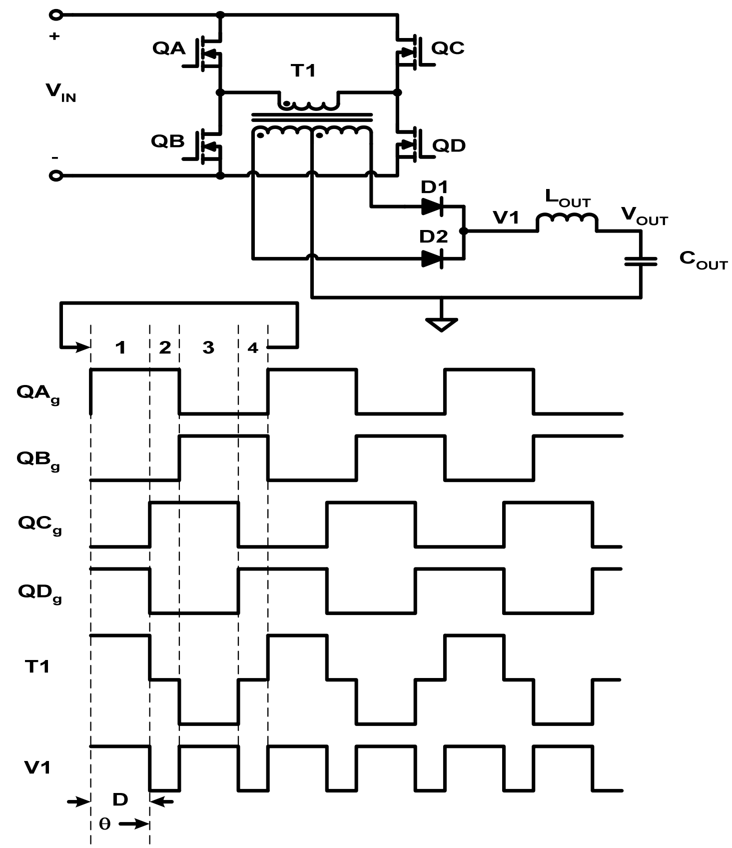
- Zero Voltage Switching (ZVS) on Primary
  - ✓ Efficiency > 92% achievable.
- Buck derived topology
  - ✓ Works over a wide input range
- Reduced magnetic size
  - ✓ Design for > fsw

$$V_{OUT} = D \times V_{IN} \frac{N_S}{N_P}$$



FSFB How Does it Work

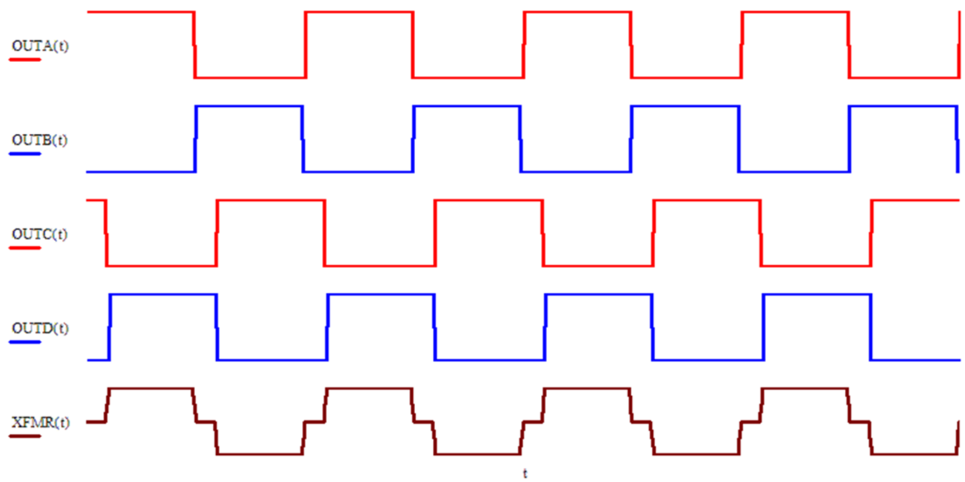
- QA..QD - 50% On/Off
- QA and QB 180 out of phase
- QC and QD 180 out of phase
- QA and QB Gate Drives Fixed
- D is achieved by Phase Shifting (Ө) QC and QD Gate Drives

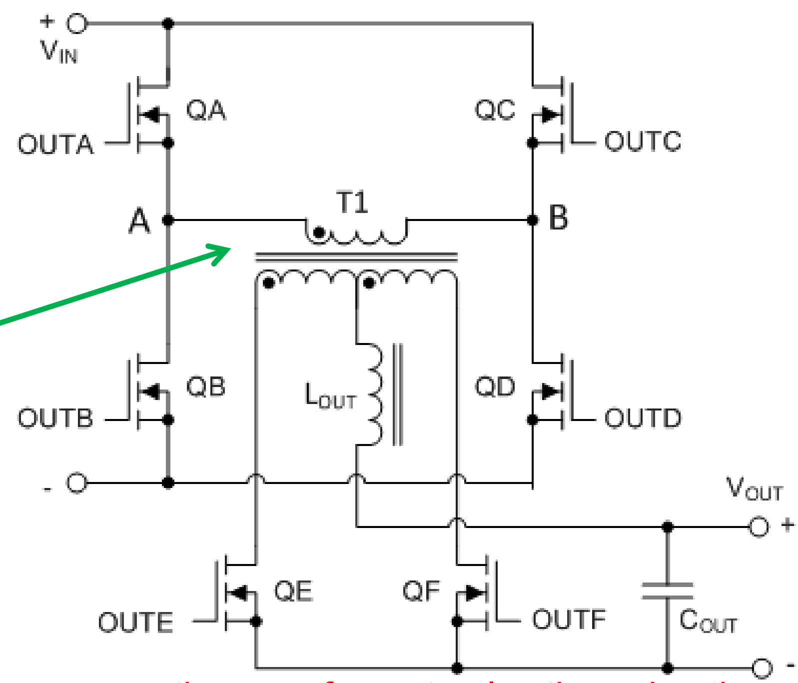


$$D = \frac{V_{OUT}}{V_{IN}} \times \frac{N_P}{N_S}$$

	ON	OFF
1	A ; D	B ; C
2	A ; C	B ; D
3	B ; C	A ; D
4	B ; D	A ; C

Phase Shifted Full Bridge (FSFB)





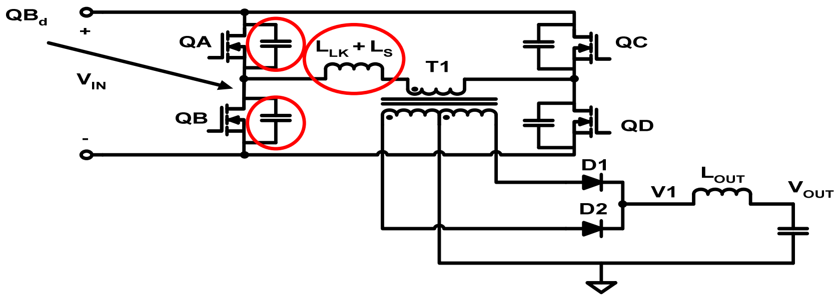
Buck Derived topology → $V_{OUT} = D\, V_{IN} \frac{N_S}{N_P}$

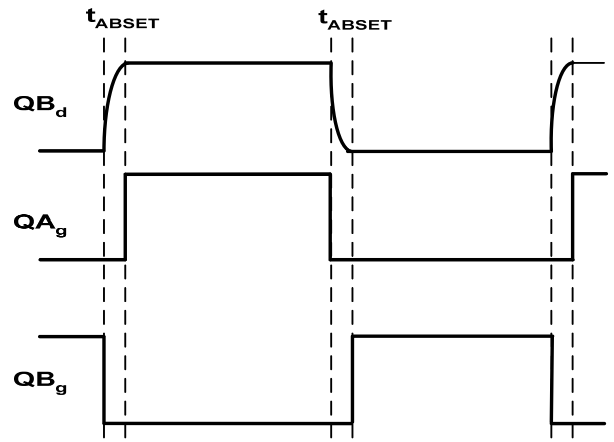
OUTA, OUTB – reference pair

D controlled by phase shifting OUTC & OUTD

Mouse over the waveforms to play the animation

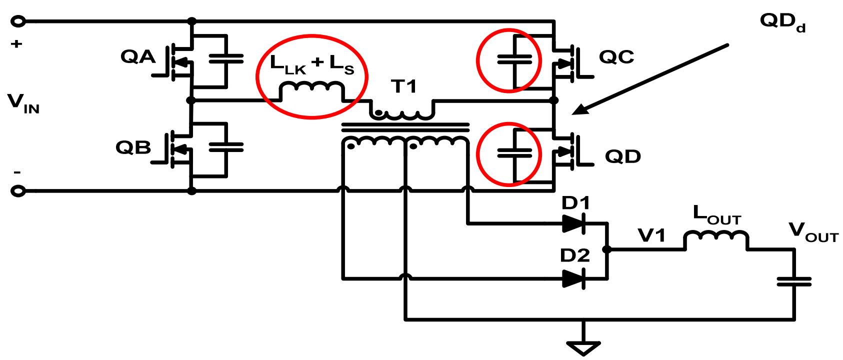
How is ZVS Achieved @ QB_d

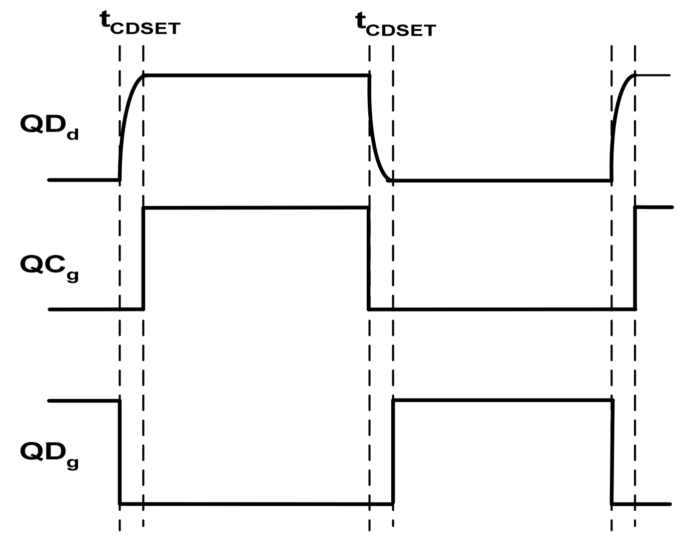




- $L_{LK} + L_S$ Tanking with Capacitance at Switch Node (QB_d)
  - $L_{LK} + L_S$ Stored Energy is Used
- Add Delay QA_g and QB_g (t_{ABSET}) Turn on
- Allows for ZVS at switch node QB_d

How is ZVS Achieved @ QD_d





- L_{LK}+ L_S Tanking with Capacitance at Switch Node (QD_d)
  - Easier to achieve ZVS
  - Reflected Output Current Provides Energy for LC Tank
- Add Delay QC_g and QD_g (t_{CDSET}) Turn on
- Allows for ZVS at switch node QD_d

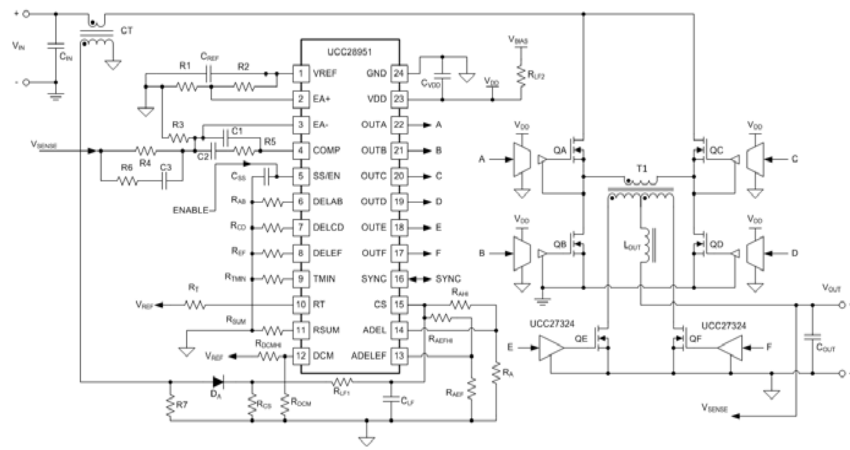
UCC28951-Q1 Phase-Shifted Full-Bridge Controller for Wide Input Voltage Range

Features

- Qualified for Automotive Applications
- Enhanced Wide Range Resonant Zero Voltage Switching (ZVS) Capability
- Direct Synchronous Rectifier (SR) Control
- Light-Load Efficiency Management Including
  - Burst Mode Operation
  - Discontinuous Conduction Mode (DCM), Dynamic SR On and Off Control with Programmable Threshold
  - Programmable Adaptive Delay
- Average- or Peak- Current Mode Control

Benefits

- Qualified for Automotive environment
- Highly integrated Controller for High Power Density Power Designs
- High efficiency across load
- Reduced power stage component stress with ZVS for improved reliability
- Optimized for Wide Vin conditions found with on-vehicle battery storage systems as input



Applications

- Electric Vehicle DC-DCs, Inverters and On-board Chargers
- Solar Inverters
- Server Power Supply
- UPS

24-pin TSSOP

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The Flyback for auxiliary power applications

The Flyback is the topology of choice for isolated auxiliary power applications:

- Low cost topology with low parts count
- Handles a wide range of input voltages
- Can easily support multiple outputs
- Outputs can be higher or lower than the input
- Isolation

The main disadvantage is that does not lend itself well to high output currents >5A and high output power levels >150 W.

Flyback Example (Bias/Aux Supply 5W to 150W)

- Small Flyback PSU for Primary or Secondary Side power
- UCC28C4X-Q1 for example
- Primary side regulation with no optocoupler or secondary side regulation with an optocoupler
- Simple, low cost transformer
- Small size, SOIC8
- Fixed Frequency operation
- Webench design tool available UC28C4x Webench link

UCC28C4X-Q1 | High Performance Current Mode PWM Controller

Features

- **AEC-Q100 Qualified**
- 18V V_{DD} abs max
- 50µA Standby Current
- Low operating current of 2.3mA at 52kHz
- Programmable fixed frequency operation up to **1MHz**
- Fast **35ns cycle by cycle overcurrent limiting**
- **1A source/sink internal gate driver**
- **Rail to rail output swing with 25ns rise and 20ns fall times**
- Max duty cycle options of 50% and 100%
- Operating Temperature : -40°C to 125°C
- Packages: SOIC D-8

Applications

- **Automotive Power Supplies**
- **Battery Management System (BMS) DC-to-DC**
- **Inverter & Motor Control**
- **External amplifier**
- **Switch Mode Power Supplies**
- **DC/DC Converter**
- **Board Mount Power Modules**

Benefits

- High frequency operation with low startup, operating currents lowers startup loss and power consumption for improved efficiency
- Fast current sense to output delay time of 35ns ,1A peak output current provides capability to drive large external MOSFET and minimize switching loss
- **Pin compatible to UC284X family** and offer **5X performance** improvements

TIDA-01505, Automotive Bias Supply Reference Design (60W)
Wide V_{IN} = 40 V – 1 kV, V_{OUT} = 15V, 4A, UCC28C43-Q1
Optional Opto-coupler Feedback

Design Features

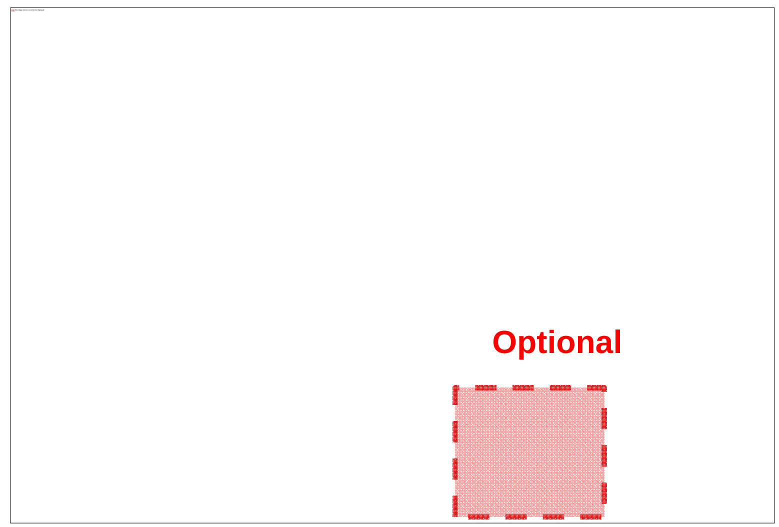
- Wide-Vin isolated Fly-back DC/DC converter over the Ultra wide input voltage range of 40V to 1000V DC, up to 1200V transient.
- Regulated output voltage 15V and output current up to 4A.
- SiC MOSFET solution with high voltage rating, low gate charge, and fast switching transients.
- SiC gate Driver adaption from an integrated MOSFET gate driver utilizing center-tapped transformer.
- Two variants included on board – with PSR regulation and with opto-coupler feedback for customer evaluation.
- Current mode control with cycle-to-cycle over current limitation.
- Automotive Grade 1 qualified Transformer with Reinforced isolation (tested at 5.7kV High-Pot).

Tools & Resources

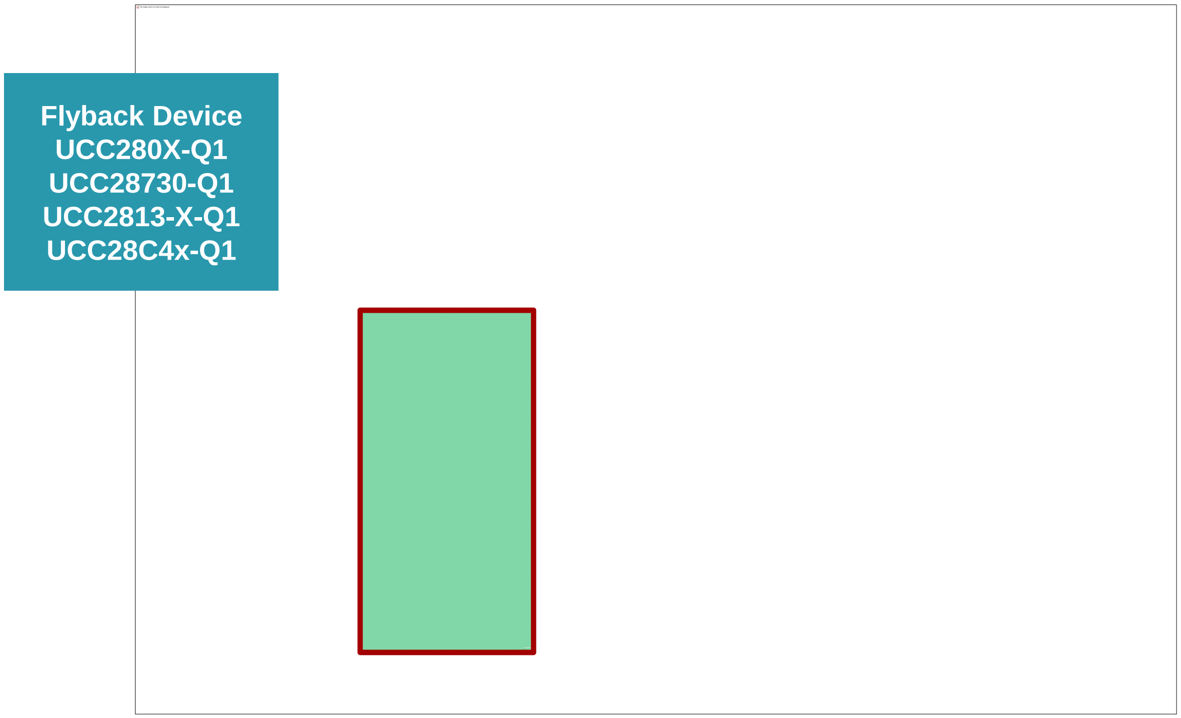
- **TIDA-01505 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files

Design Benefits

- Designed for isolated unidirectional power supplies in HEV/EV Traction Inverter systems
- Support regenerative breaking with the minimum start-up voltage of 40V
- Extendable to higher voltage and higher power range
- Automotive Grade 1 qualified Transformer with Reinforced isolation
- Two variants with and without opto-coupler included on board



Other Q1 Rated Flyback Controllers from TI



Auxiliary power converts energy from storage elements (400V Battery / 48V Battery / 12V Battery) or intermediate voltage level to points of Loads.

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Gate Driver Considerations

- MOSFET gate appears as a capacitor (to a good first approximation)
- Aim is to reduce MOSFET switching losses
- Drive MOSFET gate correctly –
  - Keep MOSFET OFF when it is supposed to be OFF
  - Keep MOSFET ON when it is supposed to be ON

- MOSFET turn-on and turn-off times must be minimised
- Needs a low impedance source
- High peak currents (4A to 5A typ) but Low average currents

Driver may or may not have to cross an isolation barrier

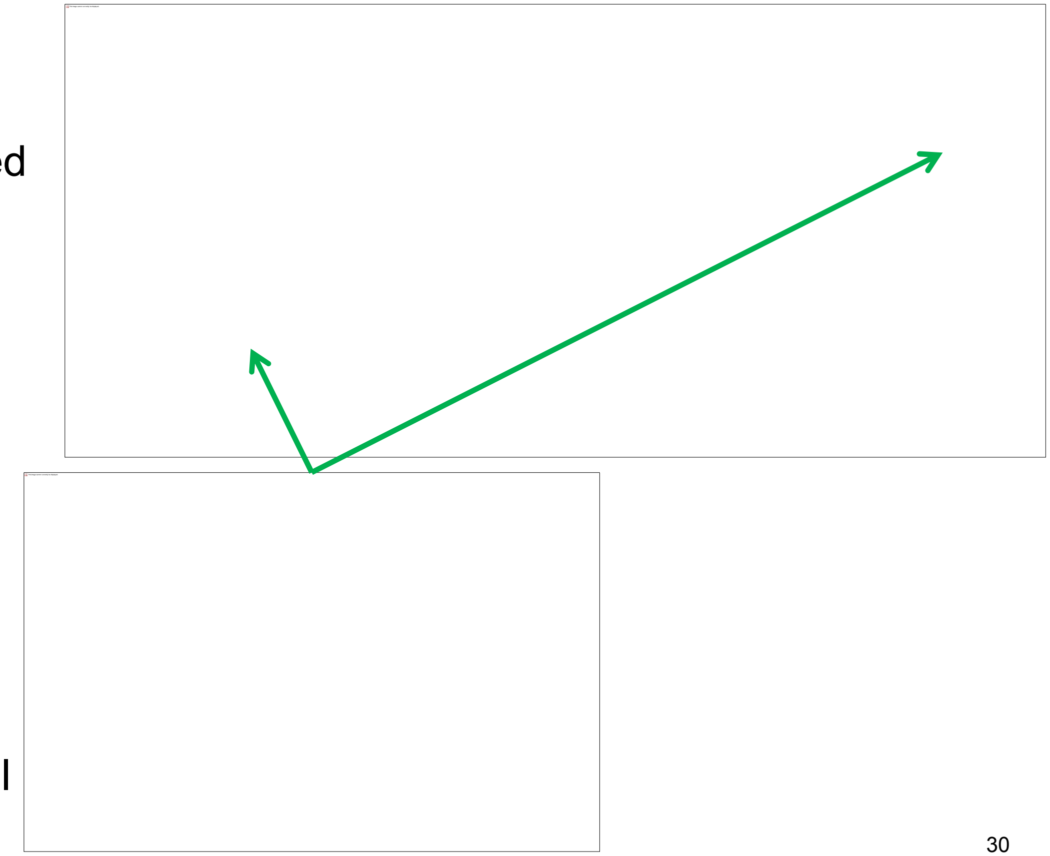
Low side Driver – MOSFET is Ground referenced

High side Driver – MOSFET is not Ground referenced

Option 1: UCC21520-Q1 Isolated Driver

- Primary/Secondary Isolation
- Switching of Primary side MOSFETs
- High Side and Low Side outputs needed
- 4 isolated outputs in total
- 2 high side drives, 2 low side drives
- Isolation to 5.7kV$_{RMS}$

- 2 x UCC21520-Q1, 4A, 6 A driver
- Low Propagation Delays
- Good Propagation Delay Matching
- Adjustable Dead Time
- Safety Features, UVLO etc.
- As with all drivers, PCB layout is critical



UCC21520-Q1 2-Channel Isolated Gate Driver

Features

- Pin-for-pin with Si823x and ADuM4223
- 6-A Peak Sink and 4-A Source Output
- 30ns Prop Delay (max), < 5ns Delay Matching, 5ns Max PWM Distortion
- 5.7kVrms Isolation Capability Input-to-Output
- >12.8kV Surge Immunity
- Programmable Overlap and Dead-time Control
- CMTI: 100V/ns (min)
- 3V to 18V Input Supply Voltage
- 6.5 V to 25 V Output Drive Supply Voltage, w/ UVLO
  - UVLO->(blank=8V, A=5V, C=12V)
- Operating range from -40 to 125ºC
- Wide Body SOIC-16 (DW) Package
- Single Input and Enable Options (see table)

Applications

- AC/DC & Isolated DC-DC Converters
- High Frequency Inverters, Motor Drives
- Si and SiC MOSFET Gate Drive
- UPS, Solar Power

Benefits

- Drop-in replacement with better performance in key areas
- High(er) drive can eliminate buffer stages and meet the requirements of a wide range of applications
- UL 1577 recognized; VDE certified
- Flexible settings to prevent shoot-through in ½ bridge applications
- Provides high noise immunity for fast/high current designs

Versions:

Option 2: Isolator (ISO7740-Q1) + Driver (UCC27712-Q1)

- Pri/Sec Isolation
- ISO7740-Q1 provides pri/sec isolation
  - 5kV RMS
- 0/10V signal from UCC28951-Q1 needs attenuation (2:1) to meet ISO7740-Q1 input level.
- UCC27712-Q1 Half Bridge Gate driver drive the MOSFETs
- ISO7740FQDWQ (F option – outputs default LOW !)

UCC27712-Q1

ISO7740F-Q1

UCC27712-Q1 Automotive 620 V 1.8/2.8 HS/LS Gate Driver

Features

- 1.8A/2.8A Current Drive Capability
- Up to 620V High-side Operation (700V abs max)
- Negative Voltage Tolerance
  - Logic Operational up to -11 V on HS pin
  - -5V Tolerance on Inputs
- Small Propagation Delay 100-ns Typical
- Delay Matching 12-ns Typical
- UVLO Protection
- Industry Standard SOIC-8 Package

Applications

- Automotive Inverters
- On-Board Chargers (PFC, Phase-Shifted Full Bridge)
- Motor Drive for Automotive Applications (Stepper Motors, Fans)

Benefits

- High Peak Current allows for fast MOSFET switching
- High Voltage Applications
- Negative Voltage capability
  - Increases Robustness
  - Reduces External Clamp circuitry
- Fast propagation delay supports higher frequency
- Ensures the driving of paralleled gates simultaneously

UCC27524A1-Q1 Gate Driver IC

- UCC27524A1-Q1 Dual 5-A High-Speed, Low-Side Gate Driver
  - Drive SRs
  - Drive Primary Side MOSFETs
- Two independent channels
- Independent enable on each channel
- Fast, matched rise and fall times
- Outputs LOW when inputs floating

- SRs are large rectifier MOSFETs.
  - Up to 5A peak for fast turn-on and turn-off

UCC27524A/A1-Q1 Automotive 18V 5A/5A Low Side Driver

Features

- ± 5A Peak Current Drive Capability (@VDD=12V)
- VDD Operating range 4.5V to 18V
- 12ns (typ) Propagation Delay
- Ability to Handle Negative Voltages
  - Inputs (-2V for 200ns)
  - Outputs (-5V)
- TTL Input Threshold
- Individual Enable Pin
- Available in MSOP-8 PowerPad and SOIC-8 Package

Benefits

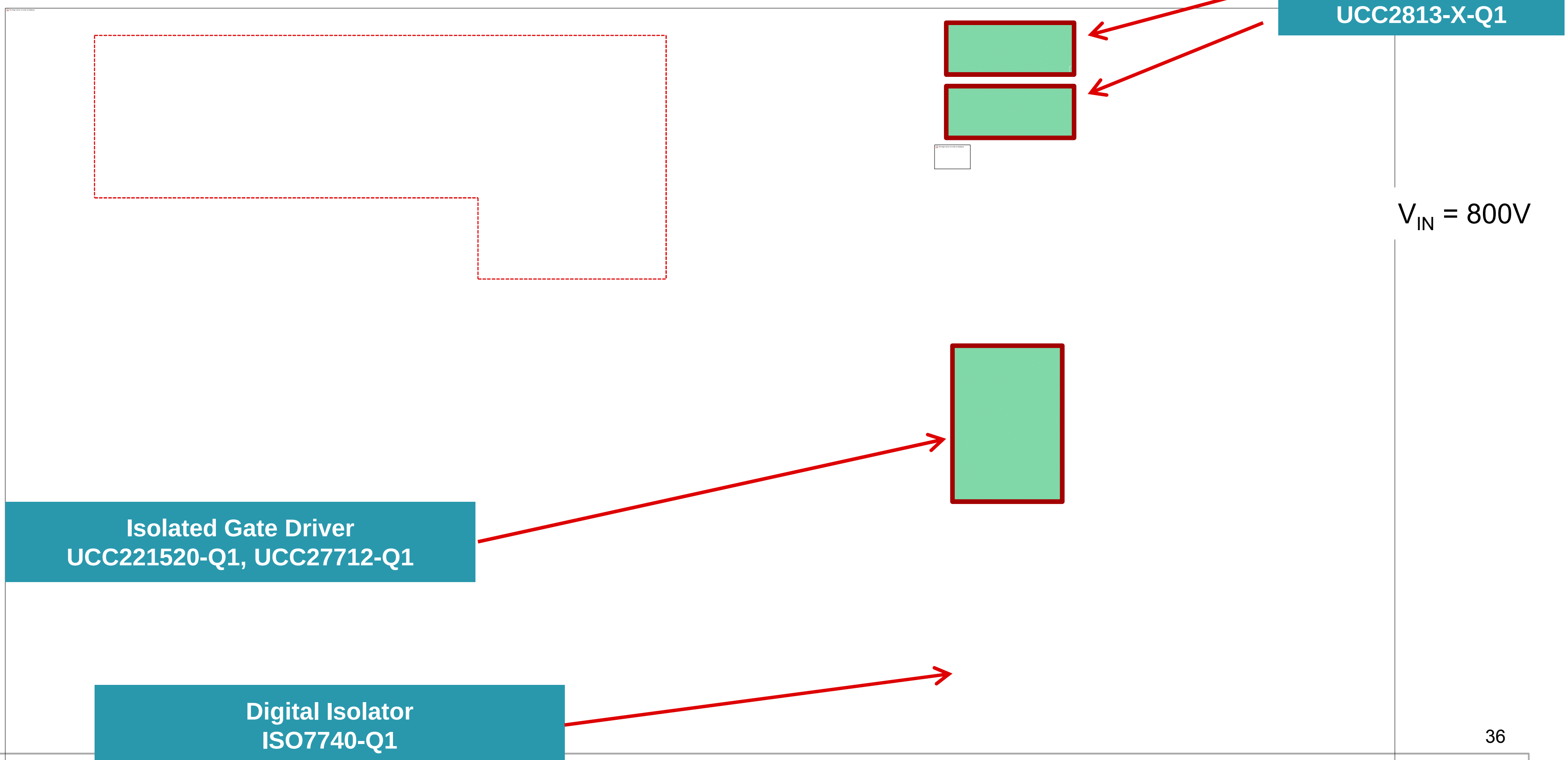
- High Peak Current allows for fast MOSFET switching
- Wide Vdd allows headroom for 12 V Applications
- Fast propagation delay supports higher frequency
- Allows for a more robust system
- Reduces External Clamp circuitry
- TTL Input allows for a more robust system

Applications

- On-Board (OBC) & Wireless Charger
- 48-12V DCDC
- 400-12V DCDC
- Auxilliary inverter

Part Number (Datasheet Link)	Protective Overcoat with BOAC
UCC27524A-Q1	No
UCC27524A1-Q1	Yes

Traction Inverter Example – High Voltage



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Discussion on Batteries

Volt/Time characteristic is approximately Linear

- Power delivered is therefore a linear function of time during CI phase

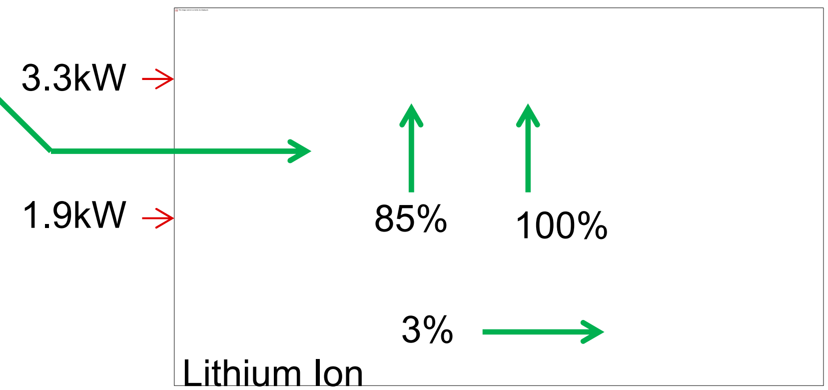
Charging time is long compared to thermal time constants in charger – typ 8 hour charge cycle

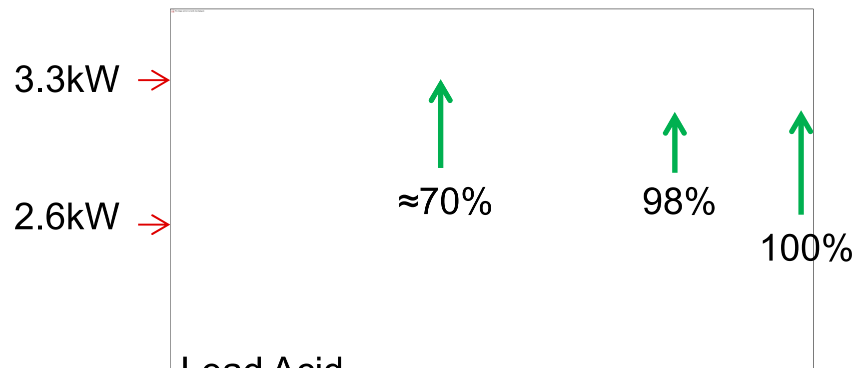
Power dissipated in charger is as important as efficiency

Good efficiency needed over wide Vout/Iout range

Not Considered here:

- Initial charging, battery stack management, thermal issues, battery lifetime





Typical Battery Charger Specifications

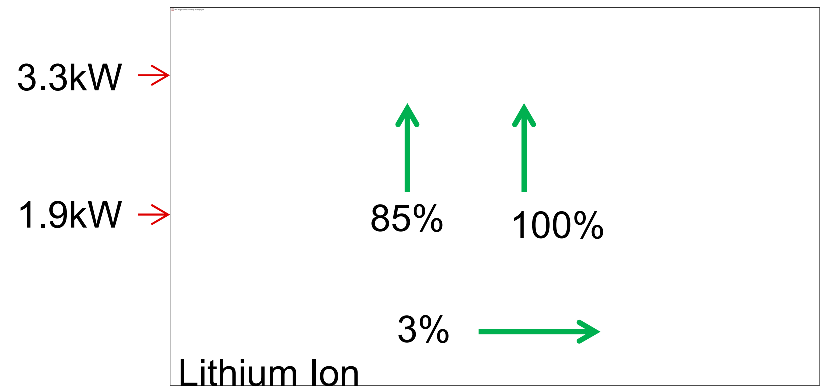
Input: Universal Single Phase Line with PFC

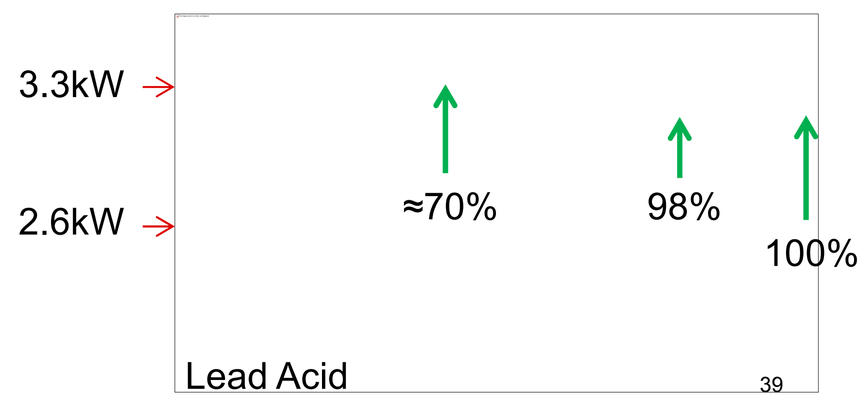
Output Voltage:
- 1.75:1 range (Li-Ion), 400V/230V
- 1.25:1 range (Lead Acid), 14.1V/11.4V

Output Power
- Pout: 3.3kW (typ), increases during charging

CI and CV modes
- ‘Normal’ protections (OCP, OTP etc…)

Topologies Required
- AC/DC: Boost PFC (UCC28070-Q1)
- DC/DC: PSFB (UCC28951-Q1)





CI / CV operation for OBC (UCC28951-Q1)

Two feedback paths

- One measures output current
  - Compare to reference
  - Output error signal (power demand)
- One measures output voltage
  - Compare to reference
  - Output error signal (power demand)
- Diode ‘or’ errors – lowest error ‘wins’
  - Automatic CV / CI transition

Lowest error ‘wins’

& Controls the output

Low side sense at 400Vout

High side sense at 12Vout is possible

- +

Float signal from MCU - Lead Acid only

How to Design Multi-kW Converters for Electric Vehicles

Topics:

HEV/EV Powertrain Solution for On-Board Charger

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.

Solution

1-phase Analog OBC:
- PFC Controller
- Isolated DCDC Controller
- Flyback Controller for Aux Power
- Dual Channel Driver

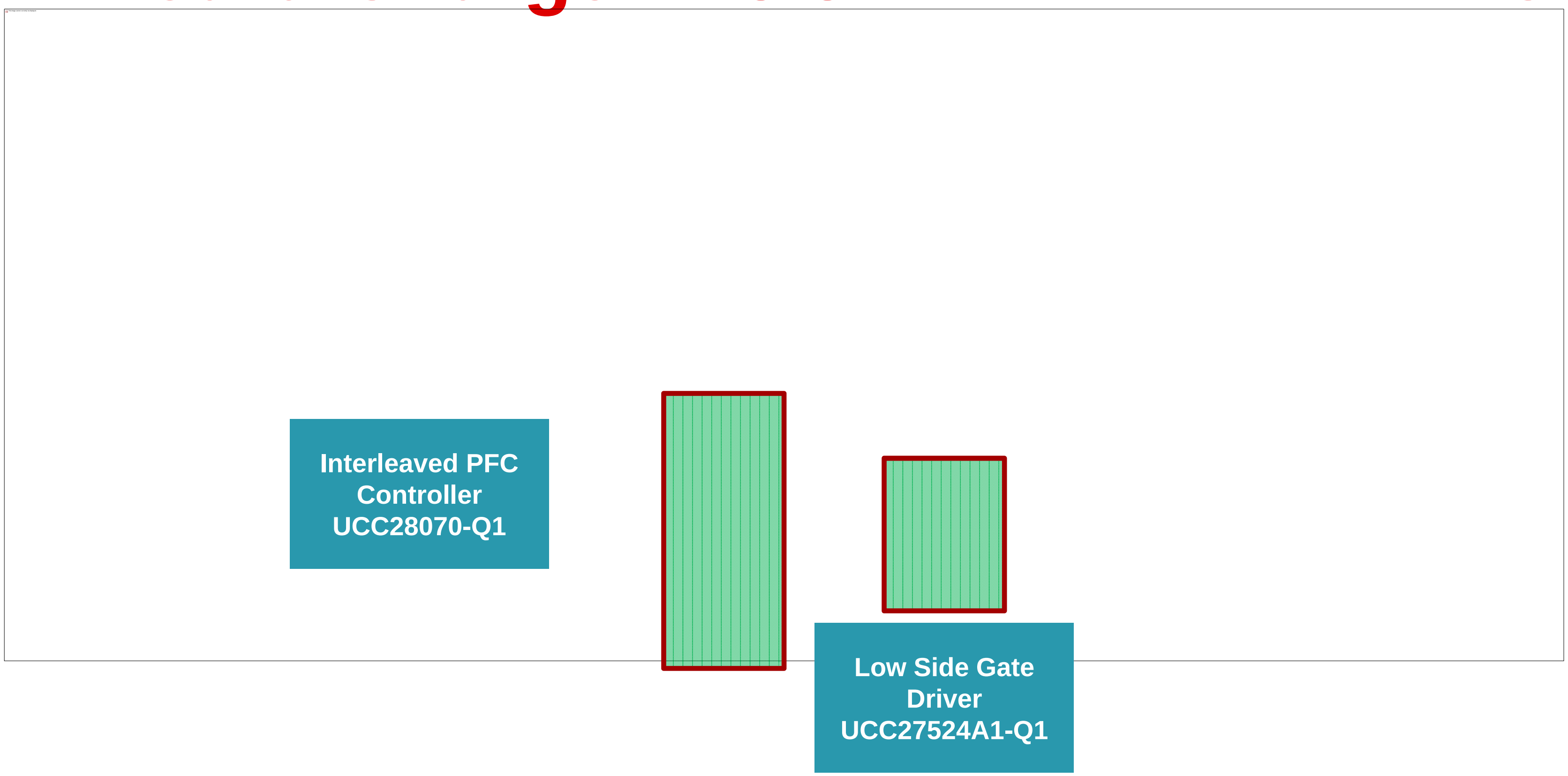
3-phase Analog OBC:
- 3x PFC Controller
- 3x Isolated DCDC Controller
- 3x Flyback Controller for Aux Power
- 3x Dual Channel Driver

Digital OBC and Wireless Charging:
- Flyback Controller for Aux Power
- Dual Channel Driver

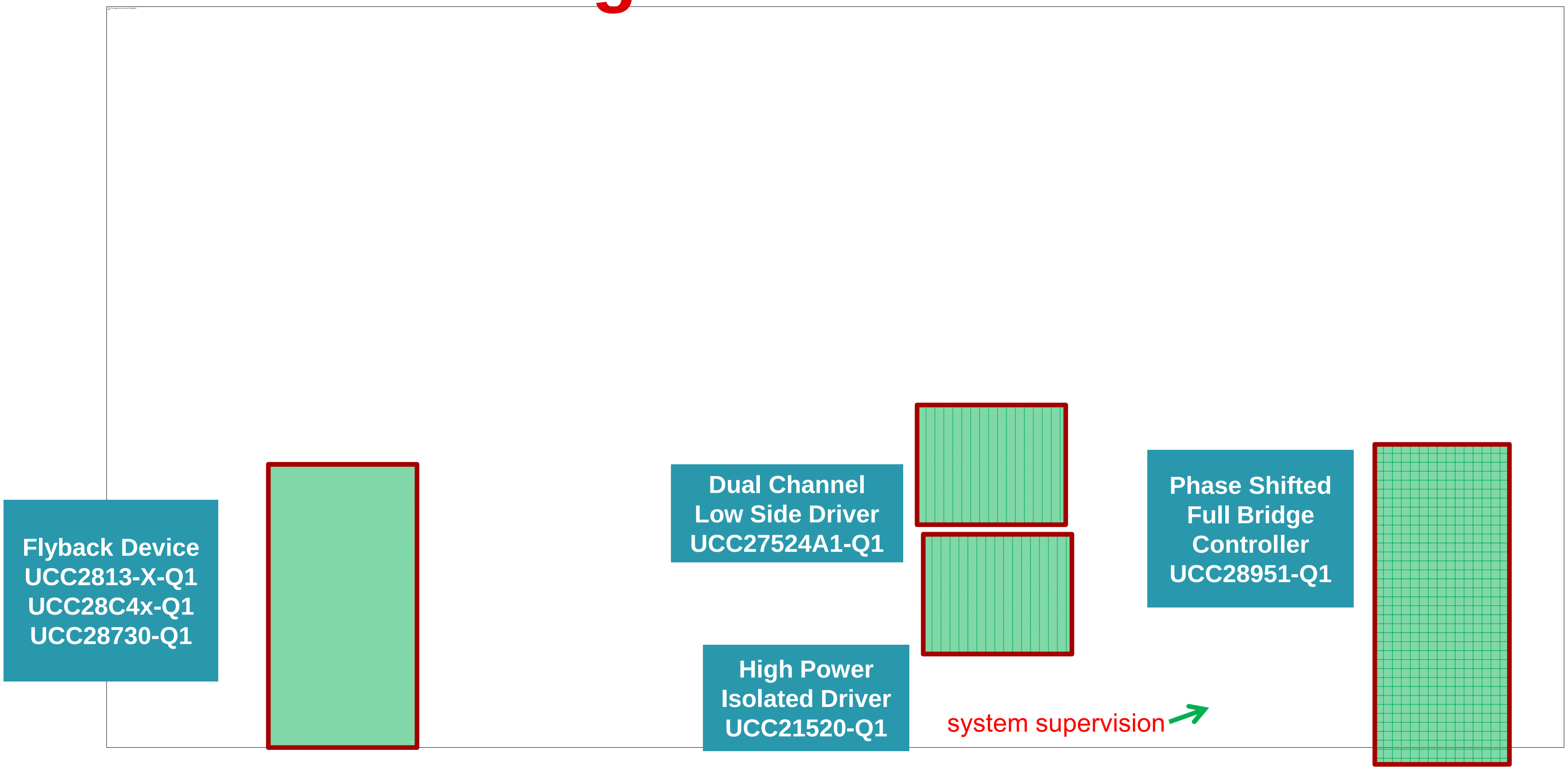
Key Components

- Phase Shifted Full Bridge Controller: UCC28951-Q1, UCC2895-Q1 (no SR)
- Interleaved CCM PFC: UCC28070-Q1
- Fixed Frequency Flyback: UCC28C4X-Q1 and UCC280X-Q1
- Dual Channel Low Side Gate Driver: UCC27524A1-Q1
- Half Bridge Gate Driver: UCC27712-Q1
- Isolated Dual Channel Gate Driver: UCC21520-Q1, UCC21222-Q1

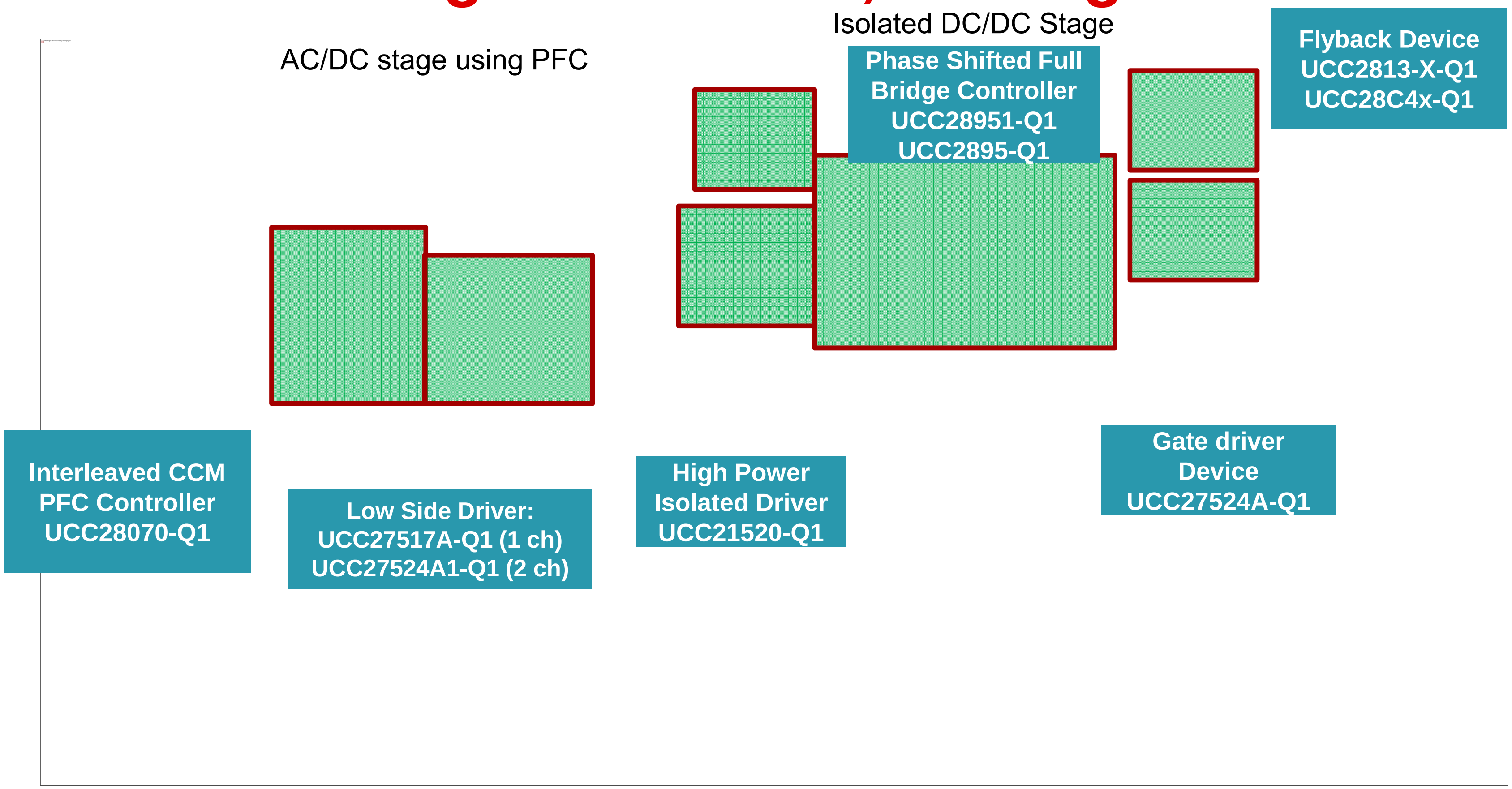
On Board Charger < 3.3kW PFC



On Board Charger < 3.3kW DC-DC



On-Board Charger - 3 Phase, Analog Control



Three Phase System > 3.3kW

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

App Note: Synchronizing Three or more UCC28951-Q1

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

Current Sharing PSFB
With (optional) SYNC

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

How to Design Multi-kW Converters for Electric Vehicles

Topics:

1. Electric Vehicle (EV) Power Systems
2. On Board Charger (OBC) Overview
3. Power Factor Correction (PFC)
4. The Phase Shifted Full Bridge (PSFB), 500 W to 3.3 kW +
5. Auxiliary Power, 5 to 150W
6. Gate driver considerations
7. Introduction to Battery Chargers
8. HEV/EV Powertrain Solutions
9. References/Design Resources

References

Ref 1: Fundamentals of Power Electronics, Erickson and Maksimovic; Springer 2001, Table 18.3, summary of rectifier current stresses.

Ref 2: Analytic Expressions for currents in the CCM PFC stage, http://www.ti.com/lit/ml/slyy131/slyy131.pdf , Gillmor.

Ref 3: Predicting output-capacitor ripple in a CCM boost PFC circuit, https://e2e.ti.com/blogs_/b/powerhouse/archive/2016/06/14/predicting-output-capacitor-ripple-in-a-ccm-boost-pfc-circuit Gillmor

Ref 4: SLUP279 An Interleaving PFC Pre-Regulator for High-Power Converters. O'Loughlin

Ref 5: Capacitor Ripple current in an interleaved PFC converter, Pratt and Jinsong, IEEE transactions on Power Electronics, Vol 24, No 6 June 2009.

Ref 6: http://www.ti.com/lit/an/slua479b/slua479b.pdf Interleaved PFC design review. O'Loughlin

Blog: Are-you-ready-for-totem-pole-pfc

GaN FET-Based CCM Totem Pole Bridgeless PFC

Magnetics Design Handbook, Dixon.

Understanding the basics of flyback converter design

Synchronizing Three or More UCC28950 PSFB Controllers http://www.ti.com/lit/an/slua609/slua609.pdf

Design Resources

- Power factor correction (PFC) controller
  - http://www.ti.com/lsds/ti/power-management/power-factor-correction-overview.page
- Isolated DC/DC controller
  - http://www.ti.com/lsds/ti/power-management/pwm-resonant-controller-overview.page
- TI Reference designs
  - http://www.ti.com/general/docs/refdesignsearchresults.tsp
- Technical Support at TI E2E™ Community
  - https://e2e.ti.com/
- High Volt Interactive Training Series
  - https://training.ti.com/high-voltage-training
- Power Topologies Quick Reference Guide
  - http://www.ti.com/lit/ug/slyu032/slyu032.pdf
- Power Topologies Handbook
  - https://www.ti.com/seclit/ug/slyu036/slyu036.pdf
- Power Supply Design Seminars
  - http://www.ti.com/ww/en/power-training/login.shtml?DCMP=pwr-psds-archive&HQS=pwr-psds-archive-psds
- Power Stage Designer™
  - http://www.ti.com/tool/powerstage-designer?DCMP=powerstagedesigner&HQS=powerstagedesigner
- Introduction to Power Electronics
  - https://training.ti.com/introduction-power-electronics?HQS=pwr-null-null-pentonever-asset-tr-null-wwe

Summary

- EV/HEV Systems are Complex and require many DC to DC and AC to DC power converters
  - Auxiliary and bias supplies, flyback converters, 5 W to 150 W.
    - ✓UCC28700-Q1, UCC28730-Q1, UCC28C4X-Q1, UCC2813-X-Q1
  - To fully utilize line power requires PFC >1.92 kW to 19.2 kW
    - ✓UCC28070-Q1, Interleaved PFC
  - To deliver high power DC to DC power requires soft switching and synchronization.
    - ✓UCC28950/1-Q1

Analog AC/DC and Isolated DC/DC solutions for Automotive HEV/EV Applications

Thank You

Mike O'Loughlin, Colin Gillmor