# How to Design Multi-kW Converters for Electric Vehicles



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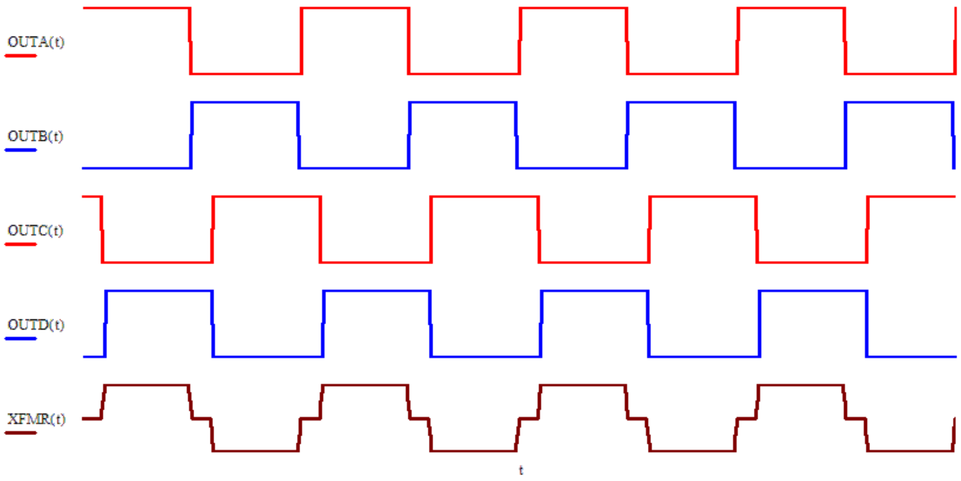
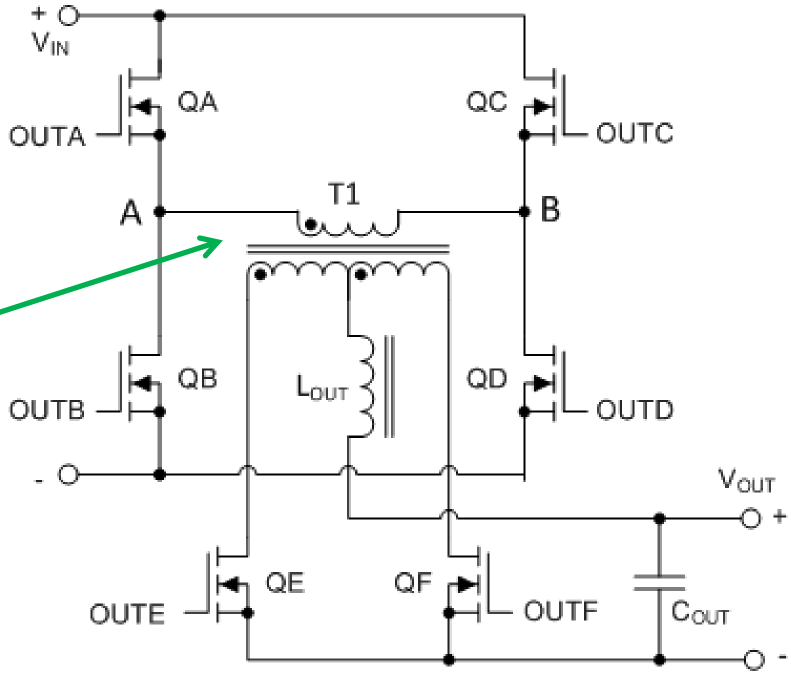
# Phase Shifted Full Bridge




PA Leg
(Passive/Active)
Left Leg
QA, QB

AP Leg
(Active/Passive)
Right Leg
QC, QD




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

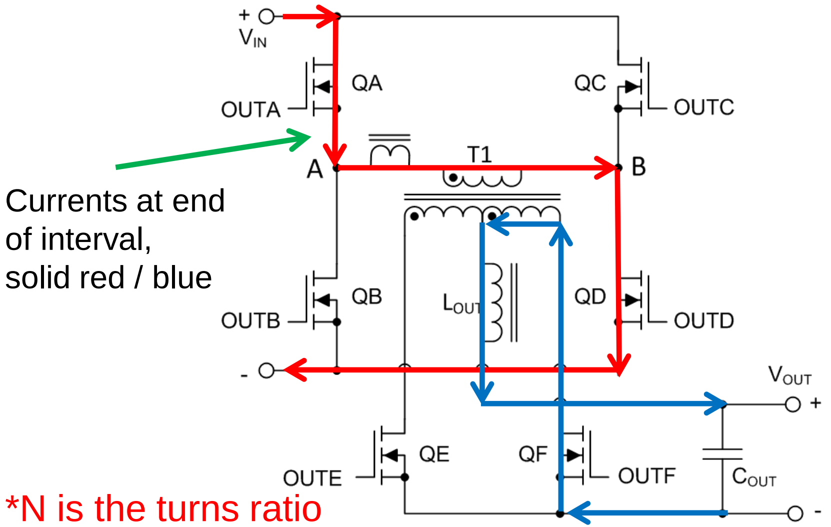
OUTA, OUTB – reference pair

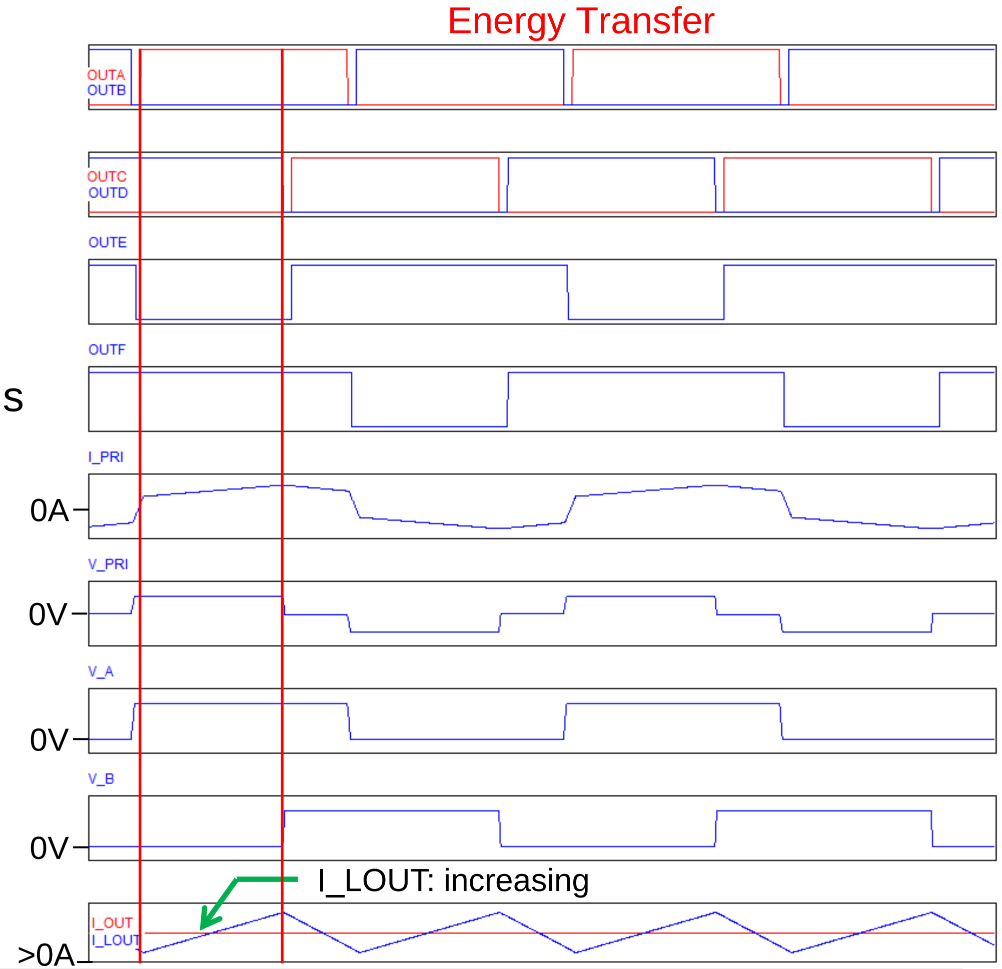
D controlled by phase shifting OUTC & OUTD

QE, QF are SRs, Diode rectification is possible

# Timing Diagram: 1

- QA, QD, QF are ON: others are OFF
- First energy transfer interval
- I_PRI is Iout /N* + Imag.
- QF current is Iout
- Current flow in red (pri) and blue (sec) paths



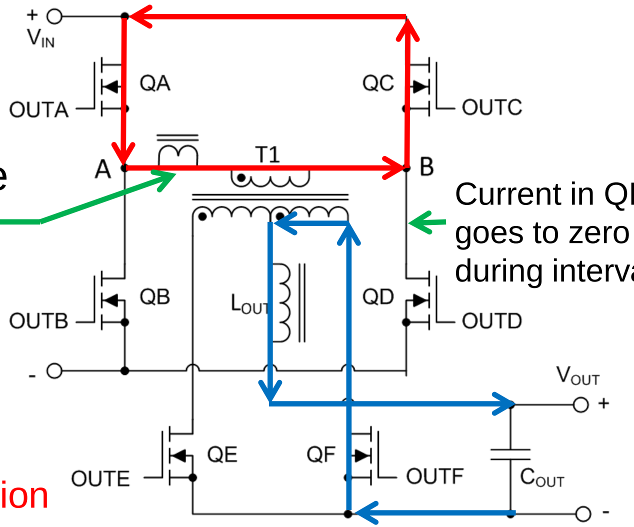




*N is the turns ratio

# Timing Diagram: 2

- QA, QF are ON: QC is OFF
- QD turns OFF
- Node B charges to Vin as I_PRI current moves out of QD and into QC Body Diode*
- QC: turns ON

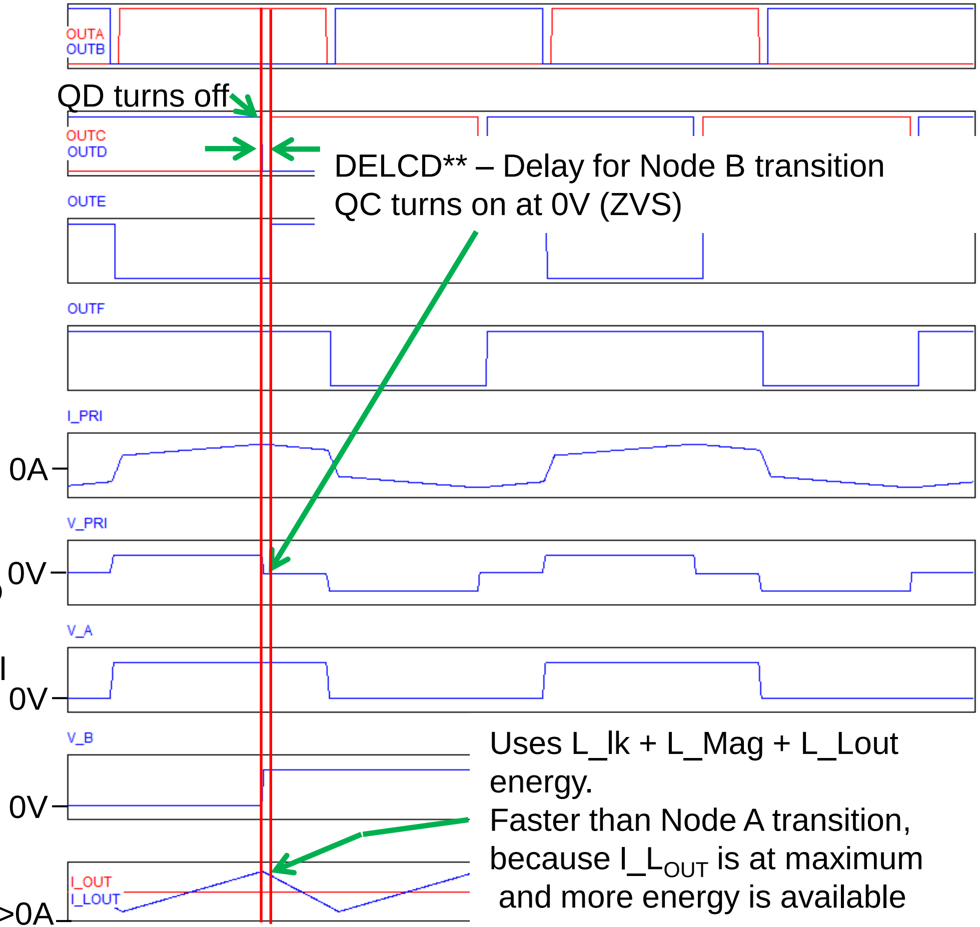
Leakage Inductance L_lk




Current in QD goes to zero during interval

*ZVS transition

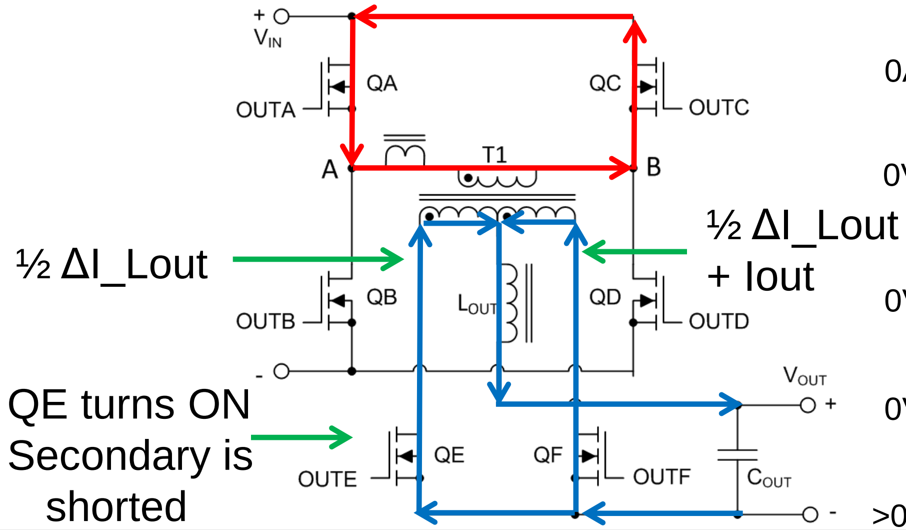
ZVS (Right leg transition)

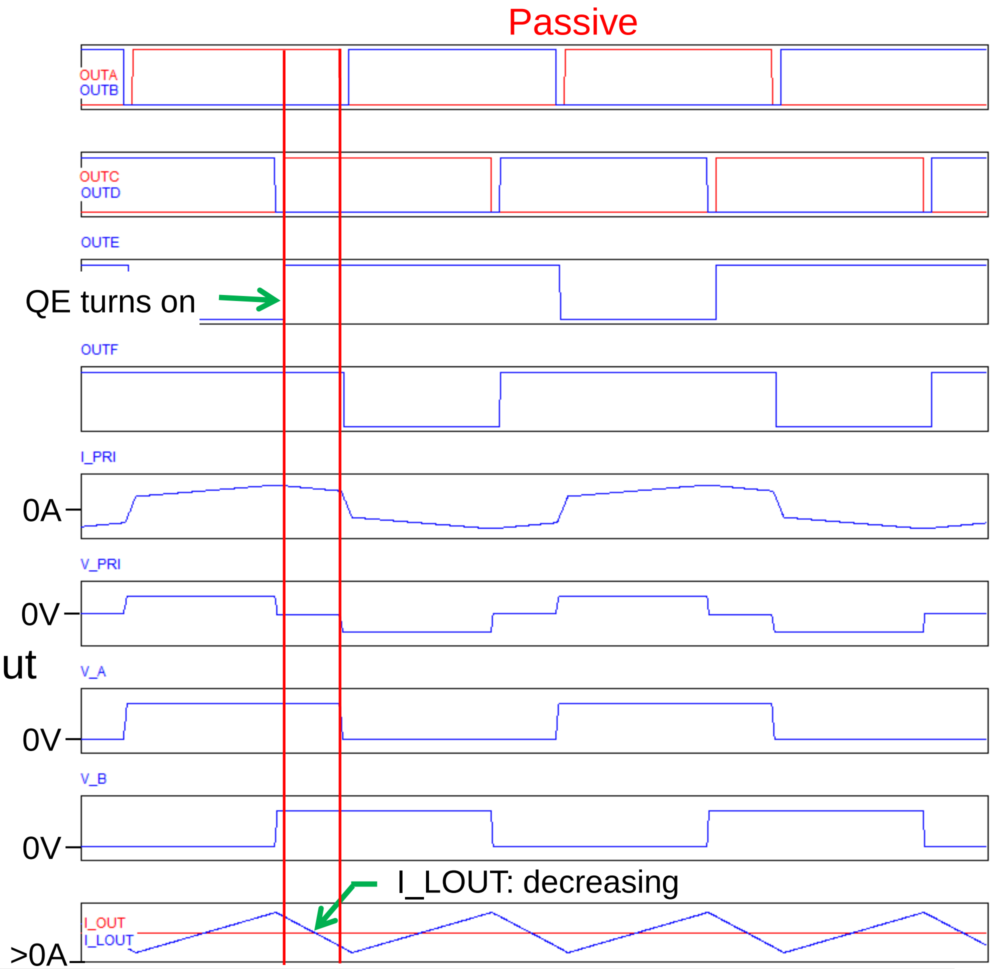



Uses L_lk + L_Mag + L_Lout energy.
Faster than Node A transition, because I_$L_{OUT}$ is at maximum and more energy is available

# Timing Diagram: 3

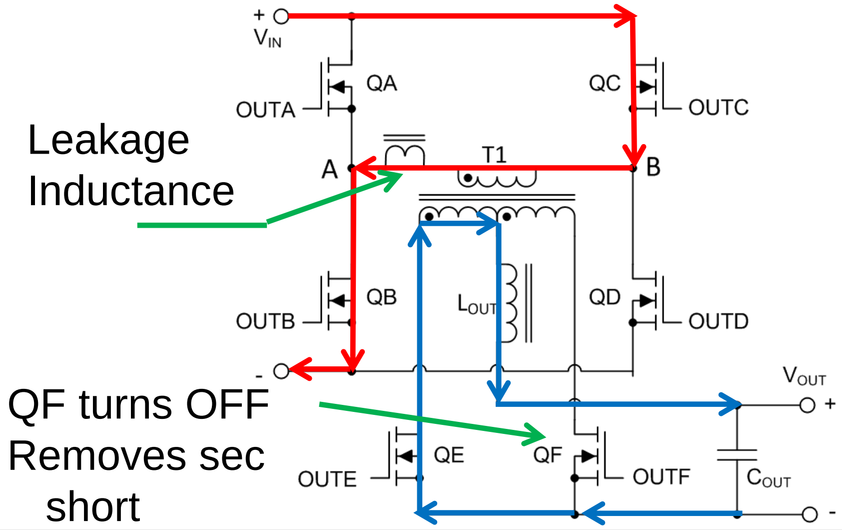
- QA, QC, QE, QF are ON: others are OFF
- T1 Primary is short circuited, $V_{XFMR}$ = 0V
- T1 Sec is short circuited by QE & QF
- Output current supplied by Lout
- Current flows asymmetrically in T1 Sec !

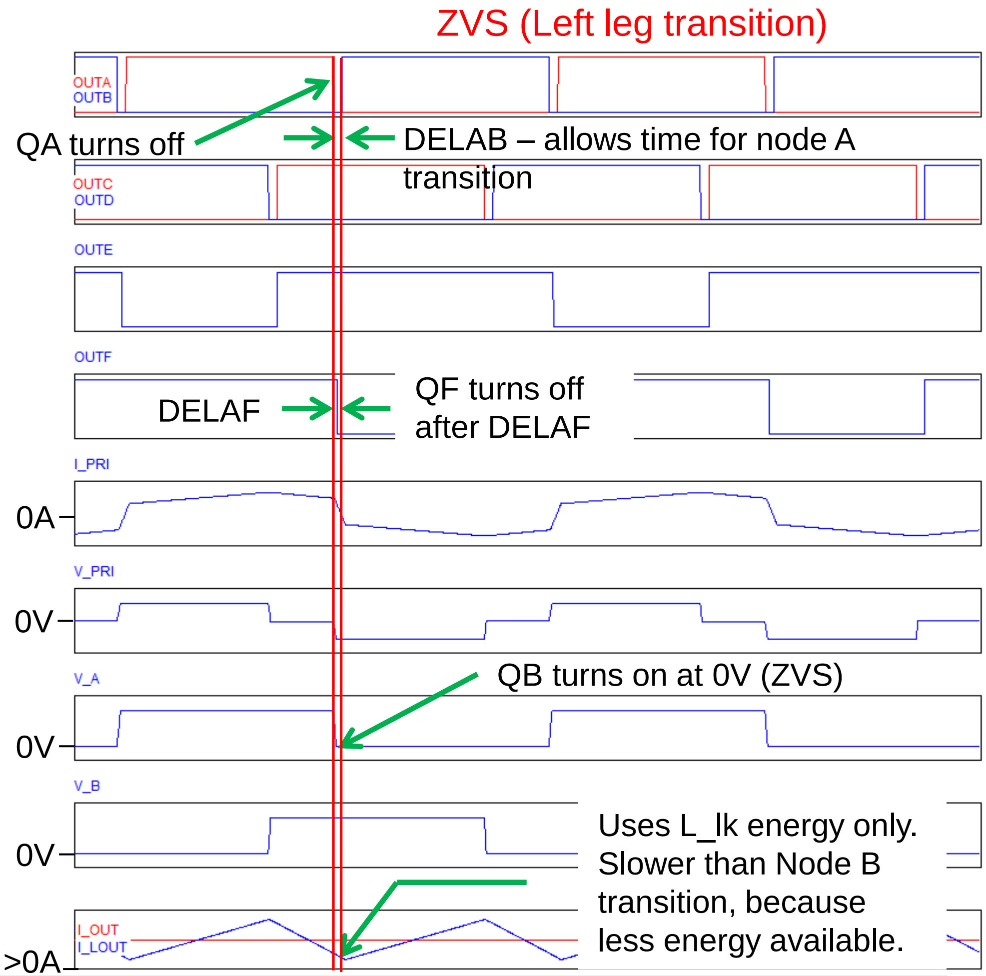


# Timing Diagram: 4

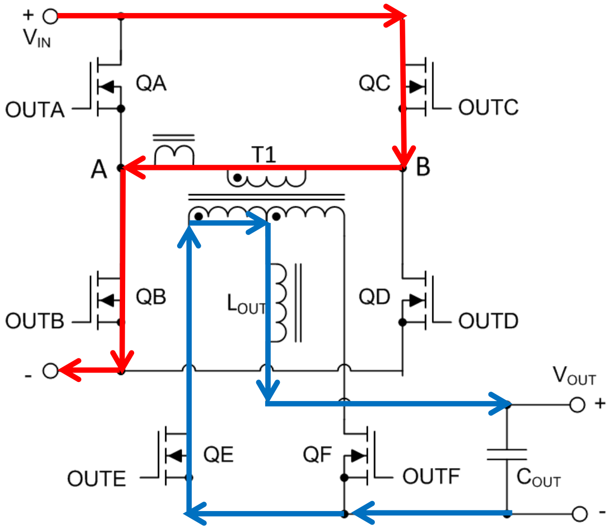
- QA, QC, QE are ON: QB is OFF
- QA turns OFF
– Node A charges to GND as I_PRI current moves out of QA and into QB Body Diode
- QB: turns ON

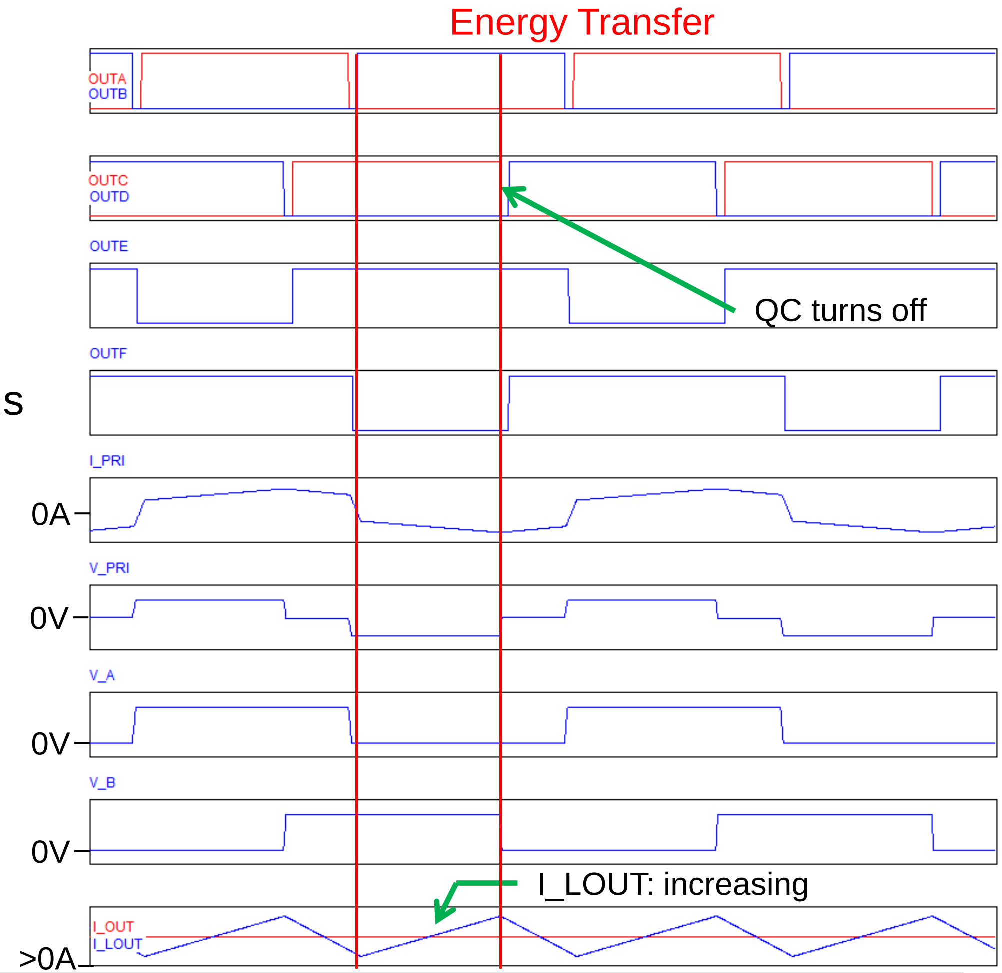


# Timing Diagram: 5

- QB, QC, QE are ON: others are OFF
- Second energy transfer interval
- I_PRI is Iout /N* + Imag
- QE current is Iout
- Current flow in red (pri) and blue (sec) paths



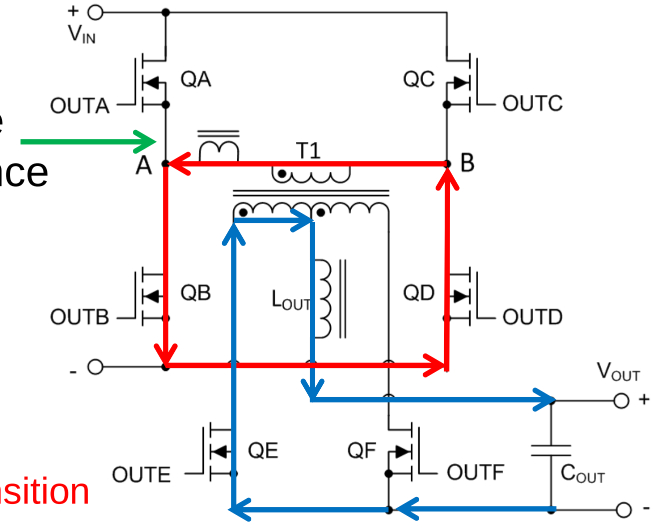




*N is the turns ratio

# Timing Diagram: 6

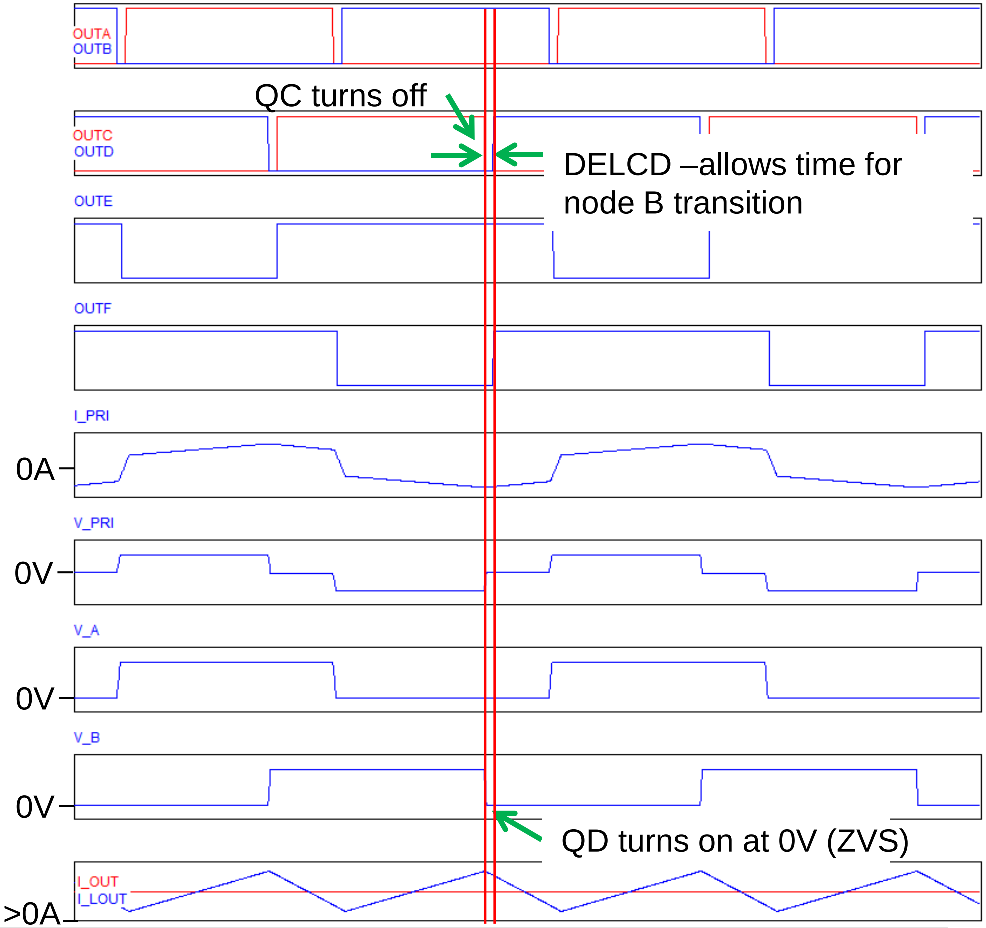
- QB, QC, QE are ON: QD is OFF
- QC turns OFF
- Node B charges to Gnd as I_PRI current moves out of QC into QD Body Diode*
- QD: turns ON

Leakage Inductance



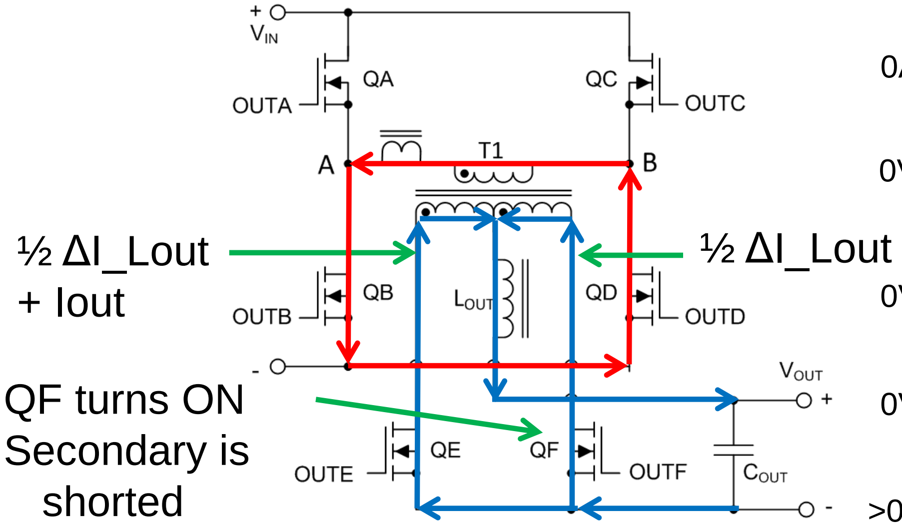

*ZVS transition

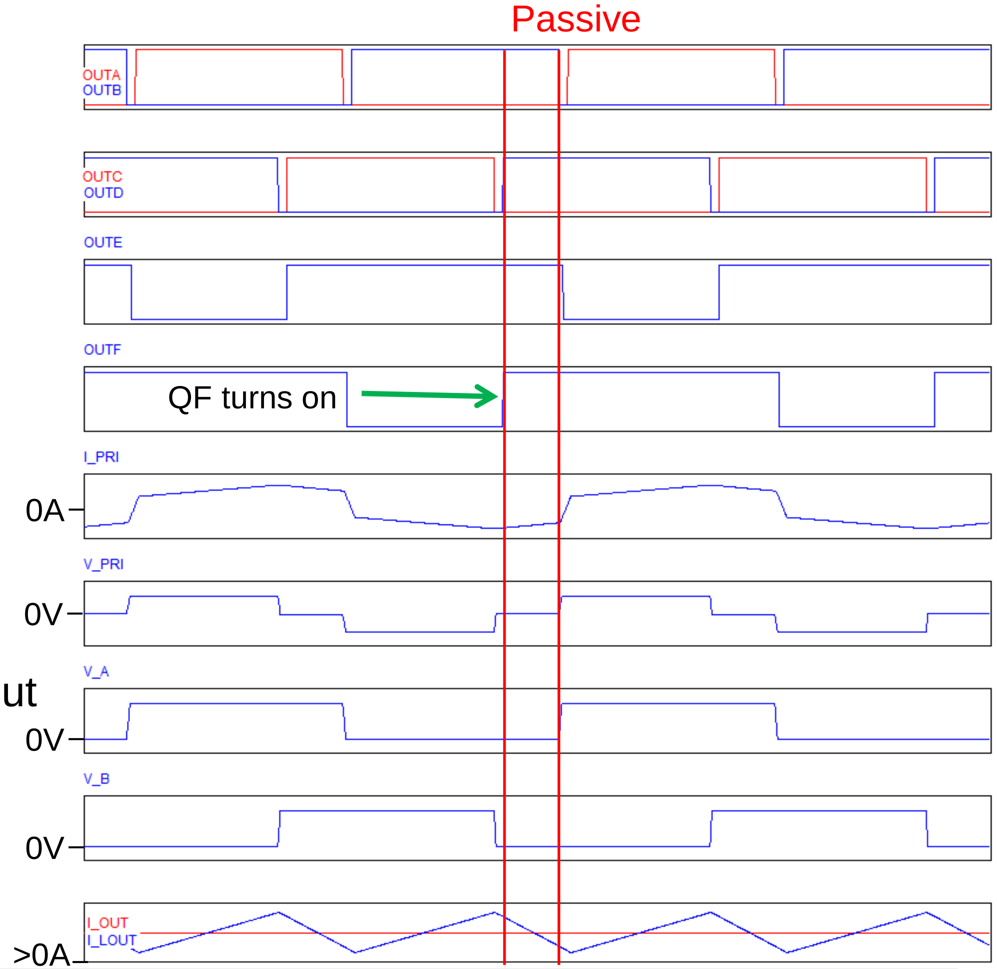
ZVS (Right leg transition)



# Timing Diagram: 7

- QB, QD, QE, QF are ON: others are OFF
- T1 Primary is short circuited, $V_{XFMR}$ = 0V
- T1 Sec is short circuited by QE & QF
- Output current supplied by Lout
- Current flows asymmetrically in T1 Sec



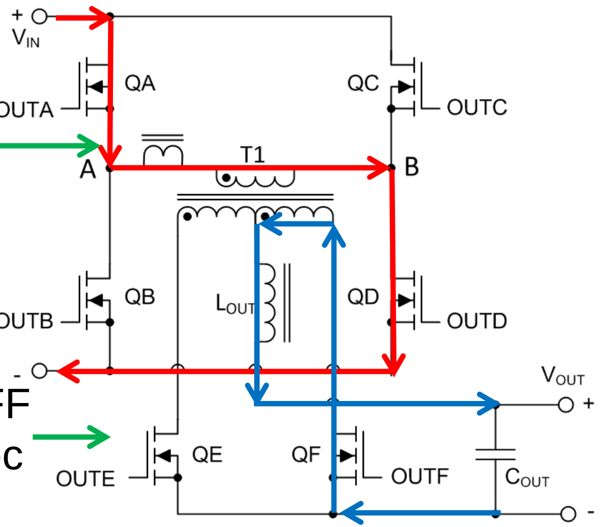



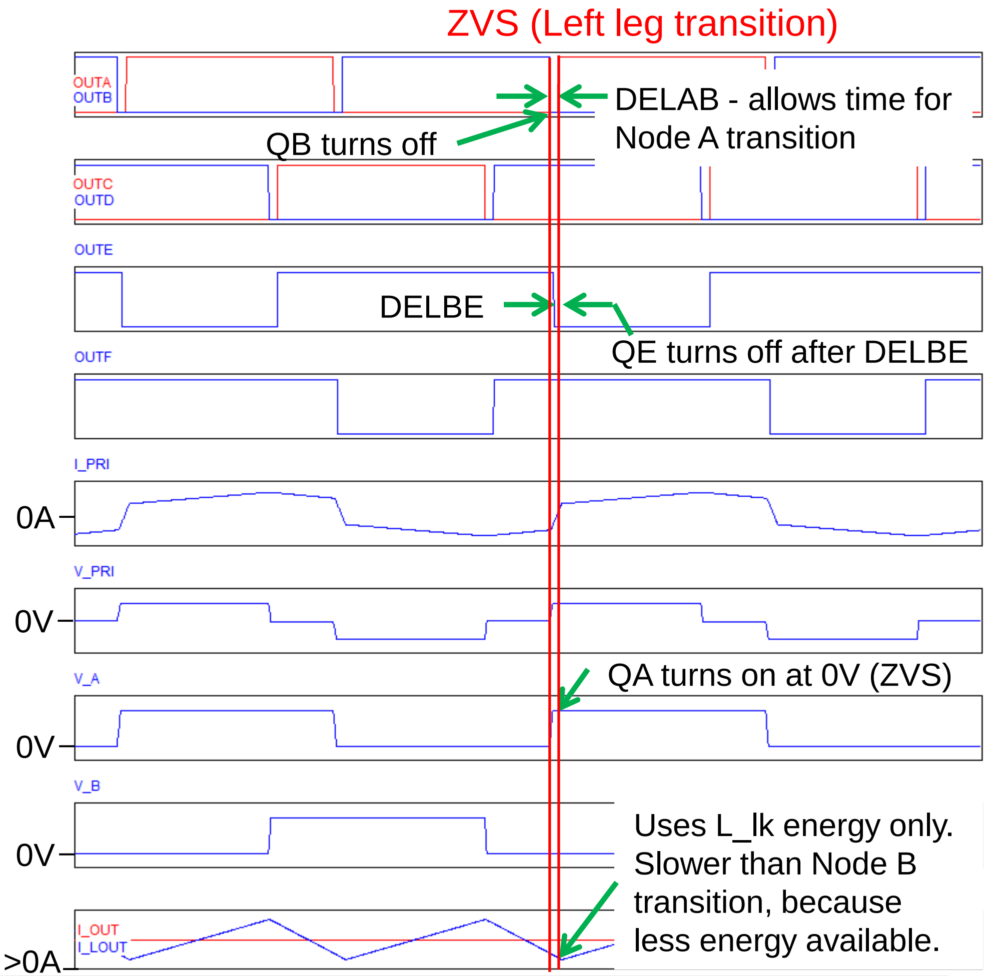
# Timing Diagram: 8

- QB, QD, QF are ON: QA is OFF
- QB turns OFF
- – Node A charges to Vin as I_PRI current moves out of QB into QA Body Diode
- QA: is turned ON

Leakage Inductance

QE turns OFF Removes sec short



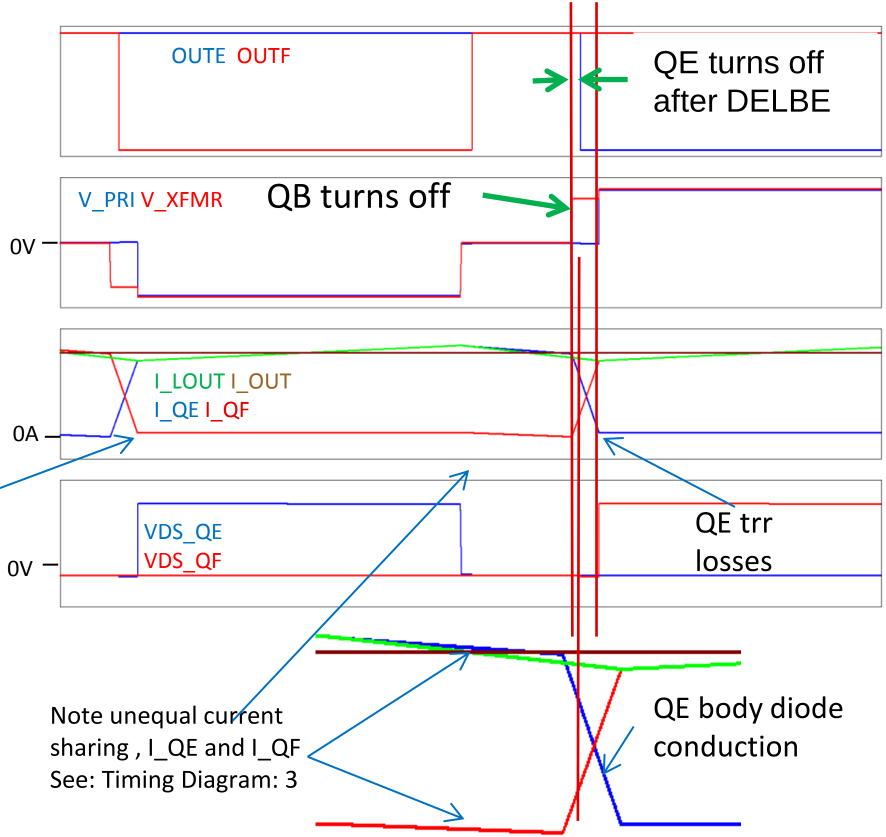



# SR Transitions: PA

PA = Passive/Active (Left leg)

- Current has to transfer out of one SR into the other.
- This takes time, di/dt is set by leakage inductance
- SRs always switch with zero volts.
- SR turns off before current goes negative
- Body diode conduction interval after SR turned off
- DELBE associated with positive transition at PA leg
- DELAF associated with negative transition at PA leg
- DELBE = DELAF

SR current will go negative* and be carried in Channel if SR not turned off in time.
Destructive voltage spike if SR is turned off with negative* current
Very important to avoid this



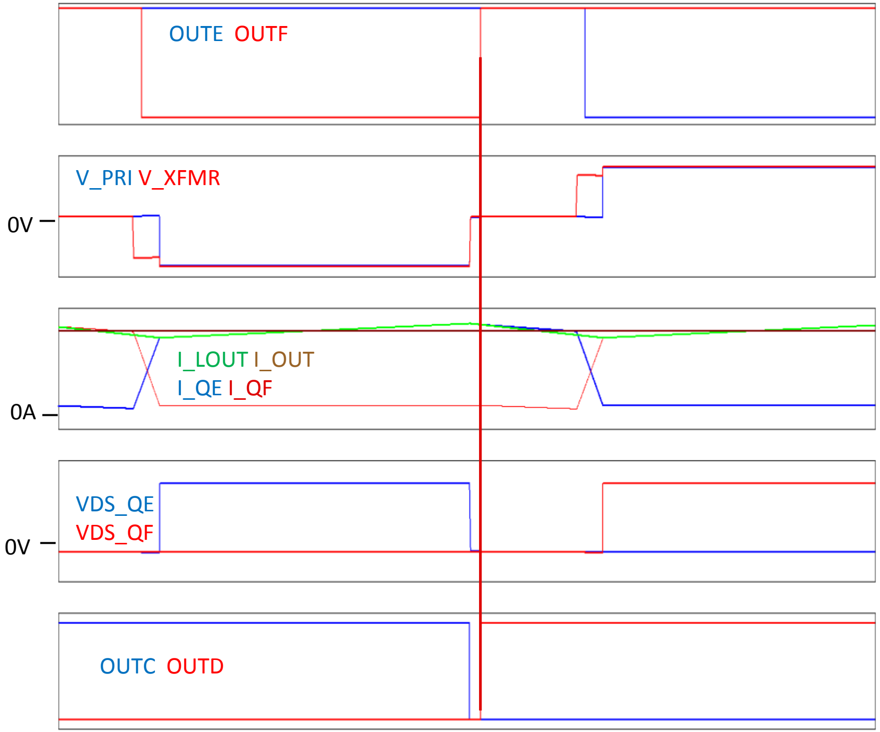

* Negative current means from drain to source.

# SR Transitions: AP

AP = Active/Passive (Right Leg)

- SRs see ZVS at AP transition
- SR turn on is co-incident with primary side switch OUTD/OUTF and OUTC/OUTE

The transformer secondary becomes short circuited when the second SR turns on (OUTD in this diagram)



# PSFB: Other Features

Adaptive Delays: The time needed to achieve ZVS for both Left and Right legs is a function of the transformer current. Some controllers allow the user to change the delay times of the primary and secondary switches as a function of the current,

UCC28950, UCC28951-Q1, UCC2895-Q1 all offer adaptive delays.

SR disable: The ability to disable the SRs and revert to diode rectification at light loads. This prevents reverse currents in the resonant tank and improves light load efficiency.

Bi-Directional operation: The PSFB isn't well suited to bi-directional operation but we do have some examples -

PMP5726  This is a slow drain modulation power converter – not truly bi-directional but it allow SRs to operate right down to zero load for improved transient response.

TIDA-00653 A 48V/12V bidirectional battery charger. PSFB in forward direction. Push-Pull in reverse direction

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# Thank You



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