Flyback with Active Clamp: a suitable topology for Low Power and very wide Input Voltage Range applications

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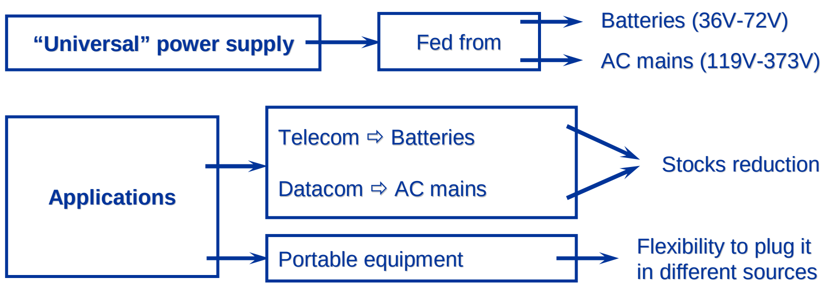
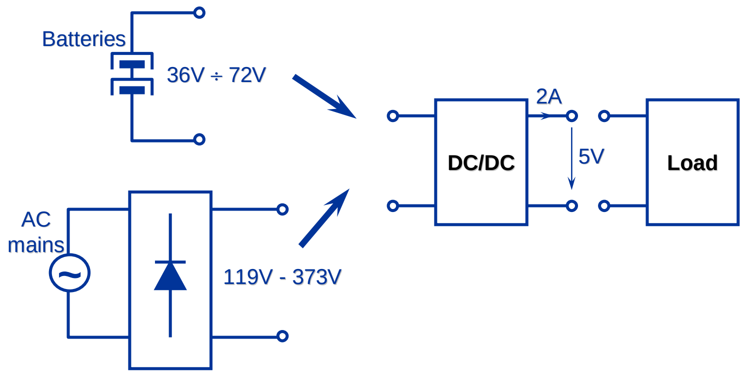
Motivation



Dallas, APEC´02 (March 10-14, 2002)

Specifications

Input voltage range →	36V ÷ 373V (1:10)
Low power →	10W

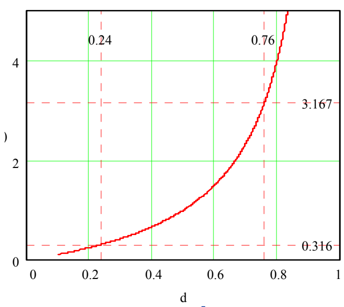


Critical issues to select the topology

Simplicity →	Size and cost
Isolation →	373V → 5V
Regulation capability →	1:10 V_{IN} range

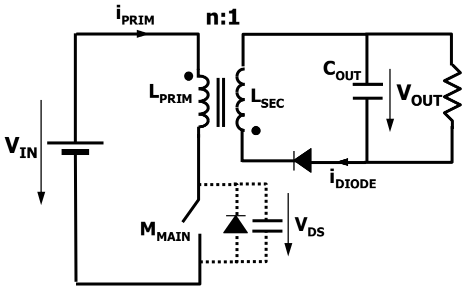
Flyback type topologies

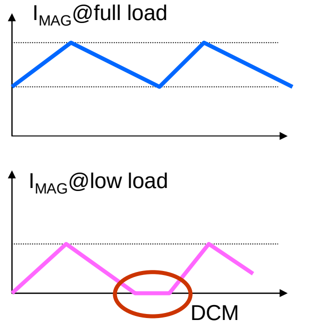
$$\text{gain} = \frac{d}{1-d}$$



24% < d < 76%

Flyback topology: DCM





Discontinous Conduction Mode

$$\frac{V_o}{V_{IN}} = d\sqrt{\frac{T}{2L_M R_L}}$$

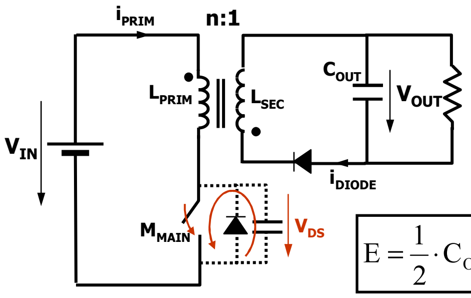
Load dependent

- Minimum load
- Increase transformer size

→ to avoid DCM

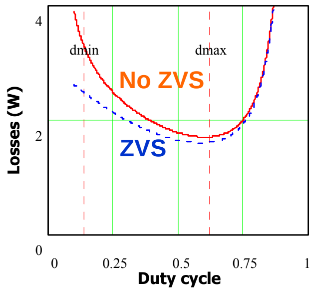
Regulation capability is constrained

Flyback topology: Turn-on losses



$$E = \frac{1}{2} \cdot C_{OSS} \cdot V_{DS}^2$$

f_{SW} = 150kHz

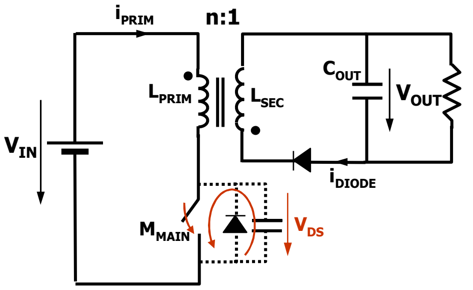


NO ZVS →	3.3W @ V_{IN} = 373V
ZVS →	2.4W @ V_{IN} = 373V

Turn-on losses are 30% of total losses at high V_{IN}

ZVS should be regarded to select the topology

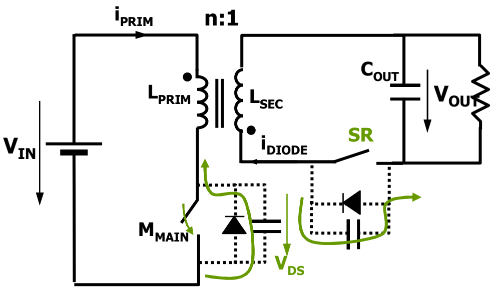
Flyback topology: summary

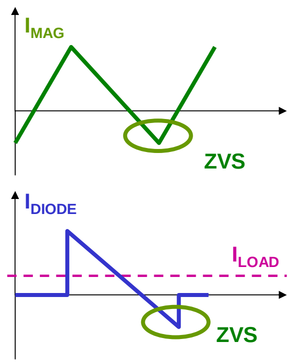


- ✓ Very simple topology
- ⊘ It goes into DCM
- ⊘ ZVS is NOT feasible

NO SELECTED: V_{IN} range too wide

Flyback with Synchronous Rectification



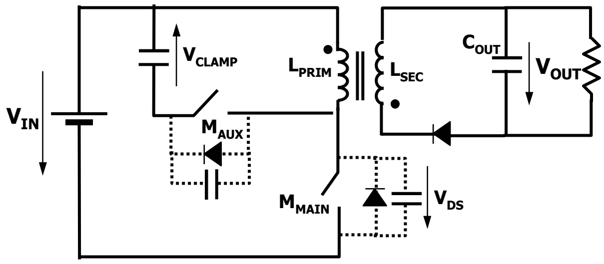


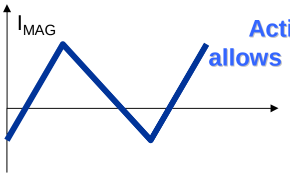
- ✓ NO DCM: good regulation capability
- ✓ ZVS achievable by negative I_{MAG}
- ✓ Synchronous rectification
- ⊘ SRs should be extrernally driven
- ⊘ Higher RMS secondary current

High RMS current → Resistive losses
→ Output filter

More suitable at lower V_{OUT} (1.5V, 3.3V)
Trade-off: ZVS - Conduction losses

Flyback with Active Clamp



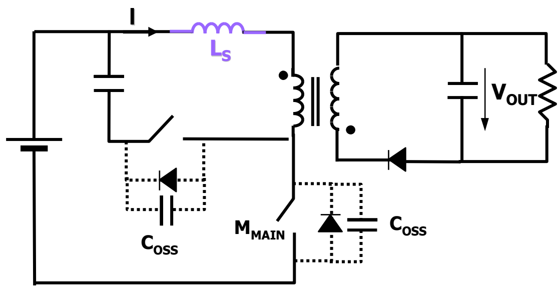


NO DCM: good regulation

Flyback with AC: Series inductance for ZVS

ZVS with the leakage inductance + extra inductance [4]

$$\frac{1}{2}L_s I^2 > \frac{1}{2}C_{OSS}V_{DS}^2$$



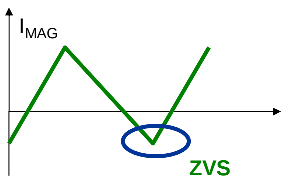
L_{LK} is not enough, extra L_S should be added in a low power (10W) high V_{IN} (373V) application

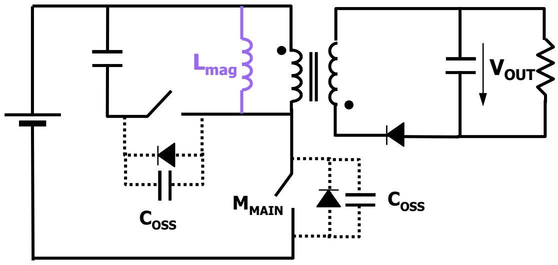
Flyback with AC: ZVS with L_{MAG}

UPM DIE

With the Magnetizing Inductance

[5] C.P. Hence, et al APEC'88



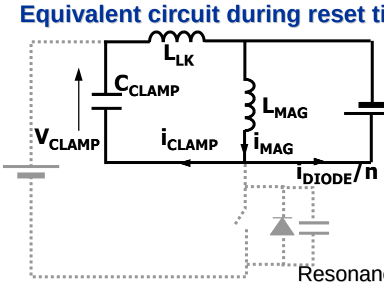


- ✔ No extra inductance for ZVS
- ✔ Smaller transformer size since ΔI_{MAG} is higher
- Current ripple is not very high in a low power application

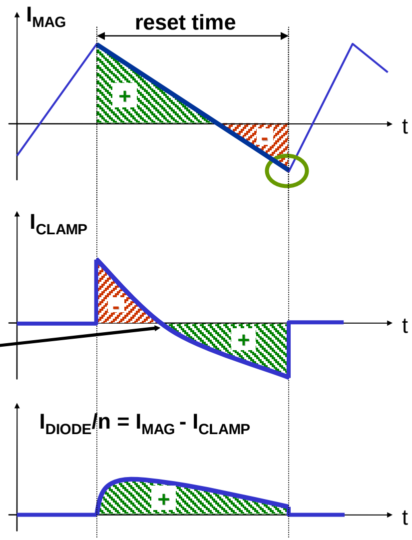
Flyback with AC: Operation during reset time

UPM DIE

Equivalent circuit during reset time

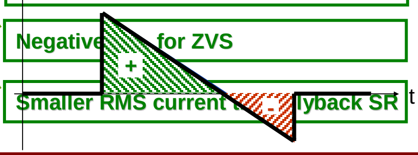


Resonance between C_{CLAMP} and L_{LK}



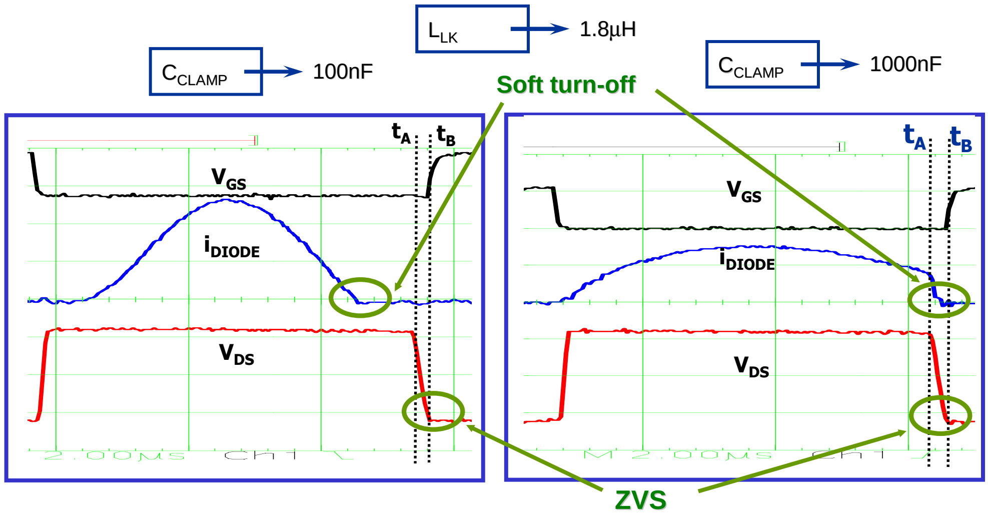
- ✔ Leakage energy is recycled
- ✔ Negative … for ZVS
- ✔ Smaller RMS current … flyback SR

Flyback with SR



UPM DIE

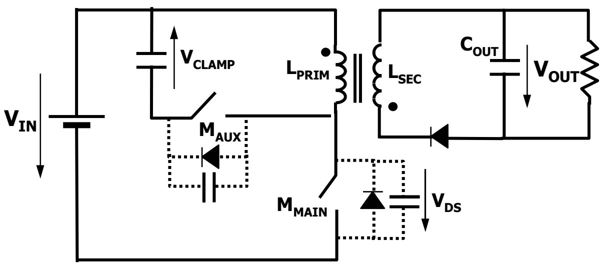
Flyback with AC: Analysis of diode turn-off



Soft turn-off of diode

UPM DIE

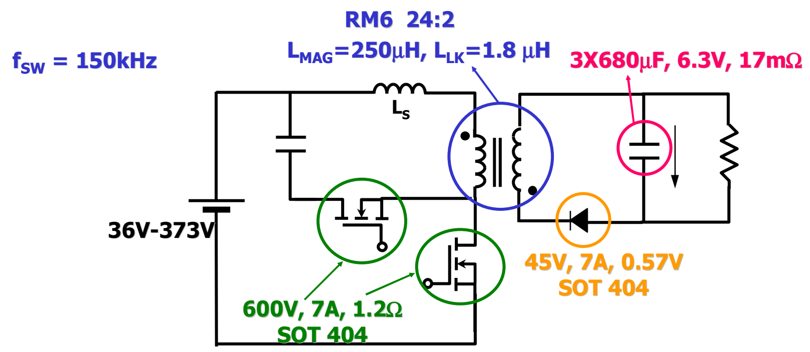
Flyback with Active Clamp, ZVS with L_{MAG}



- ✔ NO DCM: good regulation
- ✔ ZVS achievable
- ✔ Soft diode turn-off
- ⊘ Two MOSFETs to be driven: Cost
- ✔ Leakage energy is recycled
- ✔ Depending on L_{LK} - C_{clamp}, smaller RMS secondary current

Selected topology for this 5V, 10W application

Power supply design

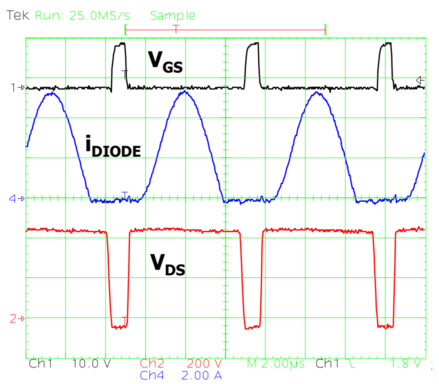


Design of f_{SW} and L_{MAG}: Trade-off between ZVS and circulating energy (ΔI_{MAG})

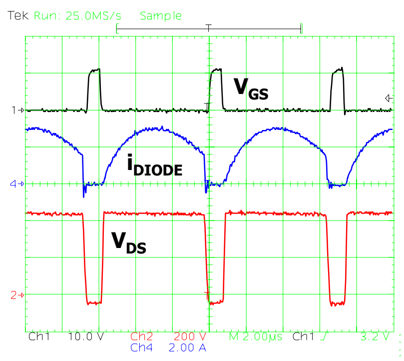
Measurements

V_{IN} = 373V

C_{CLAMP} → 100nF



C_{CLAMP} → 1000nF



C_{CLAMP} value affects i_{DIODE} waveform at high V_{IN}

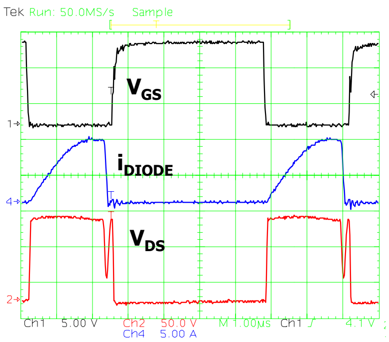
Measurements

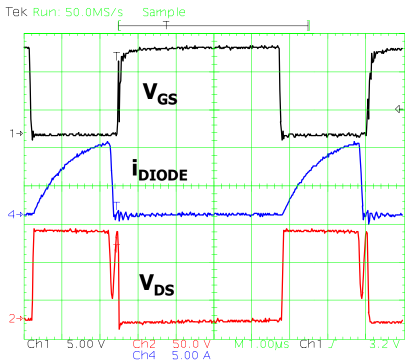
UPM DIE

V_{IN} = 36V

C_{CLAMP} → 100nF

C_{CLAMP} → 1000nF

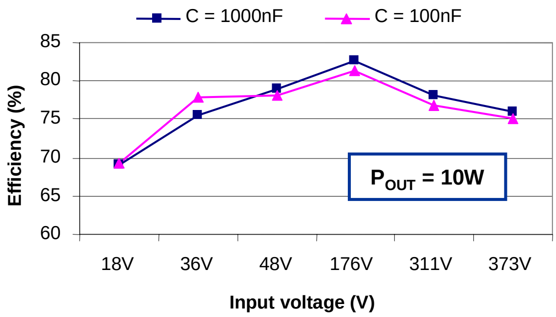




C_{CLAMP} does not affect i_{DIODE} waveform at low V_{IN}

Measurements

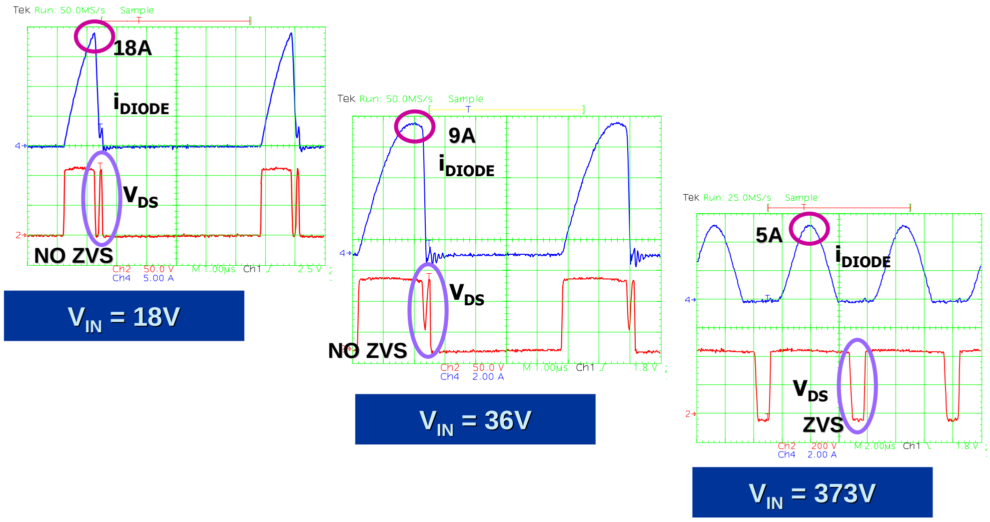
UPM DIE



- C_{CLAMP} = 1000nF provides higher efficiency at high V_{IN} since RMS current is smaller
- The converter operates even with V_{IN} = 18V (1:20 range)
- For the sake of size: C_{CLAMP} = 100nF

UPM DIE

Waveform measurements for C_{CLAMP}=100nF



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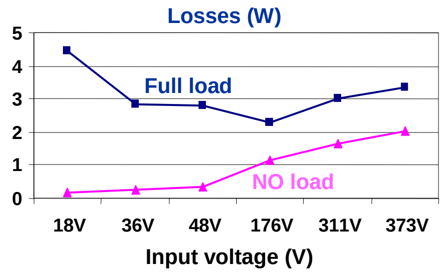
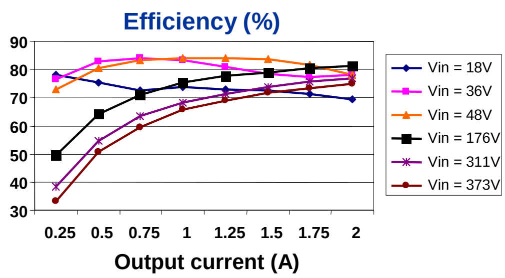
Losses with C_{CLAMP} = 100nF





- Losses at V_{IN} = 311V are 3W with ZVS.
  If partial ZVS (125V hard switching), measured losses are 5W at V_{IN} = 311V

Conclusions

Flyback with Active Clamp and L_{MAG} for ZVS → is a good solution for →
- Low power (10W)
- Wide V_{IN} range (1:10) application

Higher complexity than Flyback but Flyback with AC provides:
- Wide regulation capability (NO DCM)
- ZVS capability
- Smaller RMS secondary current
- Soft turn-off of the rectifier diode

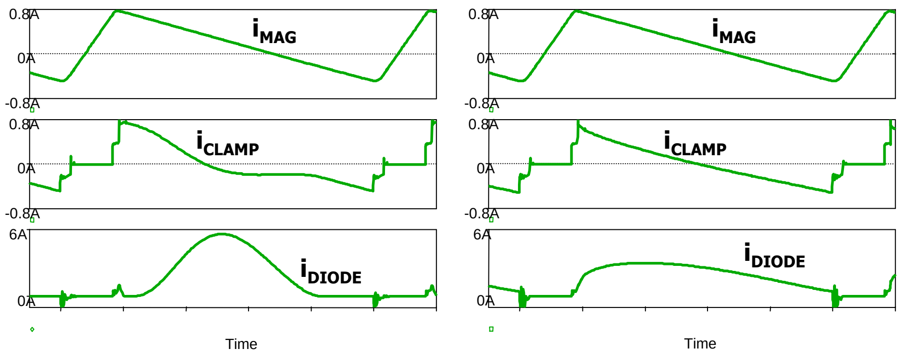
Topology analized in detail:
- f_{SW} - L_{MAG}
- C_{CLAMP} - L_{LK}

→ Important design parameters

Flyback with AC: Operation during reset time

Turns ratio → 12:1 | L_{MAG} → 250µH | L_{LK} → 1.8µH

C_{CLAMP} = 100nF | C_{CLAMP} = 1000nF

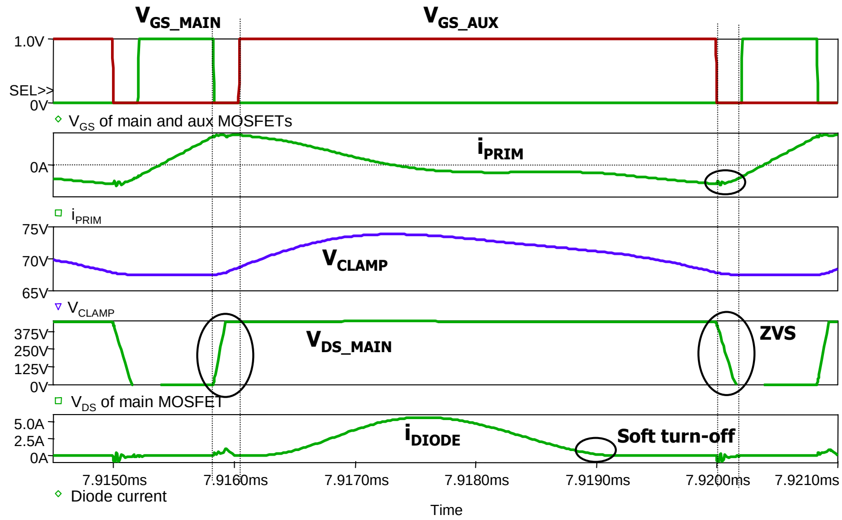


C_{CLAMP} and L_{LK} become important design parameters

Power supply design

C_{CLAMP} → 100nF

UPM DIE



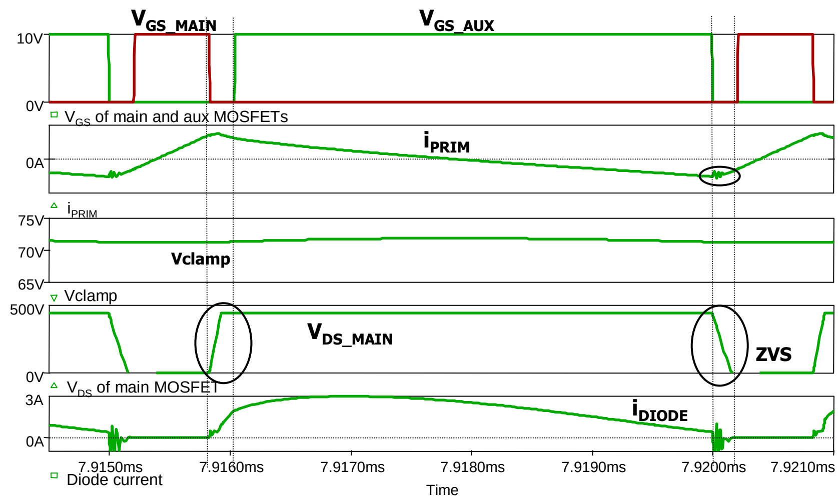
Time delays for ZVS

ZVS at V_{IN} bigger than 80V

Power supply design

C_{CLAMP} → 1000nF

UPM DIE



Time delays for ZVS

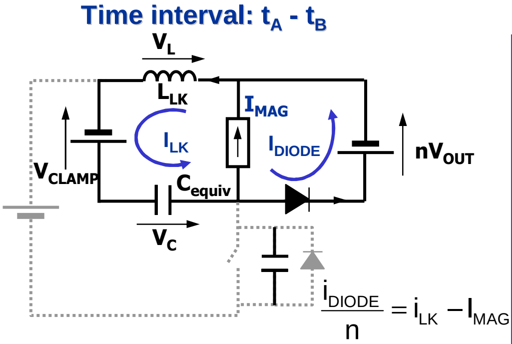
ZVS at V_{IN} bigger than 80V

UPM DIE

Flyback with AC: Analysis of diode turn-off

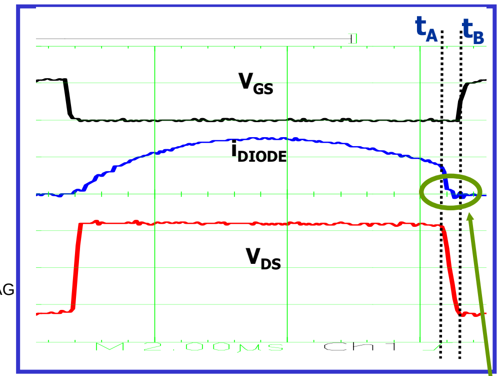
C_{CLAMP} → 1000nF L_{LK} → 1.8µH

Time interval: t_A - t_B



$$\frac{i_{DIODE}}{n} = i_{LK} - I_{MAG}$$

$$\frac{d\left(\frac{i_{DIODE}}{n}\right)}{dt} = \frac{di_{LK}}{dt}$$



Soft turn-off of diode