ON Semiconductor®

Design of a QR Adapter with Improved Efficiency and Low Standby Power

Agenda

1. Quasi-Resonance (QR) Generalities
2. The Valley Lockout Technique
3. The NCP1379/1380
4. Step by Step Design Procedure
5. Performances of a 60 W Adapter Featuring Valley Lockout

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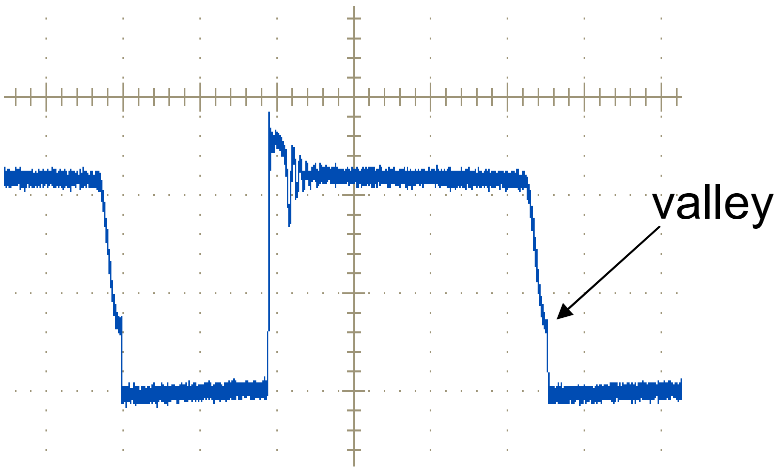
What is Quasi-Square Wave Resonance ?

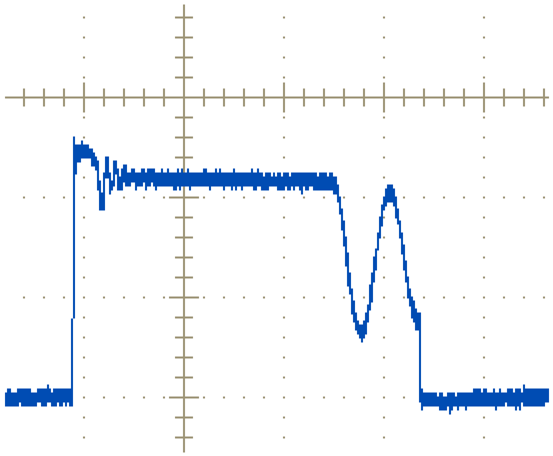
- MOSFET turns on when $V_{DS}(t)$ reaches its minimum value.

➢ Minimizes switching losses

➢ Improves the EMI signature



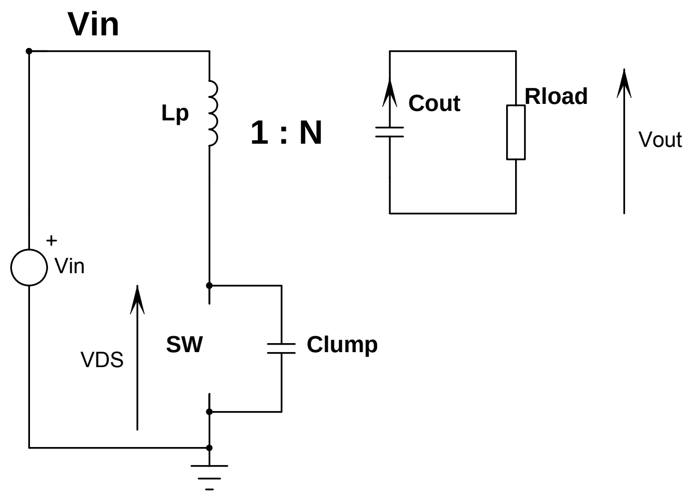
MOSFET turns on in first valley

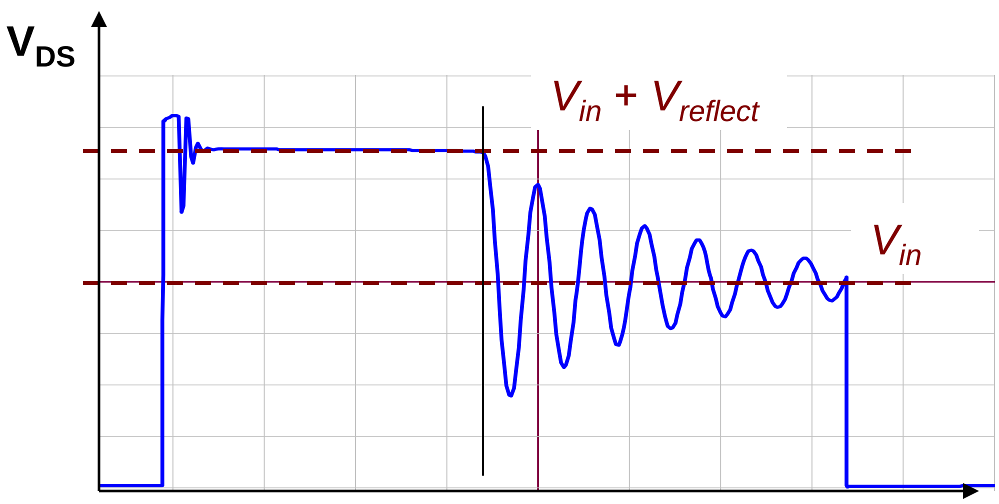


MOSFET turns on in second valley

Quasi-Resonance Operation

- In DCM, V_{DS} must drop from (V_{in} + $V_{reflect}$) to V_{in}
- Because of L_p-C_{lump} network → oscillations appear
- Oscillation half period: $t_x = \pi\sqrt{L_p C_{lump}}$





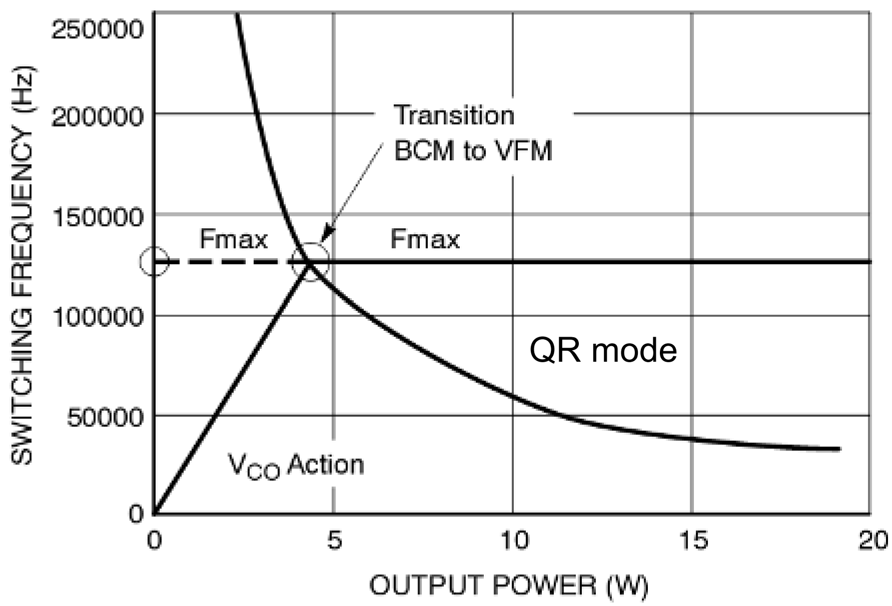
A Need to Limit the Switching Frequency

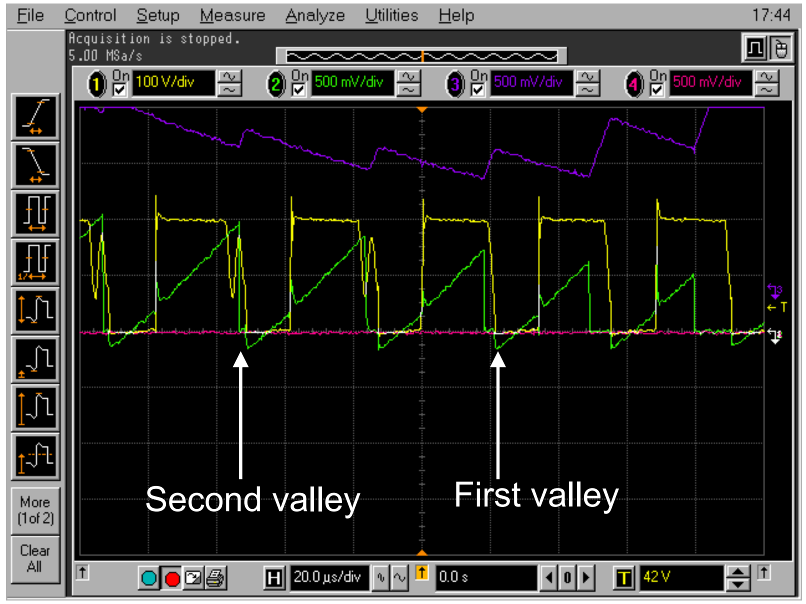
- In a self-oscillating QR, F_{sw} increases as the load decreases

  ➨ Higher losses at light load if F_{sw} is not limited

- 2 methods to limit F_{sw}:
  - Frequency clamp with frequency foldback
  - Changing valley with valley lockout

Frequency Clamp in QR Converters





- ❑ In light load, frequency increases and hits clamp
  - ➢ Multiple valley jumps
  - ➢ Jumps occur at audible range
  - ➢ Creates signal instability

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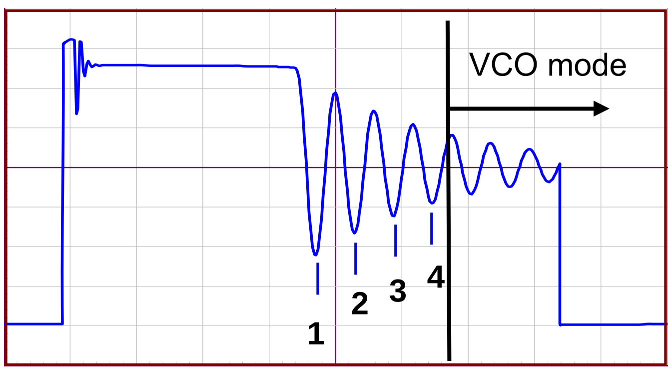
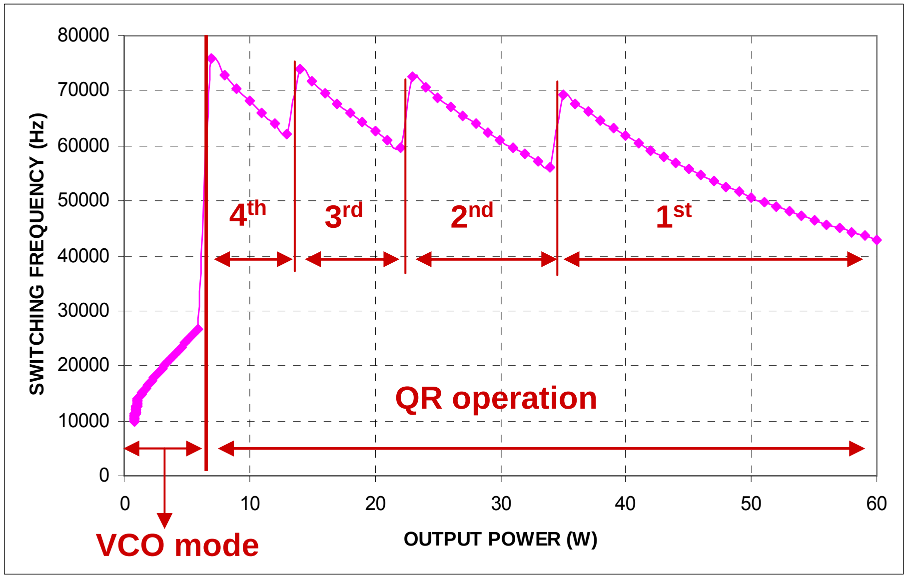
The Valley Lockout

- As the load decreases, the controller changes valley (1st to 4th valley in NCP1380)
- The controller stays locked in a valley until the output power changes significantly.

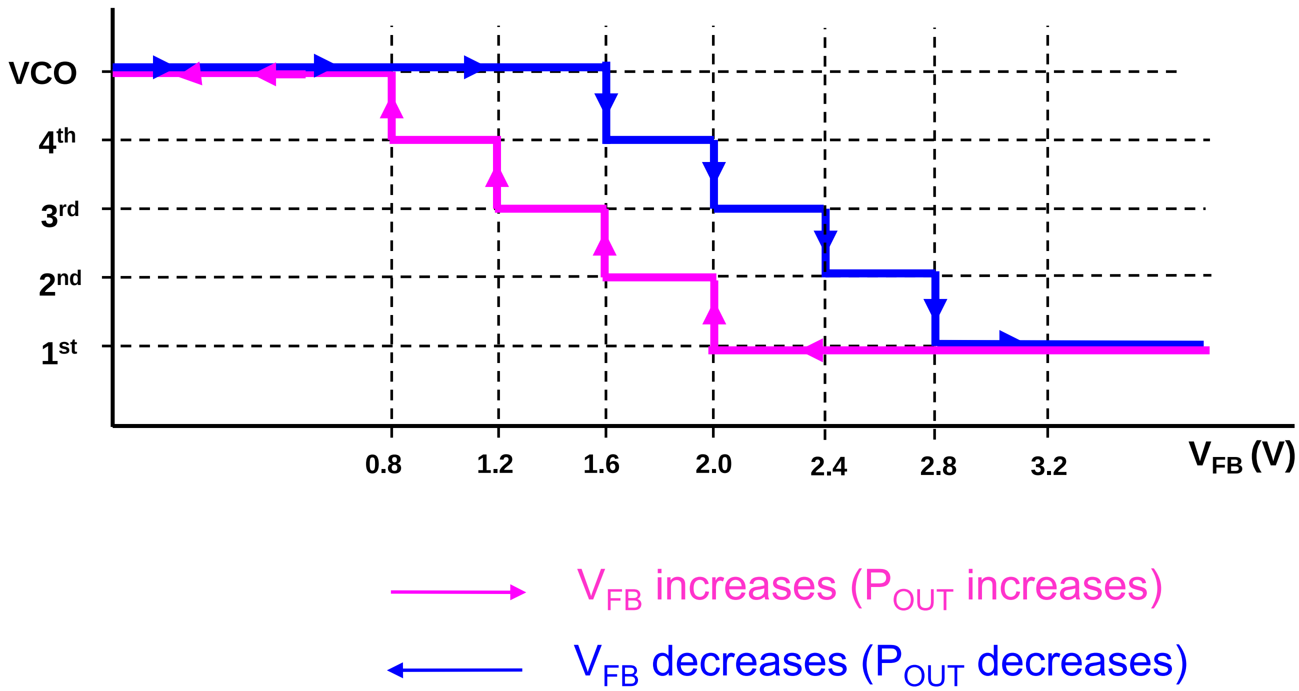
  - No valley jumping noise
  - Natural switching frequency limitation





The Valley Lockout

- FB comparators select the valley and pass the information to a counter.
- The hysteresis of FB comparators locks the valley.
- 2 possible operating set points for a given FB voltage.



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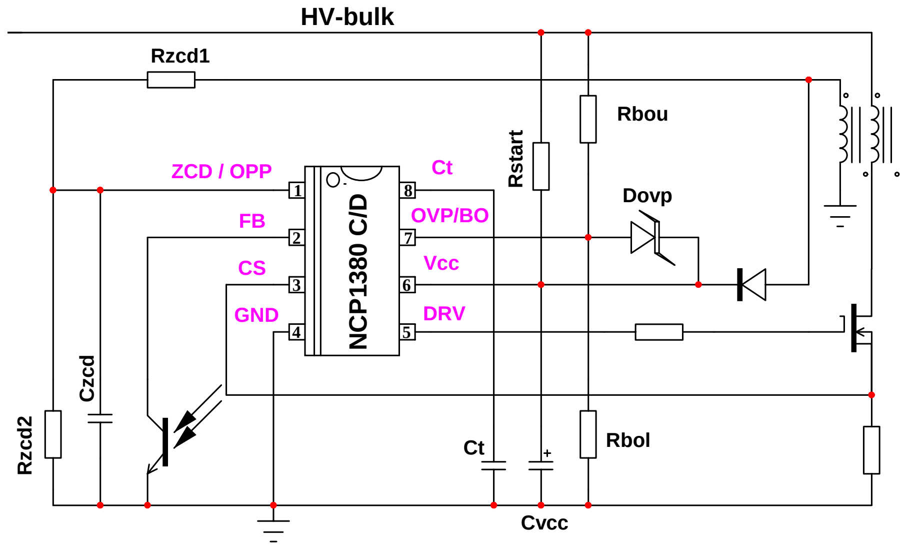
NCP1379/1380 Features

- Operating modes:
  - QR current-mode with valley lockout for noise immunity
  - VCO mode in light load for improved efficiency

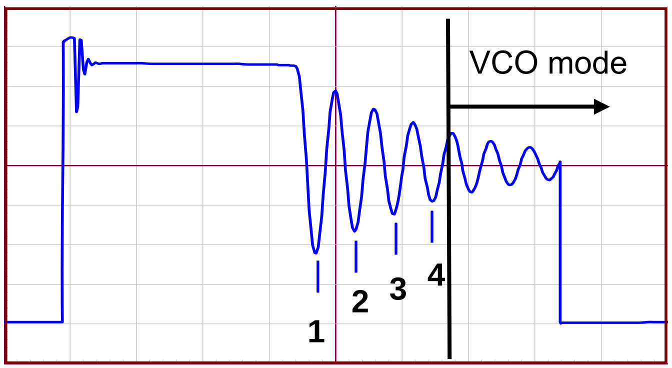
- Protections
  - Over power protection
  - Soft-start
  - Short circuit protection
  - Over voltage protection
  - Over temperature protection
  - Brown-Out

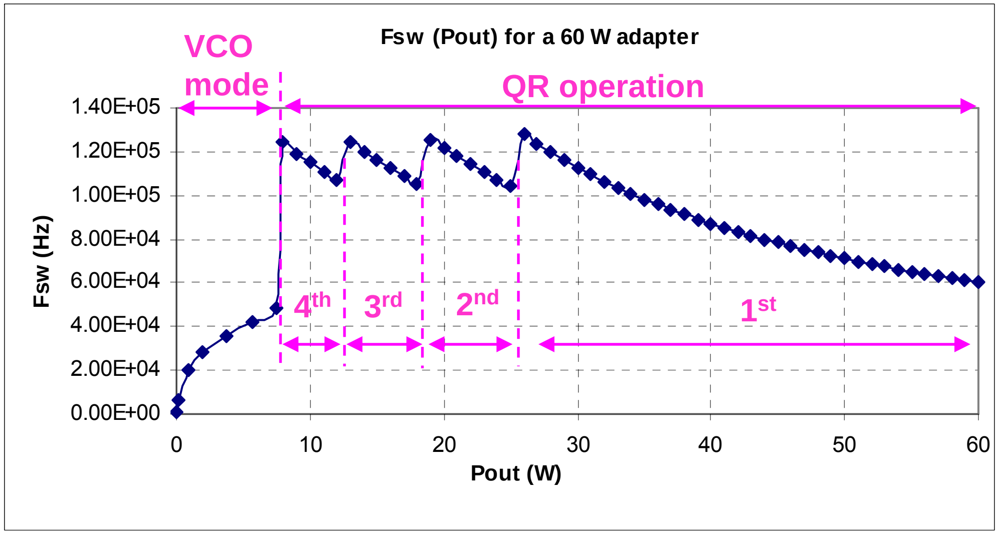


❑ Mass production: Q4 2009

QR Mode with Valley Lockout

- **Operating principle:**
  - Locks the controller into a valley (up to the 4^{th}) according to FB voltage.
  - Peak current adjusts according to FB voltage to deliver the necessary output power.

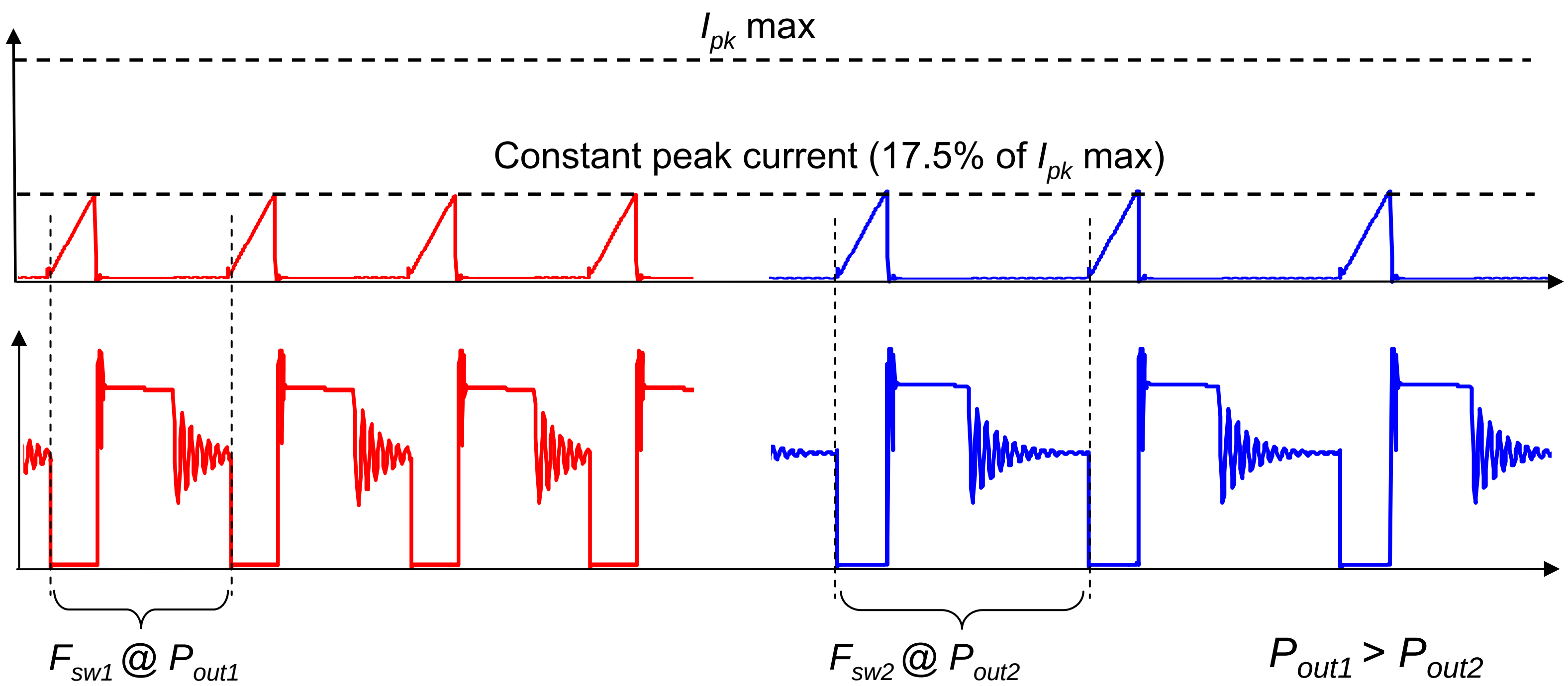




- **Advantages**
  - Solves the valley jumping instability in QR converters
  - Achieves higher min F_{sw} and lower max F_{sw} than in traditional QR converters
  - Reduce the transformer size

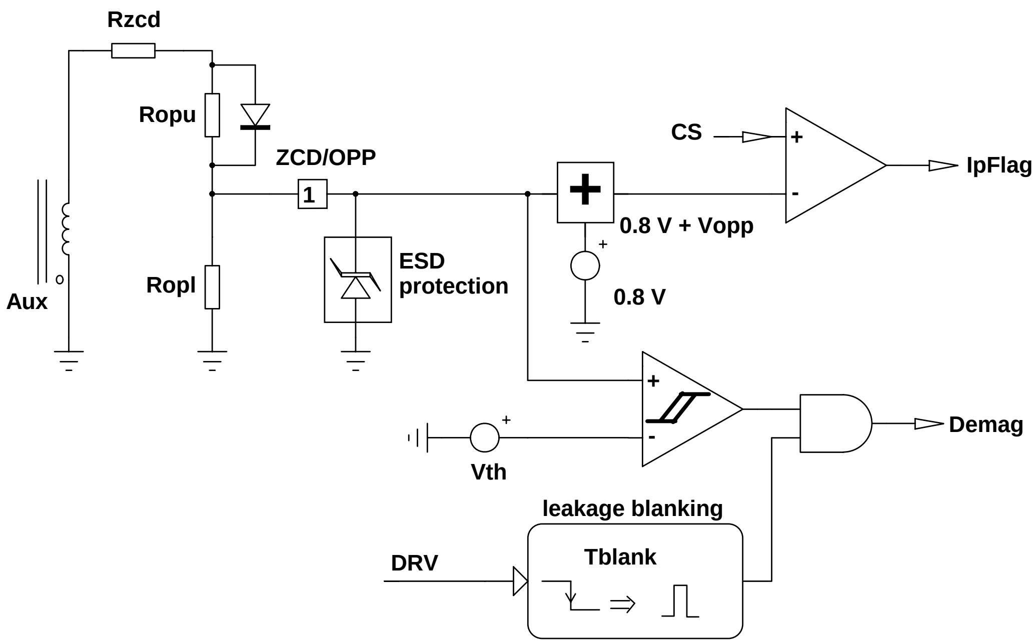
VCO Mode

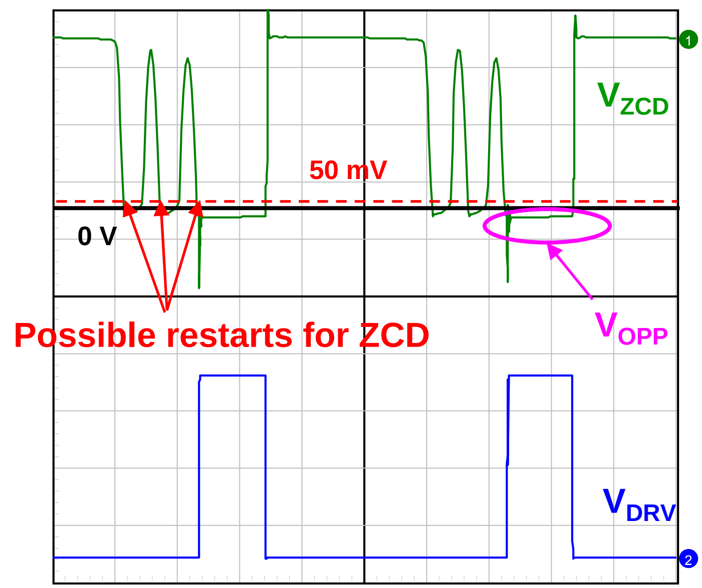
- Occurs when V_{FB} < 0.8 V (P_{out} decreasing) or V_{FB} < 1.4 V (P_{out} increasing)
- Fixed peak current (17.5% of $I_{pk,max}$), variable frequency set by the FB loop.



Combined ZCD and OPP

- Zero-Crossing Detection (ZCD) and Over Power Protection (OPP) are achieved by reading the Aux. winding voltage
  - ZCD function used during the off-time of MOSFET (positive voltage).
  - OPP function used during the on-time of MOSFET (negative voltage)





NCP1380 Versions

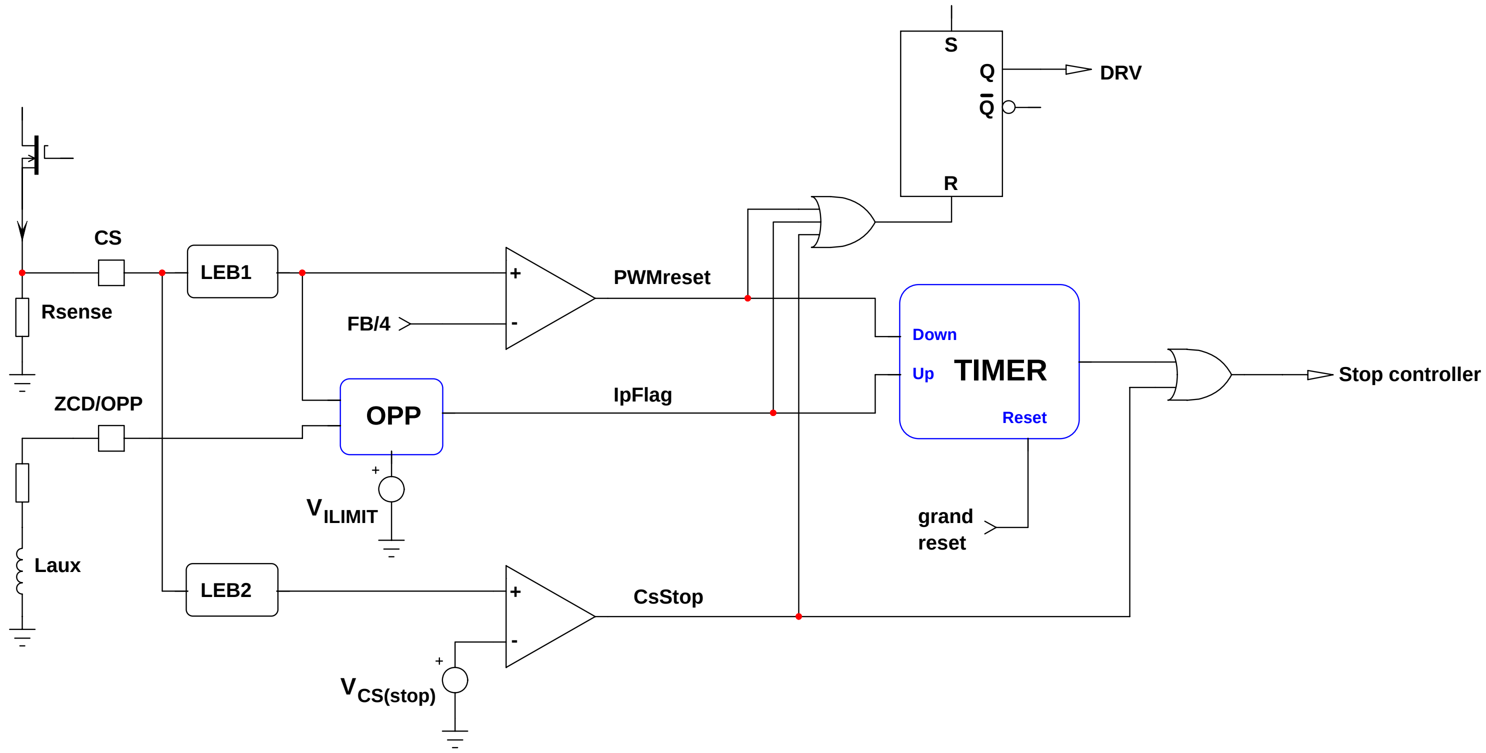
- 4 versions of NCP1380: A, B, C and D

	OTP	OVP	BO	Auto-Recovery Over current protection	Latched Over current protection
NCP1380 / A	X	X			X
NCP1380 / B	X	X		X	
NCP1380 / C		X	X		X
NCP1380 / D		X	X	X	

OTP: Over Temperature Protection
OVP: Over Voltage Protection
BO: Bown-Out

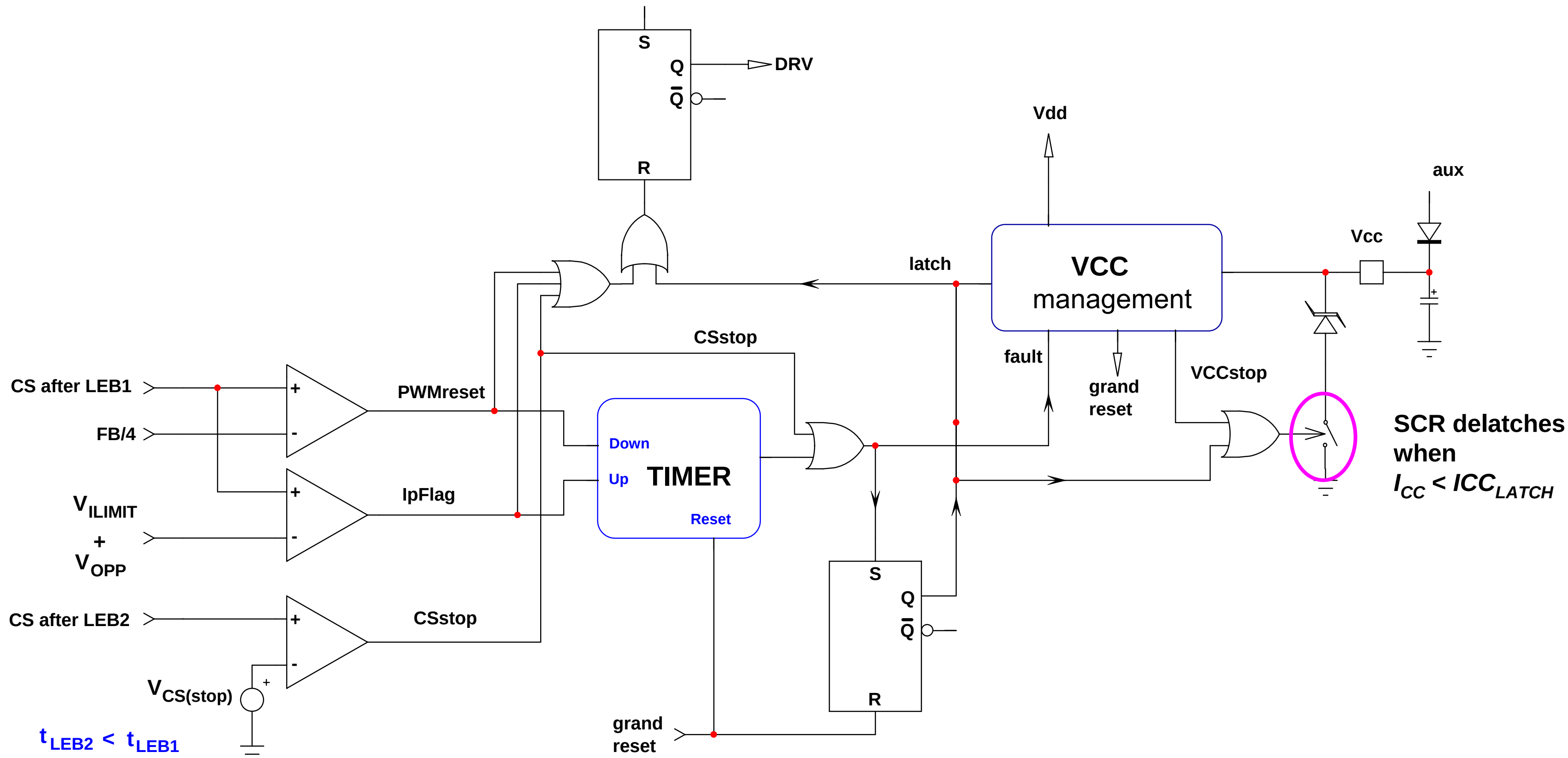
Short-Circuit Protection

- Internal 80 ms timer for short-circuit validation.
- Additional CS comparator with reduced LEB to detect winding short-circuit.
- $V_{CS(stop)} = 1.5 * V_{ILIMIT}$



Short-Circuit Protection (A and C versions)

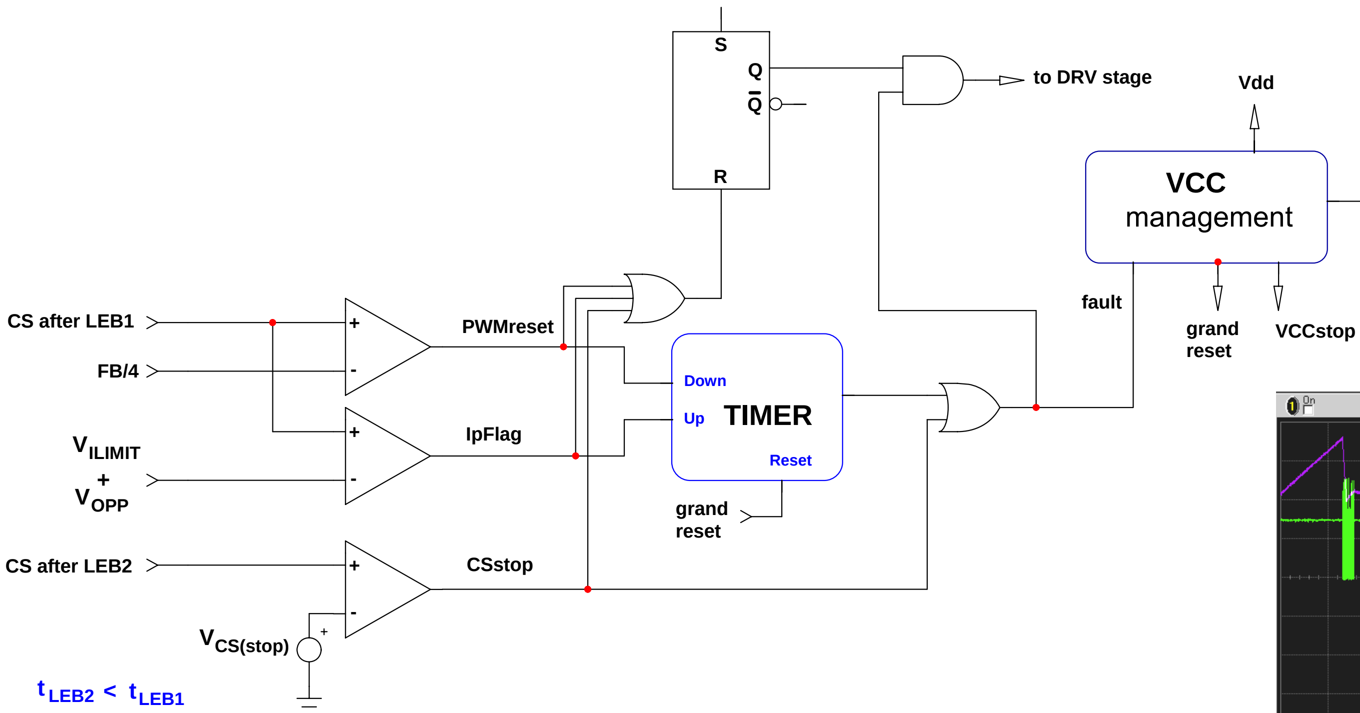
- A and C versions: the fault is latched.
  - V_{CC} is pulled down to 5 V and waits for ac removal.

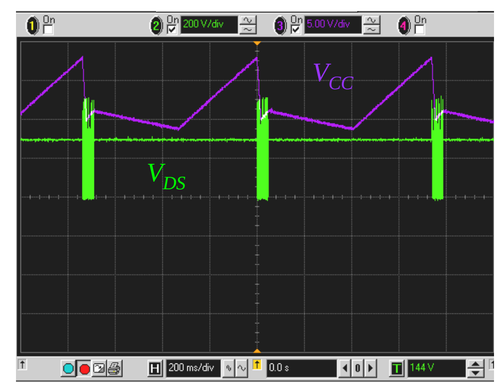


Short Circuit Protection (B and D)

- Auto-recovery short circuit protection: the controller tries to restart
- Auto-recovery imposes a low burst in fault mode.

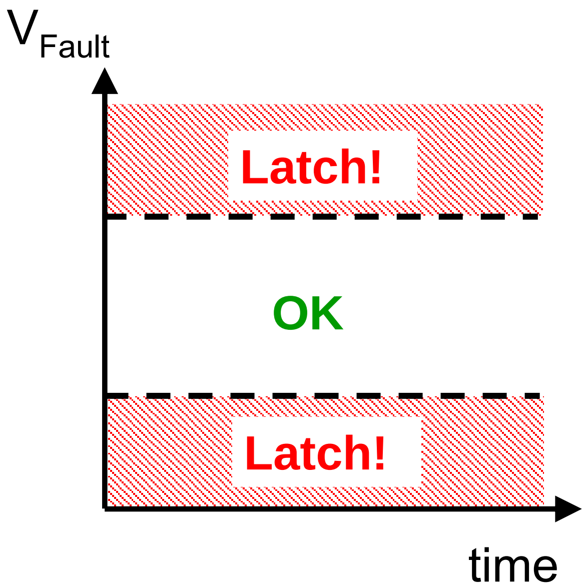
➡ Low average input power in fault condition



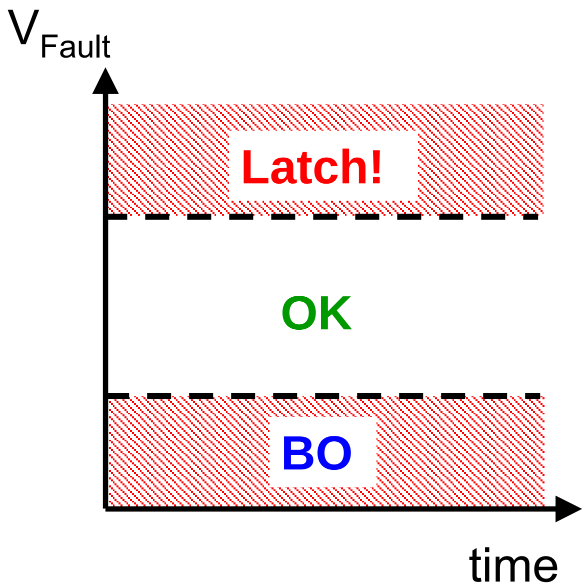


Fault Pin Combinations

- OVP / OTP
  - NCP1380 A & B versions



- OVP / BO
  - NCP1380 C & D versions, NCP1379



- OVP and OTP or OVP and BO combined on one pin.
- Less external components needed.

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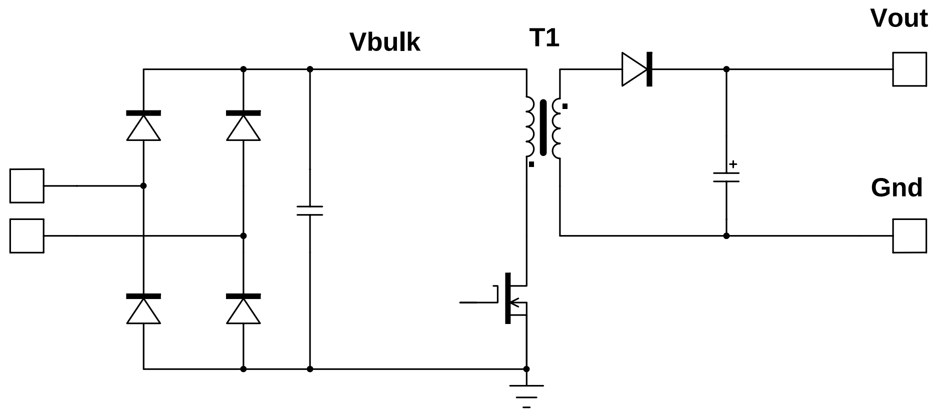
Step by Step Design Procedure

- Calculating the QR transformer
- Predicting the switching frequency
- Implementing Over Power Compensation
- Improving the efficiency at light load with the VCO mode
- Choosing the startup resistors
- Implementing synchronous rectification

Design Example

- Power supply specification:
  - V_{out} = 19 V
  - P_{out} = 60 W
  - $F_{sw,min}$ = 45 kHz (at V_{in} = 100 Vdc)
  - 600 V MOSFET
  - V_{in} = 85 ~ 265 Vrms
  - Standby power consumption < 100 mW @ 230 Vrms



Turns Ratio Calculation

- Derate maximum MOSFET BV_{dss}:

$$V_{ds,max} = BV_{dss} k_D$$

k_D: derating factor

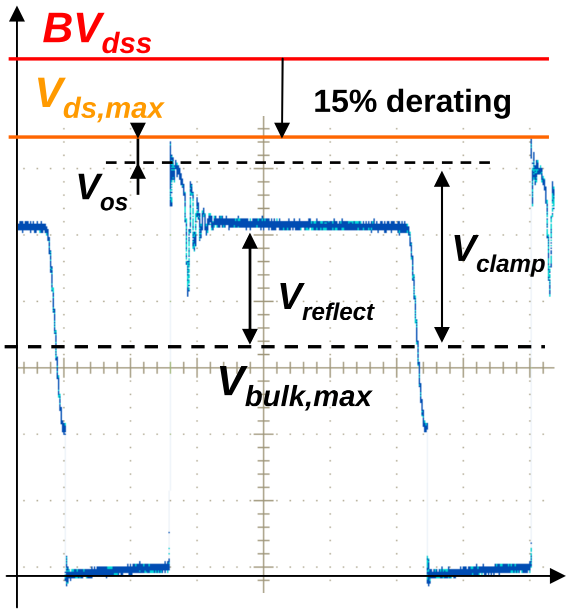
- For a maximum bulk voltage, select the clamping voltage:

$$V_{clamp} = V_{ds,max} - V_{in,max} - V_{os}$$

V_{os}: diode overshoot

- Deduce turns ratio:

$$N_{ps} = \frac{N_s}{N_p} = \frac{k_c (V_{out} + V_f)}{V_{clamp}}$$

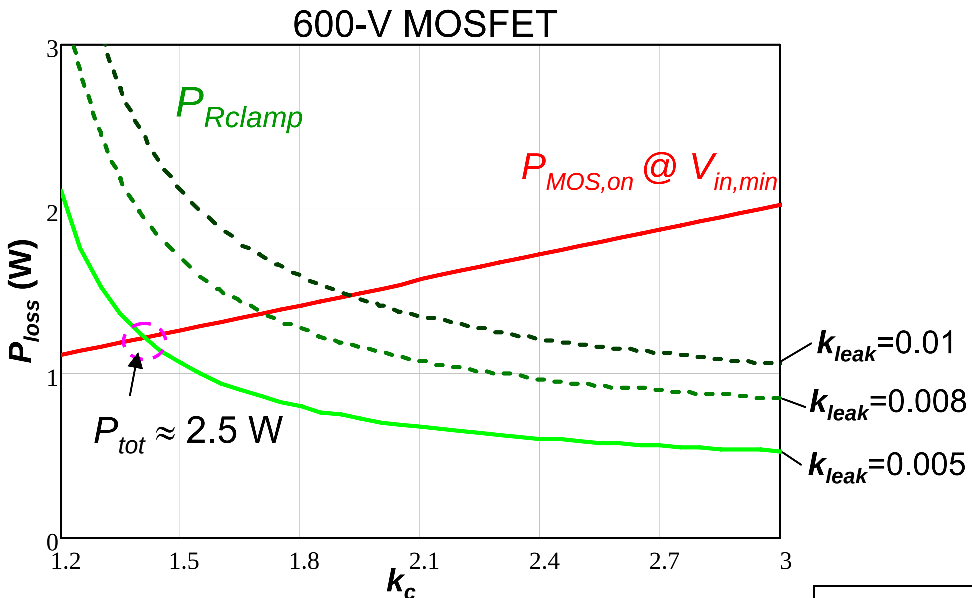


k_c: clamping coef.

$k_c = V_{clamp} / V_{reflect}$)

How to Choose k_c

- k_c choice dependant of L_{leak} (leakage inductance of the transformer)
- k_c value can be chosen to equilibrate MOS conduction losses and clamping resistor losses.



$$\begin{cases} P_{Rclamp} = k_{leak} \dfrac{P_{out}}{\eta} \dfrac{k_c}{k_c - 1} \\ P_{MOS,on} = R_{dson} \dfrac{4P_{out}^{2}}{3\eta^2 V_{in,min}} \left(\dfrac{1}{V_{in,min}} + \dfrac{k_c}{BV_{dss}k_D - V_{in,max} - V_{os}} \right) \end{cases}$$

Curves plotted for:

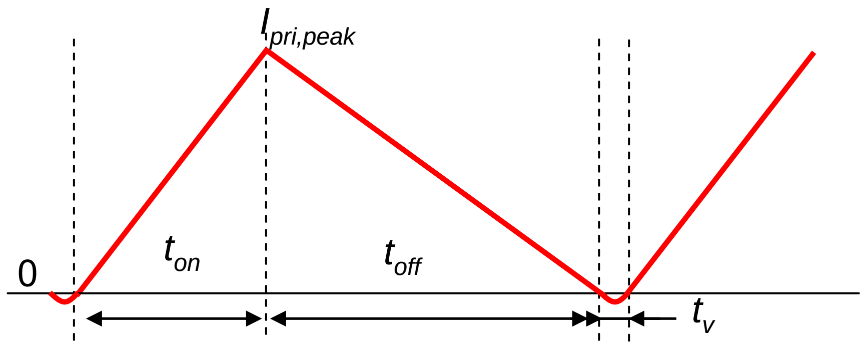
R_{dson} = 0.77 Ω at T_j = 110 °C

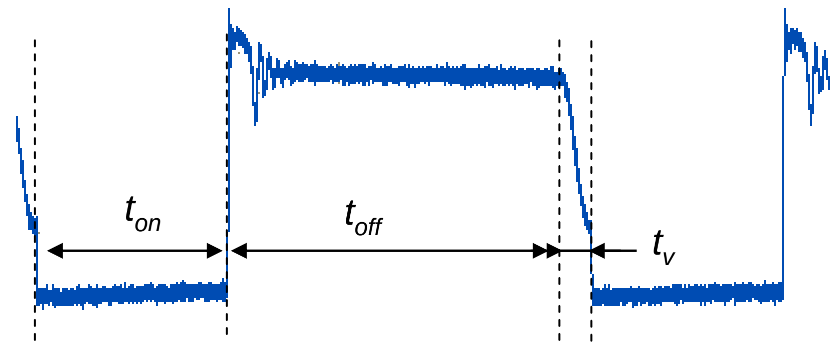
P_{out} = 60 W

$V_{in,min}$ = 100 Vdc

Primary Peak Current and Inductance

- $P_{out} = \frac{1}{2} L_{pri} I_{pri,peak}{}^2 F_{sw} \eta$ DCM





- $T_{sw} = \frac{I_{pri,peak} L_{pri}}{V_{in,min}} + \frac{I_{pri,peak} L_{pri} N_{ps}}{V_{out} + V_f} + \pi \sqrt{L_{pri} C_{lump}}$ ← C_{oss} contribution alone.

$$I_{pri,peak} = 2 \frac{P_{out}}{\eta} \left(\frac{1}{V_{in,min}} + \frac{N_{ps}}{V_{out} + V_f} \right) + \pi \sqrt{\frac{2 P_{out} C_{lump} F_{sw}}{\eta}}$$

$$L_{pri} = \frac{2 P_{out}}{I_{pri,peak}{}^2 F_{sw} \eta}$$

RMS Current

- Calculate maximum duty-cycle at maximum P_{out} and minimum V_{in}:

$$d_{max} = \frac{I_{pri,peak} L_{pri}}{V_{in,min}} F_{sw,min}$$

- Deduce primary and secondary RMS current value:

$$I_{pri,rms} = I_{pri,peak} \sqrt{\frac{d_{max}}{3}}$$

$$I_{sec,rms} = \frac{I_{pri,peak}}{N_{ps}} \sqrt{\frac{1 - d_{max}}{3}}$$

$I_{pri,rms}$ and $I_{sec,rms}$ → Losses calculation

Design Example

- Based on equations from slides 11 to 14:
  - Turns ratio: $$N_{ps} = \frac{k_c (V_{out} + V_f)}{B_{Vdss} k_D - V_{in,max} - V_{os}} = \frac{1.3 \times (19 + 0.8)}{600 \times 0.85 - 375 - 10} \Rightarrow \boxed{N_{ps} \approx 0.25}$$
  - Peak current: $$I_{pri,peak} = \frac{2P_{out}}{\eta}\left(\frac{1}{V_{in,min}} + \frac{N_{ps}}{V_{out} + V_f}\right) + \pi\sqrt{\frac{2P_{out}C_{lump}F_{sw}}{\eta}}$$ $$= \frac{2 \times 60}{0.85}\left(\frac{1}{100} + \frac{0.25}{19.8}\right) + \pi\sqrt{\frac{2 \times 60 \times 250p \times 45k}{0.85}} \Rightarrow \boxed{I_{pri,peak} = 3.32\,A}$$
  - Inductance: $$L_{pri} = \frac{2P_{out}}{I_{pri,peak}{}^2 F_{sw}\eta} = \frac{2 \times 60}{3.32^2 \times 45k \times 0.85} \Rightarrow \boxed{L_{pri} = 285\,\mu H}$$
  - Max. duty-cycle: $$d_{max} = \frac{I_{pri,peak} L_{pri}}{V_{in,min}} F_{sw,min} = \frac{3.32 \times 285\mu}{100} 45k \Rightarrow \boxed{d_{max} = 0.43}$$
  - Primary rms current: $$I_{pri,rms} = I_{pri,peak}\sqrt{\frac{d_{max}}{3}} = 3.32\sqrt{\frac{0.43}{3}} \Rightarrow \boxed{I_{pri,rms} = 1.26A}$$
  - Secondary rms current: $$I_{sec,rms} = \frac{I_{pri,peak}}{N_{ps}}\sqrt{\frac{1 - d_{max}}{3}} = \frac{3.32}{0.25}\sqrt{\frac{1 - 0.43}{3}} \Rightarrow \boxed{I_{sec,rms} = 5.8\,A}$$