

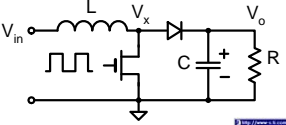
Mor M. Peretz, Switch-Mode Power Supplies [5-1]

Parasitic effects Snubbers and clamps

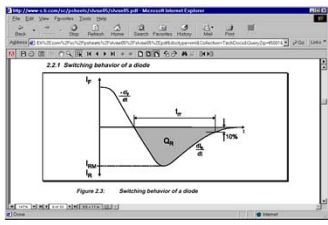
- Turn on and turn off effects
 - Turn on - diode reverse recovery
 - Turn off – di/dT effect on transistor
 - Turn off – diode forward recovery
 - Mosfet gating
- Transistor protection - Clamp
 - Flyback leakage problem
 - Clamp configuration
 - Component selection
- Diode protection – Snubber
- Switching snubbers and lossless (ZVS) snubber

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Diodes reverse recovery

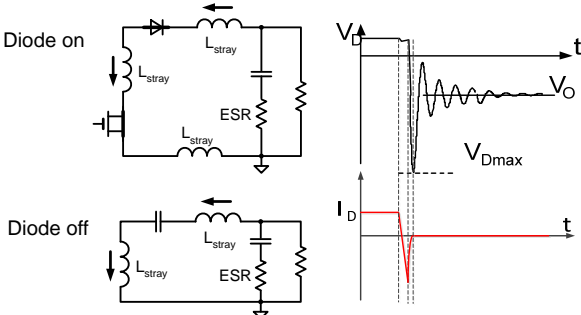


Diode on – bidirectional current flow



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Diodes recovery – spike and oscillations



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Transistor turn off - parasitics

Transistor on

Transistor off

V_{DS}

I_{DS}

V_O

t

D

G

R_G

L_D

L_S

S

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Transistor turn off – diode forward recovery

I

V_D

V_{PK}

V_F

t

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Mosfet gating

D

G

R_L

R_G

C_{GS}

V_{gs}

V'_{gs} (real)

L_S

V_{gs}

V'_{gs}

Depend on Q

$$Q = \frac{\sqrt{L_S}}{R_L + R_G} C_{GS}$$

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Flyback leakage problem

Voltage spike can develop HIGH voltage

$V_c - ?$

V_{DS}

$V - ?$

t

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Clamp

Zener diode

D - C - R

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Clamp configurations

$V_c > V_{in} + \frac{n_1}{n_2} V_o$

$V_c > \frac{n_1}{n_2} V_o$

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Parasitic inductance and physical placement

Connection of the clamp/snubber should be **directly** on the element

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Clamp design

Equivalent circuit

Current waveform

Assuming small ripple on the clamp capacitor (will be designed that way)

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Calculation of clamp components

$$I_{av} = \frac{I_{pk} \cdot t_p}{2} \cdot f_s$$

$$\frac{V_o \frac{n_1}{n_2} - V_{cc}}{L_{lk}} > \frac{I_{av}}{C_c R_c}$$

$$I_{av} R_c > V_{cc_av}$$

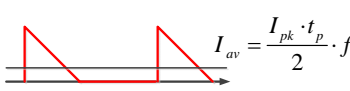
$$C_c R_c > T_s$$

$$\frac{dI_p}{dt_p} = \frac{V_o \frac{n_1}{n_2} - V_{cc}}{L_{lk}}$$

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Design procedure

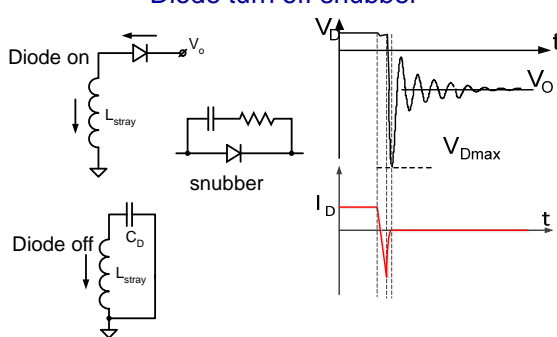
1. Select $V_{Cc\ av} > V_o'$
2. Calculate $I_{p\ av}$
3. Select $R_c = \frac{V_{cc\ av}}{I_{av}}$
4. Select $C_c \cdot T > T_s$
5. Adjust values



$$I_{av} = \frac{I_{pk} \cdot t_p}{2} \cdot f_s$$

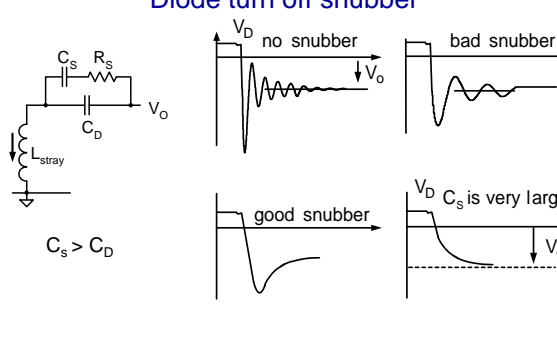
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Diode turn off snubber



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Diode turn off snubber



$C_s > C_D$

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Snubber design

Required values
 I_{pk} (reverse current)
 Stray inductance

$$\frac{L_{stray} I_{pk}^2}{2} = \frac{C_s (V_o + \Delta V)^2}{2}$$

Resistor for damping $C_s R_s < T_s$
 C_s needs to discharge

Use simulation to optimize the snubber

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Switching snubber

The objective: avoid overlap of current and voltage
 Slow the rise of either current or voltage

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Switch snubber

dV/dt (at turn off) can be slow down by adding external snubber capacitor C

Turn off

$$\frac{dV}{dt} = \frac{I}{C + C_{ds}}$$

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Switch snubber

Problem at turn on

$$E_c = \frac{CV_o^2}{2} \quad P_d = \frac{CV_o^2}{2} \cdot f_s$$

Dissipated through the transistor

Solution

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Switch snubber design

If $R_{ds\ on} < R_s$ most energy will be lost to $R_s \rightarrow$ Heat
 Selection of $C_s \rightarrow$
 Selection of $R_s \rightarrow$ to ensure reset

$$T = \frac{1}{R_s C_s} \ll t_{on} \quad t_{on} \approx 4R_s C_s$$

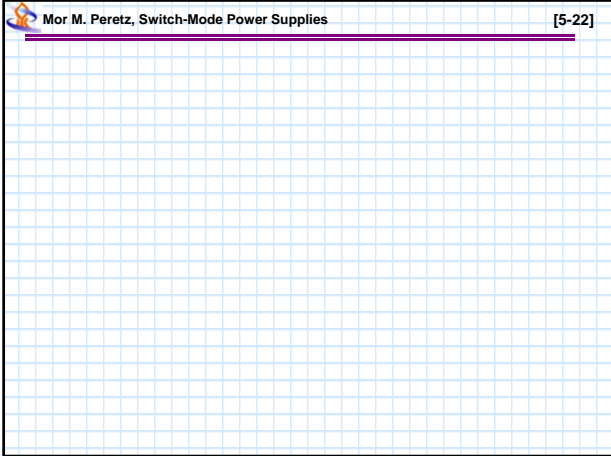
Question: how VDS will look if C_s is not fully discharged?

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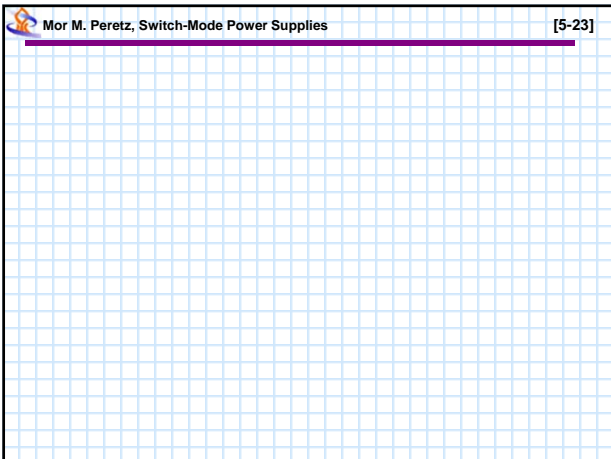
Lossless (ZVS) snubber

C_1, C_2 of transistor plus external

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