

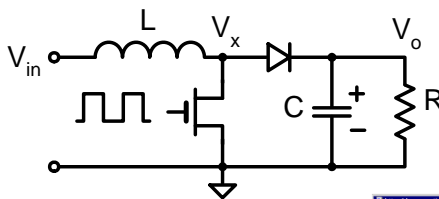


## Parasitic effects Snubbers and clamps

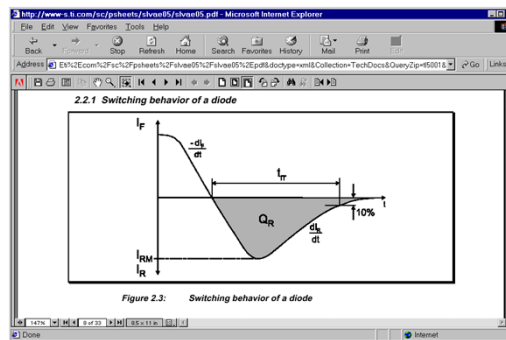
- Turn on and turn off effects
  - Turn on - diode reverse recovery
  - Turn off –  $di/dt$  effect on transistor
  - Turn off – diode forward recovery
  - Mosfet gating
- Transistor protection - Clamp
  - Flyback leakage problem
  - Clamp configuration
  - Component selection
- Diode protection – Snubber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



## Diodes reverse recovery

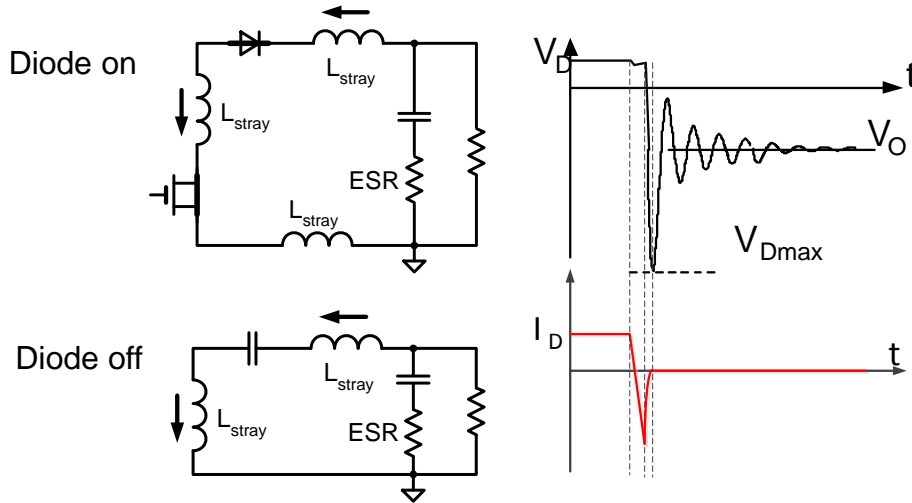


Diode on – bidirectional current flow

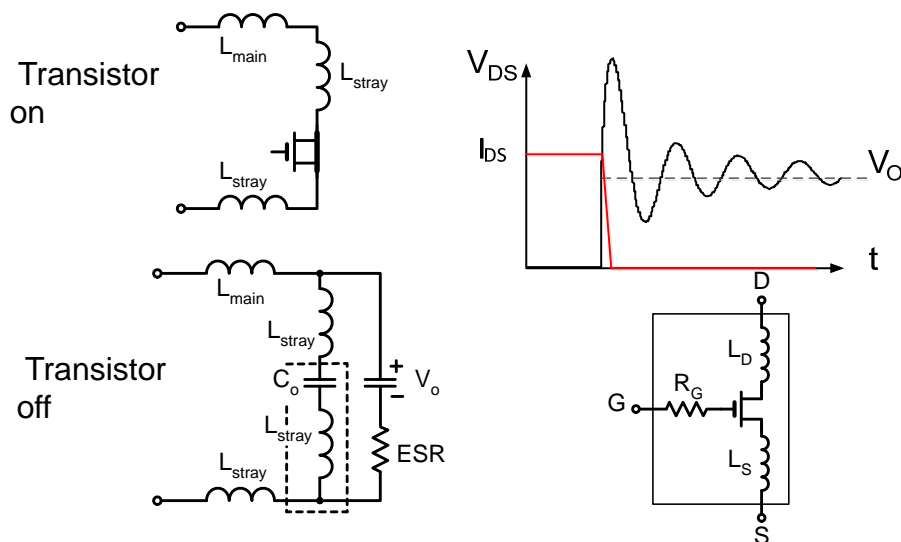




### Diodes recovery – spike and oscillations

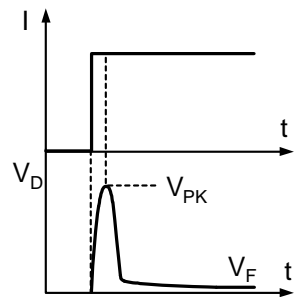
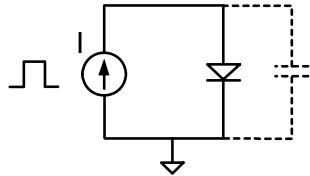


### Transistor turn off - parasitics

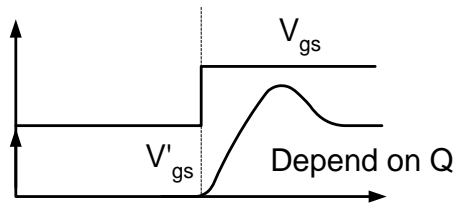
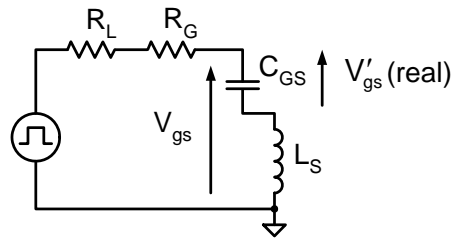
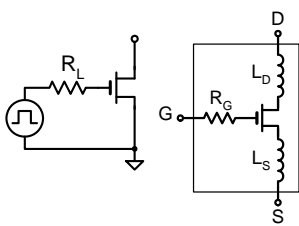




### Transistor turn off – diode forward recovery



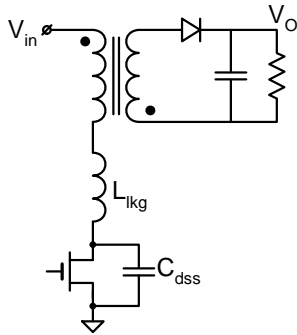
### Mosfet gating



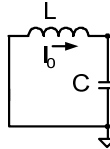
$$Q = \frac{\sqrt{L_S}}{R_L + R_G} \sqrt{C_{GS}}$$



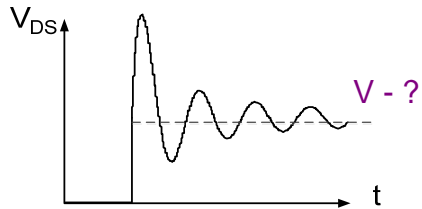
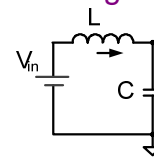
### Flyback leakage problem



Voltage spike can develop HIGH voltage



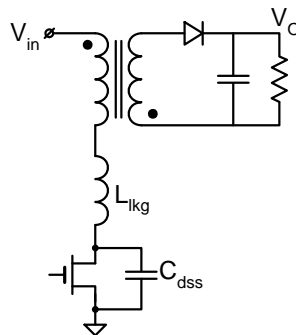
$V_C - ?$



### Clamp

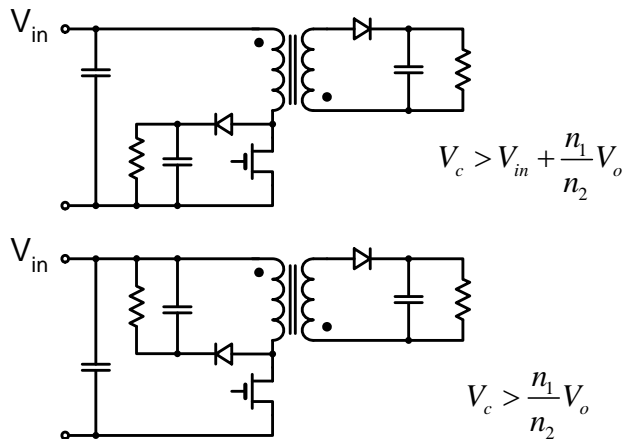
Zener diode

D - C - R

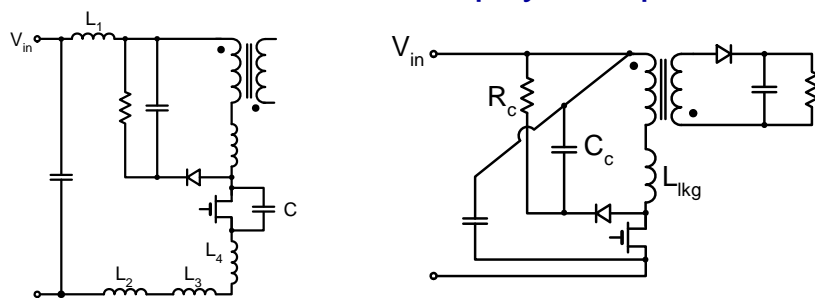




### Clamp configurations



### Parasitic inductance and physical placement

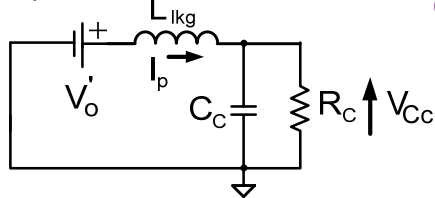


Connection of the clamp/snubber should be **directly** on the element



### Clamp design

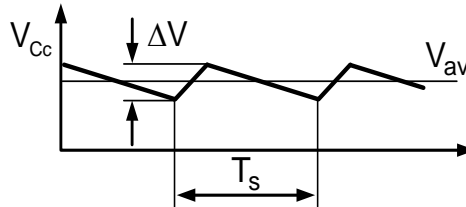
Equivalent circuit



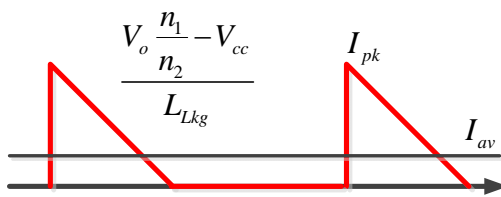
Current waveform



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



### Calculation of clamp components



$$I_{av} R_c > V_{cc\_av}$$

$$C_c R_c > T_s$$

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

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



## Design procedure

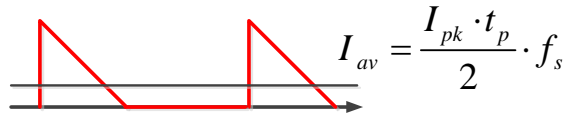
1. Select  $V_{Cc\ av} > V_o'$

2. Calculate  $I_{p\ av}$

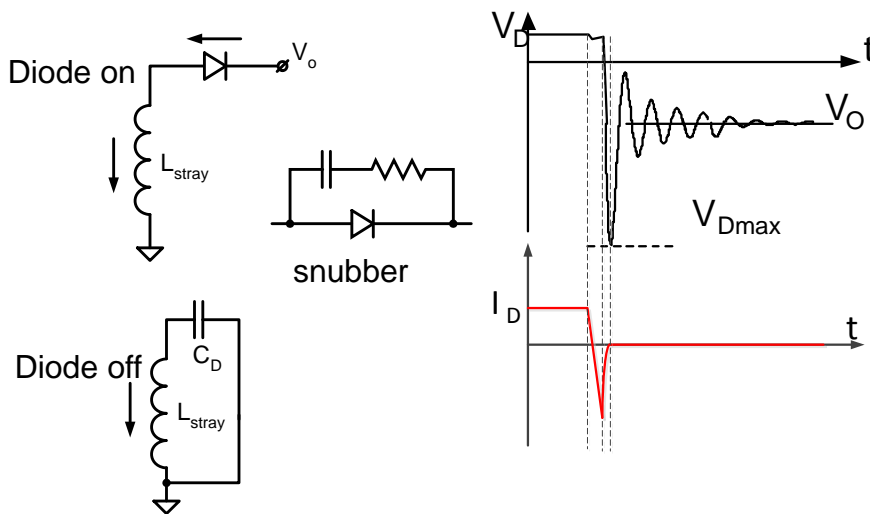
3. Select  $R_c = \frac{V_{cc\ av}}{I_{av}}$

4. Select  $C_c \ T > T_s$

5. Adjust values

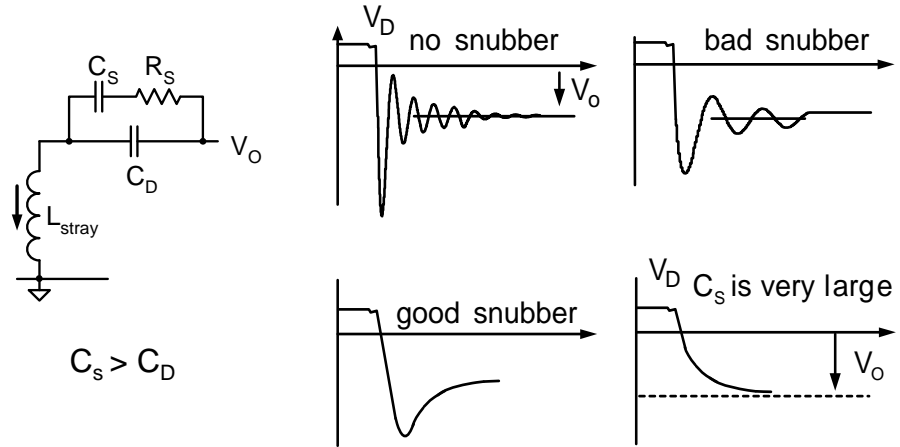


## Diode turn off snubber

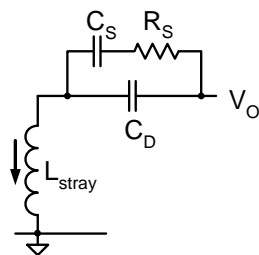




### Diode turn off snubber



### Snubber design



Required values  
 I<sub>pk</sub> (reverse current)  
 Stray inductance

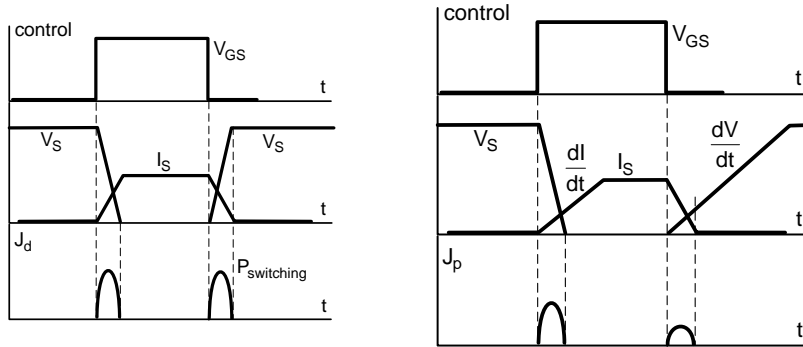
$$\frac{L_{stray} I_{pk}^2}{2} = \frac{C_s (V_o + \Delta V)^2}{2}$$

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

Use simulation to optimize the snubber



### Switching snubber

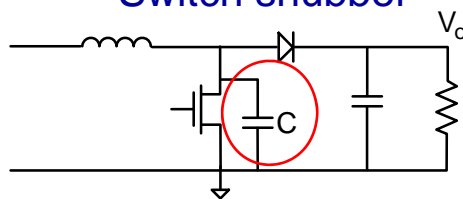


The objective: avoid overlap of current and voltage

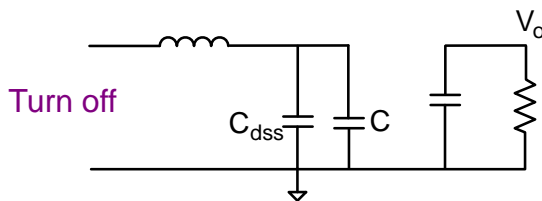
Slow the rise of either current or voltage



### Switch snubber



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

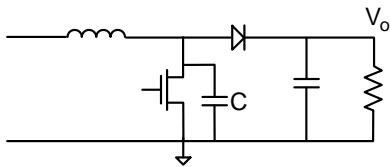


$$\frac{dV}{dt} = \frac{I}{C + C_{dss}}$$



### Switch snubber

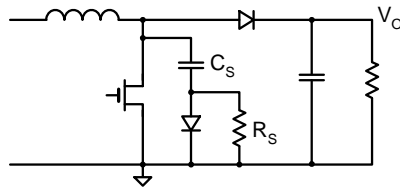
Problem at turn on



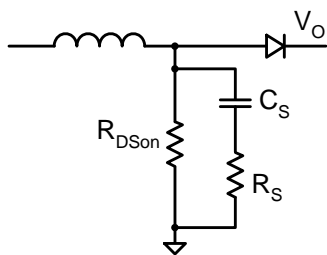
$$E_C = \frac{CV_o^2}{2} \quad P_d = \frac{CV_o^2}{2} \cdot f_s$$

Dissipated through the transistor

Solution



### Switch snubber design



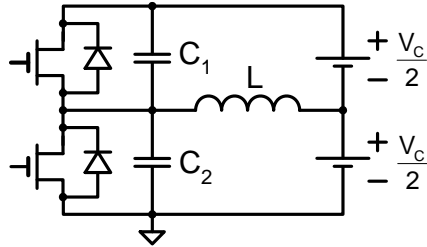
If  $R_{ds\ on} < R_s$  most energy will be lost to  $R_s \rightarrow$  Heat  
Selection of  $C_s \rightarrow$   
Selection of  $R_s \rightarrow$  to ensure reset

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

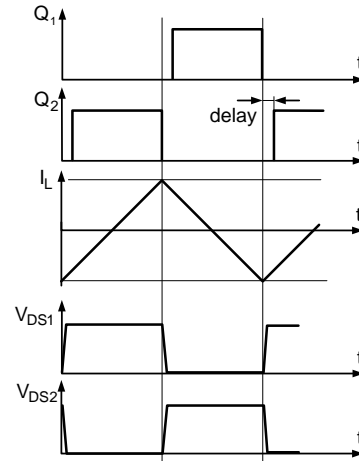
Question: how VDS will look if Cs is not fully discharged?




### Lossless (ZVS) snubber

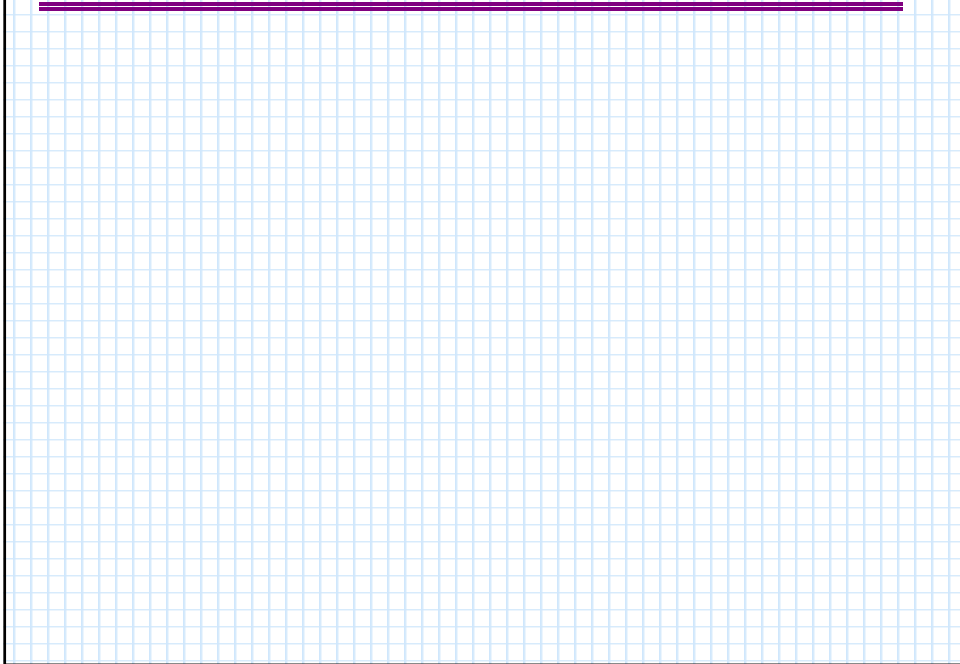



$C_1, C_2$  of transistor plus external



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