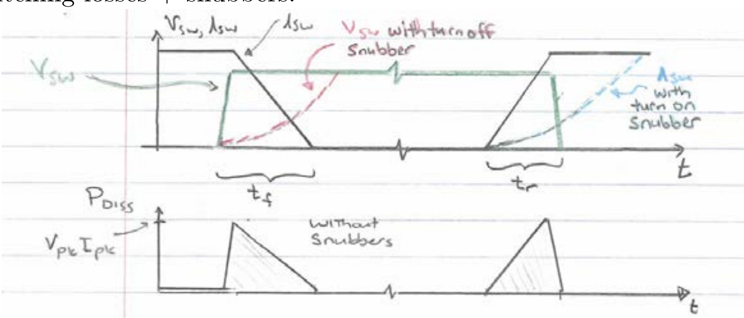
6.622 Power Electronics *Prof. David Perreault*

Lecture 33 - Soft-Switching 1

1 Review

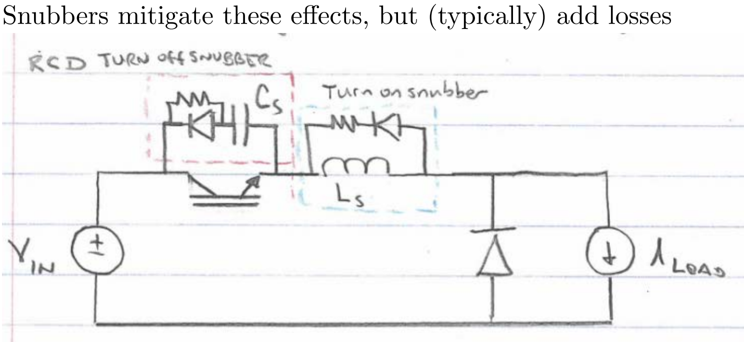
Switching losses + snubbers:



The voltage/current overlap (without snubbers) has three deleterious effects:

1. Loss + limited $\eta + f_{sw}$ (overlap + capacitive discharge loss)
2. EMI due to high $\frac{di}{dt} + \frac{dv}{dt}$
3. switching locus may exceed SOA + $\frac{di}{dt}, \frac{dv}{dt}$ limits allowed

Snubbers mitigate these effects, but (typically) add losses



Today: Soft-switching techniques try to mitigate these effects <u>without</u> adding loss.
General methods:
"zero voltage" switching (ZVS)
"zero current" switching (ZCS)
Can be applied at turn on and/or turn off

- Turn off snubber looks like ZVS in the limit
- Turn on snubber looks like ZCS in the limit

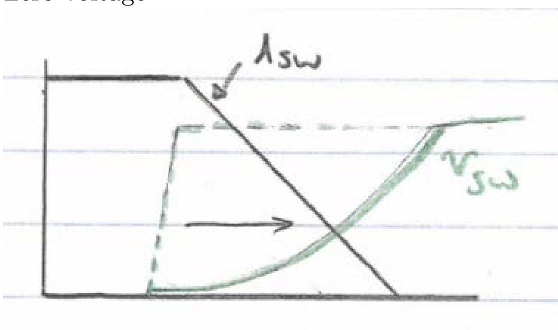
But we need to <u>recover</u> the snubber energy!

2 Soft Switching

:

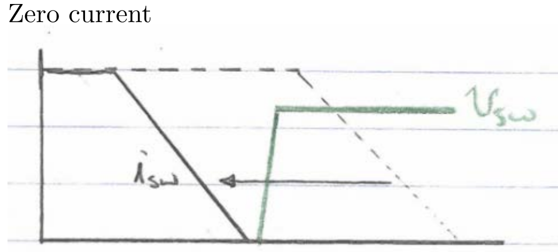
Turn off

Zero voltage



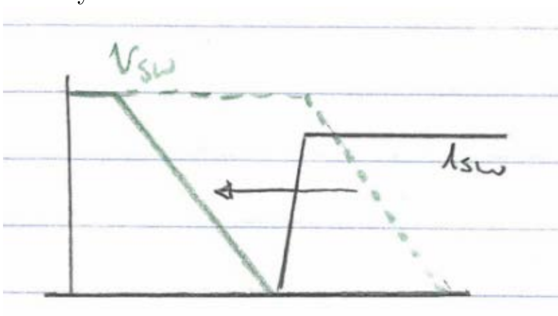
⋆ Delay V-rise on switch

Zero current

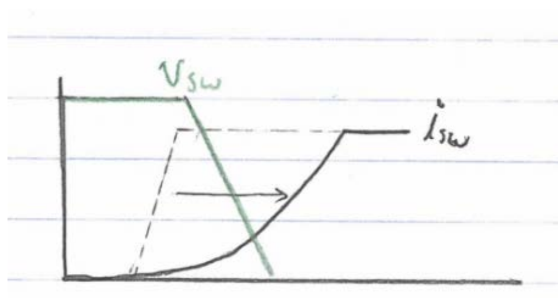


⋆ Make current in switch /*rightarrow* 0 <u>BEFORE</u> turning off switch

Turn on



⋆ Make switch voltage go to zero <u>before</u> switch turn on

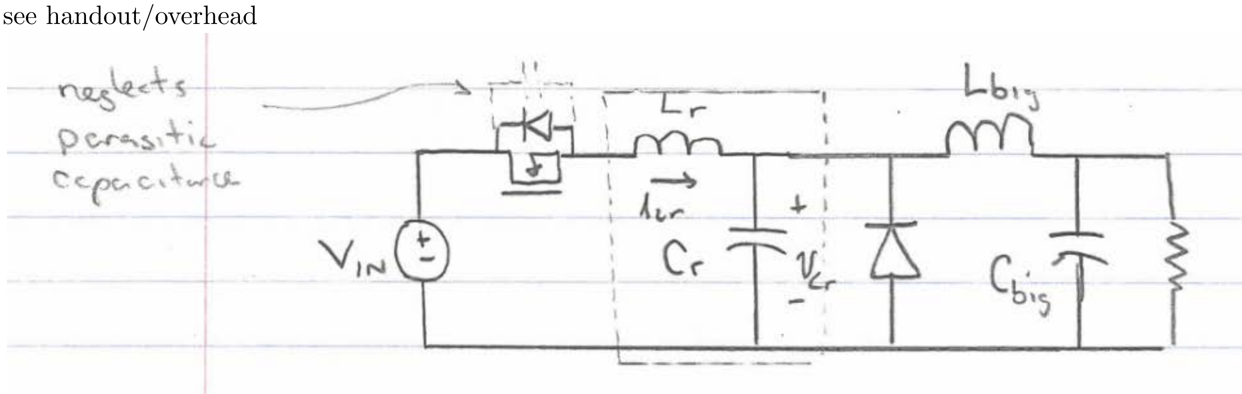


⋆ Delay current rise on switch

- So, we can reduce overlap loss by either delaying voltage or current rise in the switch, or by arranging the switching event to take place when voltage and/or current will naturally be zero.
- These techniques typically require additional control or circuit complexity, or may add conduction loss or peak device stress, but the tradeoff may often be worth it!
- ZVS turn on additionally reduces capacitor discharge loss (important at very high frequencies) while ZCS turn on reduces loss in parasitic inductance.
- Varying degrees of "softness" exist, depending on the degree to which waveform rises are delayed, slopes at transitions, etc.

3 Example: ZCS Quasi-Resonant Buck Converter (Full wave)

→ see handout/overhead



Go through operational cycle:

- Main switch turns on ZCS
- Main switch/diode turns off ZCS
- Diode turns on ZCS
- Diode turns off ZCS

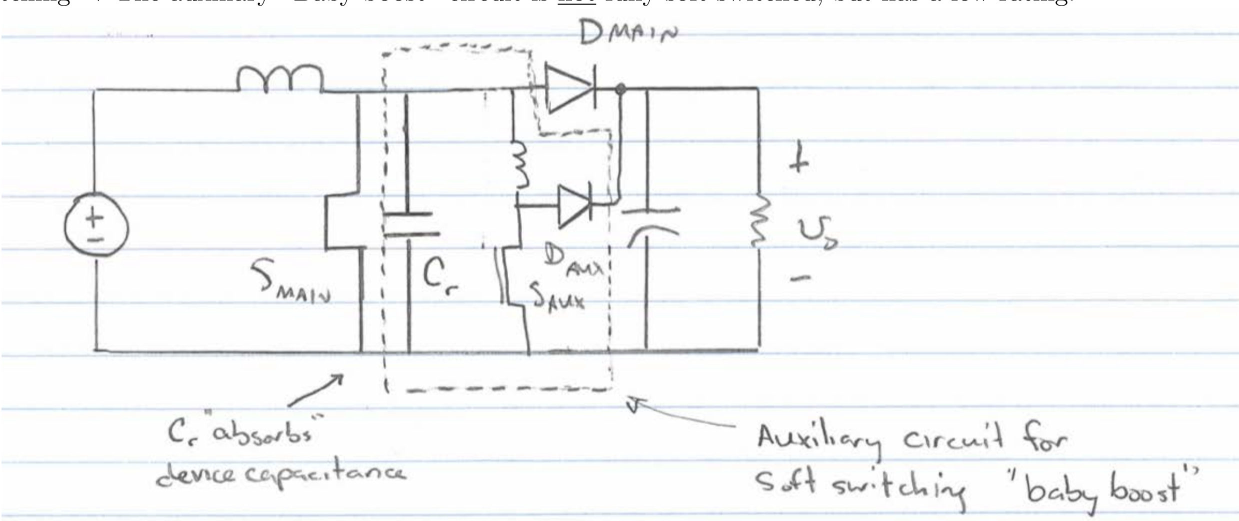
V_{out} controlled by f_{sw} control/pulse density modulation
Show experimental waveforms at light, heavy load

Advantages:
Smooth (mostly soft) waveform transitions
Low switching losses to moderate frequencies
Disadv:

- ZCS turn on still loses junction cap energy
- ZCS turn off of devices can still have ringing w/ device junction cap
- High conduction losses (compared to P_{wm}) due to resonant action and energy slosh
- diode voltage rating 2x
- requires frequency control over very wide range

4 Example: 2VT Boost Converter

Add an auxiliary circuit to the conventional P_{WM} boost converter to enable the main devices to have ZVS switching → The auxiliary "Baby boost" circuit is <u>not</u> fully soft switched, but has a low rating.



Auxiliary circuit operates only @ switching transitions

- Allows ZVS switching of main switch and diode
- especially valuable @ high output voltage where main diode reverse recovery (+ switch capacitave discharge loss) are important

Auxiliary circuit is not fully soft switched (compromise between full soft switching + hard switching)

- ZCS turn on of S_{aux}, but capacitive discahrge remains

- SCS turn off of D_{aux}
- loss is limited because auxiliary circuit elements can be small