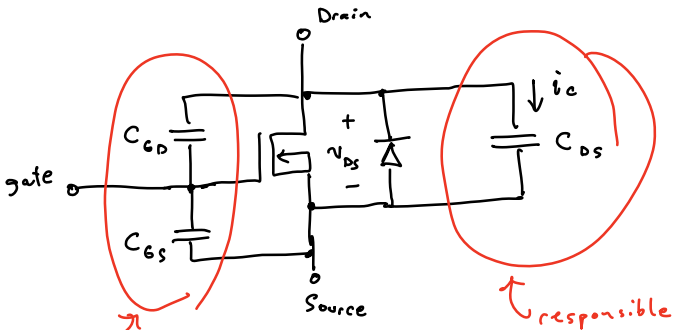
Lecture # 15, 11/3/21

- Today
  - → Finish MOSFETs & IGBT's
  - → This is the last lecture which can be on exam.

- Capacitances in MOSFET



dominate losses on gate driver side

responsible for "power stage side" losses

- What causes finite turn on/off times which cause losses?
  - → A: Takes finite amt of time to charge/discharge device capacitances.

C_{GS} → largest, nearly constant

C_{GD} → small, highly nonlinear & voltage dependent

C_{DS} → intermediate, highly nonlinear " " "

→ take closer look since causes power stage losses

$$C_{DS}(v_{ds}(t)) = \frac{C_0}{\sqrt{1+\frac{v_{ds}}{v_0}}} \approx C_0\sqrt{\frac{v_0}{v_{ds}}} = C_0' \frac{1}{\sqrt{v_{ds}}}$$

constants: C_0, v_0

$C_0' = C_0\sqrt{v_0}$

Look @ C_{DS} sw. loss during on $\rightarrow$ off transition

$v_{ds} \approx 0$ — no energy in C_{DS}

$v_{ds} = V_{off}^{blocking}$ — $\cdots$ C_{DS} stores energy

$$W_{C_{DS}} = \text{energy in } C_{DS} \text{ cap} = \int_{\text{over time of transition}} v_{ds}\, i_c\, dt$$

$$\because i_c = C_{DS}\frac{dv_{DS}}{dt}$$

V_{DS} ← off blocking voltage

$$= \int_0^{V_{DS}} v_{ds}(t)\, C_{DS}(v_{DS})\, dv_{DS}$$

$$= \int_0^{V_{DS}} v_{DS}\frac{C_0'}{\sqrt{v_{ds}}}\, dv_{ds} = \int_0^{V_{DS}} C_0'\sqrt{v_{ds}}\, dv_{ds}$$

$$= \frac{2}{3} C_0' v_{ds}^{3/2}\Big|_0^{V_{DS}} = \frac{2}{3} C_0' V_{DS}^{3/2}\, \frac{V_{DS}^{1/2}}{V_{DS}^{1/2}}$$

$$= \frac{2}{3} C_0' \frac{V_{DS}^{4/2}}{V_{DS}^{1/2}} = \frac{2}{3} C_{DS}(V_{DS})\, V_{DS}^2$$

$C_{DS}(V_{DS})$

$$= \frac{1}{2}\left(\frac{4}{3} C_{DS}(V_{DS})\right) V_{DS}^2 = \frac{1}{2} C_{eq} V_{DS}^2$$

C_{eq}

→ Equiv loss into a regular/linear cap w value

$$C_{eq} = \frac{4}{3} C_{DS}(V_{DS})$$

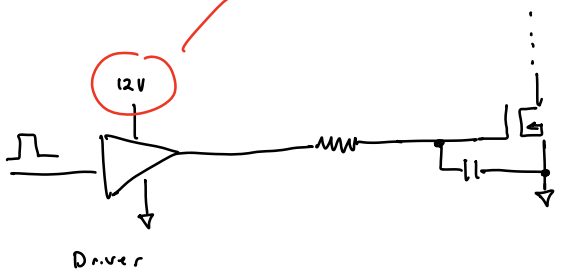
$$P_{loss_{DS}} = f_s \left(\frac{1}{2} C_{eq} V_{DS}^2 \right)$$

loss is actually in rest of ckt resistances

... can do similar analysis on gate to get

$$P_{loss_{GS}} = f_s \left(\frac{1}{2} C_{GS} V_{GS_{ON}}^2 \right)$$

Gate driver voltage



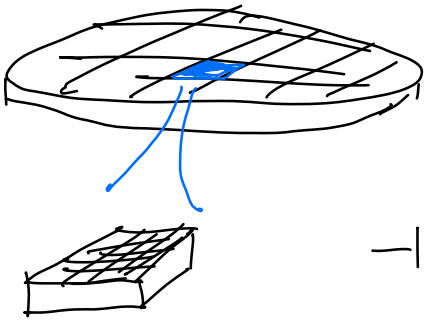
- MOSFET Recap

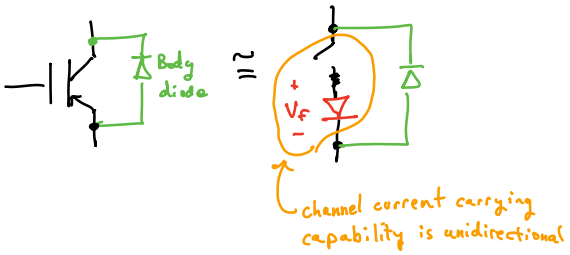
  Device for voltages ≈ 600V & below

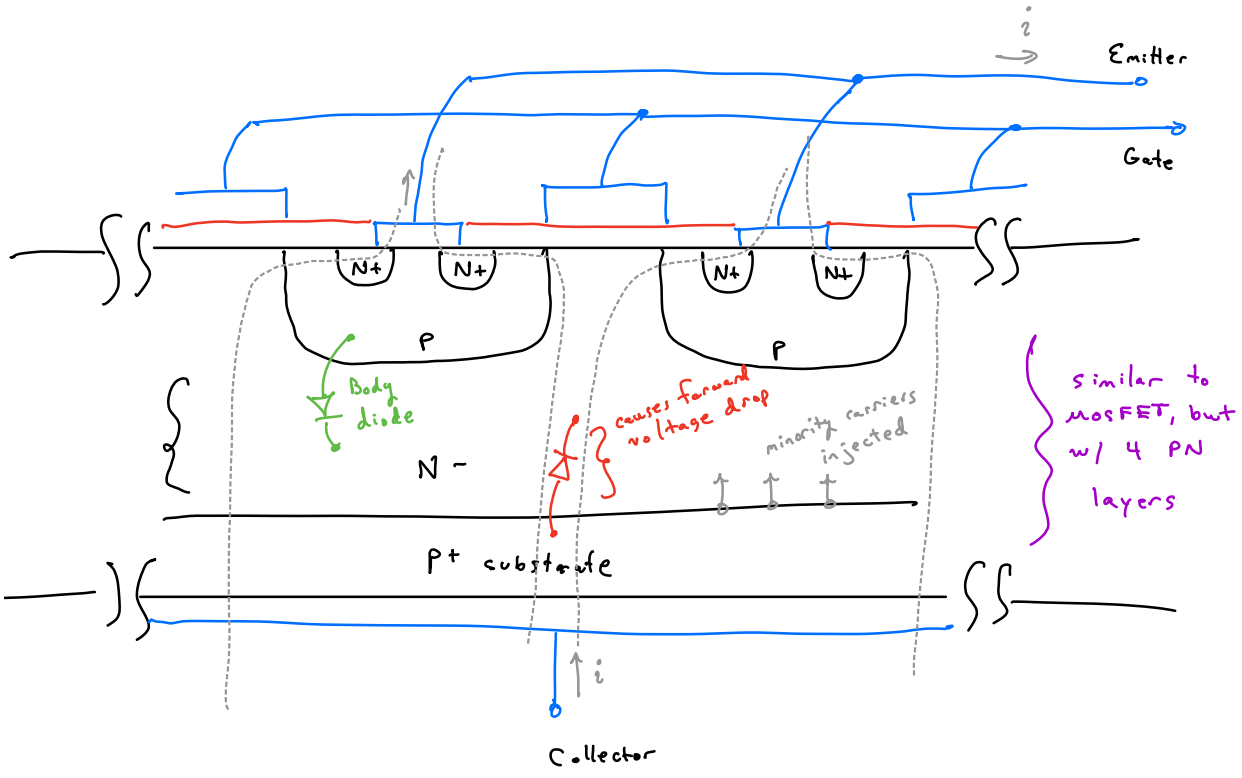
  R_{on} ∝ blocking voltage

  f_s ≈ 10's of kHz up to a few/10 MHz

– Insulated Gate Bipolar Transistor (IGBT)



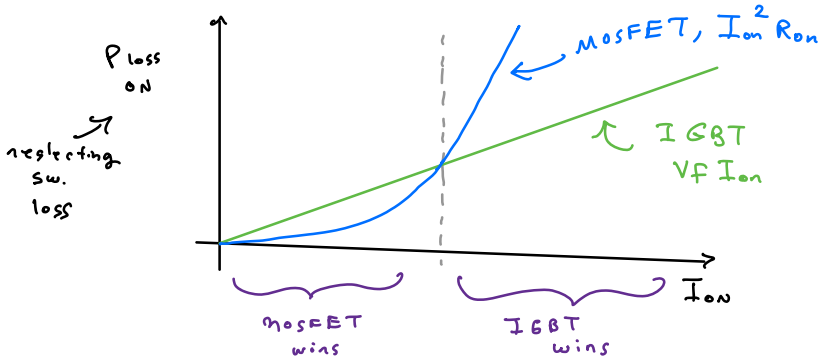




Differences from MOSFET:

- Lower R_{on} ☺
- Diode forward v drop in conduction path ☹
- Slower sw. times ☹
- Higher breakdown voltages ☺

- IGBT vs MOSFET (Conduction Loss only)



- "Current Tailing" in IGBTs

current approaches zero slowly when turning off