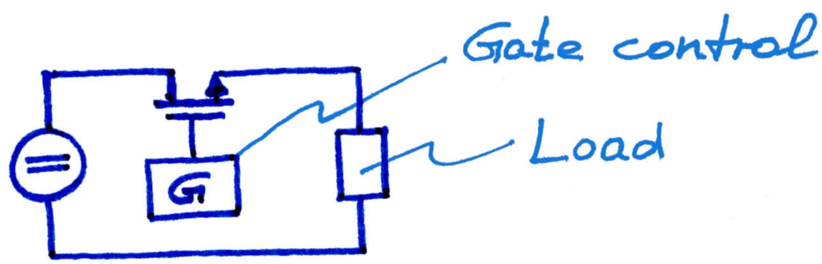
FET as an ON / OFF switch

Switch  ON ↳ Closed   OFF ↳ Open

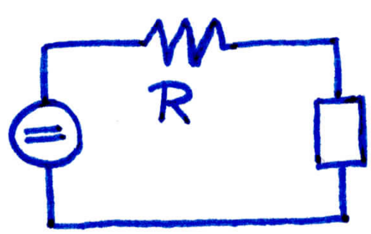
 ON   OFF

Switching loads (Motor, lights, TV, PC, electromagnet ...)

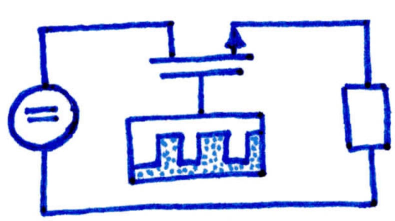
* ON and OFF (not dimmed)



* Dimming with a resistor



* Dimming with a switch (e.g. f=1kHz 50% duty cycle)



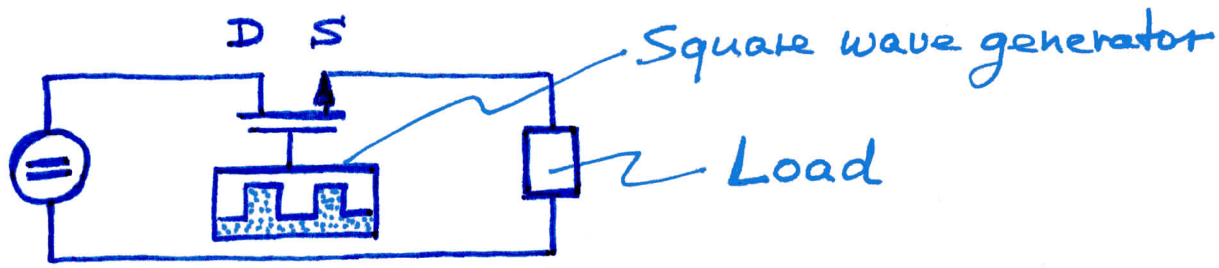
Q: Which of the two dimming methods is better?

⇒ Switched dimming is better because power is not wasted in a resistor.

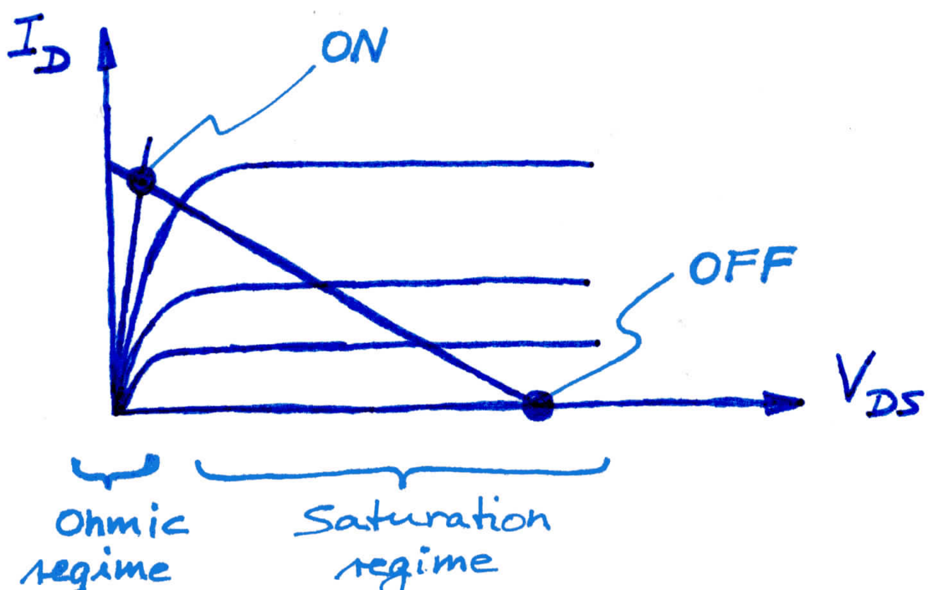
⇒ We need a good switch

Perfect switch: $R_{ON} = 0\Omega$ $R_{OFF} = \infty\Omega$

An FET can be used as a switch



FET output characteristic



ON ⇒ Ohmic regime ⇒ R_{ON}

OFF ⇒ Saturation regime ⇒ R_{OFF}

OFF state

FET operates in saturation regime

Recall:

$$I_D = \frac{1}{2} k \left(V_{GS} - V_{th} \right)^2$$

$$V_{GS} < V_{th} \Rightarrow I_D = 0$$

$$\Rightarrow \boxed{R_{OFF} = \infty}$$

$\Rightarrow$ Perfect OFF state

ON state

FET operates in ohmic regime

Recall:

$$I_D = k \left(V_{GS} - V_{th} \right) V_{DS}$$

$$\Rightarrow G_{ON} = \frac{1}{R_{ON}} = \frac{d I_D}{d V_{DS}} = k \left(V_{GS} - V_{th} \right)$$

$$\Rightarrow \boxed{R_{ON} = \frac{1}{k \left(V_{GS} - V_{th} \right)}}$$

$\Rightarrow$ $R_{ON} > 0$ $\Rightarrow$ Not perfect

Q: How can we minimize R_{ON}?

$\Rightarrow$ $V_{GS} \gg V_{th}$

$\Rightarrow$ Geometry of FET $\Rightarrow$ $k = k' \frac{W_G}{L_G}$ $\Rightarrow$

Wide W_G and short L_G will increase k and decrease R_{ON}.

Example:

Switching FET: $k = 10 \, A/V^2$ $\quad V_{th} = 2V$

Choose V_{GS} so that $R_{ON} = 10m\Omega = 0.01\Omega$

Solution: $R_{ON} = 1/k(V_{GS} - V_{th})$

$$\Rightarrow V_{GS} = \frac{1}{k R_{ON}} + V_{th} = \frac{1}{10\frac{A}{V^2}\, 10m\Omega} + V_{th}$$

$$= 10\,V + 2V = \underline{\underline{12\,V}}$$

Switching FETs (Switching MOSFETs) are common in all kinds of appliances: TV, Washing machine, Dryer, Cell phone, Cars, Lights, IOT, etc.

There is a transition

Mechanical switch $\Rightarrow$ FET switch