Electronics Switches & Controls

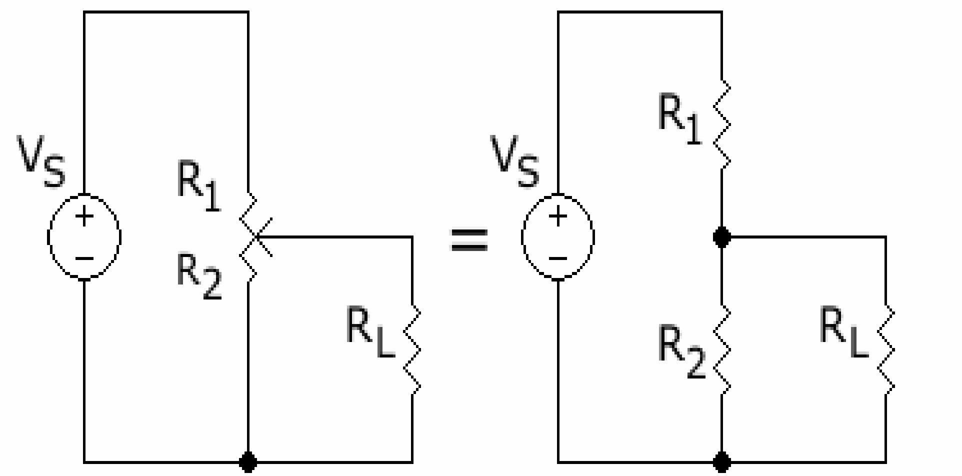
- **Conventional controls**
  - **Potentiometer**
  - **switches**
- **Transistor as switches and controls**
  - **FET-based**
  - **BJT-based**

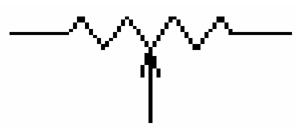
Variable potentiometers

-Variable resistance sometime needed (see Labs)

- potentiometer provides such a variable resistance.

-Make sure the circuit works for any transitor from this batch.

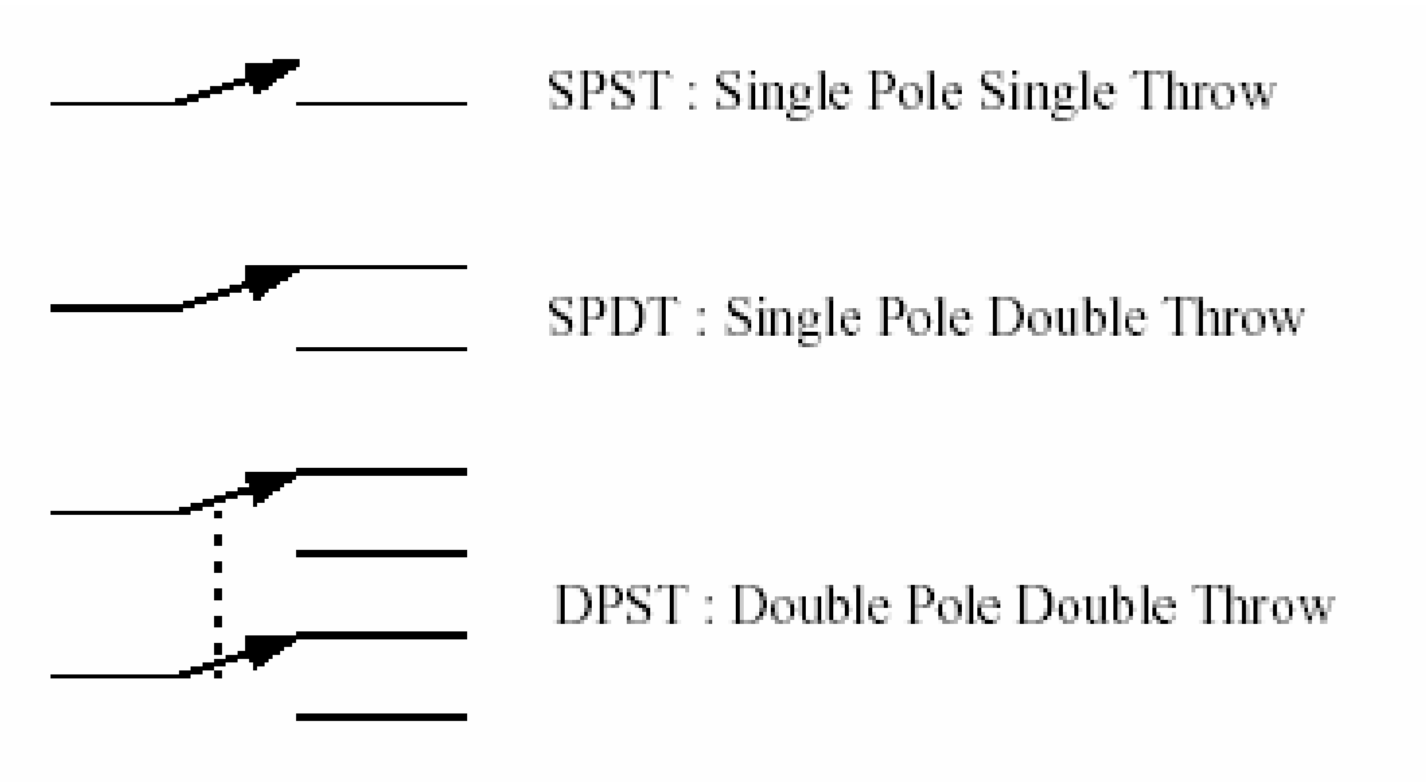




$$V_L = \frac{R_2 R_L}{R_1 R_L + R_2 R_L + R_1 R_2} \cdot V_s$$

Electronics Switches

-Switches are elements with two states « Open » and « Close »

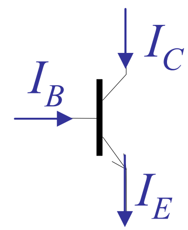


-Simplest switches are mechanical switches

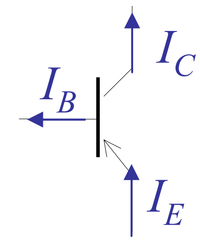
Refresher on transistors

-Transistors can be used as switches, to control resistance, etc…

- **BJT**



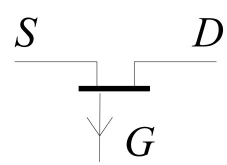
NPN



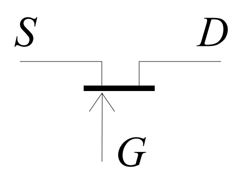
PNP

$\rightarrow I_E = I_B + I_C$

- **FET**



JFET P-channel

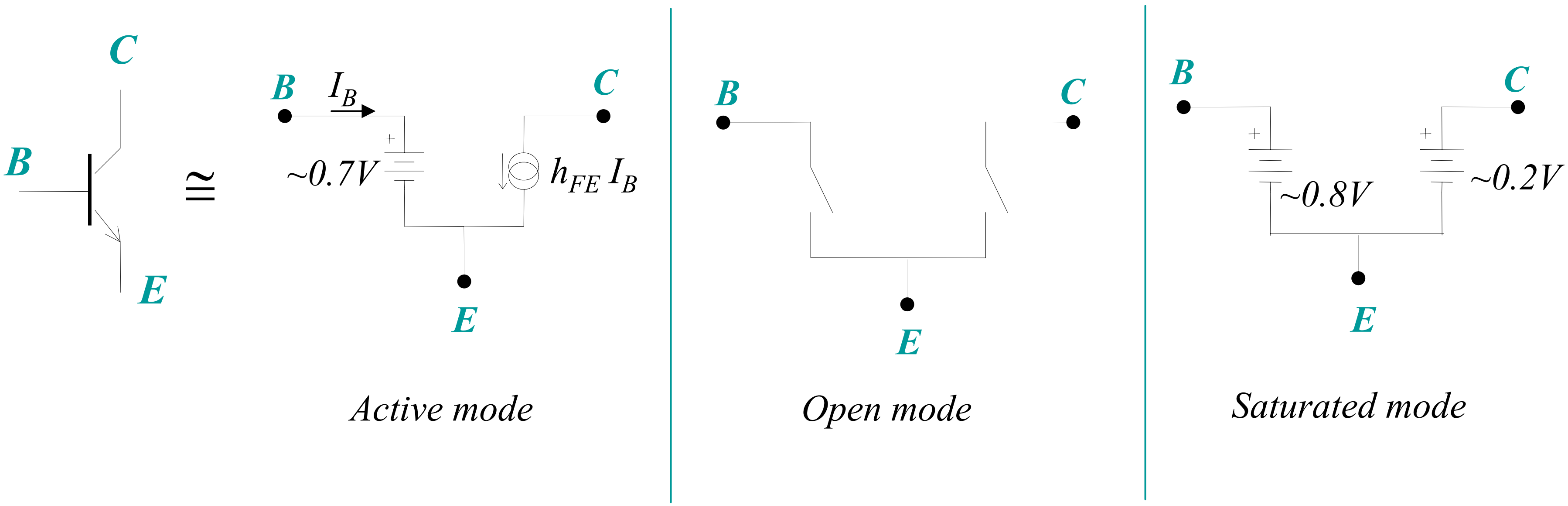


JFET N-channel

$\rightarrow I_G = I_S + I_D$

Operating mode a a NPN BJT

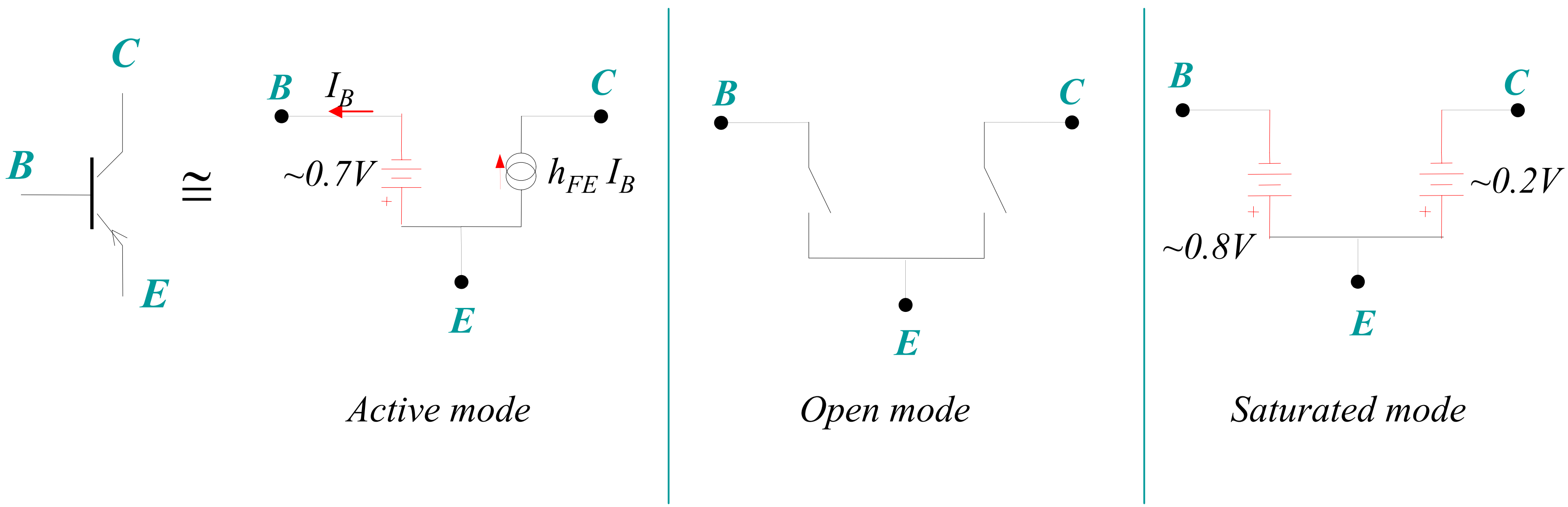
Active mode :	$V_{BE} \approx 0.7V$	$\sim 0.3V < V_{CE} < V_{CC}$	$I_c \approx \beta I_B$
Open mode :	$I_B \cong 0$	$V_{CE} \cong V_{CC}$	$I_C \approx 0$
Sat. mode :	$V_{BE} \approx 0.8V$	$V_{CE} \approx 0.2V$	$I_c \neq \beta I_B$



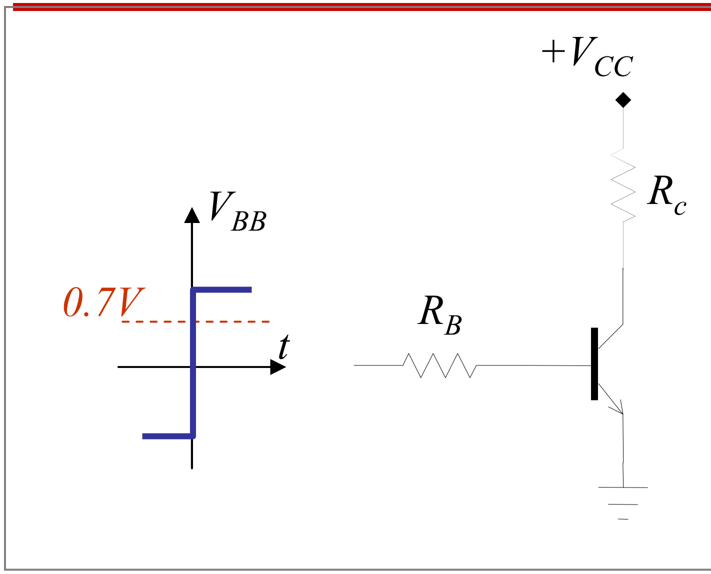
V_{CC} = *external voltage source supplytin C et E.* V_{CE} *cannot be larger than Vcc!*

Operating mode a a NPN BJT

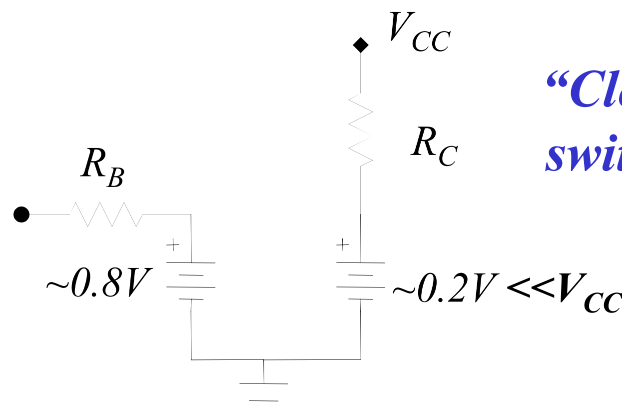
Active mode :	$V_{BE} \approx -0.7V$	$\sim -0.3V < V_{CE} < V_{CC} \quad (<0)$	$I_c \approx \beta I_B$
Open mode:	$I_B \cong 0$	$V_{CE} \cong V_{CC}$	$I_C \approx 0$
Sat. Mode:	$V_{BE} \approx -0.8V$	$V_{CE} \approx -0.2V$	$I_c \neq \beta I_B$



BJT as a switch



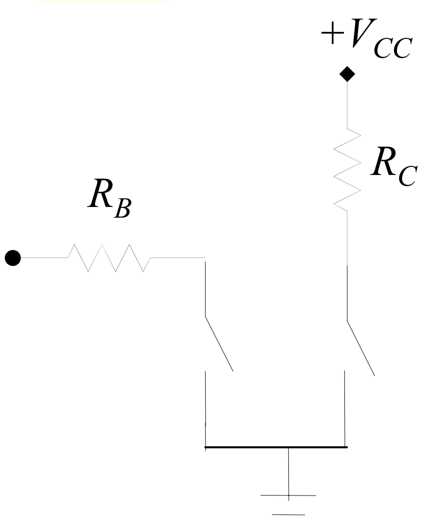
$t>0$: $V_{BE} > \sim 0.8V$, so that $R_c I_c \sim V_{CC}$ $\rightarrow V_{CE} \sim$ few 100mV



"Closed switch"

$$I_{R_C} = \frac{V_{CC} - 0.2}{R_C} \cong \frac{V_{CC}}{R_C}$$

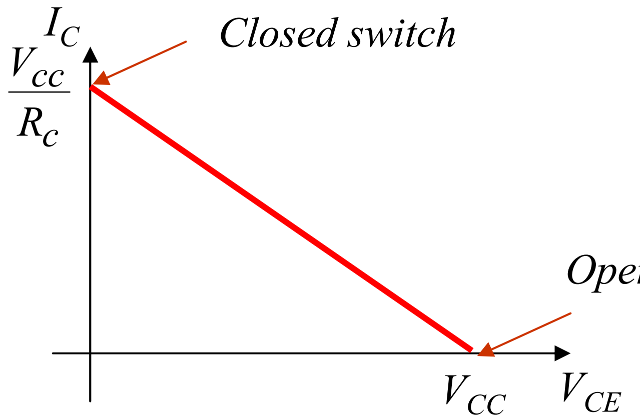
$t<0$: $V_{BE} < 0.7V \rightarrow$ **Open mode**

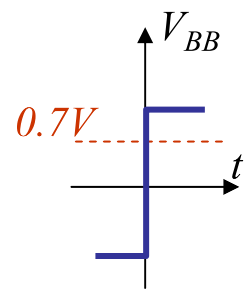


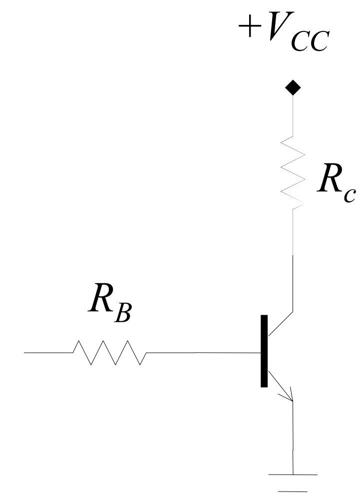
"Open switch"

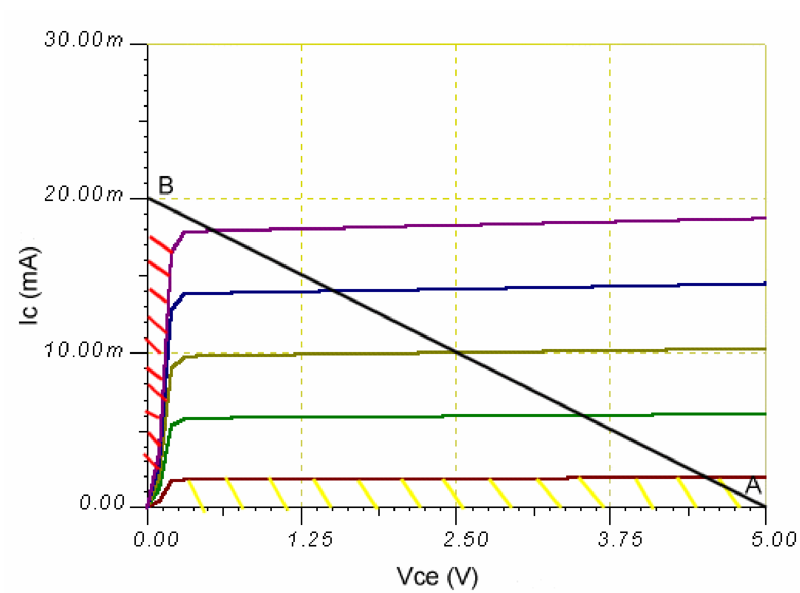
$$I_{R_C} = 0$$

BJT as a switch









$$I_{B_{\min}\,(\text{Closed switch})} \cong \frac{V_{cc}}{R_c\beta} \cong \frac{V_{BE_{\min}} - 0.8}{R_B}$$

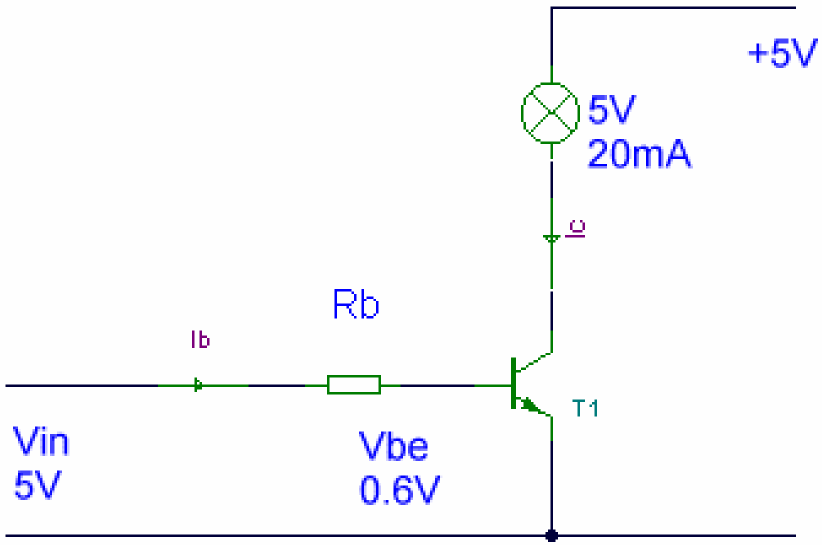
BJT as a switch: turning on/off a light

-BJT with 5 V voltage source,

- Design a system to switch a 20 mA, 5V lamp on and off,

- The gain factor for a given batch of transitor varies between 100<β<500,

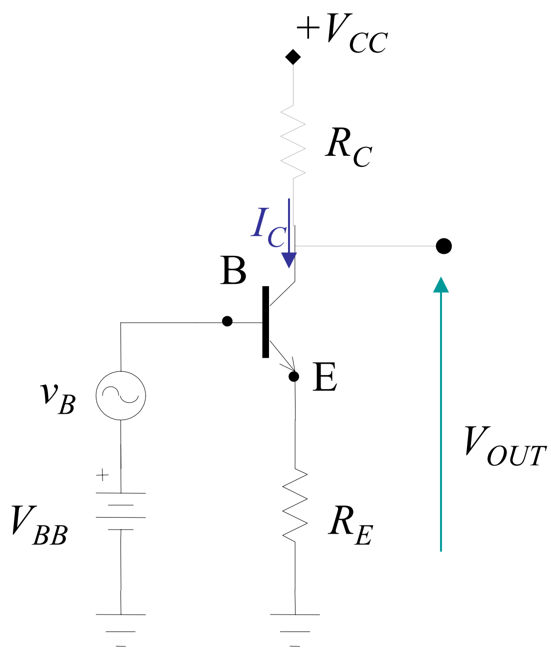
-Make sure the circuit works for any transitor from this batch.



$$i_B = \frac{1}{\beta} i_c \Rightarrow \max(i_B) = \frac{1}{\min(\beta)} i_c \Rightarrow \max(i_B) = 0.2mA$$

$$V_{IN} = V_{BE} + R_B i_B \Rightarrow R_B = \frac{V_{IN} - V_{BE}}{i_B} = \frac{5 - 0.6}{0.2} 10^3 = 22\,k\Omega$$

BJT as an amplifier



assumptions :

- Transistor operates in **active mode** when $\boldsymbol{v_B = 0}$
- **Amplitude** of v_B signal **small** enough to have active mode operation
- In 1st **approximation** : $V_B \equiv V_{BB} + v_b$

$$\rightarrow I_E \approx \frac{V_B - V_{BE}}{R_E} \approx I_C = \bar{I}_C + i_c \qquad (I_B << I_C)$$

Neglecting variation of V_{BE} : $\rightarrow i_c \approx \dfrac{v_B}{R_E}$

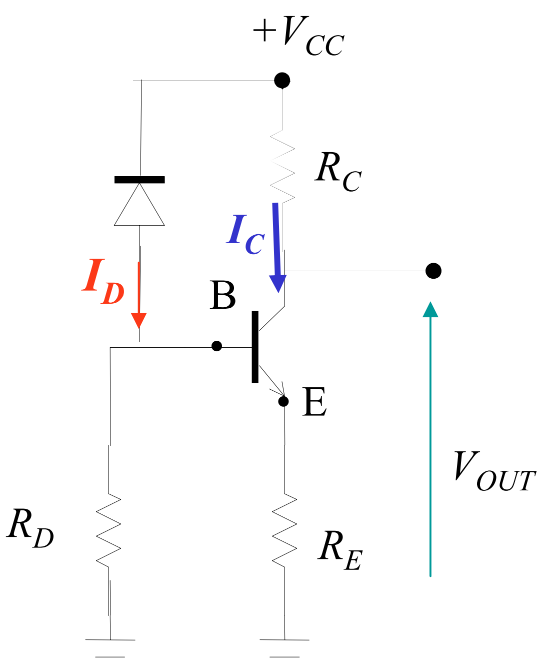
Finally : $V_{out} = V_{cc} - R_c I_C = V_S + v_s$ with : $V_S = V_{cc} - R \cdot \bar{I}_C$

and $v_s = -R_c i_c = -\dfrac{R_c}{R_E} v_b$ Signal v_B is amplified by a factor $A_v = -\dfrac{R_c}{R_E}$

BJT as an amplifier: light detection

- Previous circuit can be used to amplify low intensity signal, e.g. such as produced in photodiode (typically 1 μA/1μW of incident light)

- Circuit is modified as follows:



Output voltage is given by:

$$V_{OUT} = V_{CC} - R_C I_C$$

From ground-E-B-ground loop:

$$I_C = \frac{V_B - V_{BE}}{R_E} \approx \frac{R_D I_D - V_{BE}}{R_E} \approx \frac{R_D I_D - 0.7}{R_E}$$

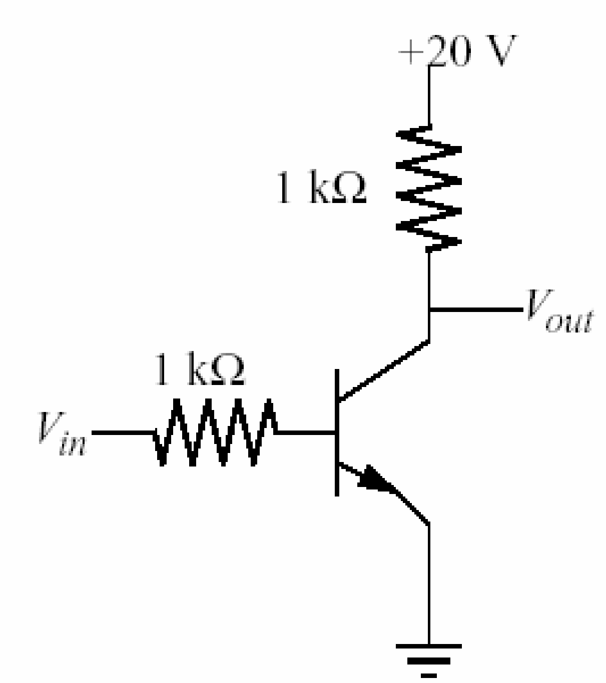
Finally output voltage is:

$$V_{OUT} = V_{CC} - (R_D I_D - 0.7)\frac{R_C}{R_E}$$

$$= V_{CC} + 0.7\frac{R_C}{R_E} - \frac{R_D R_C}{R_E} I_D$$

$$= \overline{V}_{OUT} - \frac{R_D R_C}{R_E} I_D$$

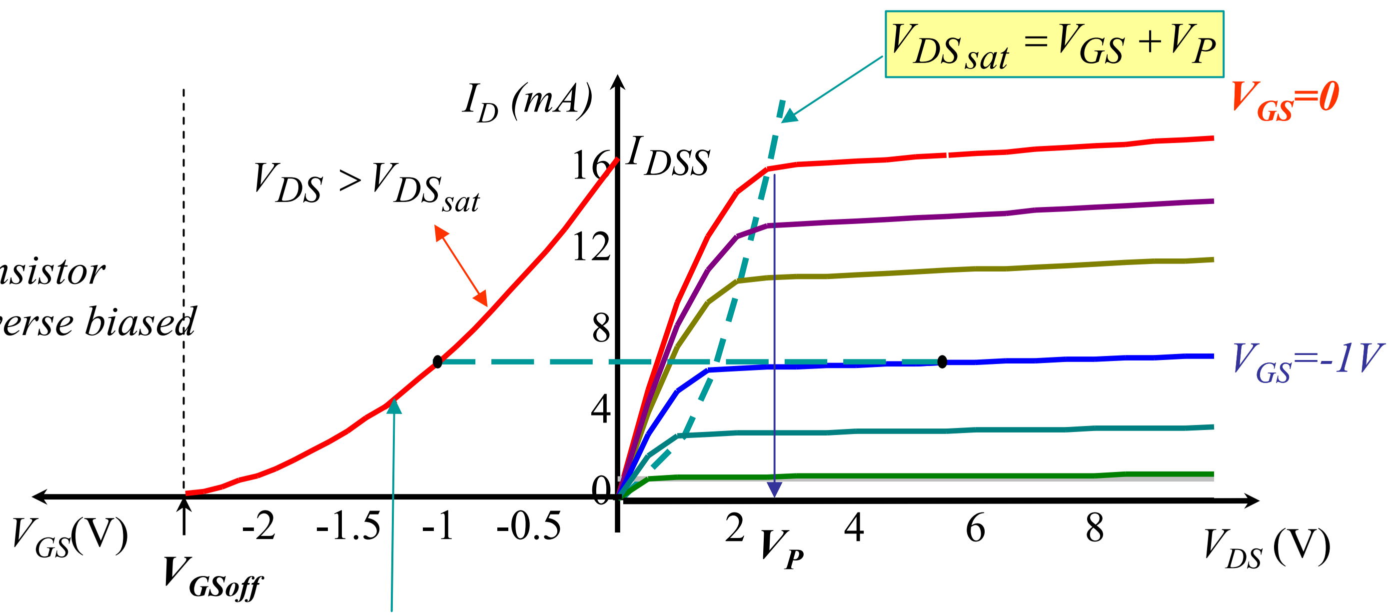
Two-states electronics



- When V_{in}=0 transistor is open, V_{out} = 20 V
- As V_{in} increases the transistor turns on (active mode) and current begin to flow → V_{out} is lowered toward ground.
- Eventually V_{BE}~ 0.8 V (saturated mode), and when V_{in}~ 1 V
  → $I_c=\beta I_b$~ 20 mA so V_{OUT} is close to 0
- This circuit has only two output states (with exception of 0.8 V <V_{in} <1 V)

- Two-states electronics important components of digital electronics

FET as control



Pinch-off regime for $V_{DS} > V_{DS_{sat}}$:

$$I_D \cong I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS_{off}}}\right)^2 = k\left(V_{GS} - V_{GS_{off}}\right)^2 \qquad k = \frac{I_{DSS}}{V_{GS_{off}}^{\;2}}$$

Linear (Ohmic) regime for $V_{DS} < V_{DS_{sat}}$:

$$I_D \cong 2k\left[\left(V_{GS} - V_{GS_{off}}\right) - \frac{V_{DS}}{2}\right]\cdot V_{DS}$$

FET as control

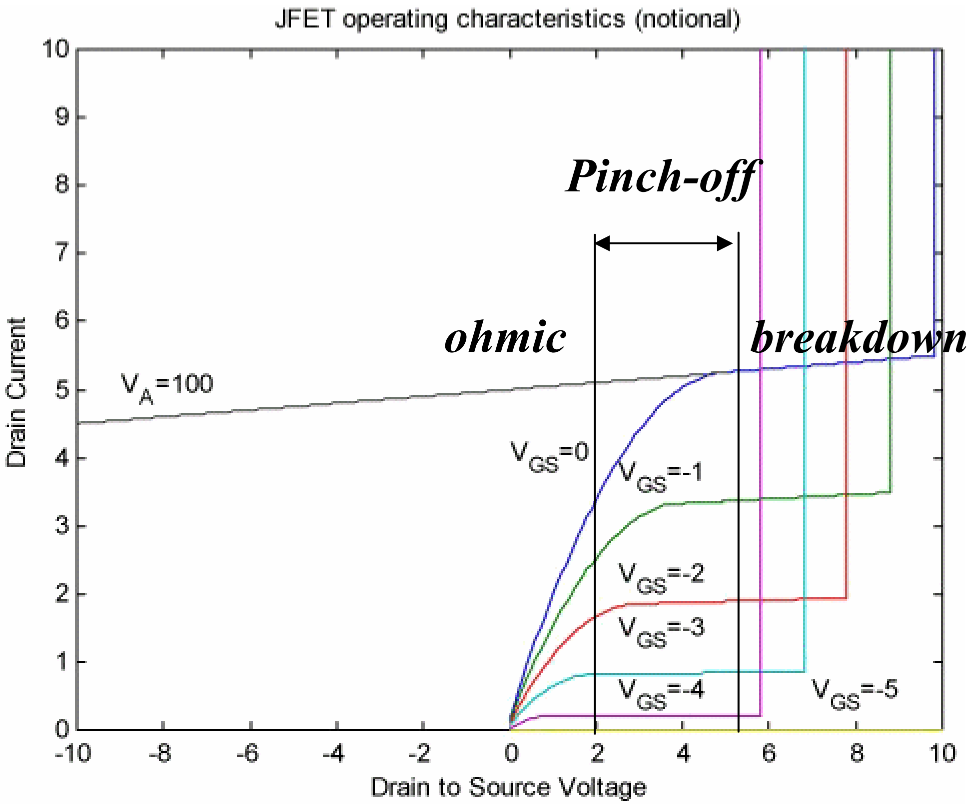
•When **VGS ≤ VGSoff**, the channel is depleted ➔ transistor is **blocked**

•When **VGSoff < VGS< 0**, and **VDS > VGS+VP** , (with *VP*~ |VGSoff|),
➔ ***ID* saturate** and its value is **quadractically dependent upon *VGS.***

•*VP* is the value of VDS for which ID saturates and VGS is zero.

•The pich-off regime occurs for VDS= VGS+VP (VGS is non zero)

•For 0 < VDS<< VGS+VP , ID is proportional to VDS (linear regime) and the slope is smaller as VGS tends toward VGSoff.

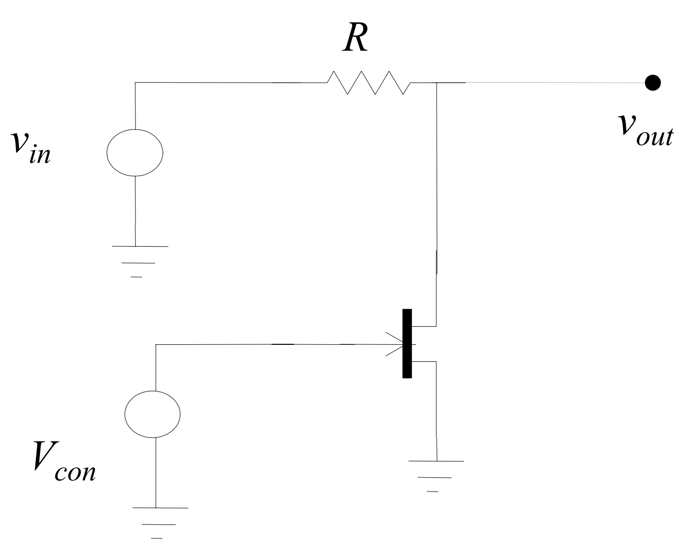


FET as resistance control

For $V_{GS} > V_{GSoff}$ and $V_{DS} < V_{GS} + V_P$:

$$R_{DS} \cong \frac{1}{k \cdot \left[(V_{GS} + V_P) - \frac{V_{DS}}{2} \right]}$$

example:



$$\rightarrow v_{out} = \frac{R_{DS}}{R_{DS} + R} v_{in}$$

= variable attenuation **controlled** by V_{con}

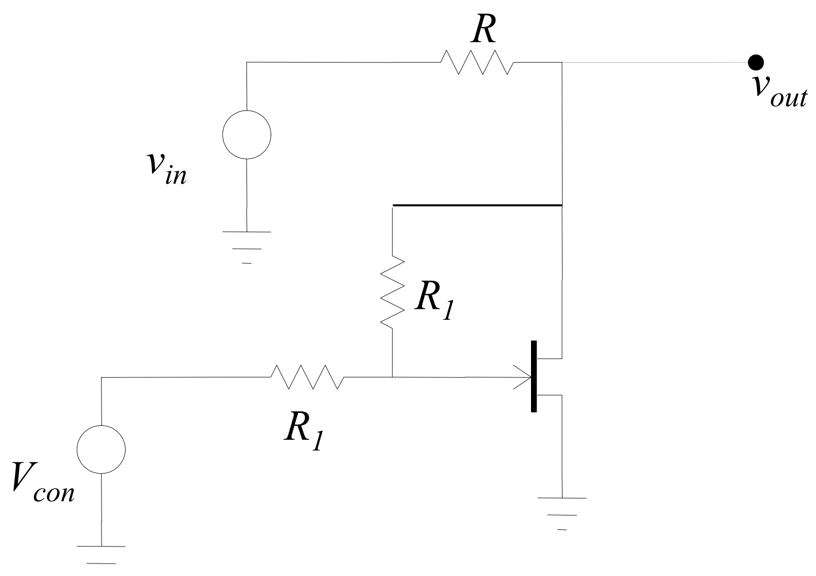
Choosing $R >> R_{DS_{on}}$, v_{out} varies between ~0 et v_{in}

Problem:

R_{DS} depends on $V_{DS} \rightarrow$ nonlinear response

FET as resistance control: a better solution

$$R_{DS} \cong \frac{1}{k \cdot \left[\left(V_{GS} + V_P \right) - \frac{V_{DS}}{2} \right]}$$



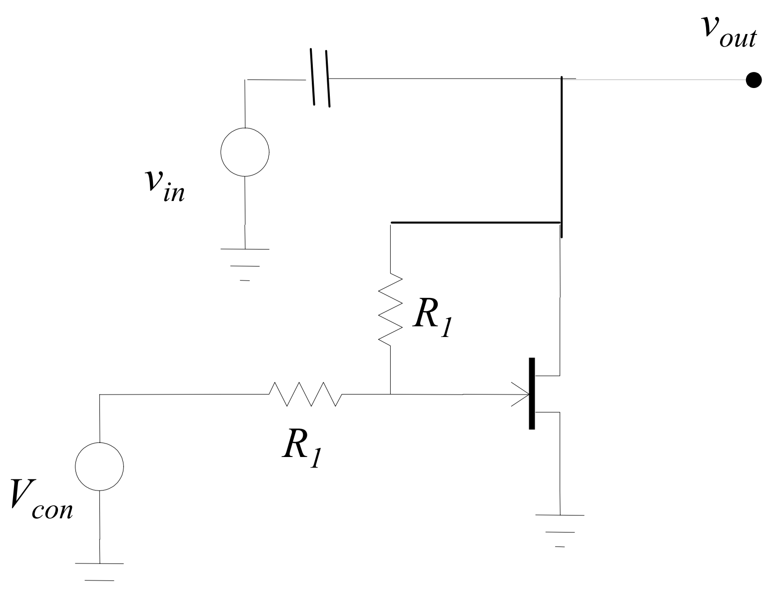
$$\rightarrow V_{GS} = \frac{V_{DS}}{2} + \frac{V_{com}}{2} \quad \left(I_G \approx 0 \right)$$

$$\rightarrow R_{DS} \approx \frac{1}{k\left(V_{com} + V_P \right)}$$

Better linearity than circuit in previous slide

FET as resistance control: variable frequency filter

- variably controlled resistance in an low (or high) pass filter
- Dynamical adjustment of cut off frequency

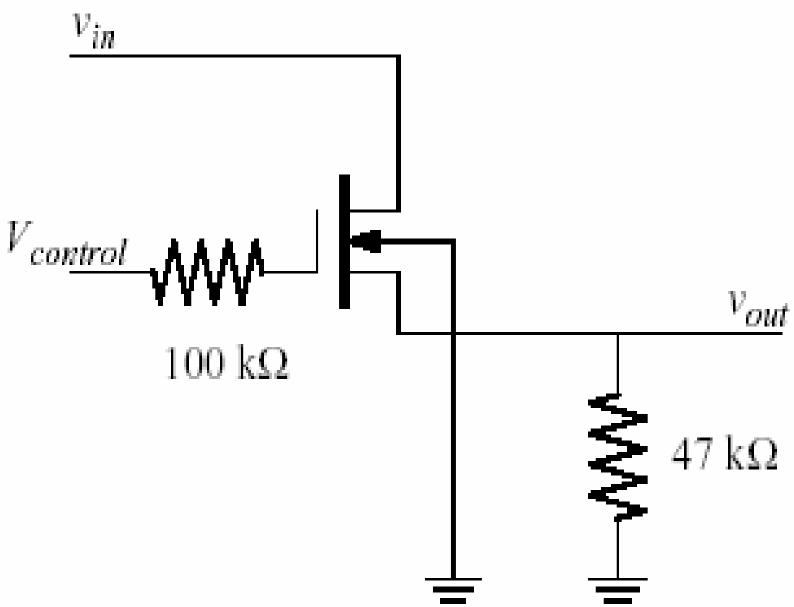


$$\rightarrow R_{DS} \approx \frac{1}{k(V_{com} + V_P)}$$

$$\omega \approx \frac{1}{R_{DS} C}$$

FET switch based on MOFSET

- Based on a voltage divider $$v_{OUT} = \frac{47k\Omega}{R_{DS} + 47k\Omega} v_{in}$$



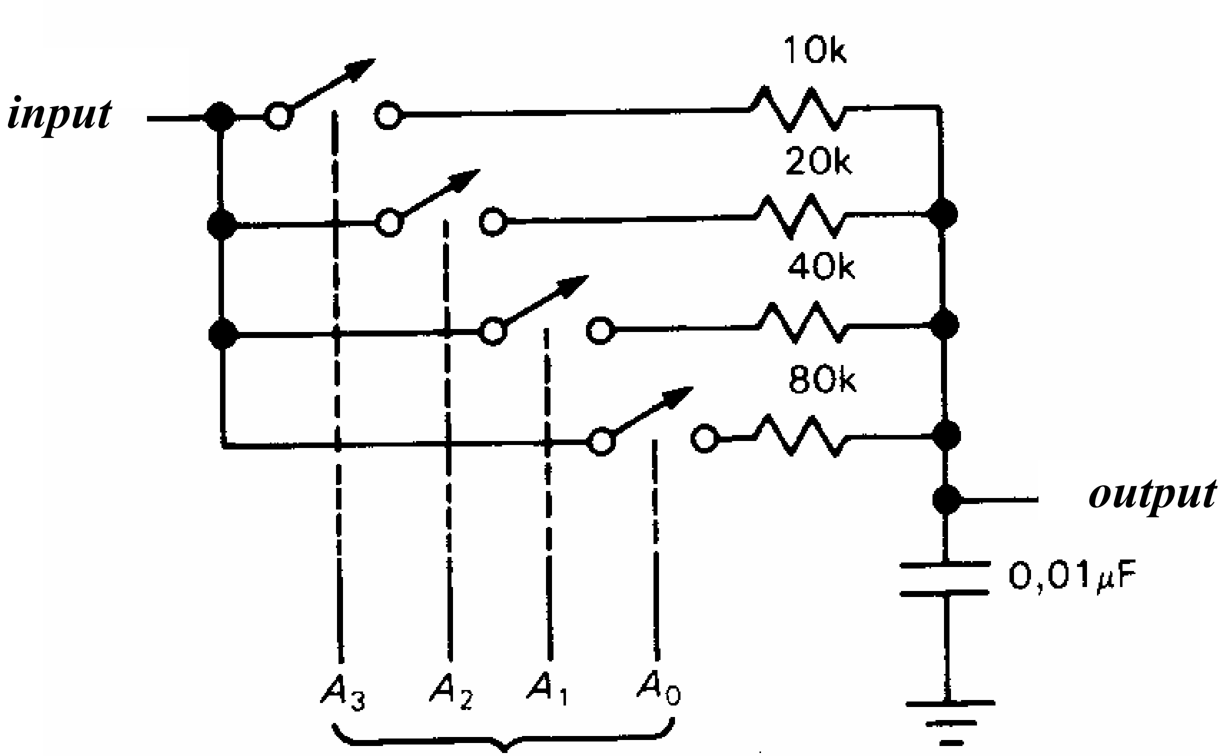
- When gate at ground

$$R_{DS} > 10^{10}\ \Omega \Rightarrow v_{OUT} \approx 0$$

- When gate at +15 V

$$R_{DS} \approx 100\ \Omega \Rightarrow v_{OUT} \approx v_{in}$$

FET switch based on MOFSET: example of application



Selection of cut-off frequency