ELECTRONIC DEVICES

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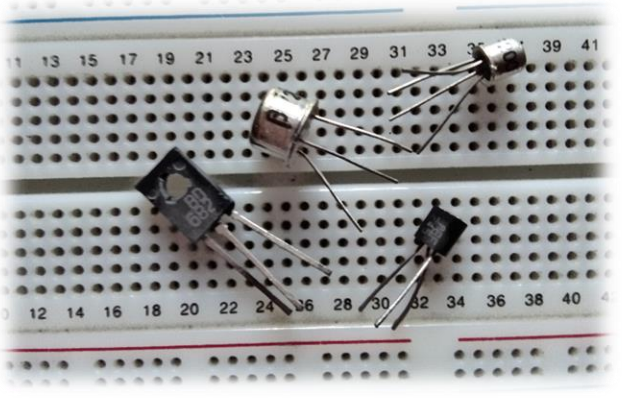
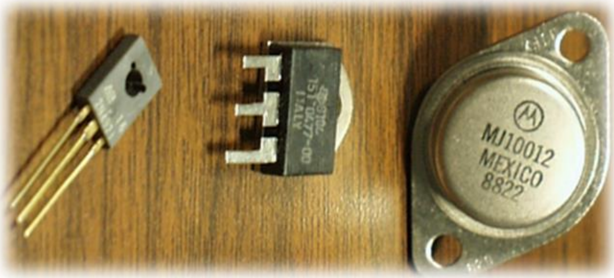
C11 – Transistors. BJTs.



Contents

Transistors



- 1926 - JE Lilienfeld (physicist, engineer)

  first patent of a field effect transistor – could not be built

- 1947, Bell Labs, USA - J Bardeenn, W Brattain, W Shockley

  first built transistor

- 1956 J Bardeenn, W Brattain, W Shockley

  Nobel prize in physics

The invention of the transistor in 1947 is included on the list of IEEE milestones

But what is a transistor?

Transistors

= active semiconductor devices, with three terminals

- used to amplify or switch signals
- essential components of electronic circuits
- discrete or integrated

Operating principle:

The voltage applied between two terminals (command) controls the current through the third terminal

transistors ≡ **voltage-controlled current sources**

Transistors

= active semiconductor devices, with three terminals

- used to amplify or switch signals
- essential components of electronic circuits
- discrete or integrated

"Putting sixty-four transistors on a chip allowed people to dream of the future. Putting four million transistors on a chip actually gave them the future."

- Malcolm Gladwell

Intel 4004, 1971, 10 μ, 14 mm^2, 2,300 transistors

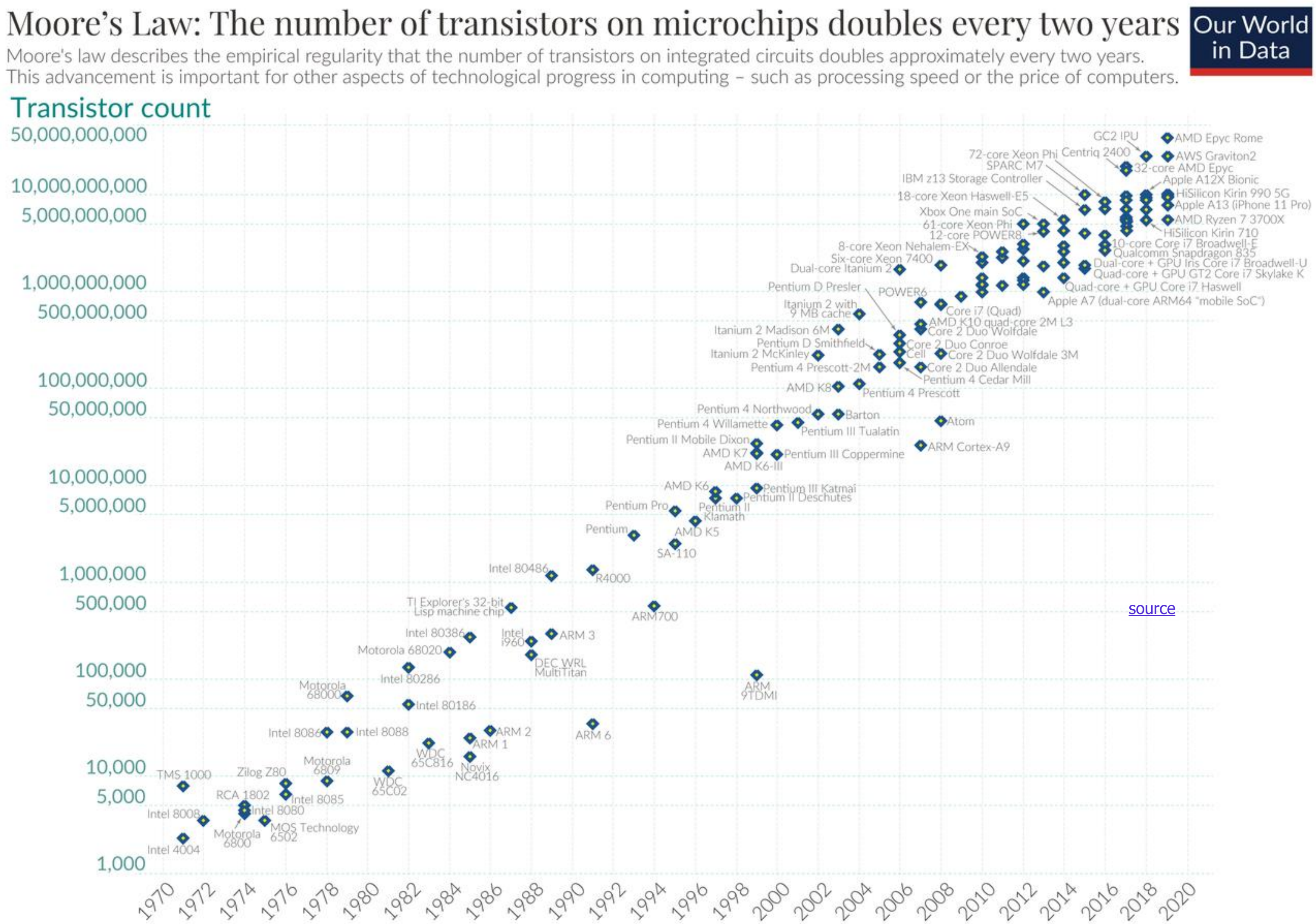
Pentium 4, 2006, 65 nm, 90 mm^2, 184,000,000 transistors

Core i7 Haswell-E, 8-core, 2014, 22 nm, 355 mm^2, 2,600,000,000 transistors

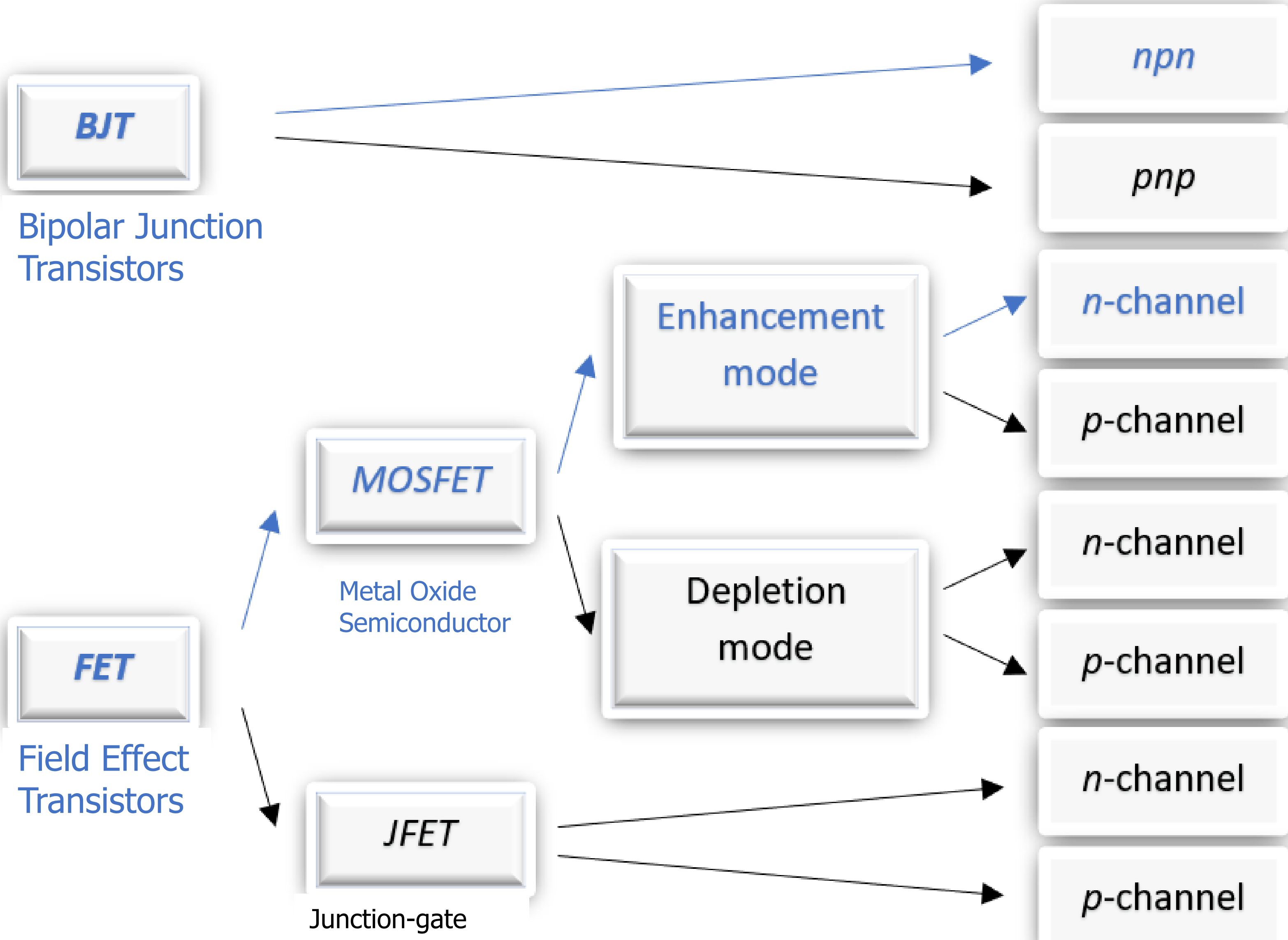
Xeon_Broadwell-E5, 22-core, 2016, 14 nm, 456 mm^2 , 7,200,000,000 transistors

Apple M2 Max 12-core, 2023, 5 nm, 67,000,000,000 transistors

Transistors



Types of transistors



➢ Operating principle

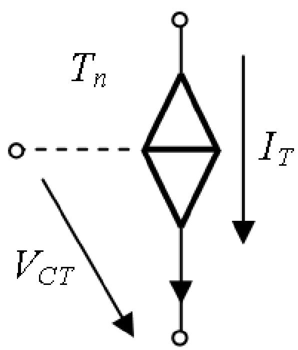
transistors ≡ non-linear **voltage-controlled current sources**

square – MOSFET; exponential – BJT

dc model – ideal VCCS

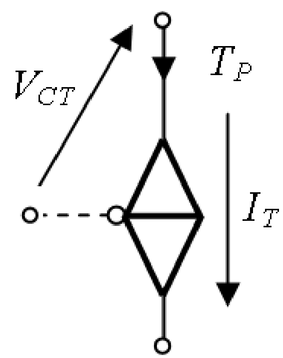
n-type

- n-channel MOSFET
- npn BJT



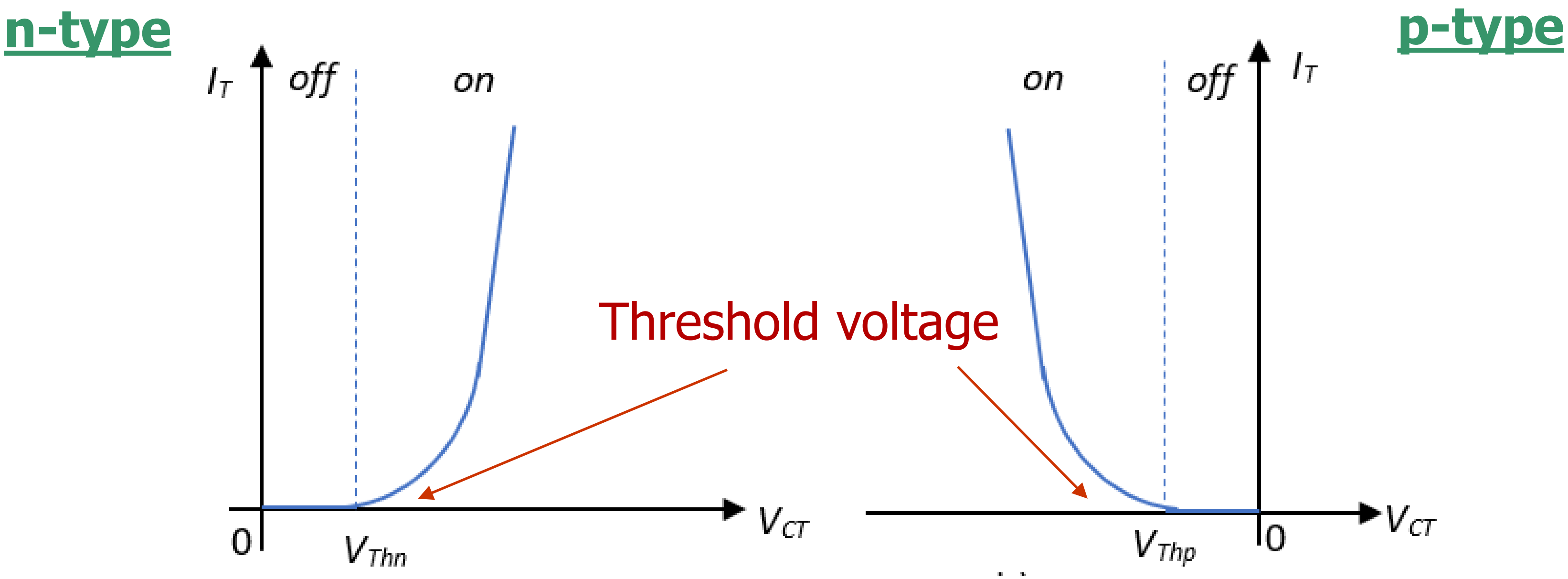
p-type

- p-channel MOSFET
- pnp BJT



Operating regions

transistors ≡ non-linear **voltage-controlled current sources**



- $V_{CT} < V_{Thn}$, T_n – off, $I_T = 0$
- $V_{CT} > V_{Thn}$, T_n – on, $I_T > 0$

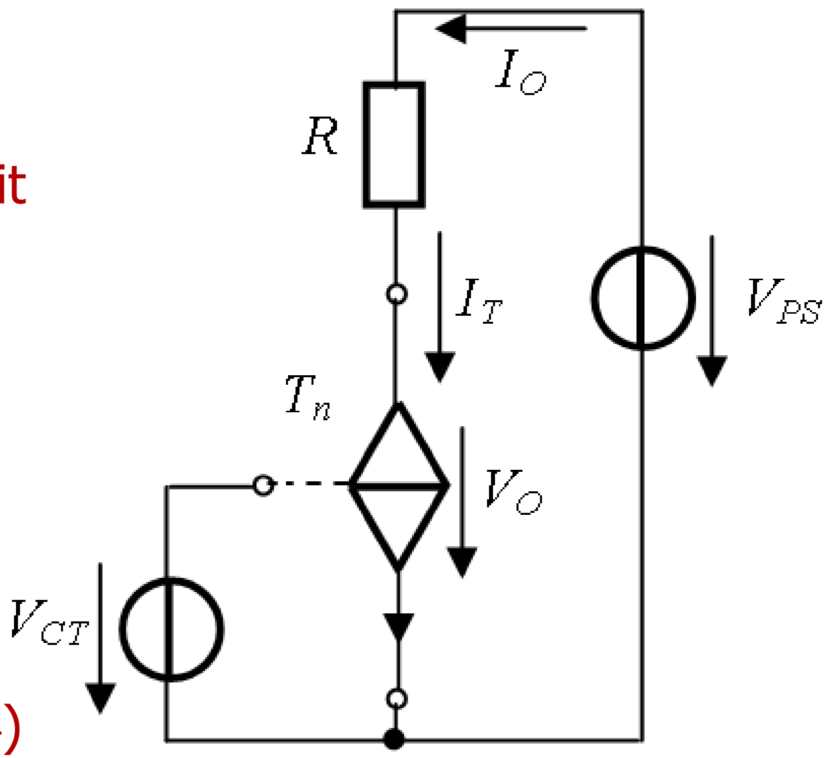
- $V_{CT} > V_{Thp}$, T_p – off, $I_T = 0$
- $V_{CT} < V_{Thp}$, T_p – on, $I_T > 0$

n-type transistors. Transfer characteristics.

n-type transistors

Using the n-type transistor, T_n, in a circuit

- series supply – voltage source
- parallel supply – current source



Output quantities: I_O, V_O

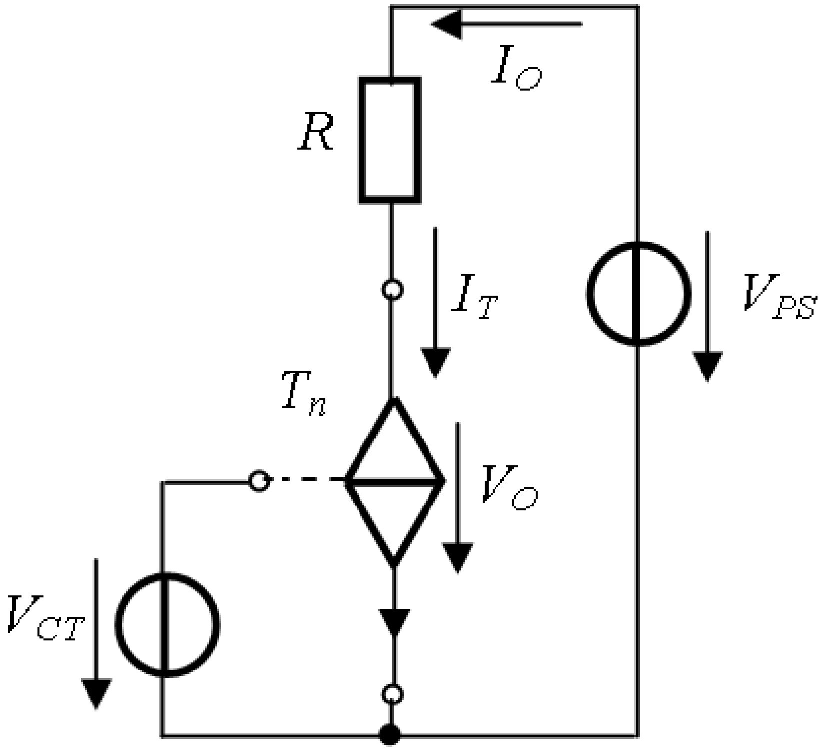
Transfer characteristics: $I_O(V_{CT})$, $V_O(V_{CT})$

$$I_T = I_O$$

Why is R necessary?

n-type transistors. Transfer characteristics.

➢ Transfer characteristics



- $V_{CT} < V_{Thn}$, T_n – off, $I_O = I_T = 0$
- $V_{CT} > V_{Thn}$, T_n – on, $I_O = I_T > 0$

$V_{PS} = RI_O + V_O$

$V_O = V_{PS} - RI_O$

$V_{CT}\uparrow$, $I_O\uparrow$, $V_O\downarrow$

$V_{O,min} = 0$

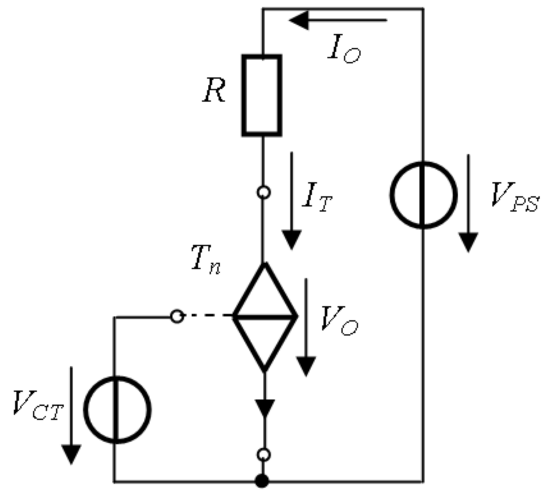
$$I_{Oex} = \frac{V_{PS}}{R}$$

I_{Oex} – maximum possible value of I_O, in the given circuit

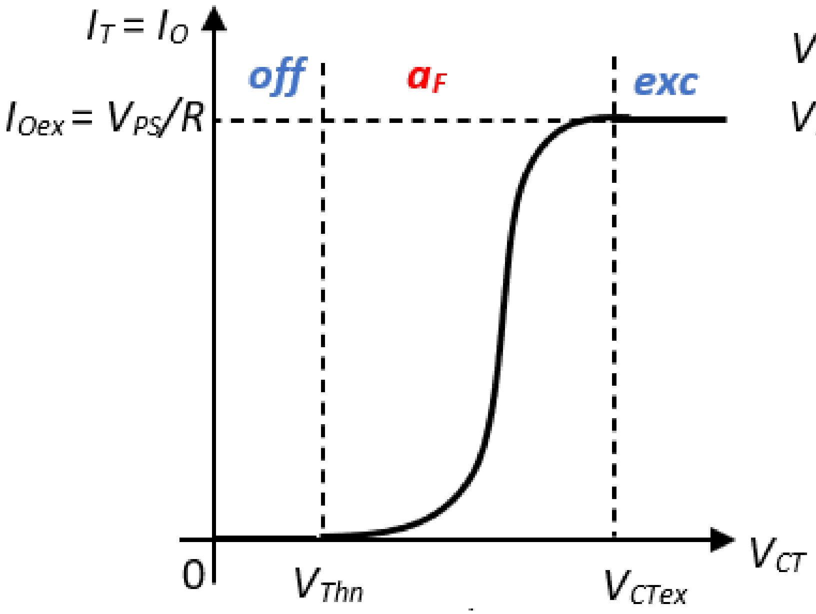
Plots for $I_O(V_{CT})$, $V_O(V_{CT})$?

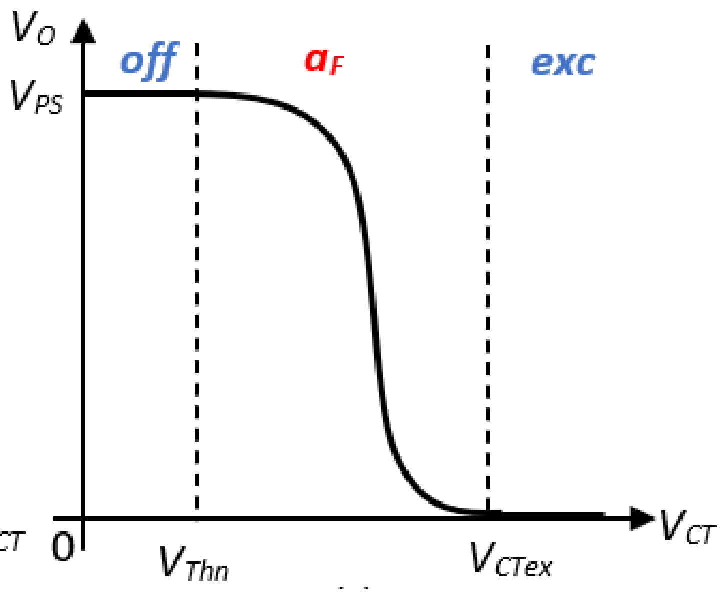
n-type transistors. Transfer characteristics.

➢ Transfer characteristics



- $V_{CT} < V_{Thn}$, T_n – off, $I_O = I_T = 0$
- $V_{CT} > V_{Thn}$, T_n – on, $I_O = I_T > 0$





n-type transistors. Transfer characteristics.

➢ Transfer characteristics

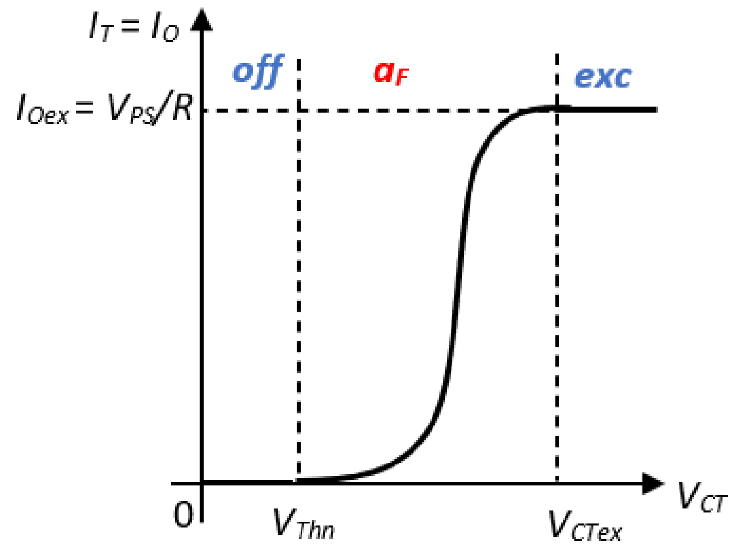
- Two extreme regions, passive:
  - **cutoff (off)**
    $I_O = 0$; $V_O > 0$; ideal switch in off state
  - **extreme conduction (exc)**
    $I_O = I_{Oex}$; $V_O = 0$; ideal switch in on state

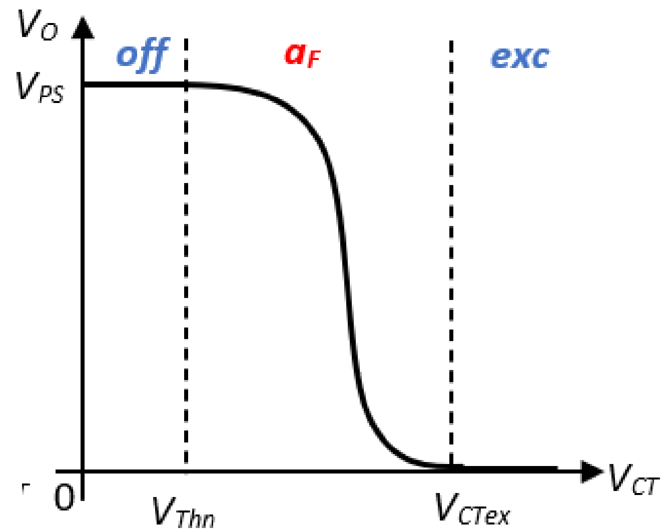
$V_{CT} < V_{Thn}$ or $V_{CT} > V_{CTex}$ - **switching transistor**

- An intermediate region, active:

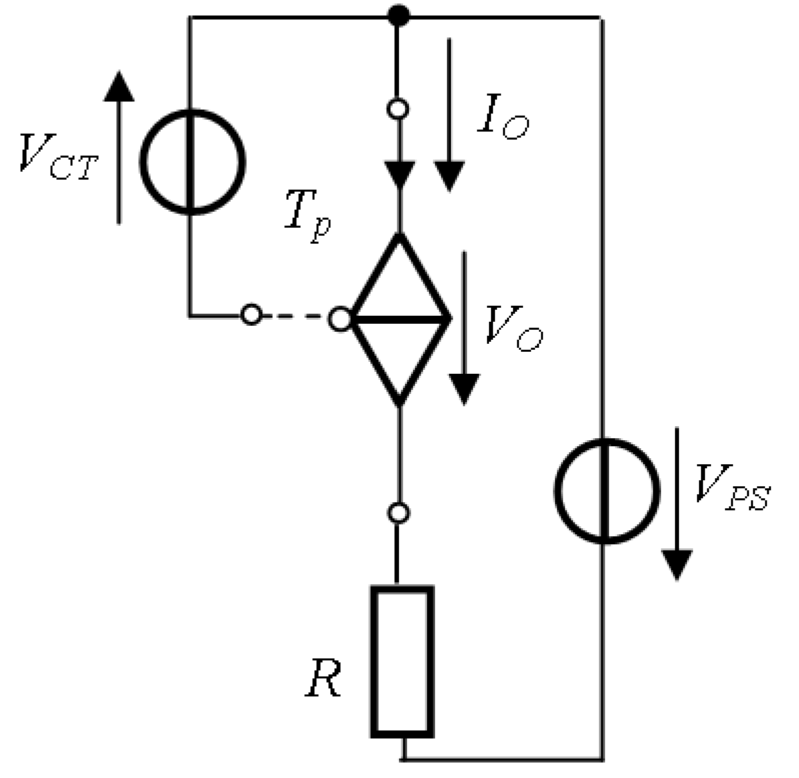
active forward region **(a_F)**

$V_{Thn} < V_{CT} < V_{CTex}$ – **permanent conduction (amplifier)**





p-type transistors. Transfer characteristics.



➢ p-type transistors

Using the p-type transistor, T_p, in a circuit

- series supply – voltage source
- parallel supply – current source

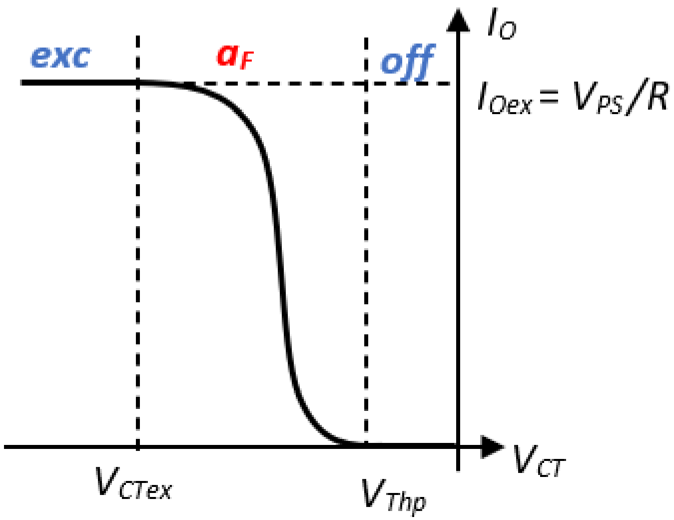
Output quantities: I_O, V_O

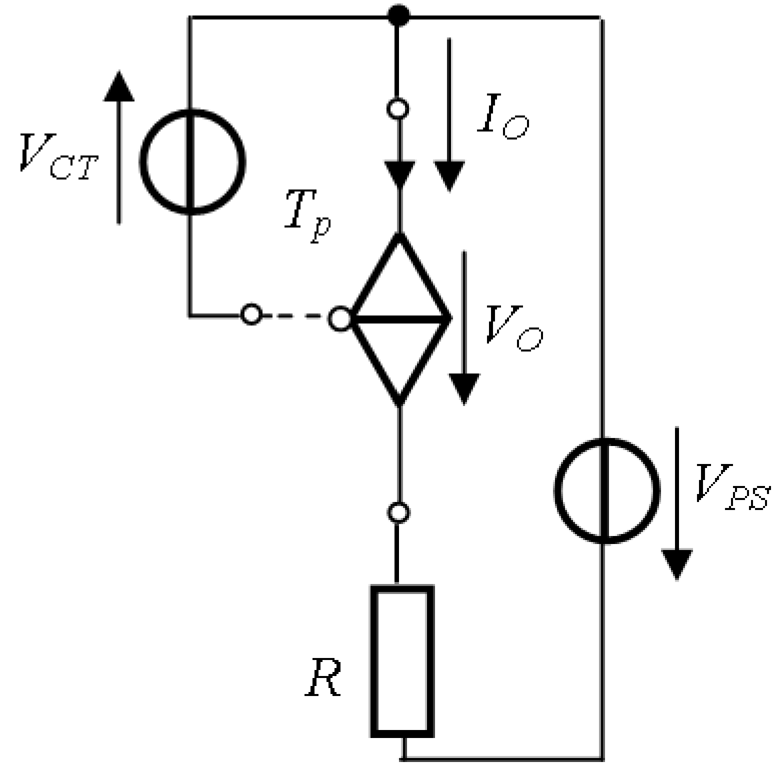
Transfer characteristics: $I_O(V_{CT})$, $V_O(V_{CT})$

$$I_T = I_O$$

p-type transistors. Transfer characteristics.

➢ Transfer characteristics



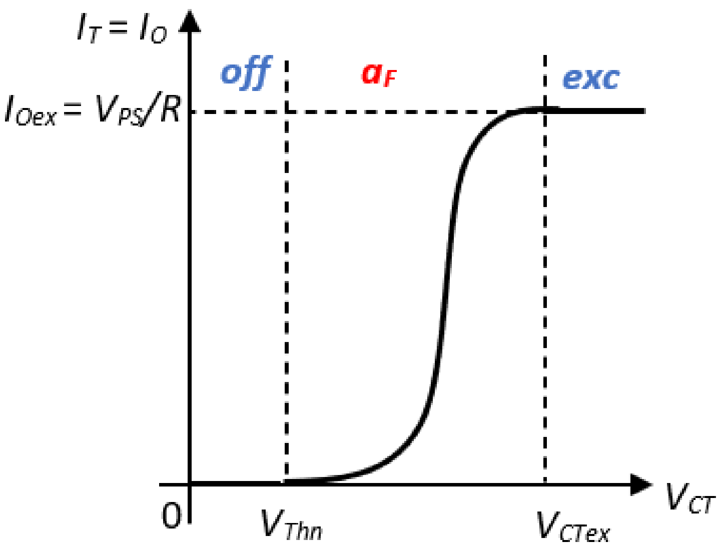


- **cutoff (off)** $V_{CT} > V_{Thp}$
- **extreme conduction (exc)** $V_{CT} < V_{CTex}$
- **active region (a$_F$)** $V_{CTex} < V_{CT} < V_{Thp}$

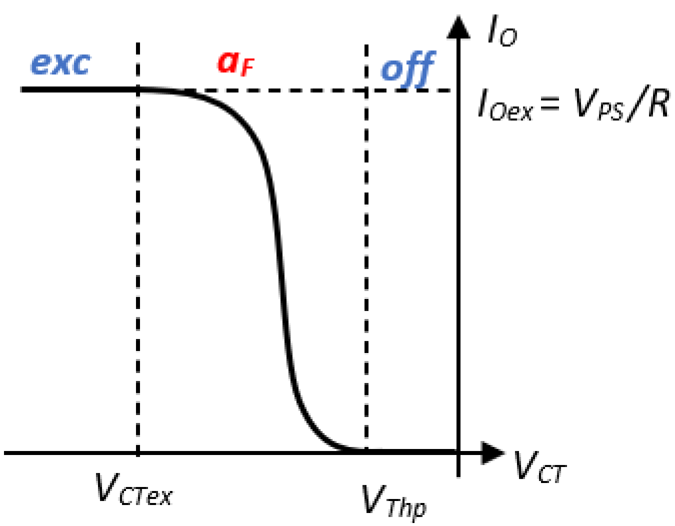
p-type transistors. Transfer characteristics.

➢ Who determines the boundaries between operating regions?

Tn



Tp



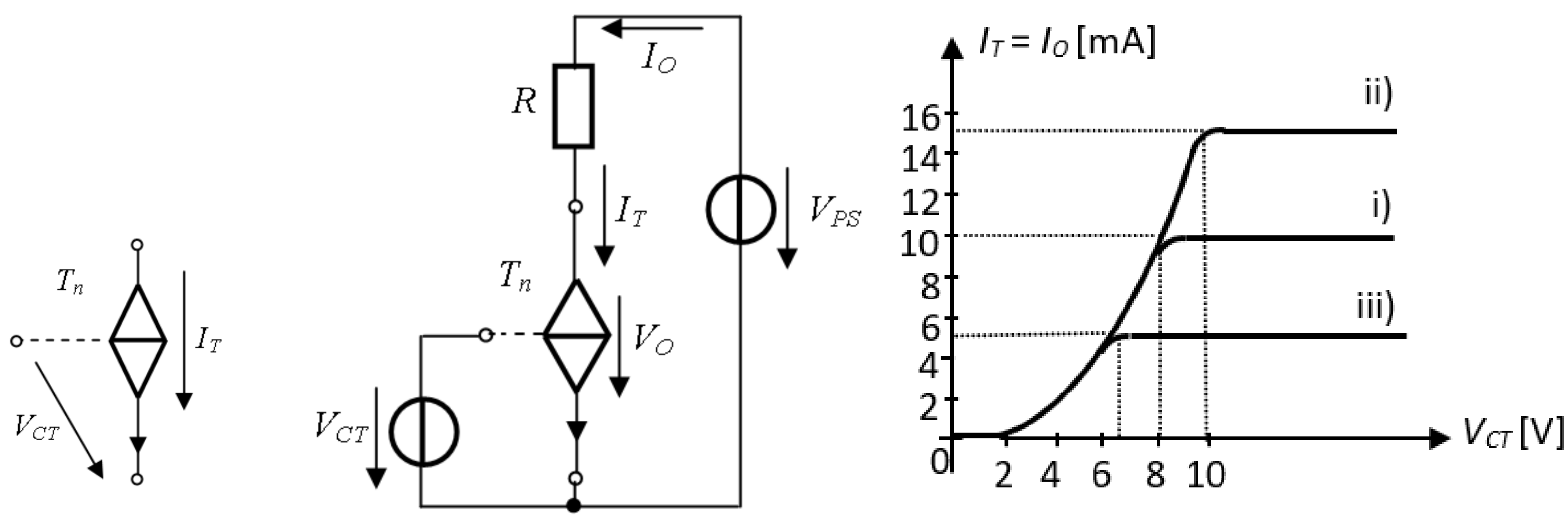
- border (off) - (a_F), $V_{CT} = V_{Th}$: the **transistor** (by its V_{Th})
- border (a_F) - (exc), $V_{CT} = V_{CTex}$:

  transistor (by means of $I_O(V_{CT})$)

  R and $\mathbf{V_{PS}}$ (by I_{Oex})

Example

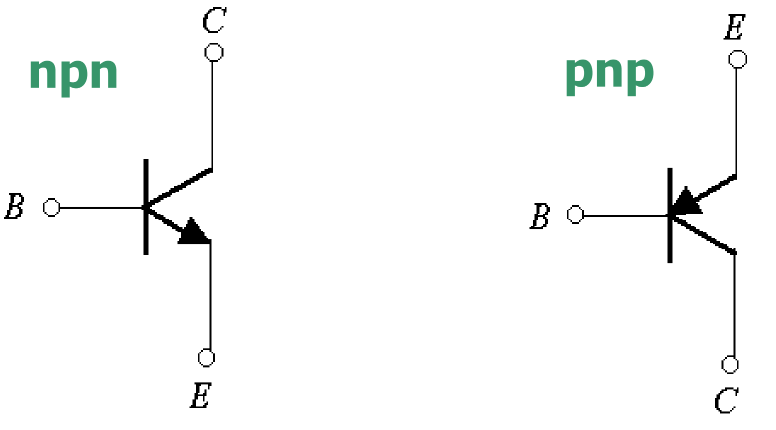
- Determine the boundaries between the operating regions of T and compute I_{Oex} and V_{CTex} for:
  - i) $V_{PS} = 10V$; $R = 1\ k\Omega$
  - ii) $V_{PS} = 15\ V$; $R = 1\ k\Omega$
  - iii) $V_{PS} = 10\ V$; $R = 2\ k\Omega$
- Resize the circuit so that $I_{oex} = 20$ mA.



Bipolar junction transistors (BJTs)

- Bipolar junction transistors (BJTs)

Circuit symbols



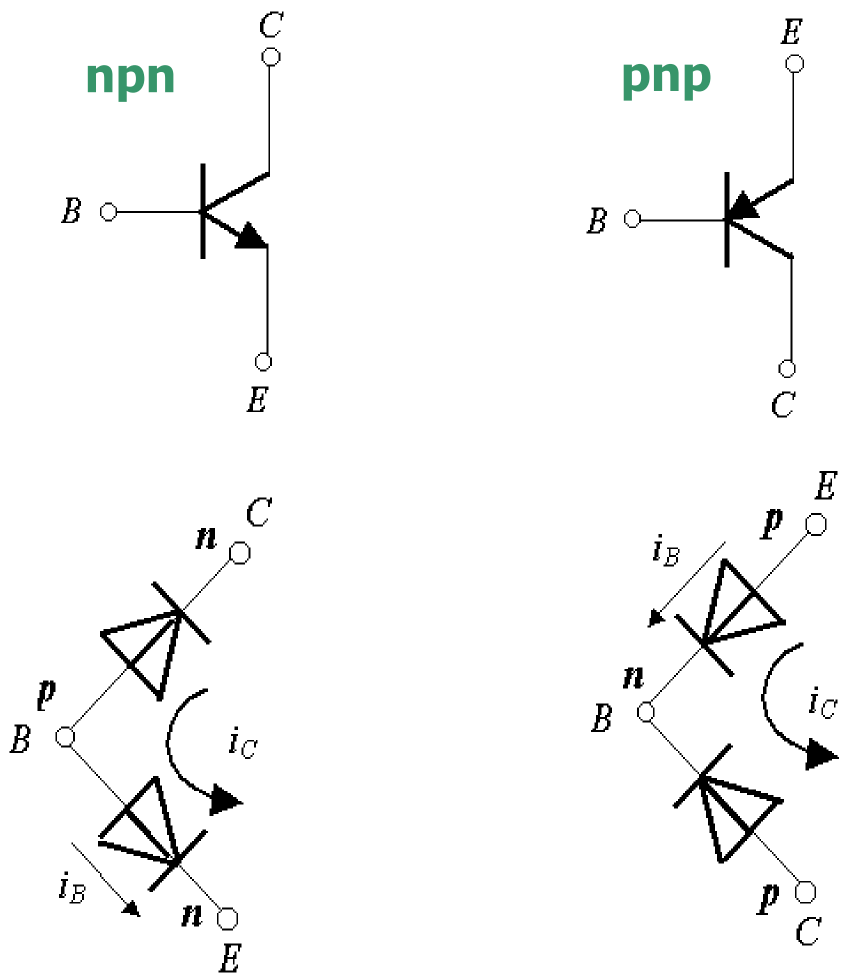
B – base
C – collector
E – emitter

The arrow on the emitter terminal indicates the direction of the positive current.

Bipolar junction transistors (BJTs)

➢ Bipolar junction transistors (BJTs)

An ohmmeter's view



!There are interactions between the two junctions!

Summary

Looks like transistors are not that scary, after all! Their fundamental features were revealed today:

- Types of transistors
- Operating principle. Operating regions.
- n-type transistors. Transfer characteristics.
- p-type transistors. Transfer characteristics.
- Bipolar junction transistors (BJTs)

Next week: BJT operation

To do: Find out what used to be called **Transistor** in the pre-Internet, pre-TV era ☺