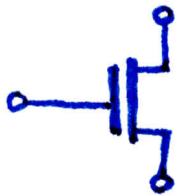
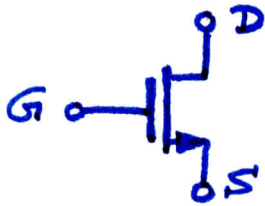


# Integrated circuits (ICs)

①

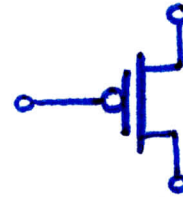
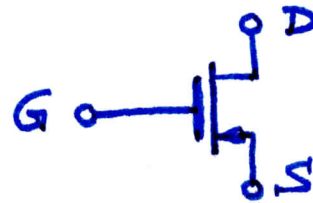
ICs use two types of FETs

N-channel



$$V_{th} > 0$$

P-channel



$$V_{th} < 0$$

Both FETs are enhancement-type FETs.

$$\Rightarrow V_{GS} = 0 \quad \Rightarrow I_D = 0$$

In real devices, there is no difference between S and D.  $\Rightarrow$  No difference in circuit symbols between S and D.

In ICs, resistors are to be avoided. ②

Q: Why?  $\Rightarrow$  Because resistors generate heat.

In ICs, transistors are either ON ( $R_{ON} = 0$ ) or OFF ( $R_{OFF} = \infty$ )

Q: Do transistors generate heat?

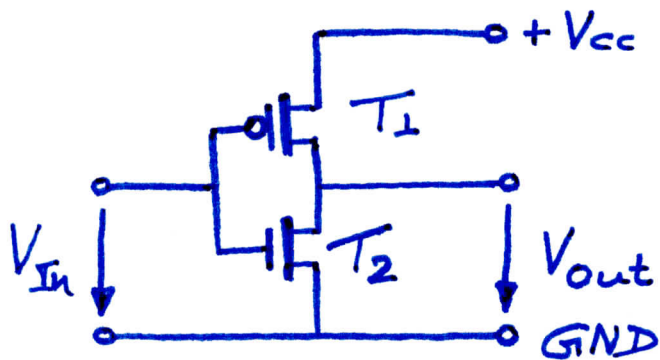
If  $R_{ON} = 0$  and  $R_{OFF} = \infty$ , no heat is generated.

Nevertheless, heat generation is a major problem in Si IC technology.

Q: Is a fan a good solution?

$\Rightarrow$  Not really, because we do not like fans (noise).

# Example: CMOS inverter



$T_1 \Rightarrow$  P-channel

$T_2 \Rightarrow$  N-channel

Assume:  $V_{cc} = 5V$      $V_{th1} = -2V$      $V_{th2} = 2V$

$V_{In} = 0V \Rightarrow T_1 = \text{ON}$      $T_2 = \text{OFF}$

$\Rightarrow V_{out} = V_{cc} = 5V$

$V_{In} = 5V \Rightarrow T_1 = \text{OFF}$      $T_2 = \text{ON}$

$\Rightarrow V_{out} = \text{GND} = 0V$

$\Rightarrow$  We have an inverter.

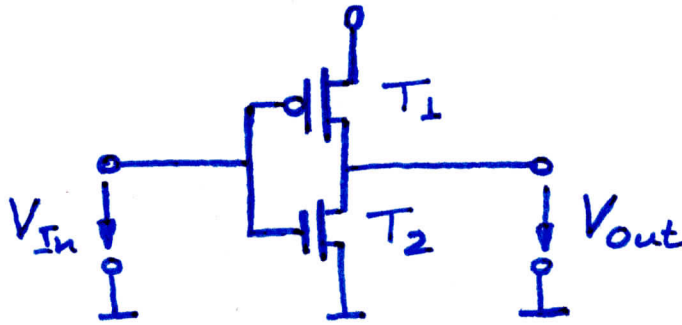
$\Rightarrow$  This is called a CMOS inverter

$\Rightarrow$  CMOS technology

$\hookrightarrow C = \text{Complementary}$

CMOS  $\Rightarrow$  Always N & P-channel FETs

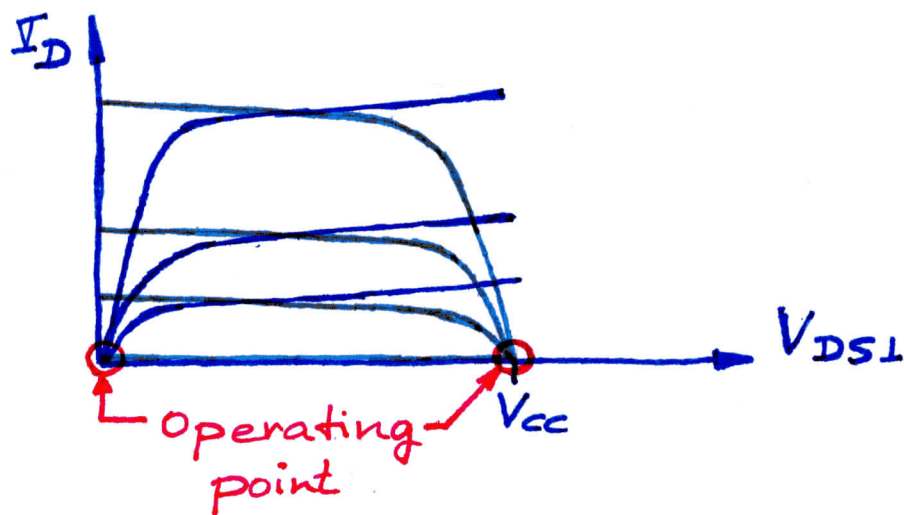
# Load line of CMOS inverter



$$V_{CC} = V_{DS1} + V_{DS2}$$

$$I_D = I_{D1} = I_{D2}$$

$$V_{DS2} = V_{CC} - V_{DS1}$$



Convince yourself that these are the two operating points of the CMOS inverter.

CMOS highly advantageous technology

$\Rightarrow$   $>95\%$  of ICs are CMOS ICs.

Q: What is the great advantage of a CMOS circuit?

Static power consumption is zero.

Q: Is CMOS power consumption zero in practice?

$\Rightarrow$  No, because parasitic capacitances need to be charged and discharged, causing some resistive power losses.

$R_{on}$  is close to zero but not zero.