



EECS 16B

Designing Information Devices and Systems II

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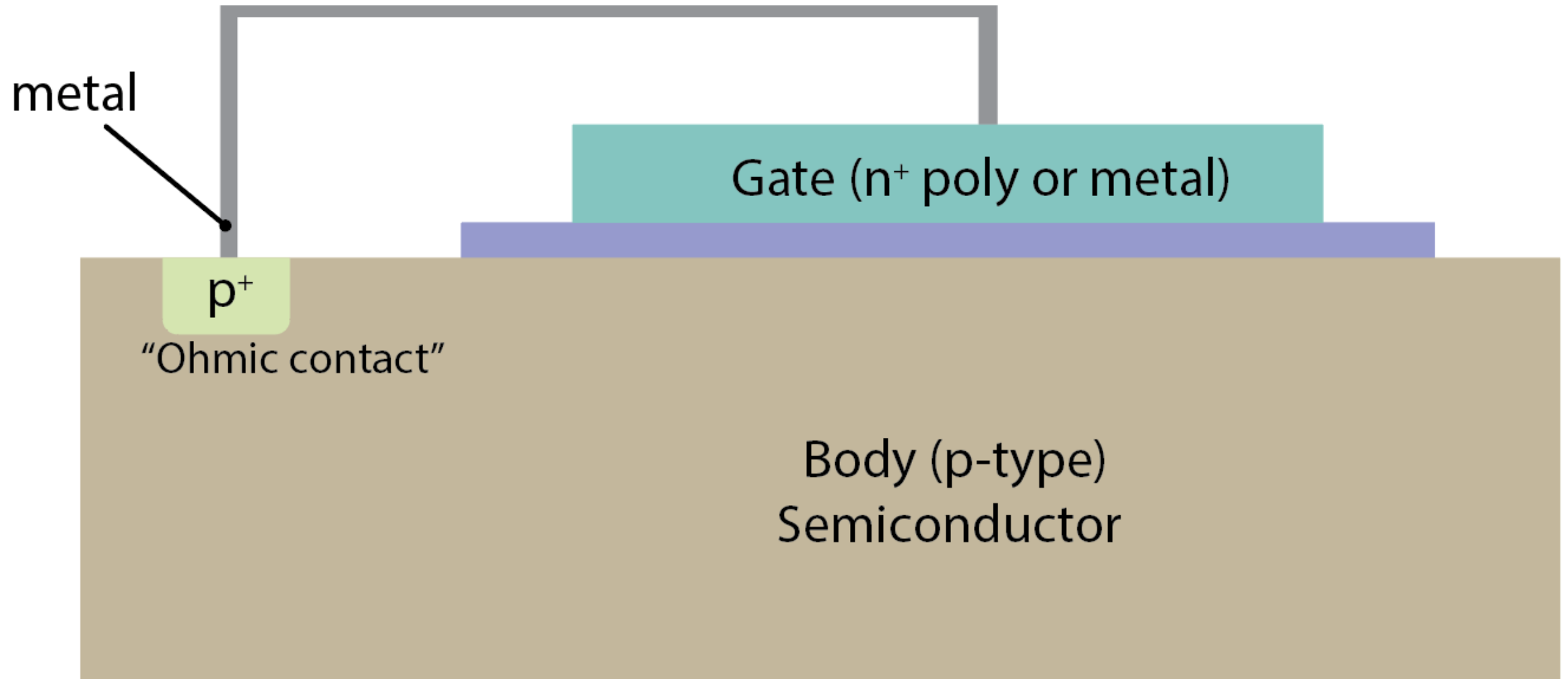
Module 3: CMOS Models and Digital Logic Gates and Applications

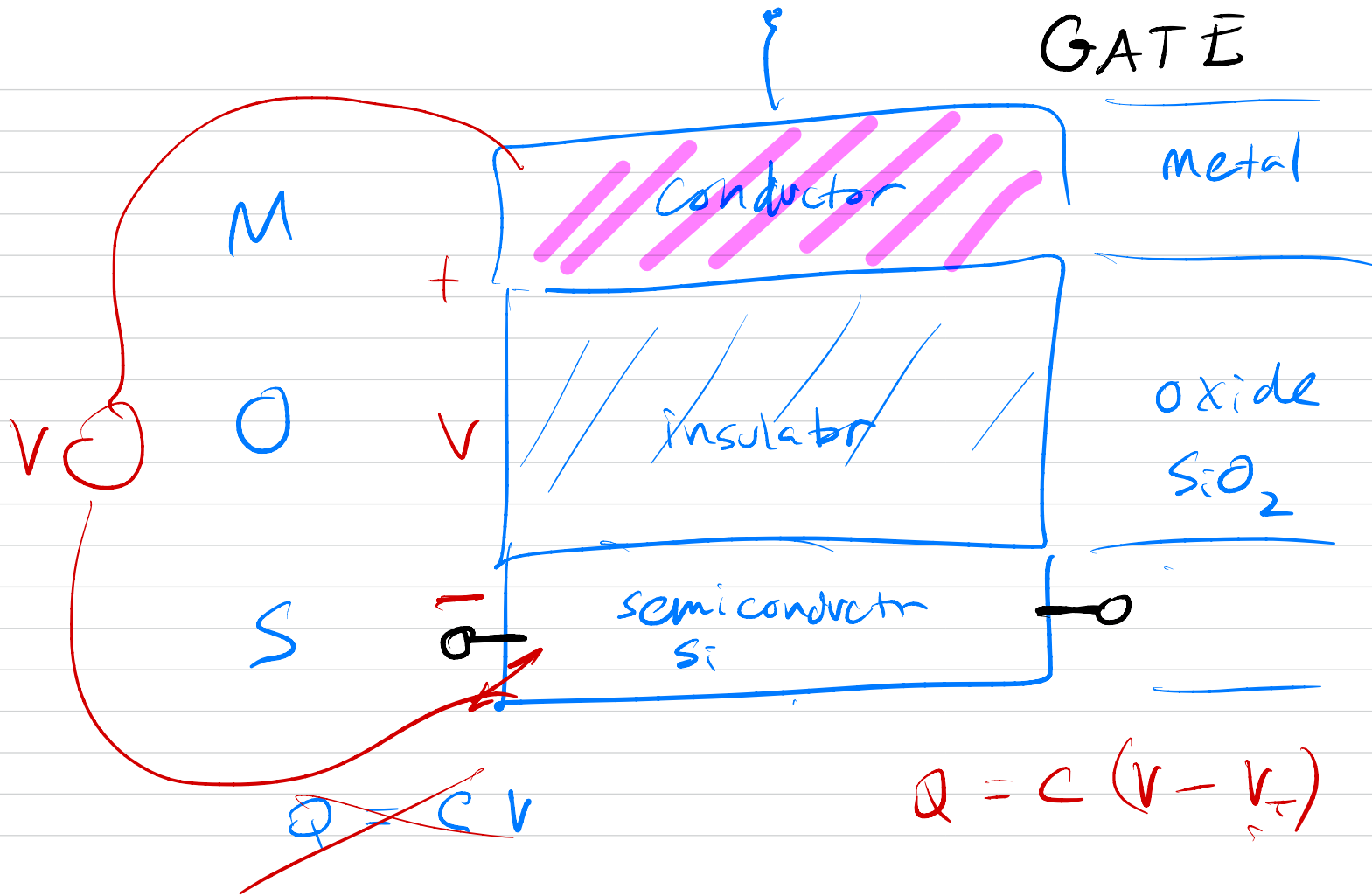
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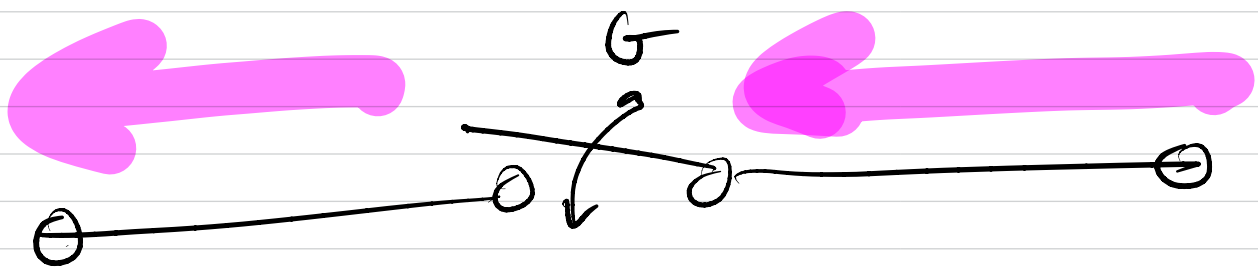
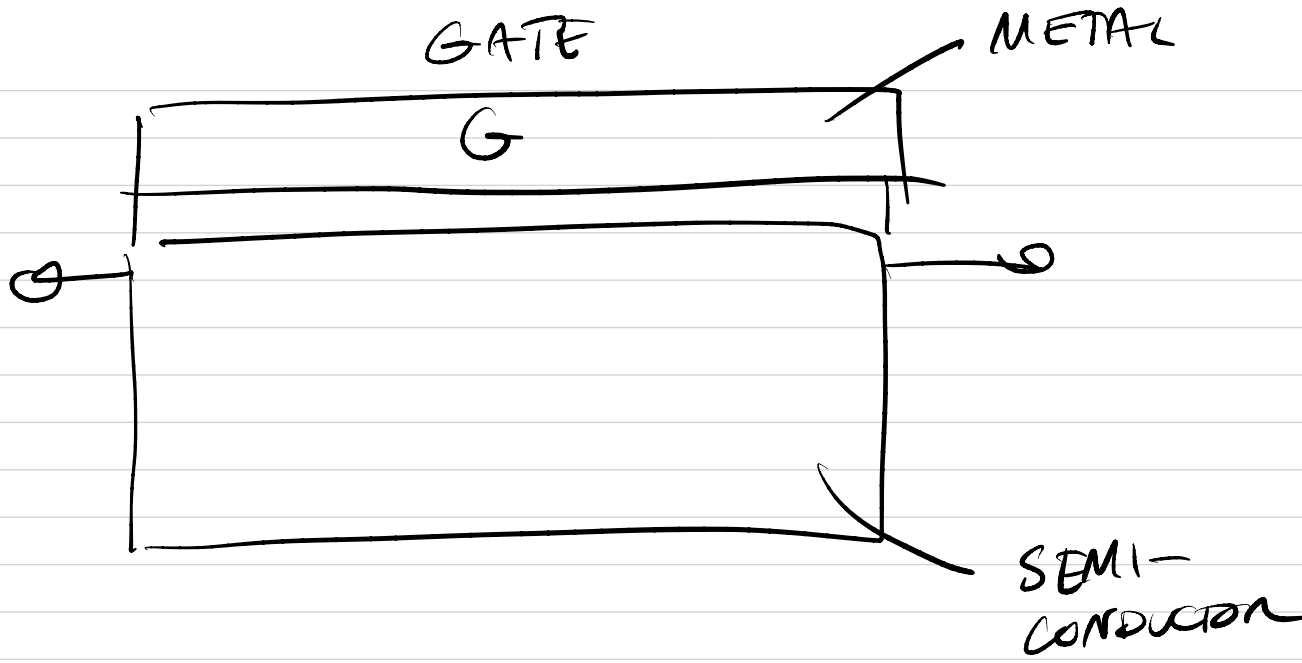
Outline

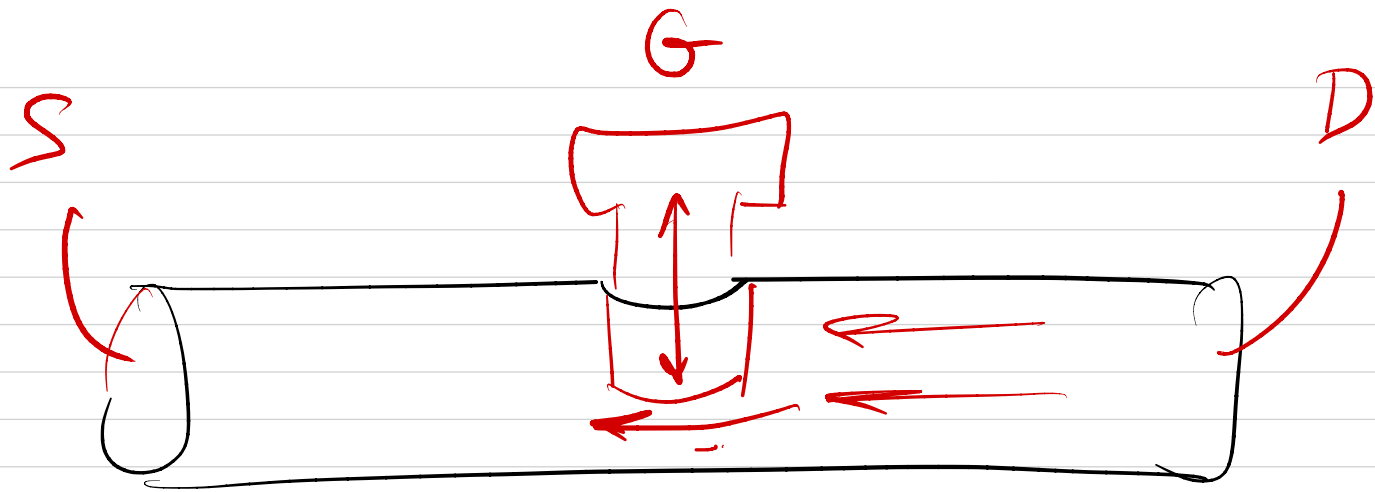
- Introduction to Transistors
- Simple Transistor Models
- Logic Gates
- Maximum Clock Rates : RC Circuit
- Op-amp settling behavior
- Applications:
 - Analog-to-Digital Conversion (ADC)
 - Digital-to-Analogaog Conversion (DAC)
 - Maximum conversion times : RC Circuits !

MOS Capacitor



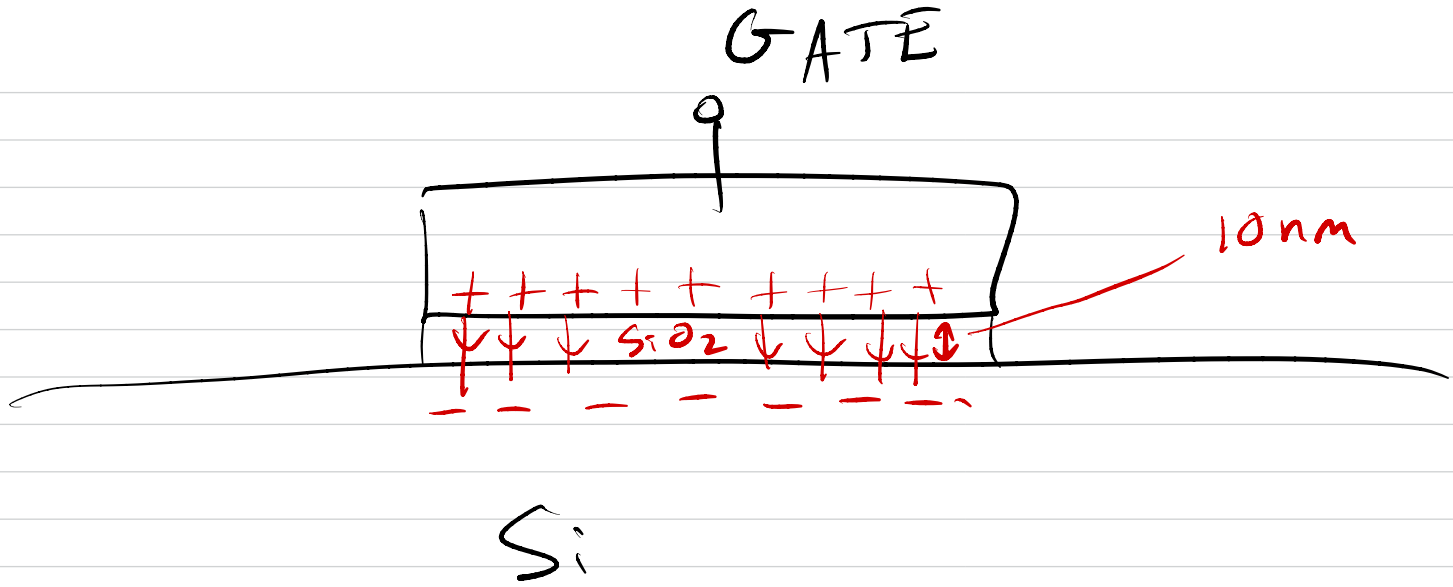


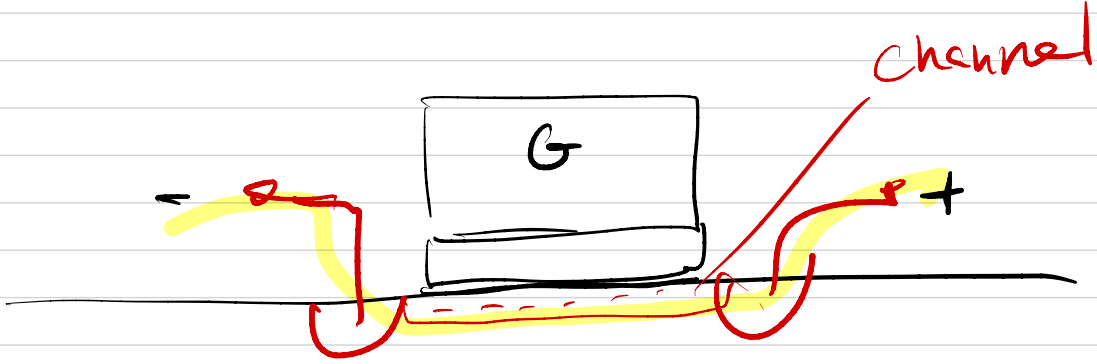
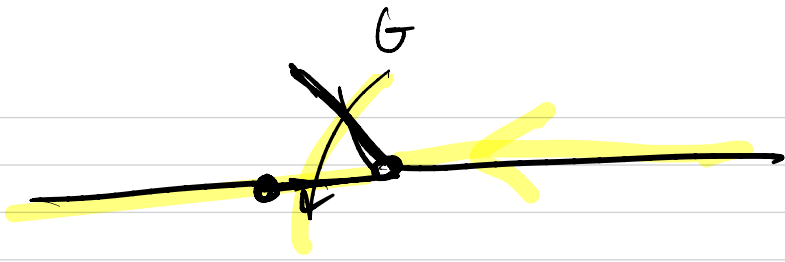




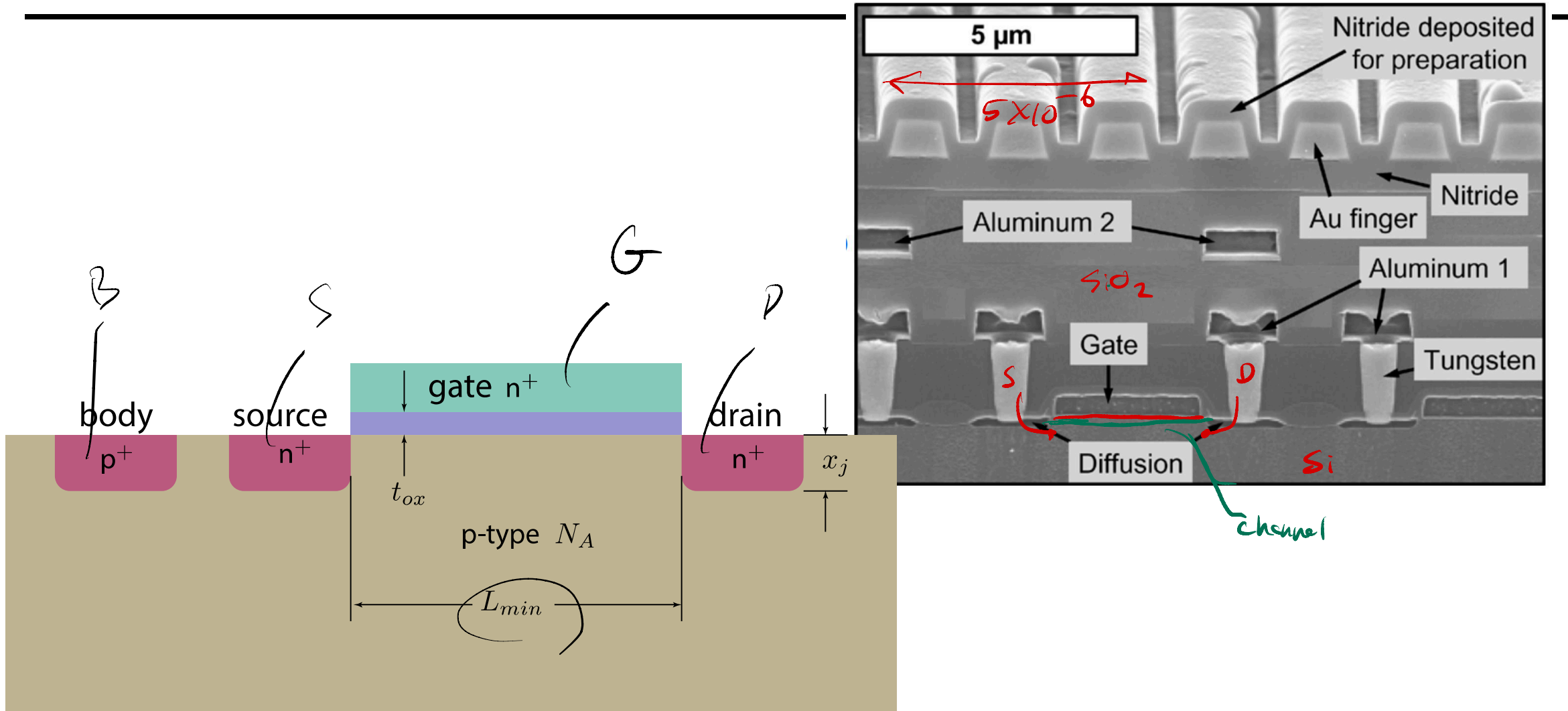
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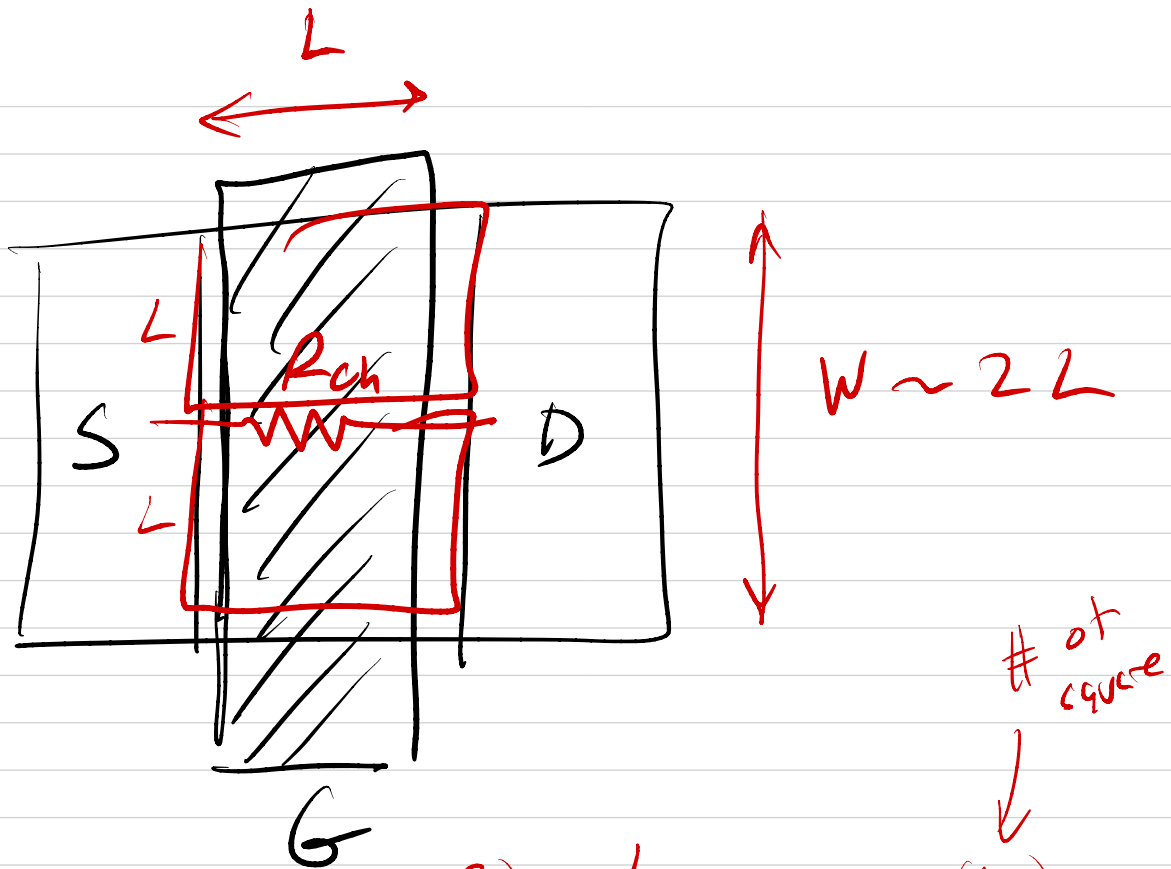
DRAIN





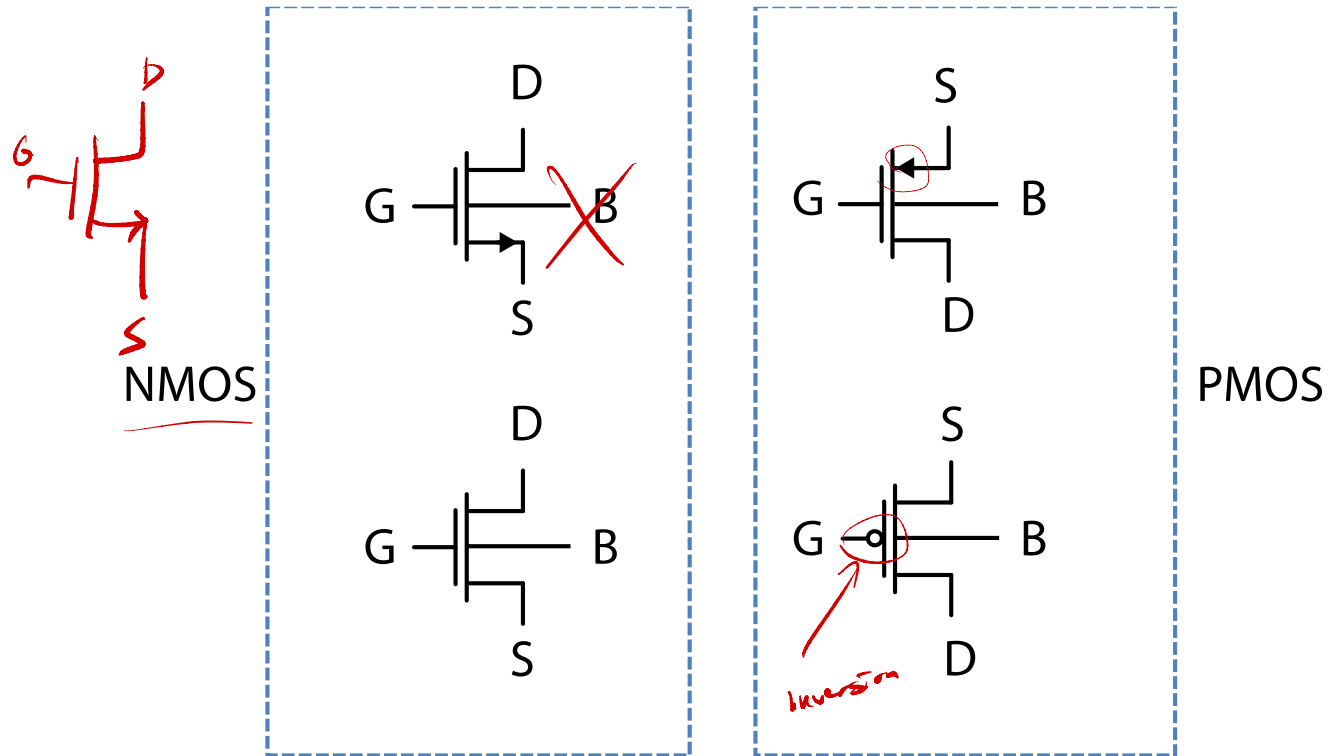
Preview: Transistor





$$R_{ch} = \int \frac{L}{W \cdot t} = \left(\frac{P}{t}\right) \frac{L}{W} = R_D \left(\frac{L}{W}\right)$$

MOS Transistor Schematic



Toy Physical Model of Transistor

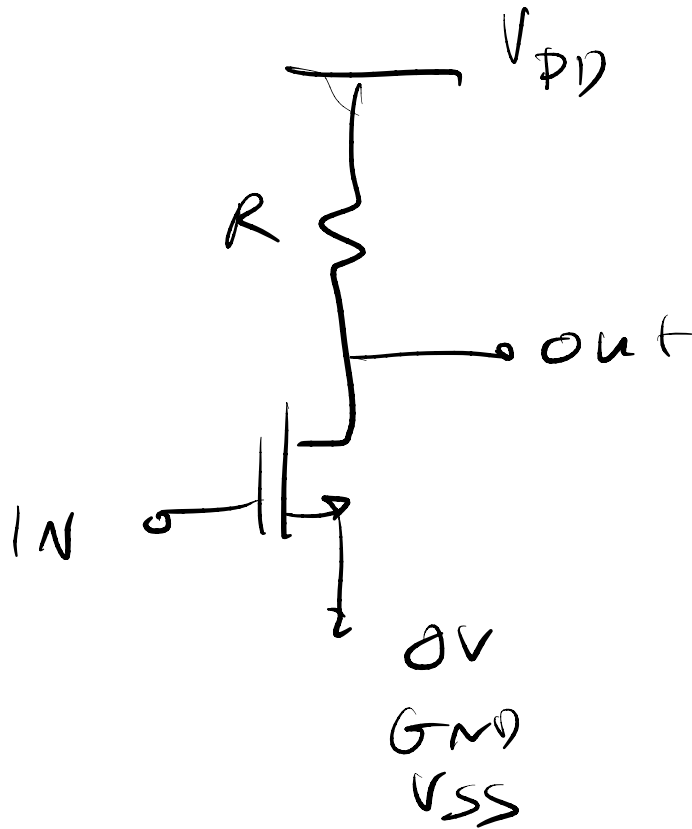
- If we charge up the MOS capacitor, we create a channel that allows current to flow from the source to drain (electron flow)
- If the voltage at the gate is not sufficient to pass a threshold, the path is too resistive and we model it as an open circuit.

Transistors Have Polarity

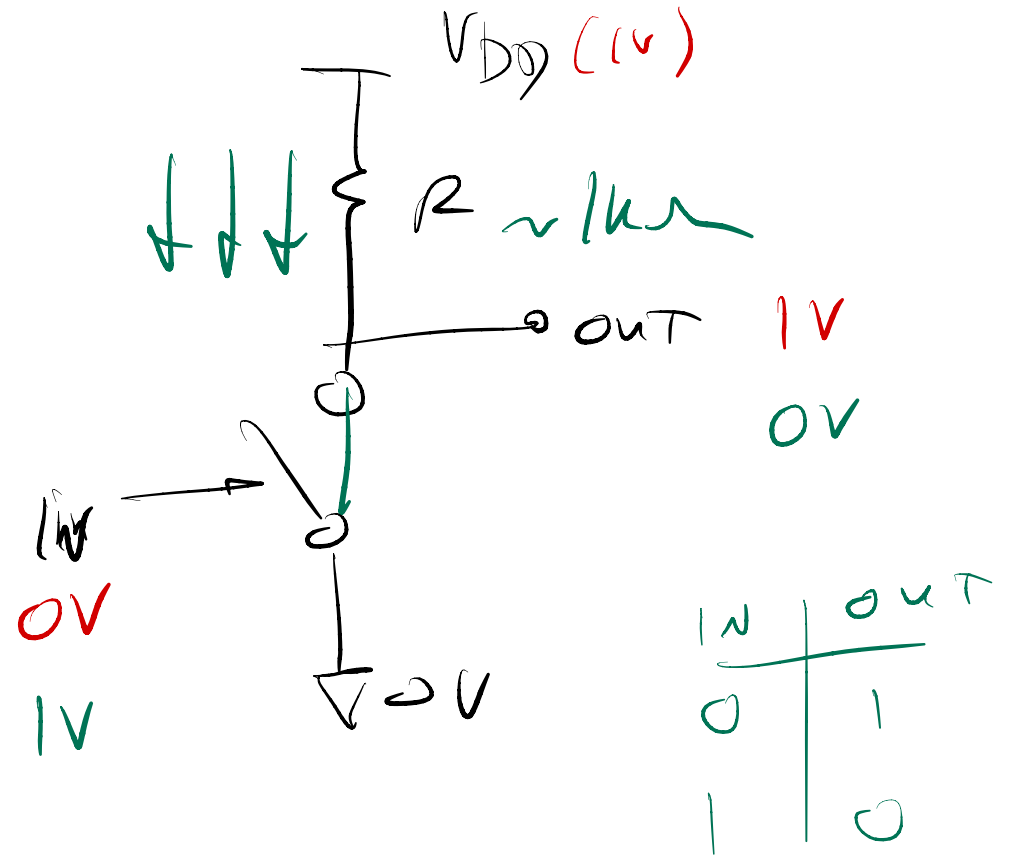
- You can build two kinds of transistors, ones that use electron flow to establish current and another that uses “holes” (positive charges with about twice the mass of electrons).
- Holes are legitimate quasi-particles that represent electrons moving among the various bonding states (valence band) in a crystal

Complementary is a compliment !

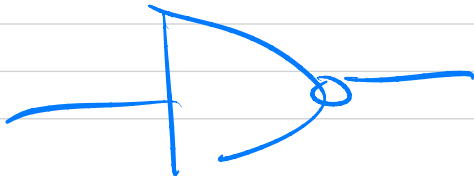
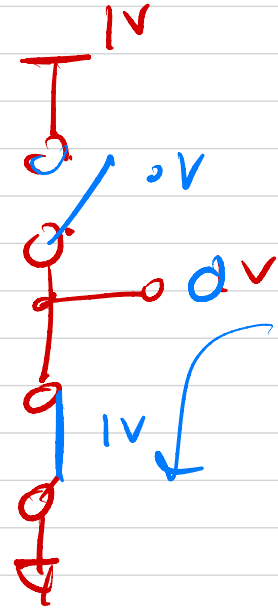
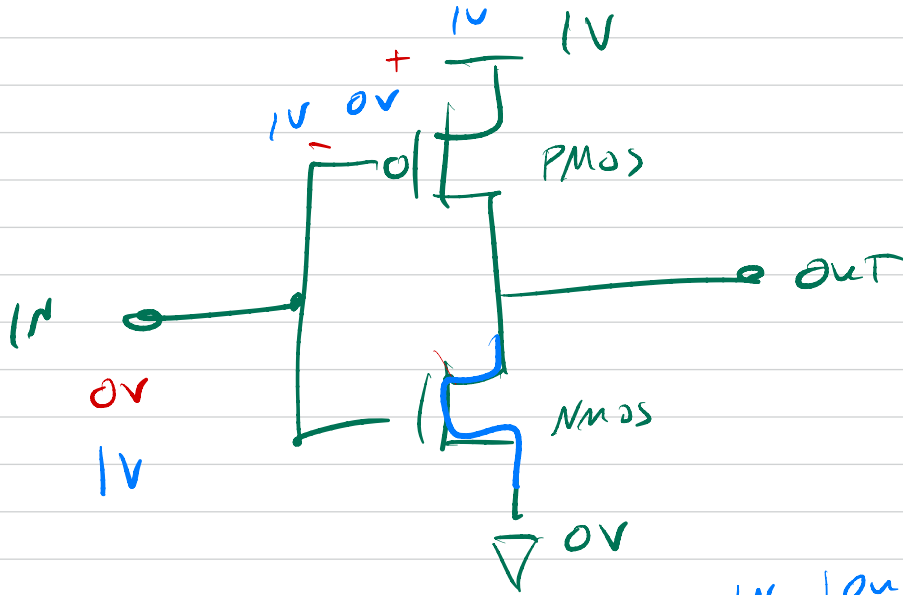
- NMOS + R versus CMOS power consumption



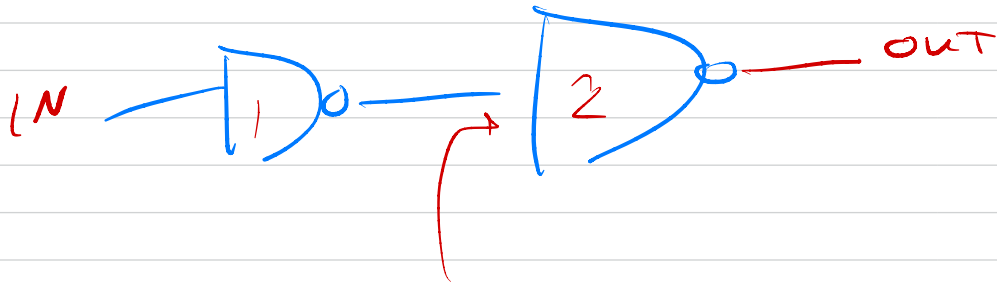
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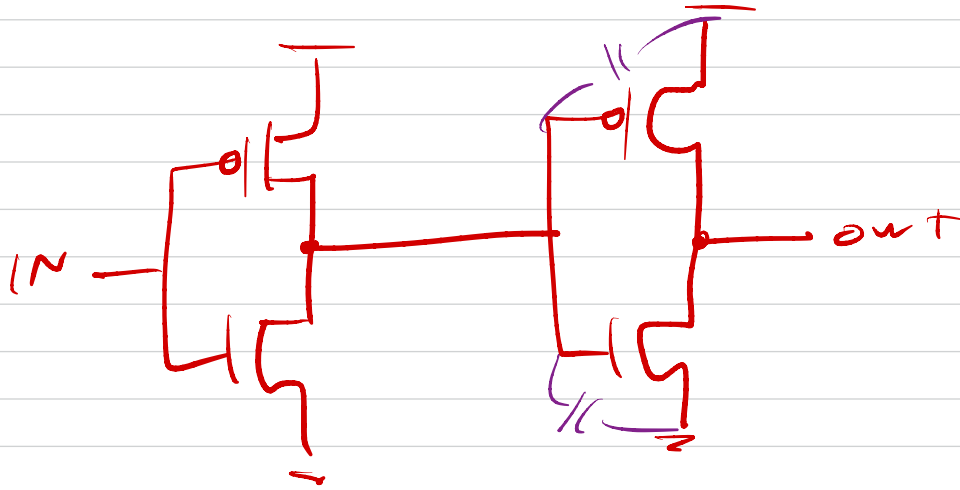
NMOS + PMOS = CMOS

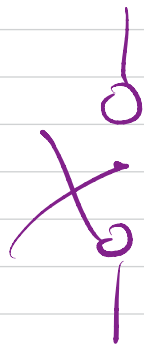


IN	out
0	1
1	0

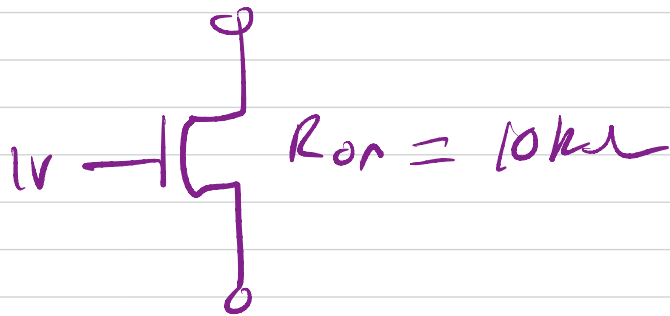
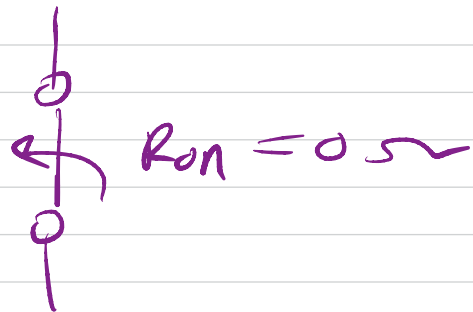


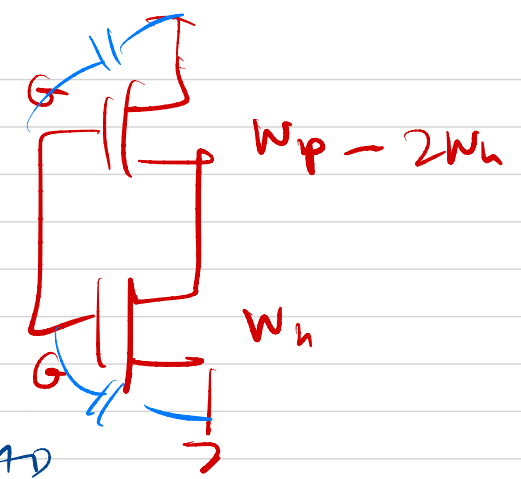
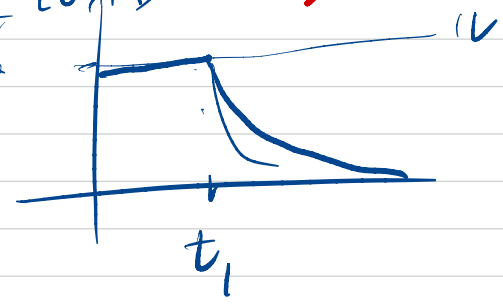
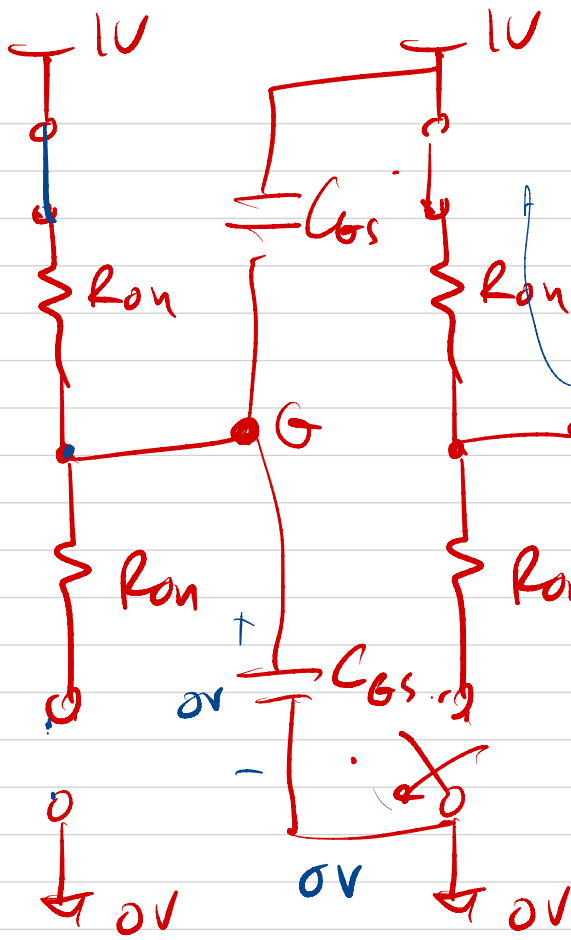
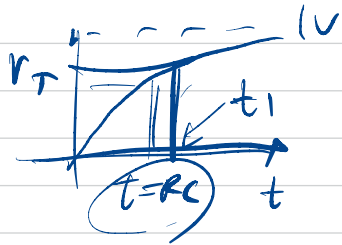
IN	out
0	0
1	1





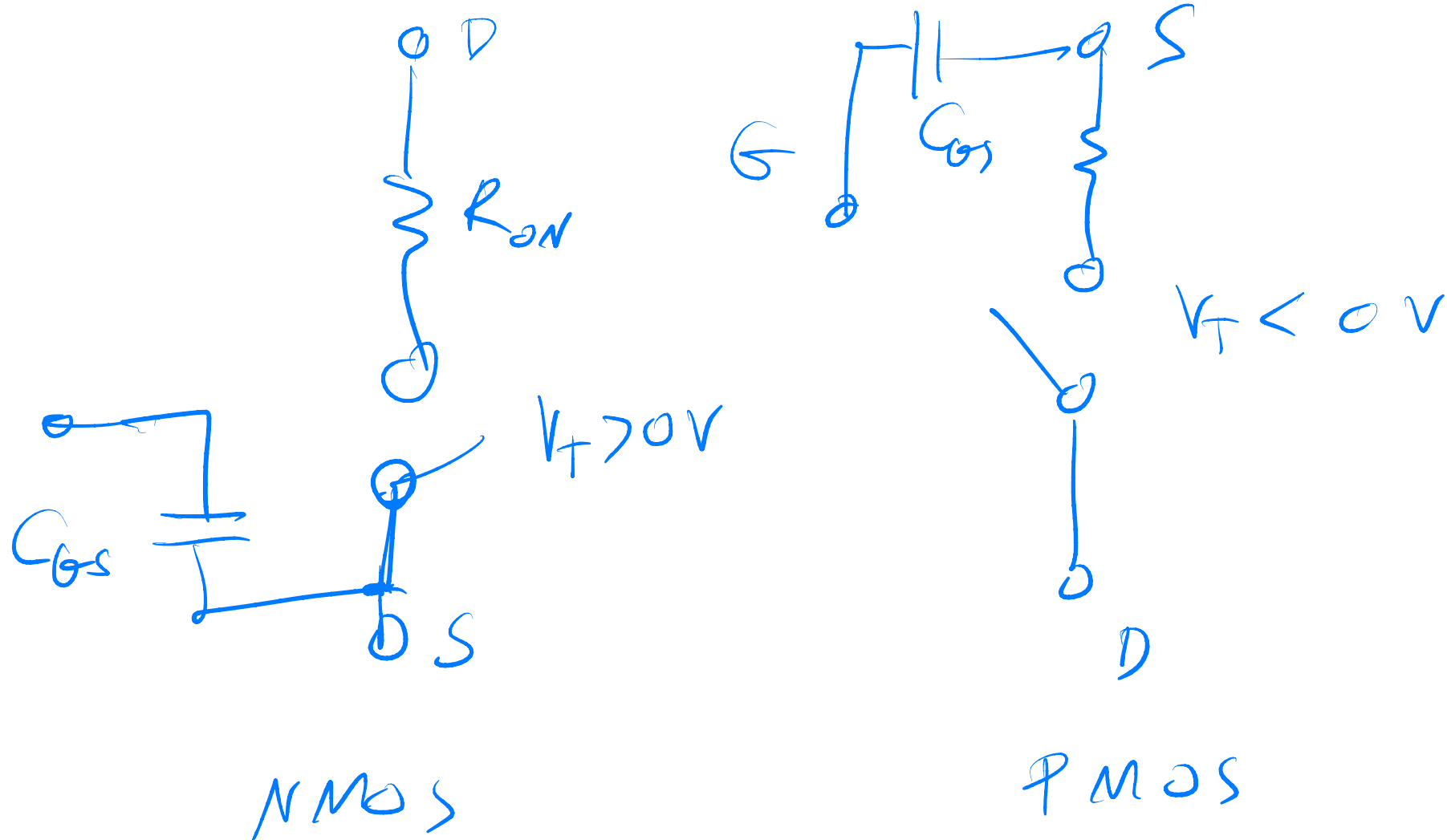
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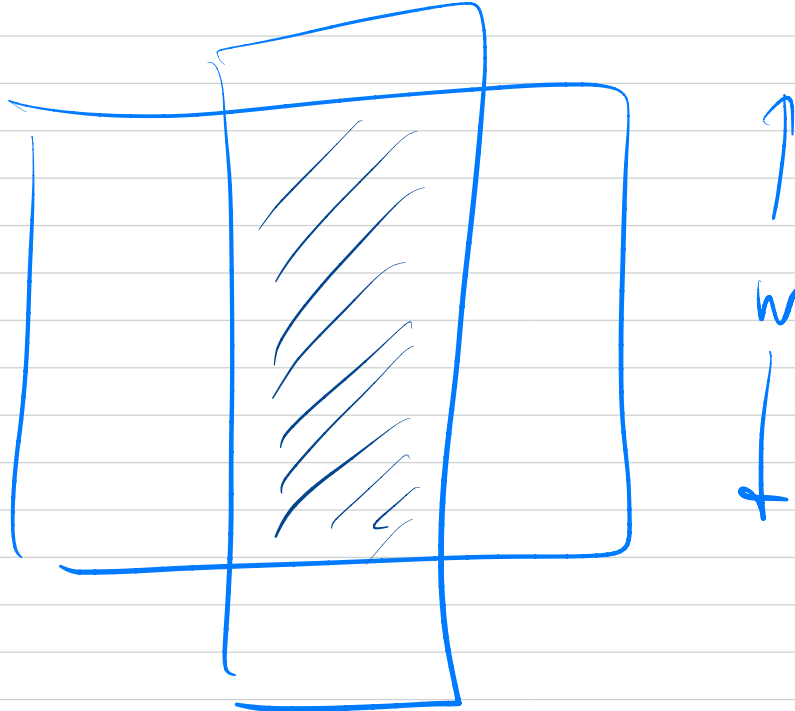


$W_p - 2W_n$
 W_n

Transistor As Switch

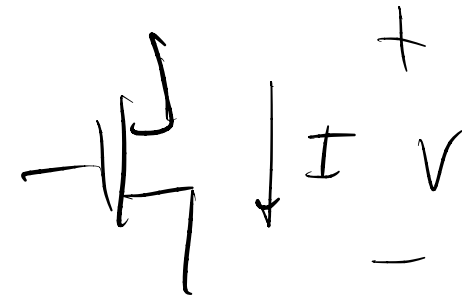
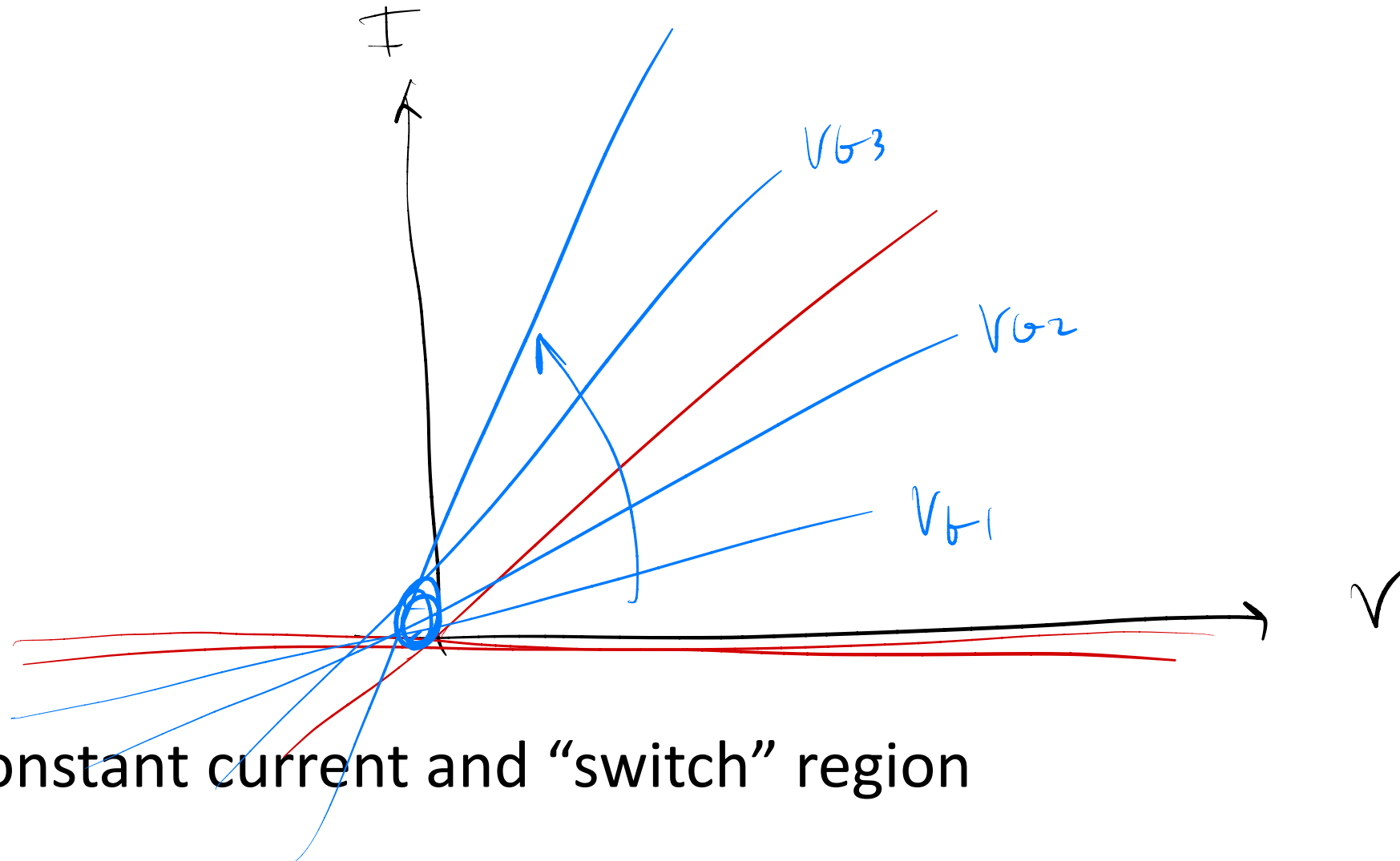


L_{min}

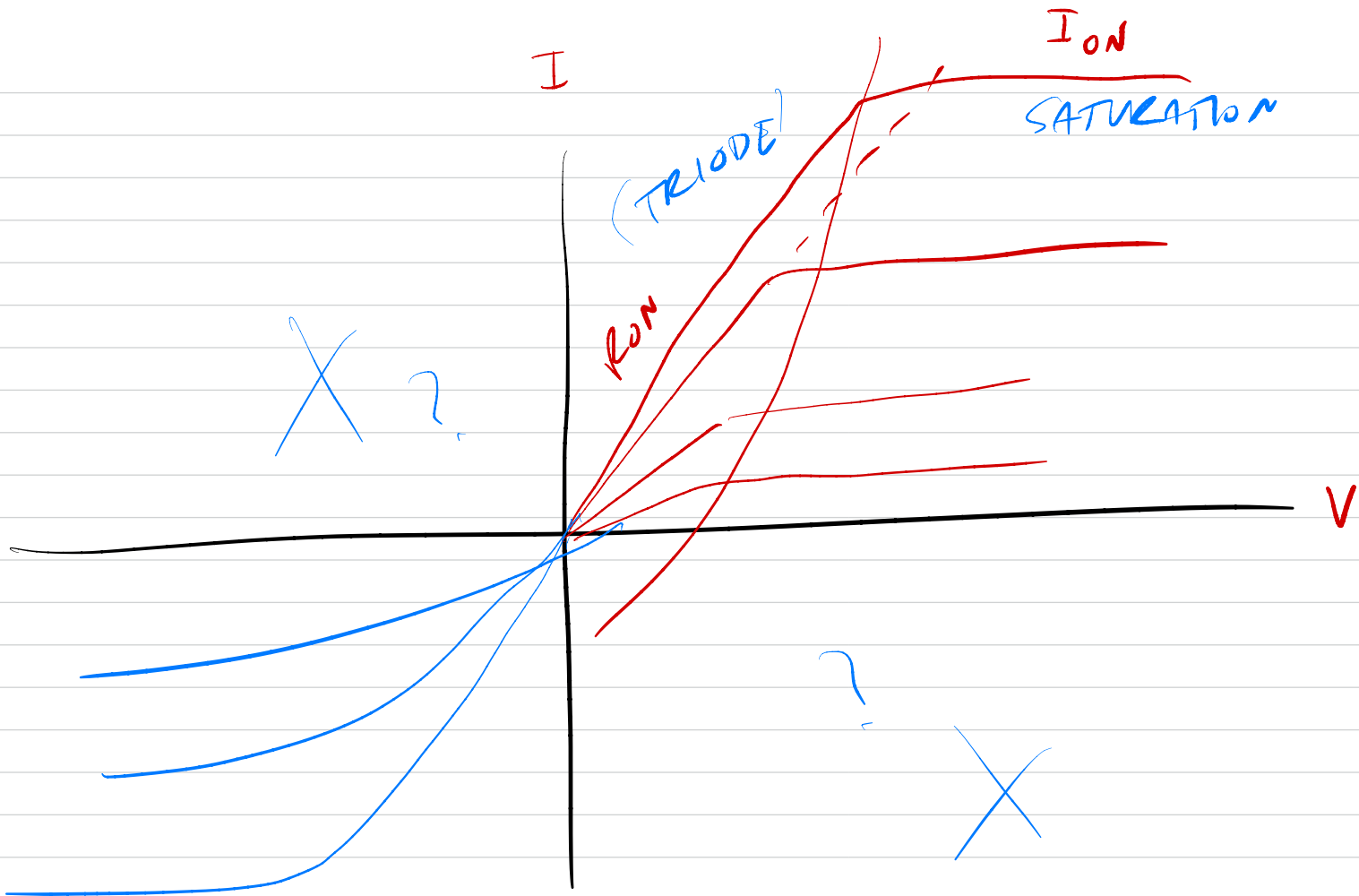


$$\tau = RC \propto \frac{L}{w} \cdot (w \times L)$$

Transistor I-V Curve



- Constant current and “switch” region



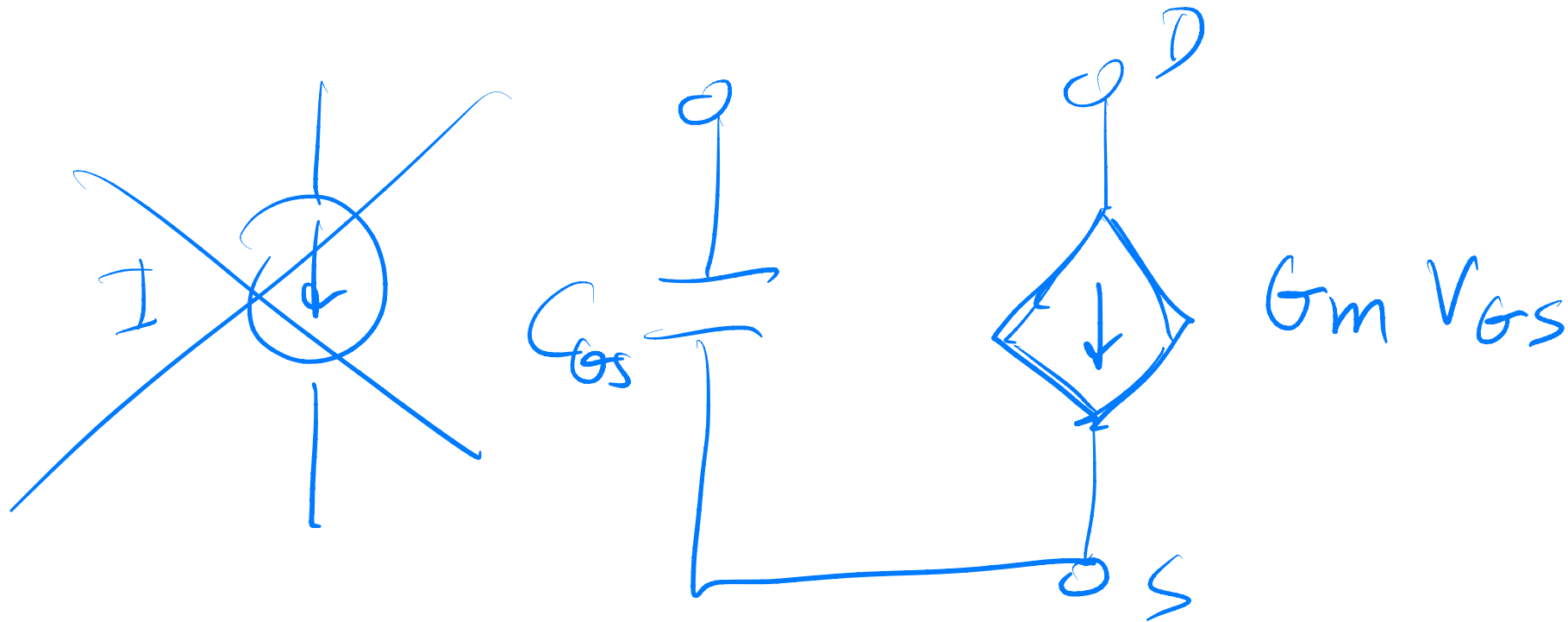
Switch On-Resistance

Switch Gate Capacitance

Switch Off Capacitance

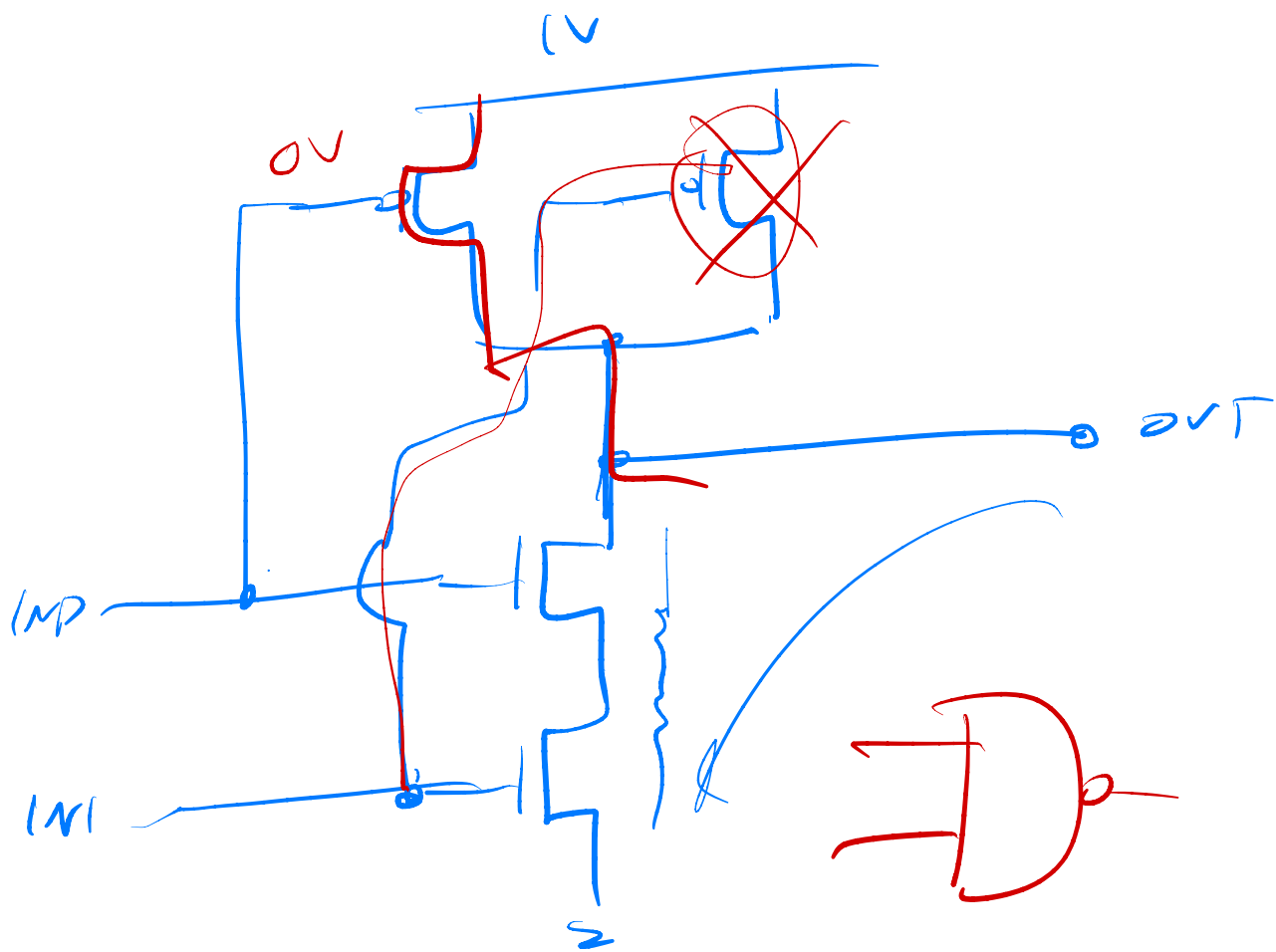
Transistor as a Transconductor

- The channel conductivity is modulated by the gate voltage.
- What's a circuit element that has this property?



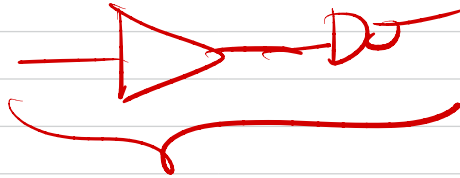
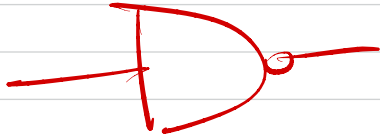
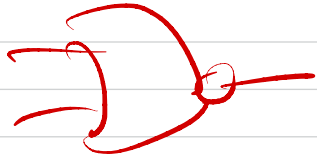
CMOS Inverter

Logic Gates

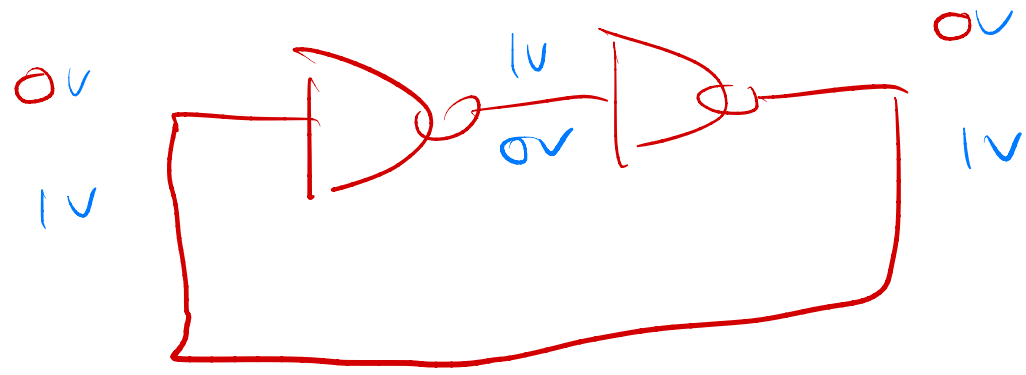


I_1	I_2	OUT
0	0	1
0	1	1
1	0	1
1	1	0

NAND GATE



Static RAM (SRAM)



BISTABLE