Lecture 05: CMOS Amplifiers: Single-Ended First Part

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Reference: Razavi (Fundamentals) - Chapter 7

Slides by: Razavi & J. Ardila

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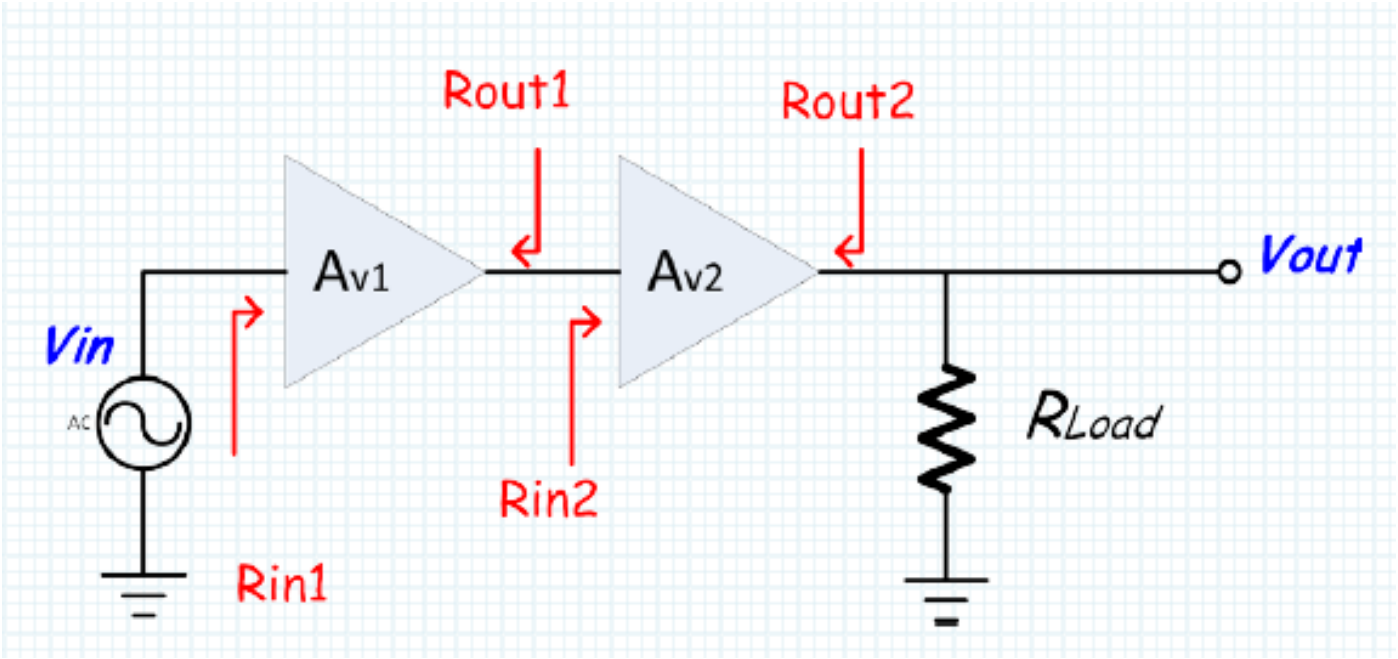
Outline

- General Considerations
- Common-Source Stage
- Common-Gate Stage
- Source-Follower Stage

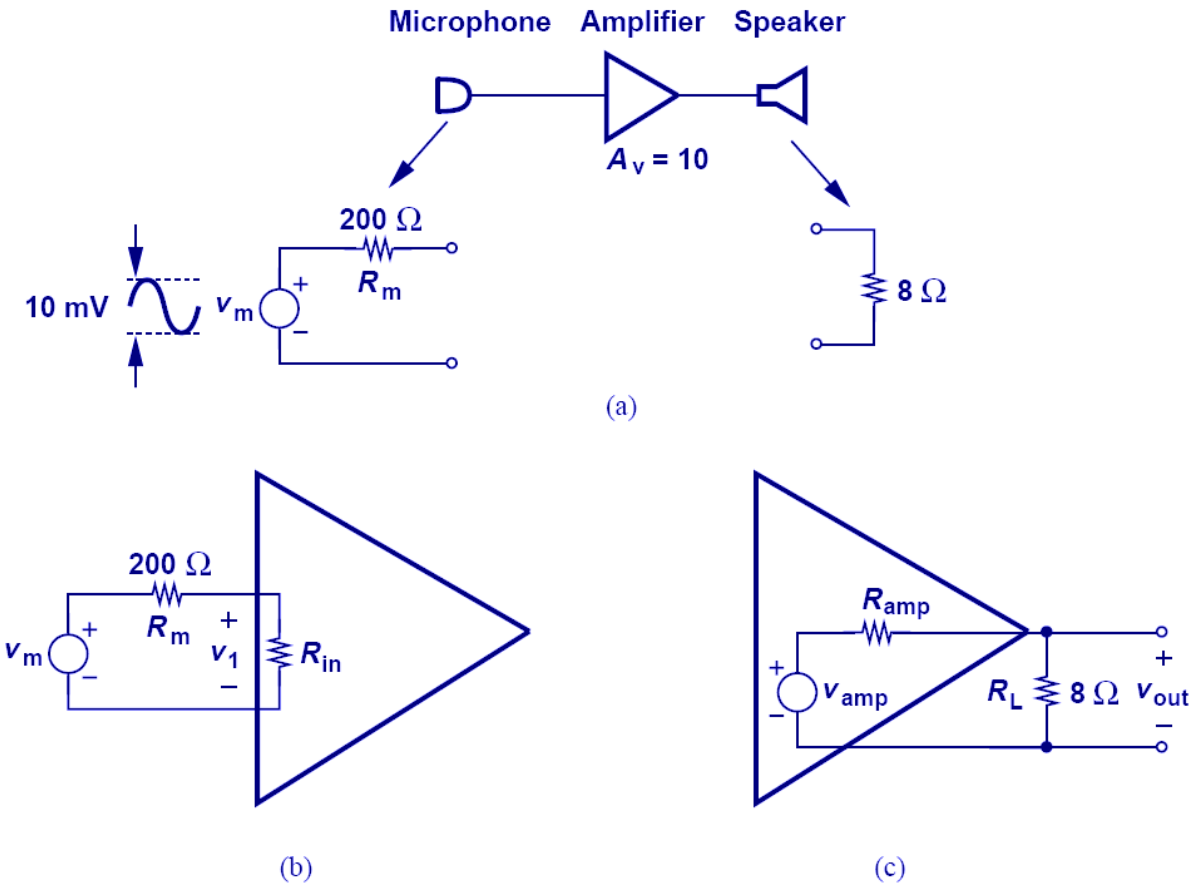
Amplifier

- **Amplification Why?**



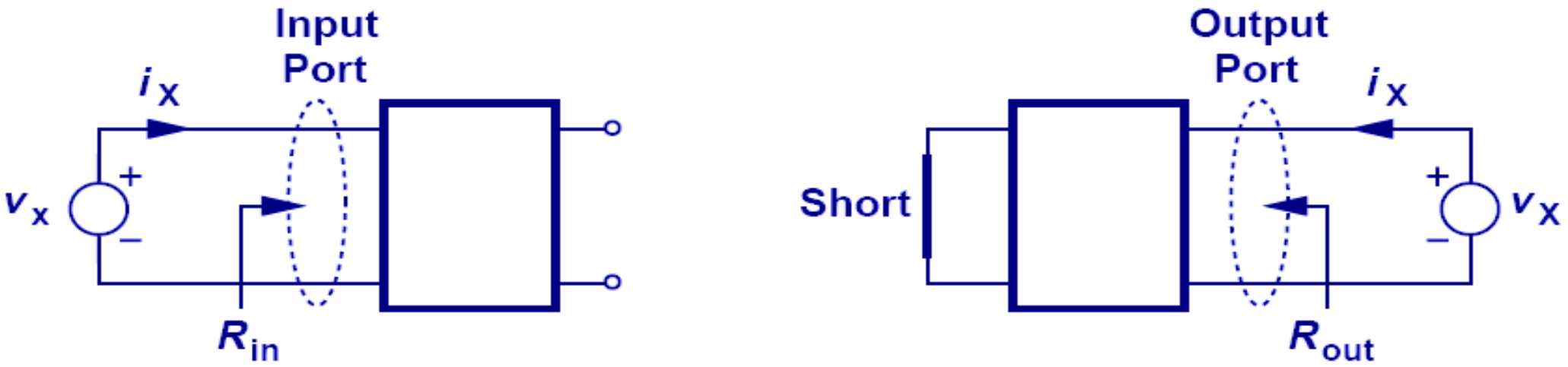
- **Amplification is one of the most important concepts and function in electronics.**
- **We need and we want to amplify signals.**

Voltage Amplifier



- In an ideal voltage amplifier, the input impedance is infinite and the output impedance zero.
- But in reality, input or output impedances depart from their ideal values.

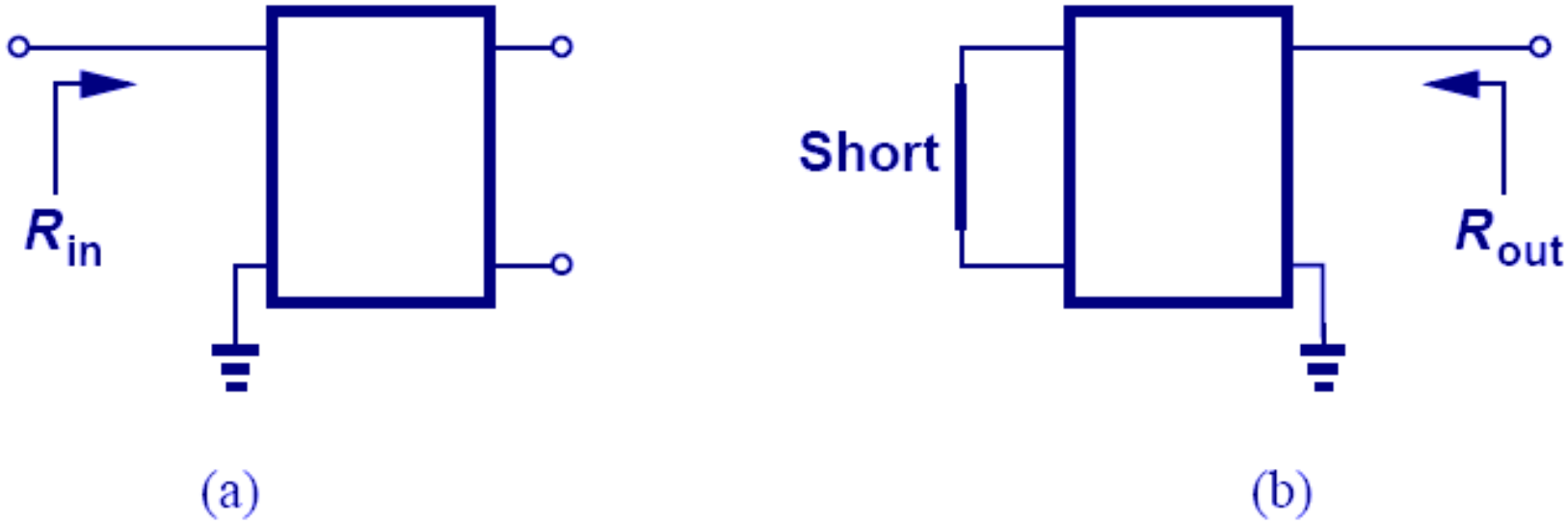
Input/Output Impedances



$$R_x = \frac{V_x}{i_x}$$

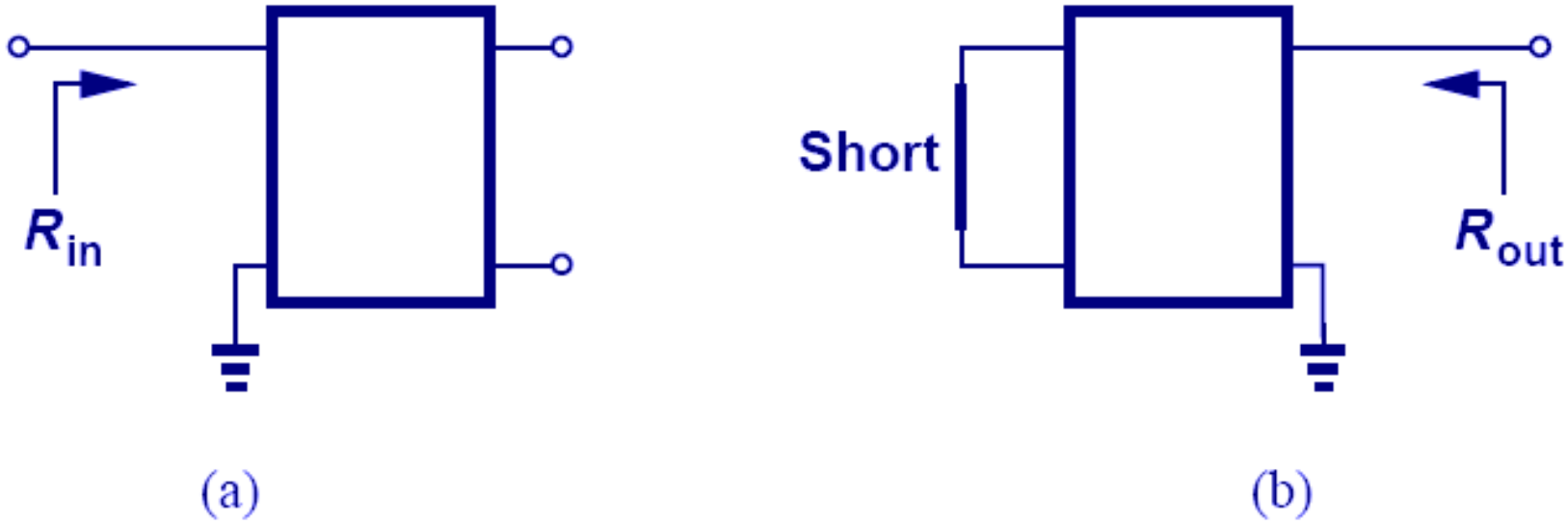
- The figure above shows the techniques for measuring input and output impedances.

Impedance at a Node



- When calculating I/O impedances at a port, we usually ground one terminal while applying the test source to the other terminal of interest.
- Nodal impedance exercises

Impedance at a Node

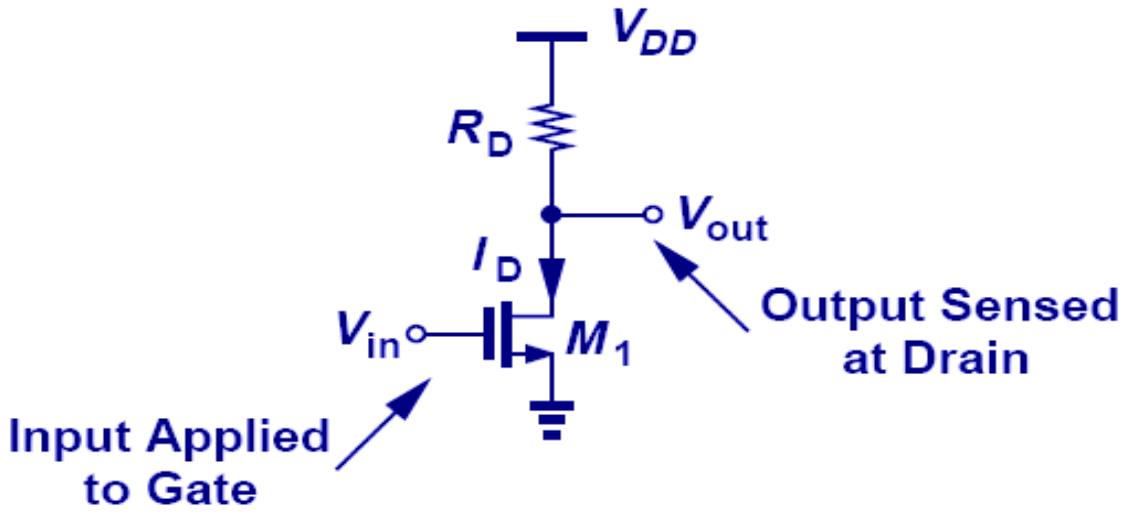


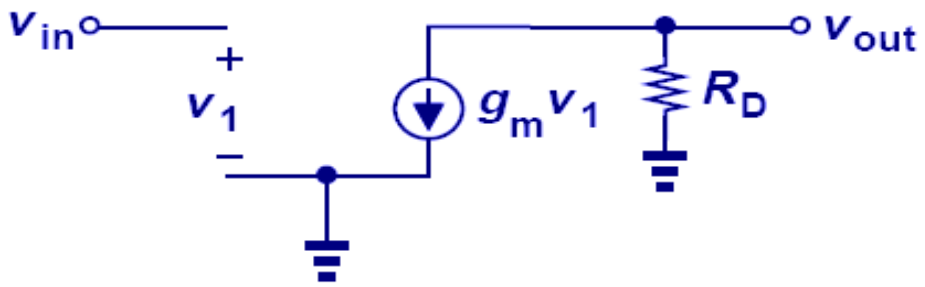
- When calculating I/O impedances at a port, we usually ground one terminal while applying the test source to the other terminal of interest.
- Nodal impedance exercises TALLER!

taller_rnodales

Common-Source Stage

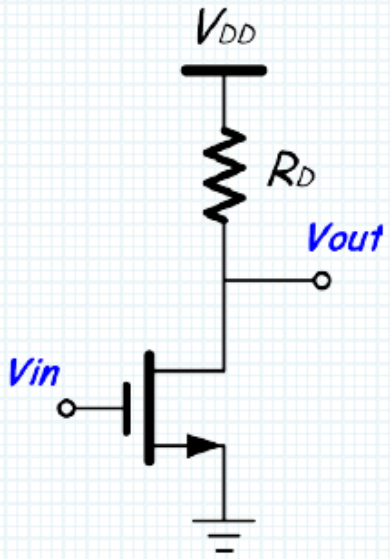
- How do you solve this?
- What is the meaning of “solving”?
- What are we doing?





Common-Source Stage

Fuente Común (Common Source CS)



- Es la configuración más sencilla de amplificador de tensión.
- A través de ella se repasarán varios conceptos.

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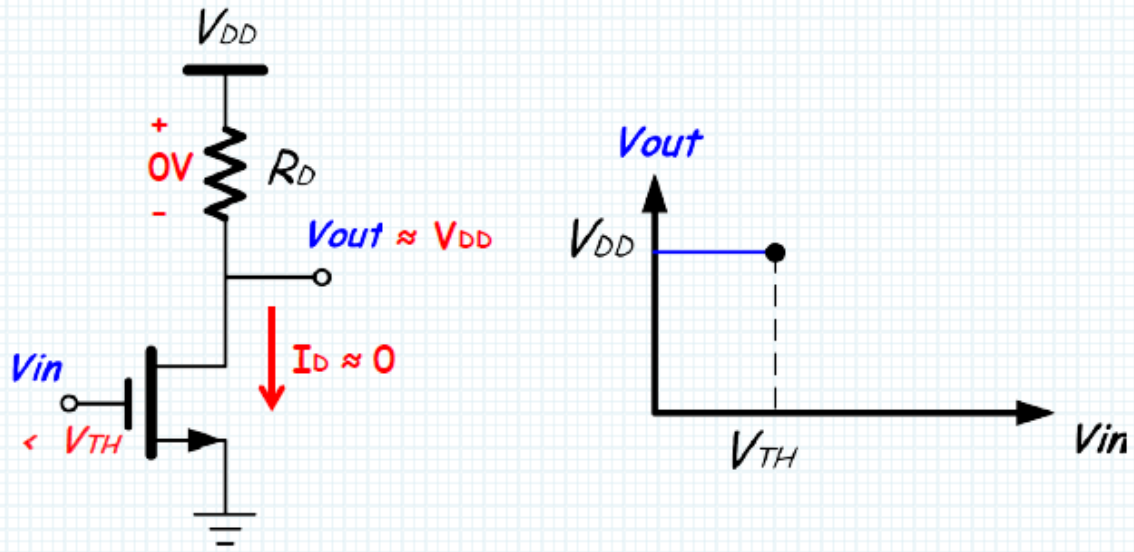
Common-Source Stage

CS. Análisis a gran señal



Mientras Vin no supere la tensión de umbral VTH el transistor estará apagado y su corriente será aproximadamente igual a cero amperios. Esto se mantendrá así hasta que Vin = VTH

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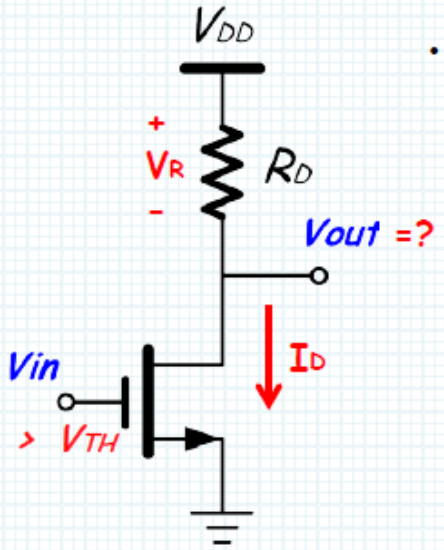
Common-Source Stage

CS Análisis gran señal



- Vout comienza en un valor alto (≈VDD) como se vio antes. Por tanto, se puede asumir que el transistor encenderá en saturación.

$$I_D = 0.5*\beta*(V_{in}-V_{TH})^2$$

siendo $\beta = \mu_n C_{ox} * W/L$

$$V_R = I_D * R_D.$$

$$V_{out} = V_{DD} - V_R$$
$$= V_{DD} - I_D * R_D$$

$$V_{out} = V_{DD} - 0.5*\beta*R_D*(V_{in}-V_{TH})^2$$

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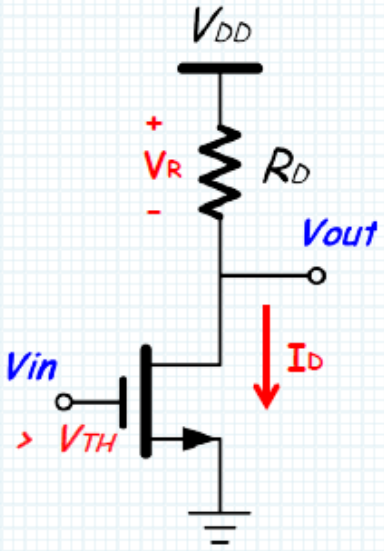
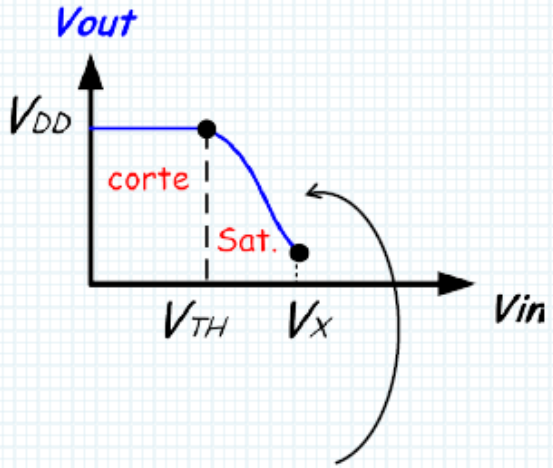
Common-Source Stage

CS Análisis gran señal





$$Vout = V_{DD} - 0.5*\beta*R_D*(Vin-V_{TH})^2$$

Esta ecuación corresponde a una parábola que abre hacia abajo. La condición se mantendrá hasta que el transistor entra en la región de triodo. **P:** ¿Por qué se sabe que entrará en triodo?

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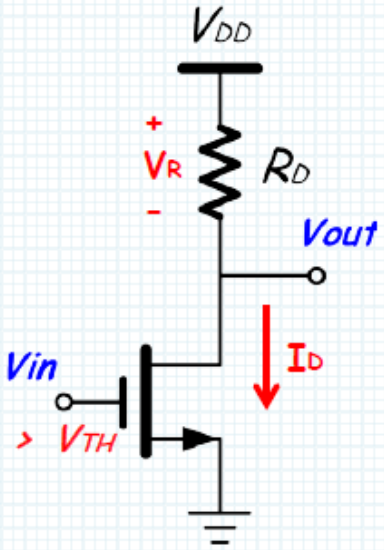
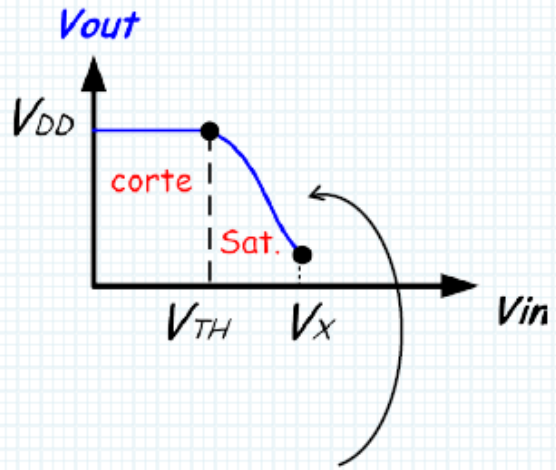
Common-Source Stage

CS Análisis gran señal





$$Vout = V_{DD} - 0.5*\beta*R_D*(Vin-V_{TH})^2$$

R: Observe que a medida que aumenta Vin, la tensión Vout está decreciendo. Esto favorece la operación en triodo ($V_D < V_G - V_{TH}$). El transistor entrará en triodo cuando la tensión Vin alcance un valor Vx desconocido tal que: Vout = **Vx** - V_{TH}

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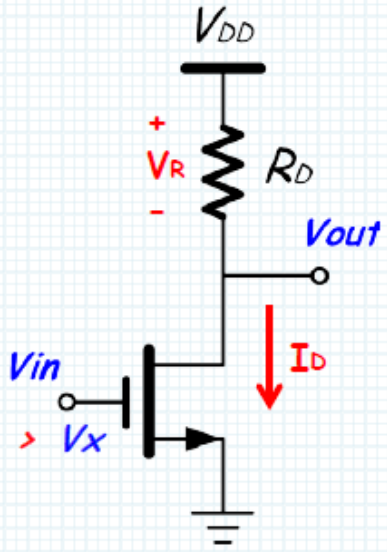
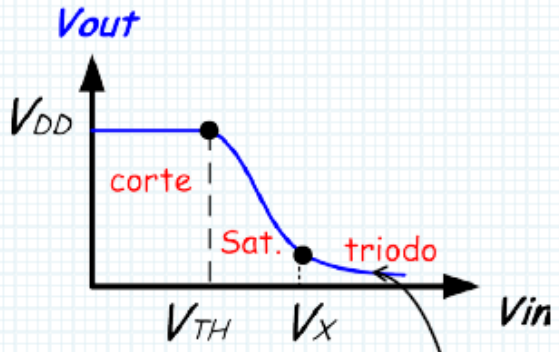
Common-Source Stage

CS Análisis gran señal





A partir de esta región la ecuación que describe a la corriente se modifica:

$$I_D = \beta*[(V_{in}-V_{TH})V_{out}-0.5*V_{out}^2]$$

Y por tanto,

$$V_{out} = V_{DD} - \beta*[(V_{in}-V_{TH})V_{out}-0.5*V_{out}^2]*R_D$$

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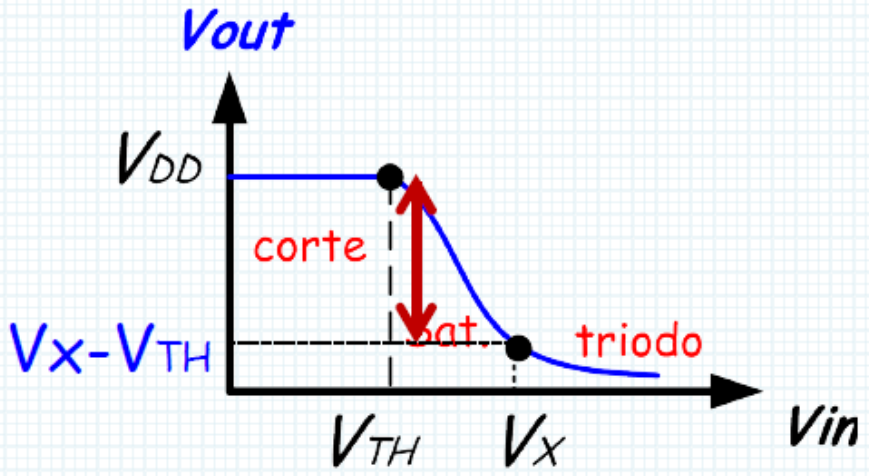
Common-Source Stage

Rangos de excursión

- Máximo nivel de salida: V_{DD}
- Mínimo nivel de salida: $V_X - V_{TH}$
- Rango a la salida: $V_{DD} - (V_X - V_{TH})$



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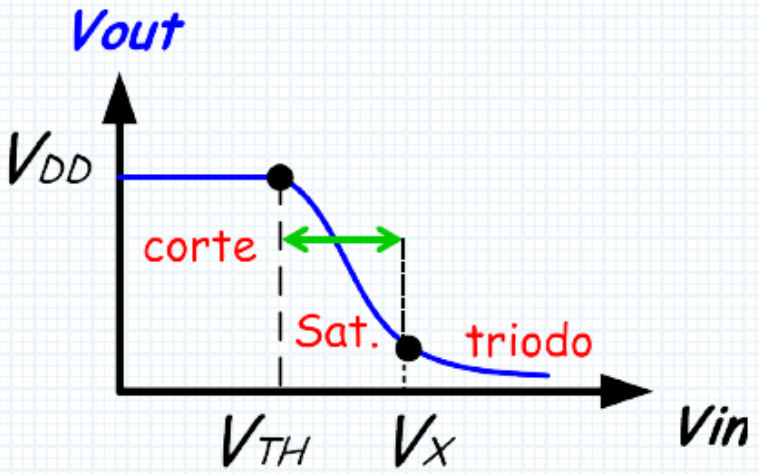
Common-Source Stage

Rangos de excursión

- Máximo nivel de entrada: V_X
- Mínimo nivel de entrada: V_{TH}
- Rango de excursión a la entrada: $V_X - V_{TH}$



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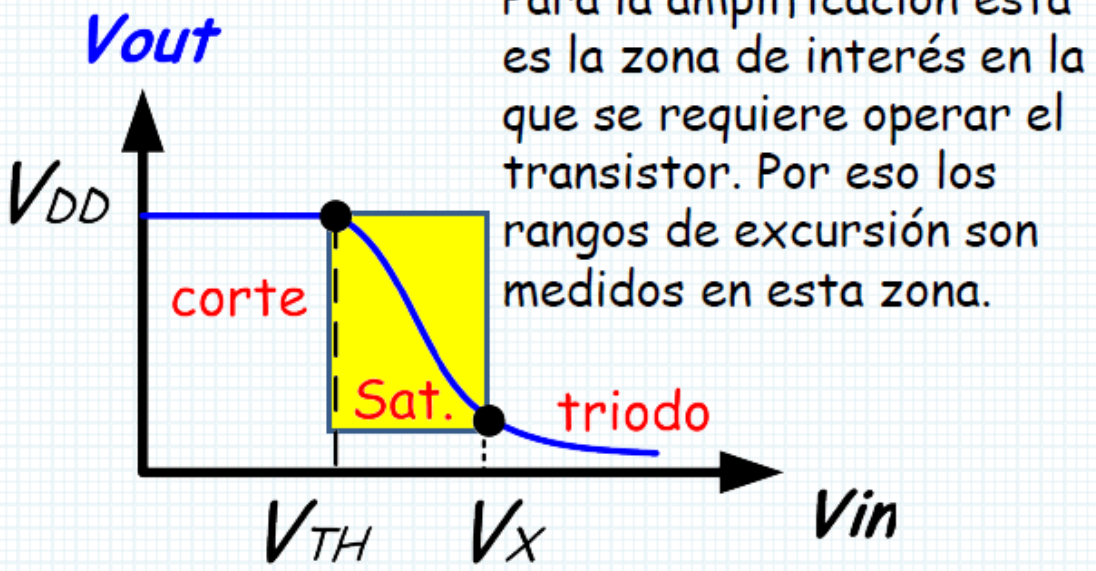
Common-Source Stage

Zona de interés



Para la amplificación esta es la zona de interés en la que se requiere operar el transistor. Por eso los rangos de excursión son medidos en esta zona.

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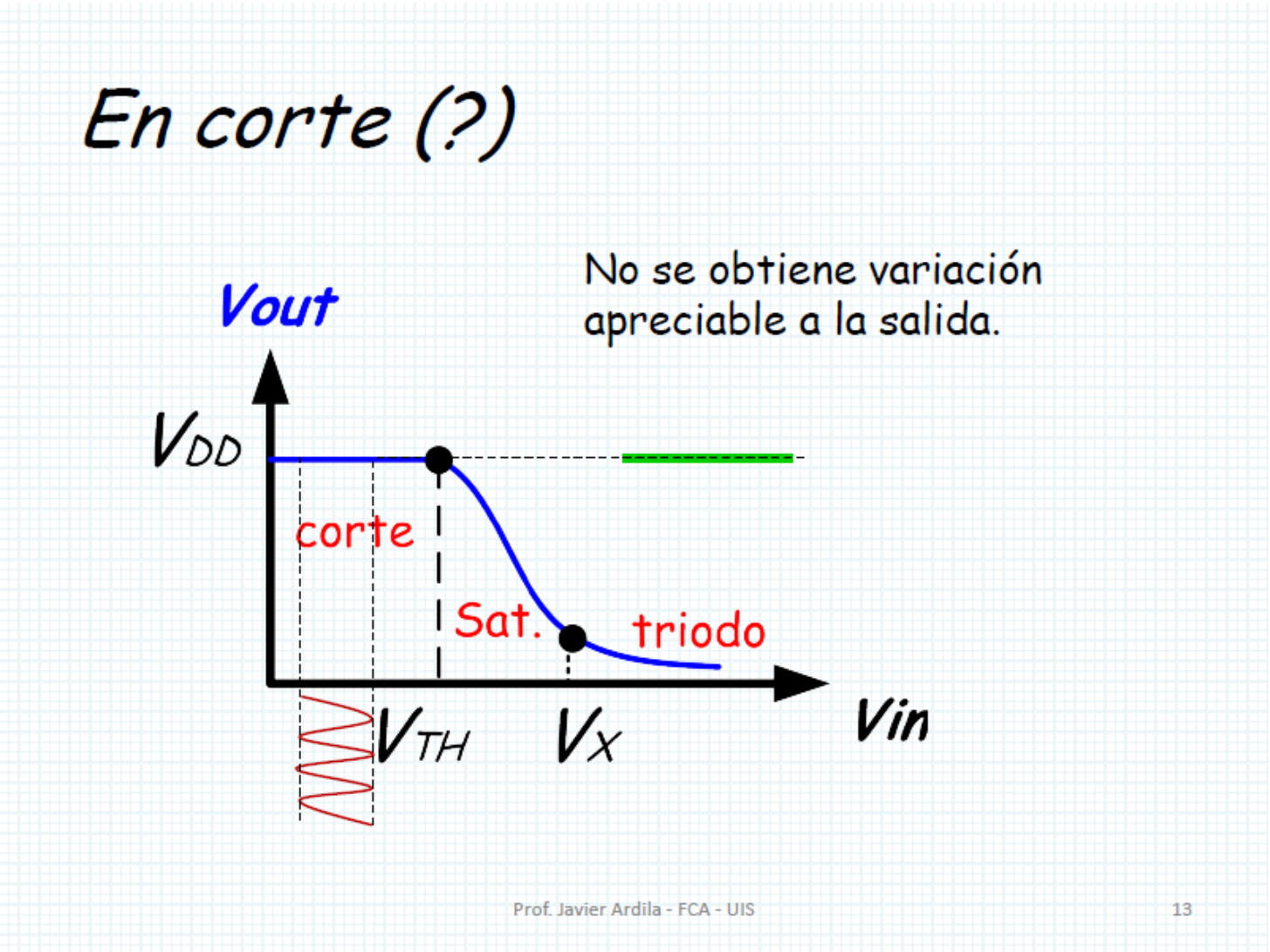
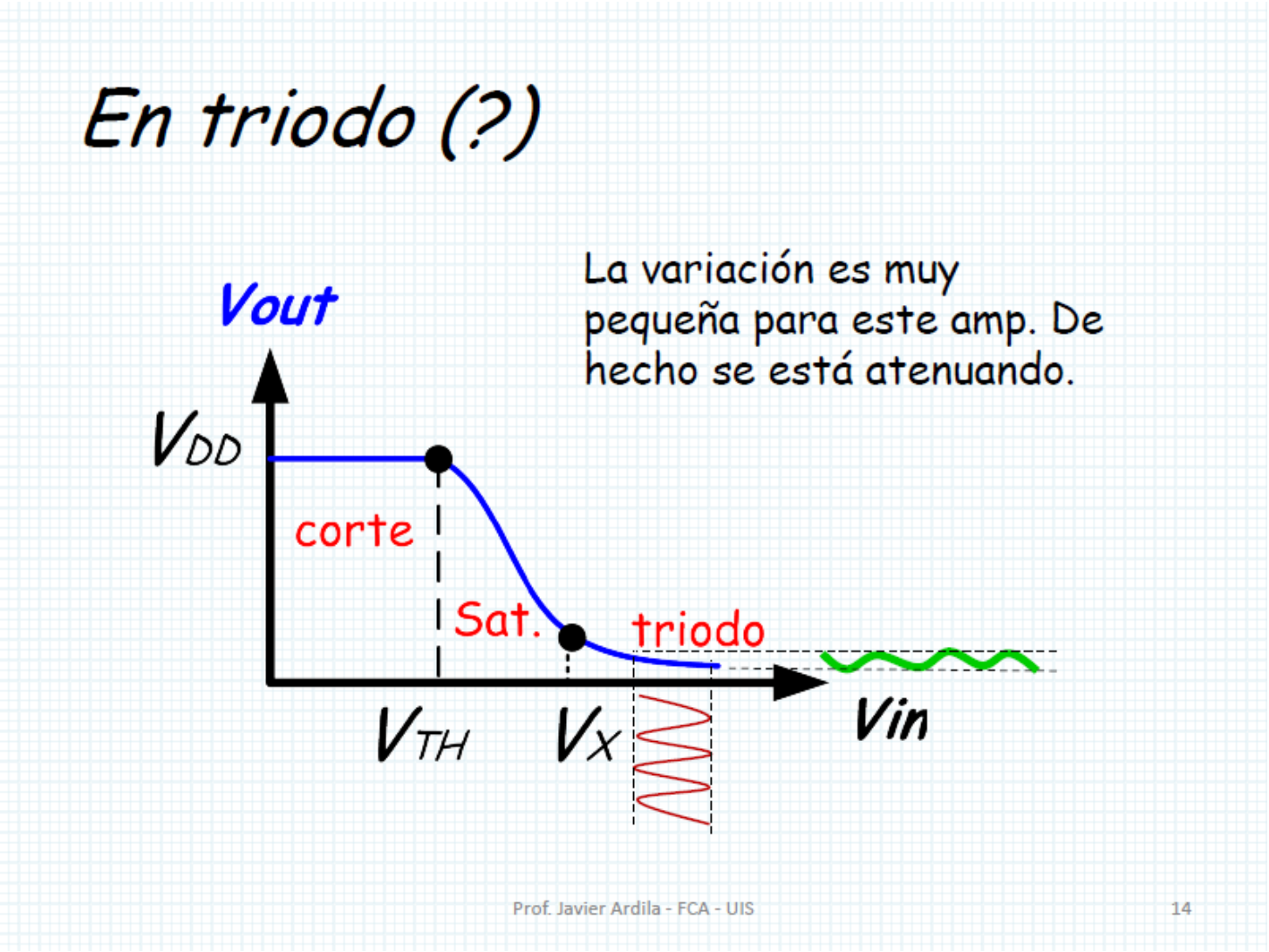
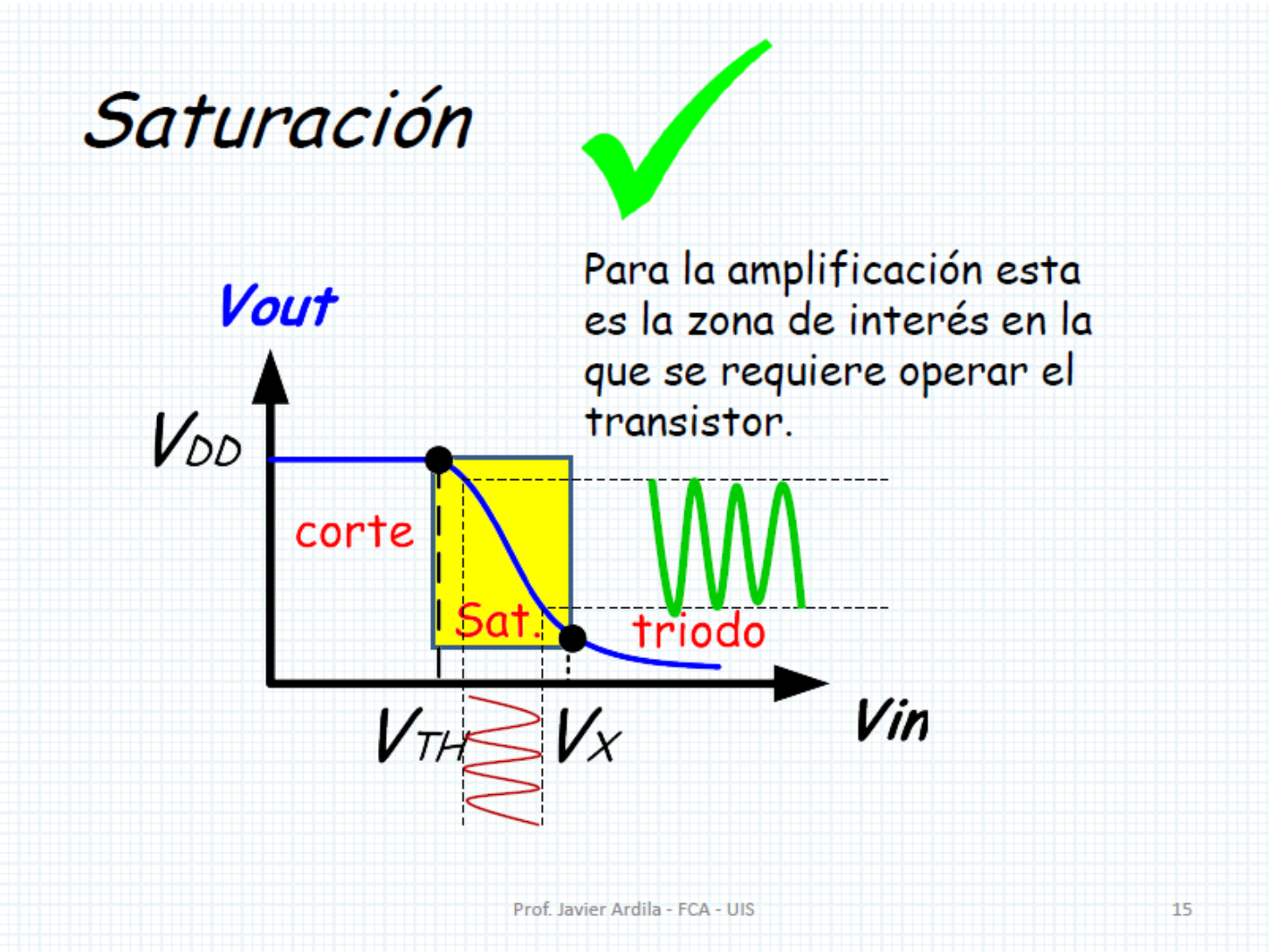
Common-Source Stage



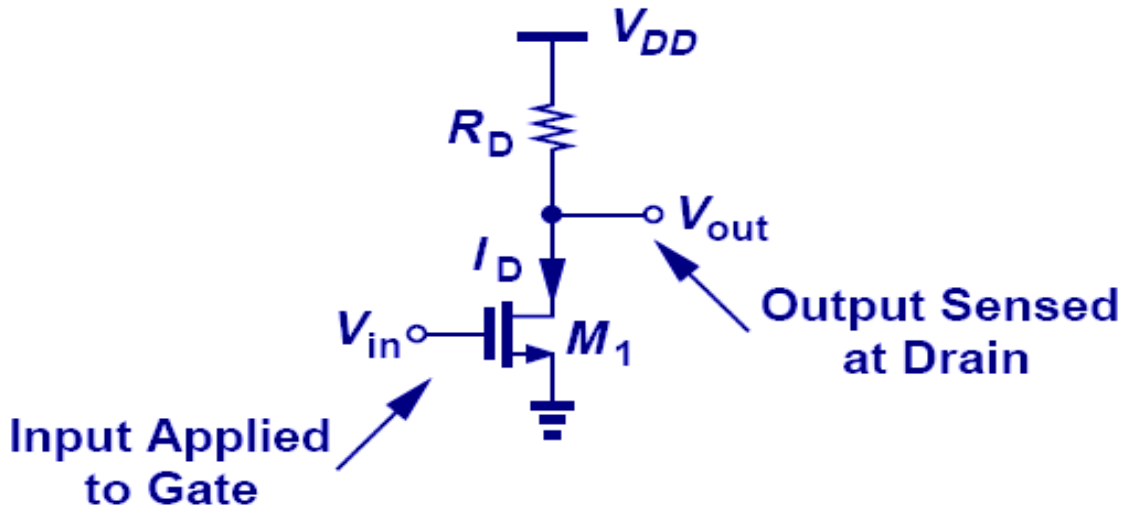
Common-Source Stage

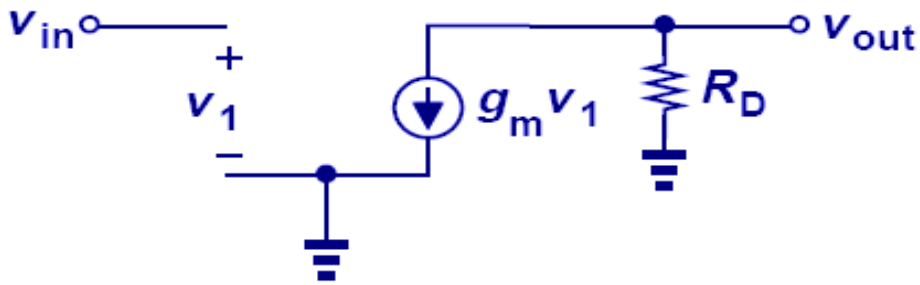


Common-Source Stage



Common-Source Stage with λ=0



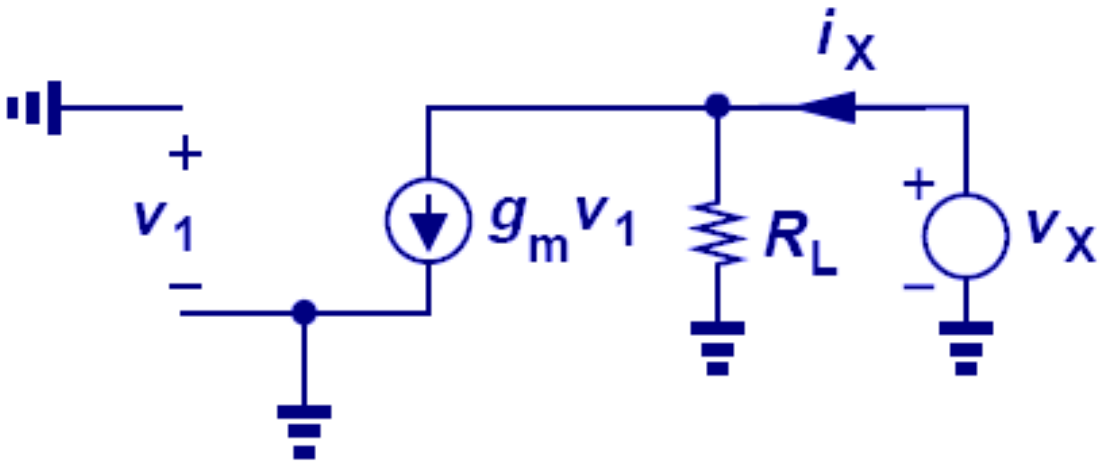


$$\lambda = 0$$

$$A_v = -g_m R_D$$

$$A_v = -\sqrt{2\mu_n C_{ox} \frac{W}{L} I_D} R_D$$

Common-Source Stage with λ=0

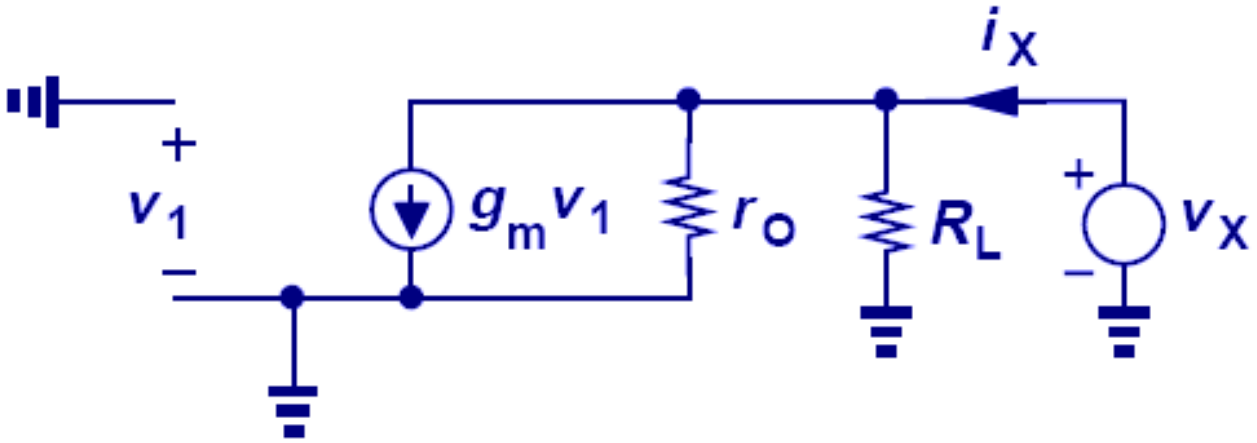


$$A_v = -g_m R_L$$

$$R_{in} = \infty$$

$$R_{out} = R_L$$

Common-Source Stage with λ≠0



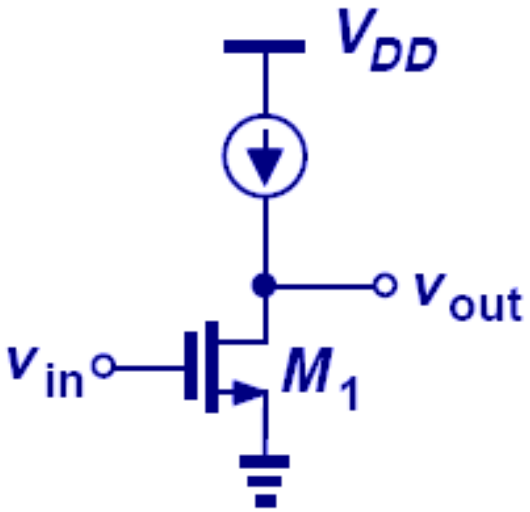
$$A_v = -g_m(R_L \| r_O)$$

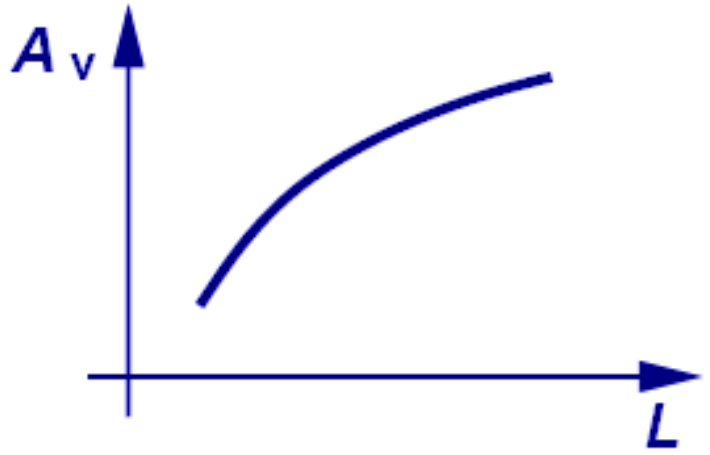
$$R_{in} = \infty$$

$$R_{out} = R_L \| r_O$$

- **However, Early effect and channel length modulation affect CE and CS stages in a similar manner.**

CS Gain Variation with Channel Length

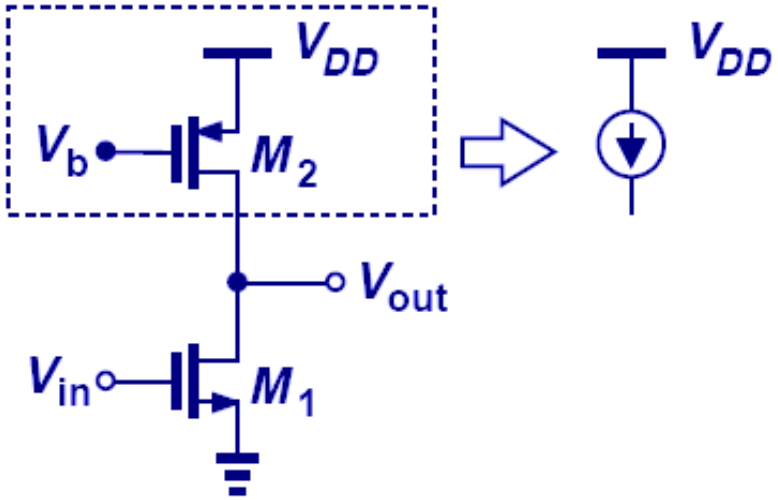


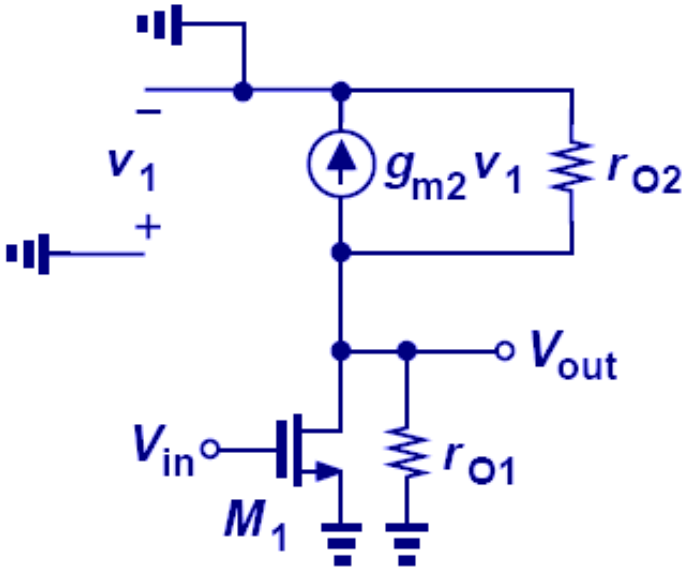


$$|A_v| = \frac{\sqrt{2\mu_n C_{ox}\frac{W}{L}}}{\lambda\sqrt{I_D}} \propto \sqrt{\frac{2\mu_n C_{ox} WL}{I_D}}$$

- **Since λ is inversely proportional to L, the voltage gain actually becomes proportional to the square root of L.**

CS Stage with Current-Source Load



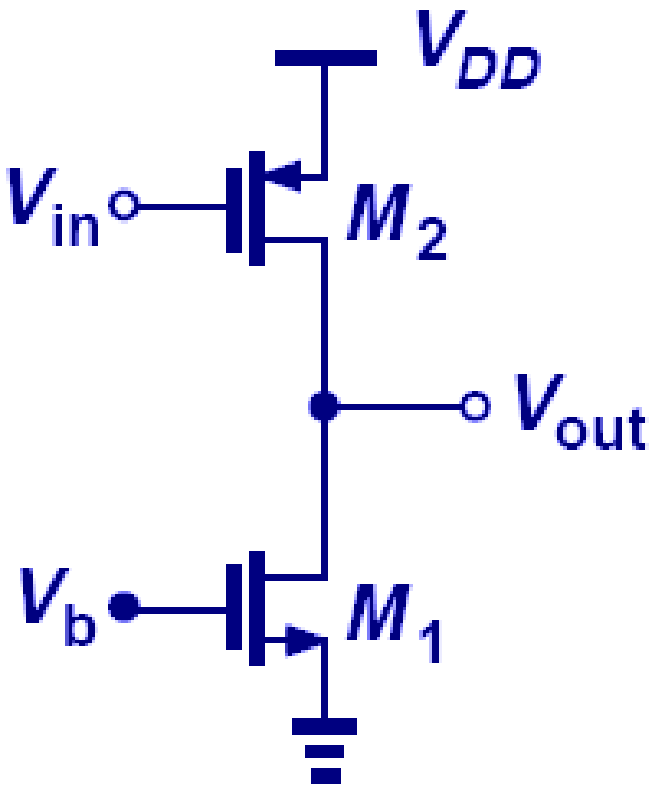


$$A_v = -g_{m1}(r_{O1} \| r_{O2})$$

$$R_{out} = r_{O1} \| r_{O2}$$

- To alleviate the headroom problem, an active current-source load is used.
- This is advantageous because a current-source has a high output resistance and can tolerate a small voltage drop across it.

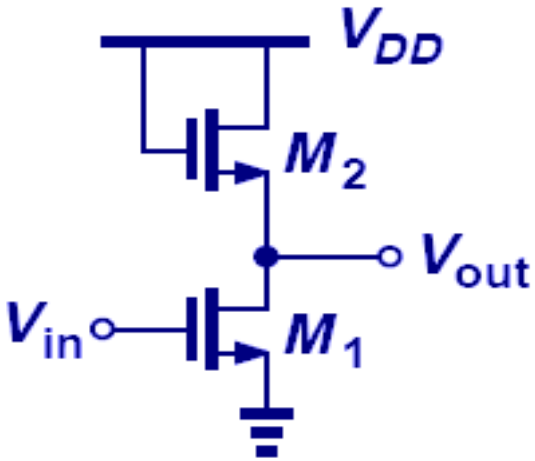
PMOS CS Stage with NMOS as Load

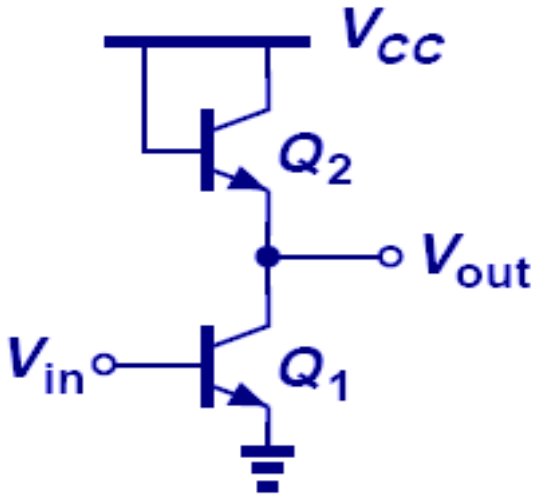


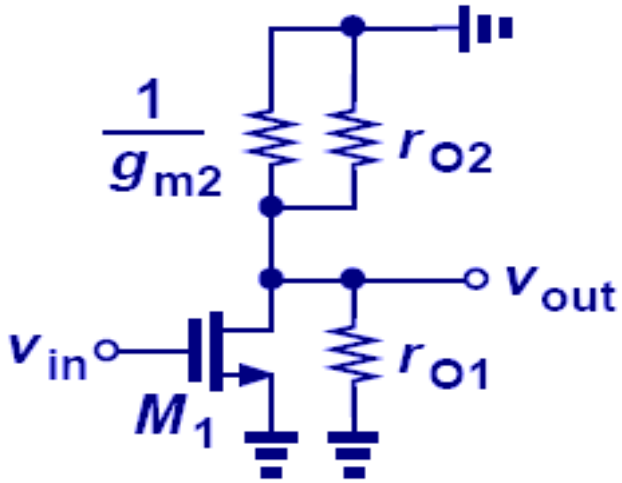
$$A_v = -g_{m2}(r_{O1} \| r_{O2})$$

- **Similarly, with PMOS as input stage and NMOS as the load, the voltage gain is the same as before.**

CS Stage with Diode-Connected Load





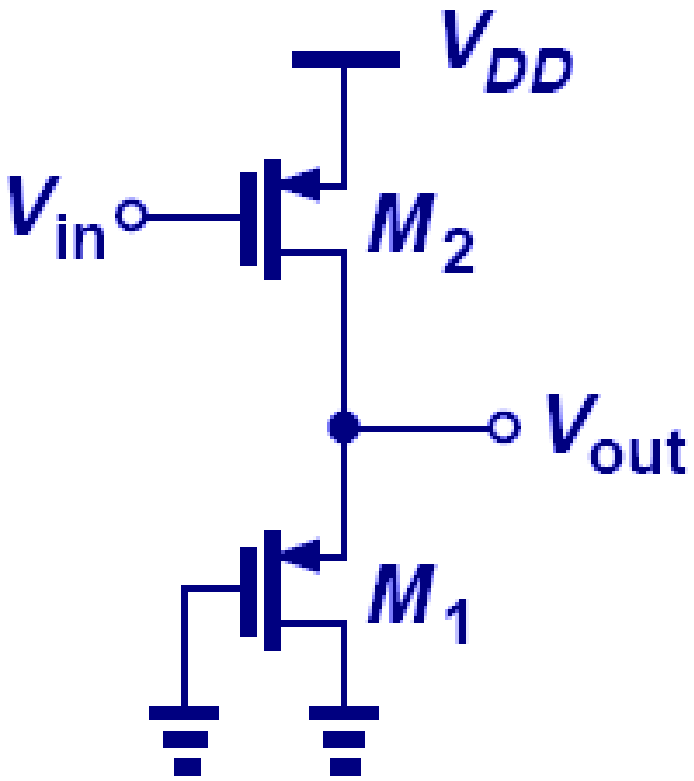


$$A_v = -g_{m1} \cdot \frac{1}{g_{m2}} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}$$

$$A_v = -g_{m1}\left(\frac{1}{g_{m2}} \| r_{O2} \| r_{O1}\right)$$

- **Lower gain, but less dependent on process parameters.**

CS Stage - Diode-Connected PMOS Device



$$A_v = -g_{m2}\left(\frac{1}{g_{m1}} \| r_{o1} \| r_{o2}\right)$$

- **Note that PMOS circuit symbol is usually drawn with the source on top of the drain.**

Something else about basic amp. stages

Common-Source Stage	Source Follower	Common-Gate Stage	Cascode
With Resistive Load	With Resistive Bias	With Resistive Load	Telescopic
With Diode-Connected Load	With Current-Source Bias	With Current-Source Load	Folded
With Current-Source Load			
With Active Load			
With Source Degeneration			

Thanks

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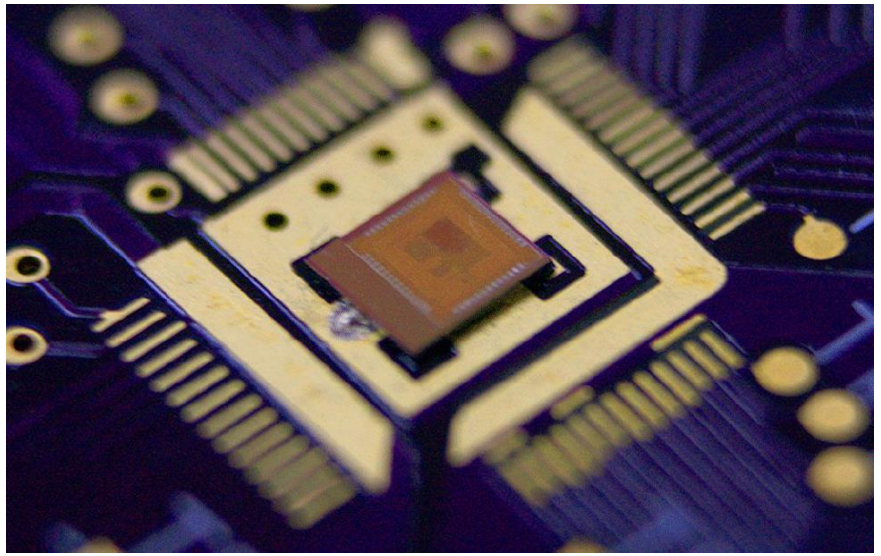

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