Electrical and Electronics Circuits (4190.206A 002)

- HW Problem 1-6: the resistance values were missing, and now it is updated as 4R, 2R, R. Please check the updated file.
- HW #1 is due on Oct. 7, 2019 3:15pm
- Make-up class
  - 9/30 (Mon) 7pm-8:15pm (the class attendance won't be checked, and video recording of the class will become available at ETL)
  - There will be still a regular class between 2:00pm~3:15pm on 9/30 (Mon)
- 1st mid-term exam: 10/21(Mon) or 10/23(Wed)
- 2nd mid-term exam: 11/13(Wed) or 11/18(Mon)
- Final exam: 12/11 (Wed) 2:00pm~3:15pm
- There will be a class on 10/9 (Wed) Hangul Day, but the class attendance won't be checked, and video recording of the class will become available at ETL.
- Grades: 3 exams 30, 30, 30% homework + attendance: 10% (If you cannot attend the class for official reason, please let me or TA know in advance.)
- **Self-attendance check**

Review

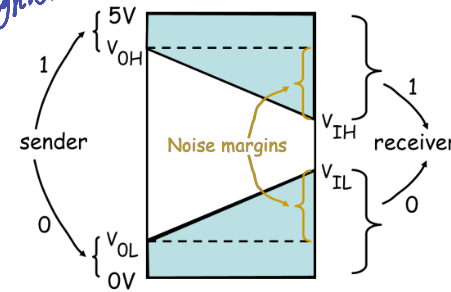
- Digital abstraction
  - Why go from analog to digital?
  - Definition of forbidden region, $V_{OH}, V_{OL}, V_{IH}, V_{IL}$
  - Static discipline
- Binary logic
  - (Binary number representation)
  - (AND, OR, NOT), NAND, NOR gates
  - Desired truth table ➔ sum-of-products, then use simplification relations
  - Implementation of logic gates using combination of digital switches and voltage drop across resistors ➔ NOT, NAND, NOR and many other combinations
- MOSFET
  - Metal-Oxide Semiconductor Field-Effect Transistor
  - S model ("Switch" model): V_{GS} vs. V_T

universal set.

univalsal gate.

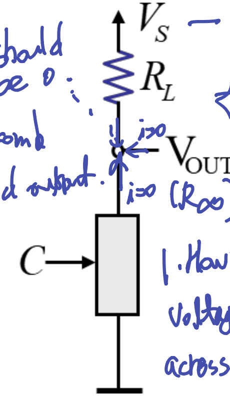
using OR

even if there exist some noise, the signal will accepted as 0, 1.



$\frac{V_{drop}}{R_L} = 0.$ ∴ should be 0.

⇒ required comb then, desired output.



— fixed

i=0

i=0 (R∞)

1. How much voltage drop across the element = amount of current

(Blue: assumption)

And then,

2. ideal assumption, | fixed.

there won't any current across the path Vout →

Goal: deliver analog signal to other.

Analog-Digital Conversion

- problem : noise.
- need ways to interface

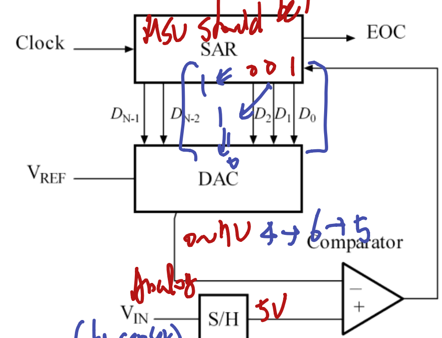
analog →ADC→ computer digital →DAC→ analog

voltage → discretize → voltage

- Motivation for digital abstraction
  - Analog signals are too noisy
  - ➔ Convert the analog signals to digital values and transmit the digital values
  - ➔ Process (or calculate) digital values
  - ➔ Then what? E.g. change of the room temperature, music playing, change of the LED brightness, video playing, self-driving car, communication, printer, … almost everything connected to the digital device works in the analog world
- Digital device requires a way to interface with the analog world
  - Analog-to-digital converter (ADC)
  - Digital-to-analog converter (DAC)
- In one of your HW problems, you will see how to implement DAC using a simple resistor network.
- Implementation of ADC
  - Successive approximation register (SAR) ADC
  - Implemented with the help of digital controller

= binary search concept

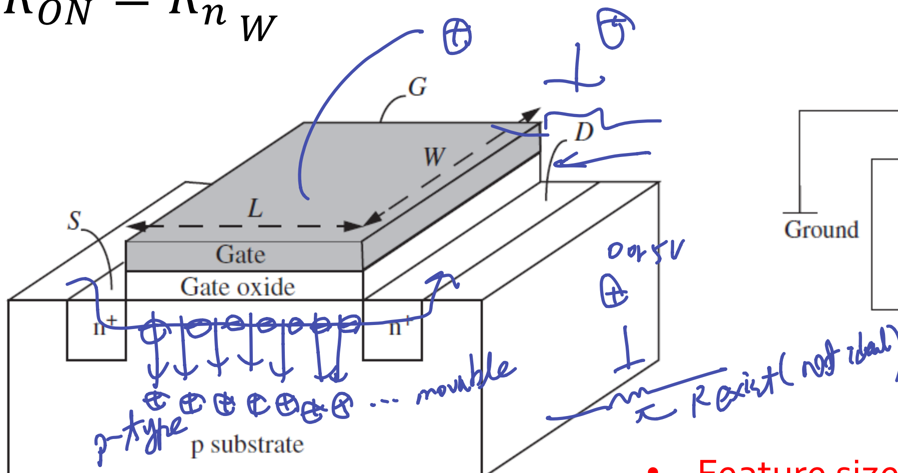
As increasing resolution n(line) ↑

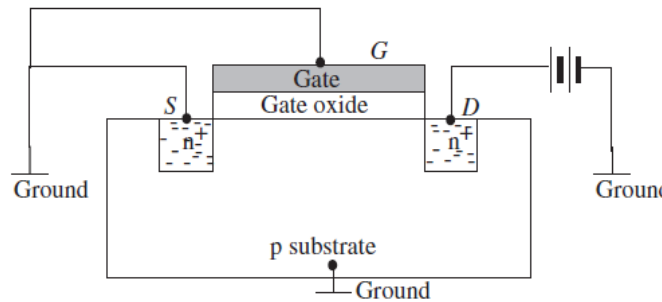


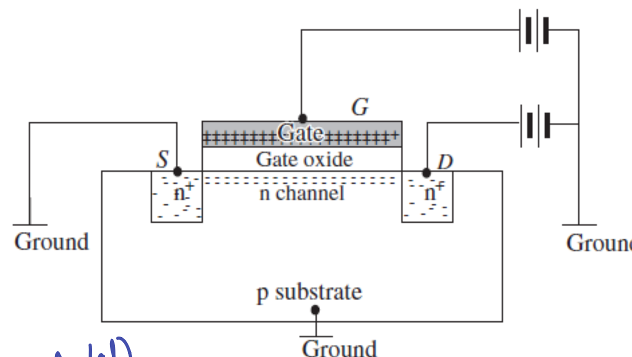
MOSFET Device Structure

- Metal-Oxide Semiconductor Field-Effect Transistor
- PN junction
- Resistance between S and D:

$$R_{ON} = R_n \frac{L}{W}$$







- Feature size
- Moore's law

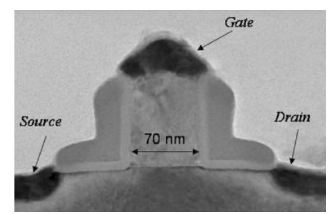
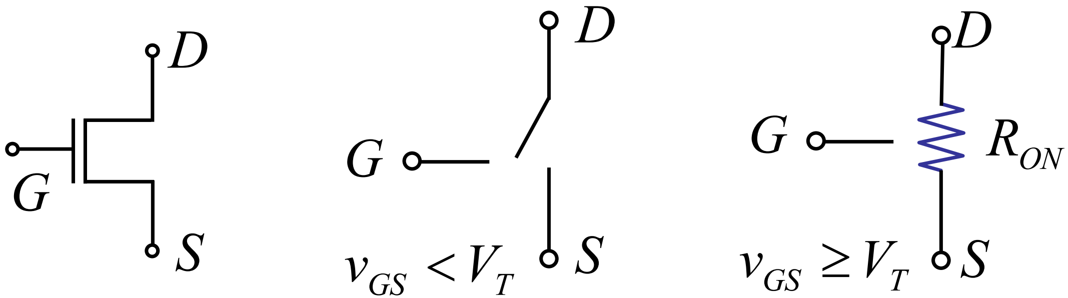


FIGURE 6.38 A cross-sectional picture of Intel's 0.13-μm generation logic transistor.

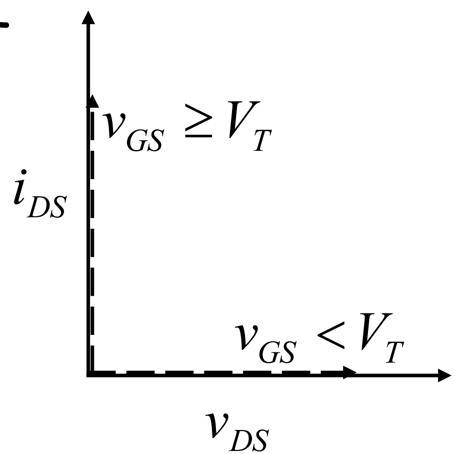
9Ω
amplifier (0~1V)
1Ω (0~0.1V)

Switch Resistor (SR) Model of MOSFET

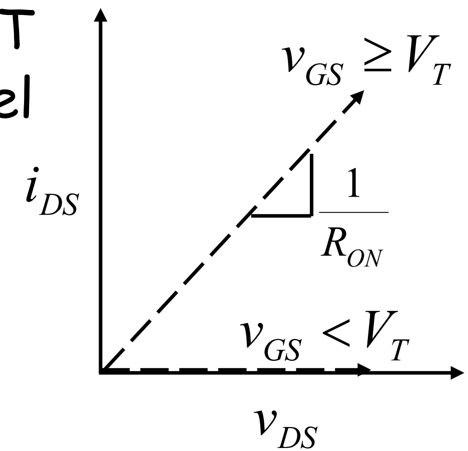
- When MOSFET switch is turned on, there is resistance
- For example, $R_{ON} = 1k\Omega$



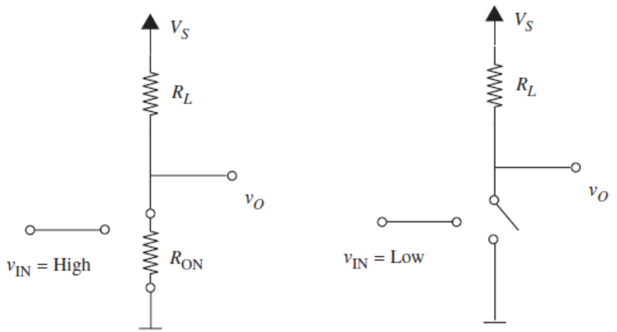
MOSFET
S model

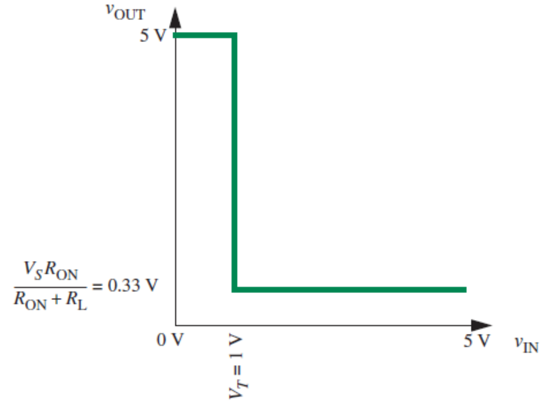


MOSFET
SR model



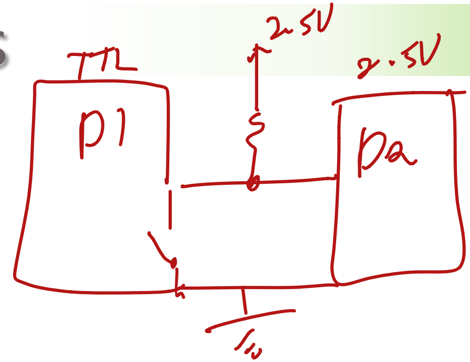
What Determines Resistor Value in Inverter?

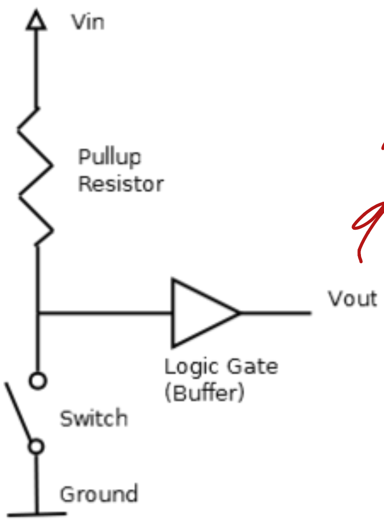




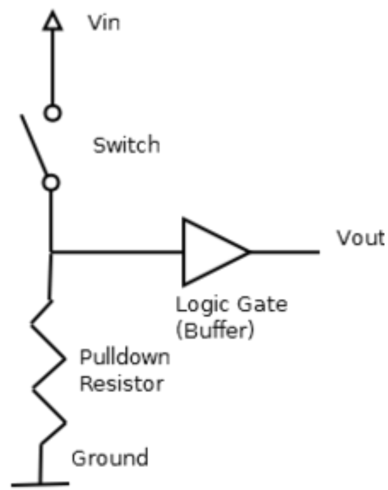
- When v_{IN}=High, $v_{OUT} = V_S \frac{R_{ON}}{R_{ON}+R_L}$
- If $V_S = 5V, V_T = 1V, R_{ON} = 1k\Omega, R_L = 14k\Omega$, $v_{OUT} = 0.33V$

Pull-up and Pull-down Resistors



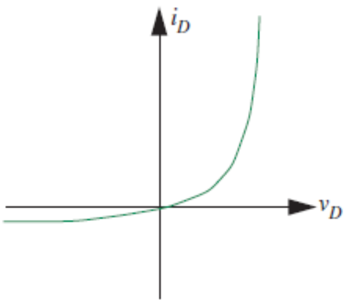


0 or Volt



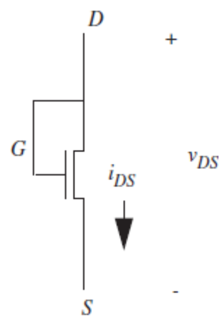
Why Nonlinear Circuits?

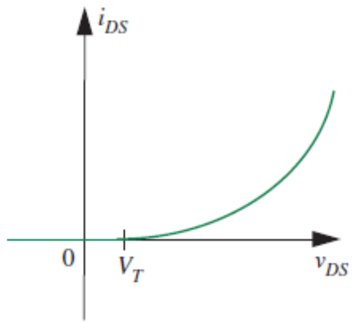
- Diode
  - $i_D = I_s(e^{v_D/V_{TH}} - 1)$ where I_s is typically $10^{-12}A$ and V_{TH} is typically 0.025V



- MOSFET with gate and drain tied together

$$i_{DS} = \begin{cases} \dfrac{K(v_{DS} - V_T)^2}{2} & \text{for } v_{DS} \geq V_T \\ 0 & \text{for } v_{DS} < V_T \end{cases}$$



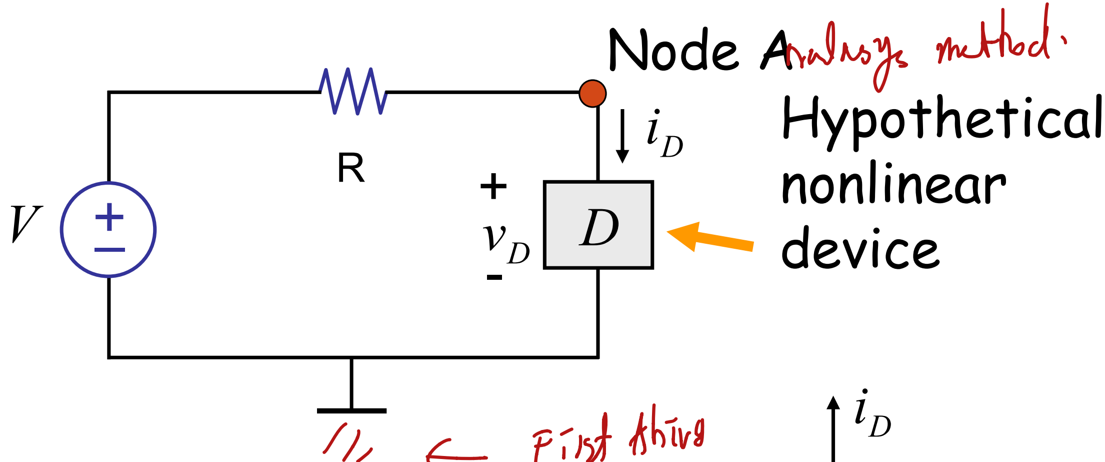


For the next several lectures...

- Goal: show how to implement amplifier using MOSFET

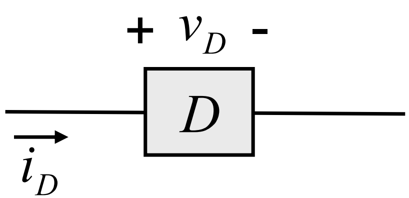
- Chap. 4 Analysis of Nonlinear Circuits
  - Analytical Solutions (4.2)
  - Graphical Analysis (4.3)
  - Piecewise Linear Analysis (4.4)
  - Incremental Analysis (4.5)
- Chap. 7 The MOSFET Amplifier
  - Large-Signal Analysis of the MOSFET Amplifier (7.6)
  - Operating Point Selection (7.7)
- Chap. 8 The Small-Signal Model

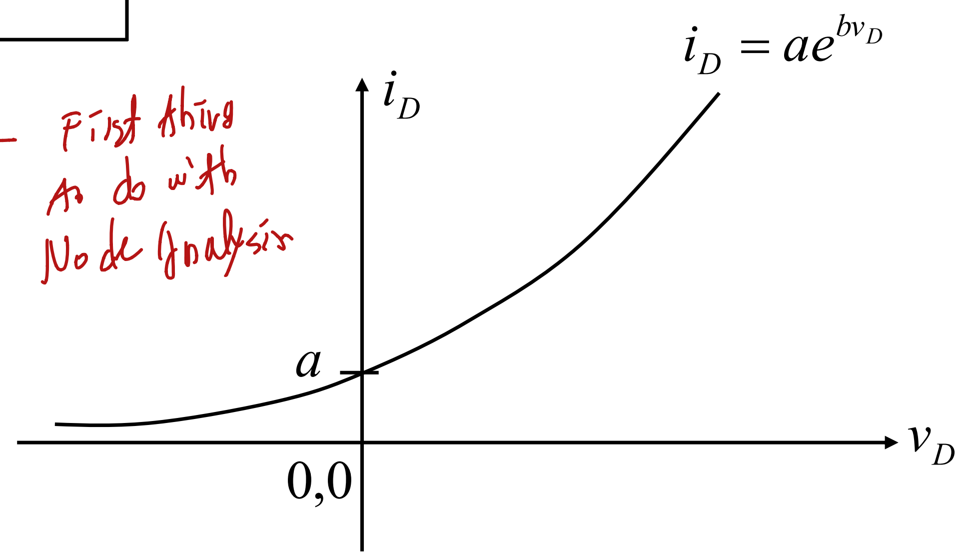
Hypothetical Nonlinear Element



Analysis method.

First thing to do with Node Analysis





(Curiously, the device supplies power when v_D is negative)

Analytical Method

- Apply KCL at node A (the node method),

$$\frac{v_D - V}{R} + i_D = 0 \qquad ①$$

$$i_D = ae^{bv_D} \qquad ②$$

2 unknowns   2 equations

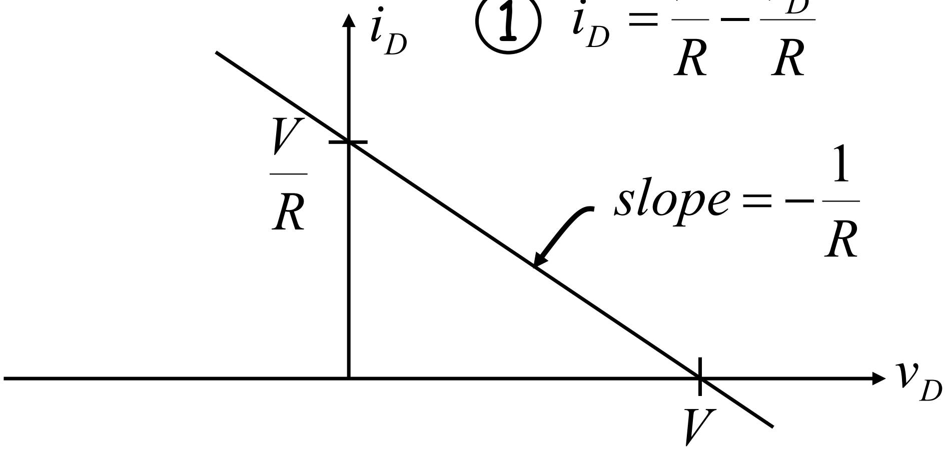
Solve the equation by

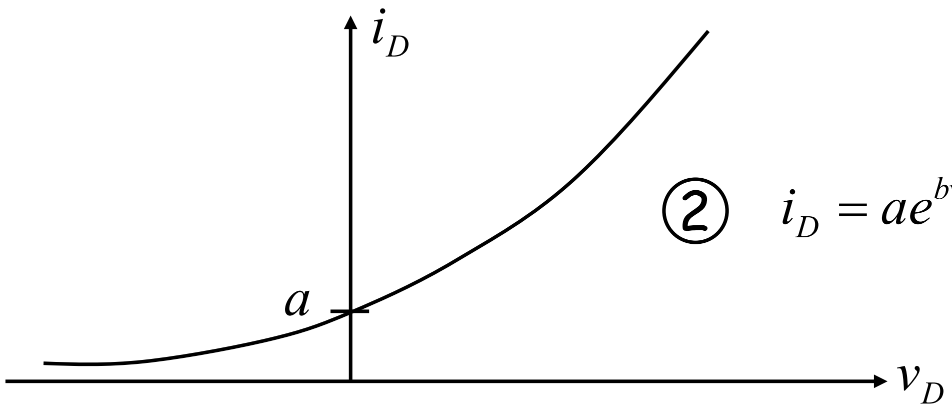
- trial and error
- numerical methods

Graphical Method

The solution should satisfy both equations

① $i_D = \frac{V}{R} - \frac{v_D}{R}$



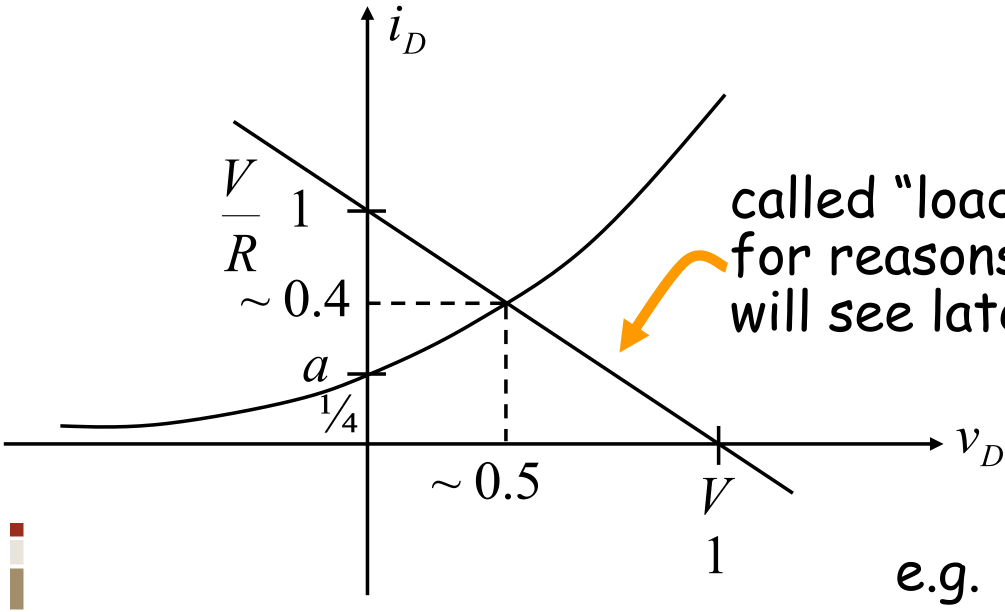


② $i_D = ae^{bv_D}$

$\frac{V_D - V}{R} + 0 = i_D$

Graphical Method

Combine the two constraints



called "loadline" for reasons you will see later

e.g. $V = 1$ $\qquad v_D = 0.5V$

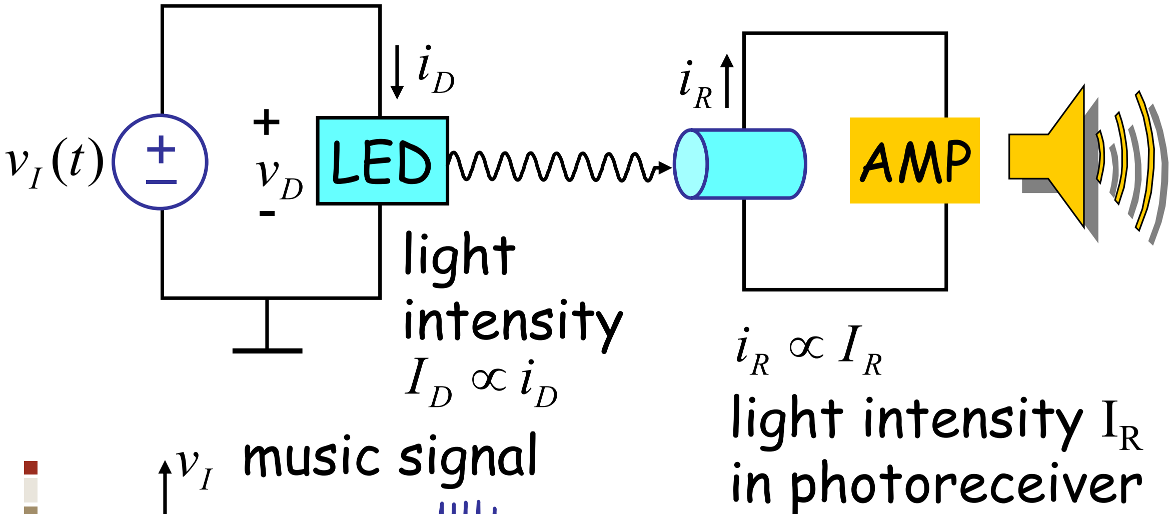
$R = 1$ $\qquad i_D = 0.4A$

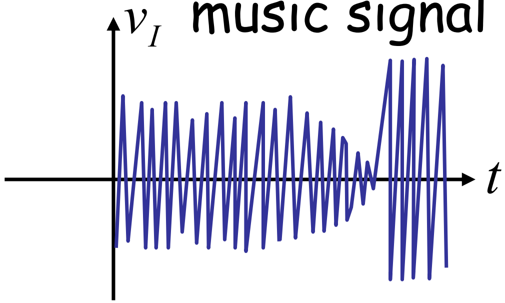
$a = \frac{1}{4}$

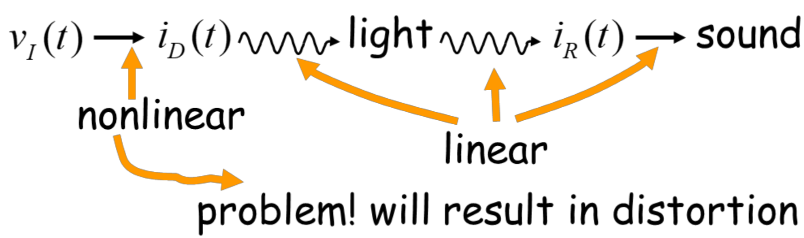
$b = 1$

Incremental Analysis

- Assume our hypothetical LED is having $i_D = ae^{b \cdot v_D}$

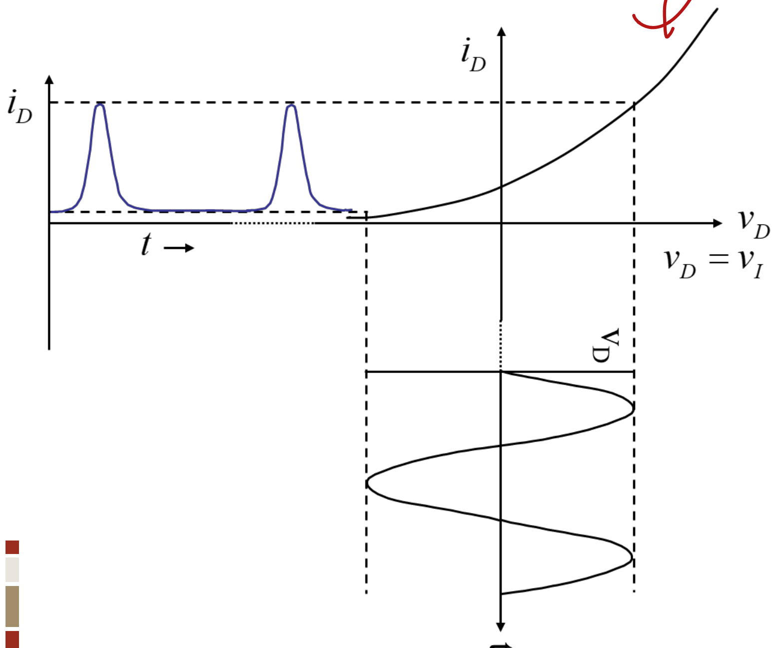


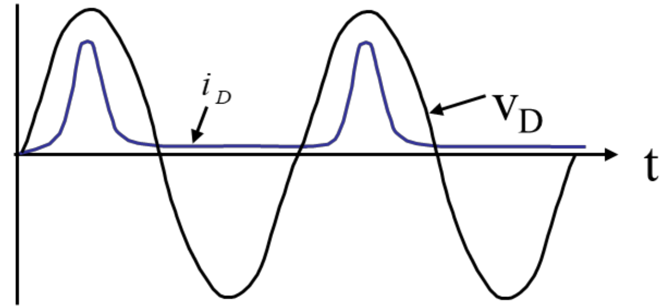




Incremental Analysis

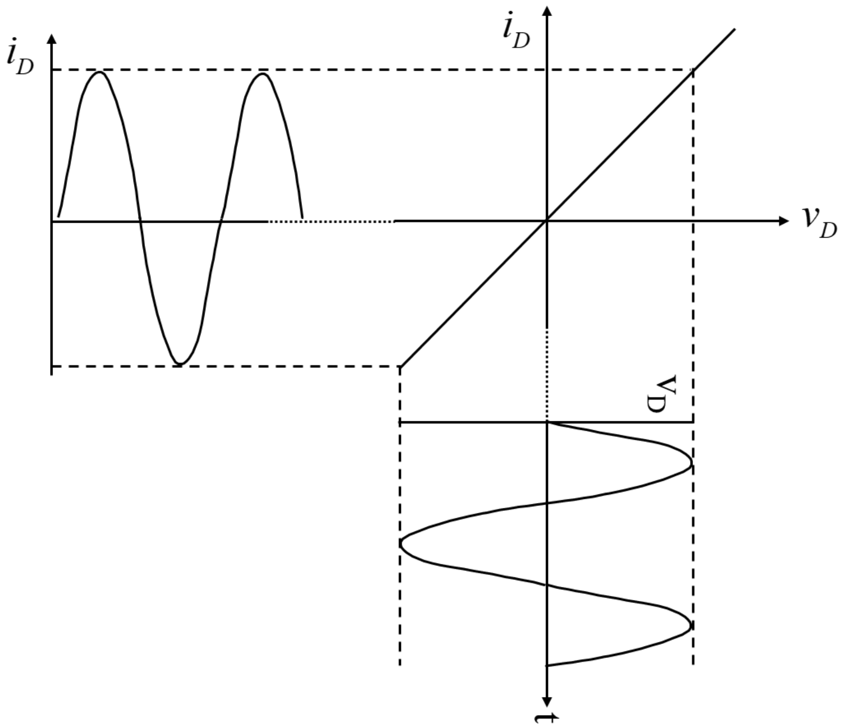
Non linear





Incremental Analysis

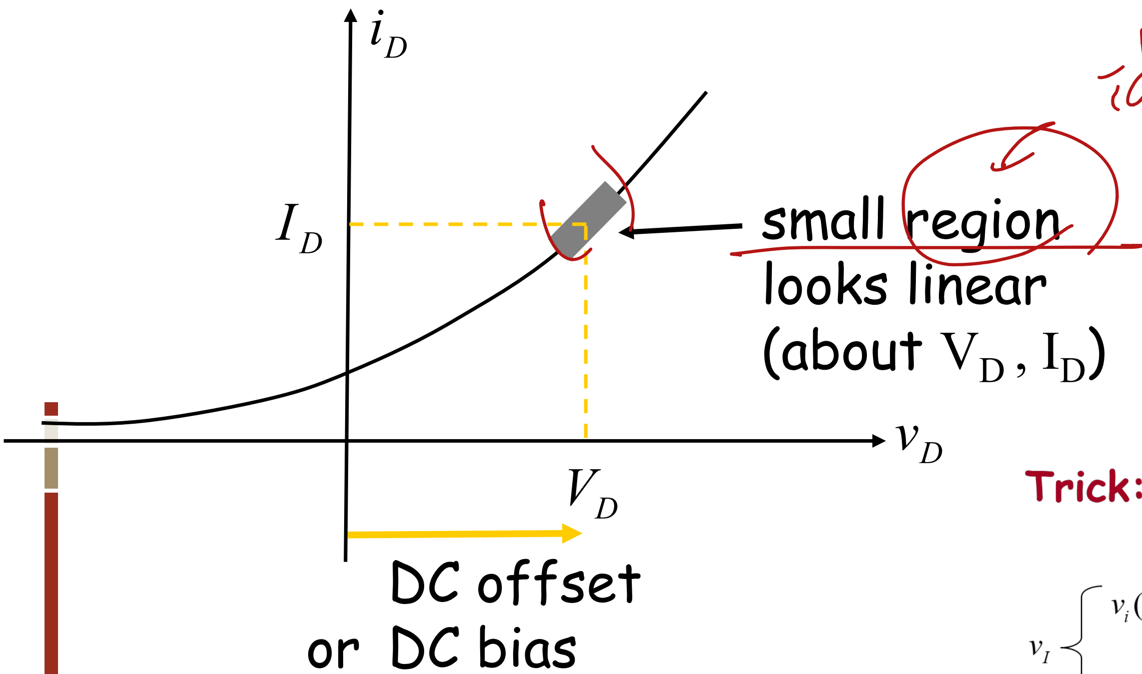
- What we need is linear amplifier



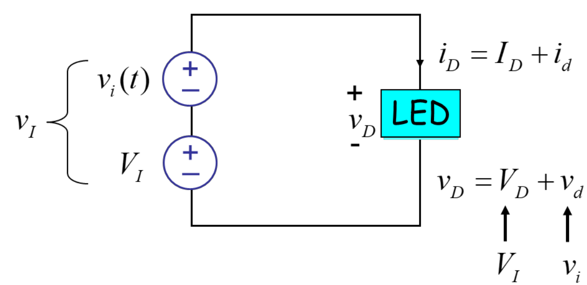
Linear amplifier from nonlinear element

- How can we implement linear amplifier from nonlinear components?

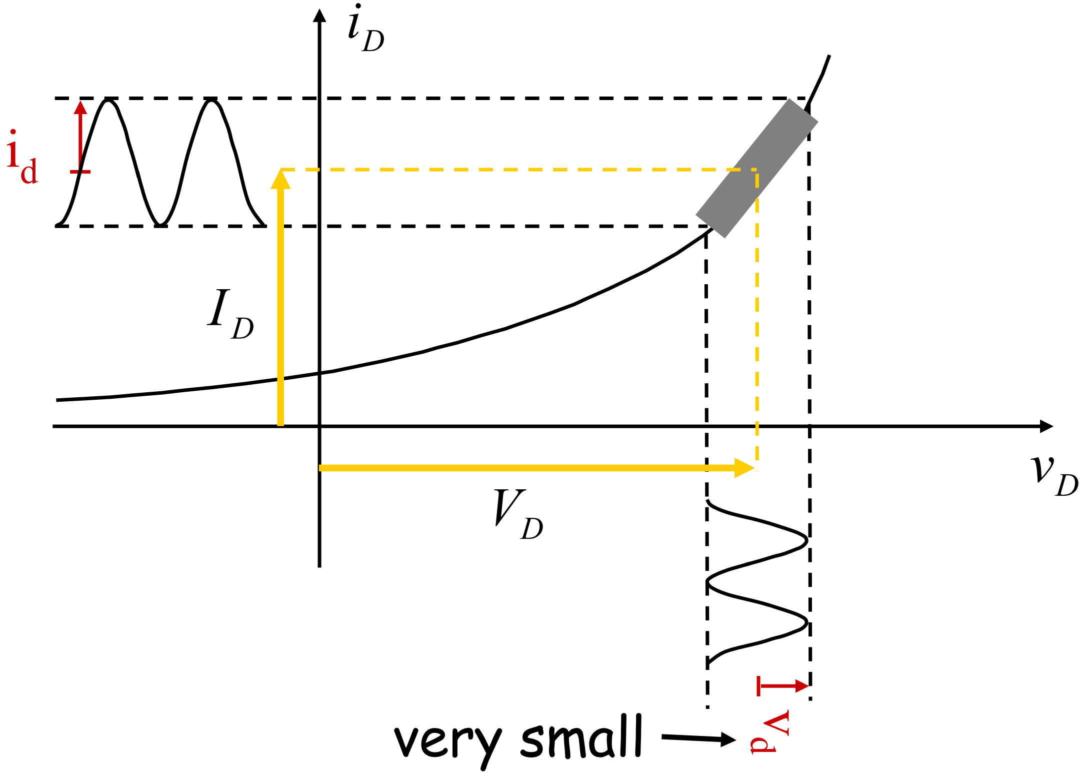
idea of linear ampl.



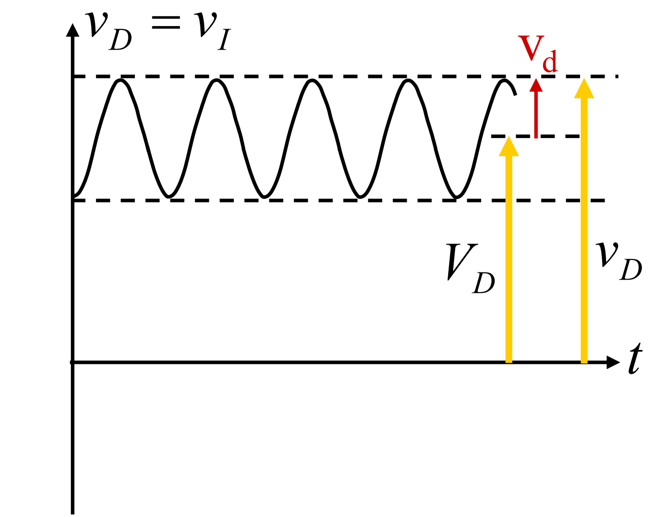
Trick:

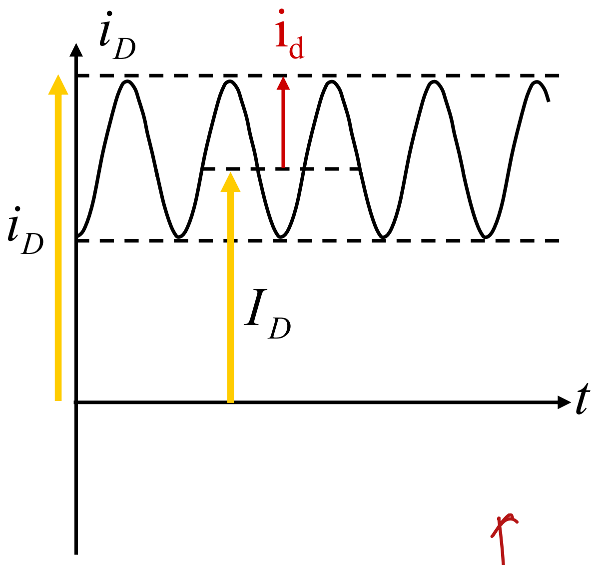


Result



Result



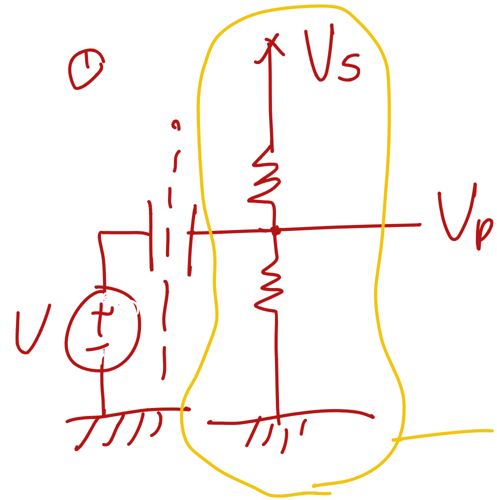


~linear!

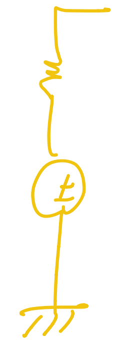
because the problem is

How can we apply and remove bias?

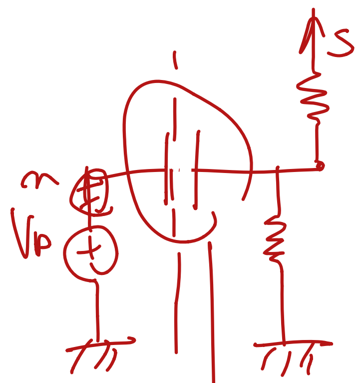
- How to add bias?

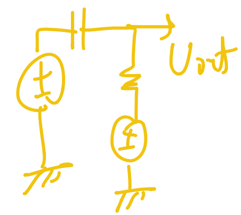


single V.S



- How to remove bias?





Blocking C.D's

Why is the small signal response linear?

- Can we guarantee that the response with respect to the small signal input always linear?

$$i_D = f(v_D)$$

nonlinear

We replaced

$$v_D = V_D + \Delta v_D$$

V_d

large DC

b:m

increment about V_D

Vk v

→ DC bias @

Combinational signal

using Taylor's Expansion to expand $f(v_D)$ near $v_D = V_D$:

$$i_D = f(V_D) + \left.\frac{df(v_D)}{dv_D}\right|_{v_D=V_D} \cdot \Delta v_D$$

$$\cancel{+ \frac{1}{2!}\left.\frac{d^2 f(v_D)}{dv_D^2}\right|_{v_D=V_D} \cdot \Delta v_D^{\,2}} + \cdots$$

neglect higher order terms because Δv_D is small

$$i_D \approx \underbrace{f(V_D)}_{\substack{\text{constant} \\ \text{w.r.t. } \Delta v_D}} + \underbrace{\left.\frac{d f(v_D)}{d v_D}\right|_{v_D = V_D}}_{\substack{\text{constant w.r.t. } \Delta v_D \\ \text{slope at } V_D,\, I_D}} \cdot \Delta v_D$$

We can write

$$I_D + \Delta i_D \approx f(V_D) + \left.\frac{d f(v_D)}{d v_D}\right|_{v_D = V_D} \cdot \Delta v_D$$

equating DC and time-varying parts,

$$I_D = f(V_D) \longrightarrow \text{operating point}$$

$$\Delta i_D = \underbrace{\left.\frac{d f(v_D)}{d v_D}\right|_{v_D = V_D}}_{\text{constant w.r.t. } \Delta v_D} \cdot \Delta v_D$$

so, $\mathrm{D}i_D$ μ $\mathrm{D}v_D$

By notation,

$\mathrm{D}i_D = i_d$

$\mathrm{D}v_D = v_d$

Example

$$i_D = a\,e^{b v_D}$$

$$I_D + i_d \approx a\,e^{bV_D} + a\,e^{bV_D} \cdot b \cdot v_d$$

Equate DC and incremental terms,

$$\boxed{I_D = a\,e^{bV_D}}$$ → operating point

- aka bias pt.
- aka DC offset

$$i_d = a\,e^{bV_D}\, b \cdot v_d$$

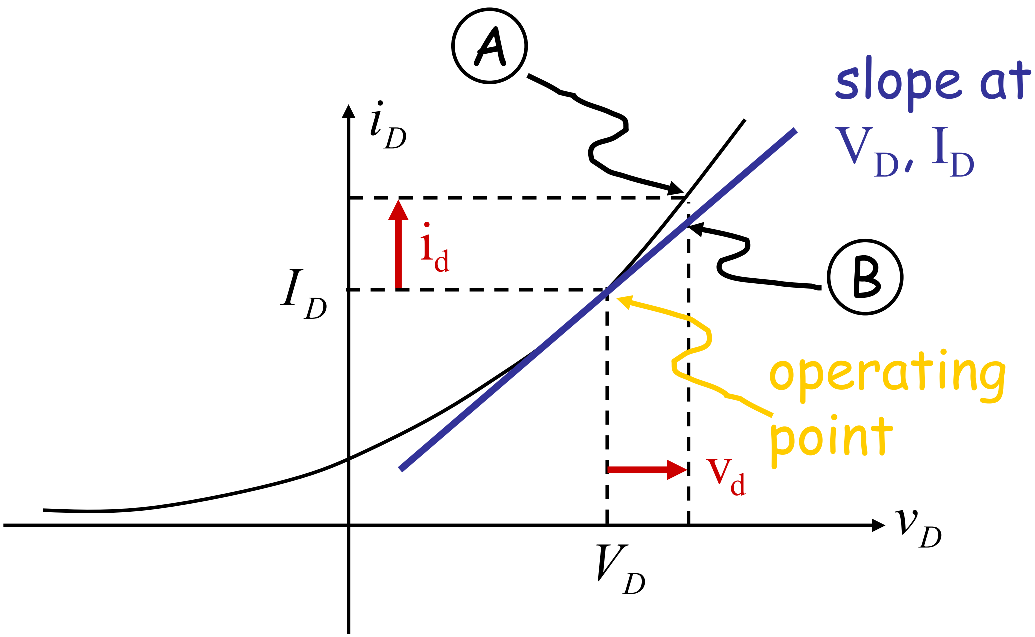
$$i_d = \underbrace{I_D \cdot b}_{\text{constant}} \cdot v_d$$ → small signal behavior

constant → linear!

Graphical Interpretation

$I_D = a\, e^{bV_D}$ → operating point

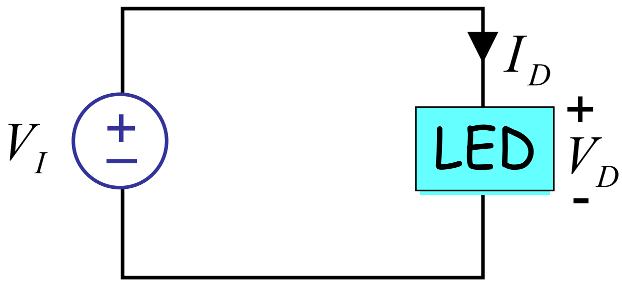
$i_d = I_D \cdot b \cdot v_d$



we are approximating A with B

Combined Together

Large signal circuit:



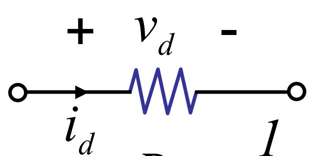
$$I_D = a\, e^{bV_D}$$

By using graphical or analytical solution, find bias point.

Small signal reponse: $i_d = I_D\, b\, v_d$

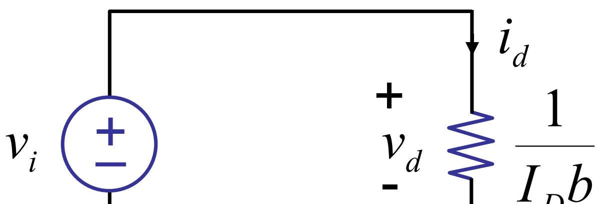
Linearization

behaves like:



$$R = \frac{1}{I_D\, b}$$

small signal circuit:



Linear!