Intro to ECSE Class 11: Diodes and Differential Resistance

I] Overview of Lab02: Parts A & B

1. Introduce the concept of linearity
2. Give you another tool for solving and designing circuits: nodal analysis
3. Provide an example of non-linearity: diodes

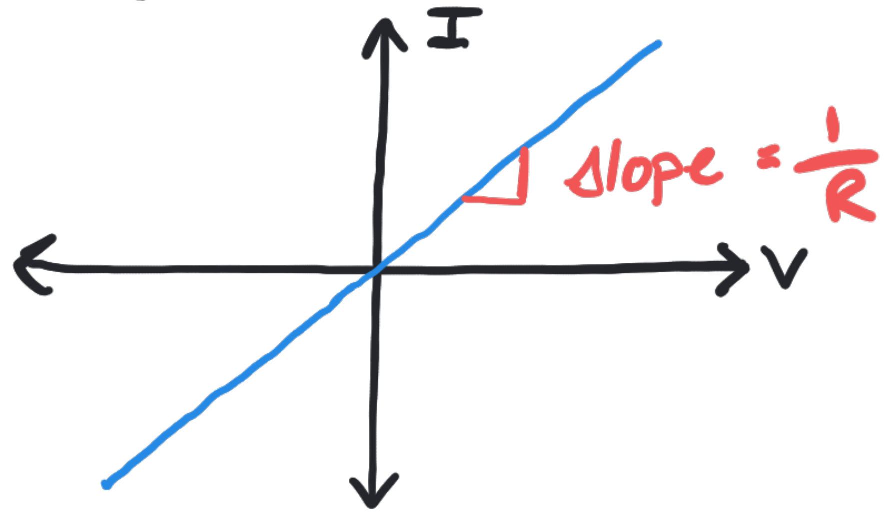
Part A: Defining Linear & Non-Linear Device IV Characteristics (today)

Part B: Solving Linear Resistive Networks Using Nodal Analysis

II] Linear and Non-Linear IV Characteristics

1. Resistor

- IV Characteristic



$V = IR$

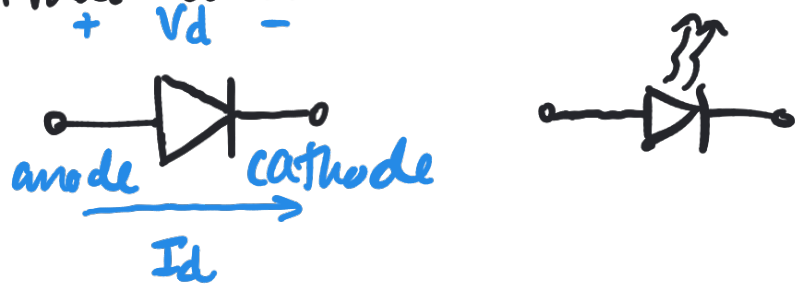
$\Delta V = \Delta I\, R$ → slope: $\frac{\Delta I}{\Delta V} = \frac{1}{R}$

- $V = IR$ → straight line → linear component

2. Diode : allows current to flow in only one direction

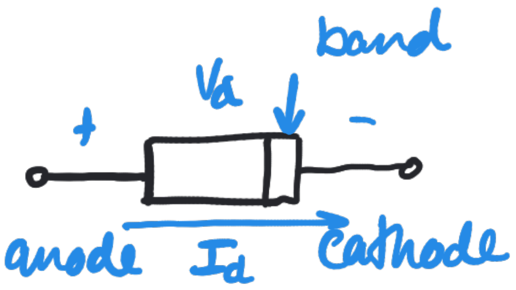
a) circuit symbol

"normal" diode | LED

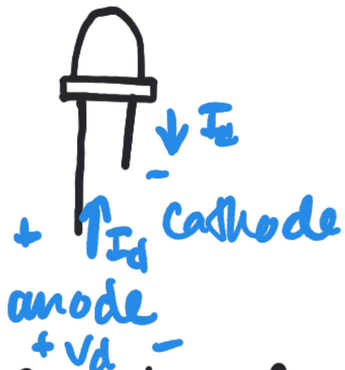


· actual part appearance

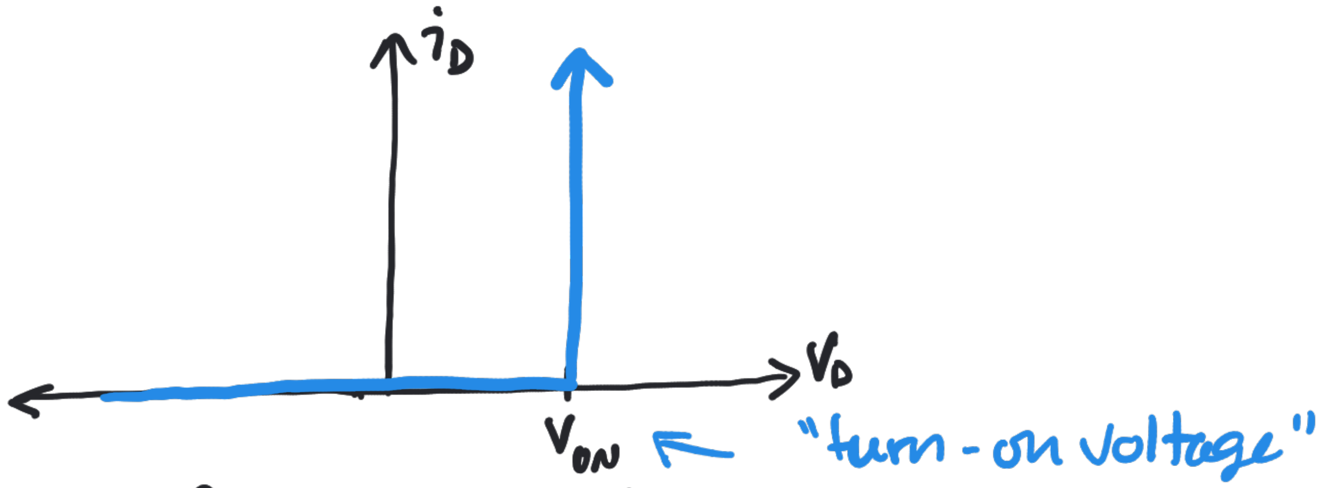
Si diode :



LED :



b) Model #1 : Simple ideal diode model



$$i_D = \begin{cases} 0 & V_d < V_{ON} \\ \infty & V_d \geq V_{ON} \end{cases}$$

· Turn-on voltage V_{ON} : Voltage when current starts to flow

· Typical values of V_{ON}
  · Si : 0.7V
  · LEDs : 1.5V+ → depends on color

· useful for simple analysis of diode circuits

Example:

- Find V_{R1} and I_{R1}

$V_{ON} = 2.5V$ - fixed regardless of current

- Use KVL: $-12V + V_{R1} + 2.5V = 0 \rightarrow V_{R1} = 9.5V$ (V_{ON})
- Use Ohm's Law: $I_{R1} = \frac{V_{R1}}{R_1} = \frac{9.5V}{500\Omega} = 19mA$

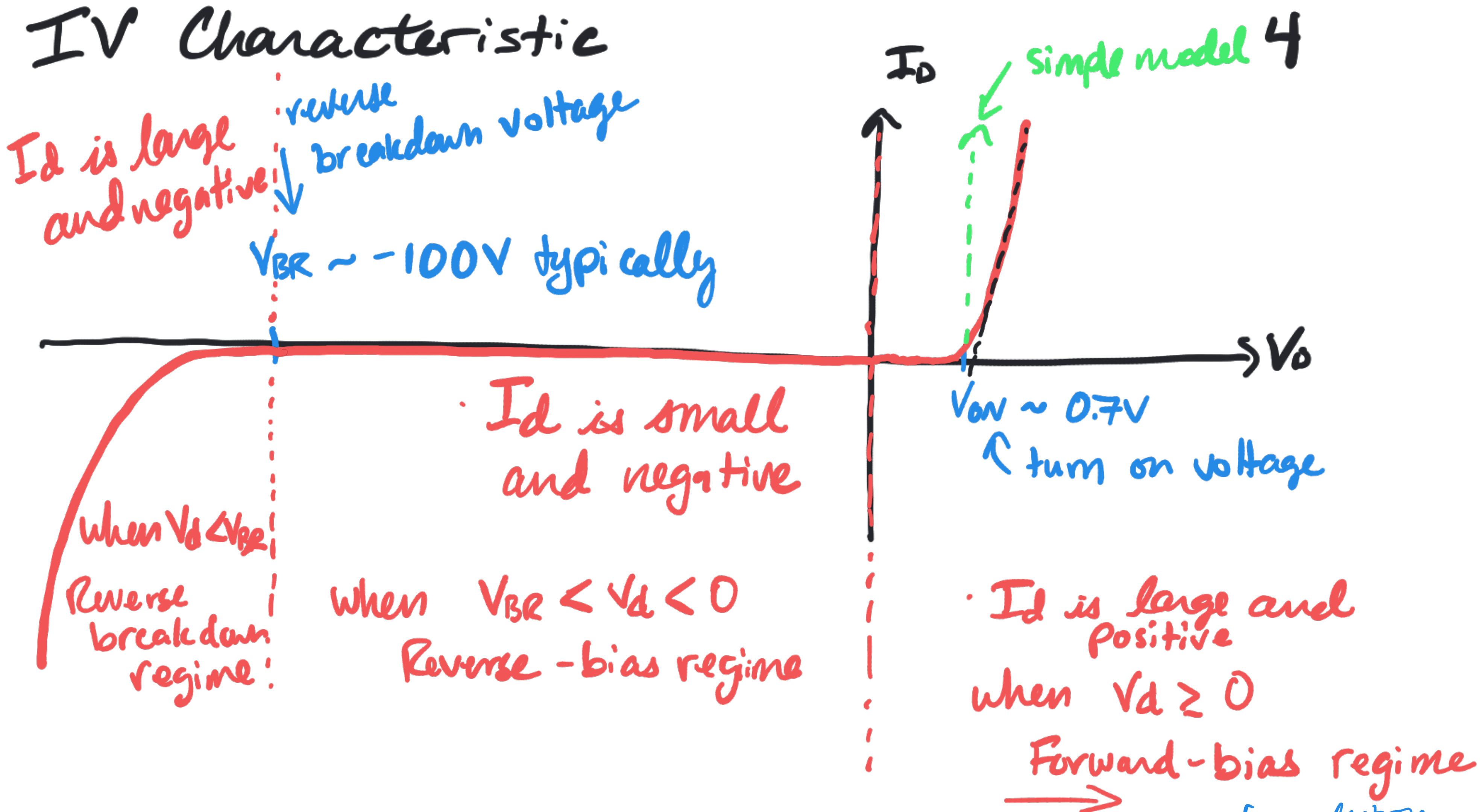
C) The actual ideal diode model

- Differences compared to simple model
  - I_d is not infinity for $V_d > V_{ON}$ (resistance of IV curve is not 0)

current flows in the "wrong" direction:

- If $V_d < V_{ON}$, a small negative current flows
  - ↳ I_S : saturation current
- If $V_d < V_{BR}$ (reverse breakdown voltage), a large negative current will flow

- IV Characteristic



- Ideal diode equation: $I_d = I_s\left(e^{\frac{qV_d}{nk_BT}} - 1\right)$
  - q: charge of an electron
  - k_B: Boltzmann's constant
  - T: temperature
  - n: ideality factor ($1 < n < 2$ typically)
  - I_s: saturation current, what flows in reverse bias

- In forward bias $V_d > V_{ON}$

  $I_d \sim I_s e^{\frac{qV_d}{nk_BT}}$

- In reverse bias $V_d < 0$

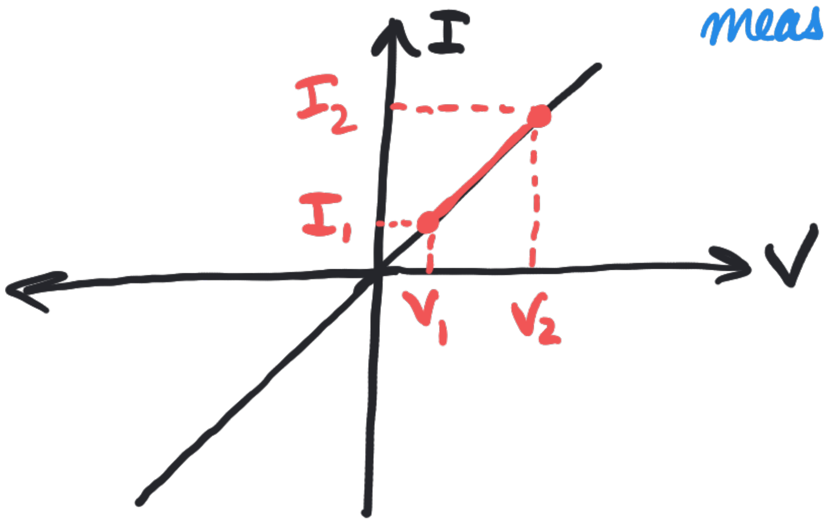
  $I_d \sim -I_s$

- In reverse breakdown: not in equation

3. Differential Resistance

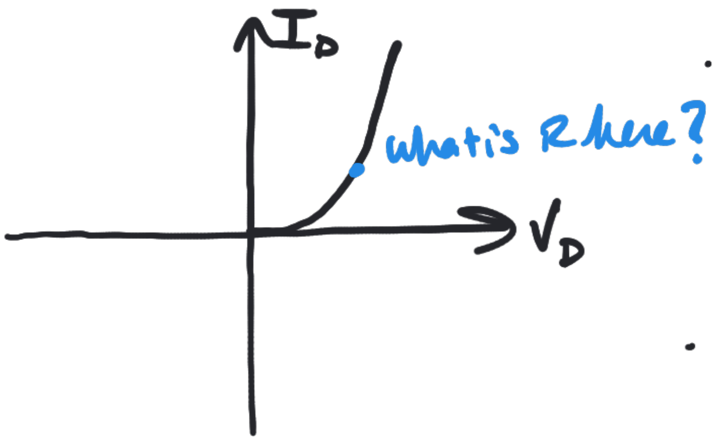
- So far we have defined resistance on an IV characteristic as $R = \frac{\Delta V}{\Delta I}$

or $$R = \frac{V_{R2} - V_{R1}}{I_{R2} - I_{R1}} = \frac{\Delta V}{\Delta I}$$



measure 2 points (V_{R1}, I_{R1})
(V_{R2}, I_{R2})

- But what about non-linear IV Characteristics?



- $R = \frac{\Delta V}{\Delta I} \rightarrow \left.\frac{dV}{dI}\right|_{(V_0, I_0)} = R_{diff}$

- We need: calculus → relation to slope of IV curve at a point (V_0, I_0)

- Differential Resistance: local measure of resistance
  how much does V change (dV) for a small change in I (dI)

$$R_{diff} = \left.\frac{dV}{dI}\right|_{(V_0, I_0)}$$

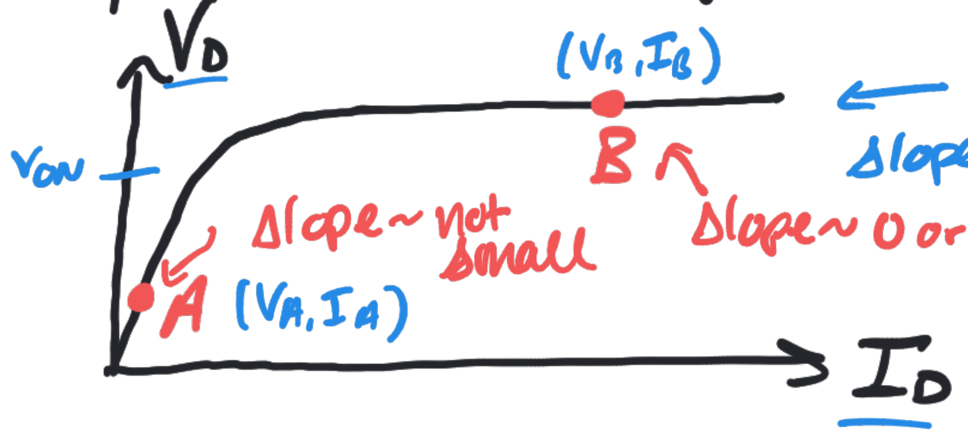
$\rightarrow V = IR$

$$\frac{d}{dI}(V) = \frac{d}{dI}(IR)$$

$$\frac{dV}{dI} = R$$

- What is "resistance" then?
  - It's how much V changes for a change in I

Example: diode in forward-bias

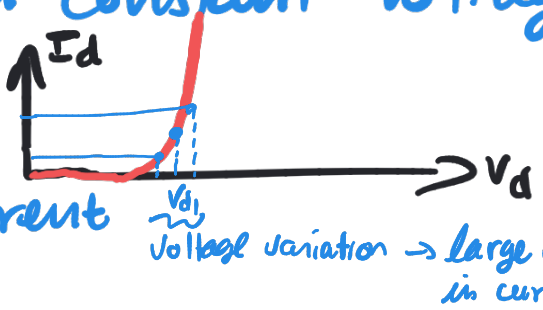


$R_{diff} = \left.\frac{dV}{dI}\right|_{(V_o, I_o)}$

- At which point is R_{diff} smaller?
  - R_{diff} for a diode is very small for $V_d > V_{on}$
    small changes in Vd lead to large changes in I_d

- Consequences of varying differential resistance for diodes:

→ Voltage vs. current control: it's difficult to drive a diode at a constant voltage & current using voltage
→ drive a diode with current



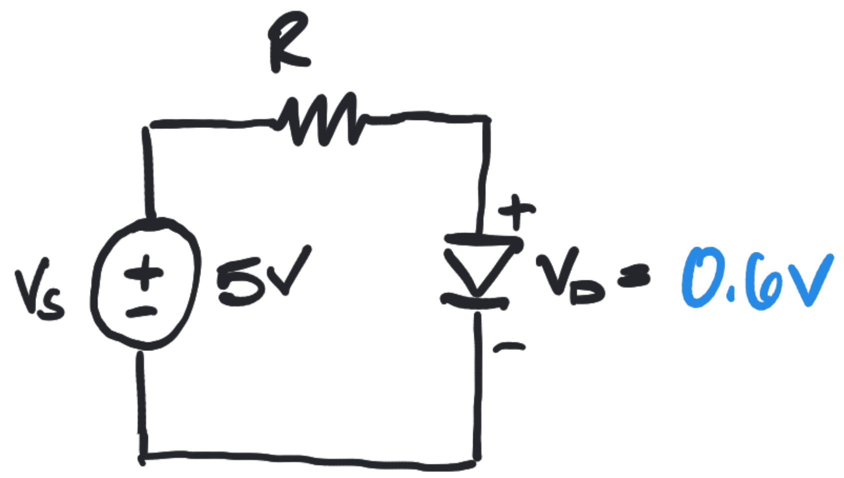
→ current limiting:

- If we give a diode too much current it can break. We should put a resistor in series with the diode to keep the current at a safe level

4. Current-Limiting Resistor

- Given the max. current & turn-on voltage of a diode, we can choose a resistor to limit the current to a safe value

- How do we find the max. current for a diode?
  - I_{max} = 300mA
  - V_{ON} = 600mV @ 1mA



4.4V = V_R

Choose R so that I_d << 300mA

say I_R = 150mA

$$R = \frac{V_R}{I_R} = \frac{4.4V}{150mA} = 30\Omega$$

- What value of R will limit the current to a safe value? for this case $R > 30\Omega$
  typically we use $R \sim 100\Omega$