1/8/12

Lecture 2

Note Title 31-07-2012

Topics covered:

→ Linear networks overview (LTI)

→ Non linear networks

→ Notion of incremental linearity to analyse nonlinear networks (under certain conditions)

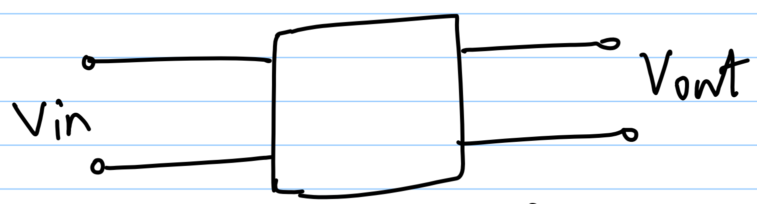
→ Non linear elements

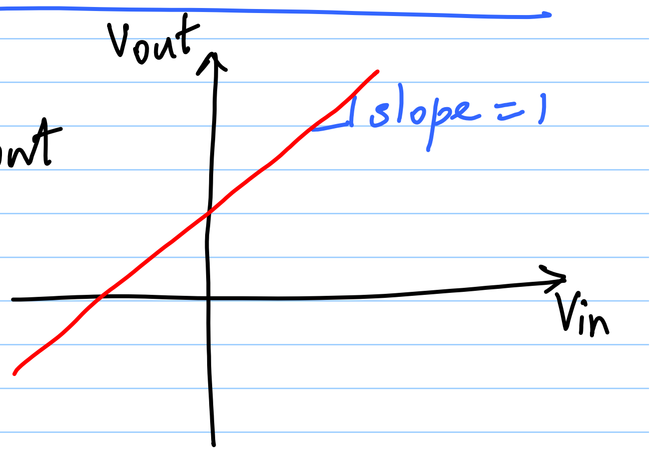
* Diodes
* MOSFET
* BJT

Blackbox treatment

→ Design of amplifiers using MOSFETs & BJTs

→ Negative Feedback





* Is this linear?

Linear: $\left.\begin{array}{l} x_1 \to y_1 \\ x_2 \to y_2 \end{array}\right\}$ $a x_1 + b x_2 \to a y_1 + b y_2$

$\forall\, a, b, x_1, x_2$

i.e. Superposition holds true

e.g. $x_1 = 0$, $y_1 = 2$

$x_2 = 1$, $y_2 = 3$

$x_1 + x_2 = 1 \Rightarrow y_1 + y_2 = 5 \; (\neq 3)$

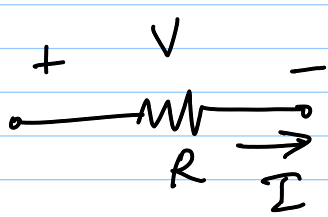
* Input $= 0 \Rightarrow$ Output $= 0$ is a necessary condition for linearity
* Impulse response $\Rightarrow$ defines LTI system

but – all practical systems are NON LINEAR

Linear elements : R, L, C

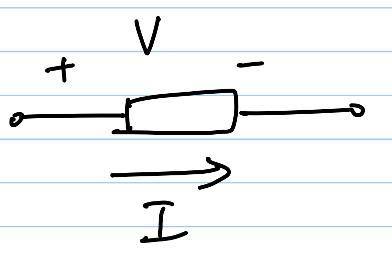
2-T element defined by V-I relationship

e.g.



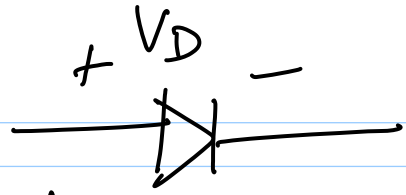
$$I = \frac{V}{R}$$

Similarly L, C $\rightarrow$ diff. / integral relationship (still linear)



$$I = f(V)$$

Diode



anode $\xrightarrow[I_D]{}$ cathode

from SSD theory, you can show that

$$I_D = I_s \left\{ \exp\left(\frac{V_D}{V_t}\right) - 1 \right\}$$

where I_s = saturation current

V_t = thermal voltage

$= \frac{kT}{q} \approx 25\text{ mV} @ RT$

$V_D > 0 \Rightarrow$ forward biased

$V_D < 0 \Rightarrow$ reverse biased

for $V_D >>$ few V_T,

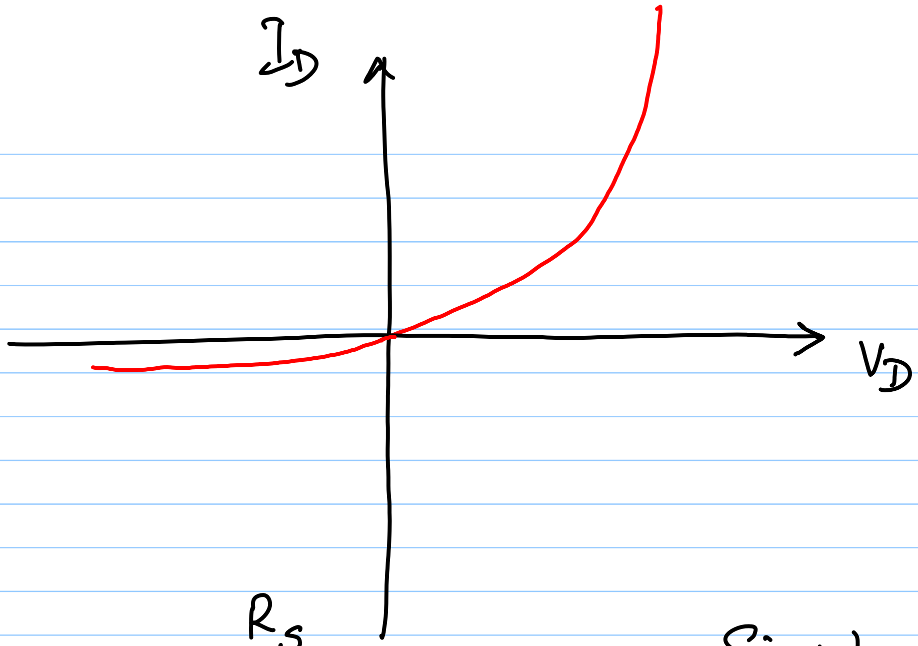
$$\exp\left(\frac{V_D}{V_t}\right) >> 1$$

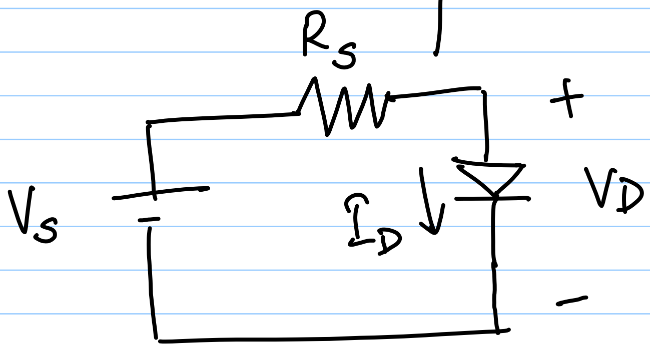
$$\Rightarrow I_D \approx I_s \exp\left(\frac{V_D}{V_t}\right)$$

$$\text{or} \quad V_D = V_T \ln\left(\frac{I_D}{I_s}\right)$$

for $\frac{V_D}{V_t} << 0$, $\exp\left(\frac{V_D}{V_t}\right) << 1$

$$\Rightarrow I_D \approx -I_s$$





Simple Nonlinear network

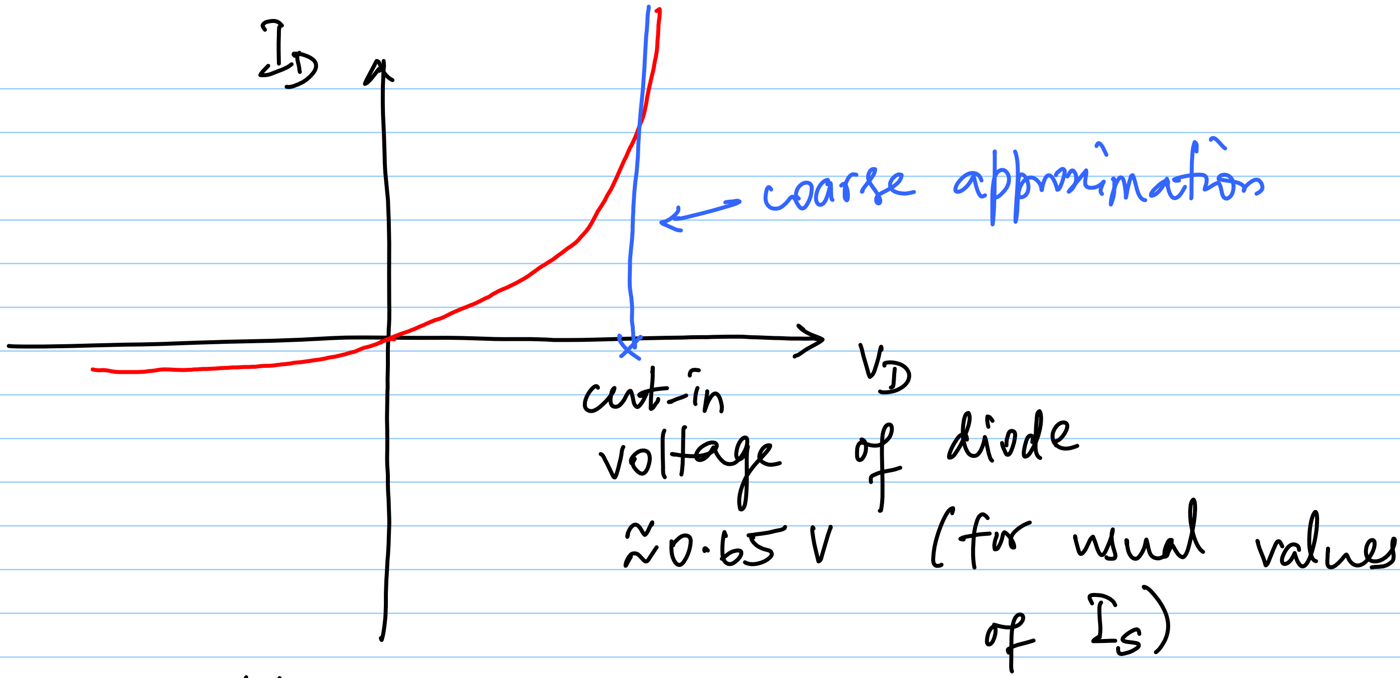
<u>KVL</u>

$$V_S = V_{R_S} + V_D$$
$$= I_D R_S + V_D$$
$$= I_D R_S + V_t \ln\left(1 + \frac{I_D}{I_S}\right)$$

to find out V_D, I_D

<u>several methods</u>

1) zeroth order method
   - use exponential characteristic to approximate V_D

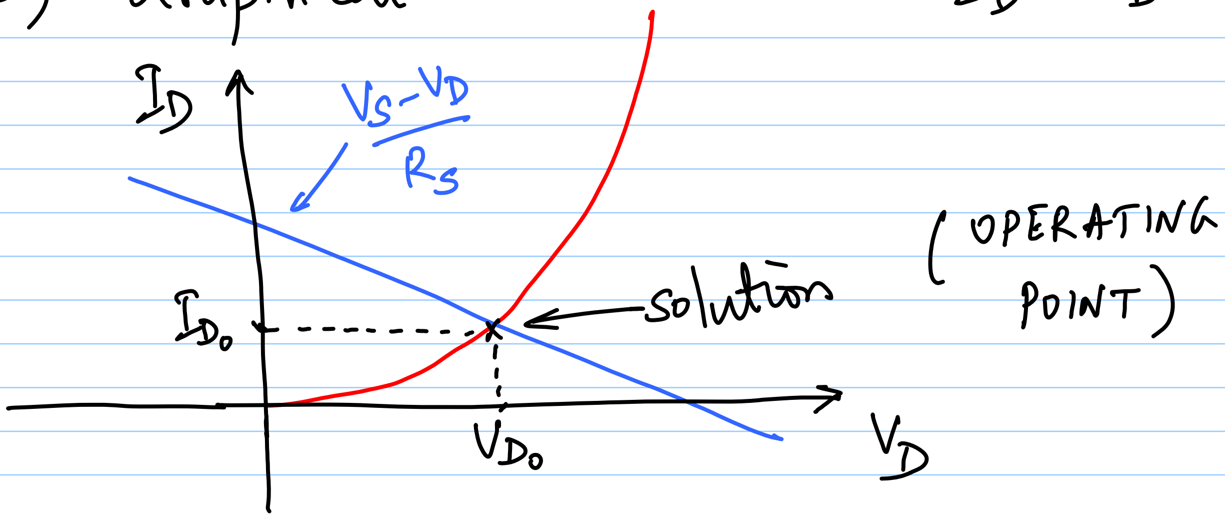


voltage drop across a fwd biased diode (V_D) $\approx$ 0.65 V

$$\Rightarrow \quad I_D \approx \frac{V_S - 0.65}{R_S}$$

2) Numerical solution (iteration)

3) Graphical solution on $I_D - V_D$ plot



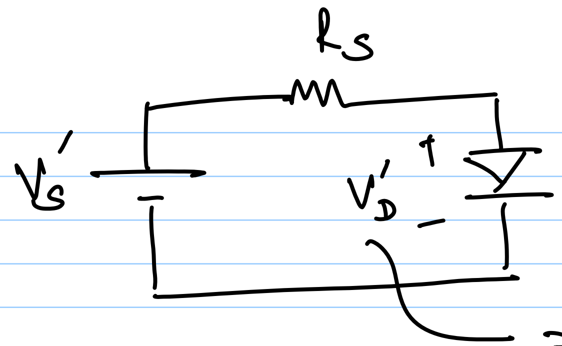
$$I_D = I_S \exp\left(\frac{V_D}{V_t}\right) \leftarrow \text{diode eq.}$$

$$I_D = \frac{V_S - V_D}{R_S} \leftarrow \text{KVL eq.}$$

solution is at intersection of the two curves.

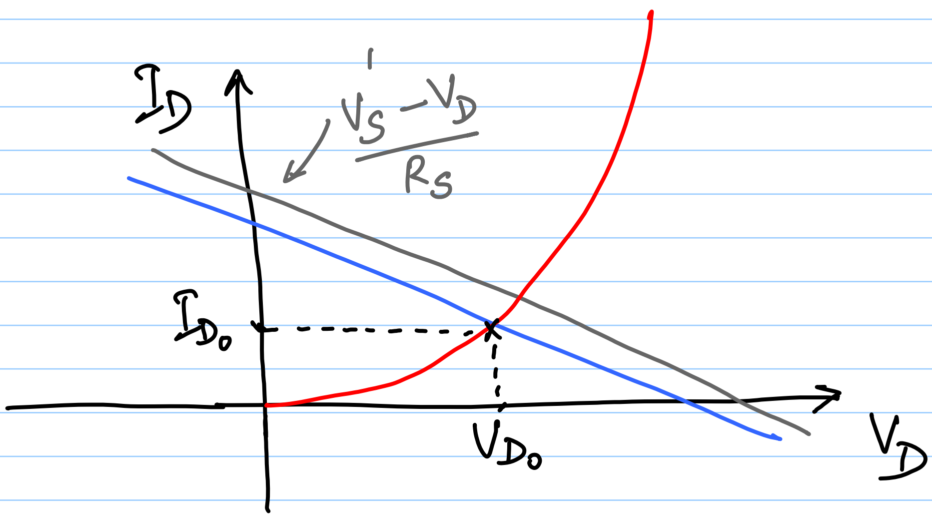
If V_S (or R_S) changes, can we find the new solution easily?

e.g. $V_S' = V_S + \Delta V_S$



$$\downarrow I_D' = I_{D0} + \Delta I_D$$

$$V_D' = V_{D0} + \Delta V_D$$



Orig. Sol. :

$$\frac{V_S - V_{D_0}}{R_S} = I_{D_0} = I_S\left\{\exp\left(\frac{V_{D_0}}{V_t}\right) - 1\right\}$$

$$\frac{V_S' - V_D'}{R_S} = I_D' = I_S\left\{\exp\left(\frac{V_D'}{V_t}\right) - 1\right\}$$

$$\frac{(V_S + \Delta V_S) - (V_{D_0} + \Delta V_D)}{R_S} = I_{D_0} + \Delta I_D$$

$$= I_S\left\{\exp\left(\frac{V_{D_0} + \Delta V_D}{V_t}\right) - 1\right\}$$

$$\frac{V_S - V_{D_0}}{R_S} + \frac{\Delta V_S - \Delta V_D}{R_S} = I_{D_0} + \Delta I_D$$

= Taylor series expansion of diode equation around V_{D_0}

for $Y = f(x)$ around x_0

$$Y = \sum_{n=0}^{\infty} \frac{f^{(n)}(x_0)}{n!} \cdot (x - x_0)^n$$

$$= \underbrace{f(x_0)}_{\text{operating point}} + f'(x_0) \cdot (x - x_0) + \frac{f''(x_0)}{2} \cdot (x - x_0)^2 + \cdots$$

$$I_S\left\{\exp\left(\frac{V_{Do}+\Delta V_D}{V_t}\right)-1\right\}$$

$$= I_S\left\{\exp\left(\frac{V_{Do}}{V_t}\right)-1\right\} + \frac{I_S}{V_t}\exp\left(\frac{V_{Do}}{V_t}\right)\cdot(\Delta V_D)$$

$$+ \ldots \rightarrow \Delta V_D^2, \Delta V_D^3 \text{ etc.}$$

* for "small" values of ΔV_D, you can neglect ΔV_D^2, ΔV_D^3 etc.

$$\frac{V_S - V_{Do}}{R_S} + \frac{\Delta V_S - \Delta V_D}{R_S} = I_{Do} + \Delta I_D$$

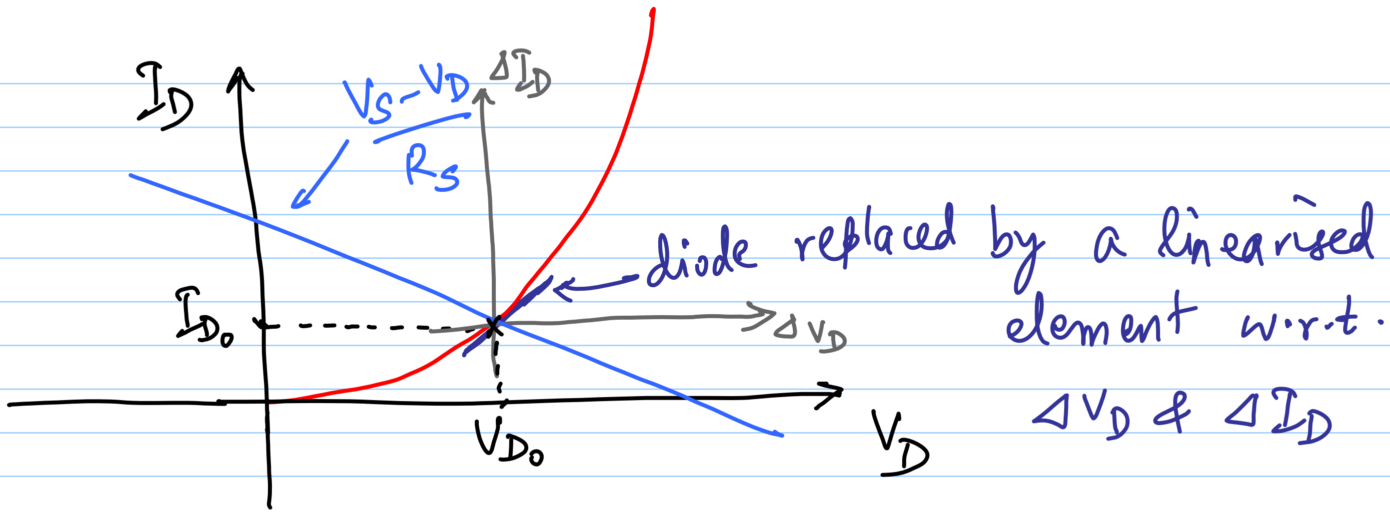
$$= I_S\left\{\exp\left(\frac{V_{Do}}{V_t}\right)-1\right\} + \frac{I_S}{V_t}\exp\left(\frac{V_{Do}}{V_t}\right)\cdot(\Delta V_D)$$

OP terms cancel out

$$\frac{\Delta V_S - \Delta V_D}{R_S} = \Delta I_D$$

$$= \frac{I_S}{V_t}\exp\left(\frac{V_{Do}}{V_t}\right)\cdot(\Delta V_D)$$

* Linear in incremental quantities ΔV_S, ΔV_D, ΔI_D



slope @ OP = conductance