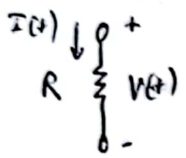
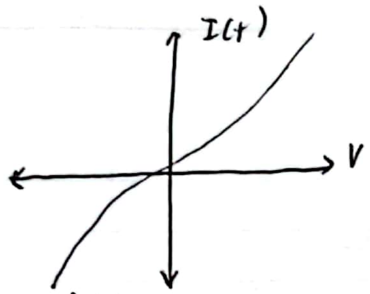
EE 536a 8/26/24 Notes

- Hashemi OH MW 9-10 am PHE 631
- Midterm is Oct. 28th
- Final is Dec 13th

Resistors





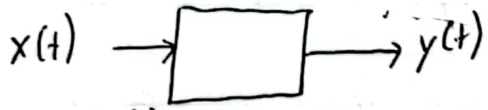
~~I(t) = f(V(t))~~

~~I(t) = f(V(t))~~ Any function can be a resistor!

$I(t) = f(V(t))$

- Linear Resistor $\Rightarrow f = \left(\frac{1}{R}\right) V(t)$

Linear System



1. $a x(t) \longrightarrow a y(t)$ Scaling Property
2. $\begin{cases} x_1(t) \longrightarrow y_1(t) \\ x_2(t) \longrightarrow y_2(t) \end{cases}$ Superposition Property

$\Downarrow$

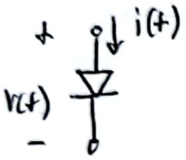
$x_1 + x_2 \longrightarrow y_1 + y_2$

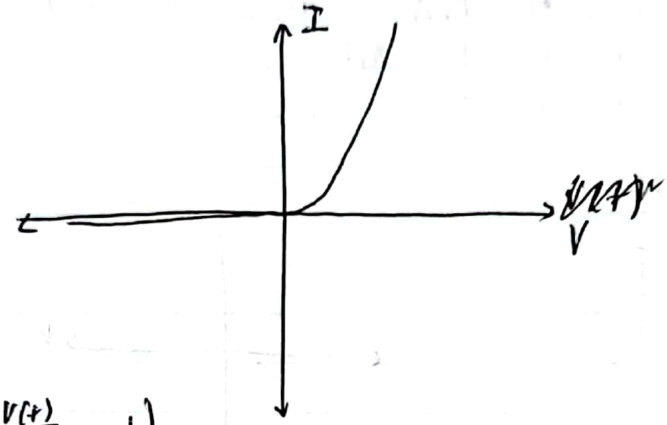
Example

$\begin{cases} x_1 \rightarrow 2x_1 + 1 \\ x_2 \rightarrow 2x_2 + 1 \end{cases}$ $x_1 + x_2 \rightarrow 2(x_1 + x_2) + 1$ ✗

Not linear!

Diode - nonlinear!



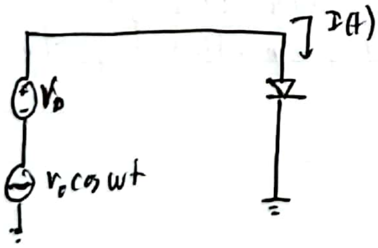


$$i(t) = I_s\left(e^{\frac{V(t)}{nV_T}} - 1\right)$$

$$V_T \doteq \frac{kT}{q} \approx 25.8\,mV \text{ @ room temp.}$$

K = boltsmann const.
T = absolute temp.
q = electron charge
n = non-ideality const. Ideally, $n=1$
I_s = saturation current (proportional to diode area)

-This class only deals with linear components.



$$I(t) = I_s\left[e^{\frac{V_0 + V_0\cos\omega t}{nV_T}} - 1\right]$$

$$= I_s e^{\frac{V_0}{nV_T}} e^{\frac{V_0}{nV_T}\cos\omega t} - I_s$$

Assumption

$\frac{V_0}{nV_T} << 1$ (factor of 10)

$$e^x = 1 + x + \frac{1}{2!}x^2 + \frac{1}{3!}x^3 \dots$$

if $x << 1 \Rightarrow e^x \approx 1 + x$

$$\frac{v_0}{nV_T} \ll 1$$

$$I(t) \approx I_s\left[e^{\frac{V_0}{nV_T}}\left(1+\frac{v_0}{nV_T}\cos w_0 t\right) - 1\right]$$

$$= \underbrace{I_s\left[e^{\frac{V_0}{nV_T}} - 1\right]}_{\substack{I_{DC} \\ = I(v_0 \cos wt)=0}} + \underbrace{\underbrace{\left(\frac{I_s e^{\frac{V_0}{nV_T}}}{nV_T}\right)}_{\substack{g_m \\ \text{transconductance} \\ = \text{linear!}}}(v_0 \cos w_0 t)}_{\text{AC component}}$$

This process of linearizing a non-linear function is referred to small signal analysis assuming the input is very small.

$$x \longrightarrow \boxed{f(\cdot)} \longrightarrow y$$

$$x = x_0 + \Delta x \,, \quad \Delta x \ll x_0$$

$$f(x) = f(x_0 + \Delta x)$$
$$= f(x_0) + f'(x)\big|_{x=x_0}\Delta x + \frac{1}{2!} f''(x)\big|_{x=x_0}(\Delta x)^2 \approx f(x_0) + f'(x)\big|_{x=x_0}$$

if Δx = small.

Taylor Series Expansion

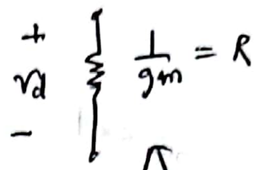
$$\underbrace{V_D}_{DC} + \underbrace{v_d}_{\substack{AC \\ \text{small-signal}}} = V_D$$

$$I_D \approx \underbrace{I_s\left(e^{\frac{V_{DO}}{nV_T}} - 1\right)}_{f(x_0)} + \frac{dI_D}{dV_D}\bigg|_{V_{DO}} v_d$$

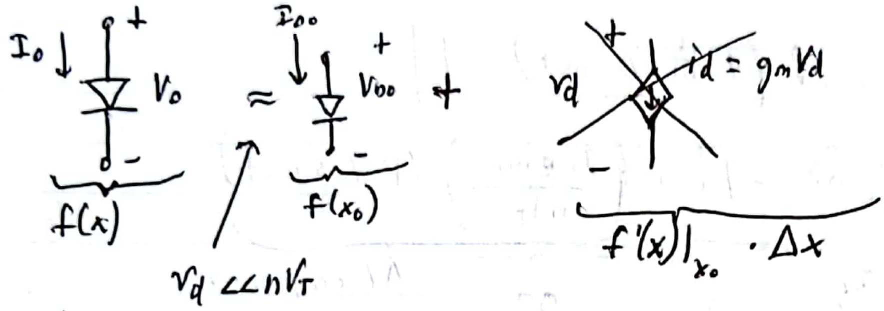
$$\frac{dI_D}{dV_D}\bigg|_{V_{DO}} = \frac{I_s}{nV_T} e^{\frac{V_D}{nV_T}}\bigg|_{V_{DO}} = \frac{I_s}{nV_T} e^{\frac{V_{DO}}{nV_T}}$$

simplified linearized diode eq.

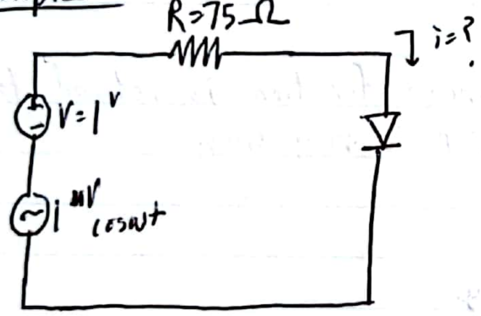
$$\approx \frac{I_s\left(e^{\frac{V_{DO}}{nV_T}} - 1\right)}{nV_T} = \frac{I_{DO}}{nV_T} \triangleq g_m$$



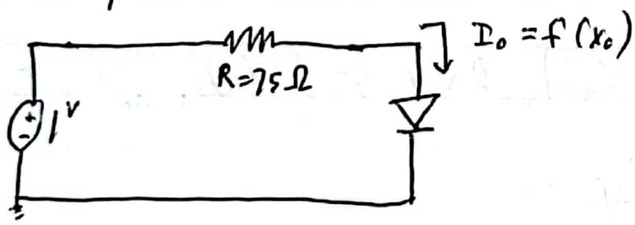
diode resistor model in small-signal!



Example



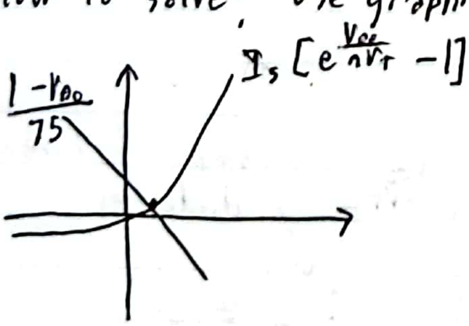
1. Solve DC problem - assume AC = 0



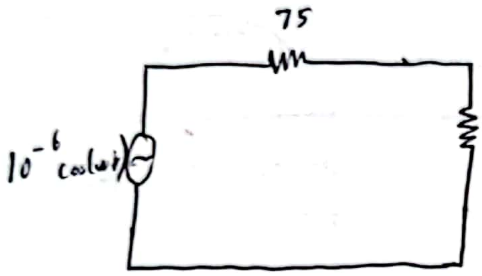
for DC, have to solve nonlinear eq.!

$$\begin{cases} I_{Do} = I_s\left[e^{\frac{V_{Do}}{nV_T}} - 1\right] \\ I_{Do} = \dfrac{1^V - V_{Do}}{75} \end{cases} \longrightarrow \begin{cases} \boxed{I_{Do} = 3mA} \\ V_{Do} = 0.7V \end{cases} \text{ (Approx)}$$

How to solve? Use graphical methods!



2. AC analysis



$\frac{1}{g_m} = \frac{1}{120\,mA/V} \approx 8\,\Omega$

$$g_m = \frac{I_{DQ}}{nV_T} = \frac{3mA}{25mV} = 120\,mA/V$$

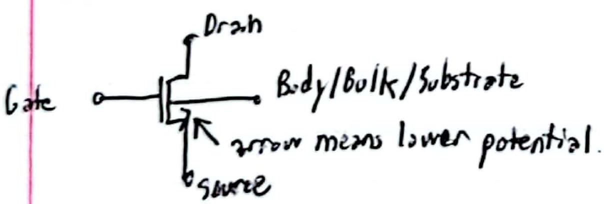
$V_T = 25mV$

$n = 1$

$$\boxed{i_d = \frac{10^{-6}\cos(\omega t)}{75+8}}$$

$$\boxed{I_D = I_{DQ} + i_d}$$

Transistor

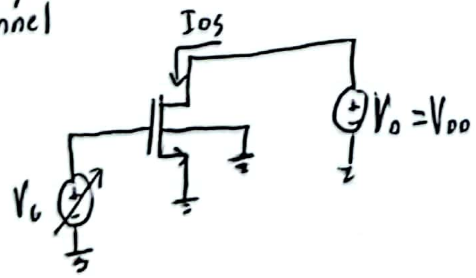


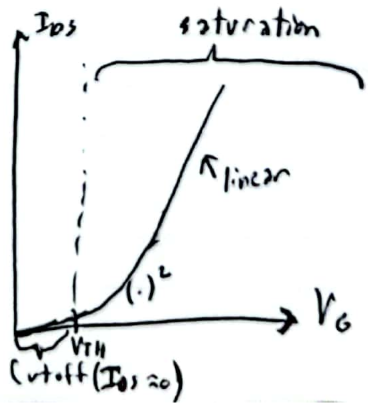
$I_{DS} = f[V_D, V_S, V_G, V_B]$

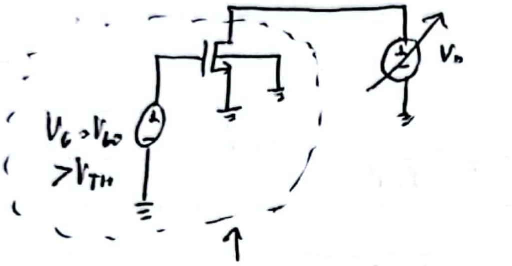
NFET

n-type Field Effect Transistor

channel







initially looks like a resistor.