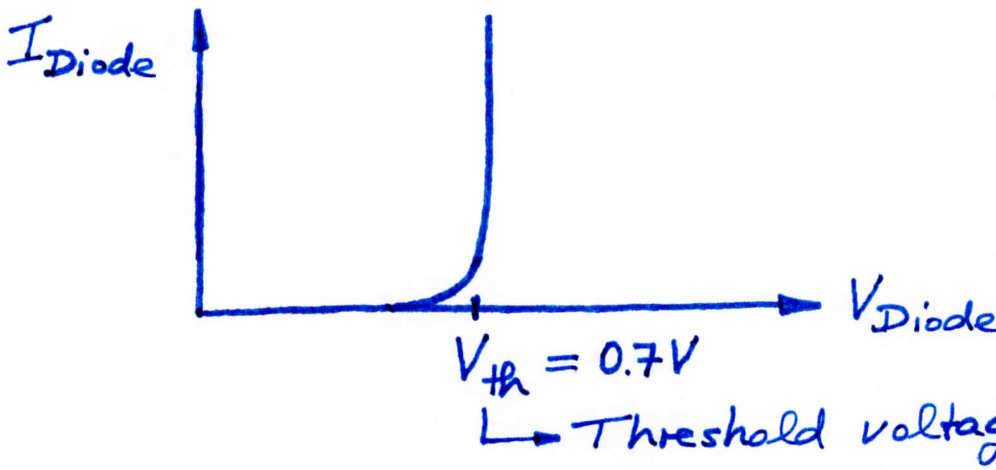
Small signal equivalent circuit of diode

Recall:

$$I = I_o\left(e^{V/V_t} - 1\right)$$

$$\approx I_o\, e^{V/V_t} \qquad \text{(forward bias)}$$

... Shockley diode equation



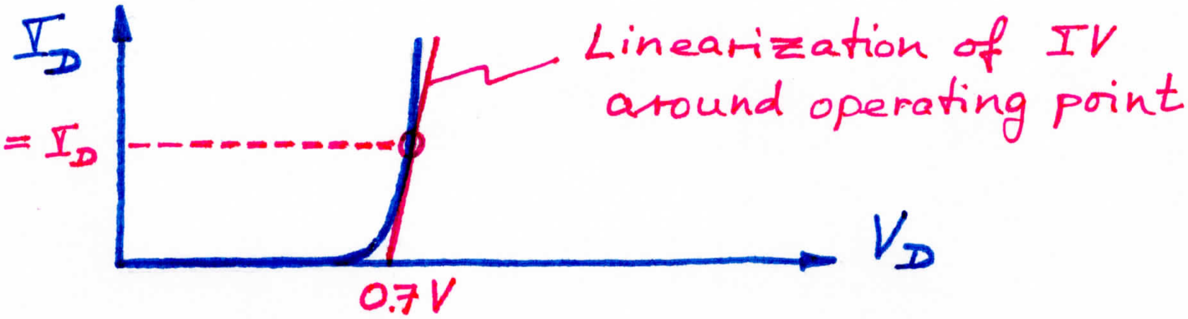
Recall:

$$r_{Diode} = r_D = \frac{V_t}{I_{Diode}}$$

V_t — Thermal voltage 26 mV

I_{Diode} — DC operating point (Quiescent point) (Q-point)

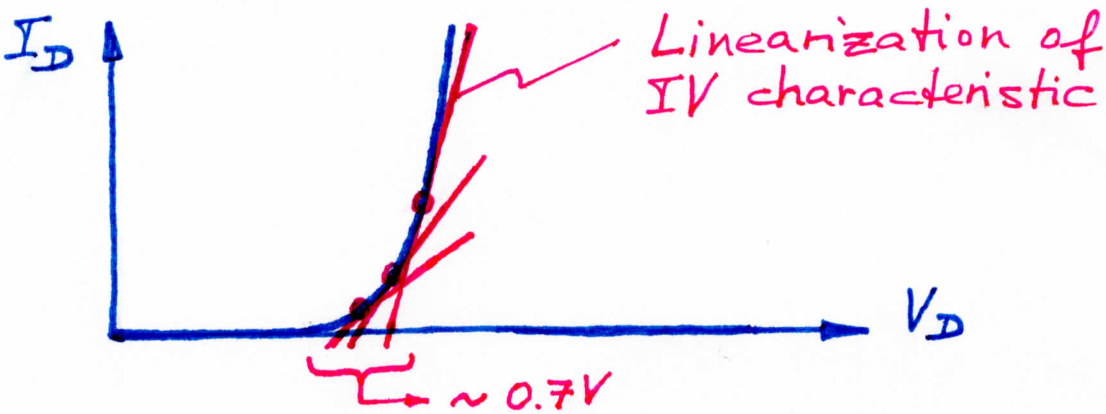
Linearization of IV characteristic



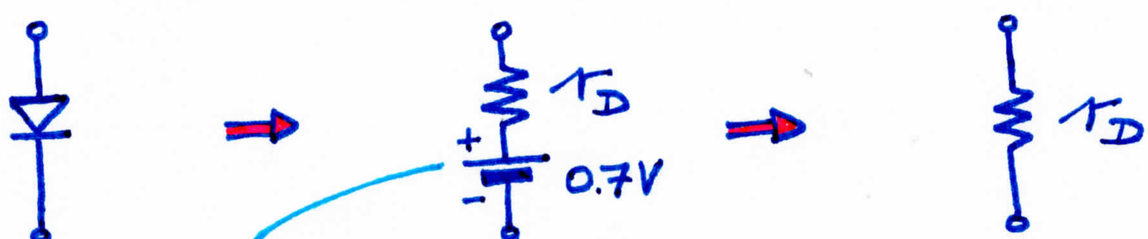
$$\Rightarrow r_D = \frac{V_t}{I_D} = \frac{26\,mV}{100\,mA} = \underline{\underline{0.26\,\Omega}}$$

↳ Low resistance due to forward bias

Examples of linearization



Equivalent circuit of linear IV line ?



Ideal voltage source
⇒ Will not incur voltage drop
⇒ $V = 0.7V = \text{constant}$

AC equivalent circuit of diode

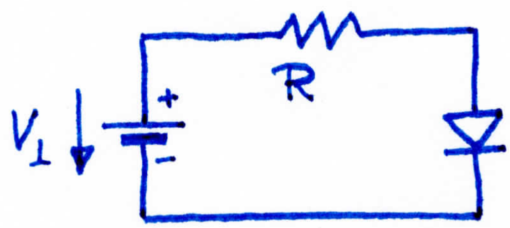
$$r_D = \frac{dV_D}{dI_D}$$

What is advantage of linearization?

⇒ We now have a linear circuit

⇒ We now can use the superposition theorem

Example



$V_1 = 5V$

$R = 1k\Omega$

Determine the DC operating point

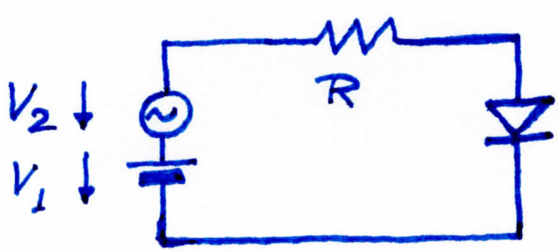
⇒ KVL $\quad V_1 = IR + V_{Diode}$

$$\Rightarrow I = \frac{V_1 - V_{Diode}}{R} = \frac{5V - 0.7V}{1k\Omega} = \frac{4.3V}{1k\Omega}$$

$$= 4.3\,mA$$

$$\Rightarrow r_D = \frac{V_t}{I} = \frac{26\,mV}{4.3\,mA} = 6.05\,\Omega$$

Let us add a small AC signal

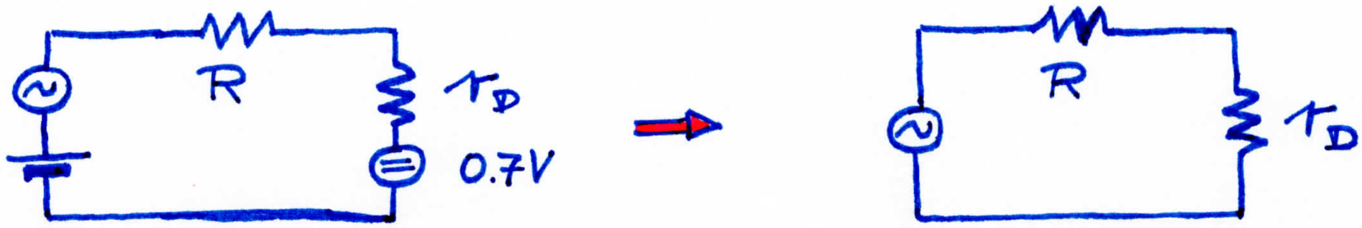


$V_1 = 5V$ (DC)

$V_2 = 10\,mV$ (AC)

$R = 100\Omega$

Linearization of circuit



Superposition principle: We can separately consider the effect of each source

Also recall: Resistance of ideal voltage source is zero. ⇒ No additional voltage drop across sources.

$$\Rightarrow \quad I_{DC} = \frac{5V - 0.7V}{100\Omega} = \frac{4.3V}{100\Omega} = 43\ mA$$

$$r_D = V_t / I = 26\ mV / 43\ mA = 0.6\Omega$$

⇒ AC voltage drop across diode

$$V_{AC,\,Diode} = \frac{r_D}{R + r_D} V_{AC} \quad \text{(Voltage divider)}$$

$$= \frac{0.6\Omega}{100\Omega + 0.6\Omega}\ 10\,mV = \underline{\underline{0.06\ mV}}$$

Summary: Train of thought

We have a non-linear circuit (e.g. diode circuit)

↓

We wish to linearize the circuit (Why?)

↓

We need to identify the point around which the circuit is linearized (⇒ DC operating point ⇒ Quiescent point ⇒ Q-point)

↓

We determine the differential properties (e.g. differential resistance) of components (e.g. diode) at the Q-point

DC analysis

↓

We can now calculate the effect of a small-signal AC input voltage (Why small signal? Why AC?)

AC analysis