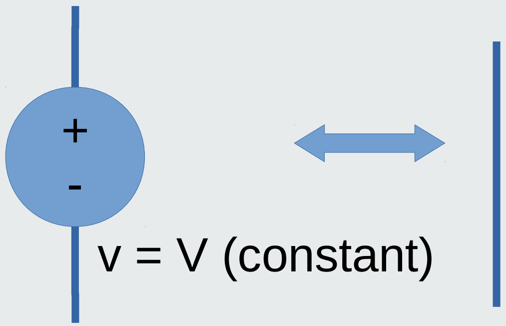
TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

Lecture 13: Diode circuit properties

- Incremental model of independent and dependent sources
- Incremental impedance of passive components
- Diodes in series
- Diodes in parallel
- Temperature effect
- Optical transmitter/receiver system

Incremental model of independent sources

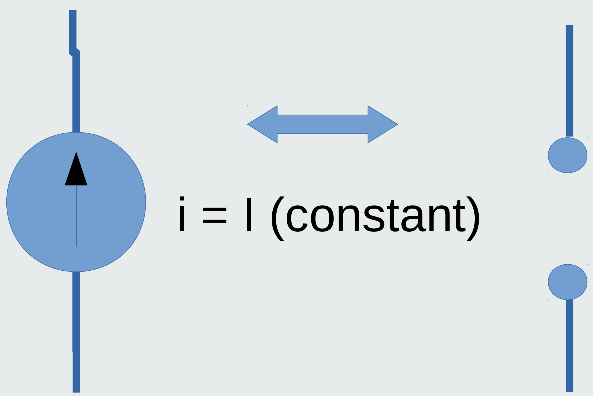


$$V = constant$$

$$dv = 0$$

$$r_v = \frac{dv}{di} = 0$$

An independent voltage source is a short-circuit in incremental terms!



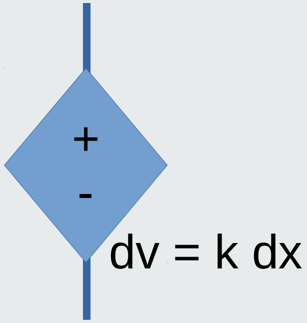
$$i = constant$$

$$di = 0$$

$$g_i = \frac{di}{dv} = 0 \Rightarrow r_i = \frac{1}{g_i} = \infty$$

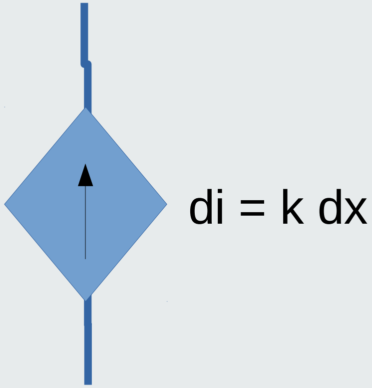
An independent current source is an open-circuit in incremental terms!

Incremental model of dependent sources



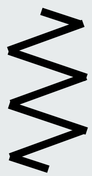
$$v = kx$$
$$dv = k\,dx$$

Dependent sources remain dependent sources in incremental terms!

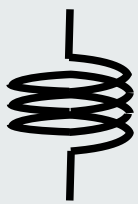


$$i = kx$$
$$di = k\,dx$$

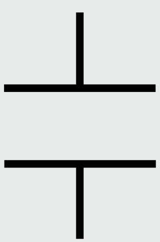
Incremental model of linear passive components



$$v = Ri$$
$$dv = R\,di$$



$$\phi = Li$$
$$d\,\phi = L\,di$$



$$q = C\,v$$
$$dq = C\,dv$$

Passive linear components unchanged in incremental terms!

Diodes in series

$$i = I_S\left(e^{\frac{v}{\eta V_T}} - 1\right)$$

Diode equation

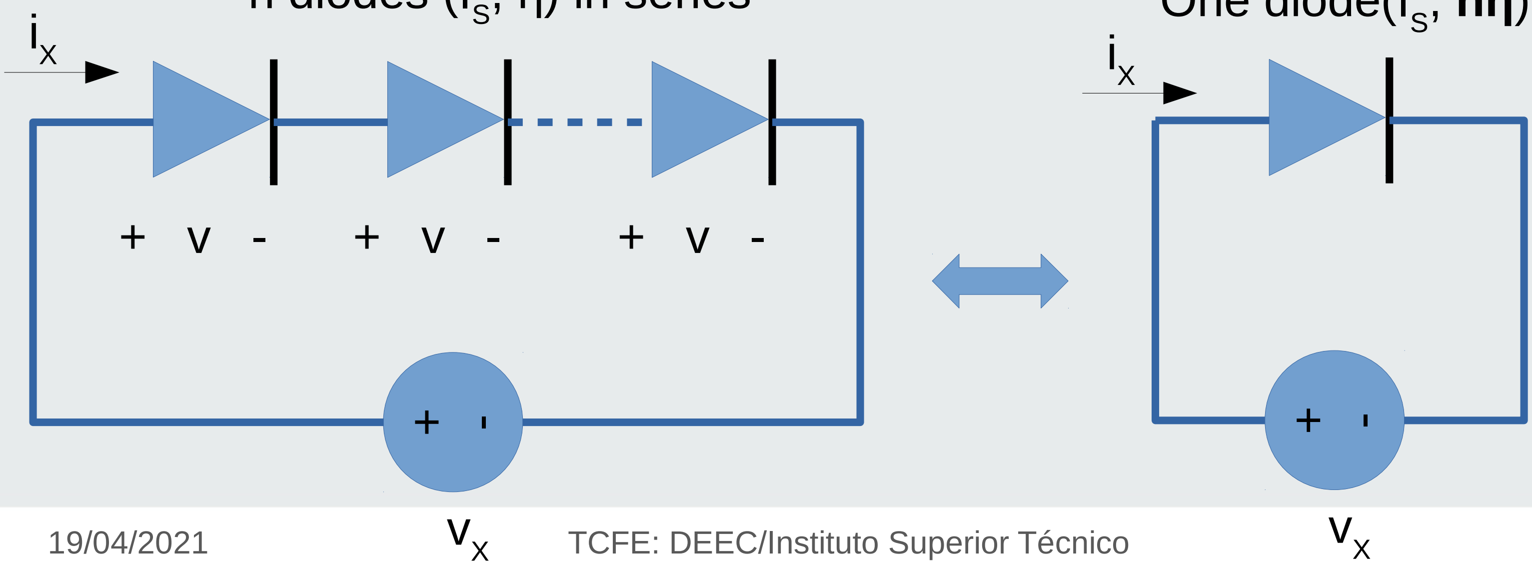
$$v = \frac{v_X}{n}$$

All diodes have same voltage because all have same current

$$i_X = I_S\left(e^{\frac{v_X}{n\eta V_T}} - 1\right)$$

n diodes (I_S, η) in series

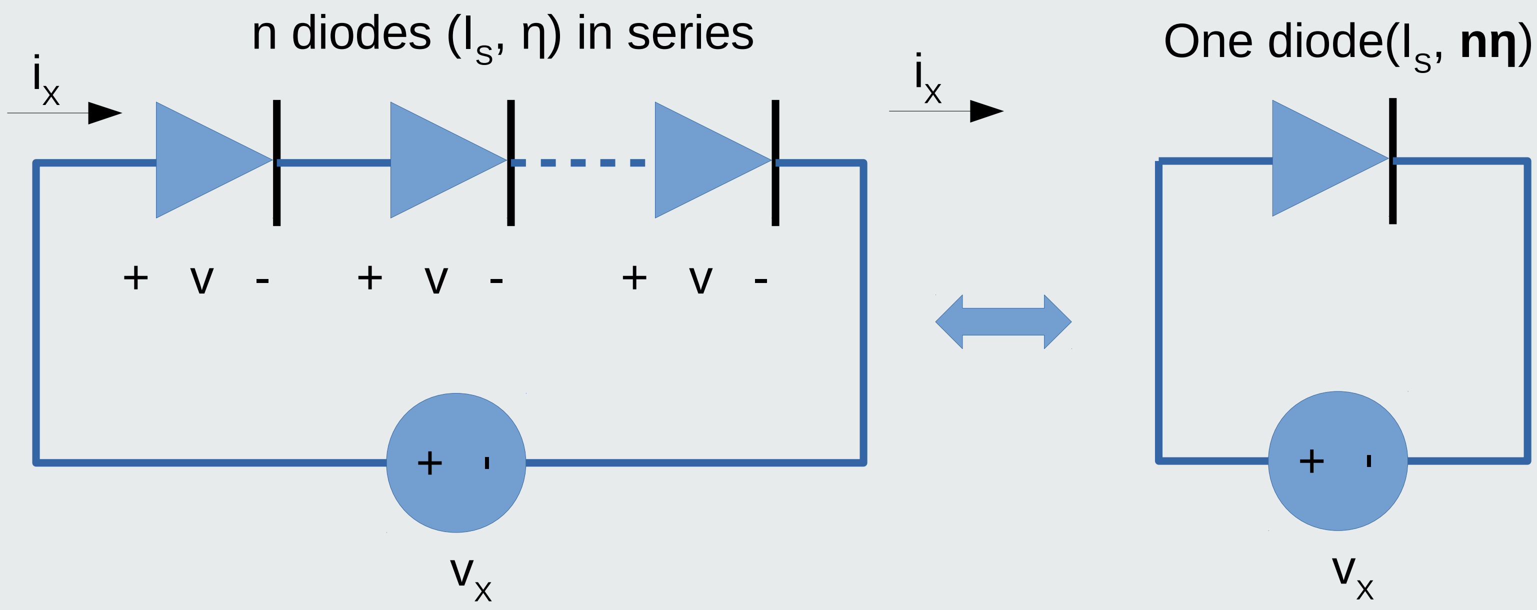
One diode(I_S, **nη**)



Diodes in series: incremental resistance

$$r_x = \frac{\eta_X V_T}{I_S e^{\frac{V_X}{\eta_X V_T}}} = \frac{n\,\eta V_T}{I_S e^{\frac{n V_D}{n\,\eta V_T}}} = n\frac{\eta V_T}{I_S e^{\frac{V_D}{\eta V_T}}} = n\,r_d$$

Series of incremental resistances!



Diodes in parallel

$$i = I_S\left(e^{\frac{v}{\eta V_T}} - 1\right)$$

Diode equation

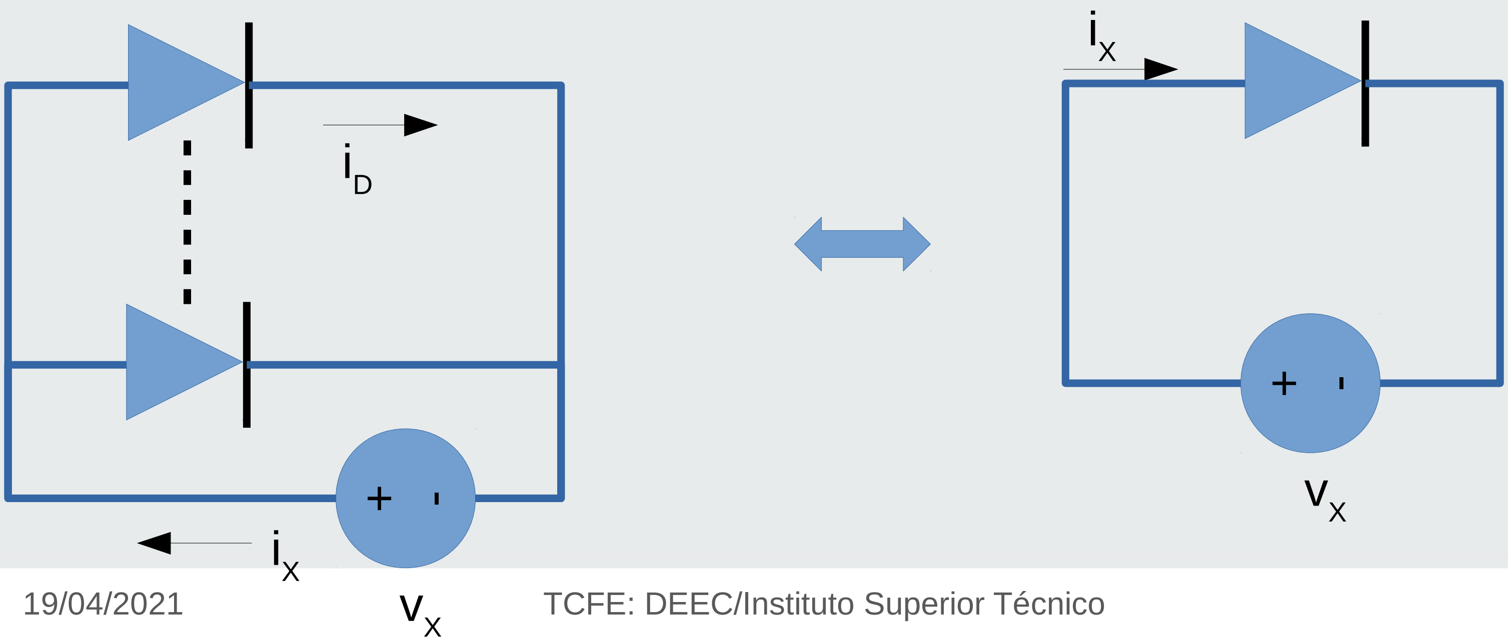
$$i_X = n\, i$$

$$i_X = n\, I_S\left(e^{\frac{v_X}{\eta V_T}} - 1\right)$$

All diodes have same current because all have same voltage

n diodes (I_S, η) in parallel

One diode(**nI_S**, η)



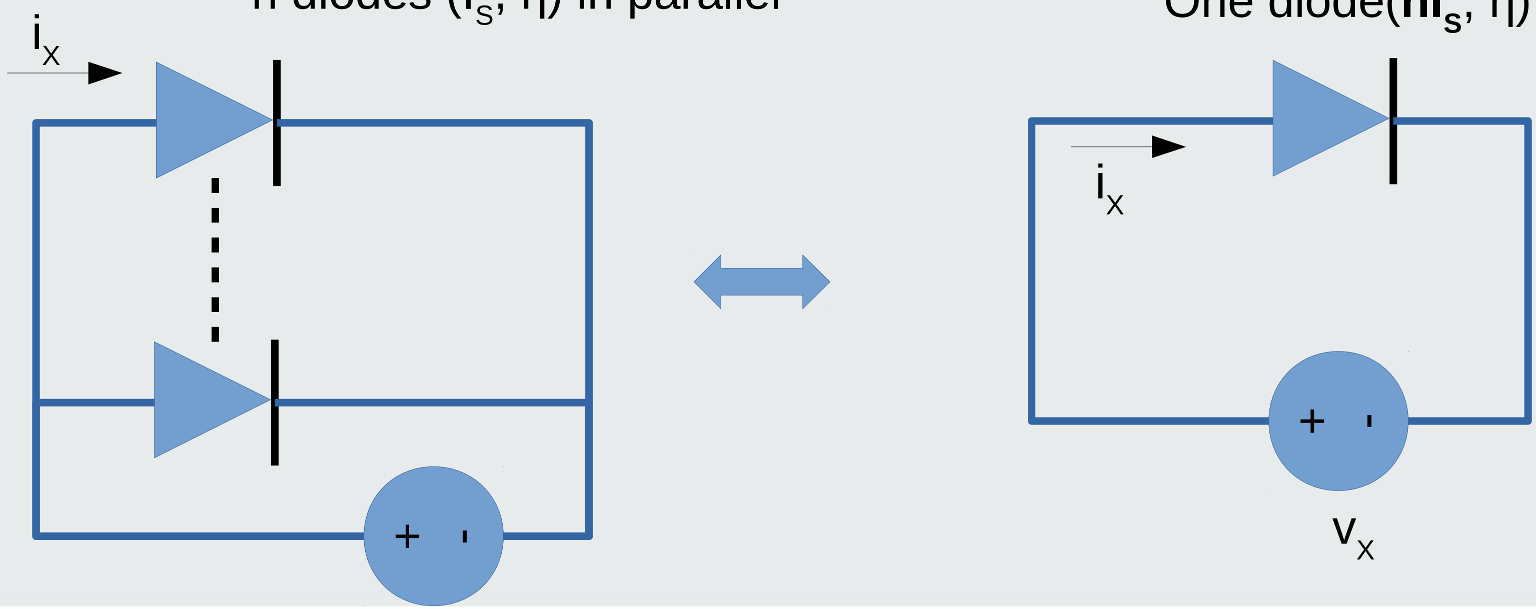
Diodes in parallel: incremental resistance

$$r_x = \frac{\eta_X V_T}{I_{SX}\, e^{\frac{V_X}{\eta_X V_T}}} = \frac{\eta V_T}{n\, I_S\, e^{\frac{V_D}{\eta V_T}}} = \frac{r_d}{n}$$

Parallel of incremental resistances!

n diodes (I_s, η) in parallel

One diode(**nI_s**, η)



Temperature effect

$$i_D = I_S\left(e^{\frac{v_D}{\eta V_T}} - 1\right)$$

$$V_T = \frac{kT}{q}$$ V_T increase lowers current

$$I_S = q\,S\,n_i^2\left(\frac{1}{N_D}\sqrt{\frac{D_p}{\tau_p}} + \frac{1}{N_A}\sqrt{\frac{D_n}{\tau_n}}\right)$$

$$I_S \propto 2^{\frac{T}{10}}$$ Each 10ºC doubles the current I_S

Stronger effect than decrease due to V_T

- The diode equation suggests the current decreases exponentially with the temperature
- But I_S is a complex function of the temperature…
  - Quantum mechanics
  - Statistical mechanics

<u>Conclusion: diode current increases with T</u>

N_D: Donor (impurity that **D**onates electrons) concentration in n-side

N_A: Acceptor (impurity that **A**ccept electrons) concentration in p-side

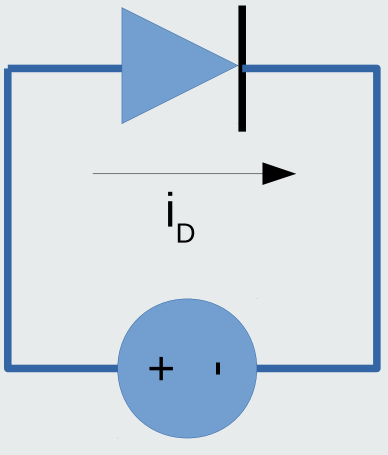
S: Junction cross-sectional area

D_p:, D_n: Diffusion coefficients for holes and electrons – T dependent

τ_p, τ_n: Lifetime for holes and electrons – also T dependent

Temperature risk

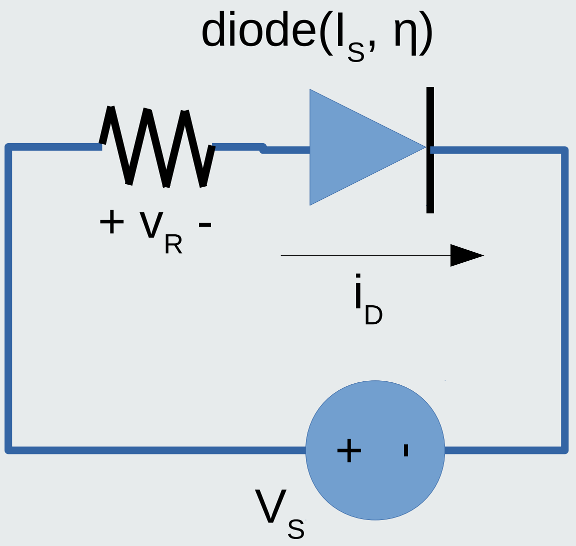
- Temperature increases I_s
- I_S increases i_D
- Excess current can heat up and burn material
- Protect your material!



Diode protection resistor from temperature effect

- Temperature increases i_D
- i_D increases v_R
- v_R decreases v_D:
  $v_R + v_D = v_S$ (constant, KVL)
- v_D decreases i_D
- This is called a negative feedback loop

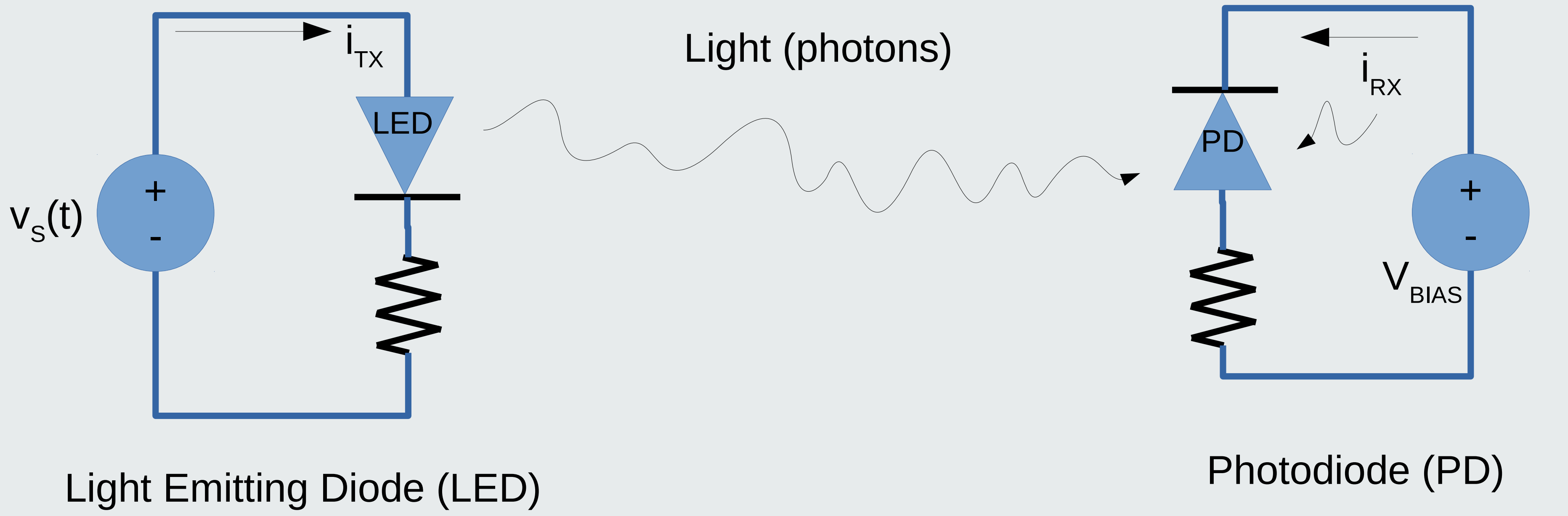
- Resistor stabilizes i_D and protects diode!!



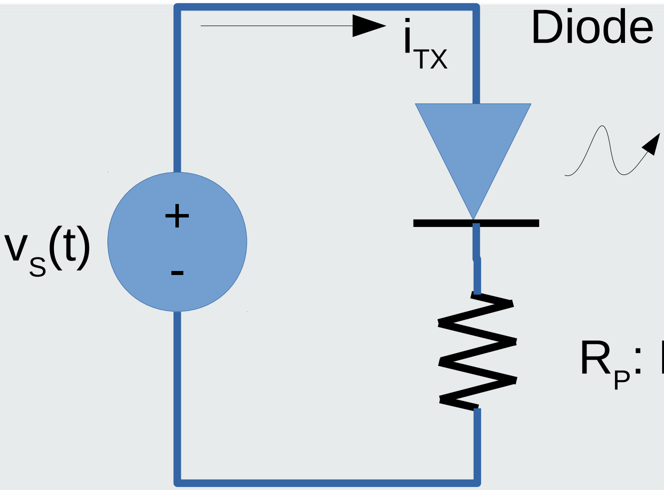
$$i_D = I_S\left(e^{\frac{v_D}{\eta V_T}} - 1\right)$$

$$v_R = R\, i_D$$

Optical Transmitter / Receiver System



Light Emitting Diode (LED) Transmitter



Diode idealised model (V_{ON},R_{ON})

Light (photons)
Light intensity (W/m²) proportional to current

R_P: Protection resistor

$$i_{TX}(t)=\frac{v_S(t)-V_{ON}}{R+R_{ON}}$$

Total current

$$l_I(t)=K_{TX}i_{TX}(t)$$

Light intensity

$$I_{TX}=\frac{V_S-V_{ON}}{R+R_{ON}}$$

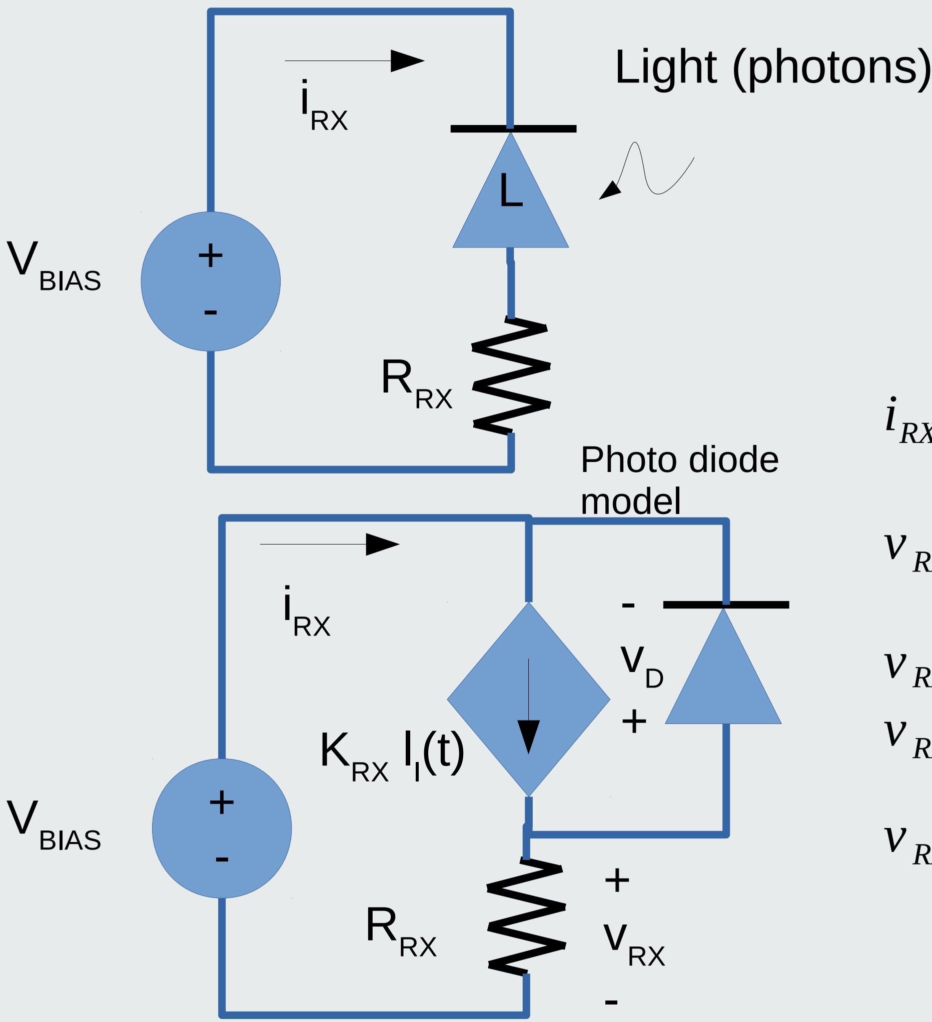
Operating point DC current

$$L_I=K_{TX}I_{TX}$$

Applications

- Signalling, e.g. ON/OFF light
- Character displays
- Infrared light for remote controls
- Etc

Photo Diode (PD) Receiver



$$i_{RX} = K_{RX}\, l_I(t) - I_S\left(e^{\frac{v_D}{\eta V_T}} - 1\right)$$

$$v_{RX} = R_{RX}\, i_{RX}$$

$$i_{RX}(t) = K_{RX}\, l_I(t) - I_S\left(e^{\frac{v_D}{\eta V_T}} - 1\right)$$

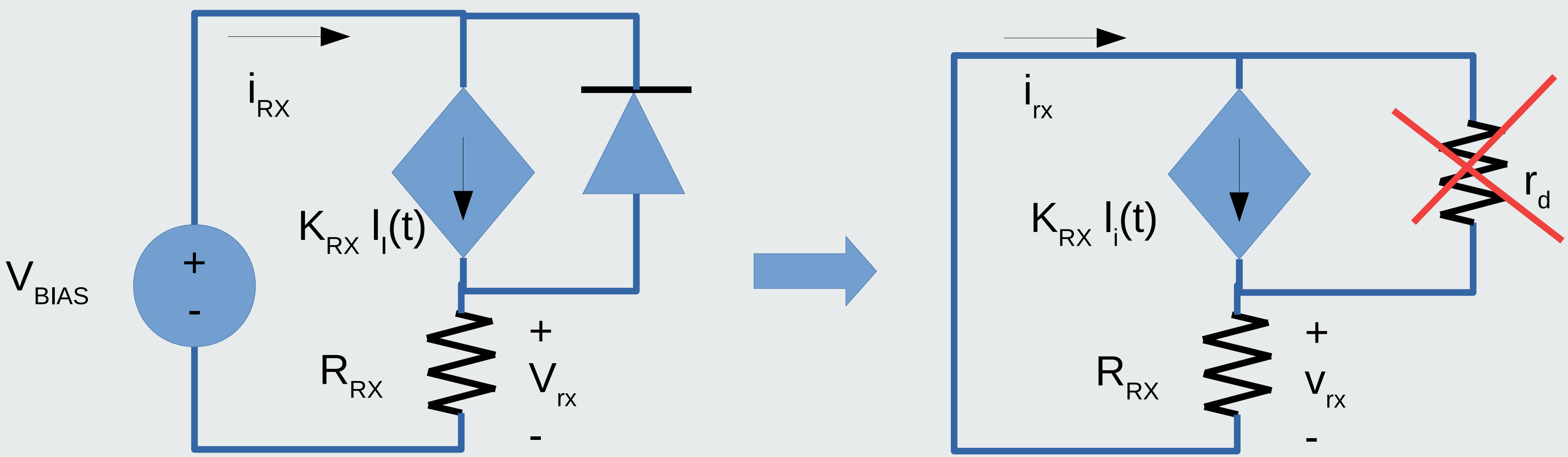
$$v_{RX}(t) = R_{RX}\, i_{RX}(t)$$

$$v_{RX}(t) = R_{RX} K_{RX}\, l_I(t) - R_{RX} I_S\left(\cancel{e^{\frac{v_{RX} - V_{BIAS}}{\eta V_T}}} - 1\right)$$

$$v_{RX}(t) = R_{RX} K_{RX} K_{TX}\, i_{TX}(t) + R_{RX} I_S$$

$$v_{RX}(t) = R_{RX} K_{RX} K_{TX} \frac{v_S(t) - V_{ON}}{R_{TX} + R_{ON}} + R_{RX} I_S$$

Receiver Incremental Model



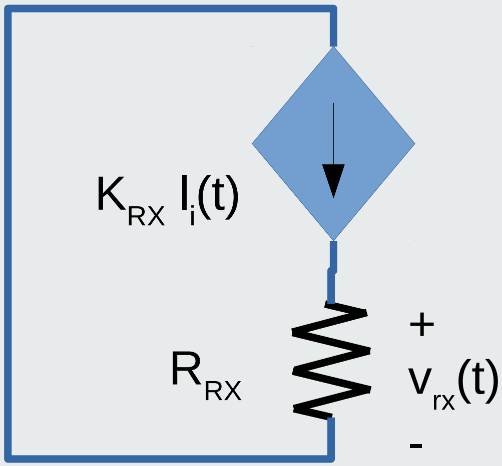
$$g_d = \frac{di_D}{dv_D} \approx 0 \Rightarrow r_d \approx \infty$$

V_{BIAS} is replaced with short circuit

Diode reversely biased has large incremental resistor r_d

Resistor r_d in parallel with R_{RX} can be neglected

Photo Diode Received Signal



$$v_{rx}(t)=R_{RX}\,K_{RX}\,l_i(t)$$

$$v_{rx}(t)=\frac{R_{RX}\,K_{RX}\,K_{TX}}{R_{TX}+R_{ON}}\,v_s(t)$$

$$l_i(t)=l_I(t)-L_I$$

$$l_I(t)=K_{TX}\,i_{TX}(t)$$

$$l_I(t)=K_{TX}\frac{v_S(t)-V_{ON}}{R_{TX}+R_{ON}}$$

$$v_S(t)=V_S+v_s(t)$$

$$L_I=K_{TX}\frac{V_S-V_{ON}}{R+R_{ON}}$$

$$l_i(t)=\frac{K_{TX}}{R_{TX}+R_{ON}}\,v_s(t)$$

Conclusion

- Incremental model of independent and dependent sources
- Incremental impedance of linear passive components
- Diodes in series
- Diodes in parallel
- Temperature effect
- Optical transmitter/receiver system