Section 22
PN Diode Large Signal Response

22.2 Turn-off and Turn-on characteristics

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PURDUE UNIVERSITY

School of Electrical and Computer Engineering

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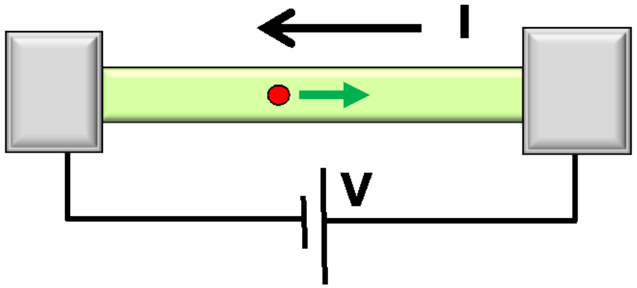
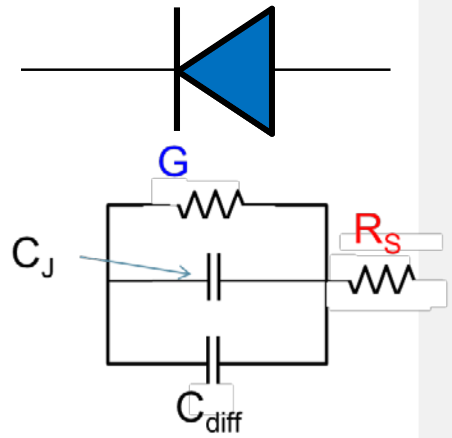
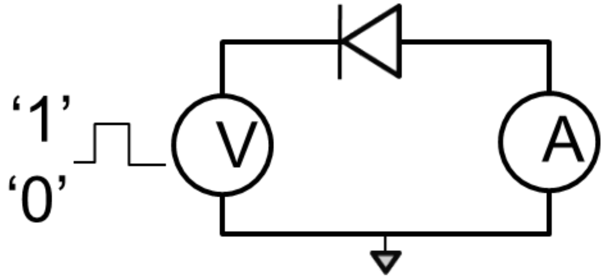


$I = G \times V$

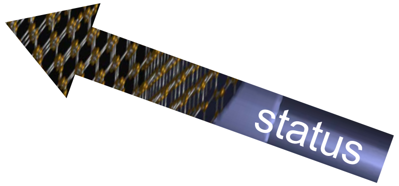
$= q \times n \times v \times A$

charge density velocity area

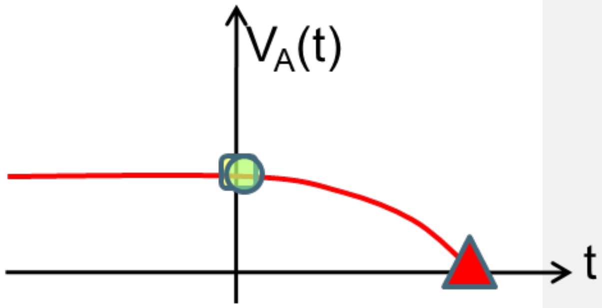


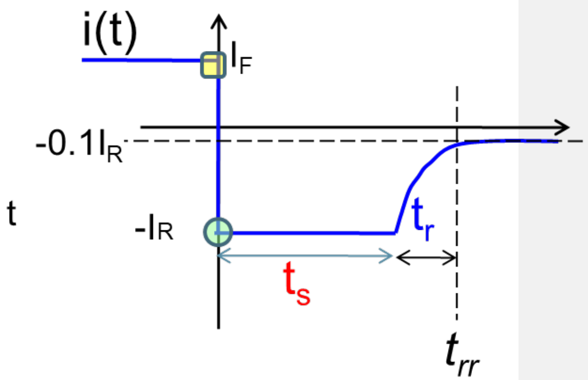


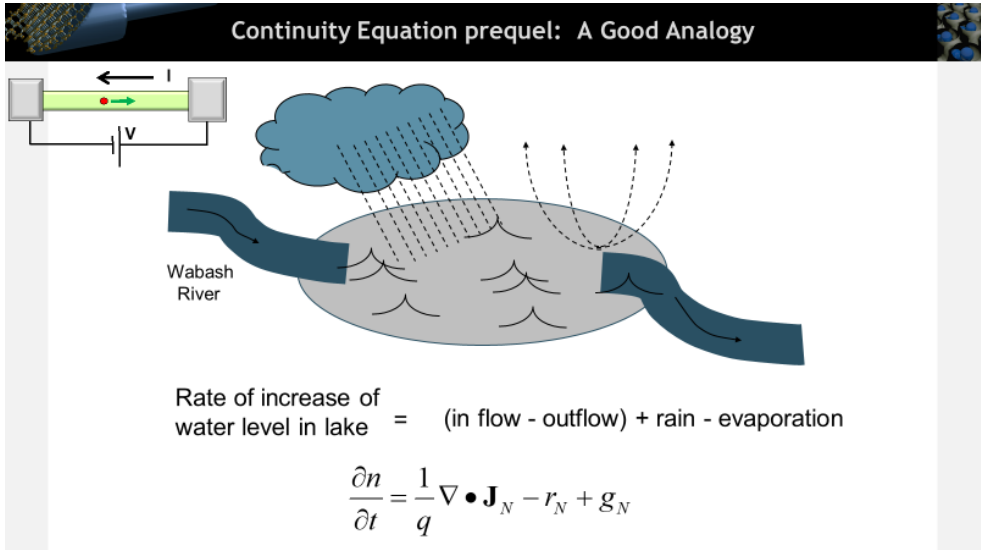
- 22.1 Charge control model
- 22.2 Turn-off and Turn-on characteristics
- 22.3



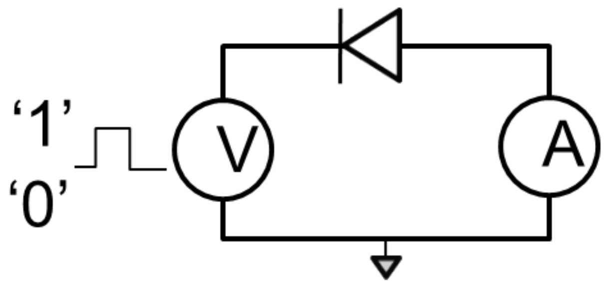
$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

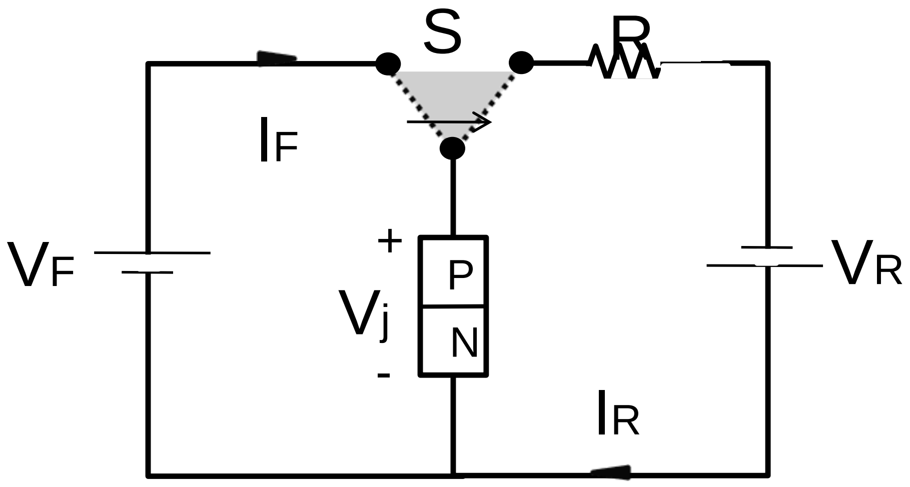


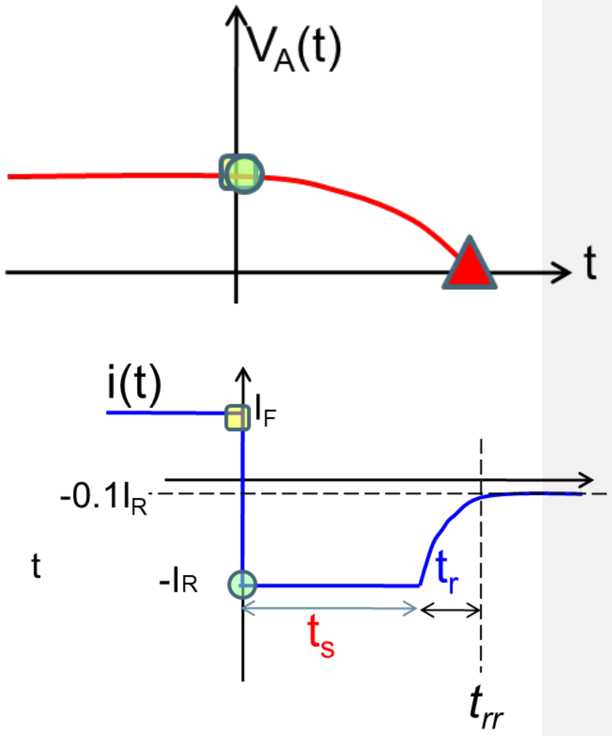




Turn-off Characteristics: Determine (t_s)



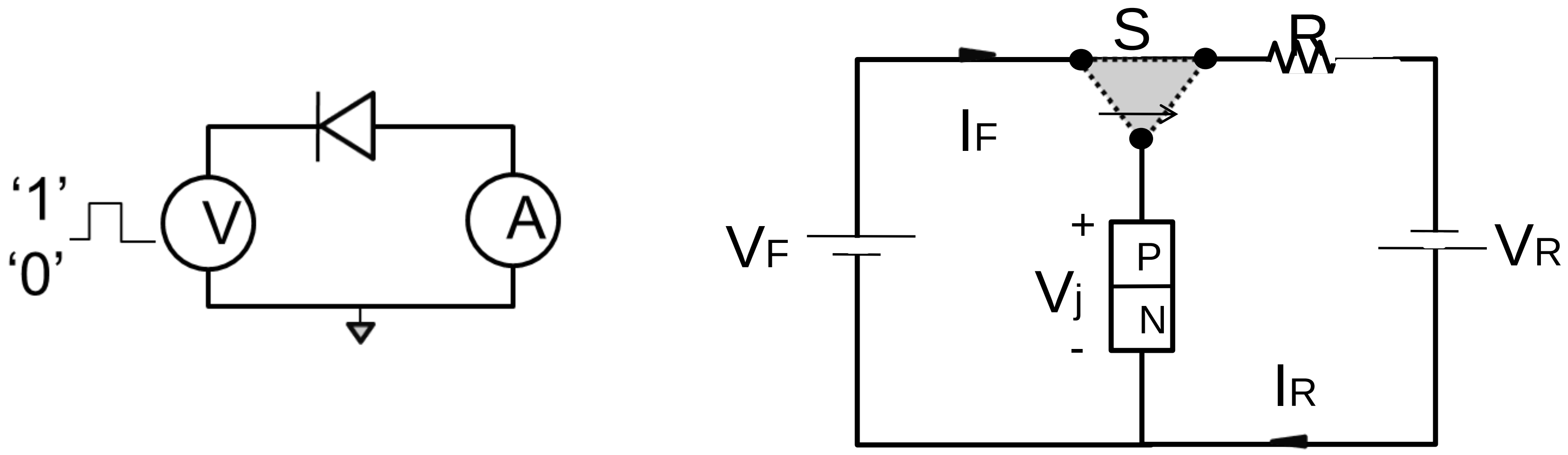




$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

Why does the voltage remain constant even for t>0?

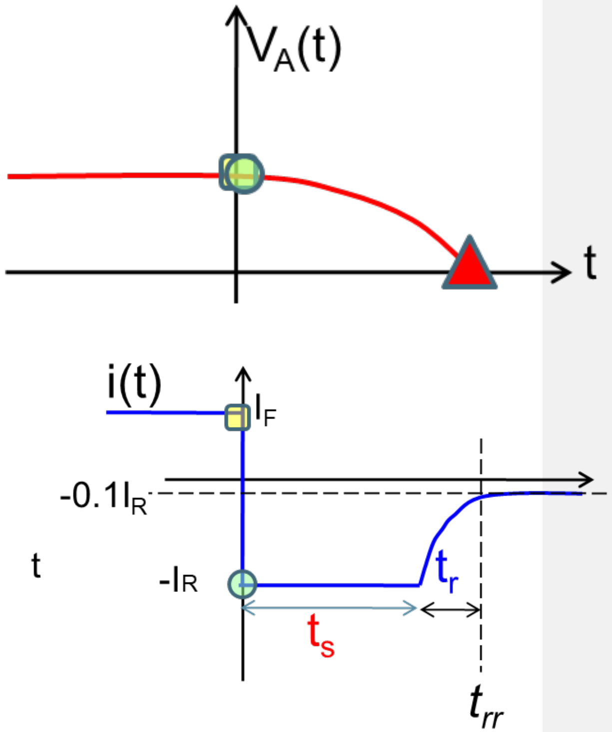
Boundary Condition



$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

$$t < 0 \quad \frac{\partial Q}{\partial t} = I_F - \frac{Q(0^-)}{\tau_n} = 0$$

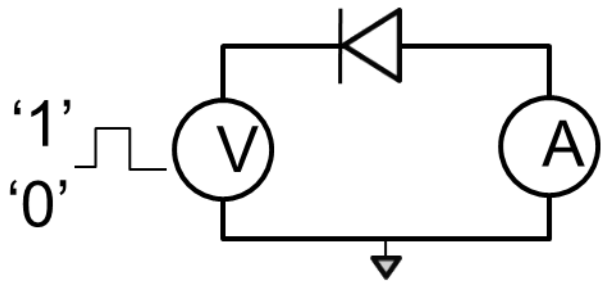
$$Q(0^-) = I_F \tau_n = Q(0^+)$$

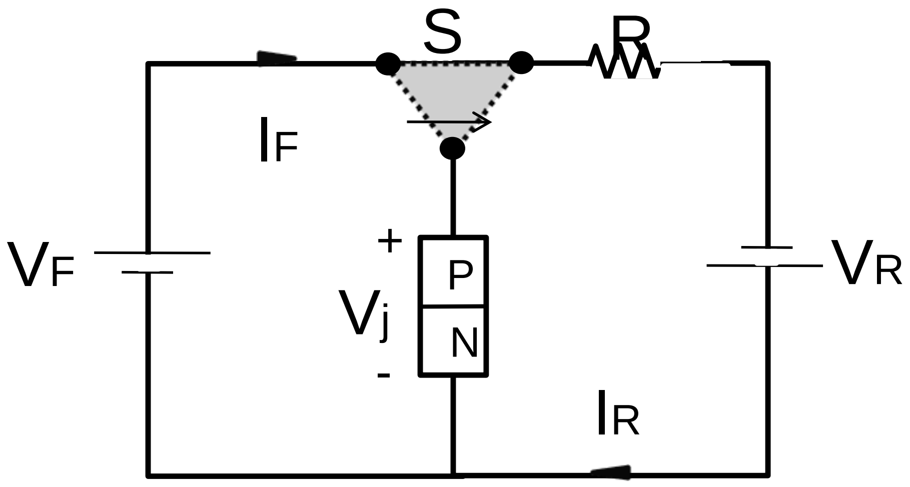


For a capacitor, voltage can not change instantly.
So charge can not change instantly ....

Why does the voltage remain constant even for t>0?

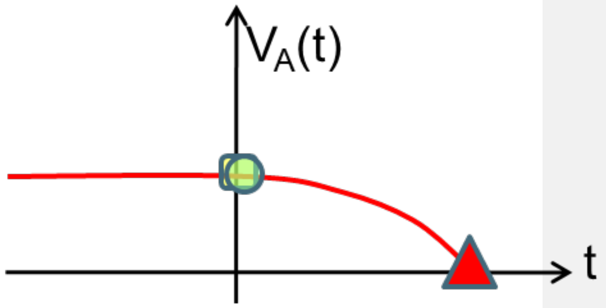
Turn-off *Current* Transient

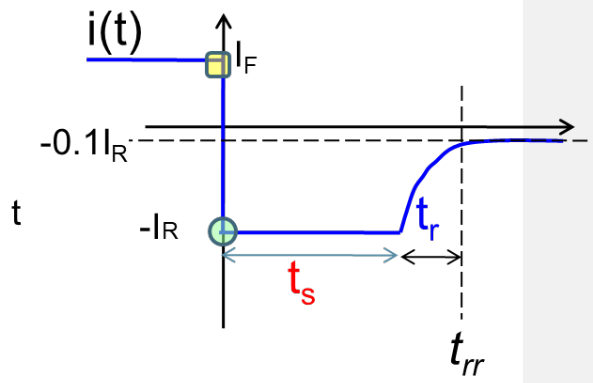




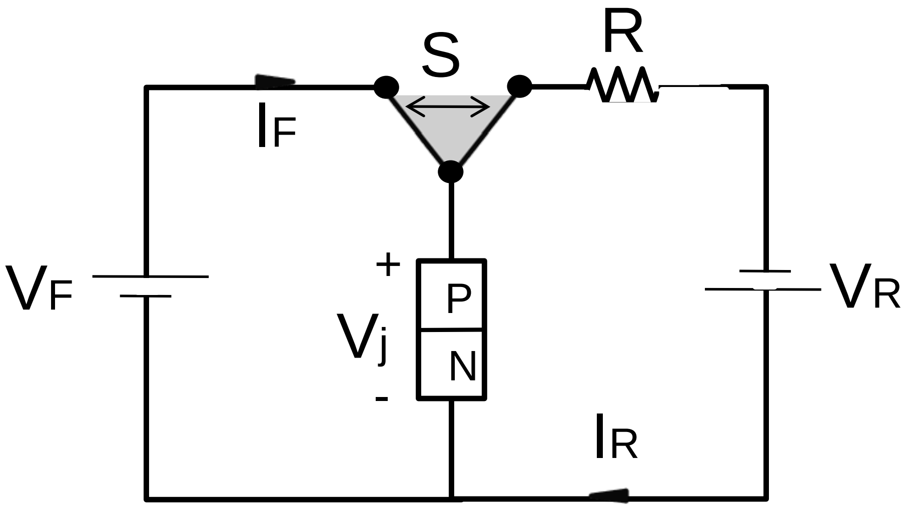
$$Q(0^-) = I_F \tau_n = Q(0^+)$$

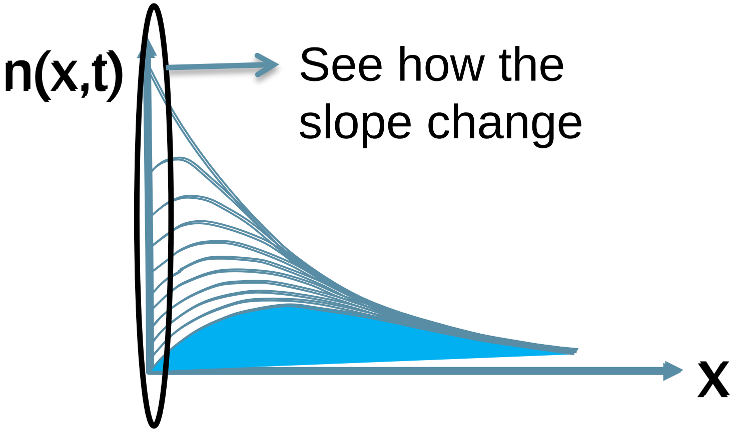
$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$





Why does the voltage remain constant even for t>0?





Approximately constant!

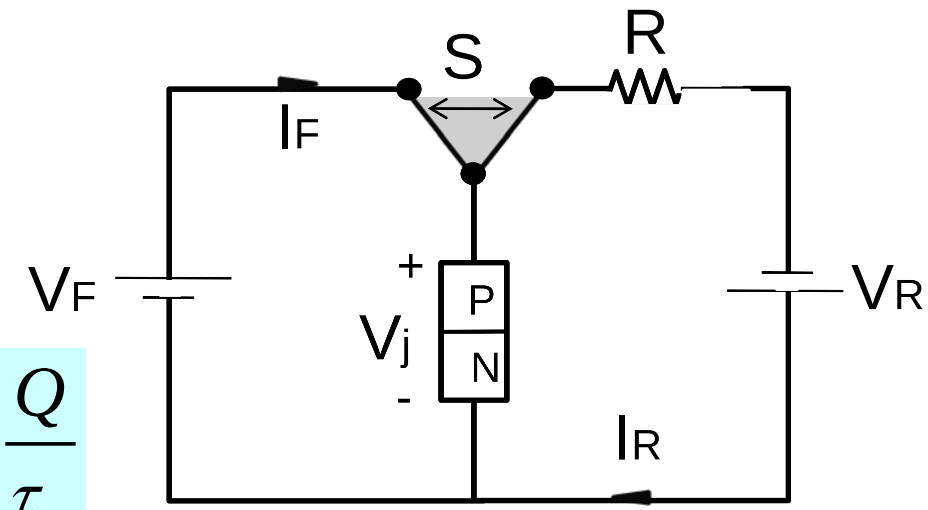
$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

$$t > 0 \quad \frac{\partial Q}{\partial t} = -I_R - \frac{Q}{\tau_n}$$

$$\int_{Q(0+)}^{Q(t_s)} \frac{dQ}{-\left(I_R + \frac{Q}{\tau_n}\right)} = \int_0^{t_s} dt$$

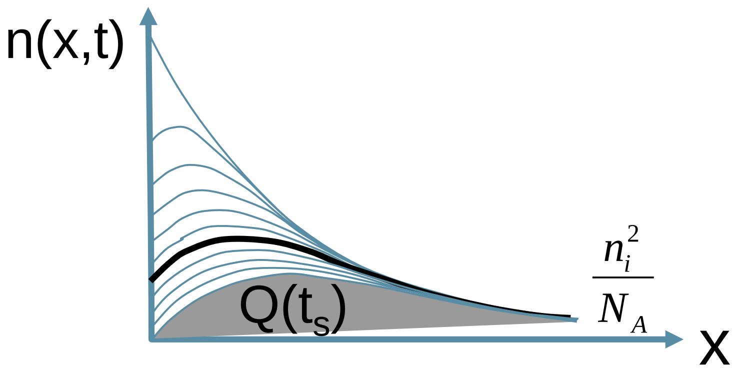
$$t_s = \tau_n \ln \frac{I_R + Q(0^+)/\tau_n}{I_R + Q(t_s)/\tau_n}$$

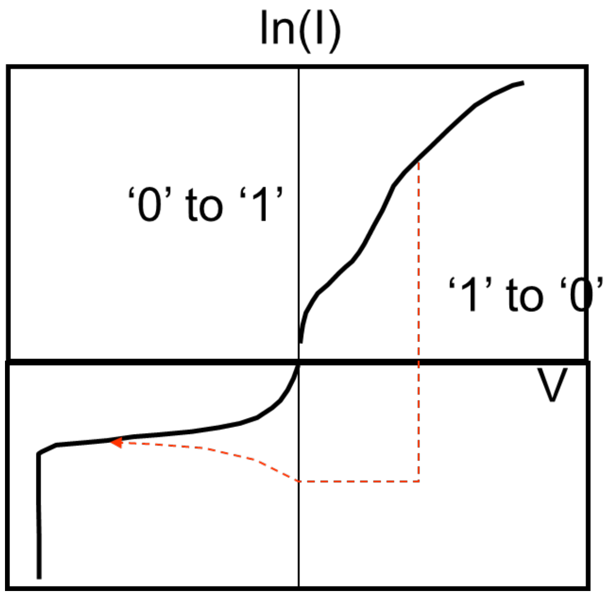
Storage Time



$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

$$t_s = \tau_n \ln \frac{I_R + Q(0^+)/\tau_n}{I_R + \cancel{Q(t_s)}/\tau_n} \qquad t_s = \tau_n \ln \frac{I_R + I_F}{I_R}$$

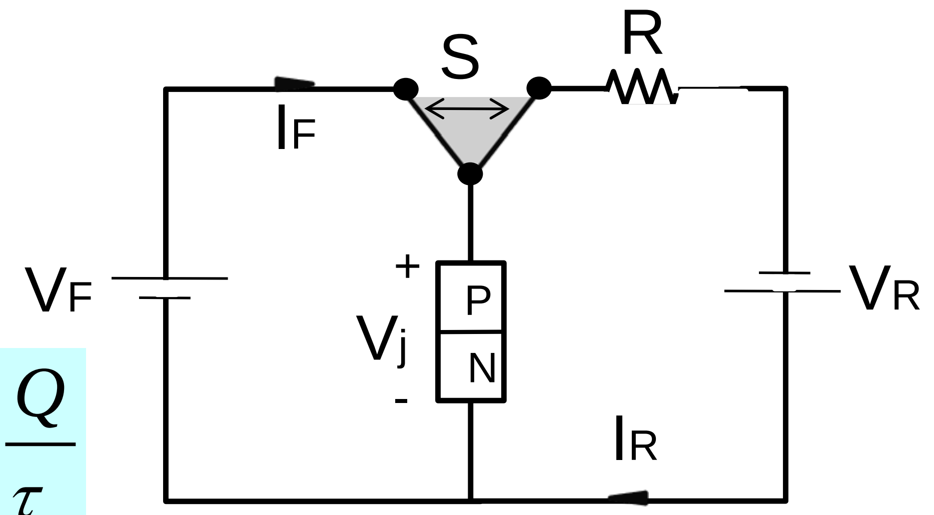




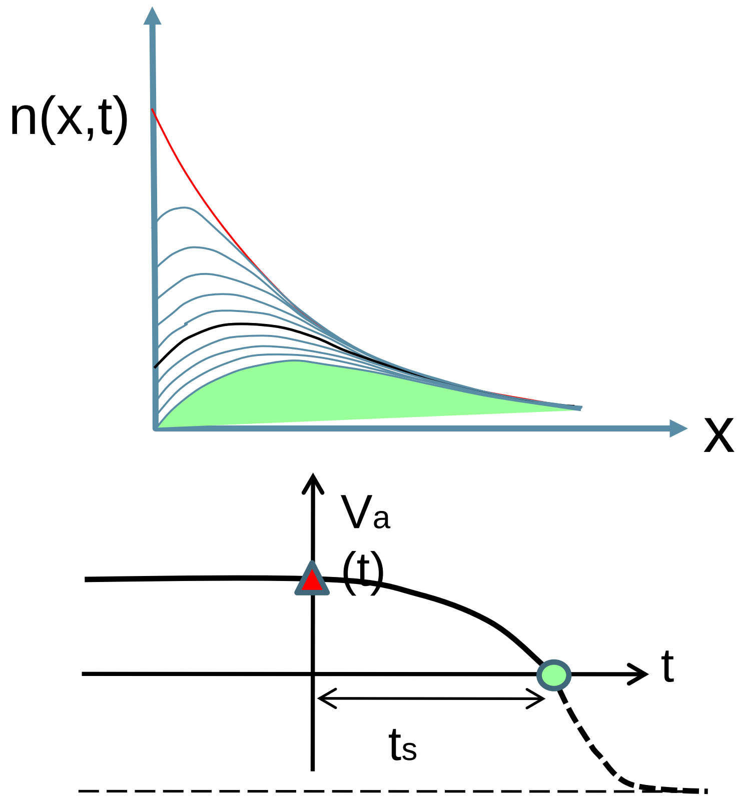
Want fast switching?

Shorten τ for fast response!
=> scattering can be good!

Turn-off *Voltage* Transient



$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$



$$Q_n(t) = \tau_p \ln\left(-I_R + (I_R + I_F)e^{-t/\tau_p}\right)$$

Allows easy calculation of $n_p(0,t)$.

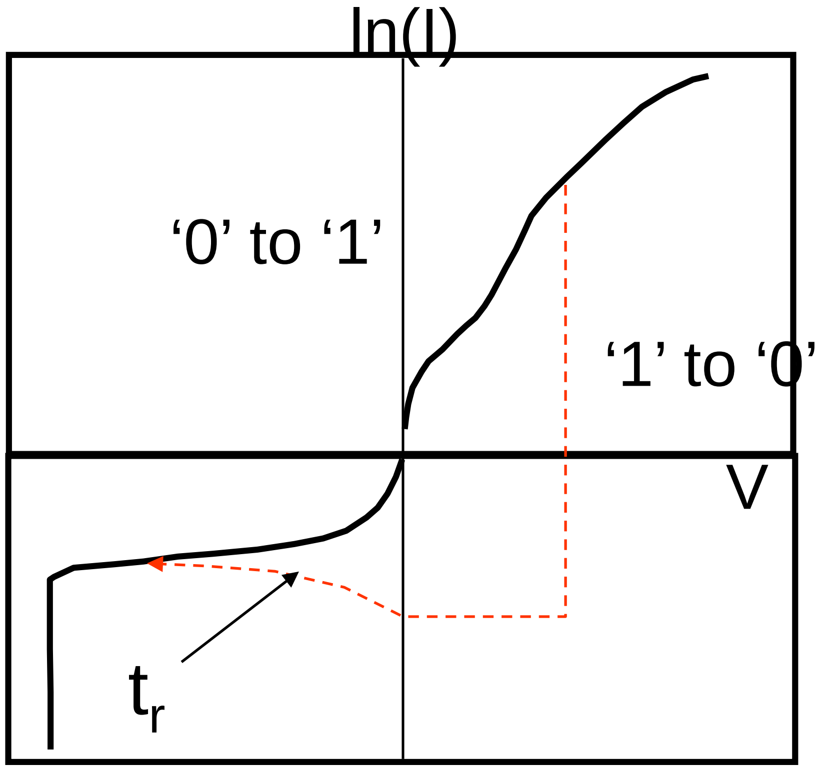
$$V_A(t) = \frac{kT}{q} \ln \frac{n_p(0,t)}{n_{po}}$$

Recovery Time (not derived here)

$$erf\sqrt{\frac{t_r}{\tau_p}} + \frac{e^{-\frac{t_r}{\tau_p}}}{\sqrt{\pi\frac{t_r}{\tau_p}}} = 1 + 0.1\frac{I_F}{I_R}$$

$$\mathrm{erf}(\sqrt{x}) = \frac{1}{\sqrt{\pi}}\int_0^x \frac{e^{-t}}{\sqrt{t}}\,dt$$

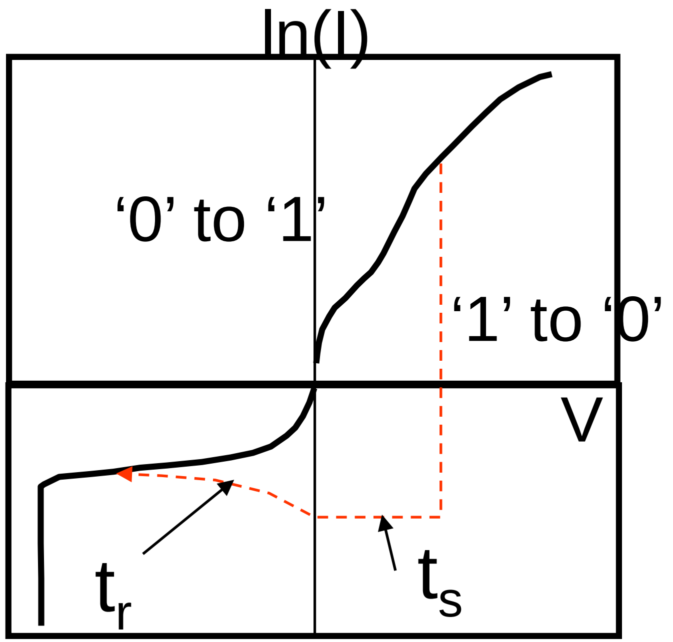
$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x \exp(-t^2)\,dt$$



Useful formula …

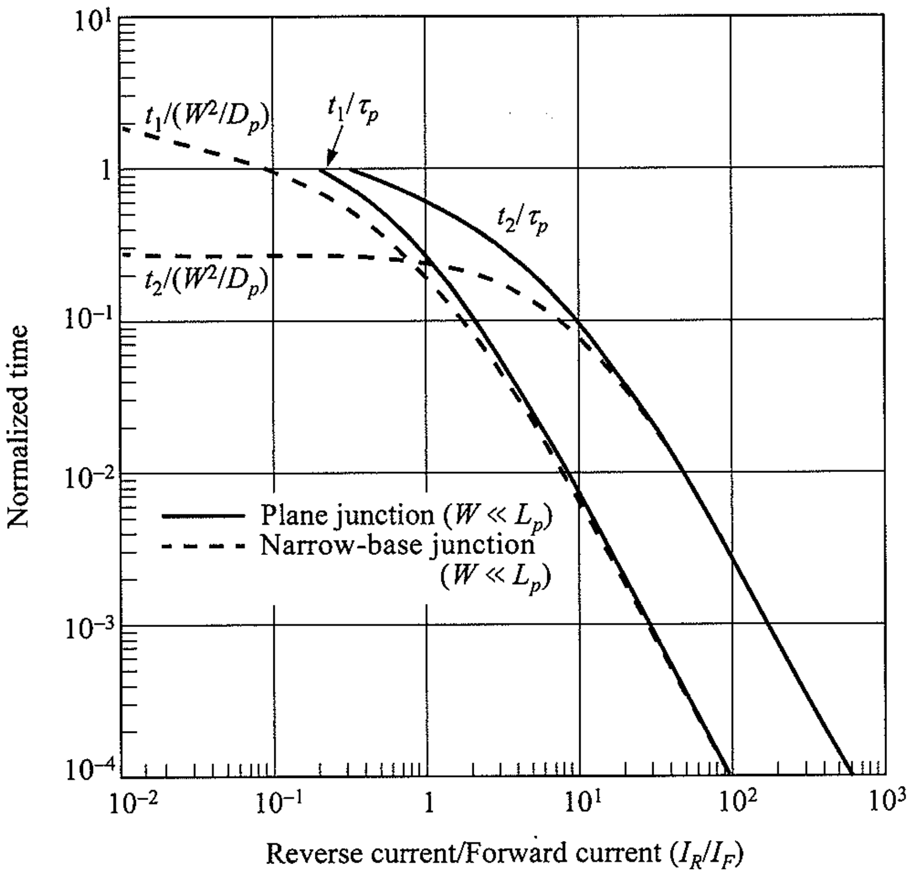
$$erf(\sqrt{x}) \approx \sqrt{1 - e^{-x\frac{1.27+0.15x}{1+0.15x}}}$$

Recovery Time



$$t_{rr} = t_r + t_f \approx \begin{cases} \dfrac{W_p^2}{2D_n}\left(\dfrac{I_R}{I_F}\right)^{-2} & (W_p \ll L_n) \\ \dfrac{\tau_p}{2}\left(\dfrac{I_R}{I_F}\right)^{-2} & (W_p \gg L_n) \end{cases}$$

Ref. Sze/Ng, p. 117



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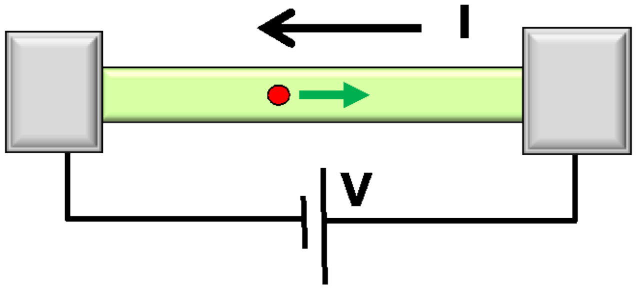

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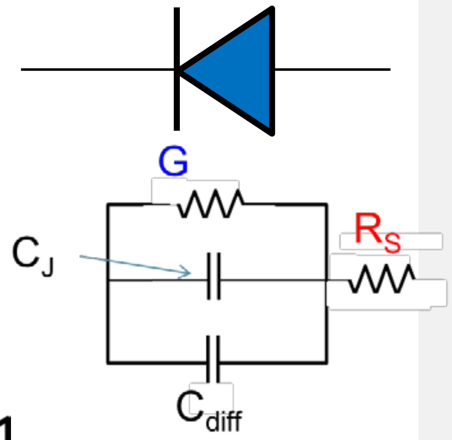
charge density velocity area



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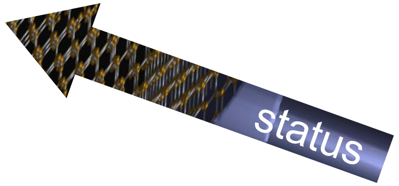

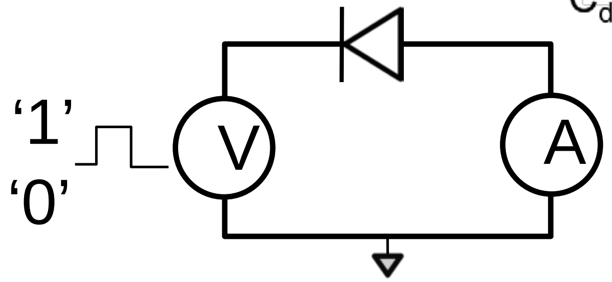

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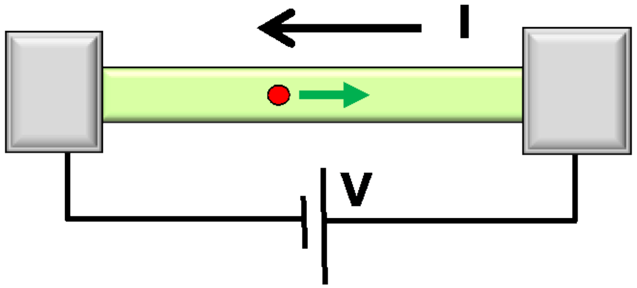

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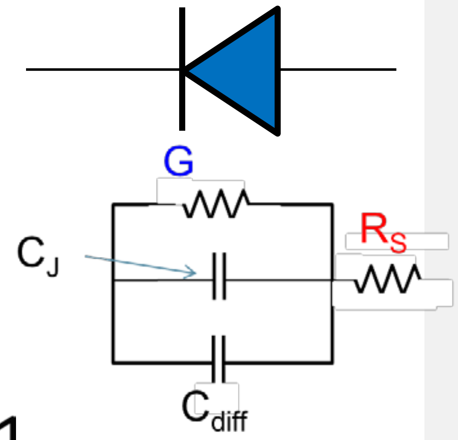

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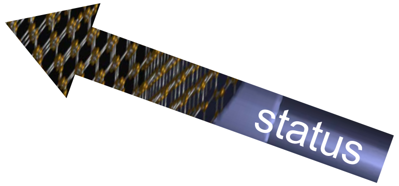

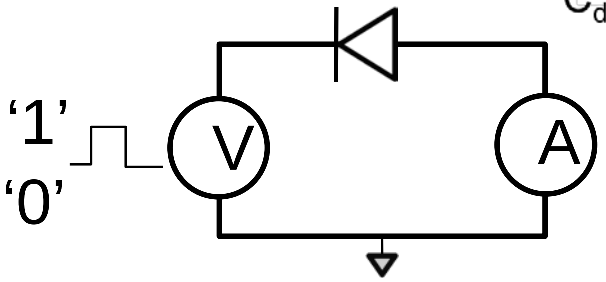

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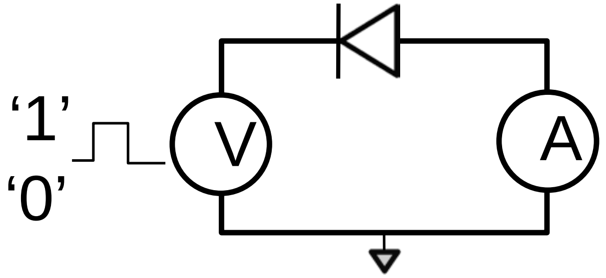
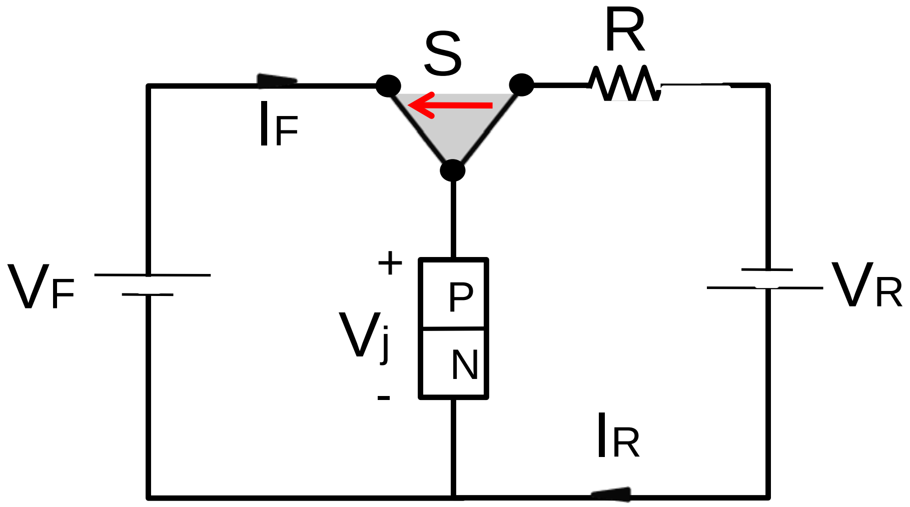
$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

Turn-on Characteristics: Boundary Condition



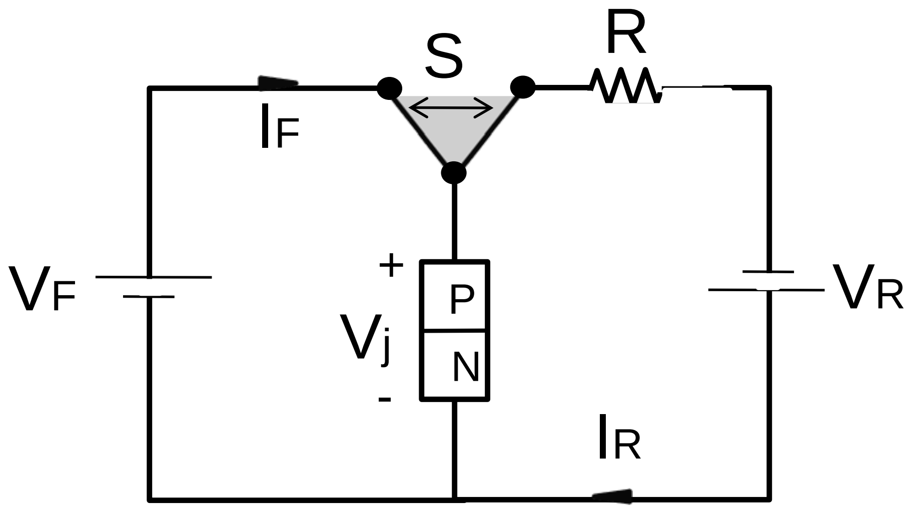


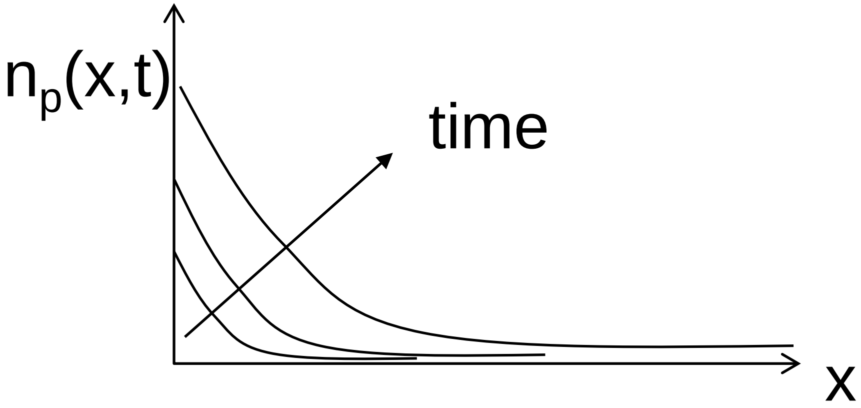
$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

$$t \to \infty \qquad \frac{\partial Q}{\partial t} = I_F - \frac{Q(t=\infty)}{\tau_n}$$

$$Q(t=\infty) = I_F \tau_n$$

Turn-on Characteristics





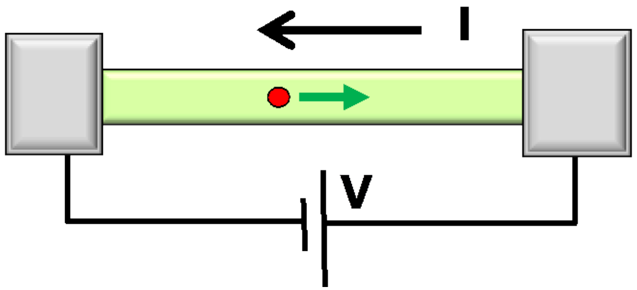
$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

$$t > 0 \quad \frac{\partial Q}{\partial t} = I_F - \frac{Q}{\tau_n}$$

$$Q(t) = Q(t \to \infty)\left(1 - e^{-\frac{t}{\tau_n}}\right) = I_F \tau_n \left(1 - e^{-\frac{t}{\tau_n}}\right)$$

Check:
$Q(t=0)=0$
$Q(t \to \infty)=I_F\ \tau_n$

PN Diode Large Signal Response



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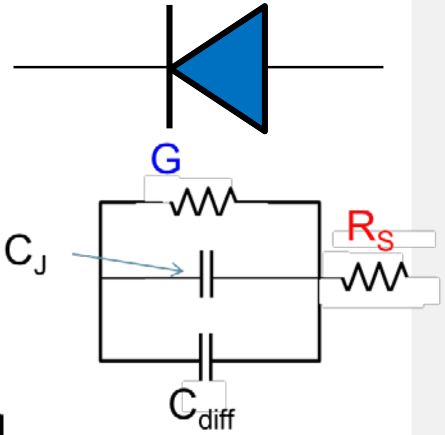

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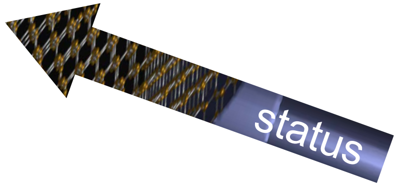

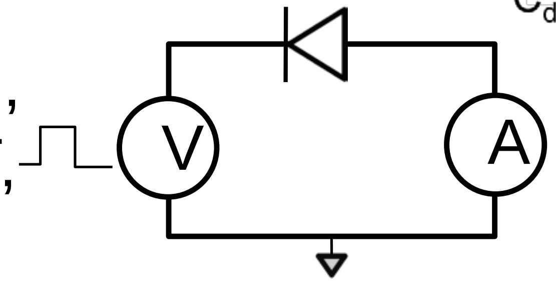

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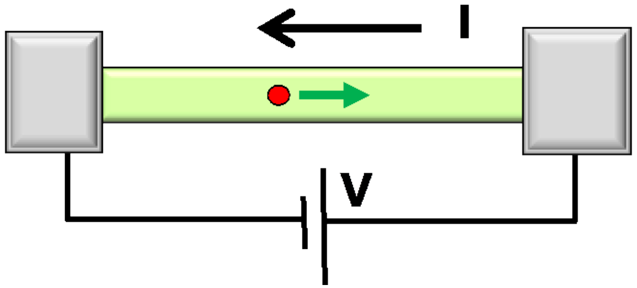

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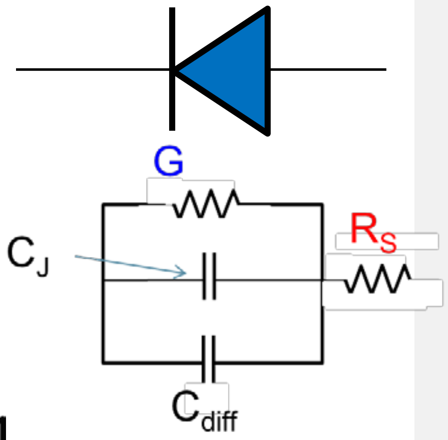

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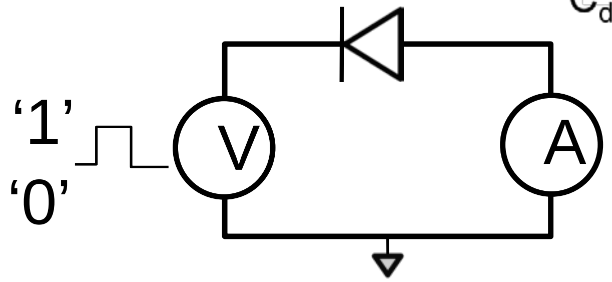
- 22.3 Steady-State expression from Charge Cont



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