Section 21
PN Diode AC Response

21.2 Majority carrier junction capacitance

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PURDUE UNIVERSITY

School of Electrical and Computer Engineering

Section 21
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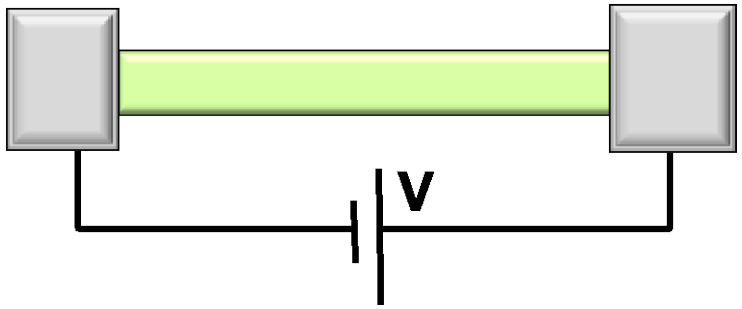
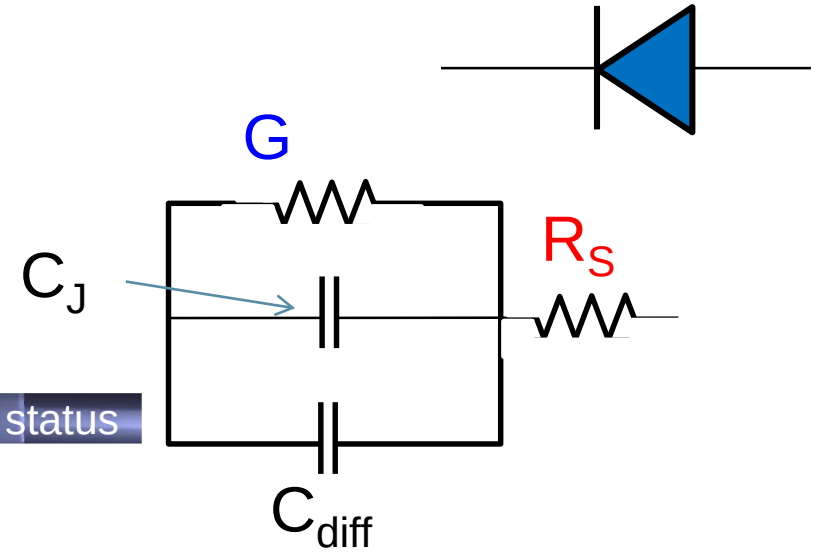


$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area



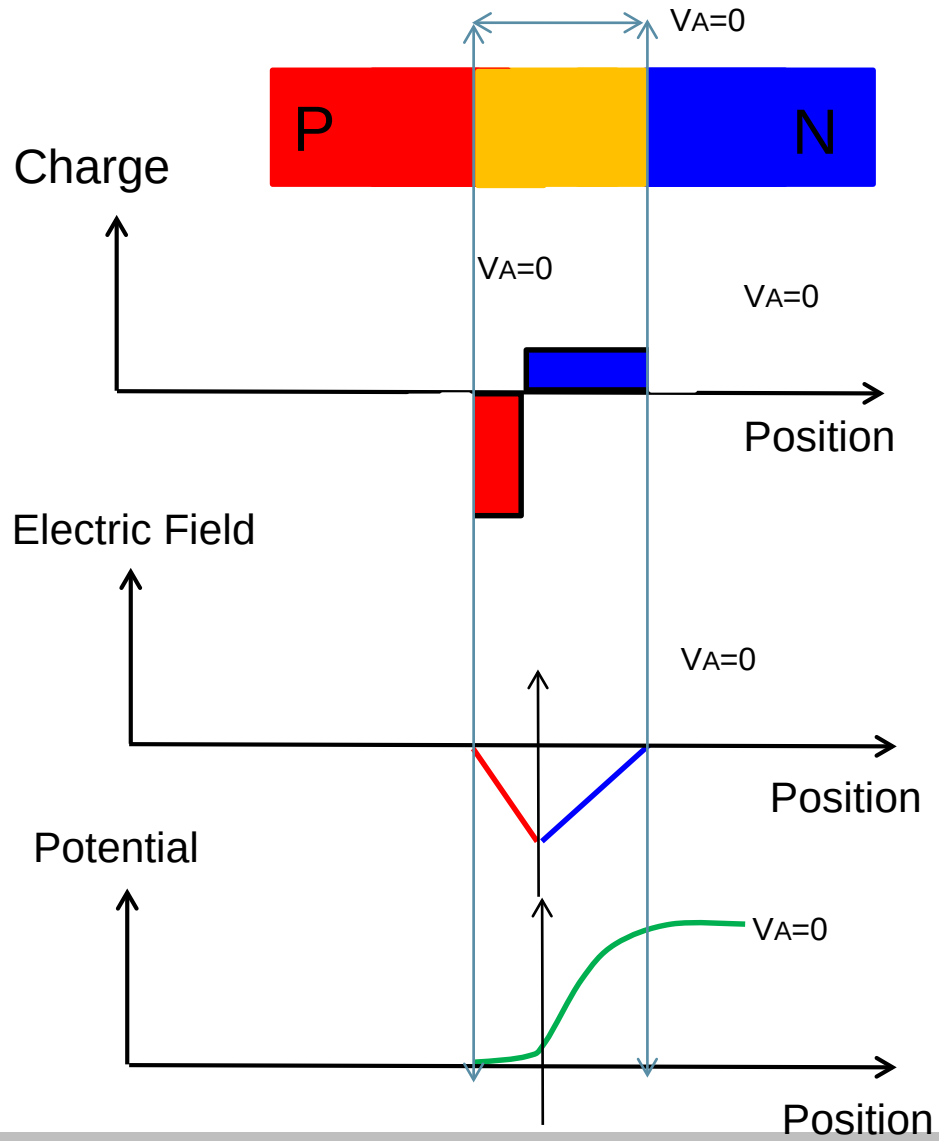
- 21.1 Conductance and series resistance
- 21.2 Majority carrier junction capacitance
- 21.3 Minority carrier diffusion capacitance

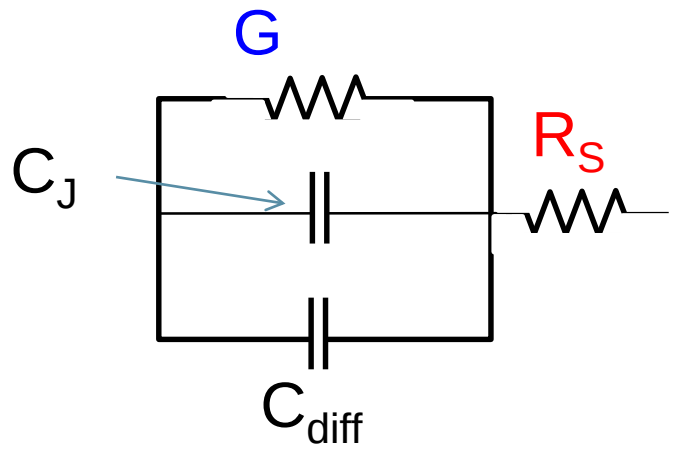
status

$$\frac{1}{g_{FB}} = R_S + \frac{m}{q\beta(I + I_0)}$$

$$\frac{1}{g_{RB}} = \frac{qn_iB_0}{2\tau\sqrt{V_{bi} - V_A}}$$

Fields and Depletion as a Function of Bias





$$x_n = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_A}{N_D(N_A+N_D)}(V_{bi}-V)}$$

Zero Bias

$$x_p = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_D}{N_A(N_A+N_D)}(V_{bi}-V)}$$

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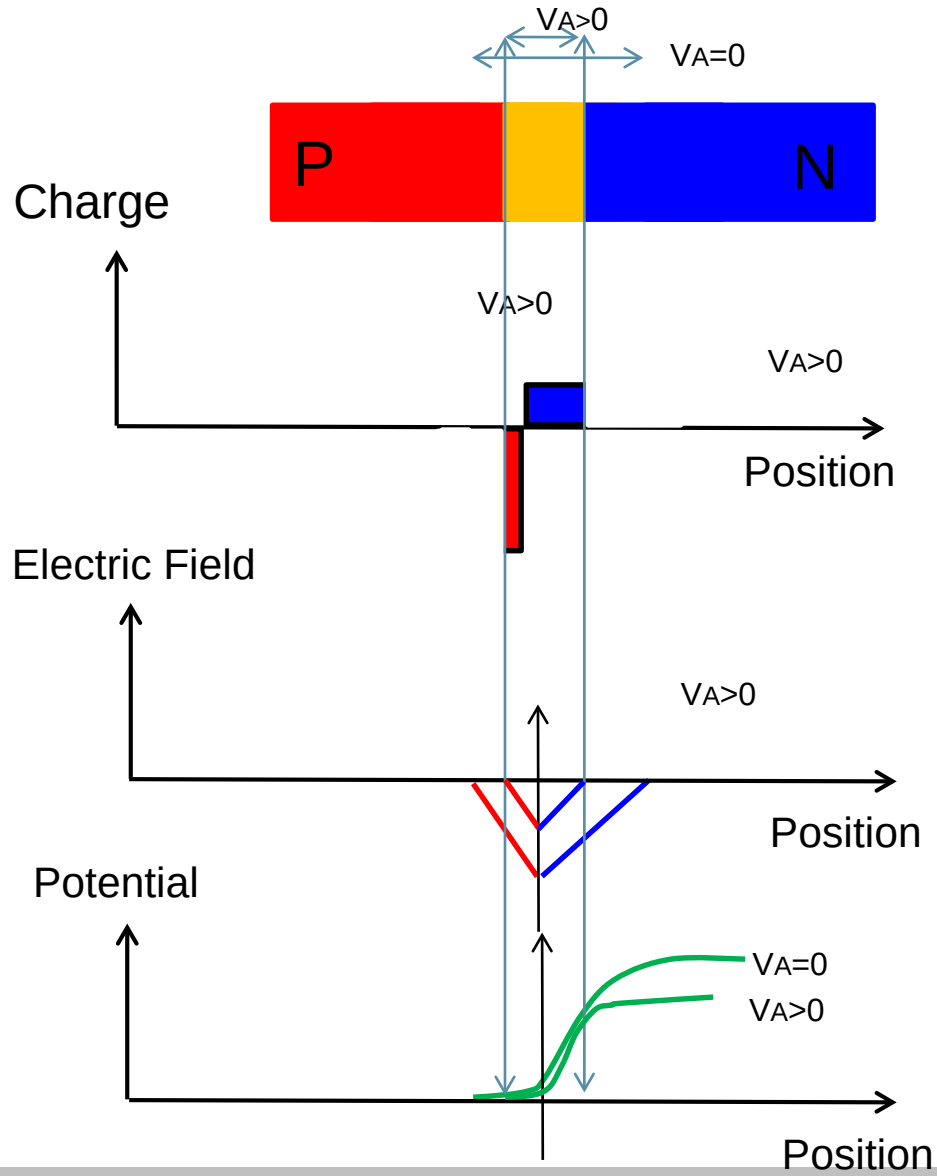

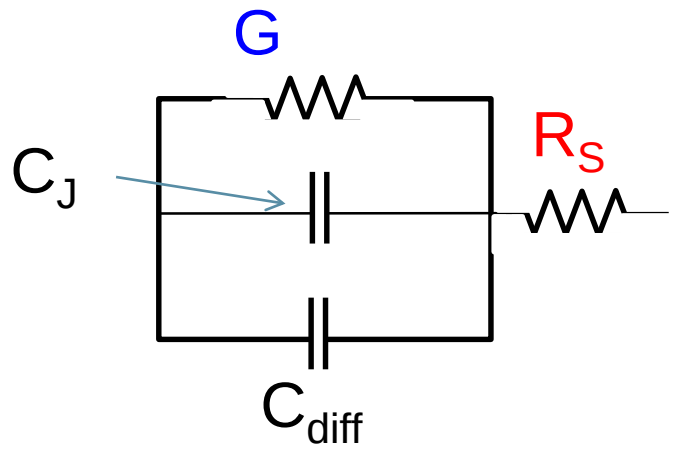

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DC + AC

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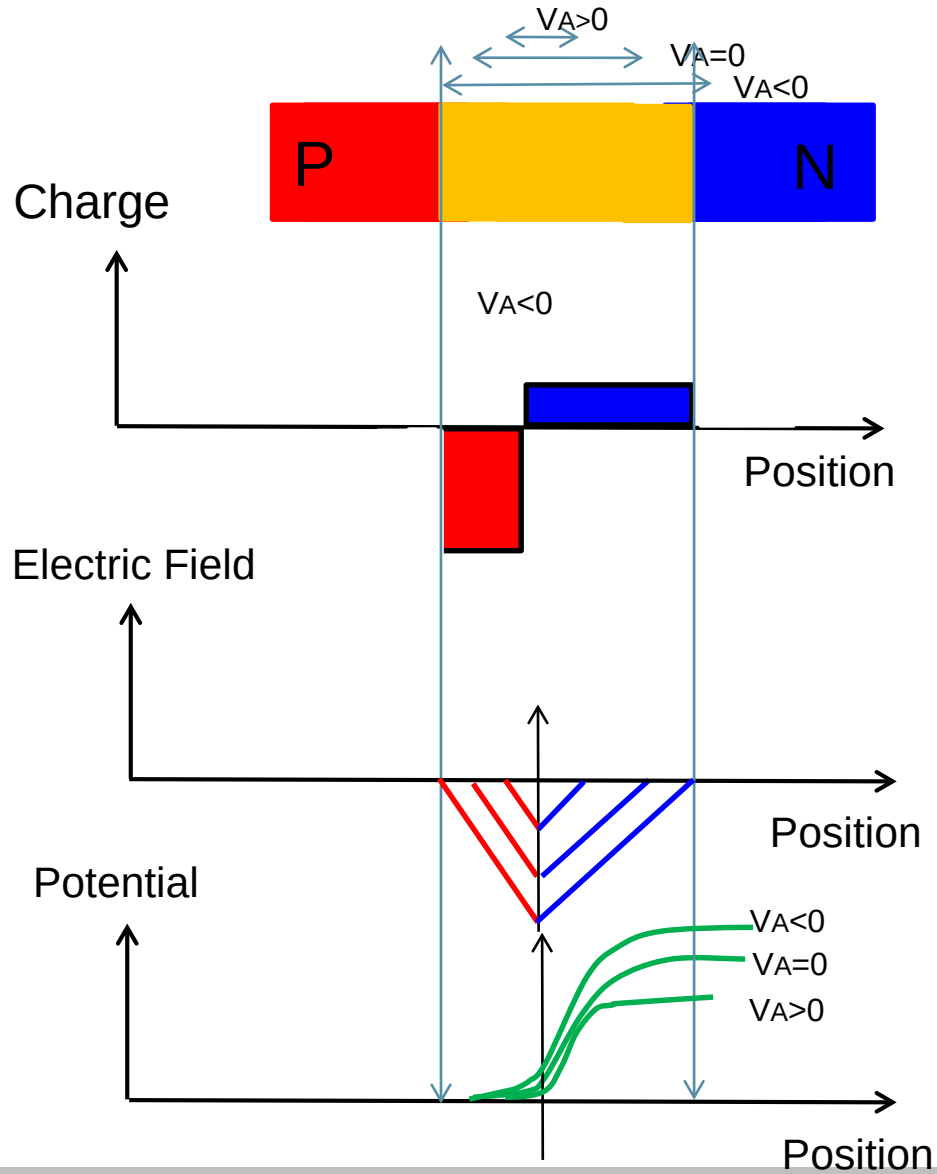

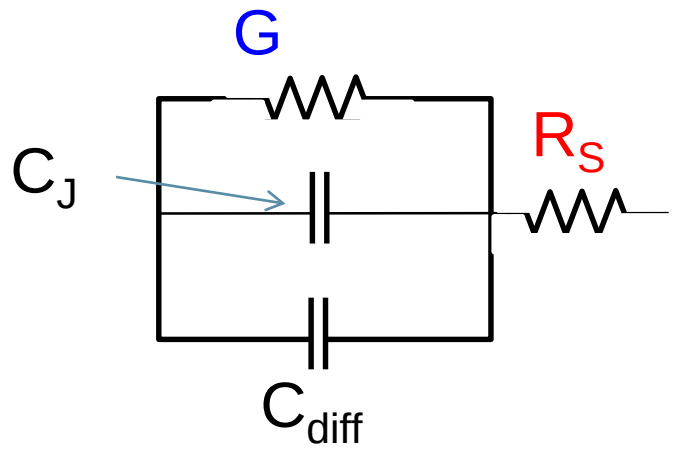

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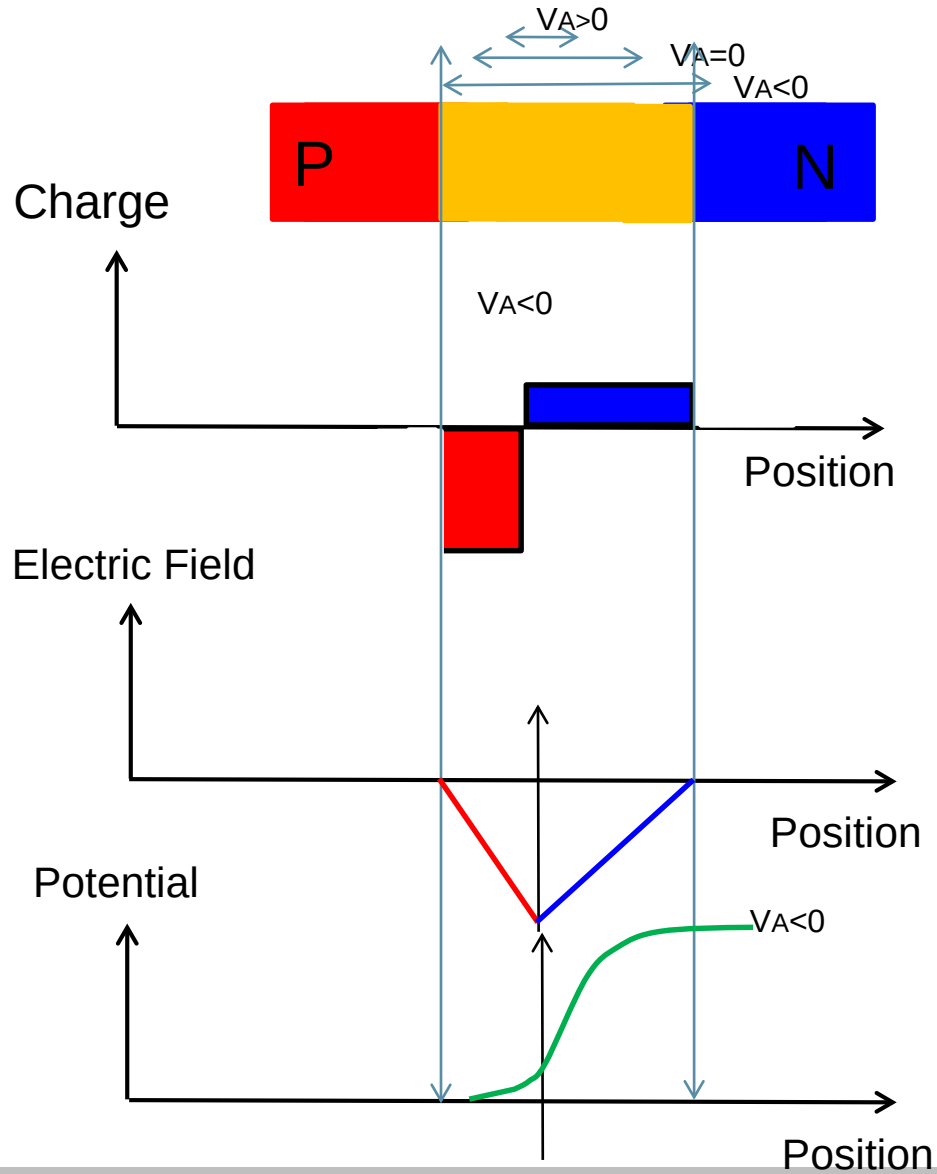

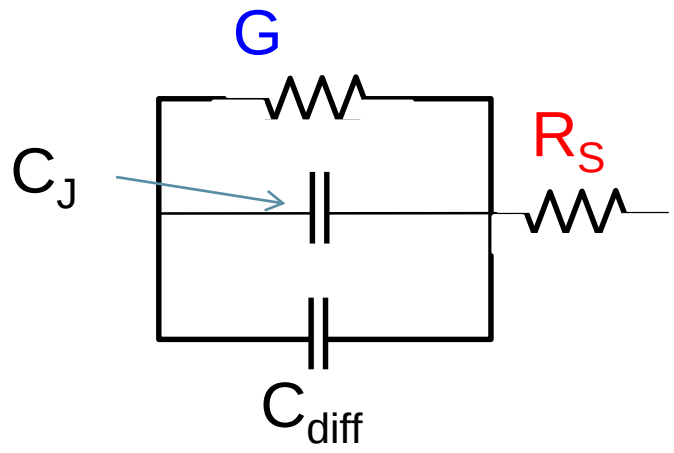

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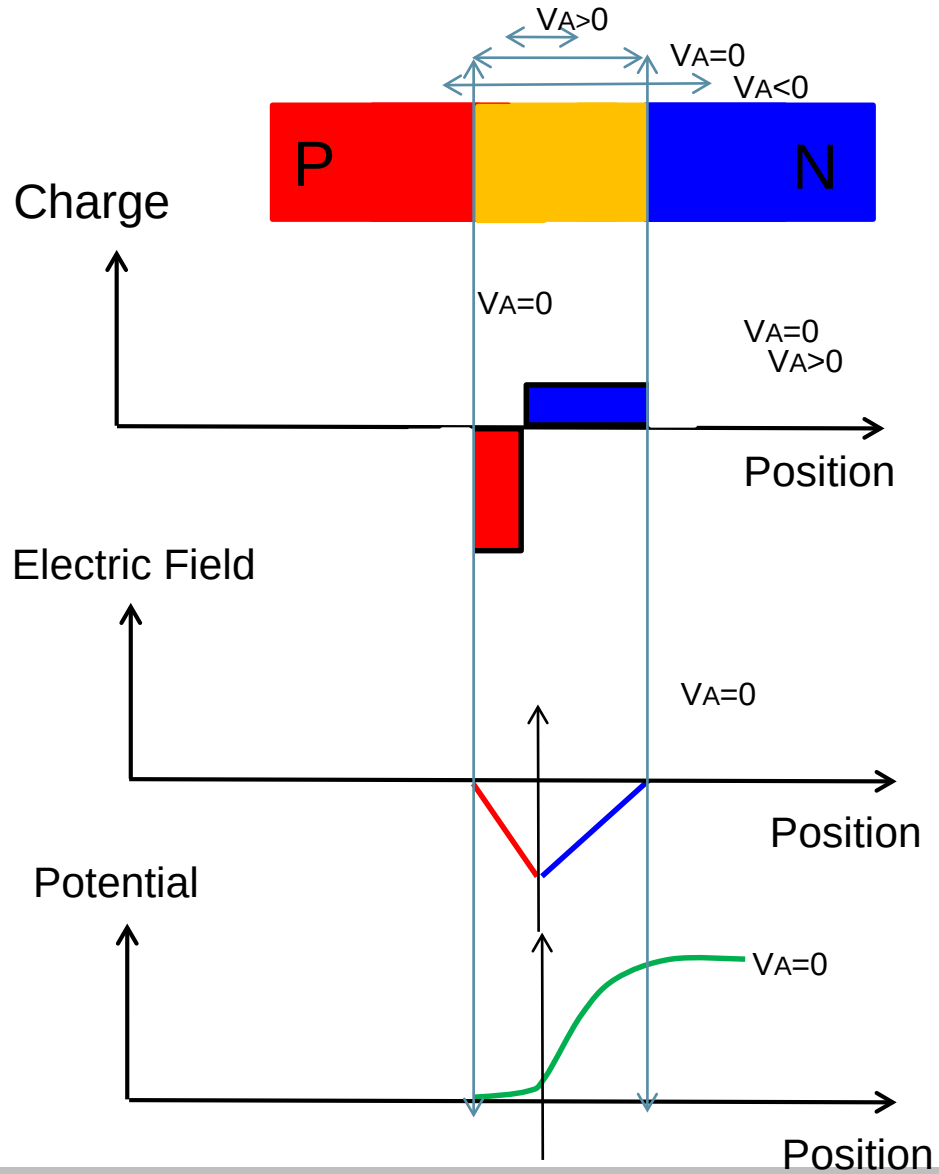

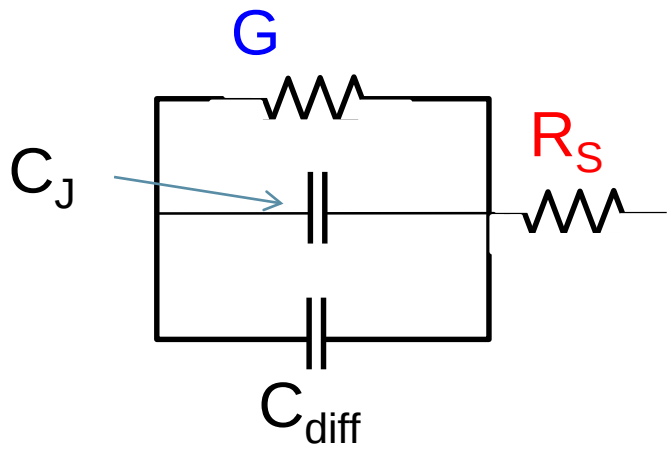

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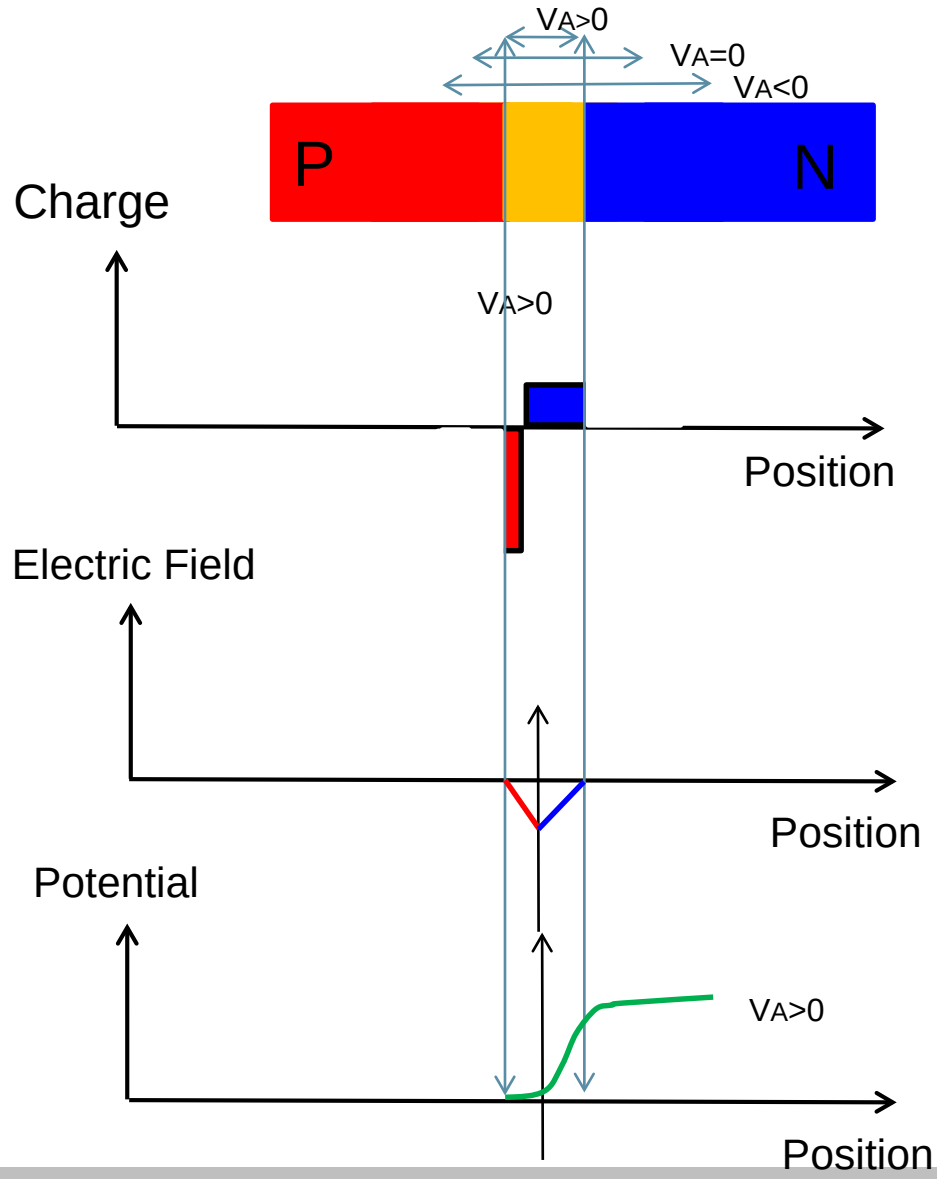

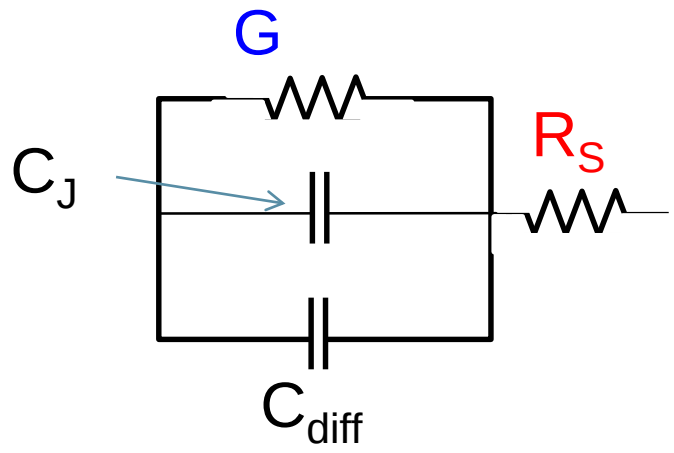

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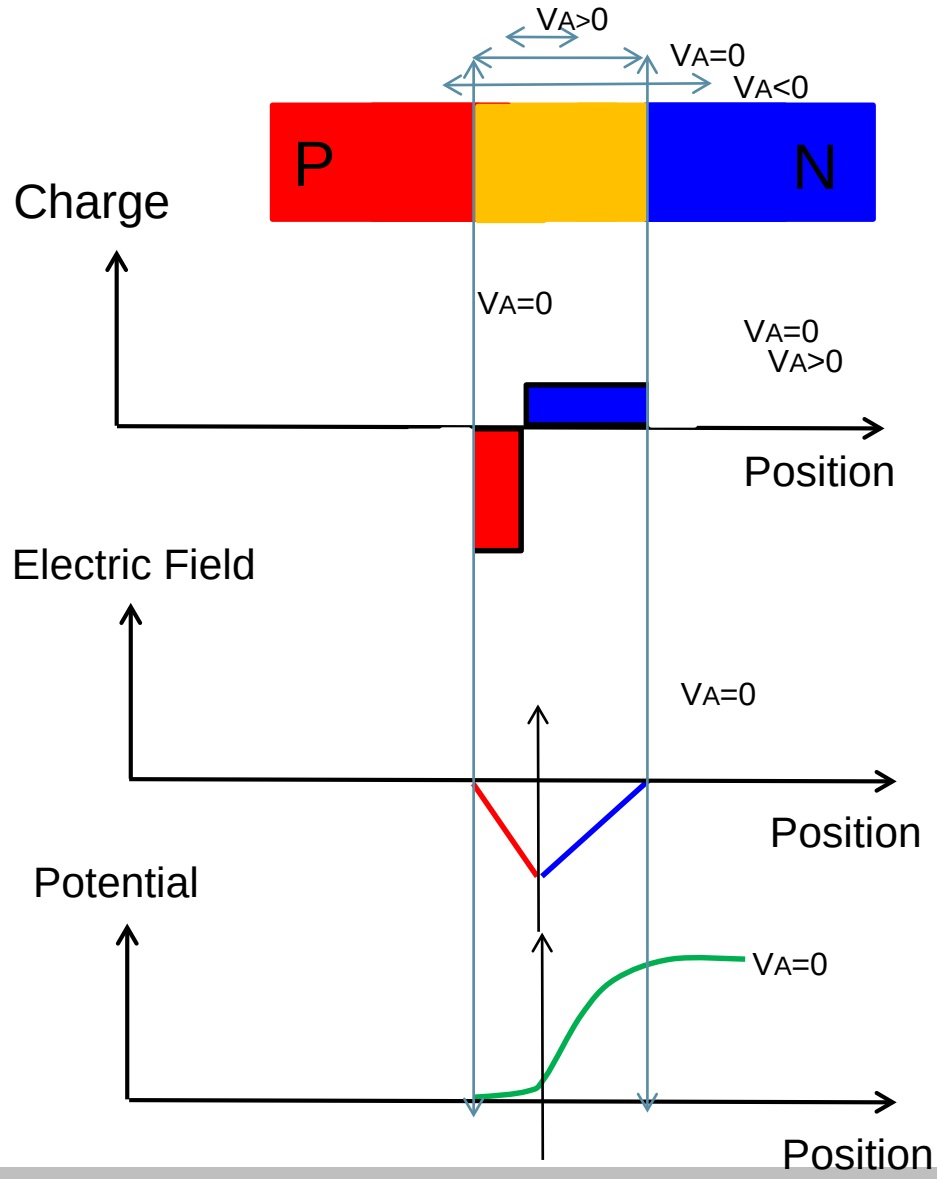

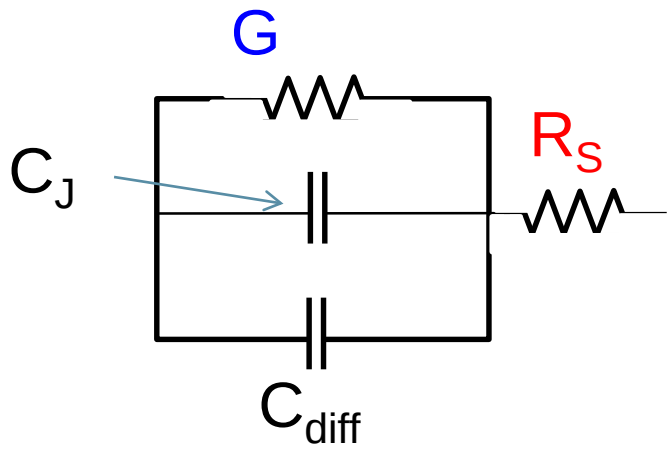

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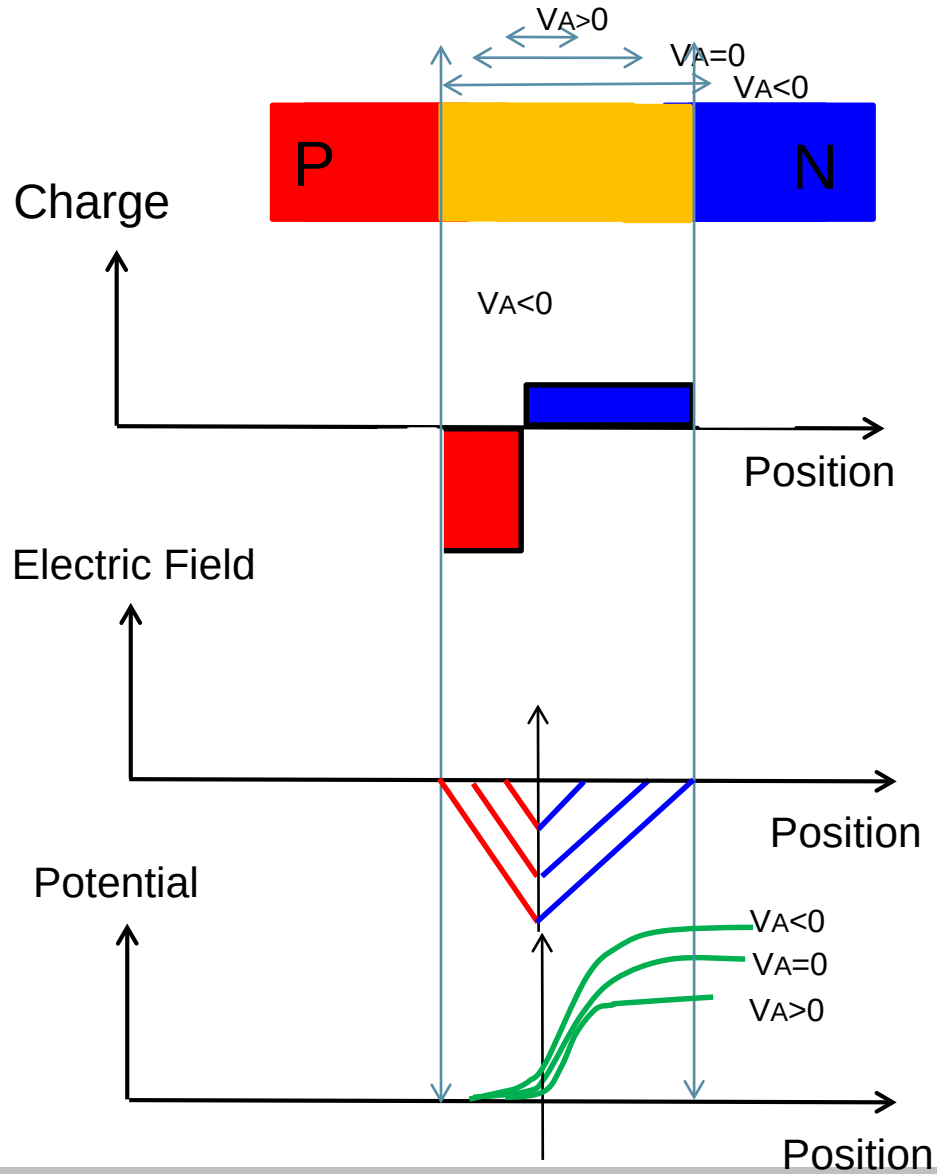

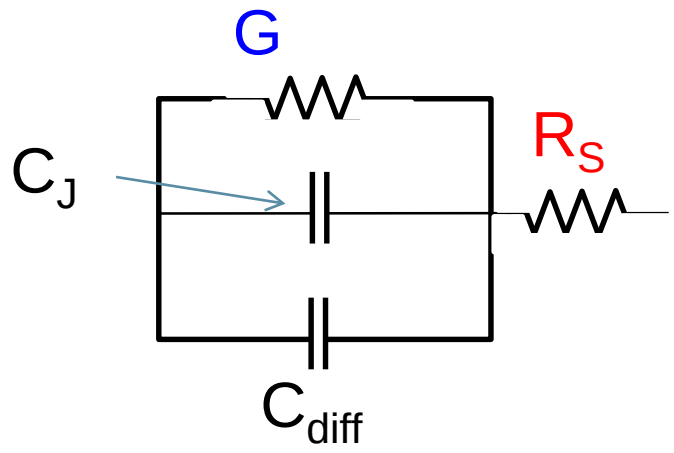

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DC - AC

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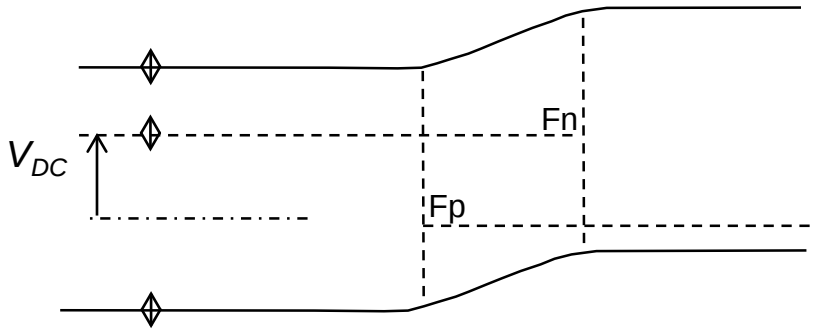
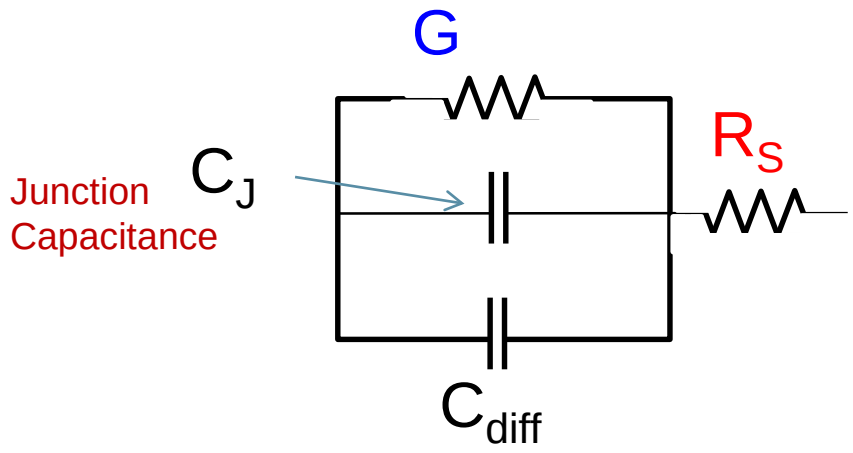
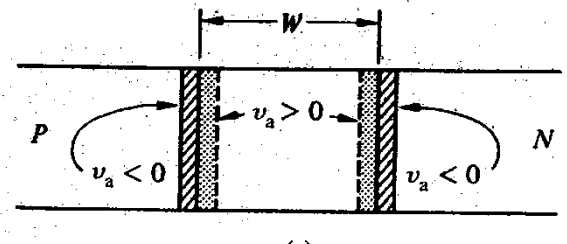
Junction Capacitance

Forward biased diode + AC signal

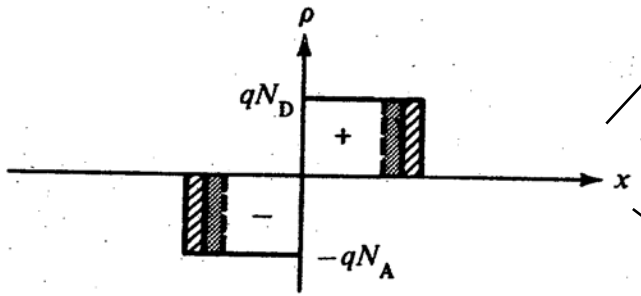


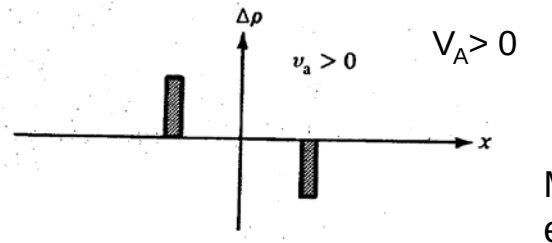


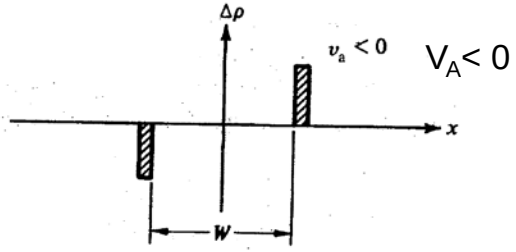
Depletion width modulation



Charge modulation

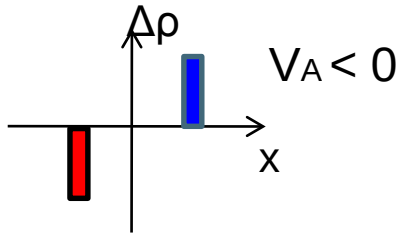


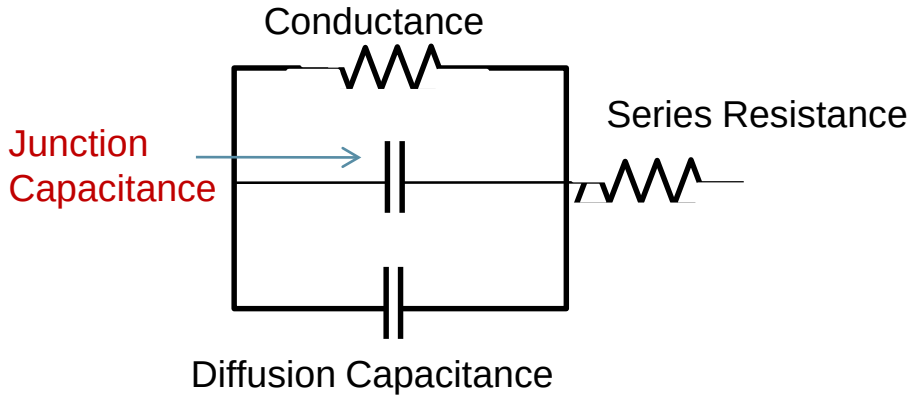




Majority carrier effect

Majority Carrier Junction Capacitance



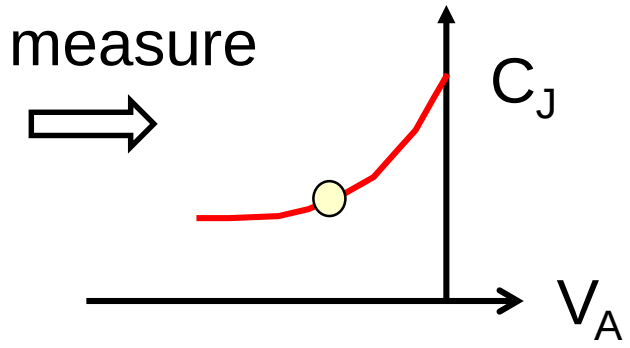


$$C_{plate} = \frac{K_s \varepsilon_0 A}{d}$$

Majority Carrier Junction Capacitance

$$C_J = \frac{K_s \varepsilon_0 A}{W_n + W_p}$$

$$C_J = \frac{K_s \varepsilon_0 A}{\sqrt{\left(\frac{2K_s \varepsilon_0}{qN_D} + \frac{2K_s \varepsilon_0}{qN_A}\right)(V_{bi} - V_A)}}$$



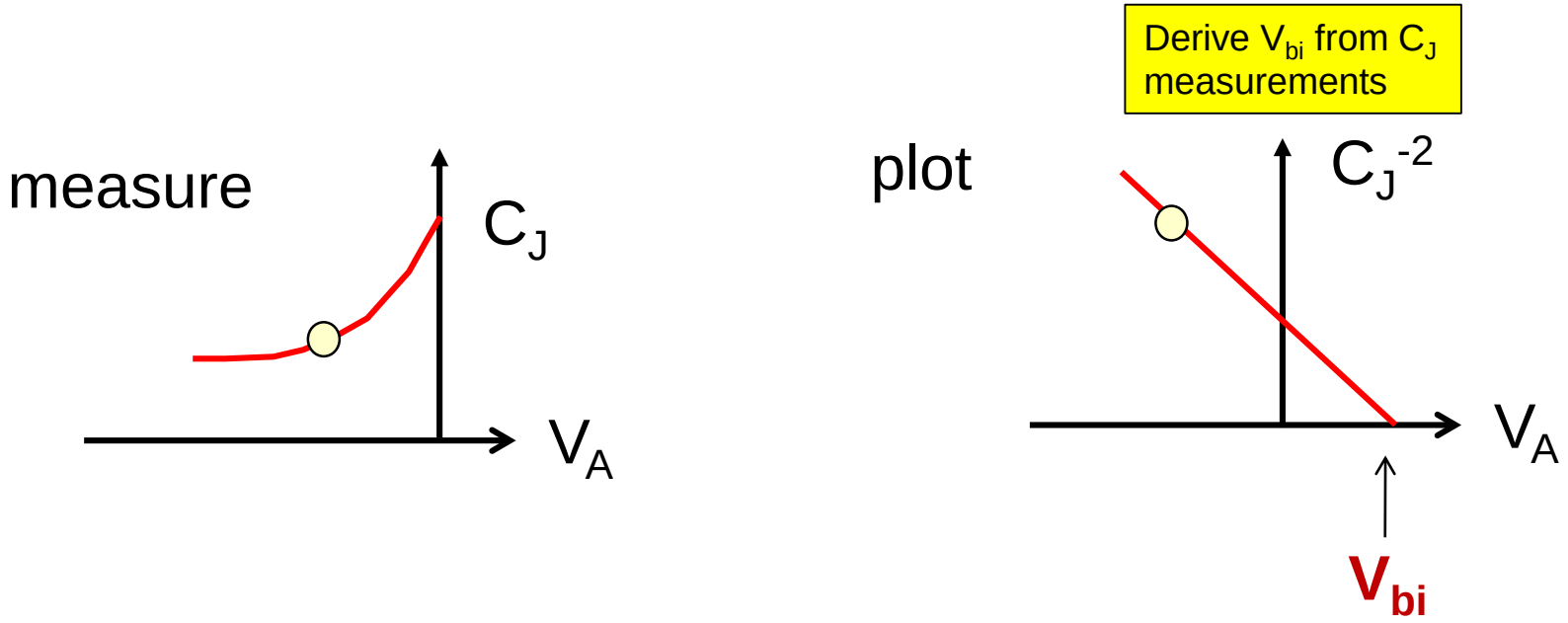
Measurement of Built-in Potential

$$C_J = \frac{K_s \varepsilon_0 A}{\sqrt{\left(\frac{2K_s\varepsilon_0}{qN_D} + \frac{2K_s\varepsilon_0}{qN_A}\right)(V_{bi} - V_A)}}$$

$$\boxed{\frac{1}{C_J^{\,2}} \approx \frac{2}{qN_D(x)K_s\varepsilon_0 A^2}(V_{bi} - V_A)}$$

(Assume single sided p^+-n junction)

Derive V_{bi} from C_J measurements

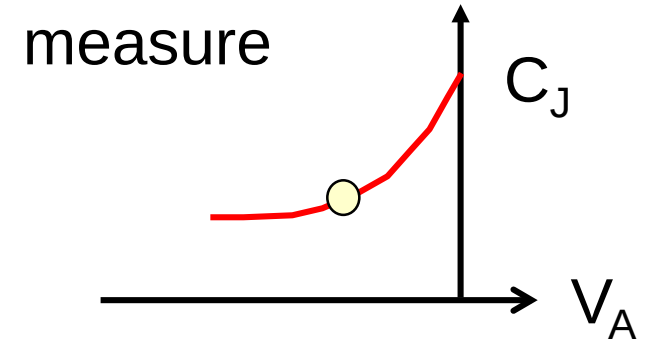


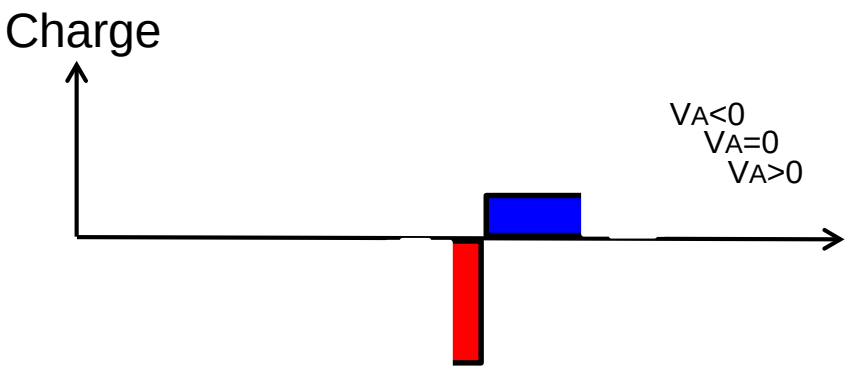
.. And Variable Doping – probe charge at depletionregion edge

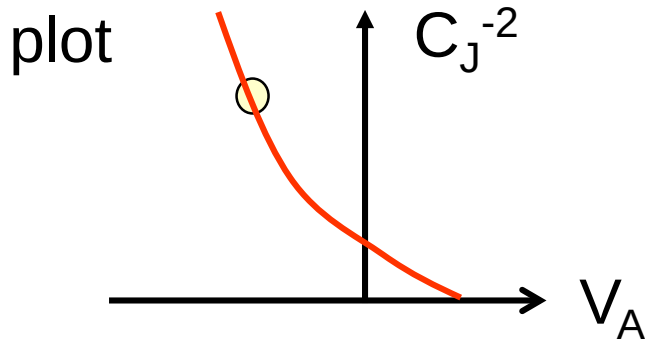
$$\frac{1}{C_J^{\,2}} \approx \frac{2}{qN_D(x)K_s\varepsilon_0 A^2}(V_{bi} - V_A)$$

$$N_D(x) = \frac{2}{qK_s\varepsilon_0 A^2}\frac{1}{d(1/C_J^2)/dV_A}$$

Measure doping concentration as a function of position







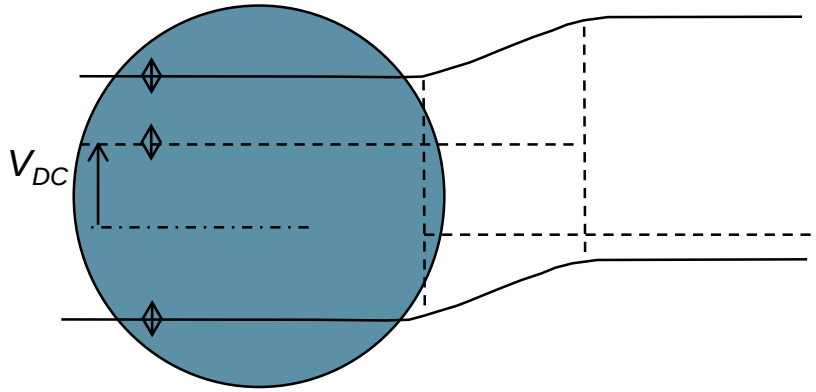
Dielectric Relaxation Time (majority side)

Majority side

$$J_n = qn\mu_N E + qD_N \nabla n$$

Neglect

$$\frac{dn}{dt} = \frac{1}{q}\frac{dJ_n}{dx} - R_n + G_n$$



$$\frac{d(\Delta n)}{dt} = \frac{1}{q}\frac{d(qn\mu_N \mathcal{E})}{dx} = N_D \mu_N \frac{d\mathcal{E}}{dx}$$

N-side

$$\frac{d\mathcal{E}}{dx} = \frac{q}{k_S \varepsilon_0}\left(p - n_0 - \Delta n + N_D - N_A\right)$$

$$N_D = n_0$$

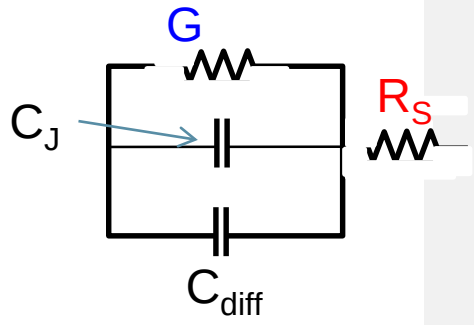
How long does it take for the signal to cross the junction?

$$\tau_d = \frac{K_s \varepsilon_0}{\sigma} \approx 0.1 \text{ ps}$$

Very fast

$$\frac{d(\Delta n)}{dt} = -\frac{qN_D\mu_N}{k_S\varepsilon_0}\Delta n = -\frac{\sigma_0 \Delta n}{k_S \varepsilon_0}$$

$$\Delta n(t) = n_0 e^{-\frac{\sigma_0 t}{k_S \varepsilon_0}} = n_0 e^{-\frac{t}{\tau_d}}$$



Overall electronic system responds => dielectric response

$$\frac{1}{C_J^{\,2}} \approx \frac{2}{qN_D(x)K_s\varepsilon_0 A^2}(V_{bi} - V_A)$$

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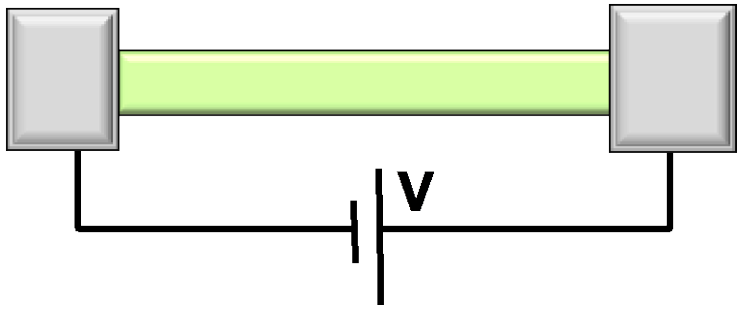

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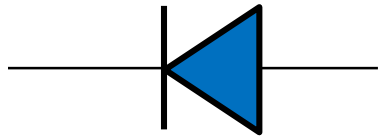

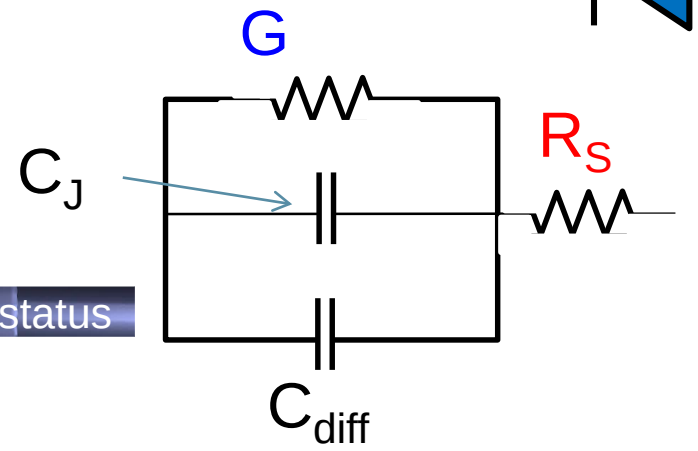

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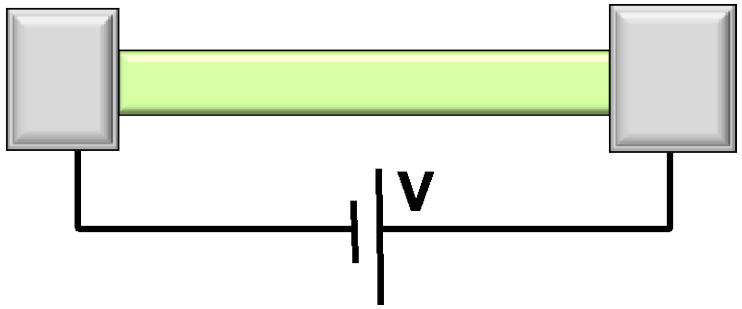

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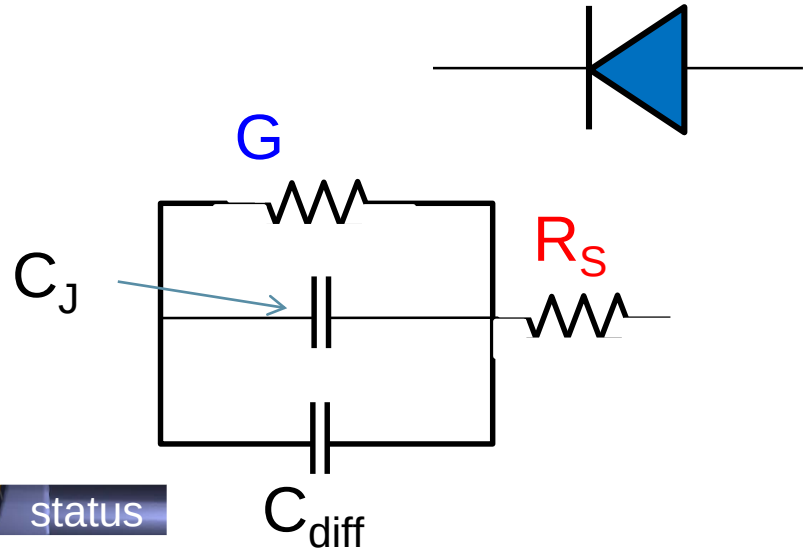

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