Section 27
Heterojunction Bipolar Transistor

27.2 Heterojunction Equilibrium Solution

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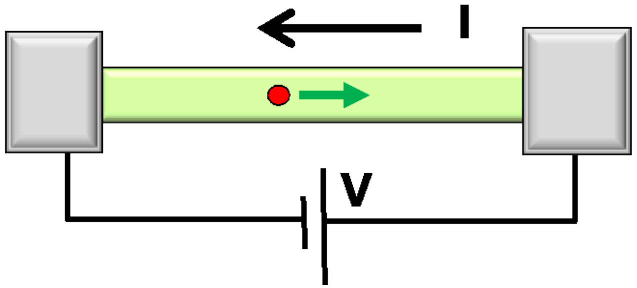

I = G × V

= **q** × **n** × **v** × A

charge density velocity area

$$\frac{n_{i,B}^2}{n_{i,E}^2} = \frac{N_{C,B}N_{V,B}e^{-E_{g,B}\beta}}{N_{C,E}N_{V,E}e^{-E_{g,E}\beta}} \approx e^{(E_{g,E}-E_{g,B})\beta}$$

1
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$$\nabla \bullet D = q\left(p - n + N_D^+ - N_A^-\right)$$

$$\beta_{DC} = \frac{I_C}{I_B}$$

$$\beta_{poly,ballistic} \rightarrow \frac{n_{i,B}^2}{n_{i,E}^2} \times \frac{N_E}{N_B} \times \frac{\upsilon_{th}}{\upsilon_s}$$

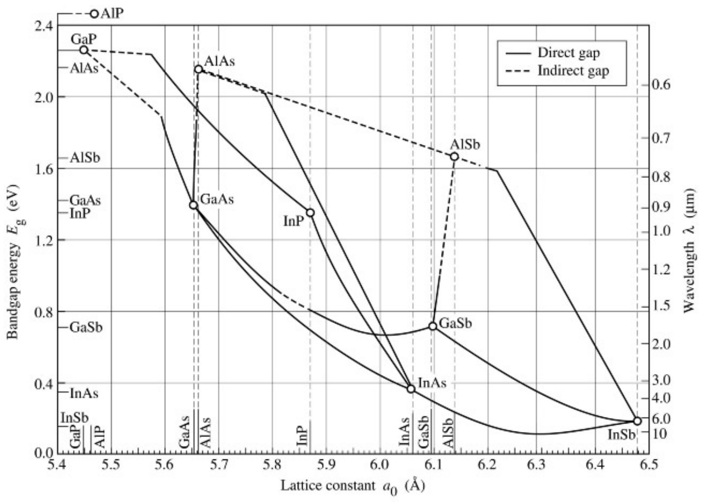
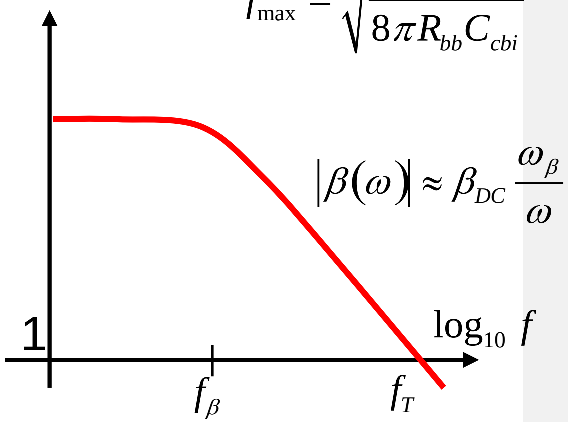


Fig. 7.6. Bandgap energy and lattice constant of various III-V semiconductors at room temperature (adopted from Tien, 1988).

$$f_{max} = \sqrt{\frac{f_T}{8\pi R_{bb} C_{cbi}}}$$



$$|\beta(\omega)| \approx \beta_{DC}\frac{\omega_\beta}{\omega}$$

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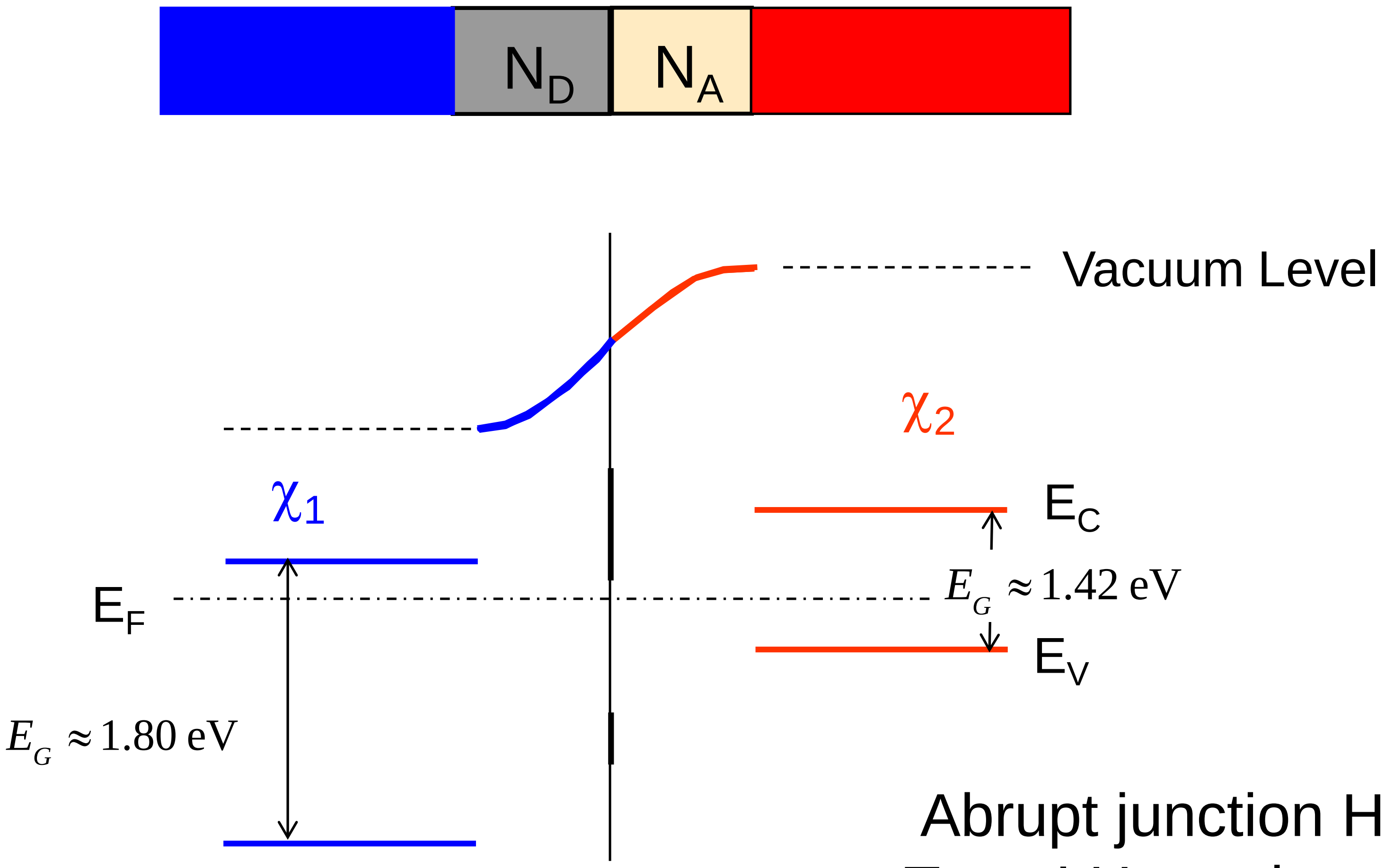
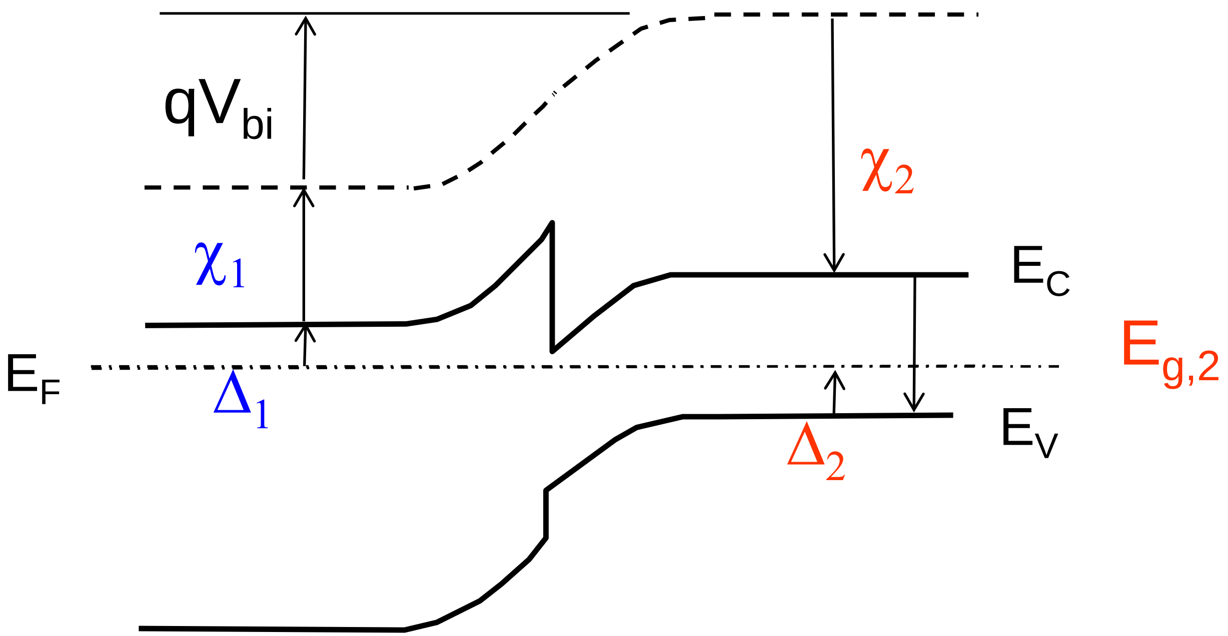
N-$Al_{0.3}Ga_{0.7}As$: p-GaAs (Type-I Heterojunction)



Abrupt junction HBT
Type-I Heterojunction

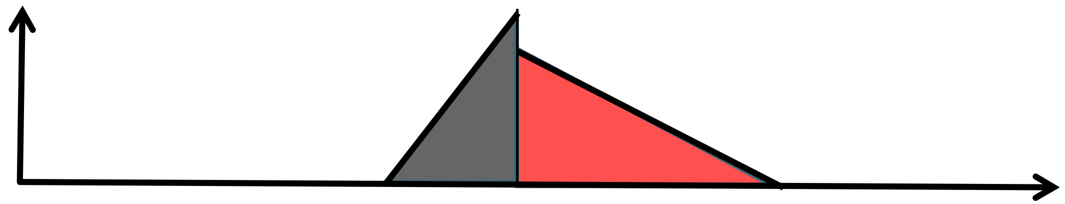
$$\Delta_1 + \chi_1 + qV_{bi} = E_{g,2} - \Delta_2 + \chi_2$$



$$qV_{bi} = E_{g,2} - \Delta_2 - \Delta_1 + \chi_2 - \chi_1$$

$$= k_B T \ln \frac{N_A N_D}{N_{V,2} N_{C,1} e^{-E_{g,2}/k_B T}} + (\chi_2 - \chi_1)$$

Interface Boundary Conditions



$$\nabla \bullet D = q\left(p - n + N_D^+ - N_A^-\right)$$

$$D\left(0^-\right) = D\left(0^+\right)$$

$$\kappa_1 \varepsilon_0 E\left(0^-\right) = \kappa_2 \varepsilon_0 E\left(0^+\right)$$

$$\kappa_1 \varepsilon_0 \left.\frac{dV}{dx}\right|_{0^-} = \kappa_2 \varepsilon_0 \left.\frac{dV}{dx}\right|_{0^+}$$

Displacement ***D*** is continuous

D is not continuous if there is a surface charge

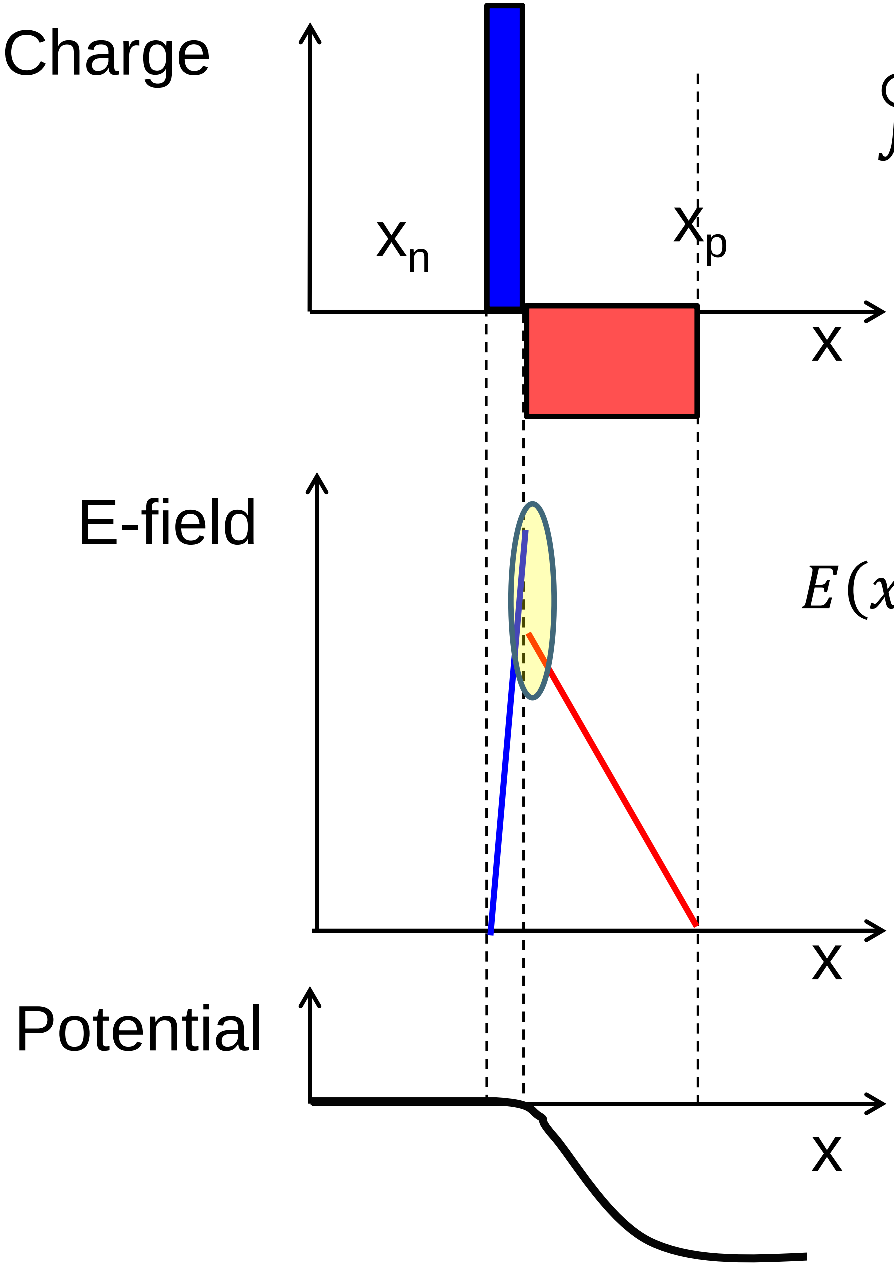
$$\rho_s = \rho_0 \delta(x_0)$$

$$\frac{dD}{dx} = \rho_0 \delta(x_0) + q\left(p(x) - n(x) + N_D^+(x) - N_A^-(x)\right)$$

$$\oint \vec{D}\, dS = \rho_{encl}$$

Zero field at edges: $\Rightarrow D(x_n) = D\left(x_p\right) \Rightarrow \rho_{encl} = 0$

Analytical Solution for Heterojunctions



$$\oint \vec{D}\, dS = \rho_{encl}$$

Zero field at edges:

$$\Rightarrow D(x_n) = D(x_p) \Rightarrow \rho_{encl} = 0$$

$$\Rightarrow N_D x_n = N_A x_p$$

Charge continuity (independent of k)

$$E(x) = \int_{-x_n}^{x} \frac{qN_D}{k_{s,E}\varepsilon_0} dx'$$

$$E(0^-) = \frac{qN_D x_n}{k_{s,E}\varepsilon_0}$$

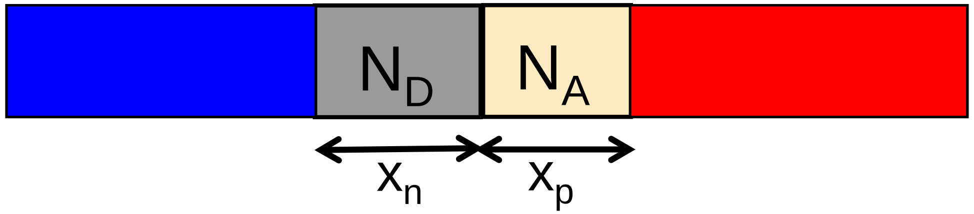
$$E(0^+) = \frac{qN_A x_p}{k_{s,B}\varepsilon_0}$$

$$V(x) = -\int_{-x_n}^{x} E(x) dx'$$

$$V_{bi} = \frac{E(0^-)x_n}{2} + \frac{E(0^+)x_p}{2}$$

$$= \frac{qN_D x_n^2}{2k_{s,E}\varepsilon_0} + \frac{qN_A x_p^2}{2k_{s,B}\varepsilon_0}$$

Base Emitter Depletion Region



$$N_E x_{n,BE} = N_B x_{p,BE}$$

$$V_{bi} = \frac{qN_E x_{n,BE}^2}{2\kappa_{s,E}\varepsilon_0} + \frac{qN_B x_{p,BE}^2}{2\kappa_{s,B}\varepsilon_0}$$

$$x_n = \sqrt{\frac{2\varepsilon_0}{q}\frac{\kappa_{s,E}\kappa_{s,B}N_B}{N_E\left(\kappa_{s,E}N_B + \kappa_{s,B}N_E\right)}V_{bi}}$$

$$x_p = \sqrt{\frac{2\varepsilon_0}{q}\frac{\kappa_{s,E}\kappa_{s,B}N_E}{N_B\left(\kappa_{s,E}N_B + \kappa_{s,B}N_E\right)}V_{bi}}$$

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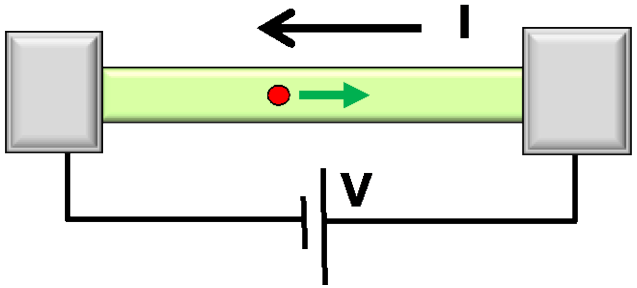

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1 2 3 4 5 6 7 8

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- 27.2 Heterojunction Equilibrium Solution ← status
- 27.3 Types of heterojunctions
- 27.4 Abrupt junction HBTs
- 27.5 Graded junction HBTs
- 27.6 Graded base HBTs
- 27.7 Double heterojunction HBTs
- 27.8 Modern Designs

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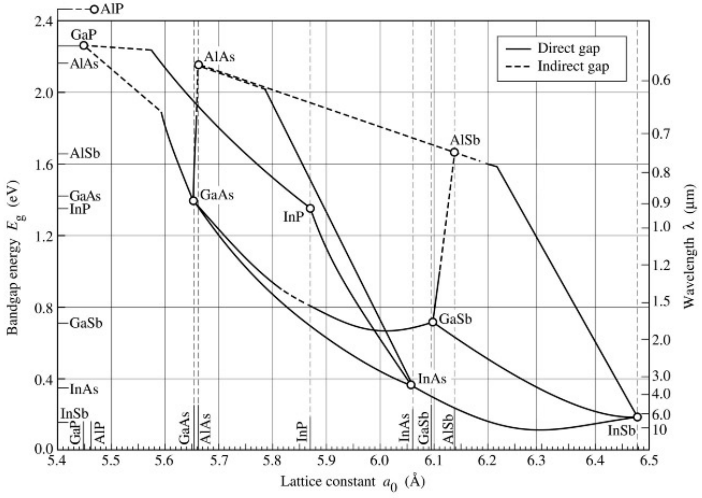

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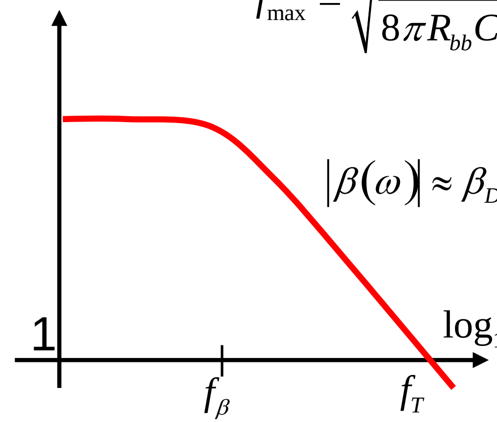

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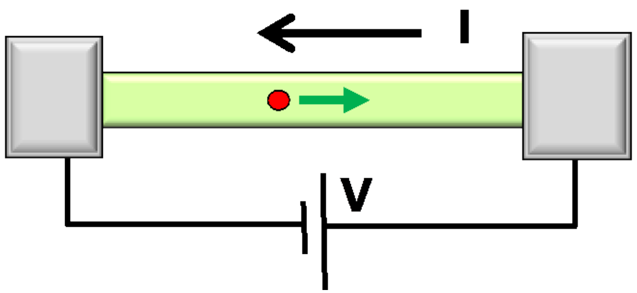
Heterojunction Bipolar Transistor



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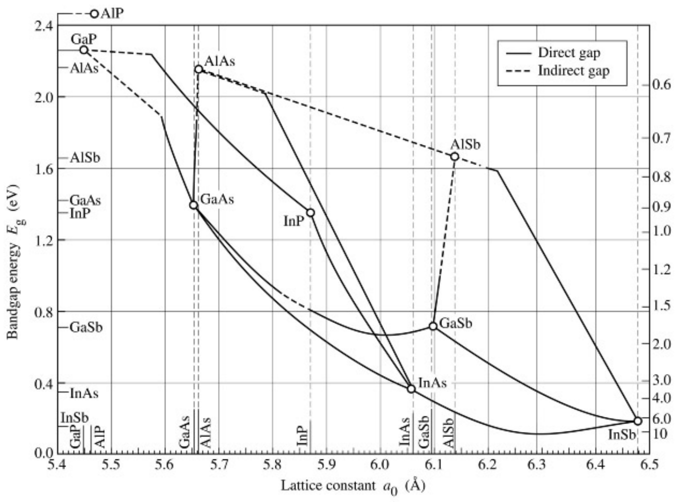

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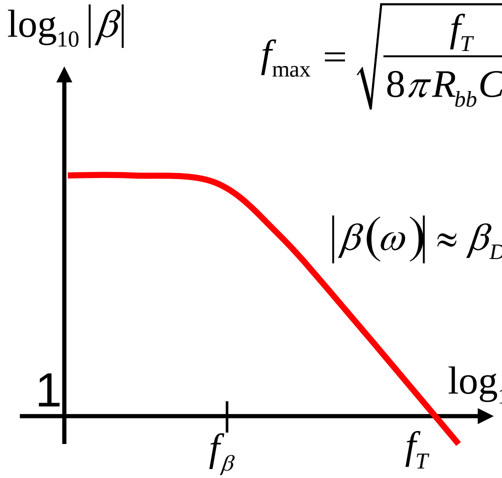

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