Lecture 9:

Diodes Circuits and BJTs

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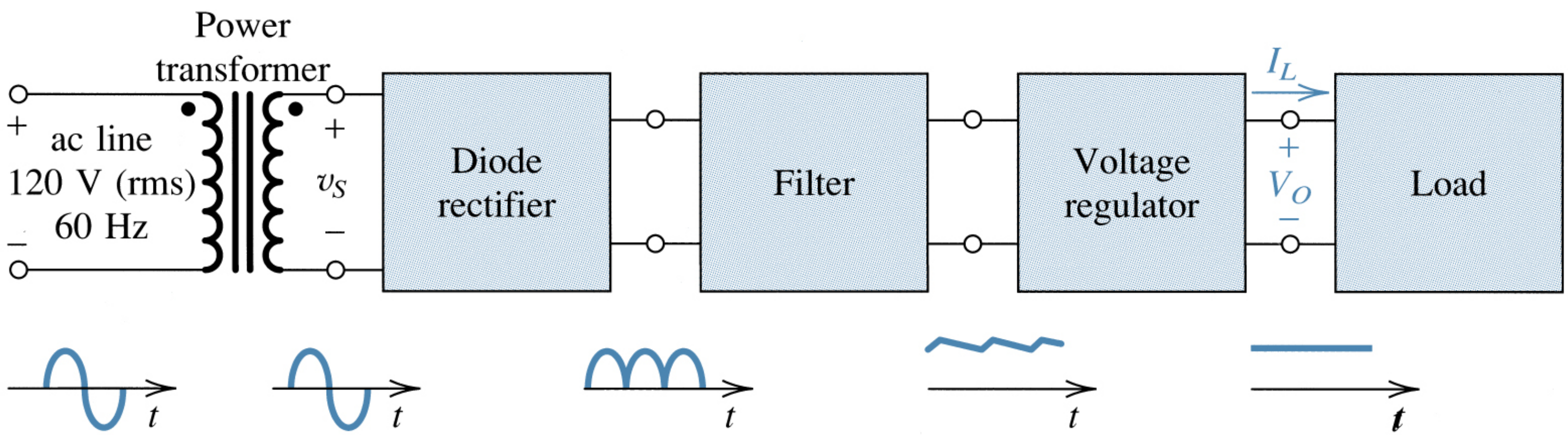
Overview

- **Reading**
  - S&S: Chapter 3.7, 4.1~3
- **Supplemental Reading**

- **Background**
  - We will finish off diode circuits with a full-wave rectifier circuit. Then, we will begin looking at transistors with the bipolar junction transistor. We will spend some time understanding how they work based on what we know about pn junctions. One way to look at a BJT transistor is two back-to-back diodes.

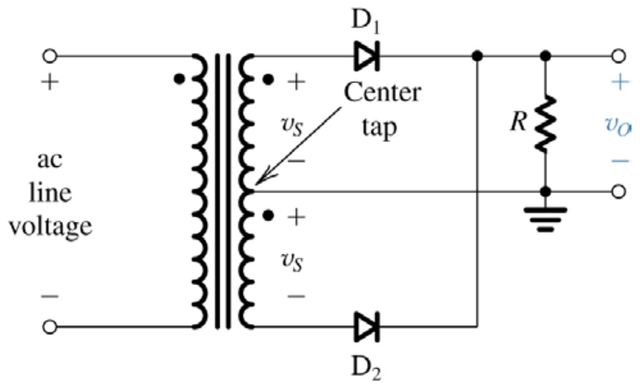
Rectifier Circuits

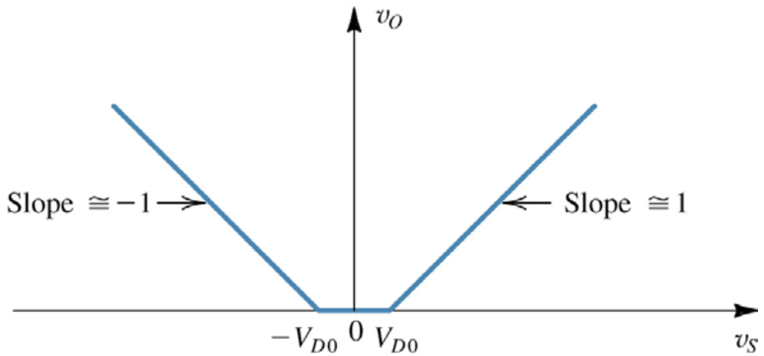
- One of the most important applications of diodes is in the design of rectifier circuits. Used to convert an AC signal into a DC voltage used by most electronics.

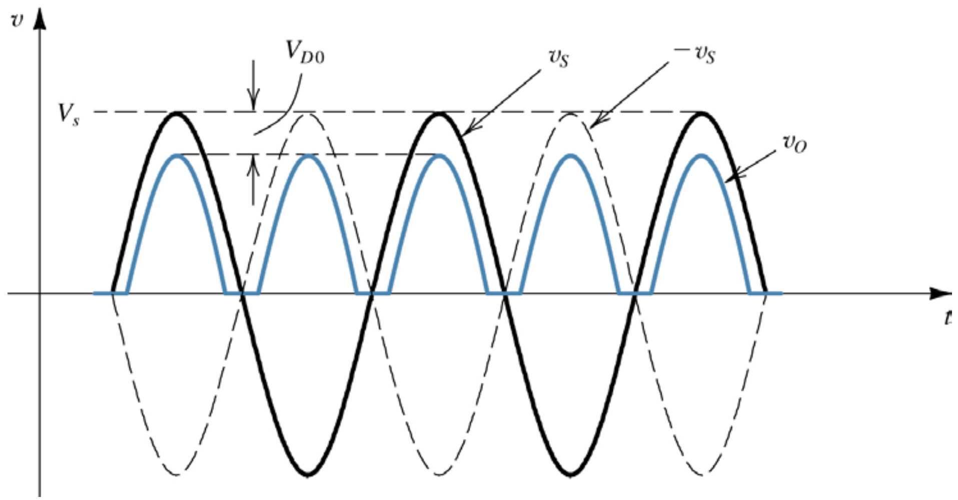


Full-Wave Rectifier

- To utilize both halves of the input sinusoid use a center-tapped transformer…

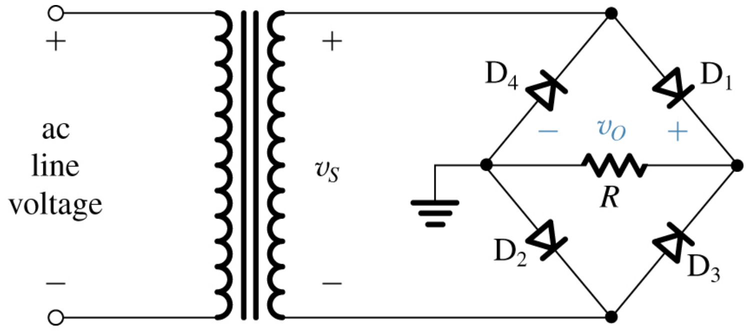


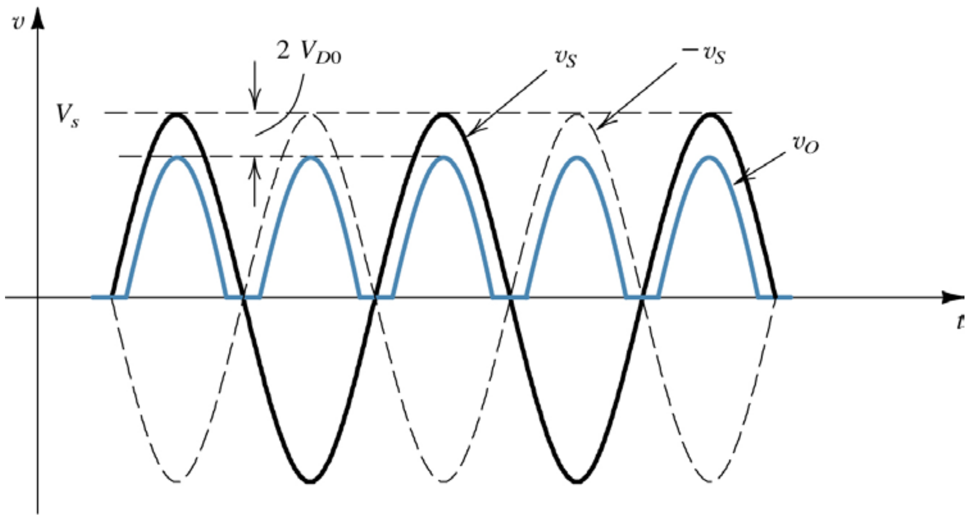




Bridge Rectifier

- Looks like a Wheatstone bridge. Does not require a center-tapped transformer.

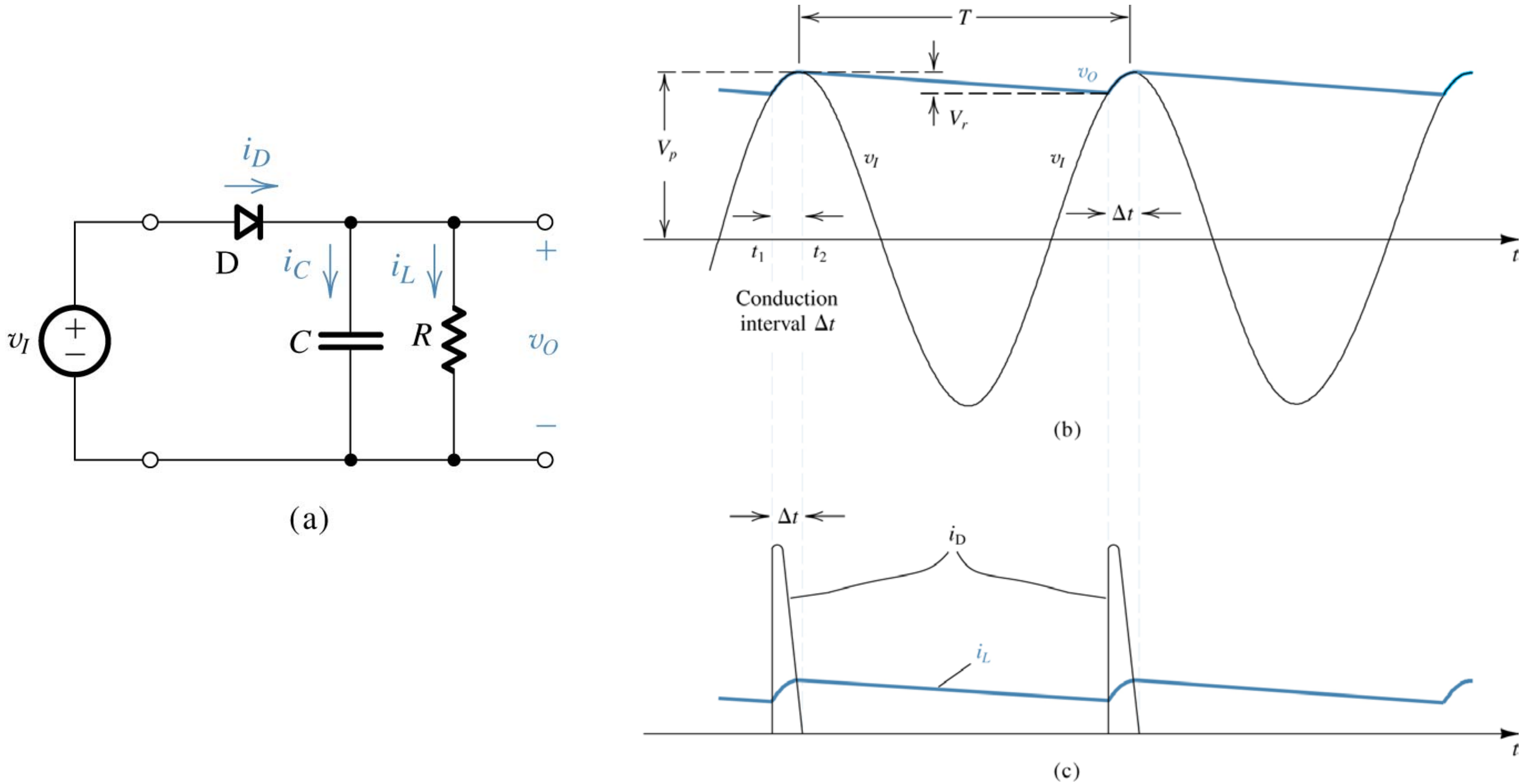




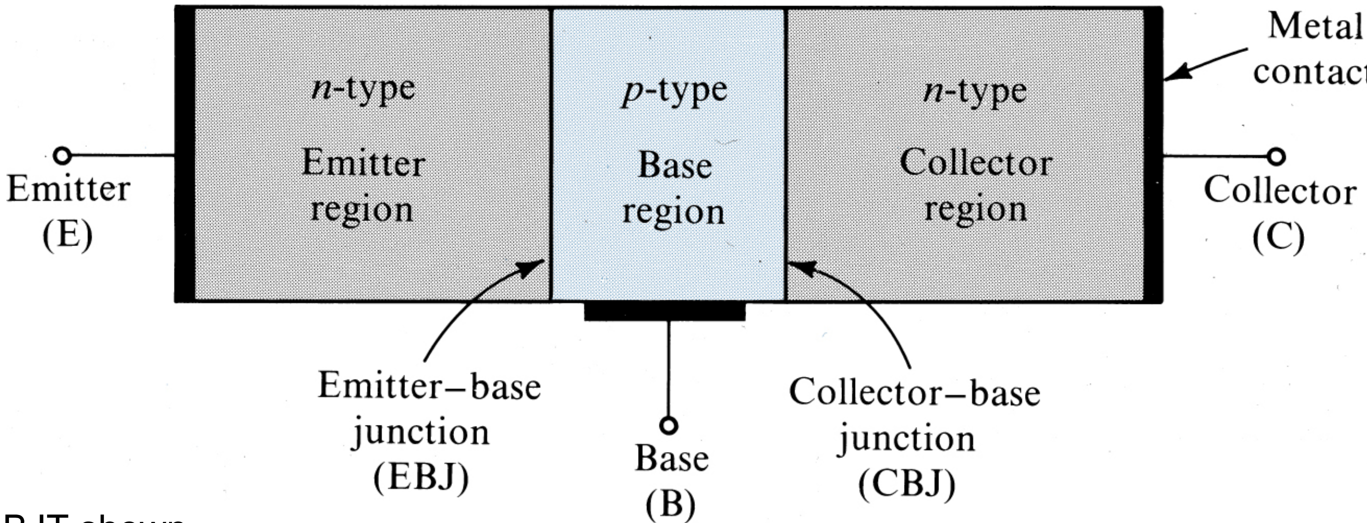
  – Requires 2 additional diodes and voltage drop is double.

Peak Rectifier

- To smooth out the peaks and obtain a DC voltage, add a cap across the output



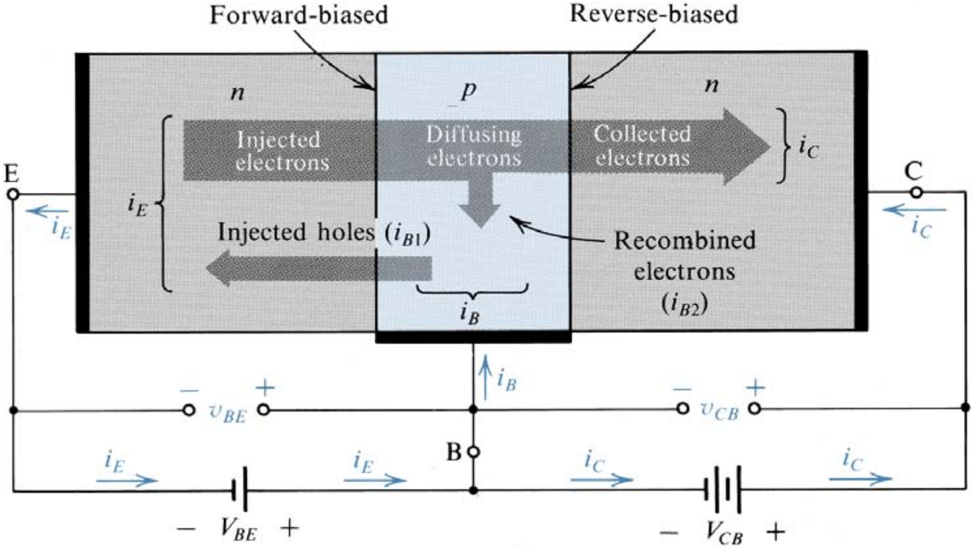
Bipolar Junction Transistor



- NPN BJT shown
- 3 terminals: emitter, base, and collector
- 2 junctions: emitter-base junction and collector-base junction
- Depending on the biasing across each of the junctions, different modes of operation are obtained – cutoff, active, and saturation

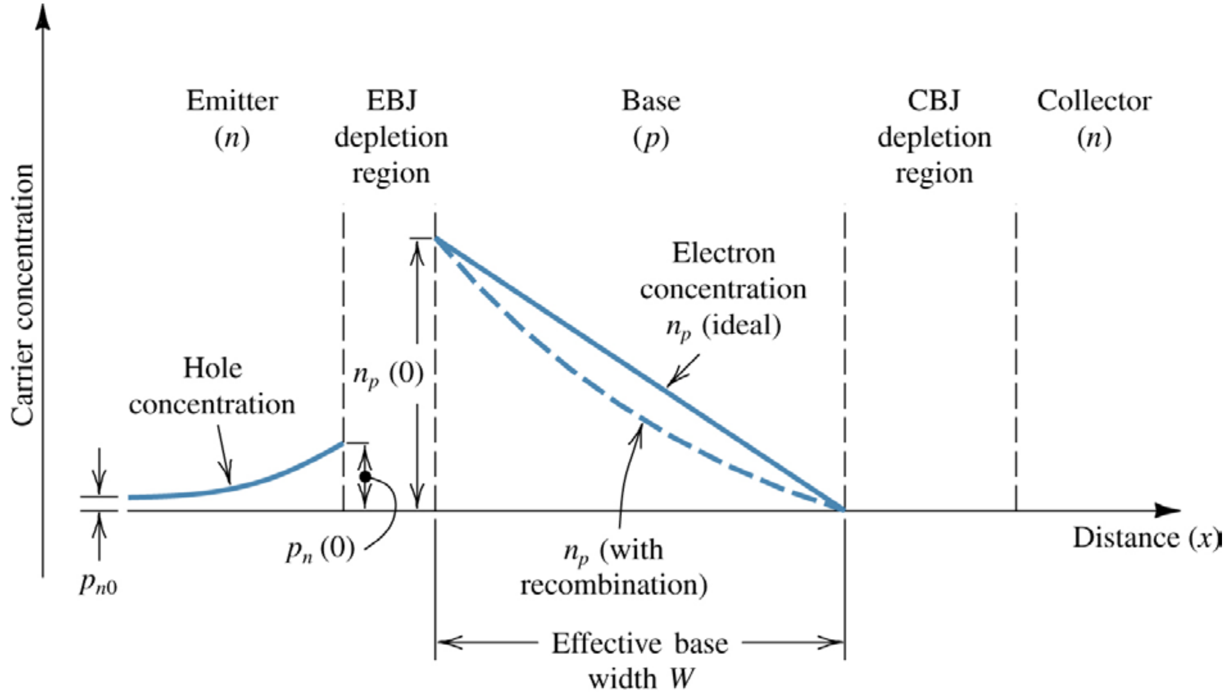
MODE	EBJ	CBJ
Cutoff	Revese	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

BJT in Active Mode



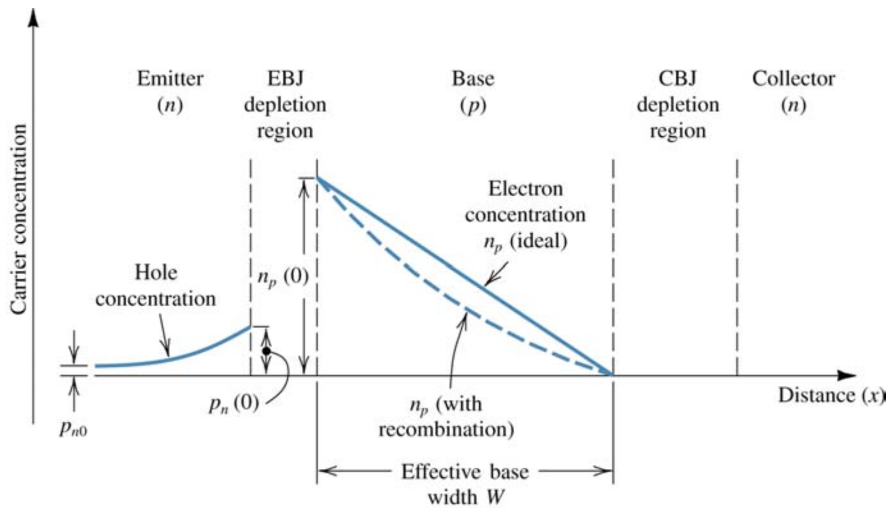
- Two external voltage sources set the bias conditions for active mode
  - Note EBJ is forward biased and CBJ is reverse biased
- Operation
  - Forward bias of EBJ injects electrons from emitter into base (small number of holes injected from base into emitter)
  - Most electrons shoot through the base into the collector across the reverse bias junction (think about band diagram)
  - Some recombine with majority carrier in n-type base

Minority Carrier Concentration Profiles



- Current dominated by electrons from emitter to base (by design) b/c of the forward bias and minority carrier concentration gradient (diffusion) through the base
  - some recombination causes bowing of electron concentration
  - base is designed to be fairly short (minimize recombination)
  - emitter is heavily (sometimes degenerately) doped and base is lightly doped
- Drift currents are usually small and neglected

Diffusion Current Through the Base



- Diffusion of electrons through the base is set by concentration profile at the EBJ

$$n_p(0) = n_{p0} e^{v_{BE}/V_T}$$

- Diffusion current of electrons through the base is (assuming an ideal straight line case):

$$I_n = A_E q D_n \frac{dn_p(x)}{dx} = A_E q D_n \left(-\frac{np(0)}{W} \right)$$

- Due recombination in the base, the current at the EBJ and current at the CBJ are not equal and differ by a base current

Collector Current

- Electrons that diffuse across the base to the CBJ junction are swept across the CBJ depletion to the collector b/c of the higher potential applied to the collector.

$$i_C = I_S e^{v_{BE}/V_T} \text{ where the saturation current } I_S = qA_E D_n n_{p0} / W$$

$$\text{can rewrite the current as } I_S = \frac{qA_E D_n n_i^2}{N_A W}$$

- Note that i_C is independent of v_{CB} (potential bias across CBJ) ideally
- Saturation current is
  - inversely proportional to W and directly proportional to A_E
    - Want short base and large emitter area for high currents
  - dependent on temperature given n_i^2

Base Current

- Base current i_B composed of two components:
  - holes injected from the base region into the emitter region

$$i_{B1} = \frac{qA_E D_p n_i^2}{N_D L_p} e^{v_{BE}/V_T}$$

  - holes supplied due to recombination in the base with diffusing electrons and depends on minority carrier lifetime τ_b in the base

$$i_{B2} = \frac{Q_n}{\tau_b}$$

And the Q in the base is $$Q_n = \frac{qA_E W n_i^2}{2N_A} e^{v_{BE}/V_T}$$

So, current is $$i_{B2} = \frac{qA_E W n_i^2}{N_A \tau_b} e^{v_{BE}/V_T}$$

- Total base current is

$$i_B = \left(\frac{qA_E D_p n_i^2}{N_D L_p} + \frac{qA_E W n_i^2}{N_A \tau_b} \right) e^{v_{BE}/V_T}$$

Beta

- Can relate i_B and i_C by the following equation

$$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

and β is

$$\beta = \frac{1}{\frac{D_p}{D_n}\frac{N_A}{N_D}\frac{W}{L_p} + \frac{1}{2}\frac{W^2}{D_n \tau_b}}$$

  - Beta is constant for a particular transistor
  - On the order of 100-200 in modern devices (but can be higher)
  - Called the common-emitter current gain
- For high current gain, want small W, low N_A, high N_D

Emitter Current

- Emitter current is the sum of i_C and i_B

$$i_E = i_C + i_B \qquad i_E = \frac{\beta + 1}{\beta} i_C$$

$$i_C = \alpha i_E \quad \text{where } \alpha = \frac{\beta}{\beta + 1}$$

α is called the common-base current gain

BJT Equivalent Circuits