Bipolar Junction Transistors (BJT)

npn E

pnp E

n-type Emitter region
p-type Base region
n-type Collector region

Emitter–base junction (EBJ)
Base (B)
Collector–base junction (CBJ)

Metal contact
Collector (C)

p-type Emitter region
n Base region
p Collector region

Metal contact
B
C
**npn BJT in “Active” Mode**

- BJT’s are biased in “active mode” for linear amplifiers (and most analog circuits)
- Base-Emitter junction is forward biased
- Base-Collector junction is reverse biased
- Electrons are injected from emitter, diffuse through base, and then swept by collector

**Question:**
What’s the difference between an npn BJT and a serially connected np and pn diodes?

**npn BJT in “Active” Mode**

\[ i_E = i_B + i_C \]

\[ i_B = \frac{i_C}{\beta} \]

- \( I_S \): Saturation current
- \( \beta \): Current gain

\[ i_C = I_S e^{v_{BE} / V_T} \]
Minority Carrier Distribution in npn BJT

1. \( n_p(0) = n_{p0} e^{\frac{eV_B}{kT}} \) (similar to pn diode)

2. \( n_p(W) = 0 \) because BC junction is reverse biased

3. \( n_p(x) \) is linear function of \( x \)

\[
I_n = A_e q D_n \frac{dn_p(x)}{dx} = -A_e q D_n \frac{n_p(0)}{W}
\]

\[
i_c = -I_n = A_e q D_n \frac{n_p}{W} e^{\frac{eV_B}{kT}} \Rightarrow i_c = I_S e^{\frac{eV_B}{kT}} , \quad \text{where} \ I_S = A_e q D_n n_{p0} \frac{N_A}{W}
\]

Cross Section of npn BJT

- E (Emitter)
- B (Base)
- C (Collector)
Voltage Polarities and Current Flow In Transistors Operating In Active Mode

Base-Emitter junction forward-biased; Base-Collector junction reverse-biased

Operation Modes for BJT: Active and Saturation

- **Active mode:**
  - BE forward biased, BC reverse biased
  - BJT's in linear amplifiers and most analog circuits are biased in active mode

- **Saturation mode:**
  - Both junctions are forward biased, BE is biased more (larger voltage) than BC
  - Used in digital circuits

- Note: Saturation modes in BJT and MOSFET (unfortunately) refer to different (opposite) regions of operation
BJT Bias Example

The BJT in the circuit has a current gain of $\beta=100$, and $i_C=1\text{mA}$ when $v_{BE}=0.7V$. Design a bias circuit (i.e., find $R_C$ and $R_E$) such that $i_C=2\text{mA}$ and $V_C=5V$.

$$R_C = \frac{15 - 5}{2mA} = 5k\Omega$$

$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_C = \frac{I_S - 1mA}{1mA} = e^{v_{BE}/V_T}$$

$$v_{BE} = V_T \ln(2) + 0.7 = 0.717V$$

$$V_E = -v_{BE} = -0.717V$$

$$R_C = \frac{V_E - (-15)}{I_C + I_B} = \frac{-0.717 + 15}{(2 + \frac{2}{100})mA} = 7.07k\Omega$$