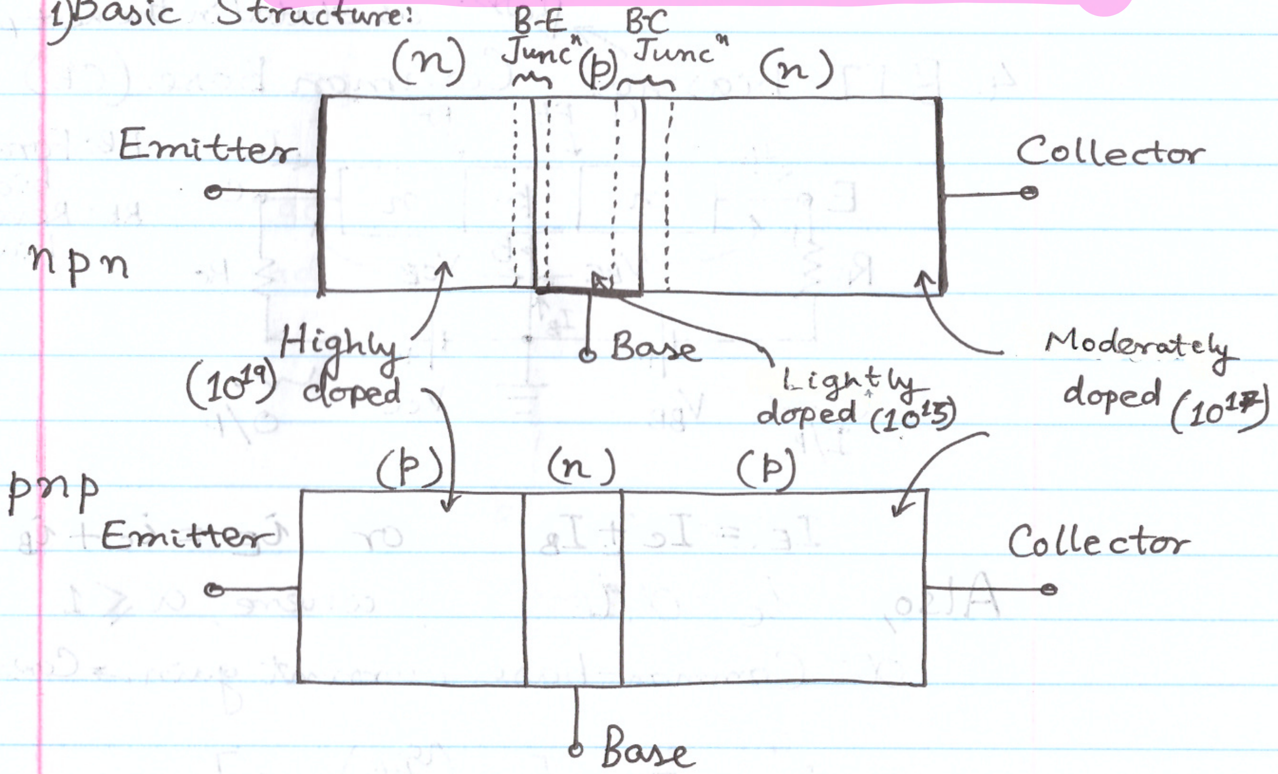
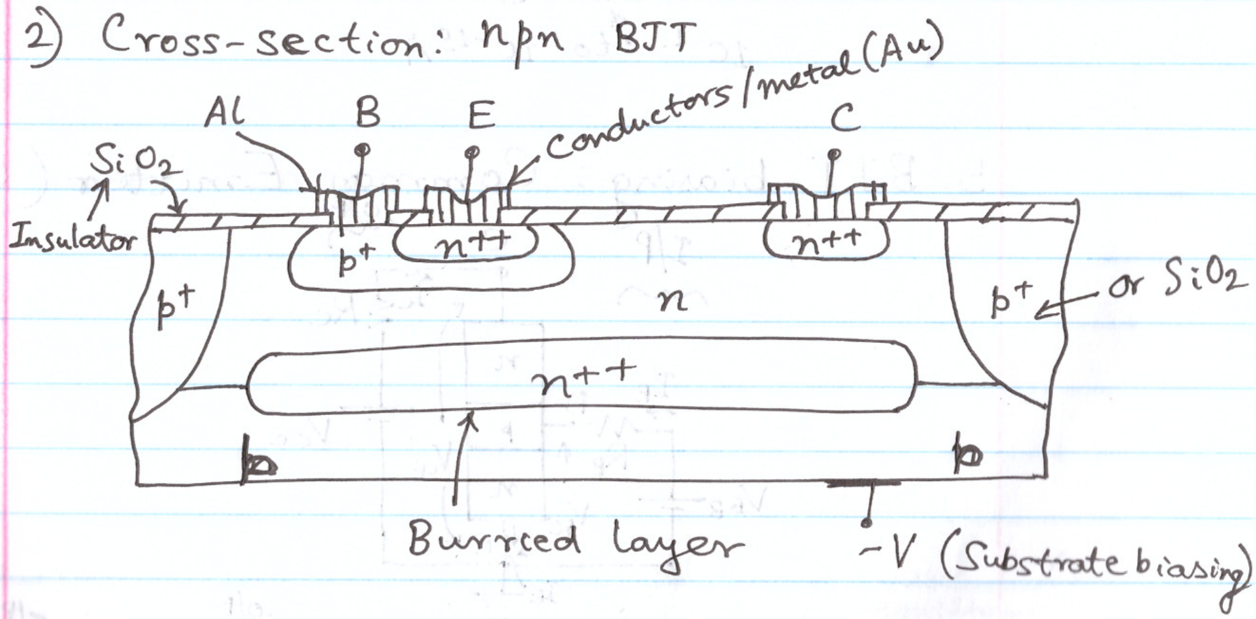
BJT
(Bipolar Junction Transistors)

1) Basic Structure:



2) Cross-section: npn BJT



3) Types of BJTs:

1) n-p-n
2) p-n-p

Transistor Currents

Figure 5.3 shows an idealized npn bipolar transistor biased in the forward-active mode. Since the B–E junction is forward biased, electrons from the emitter are injected across

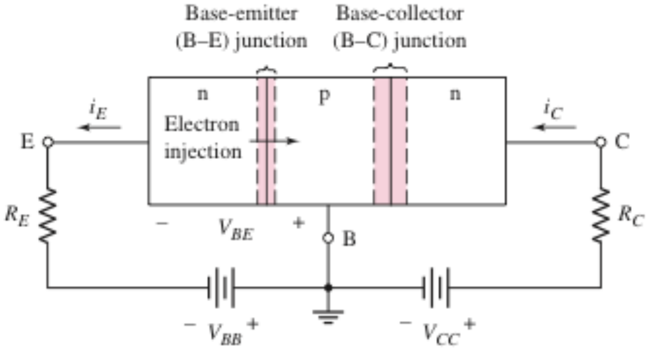


Figure 5.3 An npn bipolar transistor biased in the forward-active mode; base–emitter junction forward biased and base–collector junction reverse biased

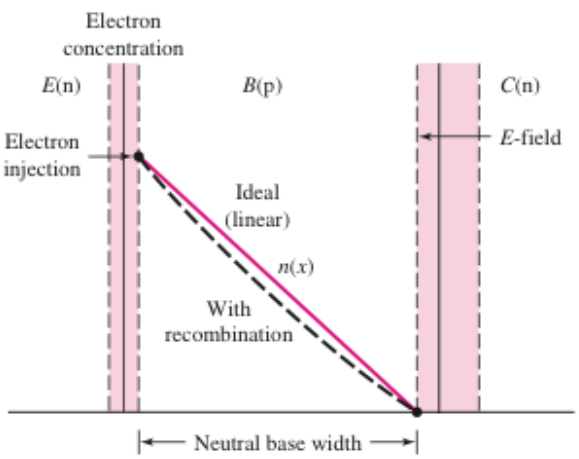


Figure 5.4 Minority carrier electron concentration across the base region of an npn bipolar transistor biased in the forward-active mode. Minority carrier concentration is a linear function versus distance for an ideal transistor (no carrier recombination), and is a nonlinear function versus distance for a real device (with carrier recombination).

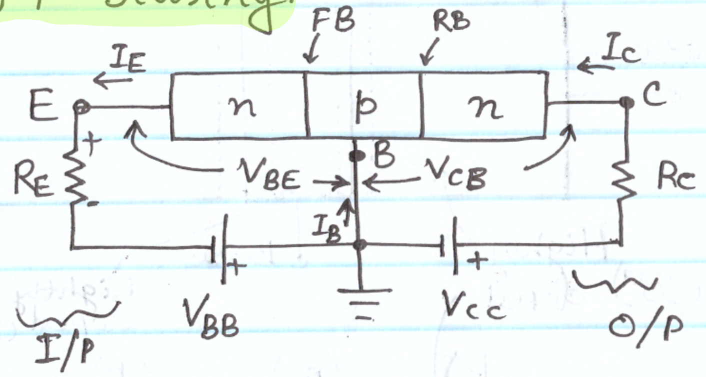
the B–E junction into the base, creating an excess minority carrier concentration in the base. Since the B–C junction is reverse biased, the electron concentration at the edge of that junction is approximately zero.

The base region is very narrow so that, in the ideal case, the injected electrons will not recombine with any of the majority carrier holes in the base. In this case, the electron distribution versus distance through the base is a straight line as shown in Figure 5.4. Because of the large gradient in this concentration, electrons that are injected, or *emitted,* from the emitter region diffuse across the base, are swept across the base–collector space-charge region by the electric field, and are *collected* in the collector region creating the collector current. However, if some carrier recombination does occur in the base, the electron concentration will deviate from the ideal linear curve, as shown in the figure. To minimize recombination effects, the width of the neutral base region must be small compared to the minority carrier diffusion length.

→ • BE junct^th is Fwd. biased.
• BC junct^th is reverse biased.

Active Region → Based on modes of operation, as stated in the next page.

4. BJT biasing: Common Base (CB)



FB: Forward biased
RB: Reverse biased

$I_c = \alpha . I_E$

$$\boxed{i_c = \alpha . i_E}$$; where, $\alpha \leq 1$

α: Common-base current gain → Constant no.

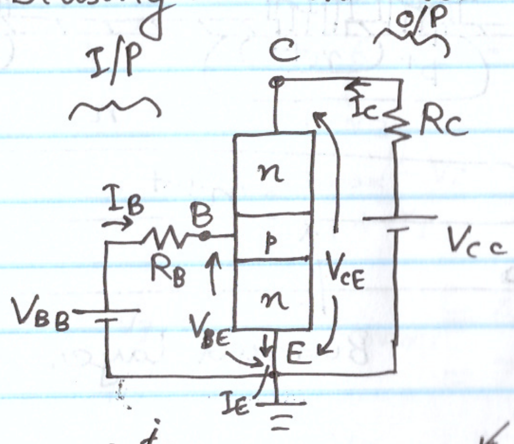
→ From Diodes

$$\boxed{i_E = I_{EO} \left[e^{\left(\frac{v_{BE}}{V_T}\right)} - 1 \right]}$$

I_{EO}: 10^{-12} to 10^{-15} A

NOTE: $I_{EO} \propto$ B-E Cross-Sectional Area

5. BJT biasing: Common Emitter (CE)



$i_E = i_c + i_B$; $i_c = \beta . i_B$

$\Rightarrow i_E = (1+\beta) i_B$

O/P: i_c, I/P: I_B

$$\boxed{i_c = \beta . I_B}$$

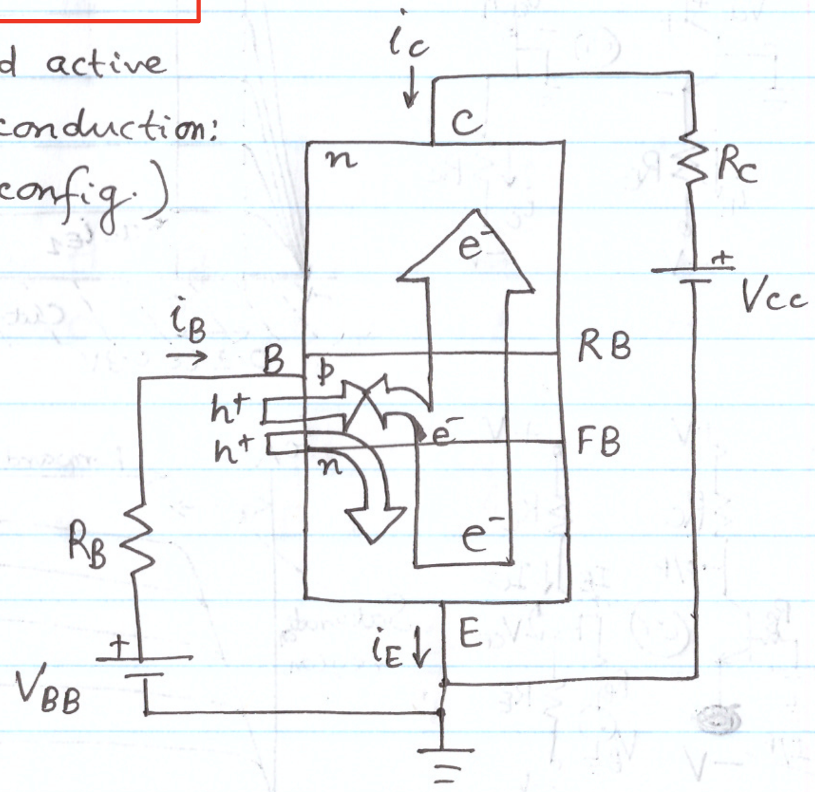
$\beta \gg 1$

β: Common emitter current gain.

&, $i_c = \left(\frac{\beta}{1+\beta}\right) i_E$

$$\boxed{\alpha = \frac{\beta}{1+\beta}} \quad (\&) \quad \beta = \frac{\alpha}{1-\alpha}$$

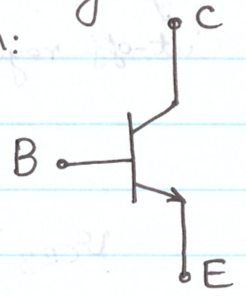
5. Forward active mode conduction: (CE config.)



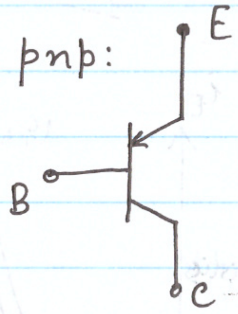
$V_{CC} > V_{BB}$

6. BJT symbols:

npn:



pnp:



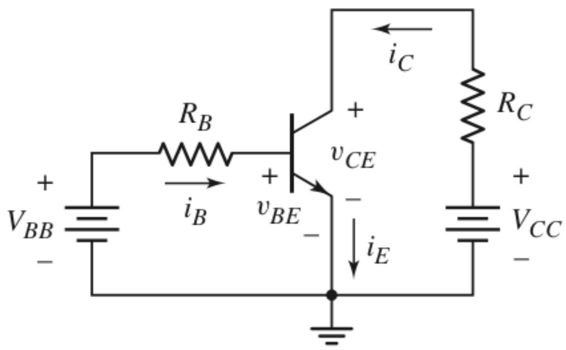
7. a. Transistor (BJT) modes of operation:
1) Common base (CB)
2) Common emitter (CE)
3) Common collector (CC)

b. Transistor (BJT) regions of operation:
1) Cut-off (OFF switch)
2) Saturation (resistor-like)
3) Active → Forward (ON switch with resistance) / → Reverse (special resistor)
4) Breakdown (causes permanent damage)

CB

The C–B voltage can be varied by changing the V^+ voltage (Figure 5.11(a)) or the V^- voltage (Figure 5.11(b)). When the collector–base junction becomes forward biased in the range of 0.2 and 0.3 V, the collector current i_C is still essentially equal to the emitter current i_E. In this case, the transistor is still basically biased in the forward-active mode. However, as the forward-bias C–B voltage increases, the linear relationship between the collector and emitter currents is no longer valid, and the collector current very quickly drops to zero.

CE



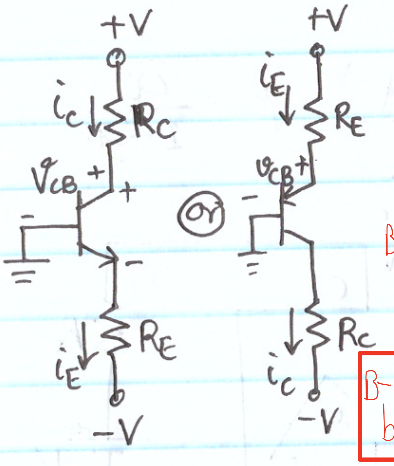
[redacted]. In this circuit, the V_{BB} source forward biases the B–E junction and controls the base current i_B. The C–E voltage can be varied by changing V_{CC}.

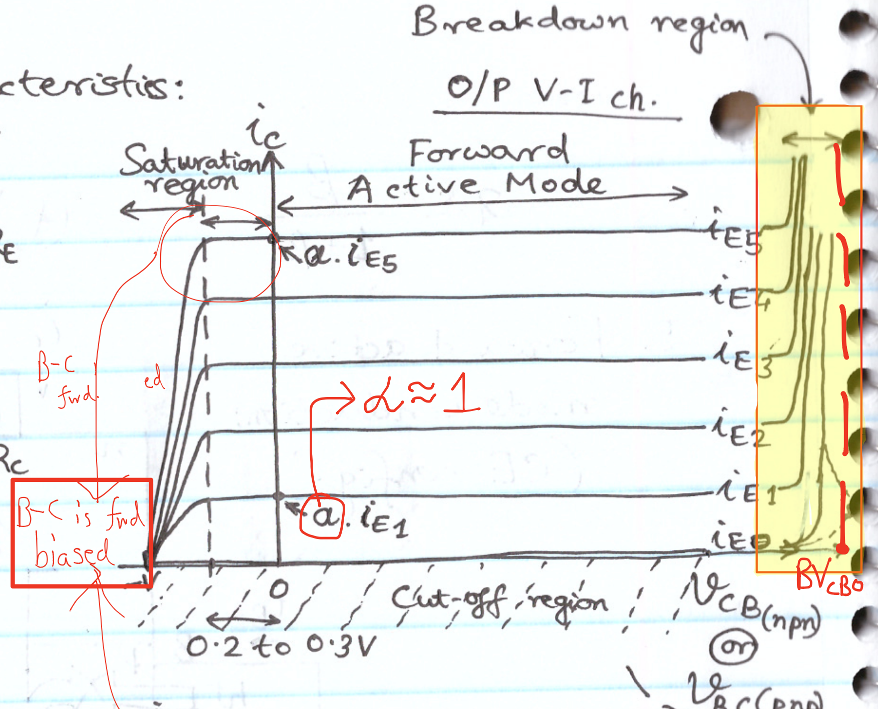
In the npn device, in order for the transistor to be biased in the forward-active mode, the B–C junction must be zero or reverse biased, which means that V_{CE} must be greater than approximately $V_{BE}(\text{on})$.[5] For $V_{CE} > V_{BE}(\text{on})$, there is a finite slope to the curves. If, however, $V_{CE} < V_{BE}(\text{on})$, the B–C junction becomes forward biased, the transistor is no longer in the forward-active mode, and the collector current very quickly drops to zero.

7c. V-I characteristics:

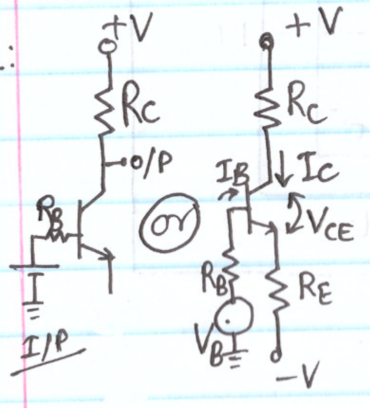
CB:

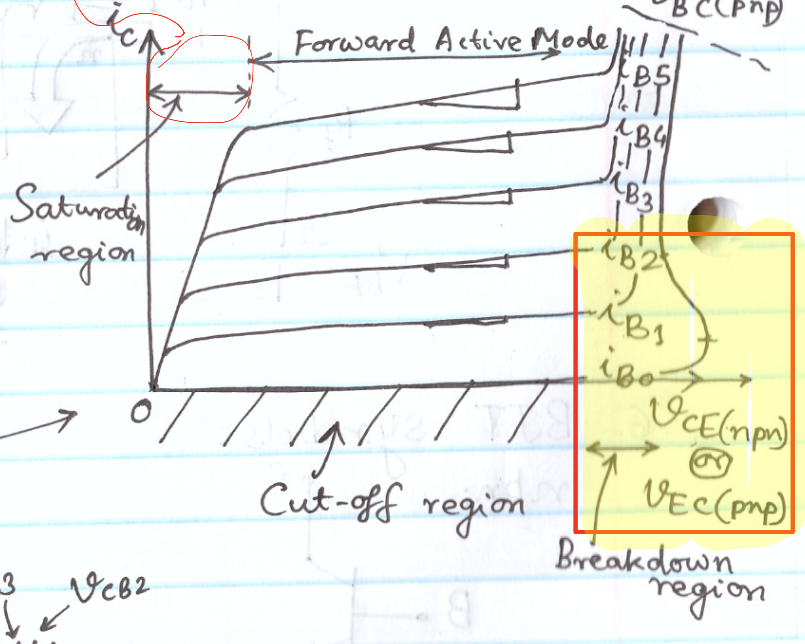
Can be treated as a const. I Source.





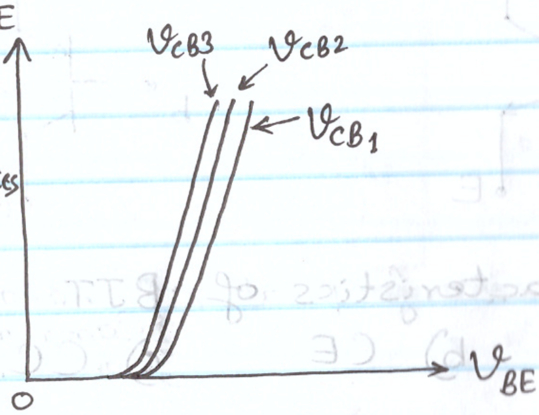
CE:



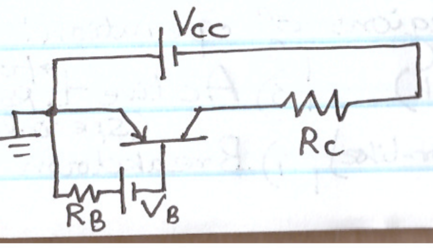


O/P V-I Characteristics

I/P V-I Characteristics (Diode-like)



$v_{CB3} > v_{CB2} > v_{CB1}$



CE config for pnp

Breakdown Voltage: Common-Emitter Characteristics

Figure 5.18 shows the i_C versus v_{CE} characteristics of an npn transistor, for various constant base currents, and an ideal breakdown voltage of BV_{CEO}. The value of BV_{CEO} is less than the value of BV_{CBO} because BV_{CEO} includes the effects of the transistor action, while BV_{CBO} does not. This same effect was observed in the I_{CEO} leakage current.

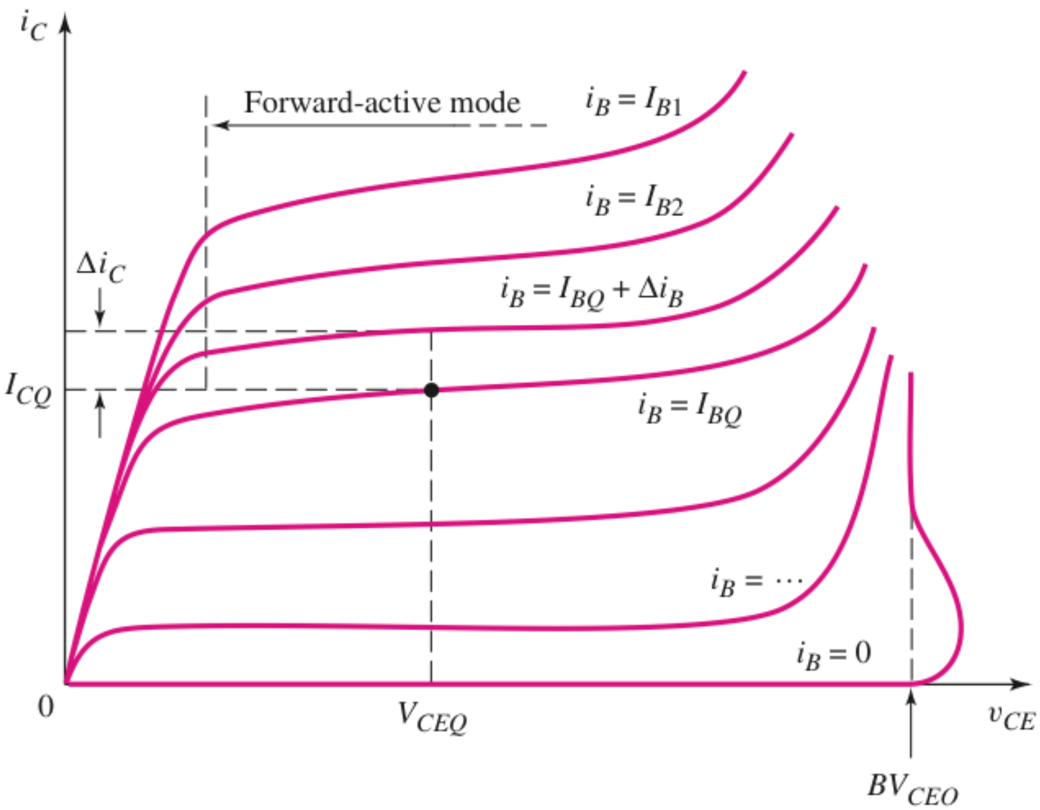


Figure 5.18 Common-emitter characteristics showing breakdown effects

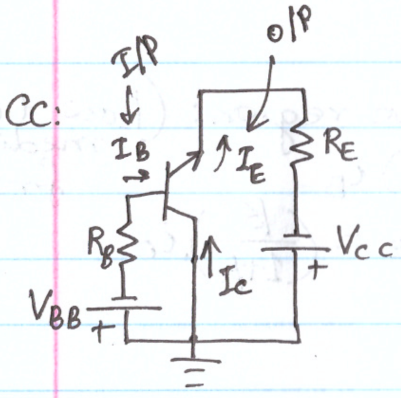
The breakdown voltage characteristics for the two configurations are also different. The breakdown voltage for the open-base case is given by

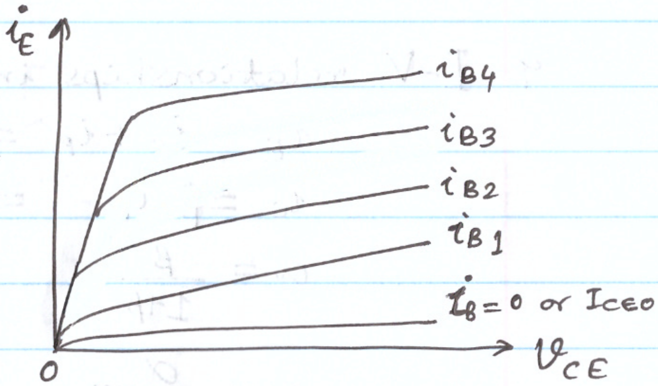
$$\boxed{BV_{CEO} = \frac{BV_{CBO}}{\sqrt[n]{\beta}}} \tag{5.22}$$

where n is an empirical constant usually in the range of 3 to 6.

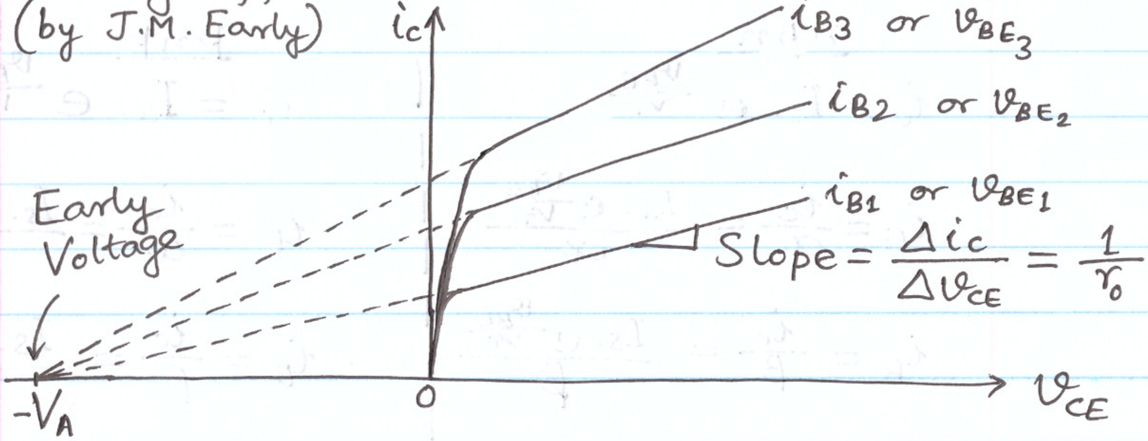
BJT (cont.)

CC:





8. Early effect & base width modulation (CE):
(by J.M. Early)



$$\text{Slope} = \frac{\Delta i_C}{\Delta v_{CE}} = \frac{1}{r_o}$$

r_o: O/P resistance

$$r_o \cong \frac{V_A}{I_C}$$

$$\boxed{i_C = I_S \cdot e^{\left(\frac{v_{BE}}{V_T}\right)} \cdot \left(1 + \frac{v_{CE}}{V_A}\right)}$$ While early effect is considered.

$|V_A|$: 50 to 300V (typically)

Base width modulation: $v_{BE}\uparrow$ $i_B\uparrow$ Junc^n width (CB) $\downarrow$

Width of base region $\uparrow$ $i_C\uparrow$

Early Effect

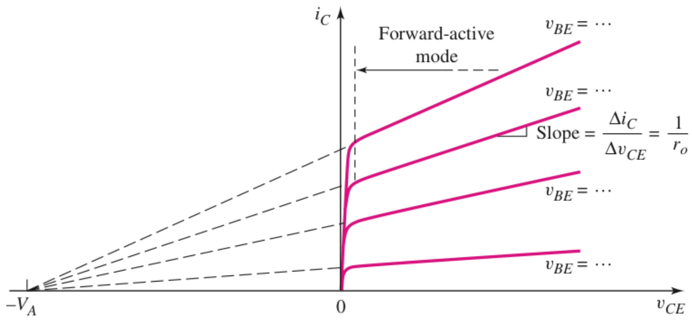


Figure 5.14 Current-voltage characteristics for the common-emitter circuit, showing the Early voltage and the finite output resistance, r_o, of the transistor

Figure 5.14 shows an exaggerated view of the current–voltage characteristics plotted for constant values of the B–E voltage. The curves are theoretically linear with respect to the C–E voltage in the forward-active mode. The slope in these characteristics is due to an effect called base-width modulation that was first analyzed by J. M. Early. The phenomenon is generally called the *Early effect*. When the curves are extrapolated to zero current, they meet at a point on the negative voltage axis, at $v_{CE} = -V_A$. The voltage V_A is a positive quantity called the **Early voltage.** Typical

Base Width Modulation

For a given value of v_{BE} in an npn transistor, if v_{CE} increases, the reverse-bias voltage on the collector–base junction increases, which means that the width of the B–C space-charge region also increases. This in turn reduces the neutral base width W (see Figure 5.4). A decrease in the base width causes the gradient in the minority carrier concentration to increase, which increases the diffusion current through the base. The collector current then increases as the C–E voltage increases.