Faculty of Engineering

ECE 335: Electronic Engineering

Lecture 10:
BJT Applications

BJT Applications

- Amplifiers
- Switches
- Logic Gates
- Current Sources

I, V NOTATIONS

I, V Notations

- It is critical to understand the notation used for voltages and currents in the following discussion of transistor amplifiers.
- This is therefore dealt with explicitly ‘up front’.
- As with dynamic resistance in diodes we will be dealing with a.c. signals superimposed on d.c. bias levels.

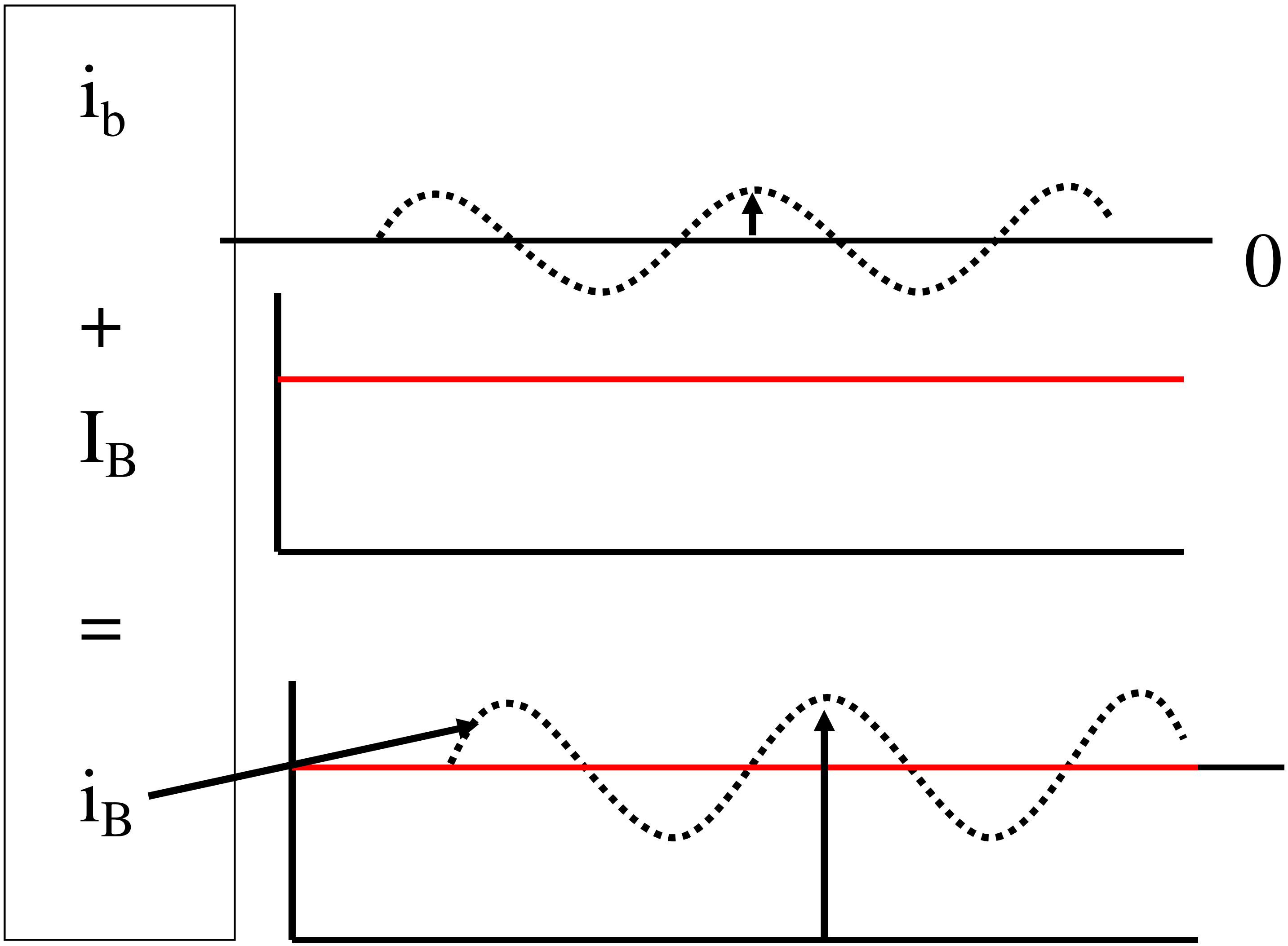
I, V Notations

- We will use a capital (upper case) letter for a d.c. quantity (e.g. I, V).
- We will use a lower case letter for a time varying (a.c.) quantity (e.g. i, v)

I, V Notations

- These primary quantities will also need a subscript identifier (e.g. is it the base current or the collector current?).
- For d.c. levels this subscript will be in *upper case*.
- We will use a *lower case subscript* for the a.c. signal bit (e.g. i_b).
- And an *upper case subscript* for the total time varying signal (i.e. the a.c. signal bit plus the d.c. bias) (e.g. i_B).This will be less common.

I, V Notations



I, V Notations

- It is convention to refer all transistor voltages to the ‘common’ terminal.
- Thus in the CE configuration we would write V_{CE} for a d.c. collector emitter voltage and V_{BE} for a d.c. base emitter voltage.

COMMON EMITTER CHARACTERISTICS

Common Emitter Characteristics

- ***For the present we consider DC behaviour and assume that we are working in the normal linear amplifier regime with the BE junction forward biased and the CB junction reverse biased***

Common Emitter Characteristics

Treating the transistor as a current node:

$$I_E = I_C + I_B$$

- Also:

$$I_C = \alpha I_E + I_{co}$$

Common Emitter Characteristics

- Hence:

$$I_C = \alpha(I_C + I_B) + I_{CO}$$

which after some rearrangement gives

$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{I_{CO}}{1-\alpha}\right)$$

Common Emitter Characteristics

- Define a common emitter current-transfer ratio β

$$\beta = \left(\frac{\alpha}{1-\alpha} \right)$$

Such that:

$$I_C = \beta I_B + \left(\frac{I_{CO}}{1-\alpha} \right)$$

Common Emitter Characteristics

- Since reverse saturation current is negligible the second term on the right hand side of this equation can usually be neglected (even though (1- α) is small)
- Thus

$$I_C \approx \beta I_B$$

Common Emitter Characteristics

- We note, in passing that, if β can be regarded as a constant for a given transistor then

$$i_c \approx \beta i_b$$

- For a practical (non-ideal) transistor this is only true at a particular bias (operating) point.

Common Emitter Characteristics

- A small change in α causes a much bigger change in ß which means that ß can vary significantly, even from transistor to transistor of the same type.
- We must try and allow for these variations in circuit design.

Common Emitter Characteristics

For example;

$\alpha = 0.98, \beta = 49$

$\alpha = 0.99, \beta = 99$

$\alpha = 0.995, \beta = 199$

Common Emitter Characteristics

- β is also known as h_{FE} and may appear on data sheets and in some textbooks as such.

- For a given transistor type data sheets may specify a range of β values

Common Emitter Characteristics

- The behaviour of the transistor can be represented by current-voltage (I-V) curves (called the characteristic curves of the device).
- As noted previously in the common emitter (CE) configuration the input is between the base *and the emitter* and the output is between the collector *and the emitter*.

Common Emitter Characteristics

- We can therefore draw an input characteristic (plotting base current I_B against base-emitter voltage V_{BE}) and
- an output characteristic (plotting collector current I_c against collector-emitter voltage V_{CE})

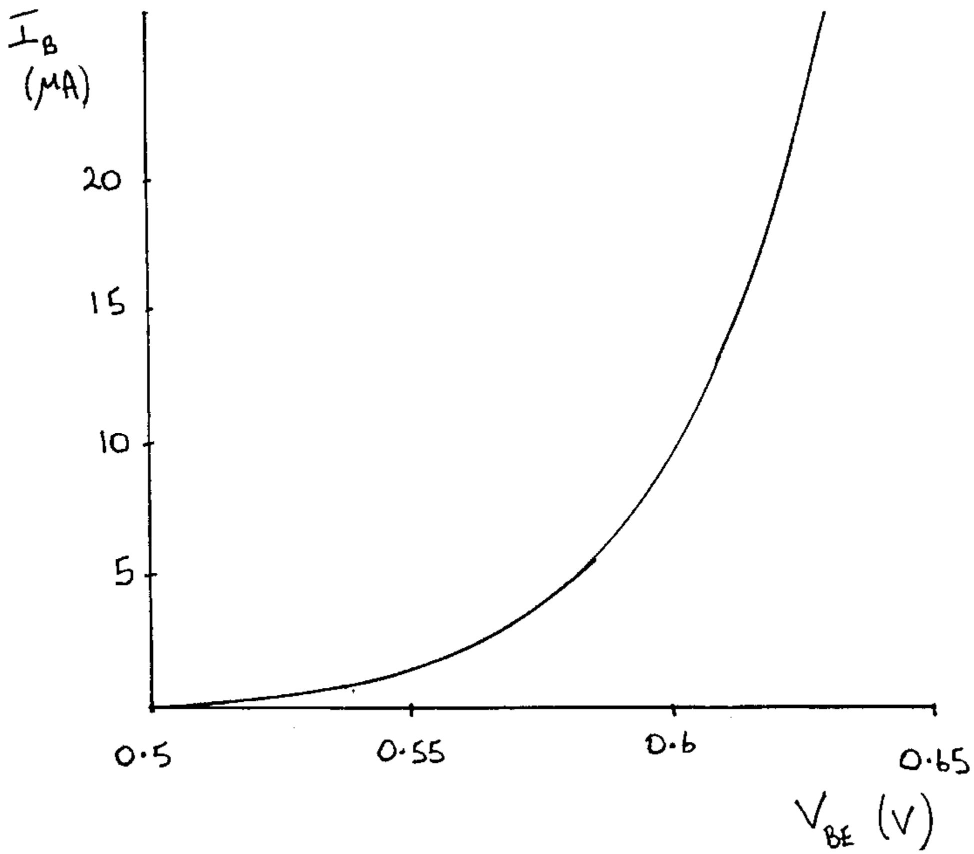
Common Emitter Characteristics

- We will be using these characteristic curves extensively to understand:
- How the transistor operates as a linear amplifier for a.c. signals.
- The need to superimpose the a.c. signals on d.c. bias levels.
- The relationship between the transistor and the circuit in which it is placed.

Common Emitter Characteristics

- Once these basics are understood we will understand:
- Why we can replace the transistor by a small signal (a.c.) equivalent circuit.
- How to derive a simple a.c. equivalent circuit from the characteristic curves.
- Some of the limitations of our simple equivalent circuit.

IDEAL CE INPUT (Base) Characteristics

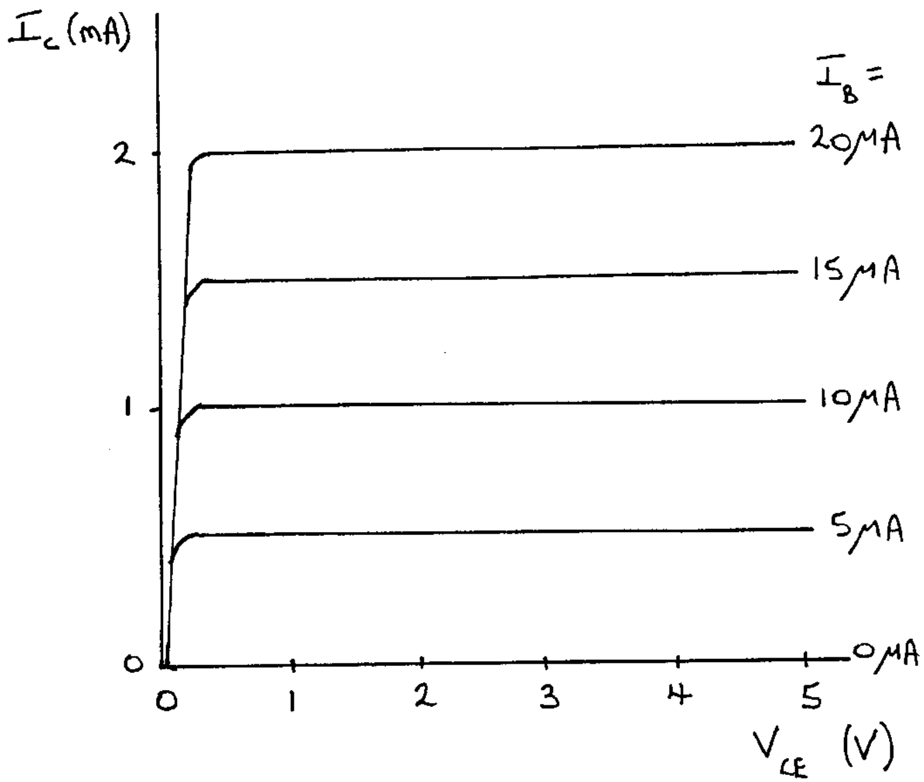


INPUT (BASE) CHARACTERISTIC

IDEAL CE INPUT Characteristics

- The plot is essentially that of a forward biased diode.
- We can thus assume $V_{BE} \approx 0.6$ V when designing our d.c. bias circuits.
- We can also assume everything we know about incremental diode resistance when deriving our a.c. equivalent circuit.
- In the ‘non-ideal’ case I_B will vary slightly with V_{CE}. This need not concern us.

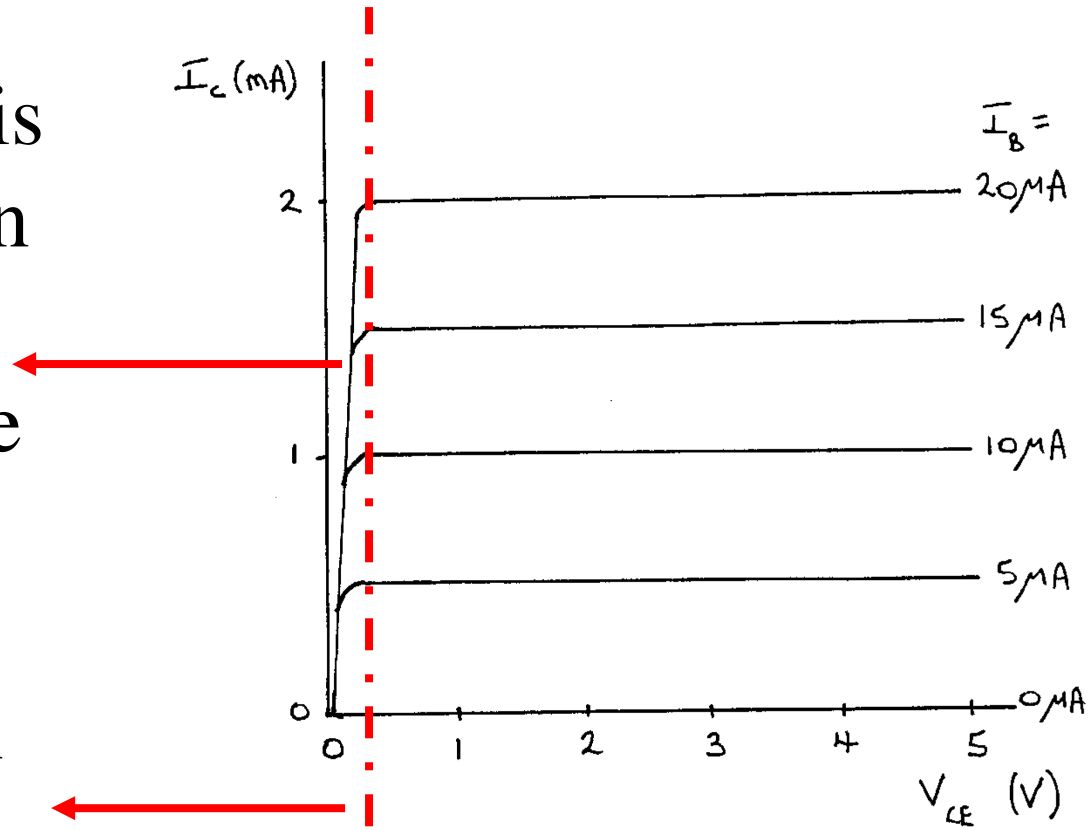
IDEAL CE OUTPUT (Collector) Characteristics



OUTPUT (COLLECTOR) CHARACTERISTIC

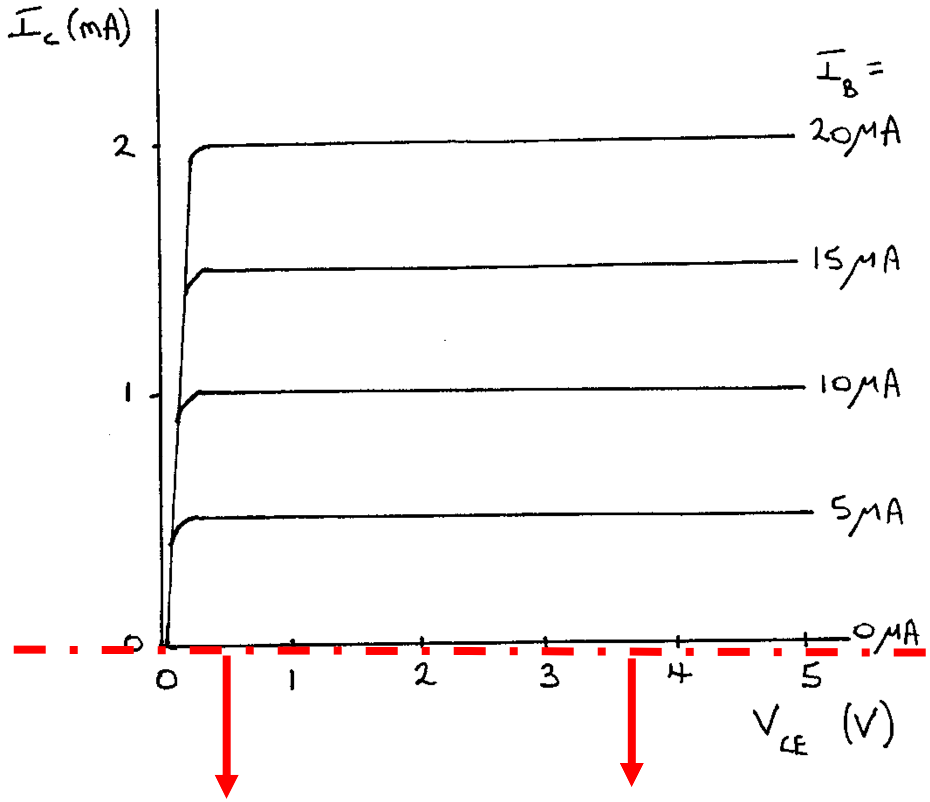
IDEAL CE OUTPUT (Collector) Characteristics

Avoid this saturation region where we try to forward bias both junctions



OUTPUT (COLLECTOR) CHARACTERISTIC

IDEAL CE OUTPUT

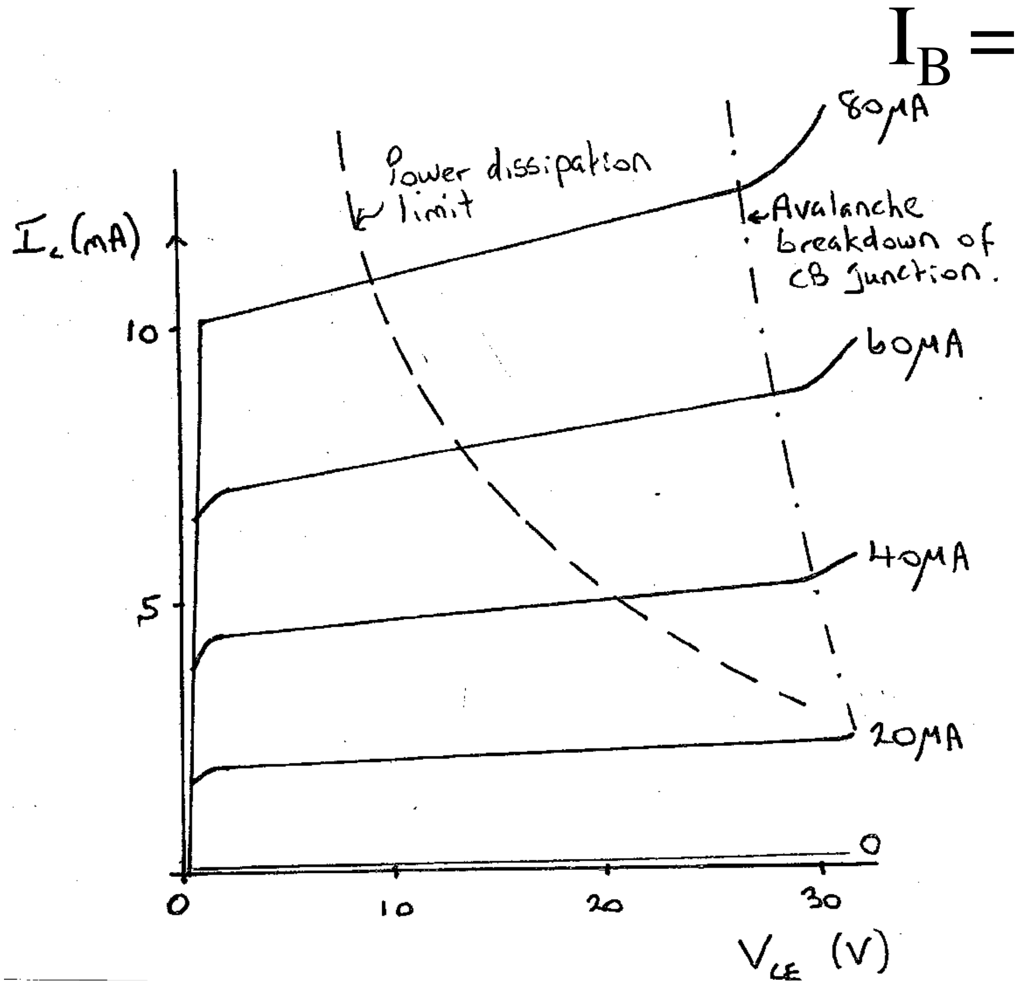


Avoid this cut-off region where we try to reverse bias both junctions (I_C approximately 0)

IDEAL CE OUTPUT (Collector) Characteristics

- The plots are all parallel to the V_{CE} axis (i.e. I_C does not depend on V_{CE})
- The curves strictly obey $I_C = \beta I_B$
- In particular $I_C = 0$ when $I_B = 0$.
- We shall work with the ideal characteristic and later on base our a.c. equivalent circuit model upon it.

ACTUAL CE OUTPUT Characteristics

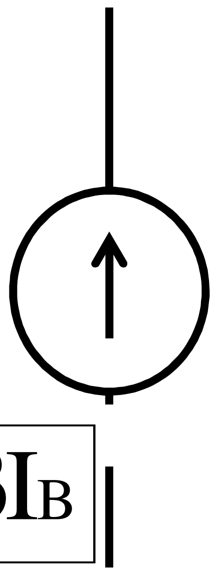


ACTUAL CE OUPUT Characteristics

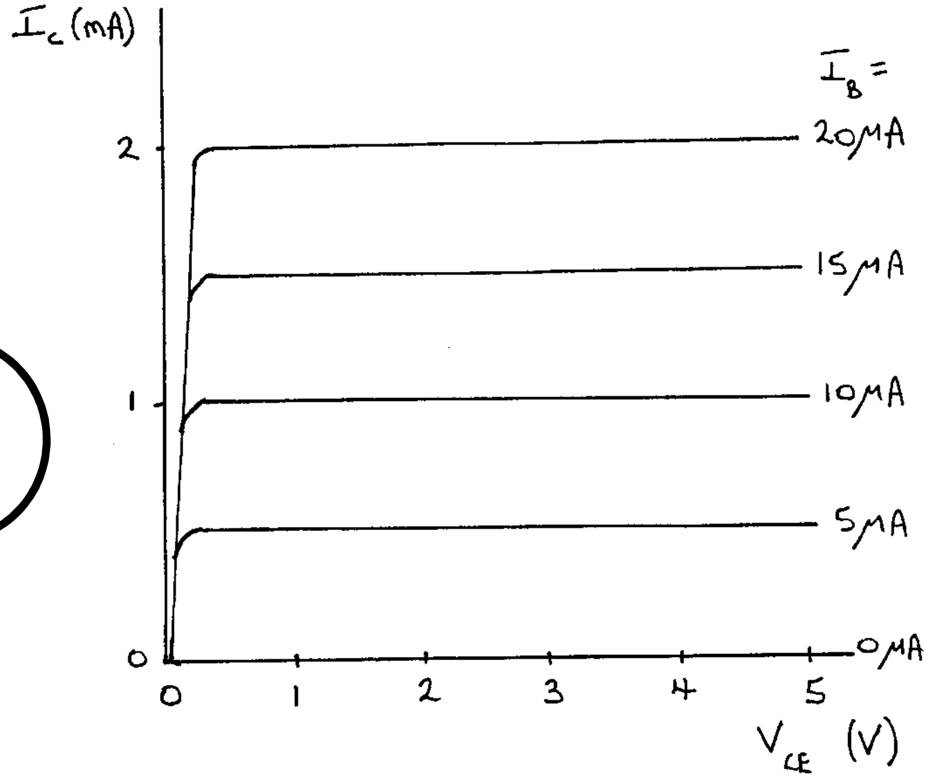
- Salient features are:
- The finite slope of the plots (I_C depends on V_{CE})
- A limit on the power that can be dissipated.
- The curves are not equally spaced (i.e β varies with base current, I_B).

THE BJT AS A CURRENT SOURCE

Current Controlled Current Source



$I_C \approx \beta I_B$



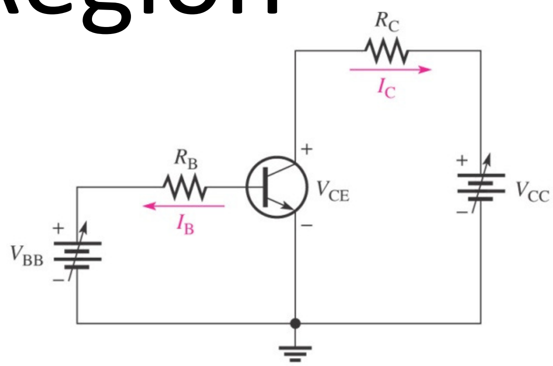
OUTPUT (COLLECTOR) CHARACTERISTIC

THE BJT AS AN AMPLIFIER

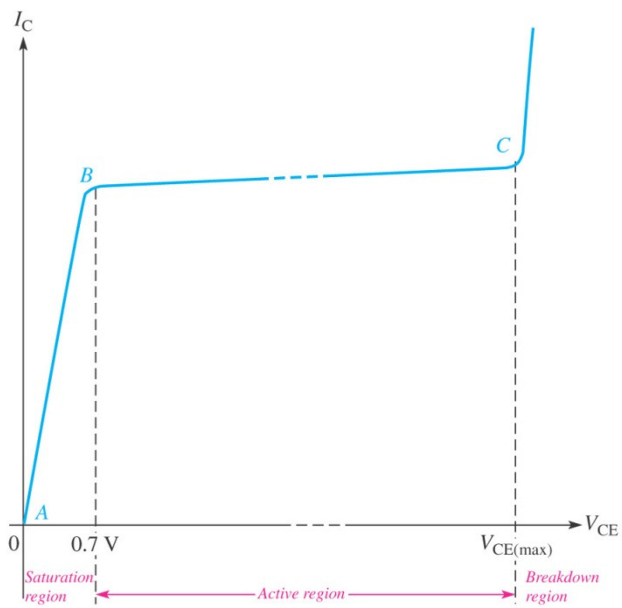
Summary of BJT Operational Regions

- BJT will operates in one of following four region
  - Cutoff region (for digital circuit)
  - Saturation region (for digital circuit)
  - Linear (active) region (to be an amplifier)
  - Breakdown region (always be a disaster)

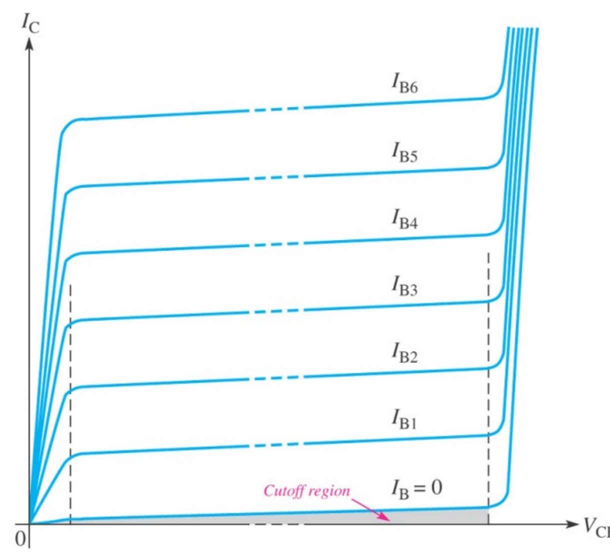
Summary of BJT Operational Region



(a) Circuit



(b) I_C versus V_{CE} curve for one value of I_B



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

DC Analysis of BJTs

- Transistor Currents:

$$I_E = I_C + I_B$$

- **alpha** (α)

$$I_C = \alpha\, I_E$$

- **beta** (β)

$$I_C = \beta\, I_B$$

  - β typically has a value between 20 and 200

DC Analysis of BJTs

- DC voltages for the biased transistor:
- Collector voltage

$$V_C = V_{CC} - I_C R_C$$

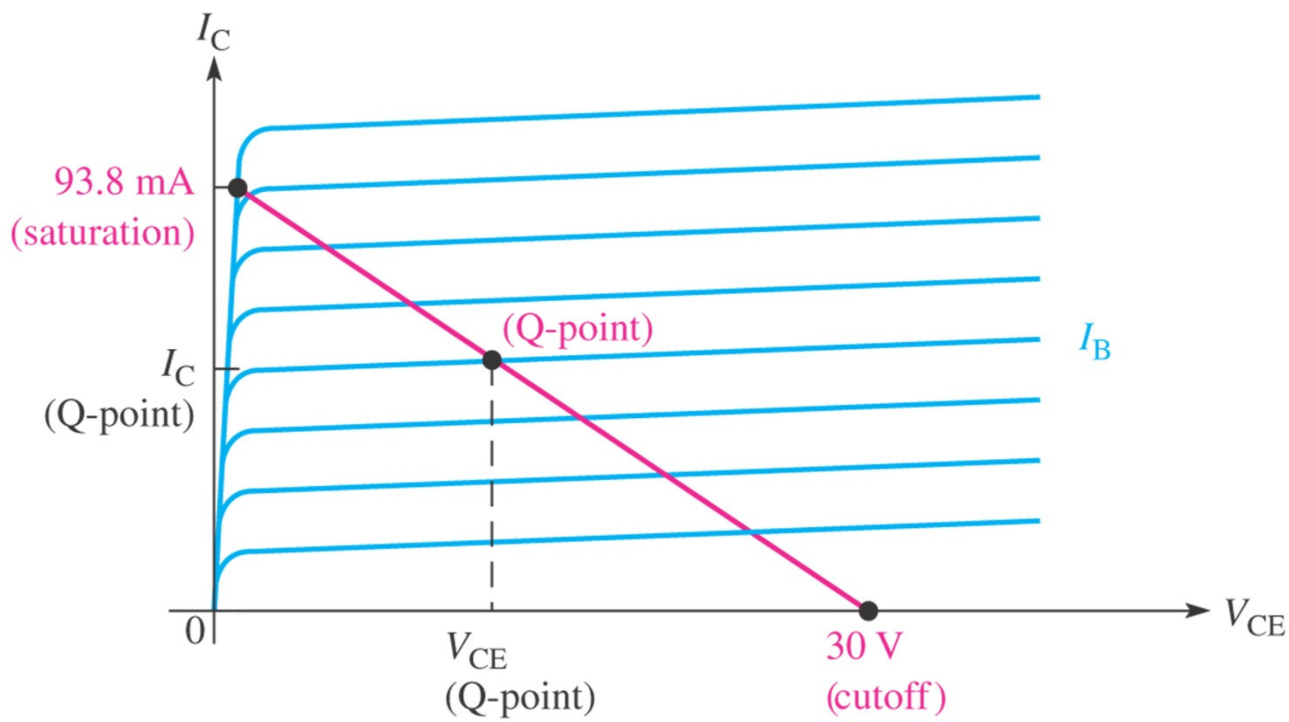
- Base voltage

$$V_B = V_E + V_{BE}$$

  – for silicon transistors, $V_{BE} = 0.7$ V
  – for germanium transistors, $V_{BE} = 0.3$ V

Q-point

- The base current, I_B, is established by the base bias
- The point at which the base current curve intersects the dc load line is the quiescent or Q-point for the circuit



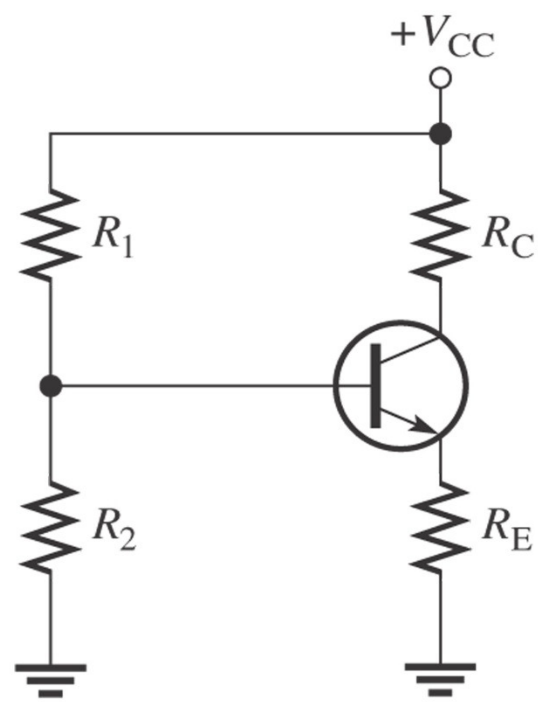
DC Analysis of BJTs

- The voltage divider biasing is widely used
- Input resistance is:

$$R_{IN} \cong \beta_{DC} R_E$$

- The base voltage is approximately:

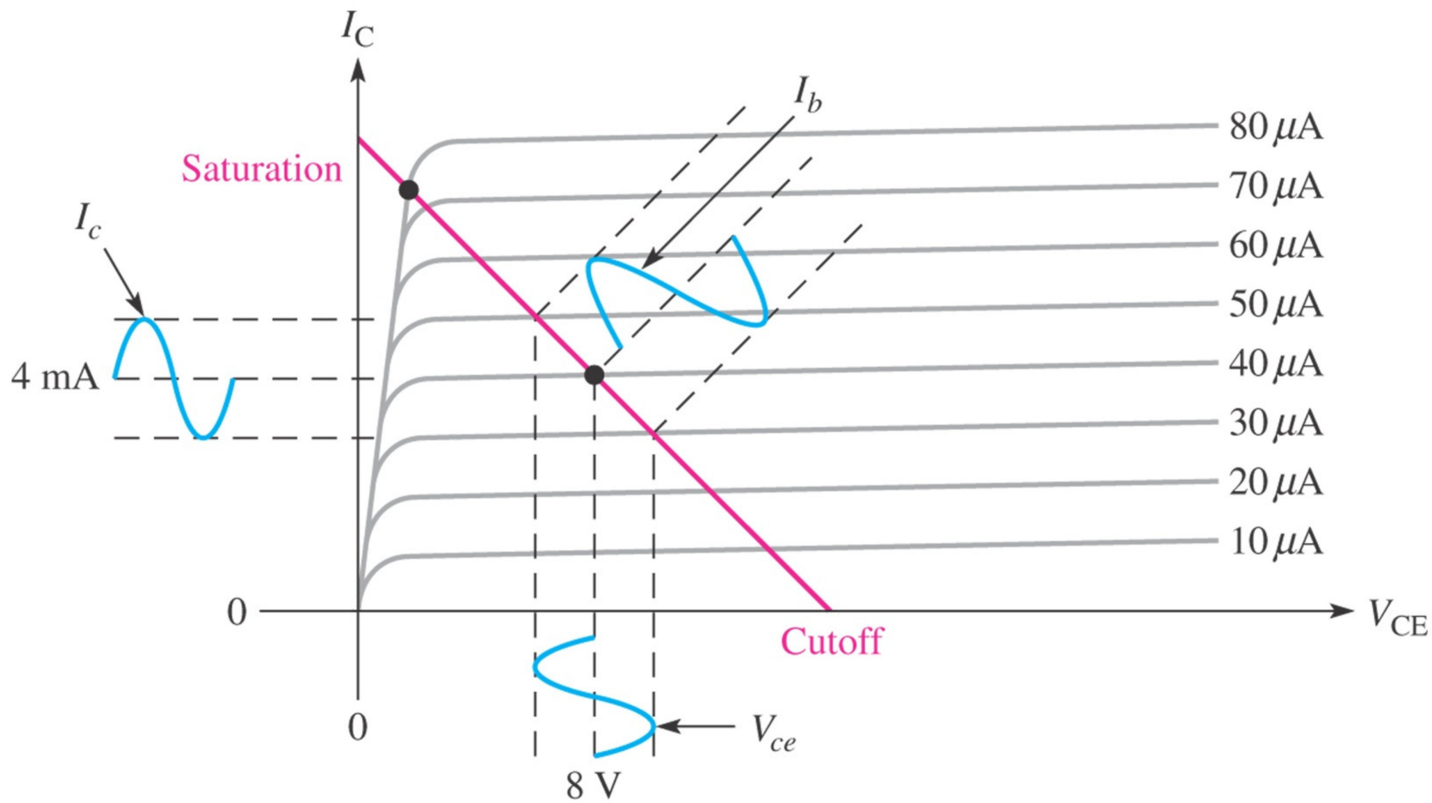
$$V_B \cong V_{CC} R_2/(R_1+R_2)$$



BJT Amplifiers

- In a class A amplifier, the transistor conducts for the full cycle of the input signal (360°)
  - used in low-power applications
- The transistor is operated in the active region, between saturation and cutoff
  - saturation is when both junctions are forward biased
  - the transistor is in cutoff when $I_B = 0$
- The *load line* is drawn on the collector curves between saturation and cutoff

BJT Amplifiers

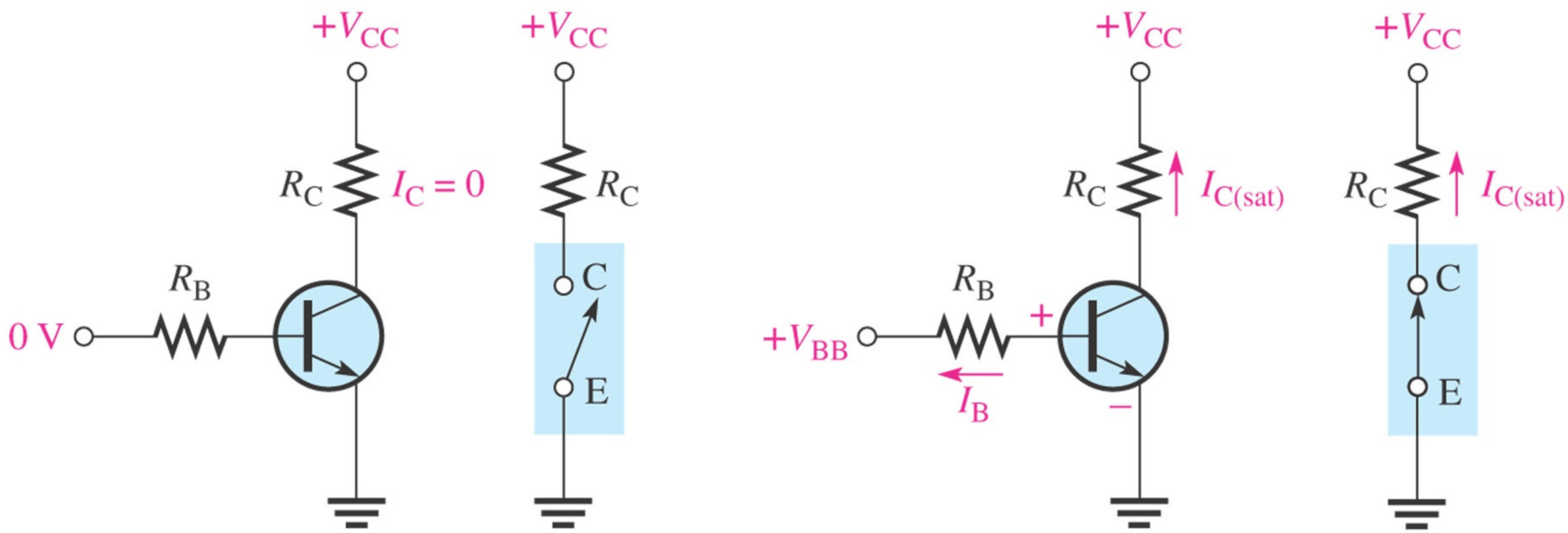


THE BJT AS A SWITCH

The BJT as a Switch

- When used as an electronic switch, a transistor normally is operated alternately in cutoff and saturation
  - A transistor is in cutoff when the base-emitter junction is not forward-biased. V_{CE} is approximately equal to V_{CC}
  - When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated

The BJT as a Switch

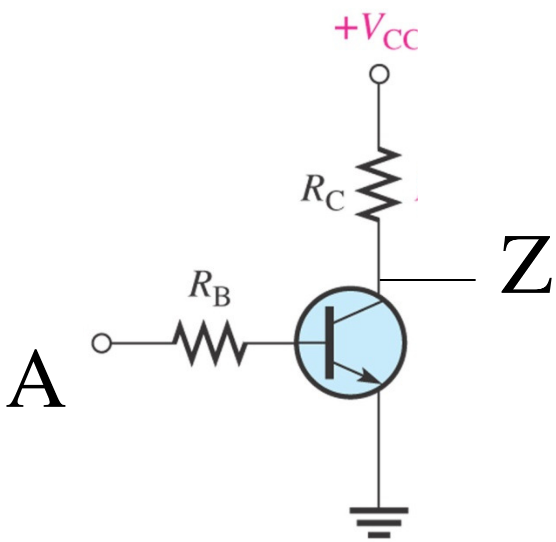


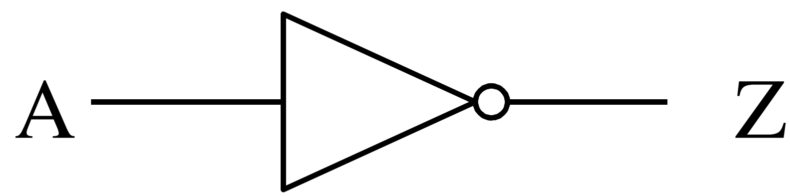
(a) Cutoff — open switch

(b) Saturation — closed switch

THE BJT AS A LOGIC GATE

The BJT as an Inverter





The BJT as a NOR Gate