BJT Amplifiers (Analog Circuits)

EE 101

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Reference material: L. Bobrow's Book

Nobel Prize in Physics 2014

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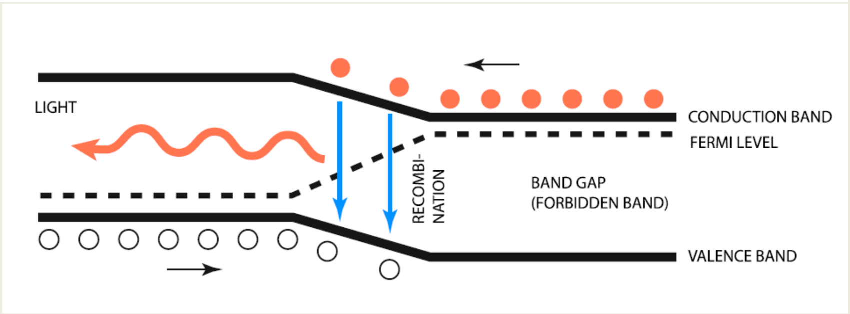
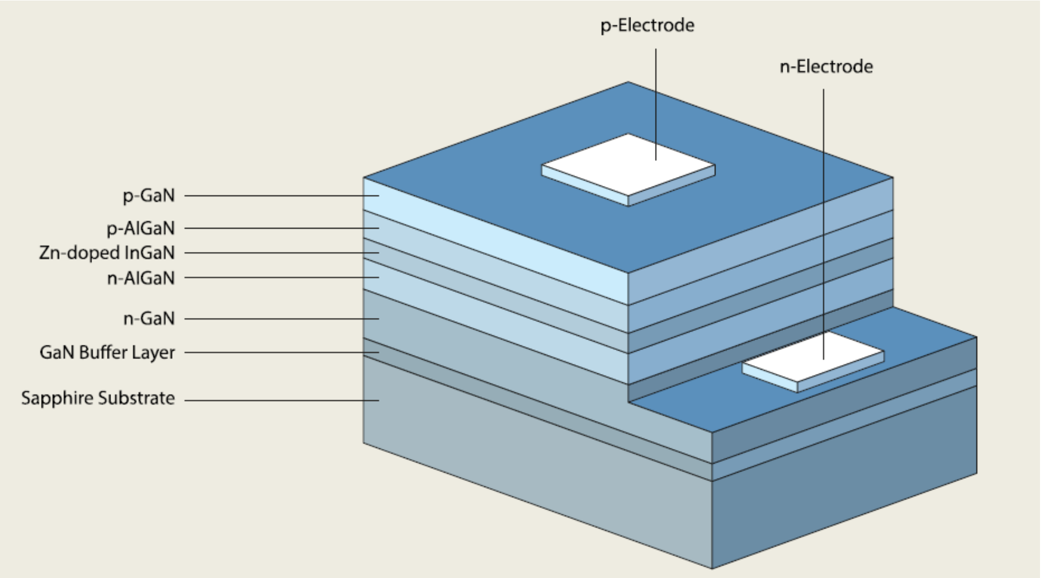
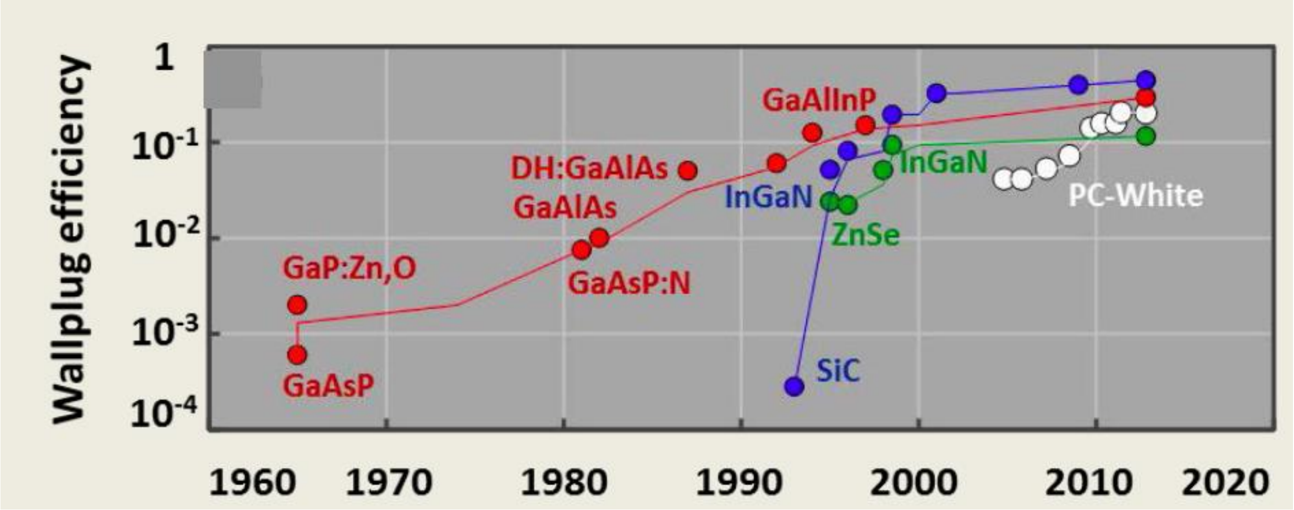
EFFICIENT BLUE LIGHT-EMITTING DIODES LEADING
TO BRIGHT AND ENERGY-SAVING WHITE LIGHT SOURCES

Blue LED


LIGHT
CONDUCTION BAND
FERMI LEVEL
RECOMBI-
NATION
BAND GAP
(FORBIDDEN BAND)
VALENCE BAND

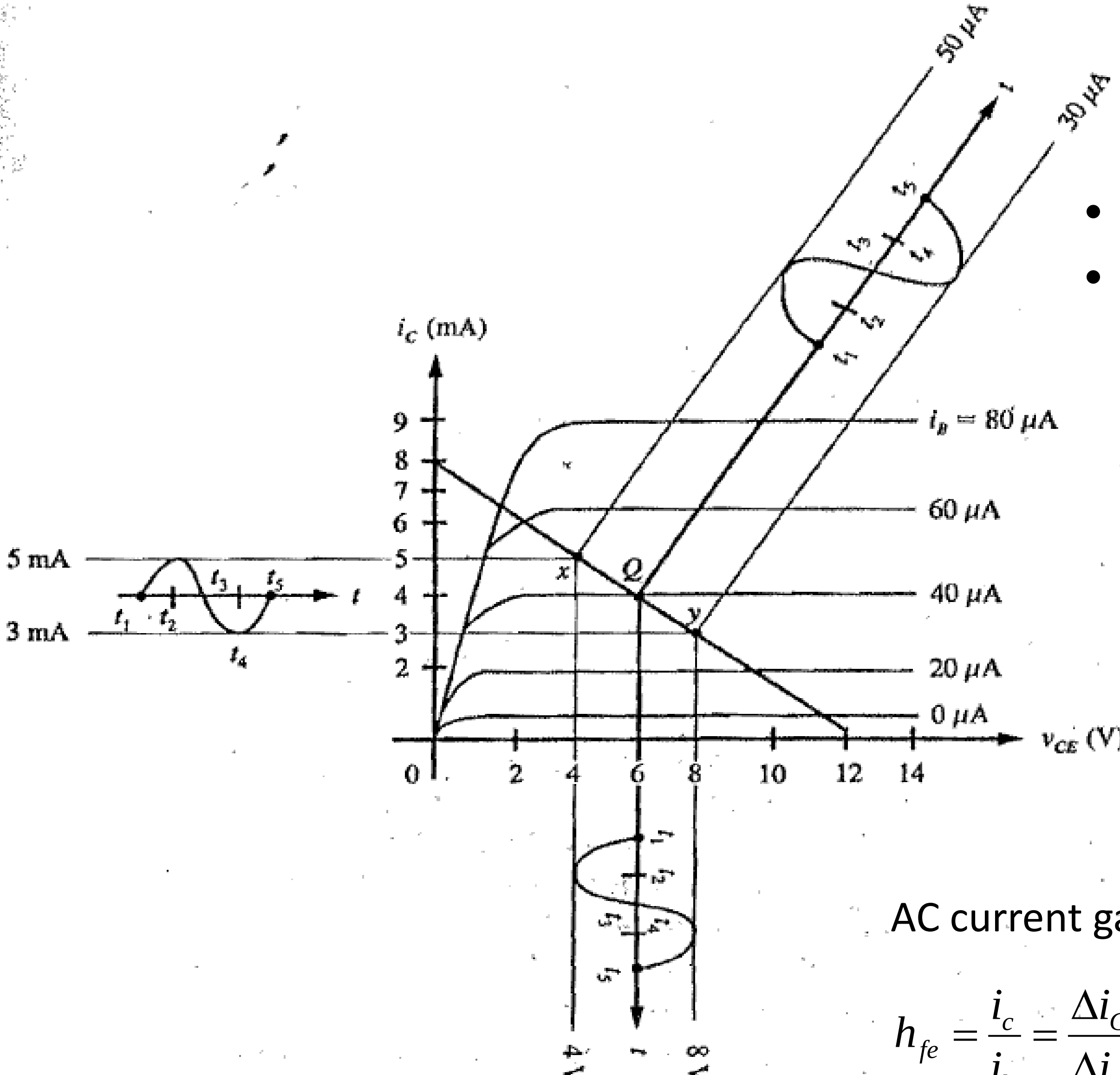

p-Electrode
n-Electrode
p-GaN
p-AlGaN
Zn-doped InGaN
n-AlGaN
n-GaN
GaN Buffer Layer
Sapphire Substrate


Wallplug efficiency
1
10-1
10-2
10-3
10-4
1960
1970
1980
1990
2000
2010
2020
GaAlInP
DH:GaAlAs
GaAlAs
InGaN
InGaN
PC-White
ZnSe
GaP:Zn,O
GaAsP:N
GaAsP
SiC

Impact

- Transformed entire lighting industry
  - 20-30% of electricity is used for lighting
  - Standard bulb → 16 lm/W (4% efficiency)
  - LED → 300 lm/W (50% efficiency)
    - 100,000 hour lifetime
- Other applications
  - Displays in electronics
  - Sensors etc.

BJT Amplifier: Collector Characteristics



- Active region operation
- Q → quiescent operating point

$$i_C = I_{CQ} + i_c = 4 + \sin \omega t \text{ mA}$$

$$i_B = I_{BQ} + i_b = 40 + 10\sin \omega t \ \mu\text{A}$$

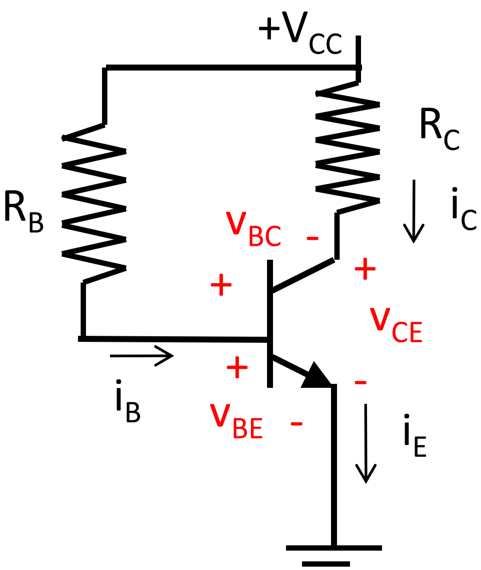
$$v_{CE} = V_{CE} + v_{ce} = 6 - 2\sin \omega t \text{ V}$$

AC current gain $h_{fe} = \beta_{ac}$

$$h_{fe} = \frac{i_c}{i_b} = \frac{\Delta i_C}{\Delta i_B} = \frac{i_{Cx} - i_{Cy}}{i_{Bx} - i_{By}} = \frac{(5-3)\times 10^{-3}}{(50-30)\times 10^{-6}} = 100$$

DC biasing of BJT: Fixed Bias

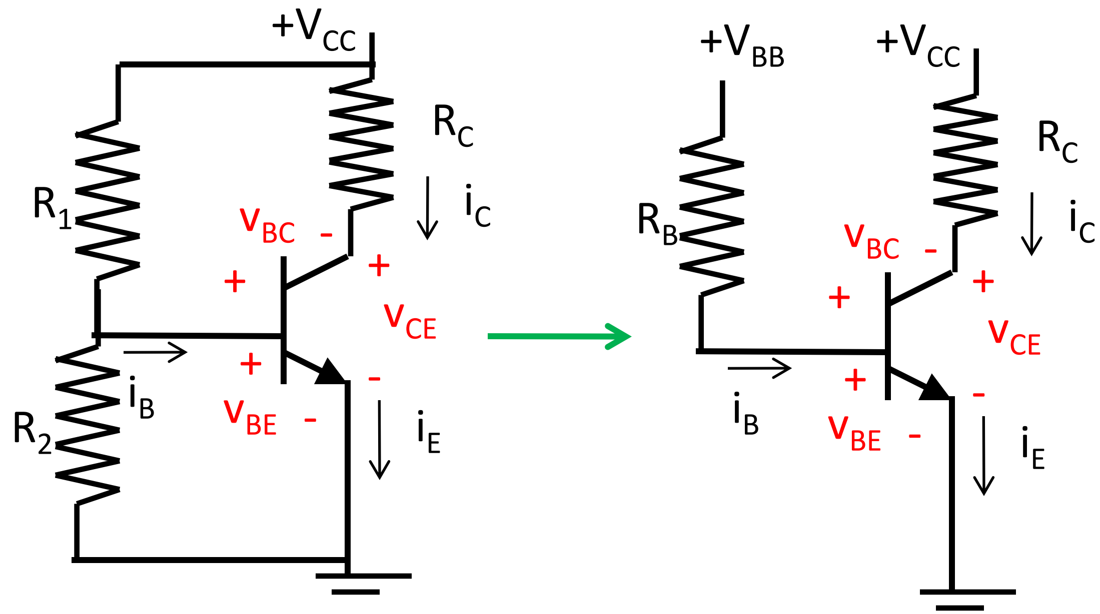
Example 1



$$i_B = \frac{V_{CC} - v_{BE}}{R_B} \qquad i_C = h_{FE} i_B$$

$$v_{CE} = -R_C h_{FE} i_B + V_{CC}$$

Example 2 (Voltage divider bias)



Thevenin Equivalent $\longrightarrow$

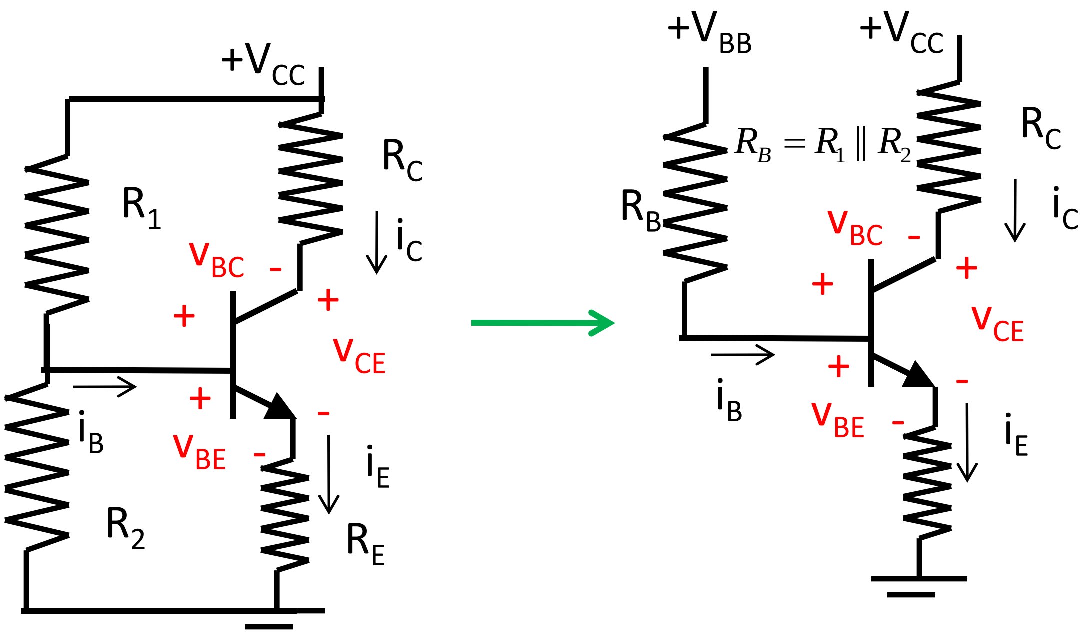
$$R_B = R_1 \parallel R_2$$

$$V_{BB} = V_{CC}(R_2 / R_1 + R_2)$$

- In fixed bias, variations (temperature, transistor-to-transistor) in h_{FE} can affect Q point
  - h_{FE} increases, i_C increases

DC biasing of BJT: Self-Bias

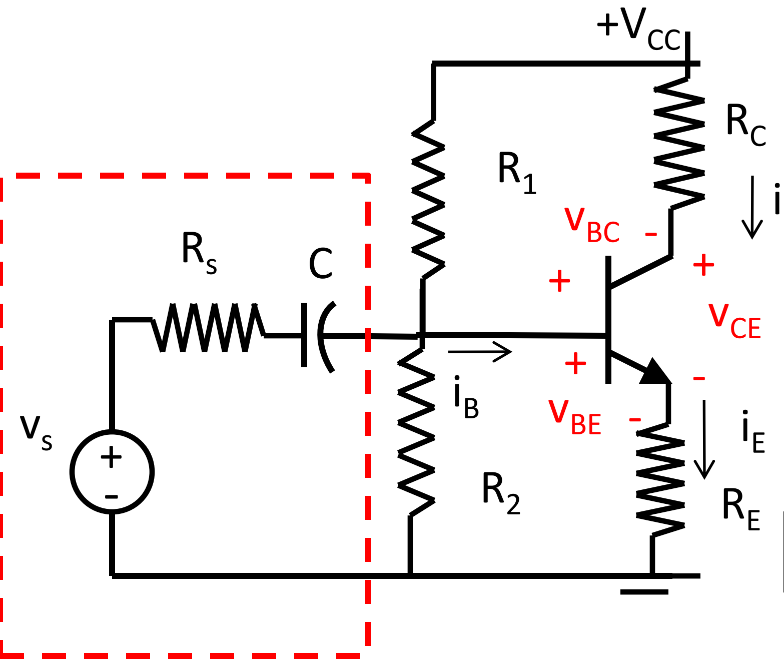
$$V_{BB} = V_{CC}(R_2 / R_1 + R_2)$$

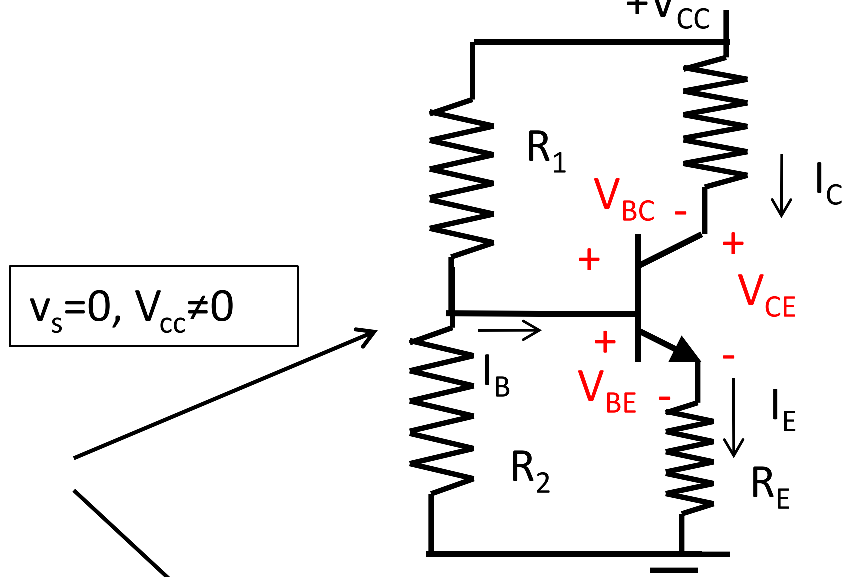


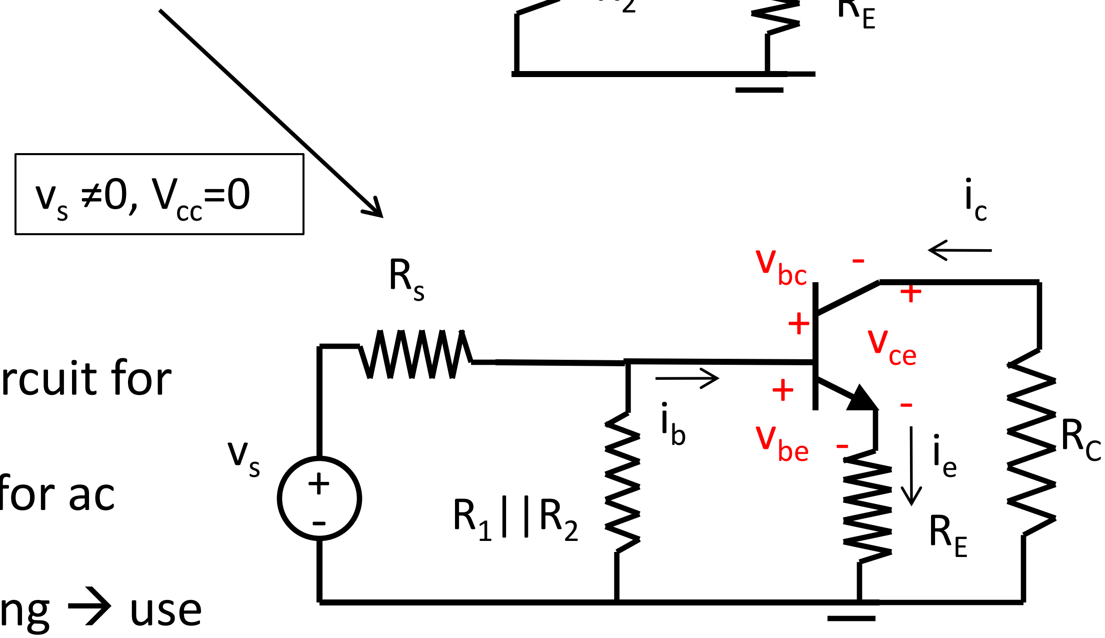
$$V_{BB} = R_B i_B + v_{BE} + R_E(i_B + i_C) \Rightarrow i_B = \frac{V_{BB} - v_{BE}}{R_B + (1 + h_{FE})R_E}$$

- If h_{FE} increases → i_C tends to increase but i_B decreases and tends to decrease i_C
- ***More stable*** Q point, also called self-biasing circuit

How to add ac signal to DC bias?



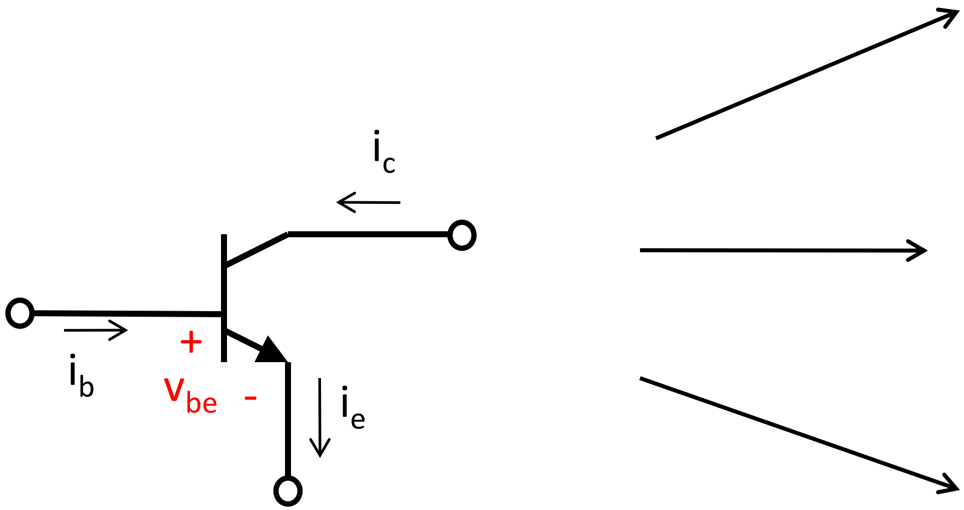


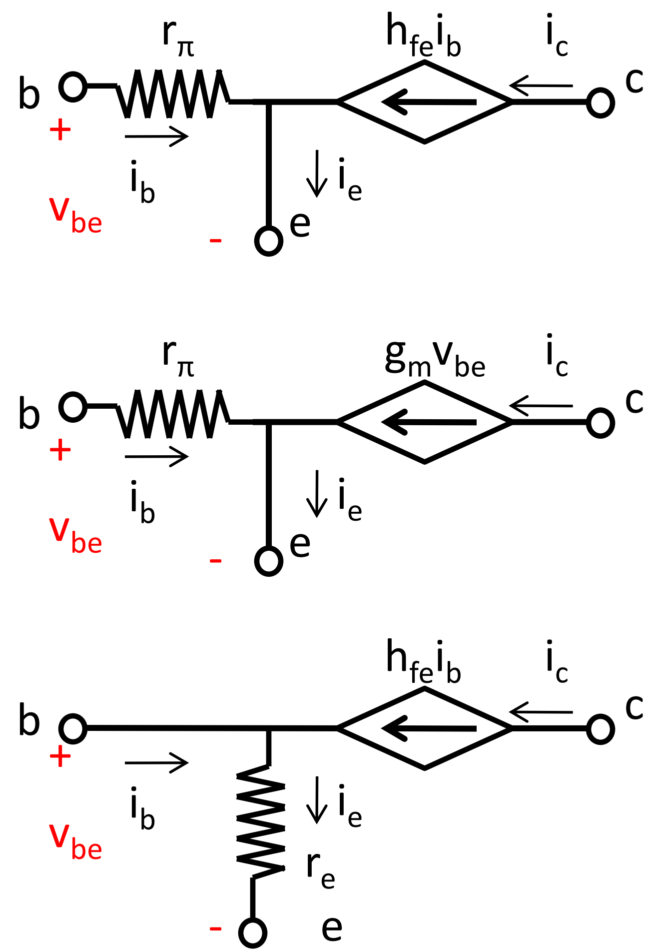


- Coupling capacitor C → open circuit for DC → no effect on dc Q point
- C large enough → short circuit for ac source v_s
- With active (linear) region biasing → use principle of superposition to analyse

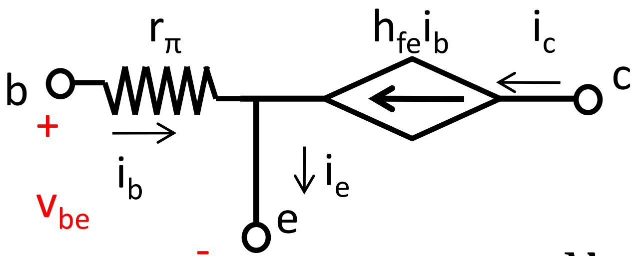
Small signal ac models

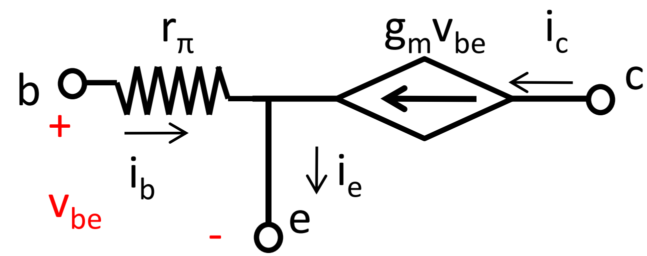
- Ac signal is small such that
  - transistor operates in active mode
  - Non-linear effects/distortions can be ignored
    - o/p characteristics are linear and parallel





Small signal model



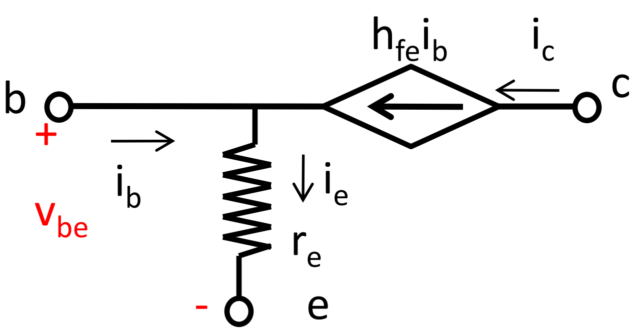


$$i_b = \frac{v_{be}}{r_\pi}$$

Ac base resistance= r_π

$$\boxed{h_{fe} i_b = h_{fe}\frac{v_{be}}{r_\pi} = g_m v_{be}}$$

Transconductance $g_m = h_{fe}/r_\pi$



$$r_e = \frac{v_{be}}{i_b + h_{fe} i_b} = \frac{v_{be}}{(1+h_{fe}) i_b} = \frac{r_\pi}{1+h_{fe}} \approx \frac{r_\pi}{h_{fe}} = \frac{1}{g_m}$$

$$\boxed{r_\pi = (1+h_{fe}) r_e \approx h_{fe} r_e}$$

g_m, r_π, r_e

For npn transistor in active mode

$$i_C = I_S(e^{v_{BE}/V_T} - 1) \approx I_S e^{v_{BE}/V_T}$$

$$di_C = d[I_S(e^{v_{BE}/V_T} - 1)] = \frac{1}{V_T}(I_S e^{v_{BE}/V_T})dv_{BE} \approx \frac{i_C}{V_T}dv_{BE}$$

$$g_m = \frac{i_c}{v_{be}} = \frac{di_C}{dv_{BE}} = \frac{i_C}{V_T}$$

Biased at $i_C = I_{CQ}$,

$$\boxed{\begin{aligned} g_m &= \frac{I_{CQ}}{V_T} \\ r_e &= \frac{1}{g_m} = \frac{V_T}{I_{CQ}} \\ r_\pi &= h_{fe} r_e = \frac{h_{fe} V_T}{I_{CQ}} \end{aligned}}$$

At room temperature,
$V_T = kT/q = 0.026$ V