Transistor electronic technologies

•Bipolar Junction Transistor

discrete or integrated circuit

discrete = individual component

•MOS (Metal-Oxide-Silicon) Field Effect Transistor

mainly used in integrated circuits

driven by digital applications but analogue

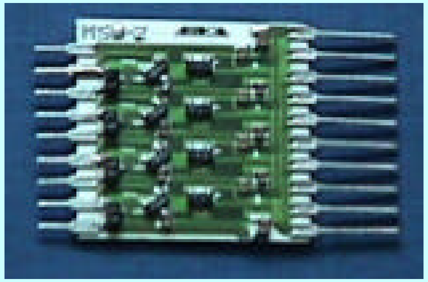
•Junction Field Effect Transistor

similar in many ways to MOS FET

discrete, not easily implemented in ICs

•so - is this a course on circuits?

No but it is necessary to understand some basics to be able to deal with more complex elements, including some features of op-amps

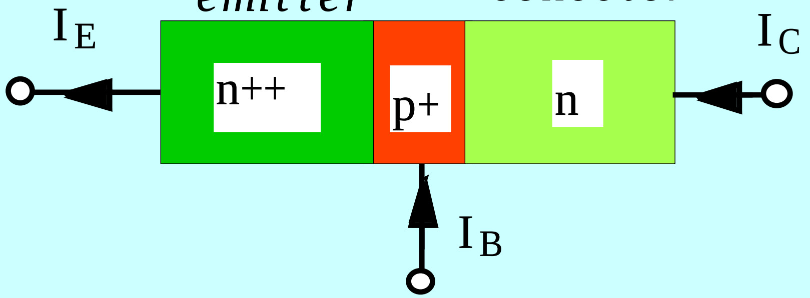


Bipolar transistor

- pnp or npn

  semiconductor, usually Si, but also Ge

  heavily doped emitter, lightly doped base



arrows show direction of current flow

- Operation - npn

  base is biased more positive than emitter

  so a forward biased diode

  collector more positive than base = *reverse biased diode*

  majority carriers from emitter diffuse across base to collector

  small fraction combine with majority carriers in base

  current reaching collector is

$$I_C = \alpha I_E$$

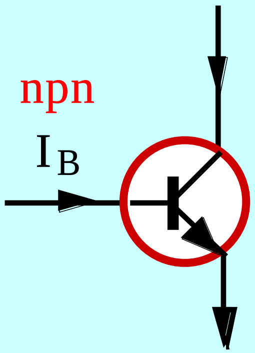
$$I_B = (1-\alpha) I_E$$

$$I_C = \beta I_B \quad = [\alpha/(1-\alpha)] I_B$$

$$\beta = \alpha/(1-\alpha) \ = \text{ d.c current gain } = h_{fe}$$

$I_E \approx I_C$

eg $\alpha = 0.99 \quad \beta = 99$



pnp transistor

- Works like npn transistor

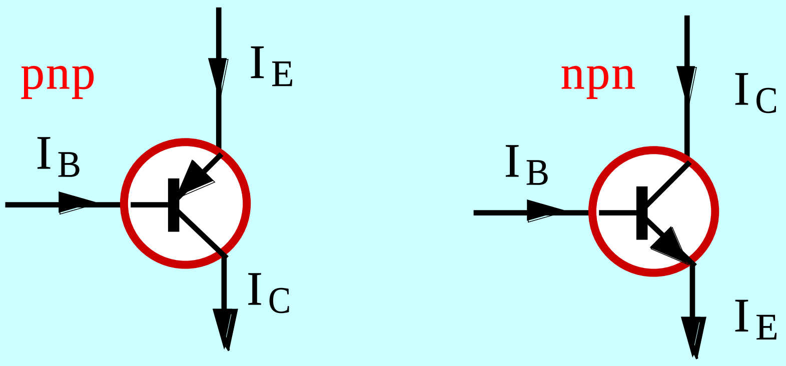
bias arrangements different

but

if emitter is positioned at top

easy to remember both pnp and npn

most positive



most negative

Slightly more precise picture

- to turn npn transistor on V_B-V_E = V_{BE} > 0.6-0.7V

  (invert for pnp)

- so we can use it as a switch by controlling V_{BE}

  $V_{BE} \approx 0$ $I_C = I_E = 0$

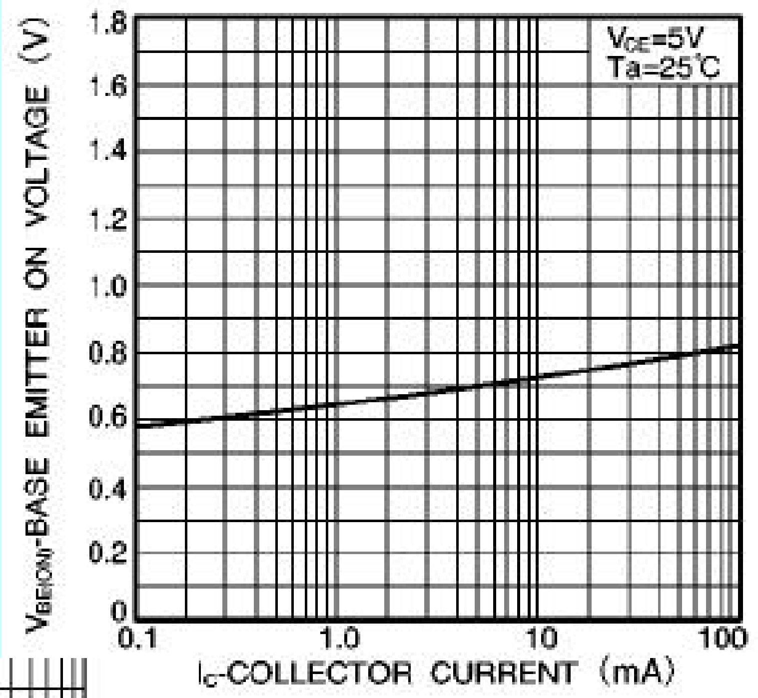
- however, if transistor is ON $V_{BE} \approx 0.7$V

  this is a consequence of the diode behaviour -

  discuss in a moment

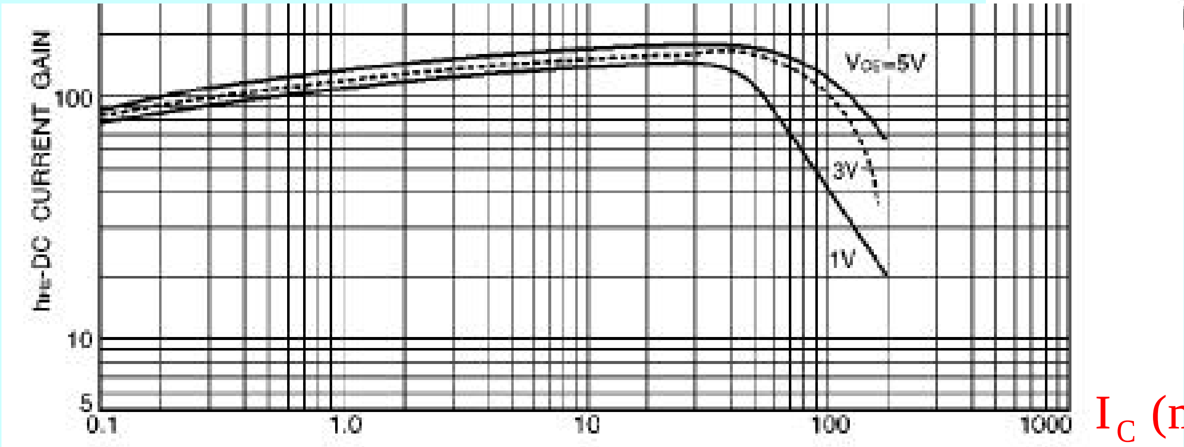
- in contrast, β is not a reliable parameter for design

2n3906 npn transistor



NB log scale for I_C

β



I_C (mA)

NB both log scales

Ebers-Moll model

- Transistor can be modelled as two back-to-back diodes

I-V behaviour of diode $I \approx I_0[\exp(qV_{BE}/kT)-1)]$

- Base-emitter diode is forward biased

$I_E = I_{E0}.[\exp(qV_{BE}/kT)-1] \approx I_{E0}\exp(qV_{BE}/kT)$ ie $V_{BE} \approx (kT/q)\log_e I_E$

this explains why V_{BE} varies so little with I

also basis of band-gap T reference

- Base-collector diode is reverse biased

$I_{BC} = I_{CO}[\exp(qV_{BC}/kT)-1] \approx I_{C0}$ - which is small

so current arriving at collector is dominated by current from emitter, which has diffused across base

- How does current vary with small change in V_{BE}?

$dI_E/dV_{BE} = i_e/v_{be} = (q/kT)I_{E0}\exp(qV_{BE}/kT) = (q/kT)I_E$

$i_e r_e = v_{be}$ with $r_e = kT/qI = 25\Omega/I_E(mA)$

NB we don't usually need to distinguish between I_C and I_E - consider them equal

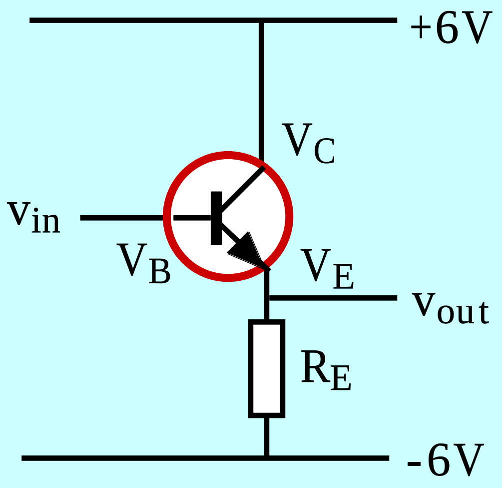
ie to ac current signals transistor looks like dynamic resistance

Emitter-follower

• DC conditions   ±6V are example values, but results don't depend on them at all

apply our rule that $V_{BE} \approx 0.7V$

$I_E = [V_E - (-6V)]/R_E \approx (V_B + 5.3V)/R_E$



• Now ac behaviour

$v_{in} = v_b = \Delta V_B = \Delta(V_E+0.7V) = v_e = v_{out}$

amplifier with gain = 1   - not very interesting!!??

• Input impedance

$R_{in} = v_{in}/i_{in}$

$i_{in} = i_b = i_c/\beta$

$i_c = i_e = v_e/R_E$

$R_{in} = \beta R_E$ high, eg $\beta \sim 100$, $R_E \sim 1k\Omega$

(more careful treatment => $R_{in} = \beta(R_E + r_e)$)

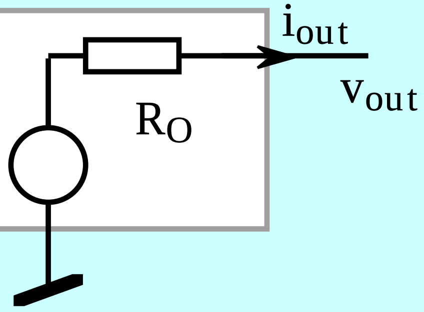
this is promising for a voltage buffer - what is the output impedance?

Emitter-follower output impedance

- How to find it? Consider the black box...

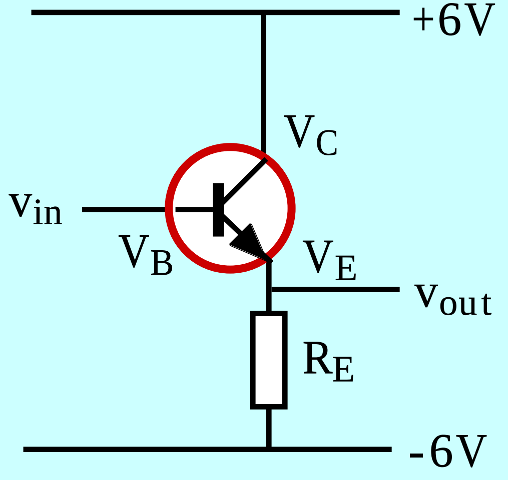
  vary v_{out} and see what happens to i_{out}

  keep other conditions fixed



- Use Ebers-Moll result $V_{BE} = (kT/q)\log_e I_E$

  $dV_{BE}/dI_E = v_{be}/i_e = (kT/qI_E)$



- If V_B is constant

  $v_{out} = v_e$

  $i_{out} = i_e$

  $Z_{out} = (kT/qI_E) = r_e = 25\Omega/I_E(mA)$

small, as required for buffer

Short footnotes

- In analysing circuits for small signal (AC) behaviour

  all fixed DC levels are equivalent to ground

  ie ac current does not need to distinguish voltage at other end of path

- This is often useful in looking at circuits to tell if routes are in parallel

- Calculations

  keep simple

  try to make approximations - 1% answers are almost never required

  if so better tools exist

  eg parallel resistances

  transistor β - assume β ≈ 100 - unless better value known or is critical

  47Ω ≈ 51Ω ≈ 50Ω

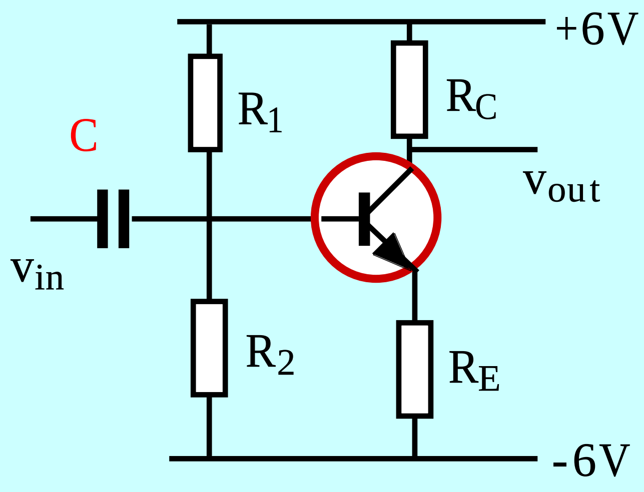
Common-emitter amplifier

- DC conditions ±6V are example values again

  $V_C = 6V - I_C R_C$

  $V_E = -6V + I_E R_E$

  Since $V_E = V_B - 0.7V$, I_E & I_C defined by bias network



- small signal, AC behaviour

  $v_e = v_b = v_{in} = i_e R_E$

  $v_{out} = -i_c R_C$

  so $v_{out}/v_{in} = -R_C/R_E$

  amplifier with gain

what's the purpose of C?

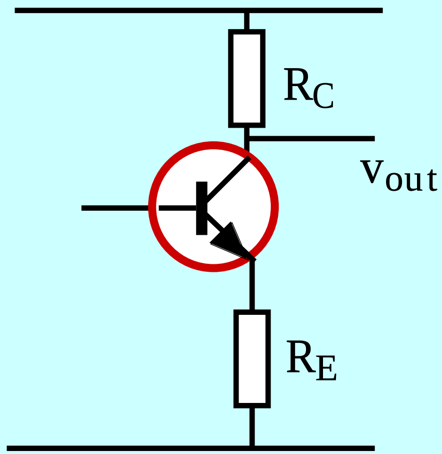
- Input impedance: signal sees bias network in parallel with transistor

  so $R_{in} = R_1 || R_2 || \beta(R_E + r_e)$ - typically a high value

Common-emitter output impedance

- Play same trick as emitter-follower

but this time, from output terminal, the two paths for i_{out} are



collector-base junction

reverse biased diode = high impedance

R_C

usually much lower than r_{cb}

no need to worry about any source impedance driving amplifier

so $Z_{out} \approx R_C$

usually relatively high

Reading circuits

- look for the building blocks

  usually blocks are "vertical columns"

- look for feedback paths

  horizontal paths,which are not DC bias, or output-input