PH231

Lead-up to Lab 4

Current amplifier done in Lab 3
now use BJT as a voltage amplifier

Main points: Lab 2

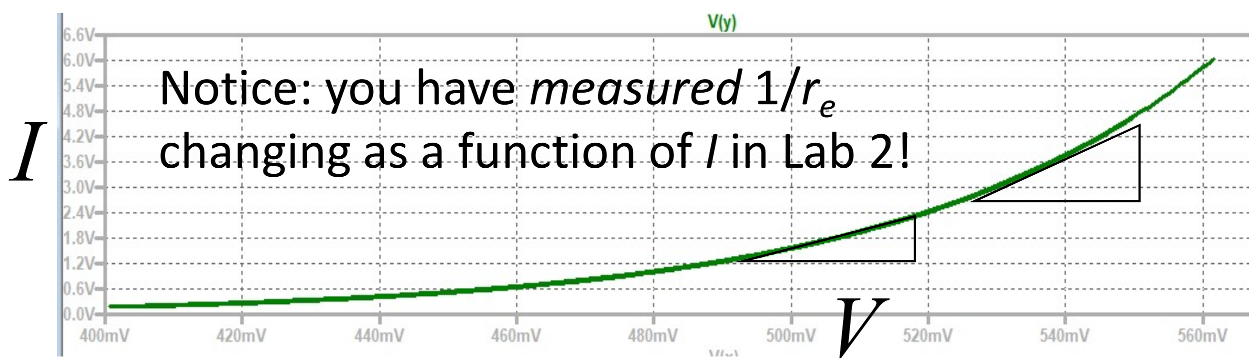
In a diode (two-terminal device), I_D v/s V_D defines the diode 'characteristic'

V_D is defined as the Voltage between Anode(P) and Cathode(N) – by convention: $V_P - V_N$ (*not* $V_N - V_P$). V_N is assumed lower than V_P since the opposite (reverse bias) is not so interesting

In forward bias the Shockley equation gives $I = I_0(e^{\frac{qV}{k_B T}} - 1)$

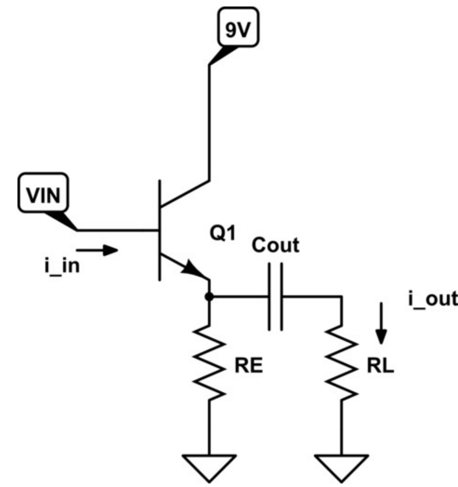
1. Since $k_B T = 25.3\ meV \sim 25 meV\ at\ room\ temp, and\ numerator\ has\ q = e$
2. Use Euler expansion of e^x : $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3} + \frac{x^4}{4!} + \cdots$ to leading term:
3. $\frac{I}{I_0} = \frac{V}{25mV} \rightarrow$ $a\ characteristic\ diode\ juncton\ resistance\ comes\ out$:

$$r_e = \frac{25mV}{I}$$



Notice: you have *measured* $1/r_e$ changing as a function of *I* in Lab 2!

Main points: Lab 3



BJT: THREE TERMINAL DEVICE C, B, E – focus on Forward Active Mode
Key concept: Arrange a "BIAS"ing circuit using resistors around the BJT
To set relative terminal voltages

- CB reverse biased – not so interesting (as long as your bias circuit guarantees $V_C > V_B$)

- We mentioned in the design steps that the BE junction (forward biased) has an equivalent resistance $r_e = \frac{25mV}{I_C}$ but ***didn't pay much attention to it….***

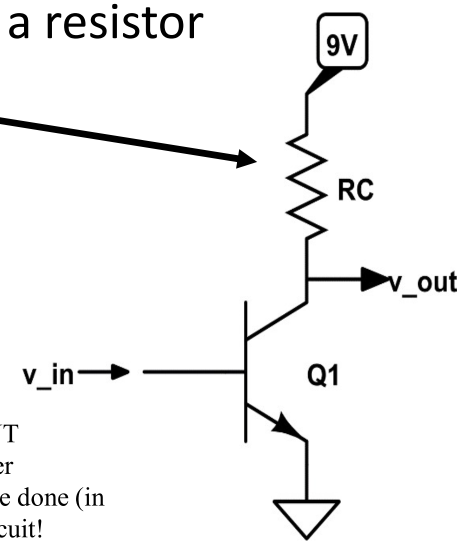
  Because we chose I_{CQ} = 10mV, so $r_e = 2.5\Omega$ was insignificant compared to R_E (510) or $R_E || R_L$ (250)

In Lab 4, r_e will be crucial to the circuit design and operation

Main points: Lab 4

BJT amplifies CURRENT: if we measure that amplified current across a resistor we get an amplified voltage….. (in this diagram $I_C R_C$

As in Lab 3, C, B, E relative voltages will have to be setup for forward-active mode



"Skeleton" diagram of the BJT working as a voltage amplifier
Note there is much work to be done (in Lab 4) to make this a real circuit!

Why is r_e more important in this design?

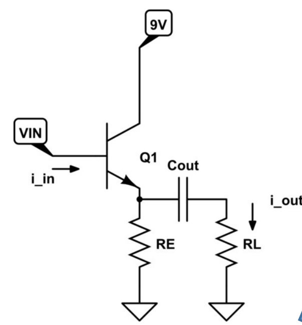
In Lab 4, r_e will be crucial to the circuit design and operation

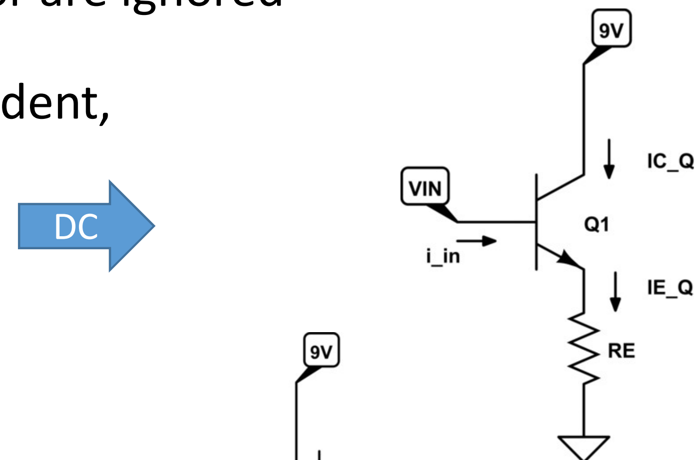
Stepping back, some principles of circuit design (actually, more like practical tips)

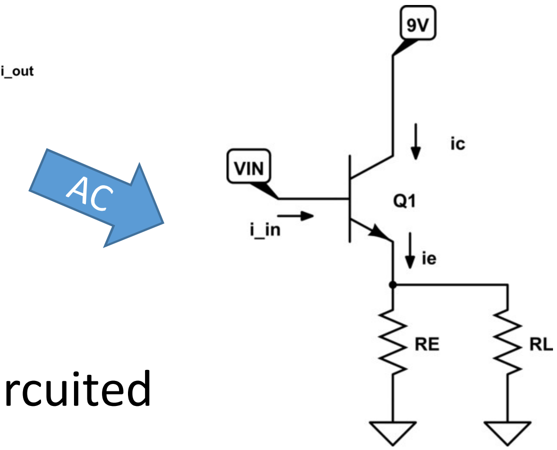
DC design (like setting the Q-point) evaluating I_Q etc, set all capacitors in the circuit to be open. i.e. any components on the other side of a capacitor are ignored

AC design: when currents and voltages are time dependent, set all capacitors to be short-circuit

Example: In Lab 3. We concluded that R_L cannot be connected to BJT's E directly, there must be a fixed R_E at E-GND to set the Q point







Hence,
in DC design ignore R_L because C_{out} is open
in AC design must use $R_E||R_L$ because C_{out} is short-circuited

Stepping back some more, to effective impedances at BJT terminals…

For rigorous derivation using BJT R_{pi} model, see B. Razavi's lecture: https://www.youtube.com/watch?v=HLJWeQYI9QI

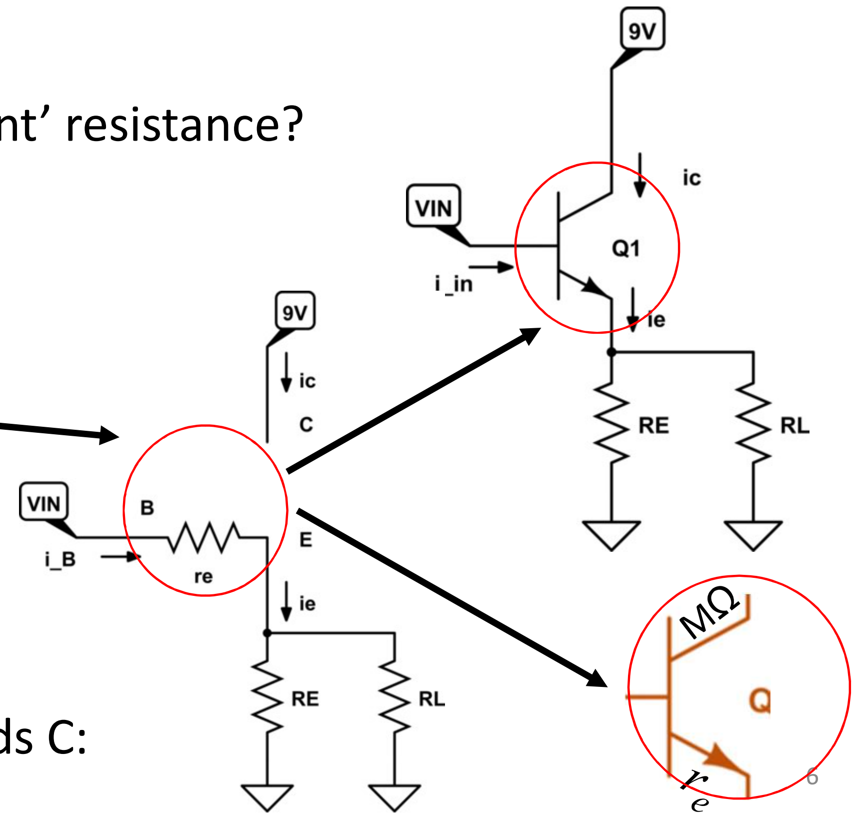
What does it mean when we say "Impedance looking into the base"?

$\frac{v_{in}}{i_{in}}$ defines some resistance – what is this 'equivalent' resistance?

In forward-active mode, CB is reverse,
BE is forward biased (with resistance $\boldsymbol{r_e}$) the
effective circuit looks like:

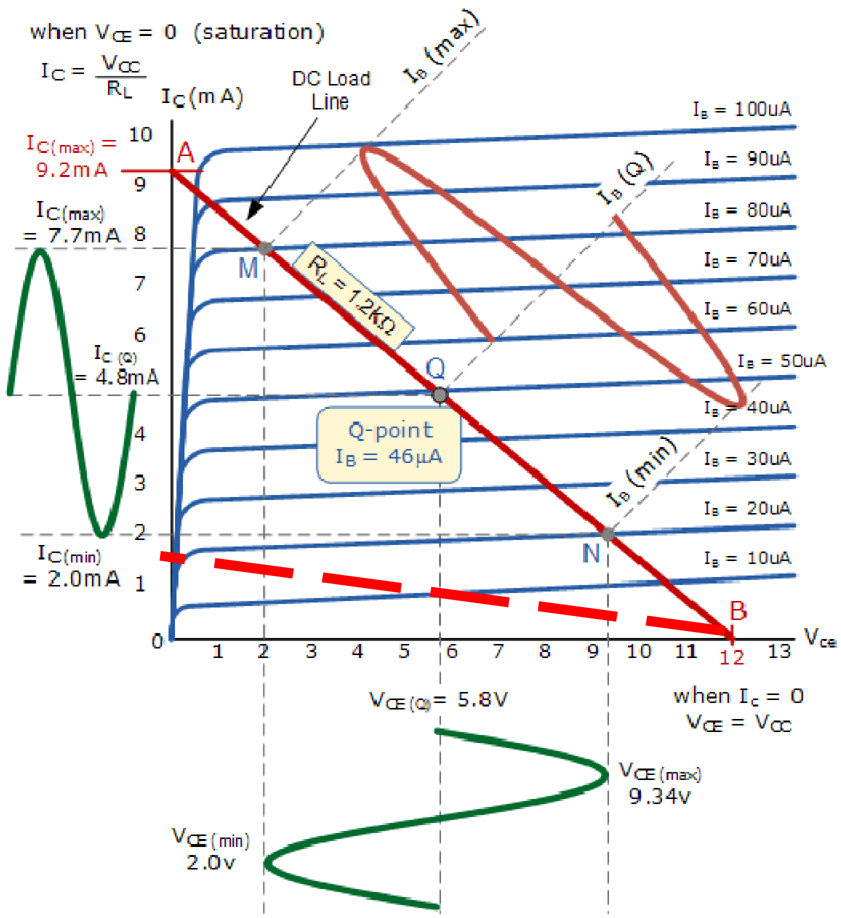
Since $i_E = i_C = \beta i_B$ the node B has voltage
v_B *across resistance* $(r_e + R_E||R_L)$ with current
$\beta i_B \rightarrow effective' R_B = \beta(r_e + R_E||R_L)$

CB is reverse biased, we don't care to look up towards C:
MΩ resistance & magically $i_C = \beta i_B$



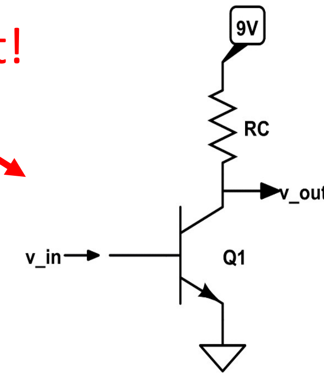
BJT Voltage amplification – set Q point low

Lab 3
We wanted large current swing



Lab 4

Note: simplistic circuit!
NOT complete!
Will solve in Lab 4



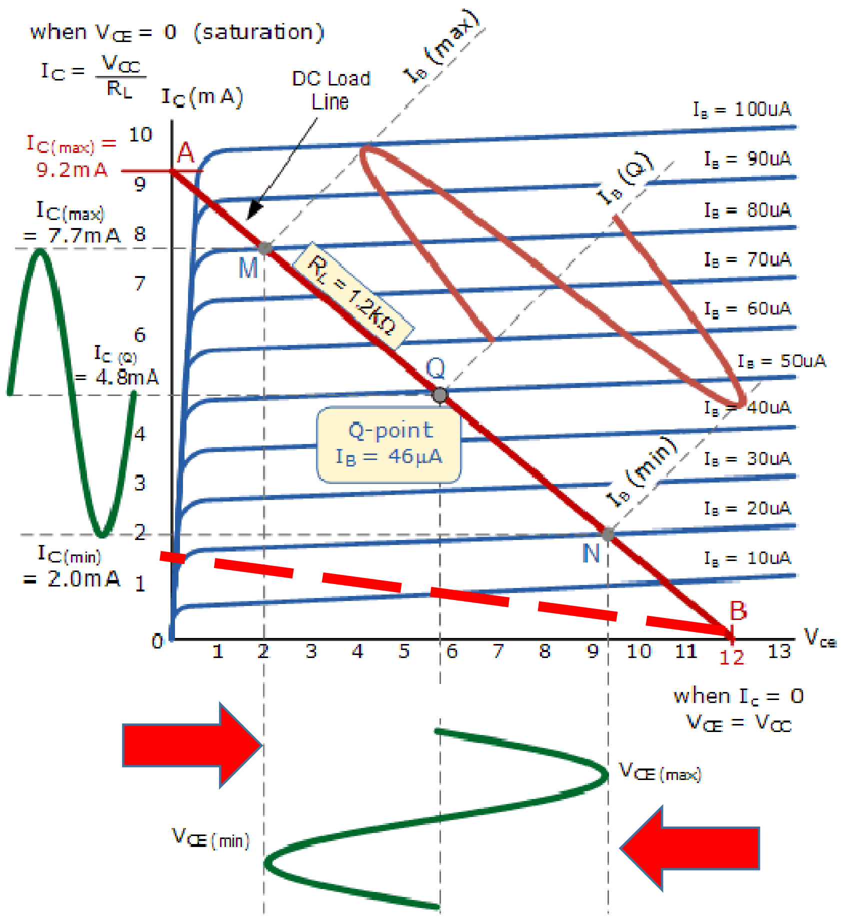
For voltage amplifier
We want large voltage swing at V_{CE} →
Hence preferable to set I_Q very low

$$V_{out} = V_{CC} - I_C R_C$$
$$V_{out} + v_{out} = V_{CC} - (I_{CQ} + i_C) R_C$$
$$\rightarrow dropping\ DC\ terms:$$
$$\boldsymbol{v_{out} = -i_C R_C}$$

If I_{CQ} high, $V_{CQ} = V_{OUT|DC}$ will be close to V_{CC} → v_{out} will hit saturation easily

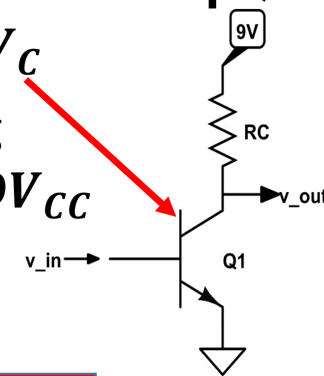
Detailed guidelines for setting I_{CQ} and $V_{E|Q}$

Lab 3
We wanted large current swing



Lab 4

BJT cares about $\boldsymbol{I_C}$, $\boldsymbol{V_{CE}}$ NOT $\boldsymbol{V_C}$



Generally we set $\boldsymbol{V_{CE}}$ to swing between $\sim\mathbf{0.1}\boldsymbol{V_{CC}}$ ***and*** $\sim\mathbf{0.9}\boldsymbol{V_{CC}}$

So **E** cannot be at GND

Why?

1) To avoid saturation & cutoff

2) In forward active: $r_e = \frac{25mV}{I_C}$

$$25mV = \frac{k_B T}{e} \; assuming \; T = 30°C!$$

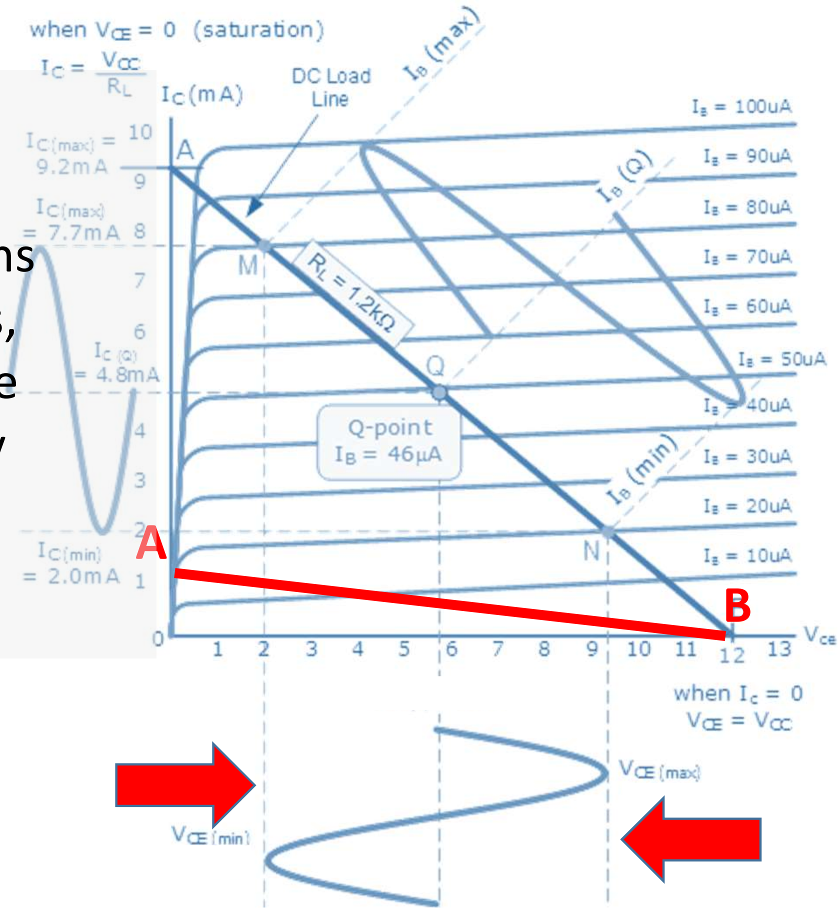
$\rightarrow$ ***this is a nonlinear effect***!

3) As $I_C = \left(I_{CQ} + i_C\right)$ changes, r_e will heat up, T rises $\rightarrow$ r_e rises: thermal runaway!

4) **So, try to keep I_{CQ} as low as possible**

Main points to remember for BJT as voltage amplifier:

Don't care much about what happens on the y-axis, so long as we remain away from saturation and cutoff



Keep I_{CQ} low and minimize AC swing of i_C

R_C dominates $i_C R_C$ voltage amplification

E should not be at GND:
if so, non-linear r_e will vary causing to thermal 'runaway'

R_E used at **E** to set **$V_{EQ} \sim 0.1V_{CC}$**
should dominate over r_e

There are 3 voltages to account for:

1) V_C should get close to, but not = V_{CC}
If $V_C = V_{CC}$, $I_C = 0$ (cut-off!)
2) V_E should be above GND (thermal r_e)
3) V_{CE} : midpoint V_{CEQ} determines DC offset of v_{out} and allowed swing permitted by (1) and (2)