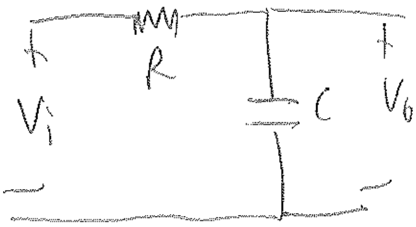
High Frequency Response of BJT amplifier

At high-frequency there are two factors that define the [3dB] cut-off points (nearly the half-power frequency)

1 — The network capacitance (parasitic and introduced)

2 — The frequency dependance of h_{fe} (β)

RC network in high frequency



$$\text{Gain} = \frac{V_o}{V_{in}} = \frac{1}{1 + j\frac{f}{f_2}} = \frac{\frac{1}{2\pi f j C}}{R + \frac{1}{2\pi f j C}}$$

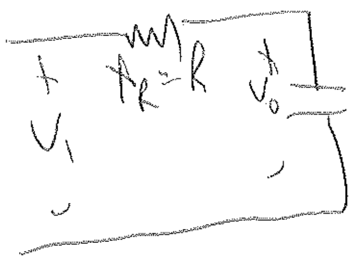
$\downarrow$ phasor

$$= \frac{1}{2\pi f R C j + 1}$$

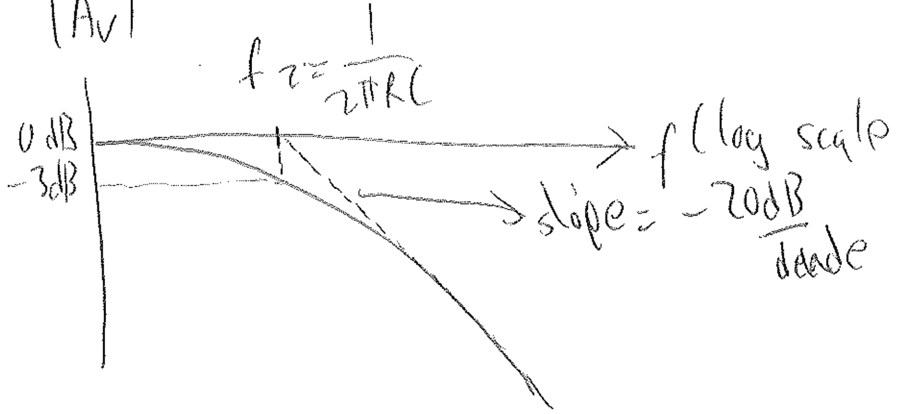
$$2\pi R C = \frac{1}{f_2}$$

$$\boxed{f_2 = \frac{1}{2\pi R C}}$$

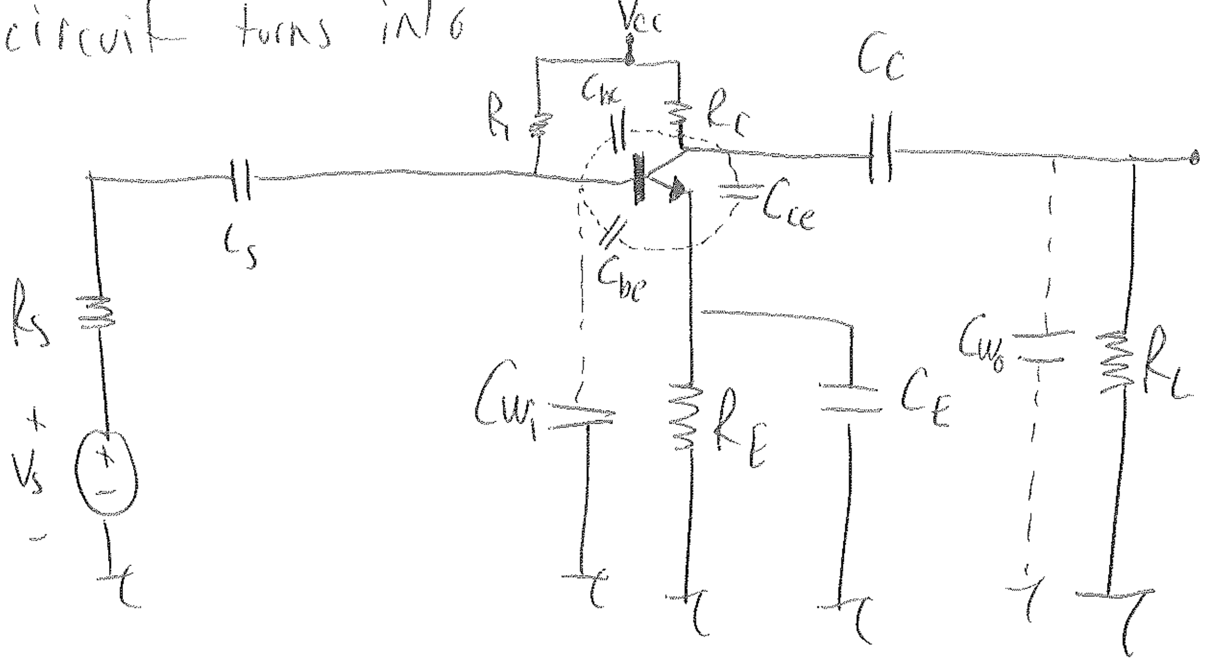
phasor



$$X_C = \frac{1}{j 2\pi f C}$$



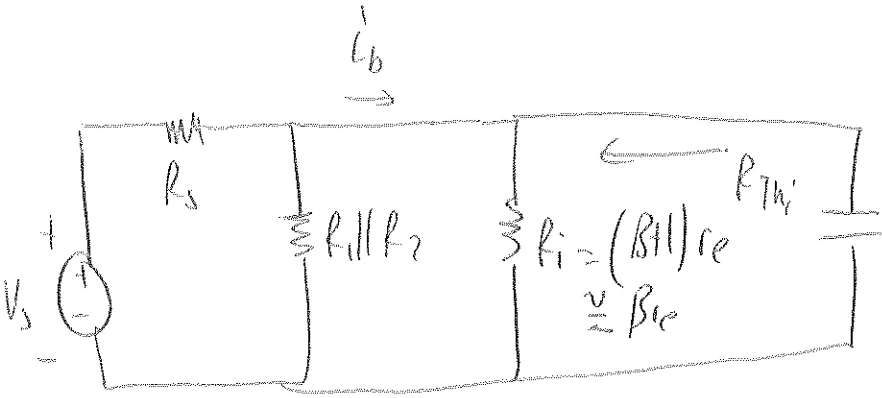
At high frequency various parasitic capacitances (C_{be}, C_{bc}, C_{ce}) of the transistor are included with wiring capacitances (C_{W_i}, C_{W_o}) introduced during construction. Hence the BJT amplifier circuit turns into

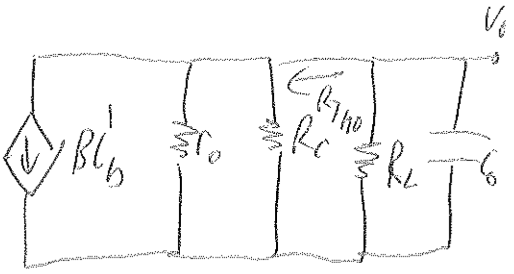


C_{bc} → parasitic high frequency capacitance between base and collector
C_{be} → " " " " " base and emitter
C_{ce} → " " " " " collector and emitter

C_{W_i} → Capacitance due to wiring in the input part of transistor
C_{W_o} → " " " " " " output part of transistor

In high frequency C_s, C_C and C_E are shorted
Due to these capacitive effects at high frequency the ~~circuit~~ equivalent circuit model of the circuit becomes





where

$C_i = C_{W_i} + C_{be} + C_{M_i}$ and $C_o = C_{W_o} + C_{ce} + C_{M_o}$

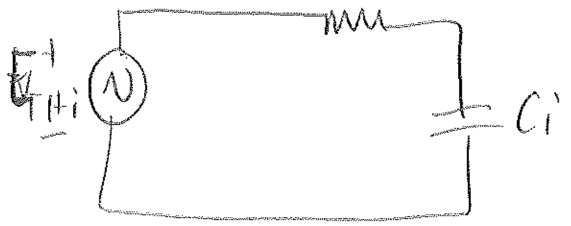
C_i includes: input wiring capacitance C_{W_i}, the transition capacitance C_{be} and the miller capacitance C_{M_i}

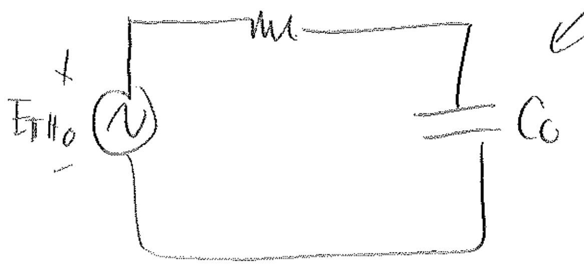
C_o includes: output wiring capacitance C_{W_o}, the parasitic capacitance C_{ce}, and the output miller capacitance C_{M_o}

To order parasitic capacitances $C_{be} > C_{bc} > C_{ce}$

The Thevenin equivalent ~~circuit~~ circuit of equivalent circuit model

input network $R_{TH_i} = R_s \| R_1 \| R_2 \| R_i$ $R_{Th_o} = R_C \| R_L \| r_o$ output network





$R_{TH_i} = R_s \| R_1 \| R_2 \| R_i$

$R_{TH_o} = R_C \| R_L \| r_o$

For the input network part −3 dB frequency is defined by

$$f_{H_i} = \frac{1}{2\pi R_{TH_i} C_i}$$ → high input part cut-off frequency

and $C_i = C_{w_i} + C_{be} + C_{M_i} = C_{w_i} + C_{be} + (1 - A_v) C_{bc}$

For the output network

$$f_{H_o} = \frac{1}{2\pi R_{TH_o} C_o}$$ → high output part cut-off frequency

with $R_{TH_o} = R_C \| R_L \| r_o$

$$C_o = C_{w_o} + C_{ce} + C_{M_o} = C_{w_o} + C_{ce} + \left(1 - \frac{1}{A_v}\right) C_{bc}$$

since $\frac{1}{A_v} \ll 1$

$$C_o \cong C_{w_o} + C_{ce} + C_{be}$$

At high frequencies C_o will decrease and consequently reduce to impedance of output parallel branches

Hence V_o will become zero as $f \to \infty$, since the reactance of C "X_C" becomes smaller.

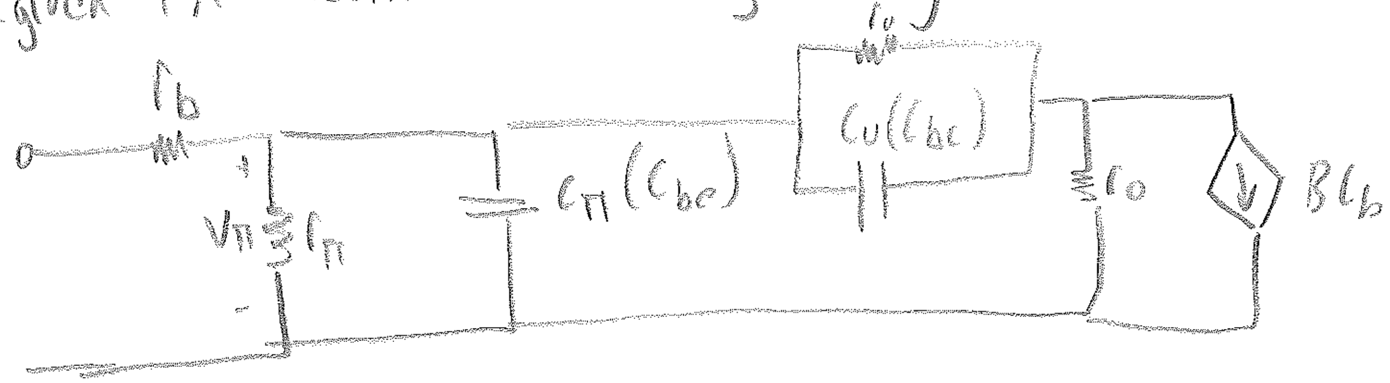
The lowest of f_{H_i} and f_{H_o} is the actual cut-off frequency of the network at high frequencies

h_{fe} (or β) variation

$$h_{fe} = \frac{h_{fe\,mid}}{1 + j\left(\frac{f}{f_\beta}\right)}$$ → nearly this equality will hold with increasing frequency

The use of h_{fe} rather than β is due to the fact that manufacturers typically use the hybrid parameters.

Hybrid π or Giacolletto model
(given in Section 5.22 Boylestad)



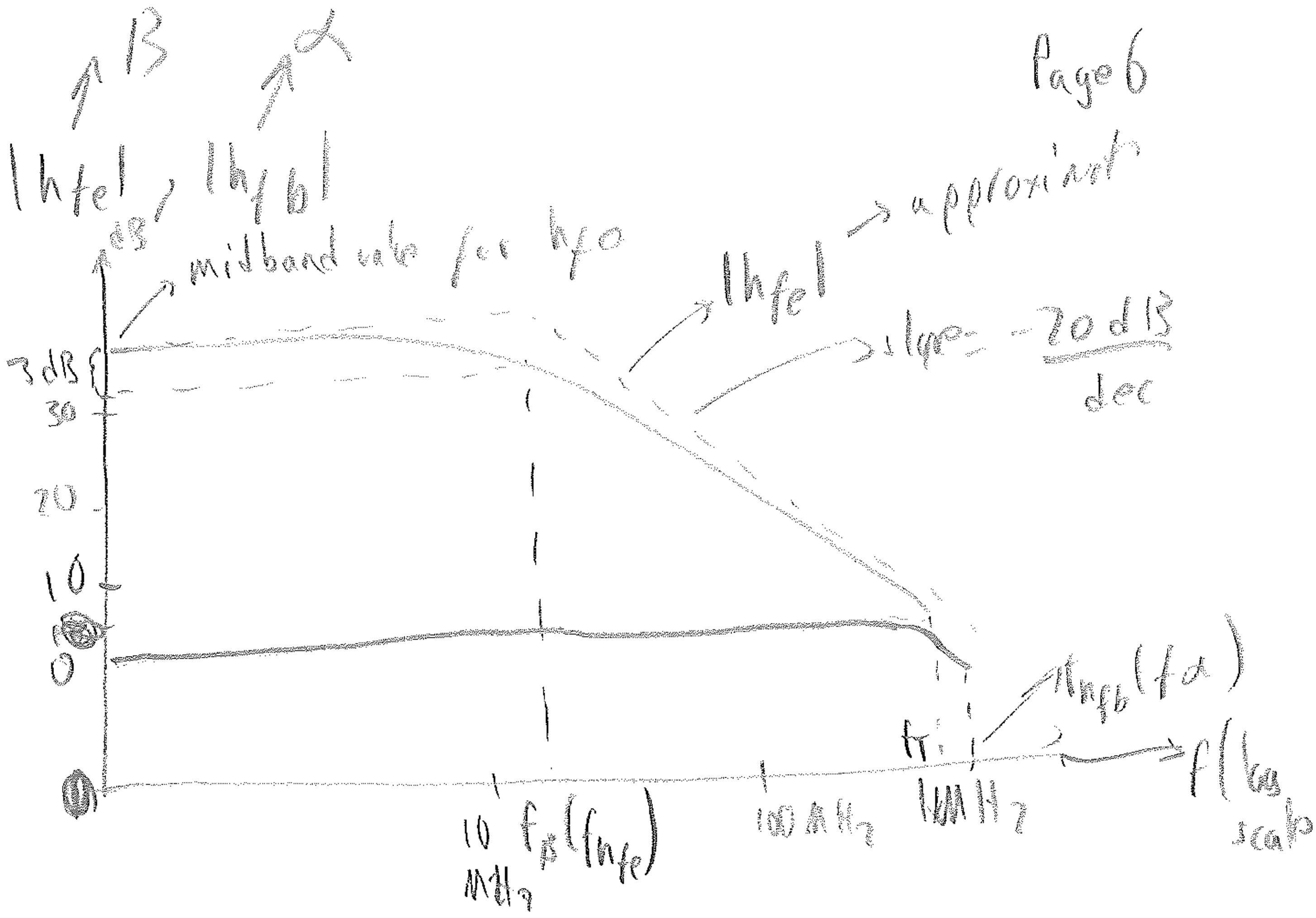
f_β (sometimes appearing as $f_{h_{fe}}$) $= \dfrac{1}{2\pi r_\pi (C_\pi + C_u)}$

as $r_\pi = \beta r_e = h_{fe_{mid}} r_e$

$$f_\beta = \frac{1}{h_{fe_{mid}} (2\pi) r_e (C_\pi + C_u)}$$

$$f_\beta \cong \frac{1}{2\pi \beta_{mid} r_e (C_\pi + C_u)}$$

Since r_e is a function of the network design,
f_β is a function of the bias configuration



$$f_\beta = f_\alpha (1-\alpha)$$

$$f_T = h_{fe_{mid}} f_\beta$$

$$f_T = \beta_{mid} f_\beta$$

$$f_\beta = \frac{f_T}{\beta_{mid}}$$

$$f_T \cong \beta_{mid} \frac{1}{2\pi \beta_{mid} (C_\pi + C_\mu) r_e}$$

$$f_T = \frac{1}{2\pi r_e (C_\pi + C_\mu)}$$