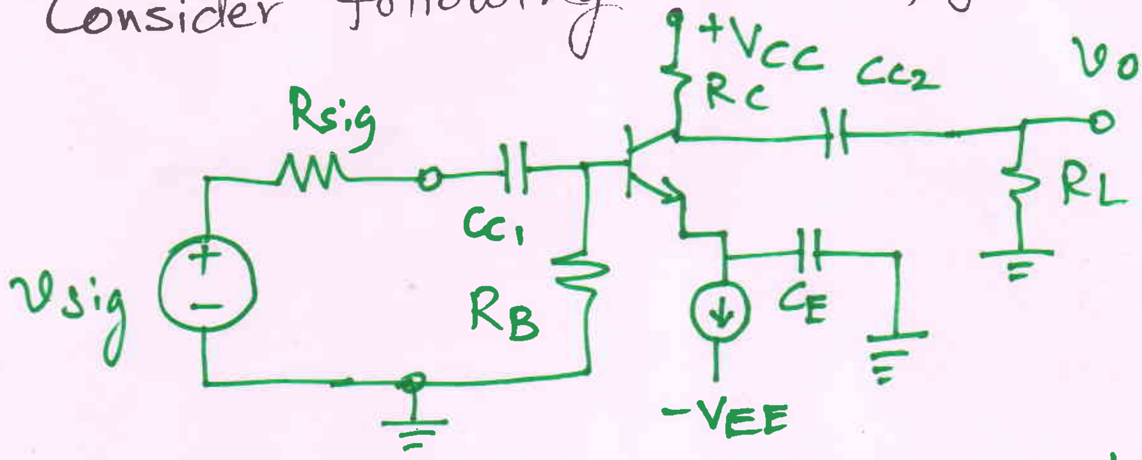
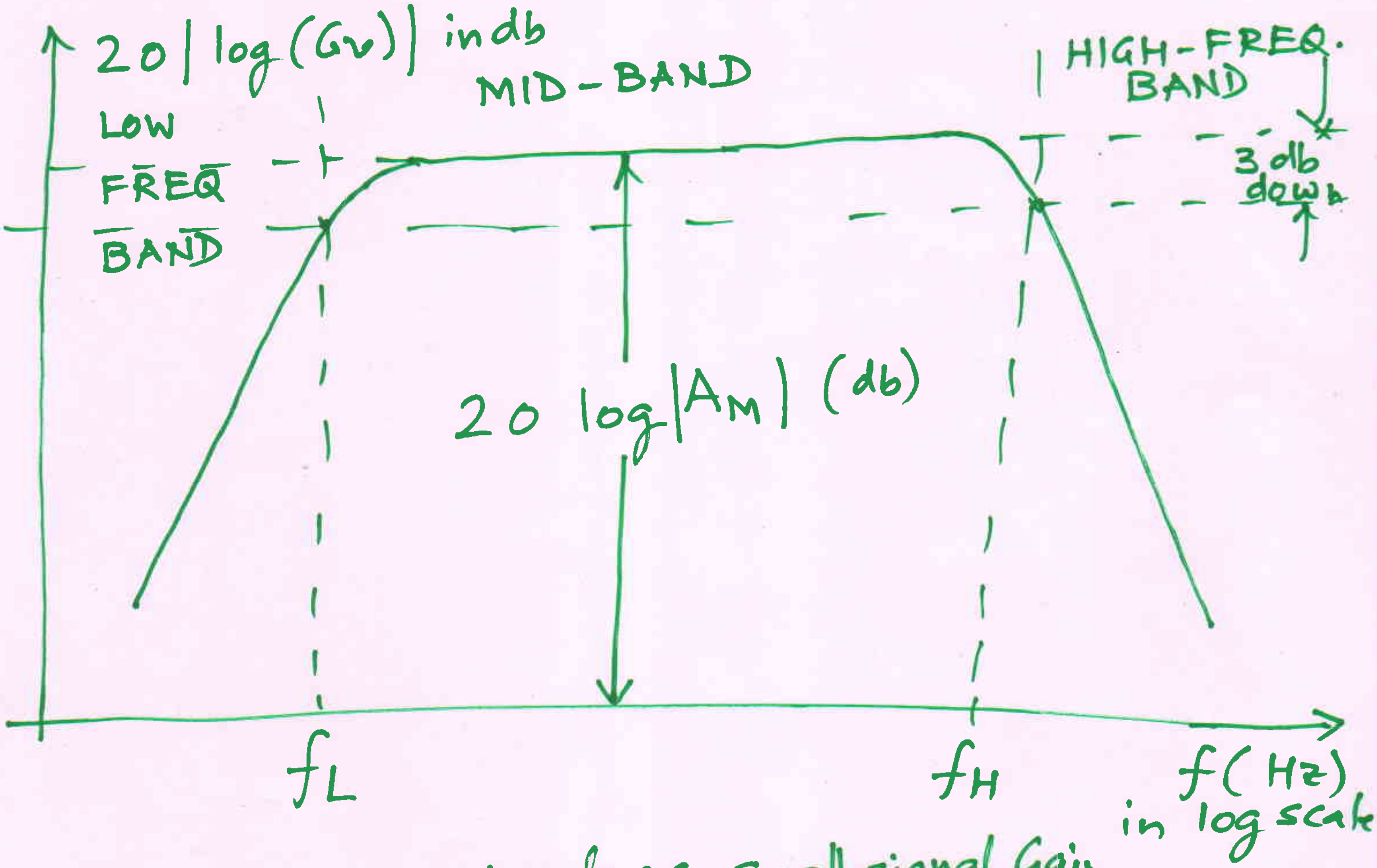
FREQUENCY RESPONSE OF THE COMMON EMITTER AMPLIFIER

Consider following CE configuration :



C_{c1}, C_{c2}, C_E = Large Values

Normalized G_v in db plotted on Log f scale:



What we considered as small signal Gain or G_v can now be called as MID BAND GAIN A_M

$$A_M = \frac{v_o}{v_{sig}} = \frac{(R_B \| r_\pi)}{(R_B \| r_\pi) + R_{sig}} \cdot g_m (r_o \| R_C \| R_L)$$

As the frequency increases, C_π and C_μ start exercising their effect and the gain starts reducing. The frequency at which gain falls to 3 db of midband gain or 0.707 of A_M is called as Upper Cutoff Frequency f_H = A_M in db − 3 db

$$\text{Gain at } f_H = |A_M| \text{ in db} - 3\text{ db}$$

$$= \frac{|A_M|}{\sqrt{2}} = |A_M| \times 0.707$$

At low frequencies C_E offers non-zero reactance and behaves like emitter degenerated which means v_o is reduced. Similarly at low frequencies C_{C_1} and C_{C_2} do not behave like perfect short circuit but offer series reactance (like Rsig) and drop off a portion of signal input or signal output voltage. This reduces v_o at lower frequency. The frequency on lower side at which $|G_v|$ or $|A_v|$ falls to 0.707 of A_M is called f_L or LOWER CUTOFF FREQUENCY.

Gain at f_L = A_M in db − 3 db

$$= \frac{|A_M|}{\sqrt{2}} = |A_M| \times 0.707$$

We define a term BANDWIDTH OF an amplifier as

$$BW = f_H - f_L$$

BW represents usable frequency band or zone or area or spectrum over which amplifier offers "reasonable" or "nearly constant" voltage gain.

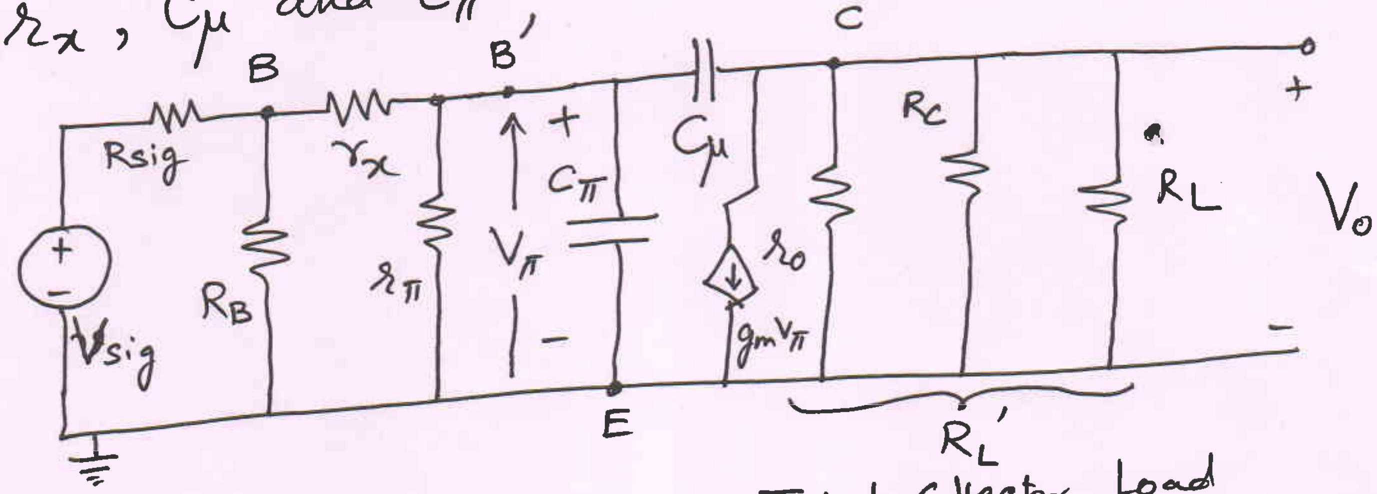
A figure of Merit for any Amplifier is defined as GAIN BANDWIDTH product

$$GB = |A_M| \times BW$$

Later on, we will see that to get larger bandwidth, we can sacrifice voltage gain.

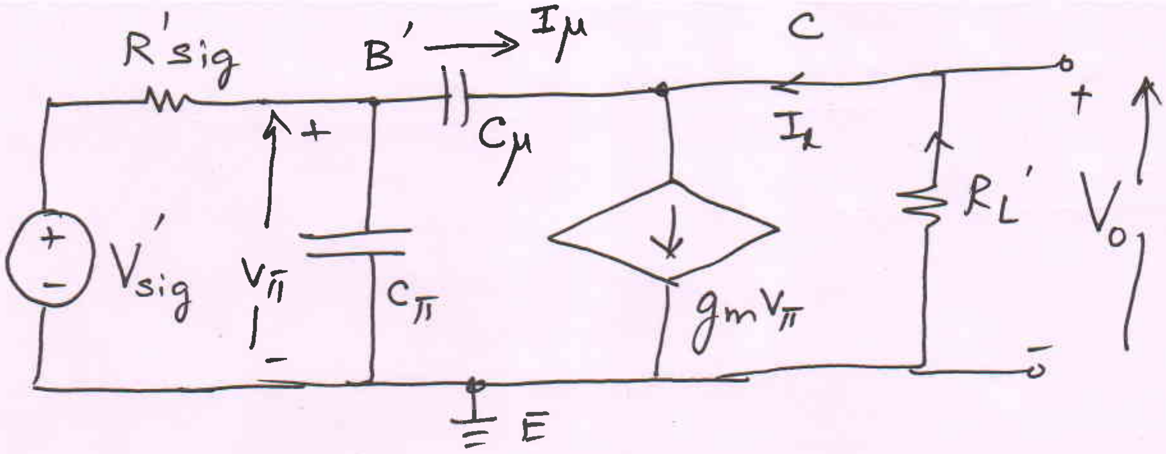
HIGH FREQUENCY RESPONSE OF A CE AMPLIFIER

Draw the high frequency model incorporating r_x, C_μ and C_π;



At high frequency C_{C_1}, C_{C_2} and C_E will be short ckt. Note that Vsig & Rsig drive a load of $r_x + (r_\pi \| C_\pi)$. The part of Vsig which appears across B' & E is V_π. This is true input to amplifier. This multiplied by g_m gives us the magnitude of current source between Collector & Emitter i.e. output terminals. There are 3 resistors in parallel in output circuit R_C, r_o & R_L. R_L' represents equivalent value of these 3 loads. The output voltage $V_o = g_m \cdot V_\pi \cdot R_L'$ without taking into consideration feedback or 'leakage' through C_μ.

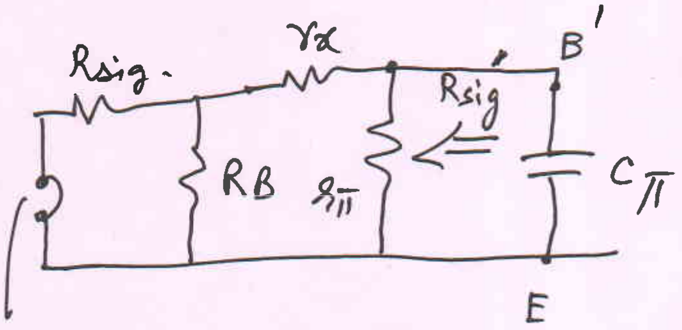
To solve, let us replace all resistors in input side by a single R_{TH} or Thevenin Equivalent as follows; with V_{TH} as Thevenin Voltage source.



$$V'_{sig} = V_{sig}\left(\frac{R_B}{R_B + R_{sig}}\right)\cdot\left(\frac{r_\pi}{r_\pi + r_x + (R_{sig} \| R_B)}\right)$$

$$R_L' = r_o \| R_C \| R_L$$

R'_{sig} = resistance seen from C_π towards left with all voltage sources short circuited & current sources open circuited.



V_{sig} short circuited.

$$R'_{sig} = r_\pi \,\|\, \left\{ \left(r_x + R_{sig} \| R_B\right) \right\}$$

Now we will represent C_μ by an equivalent Capacitance C_{eq} between B' & E in shunt with C_π.

At node C load $I_\ell = g_m V_\pi - I_\mu$

At 3 db point, f_H we can assume that $g_m V_\pi$ is quite high as compared to I_μ & $I_\ell \approx g_m V_\pi$

$\therefore V_o$ approx. $= g_m V_\pi \cdot R_L'$ - - - - ①

Approximate Voltage Gain from B' to C is same as midband gain $-g_m R_L'$. In s plane,

$$I_\mu = s C_\mu (V_\pi - V_o)$$

= sustenance ~~reactance~~ × voltage across C_μ.

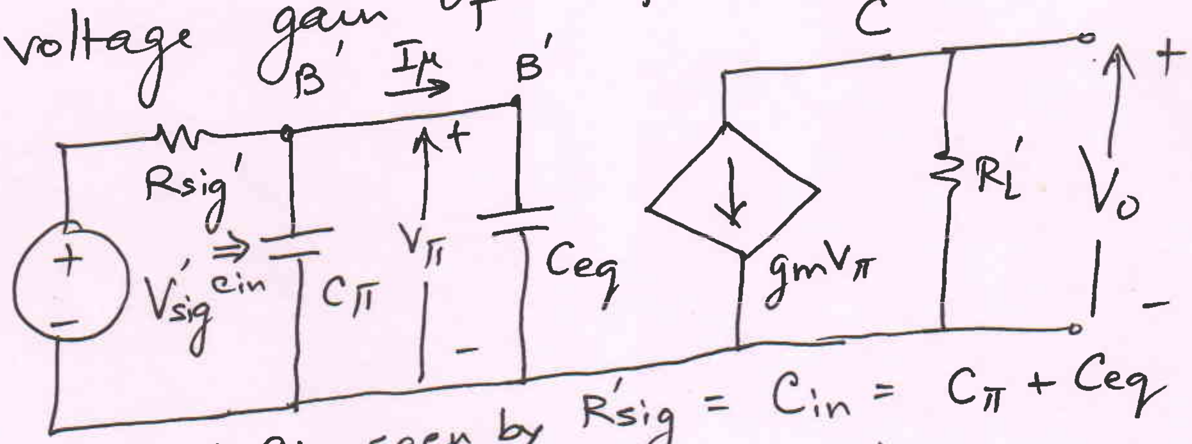
$$= s C_\mu \left[V_\pi - (-g_m R_L' V_\pi) \right]$$

$$= s C_\mu \left[1 + g_m R_L' \right] V_\pi$$

$$= s C_{eq} \cdot V_\pi$$

where $C_{eq} = C_\mu \left[1 + g_m R_L' \right]$

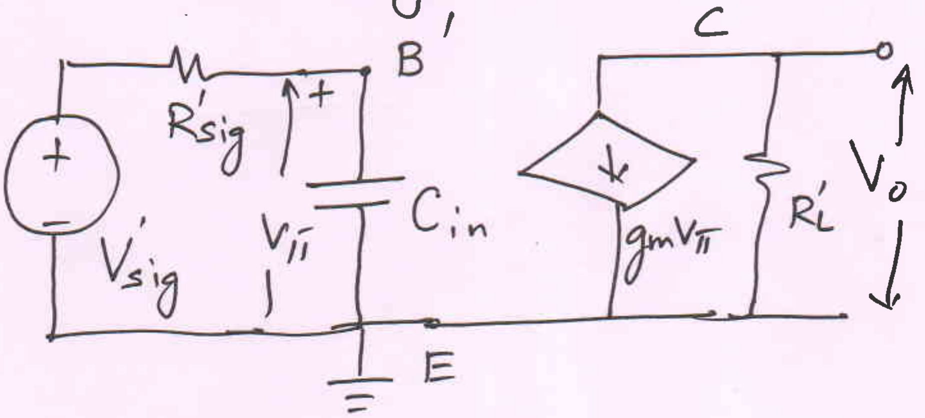
Note that $\because$ $g_m R_L'$ could be 10 to 200, a small C_μ appears as very large capacitor in shunt with C_π. Hence a small C_μ gets magnified & becomes more dominent than C_π due to high voltage gain of amplifier. The net circuit is



Total Cin seen by R_{sig}' = $C_{in} = C_\pi + C_{eq}$

$$C_{in} = C_\pi + C_\mu (1 + g_m R_L')$$

Now we have reduced input side to a single time constant circuit having a resistor R'_{sig} and capacitor C_{in}



$$V_\pi = V'_{sig} \frac{1}{1 + s/\omega_0}$$

where $\omega_0 = \dfrac{1}{R'_{sig} \cdot C_{eq}} = \dfrac{1}{R'_{sig} \cdot (C_\pi + (1 + g_m R'_L) C_\mu)}$

So we calculate overall voltage Gain

$$\frac{V_o}{V_{sig}} = -\left[\left(\frac{R_B}{R_B + R_{sig}}\right) \cdot \left(\frac{r_\pi g_m R_L'}{r_\pi + r_x + (R_{sig} \| R_B)}\right)\right]\left(\frac{1}{1 + \frac{s}{\omega_0}}\right)$$

$$= \frac{A_M}{1 + \frac{s}{\omega_0}}$$

Note that r_x is also taken into account here.

where [ ] quantity is A_M or midband gain.

Notes :

$$f_H = \frac{\omega_0}{2\pi} = \frac{1}{2\pi \cdot C_{in} \cdot R'_{sig}}$$

1. If R_{sig} is quite small compared to R_B i.e. if $R_B >> R_{sig}$ and semiconductor material resistance $r_x << R_{sig}$ then effective resistance $R'_{sig} \approx r_\pi // R_{sig}$. Now if $R_{sig} >> r_\pi$ then f_H is decided almost alone by r_π. If $R_{sig} \approx r_\pi$ then f_H is largely affected by R_{sig}. Note R_{sig} is not an amplifier property, it is the property of signal source. Thus a high R_{sig} will ~~lower~~ ~~R~~ increase R'_{sig} and produce lower value of f_H for the same amplifier. The best case is where R_{sig} is very small & r_π is very large & then f_H will be very high.
2. $C_{eq} = (1 + g_m R'_L) C_\mu$. The factor $(1 + g_m R'_L)$ is known as Miller Multiplier due to Miller Effect. Due to this CE amplifier has high C_{in} and $\therefore$ low f_H.
3. We have neglected I_μ as compared to $g_m V_\pi$. Actually at higher frequencies this is not valid & actual f_H is lower than estimated.
4. If R'_L is reduced then C_{eq} goes down & f_H goes up.