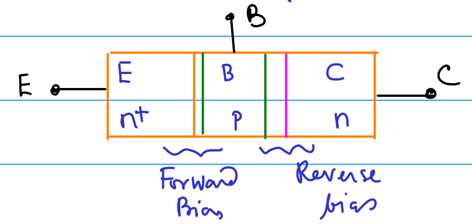
4.3.2022

Frequency Response of CE Amplifier

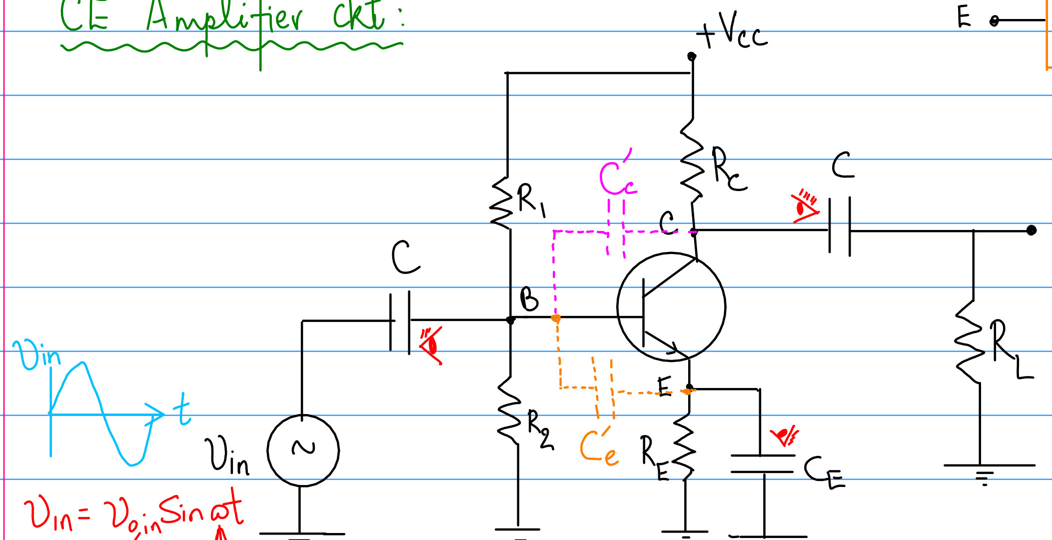
(Reference: Chapter 16, Malvino & Bates)

1. How voltage gain (A_v) of the CE amplifier changes with varying the frequency of the input signal.

2. Representation of gain (voltage / power) in units of decibel (dB)



CE Amplifier ckt:



$v_o = v_{o,out} \sin(\omega t - 180^\circ)$

$v_{in} = v_{o,in} \sin \omega t$

Ang. freq.

$\omega = 2\pi f$ where $f = \frac{1}{T}$ (in Hz)

C'_c, C'_e are the junction capacitor only operating at high-freq.

- As we know, for DC analysis:
  - the capacitors are 'OPEN'.

- For ac analysis: All the capacitors are "SHORT"

$$X_C = \frac{1}{\omega C}$$

ω / f → Mid-freq. range (1kH–50kHz)

In mid-frequency range the value of X_c is small as compared to the equivalent resistance as seen the capacitor, and hence all the ac voltage is dropped across the resistor. Therefore, the capacitors are electrically short for the ac signal.

Ques: Is this assumption valid in the low-frequencies?

— NO — $\Rightarrow$ effectively the gain reduces.

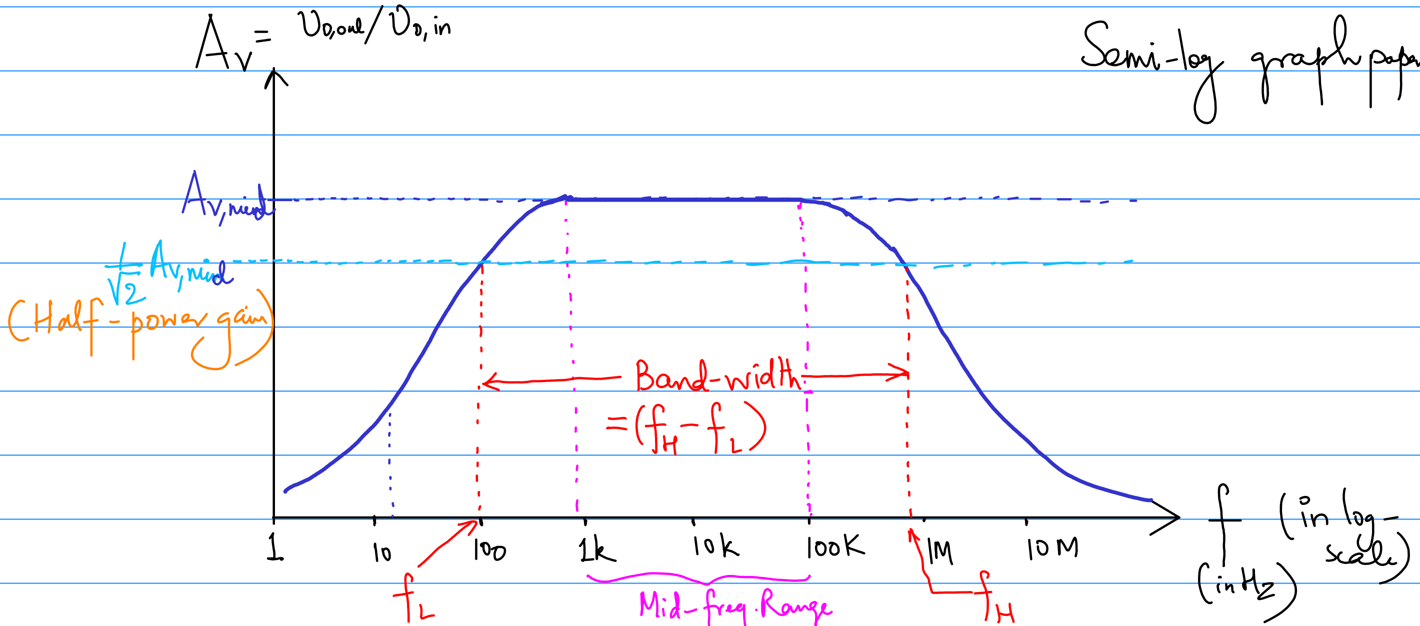
Ques: Is this assumption valid in the high-frequencies?

— YES — $\Rightarrow$ effectively the gain reduces.

Why?

- At high-frequencies, the base-emitter junction and base-collector junction effectively behaves as a capacitors and affect the input & output ac voltages.

$\Rightarrow$ Effectively the gain reduces.



Mathematically,

$$A_v(f) = \frac{A_{v(mid)}}{\sqrt{1+(f_L/f)^2}\ \sqrt{1+(f/f_H)^2}}$$

where, f_L = Lower cut-off frequency

f_H = Higher cut-off frequency.

Case (i) $f < f_L$ (ie, the frequency is lower the low cut-off freq.)

$$\frac{f_L}{f} > 1 \qquad \text{whereas} \qquad \frac{f}{f_H} \approx 0$$

$$A_v(f) \approx \frac{A_{v,mid}}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}$$

Case (ii) $f_L < f < f_H$ (ie, mid-freq. range).

$$\frac{f_L}{f} \approx 0 \qquad \frac{f}{f_H} \approx 0$$

$$A_v(f) = A_{v\,mid}$$

Case (iii) $f > f_H$ (high freq. range)

$$\frac{f_L}{f} \approx 0 \qquad \frac{f}{f_H} > 1$$

$$A_v(f) = \frac{A_{v\,mid}}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$$

Unit of voltage gain in Decibel (dB)

$$\boxed{A_v(dB) = \left[20 \log_{10} A_v\right] dB}$$

known $A_v = \frac{v_o}{v_{in}}$

eg: if $A_v = 100$

$$A_v(dB) = 20 \log_{10} 100 \ dB$$

$$= 40 dB$$

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Unit of power gain in decibel (dB)

$$\boxed{A_p(dB) = 10 \log_{10}(A_p) \ dB}$$

where $A_p = \dfrac{P_o}{P_{in}} = \dfrac{\text{ac power output}}{\text{ac power input}}$.

We have designed a multi-stage amplifier in which each stage is having voltage gain as

$$A_{v_1}, \ A_{v_2}, \ A_{v_3} \ ----- \ A_{v_n}$$

Overall gain is given as:

$$A_v = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} ----- \cdot A_{v_n}$$

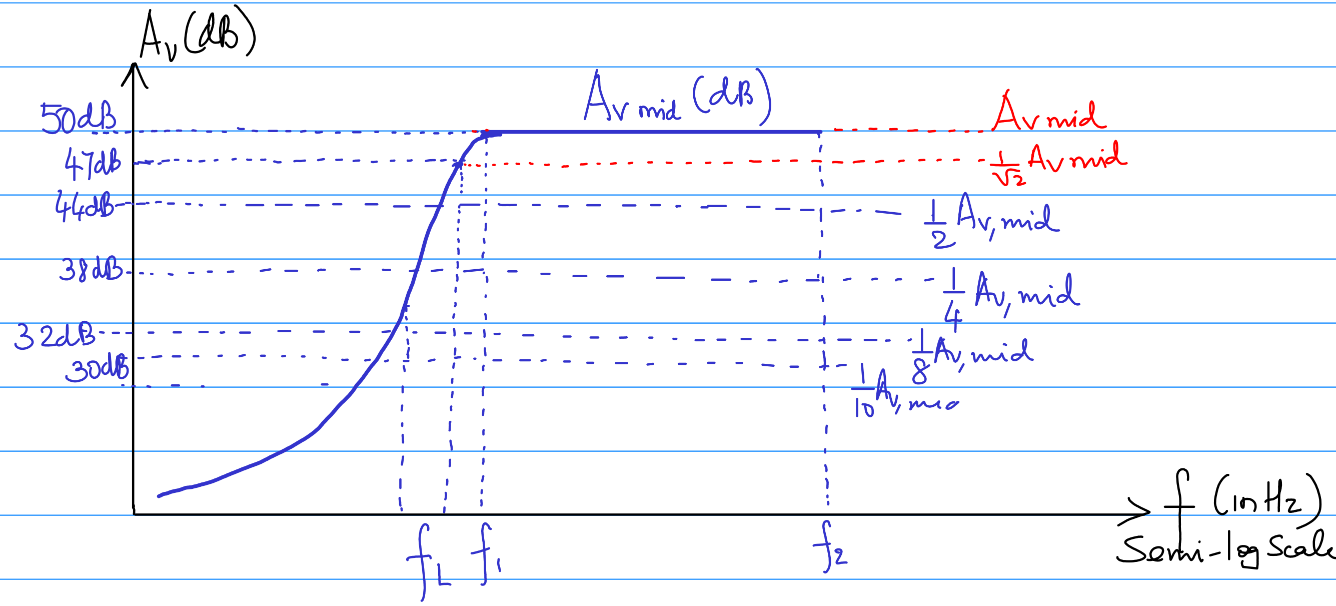
Overall gain in dB

$$A_v(dB) = 20 \log_{10} A_v$$

$$= 20 \log_{10} \left[A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots A_{v_n}\right]$$

$$= 20 \log_{10} A_{v_1} + 20 \log_{10} A_{v_2} + ----- + 20 \log_{10} A_{v_n}$$

$$\boxed{A_v(dB) = A_{v_1}(dB) + A_{v_2}(dB) + \cdots\cdots + A_{v_n}(dB)}$$



At lower cut-off frequency the voltage gain is reduced as a factor $\frac{1}{\sqrt{2}}$.

What the value of this reduction in dB.

$$\text{Red}^n \text{ in gain (dB)} = 20\log_{10}\left(\frac{1}{\sqrt{2}}\right) \text{ dB}$$

$$= \underbrace{20\log_{10} 1}_{=0} - 20\log_{10} 2^{1/2} \text{ dB}$$

$$= -20\cdot\frac{1}{2}\log_{10} 2 \text{ dB}$$

$$= -3 \text{ dB}$$

$\boxed{\text{Red}^n \text{ in gain at cut-off frequency is 3dB.}}$

* Note: 1) Whenever the voltage gain is reduced by half ($\frac{1}{2}$) the voltage gain in dB is reduced by 6dB.

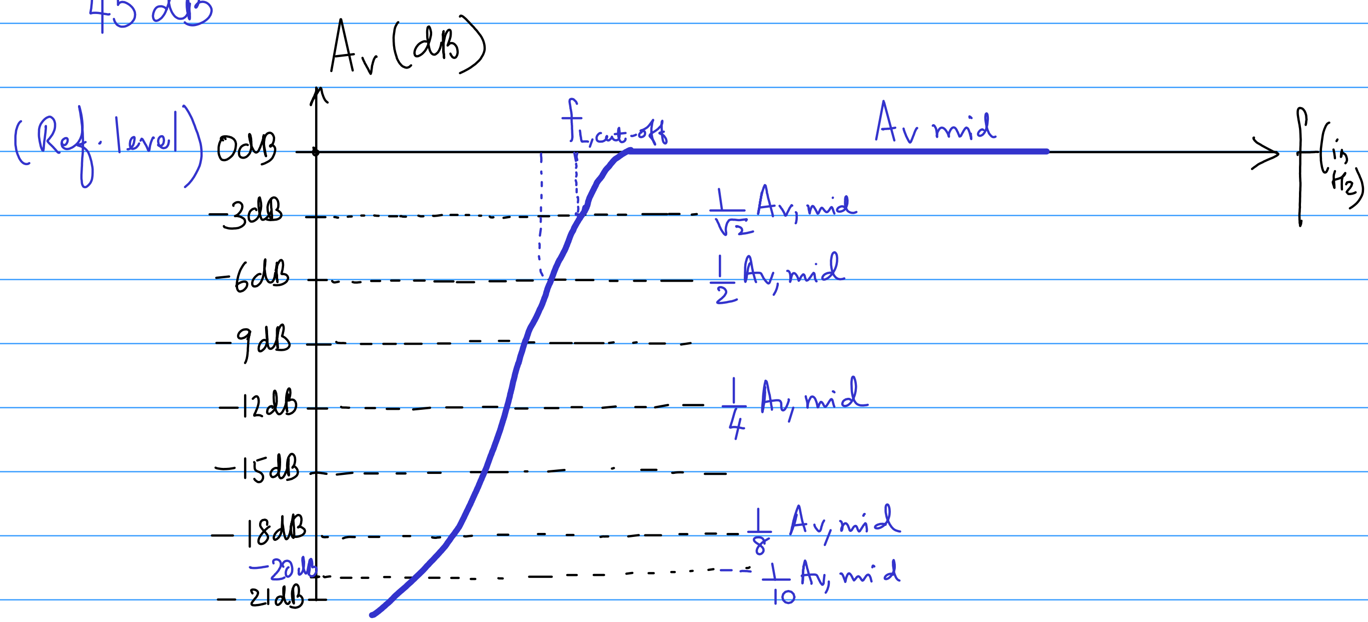
2) Whenever the voltage gain is reduced by $\frac{1}{10}$ th, the voltage gain is reduced by 20dB

Example:

Let's say mid-freq. voltage gain is 65dB

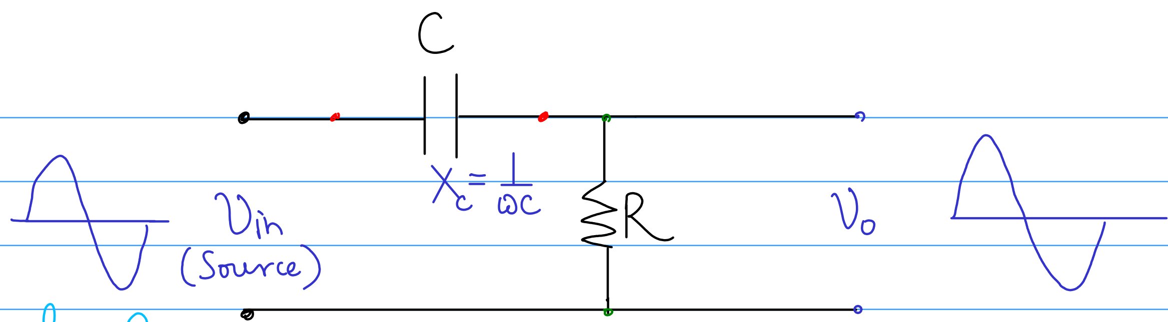
65dB → 62dB (at cut-off freq.) → 59 dB (gain redⁿ by half) → (Redⁿ by $\frac{1}{4}$ th) 53dB

65dB → (Redⁿ in $\frac{1}{10}$ of the gain) 45 dB



Low frequency response of a CE Amplifier:

We know that at low frequencies ($f \to 0$), the reactance (X_C) of the coupling & by-pass capacitors are not approximated to zero. (i.e, the capacitors are no more behaving as a "SHORT" to ac-signal.



High freq. Response:

⇒ The R-C circuit allows high-frequency signal to pass through. In other-words, it blocks the low-frequency signal.

Low freq. Response:

The capacitors are no more 'SHORT'.

⇒
$$\boxed{V_o = \frac{R}{\sqrt{X_c^2 + R^2}} \cdot V_{in}}$$