ENEE2360 Analog Electronics

T12:
Amplifier Frequency Response

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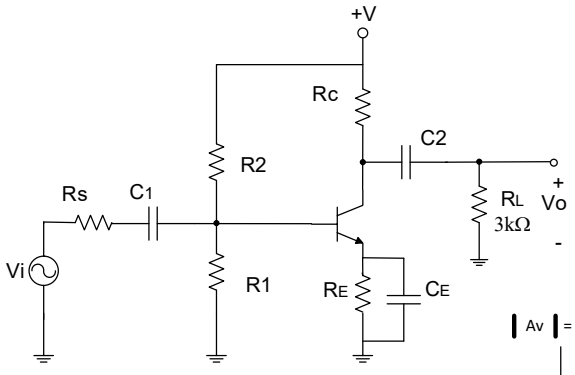
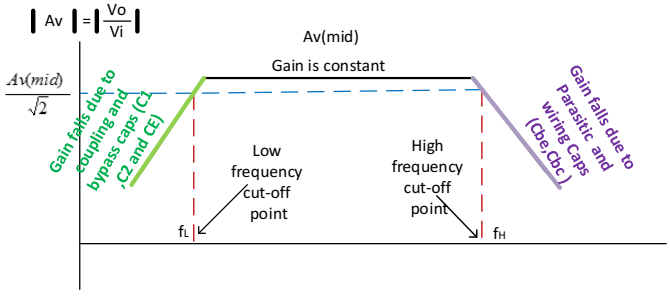
Amplifier Frequency Response

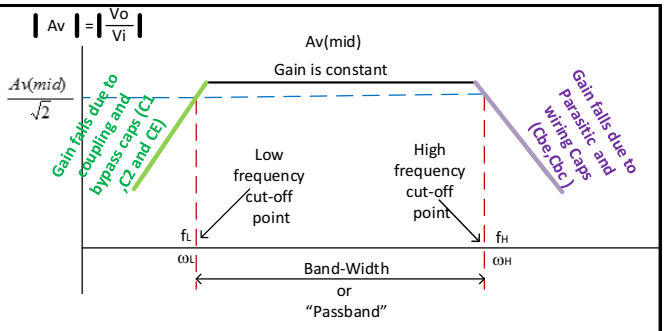
- Audio frequency signals such as speech and music are combination of many different sine waves, occurring simultaneously with different amplitude and frequency in the following range (20Hz-20kHz (audible noise) , other types of signals have their own range.
- In order for the output to be an amplified version of the input, the amplifier must amplify each and every component in the signal by the same amount
- The Bandwidth must cover the entire range of frequency components if considered amplification is to be achieved

Amplifier Frequency Response





Impedance of a cap



- The impedance of a cap is

$$X_c = \frac{1}{2\pi f C}$$

when $f < f_L$ the coupling caps C1 and C2, and the bypass cap C_E cannot be considered as short circuit since their impedance is not small enough

when $f > f_H$ the internal caps Cbc and Cbe for a BJT (or Cgs and Cgd), cannot be considered as open circuit since their impedance is not high enough

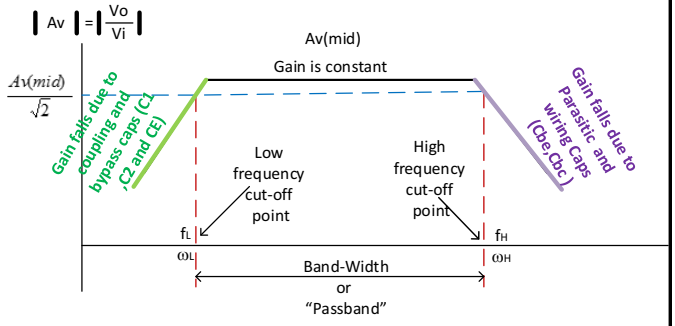
Corner Frequency

we define the corner (break and cut - off) frequency as :

$$\left|A(j\omega_L)\right| = \frac{Av(mid)}{\sqrt{2}}$$

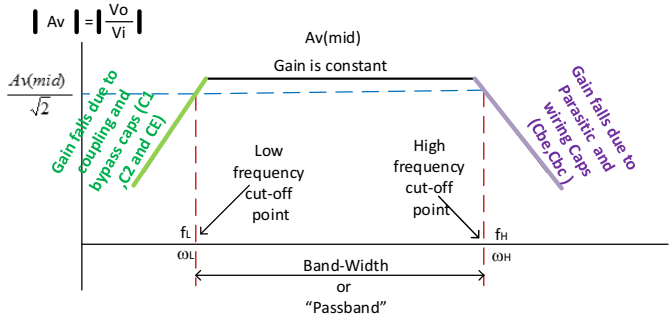
$$\left|A(j\omega_H)\right| = \frac{Av(mid)}{\sqrt{2}}$$

$$\omega_H - \omega_L = BW \quad \text{- Bandwidth}$$



$$\text{Midrange} = \text{midband} \cong 10\omega_L - 0.1\omega_H$$

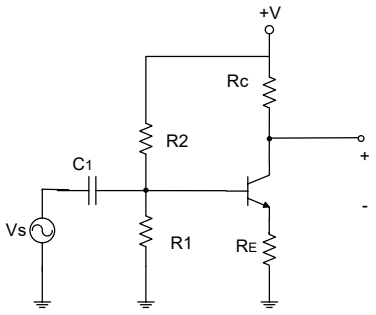
Corner Frequency



$$\text{Midrange} = \text{midband} \cong 10\omega_{\text{L}} - 0.1\omega_{H}$$

– This is the range for which the capacitors (C1, C2 and CE) are considered short circuit while the parasitic caps are considered open circuit (this is the range we have considered so far in previuos chapters)

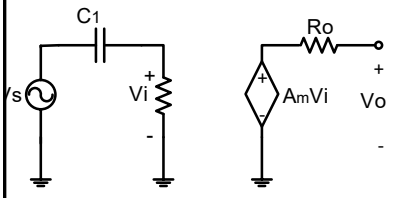
Series Capacitance and low frequency response



$$\mathrm{Vo} = \mathrm{AmVi}$$

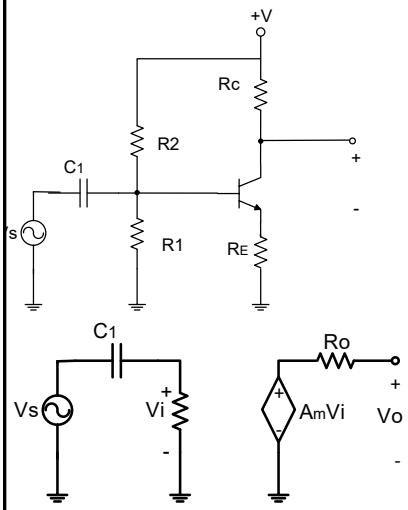
$$Vi = \frac{Ri}{Ri + \frac{1}{j\omega C1}}\mathrm{Vs} \rightarrow \mathrm{Vo} = \frac{Am.Ri}{Ri + \frac{1}{j\omega C1}}\mathrm{Vs}$$

$$\frac{\mathrm{Vo}}{\mathrm{V_S}} = \frac{Am.Ri}{Ri + \frac{1}{j\omega C1}} = \mathrm{A}(j\omega)$$



$$\rightarrow \left|\mathrm{A}(j\omega)\right| = \frac{Am.Ri}{\sqrt{(Ri)^2 + \left(\frac{1}{\omega C1}\right)^2}}$$

Series Capacitance and low frequency response



$$|A(j\omega)| = \frac{Am.Ri}{\sqrt{(Ri)^2 + \left(\frac{1}{\omega C1}\right)^2}}$$

$$= \frac{Am}{\sqrt{1 + \left(\frac{\omega_{C1}}{\omega}\right)^2}};$$

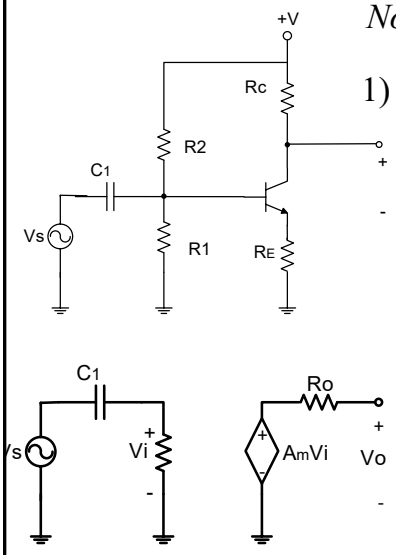
where $\omega_{C1} = \frac{1}{\text{Ri.C1}}$ is the break frequency due to C1

For $Am = 1$

- for $\omega = \omega_{C1} \rightarrow 20\log|A(j\omega)| = 20\log Am - 20\log 0.707 = -3\text{dB}$

for $\omega = 0.1\omega_{C1} \rightarrow 20\log|A(j\omega)| = -20\log 10 = -20\text{dB} \leftarrow$ High pass filter

Series Capacitance and low frequency response



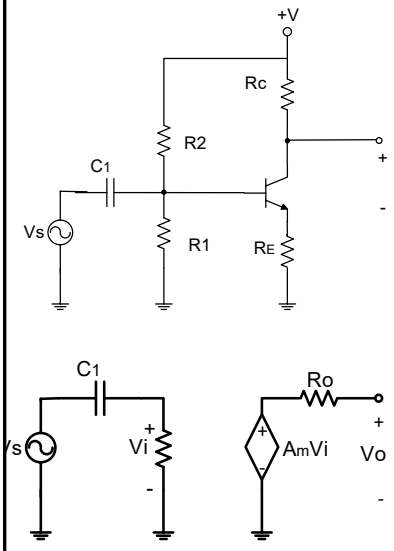
Note:

1) If there is only one cap, we find $\omega_{C1} = \dfrac{1}{Rth1.C1}$ and $\omega_L = \omega_{C1}$

2) If there is two caps C1 and C2 with ω_{C1} and ω_{C2}, then

$$A(j\omega) = Am\left(\frac{1}{1+\left(\frac{\omega_{C1}}{j\omega}\right)}\right)\left(\frac{1}{1+\left(\frac{\omega_{C2}}{j\omega}\right)}\right)$$

Series Capacitance and low frequency response



in order to find ω_L, we find magnitude of the gain at ω_L

$$|A(j\omega_L)| = \frac{Am}{\sqrt{2}}$$

solving yields

$$\omega_L^{\,2} = \frac{\omega_{C1}^{\,2} + \omega_{C2}^{\,2}}{2} + \frac{\sqrt{\omega_{C1}^{\,4} + 6\omega_{C1}^{\,2}\omega_{C2}^{\,2} + \omega_{C2}^{\,4}}}{2}$$

Series Capacitance and low frequency response

1) let $\omega_{C1} = 616$ rad/sec and $\omega_{C2} = 17.86$ rad/sec

here $\omega_{C1} >> \omega_{C2}$

$\omega_L = 616.5$ rad/sec

2) let $\omega_{C1} = 200$ rad/sec and $\omega_{C2} = 750$ rad/sec

here $\omega_{C2} >> \omega_{C1}$

$\omega_L = 798$ rad/sec

$$\omega_L{}^2 = \frac{\omega_{C1}{}^2 + \omega_{C2}{}^2}{2} + \frac{\sqrt{\omega_{C1}{}^4 + 6\omega_{C1}{}^2\omega_{C2}{}^2 + \omega_{C2}{}^4}}{2}$$

In both cases and in general

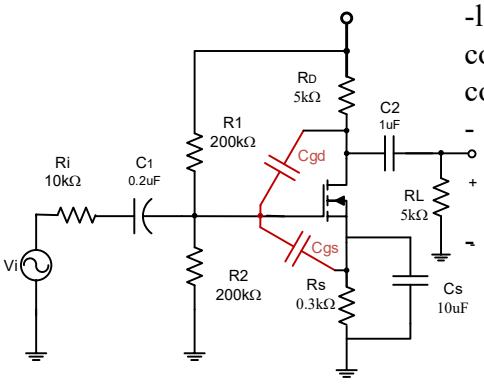
if $\omega_{C1} >> \omega_{C2}$

$\omega_{C1} < \omega_L < \omega_{C1} + \omega_{C2}$

Biggest $\omega_{C1} < \omega_L <$ sum of all ω_C's

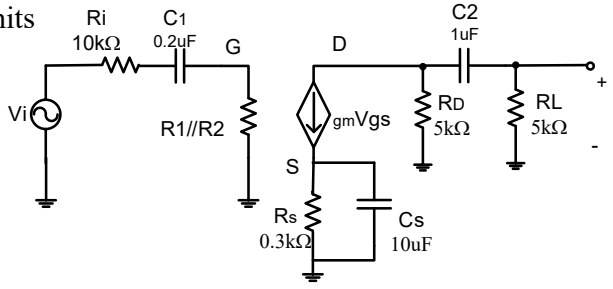
Low Frequency Response Example

- Calculate the low frequency corner frequencies due to C1,C2, Cs and estimate ω_L ?



-low frequency ac small signal equivalent circuit is constructed (here all high frequency caps Cgs, Cgd are considered as open circuits)

- We consider one capacitor each time , while all other low frequency caps are considered short circuit and its corresponding ω is found
- Finally, ω_L is estimated using the formula for upper and lower limits



Effect of each Capacitor at ω_L

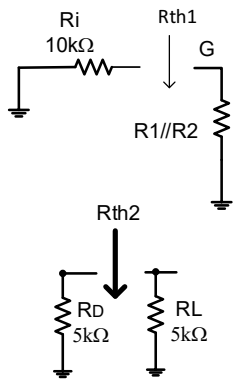
- We Calculate the low frequency corner frequencies due to each cap acting alone while all others are considered as short circuit

1) consider C1 (while C2 and Cs are shorted)

$$\omega_{C1} = \frac{1}{C1.Rth1} = 45.45 \text{ rad/sec};$$

$Rth1$ is the thevenin impedance seen by C1 while all independant sources are set to zero

$$\text{Rth1} = \text{Ri} + (\text{R1}//\text{R2})$$



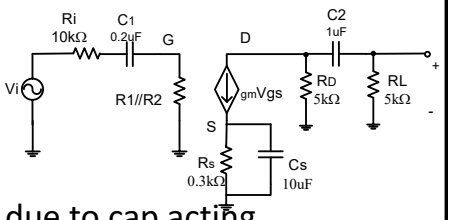
2) consider C2 (while C1 and Cs are shorted)

$$\omega_{C2} = \frac{1}{C2.Rth2} = 100 \text{ rad/sec};$$

$Rth1$ is the thevenin impedance seen by C1

$$\text{Rth2} = R_D + R_L$$

Effect of each Capacitor & ω_L



- We Calculate the low frequency corner frequencies due to cap acting alone while all others are considered as short circuit

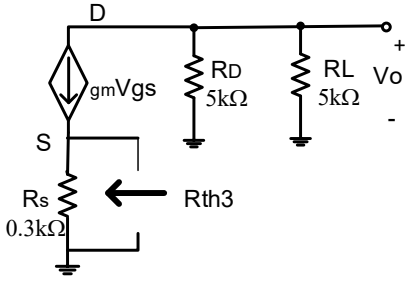
3) consider Cs (while C1 and C2 are shorted)

$$\omega_{C3} = \frac{1}{Cs.\text{Rth3}} = 1050 \text{ rad/sec;}$$

Rth3 is the thevenin impedance seen by Cs

remember $\text{rds} = \infty$

$$\text{Rth3} = \text{Rs} // \frac{1}{\text{gm}}$$



4) estimation of the ω_L

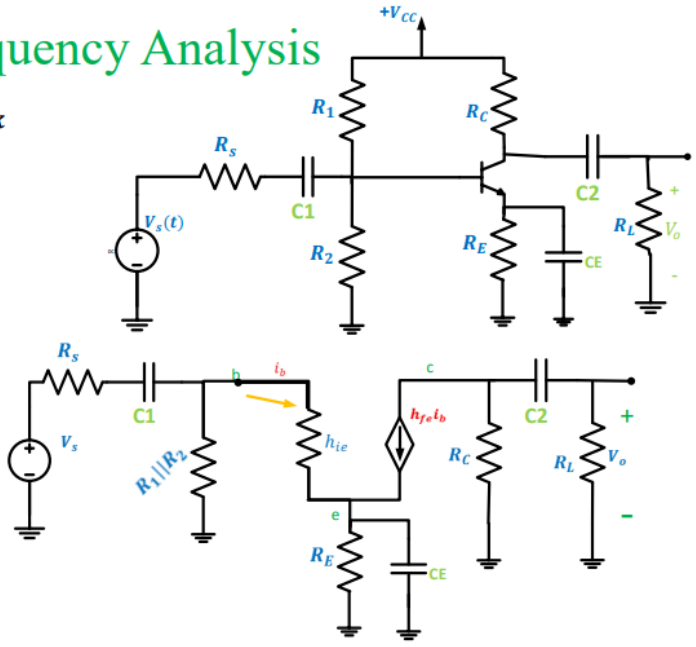
$$1050 < \omega_L < 1195.5$$

CE Amplifier low-frequency Analysis

$h_{ie} = 10.45k\,, h_{fe} = 350\,, R_1 \| R_2 = 16.67k$
$R_c = 5k\,, R_L = 2k\,, R_E = 5k\,\,, R_s = 1k$
$C_1 = 3\mu F\,\,, C_2 = 8\mu F\,\,, and\, C_E = 50\mu F$

Estimate ω_L

Ac small signal low- frequency equivalent C_{KT}



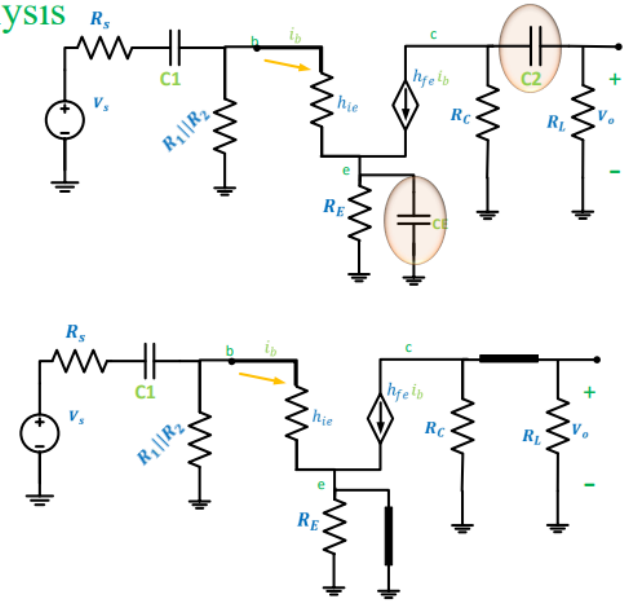
CE Amplifier low-frequency Analysis

1) To find ω_{c1} , set C_E and C_2 short

$$\omega_{c1} = \frac{1}{R_{TH_1} C_1}$$

$$R_{TH_1} = R_s + R_1 \| R_2 \| h_{ie}$$

$$\therefore \omega_{c1} = 44.9\ r/s$$



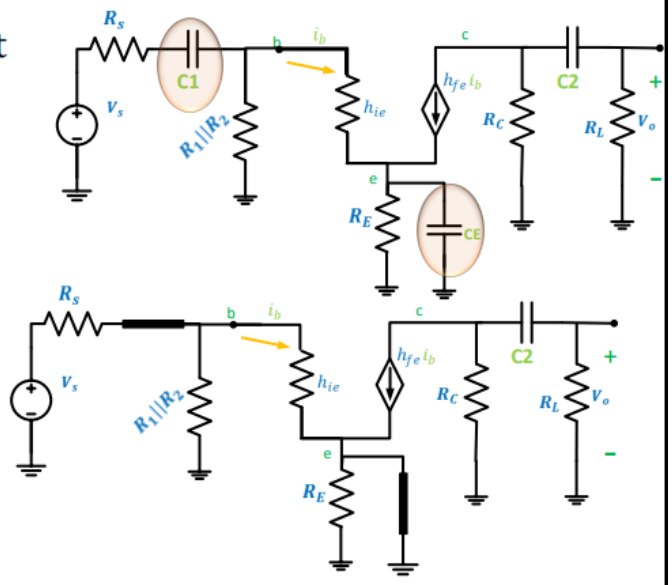
CE Amplifier low-frequency Analysis

- 2) To find ω_{c2}, set C_1 and C_E short

$$\omega_{c2} = \frac{1}{R_{TH_2} C_2}$$

$$R_{TH_2} = R_L + R_c$$

$$\omega_{c2} = 17.86\ r/s$$



CE Amplifier low-frequency Analysis

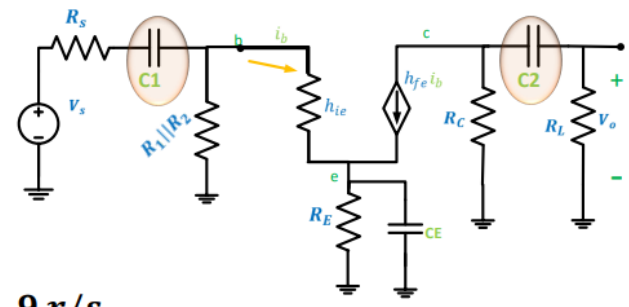
3) To find ω_{CE}, set C_1 and C_2 short

$$\omega_{CE} = \frac{1}{R_{TH_3} C_E}$$

$$R_{TH_3} = R_E \text{ II } \left(\frac{R_s IIR_1 IIR_2 + h_{ie}}{h_{fe}+1}\right)$$

$$\therefore \omega_{CE} = 616\ r/s$$

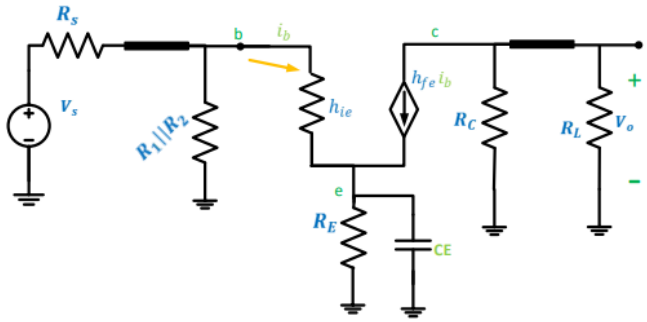
But $\omega_{c2} = 17.86\ r/s$ and $\omega_{c1} = 44.9\ r/s$



$$\omega_{C1} + \omega_{C2} + \omega_{CE} > \omega_L > \omega_{CE}$$

$$679\ r/s > \omega_L > 616\ r/s$$

$\omega_L \equiv 645\ r/s$ exact



Design of ω_L

- Previous method explained how to estimate value of ω_L in an analysis problem where all capacitor values are given, but what happens if it was desired to design an amplifier with certain ω_L and the task was to find capacitor values ?
- Design criteria to be used is:

$$\omega_{CE} = (0.7 - 0.8)\omega_L$$

$$\omega_{C1} = \omega_{C2} = (0.1 - 0.15)\omega_L$$

$C1, C2$ are input and output coupling capacitors

C_E is bypass capacitor // to R_E emitter stabilizing resistor or Rs source resistor

make sure that $\omega_{CE} + \omega_{C1} + \omega_{C3} = \omega_L$

CE Amplifier low-frequency Design

Complete the design so that $W_L = 1000\ r/s$

$$\omega_{C1} + \omega_{C2} + \omega_{CE} = \omega_l = 1000 r/s$$

$$\omega_{CE} \geq 70\%\ \omega_L$$

$$\omega_{CE} \geq 0.7\ \omega_L$$

$$\omega_{CE} = 850\ r/s$$

$$\omega_{C2} = 50\ r/s$$

$$\omega_{C1} = 100 r/s$$

CE Amplifier low-frequency Design

$$\omega_{CE} = \frac{1}{\left[R_E II \left\{\frac{R_s II R_1 II R_2 + h_{ie}}{1 + h_{fe}}\right\}\right] C_E} = 850\ r/s$$

$$\therefore C_E = 65.9 \mu F$$

$$\omega_{c1} = \frac{1}{[R_s + R_1 II R_2 II h_{ie}] C_1} = 100\ r/s$$

$$\therefore C_1 = 1.74\ \mu F$$

$$\omega_{c2} = \frac{1}{[R_C + R_L] C_2} = 50\ r/s$$

$$\therefore C_2 = 1.54\ \mu F$$

$\omega_{CE} = 850\ r/s$

$\omega_{C2} = 50\ r/s$

$\omega_{C1} = 100 r/s$

Choose $C_E = 80\ \mu F$

$C_1 = C_2 = 2\ \mu F$

$\therefore \omega_L = 982\ r/s$