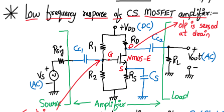
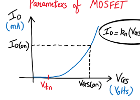
~~AEC 7.1~~ ~~24/1/22~~ AEC 23 1/9/23

* Low frequency response of CS MOSFET amplifier:–



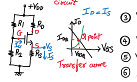
$C_{C_1} \to$ Input coupling capacitor } (Block DC & allow AC)
$C_{C_2} \to$ Output coupling capacitor
$C_S \to$ Bypass capacitor

device gain: k_n and threshold voltage: V_{th} or $V_{GS(th)}$ or V_{tn} — Parameters of MOSFET



Step1: DC analysis

① Find V_{GSQ} and I_{DQ}
→ Draw DC equivalent circuit
$f=0 \to X_C = \frac{1}{2\pi f C} = \infty$
All capacitors → replace by open-circuit



③ $V_G = \frac{R_2}{R_1+R_2} \times V_{DD}$; Input impedance of MOSFET is v.v.high, $I_G \approx 0$
④ $V_S = I_D R_S$
⑤ $V_{GS} = V_G - V_S$ ....(1.1)
⑥ $I_D = k_n(V_{GS} - V_{tn})^2$ .... (1.2)
⑦ Solve (1.1) and (1.2) to obtain V_{GSQ} and I_{DQ} values

② If k_n is not given,

$$\boxed{k_n = \frac{I_{D(on)}}{[V_{GS(ON)} - V_{GS(th)}]^2}} \quad \frac{mA}{V^2}$$

Step2: Calculate small signal parameters
① g_m ② r_o

$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$

$$\boxed{\begin{aligned} g_m &= 2k_n(V_{GSQ} - V_{tn}) \quad \frac{mA}{V} \\ r_o &= \frac{1}{\lambda I_{DQ}} \quad K\Omega \end{aligned}}$$

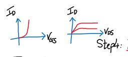
; g_m = transconductance of MOSFET device

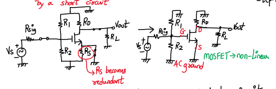
r_o or r_d ; λ = channel length modulation parameter (V^{-1})

If λ is not given, assume $\lambda = 0$
$\to r_o = \infty$

Step3: Calculate mid-band Voltage gain

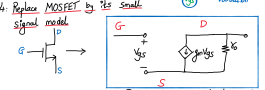
→ Draw AC equivalent circuit
→ All capacitors → replace by short-circuit
→ Any independent source → replace by a short circuit





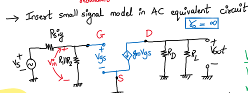
Step4: Replace MOSFET by its small signal model

$i_d = g_m V_{gs}$
$g_m = \frac{i_d}{V_{gs}}$ — represent small variation



Small-signal model of MOSFET

→ Insert small signal model in AC equivalent circuit $\boxed{r_o = \infty}$



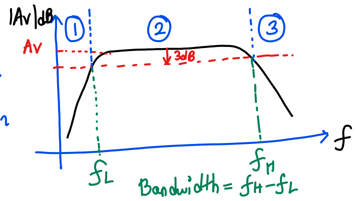
Mid-frequency / Mid-band Small-signal equivalent circuit

$\frac{V_{out}}{V_{in}} = -g_m(R_D \| R_L)$

$\frac{V_{in}}{V_s} = \frac{R_1\|R_2}{R_1\|R_2 + R_{sig}}$

→ Calculate $A_{vmid} = \frac{V_{out}}{V_s} = \frac{V_{out}}{V_{in}} \times \frac{V_{in}}{V_s}$
→ Calculate A_{vmid} in dB

$A_{vmid_{dB}} = 20\log_{10}(A_{vmid})$



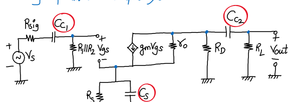
① low freq^n region
② Mid freq^n region
③ High-freq^n region

Bandwidth = $f_H - f_L$

AEC 24

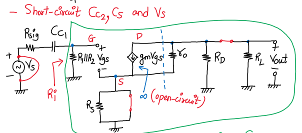
Step5: Calculate Low-cut off frequency of the circuit (f_L):

① Draw Low-frequency small-signal equivalent circuit
② Calculate $f_{LC_{C1}}$, $f_{LC_{C2}}$, f_{LC_S}
→ Keep Capacitors in AC equivalent circuit
→ Only independent source → Replace by short-circuit



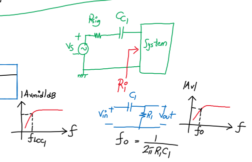
Low-frequency small-signal equivalent circuit

① Calculate $f_{LC_{C1}}$: Lower-cut-off frequency due to C_{C_1} alone
– Short-circuit C_{C_2}, C_S and V_S

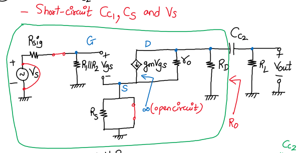


$R_i = R_1 \| R_2$;
$R_{eq} = R_i + R_{sig}$

$$\boxed{f_{LC_{C1}} = \frac{1}{2\pi R_{eq} C_{C_1}}}$$

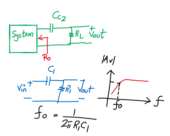


② Calculate $f_{LC_{C2}}$: Lower-cut-off frequency due to C_{C_2} alone
– Short-circuit C_{C_1}, C_S and V_S

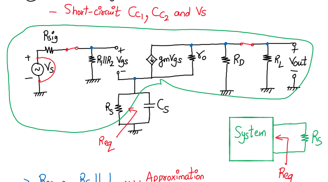


→ $R_o = r_o \| R_D$ → Capital D
Capital O → $R_{eq} = R_o + R_L$

$$\boxed{f_{LC_{C2}} = \frac{1}{2\pi(R_o + R_L)C}}$$

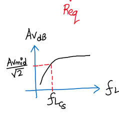


③ Calculate f_{LC_S} : Lower-cut-off frequency due to C_S alone
– Short-circuit C_{C_1}, C_{C_2} and V_S

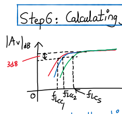


→ $R_{eq} \approx R_S \| \frac{1}{g_m}$ .... Approximation if $r_o \to \infty$

$$\boxed{f_{LC_S} = \frac{1}{2\pi R_{eq} C_S}}$$



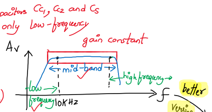
Step6: Calculating f_L

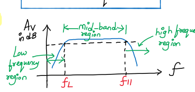


→ Select the highest frequency among $f_{LC_{C1}}$, $f_{LC_{C2}}$ and f_{LC_S} as the Lower (f_L) cut-off frequency of the amplifier.

Learning:

→ External capacitors C_{C_1}, C_{C_2} and C_S will affect only low-frequency response

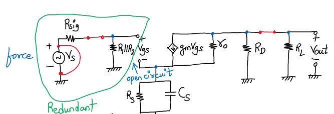


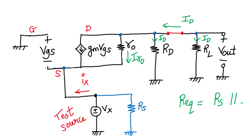


* Transient $V_{in}(t)$ $V_{out}(t)$ at one freq^n 10KHz
In transient analysis, the frequency at AC signal should fall in mid-band range

* Frequency response: Response of amplifier at different frequencies

* Procedure to calculate R_{eq}:
① Apply a test source V_x and force current i_x into it
② Find $R_{eq} = \frac{V_x}{i_x}$





$V_{out} = -I_D(R_D \| R_L)$

$R_{eq} = R_S \| \frac{V_x}{i_x}$

→ From above circuit, we can write
$V_x = -V_{gs}$

→ $I_{r_o} = \frac{V_{out} - V_x}{r_o} = \frac{V_{out} + V_{gs}}{r_o}$ .....(2.1)

→ KCL at node S,
$i_x + g_m V_{gs} + I_{r_o} = 0$
i.e $i_x + g_m V_{gs} + \left(\frac{V_{out} + V_{gs}}{r_o}\right) = 0$
i.e $i_x + \left(g_m + \frac{1}{r_o}\right)V_{gs} + \frac{V_{out}}{r_o} = 0$ ....(2.2)

→ $V_{out} = -I_D(R_D \| R_L)$
→ Substitute V_{out} in equation (2.2),
→ $i_x + \left(g_m + \frac{1}{r_o}\right)V_{gs} - \frac{I_D}{r_o}(R_D \| R_L) = 0$
→ From circuit, $\boxed{i_x = -I_D}$
→ $i_x + \left(g_m + \frac{1}{r_o}\right)V_{gs} + \frac{i_x}{r_o}(R_D \| R_L) = 0$

→ $V_{gs} = -V_x$

→ $i_x\left(1 + \frac{R_D \| R_L}{r_o}\right) = V_x\left(g_m + \frac{1}{r_o}\right)$

i.e $\frac{V_x}{i_x} = \frac{\left(1 + \frac{R_D \| R_L}{r_o}\right)}{g_m + \frac{1}{r_o}} = \frac{r_o + R_D \| R_L}{1 + g_m r_o}$

i.e $$\boxed{\frac{V_x}{i_x} = \left(\frac{r_o + (R_D \| R_L)}{1 + g_m r_o}\right)}$$

$$R_{eq} = R_S \| \left(\frac{r_o + (R_D \| R_L)}{1 + g_m r_o}\right)$$

$$\frac{\cancel{r_o}/\cancel{r_o} + \frac{(R_D \| R_L)}{r_o \to \infty} \to 0}{\frac{1}{r_o} + g_m \cancel{r_o}/\cancel{r_o}}$$

If $r_o = \infty$,

$$\boxed{R_{eq} = R_S \| \frac{1}{g_m}}$$