EHB 335E HW #5 ANALOG ELECTRONIC CIRCUITS

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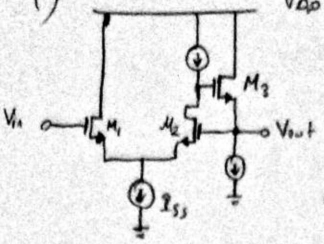
Q-1)



⇒ Assume that $V_{in}\uparrow$. Since $I_{d\,M_2}$ and $I_{d\,M_1}$ can not change, to satisfy the increase of V_{in}; V_{SS} should be increased.

⇒ Since $V_{gs2} = V_{out} - V_{SS}$ as $V_{SS}\uparrow \rightarrow V_{out}\uparrow$ ($I_{d\,M_2}$ is fixed)

⇒ Since $V_{gs3} = V_{G3} - V_{out}$ as $V_{out}\uparrow \Rightarrow V_{G3}\uparrow$ ($I_{d\,M_3}$ is fixed)

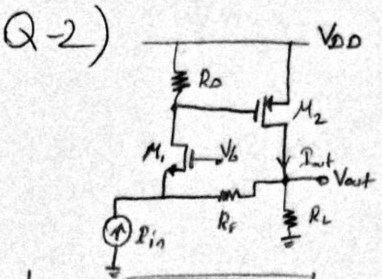
⇒ So $V_{G,3}$ is increased when V_{in} is increased. As $V_{G,3}\uparrow$, drain to source voltage of M_2 is increased, and $I_{d\,M_2}$ tends to increase, but we said that $I_{d\,M_2}$ is fixed. So, it can not increase, then this problem can be solved by decrease of V_{gs2}. Additionally, V_{out} has to decrease as V_{gs2} decrease. So, this circuit employs negative feedback.

As a summary

$$V_{in}\uparrow \rightarrow V_{SS}\uparrow \rightarrow V_{out}\uparrow \rightarrow V_{G3}\uparrow \rightarrow V_{out}\downarrow$$

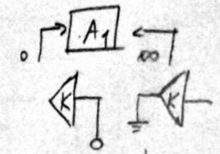
Negative feedback

Q-2)



Sensed : Current
Returned : Current ⇝ Current - Current Amplifier (Shunt - Series)

⇒ For breaking the loop ⇒

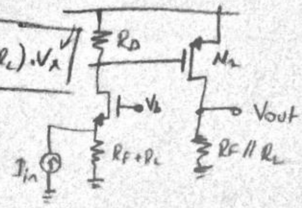


Open-Loop Gain Calculation

$\boxed{\begin{array}{l} * R_{in} = \frac{1}{g_{m1}} \parallel (R_F + R_L) \\ * R_{out} = R_F \parallel R_L \end{array}}$

⇒ With Current Divider, $\dfrac{I_1}{I_{in}} = \dfrac{R_F + R_L}{R_F + R_L + \frac{1}{g_{m1}}}$

* We can update the circuit as follows :



⇝ $\boxed{V_X = R_D \cdot I_1 = R_D \cdot \dfrac{(R_F + R_L)}{R_F + R_L + \frac{1}{g_{m1}}} \cdot I_{in}}$

$\boxed{\text{So } V_{out} = -g_{m2}(R_F \parallel R_L) \cdot V_X}$

$$\Rightarrow I_{out} = \frac{V_{out}}{R_{out}} = -g_{m2} V_X = \frac{-g_{m2} \cdot R_D (R_F + R_L)}{\frac{1}{g_{m1}} + R_F + R_L} \cdot I_{in} \; , \quad \boxed{A_I = \frac{I_{out}}{I_{in}} = -\frac{g_{m2} \cdot R_D (R_F + R_L)}{\frac{1}{g_{m1}} + R_F + R_L}}$$

To determine feedback factor K

$\rightsquigarrow$ With Current Division: $I_F = \dfrac{-R_L}{R_F + R_L} \cdot I_{out}$

$$\boxed{K = \frac{I_{out}}{I_F} = -\frac{R_L}{R_L + R_F}}$$

Closed Loop Gain: $A_{I,CL} = \dfrac{A_I}{1 + K A_I} \rightsquigarrow \dfrac{-\dfrac{g_{m2} R_D (R_L + R_F)}{\frac{1}{g_{m1}} + R_F + R_L}}{1 + \left(\dfrac{-R_L}{R_L + R_F}\right)\left(\dfrac{-g_{m2} R_D (R_L + R_F)}{\frac{1}{g_{m1}} + R_F + R_L}\right)}$

So,
$$\boxed{A_{I,CL} = -\frac{g_{m2} R_D (R_L + R_F)}{\left(\frac{1}{g_{m1}} + R_F + R_L\right) \cdot \left(1 + g_{m2} R_D R_L\right)}}$$

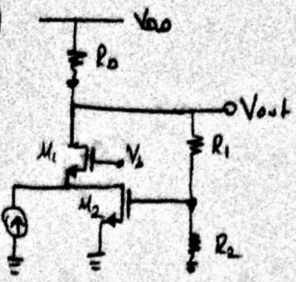
Output Impedance:

$$R_{out,CL} = \boxed{R_{out}(1 + K \cdot A_I) = (R_F \parallel R_L) \cdot \left[1 + \frac{g_{m2} R_D R_L}{\frac{1}{g_{m1}} + R_F + R_L}\right]}$$

Input Impedance:

$$R_{in,CL} = \boxed{\frac{R_{in}}{1 + K \cdot A_I} = \frac{\frac{1}{g_{m1}} \parallel (R_F + R_L)}{1 + \dfrac{g_{m2} R_D R_L}{\frac{1}{g_{m1}} + R_F + R_L}}}$$

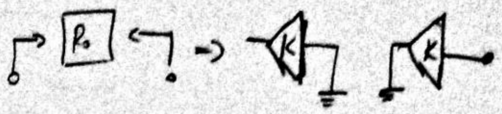
Q-3)



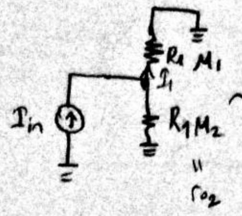
→ Sense: Voltage

Returned: Current

⇝ Voltage - Current Amplifier (Shunt - Shunt)

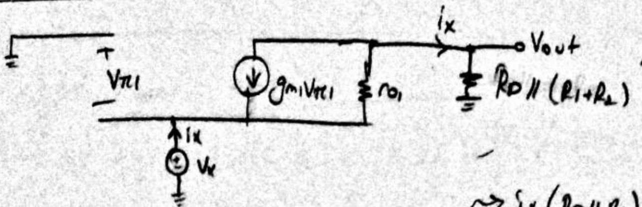


⇒ Firstly lets determine the open loop gain



$$\rightsquigarrow I_1 = \frac{R_1 M_2}{R_1 M_2 + R_1 M_1} \rightsquigarrow I_1 = \frac{r_{o2}}{r_{o2} + R_1 M_1} \cdot I_{in}$$

$R_1 M_1$



$V_{out} = i_x (R_D \parallel R_1)$

$\rightsquigarrow V_{out} = V_x - (i_x - g_{m1} V_{\pi 1}) r_{o1}$;

$V_\pi = -V_x$

$\rightsquigarrow i_x (R_D \parallel R_1) = V_x - i_x r_{o1} + g_{m1} r_{o1} V_x$

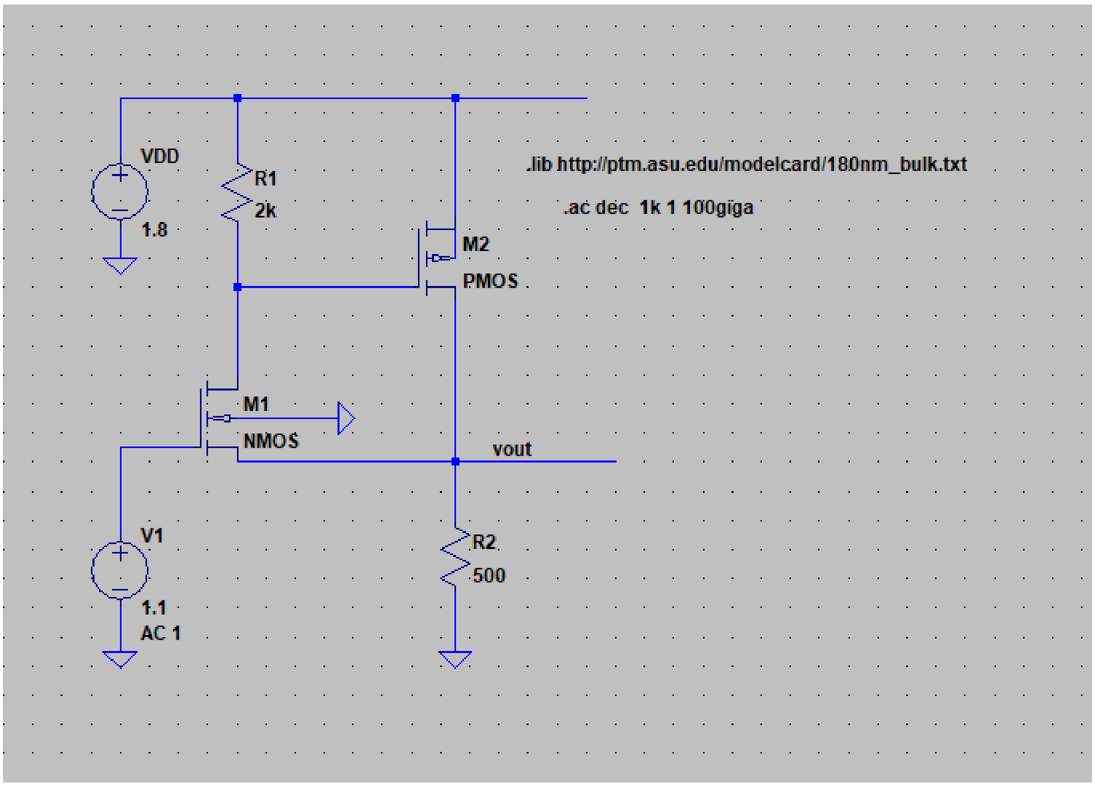
$$\text{So, } \frac{V_x}{i_x} = R_X = R_1 M_1 = \frac{r_{o1} + R_D \parallel (R_1 + R_2)}{1 + g_{m1} r_{o1}}$$

$$\text{So: } \frac{I_1}{I_{in}} = \frac{r_{o2}}{r_{o2} + \frac{R_D \parallel (R_1 + R_2) + r_{o1}}{1 + g_{m1} r_{o1}}}, \text{ Since } V_{out} = (R_D \parallel R_1) . I_1$$

$$\boxed{\text{So, } \frac{V_{out}}{I_{in}} = (R_D \parallel R_1) . \left[\frac{r_{o2}}{r_{o2} + \frac{R_D \parallel (R_1 + R_2) + r_{o1}}{1 + g_{m1} r_{o1}}} \right] = V_o}$$

Q-4)

➔ The circuit generated via LTSpice can be seen below.



a-)

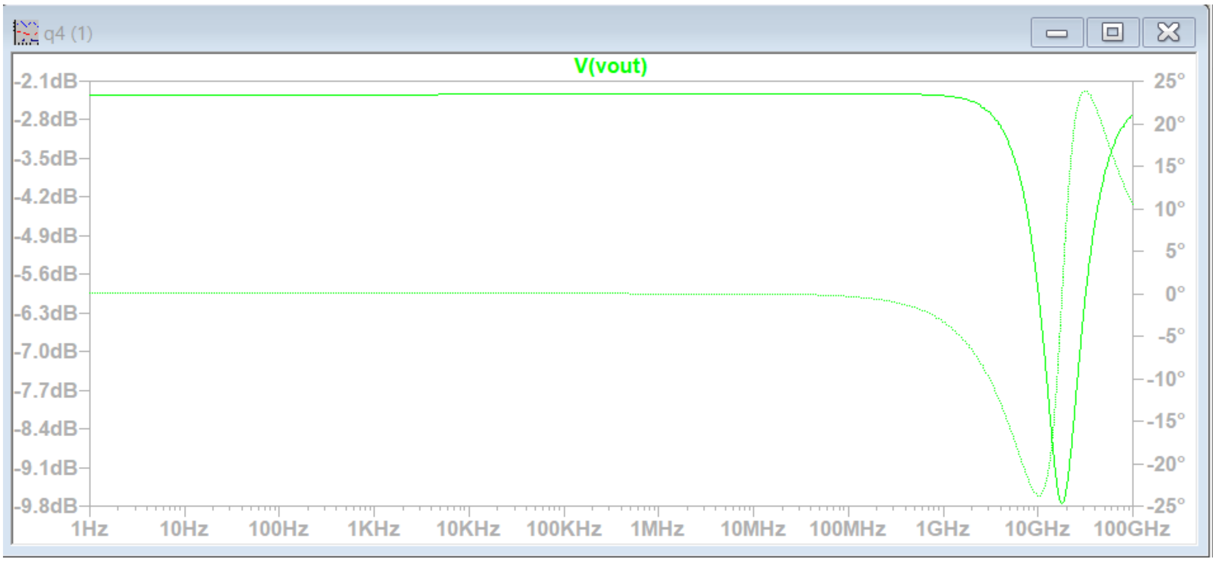
➔ The operation point analysis results of the circuit is as following.

➔ Vin value(Vn004) is as double as Vout value in DC çop point analysis.

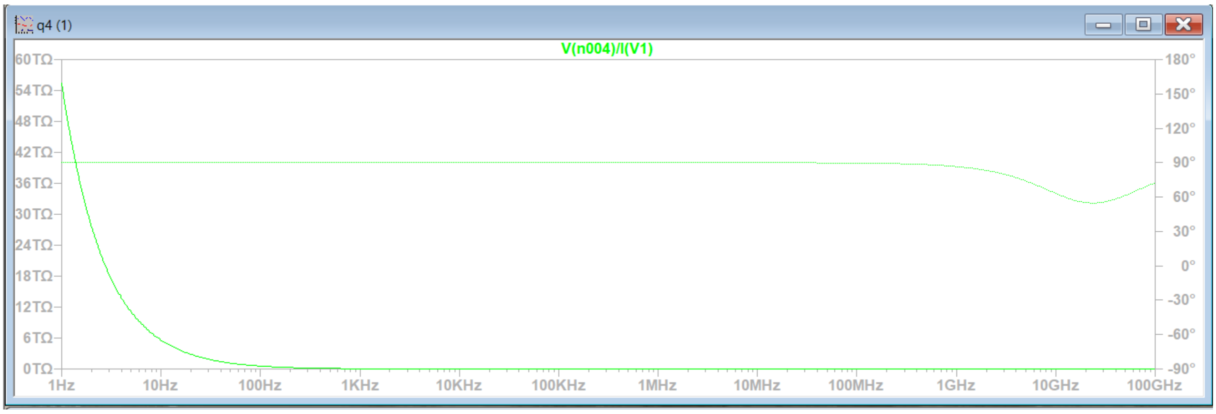
```
        --- Operating Point ---

V(n001):         1.8            voltage
V(n003):         1.22707        voltage
V(vout):         0.561053       voltage
V(n002):         1.65591        voltage
V(n004):         1.1            voltage
Id(M1):          0.000286464    device_current
Ig(M1):          0              device_current
Ib(M1):          -1.80813e-012  device_current
Is(M1):          -0.000286464   device_current
Id(M2):          0.000835643    device_current
Ig(M2):          -0             device_current
Ib(M2):          -1.65592e-012  device_current
Is(M2):          -0.000835643   device_current
I(R2):           0.00112211     device_current
I(R1):           0.000286464    device_current
I(V1):           0              device_current
I(Vdd):          -0.00112211    device_current
```

b-)

➔ The closed loop gain analysis with ac decade simulation can be seen below. We can say that the gain of circuit is about -2.3 dB



➔ For Rin, there is no change in the circuit. Ac analysis is done, then the result found as below. This value is too high, we can say that Rin is infinite.



➔ Lastly, for Rout we connect an AC = 1V, DC = 0V voltage source to the Vout node. Then we do the AC simulation again.

➔ It can be said that Vout is about 100 Ohms.