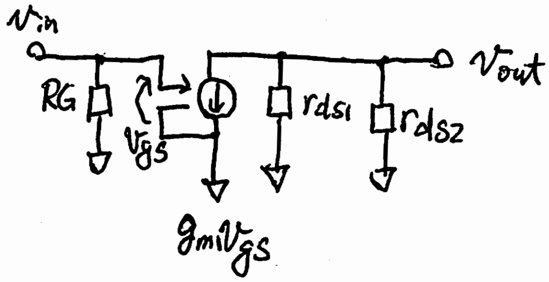
Q1

(1)



(2)

$$G = \frac{v_{out}}{v_{in}} = -g_{m1}(r_{ds1} \mathbin{/\!/} r_{ds2})$$

$$I_{D1} = \frac{\beta_n}{2}V_{OV}^2 = \frac{1m}{2}0.2^2 = 20.0\mu A$$

$$g_{m1} = \sqrt{2\beta_n I_{D1}} = \sqrt{2 \cdot 1m \cdot 20\mu} = 0.200mS$$

$$G = -0.200mS\,\frac{5M\Omega}{2} = -500倍$$

$$G(dB) = 20\log|G| = 54.0dB$$

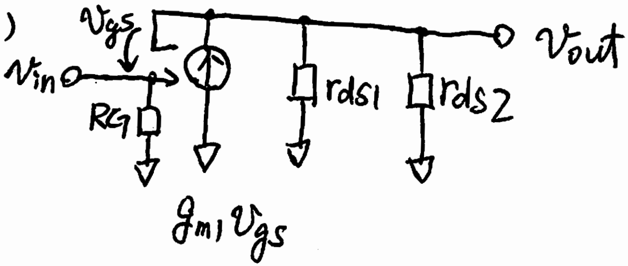
(3)

$$Z_{in} = RG = 5.00M\Omega$$

$$Z_{out} = r_{ds1} \mathbin{/\!/} r_{ds2} = \frac{5.00M}{2} = 2.50M\Omega$$

Q2

(1)



(2)

$$I_{D1} = \cancel{-}\frac{\overset{\beta_n}{\cancel{\beta_p}}}{2}V_{OV}^2 = \cancel{-}20.0\mu A$$ （I_{D1} は正）

$$g_{m1} = \sqrt{2\underset{\beta_n}{\cancel{\beta_p}}|I_{D1}|} = 0.200mS$$

$$r_{ds1} = r_{ds2} = \frac{1}{\underset{\lambda_n}{\cancel{\lambda_p}}I_{D1}} = 5.00M\Omega$$

$$G = \frac{v_{out}}{v_{in}} = \frac{g_{m1}(r_{ds1} \mathbin{/\!/} r_{ds2})}{1+g_{m1}(r_{ds1} \mathbin{/\!/} r_{ds2})} = \frac{0.2m\,\frac{5M}{2}}{1+0.2m\,\frac{5M}{2}} = \frac{500}{501} = 0.998倍$$

$$G(dB) = 20\log 0.998 = -0.0174dB$$

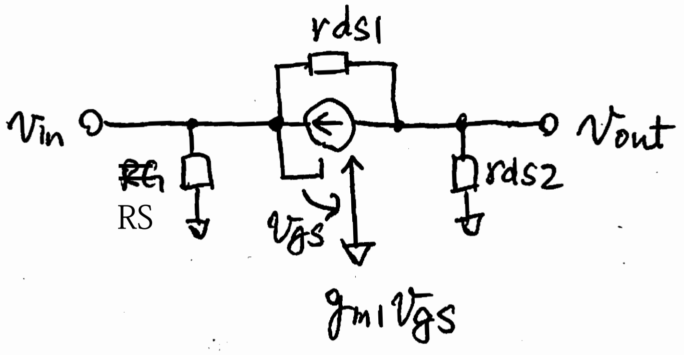
(3)

$$Z_{in} = RG = 5.00M\Omega$$

$$Z_{out} = \left.\frac{v_{out}}{i_{out}}\right|_{v_{in}=0} = \frac{\cancel{g}\ r_{ds1} \mathbin{/\!/} r_{ds2}}{1+g_{m1}(r_{ds1} \mathbin{/\!/} r_{ds2})} = \frac{\frac{5M}{2}}{1+0.2m\,\frac{5M}{2}} = 4.99k\Omega$$

Q3

(1)



(2)

$$G = \frac{v_{out}}{v_{in}} = \frac{1 + g_m r_{ds1}}{1 + \frac{r_{ds1}}{r_{ds2}}} = \frac{1 + 0.2m\,5M}{1 + 1} = 501倍.$$

$$\begin{cases} I_{D1} = \frac{\beta_n}{2} V_{ov}^2 = 20.0\,\mu A \\ g_{m1} = \sqrt{2\beta_n I_{D1}} = 0.200\,mS \\ r_{ds1} = r_{ds2} = \frac{1}{\lambda_n I_{D1}} = 5.00\,M\Omega \end{cases}$$

$$G(dB) = 20 \cdot \log 501 = 54.0\,dB$$

(3)

$$Z_{in} = \frac{v_{in}}{i_{in}} = \frac{r_{ds1} + r_{ds2}}{1 + g_{m1} r_{ds1} + \frac{r_{ds1} + r_{ds2}}{RS}}$$

$$= \frac{2.5M}{1 + 0.2m\,5M + \frac{2.5M}{50k}} = \cancel{2.08}\,k\Omega$$

8.33

$$Z_{out} = \left.\frac{v_{out}}{i_{out}}\right|_{v_{in}=0} = r_{ds1} /\!/ r_{ds2} = 2.50\,M\Omega$$

(注) ここでは、信号源の内部抵抗 rs = 0 のため、RS//rs = 0 としてZoutを求めている。実際には、rs≠0のため、Zoutは非常に大きい値となることが多い。

Q4

(1) M1: $V_{ov1} = V_{bias1} - V_{Tn}$

M2: $V_{ov2} = V_{bias2} - VDD \underset{-}{\cancel{+}} V_{Tp}$;

$V_{bias1} = \cancel{V_{bias2}\ V}\ VDD - V_{bias2}$, $V_{Tn} = -V_{Tp}$ より

$V_{ov1} = -V_{ov2}$, → n-ch の M1 と p-ch の M2 の

オーバードライブ電圧が等しいので.

↑の大きさ

$$\underline{V_{DS1} = \frac{VDD}{2}}$$

$I_{D3} = |I_{D4}| = 64|I_{D2}| = 64 I_{D1}$

$V_{ov3} = \sqrt{\frac{2I_{D3}}{64\beta_n}} = \sqrt{\frac{2\cdot 64 I_{D1}}{64\beta_n}} = \sqrt{\frac{2I_{D1}}{\beta_n}} = V_{ov1}$

$V_{GS3} - V_{Tn} = V_{GS1} - V_{Tn}$ より

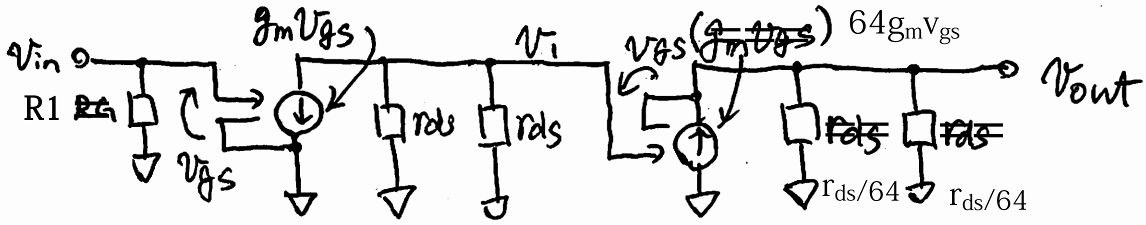
$V_{GS3} = V_{GS1} = V_{bias1}$

$V_{DS3} = V_{DS1} + V_{GS3} = \underline{\frac{VDD}{2} + V_{bias\overset{1}{\cancel{3}}}}$

(2) $g_{m3} = \sqrt{2\cdot 64\beta_n I_{D3}} = \sqrt{2\cdot 64\beta_n I_{D1}\cdot 64} = 64 g_m = 25.6 mS$

$g_{ds3} = \lambda_n I_{D3} = 64\lambda_n I_{D\cancel{3}1} = \cancel{64}g_{ds} = \frac{64}{5M} = 12.8 \mu S$

(3)



(4) $G = \frac{v_{out}}{v_{in}} = -\frac{\frac{1}{4}g_m^2 r_{ds}^2}{1+\frac{1}{2}g_m r_{ds}} = -999$ 倍.

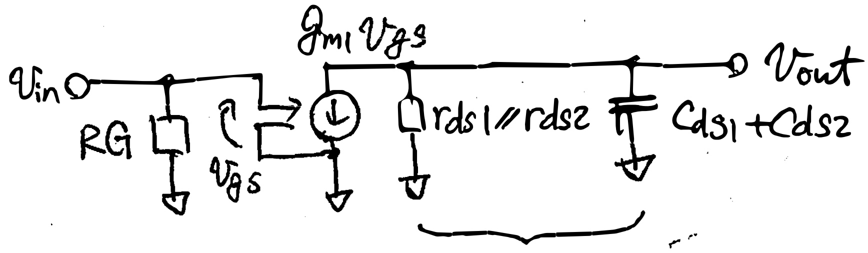
(5) $Z_{in} = \overset{R1}{\cancel{R_G}} = 10.0 M\Omega$

$Z_{out} = \left.\frac{v_{out}}{i_{out}}\right|_{v_{in}=0} = \frac{\frac{r_{ds}}{2}(1/64)}{1+\frac{r_{ds}}{2}g_m} = \overset{39.1}{\cancel{2.50k}}\Omega$

(ヒント) $v_{in} = 0$ のとき. $v_1 = 0$, (3)参照.

Q5

(1)



$$Y = \frac{1}{r_{ds1}} + \frac{1}{r_{ds2}} + j\omega(C_{ds1}+C_{ds2})$$

(2) $$G(\omega) = -\frac{g_{m1}(r_{ds1} /\!/ r_{ds2})}{1+j\omega(C_{ds1}+C_{ds2})(r_{ds1} /\!/ r_{ds2})}$$ #

(3) $$\omega_p = \frac{1}{(C_{ds1}+C_{ds2})(r_{ds1} /\!/ r_{ds2})} = \frac{1}{20fF \cdot \frac{5M\Omega}{2}} = 20.0\,M\,rad/s$$

(4) $$G(\omega \ll \omega_p) = -g_{m1}(r_{ds1} /\!/ r_{ds2}) = -0.4mS\,\frac{5M\Omega}{2} = -1000倍$$

$$|G(\omega)|(dB) = 20\log 1000 = 60.0dB$$

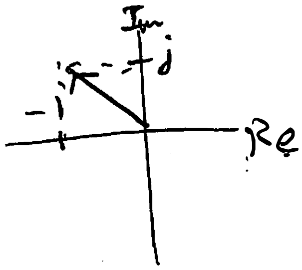
負の実数なので $\angle G(\omega) = 180°$ (または $-180°$)

(5) $\omega = \omega_p$ のとき

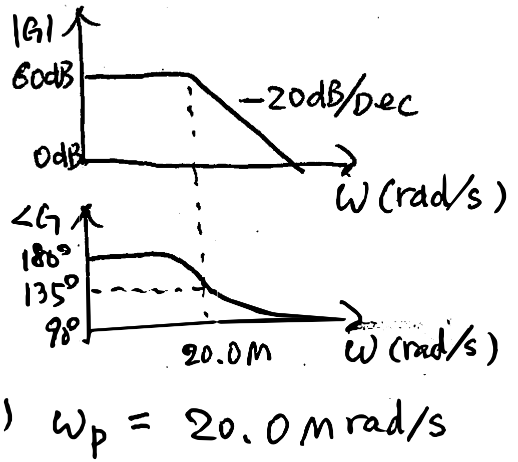
$$G(\omega_p) = -\frac{g_{m1}(r_{ds1} /\!/ r_{ds2})}{1+j} = -\frac{g_{m1}(r_{ds1} /\!/ r_{ds2})}{2}(1-j)$$

$$|G(\omega_p)| = \frac{1000}{\sqrt{2}},\ \# \quad 20\log(1000/\sqrt{2}) = 60dB - 3.01\,dB \doteqdot 57.0\,dB$$

$$\angle G(\omega_p) = 135° \ (\text{または}, -225°)$$



(6)



(7) $\omega_p = 20.0\,M\,rad/s$

$$f_p = \frac{1}{2\pi}\cdot\omega_p = 3.18\,MHz$$

$$|G(\omega=0)| = 60.0dB = 1000倍.$$

$$GB積 = |G(\omega=0)|\cdot f_p = 1000\cdot 3.18MHz = 3.18GHz$$

Q6

(1) $$H(j\omega) = \frac{-A}{1+j\omega CR(1+A)}$$

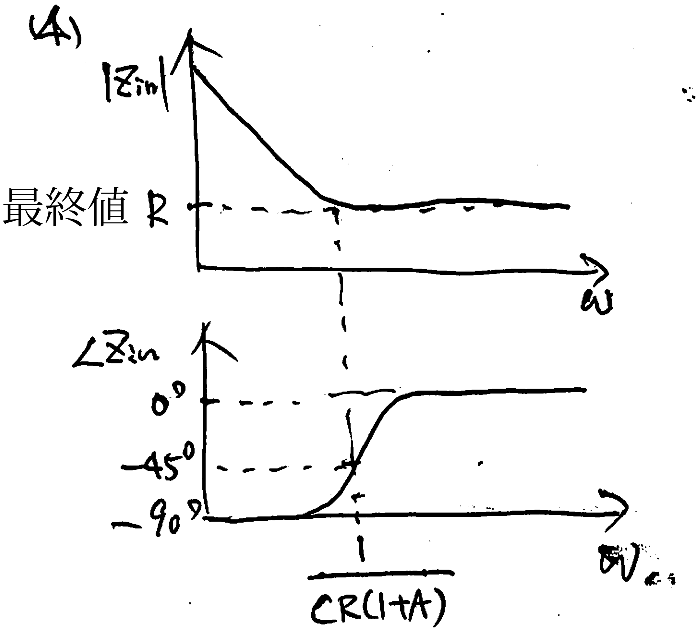
(2) $$Z_{in} = \frac{v_{in}}{i} = R + \frac{1}{j\omega \cancel{C(1+A)}}$$

C(1 + A)

(3) $\omega_p CR(1+A) = 1$ より

$$\omega_p = \frac{1}{CR(1+A)}$$

(4)



Q7.

(1) $$A(\omega) = \frac{-A_0}{1+j\omega B}$$

$$|A(\omega)| = \frac{A_0}{\sqrt{1+\omega^2 B^2}}$$

$$|A(\omega_u)| = \frac{A_0}{\sqrt{1+\omega_u^2 B^2}} = 1$$

$$\omega_u = \frac{\sqrt{A_0^2-1}}{B}$$

$$f_u = \frac{\omega_u}{2\pi} = \frac{\sqrt{A_0^2-1}}{2\pi B}$$

(2) $\omega_p = \frac{1}{B}$,

$$\text{GB積} = A_0 \cdot \frac{\omega_p}{2\pi} = \frac{A_0}{2\pi B}$$

(3) $\omega = 0$ のとき $G(\omega) = -A_0$, $\angle G(\omega) = 180°$

$\omega = 1/B$ のとき $G(\omega) = \frac{-A_0}{1+j} = \frac{A_0}{\sqrt{2}}(-1+j)$, $\angle G(\omega) = 135°$

$\omega \gg \frac{1}{B}$ のとき $G(\omega) \fallingdotseq \frac{-A_0}{j\omega B} = j\frac{A_0}{\omega B}$, $\angle G(\omega) = 90°$

(4) $$G(\omega) = \frac{-A_0 \frac{R2}{R1+R2+A_0R_1}}{1+j\omega B \frac{R1+R2}{R1+R2+A_0R_1}}$$

(5) $$\omega_p = \frac{A_0+1+\frac{R2}{R1}}{B\left(1+\frac{R2}{R1}\right)}$$

(6) $$GBP = \frac{1}{2\pi B}\frac{R2\ A0}{R1+R2} = \frac{1\ \ A0}{2\pi B\left(1+\frac{R1}{R2}\right)}$$

Q8

(1) $NF = SNR_{in} - SNR_{out} = 50\,\mathrm{dB} - 46.5\,\mathrm{dB} = 3.50\,\mathrm{dB}$

(2) $S2 = S1 + G_p = 0\,\mathrm{dBm}$

$N2 = N1 + G_p + NF = -126.5\,\mathrm{dBm}$

(3) 入力 SNR $= \dfrac{S1}{N1}(\mathrm{dB}) = -20\,\mathrm{dBm} - (-150\,\mathrm{dBm}) = +130\,\mathrm{dB}$

出力 SNR $= \dfrac{S2}{N2}(\mathrm{dB}) = 0\,\mathrm{dBm} - (-$~~126~~ 126.5 $\mathrm{dBm}) = 126.5\,\mathrm{dB}$

Q9

(1) $$v_{out} = \frac{H}{1-H} v_{in} + \frac{1}{1-H} v_d$$

(2) $$v_{out} = \frac{-A_0}{A_0 + j\omega C} v_{in} + \frac{j\omega C}{A_0 + j\omega C} v_d$$

(3) ~~(4)~~ ~~(3)~~ $v_{out} = -v_{in}$ より Gain $= -1$

(5) ~~(4)~~ (C)，理由：ループゲイン $= H(j\omega) = j\dfrac{A_0}{\omega C}$ より

ω によらず位相 $= 90°$ となるため，

正帰還，負帰還のどちらでもない．

(4) ~~(3)~~ 信号伝達関数 $= \dfrac{-A_0}{A_0 + j\omega C} = -1$

誤差伝達関数 $= \dfrac{j\omega C}{A_0 + j\omega C} = 0$

Q10

(1) $G_i = -\frac{R2}{R1}$

(2) $G_r = -\frac{R2}{R1}\frac{1}{(1+\frac{R2}{R1})\frac{1}{Ad}+1}$

(3) $R_{err} = \frac{-\frac{R2}{R1}\frac{Ad}{1+Ad+R2/R1}+\frac{R2}{R1}}{-\frac{R2}{R1}} = \frac{1}{(1+\frac{R2}{R1})\frac{1}{Ad}+1}-1$

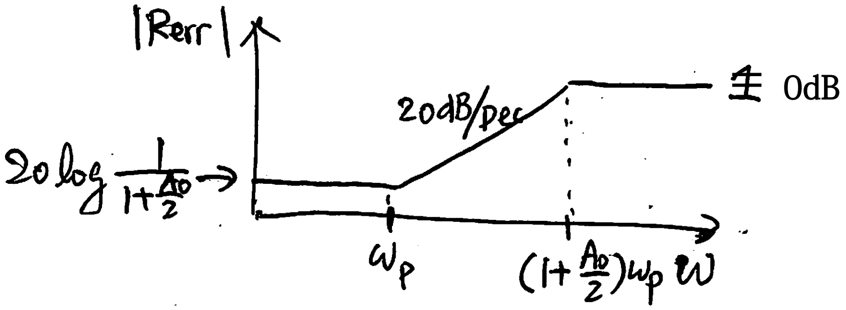
(4) $R_{err} = \frac{1}{\frac{2}{Ad}+1}-1 = -\frac{1}{1000}$

$Ad = 1998$ 倍.

(5)

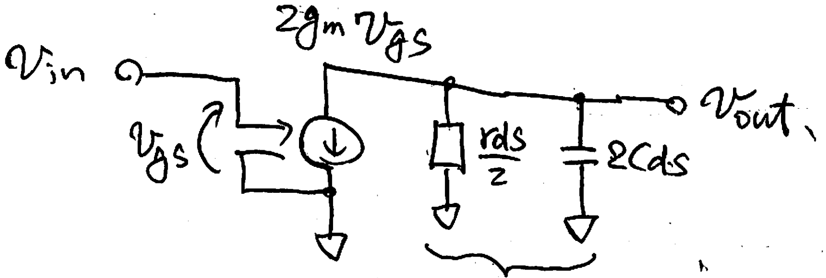
$$R_{err} = \frac{1}{\frac{2}{Ad}+1}-1 = \frac{-2}{2+Ad} = \frac{-2}{2+\frac{A_0}{1+j\omega/\omega_p}}$$

$$= \frac{-\frac{1}{1+\frac{A_0}{2}}(1+j\omega/\omega_p)}{1+j\omega/\omega_p(1+\frac{A_0}{2})}$$



Q11

(1)

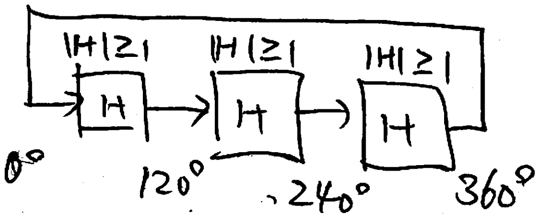


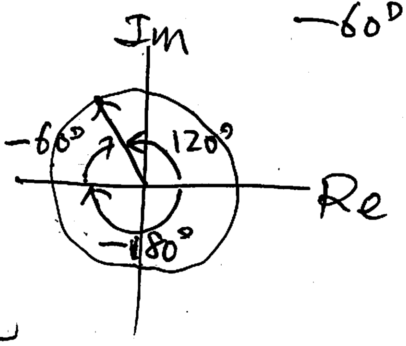
(2)

$$Z = \left(\frac{2}{r_{ds}} + j\omega 2C_{ds}\right)^{-1}$$

$$H(\omega) = \frac{v_{out}}{v_{in}} = \frac{-2g_m}{\frac{2}{r_{ds}} + j\omega 2C_{ds}} = \underset{-180^\circ}{-}\frac{g_m r_{ds}}{\underbrace{1+j\omega(C_{ds}r_{ds})}_{-60^\circ}}$$

(3)





1段当たり120°のとき正帰還

$$\omega_{osc} C_{ds} r_{ds} = \sqrt{3}$$

位相条件： $\omega_{osc} = \frac{\sqrt{3}}{C_{ds} r_{ds}}$

このとき $H(\omega_{osc}) = -\frac{g_m r_{ds}}{1+j\sqrt{3}}$

$$|H(\omega_{osc})| = \frac{g_m r_{ds}}{\sqrt{1+3}} \geq 1$$

振幅条件： $g_m r_{ds} \geq 2$.

Q12

(1) $$G_{loop} = -\frac{G}{\underset{\substack{\uparrow \\ \text{Fパラメータ}}}{A_3}} = -\frac{G}{(1-5\omega^2C^2R^2)+j\omega CR(6-\omega^2C^2R^2)}$$

(2) $$\angle G_{loop} = \tan^{-1}\frac{\omega CR(6-\omega^2C^2R^2)}{1-5\omega^2C^2R^2} = 0$$

このとき、

$$\omega_{osc} = \frac{\sqrt{6}}{CR} \quad \text{(位相条件)}$$

$$G_{loop}(\omega_{osc}) = -\frac{G}{1-5\frac{6}{C^2R^2}C^2R^2} \geqq 1$$

$$G \geqq \underset{29}{\cancel{4}} \quad \text{(振幅条件)}$$

(3) RC-LPF2段 => 発振不可

RC-LPF4段 ⇒ 発振可能

理由は、口頭で説明済み.

Q13

$$\Delta V = \frac{\Delta Q}{C} = \frac{I_L\frac{T}{2}}{C} = \frac{I_L}{C}\frac{1}{2f}$$

$$\gamma = \frac{\Delta V}{V_{DC}} = \frac{I_L}{2CfV_{DC}} = \frac{100\text{mA}}{C\cdot 2\cdot 60\text{Hz}\cdot 6.20\text{V}} \leqq 0.05$$

$$C \geqq \frac{100\text{m}}{2\cdot 60\cdot 6.20\cdot 0.05} = 2.69\text{mF}$$