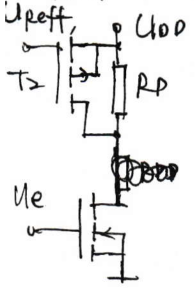
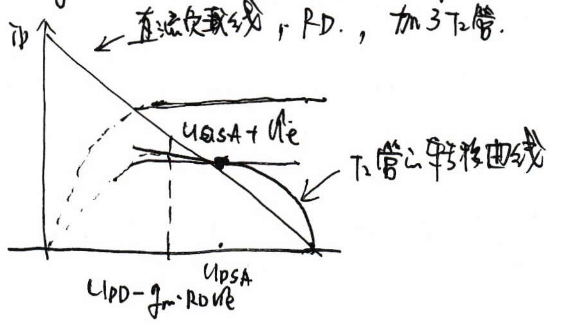
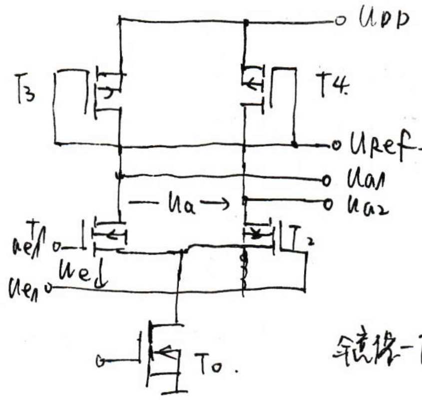
11. Einstellungschaltungen

11.1. Einstellung der Gleichtaktsspannung







Ideal System Schaltung.

$U_{DD}=3V$, $I_0=200\mu A$, $|U_{th}|=0.5V$. $\lambda=0.03V^{-1}$ $\beta_{1,\dots,4}=5\frac{mA}{V^2}$ $\beta_0=2\beta_{1\dots4}=10\frac{mA}{V^2}$

nur 共模.

$U_{e1}=U_{e2}=U_{egl,A}$, $U_e=0\Rightarrow U_a=0$. $I_0=2\cdot\frac{\beta}{2}\cdot(U_{GS}-U_{th})^2\Rightarrow U_{GS}$

$U_{GSA}=0.7V$. $U_{GS0}=0.7V$, $U_{Ref}=2.3V$, $r_{DS}=\frac{\frac{1}{\lambda}+U_{DSA}}{I_0}\approx\frac{1}{\lambda I_0}\approx\frac{1}{333.3}$

~~$\frac{I_0}{2}\cdot r_{DS}+\frac{I_0}{2}\cdot r_{DS}+\dots$~~ $U_e=U_{SA1,2}+U_{GSA}$, 若 $U_e=1.1V$. 则 $U_{SA}=0.4V$,

$U_{a,gl}=\frac{U_{DD}+U_{e,gl}-U_{GSA}}{2}=1.7V$. $\Rightarrow\frac{U_{a,gl}}{U_{e,gl}}=1$.

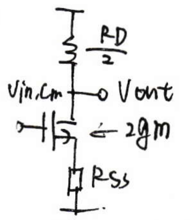
$V_{gl,1}=\frac{U_{a,gl}}{U_{e,gl}}=-1$. $V_{gl,2}=\frac{U_{a,gl}}{U_{Ref}}=-g_{m1,\dots,4}\cdot r_{ds1\dots4}=\sqrt{2\beta/I_{DA}}\cdot\frac{1}{\lambda}=\sqrt{\frac{2\times5\times10^{-3}}{1\times10^{-4}}}\cdot\frac{1}{\lambda}$

$V_{gl,3}=\frac{U_{a,gl}}{U_{GS,0}}=g_{m0}\cdot r_{ds0}$ $=-333.3$

为了研究共模的放大特性，我们先从基本的开始入手.

① 基本放大电路，差分，考虑电流源内阻，

等效电路



$A_{v,cm}=\frac{V_{out}}{V_{in,cm}}=\frac{-I_D\cdot\frac{R_D}{2}}{I_D/2g_m+I_D\cdot R_{SS}}=\frac{-\frac{R_D}{2}}{\frac{1}{2g_m}+R_{SS}}$，假设 λ，γ为0.

应当注意，由于管的工作状态，所以共模电压若有偏差，则可能进入非线性区.

② 若RD不对称：若 $R_{D1}=R_D$. $R_{D2}=R_D+\Delta R_D$.

当输入变化 $\Delta V_{in,cm}$，$\Delta V_{in,cm}\cdot g_m-2\Delta I_D\cdot R_{SS}\cdot g_m=\Delta I_D$

$\Delta I_D=\Delta V_{in,cm}\cdot(g_m/1+2g_mR_{SS})\Rightarrow\Delta V_X=-\Delta V_{in,cm}\cdot\frac{g_m}{1+2g_mR_{SS}}\Delta R_D$，会造成差模信号失真.

尾电容更会造成高频信号失真.

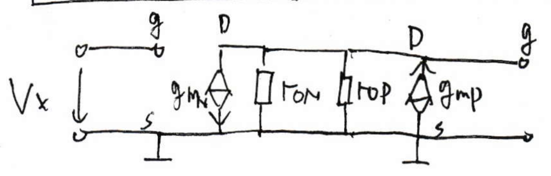
③ MOS为负载的差动对，即为Volterra的电路，先考虑理想电流源，也可以用电流源作为负载

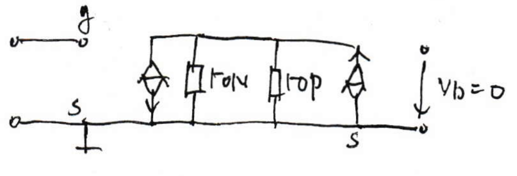
$A_{v,mos}=-g_{mN}(g_{mp}^{-1}//r_{ON}//r_{op})$

$\approx-\frac{g_{mN}}{g_{mp}}\approx-\sqrt{\frac{\mu_N(W_N/L_N)}{\mu_p(W/L)_P}}$

所以 $V_{gL,1}=-1$.(Volterra 及电流源) ← 还有待考证

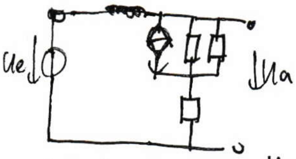
$A_{v,strom}=-g_{mN}(r_{ON}//r_{op})$





吉尔伯特单元.
① 电路的小信号增益是尾电流的函数 ($g_m = \sqrt{2\beta I_{DA}}$)
② 差动对的两个输入管为控制尾电流在两个支路的流动提供了简便的方法.
⟹ 可以控制 I_S 控制增益，$A_V = V_{out}/V_{in}$ 的变化范围可以从 0 ($I_D = 0$) ⟹ 由器件决定的最大值
⟹ 可以用 $V_{out_1} = V_1 - V_2$ 和 $V_{out_2} = V_2 - V_1$ 得到增益为正和负的信号，之后再相加即可.

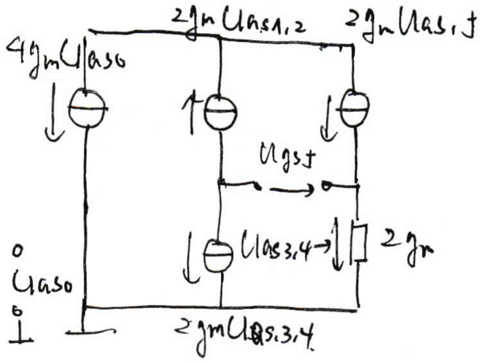
对于 $V_{gl,1} = \frac{U_{a,gl}}{U_{e,gl}} = -1$. 可以用等效电路简单验证. 近似为 −1. $\left[-\frac{R(\frac{1}{\lambda}+\frac{1}{2})-1}{\frac{1}{\lambda}+1}\right.$, 不一定对 $\left.\right]$.



对于 $V_{gl,2} = \frac{U_{a,gl}}{U_{ref}} = -g_m \cdot r_{DS3} + r_{DS1} // r_{DS0} = -g_m \cdot r_{DS1\ldots4} = \frac{1}{\lambda} = -33$. $r_{DS} = \frac{1}{\lambda I_{DA}}$.

对于 $V_{gl,3} = \frac{U_{a,gl}}{U_{GS0}} = g_{m0} \cdot r_{DS0} = \frac{1}{\lambda}$，直接分析即可，~~$g_{m0} \cdot r_{DS0}$~~，$U_{a}$ 已经计算过了.

Versorgungsspannungsreference.



等效电路，关键在于 U_{GS5}，是 的位置 (从图中看) 可以直接由方程 根据电流回路 (等效图手写的) 而不必看等效.

$4g_m U_{GS0} - 2g_m U_{GS1,2} + 2g_m U_{GS5} = 0$.
$2g_m U_{GS1,2} + 2g_m U_{GS3,4} = 0$
$U'_{a,gl} = U_{GS3,4} + U_{GS5} \Rightarrow V'_{gl3} = \frac{U'_{a,gl}}{U_{GS0}} = -2$.

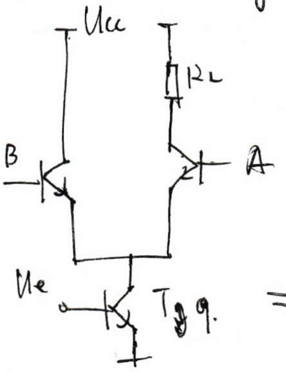
由 Skript, 图 2 等效

Gleichtaktunterdrückung bein Transkonduktanzverstärker.

$U_e^+ = U_{gl} + \frac{U_{diff}}{2} \Rightarrow i_{a1} = g_{T,gl} \cdot U_{gl} + g_T \frac{U_{diff}}{2}$
$U_e^- = U_{gl} - \frac{U_{diff}}{2} \Rightarrow i_{a2} = g_{T,gl} \cdot U_{gl} - g_T \frac{U_{diff}}{2}$

$i_M = \frac{i_{a1} + i_{a2}}{2} = \frac{g_{T,gl}}{2} U_{gl}$
$i_a = i_{a1} - i_{a2} = g_T\, \text{diff}$
$i_{a+} = -i_{a2} + i_M = g_T \cdot \frac{U_{diff}}{2}$
$i_{a-} = -i_{a1} + i_M = -g_T \frac{U_{diff}}{2}$

11.2. Einstellung der Verstärker.



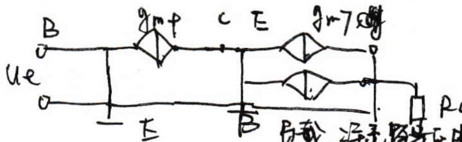
$I_{CA6} = x I_0$
$I_{CA5} = (1-x) I_0$
$I_{CA5} + I_{CA6} = I_0$
$I_{CA7} + I_{CA8} = I_{CA9}$

⟹ 回路

Skript 图.

T_6, T_5, T_7, T_8.
$U_{BE6} - U_{BE5} + U_{BE7} - U_{BE8} = 0$.
$I_6 - I_5 = (2x-1) I_0 \sim U_{BE6} - U_{BE5}$.
⟹ $2x-1)I_P \sim U_{BE8} - U_{BEP}$.
⟹ $I_8 = (1-x) I_P$，$I_7 = x I_P$.

输出端 T_9, T_8, T_7 为共射共基放大电路.



$g_m = \frac{I}{U_T}$，$g_{mp} = g_{m7} + g_{m8}$

RL，负载，流经管子的电流! 负载可以理解为 R.

那么 $V = -g_{m9} \cdot \frac{1}{g_{m7} + g_{m8}} \cdot g_{m8} \cdot R_L$ ← 这是一个近似. r_{BE} 回路忽略

$= -g_{m8} \cdot R_L \Rightarrow V = -R_L \cdot x \frac{I_{CA9}}{U_T}$

Variation: 第一个变换电路可以参考模拟乘法器. 且. $I_1 = \frac{1}{1 + e^{-\frac{U_X}{U_T}}}$，$I_2 = \frac{1}{1 + e^{\frac{U_X}{U_T}}}$

⟶ $6 - 5 + 7 - 8 = 0$
$\ln \frac{I_6}{I_5} \cdot \frac{I_7}{I_8} \cdot \ldots \to 0$
⟶ $\frac{I_6}{I_5} \cdot \frac{I_7}{I_8} = 1 \Rightarrow \frac{I_6}{I_5} = \frac{I_7}{I_8}$

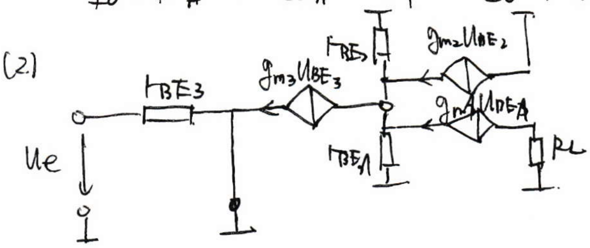
之后依据电路计算

ES-01.

(1). $U_{T4} - U_{T5} + U_{T2} - U_{T1} = 0 \Rightarrow \ln \frac{I_{C4}}{I_S} \cdot \frac{I_S}{I_{C5}} \cdot \frac{I_{C2}}{I_S} \cdot \frac{I_S}{I_{C1}} = 0 \Rightarrow \frac{I_{C4}}{I_{C5}} = \frac{I_{C1}}{I_{C2}}$, $I_{C4} + I_{C5} = I_0$, $I_{C1} + I_{C2} = I_{CA}$

$I_0 = I_{CA} \Rightarrow I_{C1} = I_{C4} = x I_0$, $I_{C2} = I_{C3} = (1-x) I_0$ $\quad U_{CE3A} = I_0 R_B = 100\mu A \cdot 3k\Omega = 300mV$

(2)



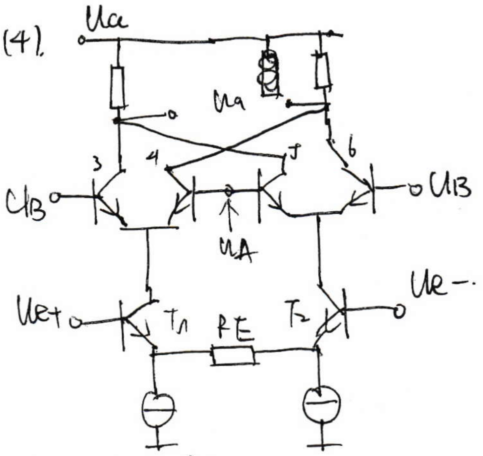
$g_m = \frac{I_C}{U_T}$

$\frac{1}{r_{be}} = \frac{I_B}{U_T}$, r_{be} 可以忽略,

(3) $V(x) = \frac{U_a}{U_e} = -g_{m3} \cdot \frac{1}{g_{m1} + g_{m2}} \cdot g_{m1} \cdot R_L$, $g_{m3} = g_{m1} + g_{m2} = \frac{I_{CA}}{U_T}$

$= -g_{m1} \cdot R_L = \frac{-x I_0}{U_T} \cdot R_L$.

(4).



$U_e^+ = U_{gl} + \frac{U_{diff}}{2} \Rightarrow i_{a1} = g_{T1} g_l \cdot U_{gl} + g_T \cdot \frac{U_{diff}}{2}$

$U_e^- = U_{gl} - \frac{U_{diff}}{2} \Rightarrow i_{a2} = g_{T1} g_l \cdot U_{gl} - g_T \frac{U_{diff}}{2}$

$I_1 = \frac{I_0}{U_T}(U_{gl} + \frac{U_{diff}}{2})$

$I_2 = \frac{I_0}{U_T}(U_{gl} - \frac{U_{diff}}{2})$

$I_3 = \frac{I_0}{U_T^2}(U_{gl} + \frac{U_{diff}}{2}) \cdot U_B$

$I_4 = \frac{I_0}{U_T^2}(U_{gl} + \frac{U_{diff}}{2}) \cdot U_A$

$I_5 = \frac{I_0}{U_T^2}(U_{gl} - \frac{U_{diff}}{2}) \cdot U_A$

$I_6 = \frac{I_0}{U_T^2}(U_{gl} - \frac{U_{diff}}{2}) \cdot U_B$

$I_3 + I_5 = \frac{I_0}{U_T^2}[U_{gl}(U_B + U_A) + \frac{U_{diff}}{2}(U_B - U_A)]$

$I_4 + I_6 = \frac{I_0}{U_T^2}[U_{gl}(U_B + U_A) + \frac{U_{diff}}{2}(U_A - U_B)]$

四象限乘法器

$I_3 + I_5 - (I_4 + I_6)$

$= I_3 - I_4 + I_5 - I_6$

$(I_3 + I_5) - (I_4 + I_6) = \frac{I_0}{U_T^2} \cdot U_{diff}(U_B - U_A)$, $U_a \sim U_B - U_A$.

Re, gegenkoppelung, Linearlisierung.

ES-02.

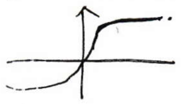
1. Aus Vorlesung (笔记中有计算过程)

$\frac{U_a}{U_g} = g_{T3} Z_0 \cdot \frac{g_{T2} Z - 1}{1 + g_{T2} Z (g_{T1} Z_0 + g_{T3} Z_0) + g_{T1} g_{T3} Z_0^2}$, $\Rightarrow g_{T1} = g_{T3} = \frac{1}{Z_0}$, $\frac{U_e}{U_g} = \frac{1}{2}$

$\frac{U_a}{U_e} = \frac{g_{T2} Z - 1}{g_{T2} Z + 1}$.

2. $G(j\omega) = -\frac{g_{T2} - j\omega C}{g_{T2} + j\omega C} = 1 \exp^{j \cdot 2\arctan(\frac{g_{T2}}{\omega C}) - j\pi}$, Allpass,

3. $-2\arctan(\frac{g_{T2}}{\omega C})$, $0° \to 140°$ $\to 0° \to 70°$



$\frac{g_{T2}}{\omega C} = \tan 70°$ $\quad C = \frac{g_{T2}}{2\pi \cdot f \cdot \tan 70°} = 57.8 pF$.

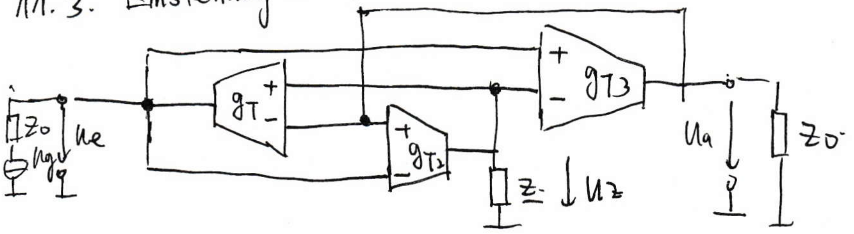
$|G j\omega| = 0.916$

$a = -20 \lg(0.916) = 0.76 dB$

4. $Z = \frac{1}{j\omega C} // r_a = \frac{\frac{1}{j\omega C r_a}}{\frac{1}{j\omega C} + r_a} = \frac{r_a}{1 + r_a j\omega C}$

$\left|\frac{U_a}{U_Z}\right| = \left|\frac{r_a \cdot g_{T2} - (1 + r_a j\omega C)}{r_a \cdot g_{T2} + (1 + r_a j\omega C)}\right| = \sqrt{\frac{(r_a g_{T2} - 1)^2 + r_a^2 \omega^2 C^2}{(r_a g_{T2} + 1)^2 + r_a^2 \omega^2 C^2}} = \sqrt{\frac{(g_{T2} - \frac{1}{r_a})^2 + \omega^2 C^2}{(g_{T2} + \frac{1}{r_a})^2 + \omega^2 C^2}}$

11.3. Einstellung der Phase



$\rightarrow g_{T1}: \frac{U_g - U_e}{Z_0} = g_{T1} \cdot (U_z - U_a) \Rightarrow U_g - U_e = g_{T1} \cdot Z_0 \cdot U_z - g_{T1} Z_0 U_a$. ①

$\rightarrow g_{T2}: -\frac{U_z}{Z} = g_{T2} \cdot (U_a - U_e) \Rightarrow -U_z = g_{T2} Z U_a - g_{T2} Z U_e$ ②

$\Rightarrow -U_a = \frac{U_z}{g_{T2} Z} - U_e$.

$\rightarrow g_{T3}: -\frac{U_a}{Z_0} = g_{T3} \cdot (U_e - U_z) \Rightarrow -U_a = g_{T3} Z_0 U_e - g_{T3} Z_0 U_z$. ③

从②式和③式中解得 $U_z(U_a)$, $U_e(U_a)$

U_e:

$-g_{T3} Z_0 U_a = \frac{g_{T3} Z_0}{g_{T2} Z} U_z - g_{T3} Z_0 U_e$. ④

$-\frac{U_a}{g_{T2} Z} = \frac{g_{T3} Z_0}{g_{T2} Z} U_e \quad \frac{g_{T3} Z_0}{g_{T2} Z} U_z$. ⑤

④ + ⑤

$-U_a (g_{T3} Z_0 + \frac{1}{g_{T2} Z}) = \left(\frac{g_{T3} Z_0}{g_{T2} Z} - g_{T3} Z_0\right) U_e$

$U_e = -\frac{g_{T3} Z_0 \cdot g_{T2} Z + 1}{g_{T3} Z_0 - g_{T3} Z_0 \cdot g_{T2} Z} U_a$

由②式

$U_z = -\left[g_{T2} Z U_a + \frac{g_{T2} Z \cdot (g_{T2} Z \cdot g_{T3} Z_0) + g_{T2} Z}{g_{T3} Z_0 - g_{T3} Z_0 \cdot g_{T2} Z}\right] U_a$

$= -\left[\frac{g_{T2} Z \, g_{T3} Z_0 - (g_{T2} Z)^2 g_{T3} Z_0 + (g_{T2} Z)^2 g_{T3} Z_0 + g_{T2} Z}{g_{T3} Z_0 - g_{T3} Z_0 \cdot g_{T2} Z}\right] U_a = -\frac{g_{T3} Z_0 \, g_{T2} Z + g_{T2} Z}{g_{T3} Z_0 - g_{T3} Z_0 \cdot g_{T2} Z} U_a$.

代入①式

$U_g = \frac{-[g_{T3} Z_0 \cdot g_{T2} Z + 1]}{g_{T3} Z_0 - g_{T3} Z_0 \, g_{T2} Z} + \frac{-[g_{T1} Z_0 \, g_{T3} Z_0 \, g_{T2} Z + g_{T1} Z_0 \cdot g_{T2} Z]}{g_{T3} Z_0 - g_{T3} Z_0 \, g_{T2} Z} - g_{T1} Z_0 U_a$.

$= -\frac{g_{T3} Z_0 \cdot g_{T2} Z + 1 + g_{T1} Z_0 \, g_{T3} Z_0 \, g_{T2} Z + g_{T1} Z_0 \cdot g_{T2} Z + g_{T1} Z_0 \, g_{T3} Z_0 - g_{T3} Z_0 \, g_{T2} Z \, g_{T1} Z_0}{g_{T3} Z_0 - g_{T3} Z_0 \, g_{T2} Z} \cdot U_a$

$= -\frac{1 + g_{T3} Z_0 \, g_{T2} Z + g_{T1} Z_0 \, g_{T2} Z + g_{T1} Z_0 \, g_{T3} Z_0}{g_{T3} Z_0 - g_{T3} Z_0 \, g_{T2} Z} U_a$.

$\frac{U_a}{U_g} = -\frac{g_{T3} Z_0 (1 - g_{T2} Z)}{1 + g_{T3} Z_0 \, g_{T2} Z + g_{T1} Z_0 \, g_{T2} Z + g_{T1} Z_0 \, g_{T3} Z_0} \Rightarrow g_{T3} Z_0 \frac{g_{T2} Z - 1}{g_{T2} Z (g_{T1} Z_0 + g_{T3} Z_0) + 1 + g_{T1} g_{T3} Z_0^2}$

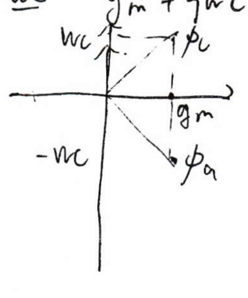
化简. $g_{T1} = g_{T3} = \frac{1}{Z_0}$ (阻抗匹配), $U_e = \frac{U_g}{2} \Rightarrow \frac{g_{T2} Z - 1}{g_{T2} Z + 1}$, $\frac{1}{2} = \frac{U_a}{U_g} \Rightarrow \frac{U_a}{U_e}$. 设 $g_{T2} = g_m$.

$\frac{U_a}{U_e} = \frac{g_m Z - 1}{g_m Z + 1}$, für $Z = \frac{1}{j\omega c}$

$\frac{U_a}{U_e} = \frac{g_m - j\omega c}{g_m + j\omega c}$

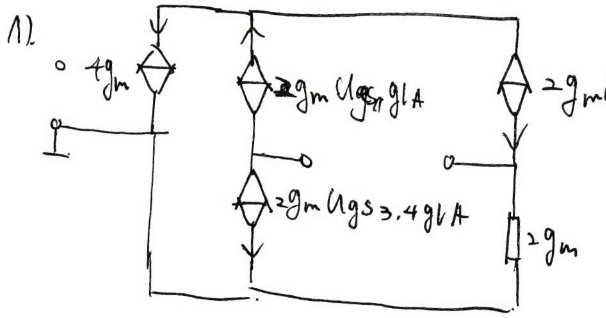
$\phi = \arctan\frac{-g_m}{\omega c} - \arctan\frac{g_m}{\omega c} = -2\arctan\frac{g_m}{\omega c} = 2\arctan\frac{g_m}{\omega c} - \pi$

$g_m \rightarrow X\phi\,(0 \sim 1) \cdot g_{m,max}$.



ES-03.

1).



$$\begin{cases} 4g_m U_{GS0} - 2g_m U_{GS1,2} + 2 g_m U_{GS,5} = 0 \\ 2g_m U_{GS1,2} + 2g_m U_{GS3,4} = 0 \\ U_{a'gl} = U_{DD} + U_{GS3,4} + U_{GS5} \end{cases}$$

$U_{GS0,A} - U_{th} = \sqrt{\frac{I_0}{2\beta_0}} = \sqrt{\frac{2I_D}{\beta}} \Rightarrow U_{GS0} = \sqrt{\frac{2I_D}{\beta}} + U_{th} = 0.624\,V = 624\,mV$

$I_{D3} = I_{D4} = I_{D2} = I_{D1} = \frac{I_{D5}}{2} = \frac{I_0}{4} \Rightarrow U_{GS1,A} = U_{GS2,A} = 624\,mV$

$U_{GS3} = U_{GS4,A} = U_{GS,5} = -624\,mV.$

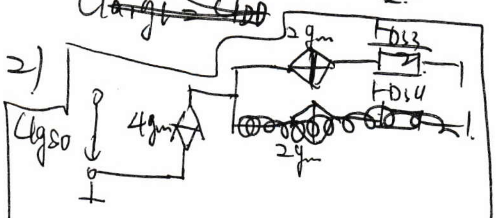
$U_{a'gl} = U_{DD} + U_{GS3,4} + U_{GS,5} = 3 - 2\times 0.624 = 1.752\,V.$

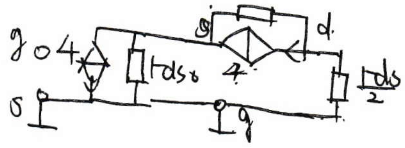
$U_{e,gl\,A} - U_{a'gl} \leq U_{th} \Longrightarrow U_{egl.Amax} = U_{th} + U_{a'gl} = 2.15\,V$

$U_{e,gl\,A} \geq U_{th} + U_s \Rightarrow U_{th} + \ldots$

$U_{e,gl} \geq U_{th} + \frac{2 U_{DD}}{\ldots} = \ldots$

2)





$$\frac{U_a}{U_{GS0}} = \frac{4g_m}{2g_m} \cdot 2g_m \cdot \frac{r_{DS}}{2} = \frac{4g_m}{4g_m} \cdot 4g_m \times \frac{r_{ds}}{2} = -2g_m \cdot r_{ds}$$

$$= -\frac{g_{m0}}{4} \cdot 2 \cdot r_{ds}$$

$$= -\frac{g_{m0}}{2} r_{ds3,4} = \sqrt{2\beta_0 \ldots} \cdot \frac{1}{\lambda I_0/2}$$

$$= \sqrt{2\beta_0 I_0 A} \cdot \frac{2}{\lambda} \cdot \frac{1}{I_0}$$

$$= 596.2$$

3). $U_{a'gl} = U_{GS3,4} + U_{GS,5} = -2U_{GS0}$

$\Rightarrow \frac{U_a}{U_e} = -2.$