Примерни задачи

Проектиране на аналогови интегрални схеми

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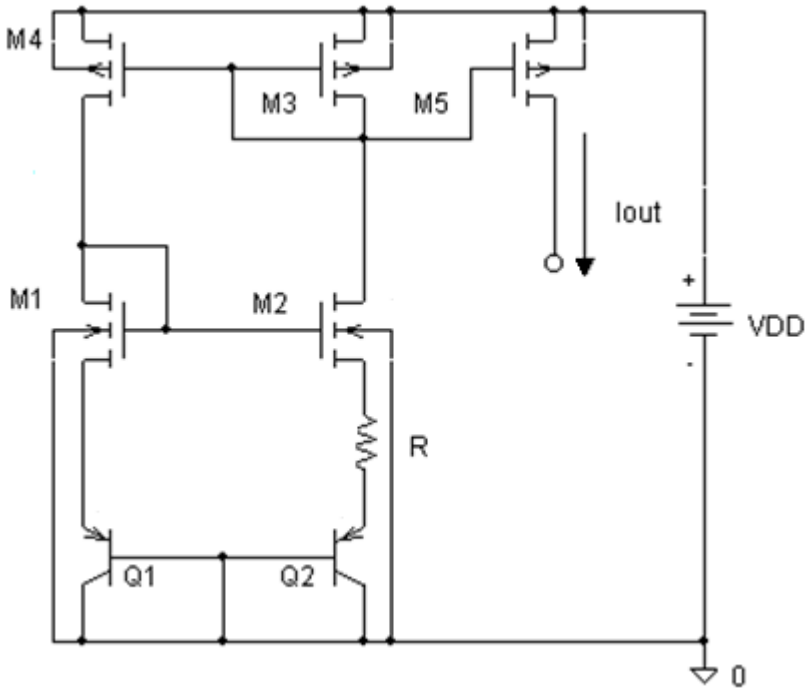
Анализ на задаващ източник на ток



Определете токовете и напреженията в схемата, ако:
R = 1789Ω.
W1/L1= 40/2; W2/L2= 20/2;
W3/L3= 48/3; W4/L4= 96/3;
W5/L5= 72/3;

nMOS

$U_{TNO} = 0{,}5V$

$K_N = 100\mu A/V^2$

$\lambda_n \approx \frac{0{,}1L_{\min}}{L}$

$L_{\min} = 0.35\mu m$

pMOS

$U_{TPO} = -0{,}5V$

$K_P = 40\mu A/V^2$

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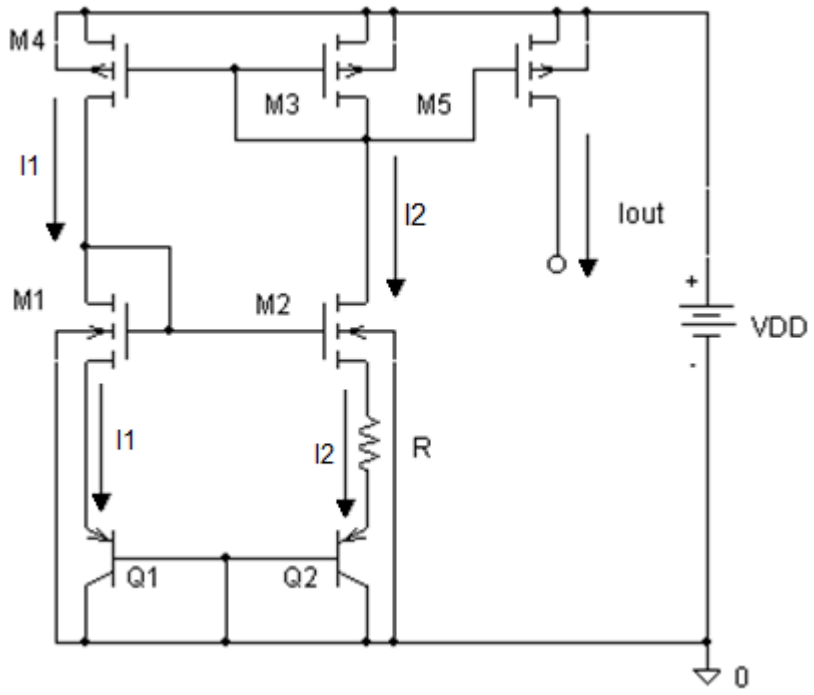
Анализ на задаващ източник на ток

Йерархичност, декомпозиция, структурност



M3-M5 и M3-M4 – прости токови огледала

M1-M2 – просто токово огледало

Q1 – (Q2 + R) – диодна двойка ; Q1≡Q2

$$I_D(M1) = I_D(M4) = I(Q1) = I1;$$
$$I_D(M2) = I_D(M3) = I(Q2) = I_R = I2$$

M3 – M4 → просто токово огледало

$$\frac{I1}{I2} = \frac{W4/L4}{W3/L3} = \frac{96/3}{48/3} = 2$$

$$I1 = 2 \cdot I2$$

M3 – M5 → просто токово огледало

$$\frac{Iout}{I2} = \frac{W5/L5}{W3/L3} = \frac{72/3}{48/3} = 1{,}5$$

$$Iout = 1{,}5 \cdot I2$$

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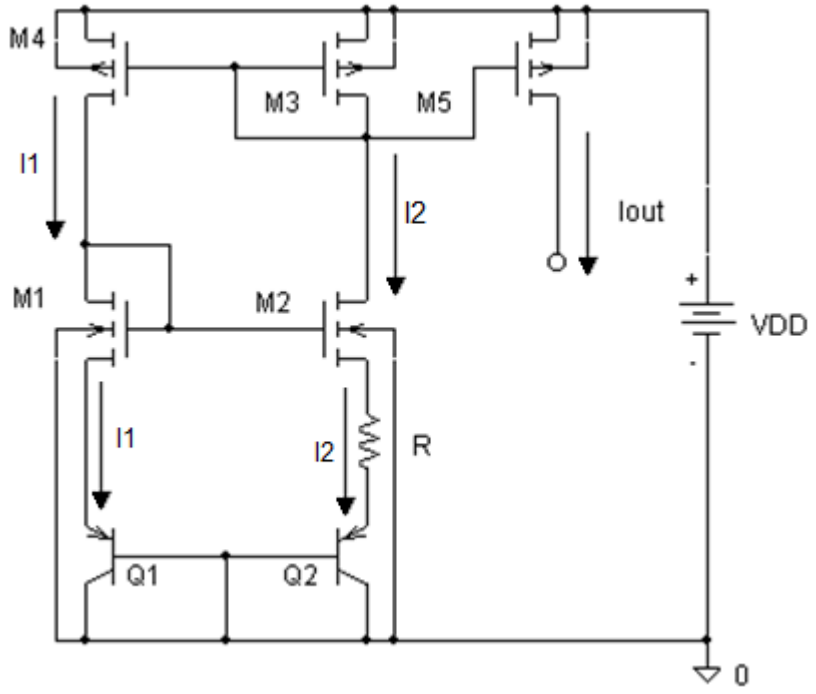

M3-M5 и M3-M4 – прости токови огледала

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Q1 – (Q2 + R) – диодна двойка ; Q1≡Q2

M1 – M2 → просто токово огледало

W1/L1=40/2; W2/L2=20/2; $I1 = 2 \cdot I2$

$$I1 = \frac{k_n}{2}\frac{W1}{L1}(U_{GS1} - U_{TN})^2$$

$$I2 = \frac{k_n}{2}\frac{W2}{L2}(U_{GS2} - U_{TN})^2$$

$$\frac{I1}{I2} = 2 = \frac{40}{2}\frac{2}{20}\frac{(U_{GS1} - U_{TN})^2}{(U_{GS2} - U_{TN})^2}$$

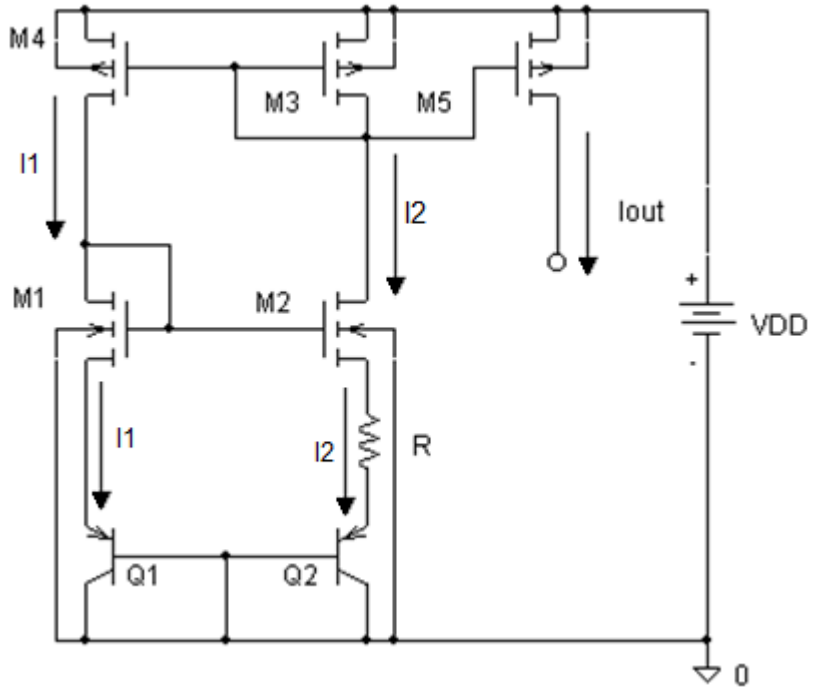
$$1 = \frac{(U_{GS1} - U_{TN})^2}{(U_{GS2} - U_{TN})^2} \quad \rightarrow U_{GS1} = U_{GS2}$$

$$U_{S1} = U_{S2}$$

$$U_{EB1} = U_{EB2} + R \cdot I2$$

Анализ на задаващ източник на ток

Йерархичност, декомпозиция, структурност



M3-M5 и M3-M4 – прости токови огледала

M1-M2 – просто токово огледало

Q1 – (Q2 + R) – диодна двойка; Q1≡Q2

Q1 – (Q2+R) → диодна двойка

$$U_{EB1} = U_{EB2} + R \cdot I2$$

$$U_{EB} = \varphi_T ln \frac{I_F}{I_s} = \varphi_T ln \frac{I_F}{A \cdot J}$$

$$U_{EB1} - U_{EB2} = R \cdot I2$$

$$\varphi_T ln \frac{I1}{A1 \cdot J} - \varphi_T ln \frac{I2}{A2 \cdot J} = R \cdot I2$$

$$Q1 \equiv Q2 \rightarrow A1 = A2$$

$$I2 = \frac{\varphi_T}{R} ln \frac{I1}{I2} = \frac{\varphi_T}{R} ln2 = \frac{0,0258}{1789} 0,69$$

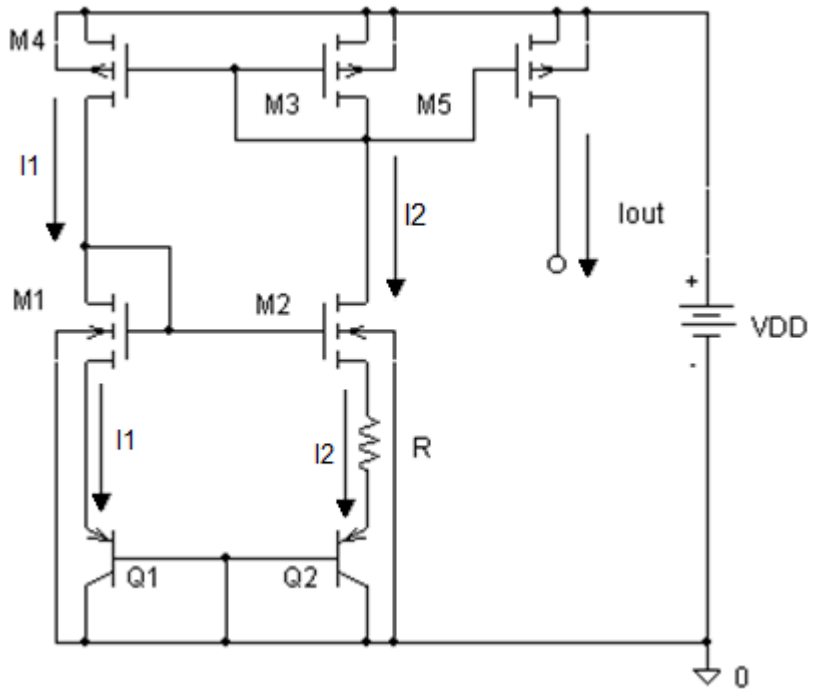
$$I2 \approx 10\mu A$$

$$I1 = 2 \cdot I2 \approx 20\mu A$$

$$Iout = 1,5 \cdot I2 \approx 15\mu A$$

Анализ на задаващ източник на ток

Йерархичност, декомпозиция и структурност



M3-M5 и M3-M4 – прости токови огледала

M1-M2 – просто токово огледало

Q1 – Q2 + R – диодна двойка ; Q1≡Q2

$$I2 = I_D(M3) = \frac{k_p}{2}\frac{W3}{L3}(U_{EFFp})^2$$

$$10\mu A = \frac{40\mu A/V^2}{2}\frac{48\mu m}{3\mu m}(U_{EFFp})^2$$

$$(U_{EFFp})^2 = 0{,}03125(V)^2$$

$$U_{EFFp} = 0{,}177V$$

$$I2 = I_D(M2) = \frac{k_n}{2}\frac{W2}{L2}(U_{EFFn})^2$$

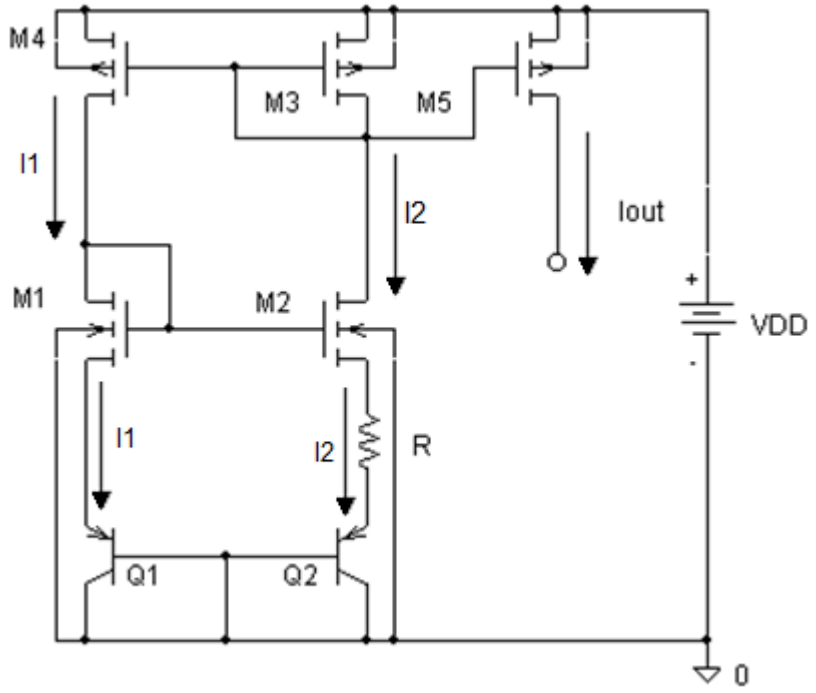
$$10\mu A = \frac{100\mu A/V^2}{2}\frac{20\mu m}{2\mu m}(U_{EFFn})^2$$

$$(U_{EFFn})^2 = 0{,}01(V)^2$$

$$U_{EFFn} = 0{,}1V$$

Анализ на задаващ източник на ток

Йерархичност, декомпозиция и структурност



$$r_{out} = \frac{1}{\lambda_5 I_{out}}$$

$$\lambda_5 = \lambda_p = \frac{0{,}2L_{min}}{L5} = \frac{0{,}2 \cdot 0{,}35\mu m}{3\mu m}$$

$$\lambda_5 = \frac{0{,}07}{3} \approx 0{,}023$$

$$r_{out} = \frac{1}{0{,}023 \cdot 15\mu A} \approx 2{,}9M\Omega$$

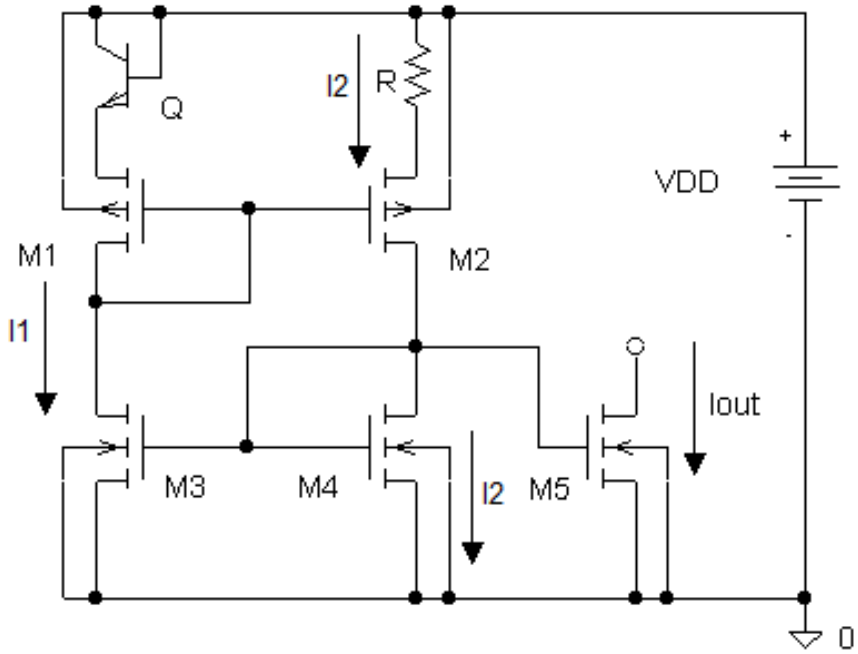
M3-M5 и M3-M4 – прости токови огледала

M1-M2 – просто токово огледало

Q1 – Q2 + R – диодна двойка ; Q1≡Q2

Проектиране на задаващ източник на ток

Оразмерете схемата на задаващия източник на ток за Iout=50μA



M4 – M3; M4 – M5 → прости токови огледала

M1– M2 → просто токово огледало

Q – R → токоопределяща група

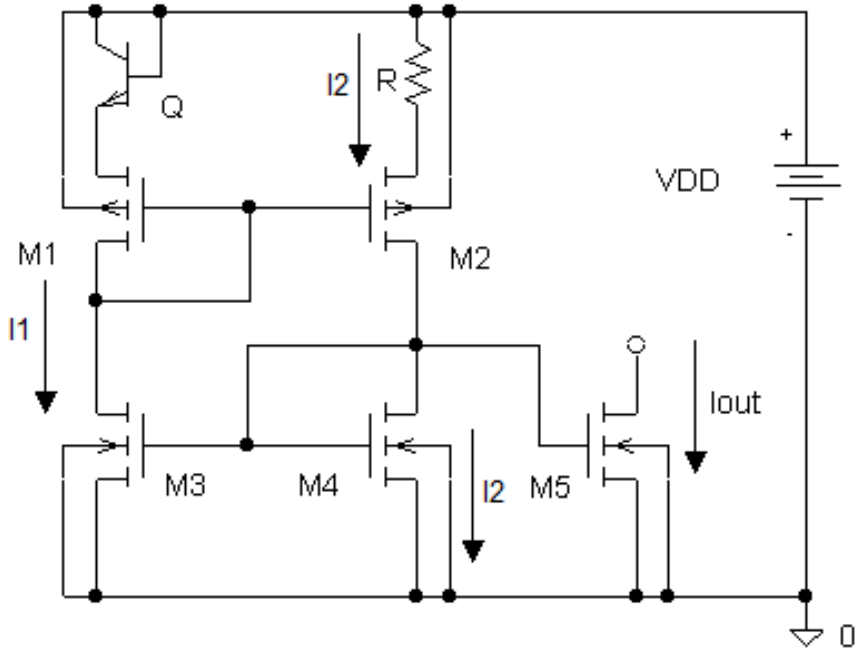
Избираме: $I1 = I2 = 10\mu A$

$\therefore\ M3 \equiv M4;\quad M1 \equiv M2;\quad \frac{W5}{L5} = 5\frac{W4}{L4}$

nMOS	$U_{TNO} = 0{,}5V$	$K_N = 100\mu A/V^2$	$\lambda_n \approx \frac{0{,}1L_{\min}}{L}$	$L_{\min} = 0.35\mu m$
pMOS	$U_{TPO} = -0{,}5V$	$K_P = 40\mu A/V^2$	$\lambda_p \approx \frac{0{,}2L_{\min}}{L}$	$L_{\min} = 0.35\mu m$

Проектиране на задаващ източник на ток

Оразмерете схемата на задаващия източник на ток за Iout=50μA



$$\lambda_5 = \lambda_n = \frac{0{,}1L_{min}}{L5} = 0{,}0175$$

$$r_{out} = \frac{1}{\lambda_5 I_{out}} = \frac{1}{0{,}0175 \cdot 50\mu A} = 1{,}14M\Omega$$

$$I_D(M4) = I2 = 10\mu A = \frac{k_n}{2}\frac{W4}{L4}(U_{eff})^2$$

$$10\mu A = \frac{100\mu A/V^2}{2}\frac{W4}{L4}(0{,}2)^2 \rightarrow \frac{W4}{L4} = 5$$

$W4 = 10\mu m; \quad L4 = 2\mu m$

$W3 = 10\mu m; \quad L3 = 2\mu m;$

$W5 = 50\mu m; \quad L5 = 2\mu m$

$W1 = 25\mu m; \quad L1 = 2\mu m$

$W2 = 25\mu m; \quad L2 = 2\mu m$

$U_{EB} = m\varphi_T ln\frac{I1}{I_s}; \; m = ?; \quad I_s = ?$

Приемаме $U_{EB} = 0{,}6V$

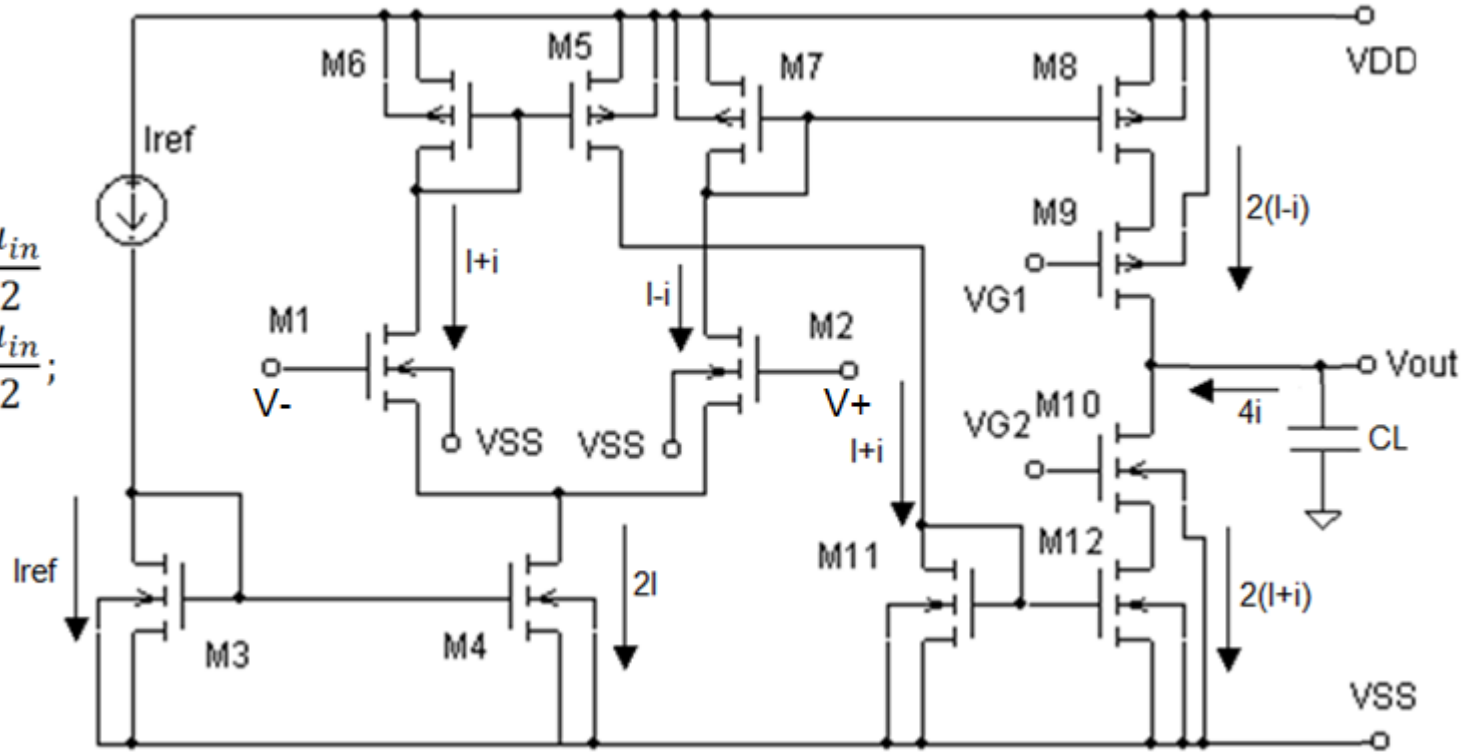
$$R = \frac{U_{EB}}{I2} = \frac{0{,}6V}{10\mu A} = 60k\Omega$$

Анализ и проектиране на операционни усилватели на проводимост (ОТА)

Анализ на ОТА

$$V_- = +\frac{u_{in}}{2}$$

$$V_+ = -\frac{u_{in}}{2};$$



Iref=20μA; W1/L1= W2/L2= W11/L11= 40/2; W5/L5=W6/L6= W7/L7=100/2;
W3/L3= W4/L4= W10/L10= W12/L12= 80/2; W8/L8= W9/L9= 200/2; CL=5pF

$U_{TNO} = 0{,}5V$ $\quad K_N = 100\mu A/V^2$ $\quad \lambda_n \approx \frac{0{,}1L_{\min}}{L}$ $\quad L_{\min} = 0.35\mu m$

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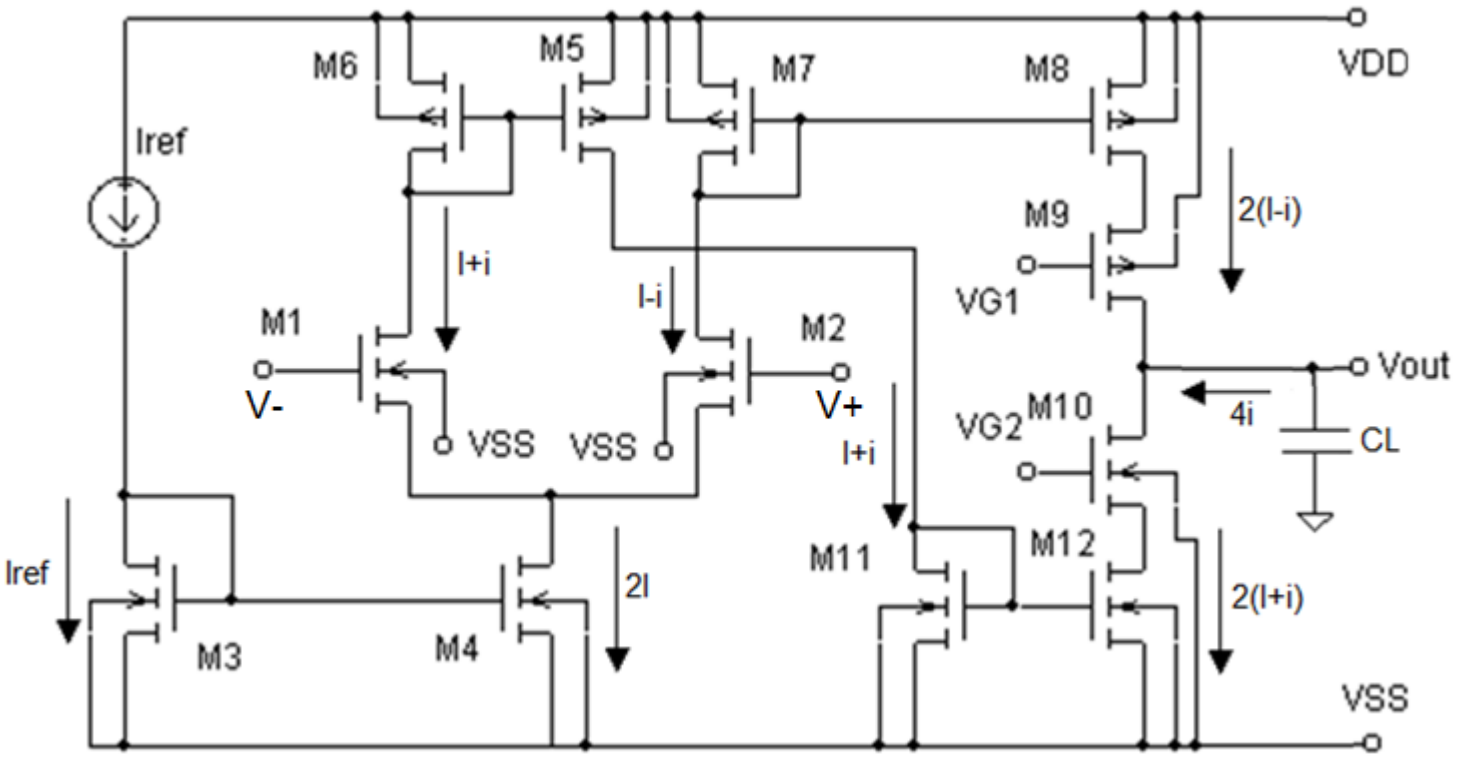
Анализ на ОТА



Iref=20μA;

W1/L1= W2/L2= W11/L11= 40/2;

W5/L5=W6/L6= W7/L7=100/2;

W3/L3= W4/L4= W10/L10= W12/L12= 80/2;

W8/L8= W9/L9= 200/2;

CL=5pF

$I_{ref} = 20\mu A;\ I = 10\mu A;\ I_D = \frac{k}{2}\frac{W}{L}(U_{eff})^2;\ U_{effn} = 0{,}1V;\ U_{effp} = -0{,}1V$

$VG1 < V_{DD} - (V_{DSsat\,8} + |U_{eff\,9}| + |U_{TP}|) = 1{,}65 - (0{,}1 + 0{,}1{+}0{,}5) = 0{,}95V$

$VG2 > V_{SS} + (V_{DSsat\,12} + U_{eff\,10} + U_{TN}) = -1{,}65 + (0{,}1 + 0{,}1{+}0{,}5) = -0{,}95V$

Анализ на ОТА

$$V_- = +\frac{u_{in}}{2}$$

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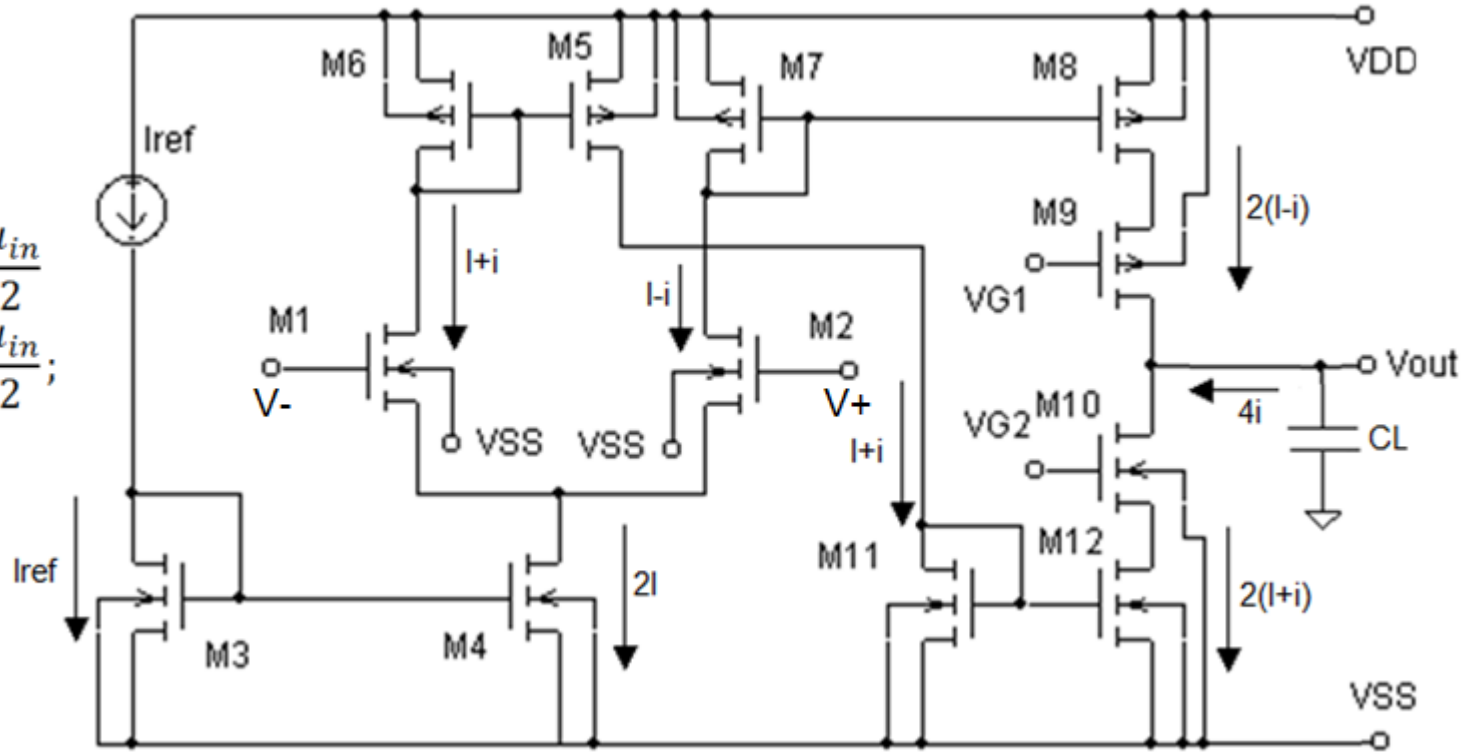

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Анализ на ОТА

$$A_u = \frac{u_{out}}{u_{in}} = -\frac{i_{out}\, r_{out}}{u_{in}} = -\frac{i_{out}}{u_{in}} r_{out} = -G_m\, r_{out}$$

$$G_m = \frac{i_{out}}{u_{in}} = \frac{4i}{u_{in}} = 2\frac{i}{u_{in}/2} = 2g_{m1} = 2g_{m2}$$

$$G_m = 2g_{m1} = 2\sqrt{2k_n \frac{W1}{L1} I} = 2\sqrt{2 \cdot 100\mu A/V^2 \frac{40}{2} 10\mu A} = 400\mu A/V$$

$$r_{out} = r_{dsp\,9-8} \| r_{dsn\,10-12}\ ; \quad r_{dsp\,9-8} = g_{m9} r_{ds9} r_{ds8};\ r_{dsp\,10-12} = g_{m10} r_{ds10} r_{ds12}$$

$$g_{m10} = g_{m9} = \sqrt{2k_n\,(W10/L10)2\,I} = \sqrt{2k_p\,(W9/L9)2\,I} = 400\mu A/V$$

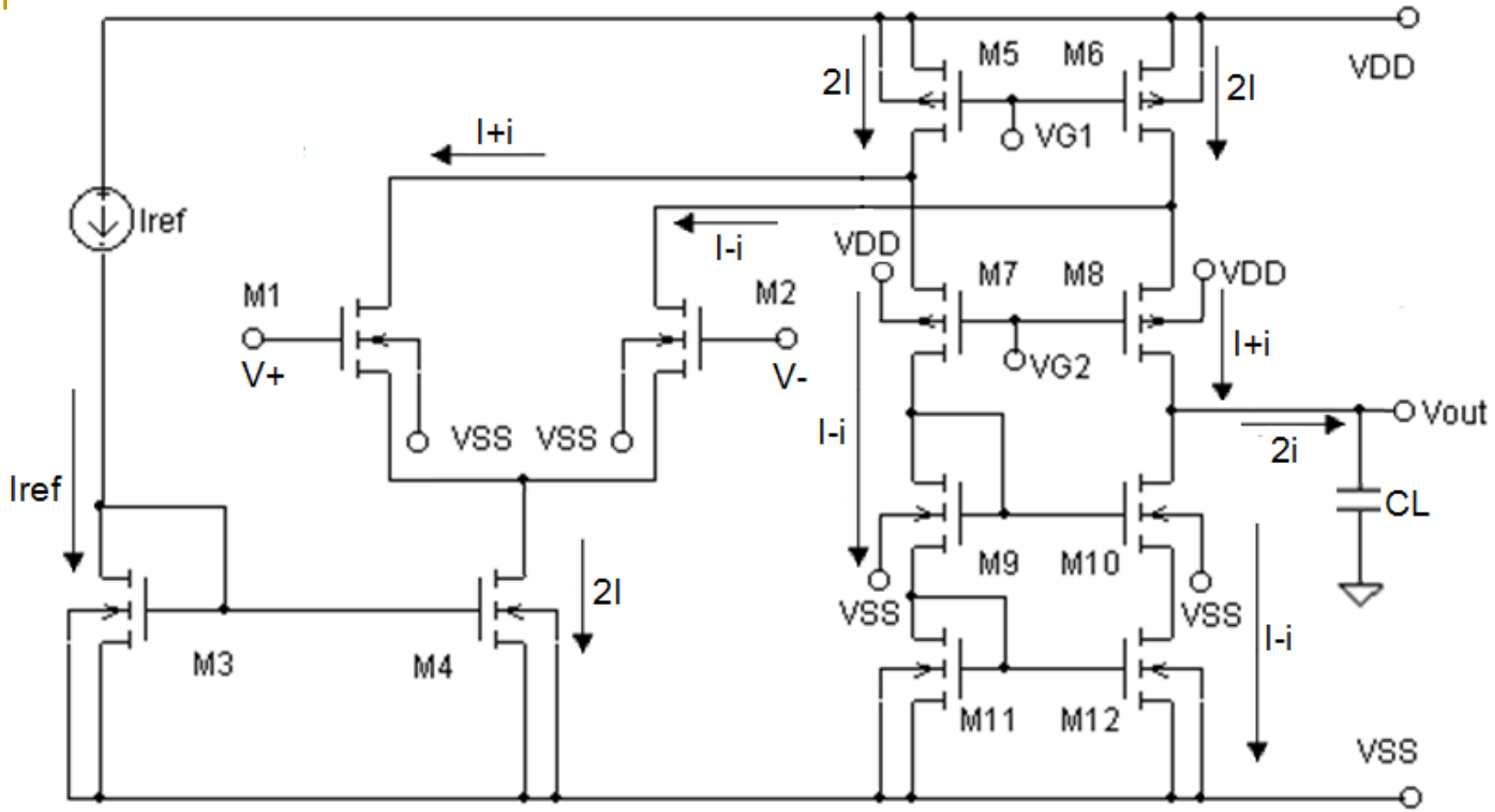
$$r_{ds10} = r_{ds12} = \frac{1}{\lambda_n 2I} = \frac{1}{0{,}0175 \cdot 20\mu A} \approx 2{,}8M\Omega; \quad r_{ds9} = r_{ds8} = \frac{1}{\lambda_p 2I} = \frac{1}{0{,}035 \cdot 20\mu A} \approx 1{,}4M\Omega$$

$$r_{dsp\,10-12} = g_{m10} r_{ds10} r_{ds12} = 3{,}14G\Omega;\ r_{dsp\,9-8} = g_{m9} r_{ds9} r_{ds8} = 784M\Omega;\ \mathrm{r_{out}} = 627M\Omega$$

$$A_u = -G_m r_{out} = -0{,}4\frac{mA}{V} \cdot 627M\Omega \approx -250000$$

$$GBW = f_u = \frac{G_m}{2\pi C_L} = \frac{0{,}4e-3}{2\pi \cdot 5e-12} = 12{,}7MHz; \qquad f_{-3dB} = \frac{1}{2\pi r_{out}\, C_L} = \frac{GBW}{A_u} = 50{,}8\ Hz$$

Проектиране на ОТА



$$V_+ = +\frac{u_{in}}{2} \qquad V_- = -\frac{u_{in}}{2}$$

Оразмерете схемата за GBW=f_u=5MHz при CL=5pF.

Проектиране на ОТА

$$GBW = f_u = A_u f_{-3dB} = G_m\, r_{out}\, \frac{1}{2\pi r_{out} C_L} = G_m \frac{1}{2\pi C_L} = \frac{i_{out}}{u_{in}} \frac{1}{2\pi C_L} = \frac{2i}{u_{in}} \frac{1}{2\pi C_L} =$$

$$= \frac{i}{u_{in}/2} \frac{1}{2\pi C_L} = \frac{g_{m1}}{2\pi C_L}$$

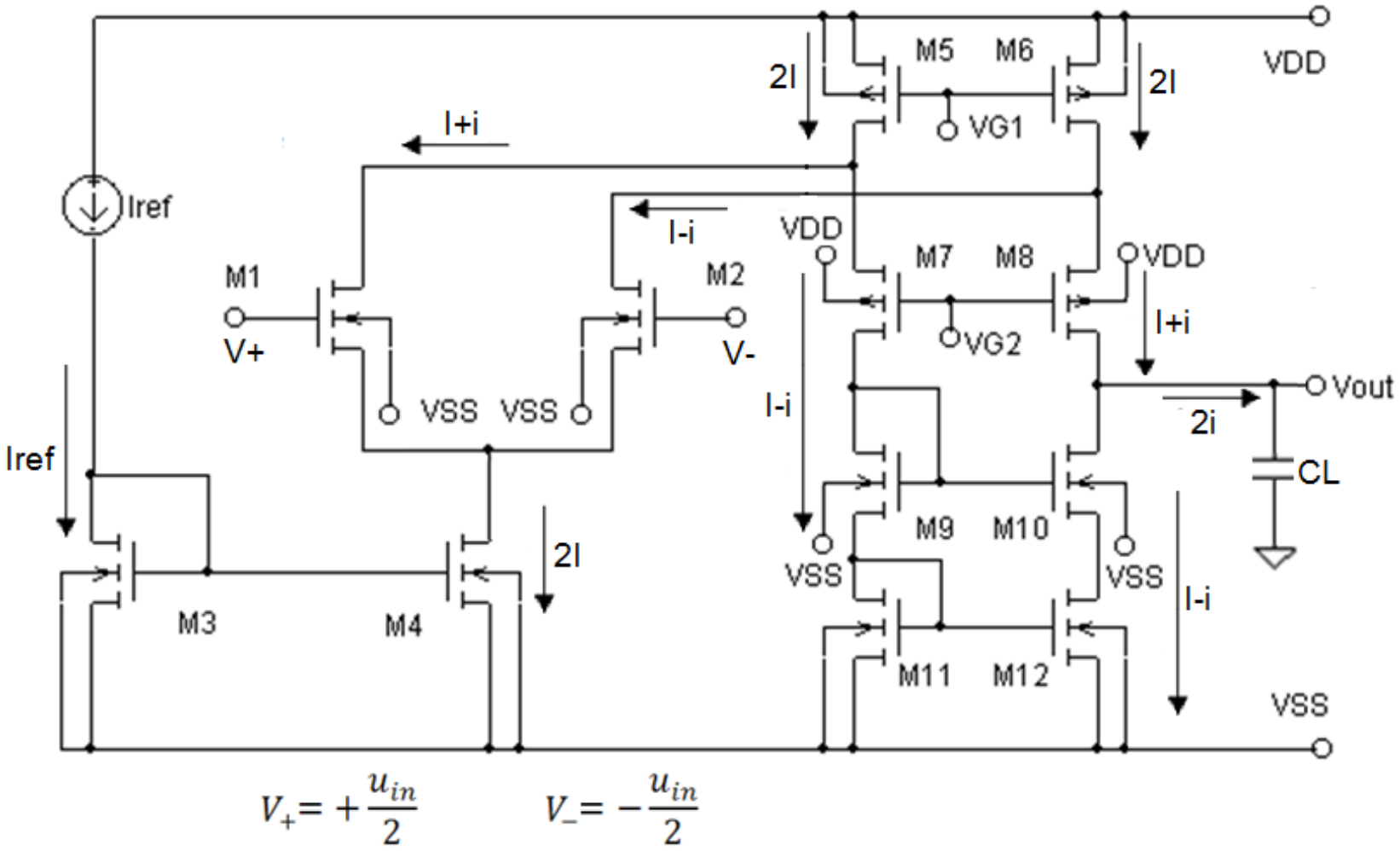
$$\frac{g_{m1}}{2\pi C_L} = GBW; \quad 5MHz = \frac{g_{m1}}{2\pi \cdot 5pF} \rightarrow g_{m1} = 157 \frac{\mu A}{V}; \quad \text{Избираме } g_{m1} = 180 \frac{\mu A}{V}$$

$$g_{m1} = \frac{2I}{U_{eff}} \rightarrow 180 \left[\frac{\mu A}{V}\right] = \frac{2I[\mu A]}{0{,}2[V]} \rightarrow I = 18\mu A; \quad \text{Избираме } I_{ref} = 9\mu A$$

Избираме $L = 2\mu m \rightarrow W1 = W2 = 18\mu m;\ W3 = 9\mu m;\ W4 = 36\mu m;$

$W5 = W6 = 90\mu m;\ W7 = W8 = 45\mu m;\ W9 = W10 = W11 = W12 = 18\mu m$

Проектиране на ОТА



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Проектиране на ОТА

$r_{out} = r_{dsp\,8-6-2} \| r_{dsn\,10-12}$

$r_{dsp\,8-6-2} = g_{m8} r_{ds8} (r_{ds6} \| r_{ds2})$; $r_{dsn\,10-12} = g_{m10} r_{ds10} r_{ds12}$

$g_{m8} = g_{m10} = 180 \frac{\mu A}{V}$; $r_{ds10} = r_{ds12} = r_{ds2} = \frac{1}{\lambda_n I} = \frac{1}{0{,}0175 \cdot 18\mu A} \approx 3{,}1 M\Omega$;

$r_{ds8} = \frac{1}{\lambda_p I} = \frac{1}{2 \cdot 0{,}0175 \cdot 18\mu A} \approx 1{,}55 M\Omega$; $r_{ds6} = \frac{1}{\lambda_p 2I} = \frac{1}{2 \cdot 0{,}0175 \cdot 2 \cdot 18\mu A} \approx 0{,}775 M\Omega$;

$r_{ds6-2} = r_{ds6} \| r_{ds2} = 0.775 M\Omega \| 3{,}1 M\Omega = 620 M\Omega$; $r_{dsp\,8-6-2} = g_{m8} r_{ds8} r_{ds6-2} = 173 M\Omega$

$r_{dsp\,10-12} = g_{m10} r_{ds10} r_{ds12} = 1{,}73 G\Omega$; $r_{out} = 157 M\Omega$

$A_u = G_m r_{out} = 0{,}18 \frac{mA}{V} \cdot 157 M\Omega \approx 28300 \approx 90\text{dB}$

$f_{-3dB} = \frac{1}{2\pi r_{out} C_L} \approx 200 Hz$

Б Л А Г О Д А Р Я !