Formulas:

$$A_v = \frac{g_{m1} \; g_{m6}}{g_{o1} \; g_{o6}} = 223{,}87$$

α $C_H = 1{,}25\,pF$

α $GBW_f = \frac{g_{mp2}}{2\pi C_H} = \frac{g_{m1}}{2\pi C_H} = 17000000 \rightarrow$ get g_{m1}

α $P_{4} = \cancel{\frac{g_{m6}}{C_L}} \approx 3\; GBW \rightarrow$ get g_{m6}

α $C_H = \frac{C_L}{4} = 1{,}25\,pF$

$g_{o4} << g_{o1}$ and $g_{o5} << g_{o6}$

$r_1 = r_2$ and $r_3 = r_4$

α $C_L = 5\,pF$

$$\Rightarrow g_{m6} = 3 \cdot 17000000 \cdot 2\pi \cdot 5 \cdot 10^{-12}$$
$$= 0{,}0016$$

$$\Rightarrow g_{m1} = 17000000 \cdot 2\pi \cdot 1{,}25 \cdot 10^{-12}$$
$$= 1{,}3352 \cdot 10^{-4}$$

$$\Rightarrow g_{o1} \cdot g_{o6} = \frac{g_{m1} \cdot g_{m6}}{223{,}87}$$
$$= 9{,}5425 \cdot 10^{-10}$$

Voltage drops V_{DS} over transistors:

$M_1 = -0{,}336\,V = M_2 \to p$

$M_3 = 0{,}336\,V = M_4 \to n$

$M_7 = -0{,}336\,V \to p$

$M_8 = -0{,}550\,V = M_5 \to p$

$M_6 = 0{,}550\,V \to n$

Get g_{o1} and g_{o6} → want most gain first stage:

→ assume $V_{OV} = 0\,V$ for all

→ gain of 223,87

⇒ first stage gain of 46,546 → choose L = 1000n

$\Rightarrow \frac{g_{m1}}{g_{o1}} = 46{,}546 \Rightarrow g_{o1} = \frac{g_{m1}}{46{,}546} = 2{,}8685 \cdot 10^{-8}$

$\Rightarrow$ gain second stage $\approx \frac{223{,}87}{46{,}546} = 4{,}8097$

$\Rightarrow \frac{g_{m6}}{g_{o6}} = 4{,}8097 = 7{,}99426$ ⇒ lowest value pickable ↓ L=60n

↳ adds buffer

$\Rightarrow g_{o6} = \frac{g_{m6}}{7{,}99426} = 2{,}0042 \cdot 10^{-7}$

$I_{D1} = \frac{g_{m1}}{22{,}2450} = 6{,}0021 \cdot 10^{-9}$

$I_{D6} = \frac{g_{m6}}{11{,}3299} = 1{,}4141 \cdot 10^{-7}$

All current from M_1 flows into M_4 at DC

All current from M_2 flows into M_3

current through $M_7 = I_{DS1} + I_{D2} = 2 \cdot I_{DS1}$

All current through M_6 goes through M_5 at DC current through M_7 comes from current mirror M_8

⇒ choose $I_{D8} = I_{D6} = 1,4141 \cdot 10^{-7}$

⇒ then $I_{BIAS} = 1,4141 \cdot 10^{-7}$

⇒ good current sources are long transistors

→ choose $L = 500nm$ for M_8 and M_5

⇒ then is L of M_7 equal to $\frac{L8}{\frac{Ids7}{Ids8}} = 5,8502 \cdot 10^{-6}$

⇒ NOTE width of M_7 is equal to width of $M8$ and is equal to $10 \cdot L8$

Next: sizing M_3 and M_4

⇒ again current mirror ($g_{o4} << g_{o2}$)!

⇒ rechoose M_2 to get $g_{o2} >> g_{o4}$

$L_2 = 500nm$ ⇒ gain stage $1 = 27$

↳ $V_{OV_2} = -0,1V$ ⇒ $g_{o2} \approx 0,5$

⇒ rechoose $V_{OV_6} = 0,1V$

⇒ After iteration ⇒ gain and bandwith not big enough

⇒ to do:

→ ~~calculate Vcm, Vout and Pdiss~~ → get from Vin and Iin.

→ calculate gds of $M_{5,8}$ and M_7 (Vov, gds plot)

→ calculate Vds, sat

→ new iteration with higher gain and GBW

→ figure out how to use RM in calculations

↳ use zero to compensate slowest pole ?

→ validate that $g_{o5} << g_{o6}$ and $g_{o4} << g_{o1}$

$$V_{cm,in,max} = V_{T2} + V_{T4} + V_{ov4} + V_{DD}$$
$$= (V_{ov2} - V_{gs2}) + (V_{ov4} - V_{gs4}) + V_{ov4} + V_{DD}$$
$$= -V_{gs2} - V_{gs4} + V_{DD}$$
$$= 1{,}0320\ V$$

$$V_{cm,in,min} = V_{ov7} + V_{ov2} + V_{T2}$$
$$= V_{ov7} + V_{ov2} + V_{ov2} - V_{gs2}$$
$$= 0 + 0 + 0 - V_{gs2}$$
$$= 0{,}0220\ V$$

V_{out}:

$$V_{DSAT6} \leq V_{out} \leq V_{DD} - V_{DSAT5}$$

$$\Rightarrow V_{gs4} - V_{T4} \leq V_{out} \leq V_{DD} - V_{gs5} - V_{T5}$$
$$\Rightarrow V_{gs4} - (V_{ov4} - V_{gs4}) \leq V_{out} \leq V_{DD} - \cancel{V_{gs5}} - (V_{ov5} - \cancel{V_{gs5}})$$
$$\Leftrightarrow 2V_{gs4} - V_{ov4} \leq V_{out} \leq V_{DD} - V_{ov5}$$

$$\Rightarrow \begin{cases} V_{out,max} = V_{DD} - V_{ov5} = 1{,}1\ V \\ V_{out,min} = 2 \cdot V_{gs4} - V_{ov4} = 0{,}18\ V \end{cases}$$

P_{diss} ?

$\Rightarrow$ equal to $V_{in} \cdot I_{in}$?

$$\Rightarrow P_{diss} = 1{,}1V \cdot I_{BIAS} + 1{,}1V \cdot I_{DS7} + 1{,}1V \cdot I_{DS5}$$

$$S = \frac{g_m}{cm} = \frac{1}{R_m\, cm}$$

~~Next: ~~Do~~ recalculations with $\frac{g_{m11}}{g_{o1}+g_{o3}}$ and $\frac{g_{m6}}{g_{o6}+g_{o8}}$~~

~~⇒ ~~cannot~~ get g_{o3} and g_{o5} small enough~~

~~↳ assume $g_{o1} \approx g_{o3}$~~

~~→ choose L_3, L_4 and L_5 based on their g_o~~

~~→ do new itaation~~

~~→ choose R_M small enough to shift pole far enough from dominant pole~~

→ How to increase g_o → increase lenght

decrease g_o → decrease lenght

→ increase V_{gs} ⇒ increase V_{ov}

⇒ ERROR in GBW

New iteration

$$\frac{g_{m1}}{g_{o1}+g_{o3}} \approx \frac{g_{m1}}{2\cdot g_{o1}}$$ → choose double the wanted gain from plot

$\frac{g_{m6}}{2g_{o6}}$ → Same

$$\Rightarrow \frac{g_{m1}}{2g_{o1}} \approx 60 \Rightarrow \text{choose } 48{,}5$$

⇒ for M_1 : $V_{ov} = 1$ and $L = 1500$ nm

$$\Rightarrow 2g_{o1} = \frac{g_{m1}}{48{,}5} =$$

⇒ choose $L_3 = 100$ nm

and $V_{ov} = -0{,}36$ V

$$\Rightarrow \frac{g_{m3}}{g_{o3}} = 14{,}23 \Leftrightarrow g_{m3} = 14{,}33 \cdot g_{o3}$$

$$\frac{g_{m6}}{2g_{o6}} \approx 20$$

⇒ for M_6 : $V_{ov} = 0$ gain of 22,28 for $l = 200$ nm

$$\Rightarrow g_{o6} = \frac{g_{m6}}{20} \cdot \frac{1}{2} = g_{o5}$$

$$\Rightarrow V_{ov5} =$$

New attempt

M_1 and M_2 $\Rightarrow$ increase g_{o1} and g_{o2}

choose $V_{OV} = \cancel{-0{,}1}\ {-0{,}2}\,V$ and $L = \cancel{100}$ nm 1000 nm

$\Rightarrow \frac{g_{m1}}{g_{o1}} = \cancel{34{,}75}\ 18{,}2$, $\frac{g_{m1}}{I_{DS1}} = \cancel{13{,}75}\ 8{,}45$, $V_{gs} = -0{,}42$

$\Rightarrow$ gain for stage 2: $\cancel{6{,}4423}$ $11{,}6599$

M_6

choose $V_{OV} = 0{,}2V$ and $L = \cancel{60}$ nm 100 nm

$\Rightarrow \frac{g_{m6}}{g_{o6}} = \cancel{7}\ 13{,}6$, $\frac{g_{m6}}{I_{DS6}} = \cancel{5{,}3}\ 6{,}95$, $V_{gs} = 0{,}56$

$\Rightarrow$ total gain $= 24\cancel{3{,}25}\ 3500$

M_3 and M_4

$\Rightarrow V_{OV} = \cancel{-0{,}1}\ {-0{,}2}\,V$ $\Rightarrow$ to decrease g_{o3} and g_{o4}

$\Rightarrow$ take $L = 60$ nm to decrease g_{o3} and g_{o4}

$\Rightarrow \frac{g_{m3}}{I_{DS3}} = \cancel{18}\ 23{,}1 \Rightarrow g_{m3} = I_{DS3} \cdot \cancel{18}$

$\frac{g_{m3}}{g_{o3}} = \cancel{6}\ \cancel{7{,}3}\ 7{,}6$ $\quad V_{gs} = 0{,}21$

M_5

$\Rightarrow V_{OV} = 0{,}2V$ and $L = 60$ nm

$\hookrightarrow$ decrease g_{o5}

$\frac{g_{m5}}{g_{o5}} = 10{,}25$ $\quad V_{gs} = -0{,}17$

$\Rightarrow$ change all V_{OV} to $\pm 0{,}2V$

→ fix stage 2 ⇒ get right gain from Matlab ⇒ figure out mistake

Aim for gain of 10 for second stage and reduce g_{o5}

$\Rightarrow \frac{g_{m6}}{g_{o6}} \approx 10 \Rightarrow$ from plot $\Rightarrow V_{ov} = 0{,}4 \quad L = 100\,nm$

$g_{o6} = \frac{g_{m6}}{10} = 1{,}6 \cdot 10^{-4}$

$g_{m6} = 0{,}0016$

$\frac{g_{m6}}{I_{DS6}} = 3{,}55 \Rightarrow I_{DS6} = \frac{g_{m6}}{3{,}55} = 4{,}507 \cdot 10^{-4}$

$V_{GS6} = 0{,}71$

$W/L = 10$
$W = 10 \cdot L$

$\underline{g_{o5}}$

$\Rightarrow I_{DS5} = I_{DS6} = 4{,}507 \cdot 10^{-4}$ for DC

$\Rightarrow$ choose $V_{ov} = 0{,}2V$ and $L = 100\,nm$ to reduce g_{o5}

$\Rightarrow \frac{g_{m5}}{g_{o5}} = 23{,}5$ and $\frac{g_{m5}}{I_{DS}} = 26{,}5$

$\Rightarrow V_{gs5} = -0{,}14$

Aim for second stage: gain of 10

assume $v_{inter} \approx 0{,}336V$

$\Rightarrow$ and $V_{out} \approx 0{,}550V$

$\Rightarrow V_{DS6} = 0{,}550V$

$V_{gs6} = V_{DS6} - V_{gd} = 0{,}550V - 0{,}336V$
$= 0{,}2140V$

$\Rightarrow \frac{g_{m6}}{g_{o6}} = 16{,}9$ and $\frac{g_{m6}}{I_{DS6}} = 25{,}4 \quad L = 80\,n$

$\Rightarrow$ for T_5: $V_{gs5} = -0{,}550V = V_{ds5} \quad I_{DS5} = I_{DS6} = 6{,}300 \cdot 10^{-5}$

what we know: $g_{m6} = 0{,}0016 \quad = 1{,}6 \cdot 10^{-3}$
$g_{m1} = 1{,}3352 \cdot 10^{-4}$

Stage 2

assume $V_{ov7} = V_{ov5} = V_{ov8} = -0{,}2V$

$V_{DS6} = 0{,}550V \Rightarrow$ voltage divided over M_5 and M_6

gain of 20 in second stage

make $g_{o5} << g_{o6}$ by making $V_{ov5} = 0{,}2$ and $V_{ov6} = \cdot 0{,}2$

$\Rightarrow$ if $g_{m6} = 1{,}6 \cdot 10^{-3} \Rightarrow$ choose $V_{ov6} = 0{,}48$

and $L_6 = 1000$ nm

$\Rightarrow \frac{g_{m6}}{g_{o6}} = 16{,}7 \Rightarrow g_{o6} = 9{,}5808 \cdot 10^{-5}$

$\Rightarrow \frac{g_{m6}}{I_{DS6}} = 4{,}55 \Rightarrow I_{DS6} = \frac{g_{m6}}{4{,}55} = 3{,}5165 \cdot 10^{-4}$

$\Rightarrow I_{DS5} = I_{DS6}$

$\Rightarrow$ in order to get $g_{o5} << g_{o6} \Rightarrow$ choose $V_{ov5} = 0{,}2V$

choose $L_5 = 1000$ nm $\Rightarrow$ current source

is not possible due to high I_{DS6}

$\Rightarrow$ gain second stage $= \frac{g_{m6}}{g_{o5} + g_{o6}}$

$\Rightarrow$ try to get $g_{o5} \approx g_{o6}$ by making them almost identical

$\Rightarrow V_{ov5} = -0{,}48V$

$\Rightarrow$ gain second stage $= 8{,}0678$

First Stage

$g_{m1} = 1{,}3352 \cdot 10^{-4}$

gain first stage: $\dfrac{g_{m1}}{g_{o1}+g_{o3}}$

$\Rightarrow$ wanted gain $= \dfrac{223{,}87}{8{,}0678} = 27{,}7486$

$\Rightarrow$ choose $L_1 = 1000\,nm$ $\Rightarrow$ $V_{ov1} = -0{,}1\,V$

$\dfrac{g_{m1}}{g_{o1}} = 34{,}5 \Rightarrow g_{o1} = 3{,}8701 \cdot 10^{-6}$

$\dfrac{g_{m1}}{I_{DS1}} = 13{,}7 \Rightarrow I_{DS1} = 9{,}7460 \cdot 10^{-6}$

$I_{DS3} = I_{DS1}$

for $\dfrac{g_{m1}}{g_{o1}+g_{o3}} \approx 27{,}74 \Rightarrow g_{o3} = \dfrac{g_{m1}}{27{,}74} - g_{o1}$

$= 9{,}4317 \cdot 10^{-7}$

$\Leftarrow$ For M_3: choose $L_3 = 1000\,nm$ and $V_{ov} = -0{,}1\,V$

$\hookrightarrow$ identical to $M_1 \Rightarrow A_{V1} \approx \dfrac{g_{m1}}{2 g_{o1}}$

$\Rightarrow$ Next iteration $\Rightarrow$ choose g_{m6} and then choose C_M

$\hookrightarrow$ why $\dfrac{g_{m1}}{3 \cdot g_{o1}}$

How to get $g_{o4} << g_{o2}$

=> make V_{ds2} small and V_{ds4} bigg

=> choose $V_{DS4} = 0,550$ and $V_{DS2} = -0,2V$

and $V_{DS7} = -0,450$

M1 and M2

$g_{m1} = 1,3352 \cdot 10^{-4}$ => $V_{ov1} = -0,114V$

=> $gain_1 = \frac{g_{m1}}{g_{o1}} = 12,5$ $L_1 = 1000n$

=> $g_{o1} = 1,0682 \cdot 10^{-5}$

$gain\text{-}eff = \frac{g_{m1}}{I_{DS1}} = 12,65$

=> $I_{DS1} = 1,0555 \cdot 10^{-5}$

M3 and M4

$I_{DS4} = I_{DS3} = I_{DS2} = I_{DS1}$

choose $L = 1000nm$

$V_{DS} = V_{GS} = 0,550V$

=>

New Iteration

⇒ second stage

⇒ $g_{m6} = 0{,}0016$

we know: $V_{GS5} = -0{,}550V = V_{ds5} = V_{ds8}$

if $V_{out} = 0{,}550V$

⇒ $V_{DS6} = 0{,}550V$

choose $L_6 = 1000\,nm$

if $g_{m6} = 0{,}0016$ ⇒ then $V_{ov} = 0{,}48V$

⇒ $\dfrac{g_{m6}}{g_{o6}} = 16{,}7$ ⇒ $g_{o6} = 9{,}5808 \cdot 10^{-5}$

⇒ $\dfrac{g_{m6}}{I_{DS6}} = 4{,}54$ ⇒ $I_{DS6} = 3{,}5242 \cdot 10^{-4}$

For M_5: $I_{DS6} = I_{DS5}$

⇒ choose $L = 1000\,nm$ to reduce g_{o5} as much as possible

⇒ from matlab calculate width M_5 so correct g_{o5} is obtained

⇒ gain stage 2: $\dfrac{g_{m6}}{g_{o5}+g_{o6}} = 9{,}0856$

⇒ gain needed for stage 1: $\dfrac{\text{gain}}{\text{gain}_{S2}} = 24{,}6402$

First stage

⇒ gain of 24,64 is needed
→ take $V_{gs7} = V_{gs8} = -0,550\,V$
$V_{ds7} = -0,450$
→ reduce g_{o4}
⇒ $L_4 = 1000\,nm$
$V_{ds4} = 0,550\,V = V_{gs4}$

→ <u>for M_1 & M_2</u>
$V_{ds1} = -0,2\,V$
→ To include gain lowering effects of M_4 choose gain of 30
⇒ $\frac{g_{m1}}{g_{o1}} = 30$ for $V_{ov_1} = 0,05\,V$ $L_1 = 1000n$
⇒ $g_{m1} = 1,2 \cdot 10^{-5}$ ⇒ $g_{o1} = 4 \cdot 10^{-7}$
⇒ $\frac{g_{m1}}{I_{DS1}} = 26,4$ ⇒ $I_{DS1} = 4,5455 \cdot 10^{-7}$

<u>for M_3 a M_4</u>
$I_{DS3} = I_{DS4} = I_{DS1}$
⇒ to accommodate I_{DS1} ⇒ Matlab has to be used to get g_{o4} and g_{m4}
⇒ choose $L = 1000\,nm$ to minimize g_{o4}

~~⇒ total gain too low ⇒ increase gain stage 1~~
~~⇒ $V_{ov_1} = 0,2$ and $L = 1000\,nm$~~
~~⇒ gain = 36,4 ⇒ $g_{m1} = 1,6 \cdot 10^{-7}$~~
~~⇒ $g_{o1} = 4,3956 \cdot 10^{-9}$~~
~~⇒ $\frac{g_{m1}}{I_{DS1}} = 33,26$ ⇒ $I_{DS1} = 4,8120 \cdot 10^{-9}$~~
↳ lowers gain stage 1

⇒ $V_{gs6} = 0,650\,V$

=> Gain stage 1 is OK according to LT spice ≈ 24 dB
=> Gain stage 2: not OK

=> $V_{GS} = 0{,}650\,V$ -> from stage 1

=> $L_6 = 1000\,nm$ => $gain = 12{,}72$
=> $g_{m6} = 17{,}8 \cdot 10^{-3}$
=> $\frac{g_{m6}}{I_{DS6}} = 3{,}6$ => $I_{DS} = 0{,}0049\,A$

=> If we want more gain from second stage
=> lower V_{GS6} => lower V_{DS2}

$350 + 0{,}2 + 0{,}650$
$= \cancel{1{,}2}$