Faculty of Engineering

Credit Hours Engineering Programs

Communication Systems Engineering Program

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Telescopic Cascode Differential Amplifier

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1. Hand analysis gm, ro, Vov

First, we assumed maximum current used is $\mathrm{ISS} = 40\ \mathrm{uA}$ since the power budget is $4\mathrm{mw}$ so the current in half of differential amplifier circuit $\mathrm{Id} = 20\mathrm{uA}$ we used small value of current with the given budget to achieve low power consumption by the telescopic cascode amplifer.

Second, we assumed ranges of the input voltage and output voltage so we can get equations of over drive voltages of each transistor

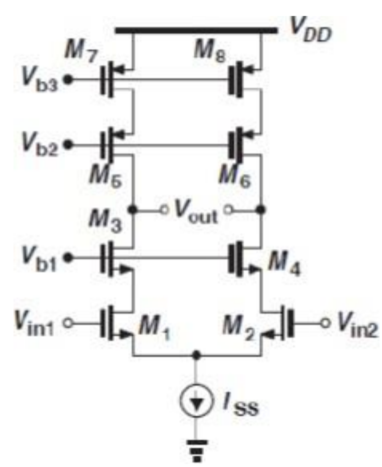
$$Vout\ range = 0.65 - 0.75 = 0.7V$$

$$Vin\ range = 0.75 - 0.8 = 0.775V$$

EQ1:

$Vin > Vth1 + Vov1 + Vovss$

$\boldsymbol{Vin(min) = Vth1 + Vov1 + Vovss}$



EQ2:

$VIN - Vn < Vth$

$Vn = Vb1 - Vgs3 = Vb1 - Vth3 - Vov3$

$Vin - Vb1 + Vth3 + Vov3 < Vth1$

$\boldsymbol{Vb1 > Vin(max) - Vth1 + Vth3 + Vov3}$

EQ3:

$Vb1 - VOUTmin < Vth3$

$\boldsymbol{Vb1 < Vth3 + VOUT(min)}$

EQ4:

$Voutmax - Vb2 < -Vth5$

$\boldsymbol{Vb2 > Vout(max) - Vth5}$

EQ5:

$1.2 - Vb2 > Vth5 + Vov5 + Vov7$

$\boldsymbol{Vb2 < 1.2 - Vth5 - Vov5 - Vov7}$ $(all\ values\ is\ positive)$

Third, we assumed transconductances are equal to each other and output resistances are ratios from each other and calculated these values from gain equation of circuit.

$$G_m = -gm_1$$
$$R_{out} = (ro1 * gm3 * ro3//ro5 * gm5 * ro7)$$
$$abs(Gain) = G_m * R_{out} = gm1 * (ro1 * gm3 * ro3//ro5 * gm5 * ro7) = 600$$

$$\frac{gm1}{Id} = 15 \qquad assumption$$

$$Vov1 = 133\,mV$$
$$gm1 = 300uS$$

$$gm3 = gm5 = gm1 = gm7$$
$$ro1 = ro7 = ro3/2 = ro5/2$$

$$Gain = gm1^2 * (\frac{ro3^2}{4}) = 600$$

$$ro5 = ro3 = 163K$$
$$ro1 = ro7 = 81.5K$$

2. Transistor analysis

After we assumed values of transconductance, and we got the value of output resistance we ratio between transconductance and current gm/id and we also got the ratio between transconductance and outputconductance gm/gds.

To get the length of the channel we used gm/id methodology by dc sweep on the gate voltage and parametric sweep over several values of channel length, using standard width, to achieve the required values for the ratios $\frac{gm}{gds}$ & $\frac{gm}{id}$, as width don't affect these ratios.

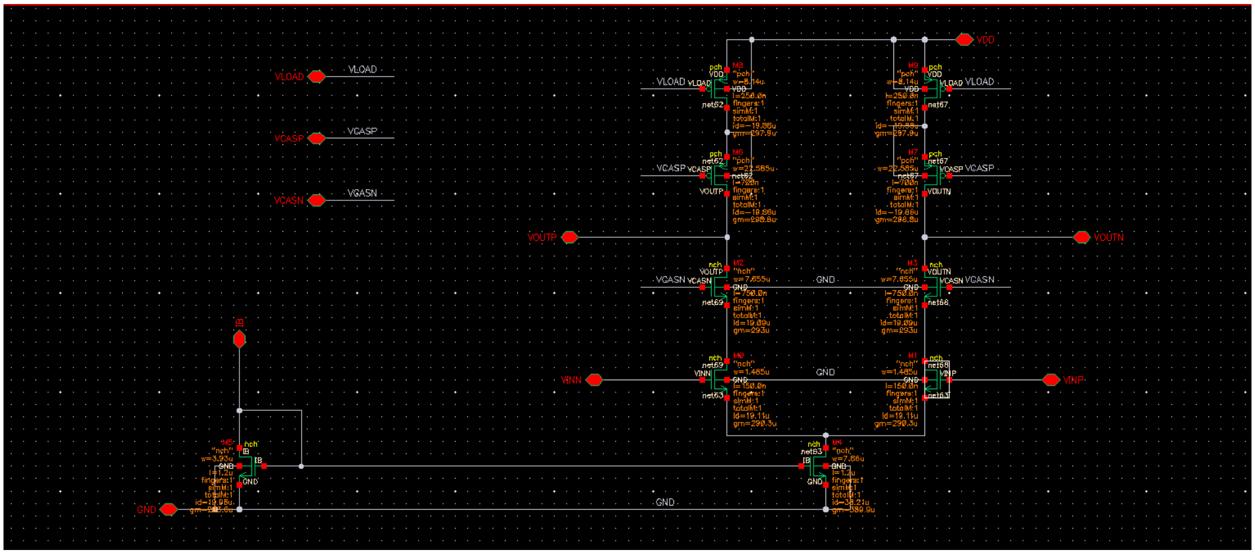
$$gm * ro = \frac{2 * I_D}{V_{vo}} * \frac{1}{\lambda * I_D} = \frac{2}{V_{ov} * \lambda}$$
$$\frac{gm}{I_D} = \frac{2 * I_D}{V_{vo}} * \frac{1}{I_D} = \frac{2}{V_{ov}}$$

To get value of transistor width we said that width is direct proportional to the current (initial values of current and width are $20uA$, $10um$) and from graph we got the value of the current.

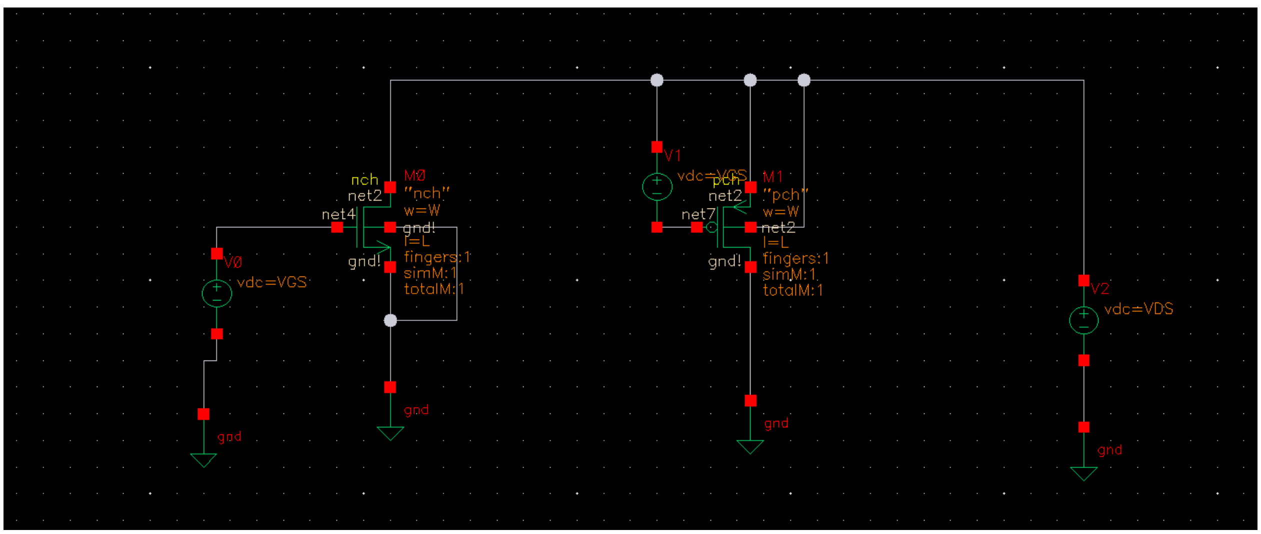
$$I_D \; \alpha \; w$$

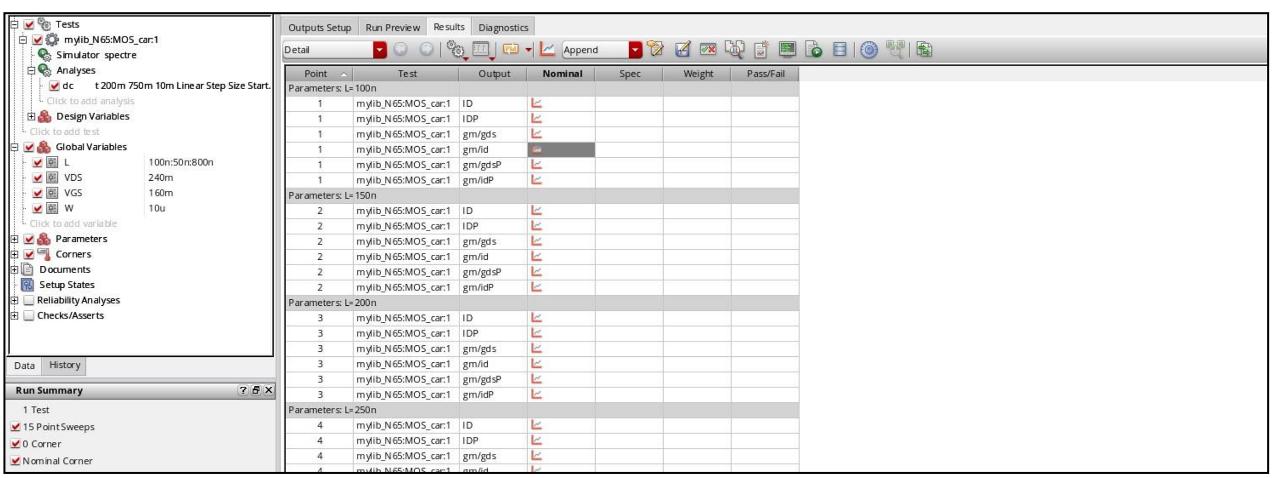
$$w_{stan} = 10\,um$$

telescopic cascode differential amplifier:



Sweeping circuit:





M1

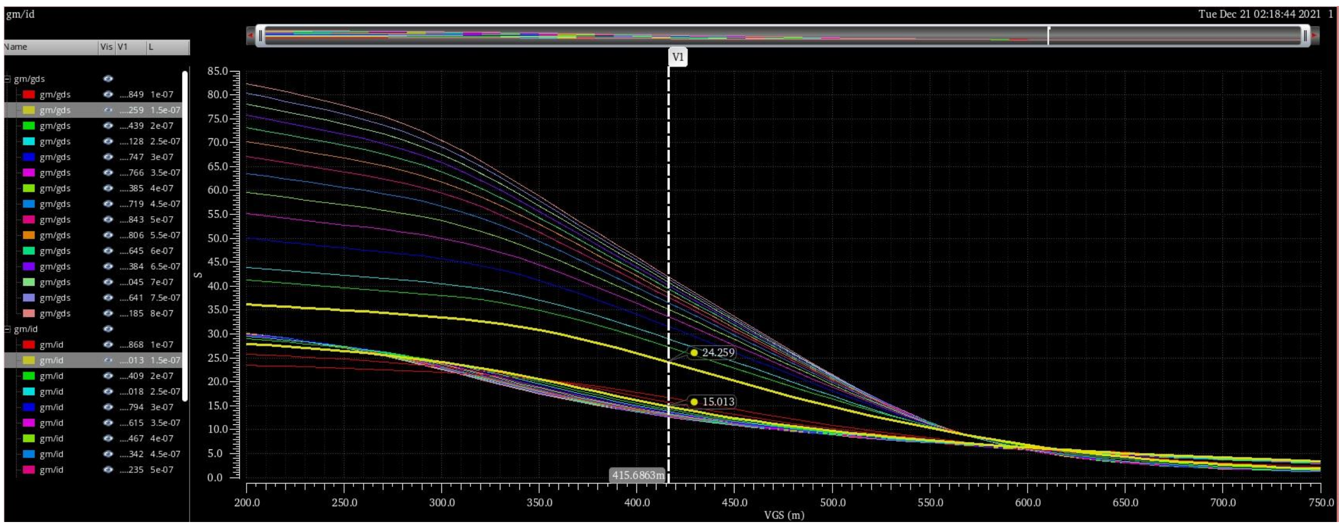
$$\frac{gm}{id} = 15$$

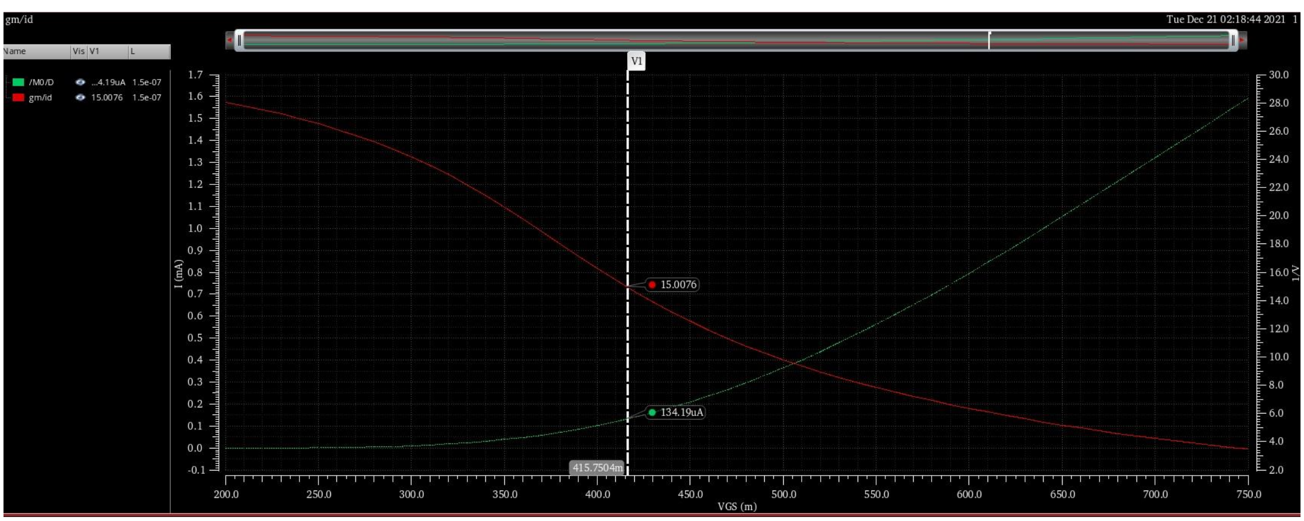
$$\frac{gm}{gds} = 24.45$$

$$l = 150\, nm$$

$$w = \frac{20}{134.6} * 10\, um = 1.486\, um$$

$$Vgs1 = 416\, mV$$





M3

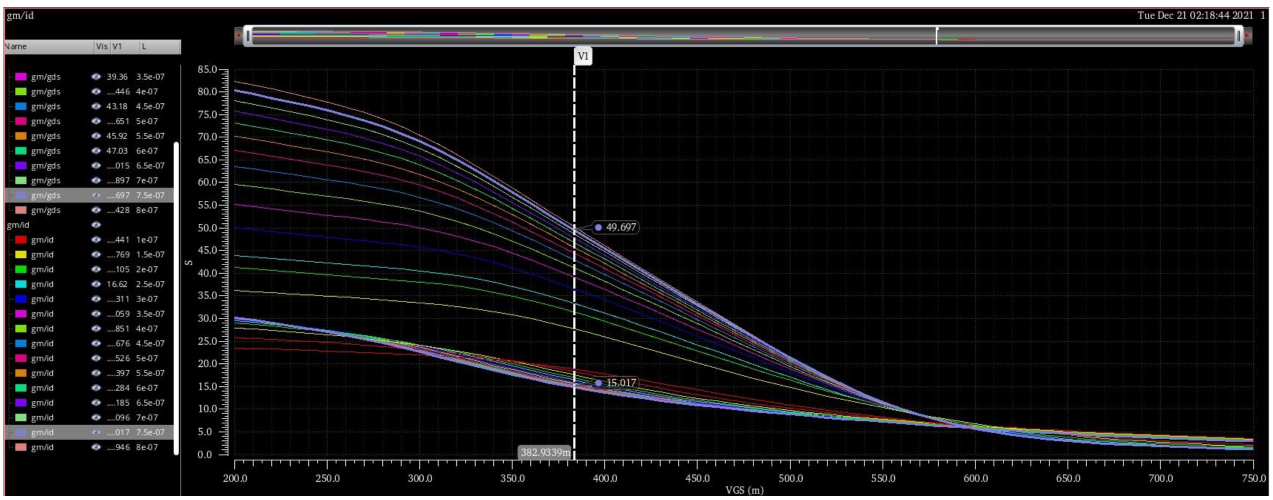
$$\frac{gm}{id} = 15$$

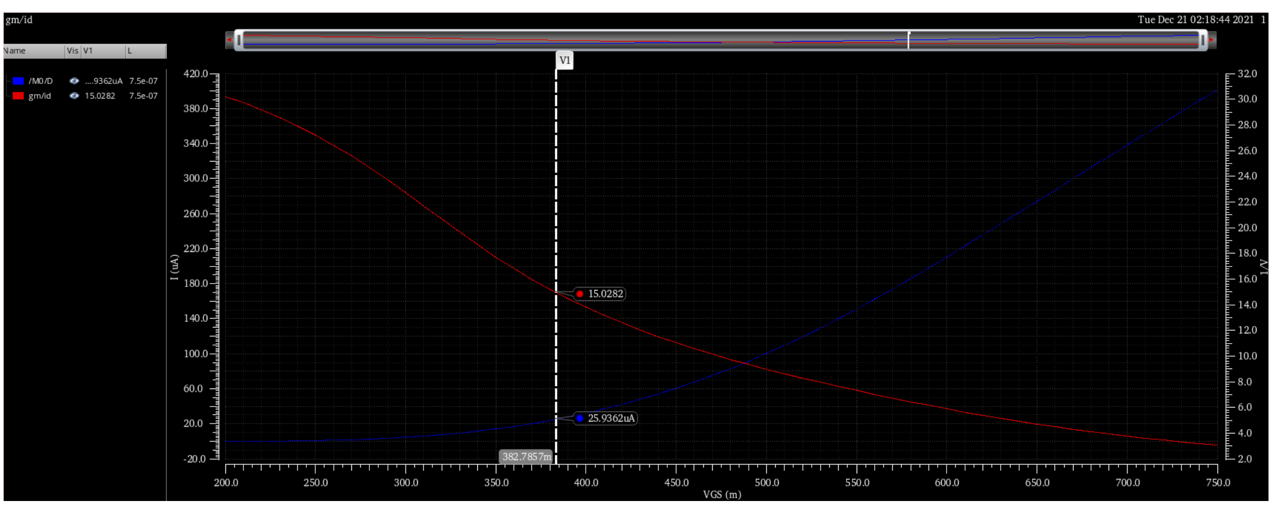
$$\frac{gm}{gds} = 48.9$$

$$l = 750\ nm$$

$$w = 7.656\ um$$

$$Vgs3 = \ 382.9\ mV$$





M5

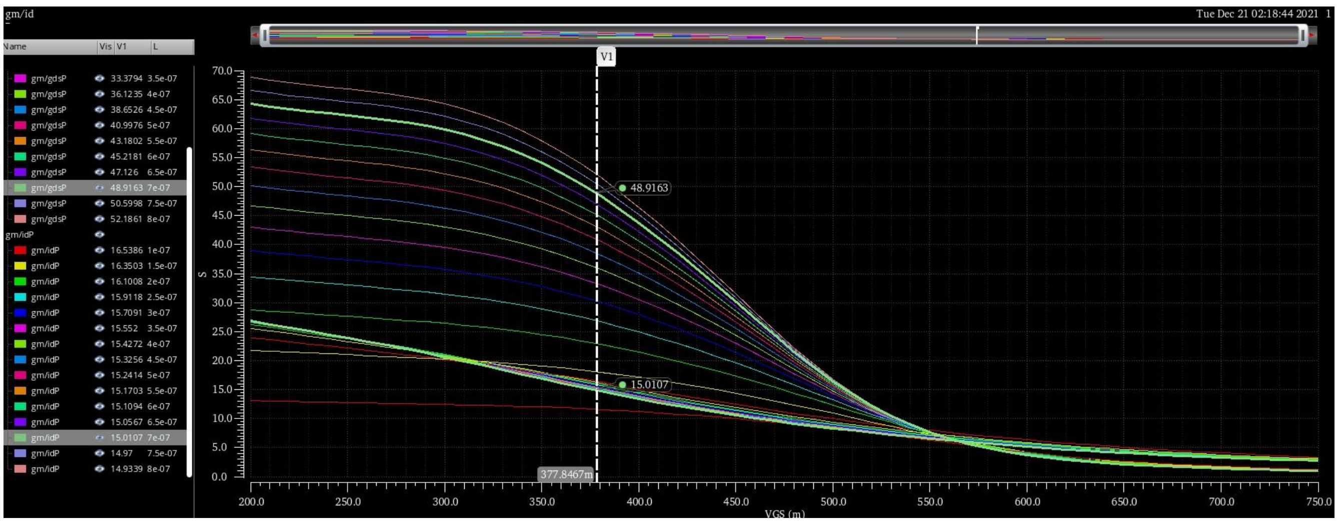
$$\frac{gm}{id} = 15$$

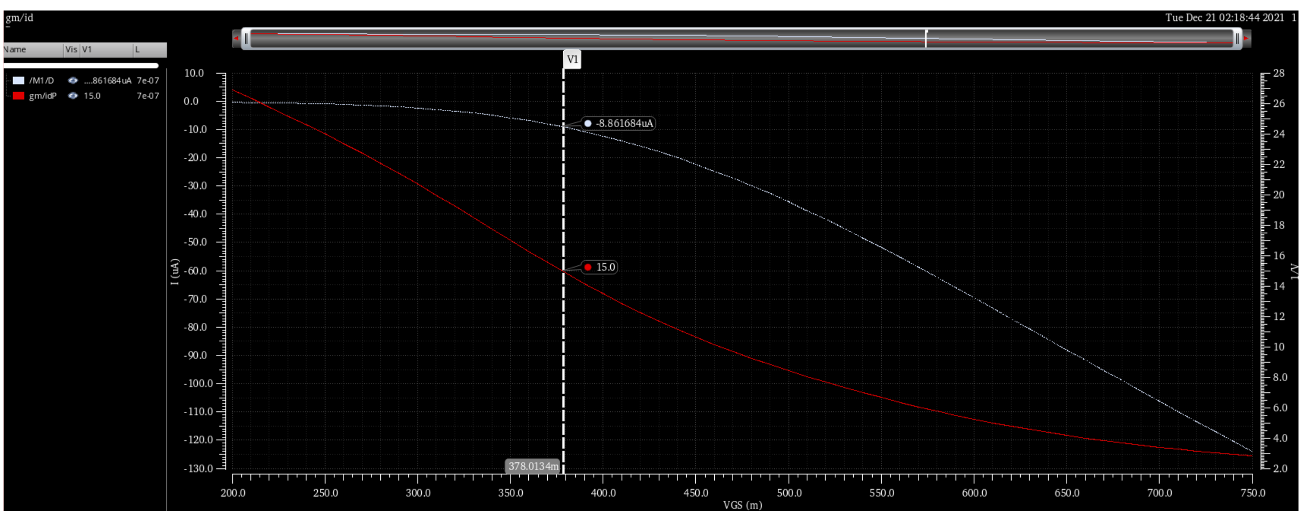
$$\frac{gm}{gds} = 48.9$$

$l = 700\ nm$

$w = 22.584\ um$

$Vgs5 = -378\ mV$





M7

$$\frac{gm}{id} = 15$$

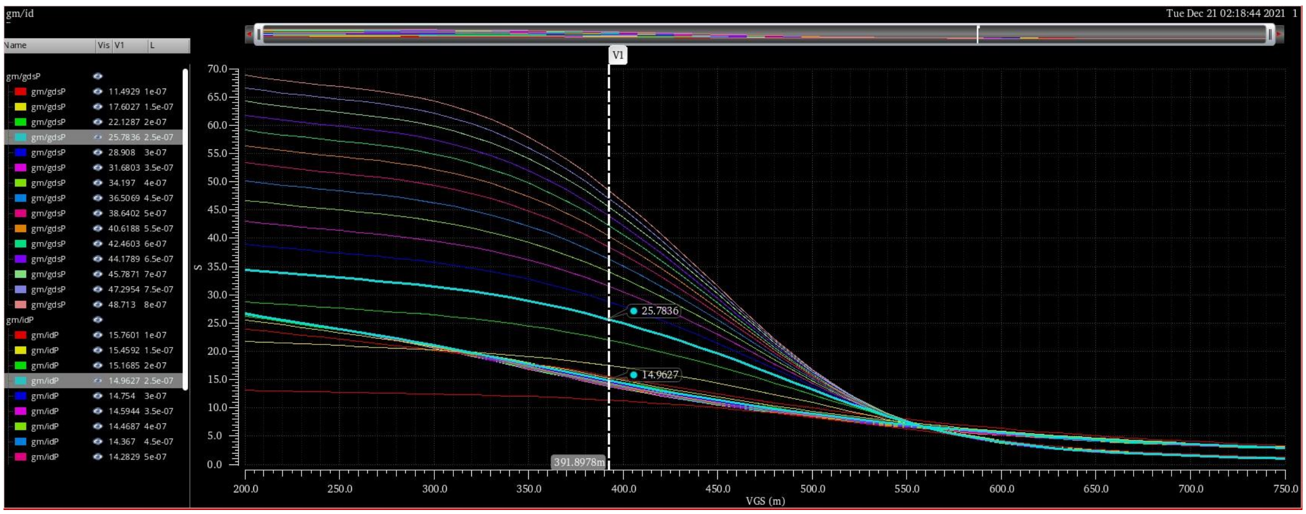
$$\frac{gm}{gds} = 24.45$$

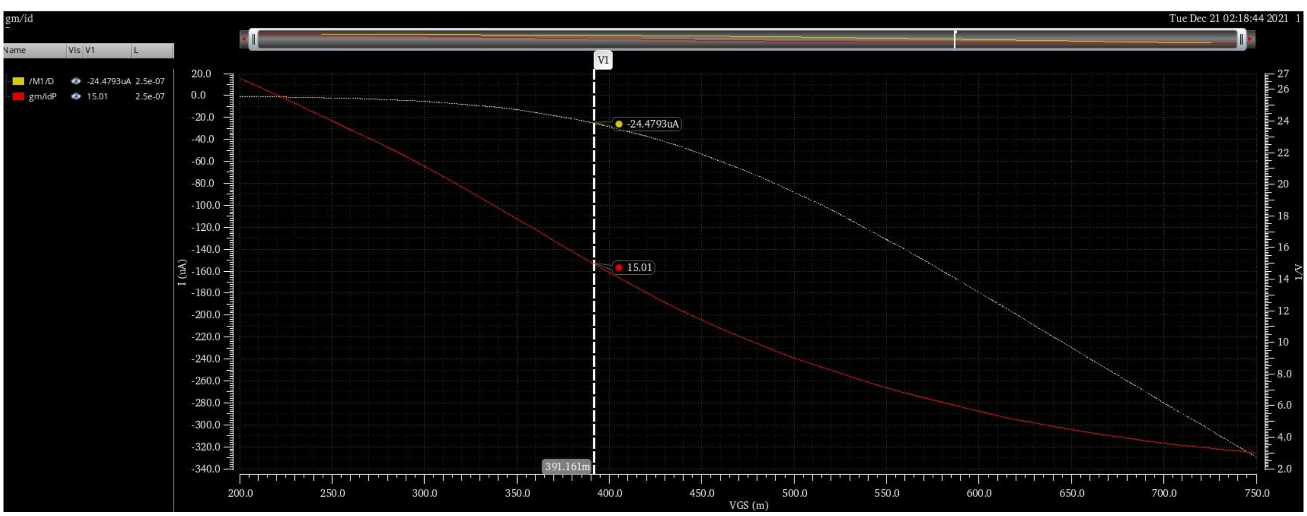
$l = 250\ nm$

$w = 8.139\ um$

$Vgs7 = -391.5\ mV$

$Vload = 1.2 - 391.5m = 0.808\ mV$





Mss

from V input common mode min and VGS1

$$Vov5 < 334\,mV$$

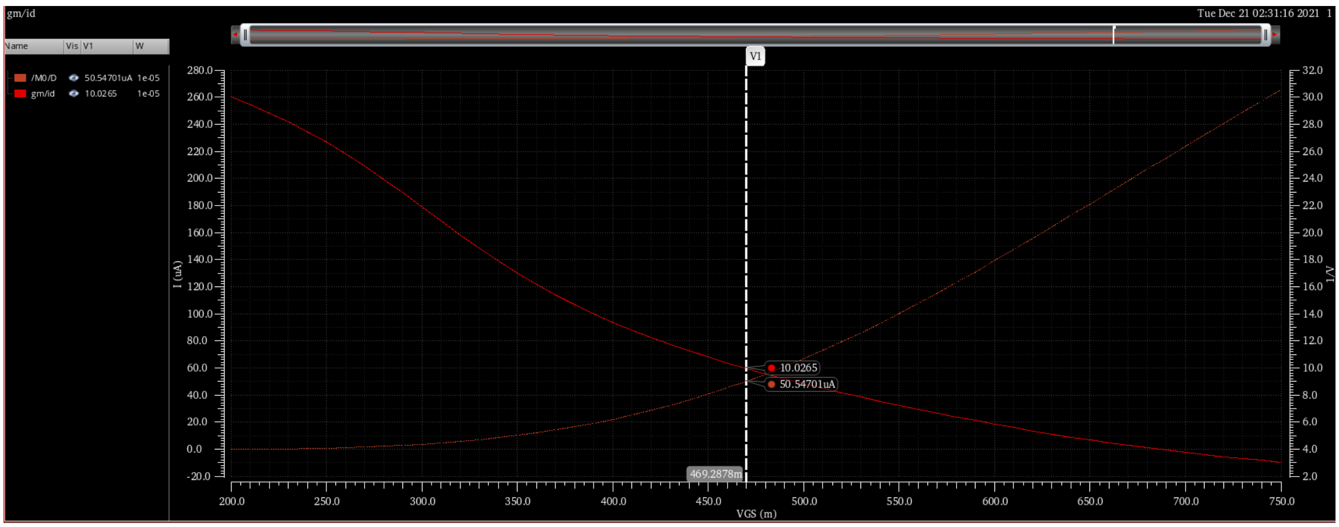
$$Vovss = 200\,mV \qquad assumption$$

$$\frac{gmss}{id} = 10$$

$$L = 1.2\,um \qquad assumption$$

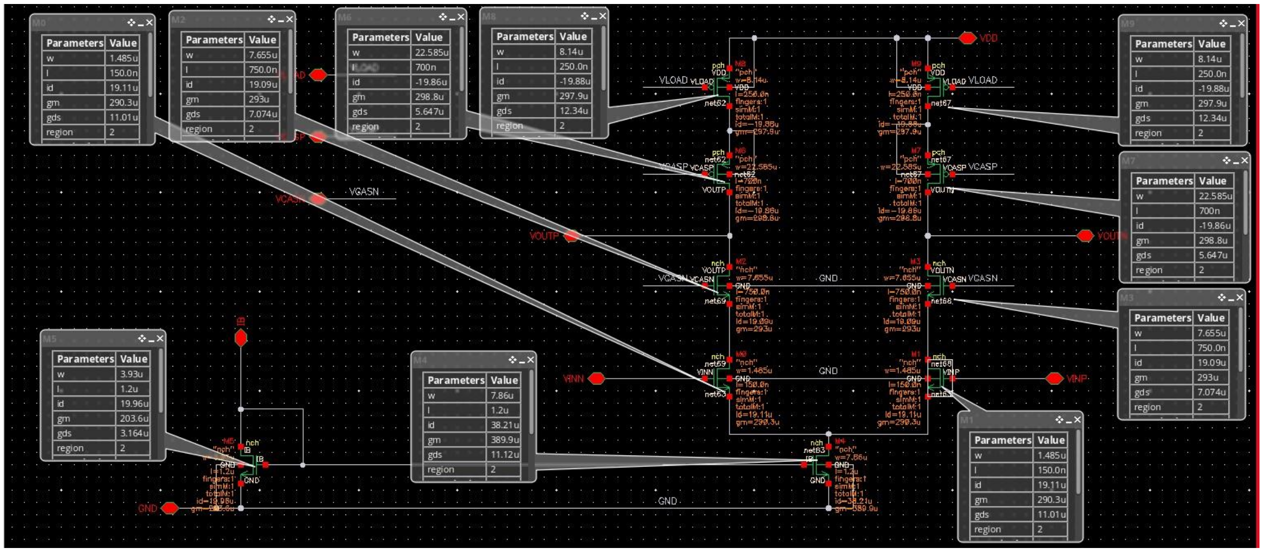
$$w = 7.86\,um$$

$$Vgsss = 474\,mV$$



3. Final Design

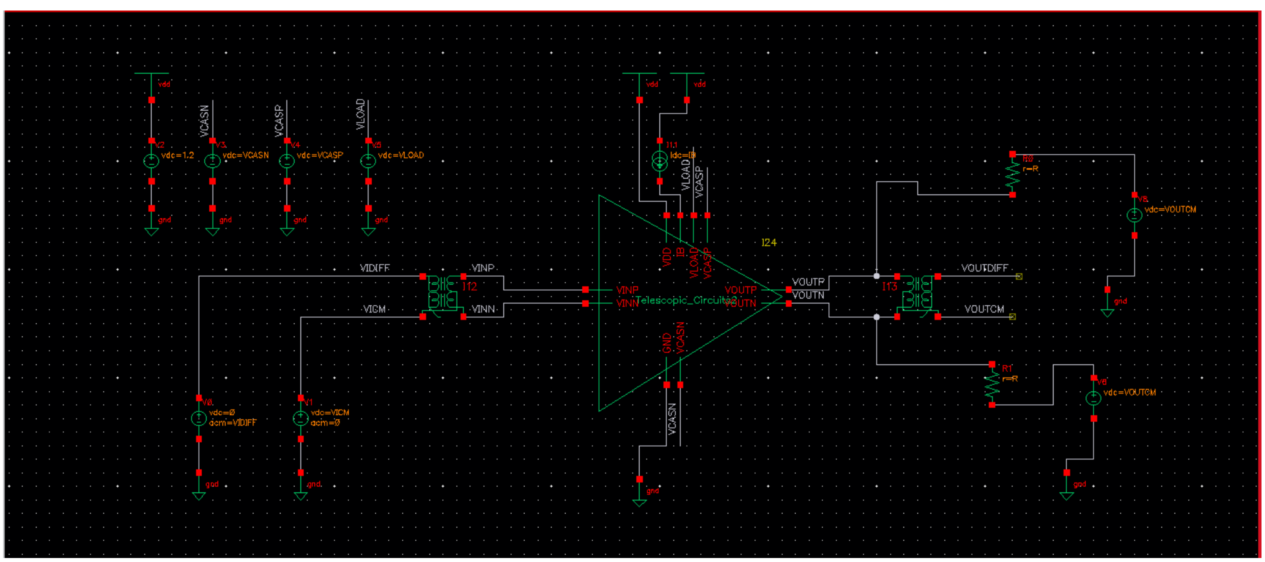
telescopic cascode differential amplifier:



Bias voltages:

Global Variables	
IB	20u
VCASN	0.95
VCASP	0.6
VICM	0.7
VIDIFF	1
VLOAD	808.5m
VOUTCM	0.72
R	1m
MOSCORNERS	"tt"

telescopic cascode differential amplifier testbench:

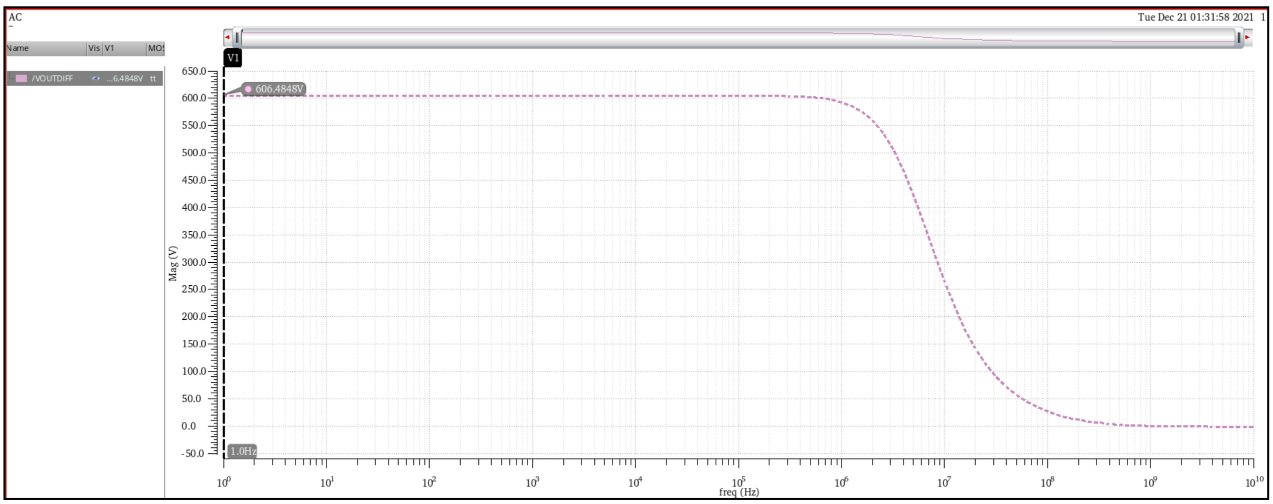


4. Gain and power

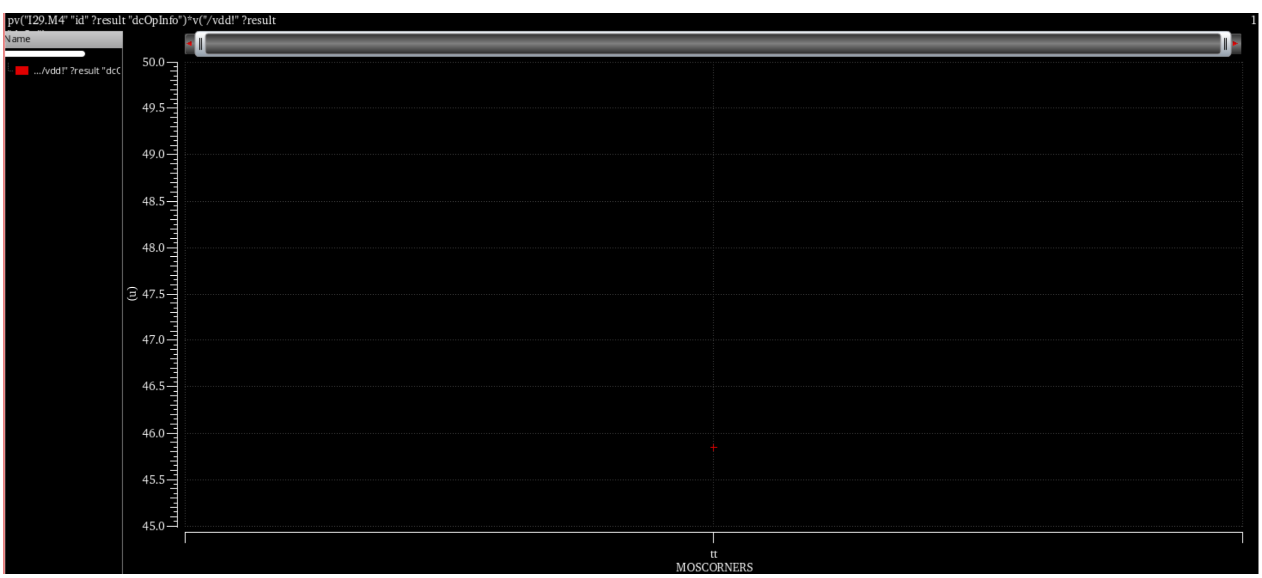
Power and gain:

Test	Output	Nominal	Spec	Weight	Pass/Fail
mylib_N65:Telescopic_Circuits2_TestBench:1	VOUTDIFF				
mylib_N65:Telescopic_Circuits2_TestBench:1	Gain	606.5			
mylib_N65:Telescopic_Circuits2_TestBench:1	power	45.85u			

gain:



Power:



5. Comparison

	gm hand	gm sim	error	ro hand	ro sim	error
M1	300 uS	290.3 uS	3.3 %	81.5 Kohm	90.8 Kohm	10 %
M3	300 uS	293 uS	2.3 %	163 Kohm	141.4 Kohm	15 %
M5	300 uS	298.8 uS	0.4 %	163 Kohm	177.1 Kohm	7.9 %
M7	300 uS	297.9 uS	0.7 %	81.5 Kohm	81.03 Kohm	0.6 %
MSS	400 uS	389.9 uS	2.5 %	-	-	-

$$gain\ error = \frac{gain\ sim - \ gain\ hand}{gain\ sim} = 0.99\%$$

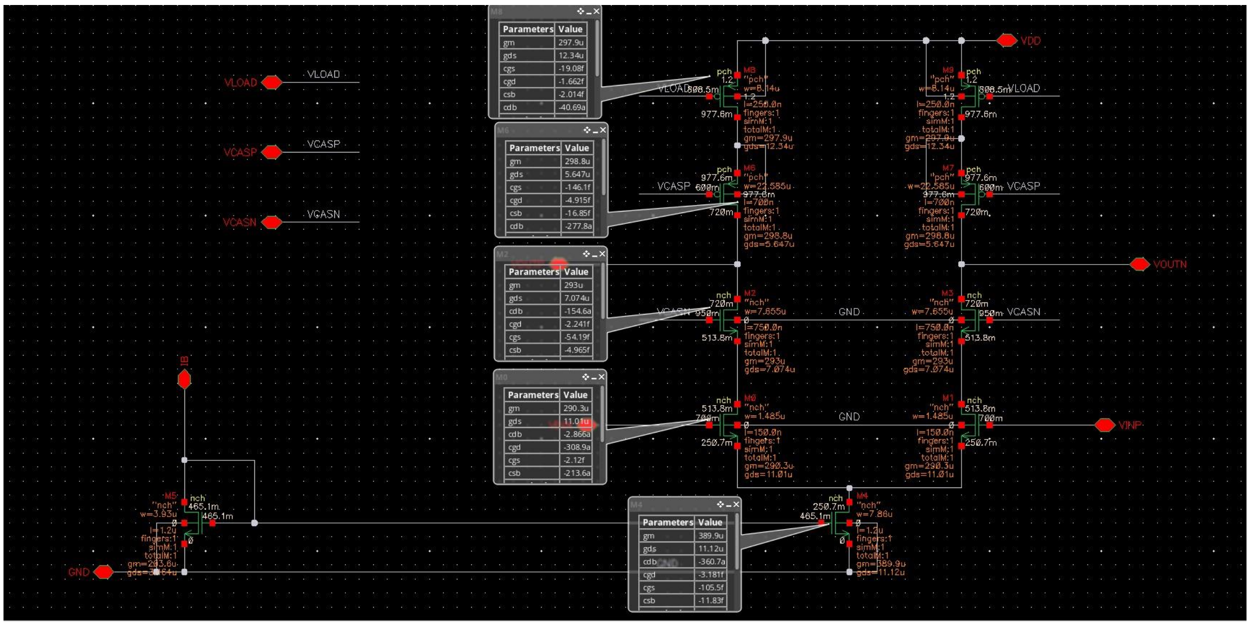
$$I_{SS}\ error = \frac{I_{SS}\ sim - I_{SS}\ hand}{I_{SS}\ sim} = 4.7\ \%$$

6. Frequency response

6.1 Hand analysis

Since the poles are close to each other so they affected each other so they are different from simulations poles results.

Frequency response of transistors:



Poles and zeros calculations:

Poles - Zeros :

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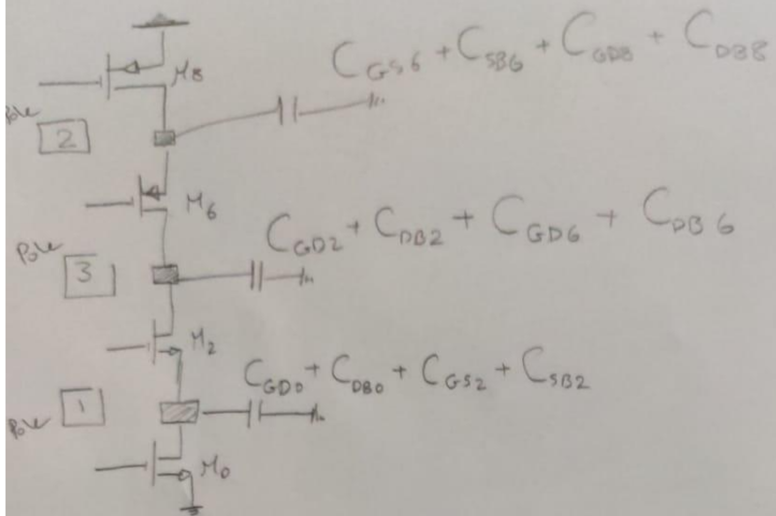


1 Pole (1) :

$$R = r_o // \frac{1}{g_{m2}}\left(1 + \frac{r_{o6}\, g_{m6}\, r_{o8}}{r_{o2}}\right)$$

$$= 90.8265\,K\Omega \,//\, 106.9379\,K\Omega = 49.113\,K\Omega$$

$$C = C_{gs2} + C_{ds2} + C_{db0} + \left(1 + \frac{1}{Av_2}\right) C_{gd}$$

$$A_v = g_{m0} R = 14.258$$

$$C = 59.488\,F$$

$$\boxed{F = 54.475 \times 10^{6}\ Hz}$$

2 Pole (2)

$81.037 K\Omega \,//\, \frac{1}{g_m}\left(1+\frac{R}{r_o}\right) \,//\, 74.444 K\Omega$

$\therefore R = 38.8 K\Omega$

$C = C_{gd8} + C_{dB8} + C_{GS6} + C_{SB6}$

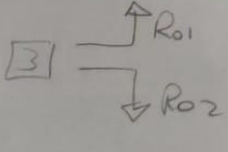
$= 164.65 F$

$\boxed{F = 24.913 \times 10^{6}\ Hz}$

3 Pole (3)

$C_{GD2} = 2.241 \times 10^{-15} F$

$C_{DB2} = 154.6 \times 10^{-18} F$



$C_{GD6} = 4.915 \times 10^{-15} F$

$C_{DB6} = 2.778 \times 10^{-18} F$

$R = R_{o1} \,//\, R_{o2}$

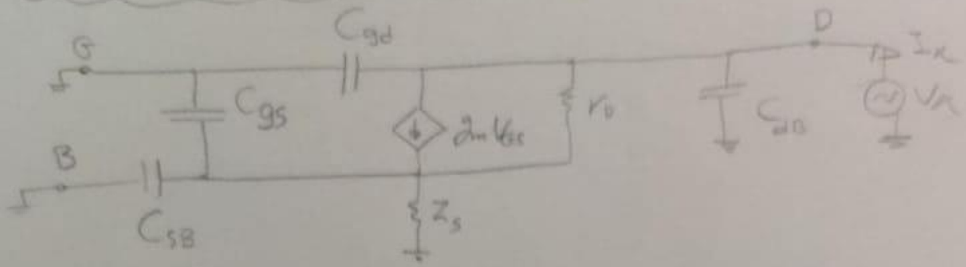
$R_{o1} = g_{m6}\, r_{o6}\, r_{o8}$

$R_{o2} = g_{m2}\, r_{o2}\, r_{o0}$

$\therefore \omega = \frac{1}{RC} \longrightarrow f = \frac{\omega}{2\pi} \longrightarrow \boxed{f = 10.466 \times 10^{6}\ Hz}$

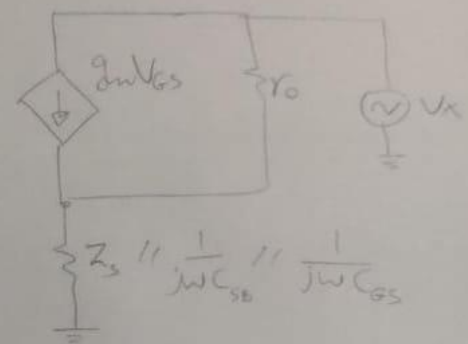
Small circuit Model used to Calc ZerosB

1



$V_{gs} = -V_s$

$X = \frac{1}{jC_{dB}\omega} // \frac{1}{j\omega C_{GD}}$



$y = \frac{1}{j\omega C_{SB}} // \frac{1}{j\omega C_{GS}}$

$Z_s = X // r_o \left[1 + g_m (Z_s // y)\right]$

Calc First Zero 8

$X = \frac{1}{j\omega (C_{dB8} + C_{gd8})} // \frac{1}{g_{s8}} = \frac{1}{j\omega (C_{gd8} + C_{db8}) + g_{ds8}}$

$Z_{LFD} = \frac{1}{j\omega (C_{dB6} + C_{gd6})} // \frac{1}{g_{s6}} \left[1 + g_{m6} \left(\frac{1}{g_{ds8} + j\omega (C_{dB8} + C_{gd8} + C_{sb6} + C_{gs6})} \right)\right]$

$j\omega 5.193F + \frac{5.697 \times 10^{-6}}{1 + 298.8 \times 10^{-6} \left(\frac{1}{12.34 \times 10^{-6} + j\omega 164.65F} \right)} \rightarrow$ Zero

$\boxed{\therefore F = 276.9 MHz}$

$$Z_{SD} = \frac{1}{j\omega(C_{dg2}+C_{gd2})} \,//\, \frac{1}{g_{ds2}}\left(1+(g_{m2}+g_{mb2})\left(\frac{1}{g_{ds1}+j\omega C_1}\right)\right)$$

$$C_1 = C_{dB0} + C_{gd0} + C_{sb2} + C_{gs2} = 59.47F$$

$$\frac{g_{ds2}}{1+(g_{m2}+g_{mb2})\left(\frac{1}{g_{ds2}+j\omega C_1}\right)} \to \infty$$

$\to 0$

$$(g_{m2}+g_{mb2})\left(\frac{1}{g_{ds2}+j\omega C_1}\right) = 1$$

$$321.96\times10^{-6}\left(\frac{1}{7.074\times10^{-6}+j\omega\, 59.478}\right) = 1$$

$$\underline{F = 841.36\, MHz}$$

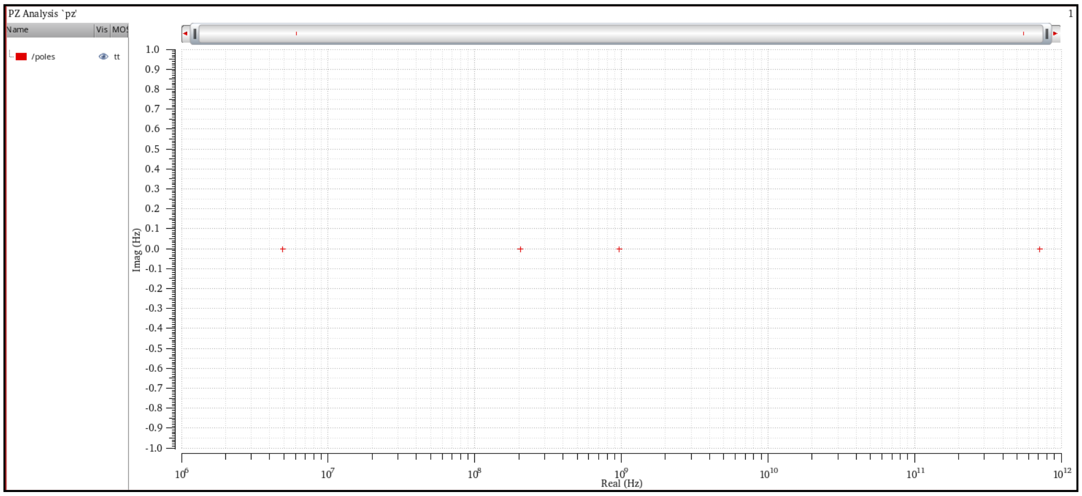
Third zero $\rightarrow$ at ∞

$\circledast$ ~~~~~~~~ $\circledast$

6.2 Simulation results

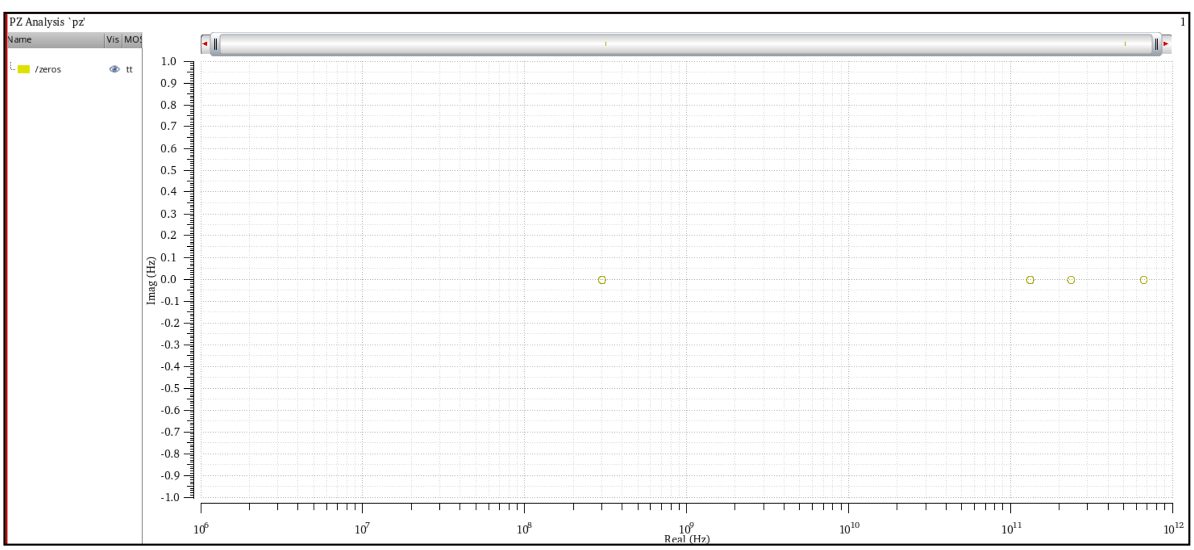
Poles:

	qfactor	/poles M...tt (Hz)
1	500.0E-3	4.852E6
2	500.0E-3	204.1E6
3	500.0E-3	965.6E6
4	500.0E-3	716.7E9

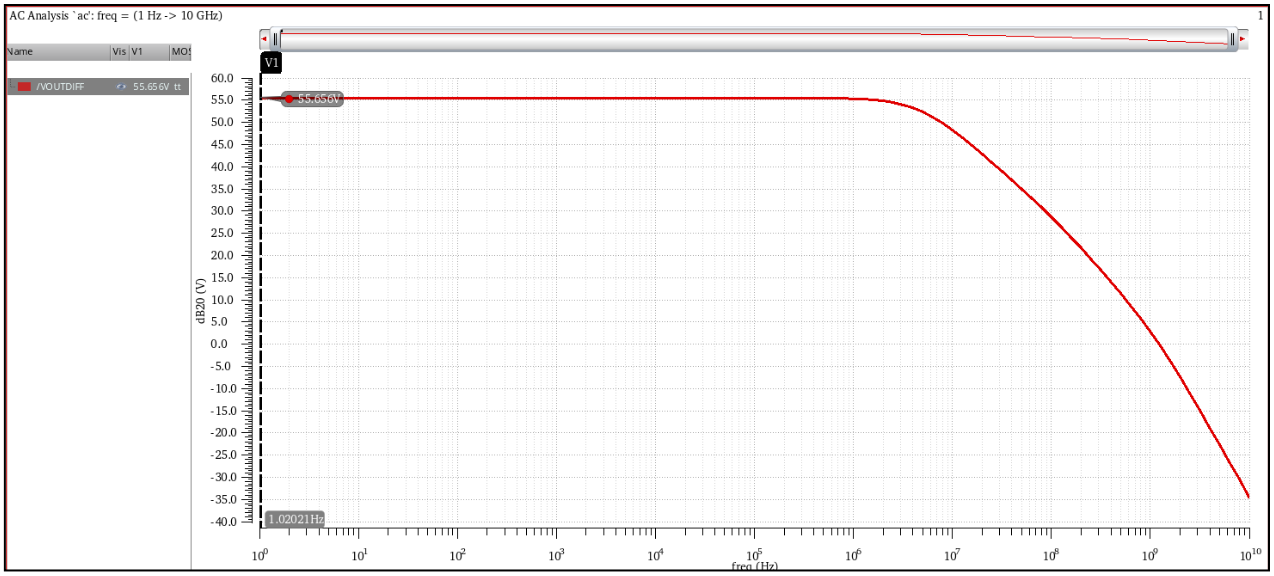


Zeros:

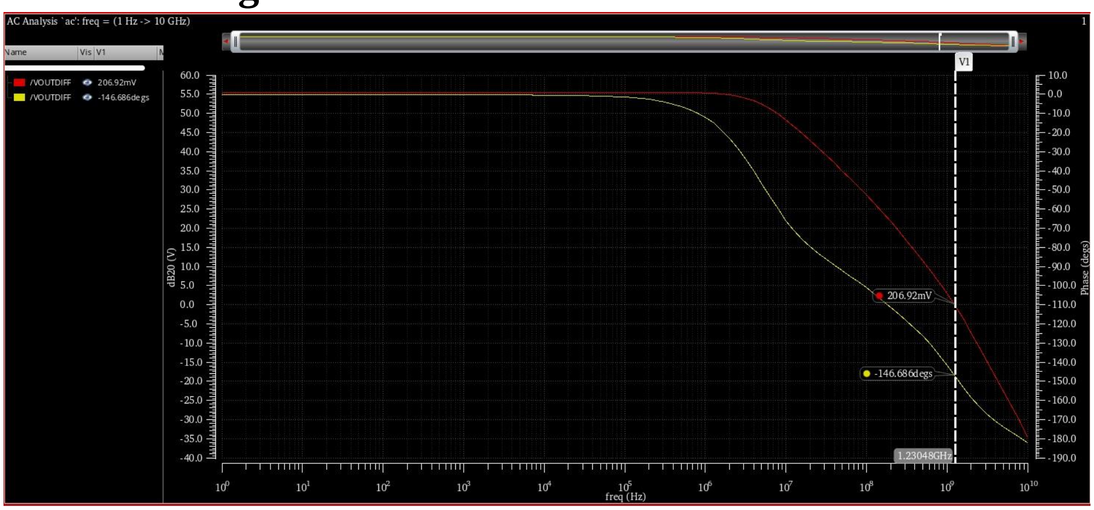
	qfactor	/poles M...tt (Hz)	qfactor	/zeros M...tt (Hz)
1	500.0E-3	4.852E6	500.0E-3	299.6E6
2	500.0E-3	204.1E6	-500.0E-3	132.6E9
3	500.0E-3	965.6E6	-500.0E-3	236.4E9
4	500.0E-3	716.7E9	500.0E-3	665.0E9



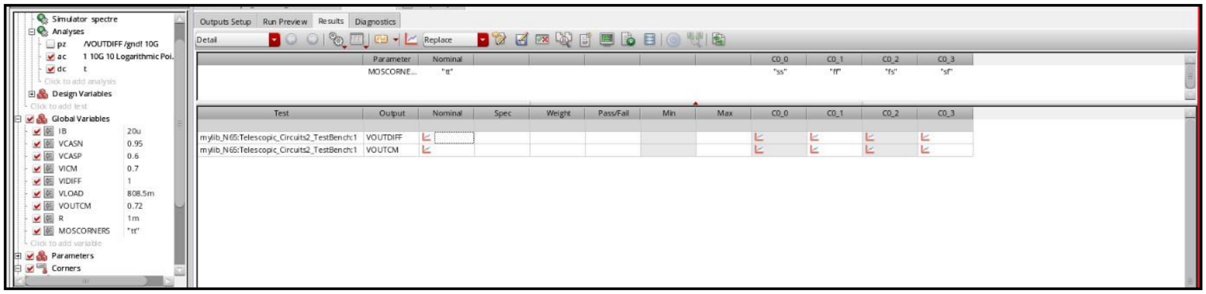
Bodie plot:

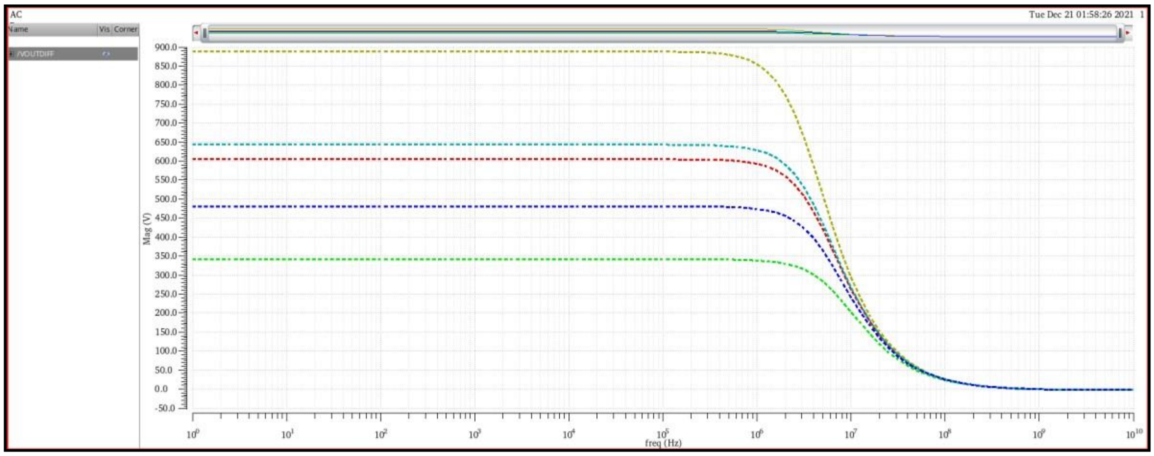


7. Phase margin



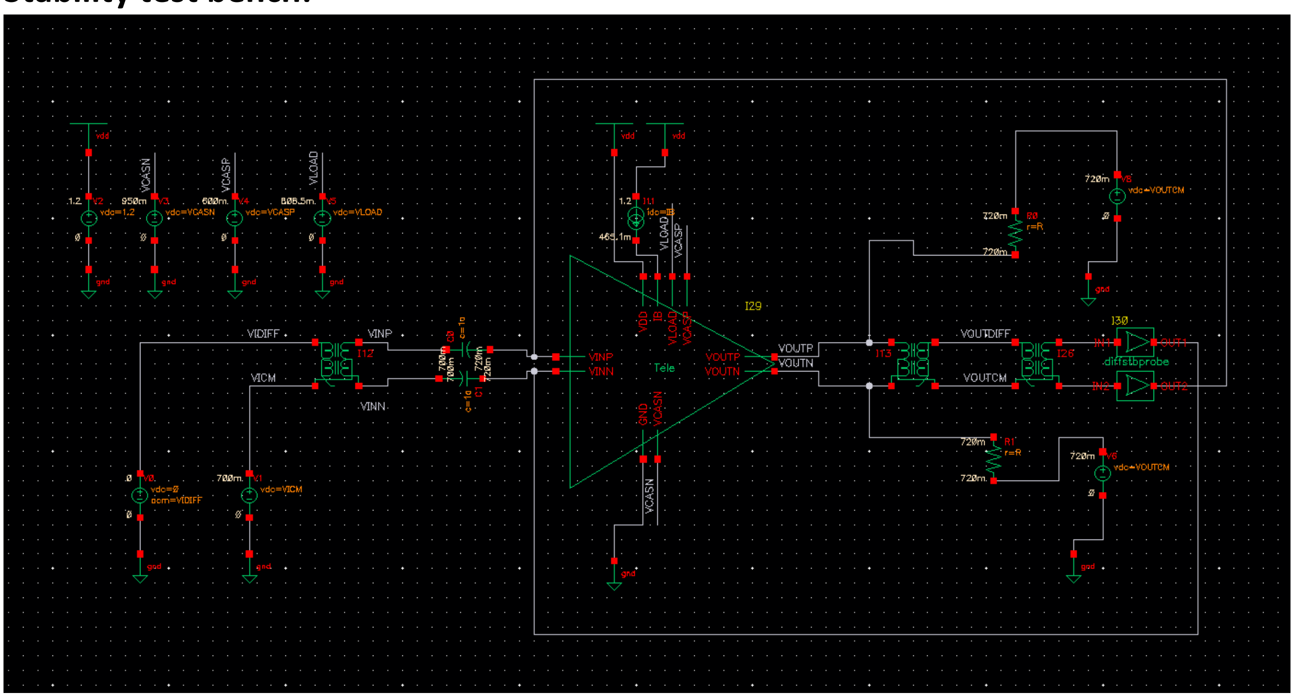
8. Corner analysis



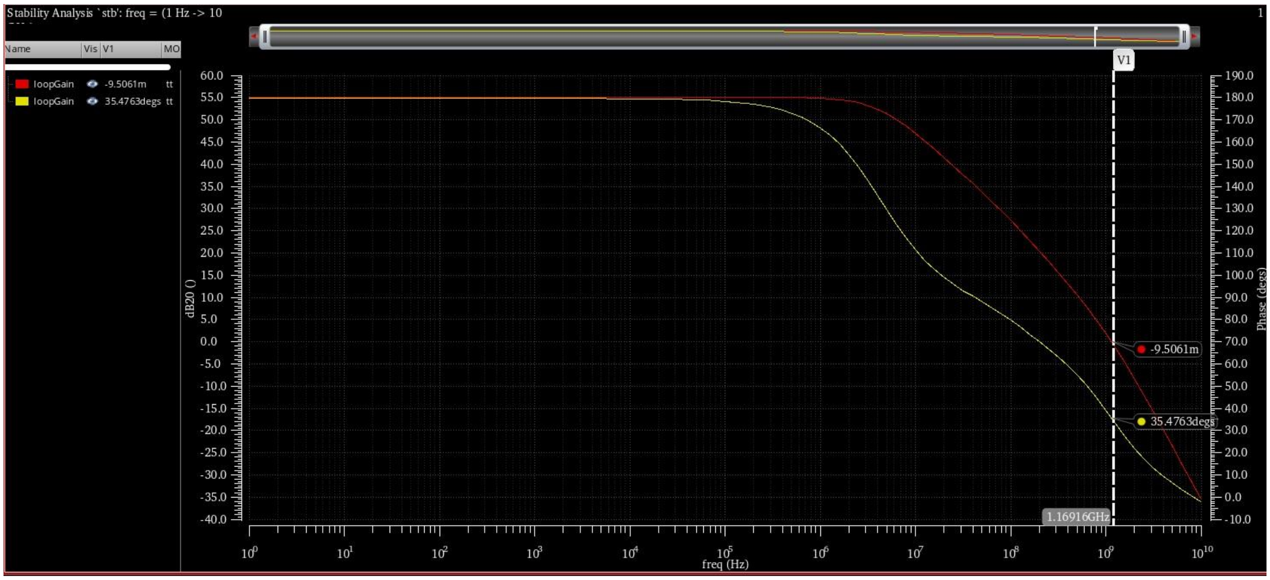


9. Stability analysis

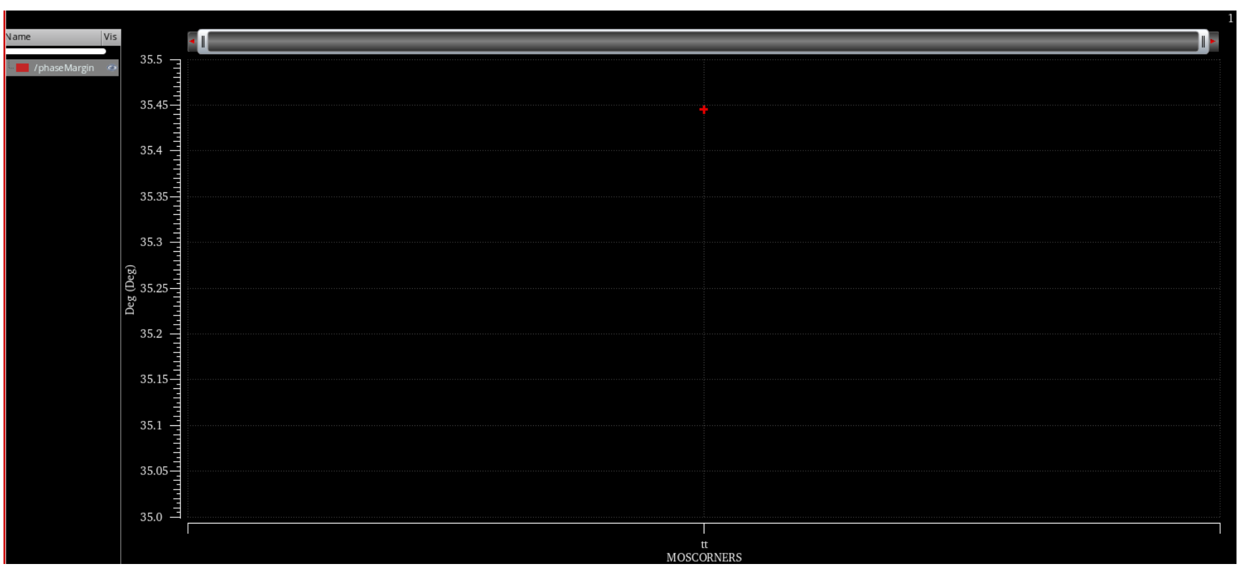
Stability test bench:



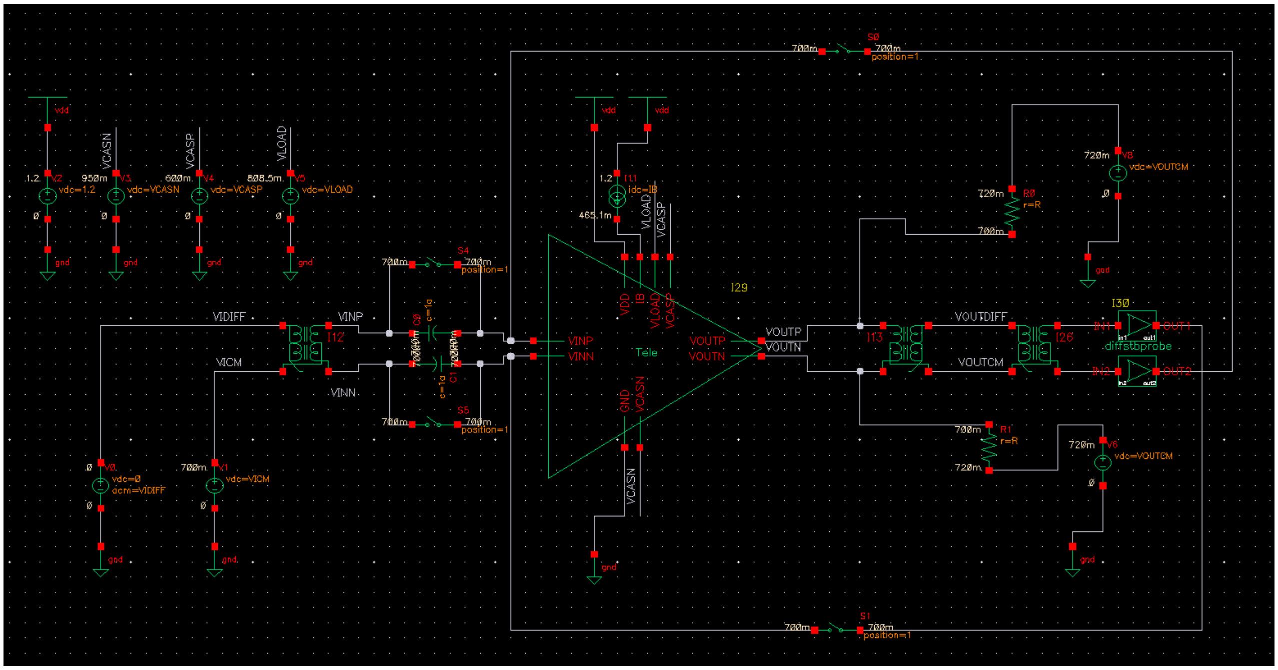
Stability loop gain:



Stability phase margin:



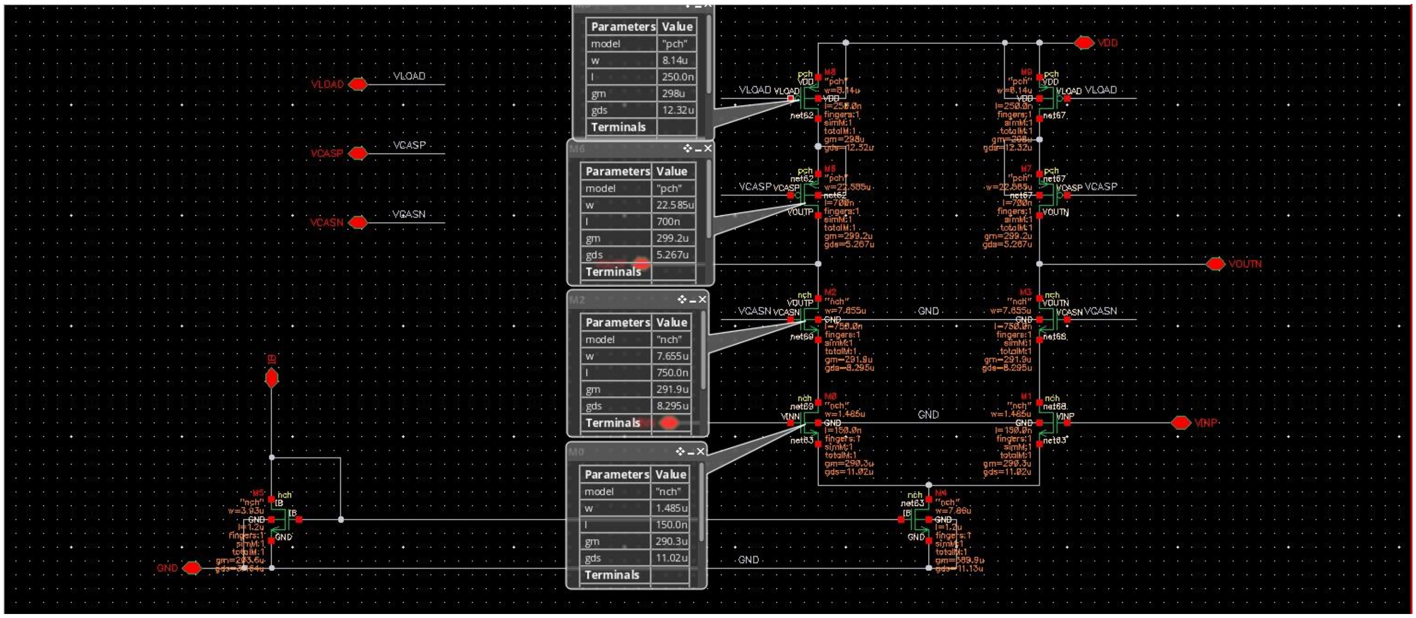
Final testbench



By changing switches conditions we can get open loop simulation and closed loop simulation as well.

10. Mistakes made then resolved

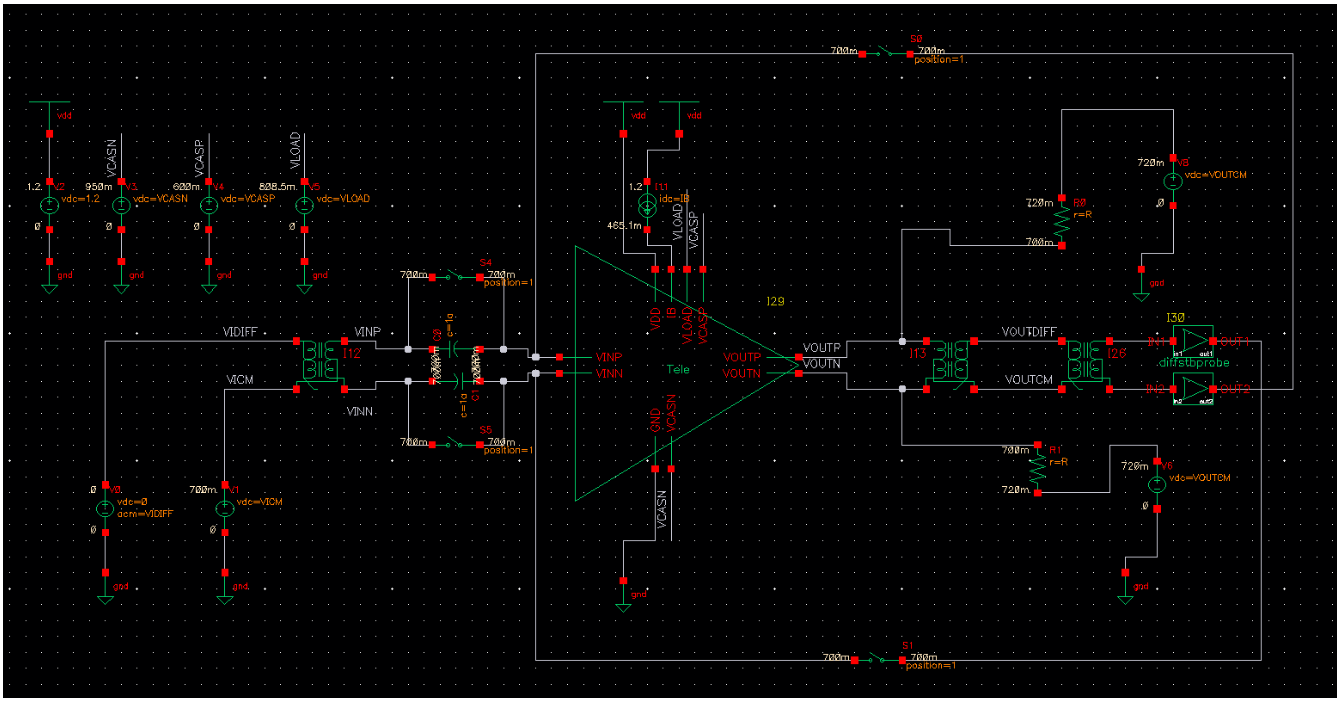
Old design:



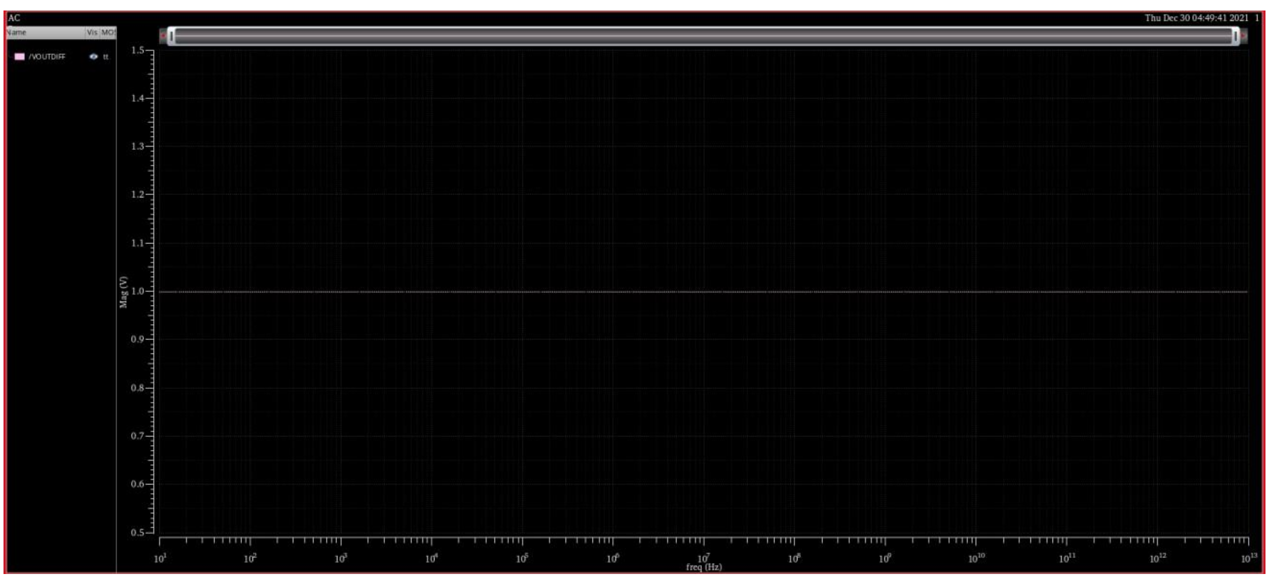
Old gain:

Test	Output	Nominal	Spec	Weight	Pass/Fail
mylib_N65:Telescopic_Circuits2_TestBench:1	VOUTDIFF				
mylib_N65:Telescopic_Circuits2_TestBench:1	Gain	575.5			
mylib_N65:Telescopic_Circuits2_TestBench:1	power	45.85u			

Stability test with wrong switch conditions:



Stability loop gain:



11. Contribution to the project

This was a big project in a short notice, so we teamed up to finish it. my contribution to the project was

- **hand analysis**
- **transistor analysis**
- **designing circuits**
- **finding gain and power**
- **getting the poles and zeros theoretical**