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HOMEWORK ROUTE FORM

Stanford Center for Professional Development Student Information

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1. $\begin{Bmatrix} f_T \\ I_D/W \end{Bmatrix}$ for $\begin{Bmatrix} 0.18\mu m \\ 0.36\mu m \end{Bmatrix}$ NMOS & PMOS at 8 S/A

		NMOS	PMOS	NMOS/PMOS
0.18μm	f_T	26.4GHz	8.84GHz	2.97
	I_D/W	42.5 $\frac{uA}{m}$	15.1 $\frac{uA}{m}$	2.81
0.36μm	f_T	7.89GHz	2.19GHz	3.58
	I_D/W	20.57 $\frac{uA}{m}$	5.90 $\frac{uA}{m}$	3.48
0.36um / 0.18um	f_T	0.299	0.246	
	I_D/W	0.484	0.391	

$f_T \cong \frac{3}{2} \frac{\mu_{n,p} V_{ov}}{L_2}$ hence expect $f_T \propto \frac{1}{L^2}$ → ratio expected to be $\boxed{\frac{1}{4}}$

$I_D/W \propto \frac{g_m}{I_D}$ Hence for 2x length expect current density to be $\boxed{\frac{1}{2}}$

2. $g_m/I_d = 7\frac{S}{A}$ all passives the same

Specs:

$R_L = 1k \quad C_L = 50fF \quad R_S = 10k \quad A_{V_0} = -4 \quad L = 0.18\mu m$

a.) Find required tail current

$\frac{g_m}{I_d} = 7\frac{S}{A} \qquad A_{V_0} = -4 = -g_m \cdot R_L \qquad g_m = \frac{-A_{V_0}}{R_L} = 4mS$

$I_d = \frac{g_m}{g_m/I_d} = 571uA = I_{Tail}/2$

$I_{Tail} = 1142uA$

b) $I_d/w = 52\ A/m \qquad I_d = 571uA \qquad w = I_d/(I_d/w) = 10.97um$

c) $f_T = 28GHz$

$C_{gg} = \frac{1}{2\pi} \cdot \frac{g_m}{f_T} = \frac{g_m}{\omega_T} = 22.5fF$

$C_{gd} = \frac{C_{gd}}{C_{gg}} \cdot C_{gg} = 5.27fF \qquad C_{dd} = \frac{C_{dd}}{C_{gg}} C_{gg} = 13.3fF$

$C_{gs} = C_{gg} - C_{gd} = 17.2fF \qquad C_{db} = C_{dd} - C_{gd} = 8.0fF$

Open Circuit Time Constant

$\tau_1 = C_{gs} \cdot R_S \qquad \tau_2 = C_{gd}(1 + |A_{V_0}|) \cdot R_S \qquad \tau_3 = R_L \cdot (C_L + C_{db})$

Pole OCT = 322 MHz

d) $C_{gs} = 18.3fF \qquad C_{gd} = 7.20fF \qquad C_{gg} = C_{gs} + C_{gd} = 25.5fF$

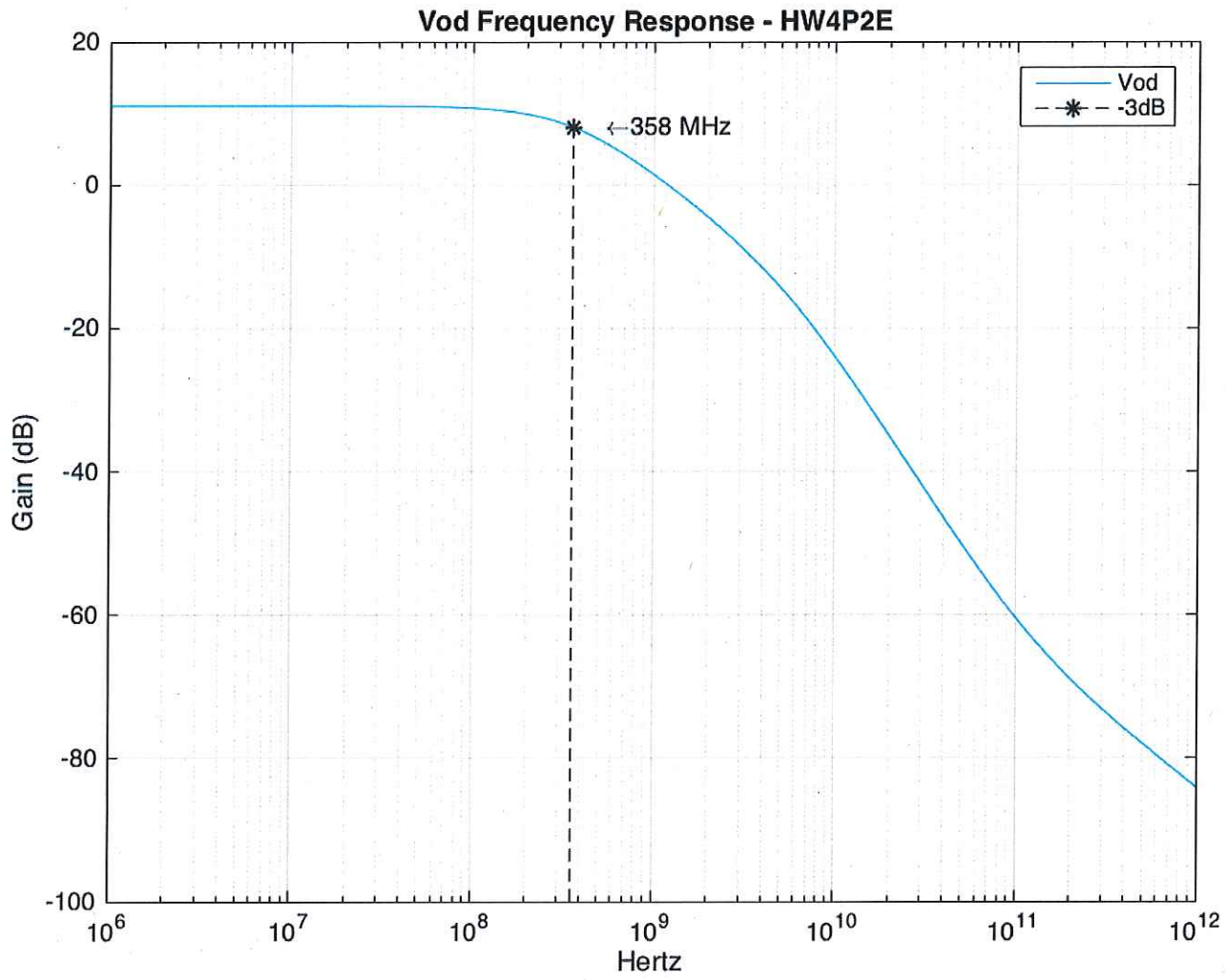
e) Printout of .op attached
Printout of $\log_f - \log_f$ plot attached

Simulation bandwidth 359MHz, -10.3% error in calculation

f) $\frac{f_{3dB}}{I_{Tail}} = 314GHz/A \quad 7\frac{S}{A}$

$\frac{f_{3dB}}{I_{Tail}} = 358GHz/A \quad 13.3\frac{S}{A}$ ← more efficient

class ex


Vod Frequency Response - HW4P2E
Vod
-3dB
←358 MHz
Gain (dB)
Hertz
20
0
-20
-40
-60
-80
-100
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}

Problem 2 Part E

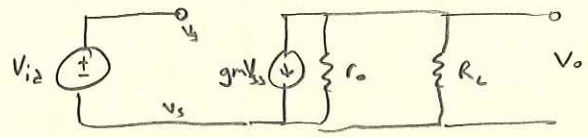
**** mosfets

subckt		
element	0:m1	0:m2
model	0:nmos214	0:nmos214
region	Saturati	Saturati
id	571.0000u	571.0000u
ibs	0.	0.
ibd	0.	0.
vgs	783.0706m	783.0706m
vds	1.0121	1.0121
vbs	-216.9294m	-216.9294m
vth	541.1596m	541.1596m
vdsat	176.8482m	176.8482m
vod	241.9110m	241.9110m
beta	22.0948m	22.0948m
gam eff	583.6854m	583.6854m
gm	4.0170m	4.0170m
gds	123.2972u	123.2972u
gmb	887.5677u	887.5677u
cdtot	12.6847f	12.6847f
cgtot	22.4760f	22.4760f
cstot	25.7820f	25.7820f
cbtot	19.4629f	19.4629f
cgs	16.2104f	16.2104f
cgd	5.2983f	5.2983f

3. DC Gain $A_{v_0} = 1$ $f_{3dB} = 1.1\text{GHz}$ $C_L = 500\,fF$ minimum I_{Tail} $R_S = 0$

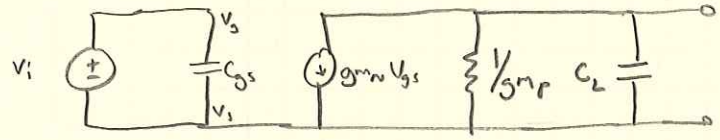
$L_p = L_n = 0.24\,um$ $V_{IC} = 1.2V$ $V_{DD} = 1.8V$

a) Low freq half ckt



$R_L = \frac{1}{g_{mp}}$ $A_{V_0} = -\frac{g_{mN}}{g_{mp} \| r_o} \approx -\frac{g_{mN}}{g_{mp}}$

b) Small ckt



$f_{3dB} = \frac{1}{2\pi C_L / g_{mp}} = \frac{g_{mp}}{2\pi C_L}$ $g_{mp} = f_{3dB} \cdot 2\pi C_L = 3.5mS$

c) $\frac{g_{mp}}{I_d} = 8\frac{S}{A}$ $I_{d_p} = I_{d_N}$ $g_{mp} = g_{mN} \Rightarrow \frac{g_{mN}}{I_d} = \frac{g_{mp}}{I_d} = 8$

Find I_{ss} and device widths

$I_d = \frac{g_{mp}}{\frac{g_{mp}}{I_d}} = 432uA \Rightarrow I_{ss} = 864uA$

$W_N = \frac{I_d}{I_d/W_N} = 13.76\mu m$ $W_p = 43\mu m$

d) -3dB BW: 903MHz

AC Response and .op list attached

e) $K = \frac{1}{2 - \frac{1.1GHz}{903MHz}} = 1.2682$

f) $I_{ss} = 1.095mA$ $f_{3dB} = 1.091GHz$

$g_m = 4.392$ $I_d = 547uA$ $\frac{g_m}{I_d} = 8.029$ → unchanged

3. g) $\frac{g_m}{I_d} \propto \frac{I_d}{W}$ hence $\frac{g_m}{I_d} \propto \frac{K}{K}\frac{I_d}{W}$

for constant $\frac{g_m}{I_d}$, increasing I_d results in increasing g_m

Constant $\frac{g_m}{I_d}$ leads to constant f_T but increasing I_d means that the fraction of C_{Load} determining the total capacitance is decreasing, hence f_{p1} increases

h) With $A_V = 1$ the C_{gd_N} capacitor is bootstrapped. With a $R_s = 0$ C_{gs_N} is not considered. Hence C_{db_N} is the only drain connected NMOS cap left. C_{gd_P} is shorted, hence we need to consider C_{db_P} and C_{gs_P}.

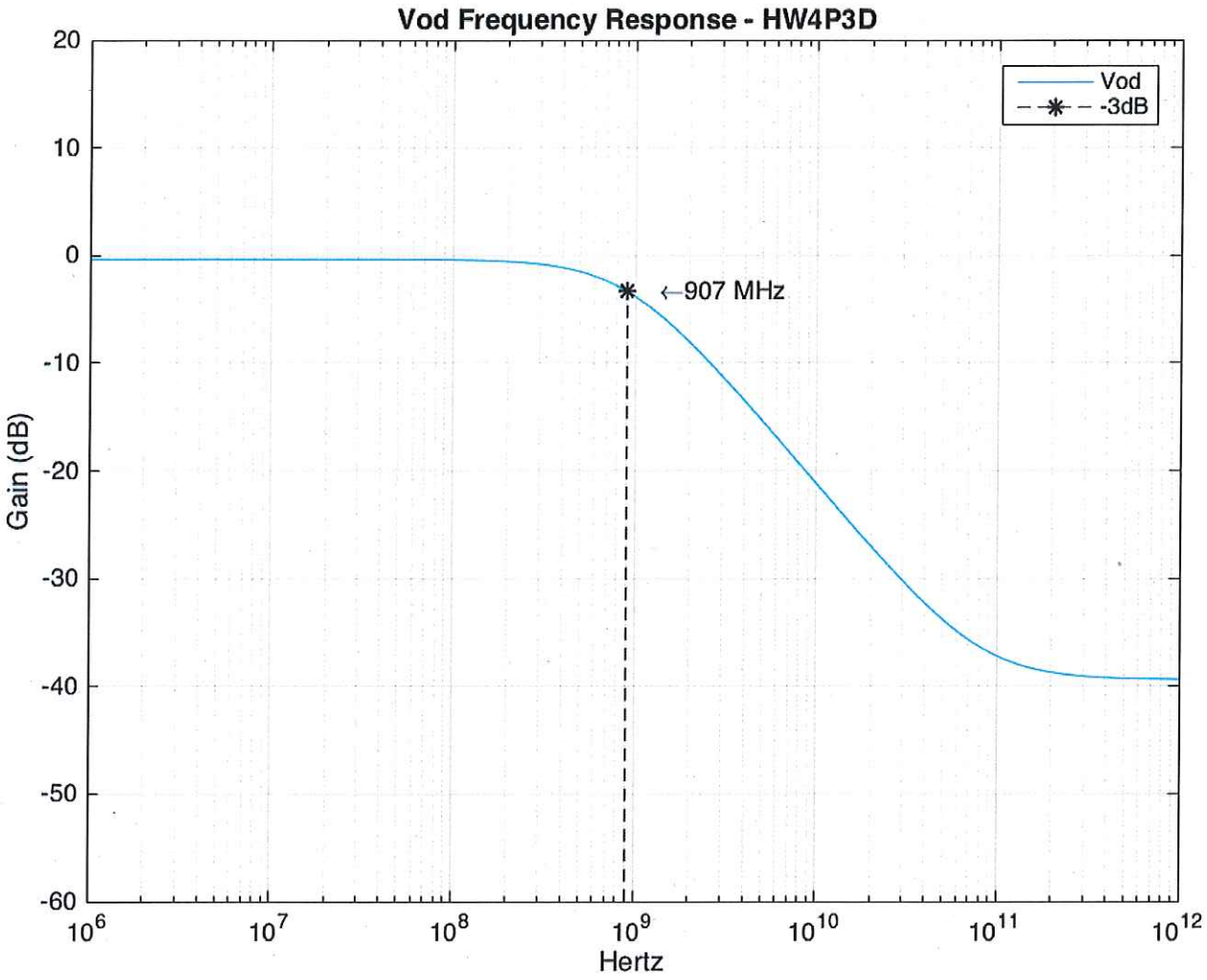
Plot attached.

I_{ss} converged to 1154 uA final ratio 1.33

i) PMOS width = 54.4 μm NMOS width = 18.4 μm

j) Bandwidth:

Plot and .op list attached.


Vod Frequency Response - HW4P3D
Vod
-3dB
907 MHz
Gain (dB)
Hertz
20
10
0
-10
-20
-30
-40
-50
-60
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}

Problem 3 Part D

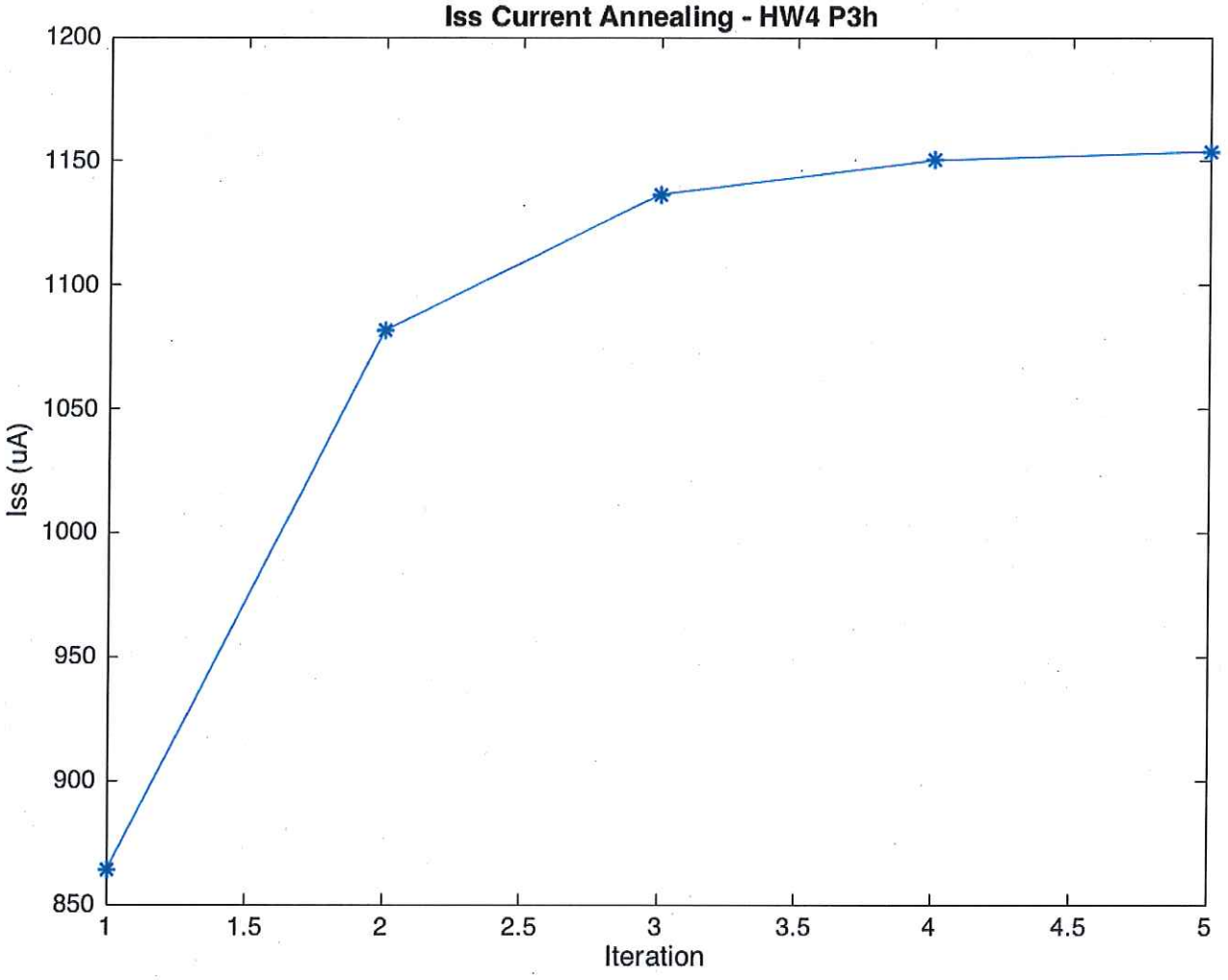
**** mosfets

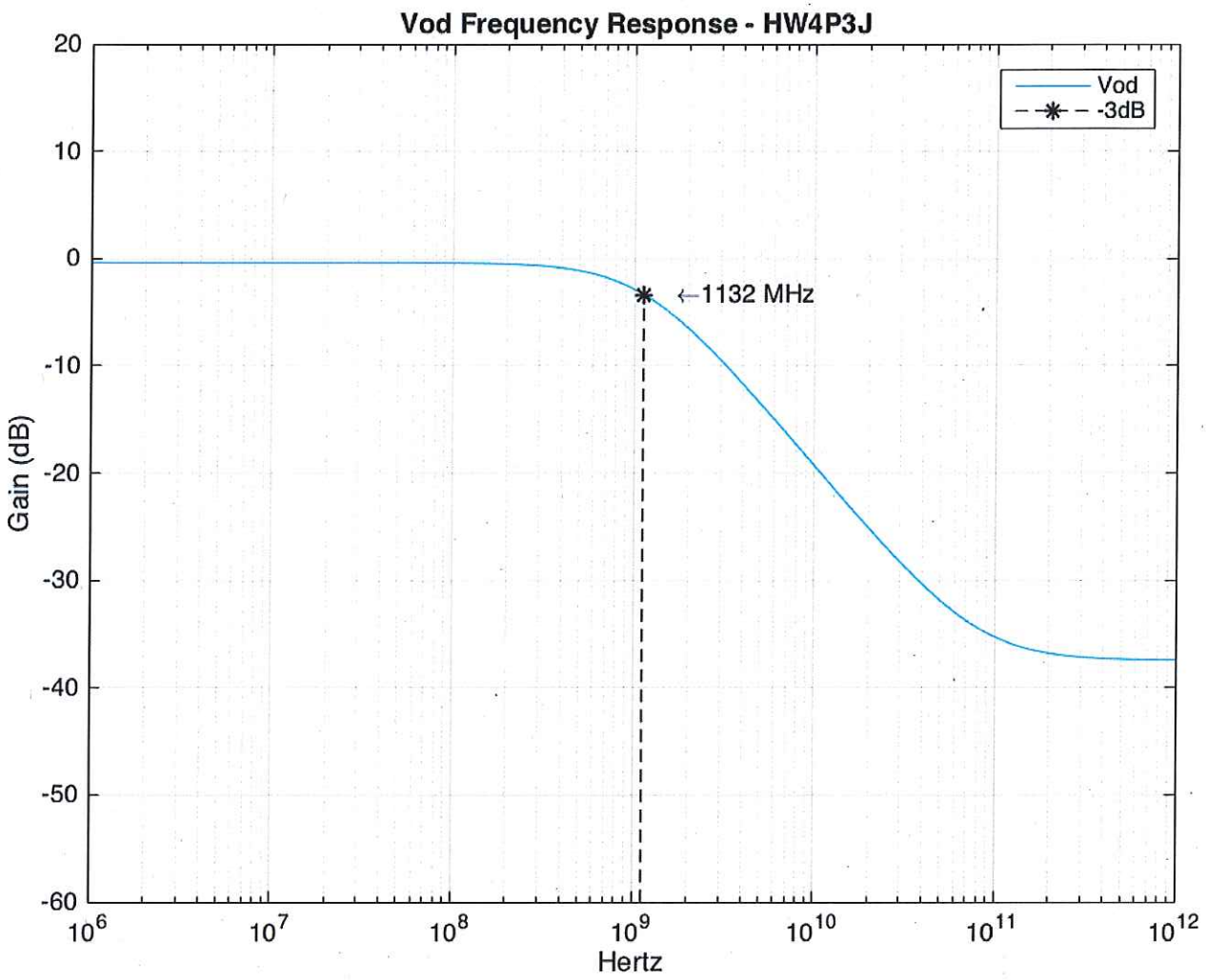
subckt				
element	0:mn1	0:mn2	0:mp1	0:mp2
model	0:nmos214	0:nmos214	0:pmos214	0:pmos214
region	Saturati	Saturati	Saturati	Saturati
id	547.7760u	547.7760u	-547.7760u	-547.7760u
ibs	0.	0.	0.	0.
ibd	0.	0.	0.	0.
vgs	766.8026m	766.8026m	-705.2563m	-705.2563m
vds	861.5463m	861.5463m	-705.2563m	-705.2563m
vbs	-233.1974m	-233.1974m	0.	0.
vth	539.3613m	539.3613m	-473.2138m	-473.2138m
vdsat	176.0868m	176.0868m	-201.6380m	-201.6380m
vod	227.4413m	227.4413m	-232.0425m	-232.0425m
beta	24.8611m	24.8611m	20.9143m	20.9143m
gam eff	584.3111m	584.3111m	535.9921m	535.9921m
gm	4.3913m	4.3913m	4.3583m	4.3583m
gds	89.8445u	89.8445u	126.0953u	126.0953u
gmb	1.0058m	1.0058m	1.3630m	1.3630m
cdtot	20.2688f	20.2688f	76.9346f	76.9346f
cgtot	43.0812f	43.0812f	141.0176f	141.0176f
cstot	48.3107f	48.3107f	159.6900f	159.6900f
cbtot	32.8565f	32.8565f	113.7785f	113.7785f
cgs	32.7243f	32.7243f	102.1611f	102.1611f
cgd	8.3798f	8.3798f	35.5343f	35.5343f

Problem 3 Part F

**** mosfets

subckt				
element	0:mn1	0:mn2	0:mp1	0:mp2
model	0:nmos214	0:nmos214	0:pmos214	0:pmos214
region	Saturati	Saturati	Saturati	Saturati
id	547.7760u	547.7760u	-547.7760u	-547.7760u
ibs	0.	0.	0.	0.
ibd	0.	0.	0.	0.
vgs	766.8026m	766.8026m	-705.2563m	-705.2563m
vds	861.5463m	861.5463m	-705.2563m	-705.2563m
vbs	-233.1974m	-233.1974m	0.	0.
vth	539.3613m	539.3613m	-473.2138m	-473.2138m
vdsat	176.0868m	176.0868m	-201.6380m	-201.6380m
vod	227.4413m	227.4413m	-232.0425m	-232.0425m
beta	24.8611m	24.8611m	20.9143m	20.9143m
gam eff	584.3111m	584.3111m	535.9921m	535.9921m
gm	4.3913m	4.3913m	4.3583m	4.3583m
gds	89.8445u	89.8445u	126.0953u	126.0953u
gmb	1.0058m	1.0058m	1.3630m	1.3630m
cdtot	20.2688f	20.2688f	76.9346f	76.9346f
cgtot	43.0812f	43.0812f	141.0176f	141.0176f
cstot	48.3107f	48.3107f	159.6900f	159.6900f
cbtot	32.8565f	32.8565f	113.7785f	113.7785f
cgs	32.7243f	32.7243f	102.1611f	102.1611f
cgd	8.3798f	8.3798f	35.5343f	35.5343f


Iss Current Annealing - HW4 P3h
Iss (uA)
Iteration
1200
1150
1100
1050
1000
950
900
850
1
1.5
2
2.5
3
3.5
4
4.5
5


Vod Frequency Response - HW4P3J
Vod
-3dB
←1132 MHz
Gain (dB)
Hertz
20
10
0
-10
-20
-30
-40
-50
-60
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}

Problem 3 Part J

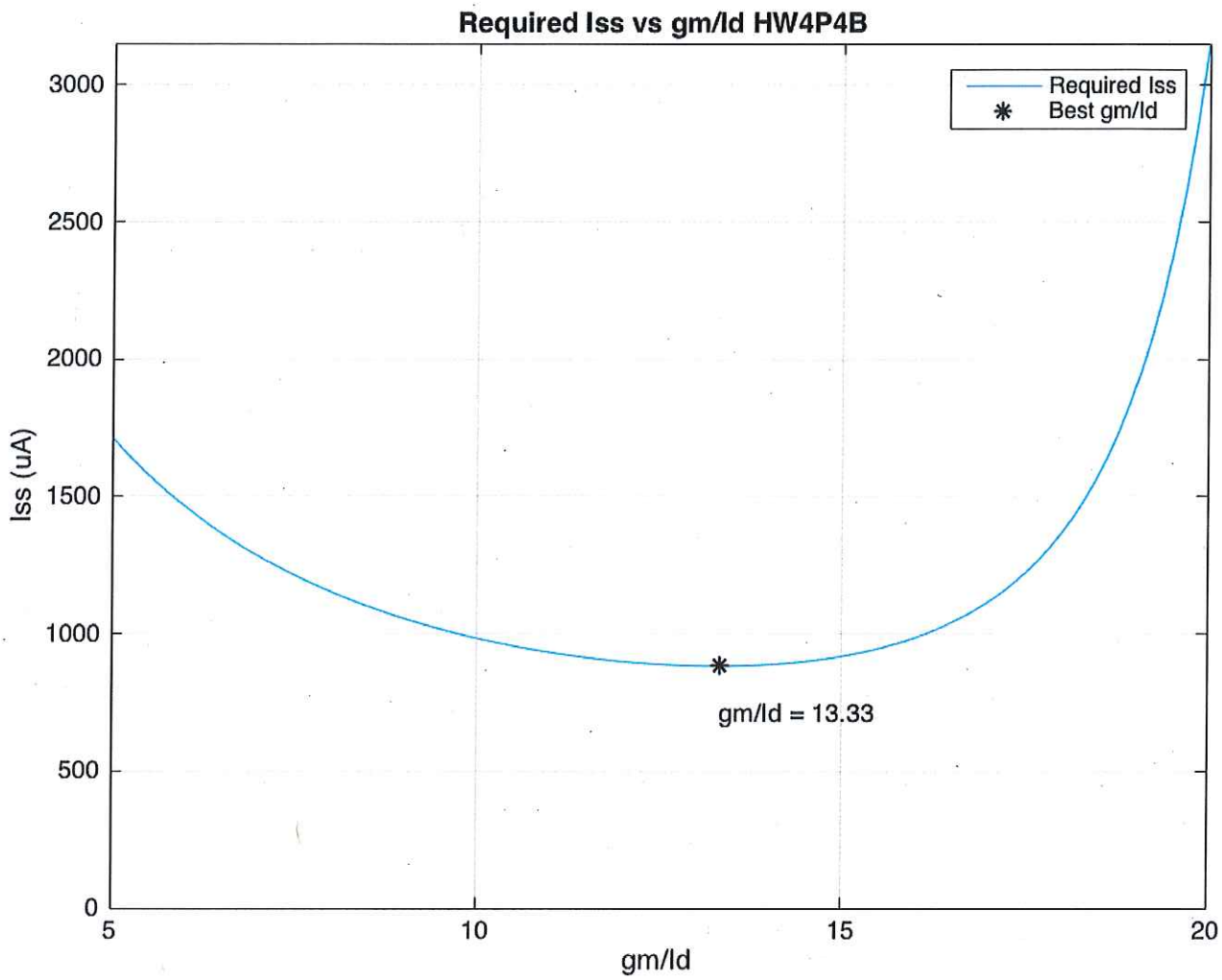
**** mosfets

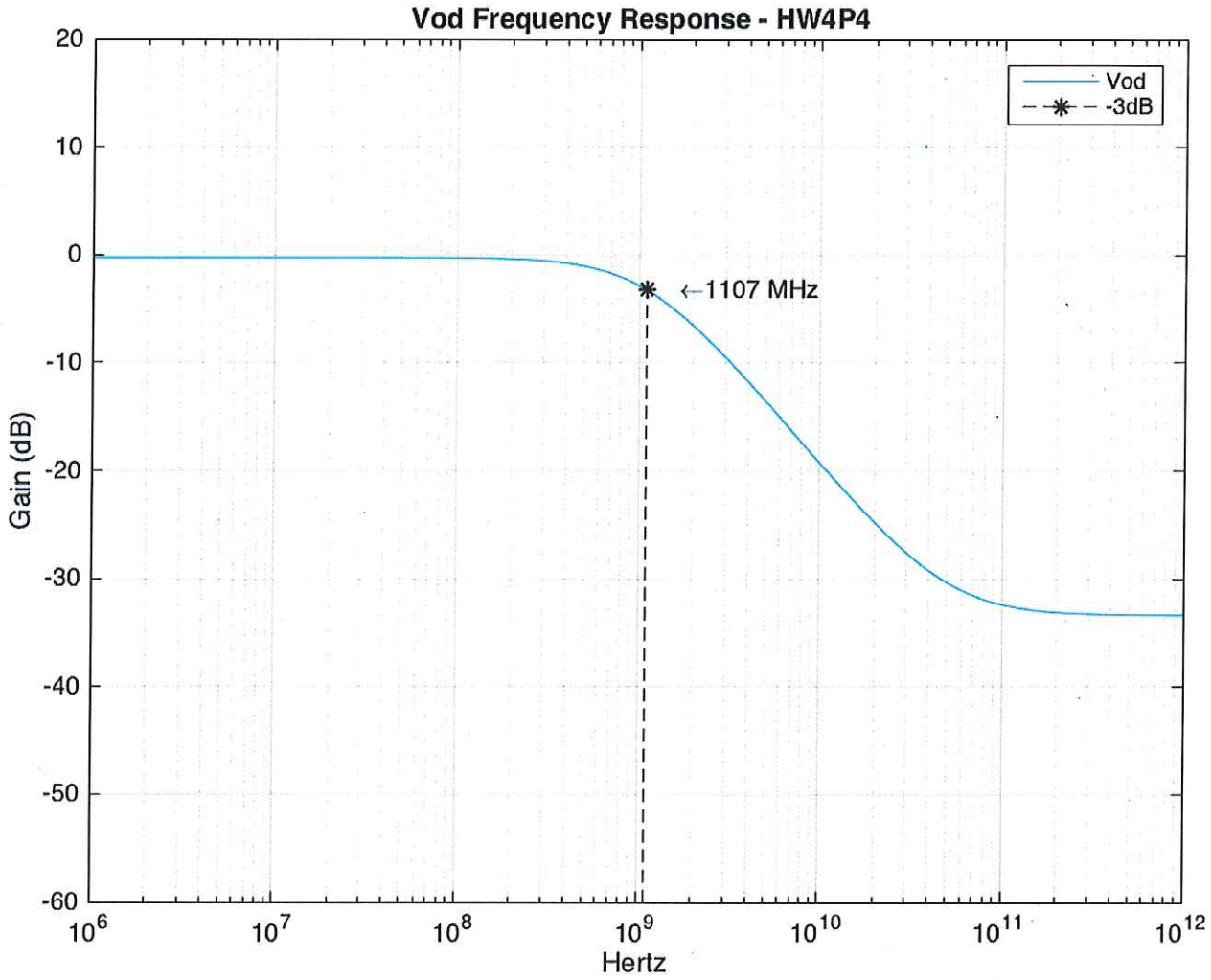
subckt element	0:mn1	0:mn2	0:mp1	0:mp2
model	0:nmos214	0:nmos214	0:pmos214	0:pmos214
region	Saturati	Saturati	Saturati	Saturati
id	577.0000u	577.0000u	-577.0000u	-577.0000u
ibs	0.	0.	0.	0.
ibd	0.	0.	0.	0.
vgs	766.9958m	766.9958m	-705.3199m	-705.3199m
vds	861.6758m	861.6758m	-705.3199m	-705.3199m
vbs	-233.0042m	-233.0042m	0.	0.
vth	539.3270m	539.3270m	-473.2214m	-473.2214m
vdsat	176.2447m	176.2447m	-201.7064m	-201.7064m
vod	227.6688m	227.6688m	-232.0985m	-232.0985m
beta	26.1364m	26.1364m	22.0171m	22.0171m
gam eff	584.3389m	584.3389m	536.0068m	536.0068m
gm	4.6204m	4.6204m	4.5895m	4.5895m
gds	94.5421u	94.5421u	132.8016u	132.8016u
gmb	1.0584m	1.0584m	1.4355m	1.4355m
cdtot	21.3001f	21.3001f	80.9822f	80.9822f
cgtot	45.3017f	45.3017f	148.4556f	148.4556f
cstot	50.7881f	50.7881f	168.1033f	168.1033f
cbtot	34.5234f	34.5234f	119.7571f	119.7571f
cgs	34.4107f	34.4107f	107.5503f	107.5503f
cgd	8.8119f	8.8119f	37.4090f	37.4090f

4. b) Plot attached

c) Nmos: 38.2um
Pmos: 124.0um

d.) Printout & Plot attached


Required Iss vs gm/Id HW4P4B
Required Iss
Best gm/Id
Iss (uA)
gm/Id
gm/Id = 13.33
0
500
1000
1500
2000
2500
3000
5
10
15
20


Vod Frequency Response - HW4P4
Vod
-3dB
←1107 MHz
Gain (dB)
Hertz
20
10
0
-10
-20
-30
-40
-50
-60
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}

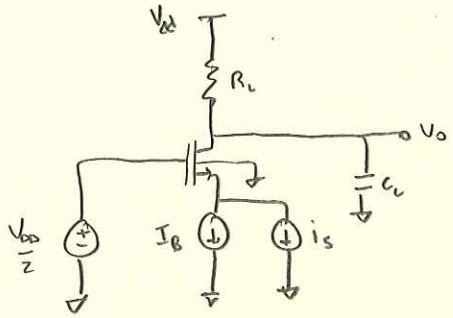
Problem 4 Part D

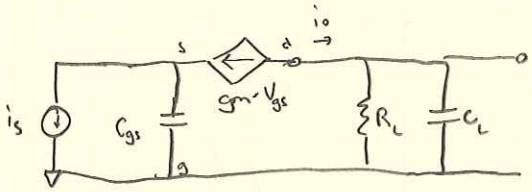
**** mosfets

subckt element	0:mn1	0:mn2	0:mp1	0:mp2
model	0:nmos214	0:nmos214	0:pmos214	0:pmos214
region	Saturati	Saturati	Saturati	Saturati
id	442.0000u	442.0000u	-442.0000u	-442.0000u
ibs	0.	0.	0.	0.
ibd	0.	0.	0.	0.
vgs	689.1093m	689.1093m	-607.5475m	-607.5475m
vds	881.5618m	881.5618m	-607.5475m	-607.5475m
vbs	-310.8907m	-310.8907m	0.	0.
vth	558.9171m	558.9171m	-473.7236m	-473.7236m
vdsat	117.8577m	117.8577m	-127.0213m	-127.0213m
vod	130.1922m	130.1922m	-133.8239m	-133.8239m
beta	54.1946m	54.1946m	48.5372m	48.5372m
gam eff	584.3667m	584.3667m	536.1561m	536.1561m
gm	5.9555m	5.9555m	5.8582m	5.8582m
gds	107.8540u	107.8540u	141.0537u	141.0537u
gmb	1.3490m	1.3490m	1.8036m	1.8036m
cdtot	43.5573f	43.5573f	177.0913f	177.0913f
cgtot	93.0095f	93.0095f	317.8289f	317.8289f
cstot	102.9546f	102.9546f	358.7041f	358.7041f
cbtot	69.7235f	69.7235f	260.9957f	260.9957f
cgs	70.1527f	70.1527f	228.1761f	228.1761f
cgd	18.3062f	18.3062f	80.8248f	80.8248f

5) a) $R_L = 6k$ $C_L = 100f$ $I_{Bias} = 100\mu A$ $V_{DD} = 1.8V$ $L = 0.18\mu$

Common gate stage - consider only C_{gs} & g_m





input impedance $= \frac{1}{g_m} \parallel \frac{1}{sC_{gs}}$ output impedance $\approx r_o(1 + g_m R_s) \to \infty$

$$\frac{i_o}{i_s} \approx \frac{1}{1 + s\frac{C_{gs}}{g_m}} \qquad V_o = i_o \cdot \left(R_L \parallel \frac{1}{sC_L}\right) = i_o \cdot \frac{\frac{R_L}{sC_L}}{sC_L R_L + \frac{1}{sC_L}} = i_o \frac{R_L}{1 + sR_L C_L}$$

$$V_o = \frac{1}{1 + \frac{sC_{gs}}{g_m}} \cdot \frac{R_L}{1 + sR_L C_L} \cdot i_s$$

b) $$\frac{V_o}{i_s} = \frac{R_L}{\left(1 + \frac{sC_{gs}}{g_m}\right)(1 + sR_L C_L)}$$

denominator

$$1 + sC_{gs}/g_m + sR_L C_L + s^2 C_{gs} C_L R_L / g_m$$

$$b_1 = C_{gs}/g_m + R_L C_L$$

$$b_2 = C_{gs} C_L R_L / g_m$$

$$\omega_{p1} = \frac{1}{b_1} \qquad \omega_{p2} = \frac{b_1}{b_2}$$

5.) c) g_m/C_{gs} such that $\frac{\omega_{p2}}{\omega_{p1}} = 100$

$\omega_{p2} \approx \frac{b_1}{b_2}$ $\omega_{p1} \approx \frac{1}{b_1}$

$\frac{\omega_{p2}}{\omega_{p1}} \approx \frac{b_1^2}{b_2} \Rightarrow$ $b_1^2 = \left(\frac{C_{gs}}{g_m} + R_L C_L\right)^2 = \frac{C_{gs}^2}{g_m^2} + R_L^2 C_L^2 + \frac{2 C_{gs} C_L R_L}{g_m}$

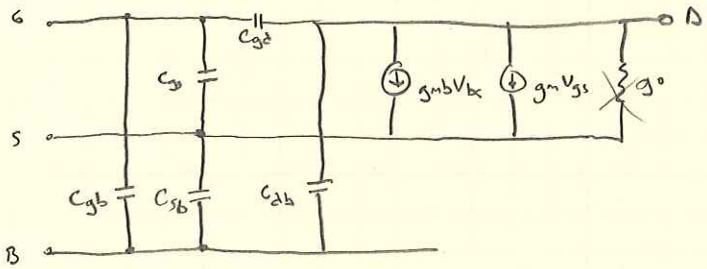
$$b_2 = \frac{C_{gs} C_L R_L}{g_m}$$

$$\frac{b_1^2}{b_2} = \frac{\frac{C_{gs}^2}{g_m^2}}{\frac{C_{gs}}{g_m} \cdot C_L R_L} + \frac{R_L^2 C_L^2}{C_L R_L \frac{C_{gs}}{g_m}} + \frac{\frac{2 C_{gs} C_L R_L}{g_m}}{\frac{C_{gs} C_L R_L}{g_m}}$$

$$= \frac{C_{gs}/g_m}{C_L R_L} + \frac{C_L R_L}{\frac{C_{gs}}{g_m}} + 2 = 2 + \frac{C_{gs}^2/g_m^2 + C_L^2 R_L^2}{C_L R_L C_{gs}/g_m} = 100$$

$$\frac{g_m}{C_{gs}} = \frac{1}{C_L R_L (49 + 20\sqrt{6})} = \frac{0.163\,nS}{fF} = 163 \times 10^9 \frac{S}{F} = 163\,Grad/s = 26GHz$$

d) SS model from Ch4 Slide 8

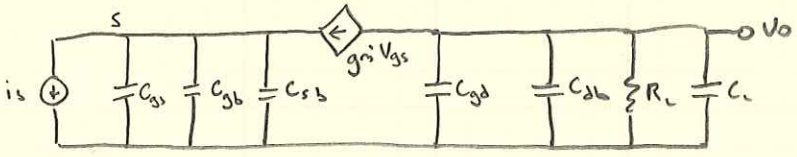


$C_{gs} = C_{gs} + C_{gb} + C_{gd}$

$C_{dd} = C_{db} + C_{gd}$

$V_g = 0$ $V_b = 0$ $\Rightarrow$ $V_{bs} = V_{gs}$ $g_m + g_{mb} = g_m'$

$C_{gs} \parallel C_{gb} \parallel C_{sb}$ $C_{gd} \parallel C_{db} = C_{dd}$



$C_{in} = C_{gs} + C_{gb} + C_{sb}$ $C_{out} = C_{gd} + C_{db} + C_L$

$$\frac{V_o}{I_s} = \frac{R_L}{\left(1 + \frac{sC_{in}}{g_m'}\right)\left(1 + sC_{out}R_L\right)}$$

5) e) $b_1 = \frac{C_{in}}{g_m'} + R_L C_{out}$ $\quad b_2 = \frac{C_{in} C_{out} R_L}{g_m'}$

$$\omega_{p2} \approx \frac{b_1}{b_2} = \frac{\frac{C_{in}}{g_m'}}{\frac{C_{in} C_{out} R_L}{g_m'}} + \frac{\frac{R_L C_{out}}{g_m'}}{\frac{C_{in} C_{out} R_L}{g_m'}} = \frac{1}{C_{out} R_L} + \frac{g_m'}{C_{in}}$$

$$\omega_{p1} \approx \frac{1}{b_1} \approx \frac{1}{\frac{C_{in}}{g_m'} + R_L C_{out}}$$

$C_{in} = C_{gs} + C_{gb} + C_{sb}$ $\quad C_{out} = C_{gd} + C_{db} + C_L$

$C_{gg} = C_{gs} + C_{gd} + C_{gb}$

$C_{dd} = C_{gd} + C_{db}$ $\quad C_{ss} = C_{gs} + C_{sb}$

$C_{in} = C_{gg} + C_{sb} - C_{gd}$ $\quad \frac{C_{dd}}{C_{gg}} = \frac{C_{gd} + C_{db}}{C_{gs} + C_{gd} + C_{gb}}$ $\quad C_{out} = C_{dd} + C_L$

$\omega_T = \frac{g_m}{C_{gg}}$ $\quad \frac{1}{\omega_T} = \frac{C_{gg}}{g_m}$

$R_L C_{out} = R_L C_{dd} + R_L C_L$ $\quad C_{dd} = \frac{C_{dd}}{C_{gg}} \cdot C_{gg} = \frac{C_{dd}}{C_{gg}} \cdot \frac{C_{gg}}{g_m} \cdot \frac{g_m}{I_d} \cdot I_{bias}$

$$\omega_{p1} \approx \frac{1}{R_L \left[C_L + \frac{C_{dd}}{C_{gg}} \frac{1}{\omega_T} \frac{g_m}{I_d} I_{bias} \right]}$$

f) Plot attached

g) $\frac{I_d}{W} = 36.2 \, uA/um$ $\quad W = 2.76um$ $\quad \omega_t = 156 Grad/s$ $\quad f_t = 24.8 GHz$

h) $g_m = 902uS$ $\quad I_d = 100uA$ $\quad \frac{g_m}{I_d} = 9.02$ $\quad \omega_t = \frac{g_m}{C_{gtot}} = 160 Grad/s$

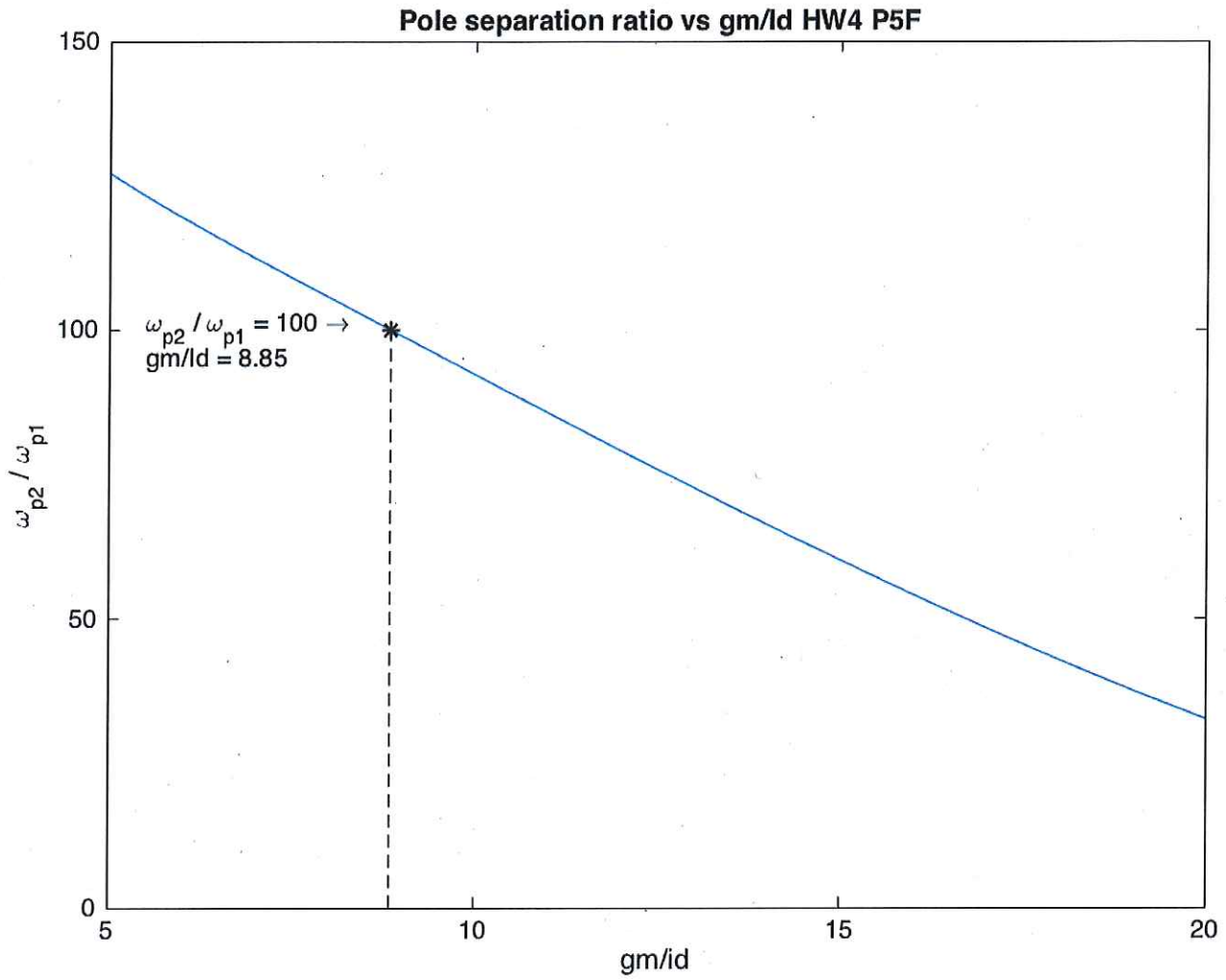
$C_{gtot} = 5.626 fF$

These values are very close to the design point

i) ω_{p1} sim $= 1.61 Grad/s$ $\quad$ ratio 104.8 $\quad$ error $= -4.62\%$

ω_{p2} sim $= 168.8 Grad/s$

j) ω_t ptC $= 163 Grad/s$ This was a very reasonable estimate.


Pole separation ratio vs gm/Id HW4 P5F
150
100
50
0
5
10
15
20
gm/id
$\omega_{p2} / \omega_{p1}$
$\omega_{p2} / \omega_{p1}$ = 100 →
gm/Id = 8.85

```
Problem 5 Part H

**** mosfets


subckt
element  0:mn1
model    0:nmos214
region     Saturati
 id       100.0000u
 ibs        0.
 ibd        0.
 vgs      723.6087m
 vds        1.0236
 vbs     -176.3913m
 vth      528.9008m
 vdsat    149.2505m
 vod      194.7079m
 beta       5.7016m
 gam eff  580.2213m
 gm       901.8837u
 gds       25.8755u
 gmb      201.3754u
 cdtot      3.3806f
 cgtot      5.6258f
 cstot      6.6973f
 cbtot      5.3412f
 cgs        4.0470f
 cgd        1.3242f
```