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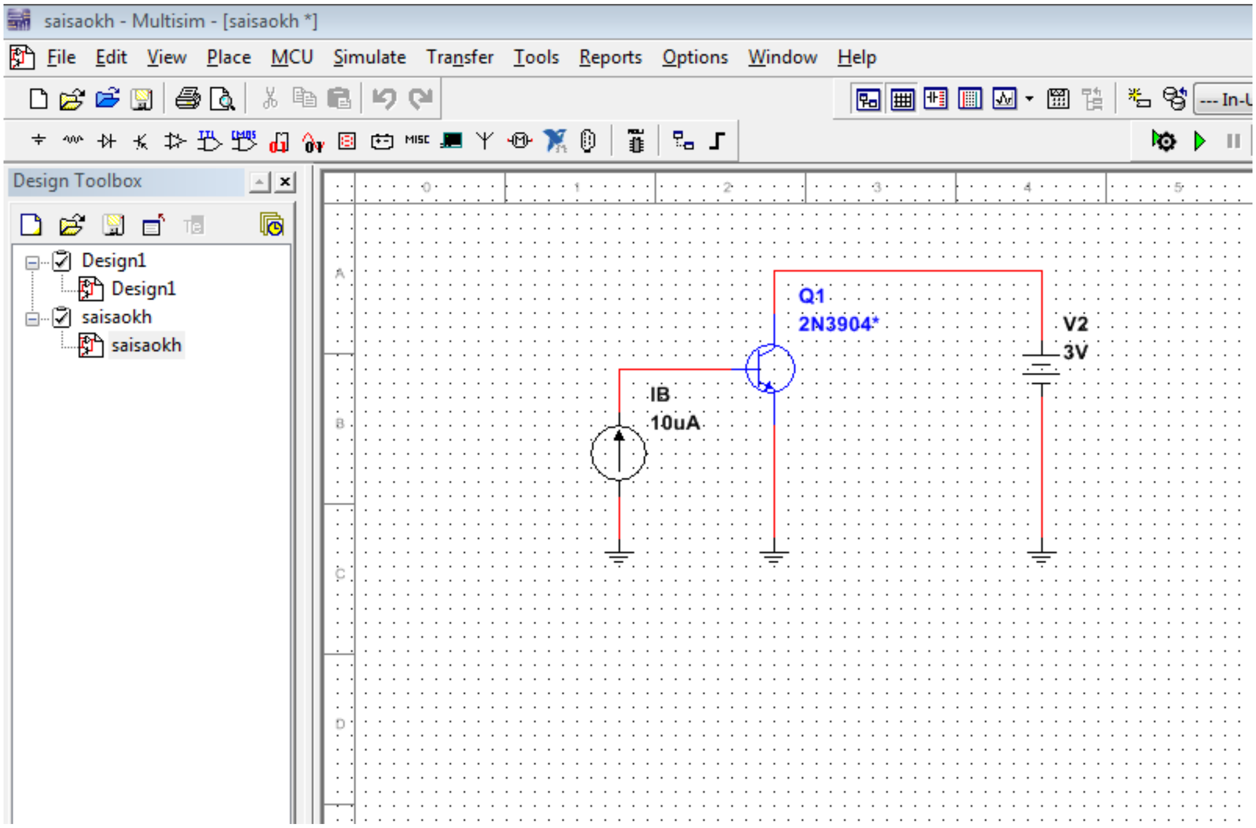
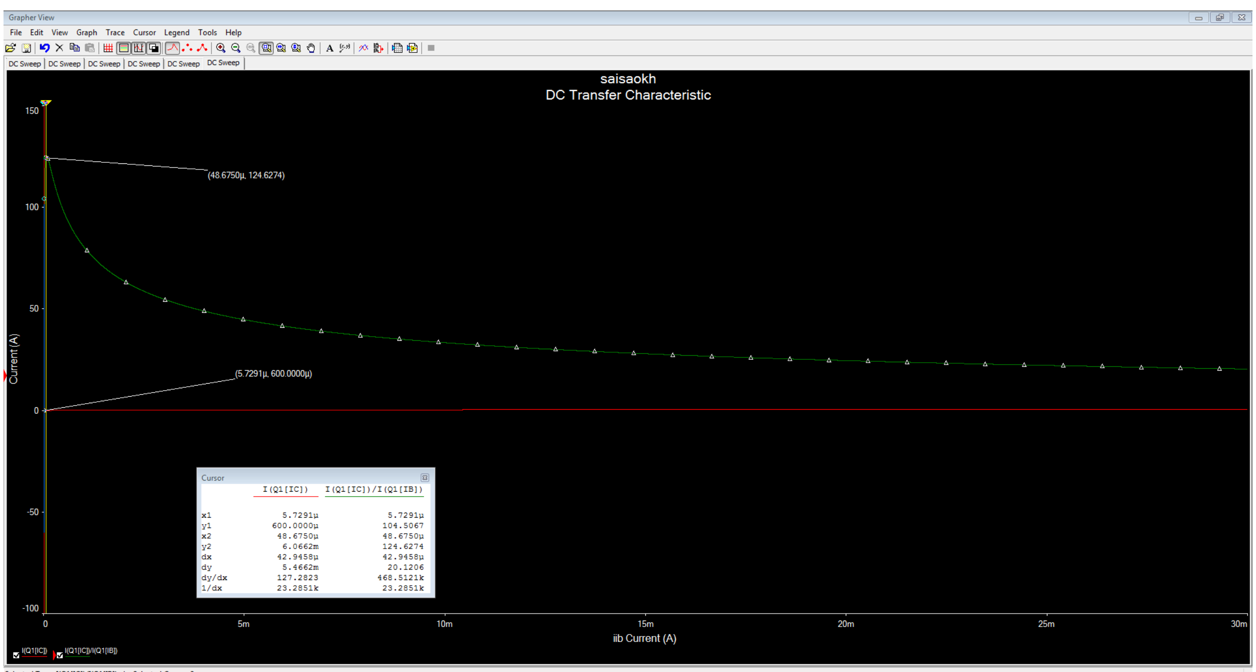
RECITATION SESSION:	**R6**
ASSIGNMENT:	**SIMULATION 4**
DUE DATE:	**DEC 5TH 2016**

Part 1:

BF =240, IB=10u, VCE=3V, $\boldsymbol{I_c} = 0.6\boldsymbol{mA}$,DC sweep





i. **Find R_C, R_E and R_B, given: $I_c = 0.6mA$, which gives $\beta_{dc} = 124.6274\ at\ V_{CE} = 3V, \beta_{dc} = 124.6274, V_{BE} = 0.7V, V_{cc} = 5V, V_{EE} = -5V, V_{CE} = 2V, V_E = -3V, V_C = 0V.$**

$$R_C = \frac{V_{cc}-V_c}{I_c} = \frac{5-0}{0.0006} = 8333.33\Omega \qquad R_E = \frac{V_E - V_{EE}}{I_c} = \frac{(-3)-(-5)}{0.0006} = 3333.33\Omega$$

$$R_B = \frac{-V_B}{I_B} = \frac{0-(V_{BE}+V_E)}{I_c/\beta_{dc}} = \frac{0-(0.7+(-3))}{0.0006/124.6274} = 477738.37\Omega$$

ii. **Given $\beta_{ac}=\beta_{dc}$, $R_{sig} = R_L = 10k\Omega$, V_T=25mV, calculate R_{in}, A_M, R_{ce}=0.**

$$r_e = \left(\frac{\beta_{ac}}{\beta_{ac}+1}\right)\left(\frac{V_T}{I_C}\right) = \left(\frac{124.6274}{124.6274+1}\right)\left(\frac{0.0250}{0.0006}\right) = 41.335\Omega \qquad R_e = R_E \parallel R_{ce} = 3333.33 \parallel 0 = 0\Omega$$

$$[(\beta_{ac}+1)(r_e+R_e)] = [(124.6274+1)(41.335\Omega + 0)] = 5192.809$$

$$R_{in} = R_B \parallel [(\beta_{ac}+1)(r_e+R_e)] = 477738.3667 \parallel [5192.809] = 5136.97\ \Omega$$

$$|A_M| = \left|-\frac{R_{in}}{R_{sig}+R_{in}} \times \frac{R_C \parallel R_L}{r_e+R_e}\right| = \left|-\frac{5136.97}{10000+5136.97} \times \frac{8333.33\parallel 10000}{41.335\Omega + 0}\right| = 37.6237$$

iii. **Expression for R_e when the emitter degeneration resistance (R_{ce}) is inserted with the reduction factor of the mid-band gain 0.8:**

$$\frac{A_M(R_e \neq 0)}{A_M(R_e = 0)} = 0.4 \text{ or } 0.8$$

$$\frac{\left|-\frac{(\beta_{ac}+1)(r_e+R_e)}{R_{sig}+(\beta_{ac}+1)(r_e+R_e)} \times \frac{R_C\parallel R_L}{r_e+R_e}\right|}{\left|-\frac{(\beta_{ac}+1)(r_e+0)}{R_{sig}+(\beta_{ac}+1)(r_e+0)} \times \frac{R_C\parallel R_L}{r_e+0}\right|} = 0.8$$

$$\frac{(\beta_{ac}+1)(r_e+R_e)}{R_{sig}+(\beta_{ac}+1)(r_e+R_e)} \times \frac{R_C\parallel R_L}{r_e+R_e} \times \frac{R_{sig}+(\beta_{ac}+1)(r_e+R_e)}{(\beta_{ac}+1)(r_e+R_e)} \times \frac{r_e+R_e}{R_C\parallel R_L} = 0.8$$

$$\frac{(\beta_{ac}+1)(r_e)+R_{sig}}{(\beta_{ac}+1)} - \frac{(\beta_{ac}+1)(r_e)+R_{sig}}{0.4(\beta_{ac}+1)} = R_e$$

$$\frac{(\beta_{ac}+1)(r_e)+R_{sig}}{(\beta_{ac}+1)}\left(1-\frac{1}{0.8}\right) = R_e$$

$$\frac{(124.6274+1)(41.335\Omega)+10000}{(124.6274+1)}\left(1-\frac{1}{0.8}\right) = R_e$$

$$\boxed{R_e = 30.234\Omega}$$

Expression for R_e when the emitter degeneration resistance (R_{ce}) is inserted with the reduction factor of the mid-band gain 0.4:

$$\frac{\left|-\frac{(\beta_{ac}+1)(r_e+R_e)}{R_{sig}+(\beta_{ac}+1)(r_e+R_e)} \times \frac{R_C\parallel R_L}{r_e+R_e}\right|}{\left|-\frac{(\beta_{ac}+1)(r_e+0)}{R_{sig}+(\beta_{ac}+1)(r_e+0)} \times \frac{R_C\parallel R_L}{r_e+0}\right|} = 0.4$$

$$\frac{(\beta_{ac}+1)(r_e+R_e)}{R_{sig}+(\beta_{ac}+1)(r_e+R_e)} \times \frac{R_C\parallel R_L}{r_e+R_e} \times \frac{R_{sig}+(\beta_{ac}+1)(r_e+R_e)}{(\beta_{ac}+1)(r_e+R_e)} \times \frac{r_e+R_e}{R_C\parallel R_L} = 0.4$$

$$\frac{(\beta_{ac}+1)(r_e)+R_{sig}}{(\beta_{ac}+1)} - \frac{(\beta_{ac}+1)(r_e)+R_{sig}}{0.4(\beta_{ac}+1)} = R_e$$

$$\frac{(\beta_{ac}+1)(r_e)+R_{sig}}{(\beta_{ac}+1)}\left(1-\frac{1}{0.4}\right) = R_e$$

$$\frac{(\beta_{ac}+1)(r_e)+R_{sig}}{(\beta_{ac}+1)}\left(1-\frac{1}{0.4}\right) = R_e$$

$$\frac{(124.627+1)(41.335\Omega)+10000}{(124.627+1)}\left(1-\frac{1}{0.4}\right) = R_e$$

$$\boxed{R_e = 181.403\Omega}$$

R_{ce} values for the reduction factor of 0.8:

$$R_e = R_E \parallel R_{ce}$$
$$30.234 = \frac{R_E(R_{ce})}{R_E+R_{ce}}$$
$$30.234(R_E + R_{ce}) = R_E(R_{ce})$$
$$30.234(3333.33 + R_{ce}) = 3333.33(R_{ce})$$
$$30.234(3333.33) = 3333.33(R_{ce}) - 30.234R_{ce}$$
$$100779.9 = 3303.096R_{ce}$$
$$\boxed{R_{ce} = 30.511\Omega}$$

R_{ce} values for the reduction factor of 0.4:

$$R_e = R_E \parallel R_{ce}$$
$$181.403\Omega = \frac{R_E(R_{ce})}{R_E+R_{ce}}$$
$$181.403\ (R_E + R_{ce}) = R_E(R_{ce})$$
$$181.403\ (3333.33 + R_{ce}) = 3333.33(R_{ce})$$
$$181.403\ (3333.33) = 3333.33(R_{ce}) - 181.403\ R_{ce}$$
$$604676.06 = 3151.93R_{ce}$$
$$\boxed{R_{ce} = 191.84\Omega}$$

iv. **Theoretical Values from simulation:**

3dB bandwidth for different R_{ce} values:

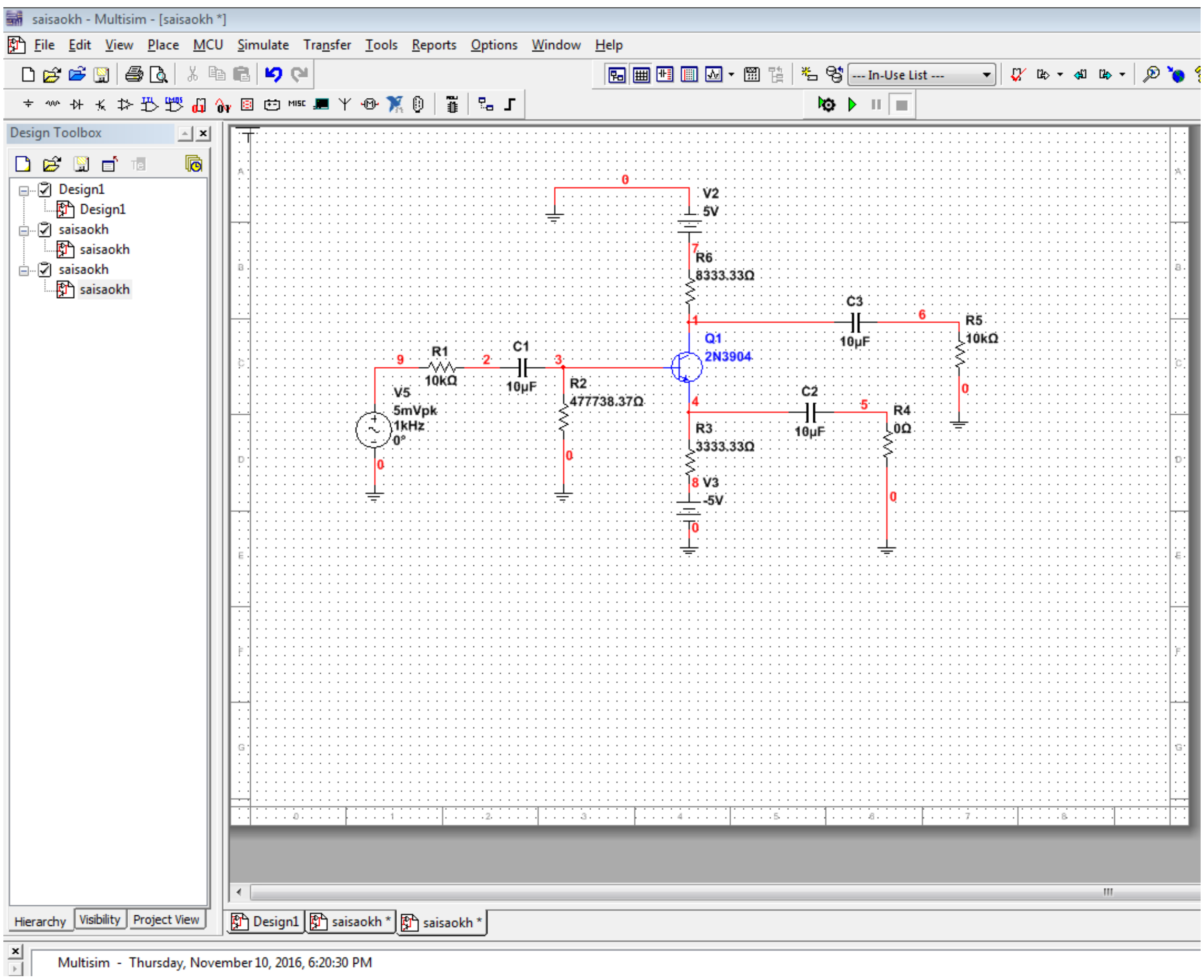
$R_{ce}(\Omega)$	$BW = f_H - f_L(\text{dB})$
0	51.874
30.511	52.695292
191.84	55.67373

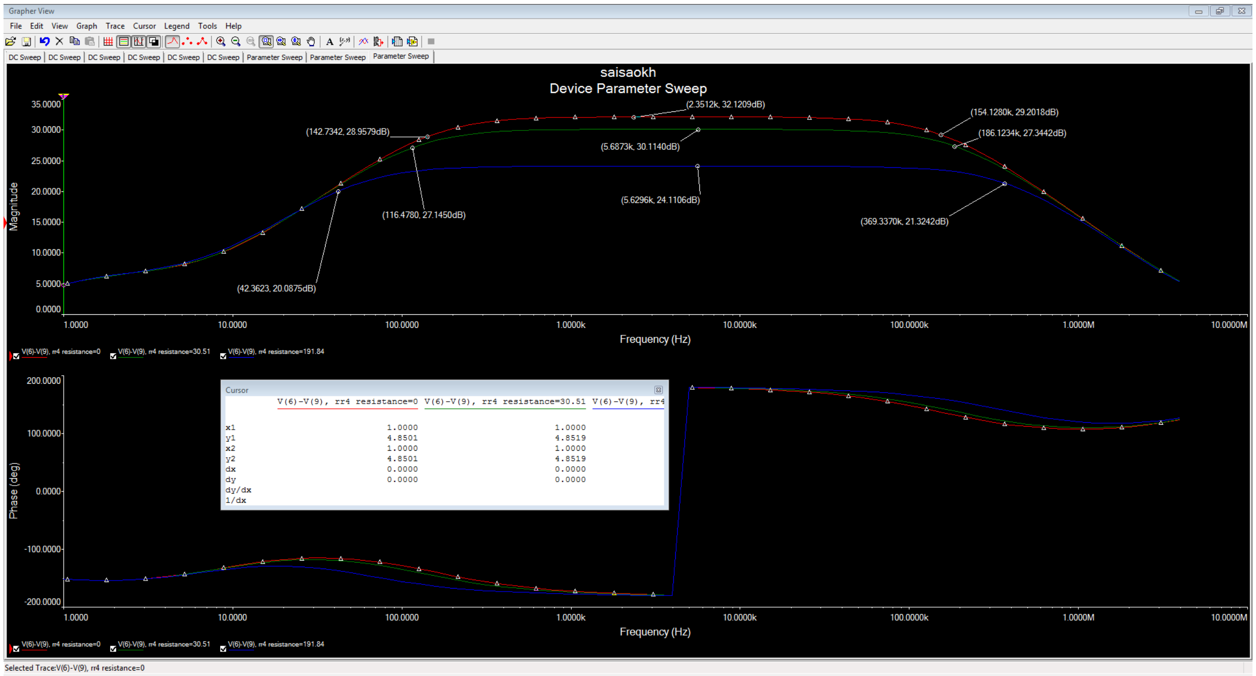
Discussion of the effect of R_{ce} :

As the R_{ce} increase so does the dB bandwidth. Although, the R_{ce} values range from 0 to 30.511Ω to191.84Ω, but the bandwidth for the corresponding R_{ce} seem to be in the same range. The bandwidth ranges from 51.87 to 52.69 to 55.67. The values don't seem to be increasing drastically although the value for the resistance for R_{ce} is changing drastically. Therefore, there seems to be no effect on the bandwidth by the value of resistance. If there is a relationship between the both, and then the only effect is that as the resistance value for R_{ce} increase the dB value for bandwidth increases as well.

Report the values of A_M and BW under each graph:

Rsig=RL=10k, C1=C2=C3=10u, R3=RE=3333.33, R6=RC=8333.33, R2=RB=477738.37, Rce=0



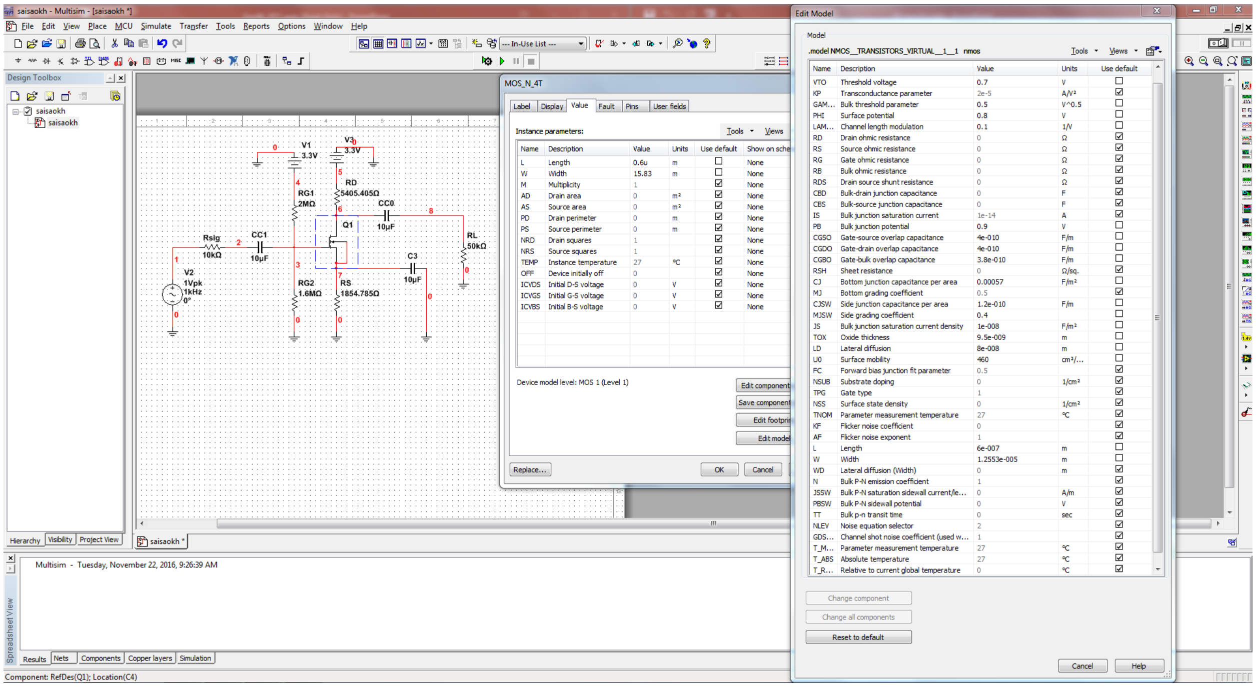


Results obtained from simulation:

Reduction Factor	$R_{ce}(\Omega)$	$A_M(dB)$	ΔA_M *	$f_H(\text{k}Hz)$	$f_L(Hz)$	$BW = f_H - f_L(\text{k}Hz)$
1	0	32.1209		154.128k	142.7342	153.985k
0.8	30.51	30.1140		186.1234k	116.4780	186.006k
0.4	191.84	24.1106		369.3370k	42.3623	369.312k

Part 2.

Circuit Schematic:



i. Find/Report f_H, f_L and A_M.

Hand calculation of W, Leff, R_D, R_S:

Given: $V_{DD} = 3.3V,\ L_{ov} = 0.08\mu m, k_n' = 170.1\frac{\mu A}{V^2}, \lambda = 0.1, V_{ov} = 0.3V, L = 0.6\mu m, P = 1mW$

$$I_D = \frac{P}{V_{DD}} = \frac{0.001}{3.3} = \boxed{3.03\ E - 4A}$$

$$L_{eff} = L - 2L_{ov} = 0.6\mu m - 2(0.08\mu m) = \boxed{0.44\mu m}$$

$$V_{DS} = \frac{V_{DD}}{3} = \frac{3.3}{3} = \boxed{1.1\text{V}}$$

$$\frac{\boldsymbol{W}}{L_{eff}} = \frac{I_D}{\frac{1}{2}k_n' V_{ov}^2(1+\lambda V_{DS})}$$

$$W = \frac{I_D}{\frac{1}{2}k_n' V_{ov}^2(1+\lambda V_{DS})} \times L_{eff}$$

$$W = \frac{3.03E-4}{\frac{1}{2}(170.1\mu)(0.3)^2(1+(0.1)(1.1))}(0.44\mu m) = \boxed{15.8338\mu m}$$

Given: $g_m = \frac{3mA}{V}, r_o = 22.2k\Omega,\ A_v = 12\frac{V}{V},\ R_L = 50k\Omega, RG1 = 2M\Omega, RG2 = 1.6M\Omega,$

$$|A_v| = g_m(\boldsymbol{RD} \| R_L \| r_o)$$

$$|A_v| = g_m\left[\frac{1}{\frac{1}{R_D}+\frac{1}{R_L}+\frac{1}{r_o}}\right]$$

$$12 = (0.003)\left[\frac{1}{\frac{1}{R_D}+\frac{1}{50000}+\frac{1}{22200}}\right]$$

$$4000 = \left[\frac{1}{\frac{1}{R_D}+6.5\times10^{-5}}\right]$$

$$\frac{1}{4000} = \frac{1}{R_D} + 6.5\times10^{-5}$$

$$2\times10^{-4} - 6.5\times10^{-5} = \frac{1}{R_D}$$

$$1.85\times10^{-4} = \frac{1}{R_D}$$

$$\boxed{R_D = 5405.405\Omega}$$

$$V_o = V_{DD} - I_D RD$$

$$V_o = 3.3 - 3.03\times10^{-4}(5405.405)$$

$$\boxed{V_o = 1.662V}$$

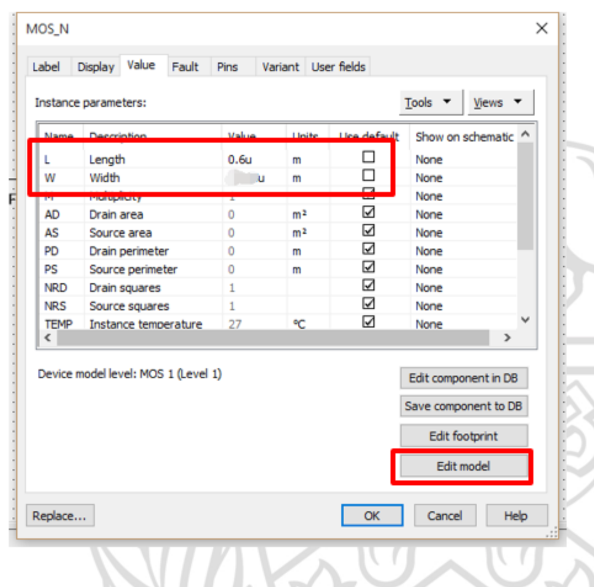
$$\boldsymbol{R_S} = \frac{V_o - \frac{V_{DD}}{3}}{I_D}$$

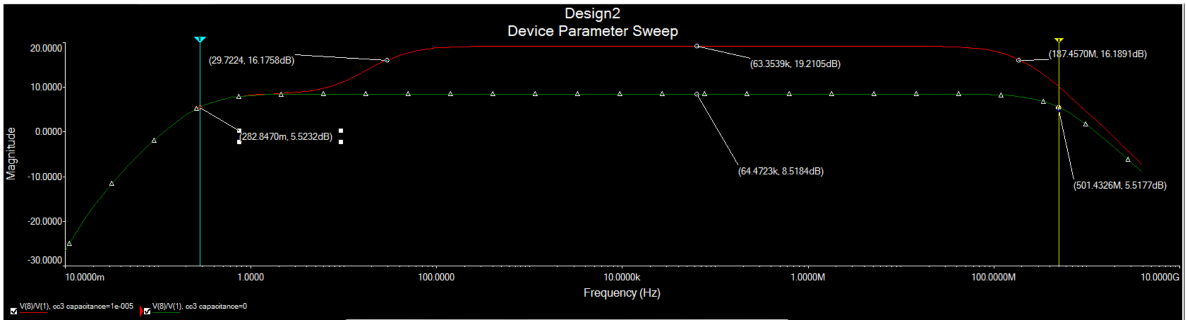
$$\boldsymbol{R_S} = \frac{1.662 - {}^{3.3}/_{3}}{3.03\times10^{-4}}$$

$$\boxed{\boldsymbol{R_S} = 1854.785\Omega}$$

Parameter sweep with plots value i.e. .5 um NMOS with L=.6 um, W=15.83 um as figure below

	5-µm CMOS Process		0.5-µm CMOS Process	
	NMOS	PMOS	NMOS	PMOS
LEVEL	1	1	1	1
TOX	8.50e-08	8.50e-08	9.50e-09	9.50e-09
UO	750	250	460	115
LAMBDA	0.01	0.03	0.1	0.2
GAMMA	1.4	0.65	0.5	0.45
VTO	1	−1	0.7	−0.8
PHI	0.7	0.65	0.8	0.75
LD	7.00e-07	6.00e-07	8.00e-08	9.00e-08
JS	1.00e-06	1.00e-06	1.00e-08	5.00e-09
CJ	4.00e-04	1.80e-04	5.70e-04	9.30e-04
MJ	0.5	0.5	0.5	0.5
CJSW	8.00e-10	6.00e-10	1.20e-10	1.70e-10
MJSW	0.5	0.5	0.4	0.35
PB	0.7	0.7	0.9	0.9
CGBO	2.00e-10	2.00e-10	3.80e-10	3.80e-10
CGDO	4.00e-10	4.00e-10	4.00e-10	3.50e-10
CGSO	4.00e-10	4.00e-10	4.00e-10	3.50e-10





ii. **Find and compare the Gain-Bandwidth product for circuits with C_S=10uF (*this is CS with ac Rs=0*) and C_S=0 (remove Cs: *this is CS with ac Rs=RS*).**

GB (without R_s): $f_H * A_M$= (187.4570M) (19.2105) = 3601.1426M

GB (with R_s): $f_H * A_M$= (501.4326M) (8.5184) = 4271.403460M

iii. **Compare the simulated A_M with your hand calculation for C_S=10uF and C_S=0uF – see below for the formulas.**

a. CS without R_S (R_S=0): $A_v=-g_m(R_D||R_L||r_o)$

$$|A_v| = g_m\left[\frac{1}{\frac{1}{R_D}+\frac{1}{R_L}+\frac{1}{r_O}}\right]$$

$$|A_v| = (0.003)\left[\frac{1}{\frac{1}{5405.405}+\frac{1}{50k}+\frac{1}{22.2k}}\right] = 12\ V/V$$

b. CS with R_S (neglecting r_o): $A_v = -\frac{g_m(R_D||R_L)}{1+g_m R_S}$

$$\frac{R_D(R_L)}{R_D+R_L} = \frac{5405.405(50000)}{5405.405+50000} = 4878.048\Omega$$

$$A_v = -\frac{(0.003)(R_D||R_L)}{1+(0.003)R_S}$$

$$A_v = -\frac{(0.003)(4878.048)}{1+(0.003)(1854.785)}$$

$$A_v = -2.229\ V/V$$

iv. **For the CS amplifier with ac Rs=0 (Cs=10 µF),**

a. **Calculate f_H and compare with simulated Bandwidth**

$C_{in} = C_{gs} + C_{gd}(1 + g_m R'_L)$

(Cgs =0.0697 , Cgd = 6.332 E-15, gm = 0.003 , RL' =4000)

Cin =0.0697

$C_{gs} = (2/3)\,(W/L)\,C_{ox} + W\,CGSO$

(W=15.83 um, L=0.6 um, Cox =, Lov 0.08 um =, CGSO= Lov x Cox)

Cgs = 0.0697

$C_{gd} = W * CGDO$

(W= 15.83 um, CGDO= 4 E-10)

C_{gd} = 6.332 E-15

RL' = RD || RL || r0

(RL=50k , RD =5405.405 Ohm , r0=22.2k Ohm)

RL' =4000 Ohm

$R'_{sig}=R_{sig}||R_G$

(R_{sig}=10k, R_G=888888.889)

R'_{sig}=9888.751 Ohm

$R_G=R_{G1}||R_{G2}$

(R_{G1}=2M Ohm, R_{G2}= 1.6 M Ohm)

R_G=888888.889 Ohm

f_H=1/ (2 pi ∏ C_{in} R'_{sig})

(C_{in} = 0.0697, R'_{sig} =9888.751)

f_H = 2.309 E-4 Hz

b. Calculate GB and compare with simulated GB.

$G_B=f_H * A_M$

(f_H = 2.309 E-4, A_M= -11.86)

G_B= -2.738 E-13

$A_M=(R_{G1}||R_{G2})\ A_v\ /\ (R_{G1}\ ||\ R_{G2}) + R_{sig} = -R_G\ A_v\ /(R_G + R_{sig})$

(R_G=888888.889, R_{sig}= 10000, Av=12)

A_M= -11.86

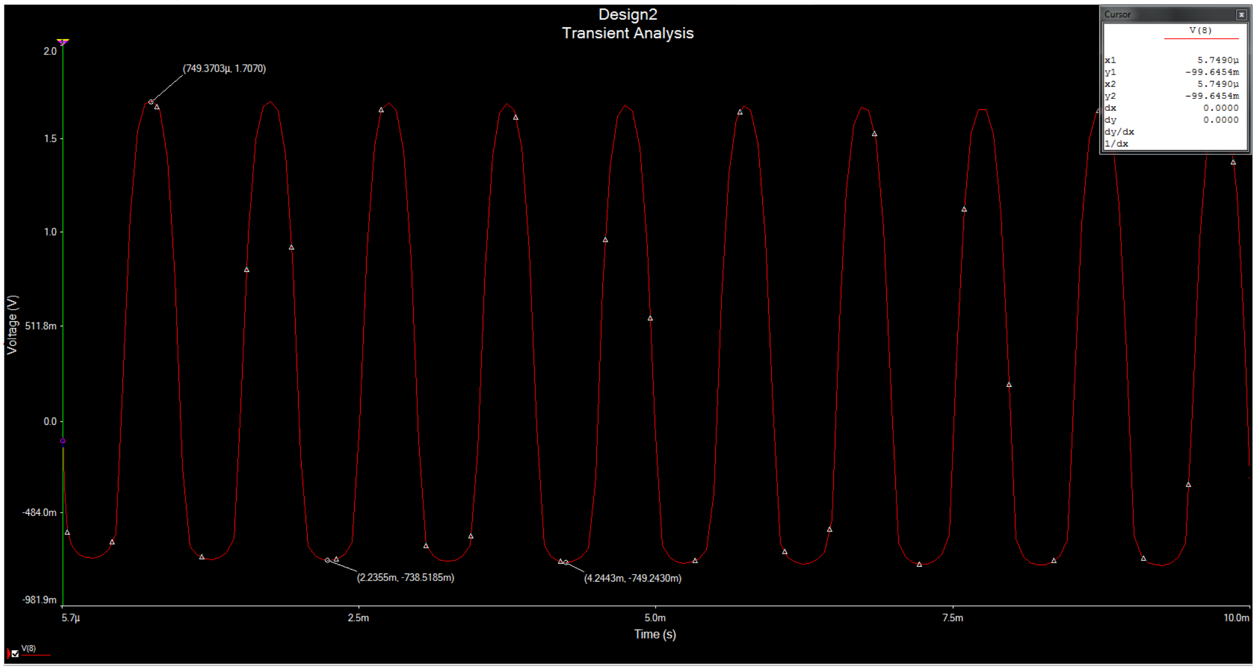
$A_v=gm[1/\ (1/R_D)+ (1/R_L)+(1/r_0)\ ]$

(gm =0.003, R_D=5405.405, R_L=50000, r_0=22200)

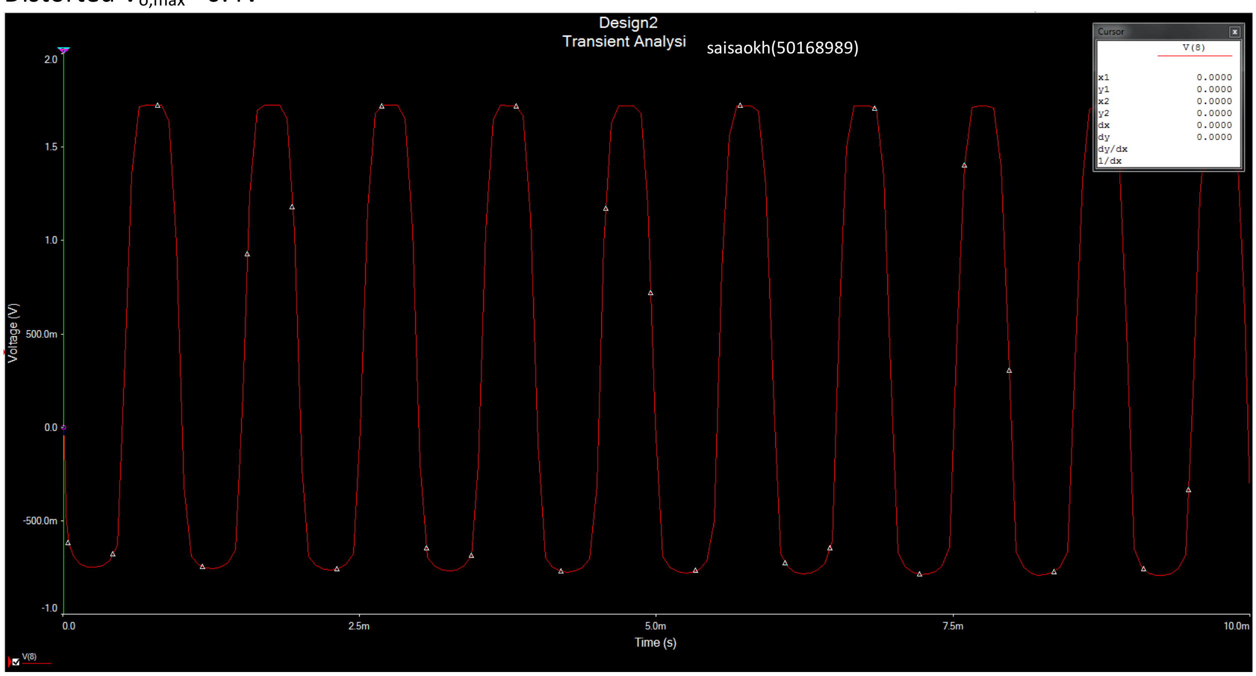
A_v=12 V/V

v. **Find the maximum undistorted amplitude for circuits.**

undistorted $V_{o,max}$= 0.3V



Distorted $V_{o,max}$= 0.4V



vi. **Compare the simulated result with your hand calculation: maximum upswing = $I_D(R_D||R_L)$; maximum downswing = $V_{DS} - V_{ov}$; and the maximum swing before nonlinear distortion= $g_m R_L' * 0.1\, V_{ov}$**

a. *Max Downswing:* $\hat{v}_d = V_{DS} - V_{ov}$ = 1.1-0.3 = 0.8V

b. max upswing $\hat{v}_d = I_D(R_D||R_L||r_o)$ (for CS amp with R_S, ignore r_o)

$\hat{v}_d = I_D(R_D||R_L||r_o)$

$$\hat{\boldsymbol{v}}_{\boldsymbol{d}} = I_D\left[\frac{1}{\frac{1}{R_D}+\frac{1}{R_L}+\frac{1}{r_O}}\right] = 0.2424\text{m}\left[\frac{1}{\frac{1}{5405.405}+\frac{1}{50k}+\frac{1}{22.2k}}\right] = 0.9694\ V \text{ (with } R_s\text{)}$$

$$\hat{\boldsymbol{v}}_{\boldsymbol{d}} = I_D\left[\frac{1}{\frac{1}{R_D}+\frac{1}{R_L}}\right] = 0.2424\text{m}\left[\frac{1}{\frac{1}{5405.405}+\frac{1}{50k}}\right] = 1.1824\ V \text{ (without } R_s\text{)}$$

c. max output swing $\hat{v}_d = g_m R_L' * 0.1\, V_{ov}$ where, $R_L' = R_D||R_L||r_o$ for CS w/o R_S; and $R_L' \approx R_D||R_L$ neglecting r_o for CS w. R_S.

$$R_L' = R_D||R_L||r_o = \frac{1}{\frac{1}{R_D}+\frac{1}{R_L}+\frac{1}{r_o}} = \left[\frac{1}{\frac{1}{5405.405}+\frac{1}{50k}+\frac{1}{22.2k}}\right] = 2.5\times10^{-4}\Omega \quad \text{(without } R_s\text{)}$$

$\hat{v}_d = g_m R_L' * 0.1\, V_{ov}$ = (0.003)(2×10^{-4})(0.1)(0.3) = $1.8\times10^{-8}V$ (without R_s)

$$R_L' = R_D||R_L = \frac{1}{\frac{1}{R_D}+\frac{1}{R_L}} = \left[\frac{1}{\frac{1}{5405.405}+\frac{1}{50k}}\right] = 2.05\times10^{-4}\Omega \text{ (with } R_s\text{)}$$

$\hat{v}_d = g_m R_L' * 0.1\, V_{ov}$ = (0.003)(2.05×10^{-4})(0.1)(0.3) = $1.845\times10^{-8}V$ (with R_s)