ASSIGNMENT 5

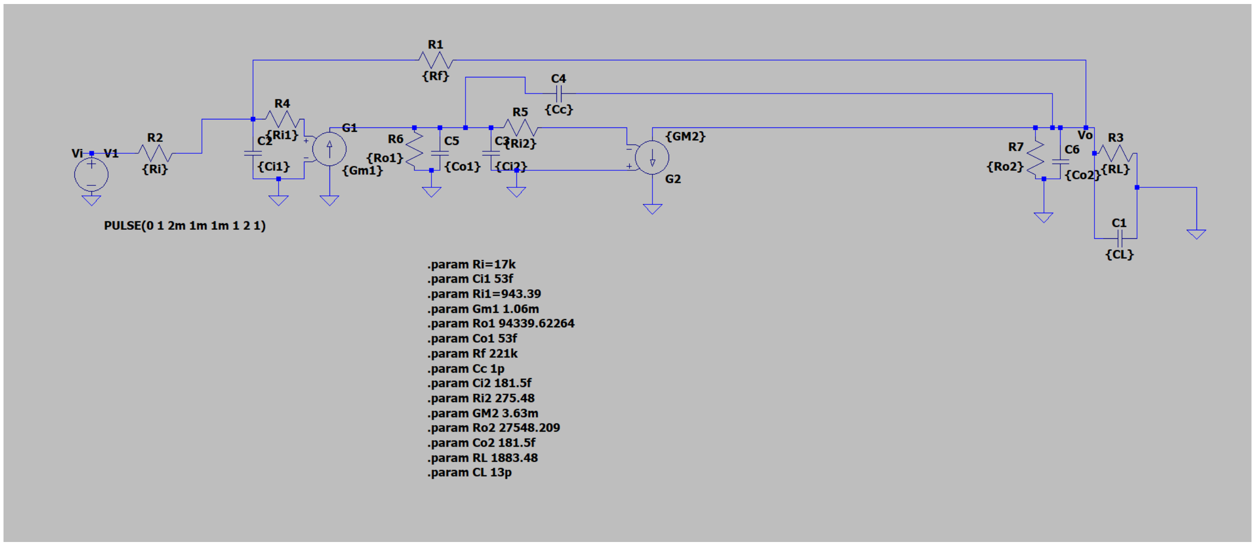
QUESTION 1

Part A

Table has all the specifications

Parameters/ Components Used	Value
Closed Loop DC Gain (K)	13
Closed Loop BandWidth (fb)	13 MHz
Gm1	1.06 mS
Gm2	3.63 mS
Ci1	53 fF
Co1	53 fF
Ro1	94339.62 ohm
Ci2	0.1815 pF
Co2	0.1815 pF
Ro2	27548.209 ohm
CL	13 pF
Cc	1 PF
RL	1883.48 Ohms
Ri	17Kohms

Wu,loop	81681408.99 rad/sec
P2(non-dominant Pole)	326725636 rad/sec



Schematic for Q1

.param Rin 17k
.param Ci1 53f

.param Gm1 1.06m
.param Ro1 94339.62264
.param Co1 53f
.param Rf 221k
.param Cc 1p
.param Ci2 181.5f

.param GM2 3.63m
.param Ro2 27548.209
.param Co2 181.5f
.param RL 1883.48
.param CL 13p

Parameters assigned
Hand Calculations

Tutorial-5

(1) Closed loop DC gain = -13

$K = 13$

Closed loop band width

$f_B = 13 MHz$

Load Capacitor $C_L = 5 + (25-17)$
$= 13 \, pF$

Load resistor $R_L = \frac{10^6}{2\pi \times 13 \times 13} = 1883.43$

Input resistance

$R_i = 17 k\Omega$

$C_C = 1 pF$ $\quad P_2 = 4 \times (\omega_{u, loop})$

closed loop bandwidth

$C_i = C_0 = \frac{G_m}{\omega_T}$ $\quad \omega_T = 2 \times 10^{10}$

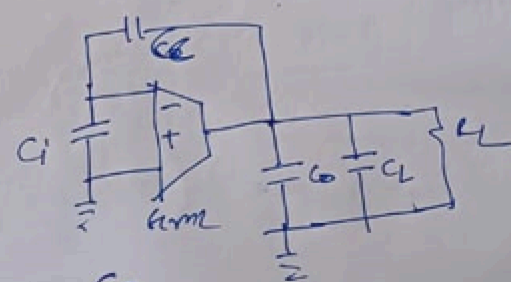
$G_0 = \frac{G_m}{100}$ $\quad R_T = \frac{1}{G_m}$

(a) closed loop bandwidth ≈ loop gain ~ unity

$= 2\pi f \; 13 \times 10^6$

$= 81681408.99$ rad/sec

$4\omega_u = P_2$



$$P_2 = \frac{\frac{1}{R_L} + \frac{C_C}{C_i + C_C}}{C_0 + C_L + \frac{C_C C_i}{C_C + C_i}}$$

$$\omega_u = \frac{\frac{1}{R_L} + \frac{C_c G_m}{C_c + \frac{G_m}{\omega_T}}}{\left(C_L + \frac{G_m}{\omega_T}\right) + \frac{C_c\left(\frac{G_m}{\omega_T}\right)}{C_c + \frac{G_m}{\omega_T}}}$$

$$4\omega_u = \frac{\frac{C_c + \frac{G_m}{\omega_T}}{R_L} + C_c G_m}{C_c\left(\frac{G_m}{\omega_T}\right) + \left(C_c + \frac{G_m}{\omega_T}\right)\left(C_L + \frac{G_m}{\omega_T}\right)}$$

$$4\omega_u\left[C_c\frac{G_m}{\omega_T} + C_cC_L + (C_c+C_L)\frac{G_m}{\omega_T} + \frac{G_m^2}{\omega_T^2}\right] = G_m C_c + \frac{C_c}{R_L} + \frac{G_m}{R_L\omega_T}$$

$$\left(\frac{4\omega_u}{\omega_T^2}\right)G_m^2 + \left[4(2C_c+C_L)\frac{\omega_u}{\omega_T} - C_c - \frac{1}{\omega_T R_L}\right]G_m + \left(4\omega_u C_c C_L - \frac{C_c}{R_L}\right) = 0$$

$$\cancel{4}\times\frac{\omega_u}{\omega_T^2}$$

$$4\times\frac{8168408.09}{4\times10^{20}}G_m^2 + G_m\left[4\times[15\times10^{-12}]\times\frac{8168408.09}{2\times10^{20}} - 10^{-12} - \frac{1}{941.74\times2\times10^{10}\times2}\right]$$

$$+\ 4\times8168408.09\times10^{-24}\times13 - \frac{10^{-12}}{941.74\times2} = 0$$

$\frac{Gm_1}{KCC} = \omega_{uloop} = 8168408.99$

$Gm_1 = 8168408.99 \times 13 \times 10^{-12}$

$= 1.06 \times 10^{-3}$

$Gm_2 = \boxed{3.63 \times 10^{-3}} / 1.2531$

$R_f = K R_i$

$= 13 \times 17 K\Omega$

$= 221 K\Omega$

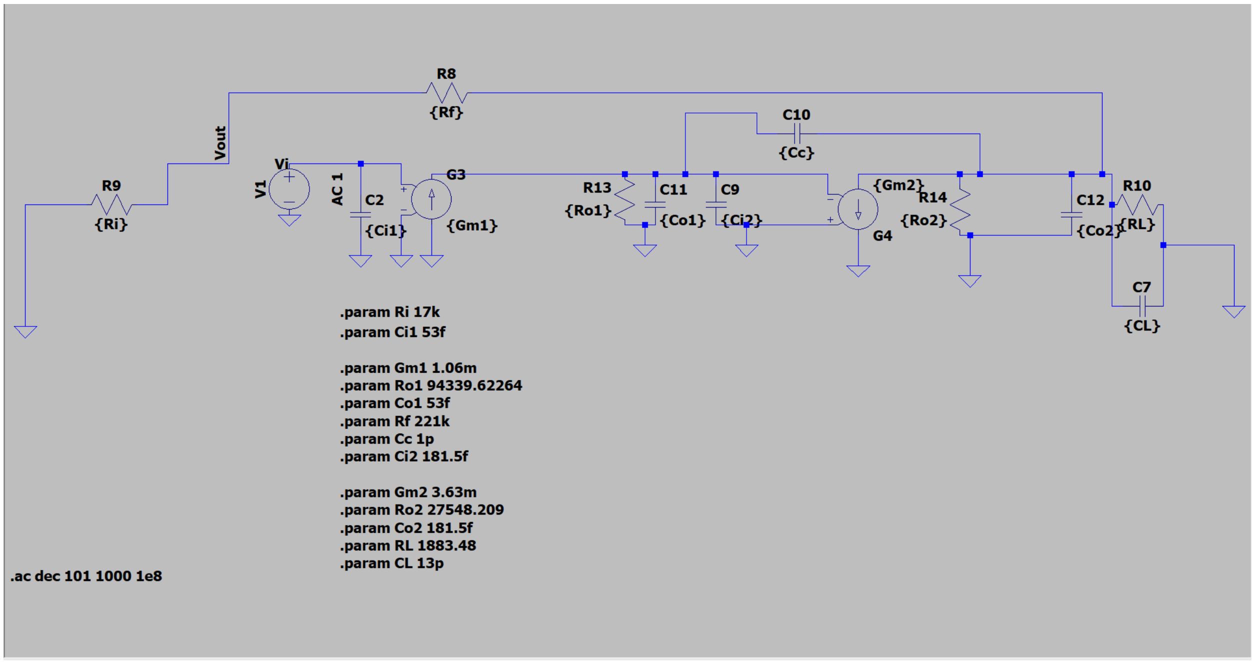
① $\boxed{C_i = \frac{Gm_1}{\omega_T} \quad C_0 = \frac{Gm_1}{\omega_T}}$ $\frac{\boxed{5.3 \times 10^{-14}}}{R_{01}}$ $RN1 = 943.39$

$= 94339.62264$

② $\boxed{C_i = \frac{Gm_2}{\omega_T} = \quad C_0 = \frac{Gm_2}{\omega_T} = }$ 1.815×10^{-13} $R_{02} = \frac{27548.209}{}$ $RN2 = 275.48$

B) LOOP GAIN and Phase Margin

Schematic:



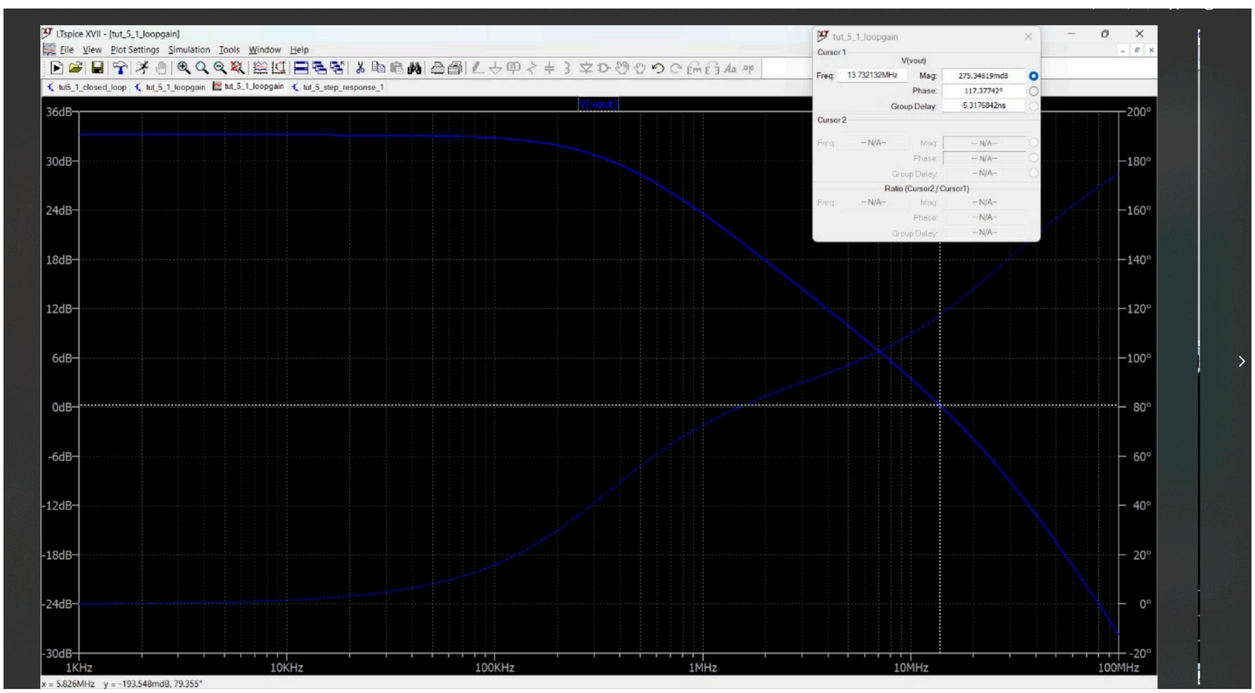


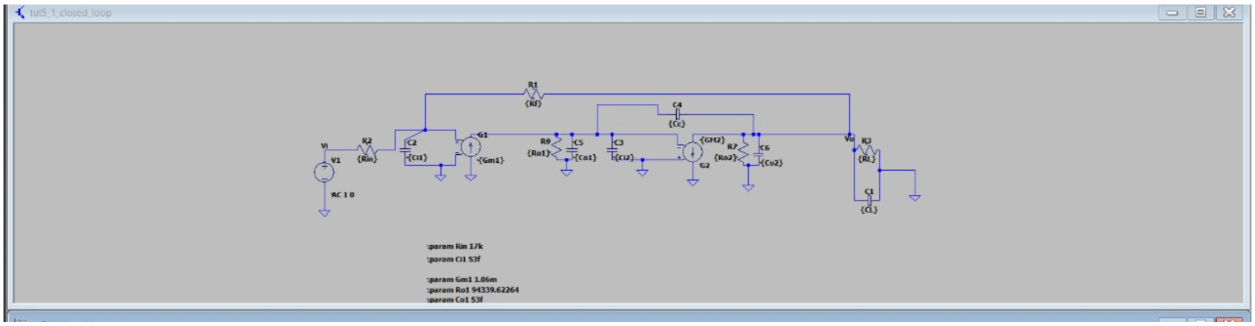
Fig 1: Magnitude and Phase of Loop Gain vs Frequency

It can be observed that the unity gain frequency is equal to approximately 13.7321 MHz (close to 13 MHz)

And the observed phase Margin at the loop gain frequency is equal to 180-117.3 = 62.7 degrees

C) Closed Loop Transfer Function

Schematic:



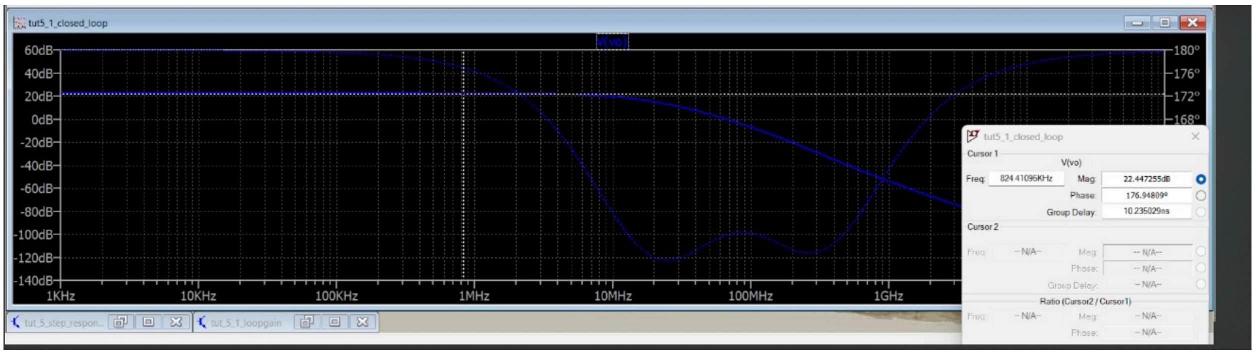


Fig 2

It can be observed from fig 2, that DC gain of the closed loop is equal to 22.447 which is corresponding to a magnitude of 13.25 (approximately 13, which is the desired one).

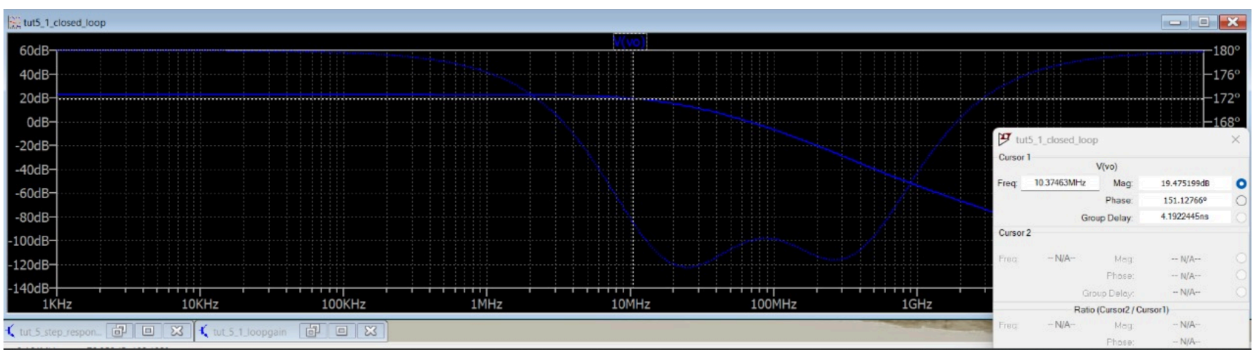


Fig 3

From fig 3, we can see that the 3-dB Bandwidth is equal to 10.37 MHz, which is close to the requirement of the question(3 dB bandwidth= 13MHz and DC gain=k=13)

D) Unit Step Response:

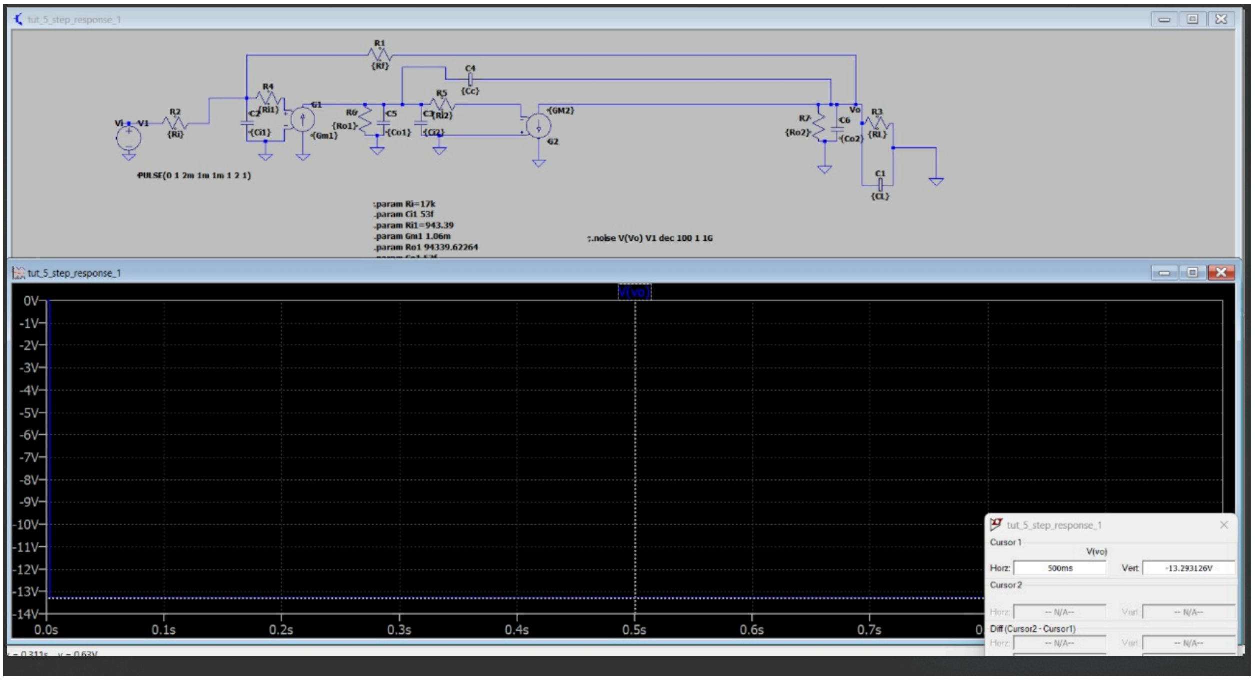


Fig 4: Unit step Response

A unit step is applied with the help of a pulse function in the input at the output with respect to time is a DC Voltage of -13.29 Volts, so there is a steady error of 0.29 volts (as the desired one is -13 volts)

E) Output and Input referred noise

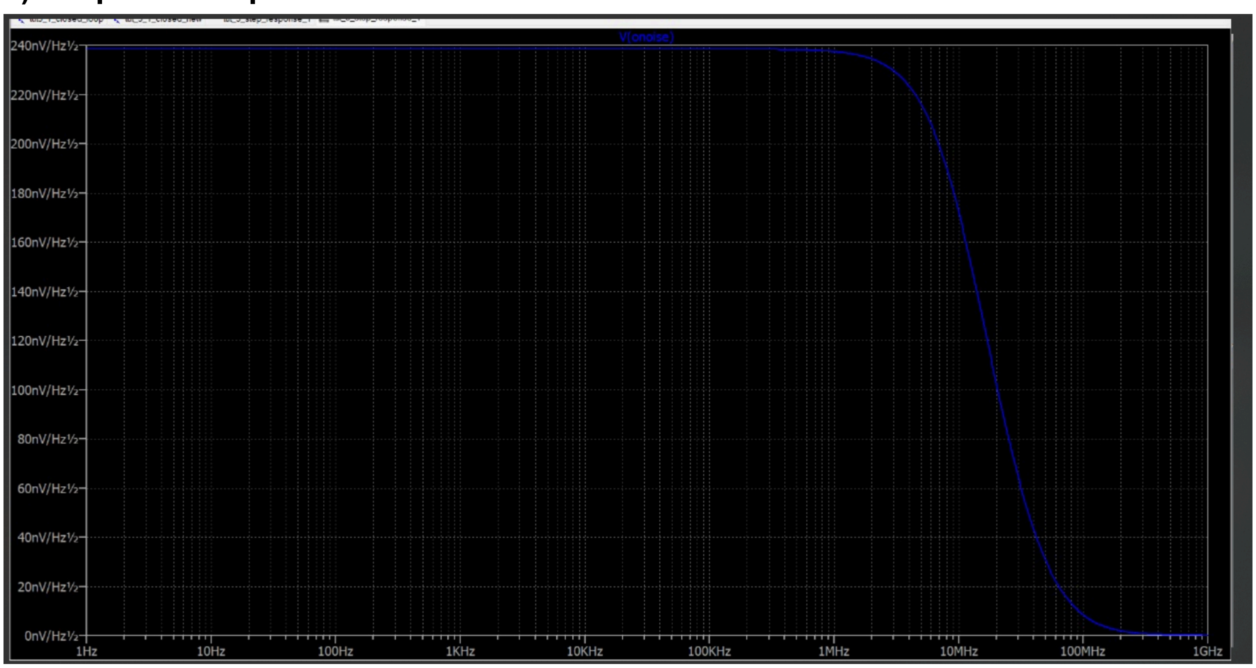


Fig 5: Output Noise PSD (in units)

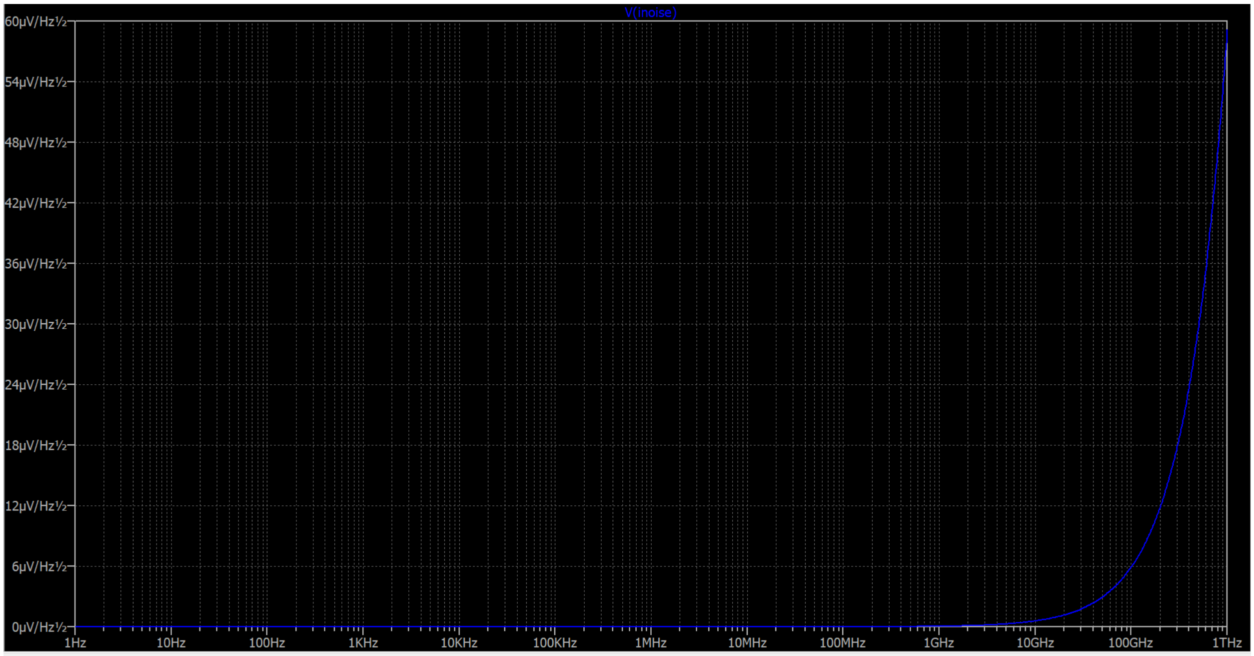
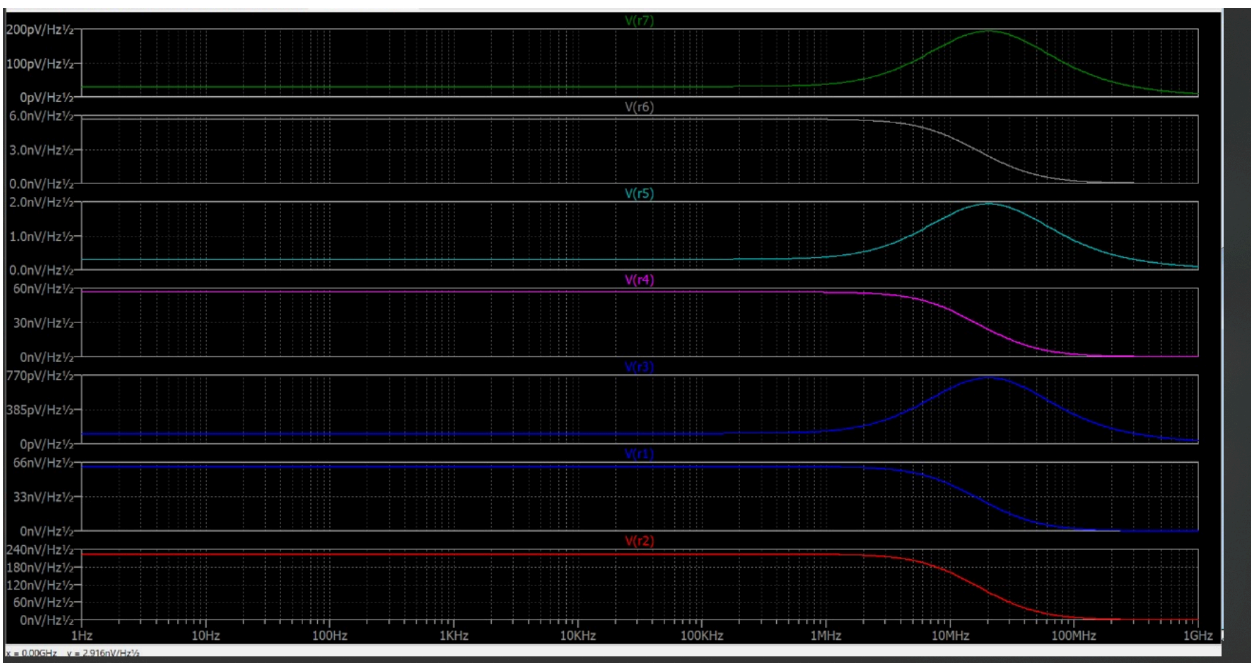


Fig 6: Input Noise PSD

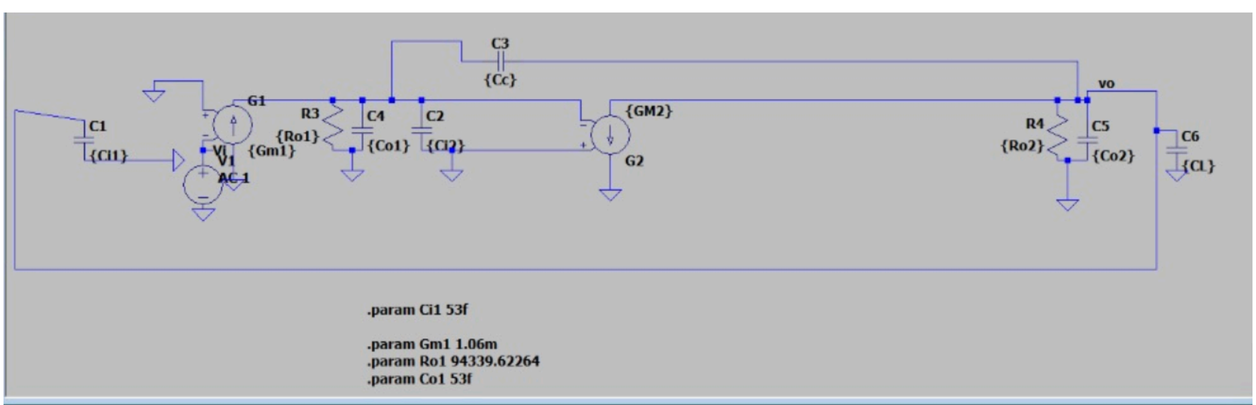


Noise contribution by different resistors

	Obtained Value	**Desired Value**

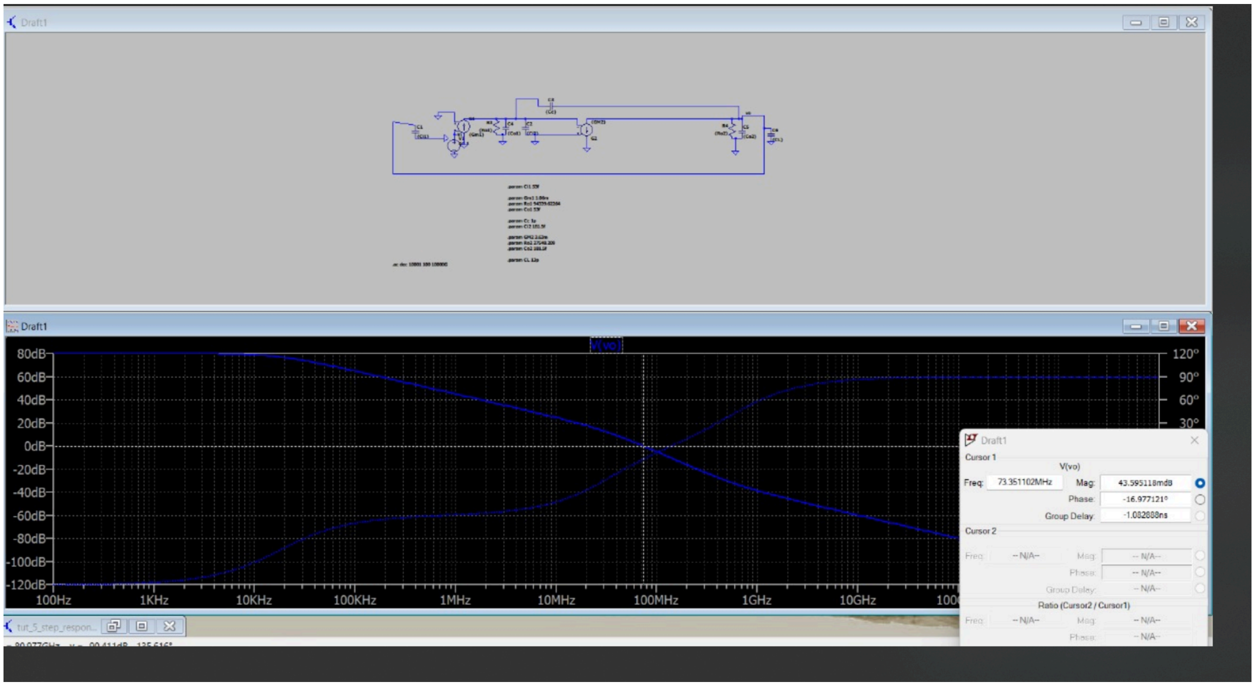
DC Gain	13.29	13
3-dB Bandwidth	10.37 MHz	13MHz
Unity Loop Gain frequency	13.73 MHz	14 MHz
Phase Margin	62.7	
Input Noise PSD at low frequency	0 Hz	
Noise Contribution by Ri (R2)	223.13685nV/Hz½	92.9%
Noise Contribution by Rf (R1)	61.879241nV/Hz½	25.78%
Noise Contribution by Gm1 (R4) RN1	56.581834nV/Hz½	23.575%
Noise Contribution by Gm2 (R5) RN2	309.1015pV/Hz½	0.128%
Noise Contribution by RL (R3)	117.04343pV/Hz½	0.04875%

Problem 2



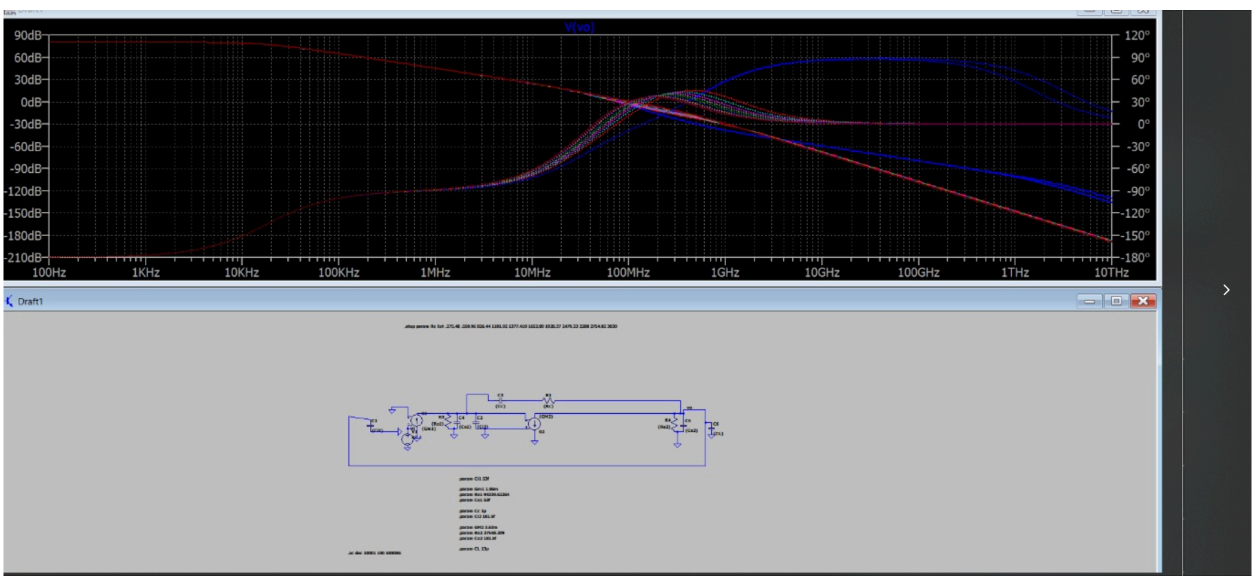
Schematic used for question 2

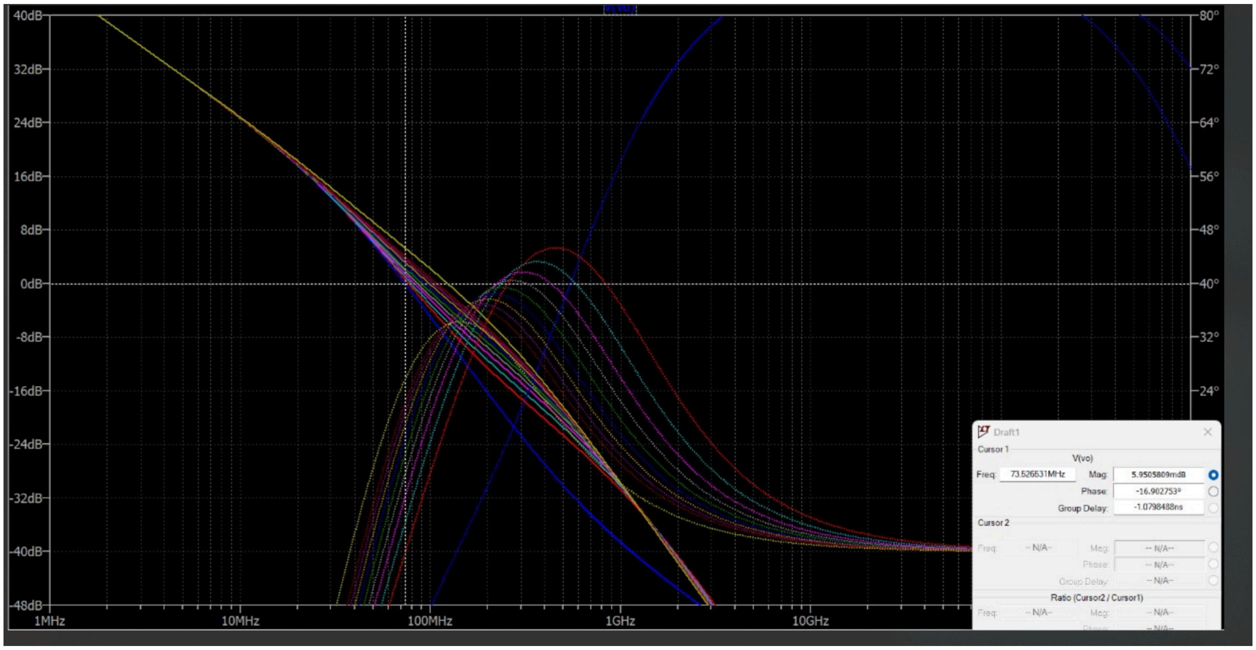
A) Conventional Miller Opamp



We can see that the voltage gain is close to 0dB, the observed phase margin is equal to 16.97 degrees

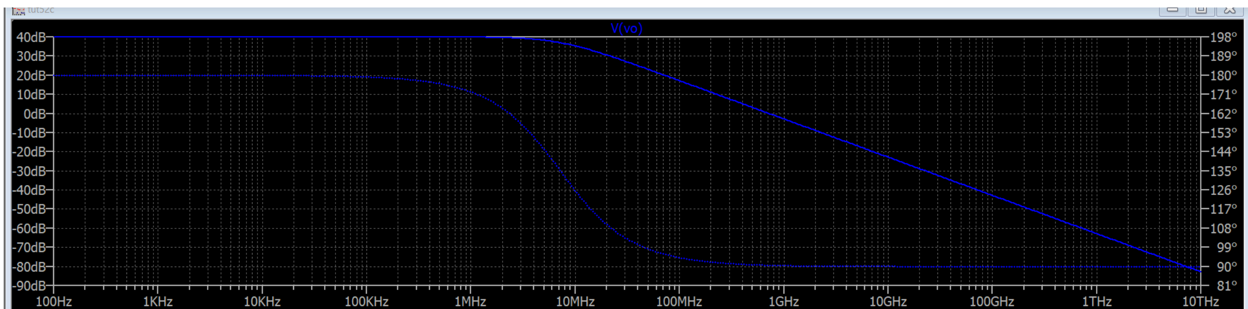
B) With Rc in series with Cc

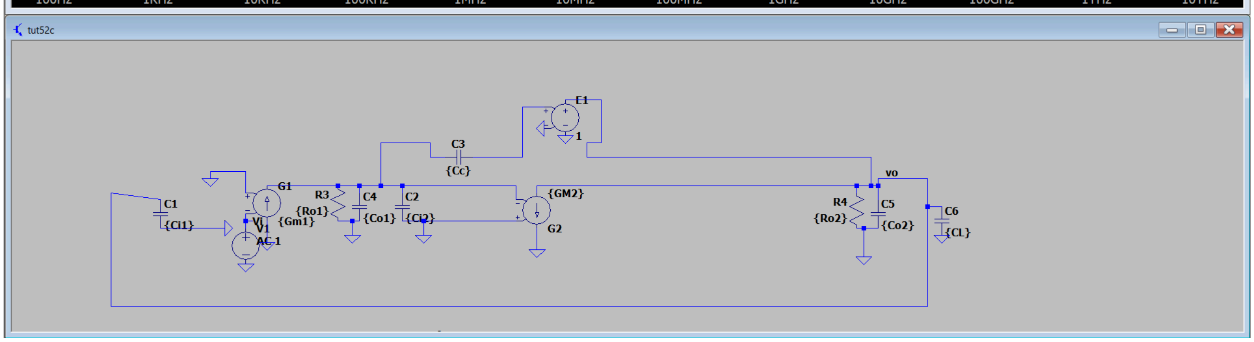




We see that PM increases as Rz increases (pm for different Rz can be seen in left side of the diagram) Hence the optimal value is obtained for Rz=10/Gm2=2.75 K ohm for which the phase margin was around 41 degrees.

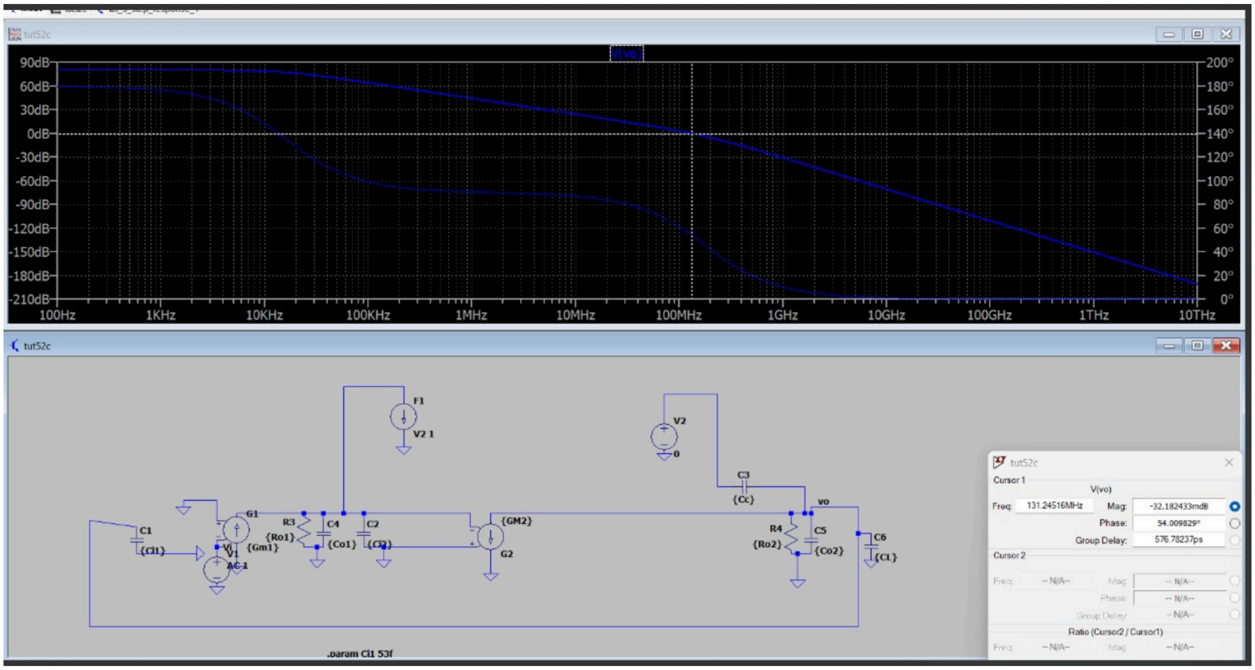
C) With a unity Gain buffer to drive Cc





The phase Margin has changed significantly from 5.2 a

D) Use of CCCS

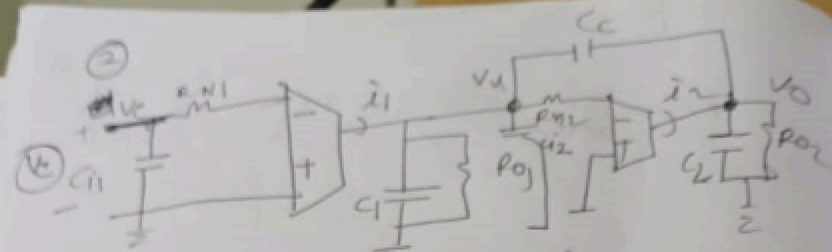


The phase Margin has changed significantly from 5.2 a

Phase margin table:

Circuit	Phase margin in degrees
5.a) Simple miller opamp	16.9
5.b) Miller opamap with Rz	41
5.c) Miller opamp with unity buffer	18
5.d) Miller opamap with cccs	40

Transfer Function



Rn2 >> Rn1 → Both noise.

$$i_2 = -G_{m2} V_u$$

$$i_1 = -G_{m1} V_e$$

$$i_1 = \frac{V_u}{R_{o1}} + V_u\, s(C_1 + C_{gs2} + C_c) - V_o s C_c$$

$$i_2 = V_o(s)(C_2 + C_c) + \frac{V_o}{R_{o2}} - V_u s C_c$$

$$(sC_c - G_{m2})\, V_u = \left[s(C_2 + C_c) + \frac{1}{R_{o2}} \right] V_o$$

$$V_u = \left(\frac{s(C_2 + C_c) + 1/R_{o2}}{sC_c - G_{m2}} \right) V_o$$

$$-G_{m1} V_e = V_o \frac{\left(s(C_2 + C_c) + 1/R_{o2}\right)}{(sC_c - G_m)} \left(\frac{1}{R_{o1}} + s(C_1 + C_{gs} + C_c) \right) - V_o s C_c$$

$$\frac{-G_{m1}}{\frac{\left(s(C_2 + C_c) + 1/R_{o2}\right)\left(1/R_{o1} + s(C_1 + C_{gs} + C_c)\right)}{(sC_c - G_m)} - sC_c} = \frac{V_o}{V_e}$$

$$\frac{V_o}{V_e} = \frac{-G_{m1}\,(sC_c - G_m)}{\left(s(C_2+C_c)+\frac{1}{R_{o2}}\right)\left(s(C_1+C_c+C_{i2})+\frac{1}{R_{o1}}\right) - sC_c(sC_c - G_m)}$$

(7) (b) by replacing

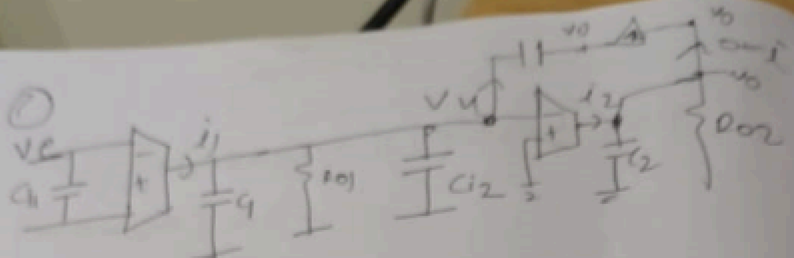
$$\frac{1}{sC_c} \Rightarrow \frac{1}{sC_c} + R_z$$

$$sC_c \Rightarrow \frac{sC_c}{1+sC_cR_z}$$

$$\frac{V_o}{V_e} = \frac{-G_{m1} \times \left(\frac{sC_c}{1+sC_cR_z} - G_m\right)}{\left[s\left(C_2+\frac{C_c}{1+sC_cR_z}\right)+\frac{1}{R_{o2}}\right]\left[s\left(C_1+\frac{C_c}{1+sC_cR_z}+C_{i2}\right)+\frac{1}{R_{o1}}\right] - \frac{sC_c}{1+sC_cR_z}\left(\frac{sC_c}{1+sC_cR_z}-G_m\right)}$$

$$= \frac{-G_m\left(s(C_c - C_cR_zG_m) - G_m\right)}{\left[\left(s(C_c+C_2(1+sC_cR_z)) + \frac{1+sC_cR_z}{R_{o2}}\right)\left(s((C_1+C_{i2})sC_cR_z+C_c) + \frac{1+sC_cR_z}{R_{o1}}\right)\right] - sC_c\left(\frac{sC_c}{1+sC_cR_z} - G_m\right)}$$

①



$i_1 = -G_{m1} v_e$

$i_2 = -G_{m2} v_x$

$i_1 = v_x (s)(C_1 + C_{i2}) + \frac{v_x}{R_{o1}}$

$i_2 = V_o sC_2 + \frac{v_o}{R_{o2}}$

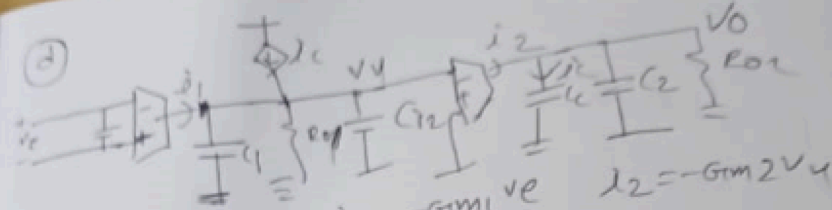
$-v_x G_{m2} = v_o \left[sC_2 + \frac{1}{R_{o2}}\right]$

$v_x = \frac{-v_o\left[sC_2 + \frac{1}{R_{o2}}\right]}{G_{m2}}$

$-G_{m1} V_e = -\left(s(C_1 + C_{i2}) + \frac{1}{R_{o1}}\right) v_o \frac{\left[sC_2 + \frac{1}{R_{o2}}\right]}{G_{m2}}$

$$\frac{G_{m1} G_{m2}}{\left[s(C_1 + C_{i2}) + \frac{1}{R_{o1}}\right]\left[sC_2 + \frac{1}{R_{o2}}\right]} = \frac{v_o}{v_e}$$

(d)



$i_1 = -G_{m1} v_e \qquad i_2 = -G_{m2} v_x$

$$i_c + i_1 = v_x(s)(C_1 + C_{i2}) + \frac{v_x}{R_{o1}}$$

$$i_2 = i_c + v_o s C_2 + \frac{v_o}{R_{o2}}$$

$$i_c = v_o s C_c$$

$$v_x = \frac{-v_o}{G_{m2}}\left[s(C_2 + C_c) + \frac{1}{R_{o2}}\right)$$

$$+G_{m1} v_e = +\left[s(C_1 + C_{i2}) + \frac{1}{R_{o1}}\right]\frac{v_o}{G_{m2}}\left(s(C_2 + C_c) + \frac{1}{R_{o2}}\right) + v_o s C_c$$

$\cancel{v_e = v_o}$

$$\frac{v_o}{v_e} = \frac{G_{m1}}{sC_c + \frac{1}{G_{m2}}\left[s(C_1 + C_{i2}) + \frac{1}{R_{o1}}\right)\left[s(C_2 + C_c) + \frac{1}{R_{o2}}\right)}$$

$$\frac{R_{o2}}{sC R_{o2} + 1}$$