# Analog IC Design Homework 5 Report


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## Question 1. – With Feedback

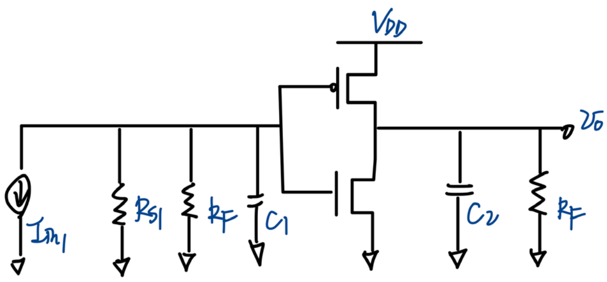
(a) 設計流程與思路一併在(g)說明

```
****** operating point status is all       simulation time is     0.
   node      =voltage        node      =voltage        node      =voltage

+0:vdd      =    1.5000  0:vout1    = 750.4936m 0:vx       = 750.4839m

subckt
element  0:mm1       0:mm2
model    0:n_18.1    0:p_18.1
region   Saturation Saturation
 id         4.0493m   -4.0494m
 ibs      -6.112e-19  3.747e-19
 ibd       -3.8663f   16.0060f
 vgs      750.4839m -749.5161m
 vds      750.4936m -749.5064m
 vbs        0.         0.
 vth      498.7108m -513.9264m
 vdsat    221.4183m -249.0028m
 vod      251.7731m -235.5897m
 beta     125.1057m  127.7853m
 gam eff  507.4492m  557.0845m
 gm        23.9604m   28.5792m
 gds        1.0869m  595.7755u
 gmb        3.6088m    8.7543m
 cdtot     93.1420f  540.9352f
 cgtot    138.0504f    1.1266p
 cstot    193.6599f    1.4859p
 cbtot    171.0663f    1.0966p
 cgs      100.8982f  894.5840f
 cgd       25.7086f  172.4379f

****** ac analysis tnom=  25.000 temp=  25.000 ******
dcgain_in_db=  59.5506
bw= 675.6105x
```

(b)

```
****      small-signal transfer characteristics

     v(vout1)/iin1                                 = -949.5797
     input resistance at              iin1         =   49.4317
     output resistance at v(vout1)                 =   18.8021
```

(c)




$$\mathrm{R_{in,open}} = R_F||R_{S1}||\left(\frac{1}{sC_1}\right)$$

$$\mathrm{R_{out,open}} = R_F \parallel r_{on} \parallel r_{op}||\left(\frac{1}{sC_2}\right)$$

$$\text{Open Loop Gain Ro} = -(\mathrm{gmn}+\mathrm{gmp})(R_F||r_{on}||r_{op}||\left(\frac{1}{sC_2}\right))(R_F||R_{S1}||\left(\frac{1}{sC_1}\right))$$

$$\mathrm{i_F} = -i_{RF} = -\frac{V_{out1}}{R_F} \Rightarrow K = \frac{i_F}{V_{out1}} = \frac{1}{-R_F}$$

$$\begin{cases} R_{in,closed} = R_{in,open}/(1+KRo) \\ R_{out,closed} = R_{out,open}/(1+KRo) \\ Closed\ Loop\ Gain\ \dfrac{V_{out1}}{I_{in1}} = \dfrac{Ro}{1+KRo} \end{cases}$$

<u>**Calculations**</u>

$(\text{In low frequency}, \mathrm{s} = \mathrm{jw} \rightarrow 0)$

$\mathrm{R_{in,open}} = R_F||R_{S1} = 980.3921569\Omega$

$\mathrm{R_{out,open}} = R_F||r_{on}||r_{op} = 372.7621921\Omega$

$\text{Open Loop Gain Ro} = -(\mathrm{gmn}+\mathrm{gmp})(R_F||r_{on}||r_{op})(R_F||R_{S1}) = -19200.76124\Omega$

$\mathrm{K} = -\frac{1}{\mathrm{R_F}} = -0.001\left(\frac{1}{\Omega}\right)$

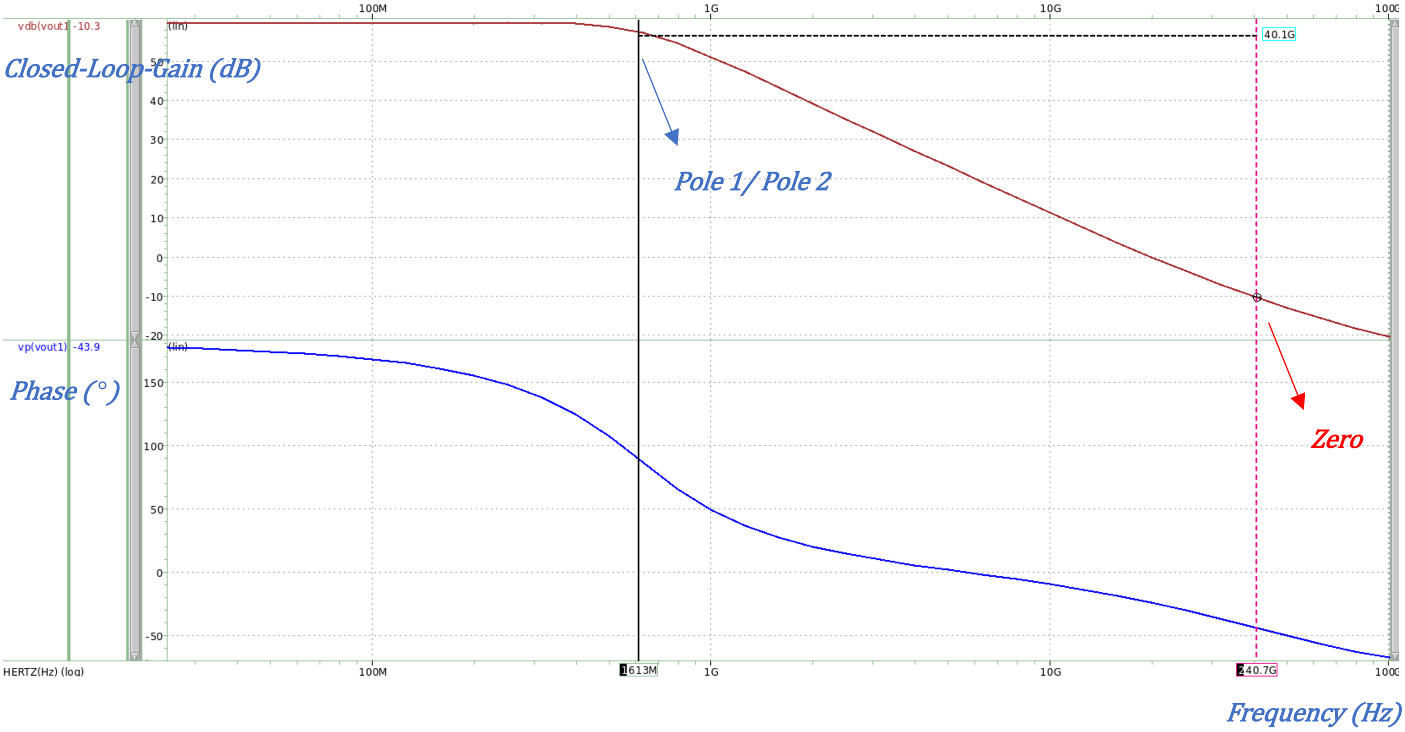
$1+\mathrm{KRo} = \left(1-0.001*(-19200.76124)\right) = 20.20076124$

$$\begin{cases} R_{in,closed} = \dfrac{R_{in,open}}{1+KRo} = 48.53243623\Omega \\ R_{out,closed} = \dfrac{R_{out,open}}{1+KRo} = 18.45287846\Omega \\ Closed\ Loop\ Gain\ \dfrac{V_{out1}}{I_{in1}} = \dfrac{Ro}{1+KRo} = -950.496915\Omega \end{cases}$$

| | Simulation | Hand Calculation | Error |
|---|---|---|---|
| **Input Impedance** | 49.4317Ω | 48.53243623Ω | 1.853% |
| **Output Impedance** | 18.8021Ω | 18.45287846Ω | 1.893% |
| **Transimpedance DC Gain** | -949.5797Ω | −950.496915Ω | 0.096% |

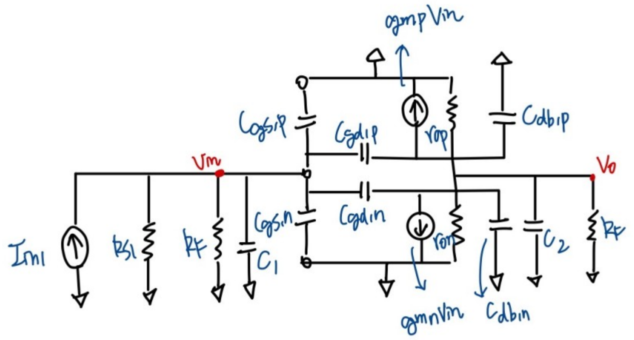
由此可觀察到手算值與模擬值差不多，但因為沒有 body effect 的關係，因此可推測誤差來源來自電路中的寄生電容。

(d)




```
 ******   pole/zero analysis


  input =  0:iin1          output = v(vout1)

       poles (rad/sec)                 poles ( hertz)
 real            imag            real            imag
 -2.42396g       2.99081g        -385.786x       476.002x
 -2.42396g       -2.99081g       -385.786x       -476.002x

       zeros (rad/sec)                 zeros ( hertz)
 real            imag            real            imag
 255.714g        0.              40.6981g        0.


****** ac analysis tnom=  25.000 temp=  25.000 ******
dcgain_in_db=  59.5506
bw= 675.6105x
```

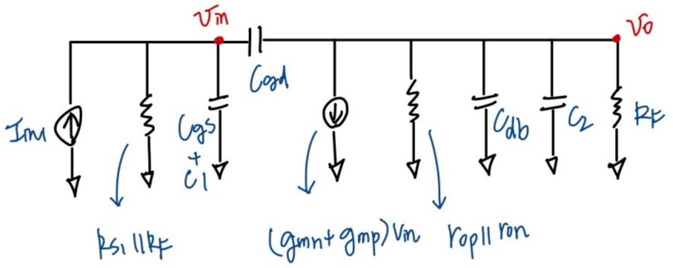
(e) Calculate the output pole and zero




let $C_{gs} = C_{gsn} \parallel C_{gsp} = C_{gsn} + C_{gsp}$

$C_{gd} = C_{gdn} \parallel C_{gdp} = C_{gdn} + C_{gdp}$

$C_{db} = C_{dbn} \parallel C_{dbp} = C_{dbn} + C_{dbp}$




$$\begin{cases} \dfrac{V_o - V_{in}}{1/sC_{gd}} = \dfrac{V_{in}}{1/s(C_{gs}+C_1)} + \dfrac{V_{in}}{R_{S1} \parallel R_F} - I_{in1} \quad \text{— ①} \\[2ex] \dfrac{V_o - V_{in}}{1/sC_{gd}} + (g_{mn}+g_{mp})V_{in} + \dfrac{V_o}{(r_{on} \parallel r_{op})} + \dfrac{V_o}{1/sC_{db}} + \dfrac{V_o}{1/sC_2} + \dfrac{V_o}{R_F} = 0 \quad \text{— ②} \end{cases}$$

$$① \Rightarrow sC_{gd} \cdot V_o - sC_{gd} V_{in} = s(C_{gs}+C_1)V_{in} + V_{in}/(R_{S1} \parallel R_F) - I_{in1}$$

$$\Rightarrow sC_{gd} V_o + I_{in1} = V_{in}\left(sC_{gd} + s(C_{gs}+C_1) + 1/R_{S1} \parallel R_F\right)$$

$$② \Rightarrow sC_{gd} V_o - sC_{gd} V_{in} + (g_{mn}+g_{mp}) V_{in} + V_o\left(\frac{1}{r_{on} \parallel r_{op}} + sC_{db} + sC_2 + \frac{1}{R_F}\right) = 0$$

$$\Rightarrow V_o\left(sC_{gd} + \frac{1}{r_{on} \parallel r_{op}} + sC_{db} + sC_2 + \frac{1}{R_F}\right) = V_{in}\left(sC_{gd} - (g_{mn}+g_{mp})\right)$$

$$\Rightarrow V_{in} = \frac{V_o\left(sC_{gd} + 1/r_{on} \parallel r_{op} + sC_{db} + sC_2 + 1/R_F\right)}{sC_{gd} - (g_{mn}+g_{mp})}$$

② substitute in ①

$$sC_{gd} V_o + I_{in1} = \frac{V_o\left(sC_{gd} + 1/(r_{on} \parallel r_{op}) + sC_{db} + sC_2 + \frac{1}{R_F}\right)}{sC_{gd} - (g_{mn}+g_{mp})} \cdot \left(sC_{gd} + s(C_{gs}+C_1) + \frac{1}{R_{S1} \parallel R_F}\right)$$

$$\Rightarrow I_{in} = \left(\frac{sC_{gd} + \frac{1}{r_{on} \parallel r_{op}} + sC_{db} + sC_2 + \frac{1}{R_F}}{sC_{gd} - (g_{mn}+g_{mp})} \cdot \left(sC_{gd} + s(C_{gs}+C_1) + \frac{1}{R_S \parallel R_F}\right) - sC_{gd}\right) V_o$$

$\therefore$ Open loop Gain $R_o$

$$R_o = \frac{V_o}{I_{m1}} = \left( \frac{sC_{gd} + \frac{1}{r_{on} \parallel r_{op}} + sC_{db} + sC_2 + \frac{1}{R_F}}{sC_{gd} - (g_{mn} + g_{mp})} \cdot \left(sC_{gd} + s(C_{gs} + C_1) + \frac{1}{R_{S1} \parallel R_F}\right) - sC_{gd} \right)^{-1}$$

let $sC_1' = sC_{gd} + sC_{db} + sC_2$ $\qquad sC_2' = sC_{gd} + sC_{gs} + sC_1$

$$1/R_1 = \frac{1}{r_{on} \parallel r_{op}} + \frac{1}{R_F} \qquad 1/R_2 = \frac{1}{R_{S1} \parallel R_F}$$

$$\Rightarrow R_o = \frac{V_o}{I_{m1}} = \left( \frac{\left(\frac{1}{R_1} + sC_1'\right)\left(\frac{1}{R_2} + sC_2'\right)}{sC_{gd} - (g_{mn} + g_{mp})} - sC_{gd} \right)^{-1}$$

$$= \left( \frac{1}{sC_{gd} - (g_{mn} + g_{mp})(R_1 \parallel \frac{1}{sC_1'})(R_2 \parallel \frac{1}{sC_2'})} - sC_{gd} \right)^{-1}$$

$$= \frac{[sC_{gd} - (g_{mn} + g_{mp})](R_1 \parallel \frac{1}{sC_1'})(R_2 \parallel \frac{1}{sC_2'})}{1 - sC_{gd}[(sC_{gd} - (g_{mn} + g_{mp}))(R_1 \parallel \frac{1}{sC_1'})(R_2 \parallel \frac{1}{sC_2'})]}$$

$$= \frac{(sC_{gd} - (g_{mn} + g_{mp})) \cdot \frac{R_1 R_2}{(R_1 sC_1' + 1)(R_2 sC_2' + 1)}}{1 - sC_{gd}\left\{(sC_{gd} - (g_{mn} + g_{mp})) \cdot \frac{R_1 R_2}{(R_1 sC_1' + 1)(R_2 sC_2' + 1)}\right\}}$$

$$= \frac{sC_{gd} R_1 R_2 - (g_{mn} + g_{mp}) R_1 R_2}{s^2(R_1 R_2 C_1 C_2 - C_{gd}^2 R_1 R_2) + s(R_1 C_1 + R_2 C_2 + C_{gd}(g_{mn} + g_{mp}) R_1 R_2) + 1}$$

$$= \frac{ds + e}{as^2 + bs + 1}$$

where $\quad a = R_1 R_2 C_1' C_2' - C_{gd}^2 R_1 R_2$

$\quad b = R_1 C_1' + R_2 C_2' + C_{gd}(g_{mn} + g_{mp}) R_1 R_2$

$\quad d = C_{gd} R_1 R_2$

$\quad e = -(g_{mn} + g_{mp}) R_1 R_2$

$\therefore$ Closed loop Gain $\left.\frac{V_{out}}{I_{in}}\right|_{closed}$

$$= \frac{R_o}{1+kR_o} = \frac{\frac{ds+e}{as^2+bs+1}}{1+k\frac{ds+e}{as^2+bs+1}}$$

$$= \frac{ds+e}{(as^2+bs+1)+kds+ke}$$

$$= \frac{ds+e}{as^2+(b+kd)s+(1+ke)}$$

From .lis file, we know that there are two poles and a zero in this circuit

, that is, the transfer function $T(s) = \frac{\alpha(1+\frac{s}{\omega_z})}{\beta(1+\frac{s}{\omega_{p1}})(1+\frac{s}{\omega_{p2}})}$, where $\alpha = e$, $\beta = 1+ke$

, then

(1) poles $as^2+(b+kd)s+(1+ke)=0$

$$\Rightarrow s = \frac{-(b+kd) \pm \sqrt{(b+kd)^2-4a(1+ke)}}{2a}$$

(2) zero $ds+e=0$

$$\Rightarrow s = \frac{-e}{d}$$

$$\begin{cases} a = R_1R_2C_1'C_2' - C_{gd}^2R_1R_2 = 6.9899E-19 \\ b = R_1C_1' + R_2C_2' + C_{gd}(g_{mn}+g_{mp})R_1R_2 = 6.5643E-09 \\ d = C_{gd}R_1R_2 = 7.24133E-08 \\ e = -(g_{mn}+g_{mp})R_1R_2 = -19200.76124 \end{cases}$$

$$\begin{cases} R_1 = \dfrac{1}{\dfrac{1}{r_{on} \parallel r_{op}} + \dfrac{1}{R_F}} = 372.7621921 \\ R_2 = R_{S1} \parallel R_F = 980.3921569 \\ C_1' = C_{gd} + C_{db} + C_2 = 1.63408E-12 \\ C_2' = C_{gd} + C_{gs} + C_1 = 2.19363E-12 \end{cases}$$

**Zero**:

$$\omega_z = -\frac{e}{d} = 2.65155E + 11\ \left(\frac{\text{rad}}{\text{sec}}\right) = 42.20078098\ (\text{GHz})$$

$\omega_{z,calculate} = 42.20078098\ (\text{GHz})$

$\omega_{z,simulation} = 40.6981\ (\text{GHz})$

$$\text{Error}(\omega_z) = \left|\frac{40.6981 - 42.20078098}{42.20078098}\right| = 0.035607895 \cong 3.561\%$$

**Poles**:

$$\omega_p = \frac{-(b + kd) \pm \sqrt{(b + kd)^2 - 4a(1 + ke)}}{2a} = -2.5052832 \pm j * 3.052031662\ (G * rad/s)$$

$$= -398.7282051 \pm j * 485.7459255\ (MHz)$$

$\omega_{p1} = -398.7282051 + j * 485.7459255\ (MHz)$

$\omega_{p2} = -398.7282051 - j * 485.7459255\ (MHz)$

$$|\omega_{p,calculation}| = \sqrt{398.7282051^2 + 485.7459255^2} = 628.4371773\ (MHz)$$

$$|\omega_{p,simulation}| = \sqrt{385.786^2 + 476.002^2} = 612.7060811\ (MHz)$$

$$\text{Error}(\omega_p) = \left|\frac{612.7060811 - 628.4371773}{628.4371773}\right| = 0.02503209 \cong 2.50\%$$

| | *\|Pole\|* | *Zero* |
|---|---|---|
| *Simulation* | 612.7060811 ($MHz$) | 40.6981 (GHz) |
| *Hand Calculation* | 628.4371773 ($MHz$) | 42.20078098 (GHz) |
| *Error* | 2.503% | 3.561% |

可以從上表觀察到公式推導之 pole 與 zero 值誤差小，存在誤差原因可能是因為電路中寄生電容的影響與數值上取位之誤差。

(f)

```
**** voltage sources

subckt
element  0:vvdd
 volts       1.5000
 current    -4.0494m
 power       6.0740m
```

$$\text{FOM} = \frac{\text{total current (uA)}}{\text{transimpedance gain (k}\Omega) * -3\text{dB bandwidth (MHz)}} = \frac{4049.4}{0.9495797 * 675.6105} = 6.311940063$$

**<u>設計思路：</u>**

條參數時，我發現 W 增加時，M1 電流上升，Gain 上升；L 增加時，Gain 會變動(gm 下降，ro 上升，因此要看 size 比例，L 上升 Gain 變大變小都可能)、-3dB bandwidth 下降(因為 Cout 隨

L 上升而增加)。我的策略是將 L 條小，這樣可以降低 ro 值並控制 bandwidth 不要太小。但在第一次調整 gain 達到要求後，Vout 與 bandwidth 還沒有達到，但參考 e 小題 pole 的公式可以看到增加 gm 值可以增加 bandwitdh 及 pole 的大小，因此由上述條小 L 策略增加 gm 之大小；第二次調整主要著重在 Vout 的部分，由於 Vout=Vx-Ix*RF=Vx-(Id,n-Id,p)*RF，我的策略是將 Id,n 調至與 Id,p 相近可以增加 Vout 值。最後達到題目要求的規格為 Wn/Ln＝35.5um/0.2um , m=2、Wp/Lp＝60um/0.3um , m=8、Iin1=15uA。

**優化思路：**

可以觀察到在 FOM 公式中電流影響是最大的，因此要降低電流，要調低 W/L 與 m 值，調低 W/L 可能造成 gmn 與 gmp 之下降，但由於上述思路分析 L 降低，總體 closed-loop gain 不一定會下降，且如上述分析 L 降低 bandwidth 可以有效控制在理想範圍內，因此總體而言，將 L 條小，再根據電路參數表現去調正 W 與 m 值，最後在電流、bandwidth 與 gain 之間的 trade-off 取得平衡是我認為最適優化方法。

# Question 2. – Without Feedback

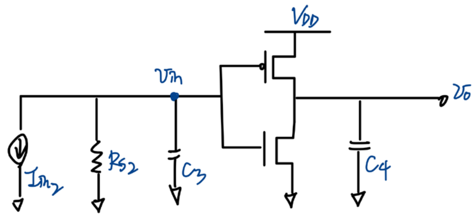
(a)

```
subckt
element  0:mm3       0:mm4
model    0:n_18.1    0:p_18.1
region   Saturation Saturation
 id         4.0541m   -4.0541m
 ibs      -6.120e-19  3.752e-19
 ibd       -3.9442f   15.6831f
 vgs      750.0000m -750.0000m
 vds      765.6154m -734.3846m
 vbs        0.          0.
 vth      498.2462m -513.9266m
 vdsat    221.4050m -249.4002m
 vod      251.7538m -236.0734m
 beta     125.1125m  127.7704m
 gam eff  507.4492m  557.0845m
 gm        23.9958m   28.5542m
 gds        1.0741m  608.3536u
 gmb        3.6123m    8.7476m
 cdtot     92.9033f  542.3872f
 cgtot    138.0470f    1.1266p
 cstot    193.6568f    1.4859p
 cbtot    170.8367f    1.0980p
 cgs      100.8882f  894.6236f
 cgd       25.7063f  172.4584f

****** operating point status is all       simulation time is     0.
   node    =voltage       node    =voltage       node    =voltage

+0:vdd      =    1.5000   0:vout2    = 765.6154m 0:vx       = 750.0000m

****** ac analysis tnom=  25.000 temp=  25.000 ******
dcgain_in_db= 123.8698
bw= 375.1525k
```

(b)

```
****      small-signal transfer characteristics

     v(vout2)/iin2                          =   -1.5619x
     input resistance at           iin2     =    50.0000k
     output resistance at v(vout2)          =   594.7208
```

(c)




(consider s=jw⟶0)

$$\mathrm{R_{out}} = r_{on} \parallel r_{op} \parallel \left(\frac{1}{sC_4}\right) = (931.0120101 \parallel 1643.780854) = 594.370032(\Omega)$$

$$\text{Gain Ro} = -(\text{gmn} + \text{gmp})\left(r_{on} \parallel r_{op} \parallel \left(\frac{1}{sC_4}\right)\right)\left(R_{S2} \parallel \left(\frac{1}{sC_3}\right)\right)$$

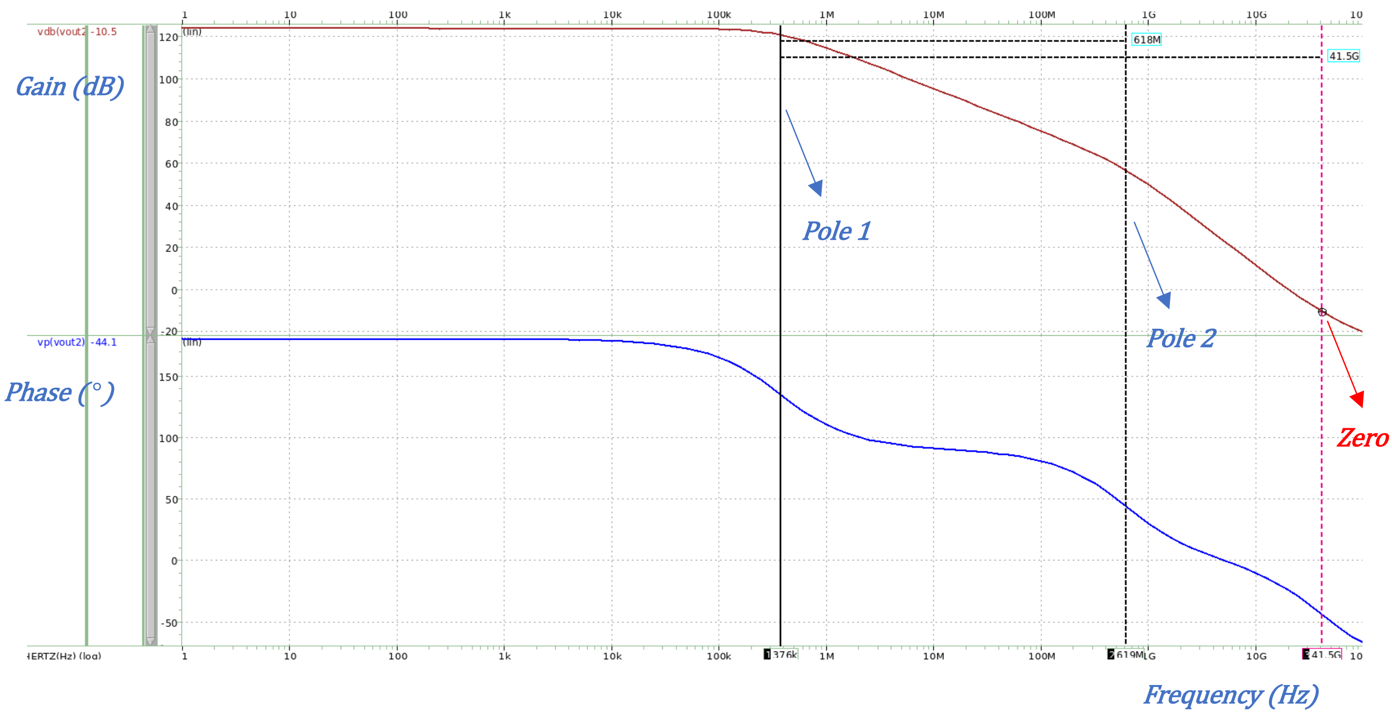
$$= -(23.9958\text{m} + 28.5542\text{m})(594.370032)(50\text{k}) = -1.561707259\ (\text{M}\Omega)$$

| | Simulation | Hand Calculation | Error |
|---|---|---|---|
| **Output Impedance** | 594.7208 (Ω) | 594.370032 (Ω) | 0.059% |
| **Transimpedance DC Gain** | -1.5619 (MΩ) | −1.561707259 (MΩ) | 0.012% |

由上述推導與計算可觀察到誤差極小，應為數值取位數之誤差造成。

(d)

```
******   pole/zero analysis

 input =  0:iin2          output = v(vout2)

        poles (rad/sec)                  poles ( hertz)
real              imag           real              imag
-2.36152x         0.             -375.848k         0.
-3.88745g         0.             -618.707x         0.

        zeros (rad/sec)                  zeros ( hertz)
real              imag           real              imag
260.646g          0.             41.4831g          0.
```



(e) 與上題 feedback 的公式類似，僅將在公式中的 RF 移除，即可得到結果。

$$\mathrm{Ro} = \frac{\mathrm{Vo}}{\mathrm{I_{in2}}} = \frac{sC_{gd}R_1R_2 - (g_{mn} + g_{mp})R_1R_2}{s^2(R_1R_2C_1'C_2' - C_{gd}^2R_1R_2) + s(R_1C_1' + R_2C_2' + C_{gd}(g_{mn} + g_{mp})R_1R_2) + 1}$$
$$= \frac{ds + e}{as^2 + bs + 1}$$

$$\begin{cases} a = R_1R_2C_1{}'C_2{}' - C_{gd}^2R_1R_2 = 1.05442E - 16 \\ b = R_1C_1{}' + R_2C_2{}' + C_{gd}(g_{mn} + g_{mp})R_1R_2 = 4.20131E - 07 \\ d = C_{gd}R_1R_2 = 5.88916E - 06 \\ e = -(g_{mn} + g_{mp})R_1R_2 = -1561707.25897 \end{cases}$$

$$\begin{cases} R_1 = r_{on} \parallel r_{op} = 594.370032 \\ R_2 = R_{S2} = 50000 \\ C_1{}' = C_{gd} + C_{db} + C_4 = 1.63529E - 12 \\ C_2' = C_{gd} + C_{gs} + C_3 = 2.19368E - 12 \end{cases}$$

**Zero**:

$$\omega_z = -\frac{e}{d} = 2.65183E + 11\ \left(\frac{rad}{sec}\right) = 42.20525785\ (GHz)$$

$$\omega_{z,calculate} \cong 42.2052\ (GHz)$$

$$\omega_{z,simulation} = 41.4831\ (GHz)$$

$$\mathrm{Error}(\omega_z) = \left|\frac{41.4831 - 42.2052}{42.2052}\right| = 0.017110613 \cong 1.711\%$$

**Poles**:

$$\omega_p = \frac{-b \pm \sqrt{b^2 - 4a}}{2a} = -1.992235598 \pm 1.989853965\ \left(G * \frac{rad}{s}\right)$$
$$= -2.381633309\ \left(M * \frac{rad}{s}\right)\ and\ -3.982089562\ \left(G * \frac{rad}{s}\right)$$

$$\omega_{p1} = -2.381633309\ \left(M * \frac{rad}{s}\right) = -379.0487137\ (kHz)$$

$$\omega_{p2} = -3.982089562\ \left(G * \frac{rad}{s}\right) = -633.7692377\ (MHz)$$

$$\mathrm{Error}(\omega_{p1}) = \left|\frac{375.848 - 379.0487137}{379.0487137}\right| = 0.844\%$$

$$\mathrm{Error}(\omega_{p2}) = \left|\frac{618.707 - 633.7692377}{633.7692377}\right| = 2.377\%$$

| | *Pole 1* | *Pole 2* | *Zero* |
|---|---|---|---|
| *Simulation* | 375.848 ($kHz$) | 618.707 (MHz) | 41.4831 (GHz) |
| *Hand Calculation* | 379.0487137 ($kHz$) | 633.7692377 (MHz) | 42.2052 (GHz) |
| *Error* | 0.844% | 2.377% | 1.711% |

可以從上表觀察到公式推導之 pole 與 zero 值誤差小，存在誤差原因可能是因為電路中寄生電容的影響與數值上取位之誤差。

## Question 3. – Discussion

(a) 首先，最明顯的差別是沒有 feedback 的電路 gain 較大，而 feedback 之 closed loop gain 小許多，這是因為回授多了一個倍率在分母，當 A0 很大時，總體增益 $\frac{A_0}{1+A_0\beta}$ 趨近於 $\frac{1}{\beta}$。再來，可以觀察到相同的電路參數下，feedback 的 bandwidth 大許多，相較非回授電路多了 $1+A_0\beta$倍；從上題與上上題推導可知輸出與輸入電阻在 RF 回授下因為並聯與除上 (1+KA) 倍因子，皆變小許多。總結來說，回授會造成放大增益的穩定，但是代價為增益大小；另外，回授可以有效的控制輸入及輸出之阻抗，並增加頻寬大小，以下整理 feedback 與無 feedback 之優缺點。

- **Feedback**

**優點：**

1. **增益穩定性**:回饋能夠穩定電路增益,使其更接近設計值,並且不易受到元件參數變異的影響。
2. **頻寬增大**：負回饋可以增大電路的頻寬，提高其頻率響應性能。
3. **失真減少**：回饋能夠減少非線性失真，改善信號質量。
4. **輸入和輸出阻抗**：回饋可以調節輸入和輸出阻抗，使其符合設計要求。

**缺點：**

1. **電路複雜度**：回饋結構增加了電路的複雜度，設計和分析變得更加困難。
2. **穩定性問題**：在某些情況下，回饋可能導致電路不穩定，特別是在高頻段。
3. **功耗增加**：由於回饋網絡的存在，總功耗可能會增加。

- **Without Feedback**

**優點：**

1. **結構簡單**：無回饋電路結構簡單，設計和分析相對容易。
2. **功耗較低**：由於沒有回饋網絡，功耗可能較低。

**缺點：**

1. **增益不穩定**：無回饋電路的增益容易受到元件參數變異的影響，難以保持穩定的增益值。
2. **頻寬較小**：無回饋電路的頻寬通常較小，頻率響應性能較差。
3. **失真較大**：無回饋電路的非線性失真較大，信號質量較差。
4. **輸入和輸出阻抗不可控**：無回饋電路的輸入和輸出阻抗難以調節，可能不符合設計要求。

(b)

| Fig. 1 | | | |
|---|---|---|---|
| Working item | Specification | Simulation | Calculation |
| Vdd (V) | 1.5 | | |
| C1, C2 (F) | 1p | | |
| transimpedance DC gain ($k\Omega$) | $> 0.85$ | 0.9495797 | 0.950496915 |
| bandwidth (MHz) | $> 650$ | 675.6105 | |
| Closed-loop poles/zeros (rad/s) | | $W_{pole} = -2.42 * 10^9 \pm j2.99 * 10^9$ $W_{zero} = 255.71 * 10^{11}$ | $W_{pole} = -2.51 * 10^9 \pm j3.05 * 10^9$ $W_{zero} = 265.16 * 10^{11}$ |
| Closed-loop input impedance ($\Omega$) | | 49.4317 | 48.5324 |
| Closed-loop output impedance ($\Omega$) | | 18.8021 | 18.4529 |
| Input common mode current (uA) | | 15 | |
| Output common mode voltage (V) | 0.75 ($\pm$ 1%) | 0.7504936 | |
| M1 (W/L), m | | 35.5um/0.2um m=2 | |
| M2 (W/L), m | | 60um/0.3um m=8 | |
| FoM (uA/($\boldsymbol{k\Omega} \times \boldsymbol{MHz}$)) | | 6.311940063 | |

| Fig. 2 | | | |
|---|---|---|---|
| Working item | Specification | Simulation | Calculation |
| Vdd (V) | 1.5 | | |
| C3, C4 (F) | 1p | | |
| transimpedance DC gain (kΩ) | - | 1561.9 | 1561.7 |
| bandwidth (MHz) | - | 0.3751525 | |
| Closed-loop poles/zeros (rad/s) | | $W_{Pole1}$=-2.36152M<br>$W_{Pole2}$=-3.88745G<br>$W_{Zero}$=260.646G | $W_{Pole1}$=-2.38163M<br>$W_{Pole2}$=-3.98209M<br>$W_{Zero}$ =265.183G |
| Closed-loop input impedance (Ω) | | 50k | |
| Closed-loop output impedance (Ω) | | 594.7208 | 594.370032 |
| Input common mode current (uA) | same as Iin1 | 15u | |
| Output common mode voltage (V) | - | 0.7656154 | |
| M3 (W/L), m | same as M1 | 35.5um/0.2um<br>m=2 | |
| M4 (W/L), m | same as M2 | 60um/0.3um<br>m=8 | |