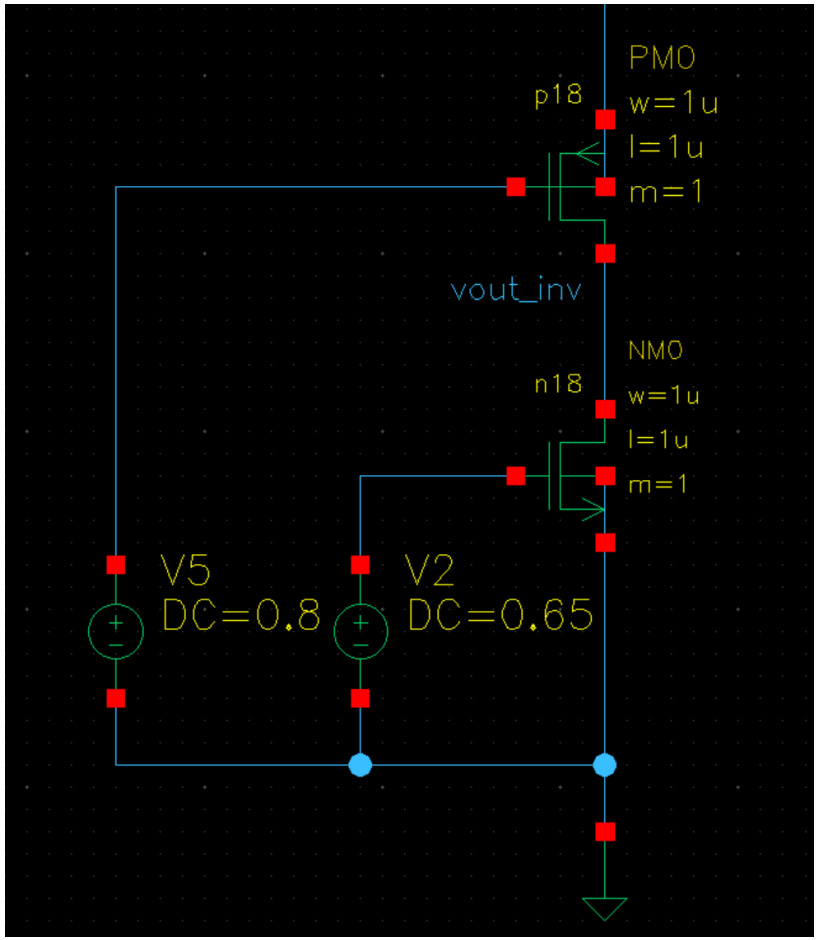
Homework 3

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ




```
########## noise analysis result at frequency 1.0000 ##########
hierarchy
device            0:mpm0
rd               1.0068e-20
rs               228.7918a
id               1.1199p
rx               1.7474x
fn               1.1552u
total            1.1552u

hierarchy
device            0:mnm0
rd               1.5904e-20
rs               1.1918f
id               2.1533p
rx               1.7325x
fn               713.4537n
total            713.4559n

#### output noise voltage                        = 1.8687u volt^2/hz
#### output rms noise                            = 1.3670m volt/hz^(1/2)
#### equivalent input noise at vv2               = 11.6463u /hz^(1/2)
#### transfer function v(vout_inv)/vv2           = 117.3763

#### integral value of noise from 1.0000hz to 1.0000hz
#### total output noise voltage                  = 0.0000 volt
#### total input noise at vv2                    = 0.0000 volt
```

- **如何确定噪声的单位?**

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

- **如何确定噪声的单位?**
  - **利用噪声的随机特性**
  - **对于不相关的噪声，总噪声为每个噪声功率之和**
  - **fn的单位应该是V^2/hz**

```
########## noise analysis result at frequency 1.0000 ##########
hierarchy
device            0:mpm0
rd               1.0068e-20
rs               228.7918a
id               1.1199p
rx               1.7474x
fn               1.1552u
total            1.1552u

hierarchy
device            0:mnm0
rd               1.5904e-20
rs               1.1918f
id               2.1533p
rx               1.7325x
fn               713.4537n
total            713.4559n

#### output noise voltage                          = 1.8687u volt^2/hz
#### output rms noise                              = 1.3670m volt/hz^(1/2)
#### equivalent input noise at vv2                 = 11.6463u /hz^(1/2)
#### transfer function v(vout_inv)/vv2             = 117.3763

#### integral value of noise from 1.0000hz to 1.0000hz
#### total output noise voltage                    = 0.0000 volt
#### total input noise at vv2                      = 0.0000 volt
```

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

- **如何确定噪声的单位?**
  - **利用闪烁噪声的频率特性**

$$\overline{dv_{ieqf}^2} = \frac{KF_F}{WL\,C_{ox}^2}\frac{df}{f}$$

  - **fn的单位应该是V^2/hz**

```
########## noise analysis result at frequency 1.0000 ##########
hierarchy
device            0:mpm0
rd               1.0068e-20
rs               228.7918a
id               1.1199p
rx               1.7474x
fn               1.1552u
total            1.1552u

########## noise analysis result at frequency 10.0000 ##########
hierarchy
device            0:mnm0
rd               1.5904e-20
rs               1.1918f
id               2.1533p
rx               1.5499x
fn               108.4840n
total            108.4862n

hierarchy
device            0:mpm0
rd               1.0068e-20
rs               228.7918a
id               1.1199p
rx               1.4997x
fn               85.5010n
total            85.5021n

#### output noise voltage                    = 193.9883n volt^2/hz
#### output rms noise                        = 440.4410u volt/hz^(1/2)
#### equivalent input noise at vv2           = 3.7524u /hz^(1/2)
#### transfer function v(vout_inv)/vv2       = 117.3763
```

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

- **如何计算KF?**

$$\overline{dv_{ieqf}^2} = \frac{KF_F}{WL\,C_{ox}^2}\frac{df}{f}$$

  - **公式描述的是等效输入噪声**
  - **仿真给出的是输出噪声**

$$KF_N = \frac{fn}{A_0^2}\cdot WLC_{OX}^2\cdot freq$$

$$= \frac{0.71u}{117^2}\cdot 1p\cdot 8.85^2u\cdot 1$$

$$= 4.0\times 10^{-27}\ C/m^2$$

```
########## noise analysis result at frequency 1.0000 ##########
hierarchy
device           0:mpm0
rd              1.0068e-20
rs              228.7918a
id              1.1199p
rx              1.7474x
fn              1.1552u
total           1.1552u

hierarchy
device           0:mnm0
rd              1.5904e-20
rs              1.1918f
id              2.1533p
rx              1.7325x
fn              713.4537n
total           713.4559n

#### output noise voltage                    = 1.8687u volt^2/hz
#### output rms noise                        = 1.3670m volt/hz^(1/2)
#### equivalent input noise at vv2           = 11.6463u /hz^(1/2)
#### transfer function v(vout_inv)/vv2       = 117.3763

#### integral value of noise from 1.0000hz to 1.0000hz
#### total output noise voltage              = 0.0000 volt
#### total input noise at vv2                = 0.0000 volt
```

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

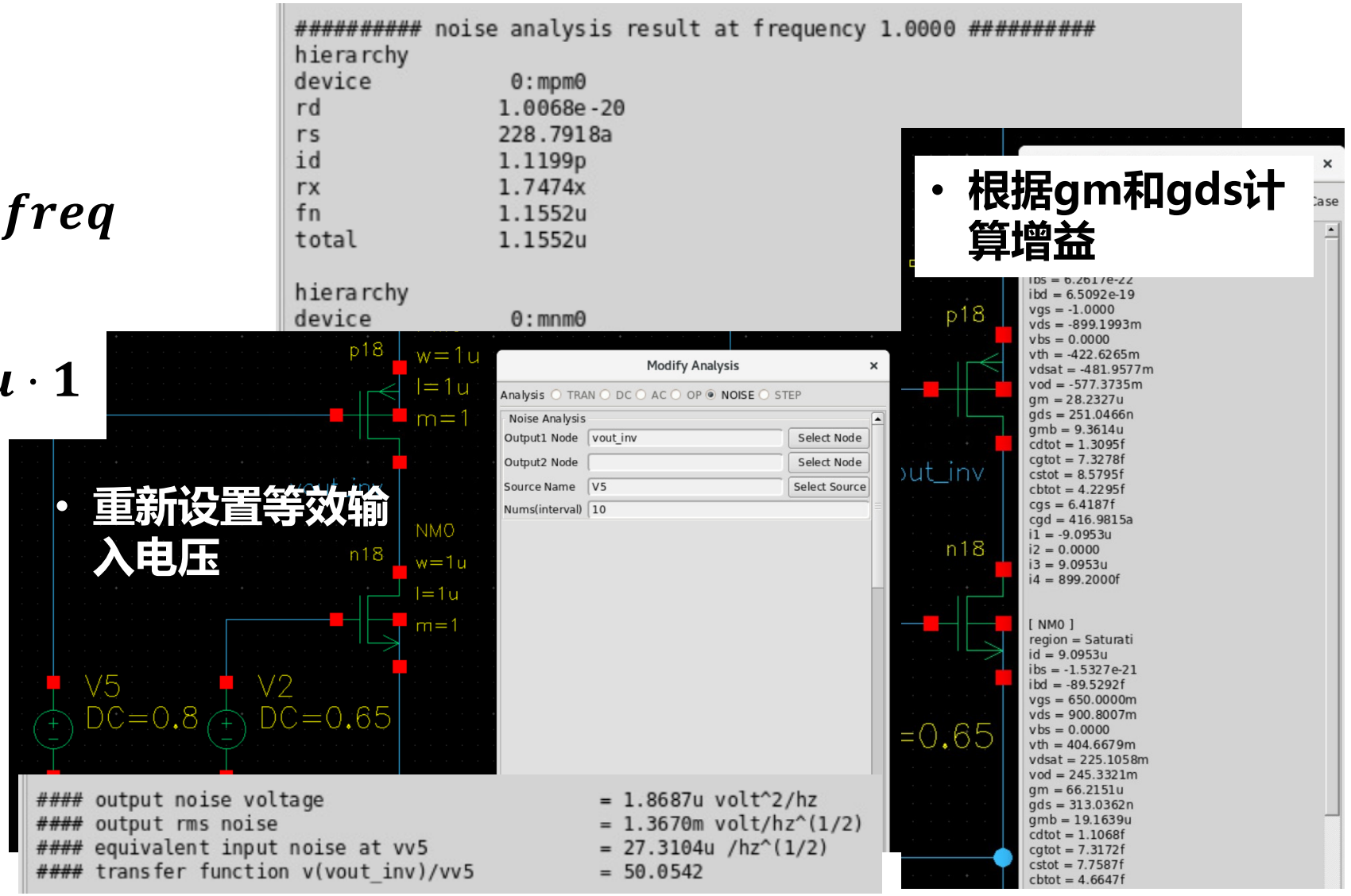
- **如何计算KF?**

$$KF_P = \frac{fn}{A_0^2} \cdot WLC_{OX}^2 \cdot freq$$

$$= \frac{1.15u}{50^2} \cdot 1p \cdot 9.12^2u \cdot 1$$

$$= 3.8 \times 10^{-26}\ C/m^2$$

- **结果与课本偏差较大!**



- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

Freq (Hz)	1	10	100	1k	10k	100k	1M
NMOS (V^2/Hz)	0.71u	108n	16.5n	2.5n	381p	58p	8.81p
PMOS(V^2/Hz)	1.15u	85.5n	6.3n	0.47n	34.7p	2.56p	0.19p

- **PMOS: Corner Freq = 200kHz**

```
########## noise analysis result at frequency 199.5262k #
hierarchy
device            0:mnm0
rd               1.5904e-20
rs               1.1917f
id               2.1533p
rx               57.4178k
fn               32.9574p
total            35.1119p

hierarchy
device            0:mpm0
rd               1.0068e-20
rs               228.7852a
id               1.1199p
rx               14.5679k
fn               1.1748p
total            2.2948p
```

- **NMOS: Corner Freq = 5MHz**

```
########## noise analysis result at frequency 5.0119x ##
hierarchy
device            0:mnm0
rd               1.5814e-20
rs               1.1705f
id               2.1148p
rx               20.4112k
fn               2.3170p
total            4.4330p

hierarchy
device            0:mpm0
rd               1.0155e-20
rs               224.7017a
id               1.0999p
rx               10.2238k
fn               30.1403f
total            1.1302p
```

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

- **如何计算γ？**
- **噪声id是什么?**

Name (Alias)	Units	Default	Description
RX			Transfers the function of thermal noise to the output. This is not noise, but is a transfer coefficient, which reflects the contribution of thermal noise to the output. For example: `V(output) = I(local)*rx`(from local to output) Where V(output) is the noise voltage at the output port, I(local) is the local noise current in the specific noise element. It is clear that rx should have an unit of impedance, therefore we call it transimpedance. By summarizing all the contributions (power) from each independent noisy element, we can get the total noise contribution(power) at the output port.
ID	V^2/Hz		Output channel thermal noise: ID = $RX^2Þ$ (channel thermal noise)^2.
FN	V^2/Hz		Output flicker noise: FN = $RX^2Þ$ (flicker noise)^2.
IFEX			Noise due to floating body
LGS			Shot noise due to lgs
LGD			Shot noise due to lgd

```
########## noise analysis result at frequency 1000.0000k ##########
hierarchy
device           0:mnm0
rd              1.5901e-20
rs              1.1909f
id              2.1518p
rx              32.0974k
fn              8.8115p
total           10.9645p

hierarchy
device           0:mpm0
rd              1.0071e-20
rs              228.6261a
id              1.1191p
rx              11.0028k
fn              189.7389f
total           1.3090p

#### output noise voltage                          = 12.2735p volt^2/hz
#### output rms noise                              = 3.5034u volt/hz^(1/2)
#### equivalent input noise at vv5                 = 70.0167n /hz^(1/2)
#### transfer function v(vout_inv)/vv5             = 50.0361

#### integral value of noise from 100.0000khz to 1000.0000khz
#### total output noise voltage                    = 4.4767m volt
#### total input noise at vv5                      = 89.4462u volt
```

- 自由确定晶体管的尺寸，通过仿真寻找NMOS和PMOS的1/f噪声的系数KF，以及热噪声系数γ

- **如何计算γ？**

$$\overline{dv_{ieqn}^2} = 4kT\gamma/g_m$$

  - **公式描述的是等效输入噪声**
  - **仿真给出的是输出噪声**

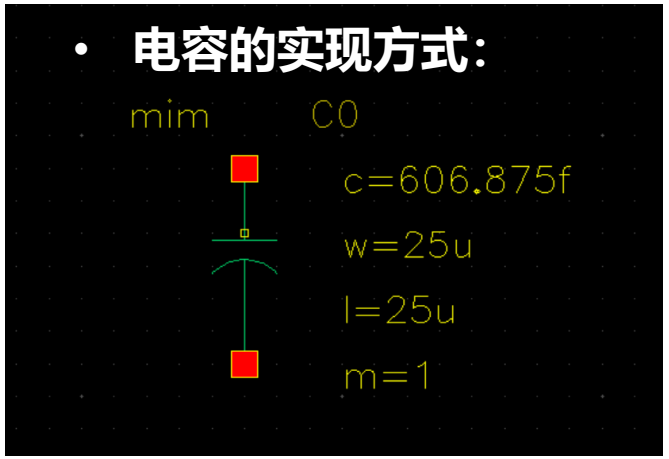
$$\gamma = \frac{\frac{id}{A_0^2}\cdot g_m}{4kT}$$

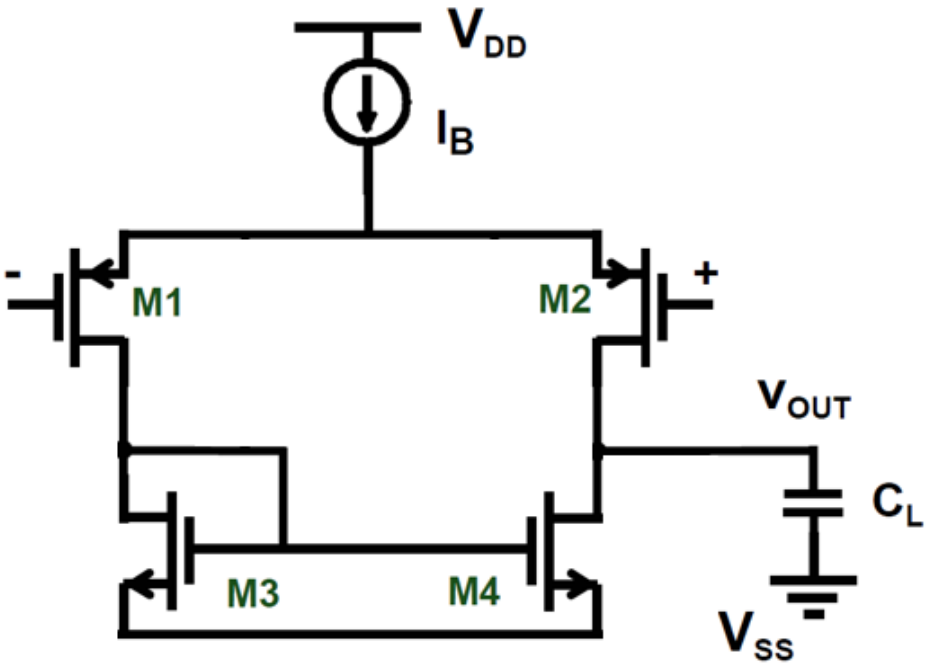
```
########## noise analysis result at frequency 1000.0000k ##########
hierarchy
device           0:mnm0
rd              1.5901e-20
rs              1.1909f
id              2.1518p
rx              32.0974k
fn              8.8115p
total           10.9645p

hierarchy
device           0:mpm0
rd              1.0071e-20
rs              228.6261a
id              1.1191p
rx              11.0028k
fn              189.7389f
total           1.3090p

#### output noise voltage                          = 12.2735p volt^2/hz
#### output rms noise                              = 3.5034u volt/hz^(1/2)
#### equivalent input noise at vv5                 = 70.0167n /hz^(1/2)
#### transfer function v(vout_inv)/vv5             = 50.0361

#### integral value of noise from 100.0000khz to 1000.0000khz
#### total output noise voltage                    = 4.4767m volt
```

$$\gamma_p = \frac{1.12p/\mathbf{50^2}\cdot 28u}{1.656\times10^{-20}} = 0.76 \qquad \gamma_n = \frac{2.15p/\mathbf{117^2}\cdot 66u}{1.656\times10^{-20}} = 0.63$$

- 对一偏置电流为100uA的五管OTA，通过晶体管的设计，使其等效输入噪声的80%来源于差分对M1和M2。

- **观察什么噪声？**
  - **总的噪声积分**
  - **可以先用带宽内高频的热噪声来计算**





$$\overline{dv_{ieqn,p}^2} = \frac{4kT}{g_{m,p}}, \qquad \overline{dv_{ieqn,n}^2} = \frac{4kT}{g_{m,n}}\left(\frac{g_{m,n}}{g_{m,p}}\right)^2$$

1:4

$$g_{m,p} : g_{m,n} = 4:1$$

- 对一偏置电流为100uA的五管OTA，通过晶体管的设计，使其等效输入噪声的80%来源于差分对M1和M2。

$$g_m \approx \mu_0 C_{ox} \frac{W}{L}(V_{GS} - V_{TH}) = \sqrt{2\mu_0 C_{ox} \frac{W}{L} I_{DS}} = \frac{2I_{DS}}{V_{GS} - V_{TH}}$$

NMOS

```
* GENERAL PARAMETERS
*
+CALCACM   = 1
+LMIN      = 1.5E-7
+WMAX      = 1.0E-4
+TOX       = '3.87E-09+DTOX_N18'
+NCH       = 3.8694000E+17
```

$KP_n \approx 280uA/V^2$

```
* MOBILITY PARAMETERS
*
+VSAT      = 8.2500000E+04        PVSAT     = -8.
+LUA       = 7.7349790E-19        PUA       = -1.
+UC        = 1.2000000E-10        PUC       = 1.5
+PRWB      = -0.2400000           PRWG      = 0.4
+U0        = '(3.4000000E-02)*(1+0.05*Sigma)'
+A0        = 0.8300000            KETA      = -3.
```

PMOS

```
* GENERAL PARAMETERS
*
+CALCACM   = 1
+LMIN      = 1.5E-7
+WMAX      = 1.0E-4
+TOX       = '3.74E-09+DTOX_P18'
+NCH       = 5.5000000E+17
```

$KP_p \approx 70uA/V^2$

```
* MOBILITY PARAMETERS
*
+VSAT      = 1.0000000E+05        UA        = 2
+PUA       = -2.0000000E-24       UB        = 1
+WUC       = 3.1668000E-17        PUC       =
+PRWB      = -0.4000000           PRWG      = 0
+U0        = '(8.6610000E-03)*(1+0.05*Sigma)'
+A0        = 1.0000000            KETA      = 2
```

$$C_{OXn} = 8.55m \qquad C_{GS} \approx \frac{2}{3} WLC_{OX} \qquad C_{OXp} = 9.12m$$

$$u_{0n} = \frac{26u}{8.55m \cdot 0.09} = 33m \qquad I_D = \frac{1}{2} u_0 C_{GS} \frac{W}{L} (V_{GS} - VTH)^2 \qquad u_{0p} = \frac{4.94u}{9.12m \cdot 0.073} = 7.4\,m$$

$$g_{m,p} : g_{m,n} = 4:1$$

$$KP_p \left(\frac{W}{L}\right)_p : KP_n \left(\frac{W}{L}\right)_n = 16:1$$

$$\left(\frac{W}{L}\right)_p : \left(\frac{W}{L}\right)_n = 64:1$$

- 对一偏置电流为100uA的五管OTA，通过晶体管的设计，使其等效输入噪声的80%来源于差分对M1和M2。

$$I_D \approx \frac{1}{2}\mu_0 C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2 \quad \Rightarrow \quad \left(\frac{W}{L}\right)_n = \frac{1u}{500n} \qquad \left(\frac{W}{L}\right)_p = \frac{64u}{500n}$$

NMOS

```
* GENERAL PARAMETERS
*
+CALCACM   = 1
+LMIN      = 1.5E-7
+WMAX      = 1.0E-4
+TOX       = '3.87E-09+DTOX_N18'
+NCH       = 3.8694000E+17
```

$KP_n \approx 280uA/V^2$

```
* MOBILITY PARAMETERS
*
+VSAT      = 8.2500000E+04        PVSAT     = -8.
+LUA       = 7.7349790E-19        PUA       = -1.
+UC        = 1.2000000E-10        PUC       = 1.5
+PRWB      = -0.2400000           PRWG      = 0.4
+U0        = '(3.4000000E-02)*(1+0.05*Sigma)'
+A0        = 0.8300000            KETA      = -3.
```

PMOS

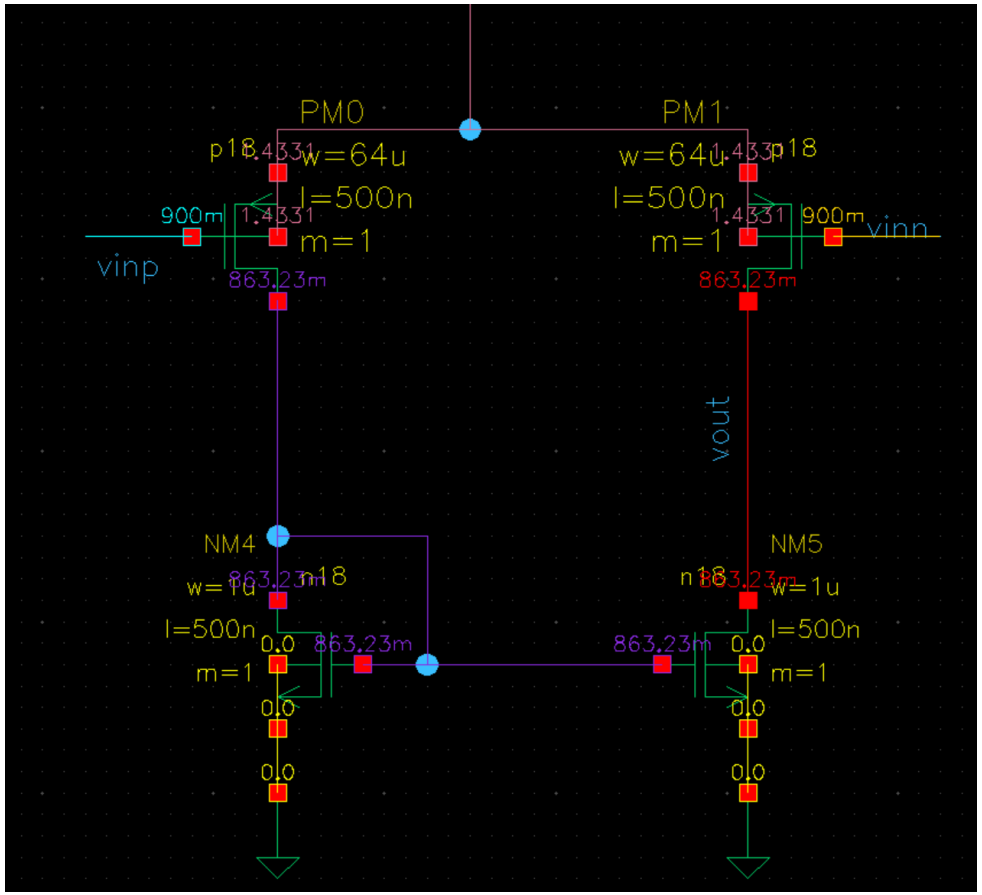
```
* GENERAL PARAMETERS
*
+CALCACM   = 1
+LMIN      = 1.5E-7
+WMAX      = 1.0E-4
+TOX       = '3.74E-09+DTOX_P18'
+NCH       = 5.5000000E+17
```

$KP_p \approx 70uA/V^2$

```
* MOBILITY PARAMETERS
*
+VSAT      = 1.0000000E+05        UA        = 2
+PUA       = -2.0000000E-24       UB        = 1
+WUC       = 3.1668000E-17        PUC       =
+PRWB      = -0.4000000           PRWG      = 0
+U0        = '(8.6610000E-03)*(1+0.05*Sigma)'
+A0        = 1.0000000            KETA      = 2
```

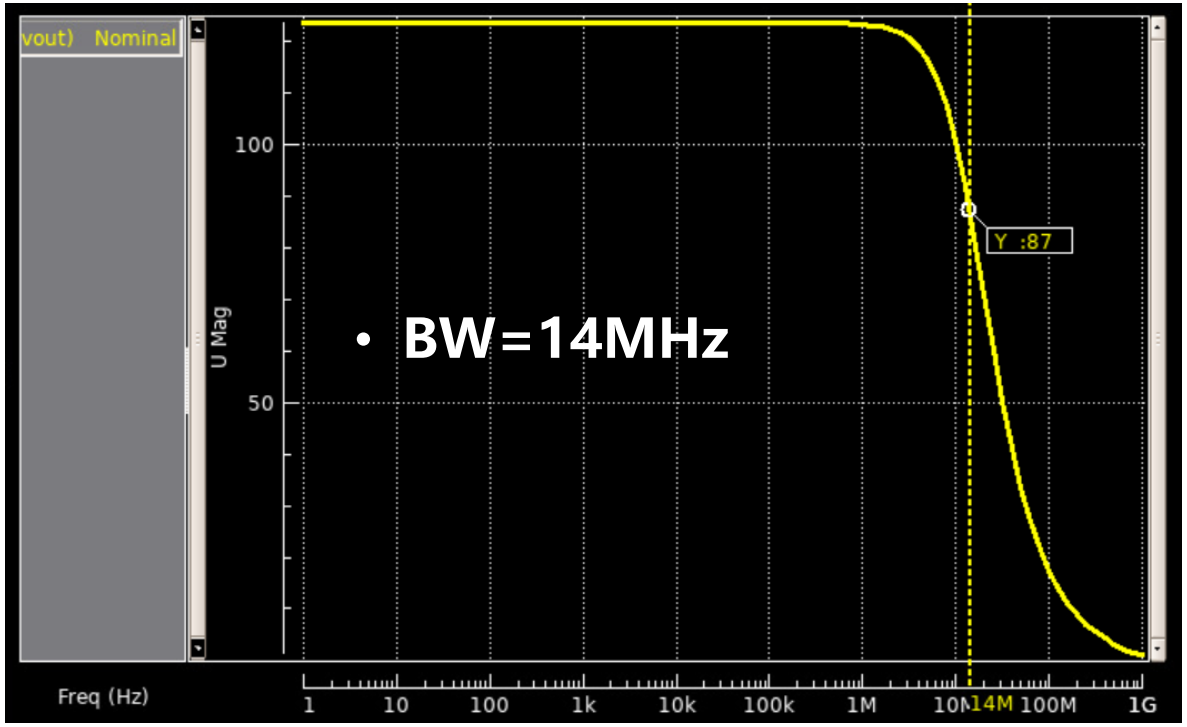
$$C_{OXn} = 8.55m \qquad C_{GS} \approx \frac{2}{3}WLC_{OX} \qquad C_{OXp} = 9.12m$$

$$u_{0n} = \frac{26u}{8.55m \cdot 0.09} = 33m \qquad I_D = \frac{1}{2}u_0 C_{GS}\frac{W}{L}(V_{GS}-VTH)^2 \qquad u_{0p} = \frac{4.94u}{9.12m \cdot 0.073} = 7.4\,m$$



- 对一偏置电流为100uA的五管OTA，通过晶体管的设计，使其等效输入噪声的80%来源于差分对M1和M2。

$$\left(\frac{W}{L}\right)_n = \frac{1u}{500n} \qquad \left(\frac{W}{L}\right)_p = \frac{64u}{500n}$$




```
########## noise analysis result at frequency 1.0000x ##########
hierarchy
device           0:mnm5
rd              1.0525e-20
rs              89.4038a
id              67.3377f
rx              10.7077k
fn              1.1576p
total           1.2250p

hierarchy
device           0:mnm4
rd              9.8855e-21
rs              83.9735a
id              63.2477f
rx              10.3775k
fn              1.0873p
total           1.1506p

hierarchy
device           0:mpm0
rd              8.7610e-22
rs              76.3880a
id              212.5966f
rx              1.0673k
fn              3.7697f
total           216.4426f

hierarchy
device           0:mpm1
rd              8.7623e-22
rs              76.3878a
id              212.5949f
rx              1.0673k
fn              3.7697f
total           216.4410f

#### output noise voltage                    = 2.8085p volt^2/hz
#### output rms noise                        = 1.6759u volt/hz^(1/2)
#### equivalent input noise at vv4           = 6.7998n /hz^(1/2)
#### transfer function v(vout)/vv4           = 246.4585
```

- 对一偏置电流为100uA的五管OTA，通过晶体管的设计，使其等效输入噪声的80%来源于差分对M1和M2。

$$\overline{dv_{n,p}^2} = 432.88f\ V^2/Hz$$

- **由于NMOS的1/f噪声远大于热噪声，差分对噪声占比只有15%**

```
########## noise analysis result at frequency 1.0000x ##########
hierarchy
device           0:mnm5
rd              1.0525e-20
rs              89.4038a
id              67.3377f
rx              10.7077k
fn              1.1576p
total           1.2250p

hierarchy
device           0:mnm4
rd              9.8855e-21
rs              83.9735a
id              63.2477f
rx              10.3775k
fn              1.0873p
total           1.1506p

hierarchy
device           0:mpm0
rd              8.7610e-22
rs              76.3880a
id              212.5966f
rx              1.0673k
fn              3.7697f
total           216.4426f

hierarchy
device           0:mpm1
rd              8.7623e-22
rs              76.3878a
id              212.5949f
rx              1.0673k
fn              3.7697f
total           216.4410f

#### output noise voltage                    = 2.8085p volt^2/hz
#### output rms noise                        = 1.6759u volt/hz^(1/2)
#### equivalent input noise at vv4           = 6.7998n /hz^(1/2)
#### transfer function v(vout)/vv4           = 246.4585
```

- 对一偏置电流为100uA的五管OTA，通过晶体管的设计，使其等效输入噪声的80%来源于差分对M1和M2。

$$\left(\frac{W}{L}\right)_p = \frac{64u}{500n} \qquad \left(\frac{W}{L}\right)_n = \frac{1u}{500n}$$

增加电流镜面积

$$\left(\frac{W}{L}\right)_n = \frac{5u}{5u} \qquad \left(\frac{W}{L}\right)_n = \frac{10u}{5u}$$

减小电流镜gm

- **通过同样的方法计算，差分对的噪声为总噪声的78%**

```
########## noise analysis result at frequency 1.0000x ##########
hierarchy
device           0:mpm0
rd              2.0698e-21
rs              140.3950a
id              394.9633f
rx              1.4545k
fn              6.8883f
total           401.9920f

hierarchy
device           0:mpm1
rd              2.0674e-21
rs              140.3925a
id              394.9424f
rx              1.4544k
fn              6.8879f
total           401.9707f

hierarchy
device           0:mnm5
rd              7.8555e-22
rs              62.9005a
id              92.4460f
rx              2.6765k
fn              27.2611f
total           119.7700f

hierarchy
device           0:mnm4
rd              7.3669e-22
rs              59.2449a
id              87.0605f
rx              2.5974k
fn              25.6730f
total           112.7928f

#### output noise voltage                      = 1.0365p volt^2/hz
#### output rms noise                          = 1.0181u volt/hz^(1/2)
#### equivalent input noise at vv4             = 3.0484n /hz^(1/2)
#### transfer function v(vout)/vv4             = 333.9804

#### integral value of noise from 1.0000hz to 1.0000xhz
#### total output noise voltage                = 1.3404m volt
#### total input noise at vv4                  = 3.9953u volt
```