# *Two stage opamp*

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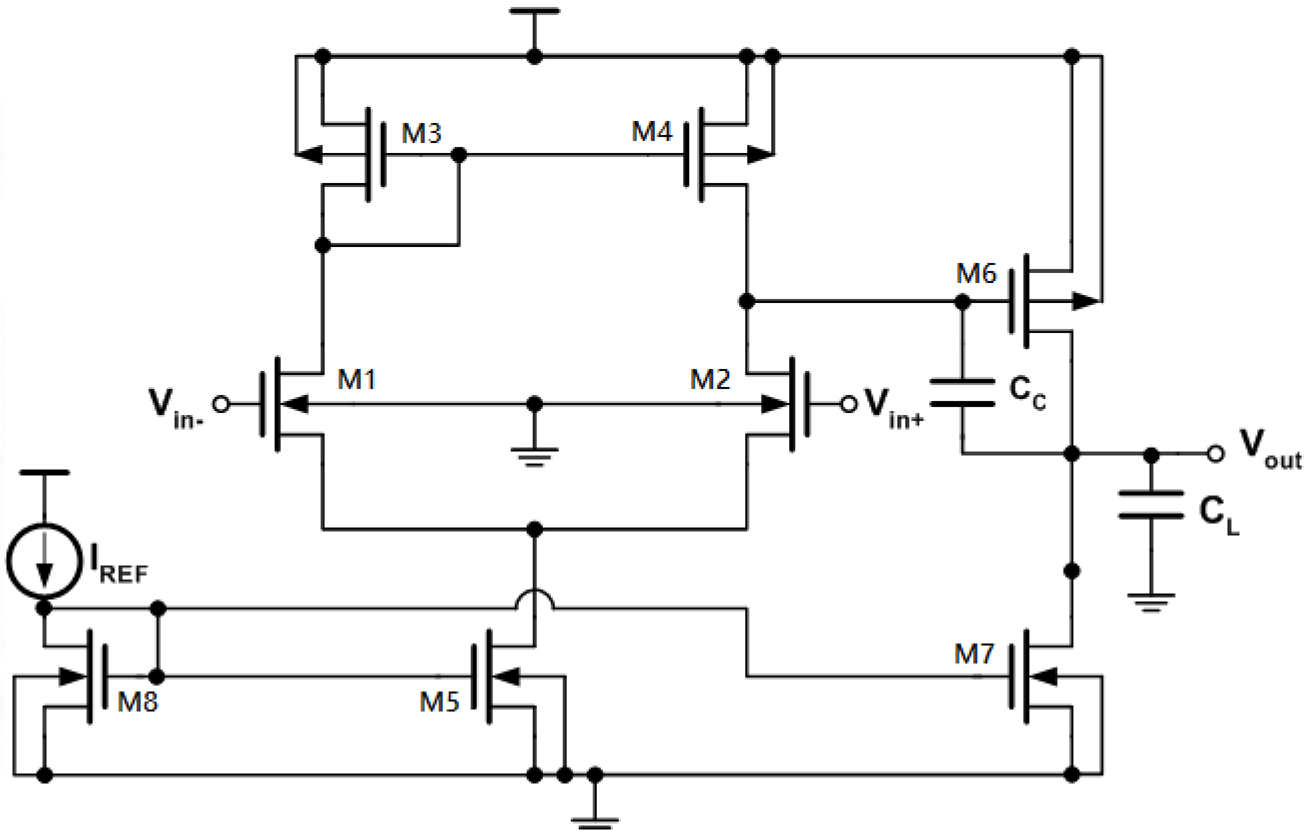
# Two stage opamp

- Vdd=1.8V, Vin+=Vin-=0.9V, $C_L$=4pF



# Design Specification

| Parameter | Value |
|---|---|
| DC Gain | >60dB |
| Phase Margin | >60 deg |
| Unit Gain Frequency | >10M Hz |
| Common mode rejection ratio (CMRR) | >60dB |
| Input Common Mode Range (ICMR) | >1V |
| Output Swing | >1V |
| Slew Rate | >10V/us |

- 作業上傳到E3, 繳交以下檔案 ,檔名: hw3 _學號
- 報告（.pdf） (ex:hw3_0560030.pdf)
    1. 每個規格需符合,並附上模擬結果
    2. 解釋設計方法
  - Spice file（.sp）(ex:hw3_0560030.sp)

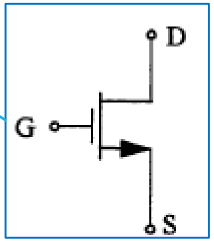
# MOS

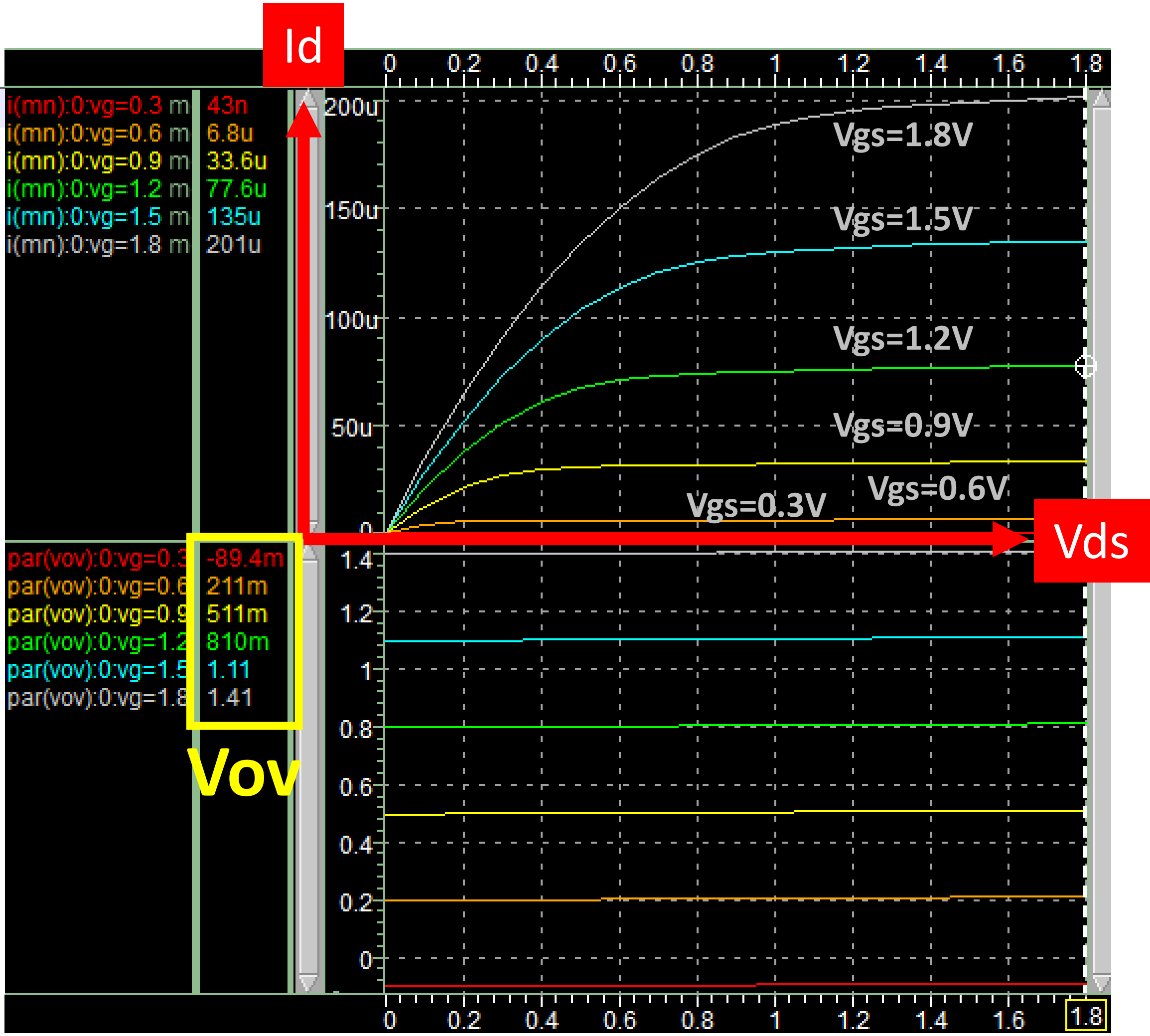
```
****** MOS ******
.option post accurate method=gear
.option probe
.lib 'cic018.l' TT
.temp 27

* Main Circuit
MN  D   G   S   B  N_18  L=1u W=1u

Vd  d   gnd     DC=1.8
Vg  g   gnd     DC=0.9
Vs  s   gnd     DC=0
Vb  b   gnd     DC=0

* Simulation Commands
.op
.dc  vd 0 1.8 0.1 sweep vg 0.3 1.8 0.3
.probe DC  V(*)
.print DC I(MN)
.probe vth = lv9(MN)
.probe vov = par('lx2(MN)-lv9(MN)')
.end
```



# MOS

- Calculate by Excel

B6 | =B2*2/B3*B5/(B4^2)

| | A | B | C | D |
|---|---|---|---|---|
| 1 | 算W | | | |
| 2 | Id | 76 | (uA) | |
| 3 | uCox | 240 | (uA/V2) | |
| 4 | vov=vgs-vth | 0.8 | (V) | |
| 5 | L | 1 | (u) | |
| 6 | W | 0.989583 | (um) | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | 算uCox | | | |
| 11 | Id | 76 | (uA) | |
| 12 | vov=vgs-vth | 0.8 | (V) | |
| 13 | W | 1 | (u) | |
| 14 | L | 1 | (u) | |
| 15 | uCox | 237.5 | (uA/V2) | |

**Operation in the *saturation* region:**

- Conditions:

(1) $v_{GS} \geq V_t \Leftrightarrow v_{OV} \geq 0$

(2) $v_{GD} \leq V_t \Leftrightarrow v_{DS} \geq v_{GS} - V_t \Leftrightarrow v_{DS} \geq v_{OV}$

- $i$-$v$ Characteristics:

$$\boxed{i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS} - V_t)^2(1 + \lambda v_{DS})}$$

**Threshold voltage:**

$$V_t = V_{t0} + \gamma\left(\sqrt{2\phi_f + |V_{SB}|} - \sqrt{2\phi_f}\right)$$

**Overdrive voltage:**

$$v_{OV} = v_{GS} - V_t$$

$$v_{GS} = V_t + v_{OV}$$

**Process parameters:**

$C_{ox} = \varepsilon_{ox}/t_{ox}$ (F/m$^2$)

$k_n' = \mu_n C_{ox}$ (A/V$^2$)

$V_A' = (V_A/L)$ (V/m)

$\lambda = (1/V_A)$ (V$^{-1}$)

$\gamma = \sqrt{2qN_A\varepsilon_s}/C_{ox}$ (V$^{1/2}$)

**Constants:**

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

$\varepsilon_{ox} = 3.9\varepsilon_0 = 3.45 \times 10^{-11}$ F/m

$\varepsilon_s = 11.7\varepsilon_0 = 1.04 \times 10^{-10}$ F/m

$q = 1.602 \times 10^{-19}$ C

# Hspice netlist

- Circuit description and testbench

```
****** two stage opamp ******
***** model/lib *****
.lib 'cic018.l' TT
***** options *****
.option post accurate method=gear
.option probe
.temp 27
.global vdd gnd
***** Source *****
Vdd     Vdd     gnd     DC=1.8
Iref    vdd     g11
Vinp    vinp    gnd     dc=0.9 ac=1
Vinn    vinn    gnd     dc=0.9

* Main Circuit
M1                      N_18 l=     w=    m=
M2                      N_18 l=     w=    m=
M3                      P_18 l=     w=    m=
M4                      P_18 l=     w=    m=
M5                      N_18 l=     w=    m=
M6                      P_18 l=     w=    m=
M7                      N_18 l=     w=    m=
M8                      N_18 l=     w=    m=
CC v12 vout
CL vout gnd 4p
```

```
***** analysis *****
.op
.ac dec 10 10 1G
.probe vdb(vout) vp(vout)
.meas AC Gain10Hz FIND vdb(vout) AT 10
.meas ac Unit_gain when vdb(vout)=0
.meas ac Phase_mar FIND vp(vout) when vdb(vout)=0

**SLEW RATE**







**ICMR**



**OUTPUT VOLTAGE SWING**








**CMRR**






.end
```

# .Measure

## (10). MEASURE Statement : AVG, RMS, MIN, MAX, & P-P

- Syntax :

```
.MEASURE DC|AC|TRAN result FUNC out_var <FROM=val1> <TO=val2>
+                      <Optimization Option>
```

- result_var : Name Given the Measured Value in HSPICE Output
- FUNC : AVG ----- Average   MAX ----- Maximun   PP ---- Peak-to-Peak
  MIN ------ Minimum   RMS ----- Root Mean Square
- out_var : Name of the Output Variable to be Measured
- <Optimization Option>: <GOAL=val> <MINVAL=val> <WEIGHT=val>

- Example:

```
.meas TRAN minval     MIN v(1,2)  from=25ns to=50ns
.meas TRAN tot_power  AVG power   from=25ns to=50ns
.meas TRAN rms_power  RMS power
```

# .Measure

## (11). MEASURE Statement : Find & When Function

- Syntax :

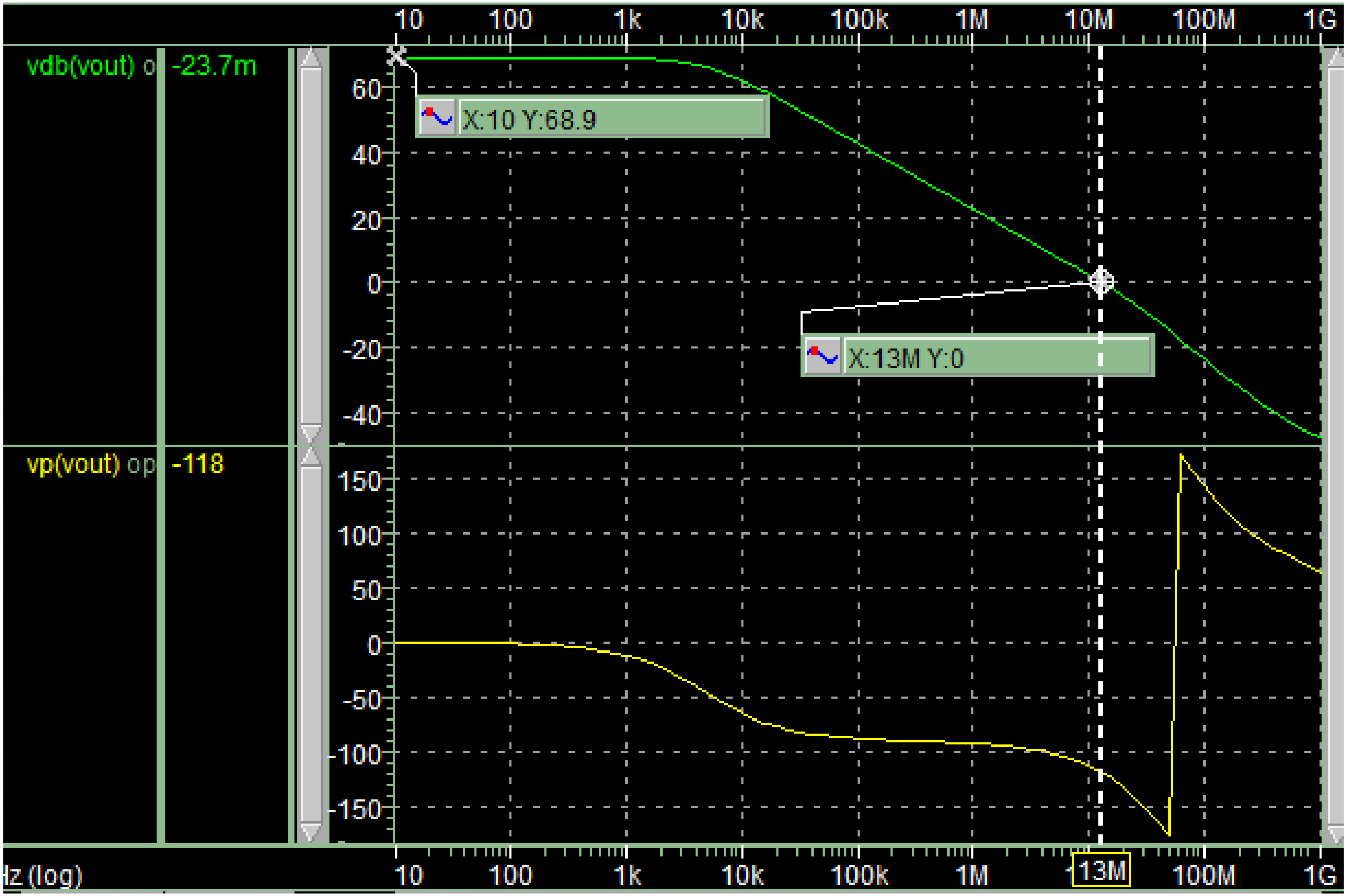
```
.measure  DC|AC|TRAN  result  WHEN  ... <Optimization Option>
.measure  DC|AC|TRAN  result  FIND out_var1 WHEN ...<Optimization Option>
.measure  DC|AC|TRAN  result_var  FIND out_var1 AT=val <Optimization Option>
```

- result : Name Given the Measured Value in HSPICE Output
- WHEN ... : WHEN out_var2=val|out_var3 <TD=time_delay>
  \+ <CROSS=n|LAST> <RISE=r_n|LAST> <FALL=f_n|LAST>
- <Optimization Option> : <GOAL=val> <MINVAL=val> <WEIGHT=val>

- Example:

```
.meas  TRAN  fifth    WHEN v(osc_out)=2.5V rise=5
.meas  TRAN  result  FIND   v(out)  WHEN v(in)=2.5V rise=1
.meas  TRAN  vmin    FIND   v(out)  AT=30ns
```

# AC analysis



10
100
1k
10k
100k
1M
10M
100M
1G
vdb(vout) o
-23.7m
60
40
20
0
-20
-40
X:10 Y:68.9
X:13M Y:0
vp(vout) op
-118
150
100
50
0
-50
-100
-150
Hz (log)
13M

# .Measure

- Unity-gain Freq, Phase margin, & DC gain(db/M):

```
.meas  AC  unitfreq       WHEN  vdb(out)=0    FALL=1
.meas  AC  phase          FIND  vp(out)       WHEN vdb(out)=0
.meas  AC  'gain(db)'     MAX   vdb(out)
.meas  AC  'gain(mag)'    MAX   vm(out)
```

- Analysis command

```
.ac dec 10 10 1G
.probe vdb(vout) vp(vout)
.meas ac Gain10Hz FIND vdb(vout) AT 10
.meas ac Unit_gain when vdb(vout)=0
.meas ac Phase_mar FIND vp(vout) when vdb(vout)=0
```

- Lis file

```
****** two stage opamp ******

 ******  ac analysis tnom=  25.000 temp=  27.000 ******
  gain10hz=  6.8925E+01
  unit_gain=  1.2983E+07
  phase_mar= -1.1773E+02
```

# CMRR

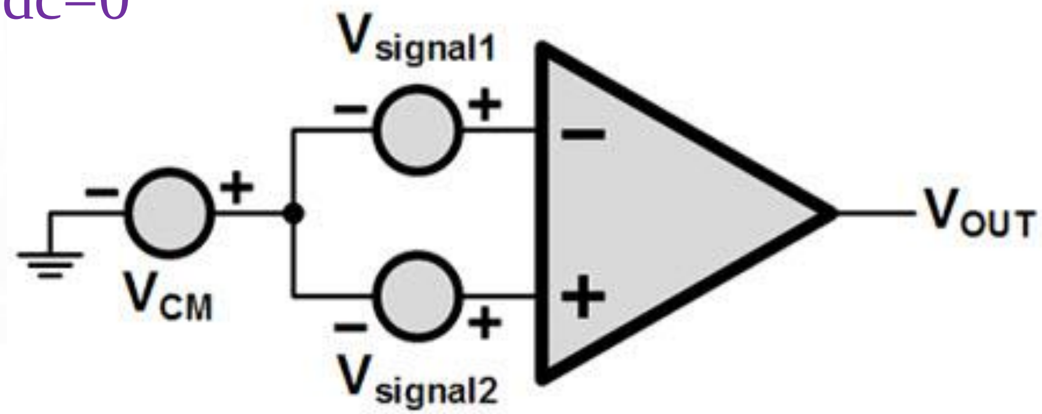
$$CMRR = \frac{A_d}{A_{cm}}$$

$$CMRR = 20\log_{10}\left(\frac{A_d}{A_{cm}}\right)\ dB$$

$$= 20\log|Ad| - 20\log|Acm|$$

- **SPICE – 求Acm**

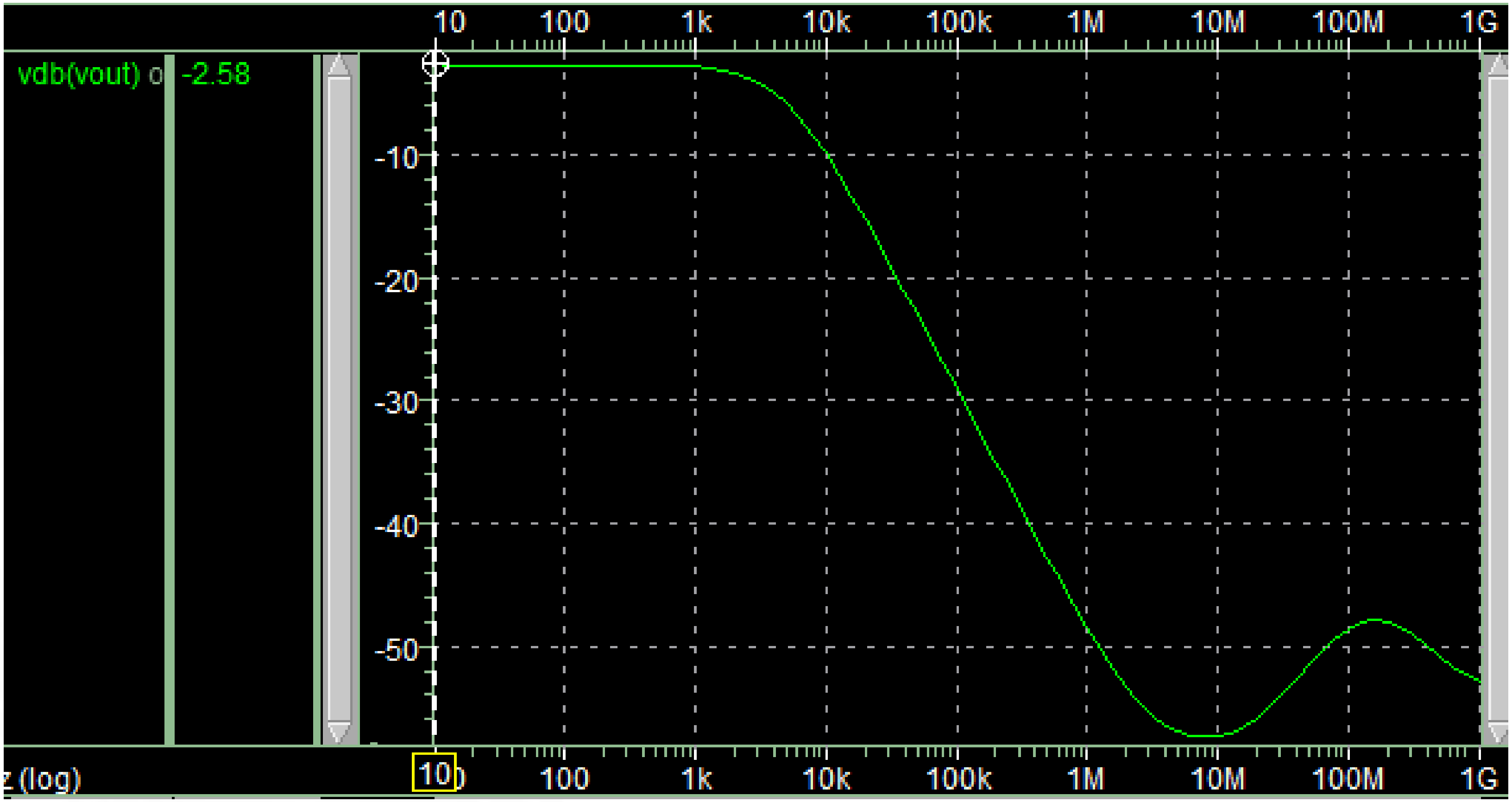
```
Vcm     vcm    gnd    dc=0.9 ac=1
Vinp    vinp   vcm    dc=0
Vinn    vinn   vcm    dc=0
.ac dec 10 10 1G
.probe vdb(vout)
```



# CMRR

$$CMRR = 20\log_{10}\left(\frac{A_d}{A_{cm}}\right) \text{ dB} = 20\log|Ad| - 20\log|Acm|$$

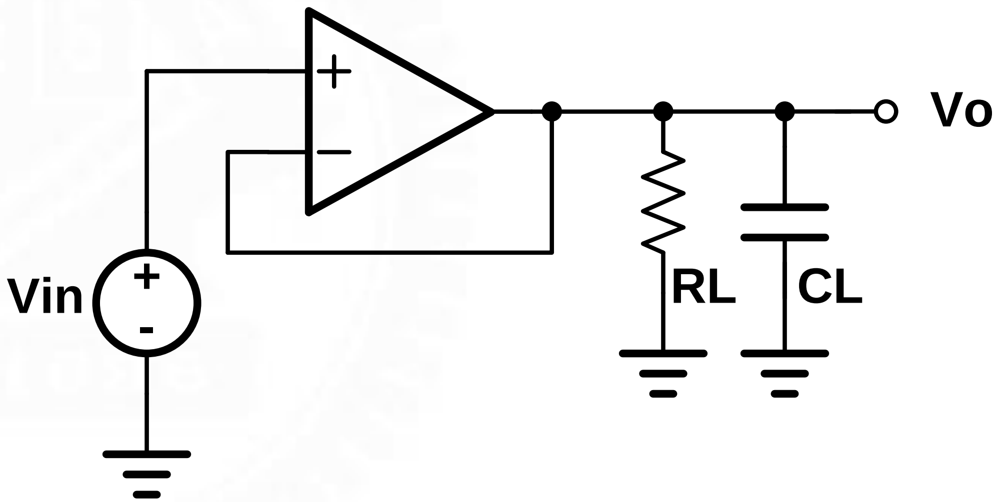
$$= 68.9dB - (-2.58dB) = 71.48dB$$



# ICMR

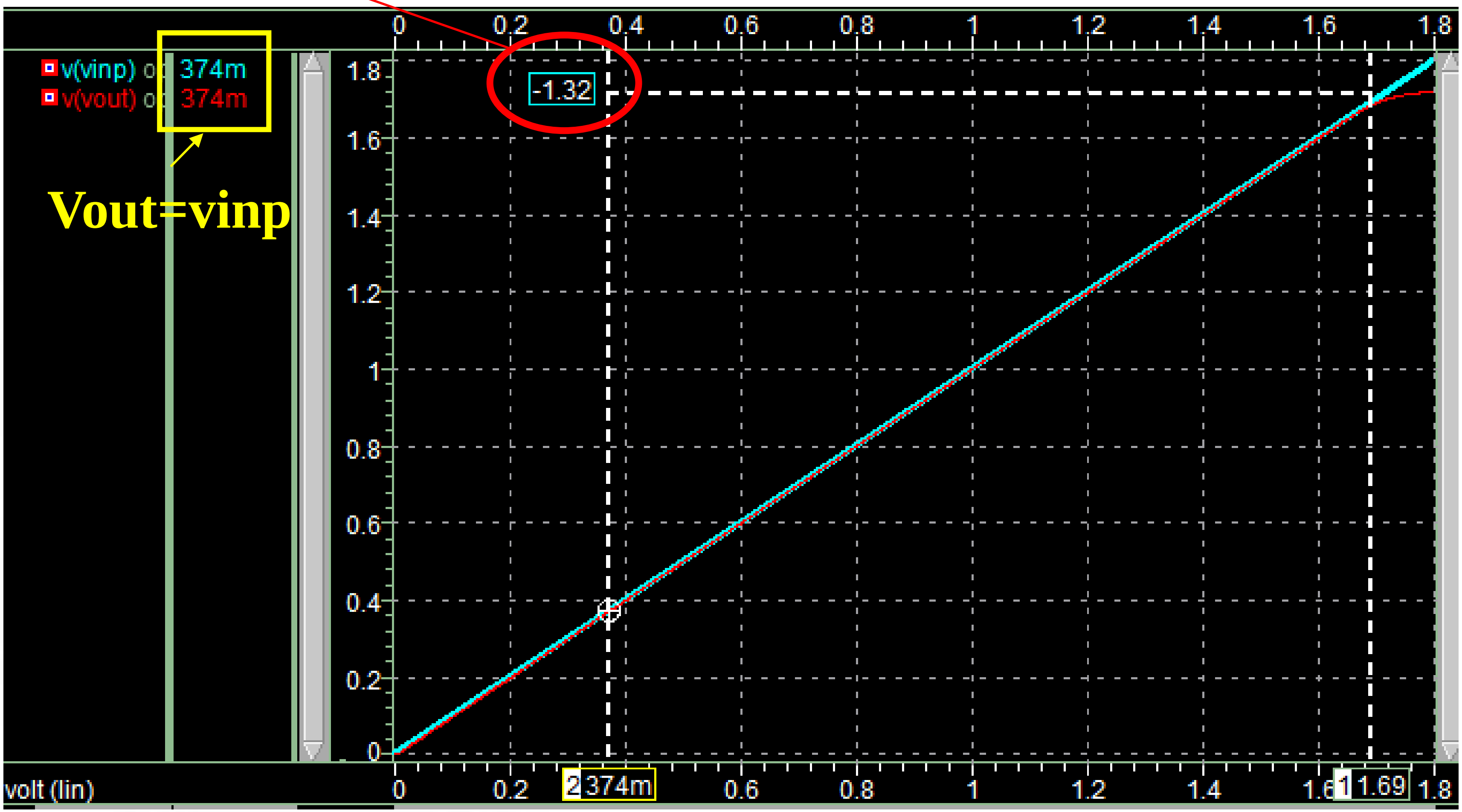
- **SPICE**

```
Vinp  vinp gnd      dc=0.9
M1  node_D  vout  node_S   node_B  N_18   l=?u  w=?u   m=?
.dc  vinp  0  1.8  1m
.probe V(vout) V(vinp)
```



# ICMR

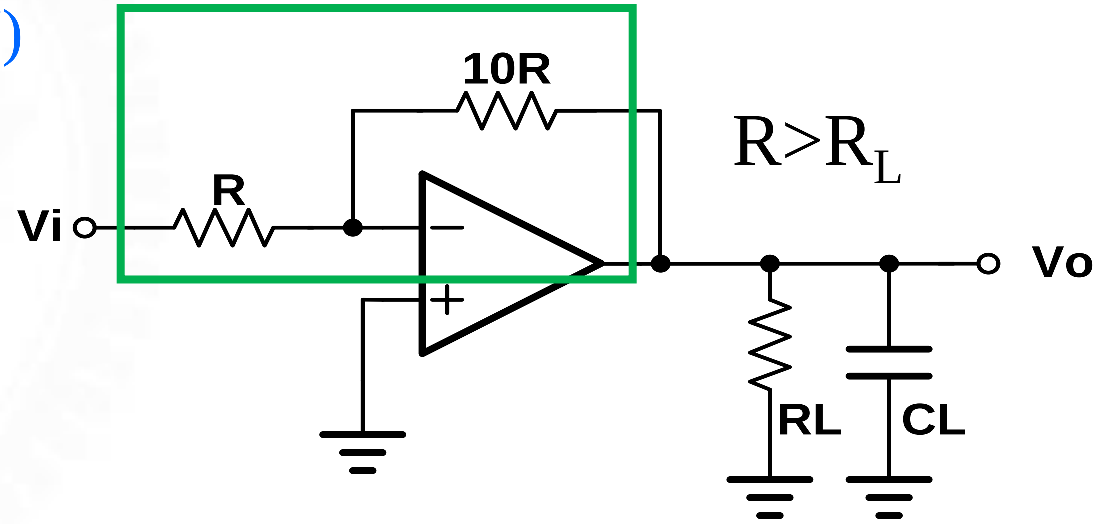
- 觀察輸出Vout能夠隨著輸入Vinp改變的電壓範圍
- ICMR=1.32V



# Output Swing

- **SPICE**

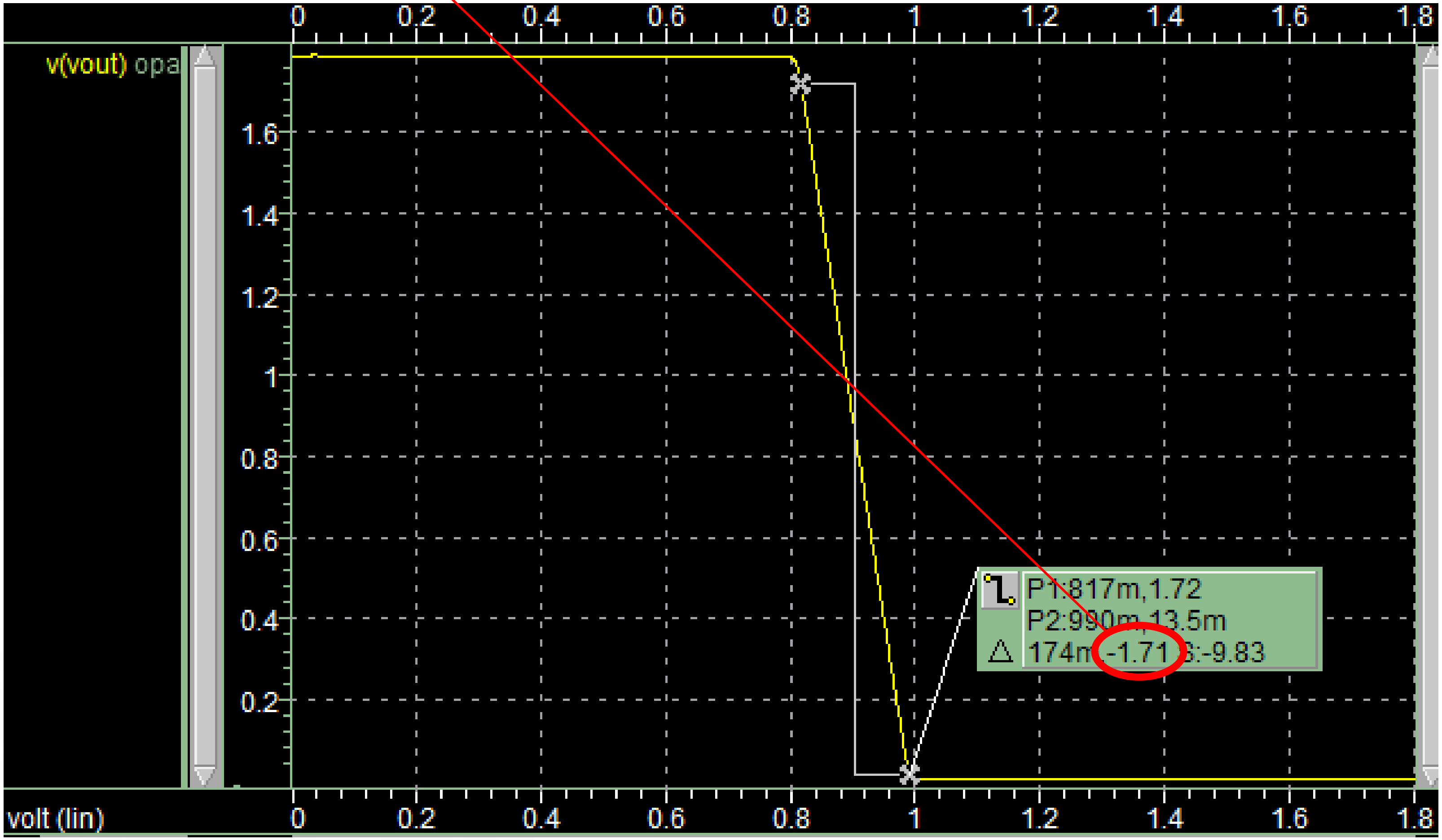
  vinp vinp gnd dc=0.9
  R1 VIN vinn ?k
  R2 vinn vout ?k
  VIN VIN gnd dc=0.9
  .dc VIN 0 1.8 1m
  .probe V(vout) V(VIN)




$R > R_L$

# Output Swing

- 觀察輸出Vout能夠隨著輸入VIN變化的電壓範圍
- Output Swing = 1.71V



# Slew Rate

- **SPICE**

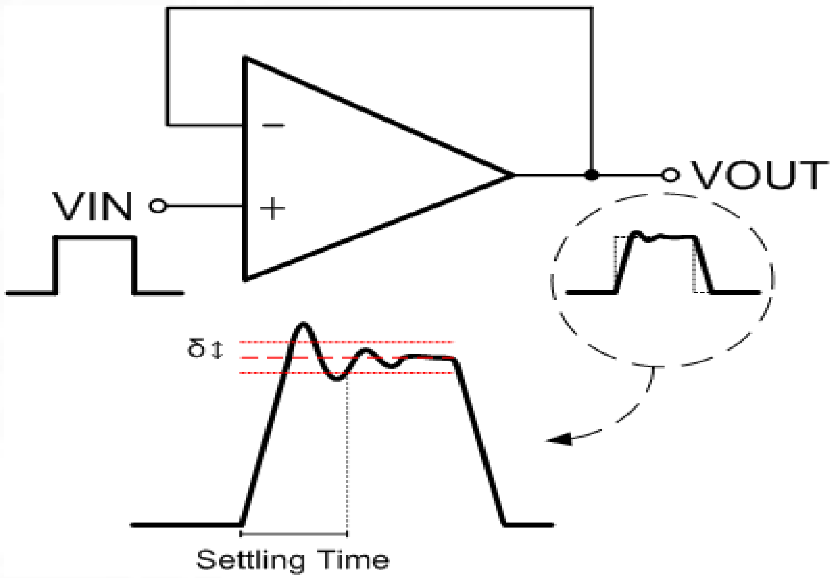
  vinp vinp gnd pulse(0v 1.8v $T_{delay}$ $T_{rise}$ $T_{fall}$ $T_{duty}$ $T_{period}$)

  M1 node_D **vout** node_S node_B N_18 l=?u w=?u m=?

  .tran 1p ??

  .probe V(vout) V(vinp)

  .meas Tran Up_Slew-Rate DERIV V(vout) AT=??

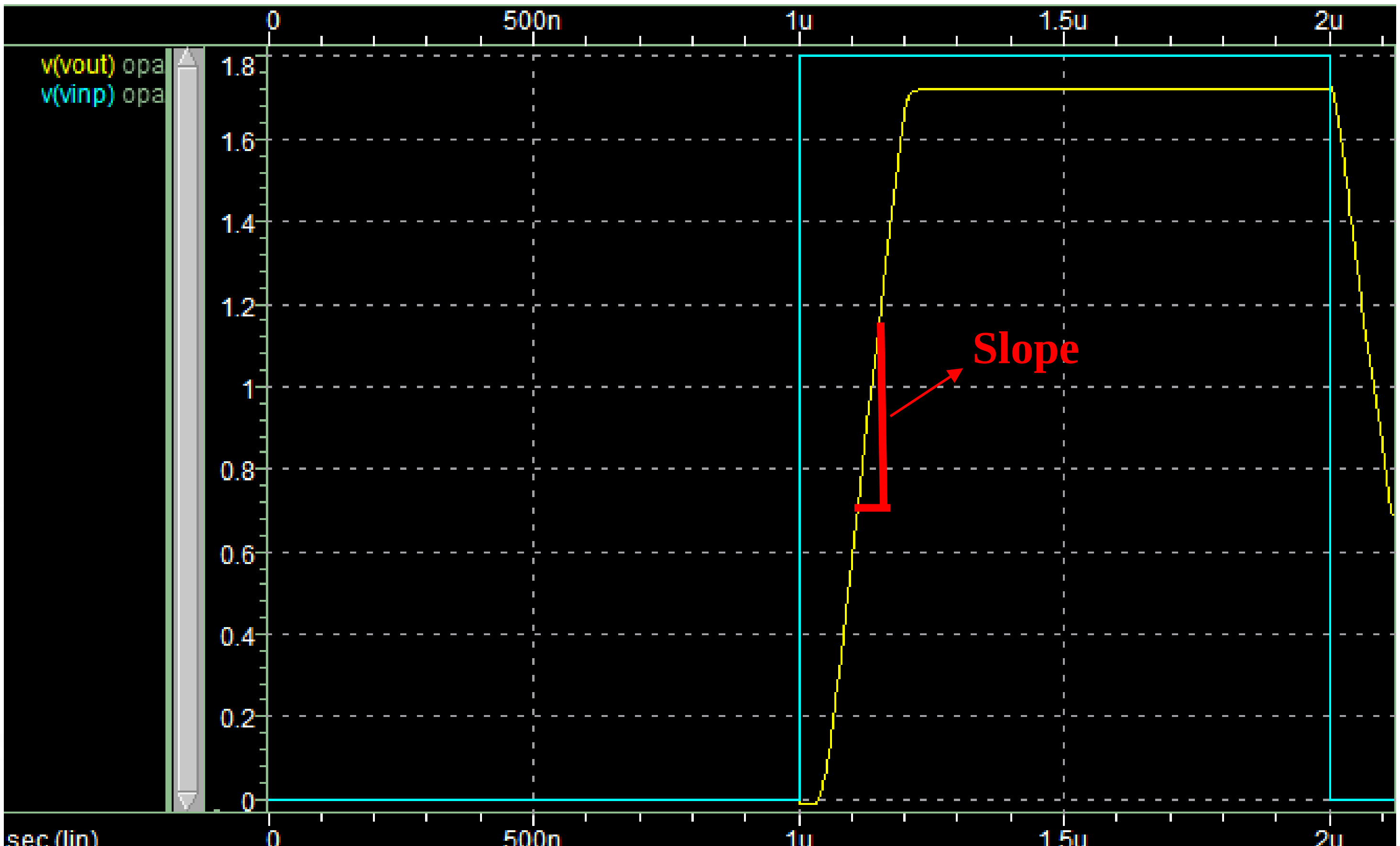


# Slew Rate

- Slew Rate = 11.7V/us

```
****** two stage opamp ******

******  transient analysis tnom=  25.000
 up_slew-rate= 1.1172E+07
```



# 課堂練習-Two stage opamp

- Vdd=1.8V, Vin+=Vin-=0.9V, $C_L$=4pF

| Parameter | Value |
|---|---|
| Gain | >40dB |
| Phase Margin | >50 deg |
| Unit Gain Frequency | >1M Hz |
| CMRR | >50dB |
| ICMR | >1V |
| Output Swing | >1V |
| Slew Rate | >1V/us |