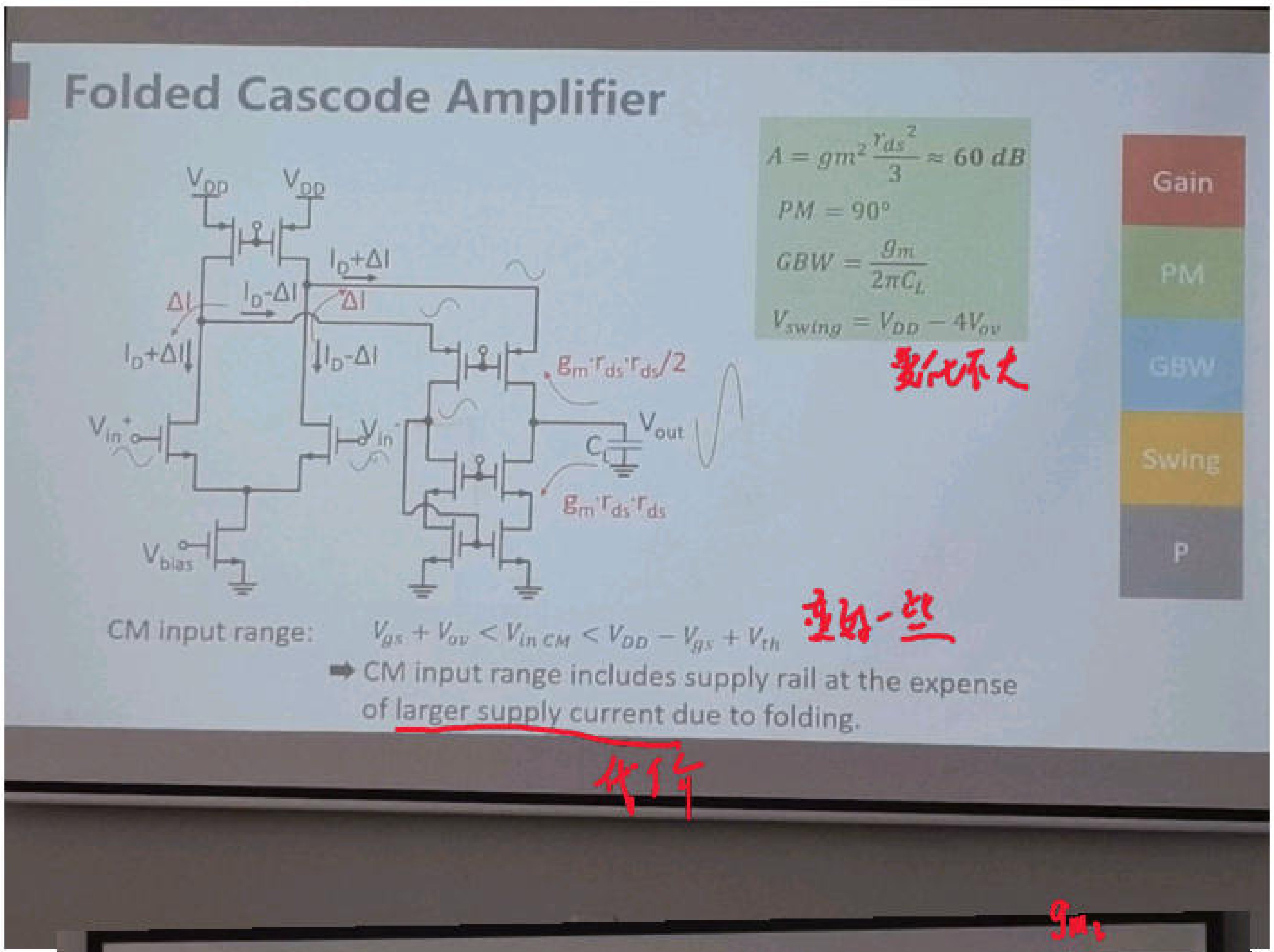
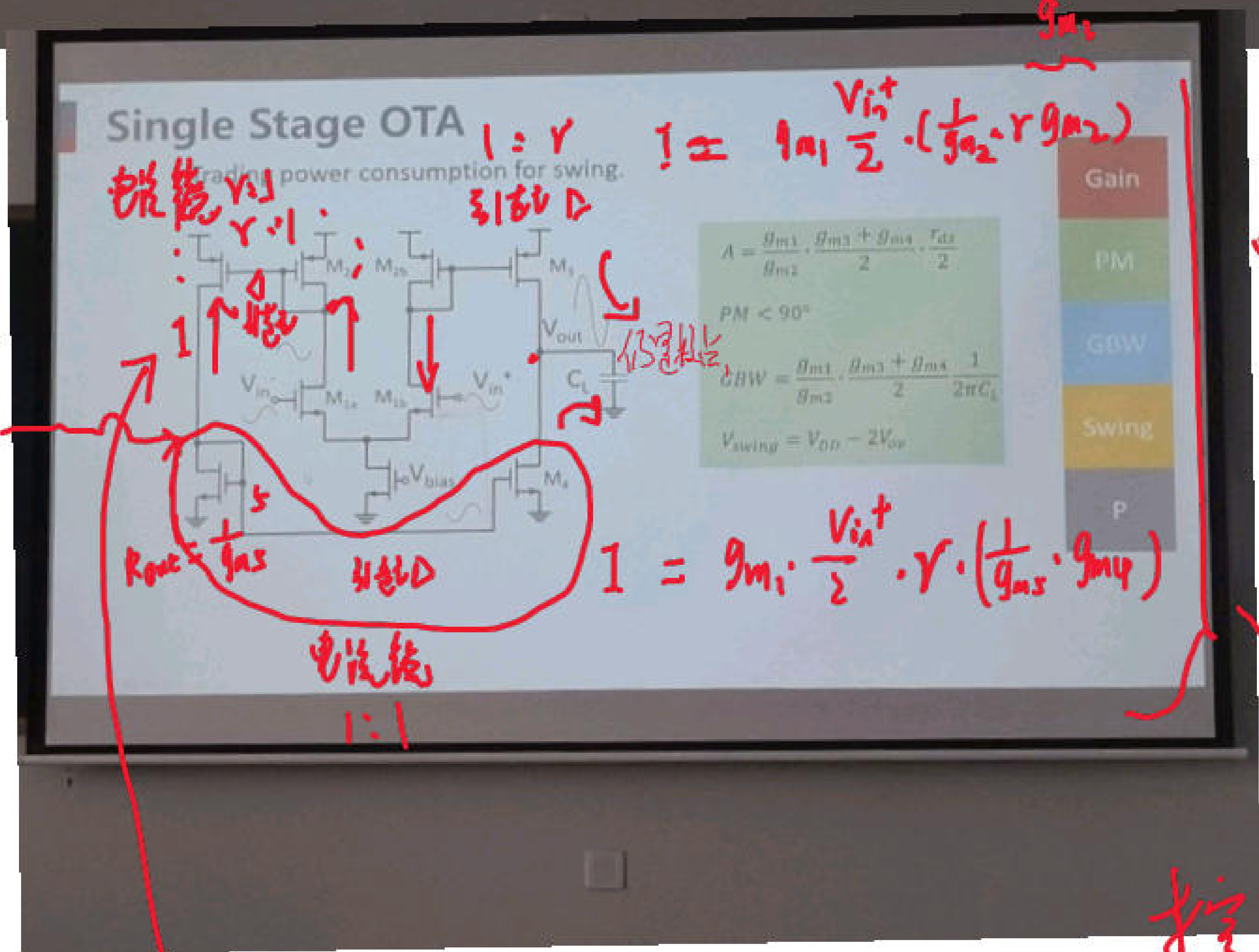




C较大

6r倍

2 + 2 + 2 = 6

寄生电容大

电流 Vin 输入

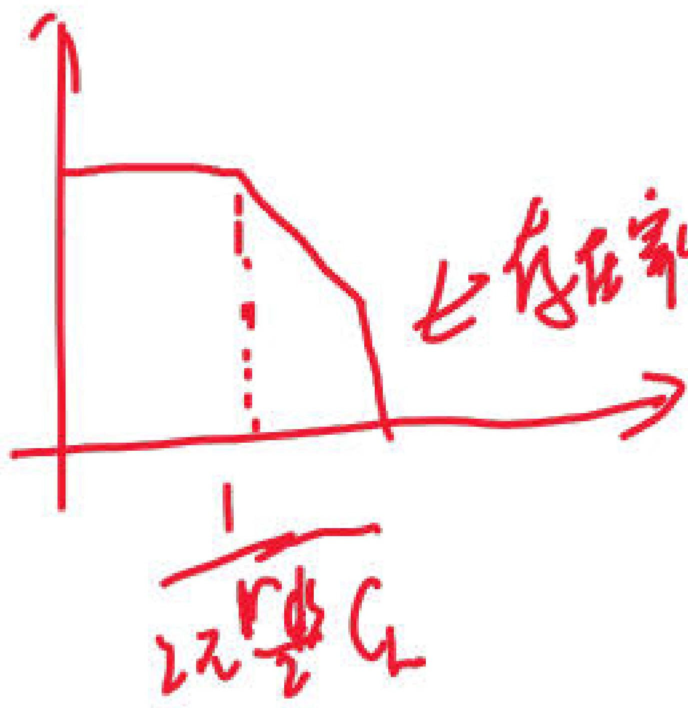
电压 Vout 输出

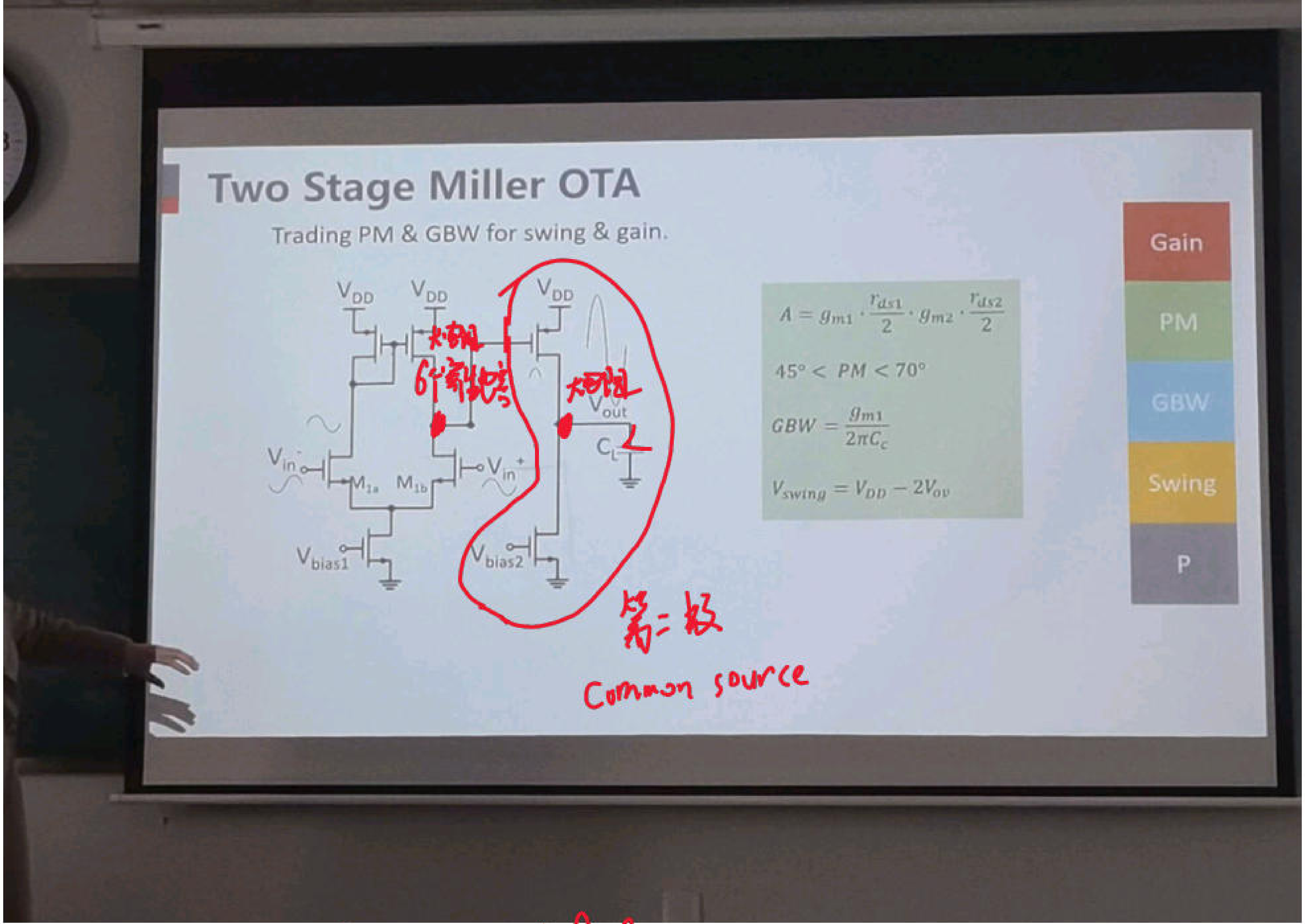
$\frac{V_{out}}{V_{in}}$ 即为 A

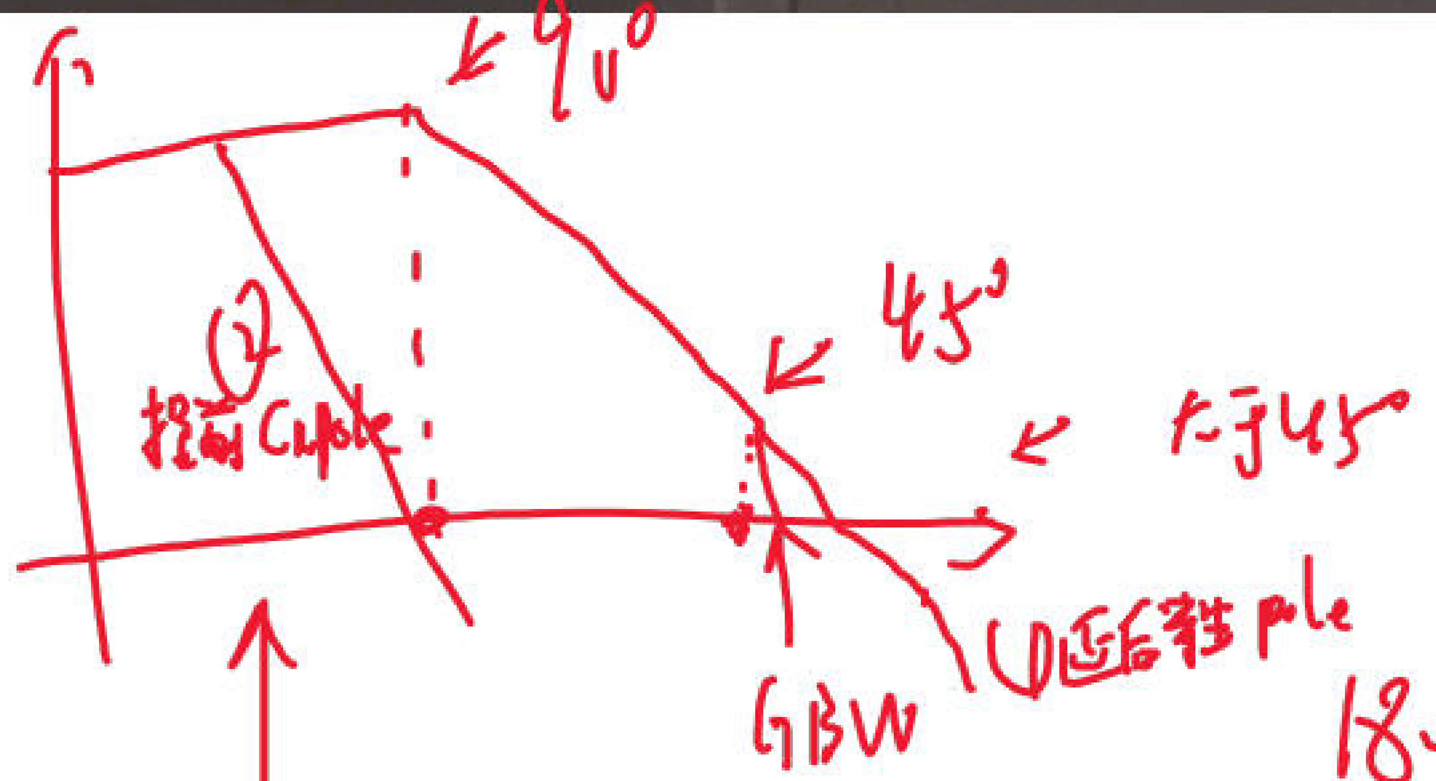
$I \cdot r_{ds} + I \cdot r_{ds} = V_{out}$

控制 r，增大 A

$I = g_{m1} \frac{V_{in}^+}{2} \cdot \frac{1}{g_{m2}} \cdot (r g_{m2})$

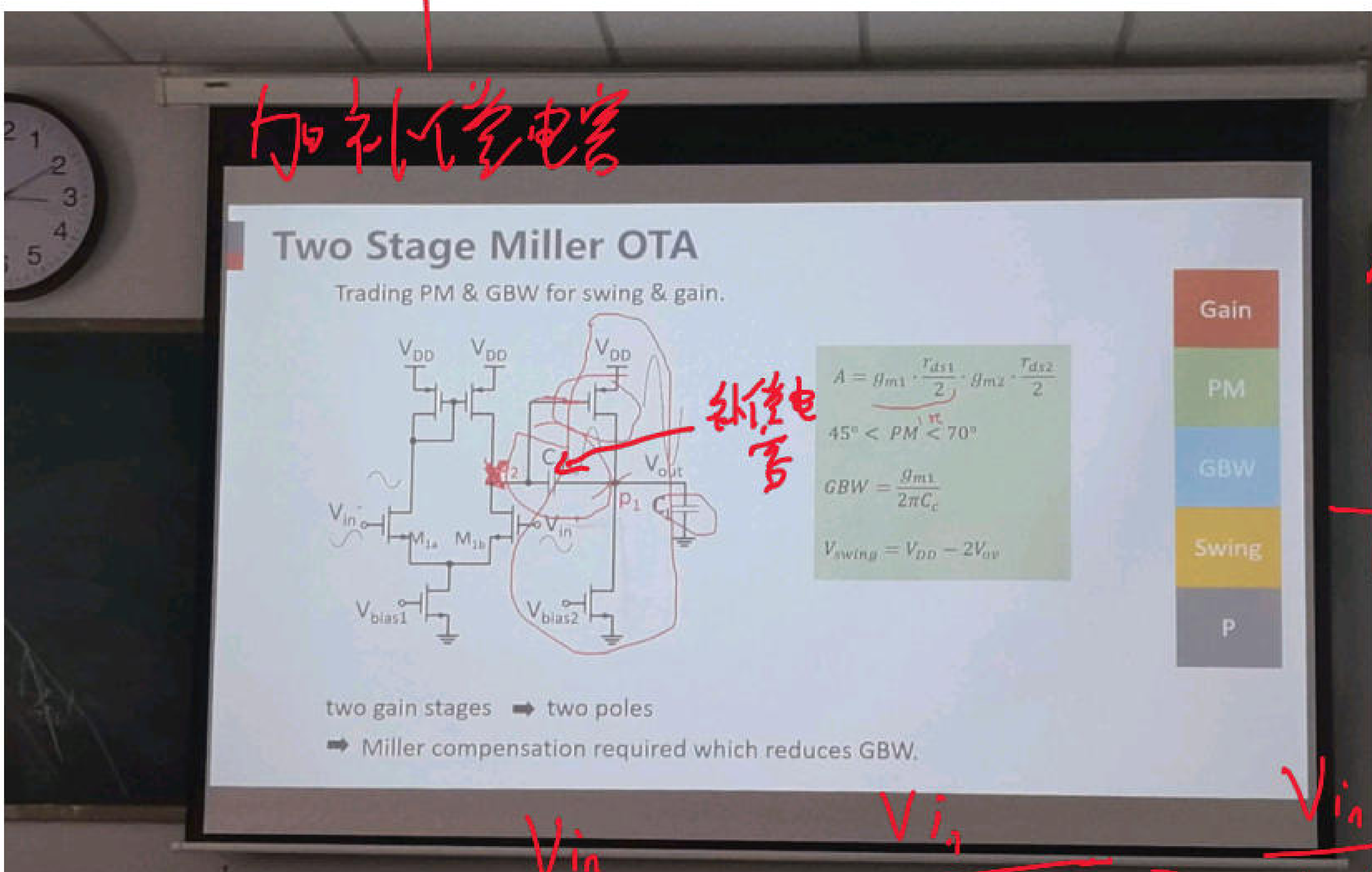






$180° - 90° - 45°(大) < 45°$

加补偿电容



$$R_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{in}}{\frac{V_{in} - V_{in}'}{\frac{1}{sC}}} = \frac{V_{in}}{\frac{V_{in} + AV_{in}}{sC}} = \frac{\frac{1}{sC}}{(1+A)}$$

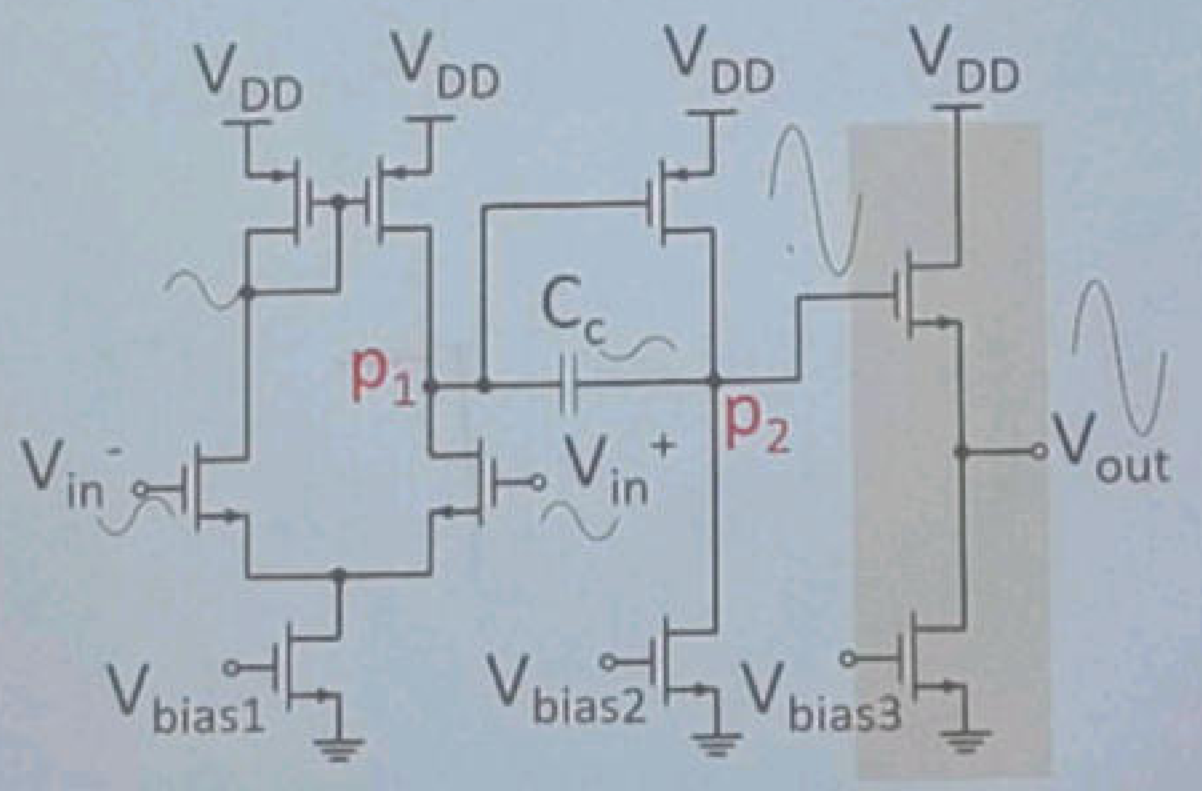
Recall

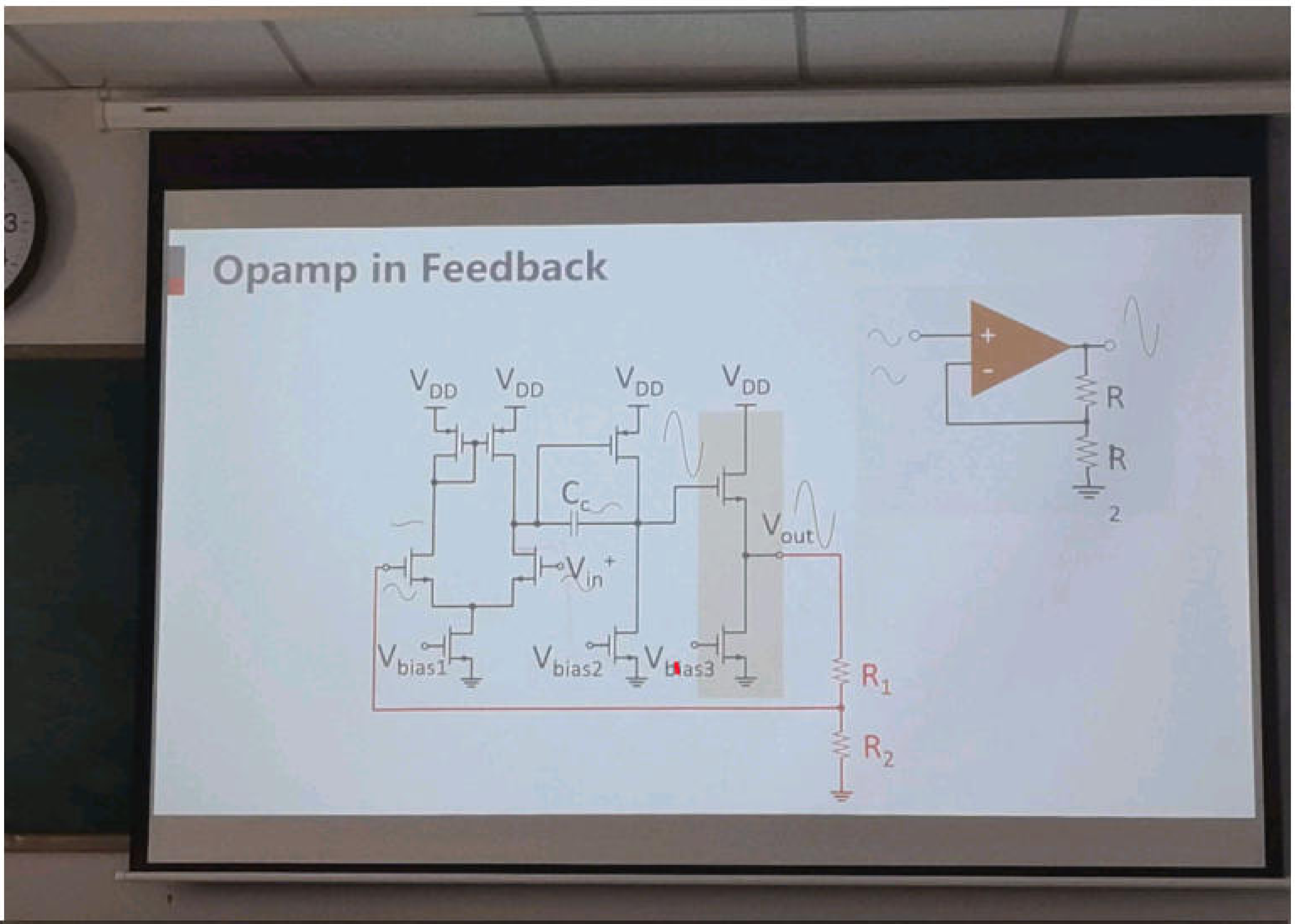
All amplifiers discussed so far are operational transconductance amplifiers (OTA).
Due to their high output impedance they behave like voltage controlled curent sources.

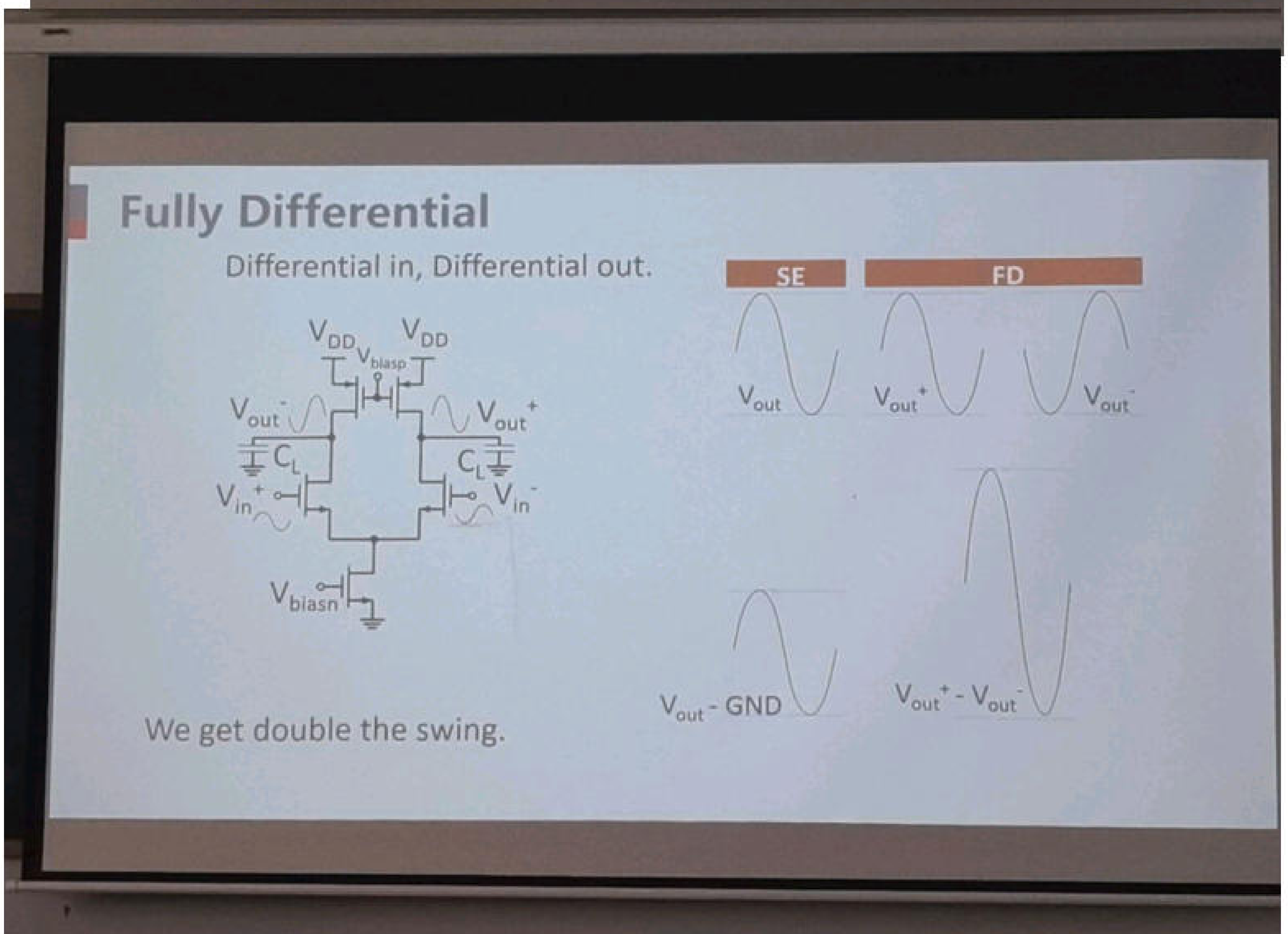
Opamp

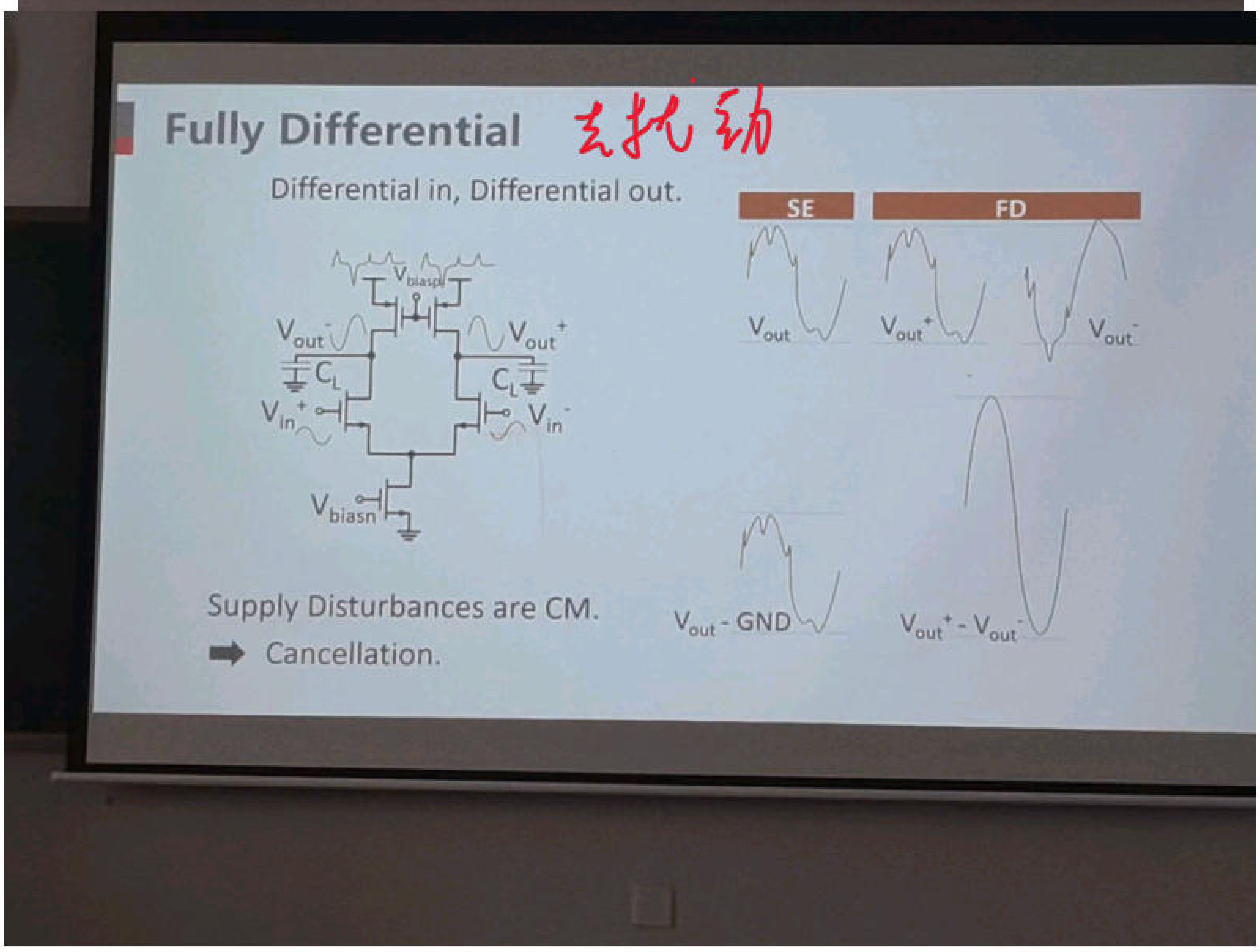
Sometimes we need to drive a resistive load.

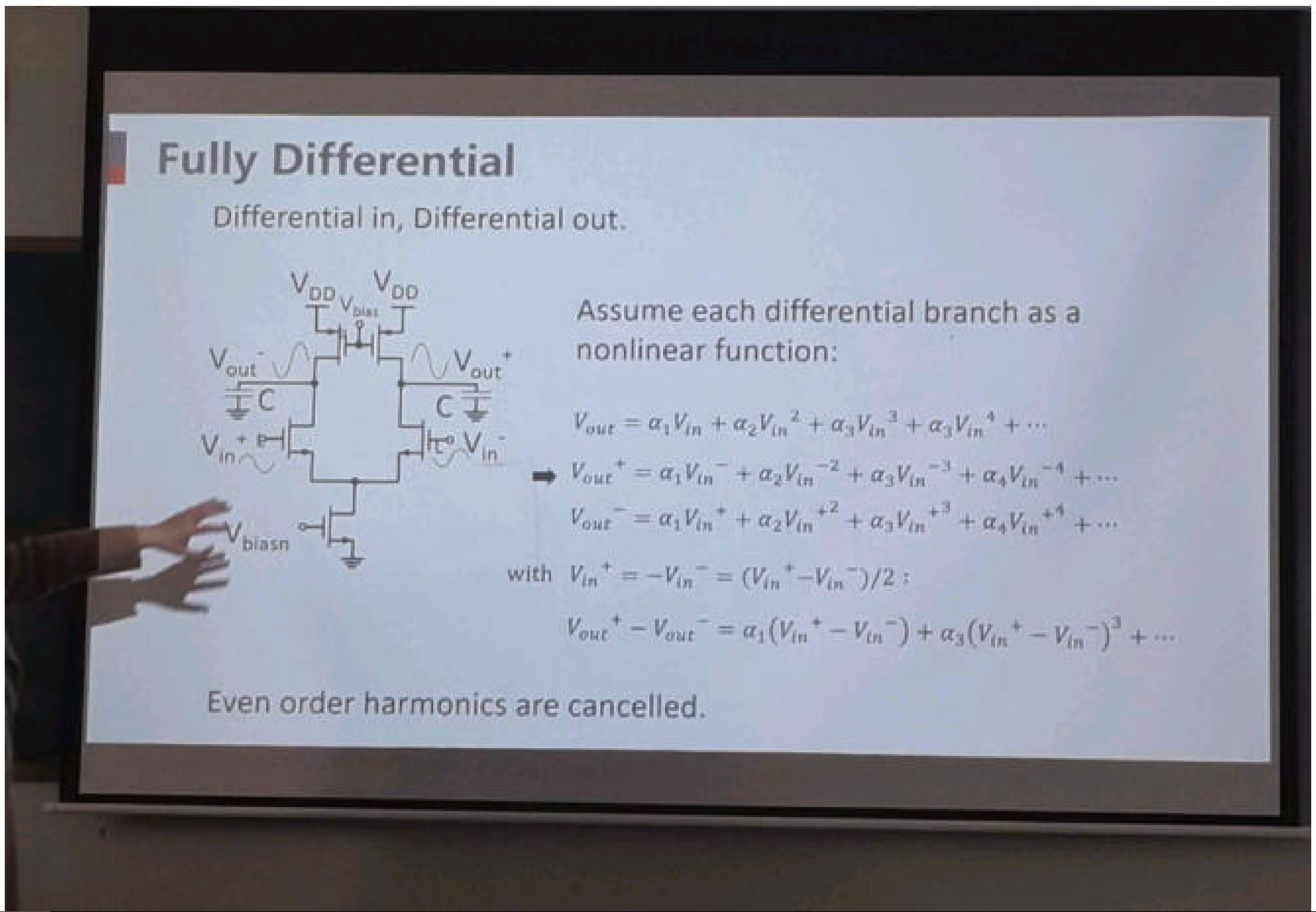
➡ Add output buffer.

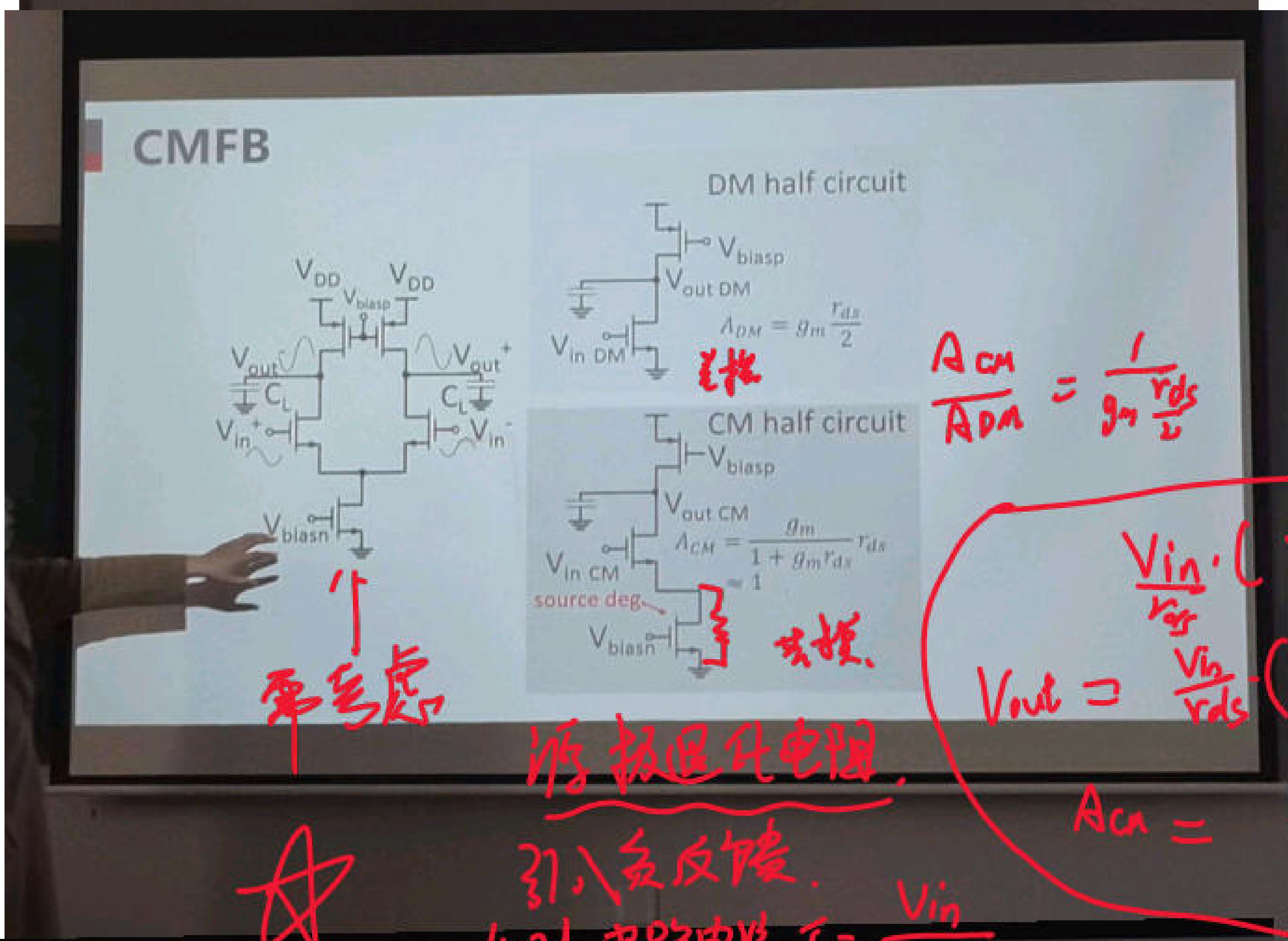



Opamp in Feedback
VDD
Cc
Vout
Vin+
Vbias1
Vbias2
Vbias3
R1
R2
R


Fully Differential
Differential in, Differential out.
VDD
Vbiasp
Vout-
Vout+
CL
Vin+
Vin-
Vbiasn
SE
FD
Vout
Vout+
Vout-
Vout - GND
Vout+ - Vout-
We get double the swing.


Fully Differential
去扰动
Differential in, Differential out.
Vbiasp
Vout-
Vout+
CL
Vin+
Vin-
Vbiasn
SE
FD
Vout
Vout+
Vout-
Vout - GND
Vout+ - Vout-
Supply Disturbances are CM.
Cancellation.





差模

共模

需考虑

$$\frac{A_{CM}}{A_{DM}} = \frac{1}{g_m \frac{r_{ds}}{2}}$$

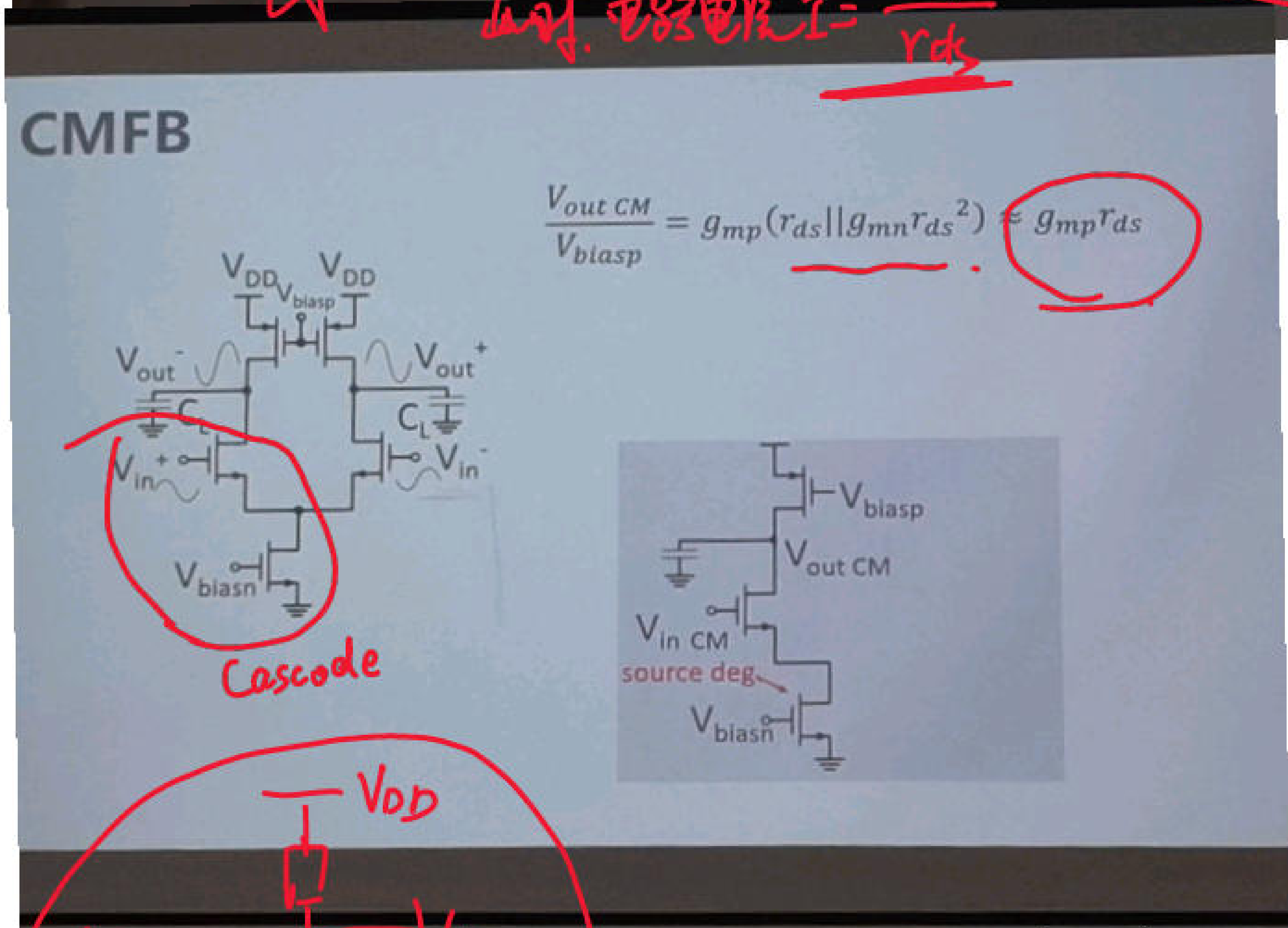
$$V_{out} = \frac{V_{in}}{r_{ds}} \cdot (r_{ds} // g_m r_{ds}^2) = \frac{V_{in}}{r_{ds}} \left(\frac{g_m r_{ds}^2}{g_m r_{ds}+1} \right)$$

$$A_{CM} = \frac{g_m r_{ds}}{g_m r_{ds}+1}$$

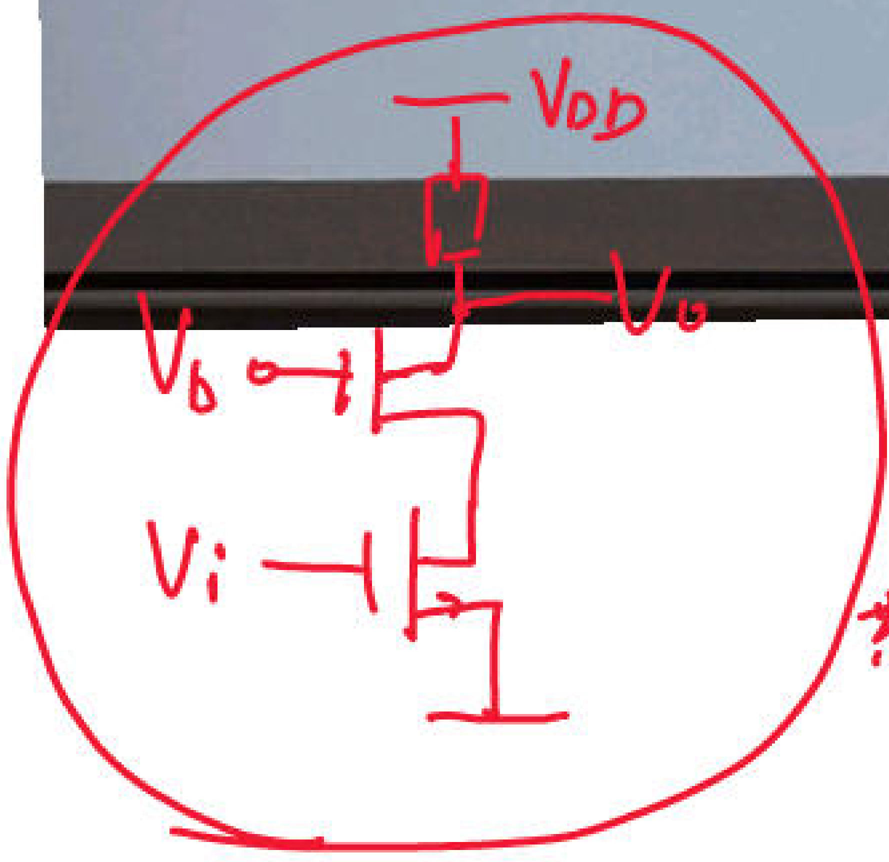
源极退化电阻，

引入负反馈.

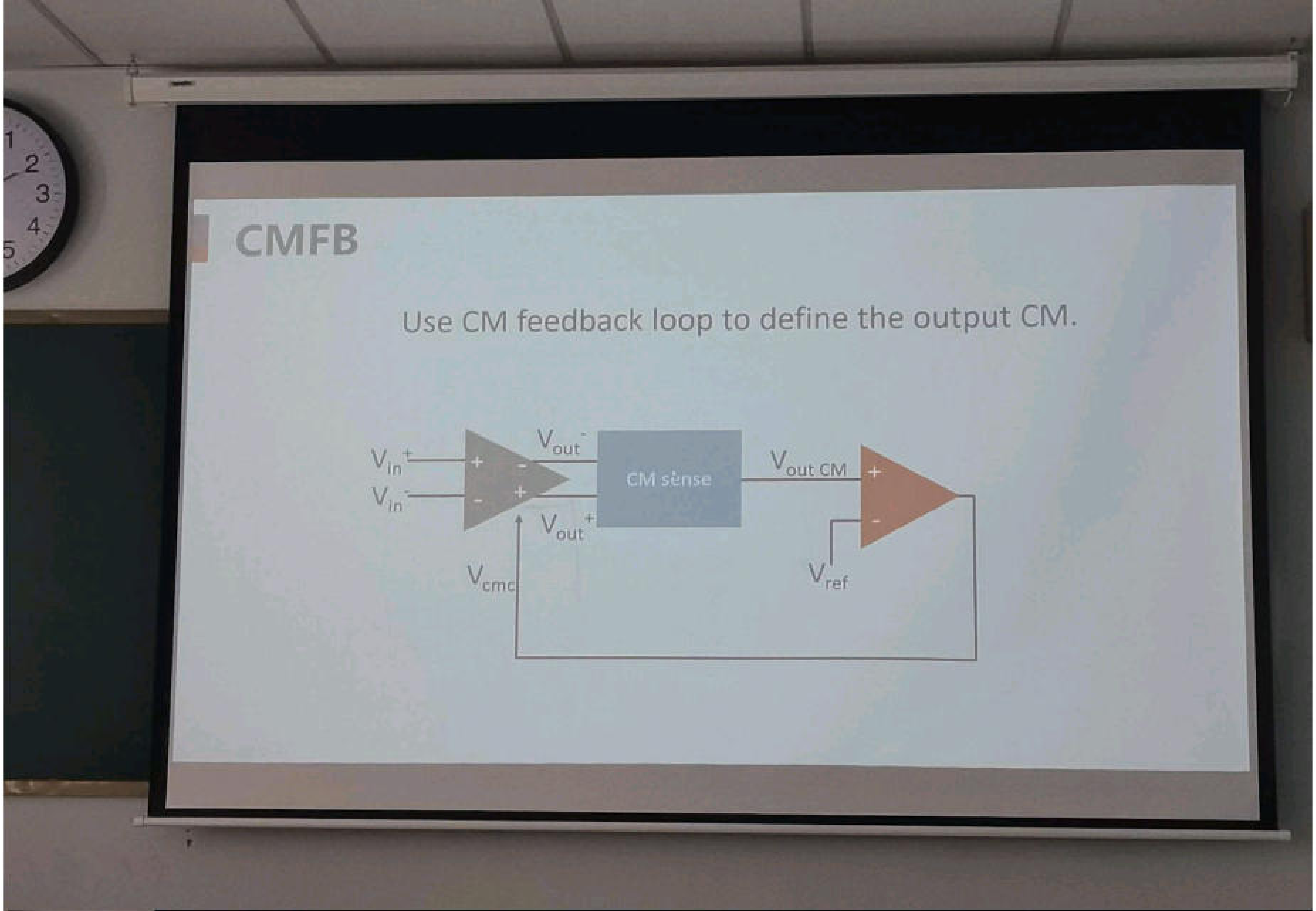
此时,电路电流 $I = \frac{V_{in}}{r_{ds}}$

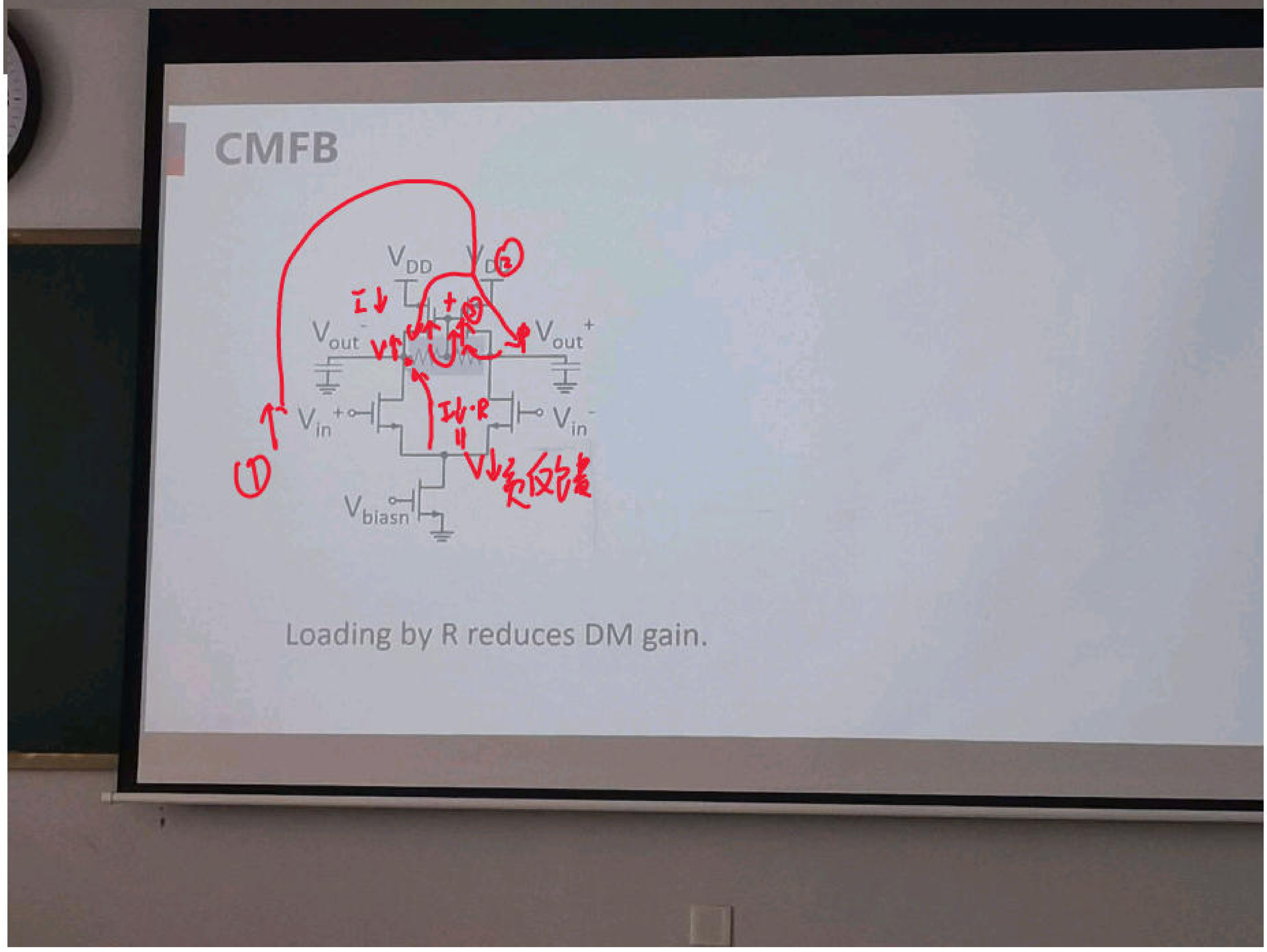


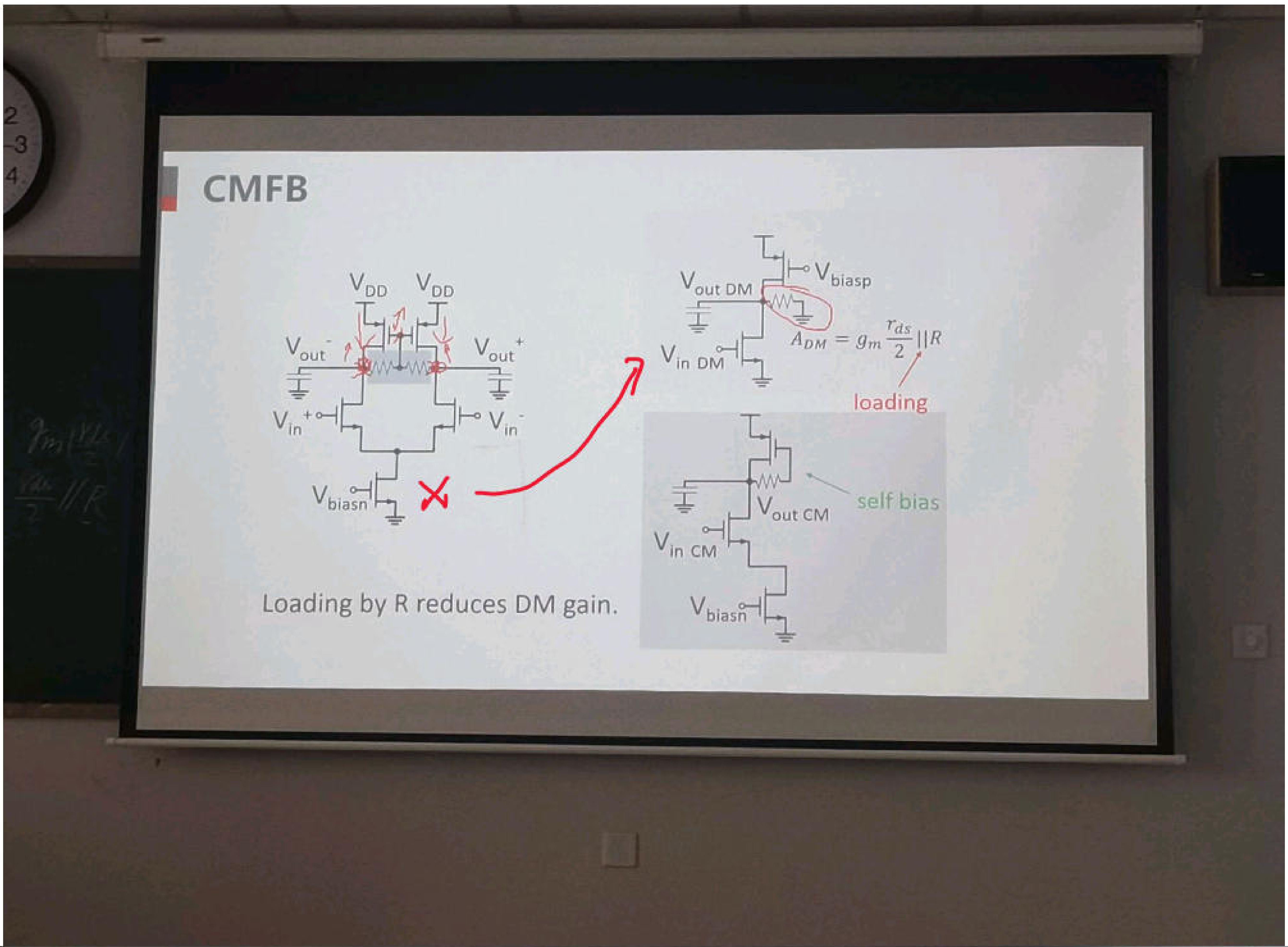
Cascode

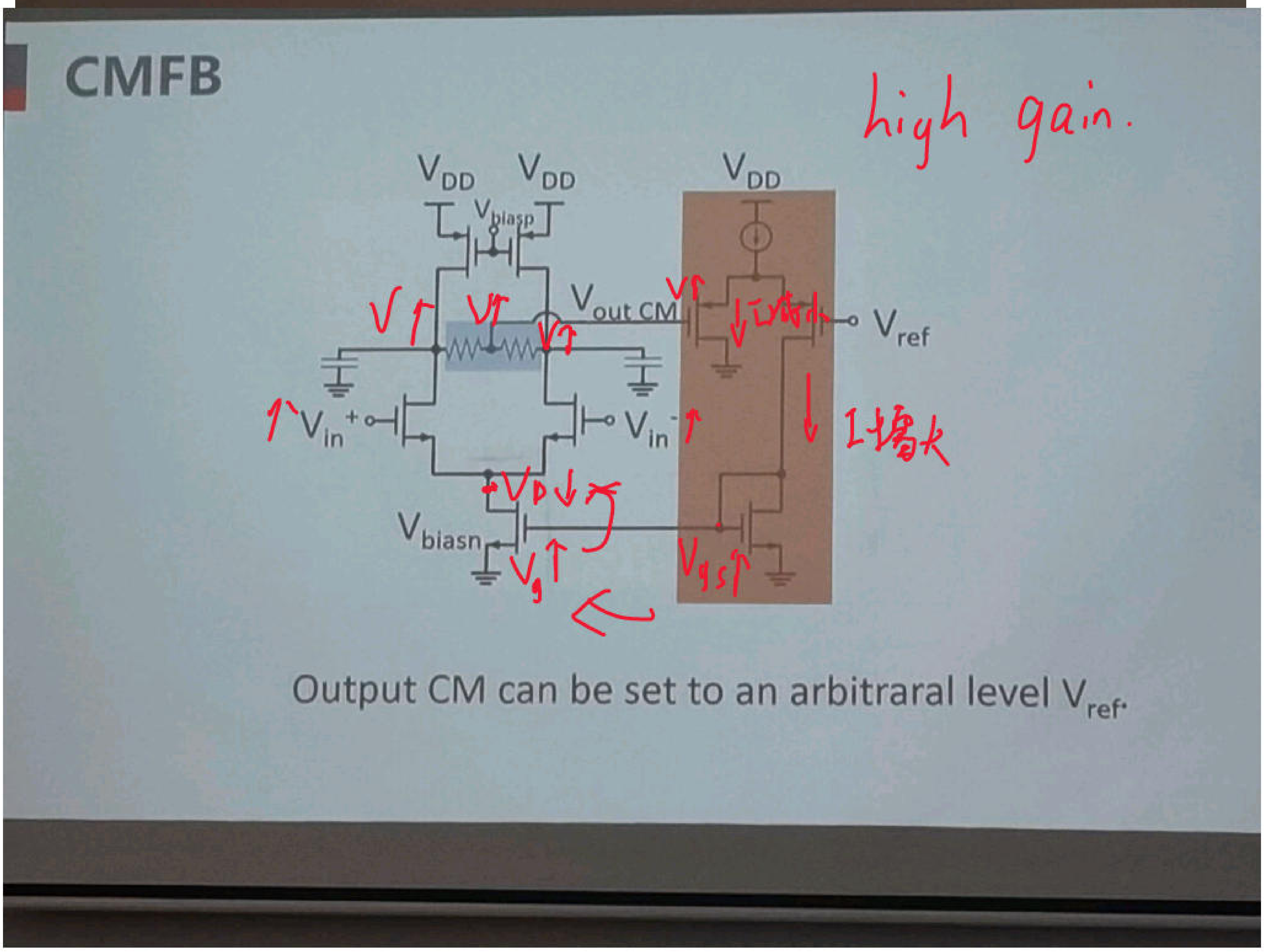


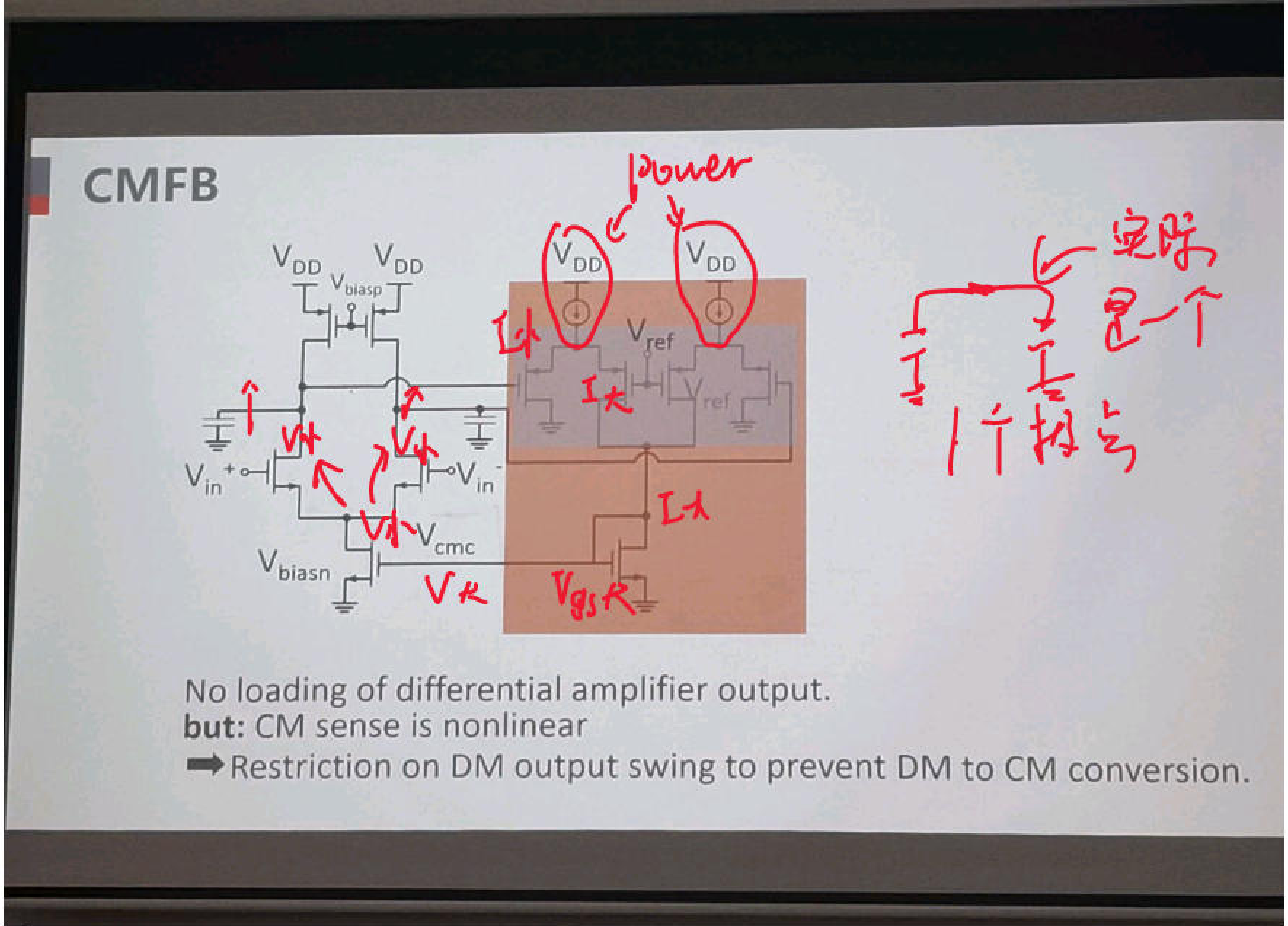
共源共栅放大器

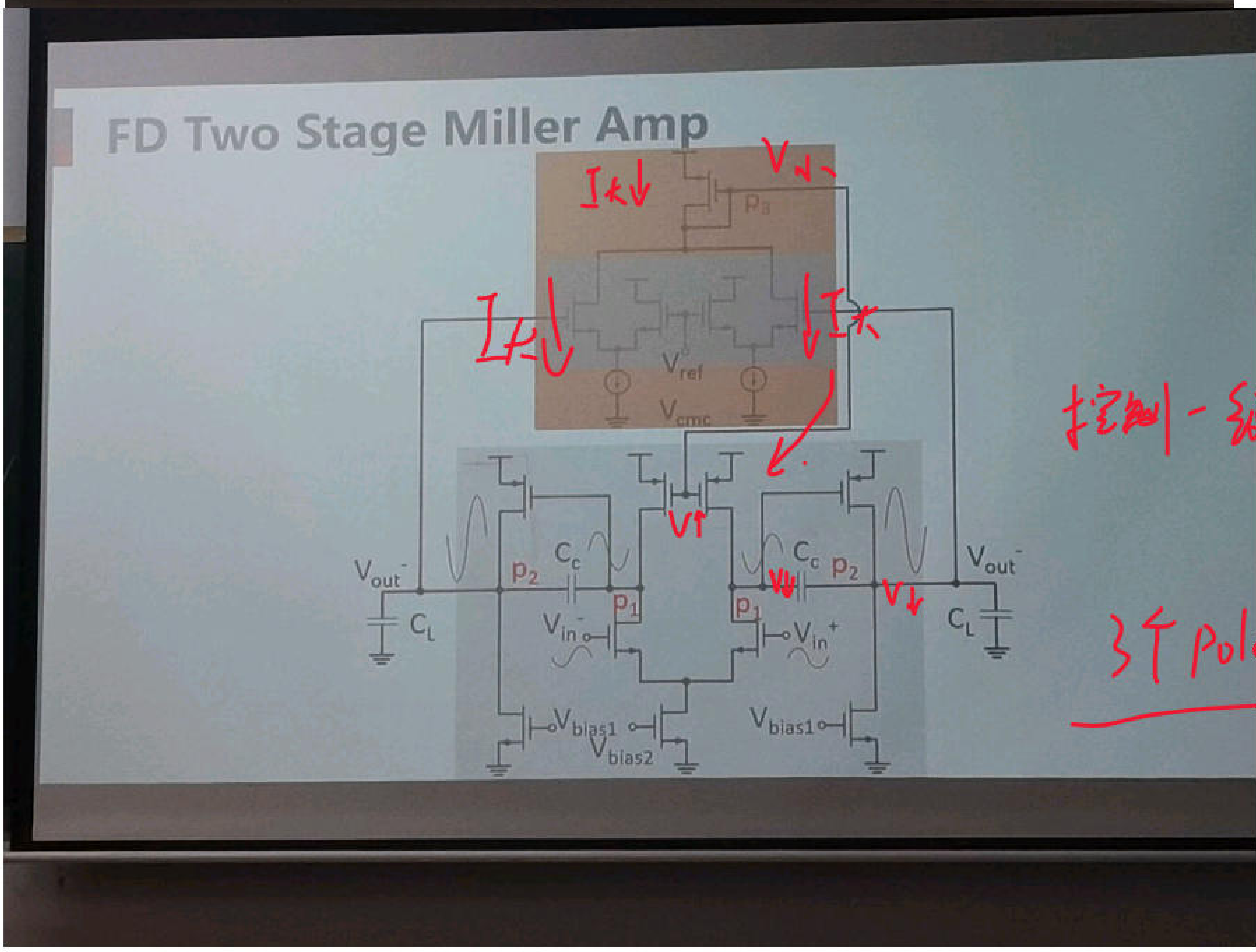

CMFB
Use CM feedback loop to define the output CM.
CM sense
Vin+
Vin-
Vout-
Vout+
Vout CM
Vref
Vcmc

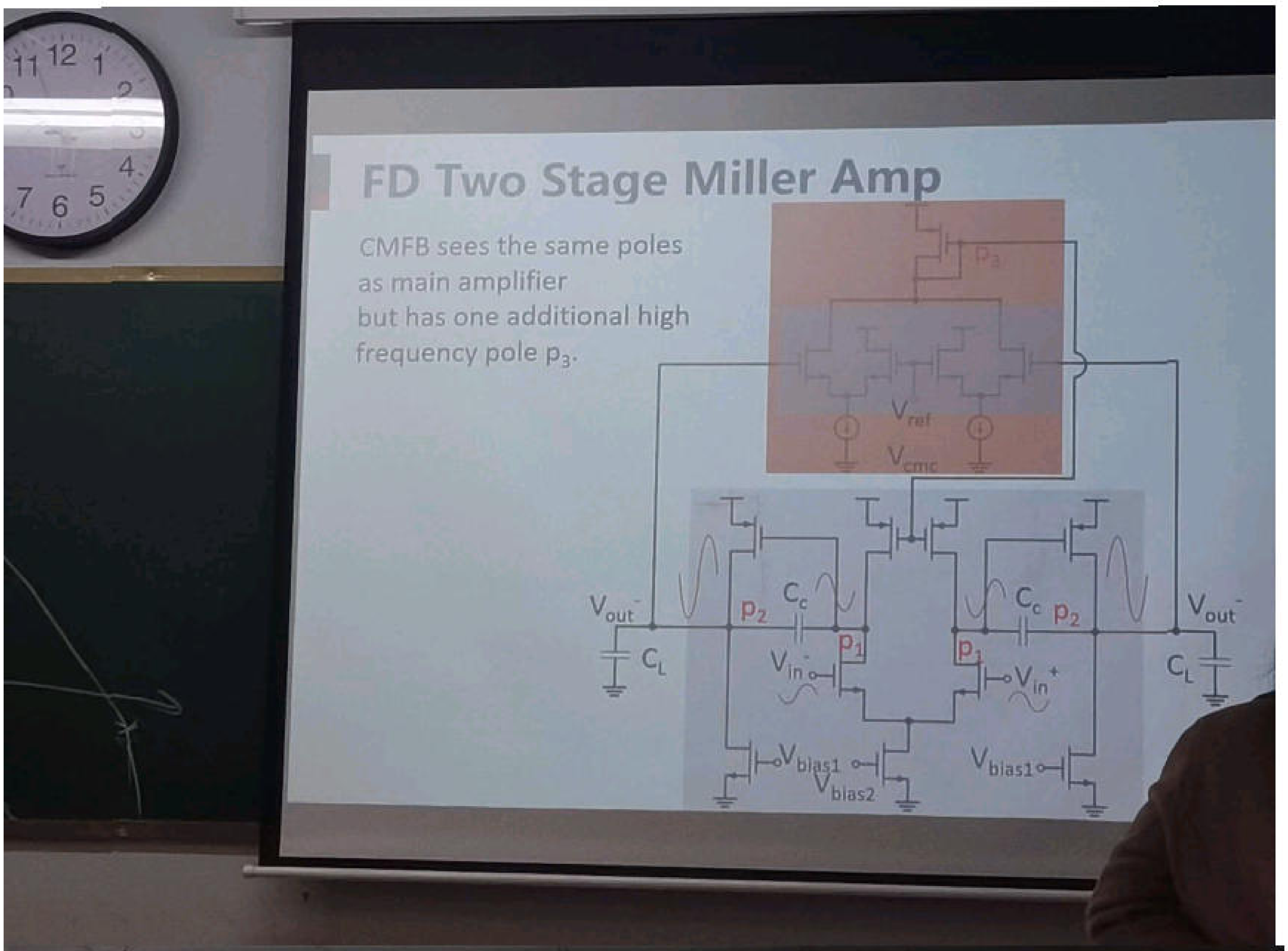

CMFB
VDD
Vout-
Vout+
Vin+
Vin-
Vbiasn
负反馈
Loading by R reduces DM gain.

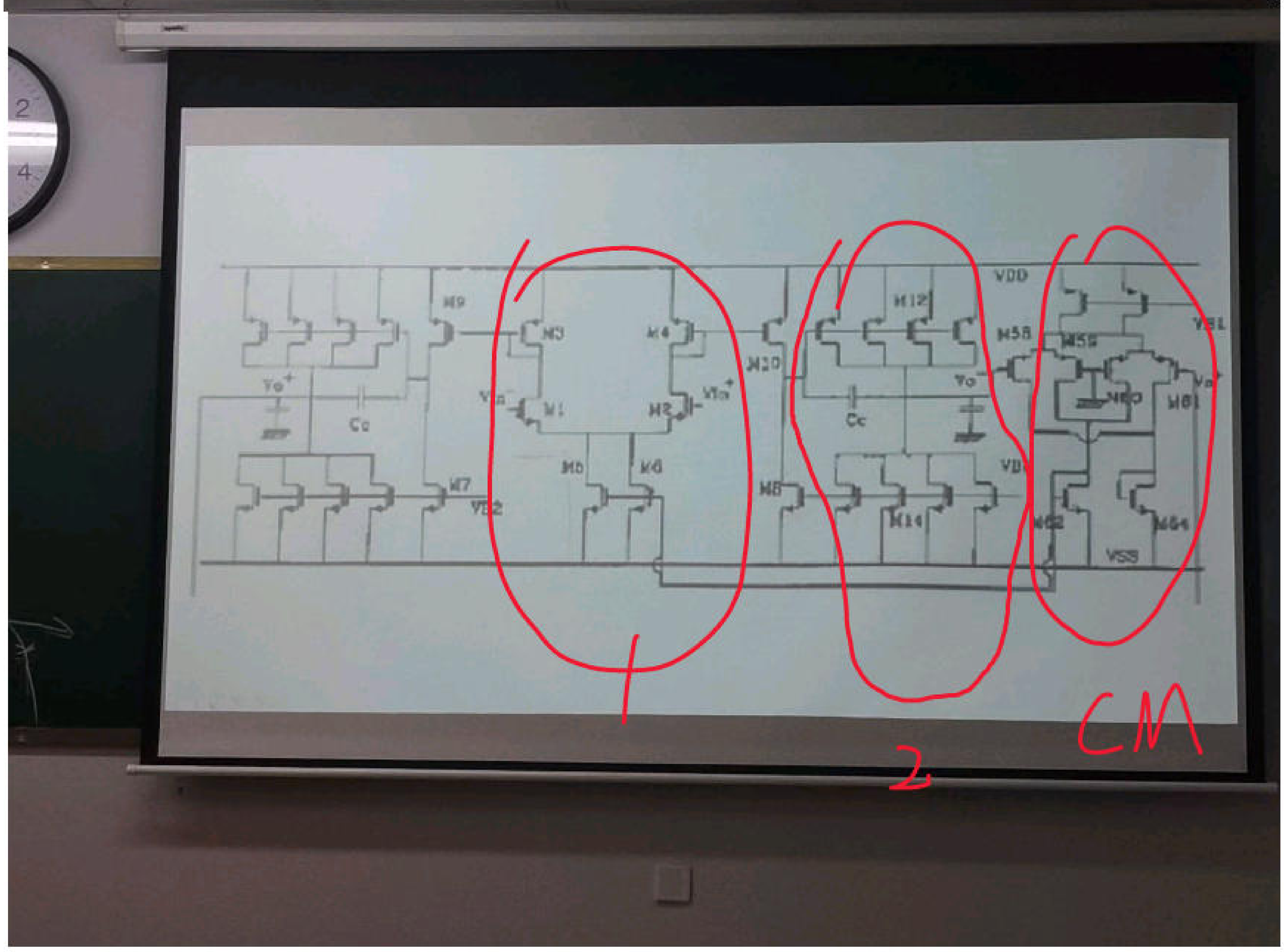

CMFB
VDD
VDD
Vout-
Vout+
Vin+
Vin-
Vbiasn
Loading by R reduces DM gain.
Vbiasp
Vout DM
Vin DM
$A_{DM} = g_m \frac{r_{ds}}{2} || R$
loading
self bias
Vout CM
Vin CM
Vbiasn

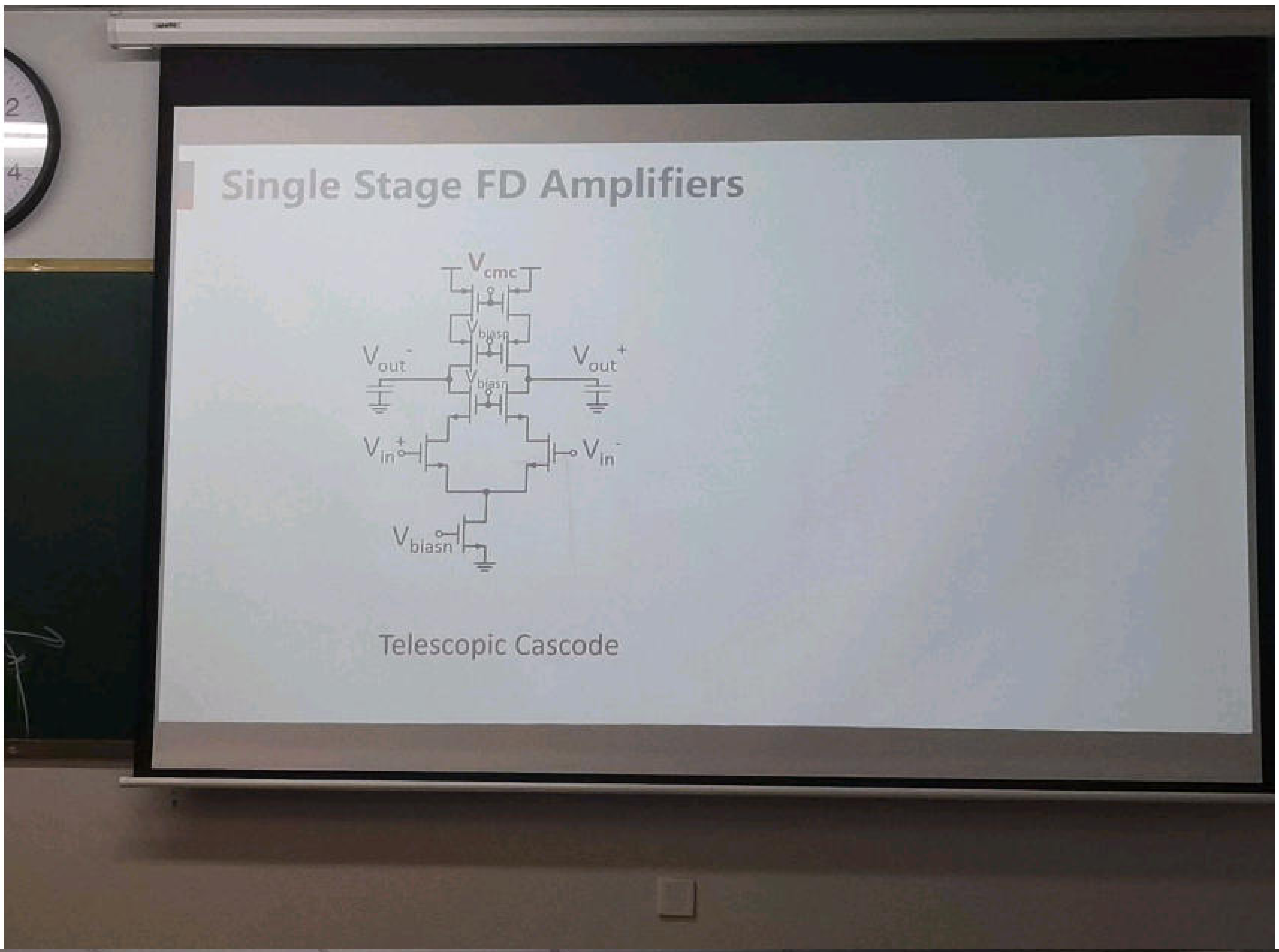

CMFB
high gain.
VDD
VDD
Vbiasp
VDD
Vout CM
Vref
Vin+
Vin-
Vbiasn
I增大
Output CM can be set to an arbitraral level Vref.

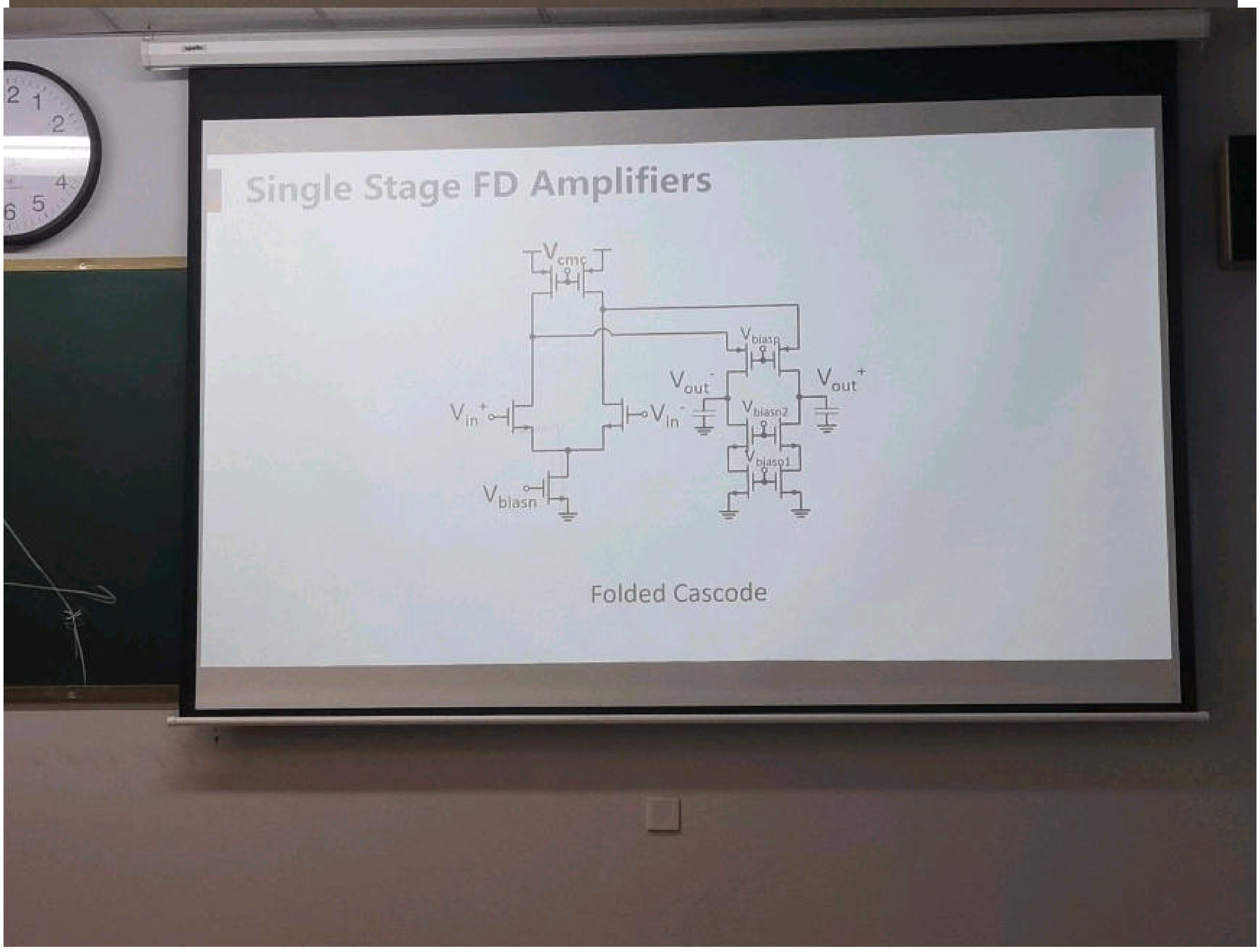

CMFB
power
V_DD
V_biasp
V_ref
V_in+
V_in-
V_cmc
V_biasn
实际
是一个
1个极点
No loading of differential amplifier output.
but: CM sense is nonlinear
➡Restriction on DM output swing to prevent DM to CM conversion.

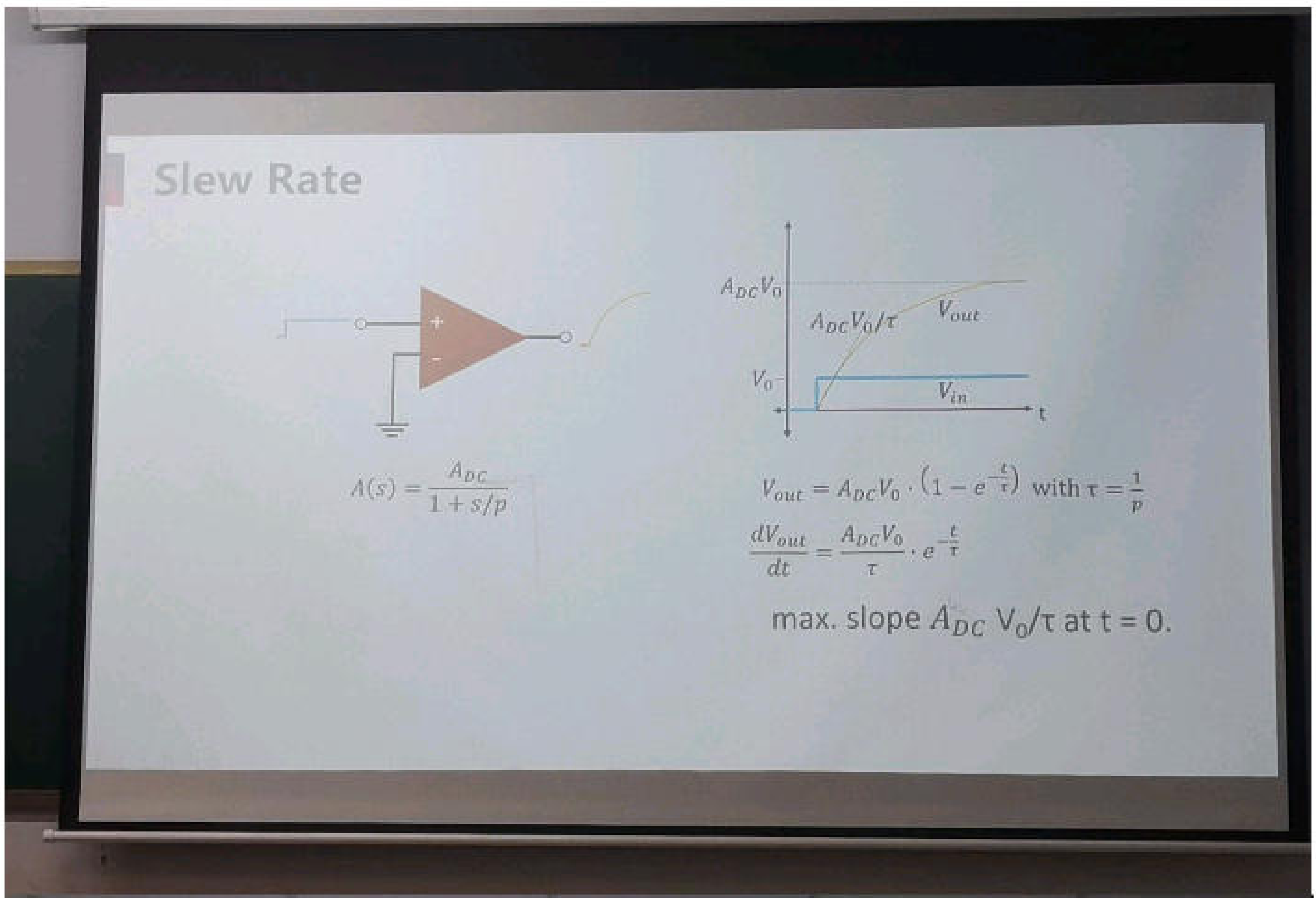

FD Two Stage Miller Amp
V_ref
V_cmc
V_out-
C_L
C_c
p2
p1
V_in-
V_in+
V_bias1
V_bias2
控制一级即可
3个pole

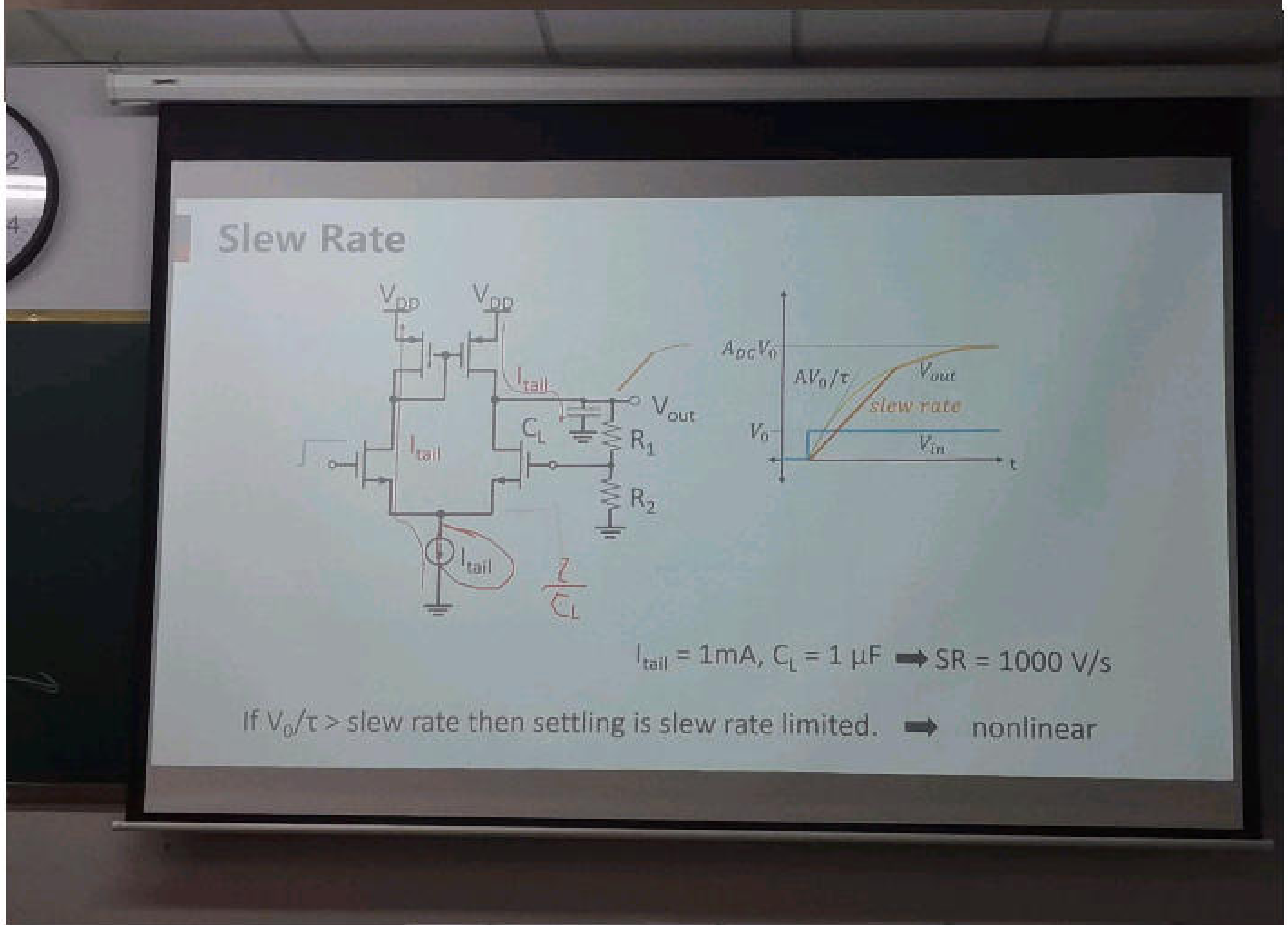

FD Two Stage Miller Amp
CMFB sees the same poles
as main amplifier
but has one additional high
frequency pole p3.
Vref
Vcmc
Vout-
CL
p2
Cc
p1
Vin-
Vin+
Vbias1
Vbias2
Vout+

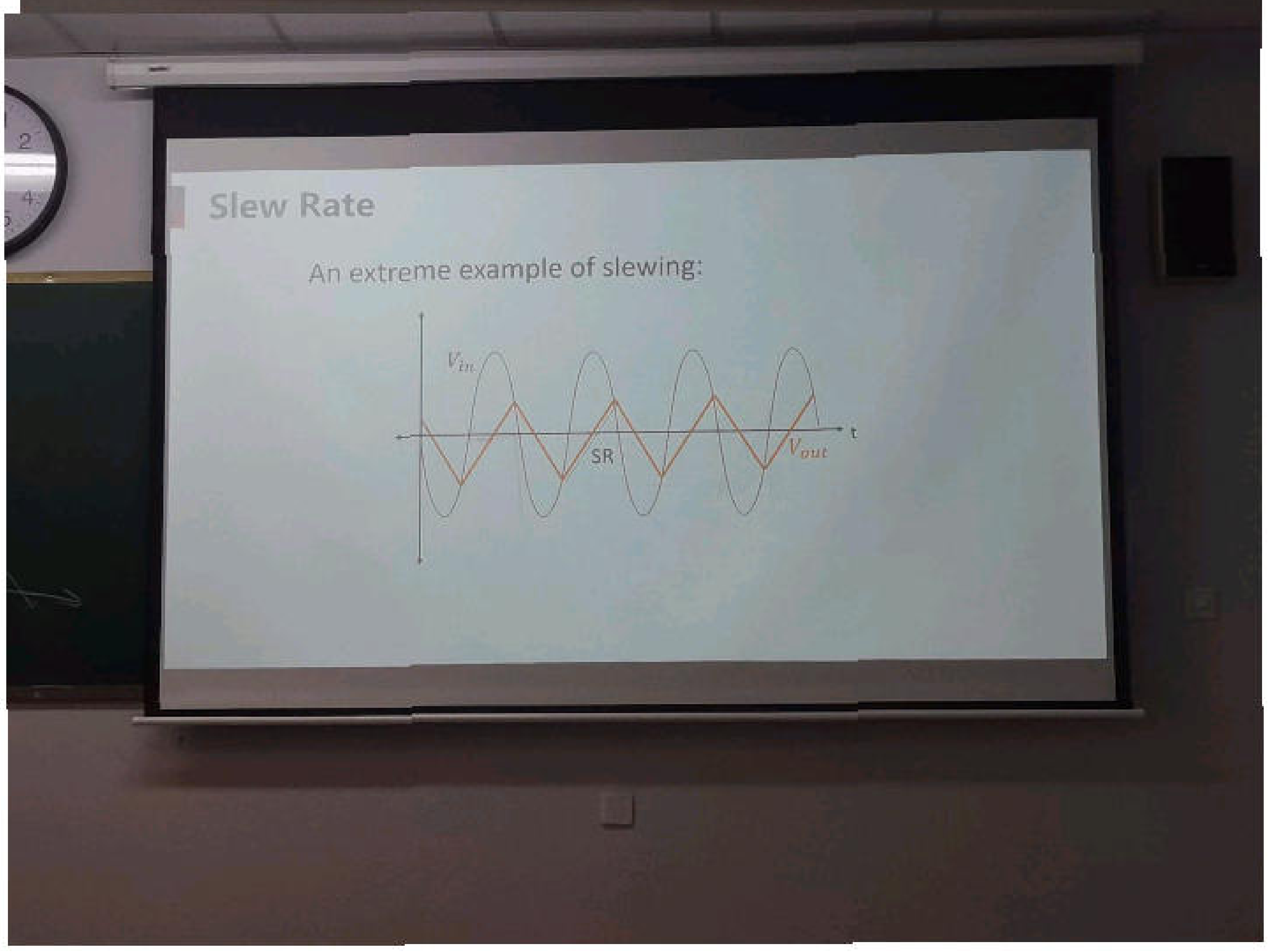

M9
M3
M4
Vin-
M1
M2
Vin+
M10
M12
M58
M56
VDD
VB1
Vo+
Cc
M5
M6
M7
VB2
M8
M14
Vo
M60
M61
M62
M64
VSS
1
2
CM

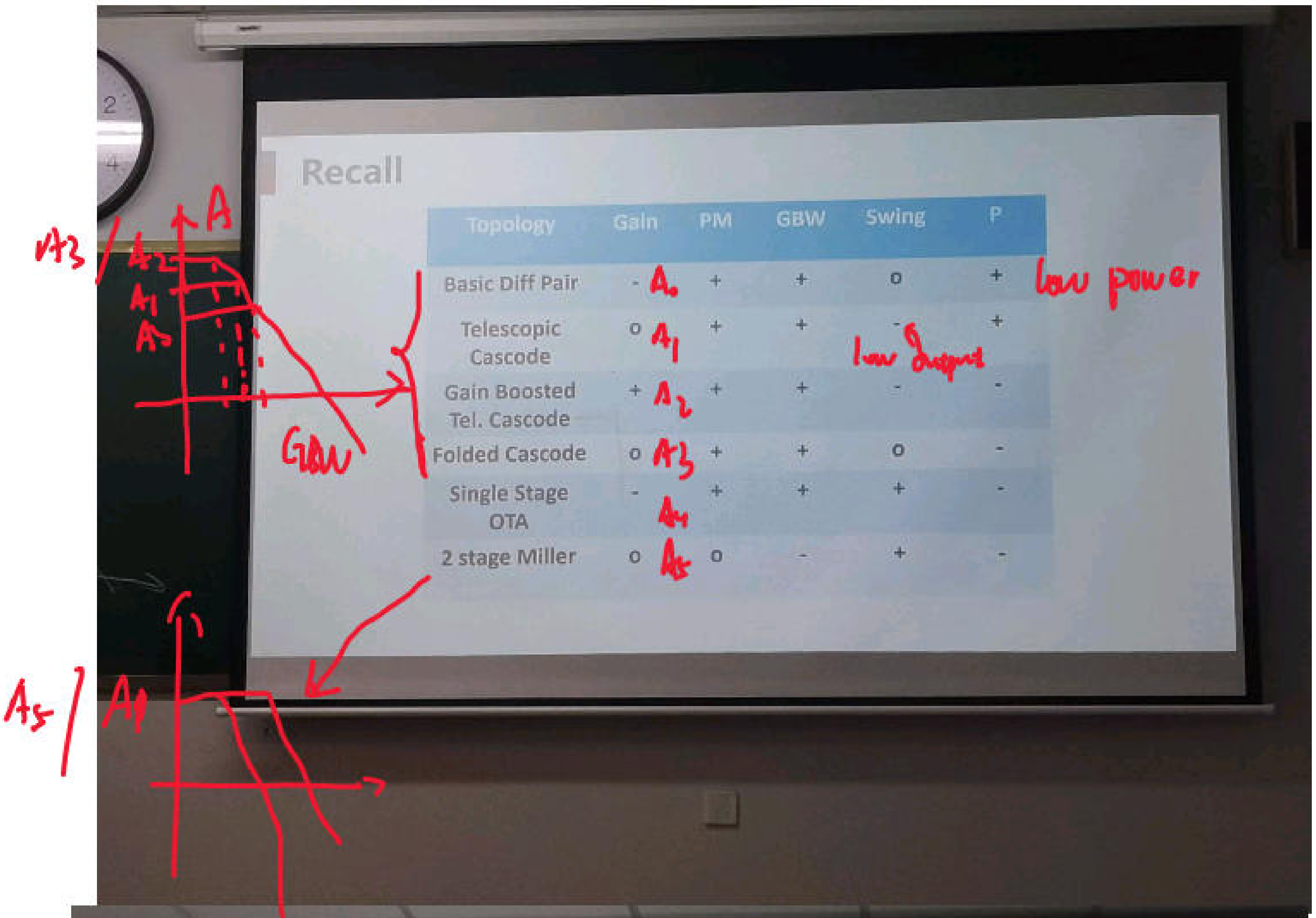

Single Stage FD Amplifiers
V_{cmc}
V_{biasp}
V_{out}^{-}
V_{out}^{+}
V_{biasn}
V_{in}^{+}
V_{in}^{-}
V_{biasn}
Telescopic Cascode

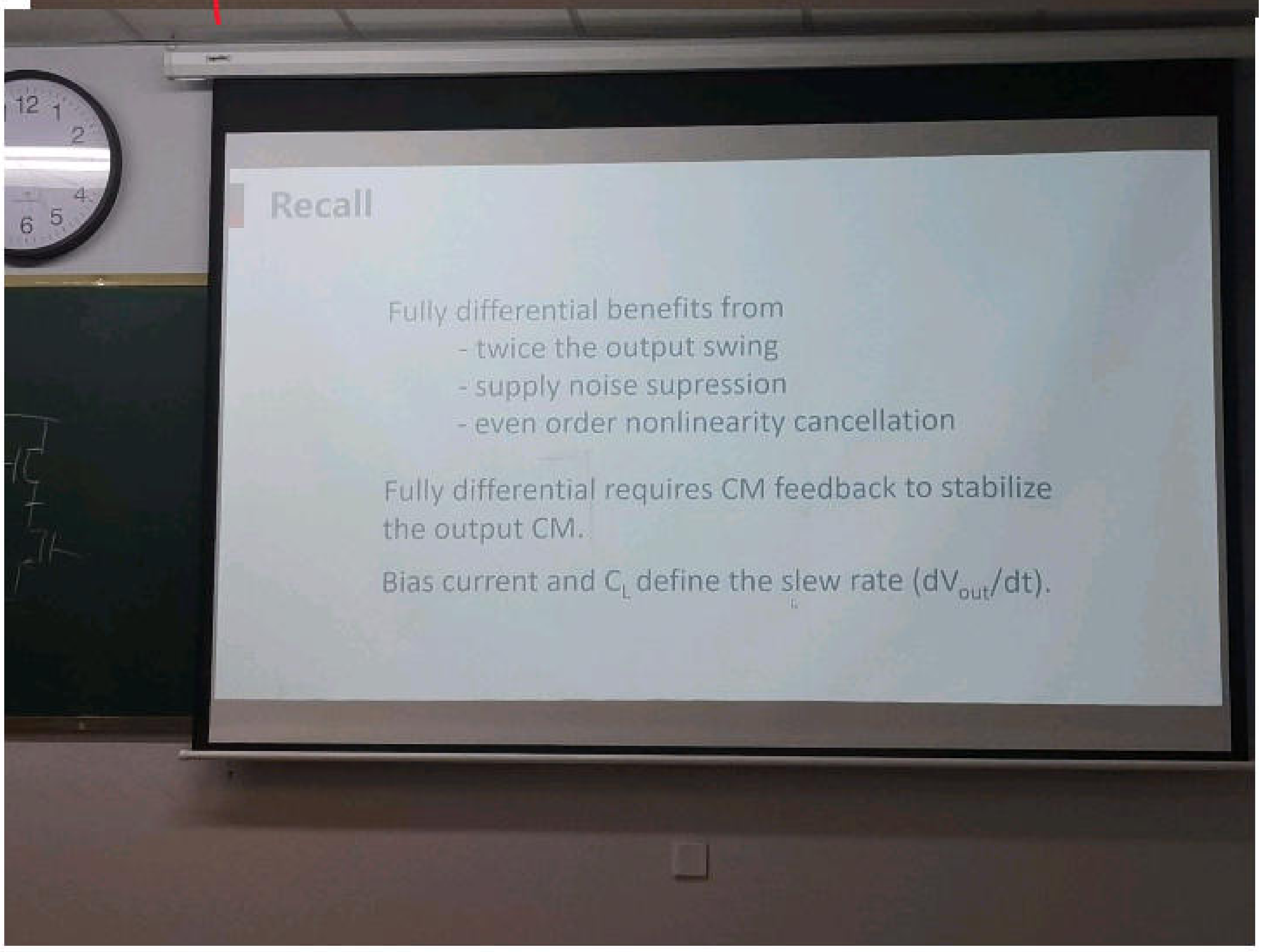

Single Stage FD Amplifiers
V_{cmc}
V_{biasp}
V_{out}^{-}
V_{out}^{+}
V_{in}^{+}
V_{in}^{-}
V_{biasn2}
V_{biasn1}
V_{biasn}
Folded Cascode


Slew Rate
$A_{DC}V_0$
$A_{DC}V_0/\tau$
V_{out}
V_0
V_{in}
t
$A(s) = \frac{A_{DC}}{1+s/p}$
$V_{out} = A_{DC}V_0 \cdot (1 - e^{-\frac{t}{\tau}})$ with $\tau = \frac{1}{p}$
$\frac{dV_{out}}{dt} = \frac{A_{DC}V_0}{\tau} \cdot e^{-\frac{t}{\tau}}$
max. slope A_{DC} V_0/τ at t = 0.


Slew Rate
V_{DD}
V_{DD}
I_{tail}
I_{tail}
V_{out}
C_L
R_1
R_2
I_{tail}
$\frac{I}{C_L}$
$A_{DC}V_0$
AV_0/τ
V_{out}
slew rate
V_0
V_{in}
t
I_{tail} = 1mA, C_L = 1 µF ➡ SR = 1000 V/s
If V_0/τ > slew rate then settling is slew rate limited. ➡ nonlinear


Slew Rate
An extreme example of slewing:
V_{in}
t
SR
V_{out}


Recall
Topology Gain PM GBW Swing P
Basic Diff Pair - + + o +
Telescopic Cascode o + + - +
Gain Boosted Tel. Cascode + + + - -
Folded Cascode o + + o -
Single Stage OTA - + + + -
2 stage Miller o o - + -
A0
A1
A2
A3
A4
A5
low power
low output
A
A3 / A2
A1
A0
GBW
A5 / A4


Recall
Fully differential benefits from
- twice the output swing
- supply noise supression
- even order nonlinearity cancellation
Fully differential requires CM feedback to stabilize the output CM.
Bias current and CL define the slew rate (dVout/dt).