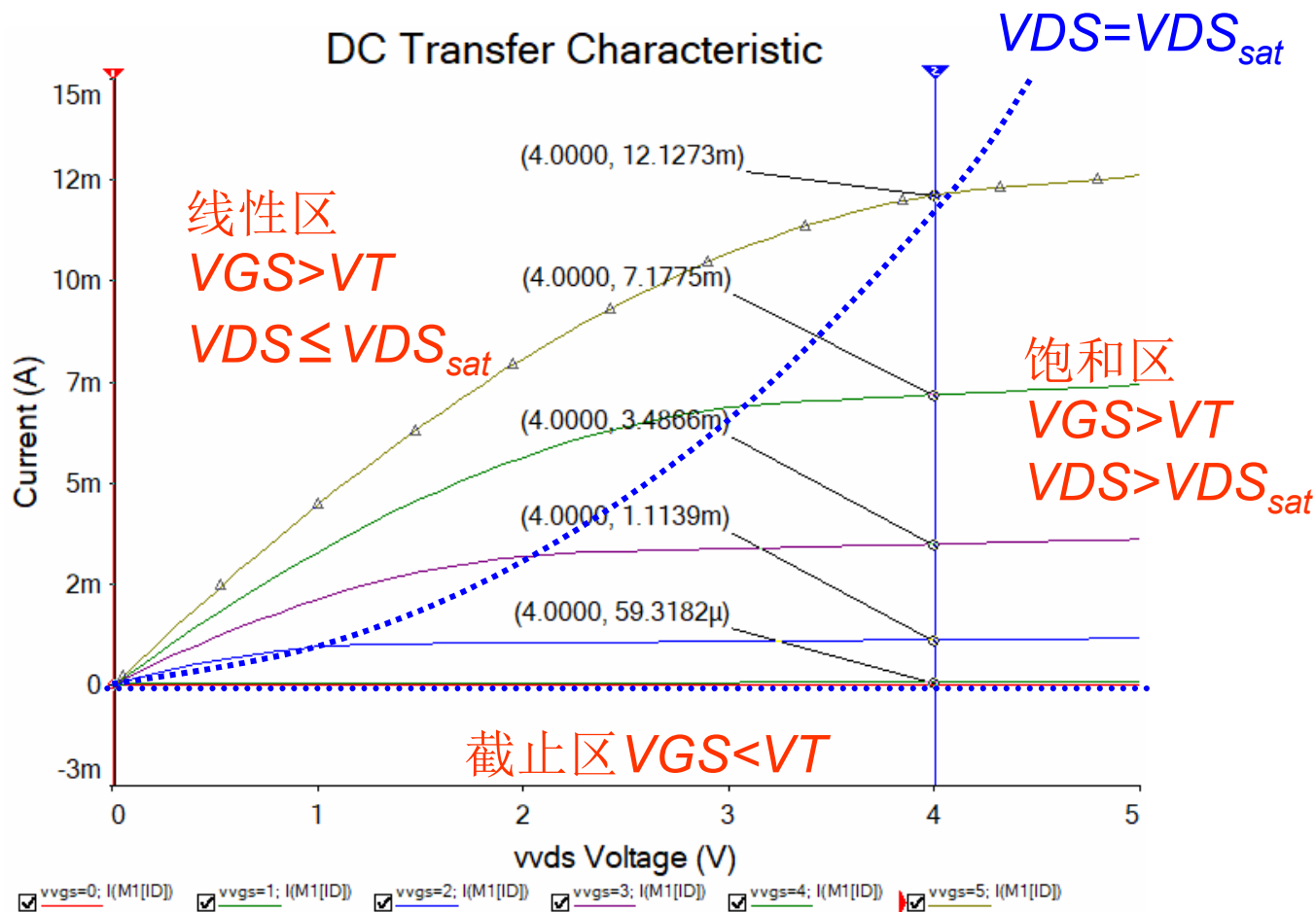# 第八章 CMOS模拟集成电路

8.5 MOS晶体管偏置电路

MOS晶体管偏置电路

◆ 确定直流工作点，规定MOS管工作区
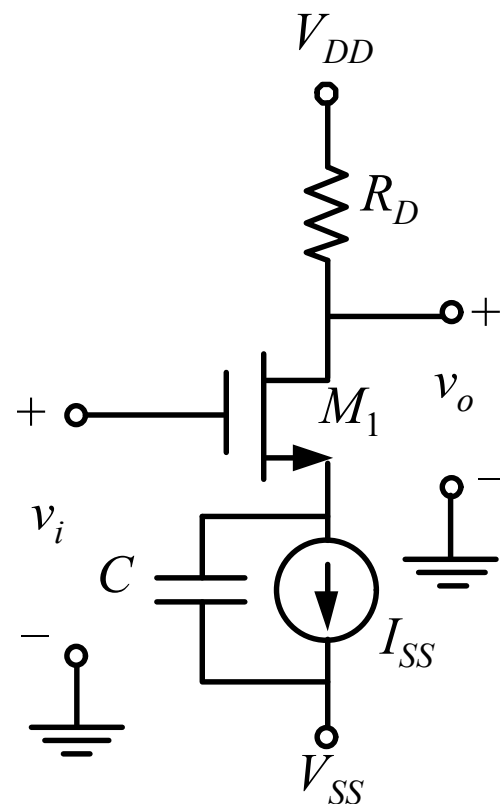
MOS管工作区

不同的工作区，MOS管特性区别很大

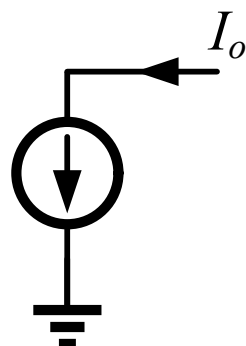# 偏置电流源电路

- ◆ 集成电路一般用电流源进行偏置
  - 电流源也常作为有源负载

- ◆ 电流源的电流决定MOS管的直流电流
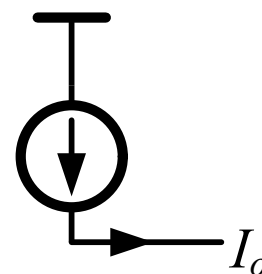 - 即MOS管的直流工作点

偏置电流源电路

电流源与电流阱

◆ 电流源分为电流阱（current sink）与电流源（current source）
  ■ 一般，统称为电流源

电流阱

电流源

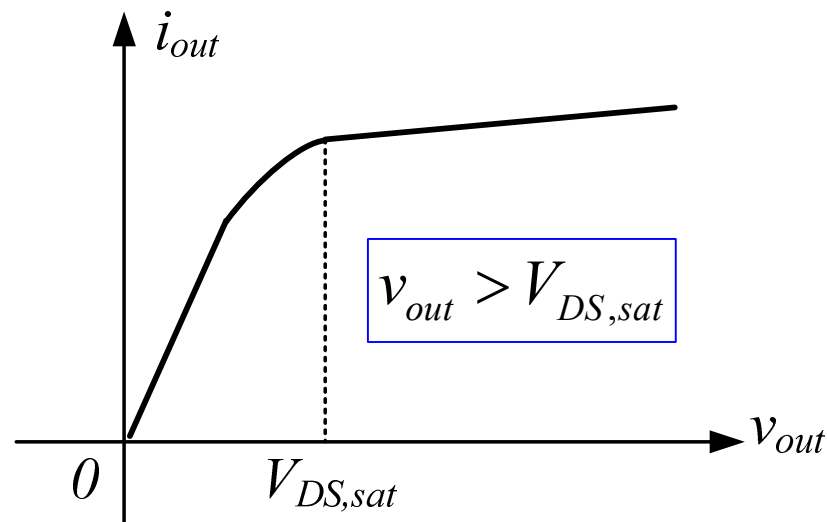◆ 理想电流源：电流与两端电压无关，相当于输出电阻无穷大

◆ 工作在饱和区的MOS管，输出电流和输出电压几乎无关，可以用于实现电流源

NMOS电流阱

- 输出电压： $v_{out} = V_{DS}$

- 饱和区条件： $v_{out} > V_{DS,sat}$

- 沟道长度调制效应，用输出电阻表示

$$r_{out} = \frac{1}{g_{ds}} = \frac{1}{\partial I_D / \partial V_{DS}}\bigg|_Q \approx \frac{1}{\lambda I_D}$$

不足：
- 输出电压必须大于特定值
- 输出电阻不是无穷大，是有限值
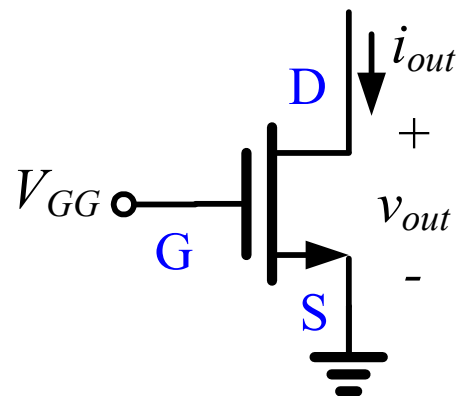
$$v_{out} > V_{DS,sat}$$

PMOS电流源

- 输出电压: $v_{out} = V_{DD} - |V_{DS}|$

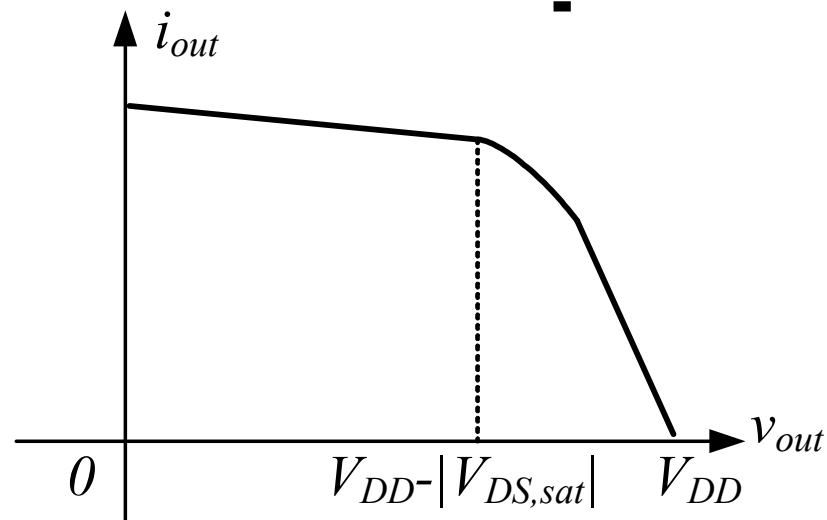- 饱和区条件: $v_{out} < V_{DD} - |V_{DS,sat}|$

- 输出电阻

$$r_{out} = \frac{1}{g_{ds}} = \frac{1}{\partial I_D / \partial V_{DS}}\bigg|_Q \approx \frac{1}{\lambda I_D}$$

不足:
- 输出电压必须小于特定值
- 输出电阻不是无穷大，是有限值
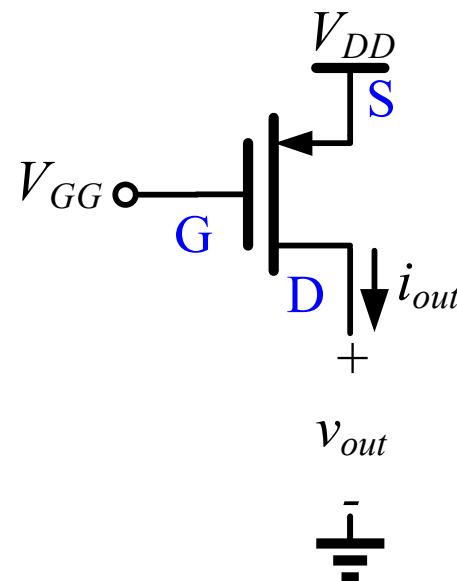
$$\boxed{v_{out} < V_{DD} - |V_{DS,sat}|}$$

电流镜

◆ 电流源的电流取决于：(1) 栅极偏置电压VGG；(2) MOS管自身的特性参数
   ▪ 容易受工艺、温度等的影响

◆ 电流镜（current mirror）
   ▪ 可以把已知电流**镜像后**作为自己的输出电流
   ▪ 只需设计1个高精度的电流源，然后通过比例镜像的方式，得到多个不同大小、同等精度的电流

NMOS电流镜电路

◆ M1：MOS二极管接法，肯定工作在饱和区

$$V_{DS1} = V_{GS1}$$

$$V_{DS1} > V_{GS1} - V_{TH1}$$

◆ 饱和区电流公式

$$I_R = \frac{1}{2}\mu_0 C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{T1})^2$$

◆ 如果M2也工作在饱和区

$$I_o = \frac{1}{2}\mu_0 C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{T2})^2$$

◆ 两个MOS管的栅源电压相等 $\boxed{V_{GS1} = V_{GS2}}$

NMOS电流镜电路

◆ 如果两个MOS管参数完全相同

$$I_R = \frac{1}{2}\mu_0 C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{T1})^2$$

$$I_o = \frac{1}{2}\mu_0 C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{T2})^2$$

$$V_{T1} = V_{T2}$$

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2$$

$$I_o = I_R$$

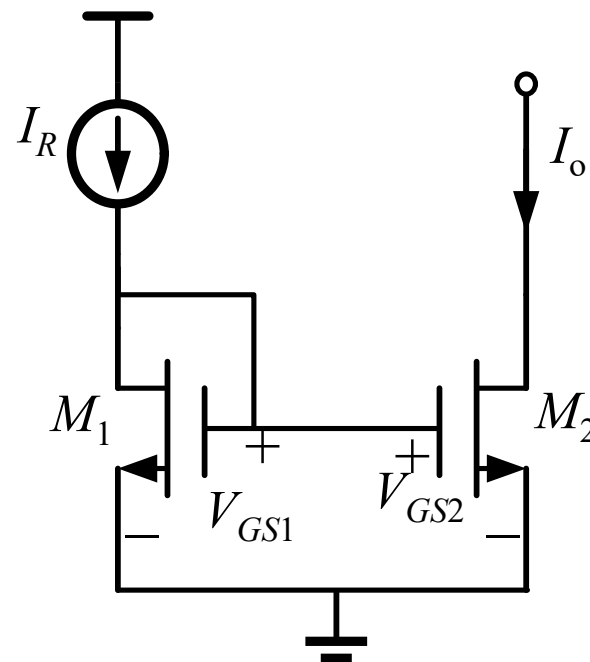◆ 说明：输出电流是参考电流的镜像

NMOS电流镜电路

- ◆ 如果两个MOS管只有宽长比不同

$$I_R = \frac{1}{2}\mu_0 C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{T1})^2$$

$$I_o = \frac{1}{2}\mu_0 C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{T2})^2$$

$$I_o = \frac{\left(W/L\right)_2}{\left(W/L\right)_1} I_R$$

$$V_{T1} = V_{T2}$$

$$\left(\frac{W}{L}\right)_1 \neq \left(\frac{W}{L}\right)_2$$

- ◆ 说明：输出电流是参考电流的比例镜像

多输出电流镜电路

- ◆ 同时提供多个电流源
- ◆ 每个输出电流，都是参考电流的（比例）镜像

$$V_{GS1} = V_{GS2} = V_{GS3} = V_{GS4}$$
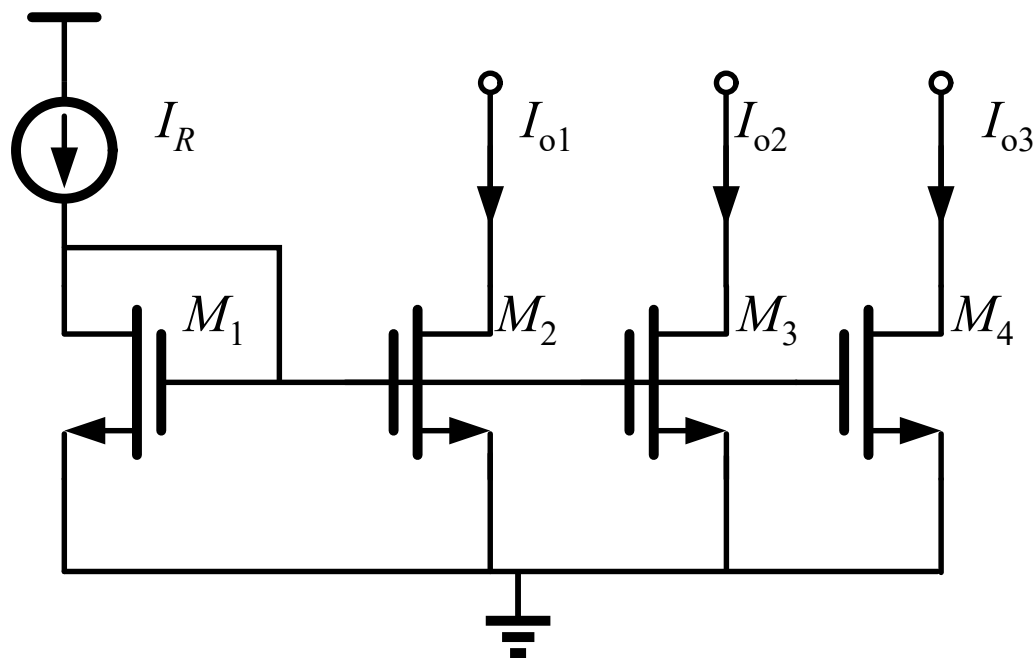
$$I_{o2} = \frac{\left(W/L\right)_3}{\left(W/L\right)_1} I_R$$

$$I_{o3} = \frac{\left(W/L\right)_4}{\left(W/L\right)_1} I_R$$

多输出电流镜电路

- 同时提供多个电流源和电流阱
- 通过控制每个MOS管的宽长比，得到所需大小的电流
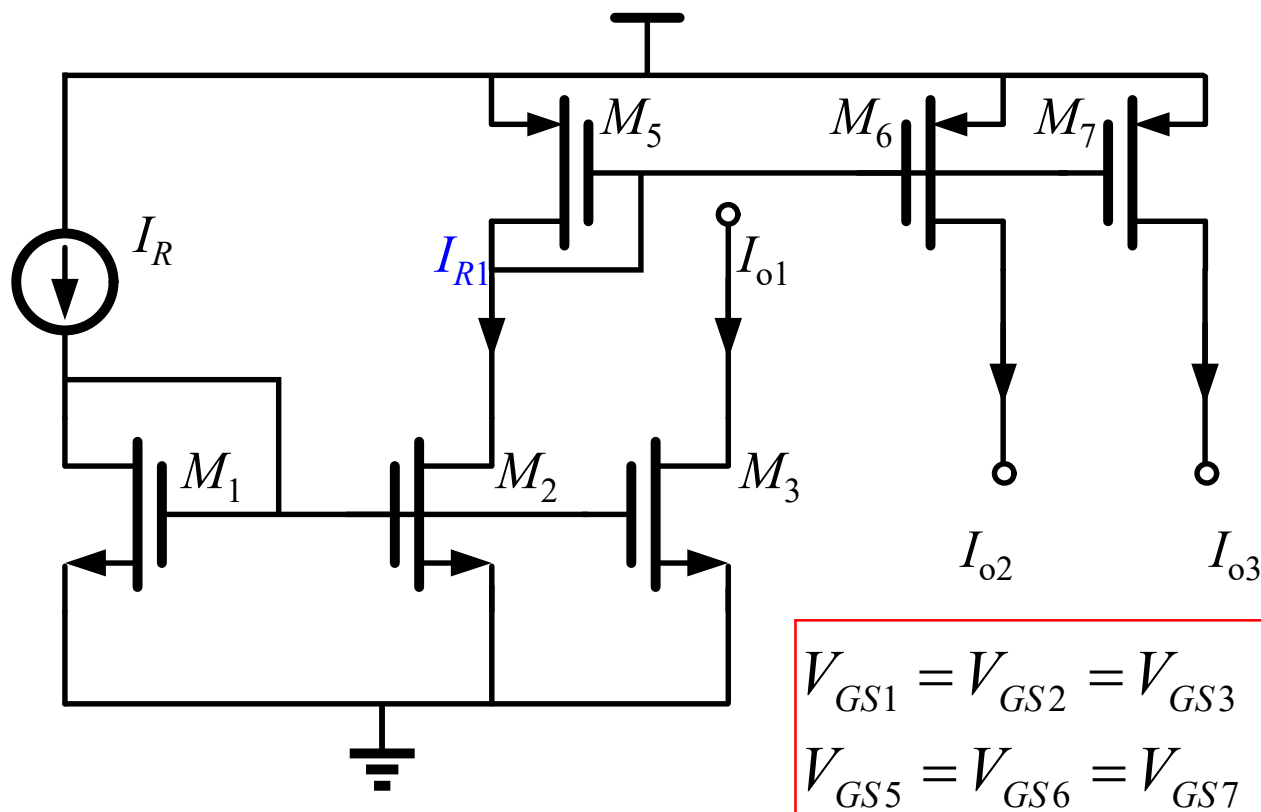
$$I_{R1} = \frac{(W/L)_2}{(W/L)_1} I_R$$

$$I_{o2} = \frac{(W/L)_6}{(W/L)_5} I_{R1}$$

$$I_{o3} = \frac{(W/L)_7}{(W/L)_5} I_{R1}$$

$$V_{GS1} = V_{GS2} = V_{GS3}$$
$$V_{GS5} = V_{GS6} = V_{GS7}$$

二级运放偏置电路

$L = 1\mu m$

差分输入级　　共源放大级

$V_{DD} = 2.5V$ ⑧

⑨ $V_{SS} = -2.5V$

$(W/L)_8 = 4$

$(W/L)_5 = 4$

$(W/L)_7 = 17$

$I_5 = I_R = 45\mu A$

$I_7 = \dfrac{17}{4} I_R = 191\mu A$
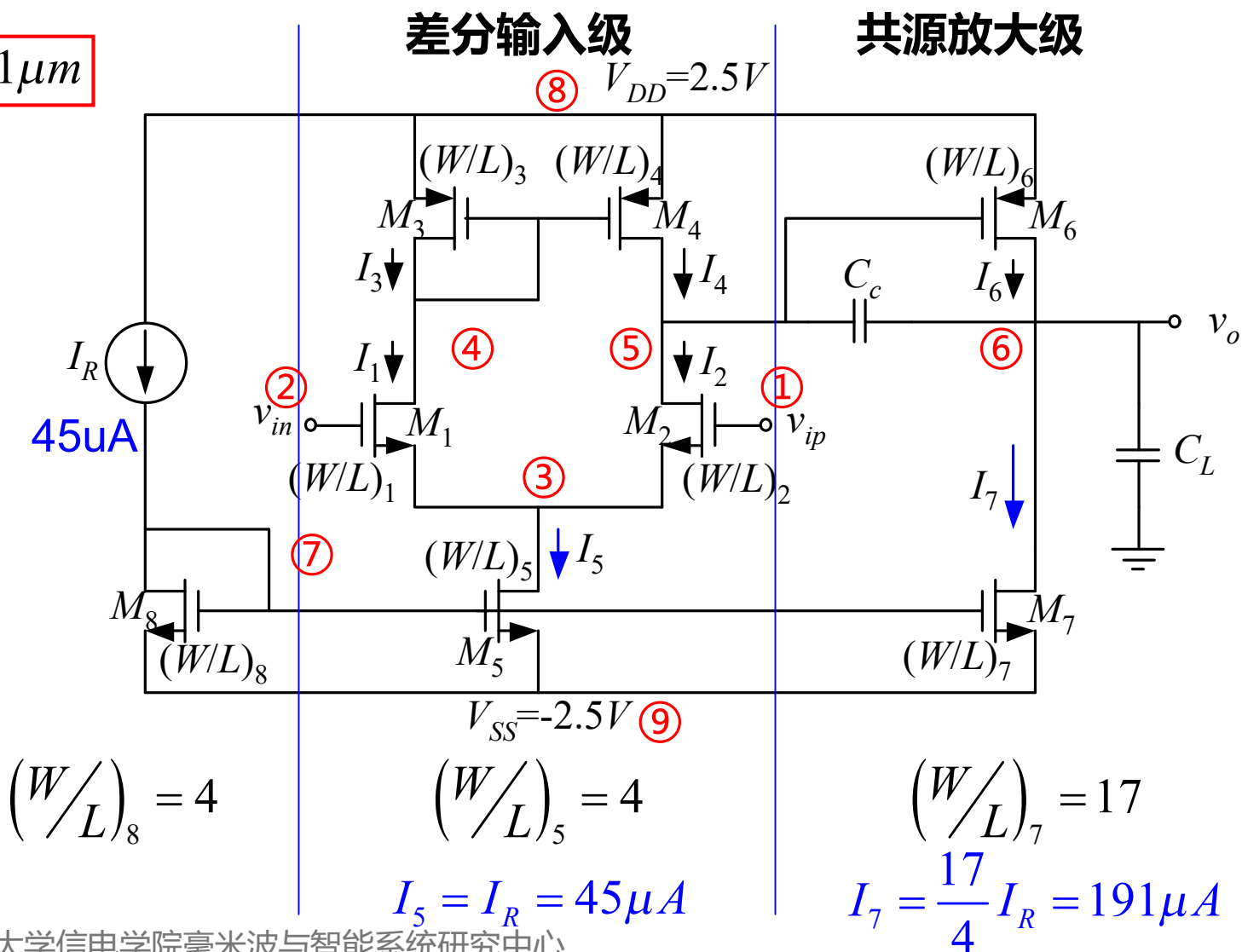
二级运放偏置电路

```
.title OPAMP_DC
* 1 vip * 2 vin * 6 vout * 8 VDD * 9 VSS
M1 4 2 3 3 n08 W = 8U   L = 1U AD = 48P   AS = 48P   PD = 28U PS = 28U
M2 5 1 3 3 n08 W = 8U   L = 1U AD = 48P   AS = 48P   PD = 28U PS = 28U
M3 4 4 8 8 p08 W = 23U  L = 1U AD = 138P  AS = 138P  PD = 58U PS = 58U
M4 5 4 8 8 p08 W = 23U  L = 1U AD = 138P  AS = 138P  PD = 58U PS = 58U
M5 3 7 9 9 n08 W = 4U   L = 1U AD = 24P   AS = 24P   PD = 20U PS = 20U
M6 6 5 8 8 p08 W = 190U L = 1U AD = 1140P AS = 1140P PD = 392U PS =392U
M7 6 7 9 9 n08 W = 17U  L = 1U AD = 102P  AS = 102P  PD = 46U PS = 46U
M8 7 7 9 9 n08 W = 4U   L = 1U AD = 24P   AS = 24P   PD = 20U PS = 20U
CC 5 6 3.0P
IBIAS 8 7 45U

VDD 8 0 DC  2.5
VSS 0 9 DC  2.5
vvip 1 0 DC 0
vvin 2 0 DC 0

.OP                          * 直流工作点仿真

*.MODEL 语句省略

.end
```

二级运放偏置电路

subckt								
element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6	0:m7	0:m8
model	0:n08	0:n08	0:p08	0:p08	0:n08	0:p08	0:n08	0:n08
region	Saturati	Saturati	Saturati	Saturati	Saturati	Saturati	Saturati	Saturati
id	22.8882u	22.8882u	-22.8882u	-22.8882u	45.7764u	-202.3046u	202.3046u	45.0000u
ibs	0.	0.	0.	0.	0.	0.	0.	0.
ibd	-25.2142f	-25.2142f	8.9245f	8.9245f	-15.8613f	23.5413f	-26.4587f	-11.3520f
vgs	913.8709m	913.8709m	-892.4533m	-892.4533m	1.1352	-892.4533m	1.1352	1.1352
vds	2.5214	2.5214	-892.4533m	-892.4533m	1.5861	-2.3541	2.6459	1.1352
vbs	0.	0.	0.	0.	0.	0.	0.	0.
vth	700.0000m	700.0000m	-700.0000m	-700.0000m	700.0000m	-700.0000m	700.0000m	700.0000m
vdsat	213.8709m	213.8709m	-192.4533m	-192.4533m	435.2008m	-192.4533m	435.2008m	435.2008m
vod	213.8709m	213.8709m	-192.4533m	-192.4533m	435.2008m	-192.4533m	435.2008m	435.2008m
beta	1.0008m	1.0008m	1.2359m	1.2359m	483.3842u	10.9241m	2.1363m	475.1855u
gam eff	400.0000m	400.0000m	570.0000m	570.0000m	400.0000m	570.0000m	400.0000m	400.0000m
gm	214.0375u	214.0375u	237.8572u	237.8572u	210.3692u	2.1024m	929.7072u	206.8011u
gds	831.6506n	831.6506n	1.0955u	1.0955u	1.7218u	9.0500u	7.3177u	1.7218u
gmb	51.1648u	51.1648u	75.7908u	75.7908u	50.2878u	669.9006u	222.2425u	49.4349u
cdtot	26.1579f	26.1579f	73.8743f	73.8743f	16.6178f	449.6269f	51.7618f	18.2092f
cgtot	17.3109f	17.3109f	48.8817f	48.8817f	8.9057f	399.7531f	35.7045f	8.9000f
cstot	62.0939f	62.0939f	139.4014f	139.4014f	33.3270f	1.1211p	126.8196f	33.3270f
cbtot	72.9264f	72.9264f	168.2634f	168.2634f	42.5562f	1.1930p	144.9203f	44.1533f
cgs	14.4939f	14.4939f	41.8214f	41.8214f	7.2470f	345.4809f	30.7996f	7.2470f
cgd	1.8242f	1.8242f	5.1256f	5.1256f	900.1977a	43.2298f	3.8832f	894.4556a

二级运放偏置电路

- ◆ 电流源的输出电阻越大，越接近理想电流源

- ◆ 增大M8/M5/M7的L，同时增大W，保持W/L不变，可以在保持电流比例关系不变的同时，提高输出电阻