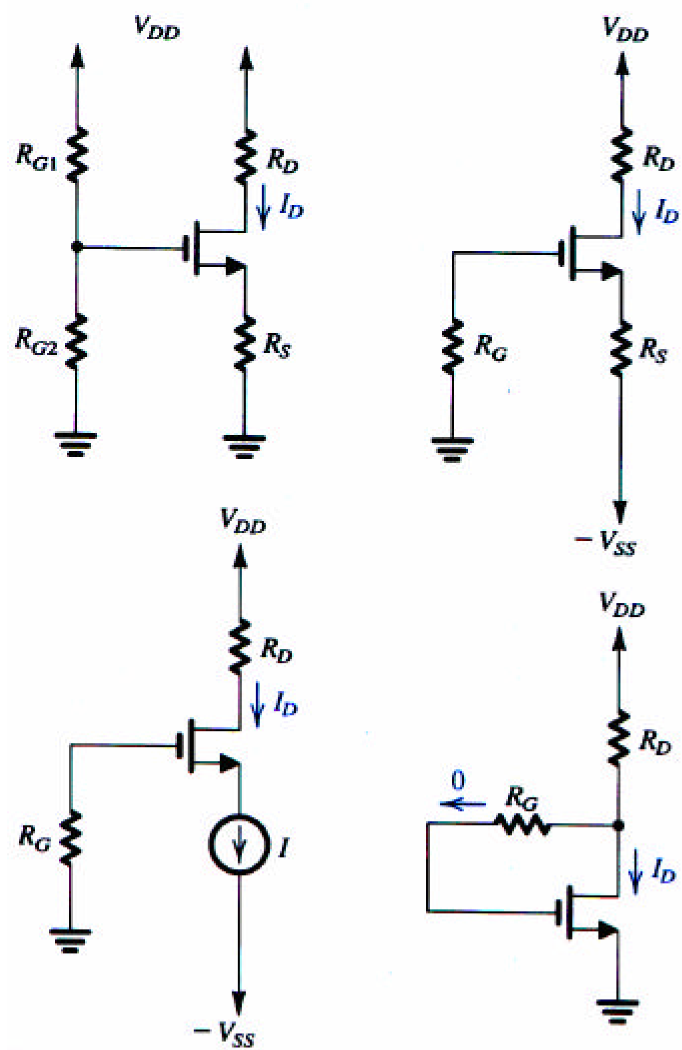
基本MOSFET放大器

1. 偏壓電路設計與分析
2. 基本MOSFET放大器
3. IC MOSFET放大器

偏壓電路設計與分析

Discrete MOSFET amplifiers的偏壓設計



1. 因為I_G=0，電路容易設計。
2. I_D和V_{GS}有關，必須小心設計。
3. R_G通常很大在MΩ範圍。在IC製程相當麻煩，故此類偏壓設計在IC設計中不太使用。

IC MOSFET amplifiers的偏壓設計

IC電路偏壓設計的一些基本原則：

1. 少用電阻，多用電晶體，省空間。即用active load。
2. 使用電流源。

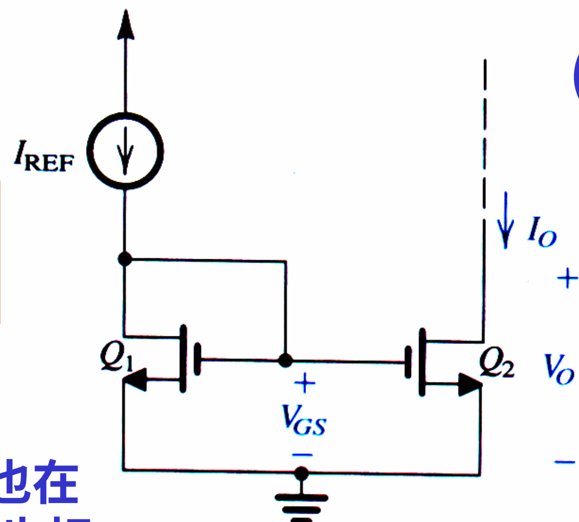
電流源一般有兩種：一種是用前面提到過的空乏型元件，將GS短路；另一種是使用電流鏡(current mirror)。

基本MOS電流鏡

1 I_{REF}決定V_{GS}。

$$I_{REF} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 (V_{GS} - V_t)^2$$

2 Q_1和Q_2有相同的V_{GS}，若也在相同的基板同時製作，V_t也相同，k'也相同，溫度也相同。



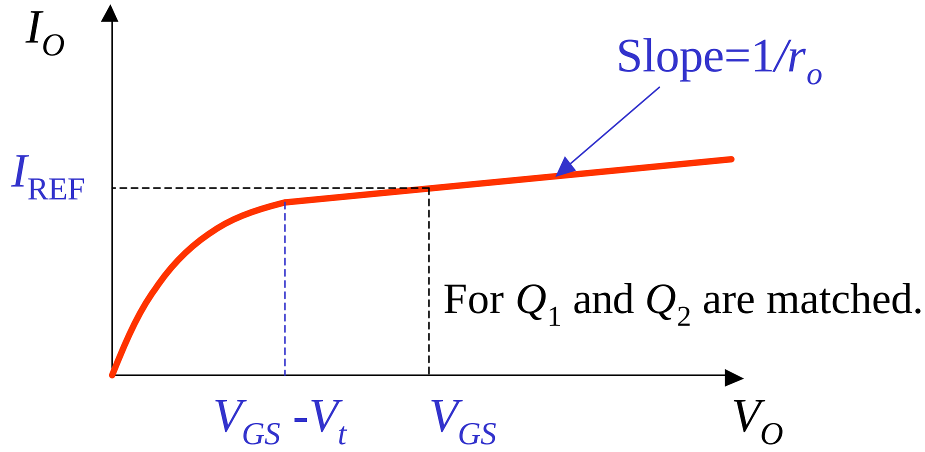
3 V_{GS}決定I_O。

$$I_O = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_2 (V_{GS} - V_t)^2$$

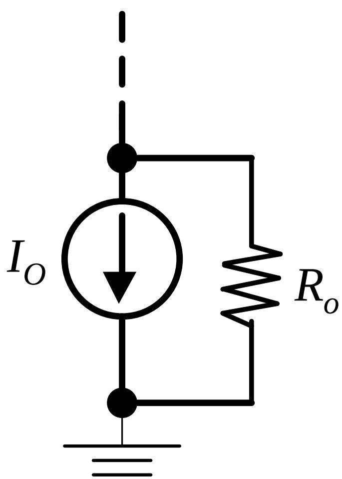
$$\frac{I_O}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1}$$

尺寸比例可以控制得很準確。

電流鏡的輸出特性

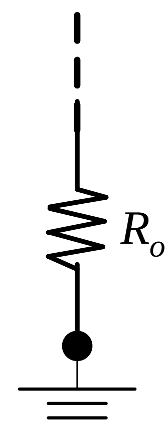


當$V_O \ge V_{GS} - V_t$之等效電路

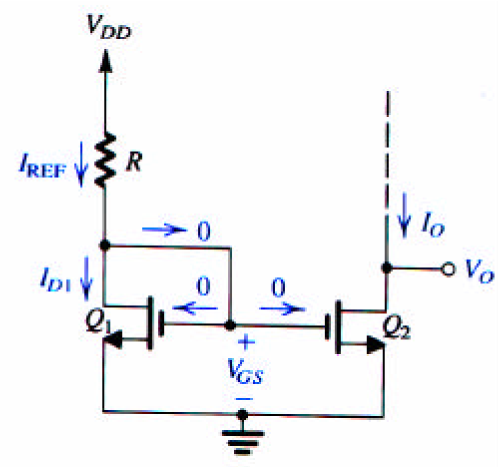


$$R_o = \frac{\Delta V_O}{\Delta I_O} = r_{o2} = \frac{V_A}{I_O}$$

小訊號模型



簡易電流鏡設計



$$I_{D1}=\frac{1}{2}k_n'\left(\frac{W}{L}\right)_1(V_{GS}-V_t)^2$$

$$I_{D1}=\frac{V_{DD}-V_{GS}}{R}$$

解I_{D1}和V_{GS}

例題

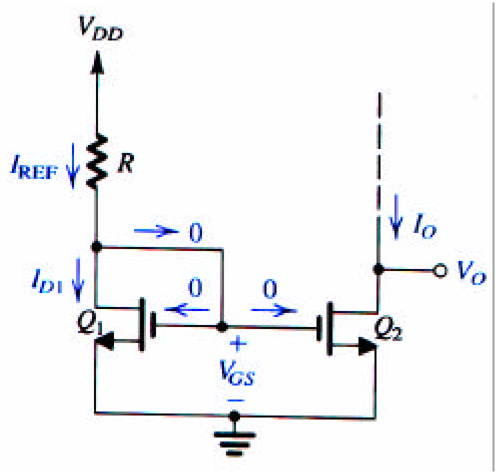
Given V_{DD} =5V and using I_{REF}=100μA, it is required to design the above circuit to obtain an output current whose nominal value is 100 μA. Find R if Q_1 and Q_2 are matched, have channel lengths of 10 μm and channel widths of 100 μm, V_t=1V and k_n'=20 μA/V^2. What is the lowest possible value of V_O? Assuming that fabrication technology results in an Early voltage that can be expressed as V_A=10L, where L is in microns and V_A in volts, find the output resistance of the current source. Also find the change in output current resulting from a 3-V change in V_O.

$$I_{D1} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 (V_{GS} - V_t)^2$$

$$100 = \frac{1}{2} \times 20 \times \frac{100}{10} (V_{GS} - 1)^2 \qquad V_{GS} = 2\text{V or } 0\text{V(X)}$$

$$R = \frac{V_{DD} - V_{GS}}{RI_{D1}} = \frac{(5-2)\text{V}}{100m\text{A}} = 30\ \text{k}\Omega$$

$$V_{O\min} = V_{GS} - V_t = 2 - 1 = 1\text{V}$$



$$L = 10m\text{m} \Rightarrow V_A = 10 \times 10 = 100\text{V}$$

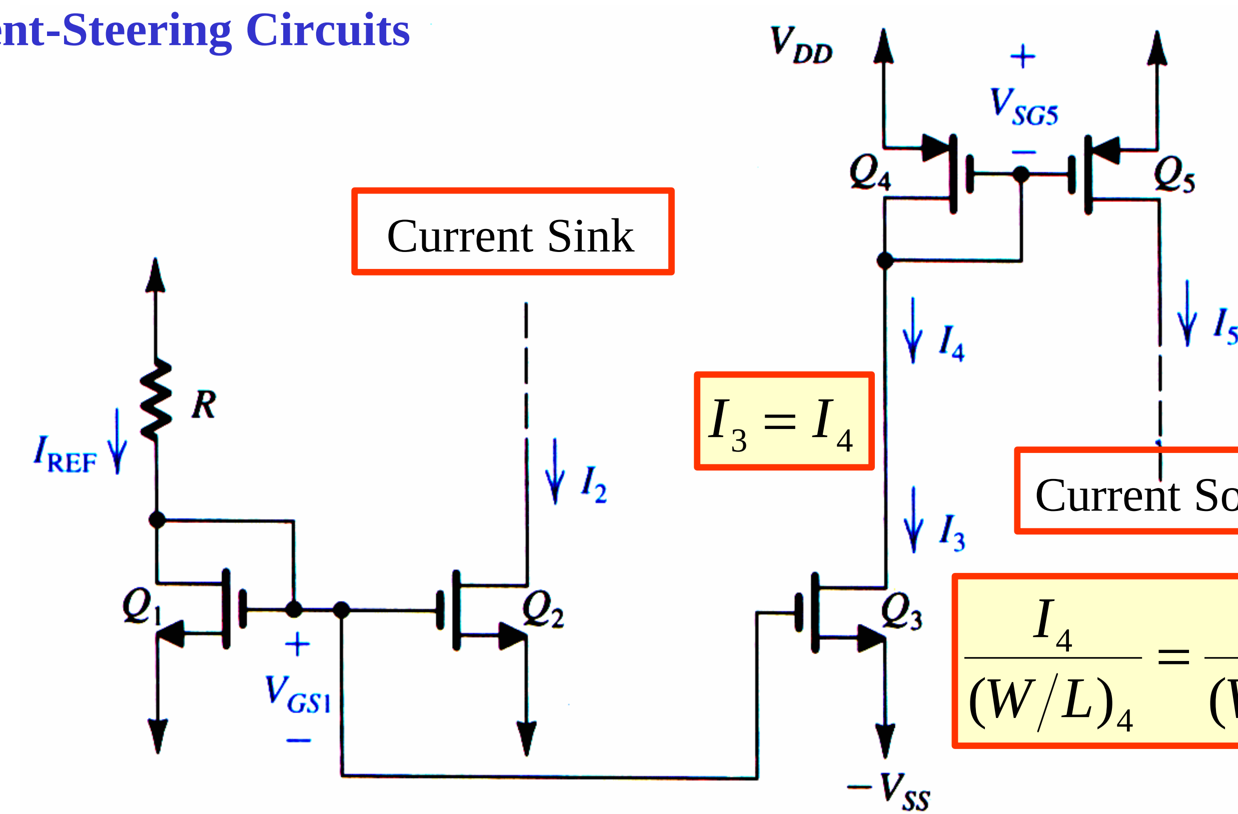
$$r_o = \frac{100\text{V}}{100m\text{A}} = 1\text{M}\Omega$$

The change in output current resulting from a 3-V change in V_O:

$$\Delta I_O = \frac{\Delta V_O}{r_o} = \frac{+3\text{V}}{1\text{M}\Omega} = +3m\text{A}$$

About 3% change in output current.

Current-Steering Circuits



$$I_3 = I_4$$

$$\frac{I_4}{(W/L)_4} = \frac{I_5}{(W/L)_5}$$

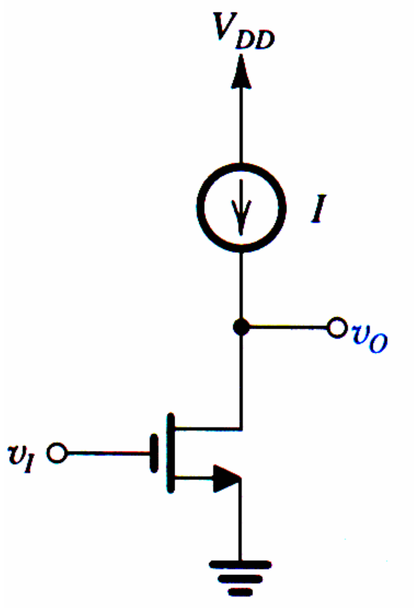
$$\frac{I_{REF}}{(W/L)_1} = \frac{I_2}{(W/L)_2}$$

$$\frac{I_{REF}}{(W/L)_1} = \frac{I_3}{(W/L)_3}$$

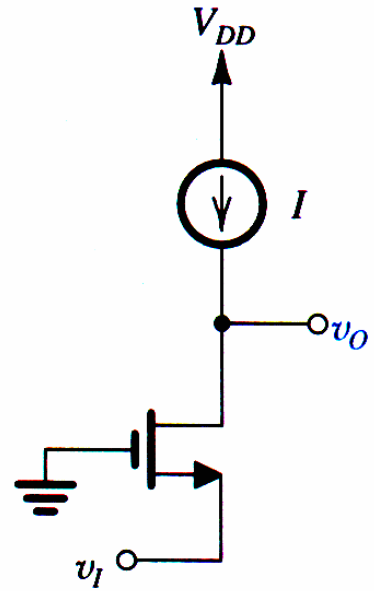
在IC設計上相當有用

基本MOSFET放大器

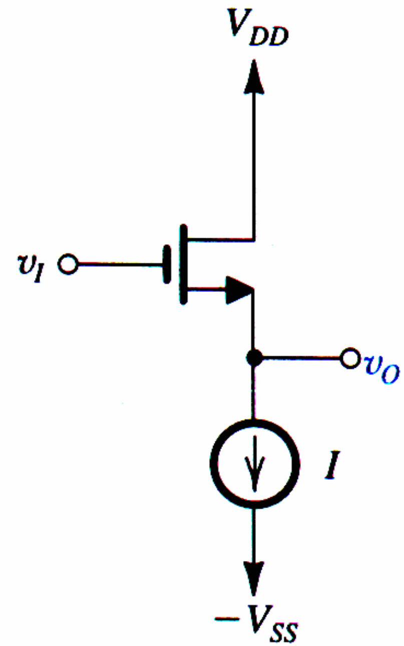
和BJT**放大器類似，基本**MOSFET**放大器有三種接法：**



Common source (CS)



Common gate (CG)



Common drain (CD)
Source follower

基本MOSFET放大器的特性(用在一般discrete電路)

同學練習自行推導

	A_{u0}	A_{i0}	R_i	R_o
CS	$-g_m R_L$	$-\infty$	∞	r_o
CG	$g_m R_L$	1	$1/g_m$	$[1+g_m R_s]r_o$
CD	$\dfrac{g_m R_L}{1+g_m R_L}$	∞	∞	$\dfrac{1}{g_m} // r_o \approx \dfrac{1}{g_m}$

和BJT放大器比較

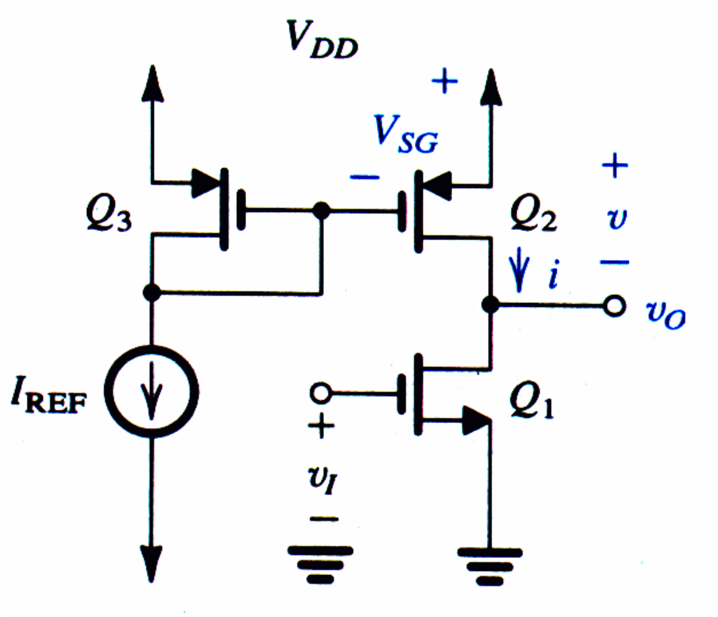
CE	$-g_m R_L$	$-b$	r_p	r_o
CB	$g_m R_L$	a	r_e	$[1+g_m (R_s // r_p)]r_o$
CC	$\dfrac{(b+1)R_L}{r_p+(b+1)R_L}$	$b+1$	$r_p+(b+1)R_L$	$\dfrac{r_p+R_s}{b+1}$

IC MOSFET放大器

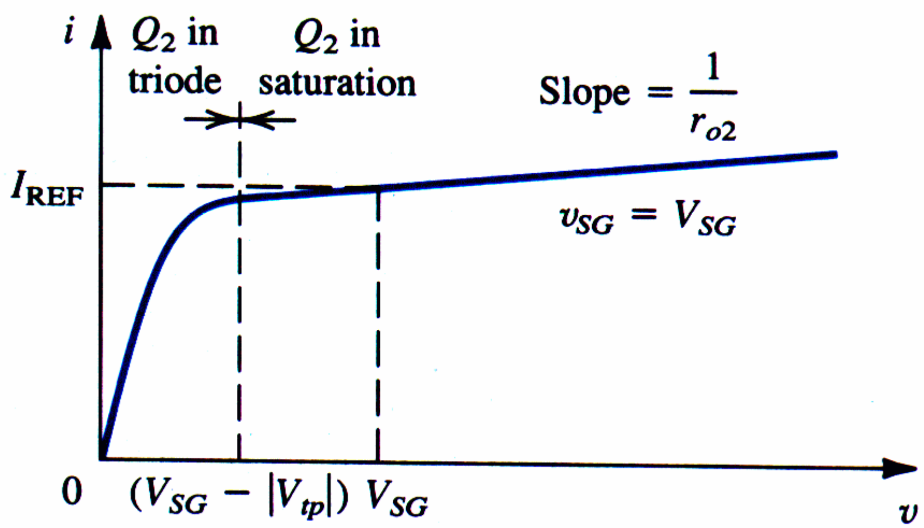
在IC設計中，儘量避免用電阻做負載，而改用電晶體電路作負載(主動式負載)，一般包括電流源及接成二極體形式的電晶體(diode-connected transistor)。

The CMOS Common-Source Amplifier

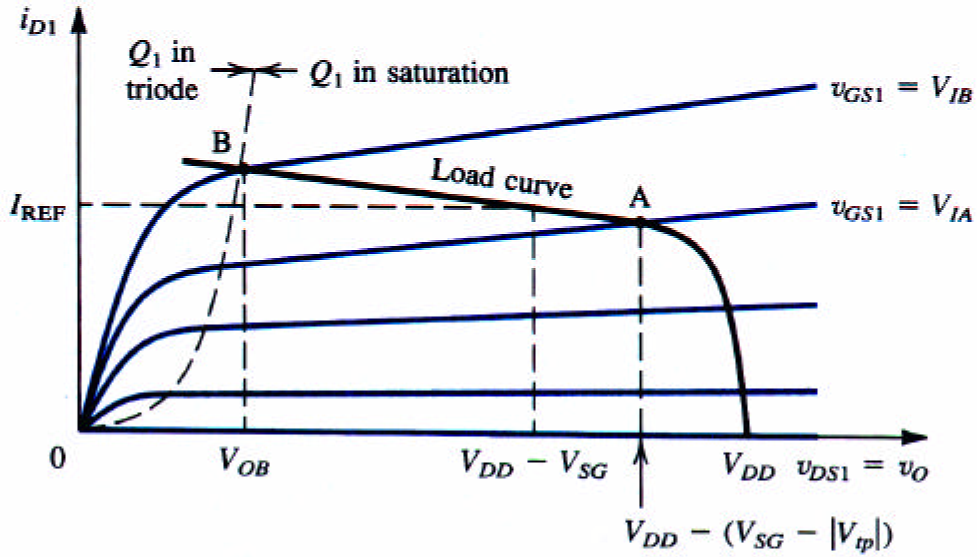
基本電路



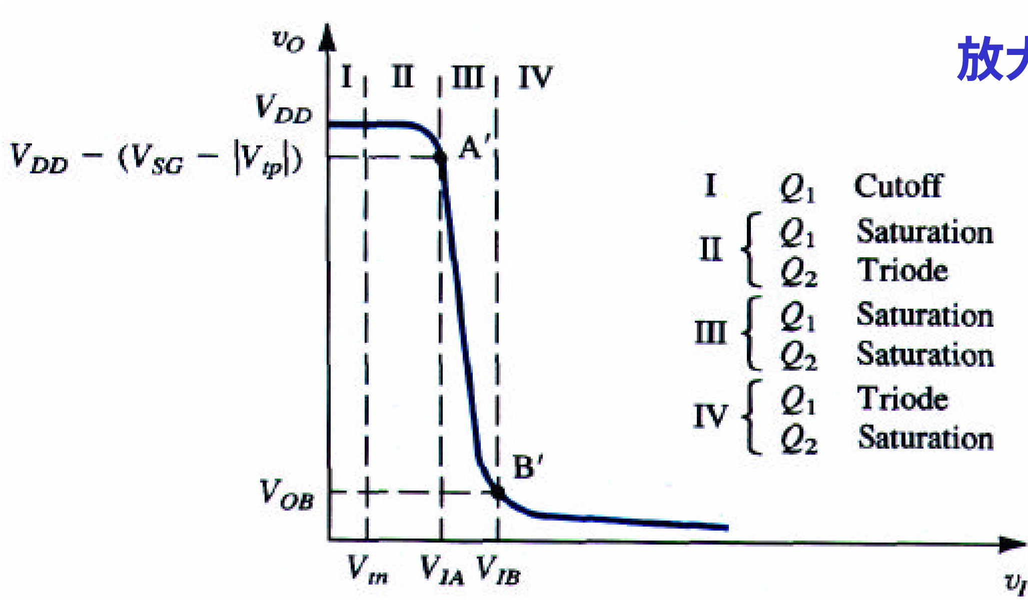
主動式負載特性圖



放大電晶體輸出特性與負載曲線



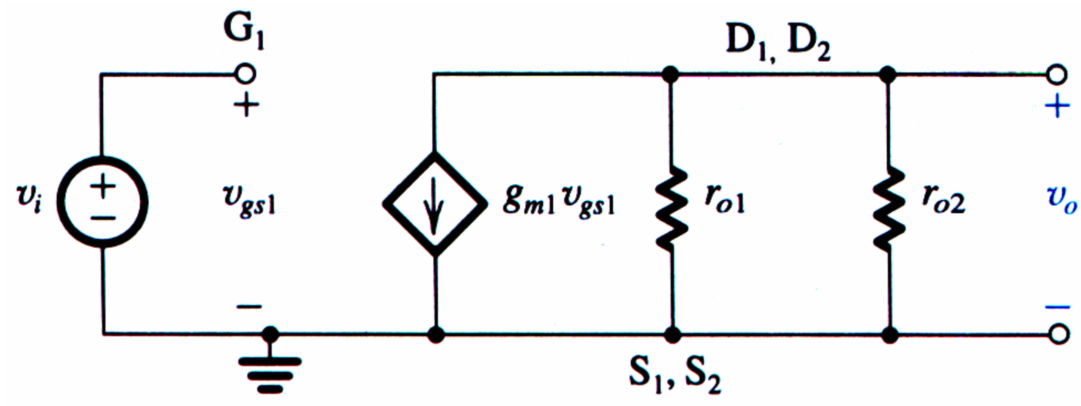
$$u + u_O = V_{DD}$$



放大器電路的轉換特性

用作線性放大器的區間在III，Q_1和Q_2都在飽和區。這個區間很小，需要有另外的回授電路確保在此區間操作。

小訊號電路分析



$$u_o = -g_{m1} u_{gs1} (r_{o1} // r_{o2})$$

$$A_u = \frac{u_o}{u_i} = \frac{u_o}{u_{gs1}} = -g_{m1}(r_{o1} // r_{o2})$$

$$r_{o2} = \frac{|V_{A2}|}{I_{REF}}, \qquad r_{o1} = \frac{|V_{A1}|}{I_{REF}}$$

$$g_{m1} = \sqrt{2k_n'\left(\frac{W}{L}\right)_1 I_{REF}}$$

$$A_u = -g_{m1}(r_{o1} // r_{o2}) = -\frac{\sqrt{2k_n'\left(\frac{W}{L}\right)_1}}{\frac{1}{|V_{A1}|}+\frac{1}{|V_{A2}|}} \frac{1}{\sqrt{I_{REF}}}$$

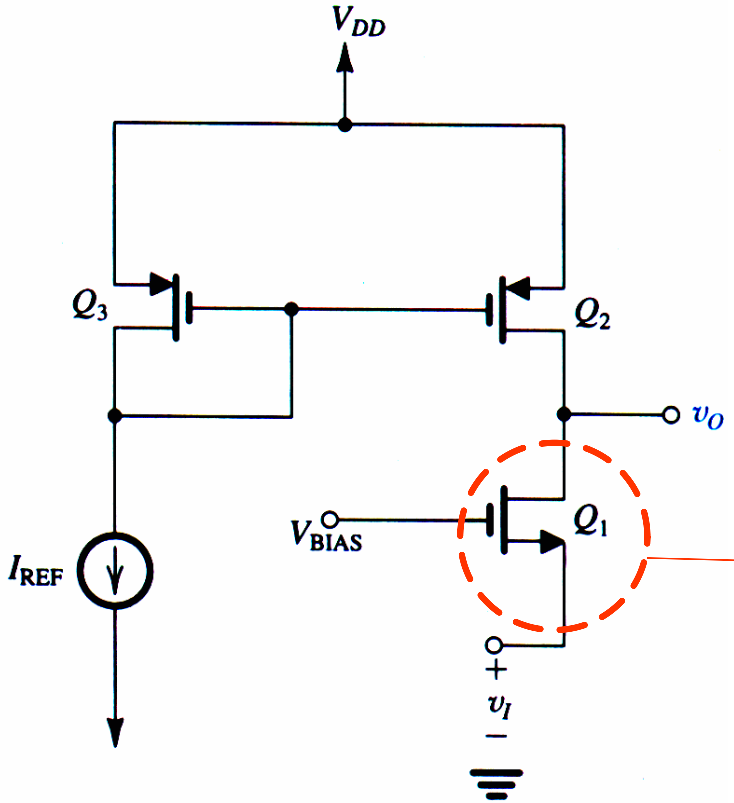
假如$|V_{A1}| \quad |V_{A2}| = V_A$

$$A_u \approx -\sqrt{2k_n'\left(\frac{W}{L}\right)_1} \frac{V_A}{\sqrt{I_{REF}}}$$

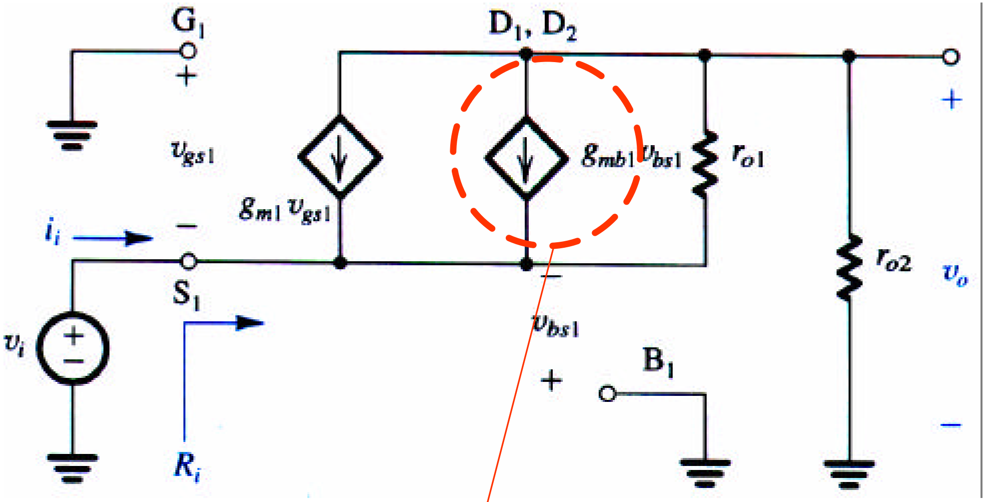
此放大器輸入和輸出阻抗都很大。電壓增益和偏壓電流的平方根成反比。另外，電壓基板效應並不影響此電路，因所有電晶體的V_{SB}均為固定值。

The CMOS Common-Gate Amplifier

基本電路



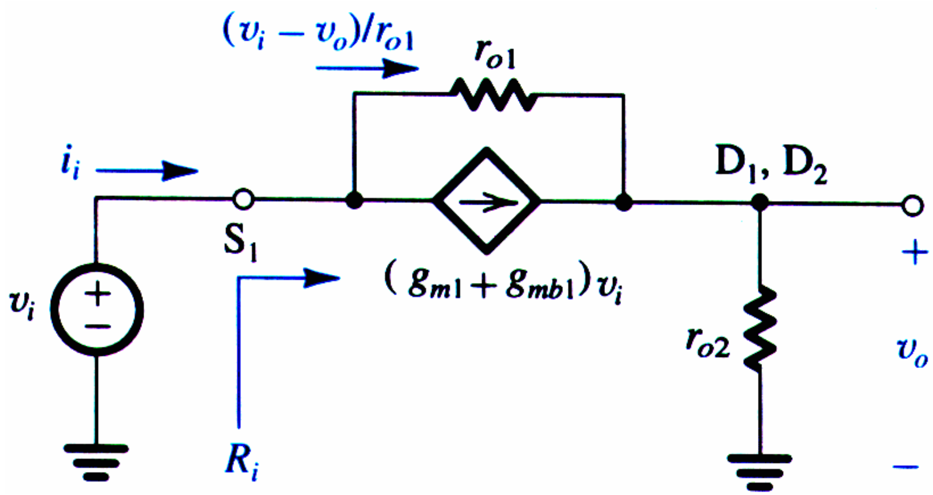
小訊號等效電路分析



必須考慮body effect

$$u_i = -u_{gs1} = -u_{bs1}$$

上頁的小訊號模型可以簡化為：



$$\frac{u_i - u_o}{r_{o1}} + (g_{m1}+g_{mb1})u_i = \frac{u_o}{r_{o2}}$$

$$A_u = \frac{u_o}{u_i} = (g_{m1}+g_{mb1}+\frac{1}{r_{o1}})(r_{o1} // r_{o2})$$

$$\frac{1}{r_{o1}} << g_{m1}$$

$$A_u \approx (g_{m1}+g_{mb1})(r_{o1} // r_{o2})$$

$$g_{mb1} = c g_{m1} \qquad c: 0.1 \sim 0.3$$

輸出阻抗

$$R_o = r_{o1} // r_{o2}$$

Body effect使增益大約20%。

輸入阻抗較一般$R_L << r_{o1}$的情形大約2倍。

輸入阻抗

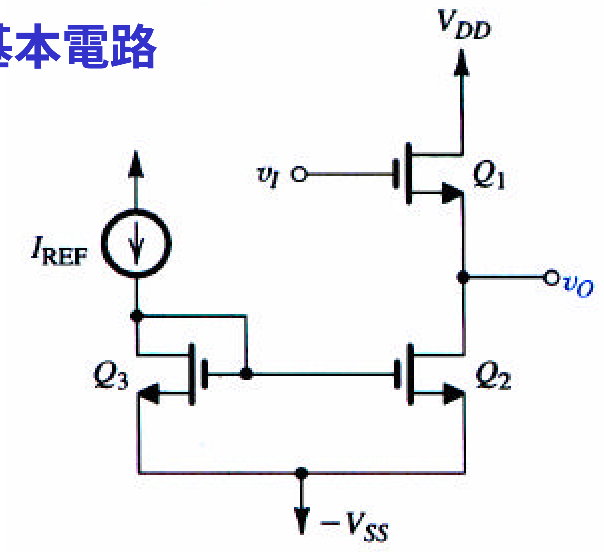
$$i_i = \frac{u_o}{r_{o2}} = \frac{(g_{m1}+g_{mb1}+\frac{1}{r_{o1}})(r_{o1} // r_{o2})u_i}{r_{o2}}$$

$$R_i = \frac{u_i}{i_i} = \frac{1}{(g_{m1}+g_{mb1}+\frac{1}{r_{o1}})}\frac{r_{o2}}{(r_{o1} // r_{o2})}$$

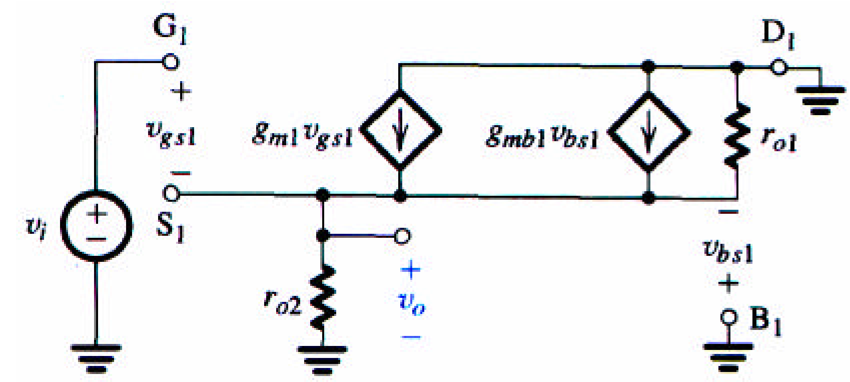
$$R_i \approx \frac{1}{(g_{m1}+g_{mb1})}\left(1+\frac{r_{o2}}{r_{o1}}\right) \approx \frac{2}{(g_{m1}+g_{mb1})}$$

The Common-Drain Amplifier or Source Follower

基本電路



小訊號等效電路分析



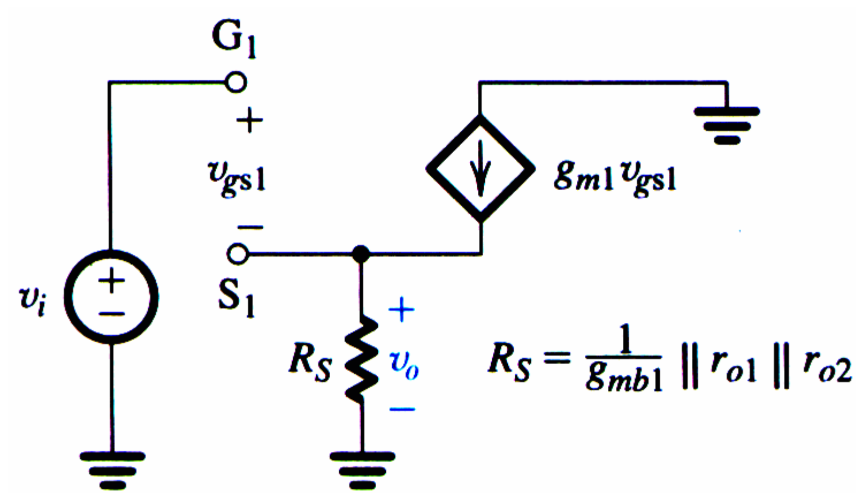
上面的小訊號模型可以簡化為：

$$u_o = u_{s1} = g_{m1} R_S u_{gs1}$$

$$u_i = u_{gs1} + u_{s1} = u_{gs1} + g_{m1} R_S u_{gs1}$$

$$A_u = \frac{u_o}{u_i} = \frac{g_{m1} R_S}{1 + g_{m1} R_S}$$

$$A_u = \frac{g_{m1}}{g_{m1} + g_{mb1} + \frac{1}{r_{o1}} + \frac{1}{r_{o2}}}$$



一般而言：$g_{m1}, g_{mb1} >> 1/r_{o1}, 1/r_{o2}$

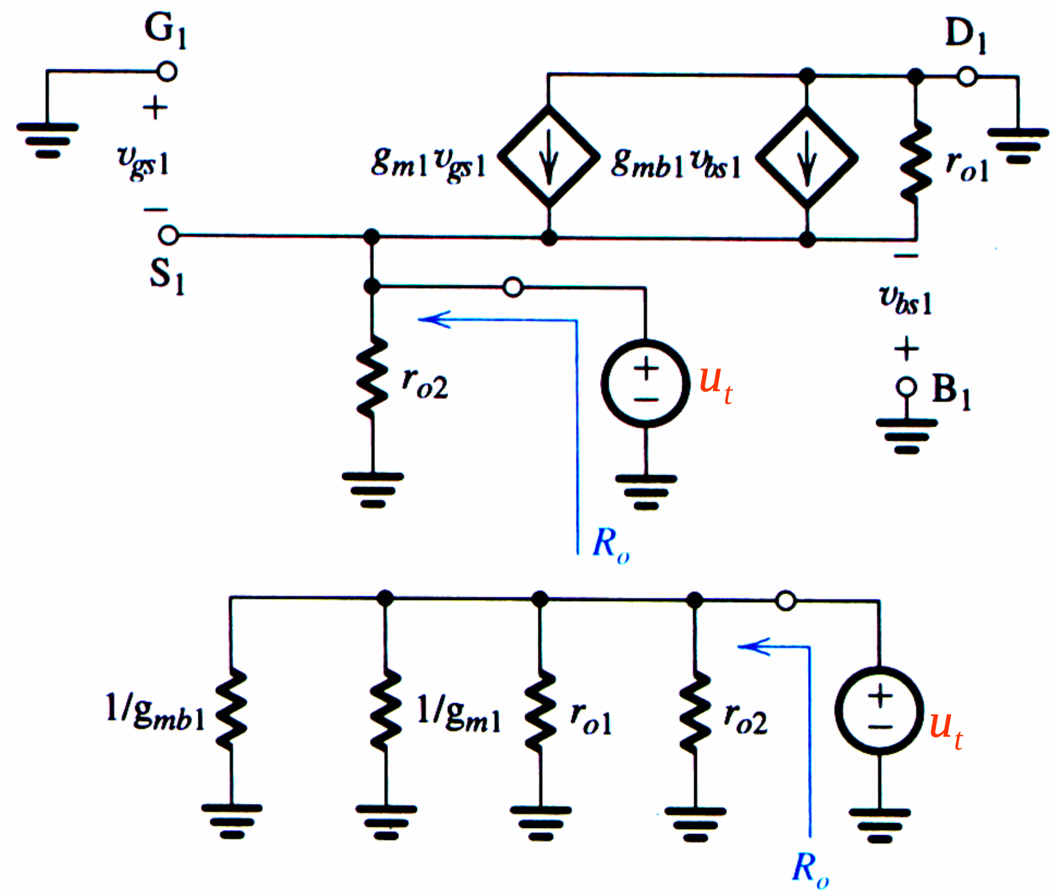
$$A_u \approx \frac{g_{m1}}{g_{m1}+g_{mb1}} = \frac{1}{1+c}$$

計算輸出阻抗

$$R_o = \frac{1}{g_{m1}} // \frac{1}{g_{mb1}} // r_{o1} // r_{o2}$$

$$R_o \approx \frac{1}{g_{m1}} // \frac{1}{g_{mb1}}$$

$$= \frac{1}{g_{m1}(1+c)}$$

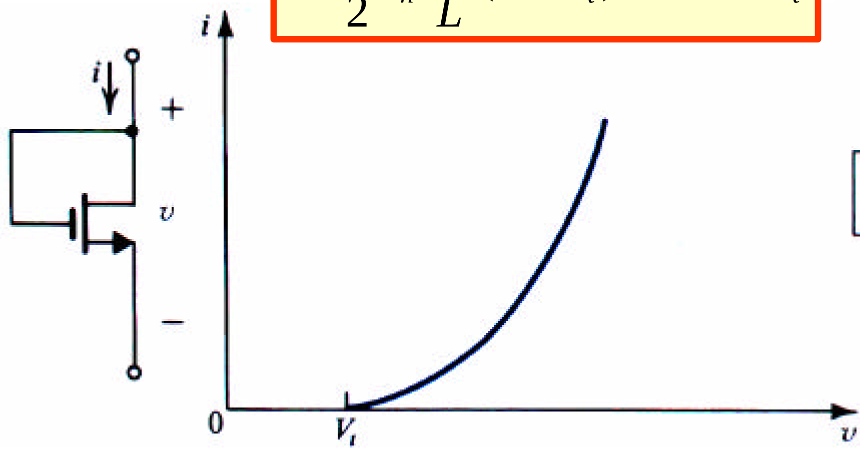


ALL NMOS Amplifier Stages

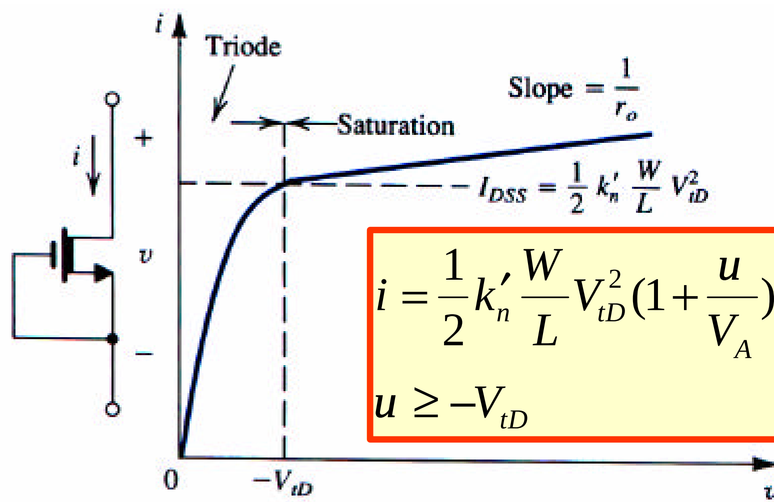
這種形式的IC放大器可以使用所謂的diode-connected transistor 的接法形成主動式負載。又可分為增強型與空乏型的接法。

Diode-connected enhancement MOS

$$i = \frac{1}{2}k_n'\frac{W}{L}(u - V_t)^2, \quad u \ge V_t$$



Diode-connected depletion MOS



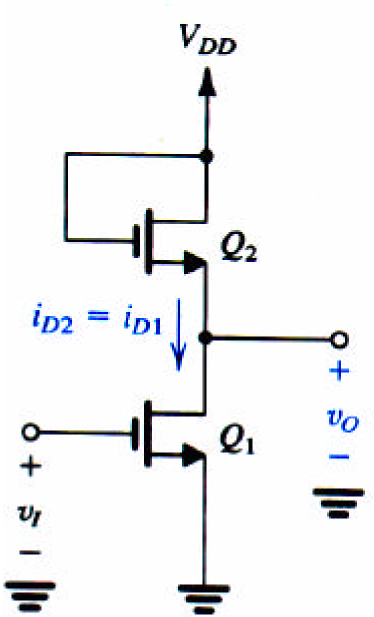
$$i = \frac{1}{2}k_n'\frac{W}{L}V_{tD}^2\left(1 + \frac{u}{V_A}\right)$$

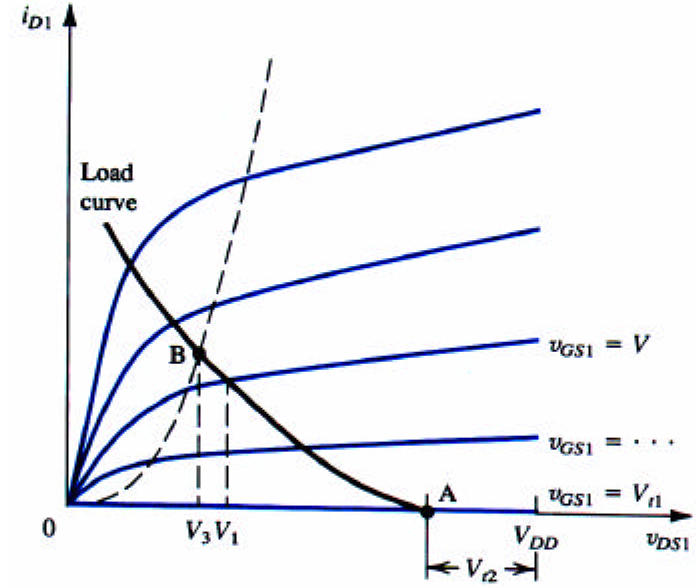
$$u \ge -V_{tD}$$

小訊號模型

$$\frac{1}{g_m} \ll r_o$$

NMOS Amplifier with Enhancement Load



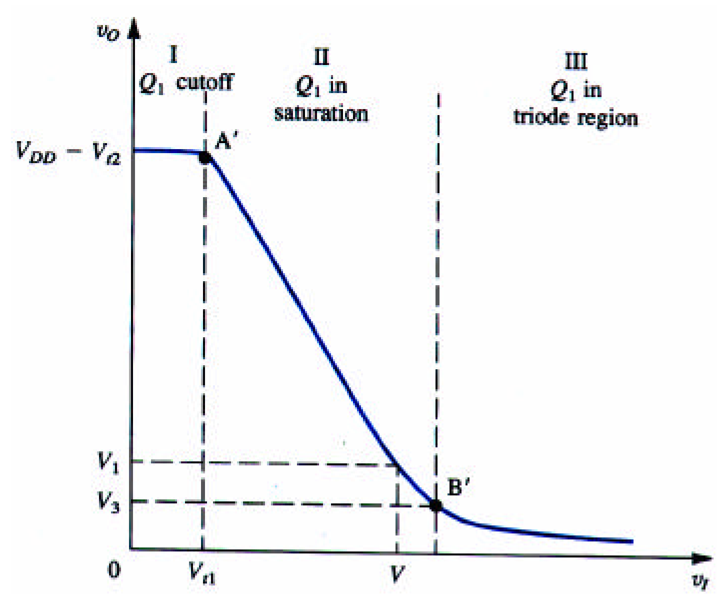


先不考慮body-effect和r_o

$$I_{D1} = I_{D2} = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_2 (V_{DD} - u_O - V_{t2})^2$$

$$= \frac{1}{2}k_n'\left(\frac{W}{L}\right)_1 (u_I - V_{t1})^2$$

$$u_O = \left(V_{DD} - V_{t2} + \sqrt{\frac{(W/L)_1}{(W/L)_2}}V_{t1}\right) - \sqrt{\frac{(W/L)_1}{(W/L)_2}}u_I$$



小訊號增益

$$A_u = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}$$

和偏壓的電流無關，只和元件尺寸有關

若考慮Q_2的body effect

$$A_u = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}\frac{1}{1+c_2}$$

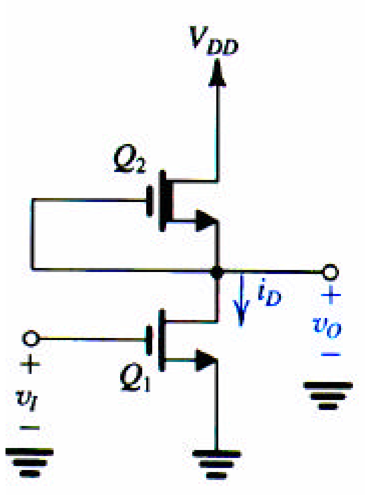
輸出阻抗

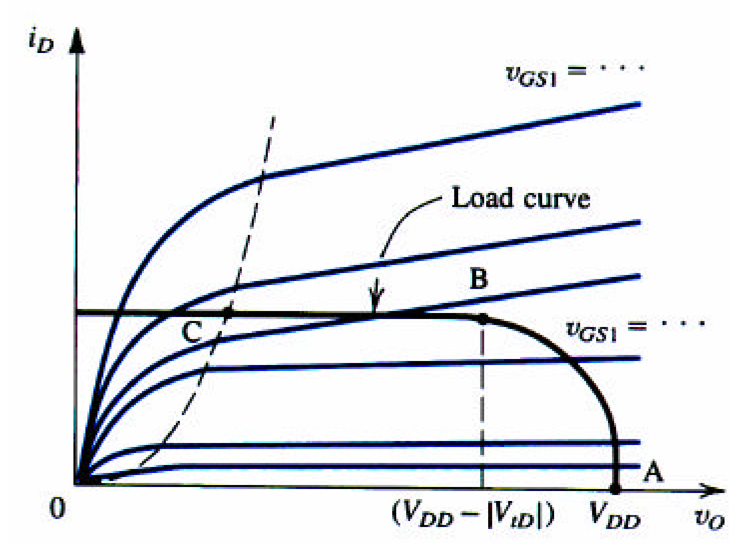
$$R_o = \frac{1}{g_{m2}} // \frac{1}{g_{mb2}} // r_{o1} // r_{o2}$$

$$R_o \approx \frac{1}{g_{m2}} // \frac{1}{g_{mb2}} = \frac{1}{g_{m2}(1+c_2)}$$

通常此類放大器的增益無法做太大。好處是非線性失真小。

NMOS Amplifier with Depletion Load



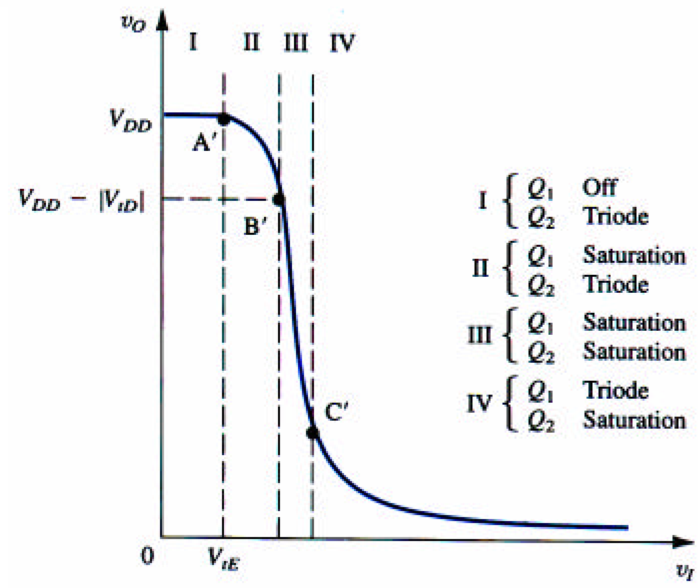


若不考慮body effect

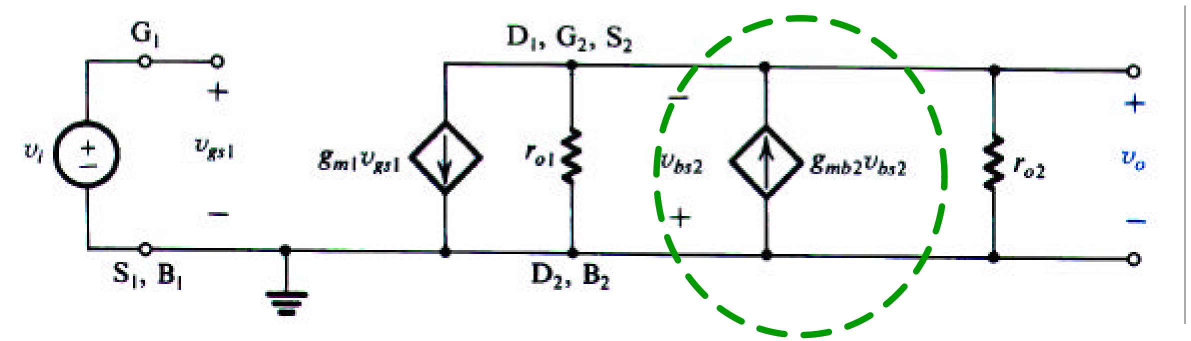
$$A_u = \frac{u_o}{u_i} = -g_{m1}(r_{o1} // r_{o2})$$

$$R_o = r_{o1} // r_{o2}$$

若考慮body effect呢？？



畫出小訊號等效電路



$$A_u = \frac{u_o}{u_i} = -g_{m1}\left[\left(\frac{1}{g_{mb2}}\right) // r_{o1} // r_{o2}\right]$$

$$R_o = \left(\frac{1}{g_{mb2}}\right) // r_{o1} // r_{o2}$$

通常 $\left(\frac{1}{g_{mb2}}\right) << r_{o1}, r_{o2}$

$$A_u \approx -\frac{g_{m1}}{g_{mb2}} = -\frac{g_{m1}}{c_2 g_{m2}} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}\frac{1}{c_2}}$$

$$R_o \approx \frac{1}{g_{mb2}} = \frac{1}{c_2 g_{m2}}$$