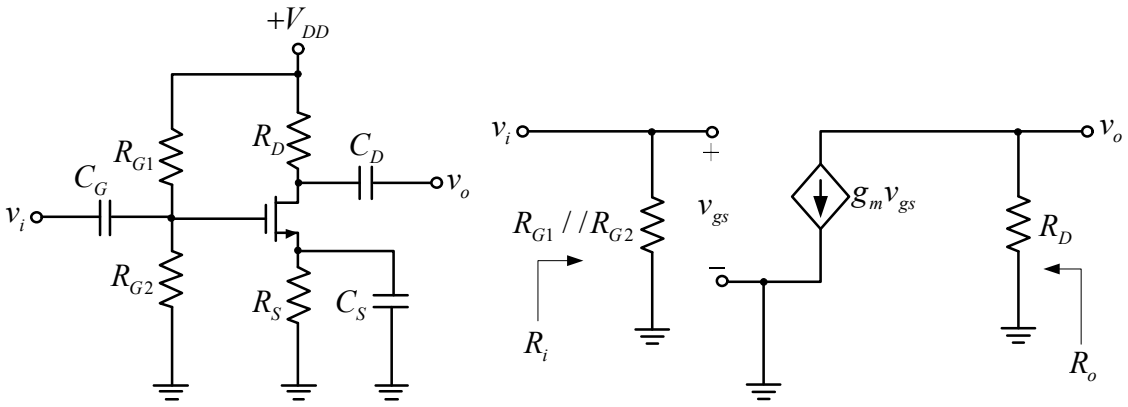
CH9 場效電晶體放大電路

CS 共源極放大器電路

不含 r_o ，不含 R_S，求 R_i 、 R_o 、 A_v ：



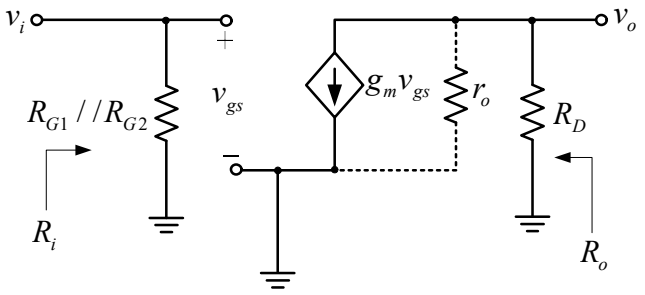
$$R_i = R_{G1} // R_{G2}$$

$$R_o = R_D$$

$$A_v = \frac{v_o}{v_i} = \frac{-g_m v_{gs} R_D}{v_{gs}} = -g_m R_D$$

CS 共源極放大器電路

含 r_o ，不含 R_S，求 R_i 、 R_o 、 A_v ：



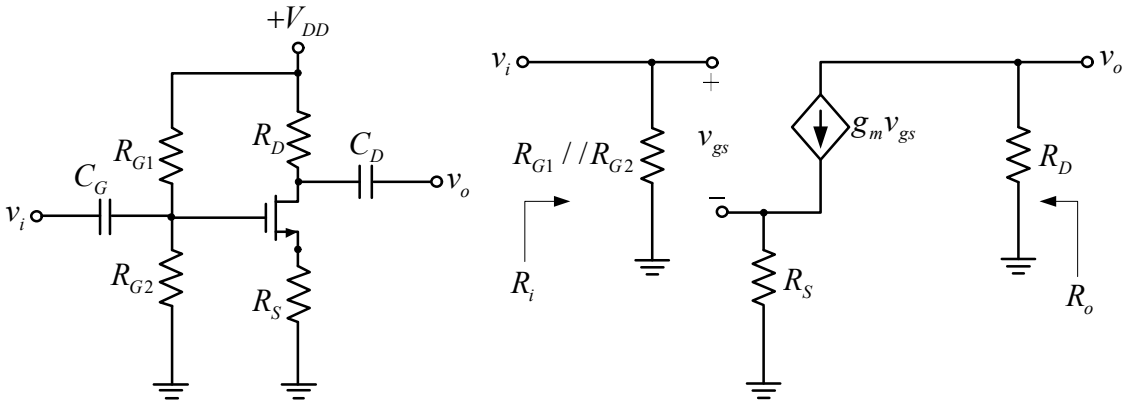
$$R_i = R_{G1} // R_{G2}$$

$$R_o = R_D // r_o$$

$$A_v = \frac{v_o}{v_i} = \frac{-g_m v_{gs} (r_o // R_D)}{v_{gs}} = -g_m (r_o // R_D)$$

CS 共源極放大器電路

不含r_o，含R_S，求R_i、R_o、A_v：



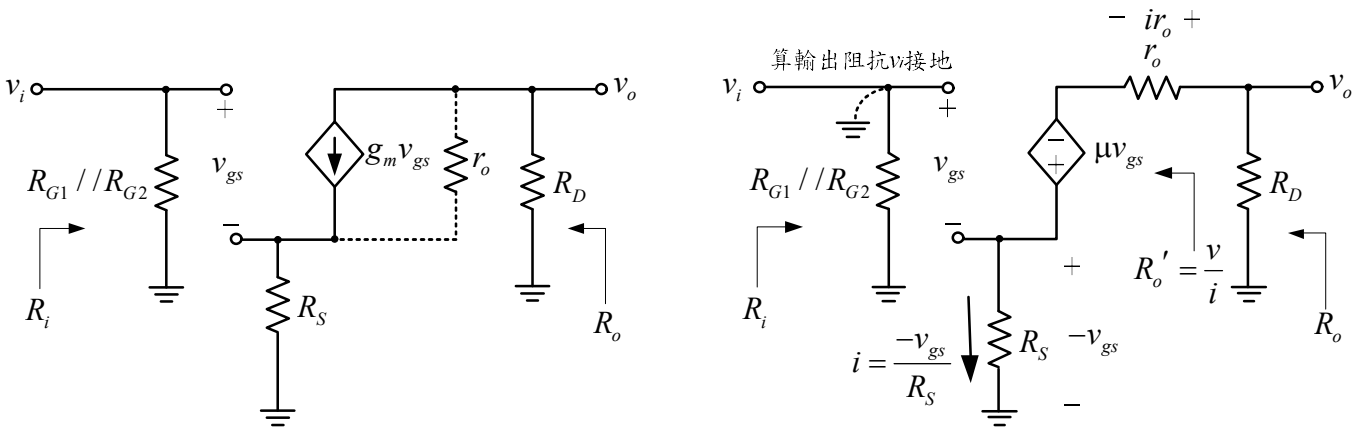
$$R_i = R_{G1} // R_{G2}$$

$$R_o = R_D$$

$$A_v = \frac{v_o}{v_i} = \frac{-g_m v_{gs} R_D}{v_{gs} + g_m v_{gs} R_S} = \frac{-g_m R_D}{1 + g_m R_S}$$

CS 共源極放大器電路

含r_o，含R_S，求R_i、R_o、A_v：（電壓源計算方式）



$$R_i = R_{G1} // R_{G2}$$

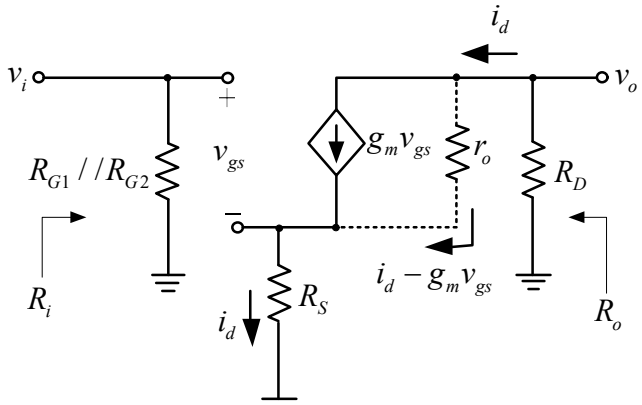
輸入端 v_i 接地：

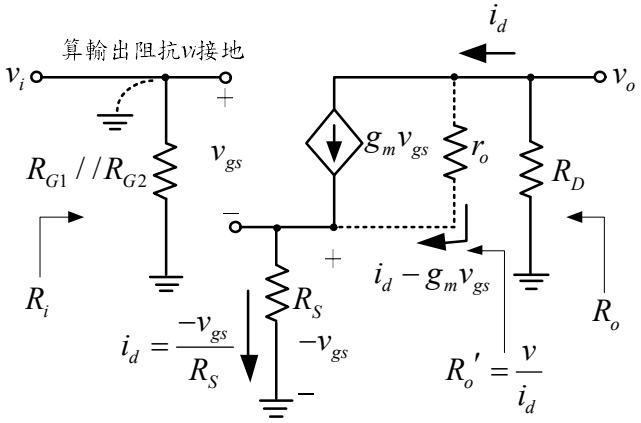
$$R_o = R_D // R_o' = R_D // \frac{v}{i} = R_D // \left[\frac{\frac{-v_{gs} r_o}{R_S} - \mu v_{gs} - v_{gs}}{\frac{-v_{gs}}{R_S}} \right] = R_D // \left[\frac{\frac{r_o}{R_S} + (\mu + 1)}{\frac{1}{R_S}} \right] = R_D // \left[r_o + (1 + \mu) R_S \right]$$

$$A_v=\frac{v_o}{v_i}=\frac{-\mu v_{gs}\times\dfrac{R_D}{R_S+R_D+r_o}}{v_{gs}+\mu v_{gs}\times\dfrac{R_S}{R_S+R_D+r_o}}=\frac{\dfrac{-\mu R_D}{R_S+R_D+r_o}}{1+\dfrac{\mu R_S}{R_S+R_D+r_o}}=\frac{-\mu R_D}{r_o+R_D+(1+\mu)R_S}$$

CS 共源極放大器電路

含 r_o，含 R_S，求 R_i、R_o、A_v：(電流源計算方式)





$R_i=R_{G1}//R_{G2}$

輸入端 v_i 接地：

$$R_o=R_D//R_o'=R_D//\frac{v}{i_d}=R_D//\left(\frac{(i_d-g_m v_{gs})r_o-v_{gs}}{i_d}\right)=R_D//\left(\frac{(\frac{-v_{gs}}{R_S}-g_m v_{gs})r_o-v_{gs}}{\frac{-v_{gs}}{R_S}}\right)=R_D//\left(\frac{(\frac{1}{R_S}+g_m)r_o+1}{\frac{1}{R_S}}\right)$$

$$=R_D//\left(\frac{\frac{r_o}{R_S}+g_m r_o+1}{\frac{1}{R_S}}\right)=R_D//\left(\frac{\frac{r_o}{R_S}+\mu+1}{\frac{1}{R_S}}\right)=R_D//\left[r_o+(1+\mu)R_S\right]$$

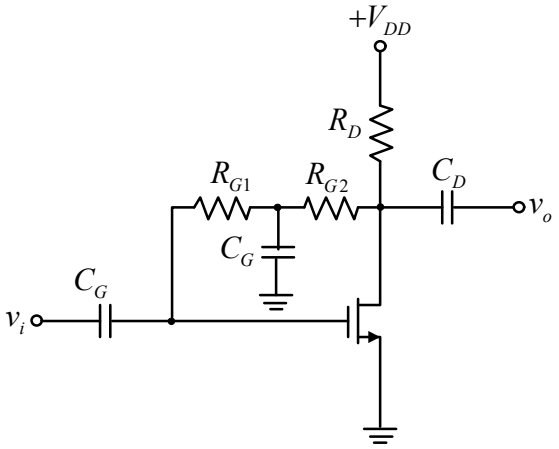
找出 i_d 與 v_{gs} 關係，利用 KVL 計算出：

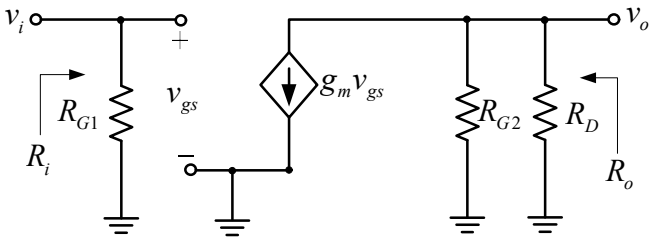
$$i_d R_D+(i_d-g_m v_{gs})r_o+i_d R_S=0\Rightarrow(r_o+R_S+R_D)i_d=g_m v_{gs}r_o\Rightarrow i_d=\frac{g_m v_{gs}r_o}{r_o+R_S+R_D}=\frac{\mu}{r_o+R_S+R_D}v_{gs}$$

$$A_v=\frac{v_o}{v_i}=\frac{-i_d R_D}{v_{gs}+i_d R_S}=\frac{-\frac{\mu R_D}{r_o+R_S+R_D}v_{gs}}{v_{gs}+\frac{\mu R_S}{r_o+R_S+R_D}v_{gs}}=\frac{-\frac{\mu R_D}{r_o+R_S+R_D}}{1+\frac{\mu R_S}{r_o+R_S+R_D}}=\frac{-\mu R_D}{r_o+R_S+R_D+\mu R_S}=\frac{-\mu R_D}{r_o+R_D+(1+\mu)R_S}$$

CS 共源極放大電路－汲極回授

不含r_o，含C_G，求R_i、R_o、A_v：





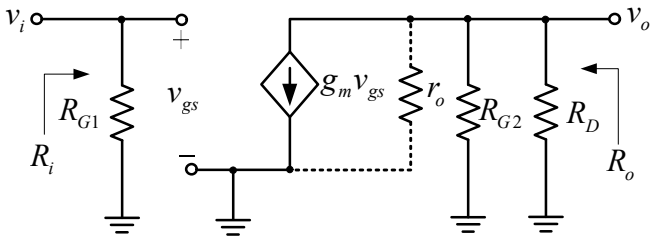
$$R_i = R_{G1}$$

$$R_o = R_{G2} // R_D$$

$$A_v = \frac{-g_m v_{gs}(R_{G2} // R_D)}{v_{gs}} = -g_m(R_{G2} // R_D)$$

CS 共源極放大電路－汲極回授

含r_o，含C_G，求R_i、R_o、A_v：



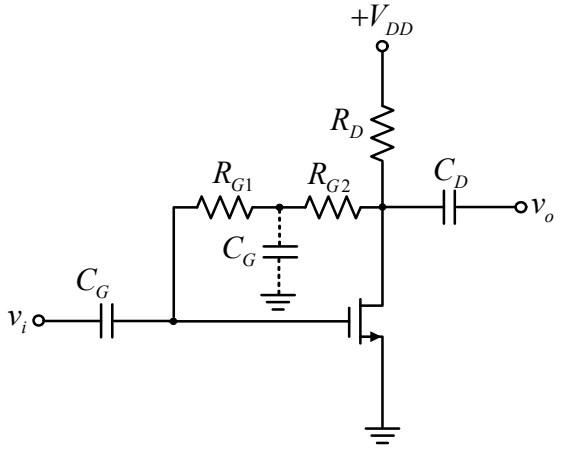
$$R_i = R_{G1}$$

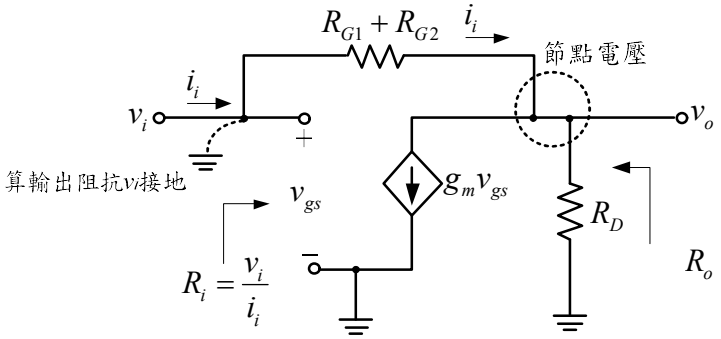
$$R_o = r_o // R_{G2} // R_D$$

$$A_v = \frac{-g_m v_{gs}(r_o // R_{G2} // R_D)}{v_{gs}} = -g_m(r_o // R_{G2} // R_D)$$

CS 共源極放大電路－汲極回授

不含r_o，不含C_G，求R_i、R_o、A_v：





找出 v_i 與 v_o 關係，利用 *KCL* 計算出：

$$v_i = v_{gs}$$

$$\frac{v_o - v_i}{R_{G1}+R_{G2}} + g_m v_{gs} + \frac{v_o}{R_D} = 0 \Rightarrow (g_m - \frac{1}{R_{G1}+R_{G2}})v_i + (\frac{1}{R_{G1}+R_{G2}} + \frac{1}{R_D})v_o = 0$$

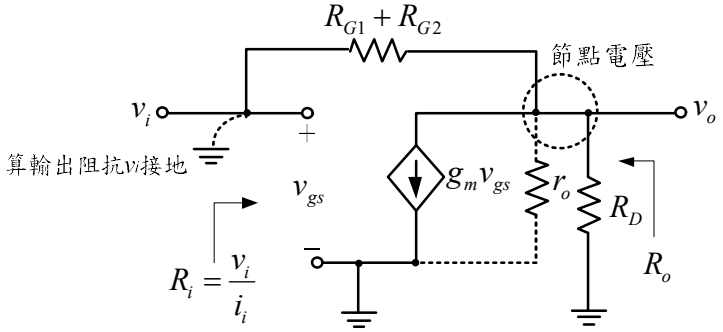
$$A_v = \frac{v_o}{v_i} = \frac{\frac{1}{R_{G1}+R_{G2}} - g_m}{(\frac{1}{R_{G1}+R_{G2}} + \frac{1}{R_D})}$$

$$R_i = \frac{v_i}{i_i} = \frac{v_{gs}}{\frac{v_i - v_o}{R_{G1}+R_{G2}}} = \frac{v_{gs}}{\frac{v_i - A_v v_i}{R_{G1}+R_{G2}}} = \frac{v_{gs}}{\frac{v_{gs} - A_v v_{gs}}{R_{G1}+R_{G2}}} = \frac{R_{G1}+R_{G2}}{1-A_v}$$

$$R_o = R_D // (R_{G1}+R_{G2})$$

CS 共源極放大電路－汲極回授

含r_o，不含C_G，求R_i、R_o、A_v：



找出 v_i 與 v_o 關係，利用 *KCL* 計算出：

$$v_i = v_{gs}$$

$$\frac{v_o - v_i}{R_{G1}+R_{G2}} + g_m v_{gs} + \frac{v_o}{r_o} + \frac{v_o}{R_D} = 0 \Rightarrow (g_m - \frac{1}{R_{G1}+R_{G2}})v_i + (\frac{1}{R_{G1}+R_{G2}} + \frac{1}{r_o} + \frac{1}{R_D})v_o = 0$$

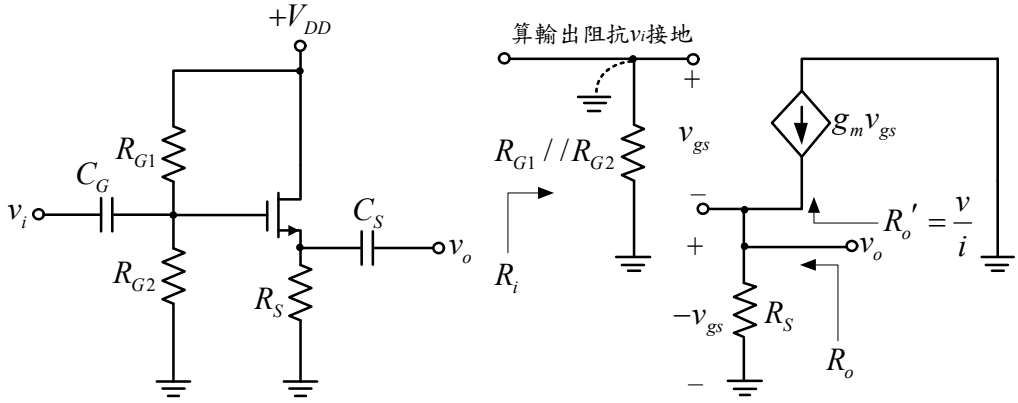
$$A_v = \frac{v_o}{v_i} = \frac{\frac{1}{R_{G1}+R_{G2}} - g_m}{(\frac{1}{R_{G1}+R_{G2}} + \frac{1}{r_o} + \frac{1}{R_D})}$$

$$R_i = \frac{v_i}{i_i} = \frac{v_{gs}}{\frac{v_i - v_o}{R_{G1}+R_{G2}}} = \frac{v_{gs}}{\frac{v_i - A_v v_i}{R_{G1}+R_{G2}}} = \frac{v_{gs}}{\frac{v_{gs} - A_v v_{gs}}{R_{G1}+R_{G2}}} = \frac{R_{G1}+R_{G2}}{1-A_v}$$

$$R_i = R_D // r_o // (R_{G1}+R_{G2})$$

CD 共汲極放大器電路

不含r_o，不含R_D，求R_i、R_o、A_v：



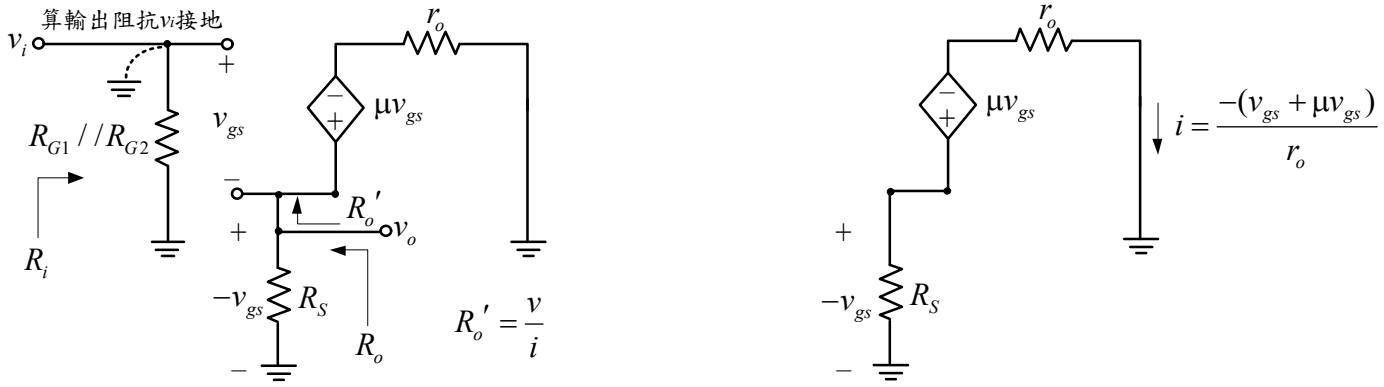
$$R_i = R_{G1}//R_{G2}$$

$$R_o = R_S//R_o' = R_S//\frac{v}{i} = R_S//\left(\frac{-v_{gs}}{-g_m v_{gs}}\right) = R_S//\left(\frac{1}{g_m}\right)$$

$$A_v = \frac{g_m v_{gs} R_S}{v_{gs} + g_m v_{gs} R_S} = \frac{g_m R_S}{1 + g_m R_S}$$

CD 共汲極放大器電路

含r_o，不含R_D，求R_i、R_o、A_v：（電壓源計算方式）



$$R_i = R_{G1}//R_{G2}$$

$$R_o = R_S//R_o' = R_S//\frac{v}{i} = R_S//\left(\frac{-v_{gs}}{\frac{-v_{gs} - \mu v_{gs}}{r_o}}\right) = R_S//\left(\frac{1}{\frac{1+\mu}{r_o}}\right) = R_S//\left(\frac{r_o}{1+\mu}\right) = R_S//\left(\frac{r_o}{1+g_m r_o}\right) = R_S//\left(\frac{\frac{r_o}{g_m}}{\frac{1}{g_m} + r_o}\right)$$

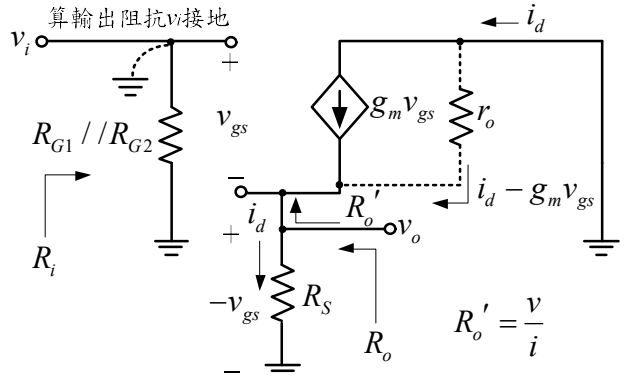
$$= R_S//r_o//\frac{1}{g_m}$$

$$A_v=\frac{\mu v_{gs}\times\dfrac{R_S}{R_S+r_o}}{v_{gs}+\mu v_{gs}\times\dfrac{R_S}{R_S+r_o}}=\frac{\dfrac{\mu R_S}{R_S+r_o}}{1+\dfrac{\mu R_S}{R_S+r_o}}=\frac{\mu R_S}{r_o+(1+\mu)R_S}=\frac{g_m r_o R_S}{r_o+(1+g_m r_o)R_S}=\frac{g_m r_o R_S}{r_o+R_S+g_m r_o R_S}=\frac{\dfrac{g_m r_o R_S}{r_o+R_S}}{\dfrac{r_o+R_S+g_m r_o R_S}{r_o+R_S}}$$

$$=\frac{\dfrac{g_m r_o R_S}{r_o+R_S}}{1+\dfrac{g_m r_o R_S}{r_o+R_S}}=\frac{g_m(R_S//r_o)}{1+g_m(R_S//r_o)}$$

CD 共汲極放大器電路

含 r_o，不含 R_D，求 R_i、R_o、A_v：（電流源計算方式）



$$R_i=R_{G1}//R_{G2}$$

輸入端 v_i 接地，找出 i_d 與 v_{gs} 關係，利用 *KVL* 計算出：

$$-v_{gs}=-(i_d-g_m v_{gs})r_o\Rightarrow v_{gs}+g_m r_o v_{gs}=i_d r_o$$

$$R_o=R_S//R_o'=R_S//\frac{v}{i}=R_S//\frac{-v_{gs}}{-i_d}=R_S//\frac{r_o}{1+\mu}=R_S//\frac{r_o}{1+g_m r_o}=R_S//\frac{\dfrac{r_o}{g_m}}{\dfrac{1}{g_m}+r_o}=R_S//r_o//\frac{1}{g_m}$$

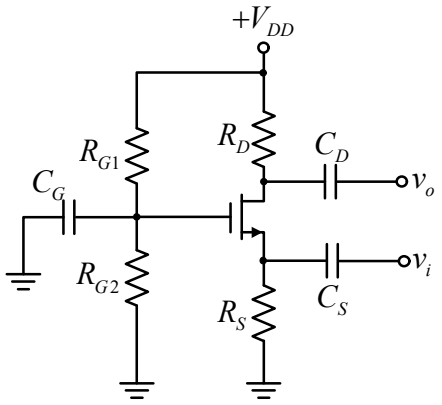
找出 i_d 與 v_{gs} 關係，利用 *KVL* 計算出：

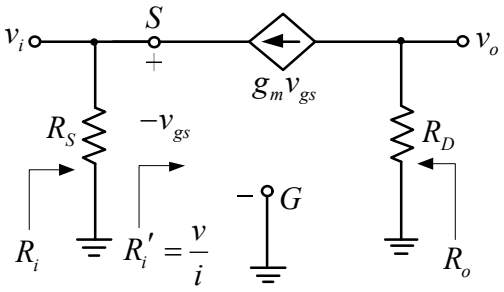
$$i_d R_S=-(i_d-g_m v_{gs})r_o\Rightarrow i_d R_S=(g_m v_{gs}-i_d)r_o\Rightarrow(R_S+r_o)i_d=g_m v_{gs} r_o\Rightarrow(R_S+r_o)i_d=\mu v_{gs}\Rightarrow\frac{v_{gs}}{i_d}=\frac{R_S+r_o}{\mu}$$

$$A_v=\frac{i_d R_S}{v_{gs}+i_d R_S}=\frac{R_S}{\dfrac{v_{gs}}{i_d}+R_S}=\frac{R_S}{\dfrac{R_S+r_o}{\mu}+R_S}=\frac{\mu R_S}{R_S+r_o+\mu R_S}=\frac{\mu R_S}{r_o+(1+\mu)R_S}$$

CG 共閘極放大器電路

不含r_o，求R_i、R_o、A_v：





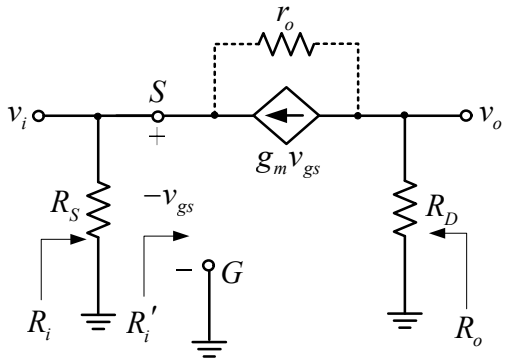
$$R_i = R_S // R_i' = R_S // \frac{v}{i} = R_S // \left(\frac{-v_{gs}}{-g_m v_{gs}} \right) = R_S // \left(\frac{1}{g_m} \right)$$

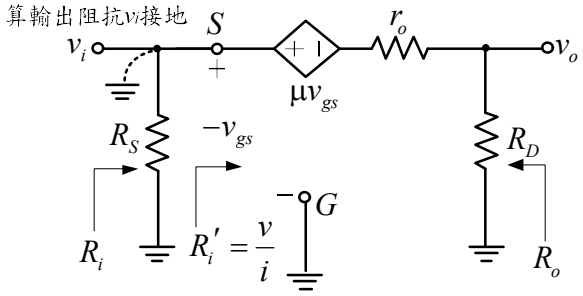
$$R_o = R_D$$

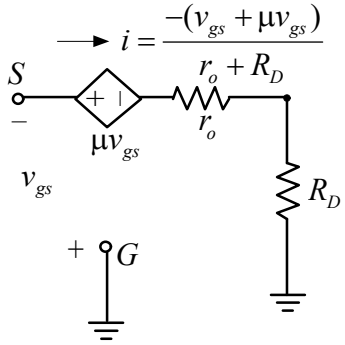
$$A_v = \frac{-g_m v_{gs} R_D}{-v_{gs}} = g_m R_D$$

CG 共閘極放大器電路

含r_o，求R_i、R_o、A_v：（電壓源計算方式）







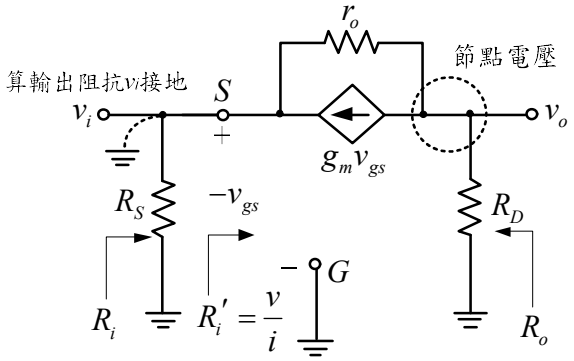
$$R_i = R_S // R_i' = R_S // \frac{v}{i} = R_S // \left(\frac{-v_{gs}}{\frac{-(1+\mu)v_{gs}}{r_o+R_D}} \right) = R_S // \left(\frac{r_o+R_D}{1+\mu} \right)$$

$$R_o = R_D // r_o$$

$$A_v = \frac{-(1+\mu)v_{gs} \times \frac{R_D}{r_o+R_D}}{-v_{gs}} = \frac{(1+\mu)R_D}{r_o+R_D}$$

CG 共閘極放大器電路

含 r_o，求 R_i、R_o、A_v：（電流源計算方式）



找出 v_i 與 v_o 關係，利用 *KCL* 計算出：

$$v_i = -v_{gs}$$

$$\frac{v_o - v_i}{r_o} + g_m v_{gs} + \frac{v_o}{R_D} = 0 \Rightarrow \frac{v_o - v_i}{r_o} - g_m v_i + \frac{v_o}{R_D} = 0 \Rightarrow (\frac{1}{r_o} + \frac{1}{R_D}) v_o = (\frac{1}{r_o} + g_m) v_i \Rightarrow \frac{v_o}{v_i} = \frac{(\frac{1}{r_o} + g_m)}{(\frac{1}{r_o} + \frac{1}{R_D})}$$

$$A_v = \frac{(\frac{1}{r_o} + g_m)}{(\frac{1}{r_o} + \frac{1}{R_D})} = \frac{(\frac{1}{r_o} + g_m) \times r_o R_D}{(\frac{1}{r_o} + \frac{1}{R_D}) \times r_o R_D} = \frac{R_D + g_m r_o R_D}{R_D + r_o} = \frac{R_D + \mu R_D}{R_D + r_o} = \frac{(1+\mu)R_D}{R_D + r_o}$$

$$R_i = R_S // R_i' = R_S // \frac{v}{i} = R_S // \left(\frac{r_o+R_D}{1+\mu} \right)$$

$$R_i' = \frac{v}{i} = \left(\frac{-v_{gs}}{-g_m v_{gs} + \frac{v_i - v_o}{r_o}} \right) = \left(\frac{-v_{gs}}{-g_m v_{gs} + \frac{-v_{gs} + \frac{R_D + g_m r_o R_D}{R_D + r_o} v_{gs}}{r_o}} \right) = \left(\frac{1}{g_m + \frac{1 - \frac{R_D + g_m r_o R_D}{R_D + r_o}}{r_o}} \right)$$

$$=\left(\frac{r_o}{g_m r_o+1-\dfrac{R_D+g_m r_o R_D}{R_D+r_o}}\right)=\left(\frac{r_o}{\mu+1-\dfrac{R_D+\mu R_D}{R_D+r_o}}\right)=\left(\frac{r_o(R_D+r_o)}{(\mu+1)(R_D+r_o)-(R_D+\mu R_D)}\right)=\left(\frac{r_o(R_D+r_o)}{(1+\mu)r_o}\right)=\left(\frac{r_o+R_D}{1+\mu}\right)$$

$R_o = R_D // r_o$

FET 放大電路型態	電壓增益 A_v	輸入阻抗 R_i	輸出阻抗 R_o
CS 共源極(不含r_o，不含R_S)	$-g_m R_D$	$R_{G1}//R_{G2}$	R_D
CS 共源極(含r_o，不含R_S)	$-g_m(R_D//r_o)$	$R_{G1}//R_{G2}$	$R_D//r_o$
CS 共源極(不含r_o，含R_S)	$\dfrac{-g_m R_D}{1+g_m R_S}$	$R_{G1}//R_{G2}$	R_D
CS 共源極(不含r_o，含R_S)	$\dfrac{-\mu R_D}{r_o+R_D+(1+\mu)R_S}$	$R_{G1}//R_{G2}$	$R_D//\left[r_o+(1+\mu)R_S\right]$

FET 放大電路型態	電壓增益 A_v	輸入阻抗 R_i	輸出阻抗 R_o
CD 共汲極(不含r_o，不含R_D)	$\dfrac{g_m R_S}{1+g_m R_S}$	$R_{G1}//R_{G2}$	$R_S//\dfrac{1}{g_m}$
CD 共汲極(含r_o，不含R_D)	$\dfrac{g_m(R_S//r_o)}{1+g_m(R_S//r_o)}=\dfrac{\mu R_S}{r_o+(1+\mu)R_S}$	$R_{G1}//R_{G2}$	$R_S//r_o//\dfrac{1}{g_m}=R_S//\dfrac{r_o}{1+\mu}$
CD 共汲極(不含r_o，含R_D)	$\dfrac{-\mu R_S}{R_D+(1+\mu)R_S}$	$R_{G1}//R_{G2}$	$R_S//\dfrac{1}{g_m}$
CD 共汲極(含r_o，含R_D)	$\dfrac{-\mu R_S}{r_o+R_D+(1+\mu)R_S}$	$R_{G1}//R_{G2}$	$R_S//\dfrac{r_o+R_D}{1+\mu}$

FET 放大電路型態	電壓增益 A_v	輸入阻抗 R_i	輸出阻抗 R_o
CG 共閘極(不含r_o)	$g_m R_D$	$R_S//\dfrac{1}{g_m}$	R_D
CG 共閘極(含r_o)	$\dfrac{(1+\mu)R_D}{r_o+R_D}$	$R_S//\dfrac{r_o+R_D}{1+\mu}$	$R_D//r_o$