# MOS Multistage Amplifiers

(1) Determine DC operating pt ($I_{DQ}$, $V_{DSQ}$)

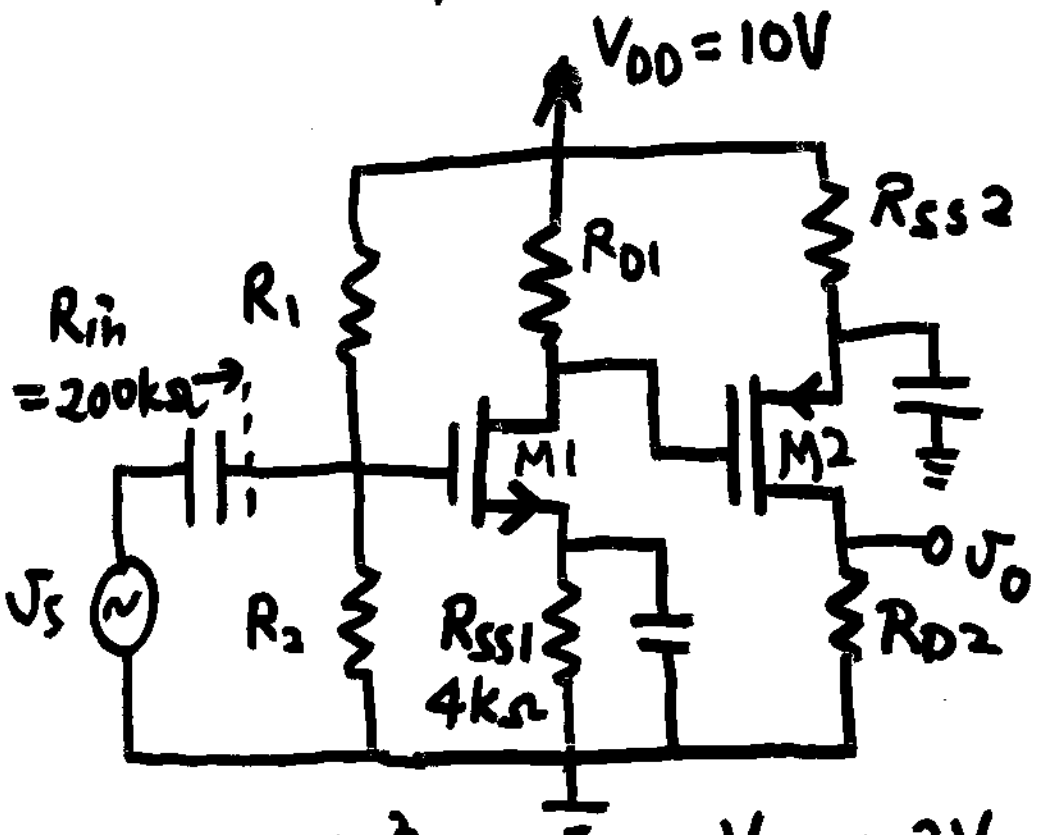
(2) Calculate small signal parameters

$g_m$, $r_o$

(3) Draw small signal ckt

(4) Calculate $A_v$, $A_i$, $R_{in}$, $R_{out}$

## CS-CS example




$K_1 = 0.1\,mA/V^2$ $\quad V_{TH1} = 2V$ $\quad \lambda_1 = \lambda_2 = 0$

$K_2 = 1.0\,mA/V^2$ $\quad V_{TH2} = -2V$

Design spec: $I_{D1} = 0.4mA$, $I_{D2} = 2mA$. $V_{DS1} = 4V$, $V_{DS2} = 5V$

For M1

$I_{D1} = 0.4\,mA$

$V_{DS1} = 4V$

$R_{SS1} = 4k\Omega$

$$V_{DD} = I_{D1}R_{D1} + V_{DS1} + I_{D1}R_{SS1}$$

$$R_{D1} = \frac{V_{DD} - V_{DS1} - I_{D1}R_{SS1}}{I_{D1}}$$

$$= 11k\Omega$$

$$I_{D1} = K_1[V_{GS1} - V_{TH1}]^2$$

$$\Rightarrow V_{GS1} = \sqrt{I_{D1}/K_1} + V_{TH1}$$

$$= 4V$$

$$V_{G1} = V_{S1} + V_{GS1} = I_{D1}R_{SS1} + V_{GS1}$$

$$= 5.6V$$

$$R_{in} = R_1 \| R_2 = 200\,k\Omega$$

$$V_{G1} = V_{DD}\frac{R_2}{R_1+R_2} = V_{DD}\frac{R_{in}}{R_1}$$

$$\Rightarrow R_1 = \frac{V_{DD}}{V_{G1}} R_{in} = 357\,k\Omega$$

$$R_2 = \frac{R_1}{R_1/R_{in} - 1} = 455\,k\Omega$$

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For M2

$$V_{G2} = V_{DD} - I_{D1} R_{D1} = 5.6\,V$$

$$V_{GS2} = -\sqrt{\frac{I_{D2}}{K_2}} + V_{TH2} = -3.41\,V$$

$$V_{S2} = V_{G2} - V_{GS2} = 9.01\,V$$

$$\Rightarrow R_{SS2} = \frac{V_{DD} - V_{S2}}{I_{D2}} = 495\,\Omega$$

$$R_{DS} = \frac{V_{DD} - I_{D2} R_{SS2} - V_{SD2}}{I_{D2}}$$

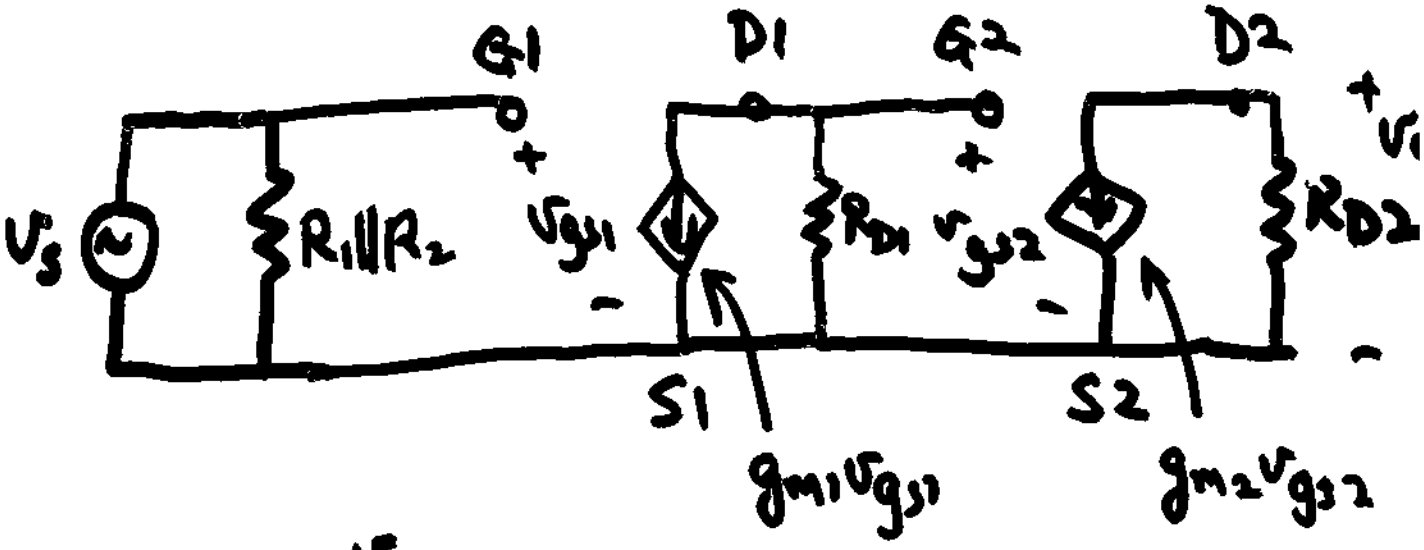
$$\approx 2\,k\Omega$$

## Small signal parameters

$$g_{m1} = 2\sqrt{K_1 I_{D1}} = 0.4\,mA/V$$

$$g_{m2} = 2\sqrt{K_2 I_{D2}} = 2.8\,mA/V$$

## Small signal ckt



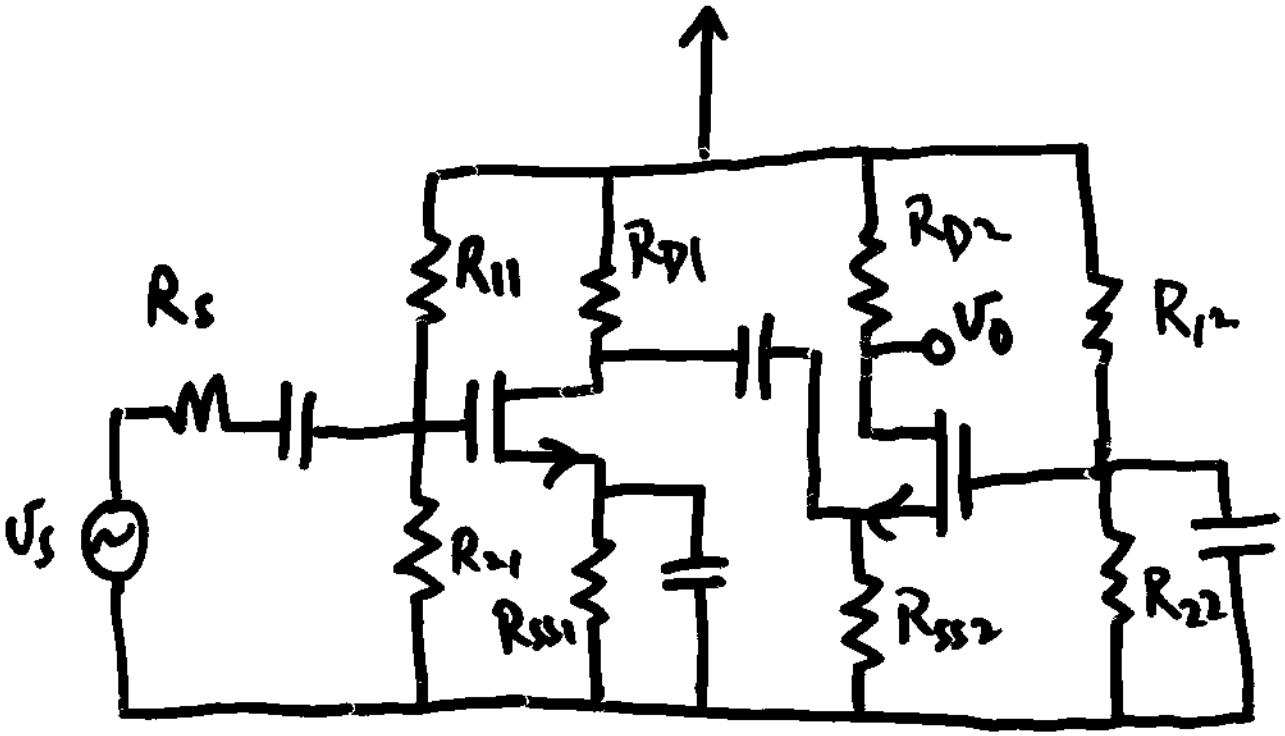

$$A_{v1} = \frac{v_{gs2}}{v_s}$$

$$= -g_{M1} R_{D1} = -4.4\ V/V$$

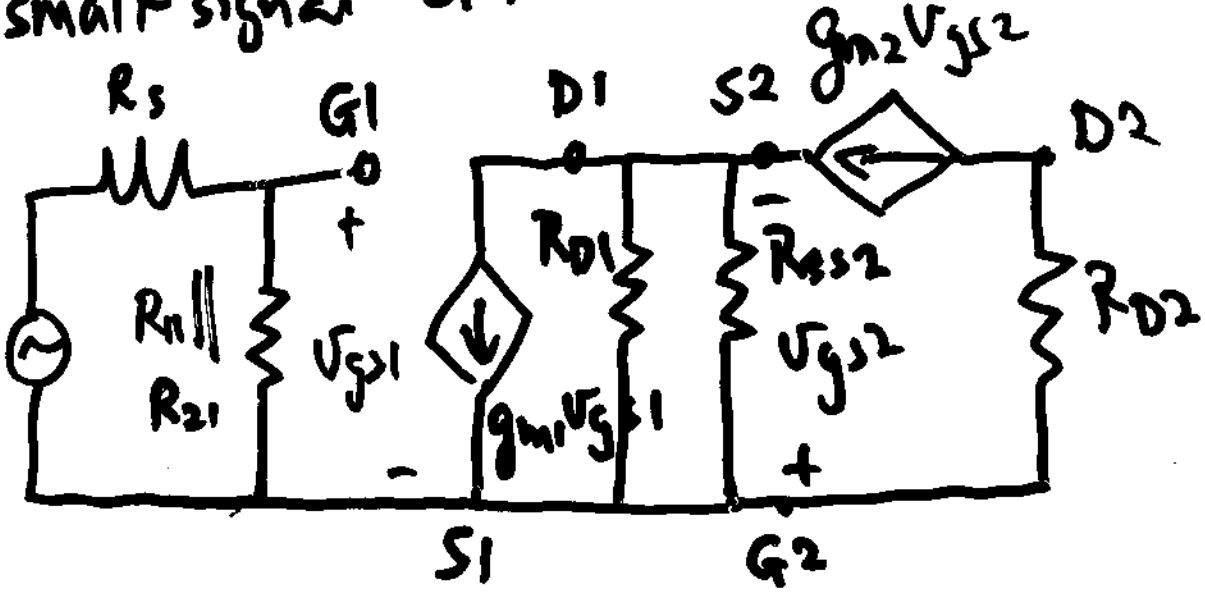
$$A_{v2} = \frac{v_o}{v_{gs2}} = -g_{m_2} R_{D2} = -5.6\ V/V$$

$$A_{vs} = A_{v1} \times A_{v2} = 24.6$$

# Cascode CS-CG




small signal ckt




$$g_{M2}V_{gs2} + \frac{V_{gs2}}{R_{D1} \| R_{SS2}} = g_{m1}V_{gs1}$$

$$v_{gs2} = \frac{g_{m1} v_{gs1}}{g_{m2} + \frac{1}{R_{D1} \| R_{ss2}}}$$

$$= \frac{(R_{D1} \| R_{ss2})\, g_{m1} v_{gs1}}{1 + g_{m2}(R_{D1} \| R_{ss2})}$$

$$v_o = -g_{m2} v_{gs2} R_{D2}$$

$$v_{gs1} = \frac{R_{11} \| R_{21}}{R_s + R_{11} \| R_{21}} v_s$$

$$A_{v_s} = \frac{v_o}{v_s} = -g_{m1} g_{m2} \frac{(R_{D1} \| R_{ss2})}{1 + g_{m2}(R_{D1} \| R_{ss2})} \cdot \frac{R_{11} \| R_{21}}{R_s + R_{11} \| R_{21}} \cdot R_{D2}$$

$$\simeq -g_{m1} R_{D2}$$