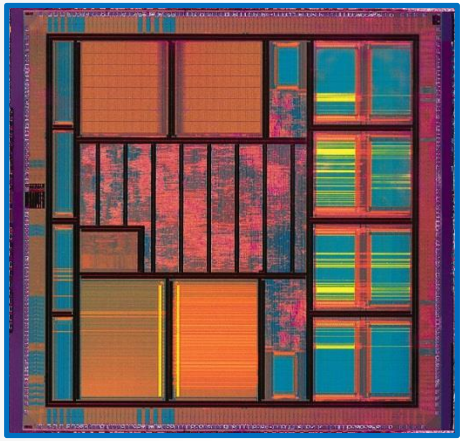
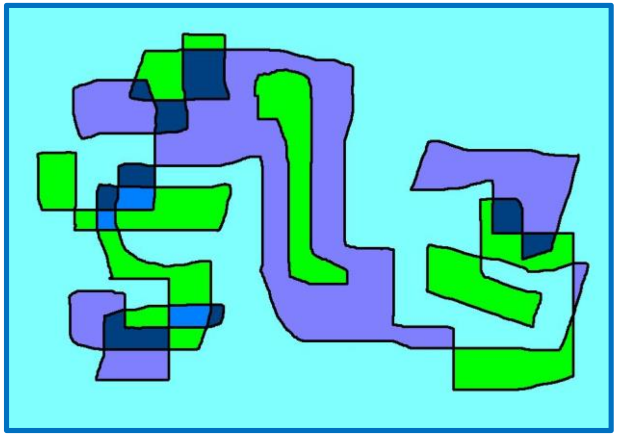
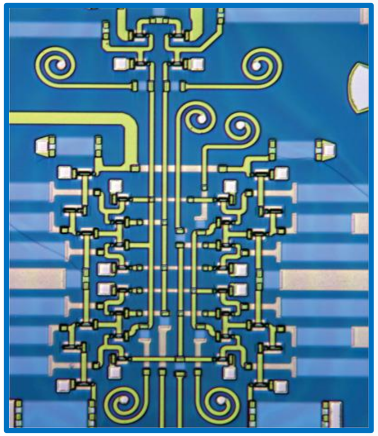






EIE 211 : Electronic Devices and Circuit Design II

Lecture $4x^2(dx/dt)$: CMOS Cascode

Table 5.3 Small-Signal Equivalent-Circuit Models for the MOSFET

Small-Signal Parameters

NMOS transistors

- Transconductance:

$$g_m = \mu_n C_{ox} \frac{W}{L} V_{OV} = \sqrt{2\mu_n C_{ox} \frac{W}{L} I_D} = \frac{2I_D}{V_{OV}}$$

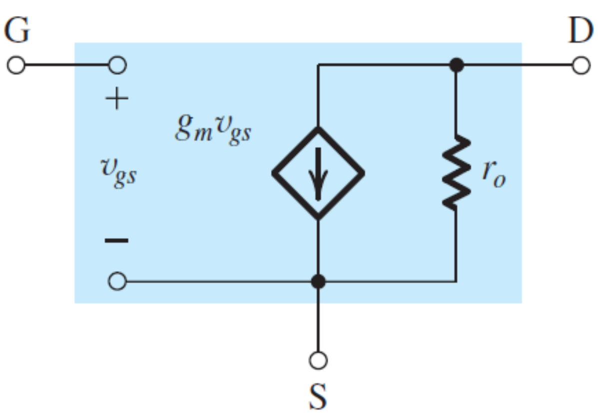
- Output resistance:

$$r_o = V_A / I_D = 1/\lambda I_D$$

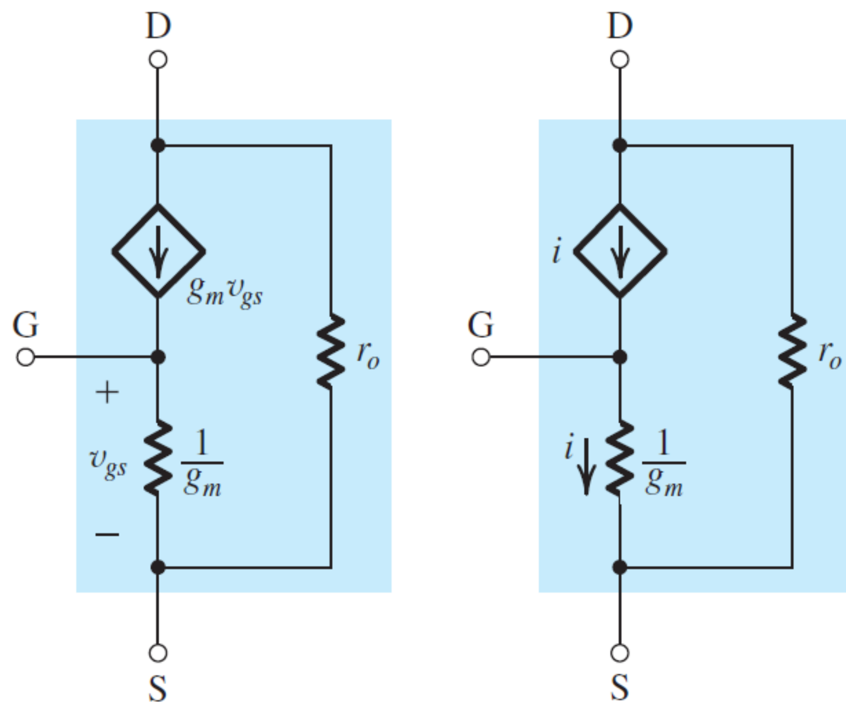
PMOS transistors

Same formulas as for NMOS *except* using $|V_{OV}|$, $|V_A|$, and replacing μ_n with μ_p.

Small-Signal Equivalent Circuit Models

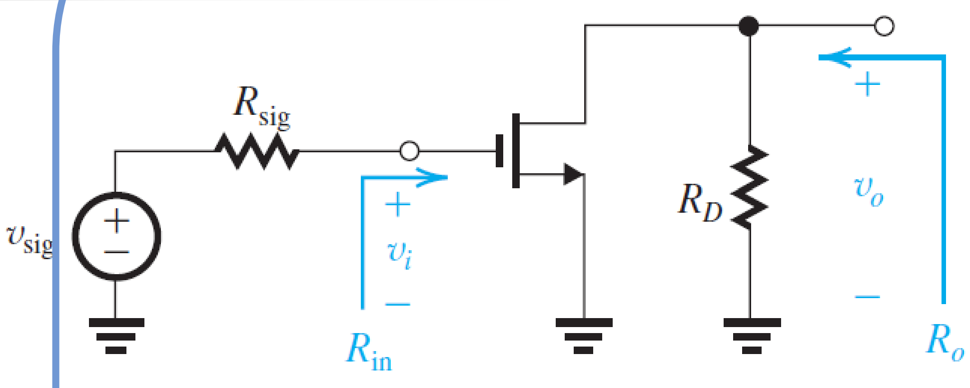


Hybrid-π model

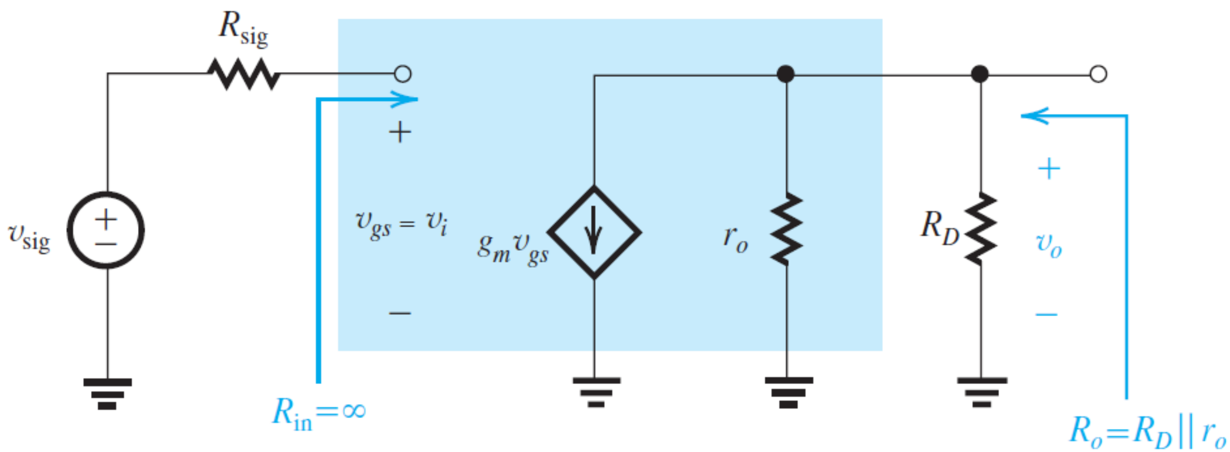


T models

Common Source Amplifier



(a)



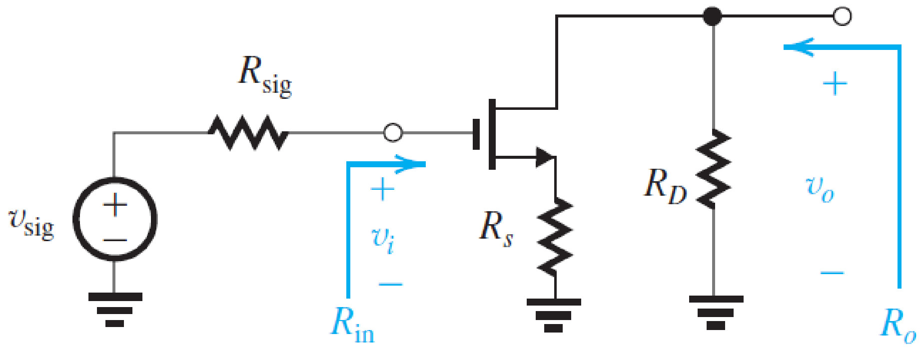
(b)

$$R_{in} = \infty$$

$$R_o = R_D \,||\, r_o$$

$$G_v = A_v = -g_m(R_D \,||\, R_L \,||\, r_o)$$

Common Source Amplifier w/ Degeneration Resistor

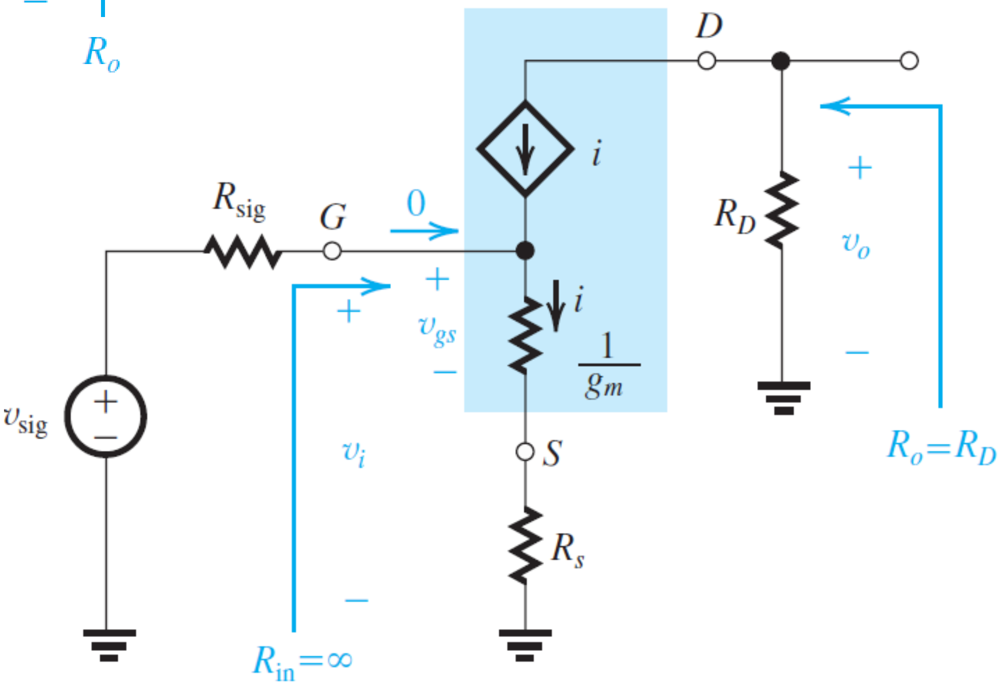


$$v_{gs} = v_i \frac{1/g_m}{1/g_m + R_s} = \frac{v_i}{1 + g_m R_s}$$

$$i = \frac{v_i}{1/g_m + R_s} = \left(\frac{g_m}{1 + g_m R_s}\right) v_i$$

$$v_o = -i \; R_D$$

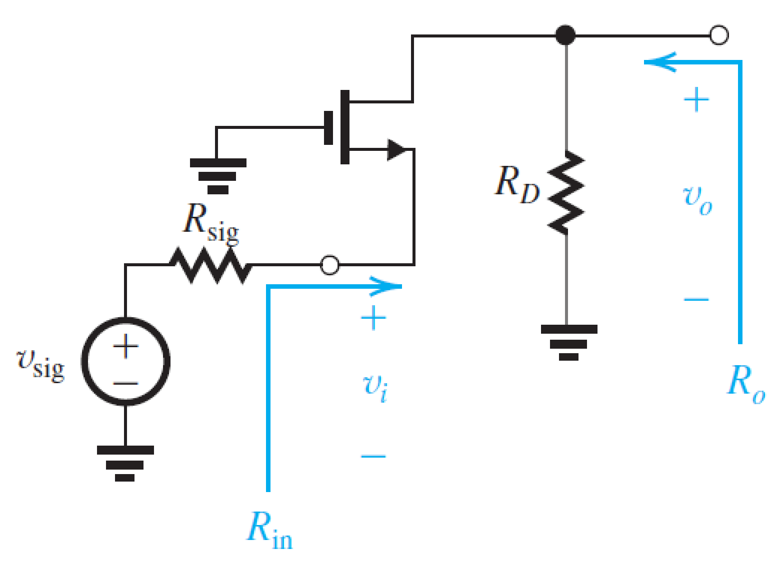
$$A_{vo} = \frac{v_o}{v_i} = -\frac{R_D}{1/g_m + R_s}$$

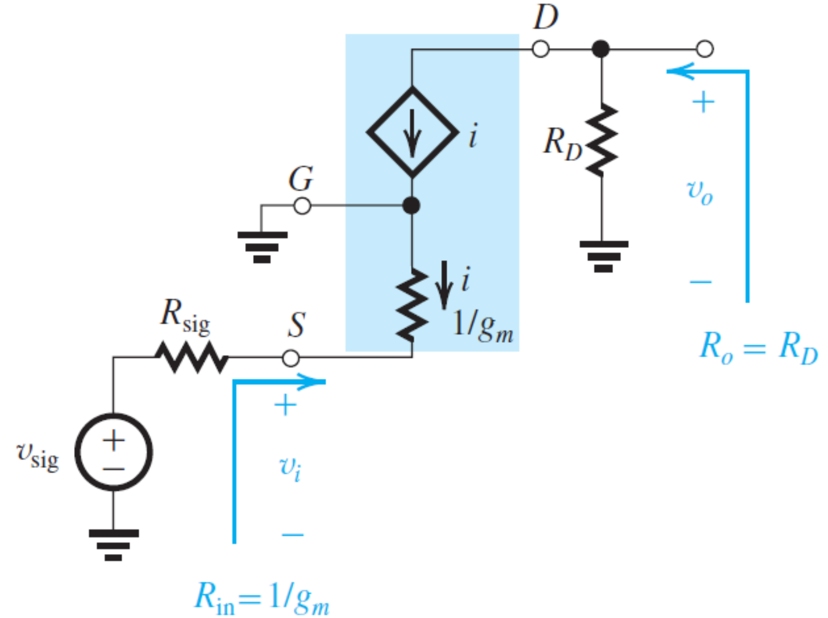


$$A_{vo} = -\frac{g_m R_D}{1 + g_m R_s}$$

$$\text{Voltage gain from gate to drain} = -\frac{\text{Total resistance in drain}}{\text{Total resistance in source}}$$

Common Gate Amplifier





$$R_{in} = \frac{1}{g_m}$$

$$R_o = R_D$$

$$v_o = -iR_D$$

$$i = -\frac{v_i}{1/g_m}$$

$$\frac{v_i}{v_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} = \frac{1/g_m}{1/g_m + R_{sig}}$$

$$A_{vo} \equiv \frac{v_o}{v_i} = g_m R_D$$

$$G_v = \frac{1/g_m}{R_{sig} + 1/g_m}[g_m(R_D \| R_L)] = \frac{(R_D \| R_L)}{R_{sig} + 1/g_m}$$

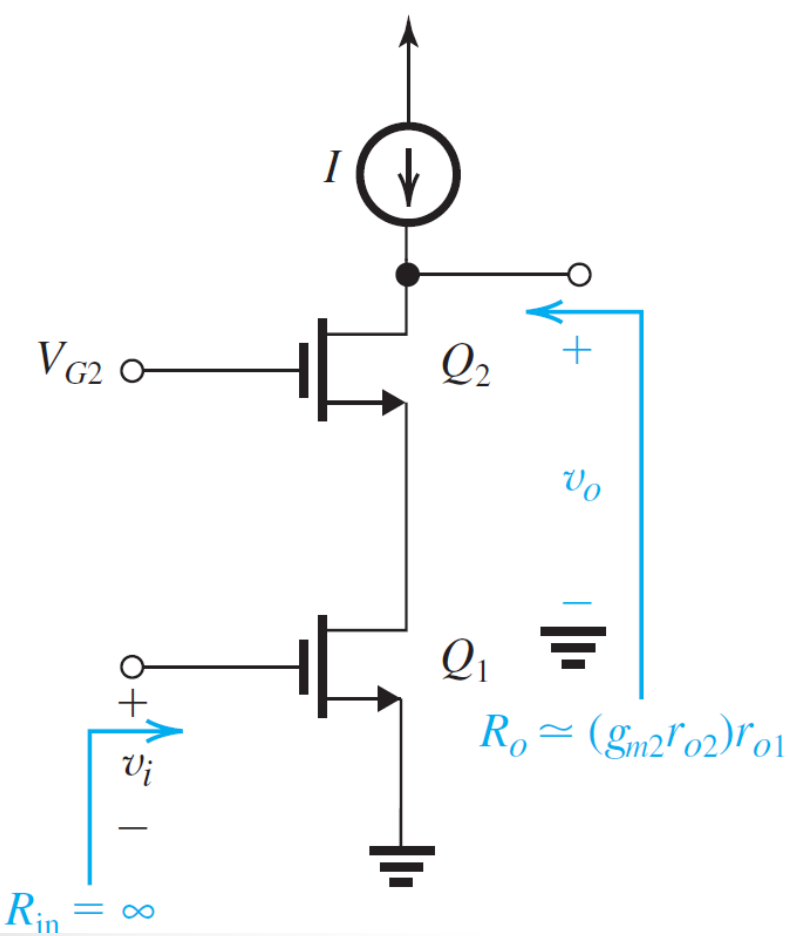
Table 5.4 Characteristics of MOSFET Amplifiers

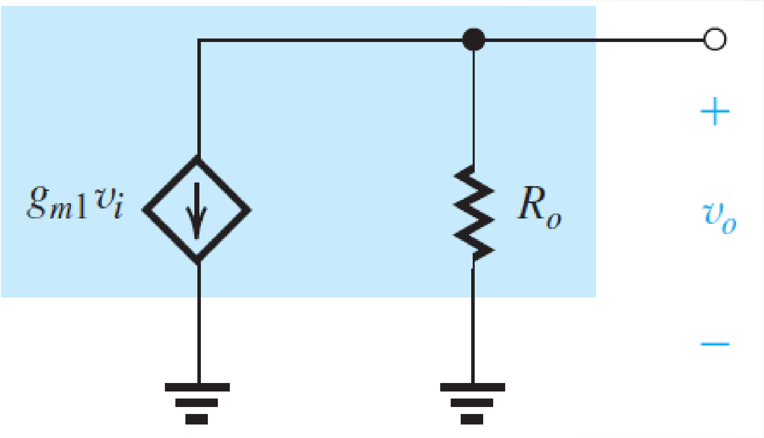
	Characteristics[a, b]				
Amplifier type	R_{in}	A_{vo}	R_o	A_v	G_v
Common source (Fig. 5.45)	∞	$-g_m R_D$	R_D	$-g_m(R_D \parallel R_L)$	$-g_m(R_D \parallel R_L)$
Common source with R_s (Fig. 5.47)	∞	$-\dfrac{g_m R_D}{1+g_m R_s}$	R_D	$\dfrac{-g_m(R_D \parallel R_L)}{1+g_m R_s}$ $-\dfrac{R_D \parallel R_L}{1/g_m + R_s}$	$-\dfrac{g_m(R_D \parallel R_L)}{1+g_m R_s}$ $-\dfrac{R_D \parallel R_L}{1/g_m + R_s}$
Common gate (Fig. 5.48)	$\dfrac{1}{g_m}$	$g_m R_D$	R_D	$g_m(R_D \parallel R_L)$	$\dfrac{R_D \parallel R_L}{R_{sig} + 1/g_m}$
Source follower (Fig. 5.50)	∞	1	$\dfrac{1}{g_m}$	$\dfrac{R_L}{R_L + 1/g_m}$	$\dfrac{R_L}{R_L + 1/g_m}$

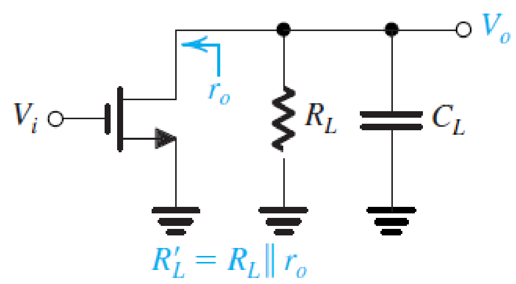
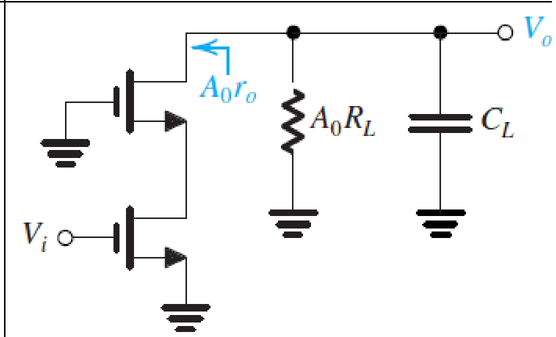
TABLE 6.5 Characteristics of BJT Amplifiers[a, b, c]

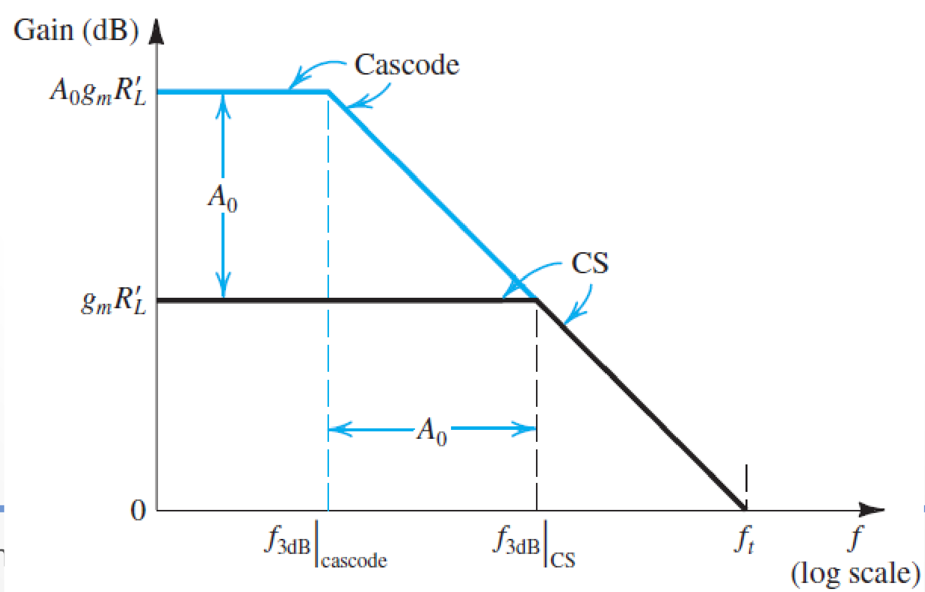
	R_{in}	A_{vo}	R_o	A_v	G_v
Common emitter (Fig. 6.50)	$(\beta+1)r_e$	$-g_m R_C$	R_C	$-g_m(R_C \parallel R_L)$ $-\alpha\frac{R_C \parallel R_L}{r_e}$	$-\beta\frac{R_C \parallel R_L}{R_{sig}+(\beta+1)r_e}$
Common emitter with R_e (Fig. 6.52)	$(\beta+1)(r_e+R_e)$	$-\frac{g_m R_C}{1+g_m R_e}$	R_C	$\frac{-g_m(R_C \parallel R_L)}{1+g_m R_e}$ $-\alpha\frac{R_C \parallel R_L}{r_e+R_e}$	$-\beta\frac{R_C \parallel R_L}{R_{sig}+(\beta+1)(r_e+R_e)}$
Common base (Fig. 6.53)	r_e	$g_m R_C$	R_C	$g_m(R_C \parallel R_L)$ $\alpha\frac{R_C \parallel R_L}{r_e}$	$\alpha\frac{R_C \parallel R_L}{R_{sig}+r_e}$
Emitter follower (Fig. 6.55)	$(\beta+1)(r_e+R_L)$	1	r_e	$\frac{R_L}{R_L+r_e}$	$\frac{R_L}{R_L+r_e+R_{sig}/(\beta+1)}$ $G_{vo} = 1$ $R_{out} = r_e + \frac{R_{sig}}{\beta+1}$

MOS Cascode

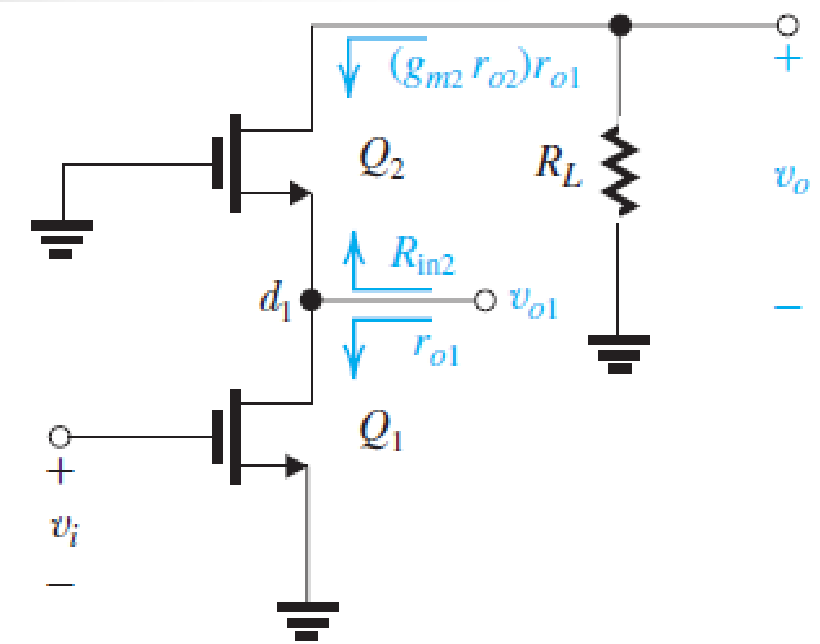


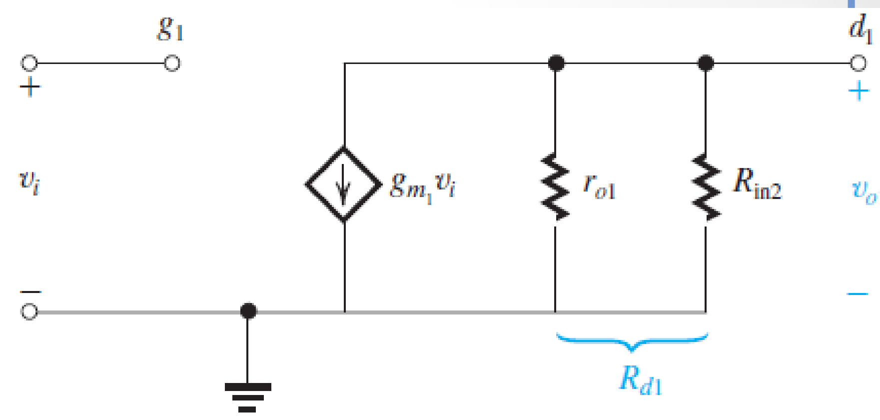


	Common Source	Cascode
Circuit		
DC Gain	$-g_m R'_L$	$-A_0 g_m R'_L$
f_{3dB}	$\frac{1}{2\pi(C_L + C_{gd})R'_L}$	$\frac{1}{2\pi(C_L + C_{gd})A_0 R'_L}$
f_t	$\frac{g_m}{2\pi(C_L + C_{gd})}$	$\frac{g_m}{2\pi(C_L + C_{gd})}$



MOS Cascode: resistance

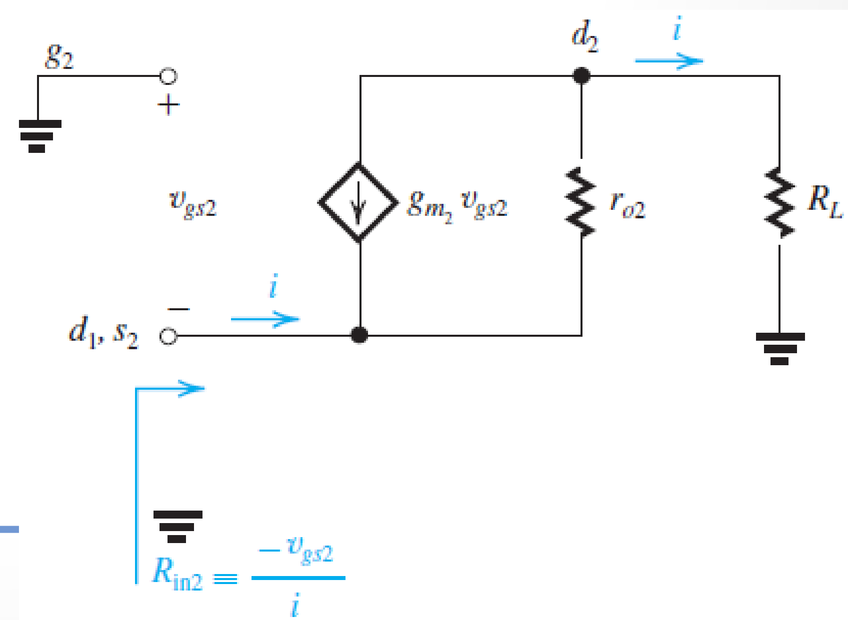




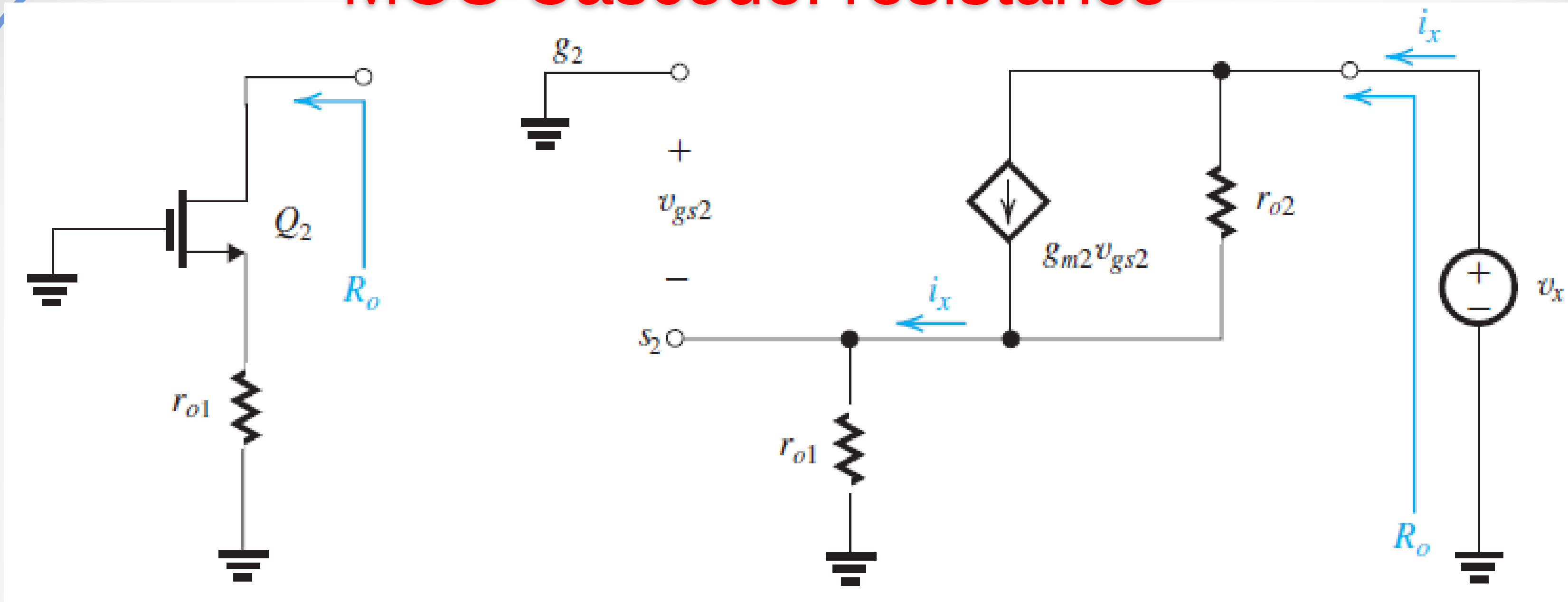
$$-v_{gs2} = (i + g_{m2} v_{gs2}) r_{o2} + i R_L$$

$$R_{in2} \equiv -v_{gs2} / i$$

$$R_{in2} = \frac{R_L + r_{o2}}{1 + g_{m2} r_{o2}}$$



MOS Cascode: resistance

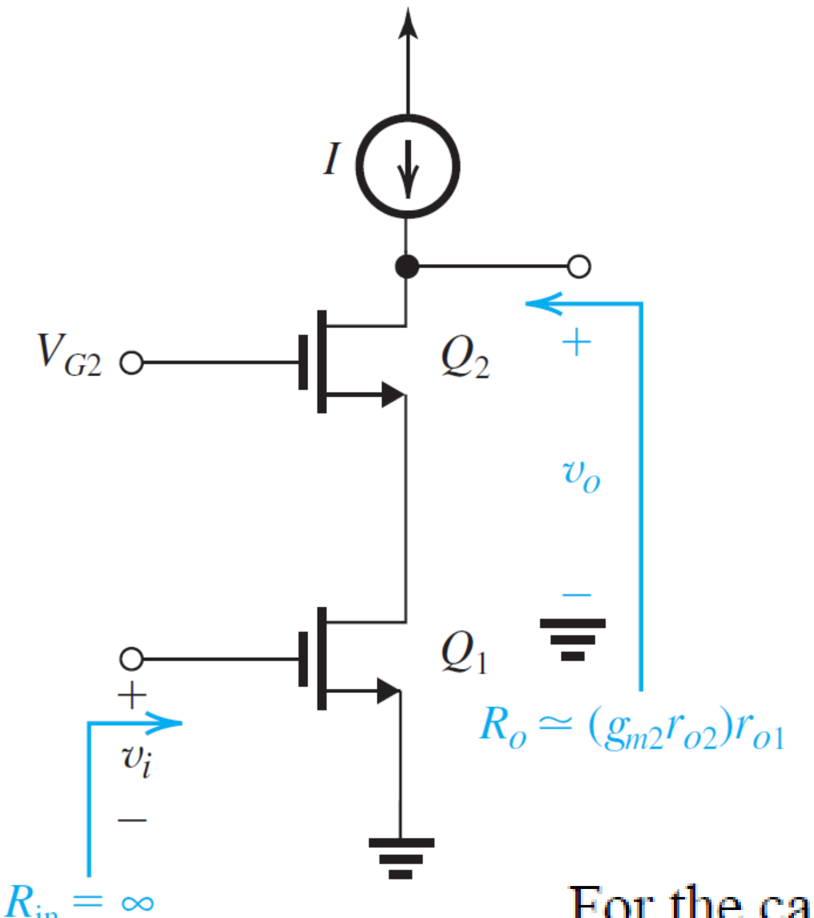


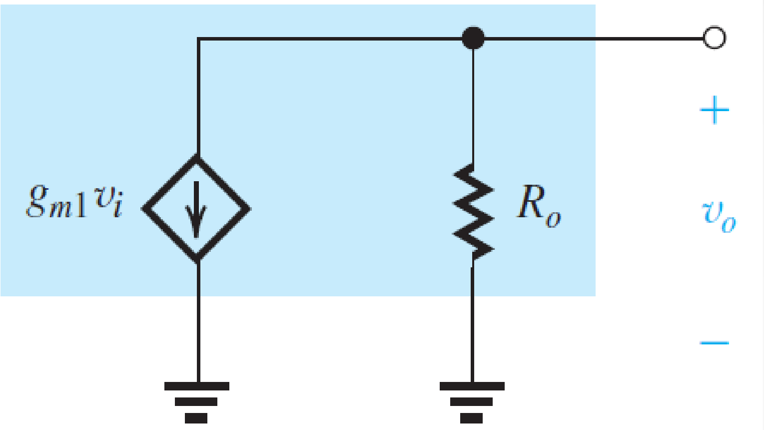
$$R_o \equiv \frac{v_x}{i_x} \qquad v_x = (i_x - g_{m2}v_{gs2})\, r_{o2} + i_x r_{o1}$$

$$-v_{gs2} = i_x r_{o1} \qquad v_x = i_x(r_{o1} + r_{o2} + g_{m2}r_{o2}r_{o1})$$

$$R_o = r_{o1} + r_{o2} + g_{m2}r_{o2}r_{o1} \simeq (g_{m2}r_{o2})r_{o1}$$

MOS Cascode: voltage gain





$$A_{vo} = \frac{v_o}{v_i} = -g_{m1}R_o$$

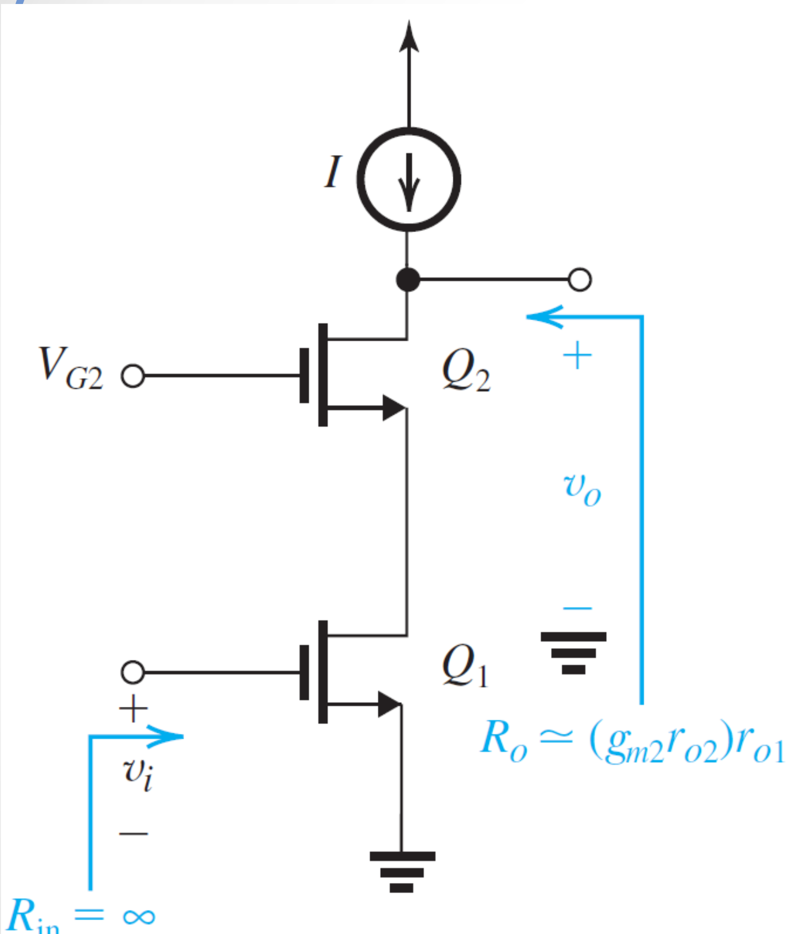
$$A_{vo} = - g_{m1} \times (g_{m2}r_{o2})r_{o1}$$

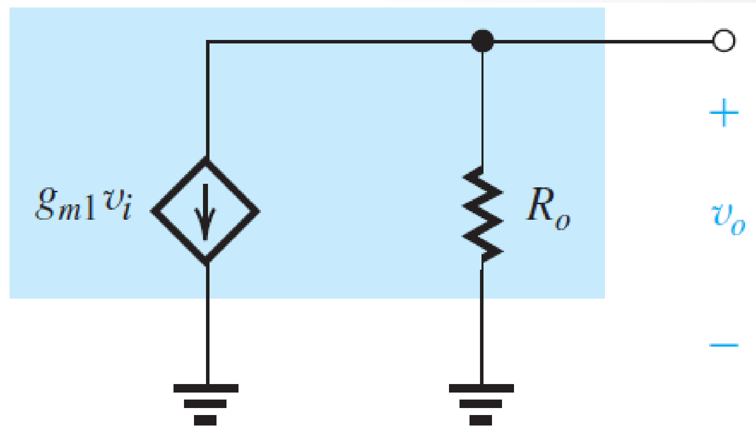
$$A_{vo} = -(g_{m1}r_{o1})(g_{m2}r_{o2})$$

For the case $g_{m1} = g_{m2} = g_m$ and $r_{o1} = r_{o2} = r_o$,

$$A_{vo} = -(g_m r_o)^2 = -A_0^2$$

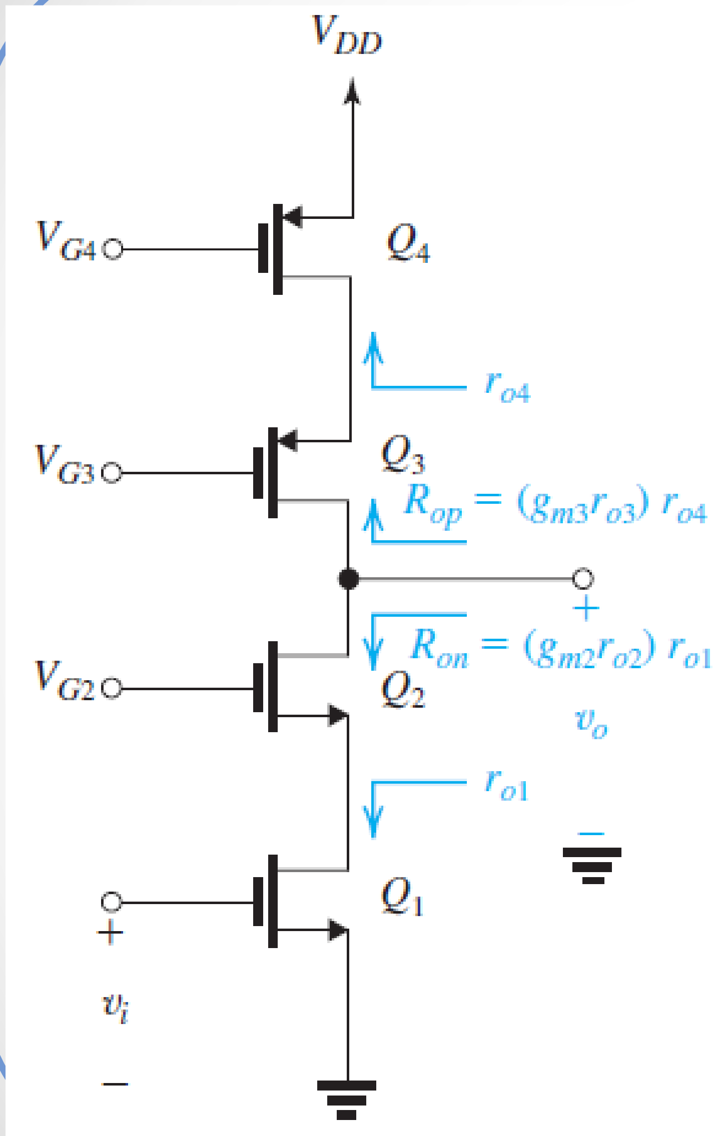
MOS Cascode: voltage gain

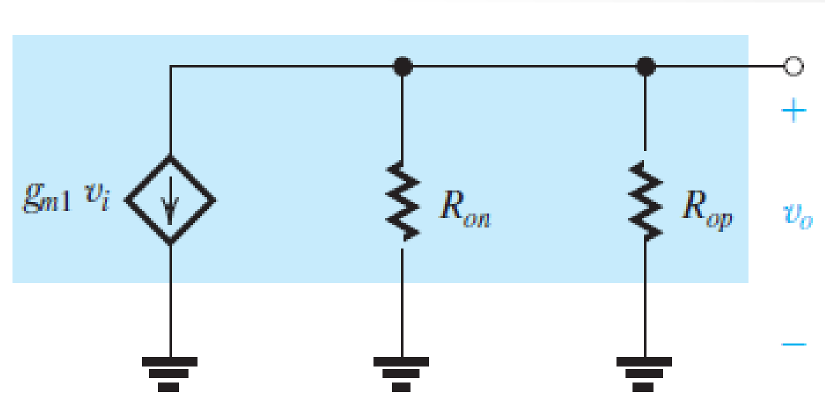




If there's a load resistance R_L connected to the output, the voltage gain will be

$$A_v = -g_{m1}(g_{m2}r_{o2}r_{o1} \| R_L)$$

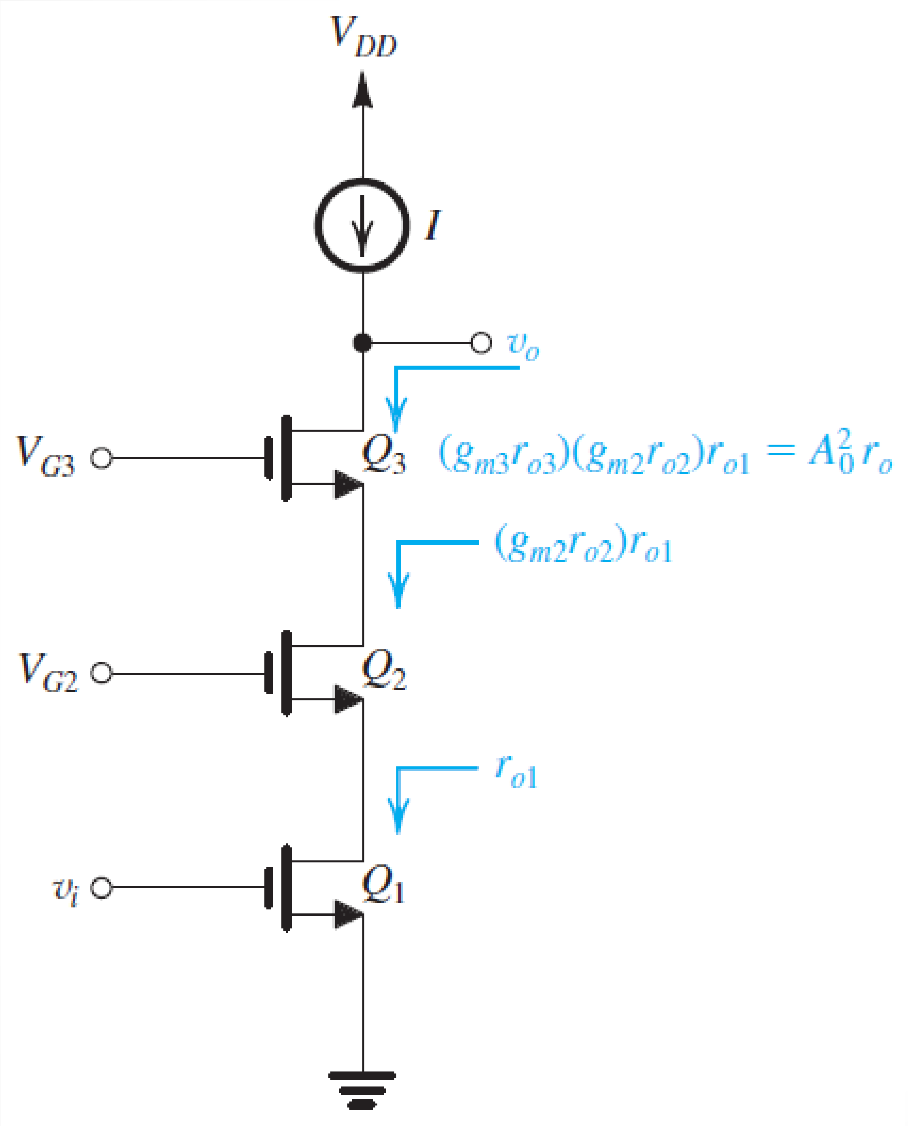




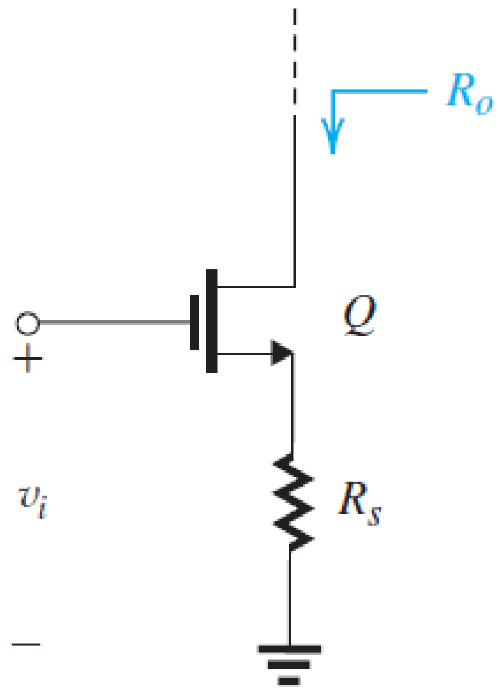
$$A_v = \frac{v_o}{v_i} = -g_{m1}[R_{on} \,\|\, R_{op}]$$

$$A_v = -g_{m1}\{[(g_{m2}r_{o2})r_{o1}] \,\|\, [(g_{m3}r_{o3})r_{o4}]\}$$

MOS Double Cascode

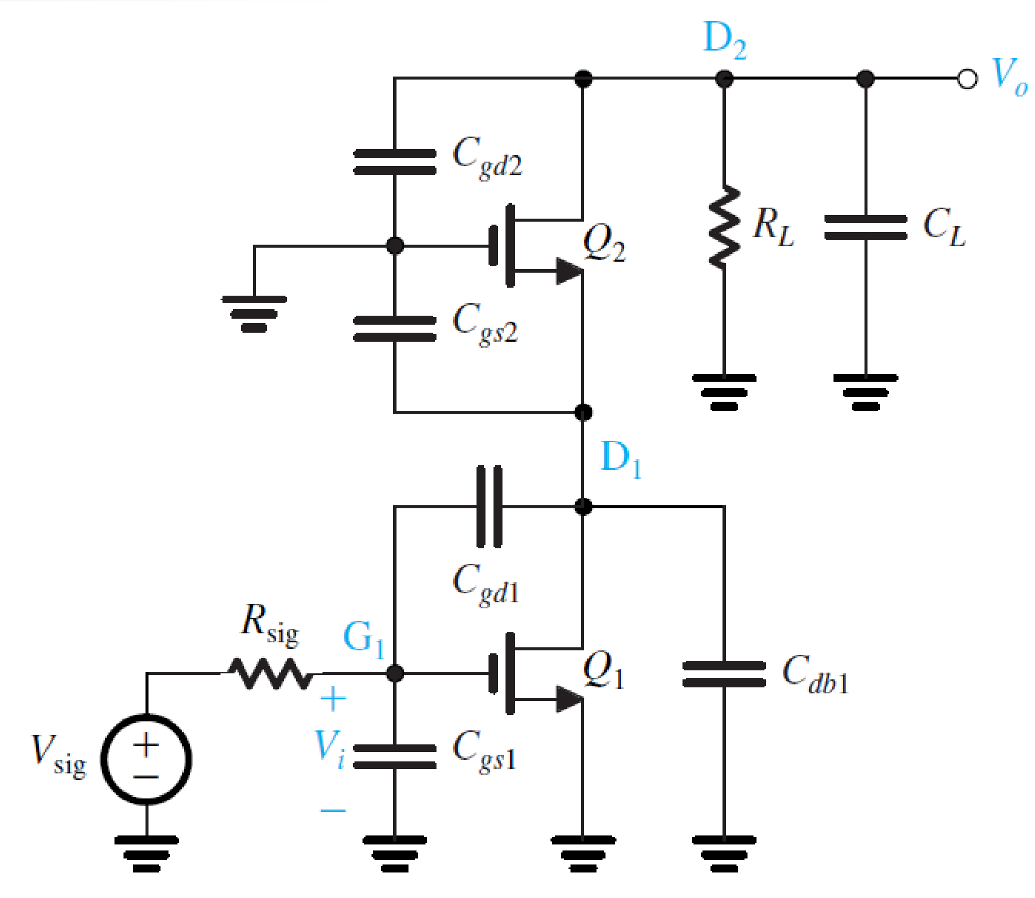


MOS Cascode: output resistance of a CS amplifier with degeneration resistor



$$R_o = R_s + r_o + g_m r_o R_s$$
$$\simeq (1 + g_m R_s)\, r_o$$

MOS Cascode Frequency Response



MOS Cascode Frequency Response

We are going to use "open-ckt" time constant method to find f_H

1. Capacitance C_{gs1} sees a resistance R_{sig}.
2. Capacitance C_{gd1} sees a resistance R_{gd1}, which can be obtained by adapting the formula in Eq. (9.84) to

$$R_{gd1} = (1 + g_{m1}R_{d1})R_{sig} + R_{d1} \tag{9.116}$$

where R_{d1}, the total resistance at D_1, is given by

$$R_{d1} = r_{o1} \| R_{in2} = r_{o1} \| \frac{r_{o2} + R_L}{g_{m2}r_{o2}} \tag{9.117}$$

3. Capacitance $(C_{db1} + C_{gs2})$ sees a resistance R_{d1}.
4. Capacitance $(C_L + C_{gd2})$ sees a resistance $(R_L \| R_o)$ where R_o is given by

$$R_o = r_{o2} + r_{o1} + (g_{m2}r_{o2})r_{o1}$$

$$\tau_H = C_{gs1}R_{sig} + C_{gd1}[(1 + g_{m1}R_{d1})R_{sig} + R_{d1}] + (C_{db1} + C_{gs2})R_{d1} + (C_L + C_{gd2})(R_L \| R_o)$$

$$f_H \simeq \frac{1}{2\pi\tau_H}$$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References

Microelectronic Circuits by Adel S. Sedra & Kenneth C. Smith. Saunders College Publishing

“Chapter 7: Frequency Response”, a lecture note by Prof. Yang Hua, Ph.D., Department of Electronic Engineering, Shanghai Jiao Tong University (SJTU), Shanghai, China