IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

Microelectronics: Devices to Circuits

Frequency Response of the Differential Amplifier

SUDEB DASGUPTA

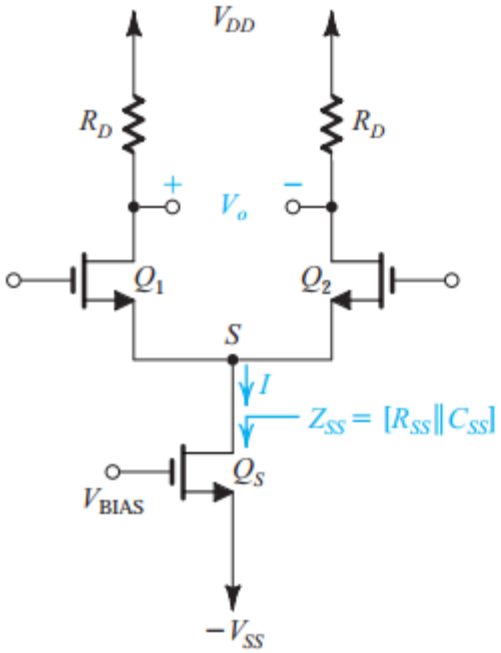
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

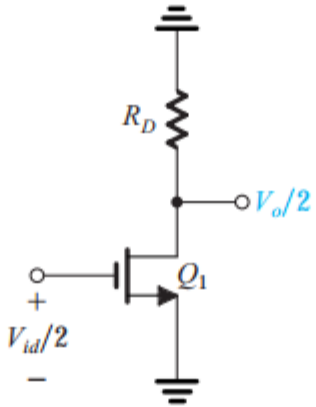


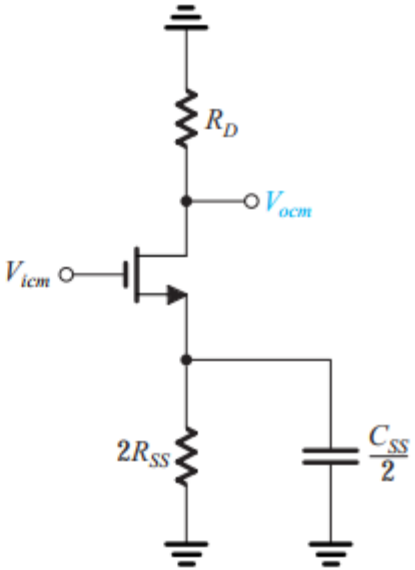
Outline

- Analysis of the Resistively Loaded MOS Amplifier
- Analysis of the Active-Loaded MOS Amplifier
- Recapitulation

Analysis of the Resistively Loaded MOS Amplifier







Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

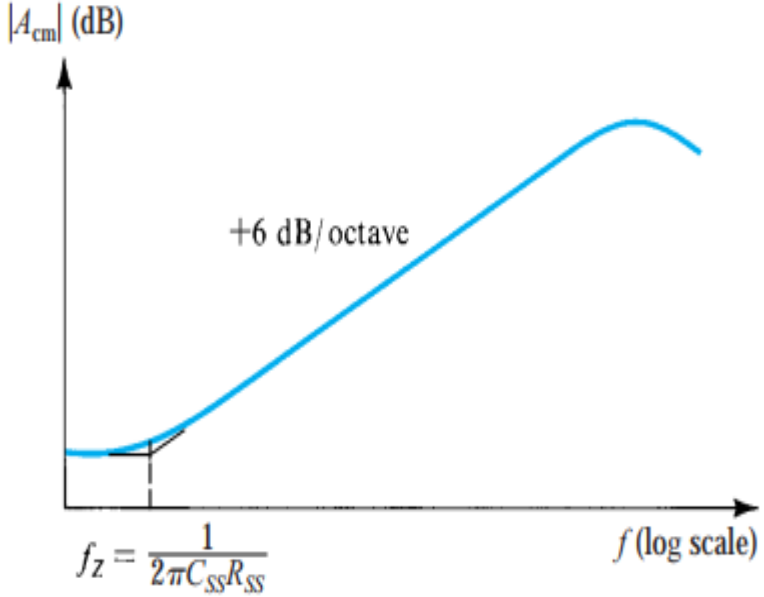
$$A_{CM} = -\left(\frac{R_D}{2R_{SS}}\right)\frac{\Delta R_D}{R_D} \qquad A_{CM}(S) = -\frac{R_D}{2Z_{SS}}\left(\frac{\Delta R_D}{R_D}\right) \qquad A_{CM}(S) = -\frac{R_D}{2}\left(\frac{\Delta R_D}{R_D}\right)Y_{SS}$$

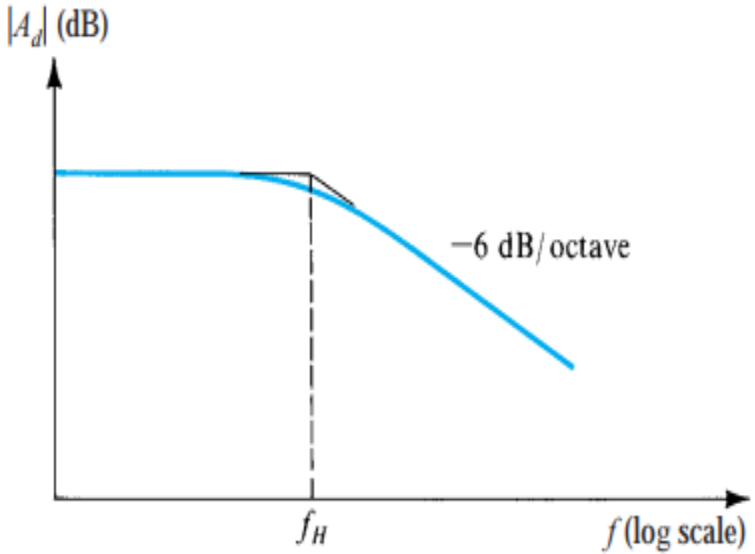
The frequency dependence of A_{cm} can be obtained by simply replacing R_{ss} by Z_{ss}.

$$A_{CM}(S) = -\frac{R_D}{2}\left(\frac{\Delta R_D}{R_D}\right)\left(\frac{1}{R_{SS}} + SC_{SS}\right) \qquad A_{CM}(S) = -\frac{R_D}{2R_{SS}}\left(\frac{\Delta R_D}{R_D}\right)(1 + SC_{SS}R_{SS}) \qquad w_Z = \frac{1}{C_{SS}R_{SS}}$$

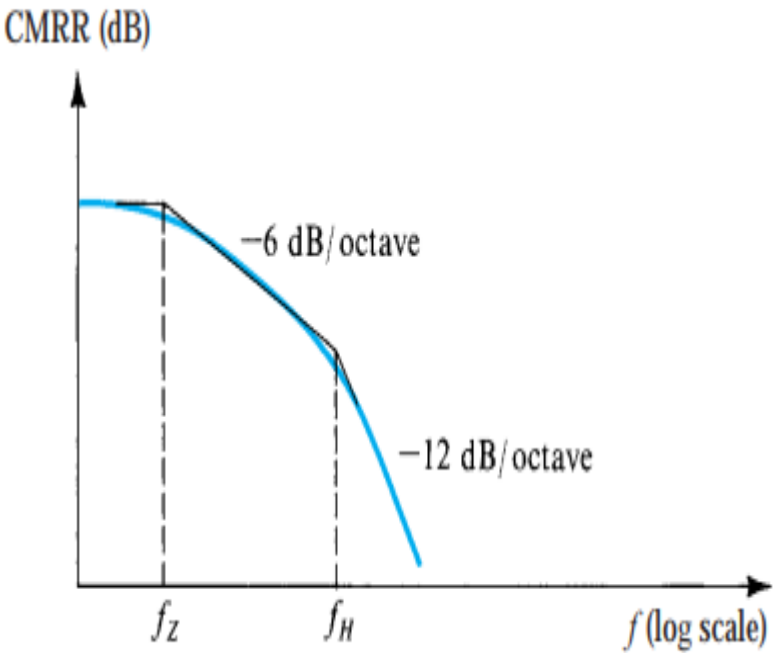
$$f_Z = \frac{1}{2\pi C_{SS}R_{SS}}$$

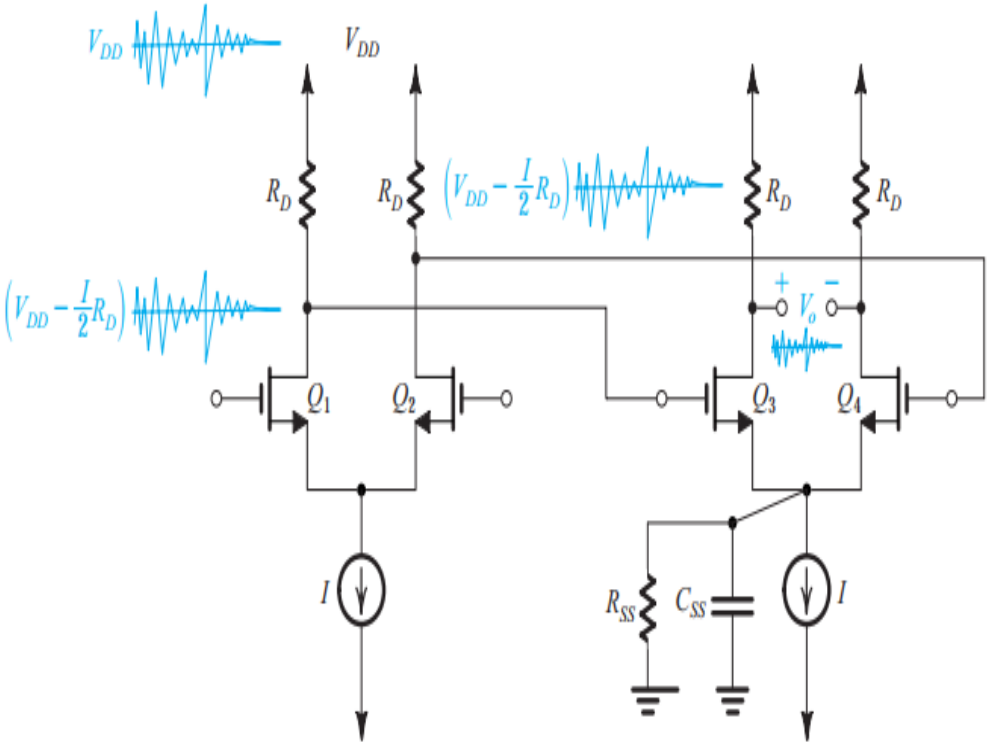
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition





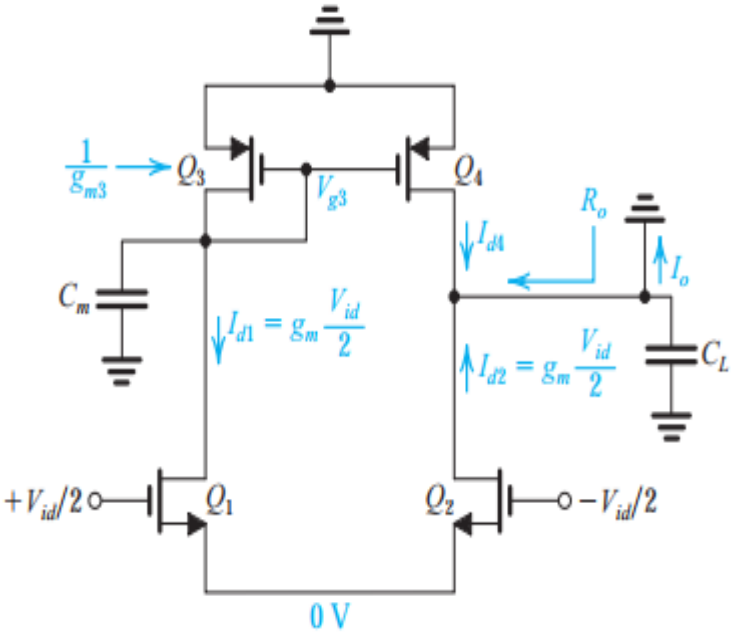
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

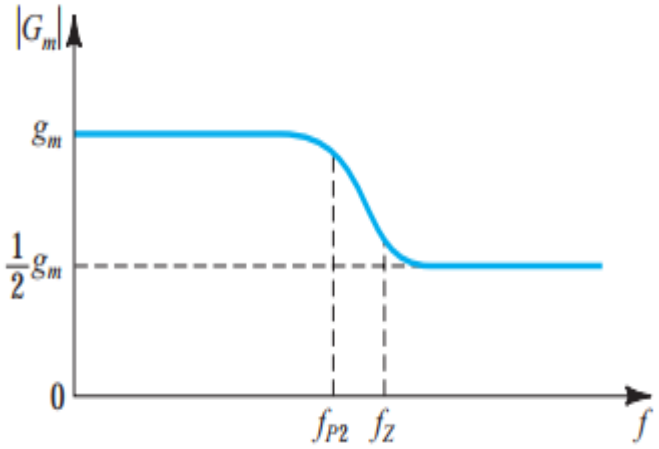




Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Analysis of the Active-Loaded MOS Amplifier





Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

$$C_m = C_{gd1} + C_{db1} + C_{db3} + C_{gs3} + C_{gs4}$$

$$C_L = C_{gd2} + C_{db2} + C_{gd4} + C_{db4} + C_x$$

$$V_{g3} = -\frac{g_m \frac{v_{id}}{2}}{g_{m3} + sC_m}$$

$$I_0 = I_{d4} + I_{d2}$$

$$I_0 = \frac{g_m \frac{V_{id}}{2}}{1 + s\frac{C_m}{g_{m3}}} + g_m \frac{V_{id}}{2}$$

$$I_{d4} = -g_{m4} V_{g3} = \frac{g_{m4} g_m \frac{V_{id}}{2}}{g_{m3} + sC_m}$$

$$f_{p2} = \frac{g_{m3}}{2\pi C_m}$$

Since $g_{m3} = g_{m4}$

$$f_z = \frac{2g_{m3}}{2\pi C_m}$$

$$G_m = \frac{I_0}{V_{id}} = g_m \frac{1 + s\frac{C_m}{2g_{m3}}}{1 + s\frac{C_m}{g_{m3}}}$$

$$I_{d4} = -g_{m4} V_{g3} \qquad I_{d4} = \frac{g_m \frac{V_{id}}{2}}{g_{m3} + s\frac{C_m}{g_{m3}}}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

C_m is approximately equal to $C_{gs2} + C_{gs4} = 2C_{gs}$

$$\frac{V_o}{V_{id}} = (g_m R_o)\left[\frac{1 + S\frac{C_m}{2g_{m3}}}{1 + S\frac{C_m}{g_{m3}}}\right]\left(\frac{1}{1 + SC_L R_0}\right)$$

$$f_{p2} = \frac{g_{m3}}{2\pi C_m} \cong \frac{g_{m3}}{2\pi(2C_{gs})} = \frac{f_T}{2}$$

$$R_0 = r_{02} \| r_{04}$$

$$f_{p1} = \frac{1}{2\pi C_L R_0}$$

$$f_Z = f_T$$

$$V_0 = I_0 \frac{1}{\frac{1}{R_0} + SC_L} = G_m V_{id} \frac{R_0}{1 + SC_L R_0}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Recapitulation

- The two capacitances C_L and C_m primarily determine the dependence of the differential gain of the amplifier on frequency.
- A_{cm} drops off at high frequencies because of the other poles of the common-mode half circuit.
- The common mode gain increases at the rate +6dB/octave(20dB/decade) starting at a relatively low frequency.

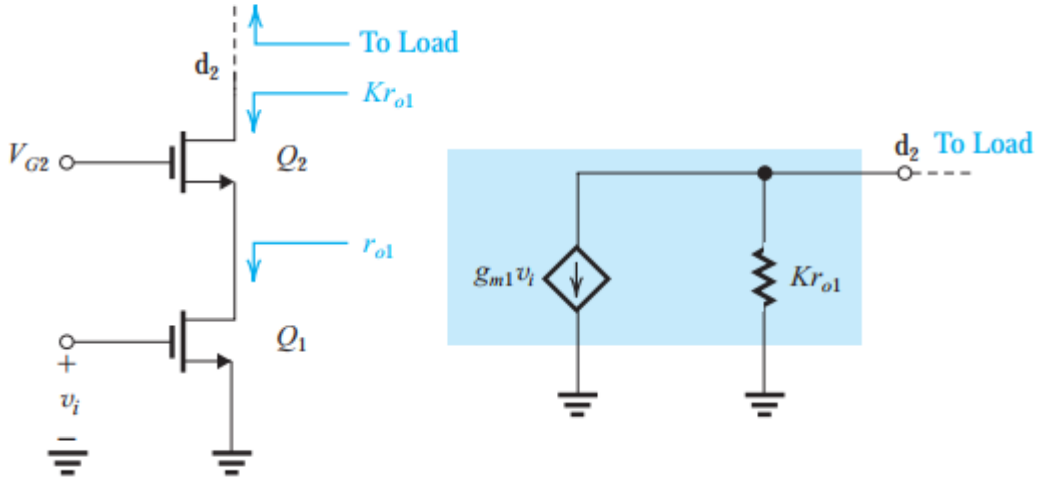
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Outline

- Cascode Amplifier
- MOS Cascode Amplifier
- Output resistance of Cascode MOS Amplifier
- Voltage Gain of Cascode Amplifier
- Cascode amplifier with a Cascode current-source load
- Recapitulation

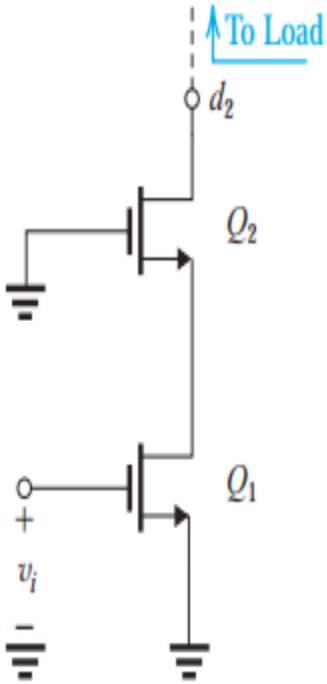
Cascode Amplifier

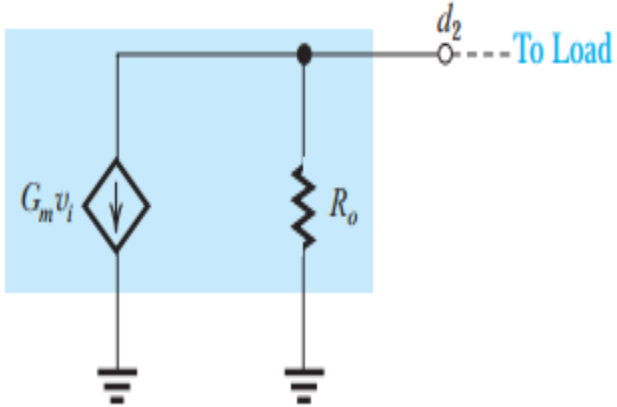
❑Cascode refers to the use of a transistor connected in the common-gate (or common-base) configuration to provide current buffering for the output of a common-source (or a common –emitter transistor).

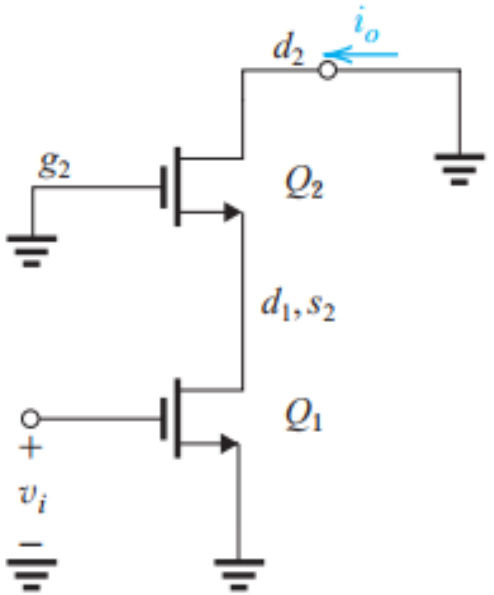


Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

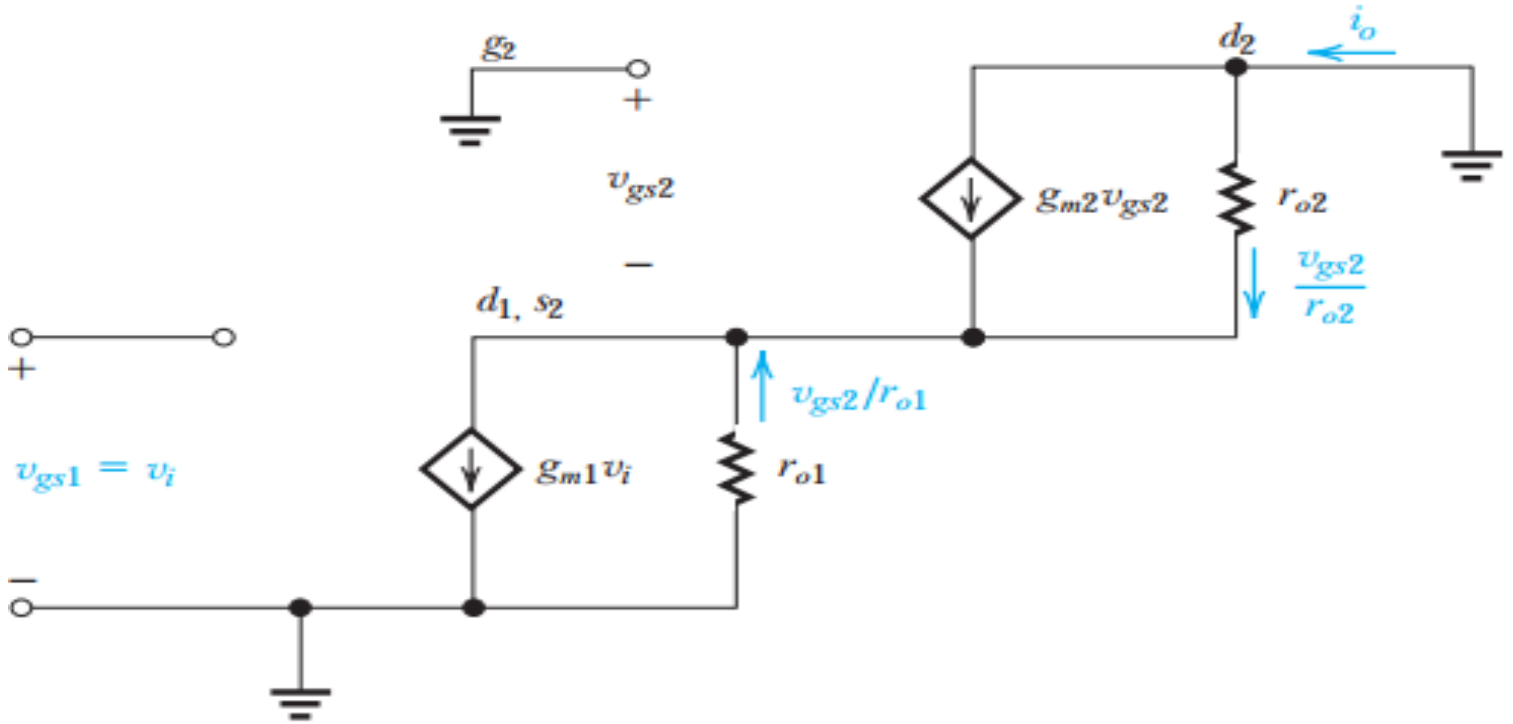
MOS Cascode Amplifier







Source: Microelectronics Circuits, Sedra and Smith, Fifth edition



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

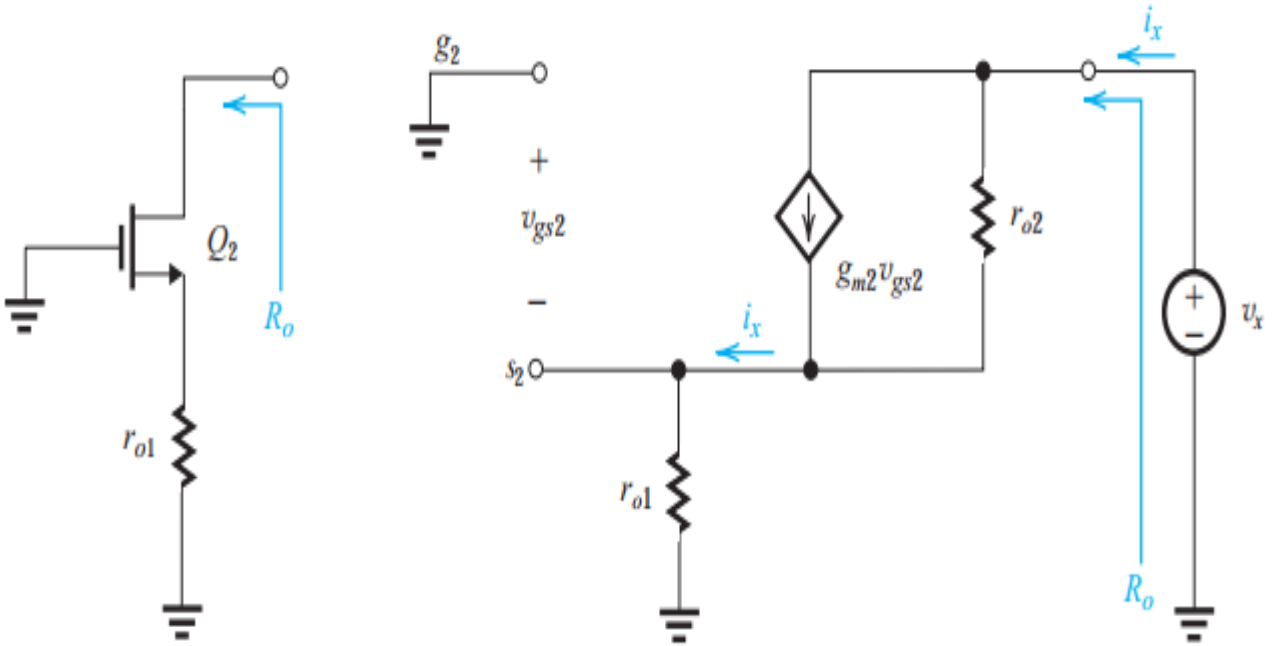
$$G_m = \frac{i_0}{v_i} \qquad g_{m2} v_{gs2} + \frac{v_{gs2}}{r_{01}} + \frac{v_{gs2}}{r_{o2}} = g_{m1} v_i \qquad (g_{m2} + \frac{1}{r_{01}} + \frac{1}{r_{o2}}) v_{gs2} = g_{m1} v_i$$

$$(g_{m2} >> \frac{1}{r_{01}}, \frac{1}{r_{o2}}) \qquad g_{m2} v_{gs2} = g_{m1} v_i \qquad i_0 = g_{m2} v_{gs2} + \frac{v_{gs2}}{r_{02}} \qquad i_0 = (g_{m2} + \frac{1}{r_{02}}) v_{gs2}$$

$$i_0 \cong g_{m2} v_{gs2} \qquad i_0 = g_{m1} v_i \qquad G_m = \frac{i_0}{v_i}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Output resistance of Cascode MOS Amplifier

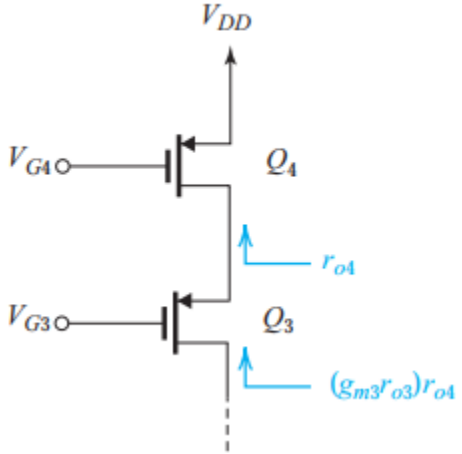


Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

$$R_0 = \frac{v_x}{i_x} \qquad -v_{gs2} = i_x r_{01}$$

$$v_x = (i_x - g_{m2} v_{gs2}) r_{o2} + i_x r_{01} \qquad v_x = i_x (r_{01} + r_{02} + g_{m2} r_{01} r_{02})$$

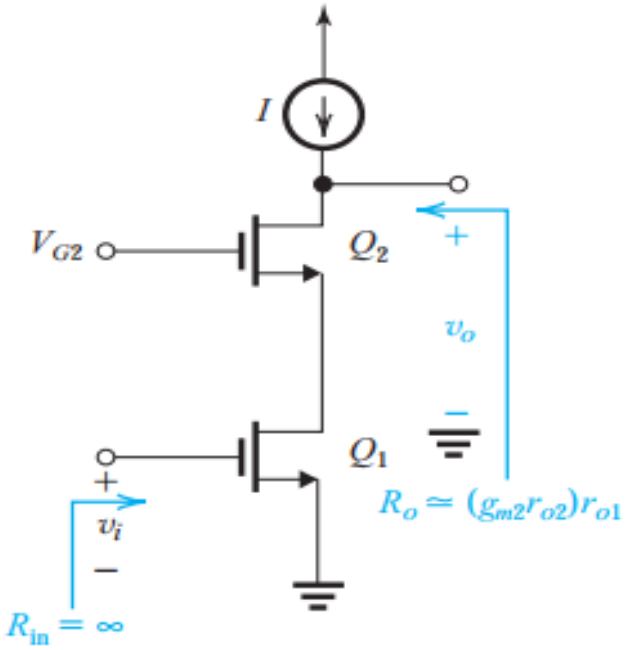
$$R_0 = r_{01} + r_{02} + g_{m2} r_{01} r_{02} \qquad R_0 \approx g_{m2} r_{01} r_{02}$$

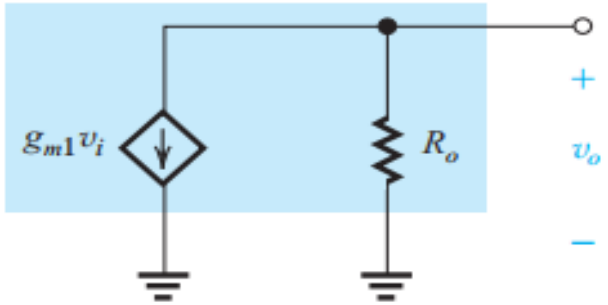


$$R_0 = (g_{m3} r_{03}) r_{04}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Voltage Gain of Cascode Amplifier





Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

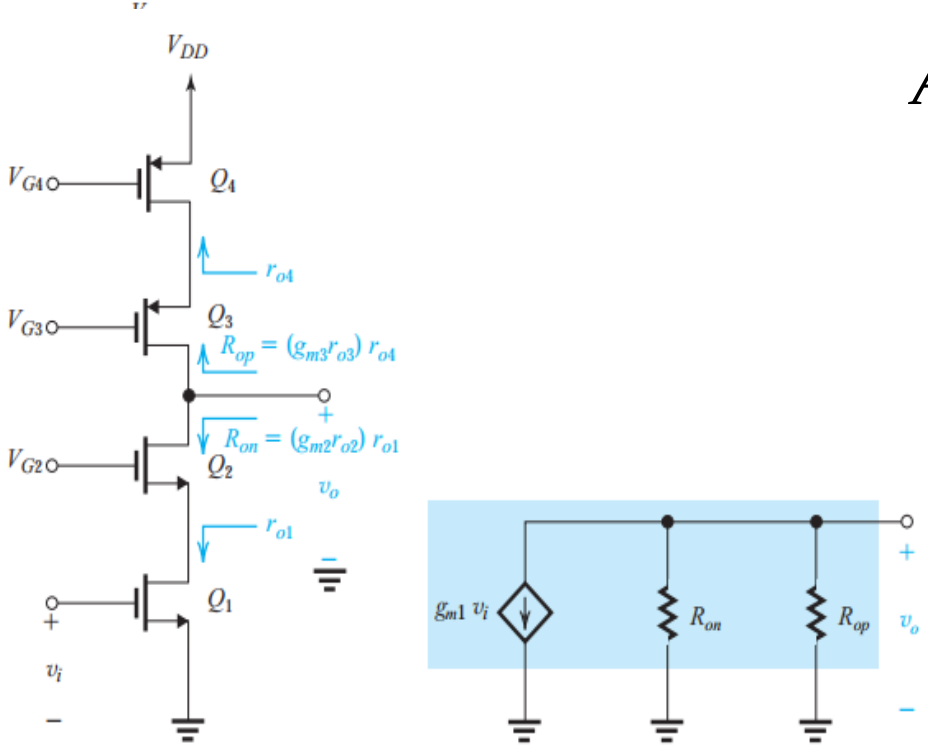
$$A_{vo} = \frac{v_0}{v_i} = -g_{m1} r_0 \qquad A_{vo} = -(g_{m1} r_{01})(g_{m2} r_{02})$$

$$g_m = g_{m1} = g_{m2} \qquad r_o = r_{o1} = r_{o2} \quad A_{vo} = -(g_m r_o)^2$$

$$A_{v0} = -A_0^2$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Cascode amplifier with a Cascode current-source load



$$A_V = -g_{m1}\left\{\left[(g_{m2}r_{02})r_{01}\right] \| \left[(g_{03}r_{03})r_{04}\right]\right\}$$

$$A_V = \frac{v_0}{v_i} = -g_{m1}\left[R_{on} \| R_{op}\right]$$

$$A_V = -\frac{1}{2}\left(g_m r_0\right)^2$$

$$A_V = -\frac{1}{2}A_0^{\ 2}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Recapitulation

- The advantage of this type of circuit is a higher frequency response.
- Higher voltage gain.
- Higher output resistance.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Thank You