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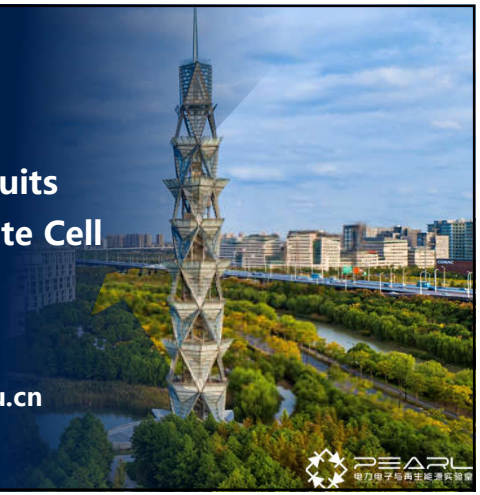
EE115 Analog Circuits
IC AMP: Common Gate Cell



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Outline

- Common-Gate Amplifiers
  - Increase the Gain of Basic Cell
  - Common-Gate Amplifiers as Current Buffers
- Reading: SEDTRA/SMITH book pages 527-539

Review: Basic MOSFET Current Source

- Neglecting channel length modulation

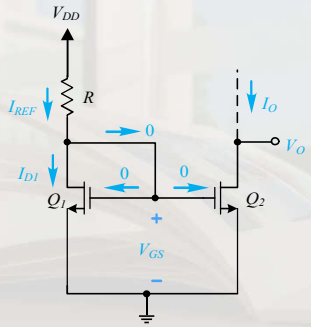


Fig. 8.1

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

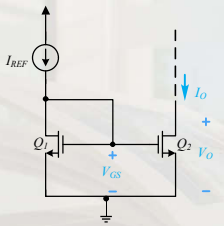
$$I_{D1} = I_{REF} = \frac{V_{DD} - V_{GS}}{R}$$

$$I_o = I_{D2} = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_2 (V_{GS} - V_{tn})^2$$

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

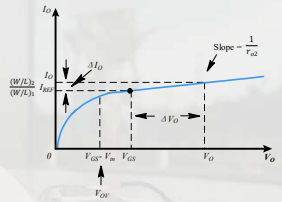
Review: MOS Current Source

- Neglecting channel length modulation



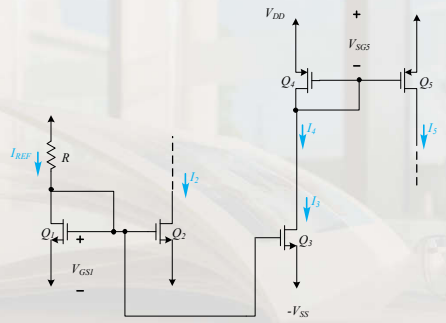
$$\frac{I_o}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1}$$

- Considering channel length modulation



$$I_O = \frac{(W/L)_2}{(W/L)_1} I_{REF}\left(1 + \frac{V_O - V_{GS}}{V_{A2}}\right)$$

Review: MOS Current Steering Circuits



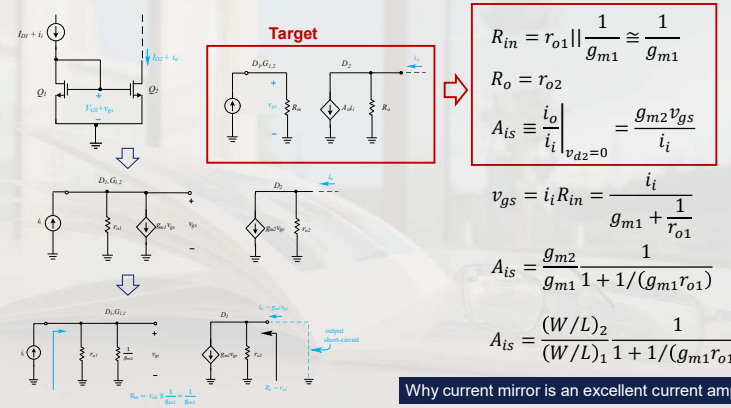
$$I_2 = I_{REF}\frac{(W/L)_2}{(W/L)_1}$$

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

$$I_4 = I_3$$

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

Review: Small-Signal Analysis



$$R_{in} = r_{o1}||\frac{1}{g_{m1}} \cong \frac{1}{g_{m1}}$$

$$R_o = r_{o2}$$

$$A_{is} \equiv \frac{i_o}{i_i}\Big|_{v_{d2}=0} = \frac{g_{m2}v_{gs}}{i_i}$$

$$v_{gs} = i_i R_{in} = \frac{i_i}{g_{m1}+\frac{1}{r_{o1}}}$$

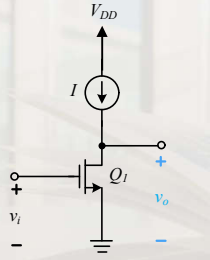
$$A_{is} = \frac{g_{m2}}{g_{m1}}\frac{1}{1+1/(g_{m1}r_{o1})}$$

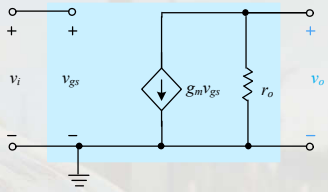
$$A_{is} = \frac{(W/L)_2}{(W/L)_1}\frac{1}{1+1/(g_{m1}r_{o1})}$$

Why current mirror is an excellent current amplifier?

Review: Basic Gain Cells w/ Ideal Current Source Load

Ideal Current Source Load





$$R_{in} = \infty$$

$$A_{vo} = -g_m r_o$$

$$R_o = r_o$$

- Intrinsic gain

$$g_m = \frac{I_D}{V_{OV}/2}$$

$$r_o = \frac{V_A}{I_D} = \frac{V_A' L}{I_D}$$

$$A_o = g_m r_o = \frac{V_A}{V_{OV}/2} = \frac{2V_A' L}{V_{OV}}$$

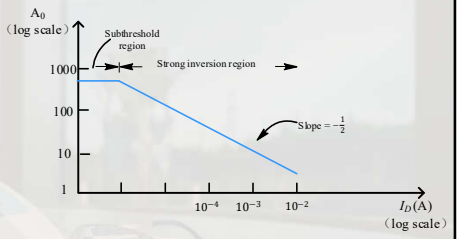
Review: Intrinsic Gain $g_m r_o$

- MOSFET

$$g_m = \sqrt{2\mu_n C_{ox}(W/L)}\sqrt{I_D}$$

$$r_o = \frac{V_A}{I_D} = \frac{V_A' L}{I_D}$$

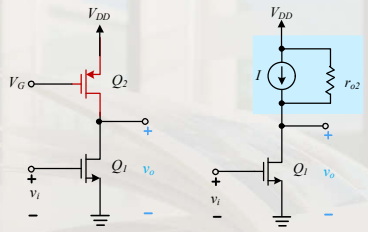
$$A_o = g_m r_o = \frac{V_A'\sqrt{2(\mu_n C_{ox})(WL)}}{\sqrt{I_D}}$$

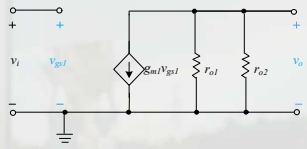


Smaller current gives higher intrinsic gain, but paid by smaller g_m and bandwidth.

Review: Output Resistance of Current Source Load

Current source loaded/active loaded





$$I = \frac{1}{2}(\mu_p C_{ox})\left(\frac{W}{L}\right)_2 [V_{DD} - V_G - |V_{tp}|]^2$$

$$r_{o2} = \frac{|V_{A2}|}{I}$$

$$A_v \equiv \frac{v_o}{v_i} = -g_{m1}(r_{o1}||r_{o2})$$

$$A_v = -\frac{1}{2} g_m r_o$$

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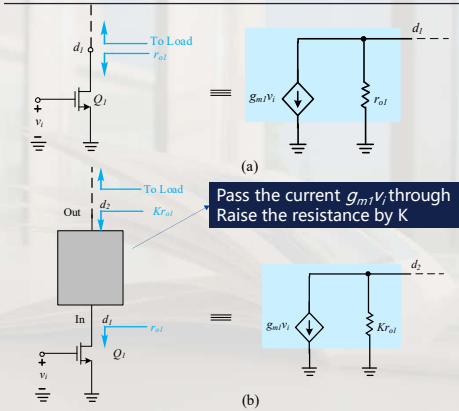
How To Increase Voltage Gain?



Pass the current $g_{m1}v_i$ through
Raise the resistance by K

- **Current buffer:** passes current **but** raises resistance level
  - Low **input resistance**
  - Unity **current gain**
  - High **output resistance**

CG, CS, CD, which circuit has the best current buffer performance?

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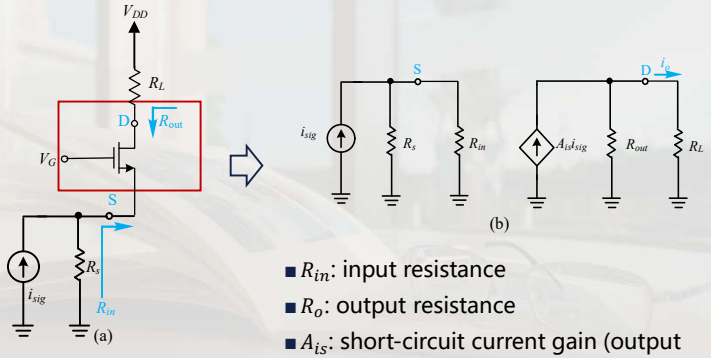
Common Gate Amplifier



- R_{in}: input resistance
- R_o: output resistance
- A_{is}: short-circuit current gain (output grounded)

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Input Resistance of CG Amplifier

$$R_{in} \equiv \frac{v_x}{i_x}$$

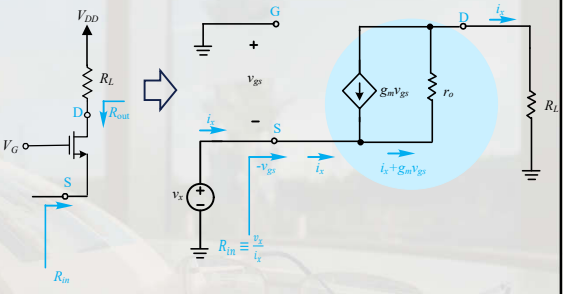
According to KVL & KCL

$$v_x = (i_x + g_m v_{gs})r_o + i_x R_L$$
$$= (i_x - g_m v_x)r_o + i_x R_L$$

$$R_{in} = \frac{r_o + R_L}{g_m r_o + 1}$$

For $g_m r_o \gg 1$

$$R_{in} \cong \frac{1}{g_m} + \frac{R_L}{g_m r_o}$$



Low R_{in}: load impedance is transformed to the input by dividing by the intrinsic gain.

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Short-Circuit Current Gain of CG Amplifier

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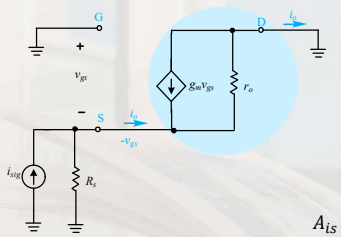

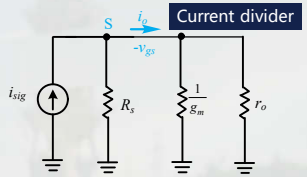

$$A_{is} \equiv \frac{i_o}{i_{sig}} = \frac{g_m + \frac{1}{r_o}}{g_m + \frac{1}{r_o} + \frac{1}{R_s}} = \frac{1 + \frac{1}{g_m r_o}}{1 + \frac{1}{g_m r_o} + \frac{1}{g_m R_s}}$$

For $g_m r_o \gg 1$ and $g_m R_s \gg 1$

$A_{is} \cong 1$

Unity current gain

Output Resistance of CG Amplifier

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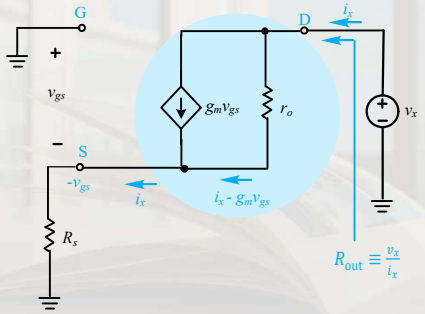

According to KVL & KCL

$$v_x = (i_x - g_m v_{gs}) r_o + i_x R_s$$

$$v_{gs} = -i_x R_s$$

$$R_{out} \equiv \frac{v_x}{i_x} = r_o + R_s + g_m r_o R_s$$

$$= r_o + (1 + g_m r_o) R_s$$

For $g_m r_o \gg 1$

$R_{out} \cong (g_m r_o) R_s$

High R_{out}: source impedance is transformed to the output by multiplying intrinsic gain.

Impedance Transformation of CG Amplifier

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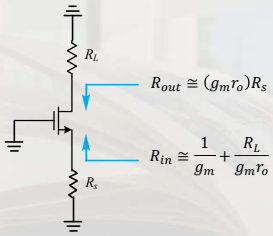
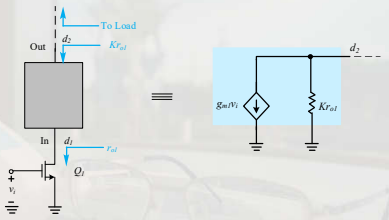
- R_S transformed to the output by multiplying by the intrinsic gain.
- R_L transformed to the input by dividing by the intrinsic gain.





CG Amplifier is an ideal current buffer load to boost voltage gain!