Analysis and Design of Analog Integrated Circuits
Lecture 5

Single Stage Amplifiers

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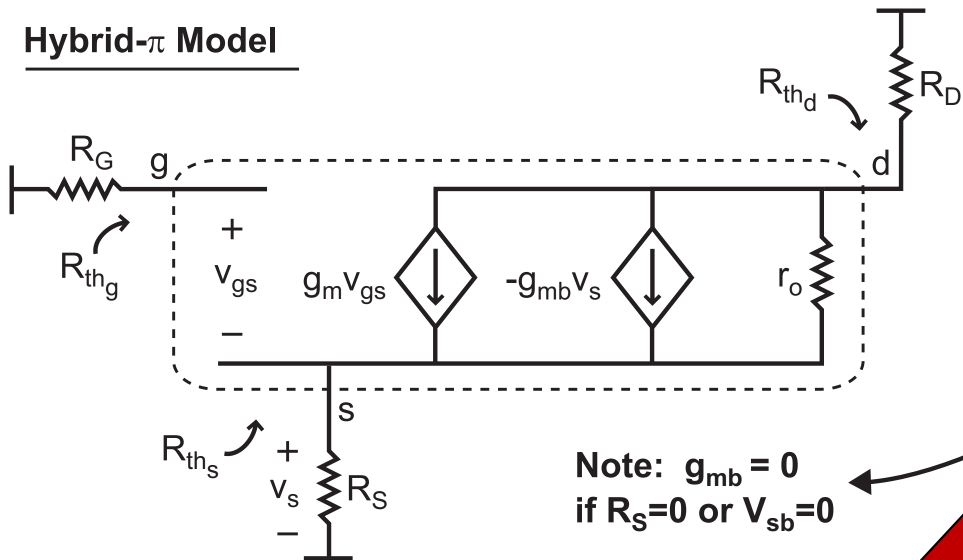
From Lecture 4: Proposed Thevenin Model for Transistor

Hybrid-π Model

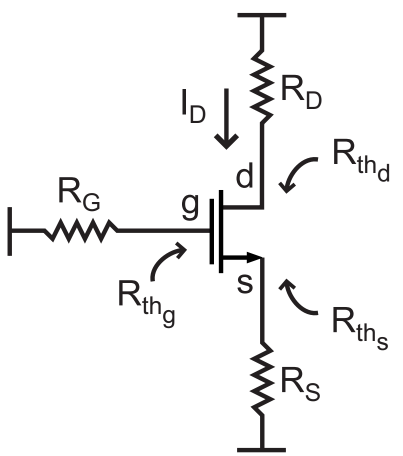


Note: $g_{mb} = 0$ if R_S=0 or V_{sb}=0

Key Small-Signal Parameters

Parameter	Strong Inversion	Weak Inversion
g_m	$\sqrt{2\mu_n C_{ox}(W/L)I_D}$	$\frac{qI_D}{nkT}$
g_{mb}	$\frac{\gamma g_m}{2\sqrt{2\lvert\Phi_F\rvert + V_{SB}}}$	$\frac{(n-1)qI_D}{nkT}$
r_o	$\frac{1}{\lambda I_D}$	$\frac{1}{\lambda I_D}$

Thevenin Resistances



Exact

$R_{th_d} = r_o(1+(g_m+g_{mb})R_S)+R_S$

R_{th_g} = infinite

$R_{th_s} = (1+R_D/r_o)\left(r_o \,\Big\|\, \frac{1}{g_m+g_{mb}}\right)$

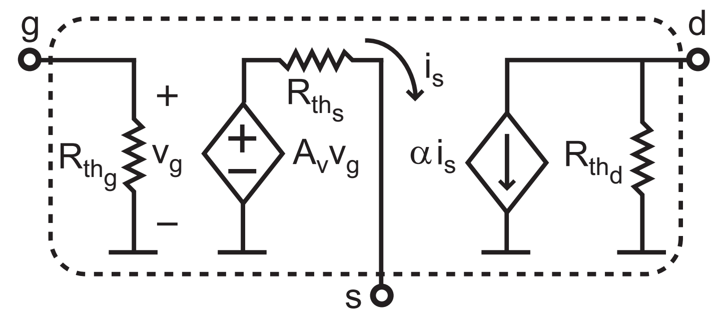
Approximation
($g_{mb} << g_m$, $g_m r_o >> 1$)

$R_{th_d} = r_o(1+g_m R_S)$

R_{th_g} = infinite

$R_{th_s} = \frac{1 + R_D/r_o}{g_m} \approx \frac{1}{g_m}$ **($R_D << r_o$)**

Proposed Small Signal Transistor Model



Exact

$A_v = g_m r_o \,\Big\|\, \frac{g_m}{g_m+g_{mb}}$

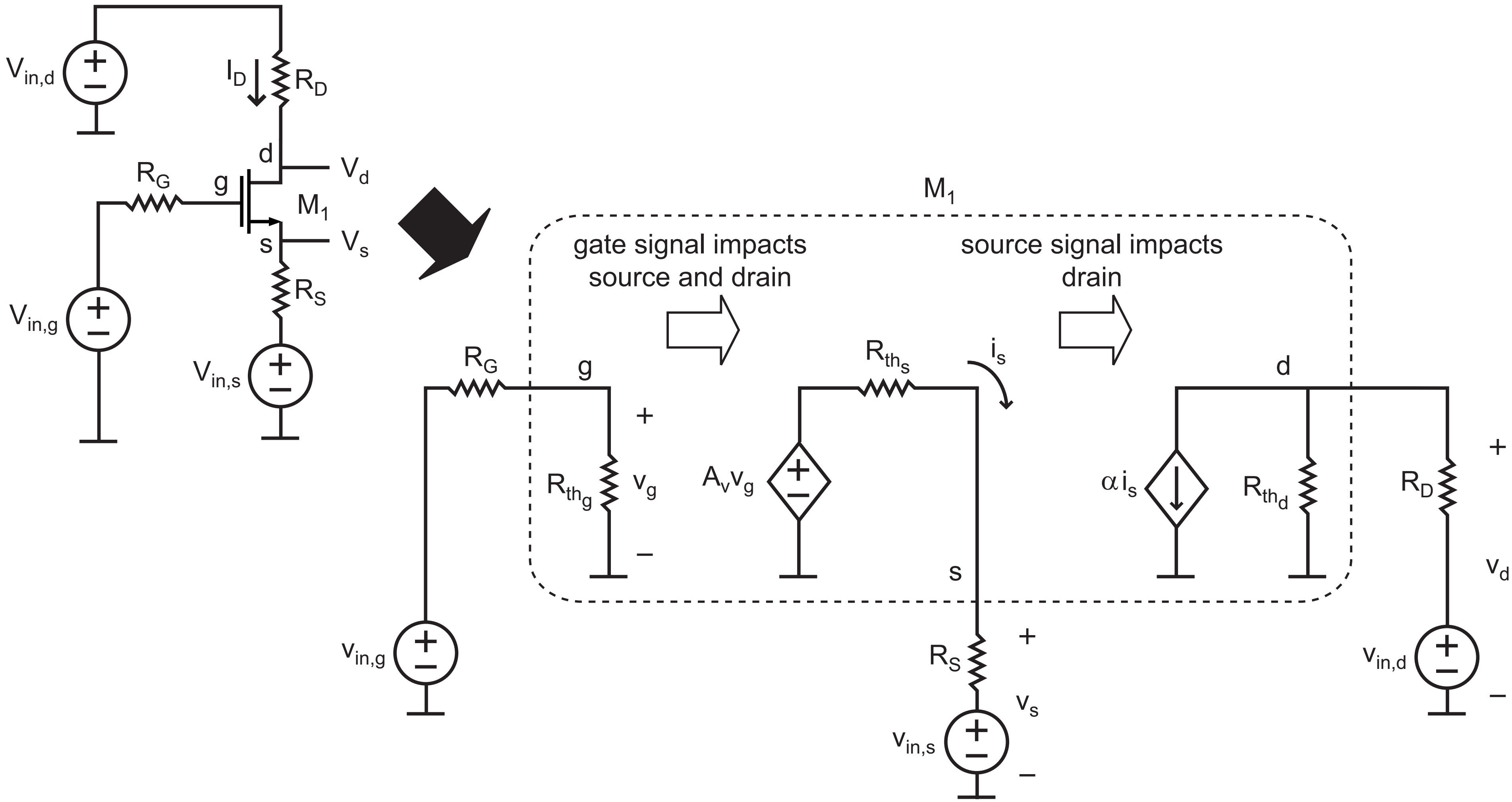
$\alpha = 1+R_D/R_{th_d}$

Approximation

$A_v = 1$ **($g_{mb}<<g_m$, $g_m r_o>>1$)**

$\alpha = 1$ **($R_D<<R_{th_d}$)**

A General View of Signal Flow in an Open Loop Device



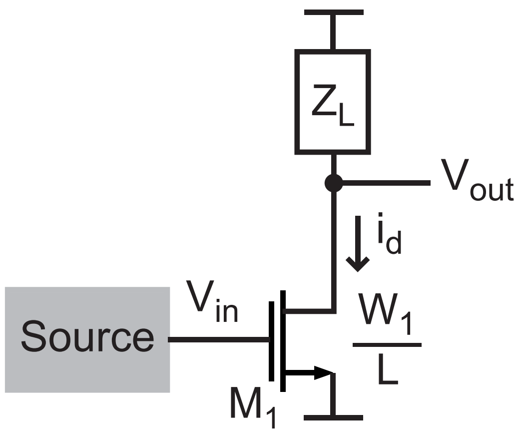
- **To first order, influence of signals go from gate to source or from gate and/or source to drain**
  - **This is only true when the device is in saturation**

Why is a CMOS Transistor Useful?

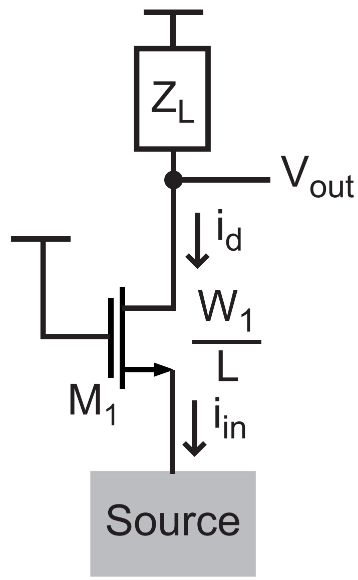
- **Key properties of a transistor:**
  - **Converts voltage to current**
  - **Funnels current between different impedance domains**
- **The above properties allow us to build amplifiers in creative ways**
  - **A number of circuit topologies are possible**
  - **A good designer can leverage the right topology to achieve the best performance for a given application**

Basic Single-Stage CMOS Amplifiers

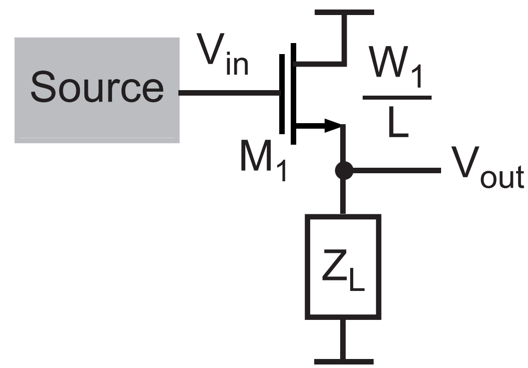
Common Source



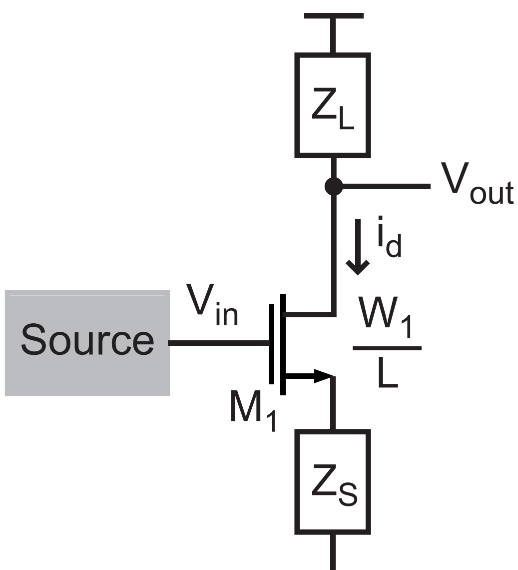
Common Gate

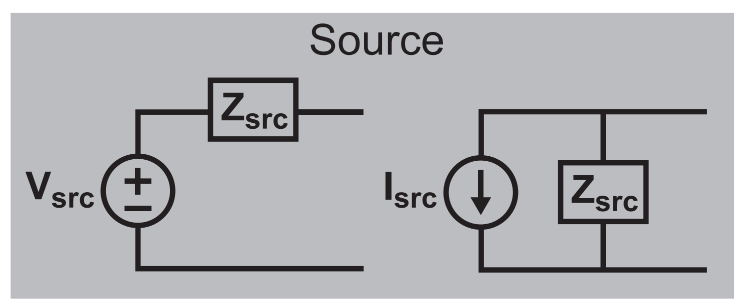


Source Follower

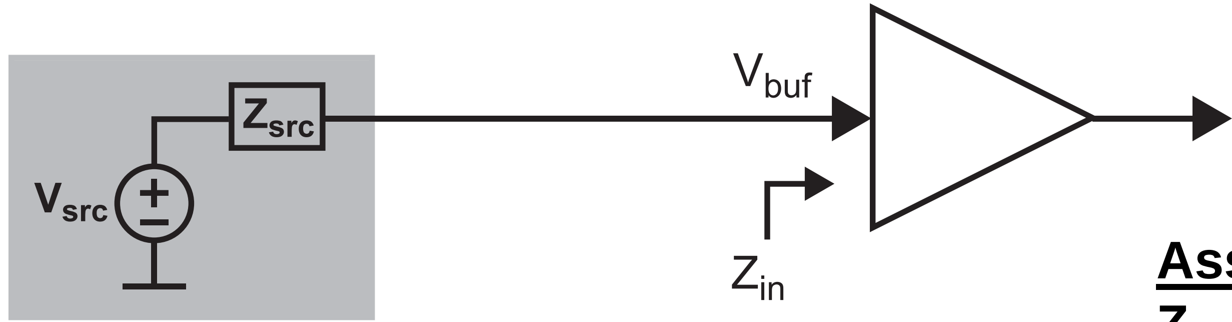


Common Source with Source Degeneration





Example: The Impact of Low Input Impedance

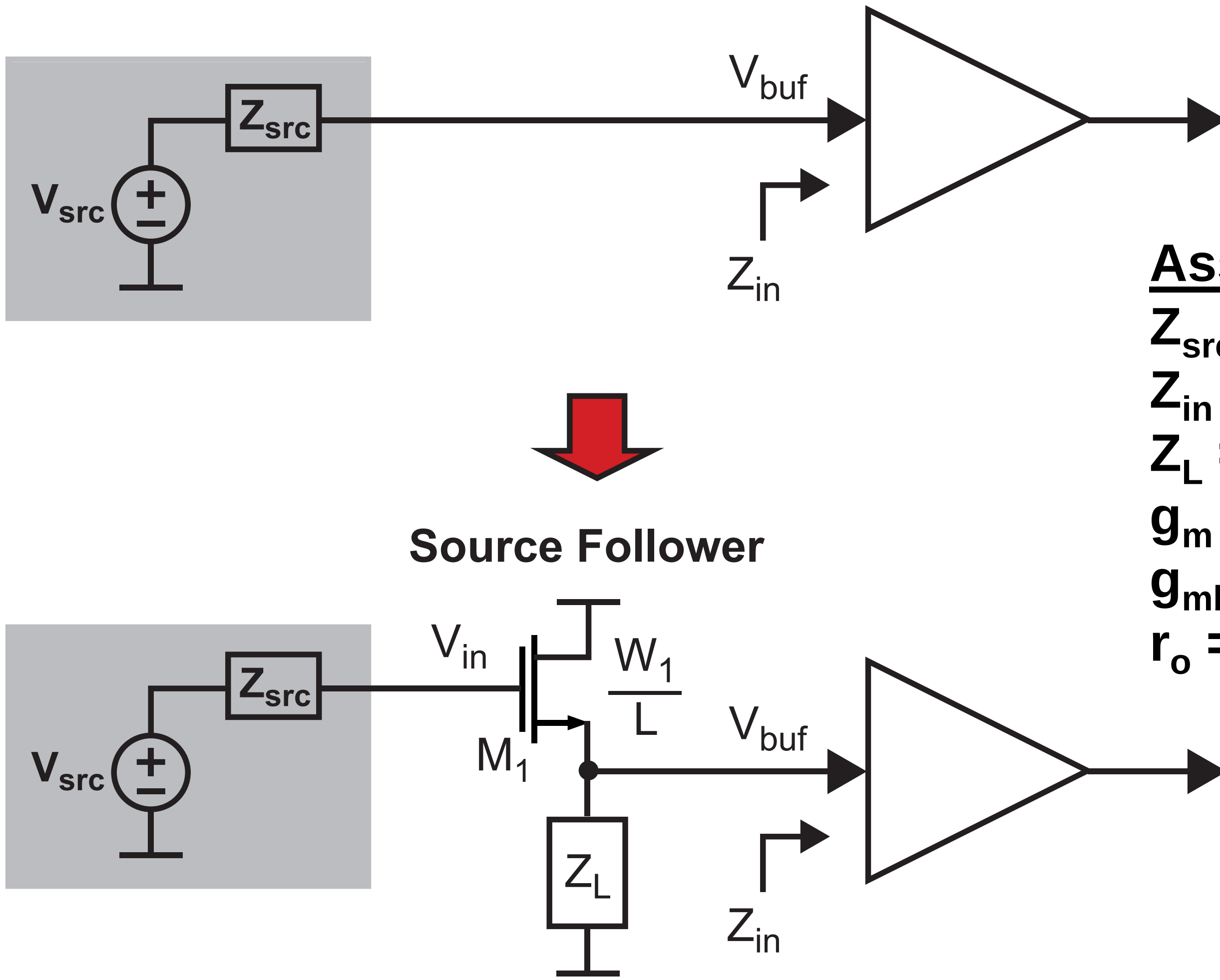


Assume:
$Z_{src} = 10k\Omega$
$Z_{in} = 100\Omega$

- **Here we consider how the gain is influenced by having a source with large impedance driving a circuit with low input impedance**
  - **Calculate the gain from V_{src} to V_{buf}**
  - **What is the impact of low Z_{in} and high Z_{src}?**

What type of amplifier stage would alleviate the impact of having high source impedance and low input impedance?

Consider a Source Follower Circuit



Assume:
Z_{src} = 10kΩ
Z_{in} = 100Ω
Z_L = 10kΩ
g_m = 1/(100Ω)
g_{mb} = 0
r_o = 100kΩ

- Calculate the gain from V_{src} to V_{buf}
- How did the source follower improve the situation?

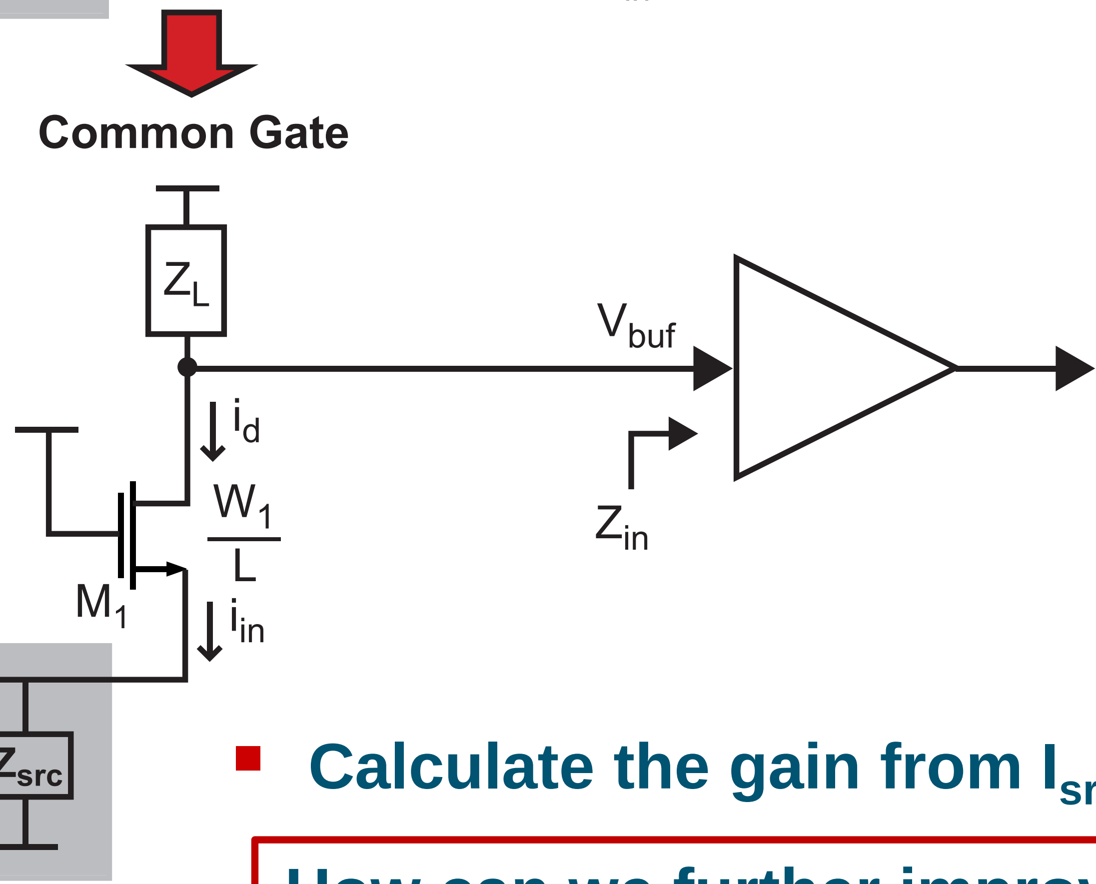
Example: The Impact of Low Source Impedance

<u>Assume:</u>
$Z_{src} = 100\Omega$
$Z_{in} = 1k\Omega$

- **Calculate the gain from I_{src} to V_{buf}**
- **What is the impact of low Z_{src}?**

What type of amplifier stage would alleviate the impact of having low source impedance?

Consider a Common Gate Amplifier



Assume:

$Z_{src} = 100\Omega$

$Z_{in} = 1k\Omega$

$Z_L = 10k\Omega$

$g_m = 1/(100\Omega)$

$g_{mb} = 0$

$r_o = 100k\Omega$

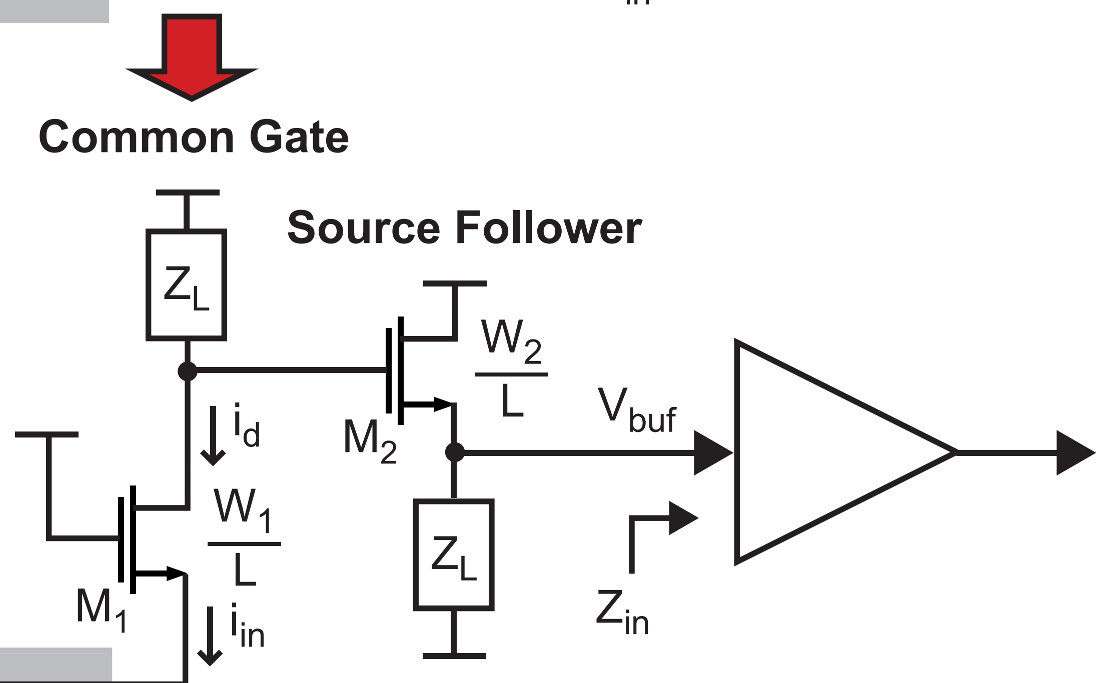
- Calculate the gain from I_{src} to V_{buf}

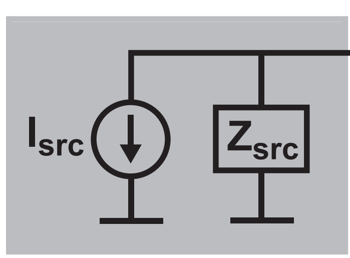
How can we further improve gain?

Add a Source Follower

<u>Assume:</u>

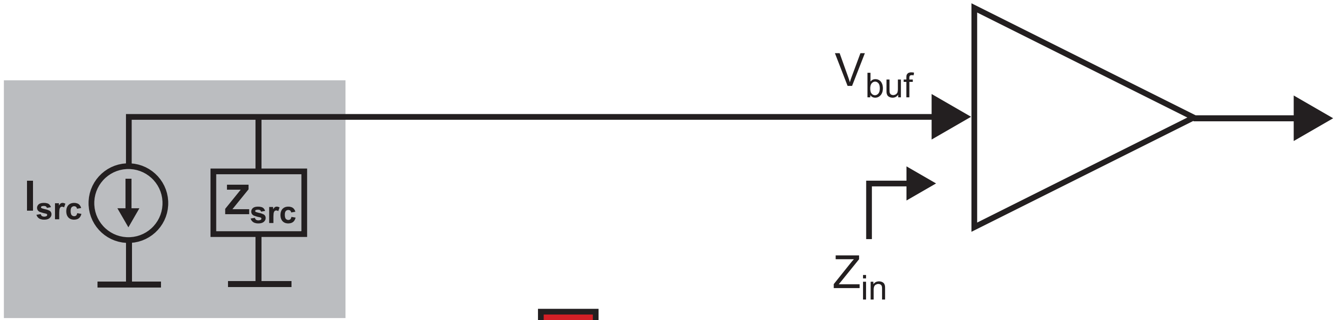
Z_{src} = 100Ω
Z_{in} = 1kΩ
Z_L = 10kΩ
g_m = 1/(100Ω)
g_{mb} = 0
r_o = 100kΩ

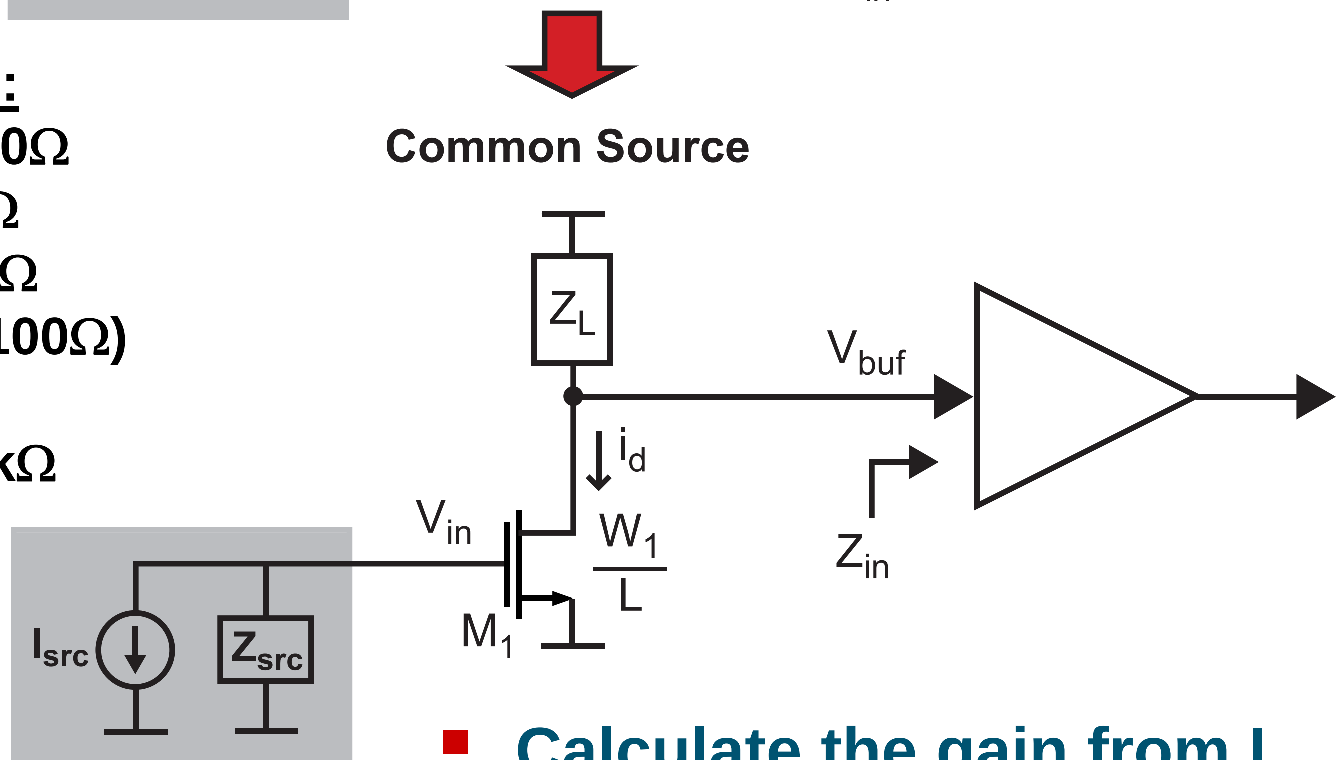




- **Calculate the gain from I_{src} to V_{buf}**
- **Did the source follower help?**

Consider Using a Common Source Amplifier Instead





Assume:

$Z_{src} = 100\Omega$
$Z_{in} = 1k\Omega$
$Z_L = 10k\Omega$
$g_m = 1/(100\Omega)$
$g_{mb} = 0$
$r_o = 100k\Omega$

- **Calculate the gain from I_{src} to V_{buf}**

How does the common gate approach compare to this?