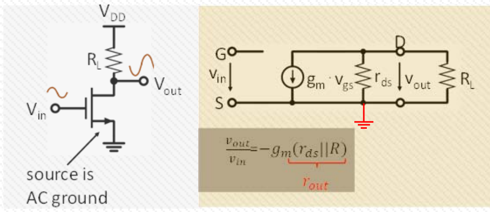
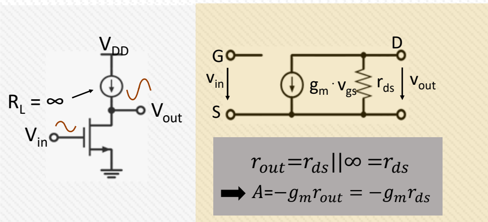
Basic Analog Blocks and Amplifiers

Common Source Amplifier



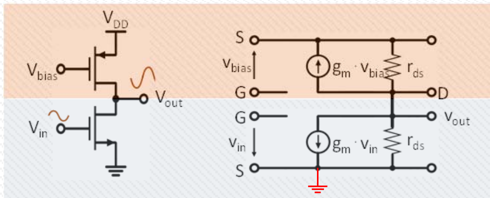
Generally we can write for an amplifier: $A = -g_m r_{out}$

Better Common Source Amplifier



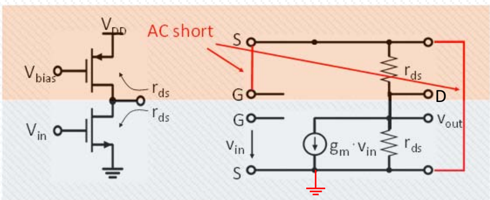
How to implement the current source load?

Better Common Source Amplifier



The PMOS load implements a current source with $r_{out} = r_{ds}$

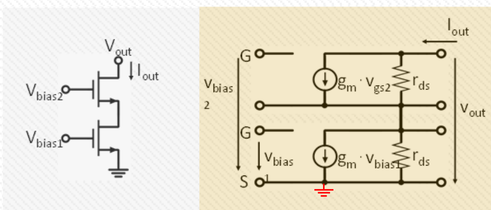
Better Common Source Amplifier



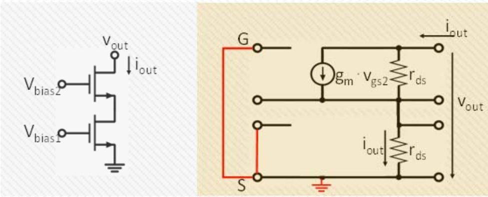
$A = -g_m r_{out} = g_m \frac{r_{ds}}{2}$

Can we still increase the gain?

Cascode Load



Cascode Load

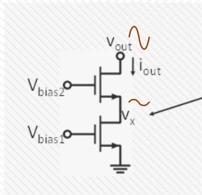


v_{gs2}=-$i_{out}r_{ds}$

➡ $v_{out} = (i_{out} + g_m i_{out} r_{ds}) \cdot r_{ds} + i_{out} r_{ds}$

➡ $r_{out} = \frac{v_{out}}{i_{out}} = (1 + g_m r_{ds}) \cdot r_{ds} + r_{ds} \approx g_m r_{ds}^2$

Intution on Cascode Load



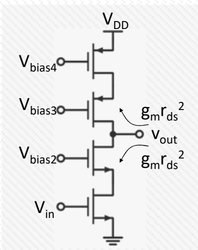
Swing is reduced by gain of upper MOS:

$v_x = \frac{v_{out}}{g_{m2} r_{ds2}}$

➡ output current reduced significantly:

$i_{out} = \frac{v_x}{r_{ds1}} = \frac{v_{out}}{g_m r_{ds2} \cdot r_{ds1}}$

Cascode Amplifier

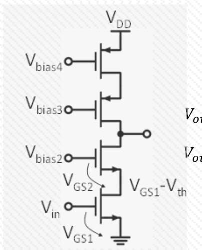


$$r_{out} = g_m \frac{r_{ds}^{2}}{2}$$

$$A = -g_m r_{out} = -\frac{(g_m r_{ds})^2}{2}$$

We squared the gain at the penalty of output swing.

Cascode Amplifier Output Swing

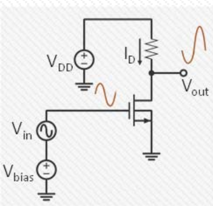


$$V_{out} < V_{DD} - V_{SG4} + V_{th} - V_{SG3} + V_{th} = V_{DD} - V_{ov4} - V_{ov3}$$

$$V_{out} > V_{GS1} - V_{th} + V_{GS2} - V_{th} = V_{ov1} + V_{ov2}$$

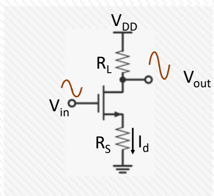
$$V_{swing} = V_{DD} - V_{ov4} - V_{ov3} - V_{ov1} - V_{ov2} = V_{DD} - 4 \cdot V_{ov}$$

Source Degeneration



Remember: CM Source amplifier is very nonlinear for large signals.

Source Degeneration



$$i_d = g_m(v_{in} - i_d R_S)$$

$$g_{meff} = \frac{i_d}{v_{in}} = \frac{g_m}{1 + g_m R_S}$$

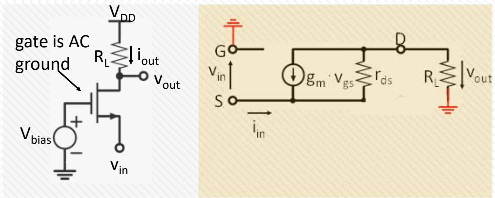
$$A = -g_{meff} R_L = -\frac{g_m R_L}{1 + g_m R_S}$$

Remember: CM Source amplifier is very nonlinear for large signals.

➡ Use **local** feedback to improve linearity.

$V_{in}\uparrow \rightarrow I_d\uparrow \rightarrow I_d R_S\uparrow \rightarrow V_{gs}\downarrow \rightarrow I_d\downarrow$

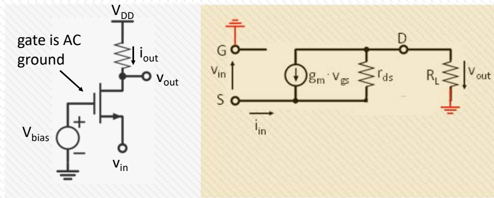
Common Gate Amplifier



Kirchhoff's current law (KCL): $\frac{v_{out}}{R_L} = g_m v_{in} - \frac{v_{out} - v_{in}}{r_{ds}}$

➡ $\frac{v_{out}}{v_{in}} = \frac{g_m r_{ds} + 1}{r_{ds} + R_L} \cdot R_L \approx g_m R_L$ expected from intuition

Common Gate Amplifier

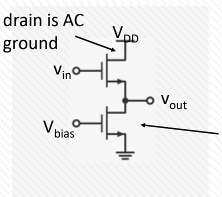


$i_{in} = \frac{v_{out}}{R_L} = v_{in} \cdot \frac{g_m r_{ds}+1}{r_{ds}+R_L} \approx v_{in}\, g_m$ ➡ $r_{in} = \frac{v_{in}}{i_{in}} = \frac{1}{g_m}$

➡ low input impedance (current input)

➡ often used as current to voltage (transimpedance) amplifier

Common Drain Amplifier



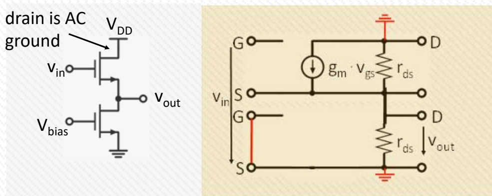
Load current is fixed by NMOS current source

$v_{in}\uparrow \rightarrow v_{out}\uparrow$

The output needs to follow the source in order to keep the current constant

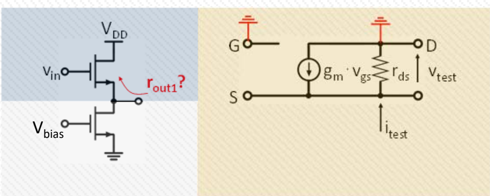
➡ often referred to as **source follower**

Common Drain Amplifier



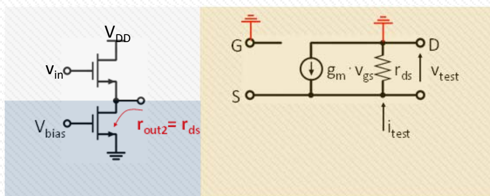
KCL: $\frac{v_{out}}{r_{ds}} = g_m(v_{in} - v_{out}) - \frac{v_{out}}{r_{ds}}$ ➡ $\frac{v_{out}}{v_{in}} = \frac{g_m}{\frac{2}{r_{ds}} + g_m} \approx 1$

Common Drain Amplifier



KCL: $i_{test} = \frac{v_{test}}{r_{ds}} + g_m v_{test}$ ➡ $r_{out1} = \frac{v_{test}}{i_{test}} = \frac{1}{\frac{1}{r_{ds}} + g_m} \approx \frac{1}{g_m}$

Common Drain Amplifier

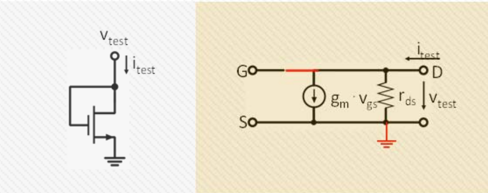


Total output resistance: $r_{out} = r_{out1} || \, r_{out2} \approx \frac{1}{g_m}$

➡ low output impedance ➡ high current gain

➡ often used as output buffer

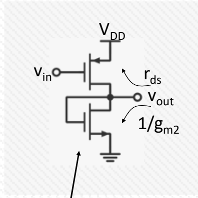
Diode Connection



KCL: $i_{test} = \frac{v_{test}}{r_{ds}} + g_m v_{test}$ ➡ $r_{out1} = \frac{v_{test}}{i_{test}} = \frac{1}{\frac{1}{r_{ds}} + g_m} \approx \boxed{\frac{1}{g_m}}$

Called diode connection, because I(V) looks like a diode characteristic.

Low Gain Amplifier



self biased load

$$r_{out} = r_{out1} || r_{out2} \approx \frac{1}{g_{m2}}$$

$$A = g_{m1} r_{out} \approx \frac{g_{m1}}{g_{m2}}$$

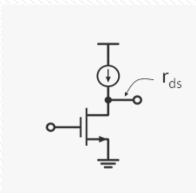
Recall

$A = g_m \cdot r_{out}$

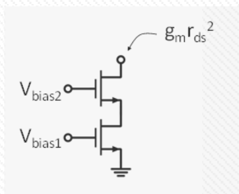
Recall

Topology	Gain	Rout	Rin
CM source	high	high	high
CM gate	high	high	low
CM drain	low	low	high

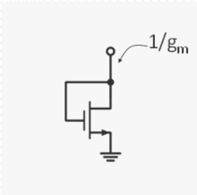
Recall



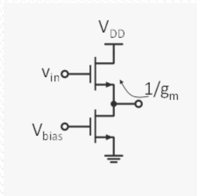
Recall



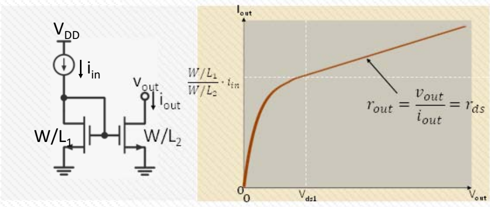
Recall



Recall



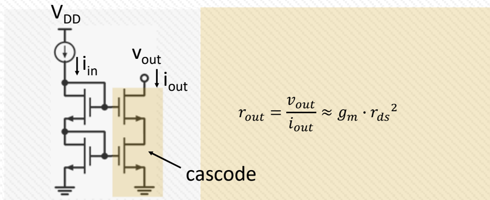
Basic Current Mirror



For an ideal current mirror the output current is independent of V_{out}.

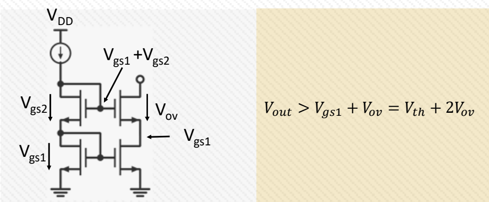
➡ large r_{out} desired

Cascode Current Mirror



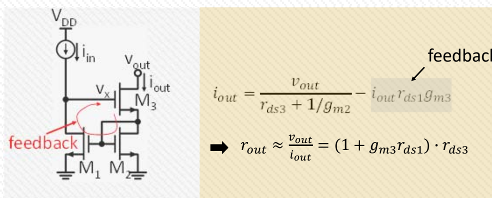
Increased output resistance due to cascoding.

Cascode Current Mirror



Reduced swing compared to basic current mirror.

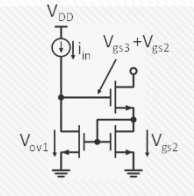
Wilson Current Mirror



Output resistance increased via feedback loop:

$V_{out}\uparrow$ ➡ $I_{out}\uparrow$ ➡ $v_x\downarrow$ ➡ $i_{out}\downarrow$

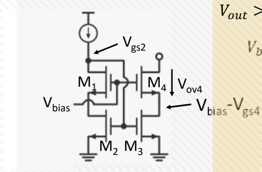
Wilson Current Mirror



$V_{out} > V_{gs2} + V_{ov3} = V_{th} + 2V_{ov}$

How to increase the output swing?

High Swing Cascode Current Mirror



$V_{out} > V_{bias} - V_{gs4} + V_{ov4} = V_{bias} - V_{th}$

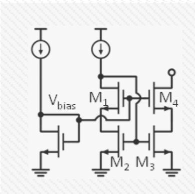
$V_{bias} > V_{gs1} + V_{ov2}$

➡ $V_{out} > V_{ov1} + V_{ov2} = 2V_{ov}$

Output swing increased by V_{th}.

How to generate V_{bias}?

High Swing Cascode Current Mirror



$V_{bias} > V_{ov2} + V_{gs1}$

Use long (L > W) diode connected transistor to generate V_{bias}.

Recall

Current Mirror	Rout	Swing
Basic	-	++
Cascode	+	-
Wilson	+	-
High Swing	+	+