

EE105 – Fall 2015 Microelectronic Devices and Circuits

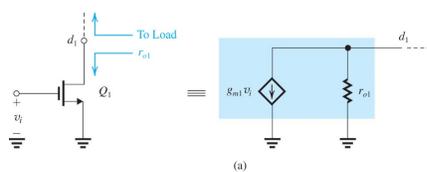
Prof. Ming C. Wu
wu@eecs.berkeley.edu
511 Sutardja Dai Hall (SDH)



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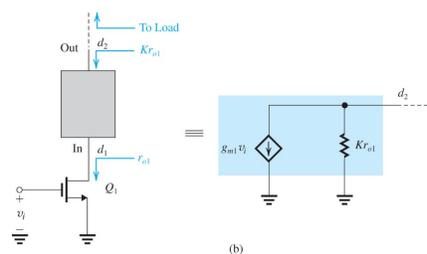
How To Increase Voltage Gain?



Open-circuit voltage gain

$$|A_{vo}| = g_{m1} r_{o1}$$

limited by r_{o1}



If we can boost up r_{o1} by a factor of K

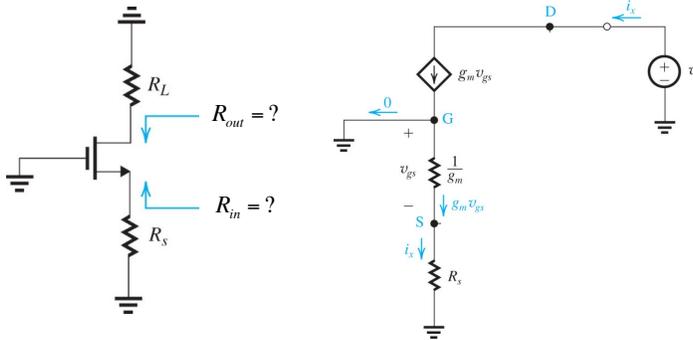
$$|A_{vo}| = g_{m1} K r_{o1}$$



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Common Gate Amplifier is an Impedance Transformer



Using T-model
 If we don't consider r_o :
 $i_x = 0$ since G is grounded
 $R_{out} = \frac{v_x}{i_x} = \infty$

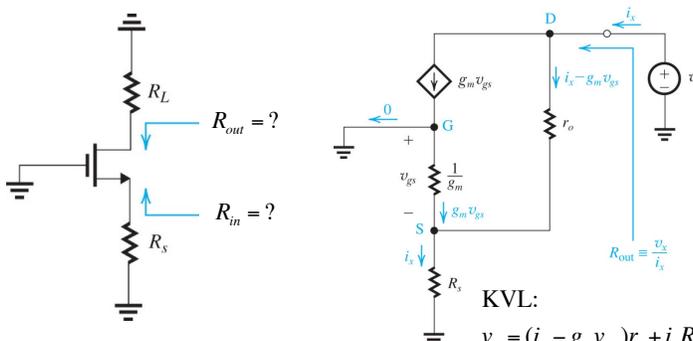
To find R_{out}
 we have to include r_o



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Common Gate Amplifier is an Impedance Transformer



KVL:

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

$$v_{gs} = 0 - v_s = -i_x R_s$$

$$v_x = (i_x + g_m i_x R_s)r_o + i_x R_s$$

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

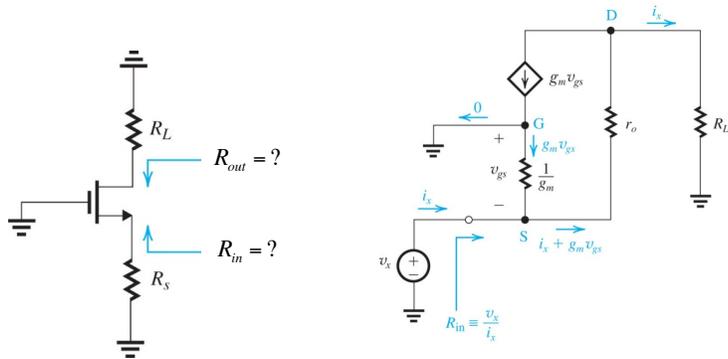
$$= r_o + (1 + g_m r_o)R_s \approx r_o + (g_m r_o)R_s$$



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Common Gate Amplifier is an Impedance Transformer



$$\text{KVL: } v_x = (i_x + g_m v_{gs})r_o + i_x R_L$$

$$v_{gs} = 0 - v_s = -v_x$$

$$(1 + g_m r_o)v_x = (r_o + R_L)i_x$$

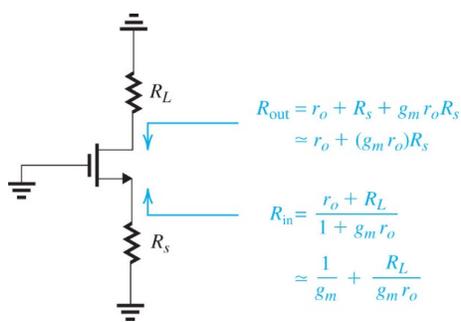
$$R_{in} = \frac{v_x}{i_x} = \frac{r_o + R_L}{1 + g_m r_o} \approx \frac{r_o + R_L}{g_m r_o} = \frac{1}{g_m} + \frac{R_L}{g_m r_o}$$



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Impedance Transformation of Common Gate Amplifier



$$R_{out} = r_o + R_s + g_m r_o R_s$$

$$\approx r_o + (g_m r_o)R_s$$

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

$$\approx \frac{1}{g_m} + \frac{R_L}{g_m r_o}$$

Impedance transformation:

Look into Drain : R_s amplified by $(g_m r_o)$

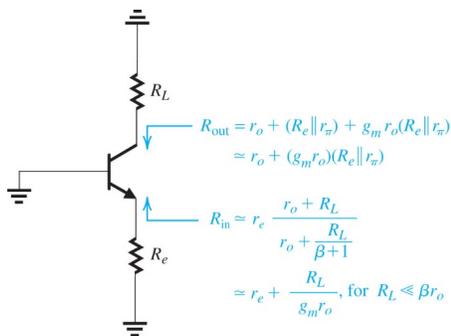
Look into Source : R_L reduced by $(g_m r_o)$



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Impedance Transformation of Common Base Amplifier



Similar impedance transformation in Common-Base BJT:

Look into Collector: $R_e \parallel r_\pi$ amplified by $(g_m r_o)$

Look into Source: R_L reduced by $(g_m r_o)$

Note R_s in MOS is replaced by $R_e \parallel r_\pi$ in BJT

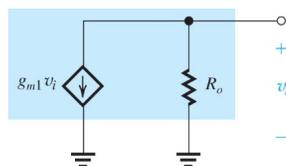
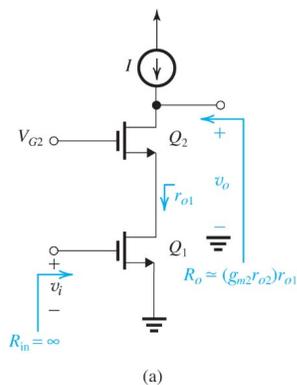
Note: for $\beta = \infty$, these formulas reduce to those for the MOSFET



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MOS Cascode Amplifier



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

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

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

Voltage gain is much higher than single-stage common source (CS) amplifier.

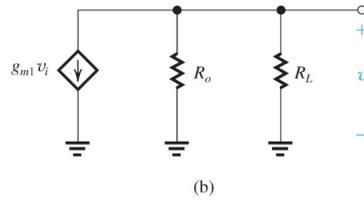
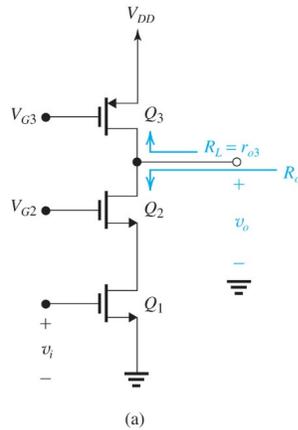
The gain of cascode is almost the square of that of CS



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Cascode Amplifier with Simple Active Load



$$A_v = -g_{m1}(R_o \parallel R_L)$$

$$R_o \approx (g_{m2}r_{o2})r_{o1}$$

$$R_L = r_{o3} \ll R_o$$

$$A_v \approx -g_{m1}r_{o3}$$

Similar gain as CS amplifier.

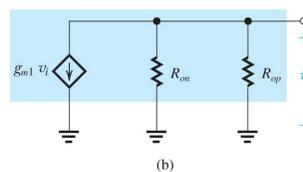
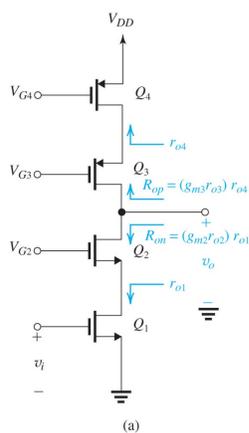
No gain boosting.



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Cascode Amplifier with Cascode Current-Source Load



$$A_v = -g_{m1}(R_{on} \parallel R_{op})$$

$$R_{on} \approx (g_{m2}r_{o2})r_{o1}$$

$$R_{op} \approx (g_{m3}r_{o3})r_{o4}$$

If all transistors are similar :

$$A_v \approx -\frac{1}{2}(g_m r_o)^2$$

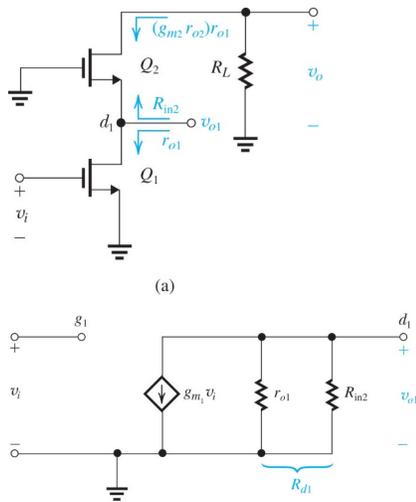
--> High gain !



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Think of Cascode as Multistage Amplifier with CS followed by CG



First stage: common source

$$A_{v1} = -g_{m1}(r_{o1} \parallel R_{in2})$$

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

Second stage: common gate

$$A_{v2} = g_{m2}r_{o2}$$

$$A_v = A_{v1}A_{v2}$$

For ideal current source load $R_L = \infty$

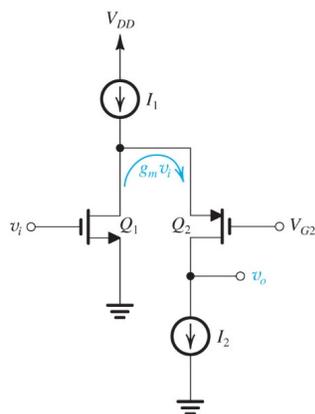
$$A_{vo} = (-g_{m1}r_{o1})(g_{m2}r_{o2})$$



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Folded Cascode



"Folding" the CG stage using PMOS.

Q_1 is biased with $I_1 - I_2$

Q_2 is biased with I_2

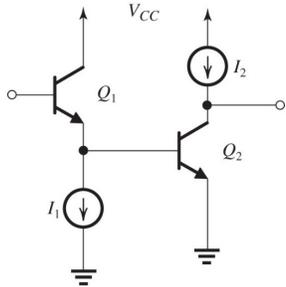
Folded cascode avoids stacking too many transistors vertically, which will be difficult for low power supply voltage V_{DD}



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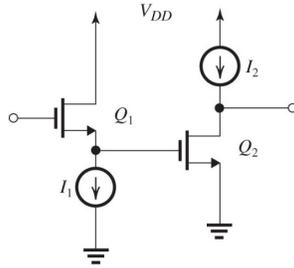


Useful Transistor Pairings



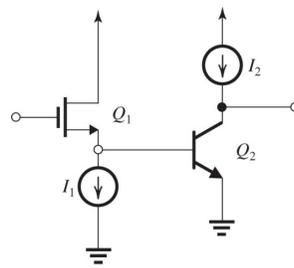
CC + CE

- High input resistance
- Much wider bandwidth than single CE amplifier (To be discussed later)



CD + CS

- Main benefit is wider bandwidth than single CE amplifier



CD + CE

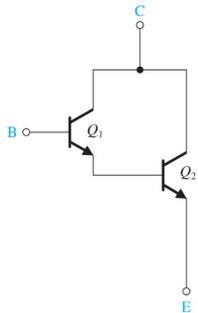
- in BiCMOS technology (BJT+CMOS)
- Similar to MOS version but use BJT for higher g_m



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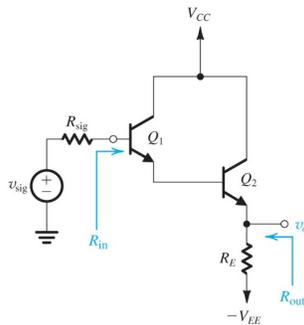


Darlington Pair



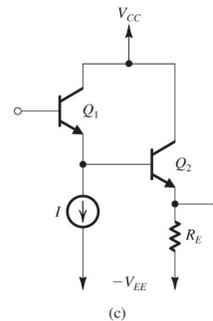
Darlington pair:

- Composite BJT with $\beta = \beta_1\beta_2$



- CC+CC: high performance source follower

$$R_{in} = r_{\pi 1} + (\beta_1 + 1)[r_{\pi 2} + (\beta_2 + 1)R_E]$$



- CC+CC: high performance source follower with separate current bias for Q1 \rightarrow high β_1



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