



Fundamentals of Microelectronics II

فصل ۹- طبقه کاسکود و آیینه های جریان

(قسمت اول - طبقه کاسکود)

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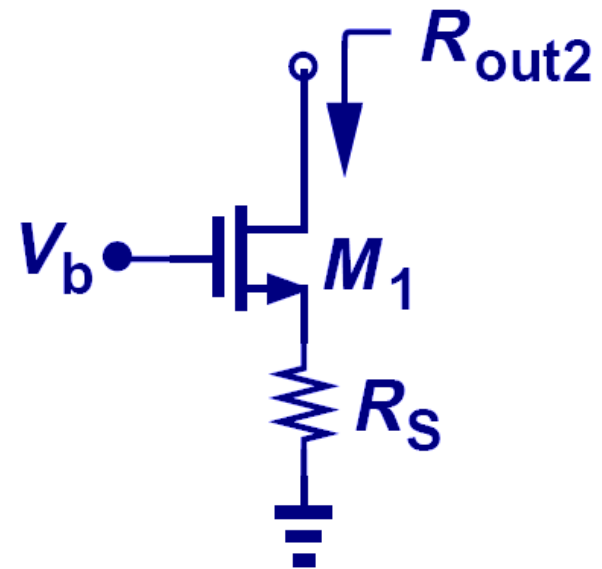
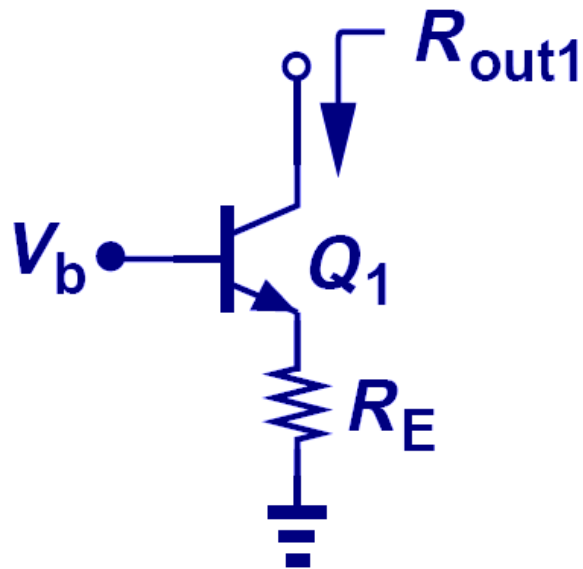
Chapter 9 Cascode Stages and Current Mirrors

➤ 9.1 Cascode Stage



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Boosted Output Impedances

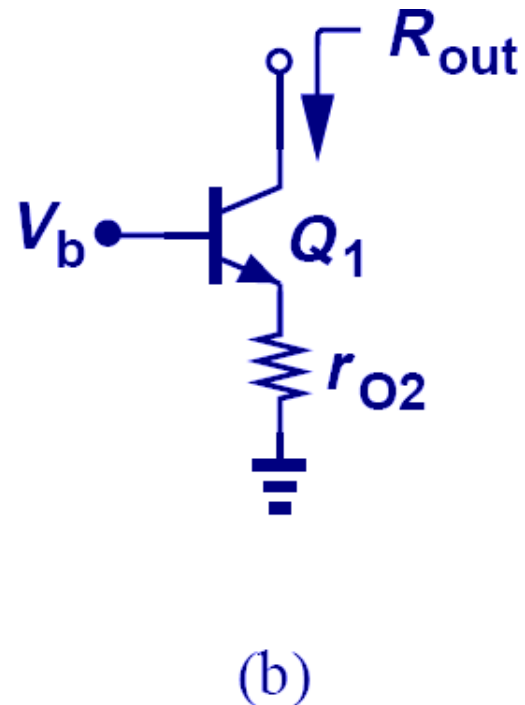
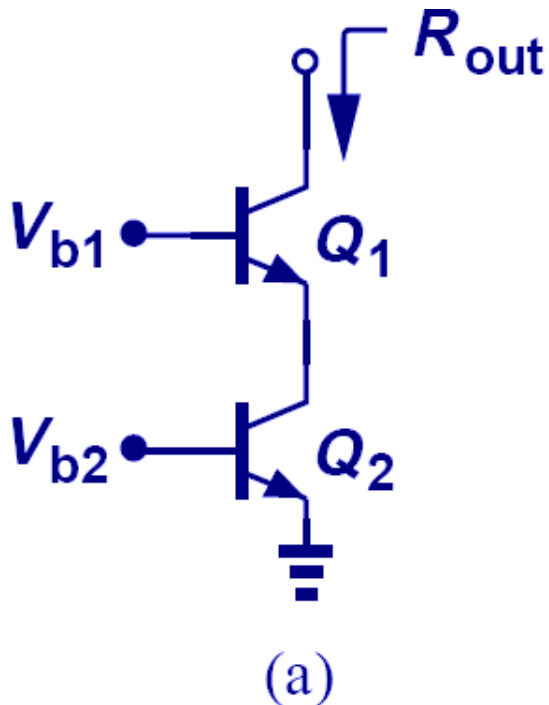


$$R_{out1} = [1 + g_m r_o](R_E \parallel r_\pi) + r_o$$

$$R_{out2} = (1 + g_m r_o)R_S + r_o$$



Bipolar Cascode Stage



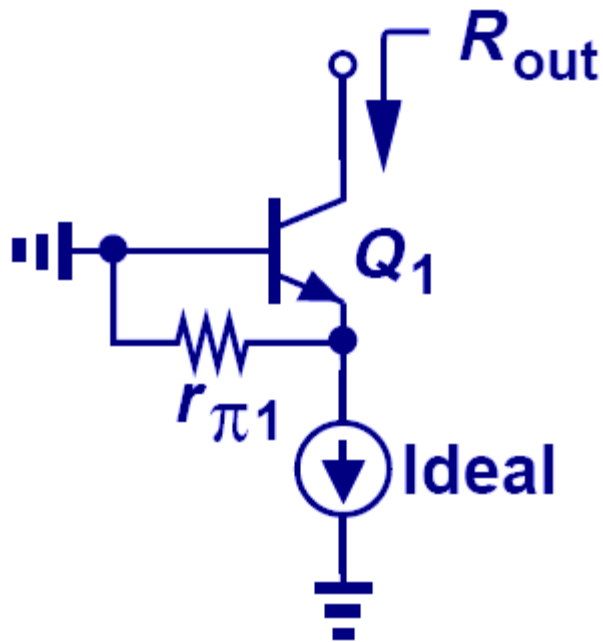
$$R_{out} = [1 + g_{m1} r_{o1}] (r_{O2} \parallel r_{\pi1}) + r_{o1}$$

$$R_{out} \approx g_{m1} r_{O1} (r_{O2} \parallel r_{\pi1})$$



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Maximum Bipolar Cascode Output Impedance



$$R_{out, \max} \approx g_{m1} r_{O1} r_{\pi 1}$$

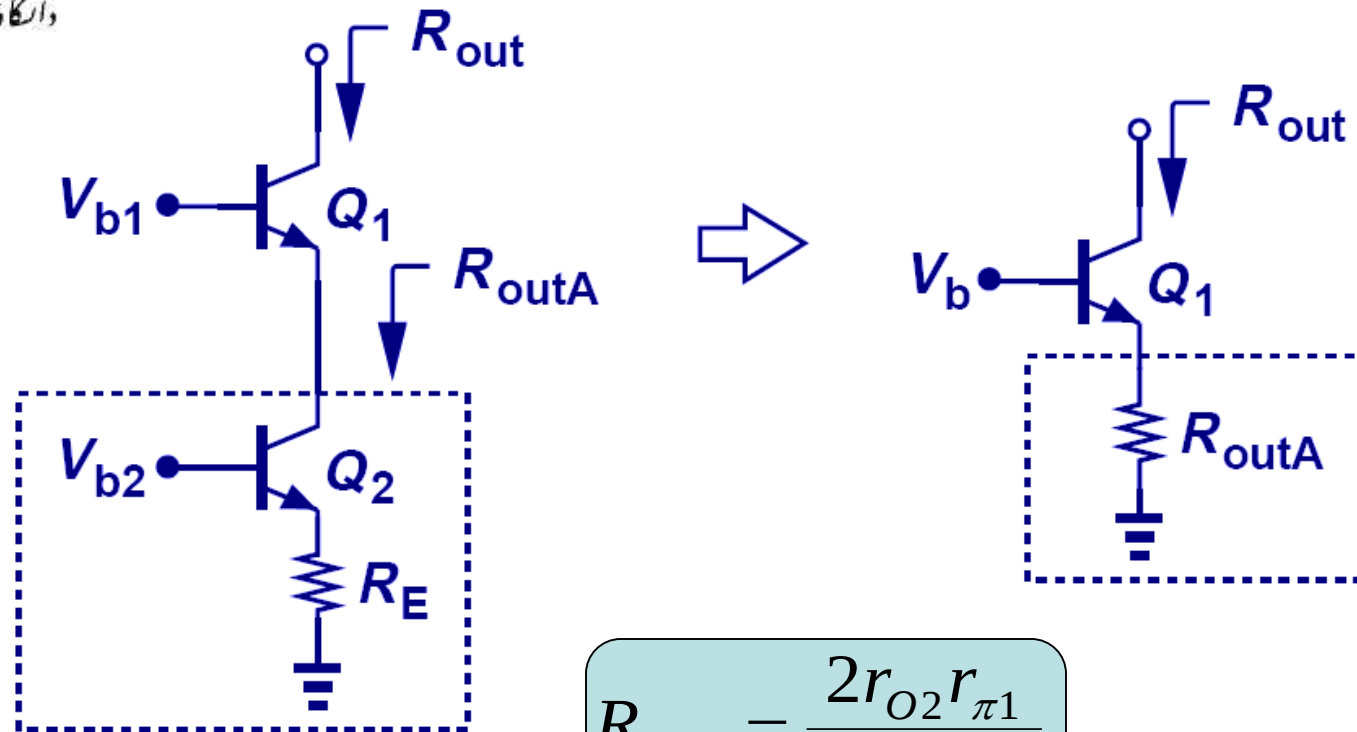
$$R_{out, \max} \approx \beta_1 r_{O1}$$

- The maximum output impedance of a bipolar cascode is bounded by the ever-present r_{π} between emitter and ground of Q_1 .



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Example: Output Impedance



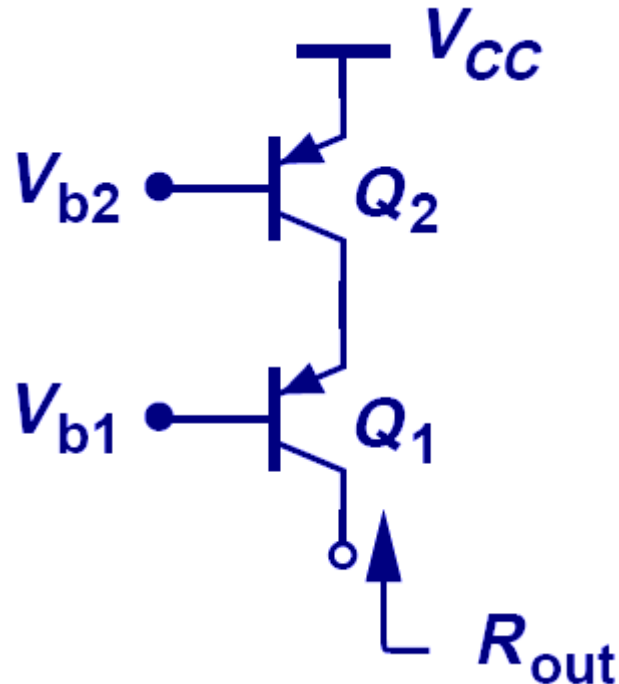
$$R_{outA} = \frac{2r_{O2}r_{\pi1}}{r_{\pi1} - r_{O2}}$$

- Typically r_{π} is smaller than r_o , so in general it is impossible to double the output impedance by degenerating Q_2 with a resistor.



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PNP Cascode Stage

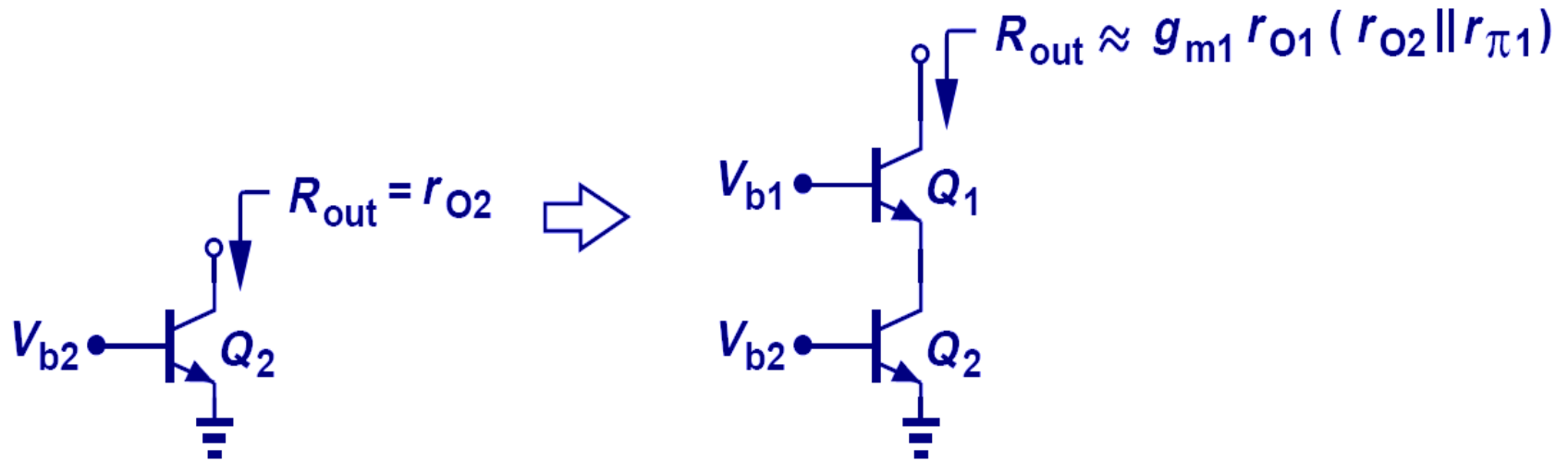


$$R_{out} = [1 + g_{m1} r_{o1}] (r_{O2} \parallel r_{\pi1}) + r_{O1}$$

$$R_{out} \approx g_{m1} r_{O1} (r_{O2} \parallel r_{\pi1})$$



Another Interpretation of Bipolar Cascode

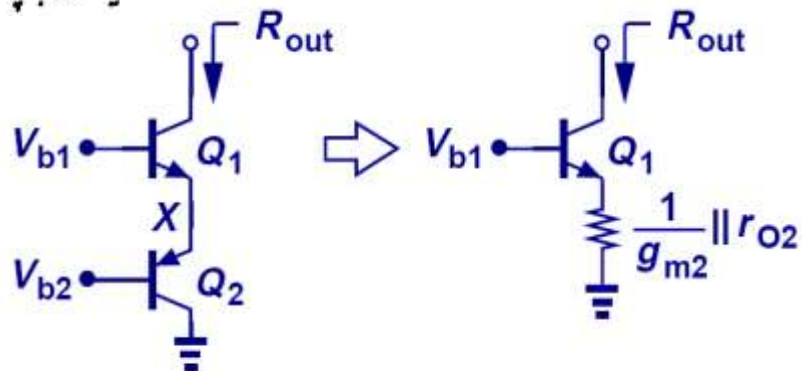


- Instead of treating cascode as Q_2 degenerating Q_1 , we can also think of it as Q_1 stacking on top of Q_2 (current source) to boost Q_2 's output impedance.

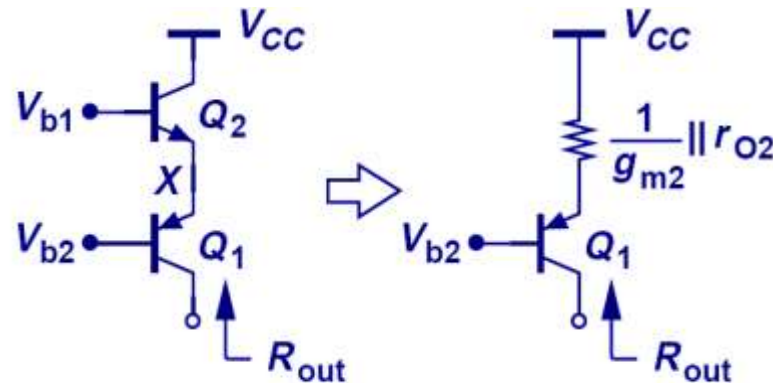


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False Cascodes



(a)



(b)

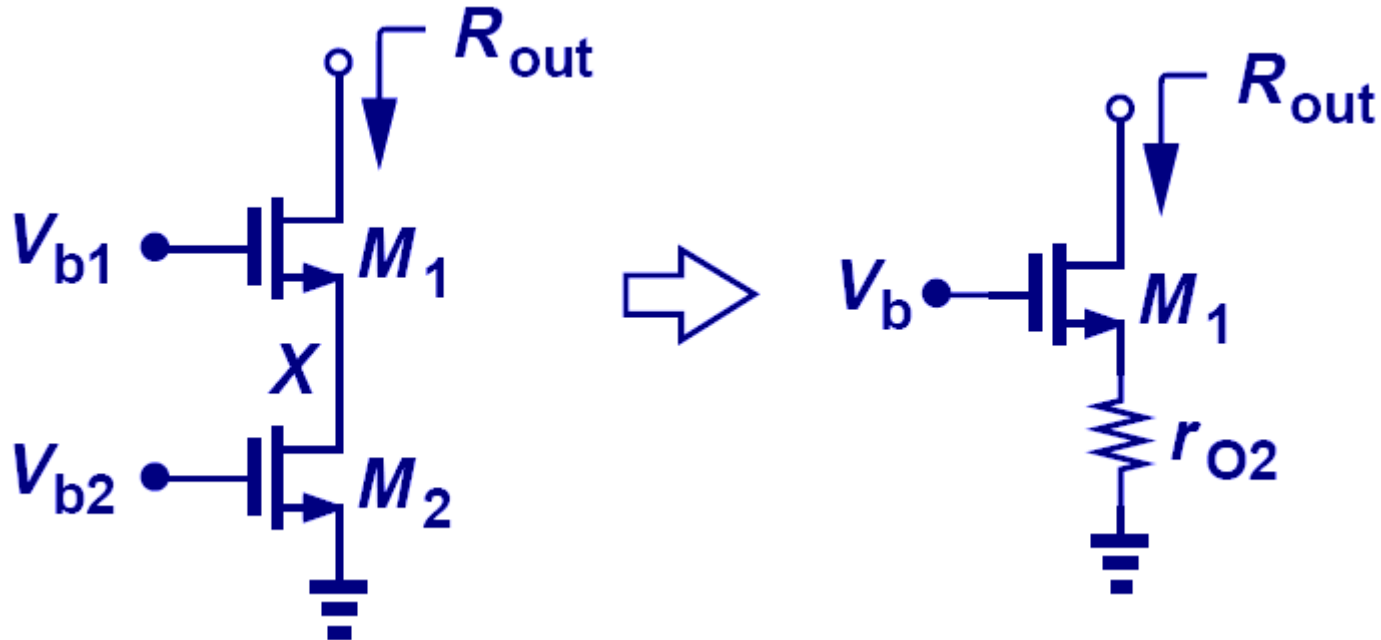
$$R_{out} = \left[1 + g_{m1} r_{o1} \right] \left(\frac{1}{g_{m2}} \parallel r_{O2} \parallel r_{\pi 1} \right) + r_{o1}$$
$$R_{out} \approx \left(1 + \frac{g_{m1}}{g_{m2}} \right) r_{O1} + \frac{1}{g_{m2}} \approx 2r_{O1}$$

- When the emitter of Q_1 is connected to the emitter of Q_2 , it's no longer a cascode since Q_2 becomes a diode-connected device instead of a current source.



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MOS Cascode Stage



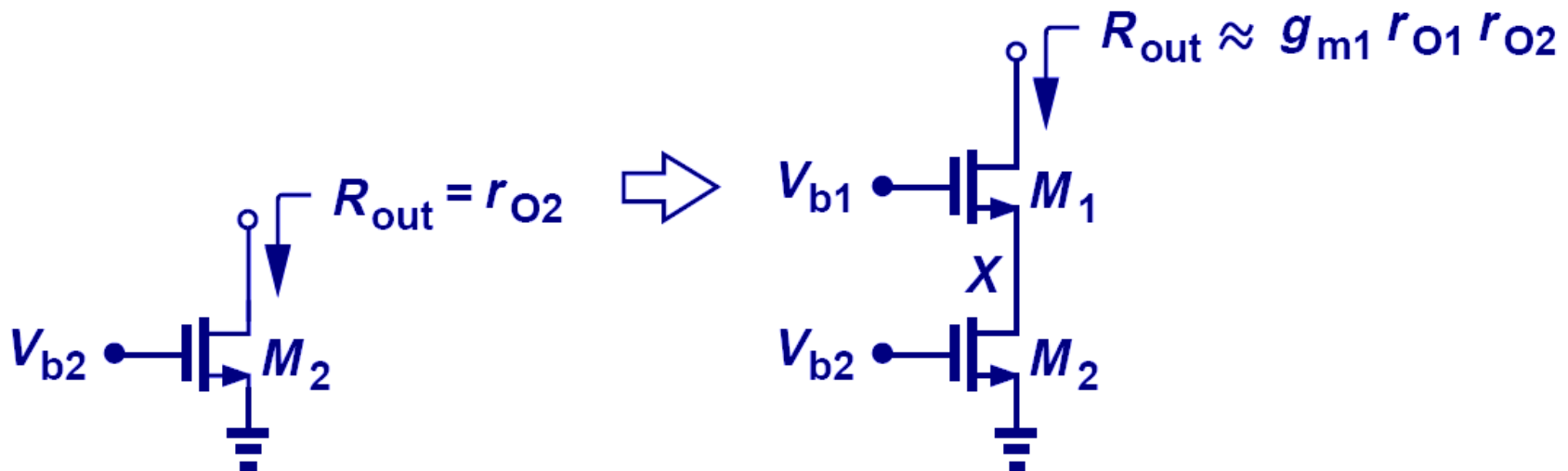
$$R_{out} = (1 + g_{m1}r_{O1})r_{O2} + r_{O1}$$

$$R_{out} \approx g_{m1}r_{O1}r_{O2}$$



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Another Interpretation of MOS Cascode

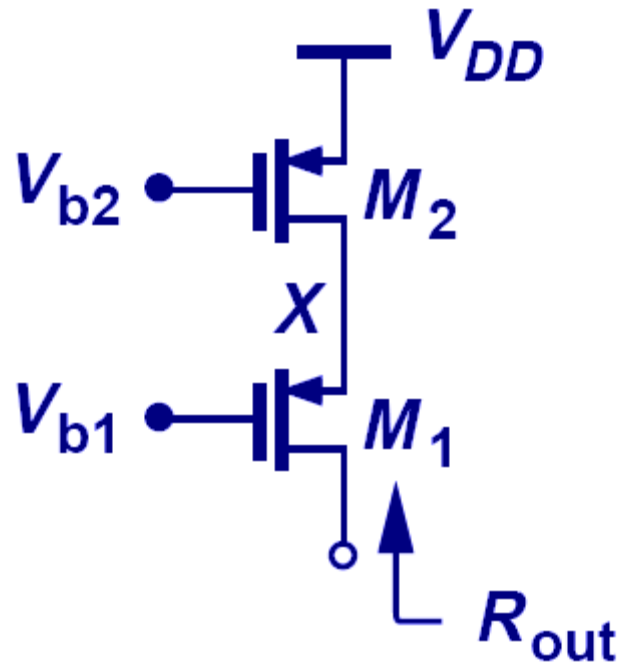


- Similar to its bipolar counterpart, MOS cascode can be thought of as stacking a transistor on top of a current source.
- Unlike bipolar cascode, the output impedance is not limited by β .



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PMOS Cascode Stage



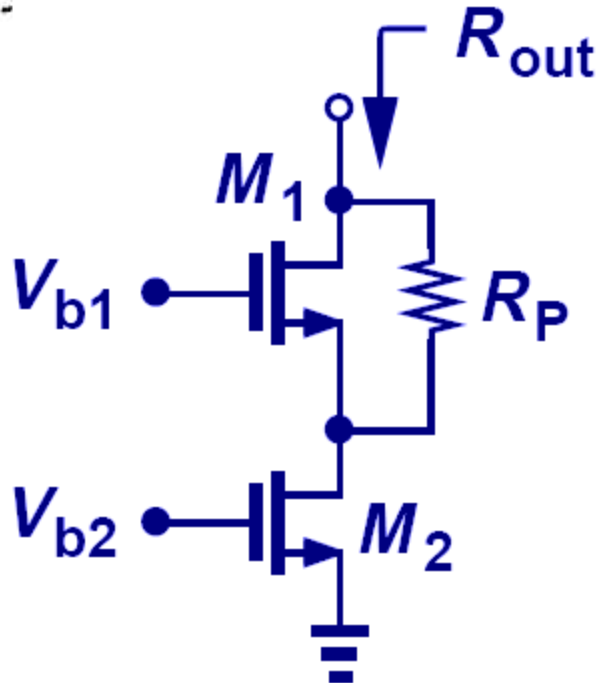
$$R_{out} = (1 + g_{m1} r_{O1}) r_{O2} + r_{O1}$$

$$R_{out} \approx g_{m1} r_{O1} r_{O2}$$



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Example: Parasitic Resistance



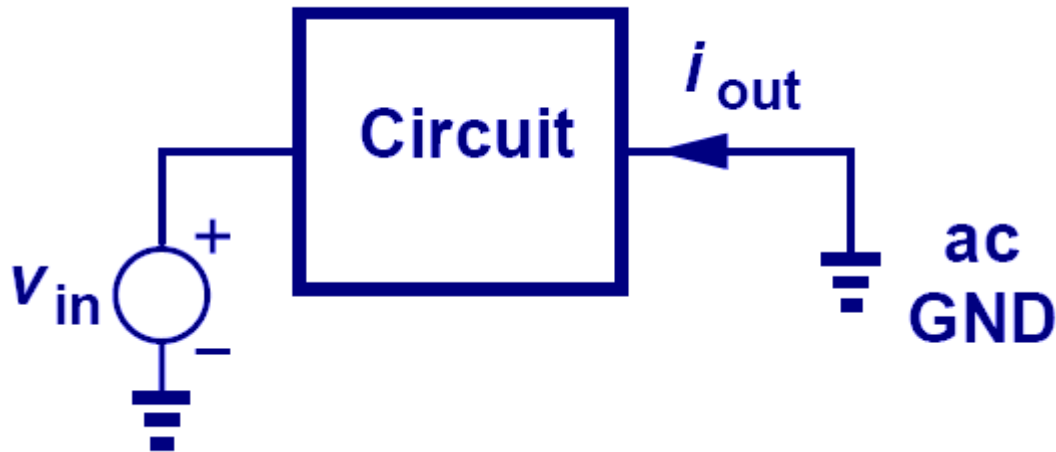
$$R_{out} = [1 + g_{m1}(r_{O1} \parallel R_P)]r_{o2} + (r_{O1} \parallel R_P)$$

- R_P will lower the output impedance, since its parallel combination with r_{O1} will always be lower than r_{O1} .



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Short-Circuit Transconductance



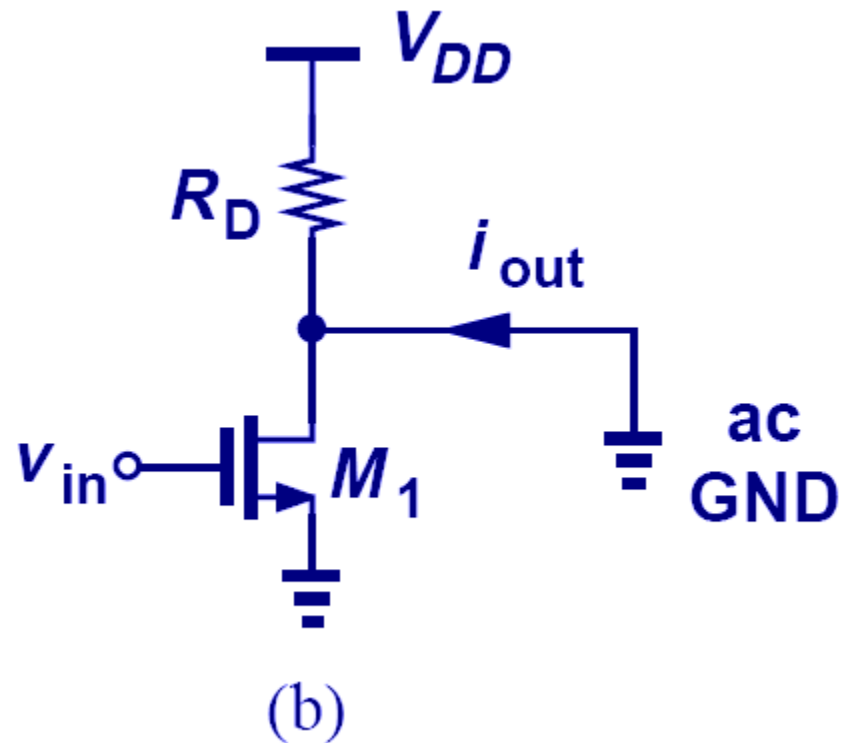
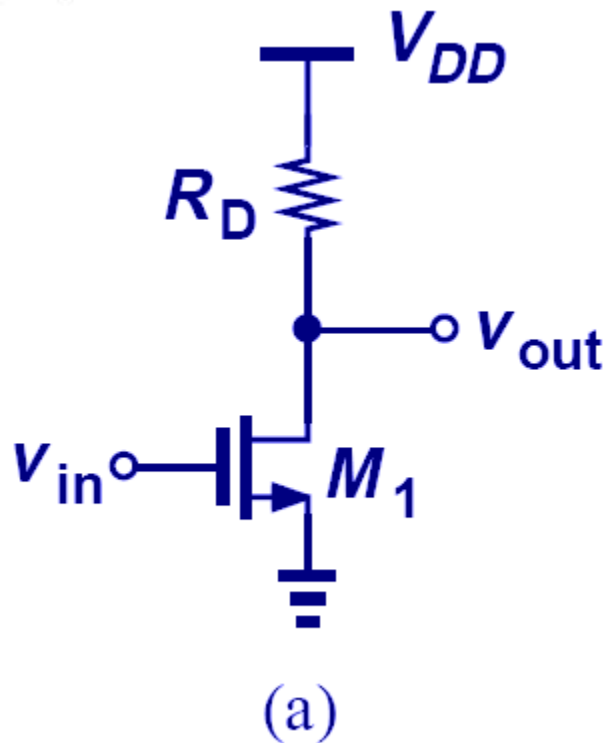
$$G_m = \left. \frac{i_{out}}{V_{in}} \right|_{v_{out}=0}$$

- The short-circuit transconductance of a circuit measures its strength in converting input voltage to output current.



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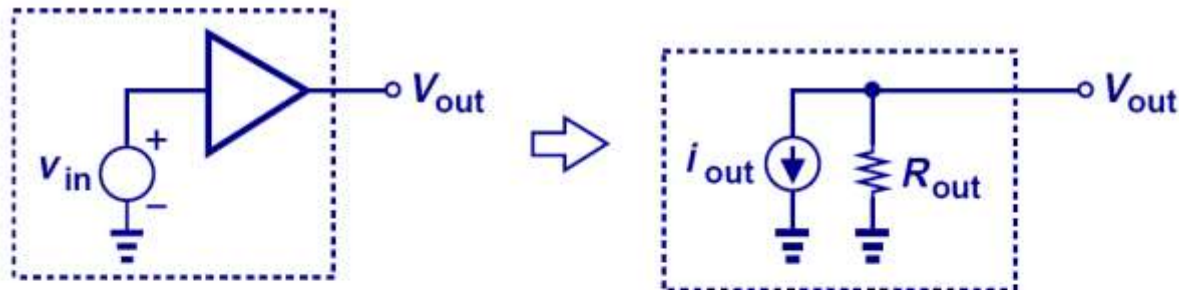
Transconductance Example



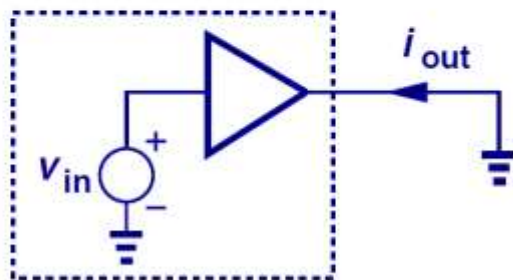
$$G_m = g_{m1}$$



Derivation of Voltage Gain



(a)



(b)

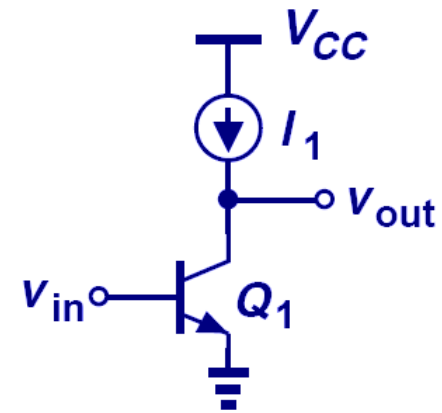
$$v_{out} = -i_{out} R_{out} = -G_m v_{in} R_{out}$$
$$v_{out} / v_{in} = -G_m R_{out}$$

- By representing a linear circuit with its Norton equivalent, the relationship between V_{out} and V_{in} can be expressed by the product of G_m and R_{out} .

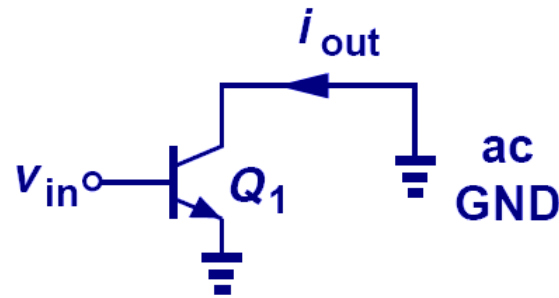


دانشگاه موهج

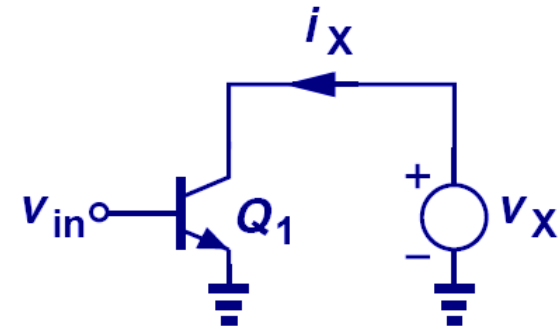
Example: Voltage Gain



(a)



(b)



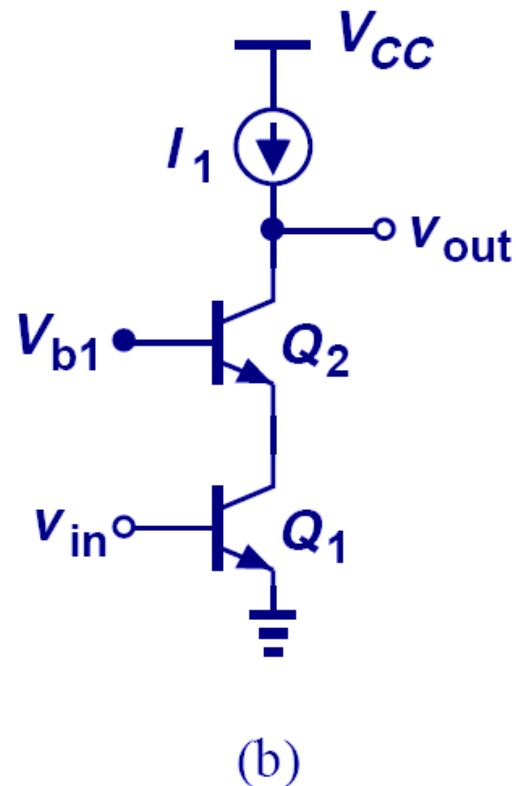
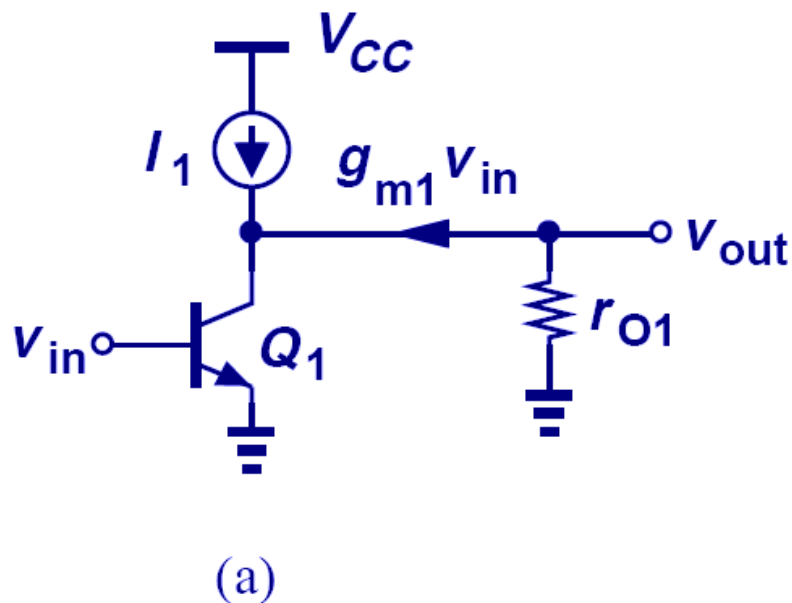
(c)

$$A_v = -g_{m1}r_{O1}$$



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Comparison between Bipolar Cascode and CE Stage

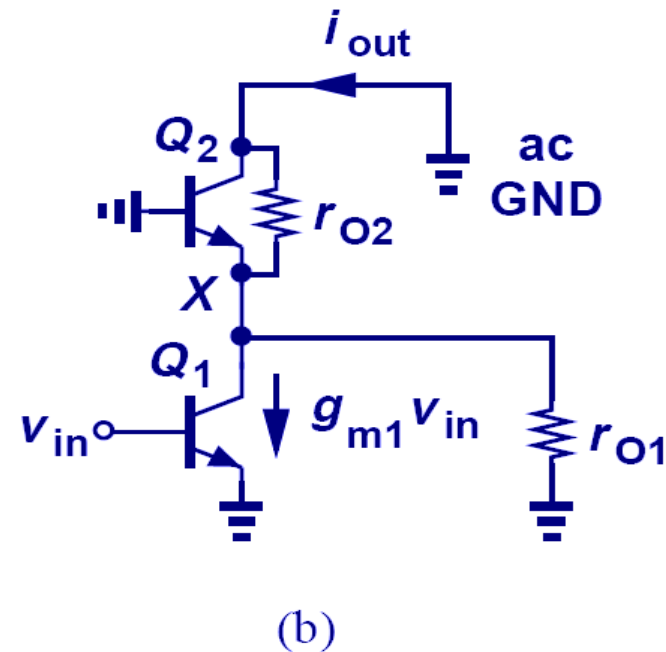
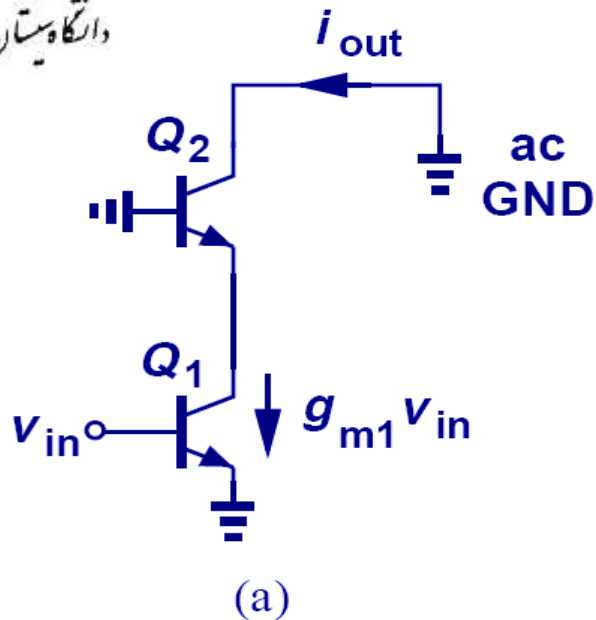


- Since the output impedance of bipolar cascode is higher than that of the CE stage, we would expect its voltage gain to be higher as well.



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Voltage Gain of Bipolar Cascode Amplifier



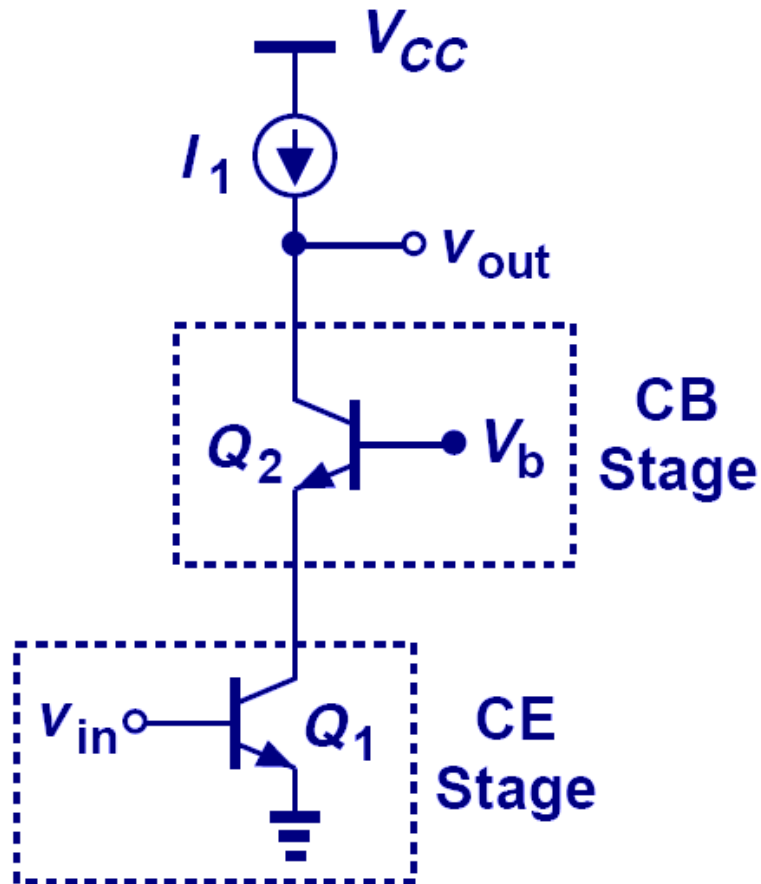
$$G_m \approx g_{m1}$$

$$A_v \approx -g_{m1} r_{O1} g_{m1} (r_{O1} \parallel r_{\pi 2})$$

- Since r_o is much larger than $1/g_m$, most of $I_{C,Q1}$ flows into the diode-connected Q_2 . Using R_{out} as before, A_v is easily calculated.



Alternate View of Cascode Amplifier

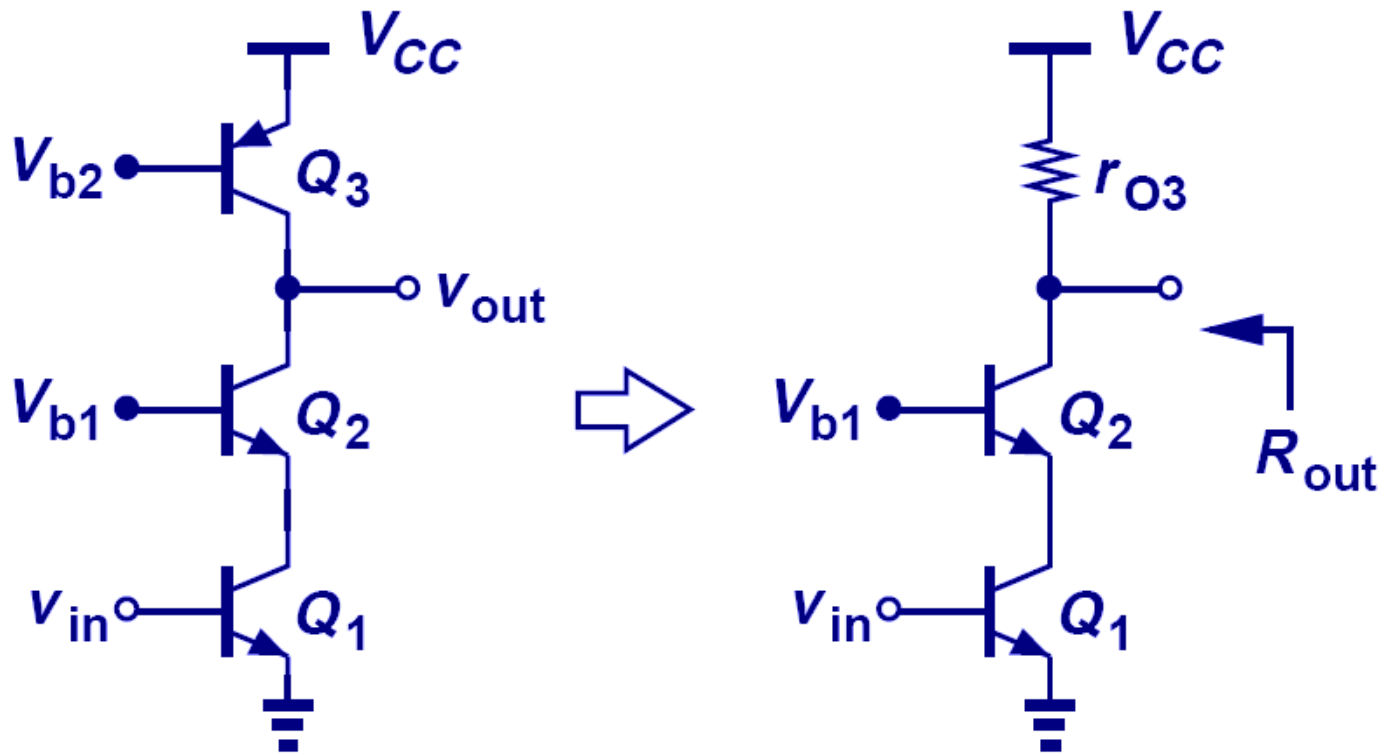


- A bipolar cascode amplifier is also a CE stage in series with a CB stage.



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Practical Cascode Stage



$$R_{out} \approx r_{O3} \parallel g_{m2} r_{O2} (r_{O1} \parallel r_{\pi 2})$$

➤ Since no current source can be ideal, the output impedance drops.