LECTURE 170 – INTUITIVE ANALYSIS OF ANALOG CIRCUITS
(READING: AH – 191-193)

Objective

The objective of this presentation is:

1.) Illustrate how to perform a small-signal, midband analysis from the schematic

2.) Introduce the Miller technique and the approximate method of solving for two poles

Outline

- Key concepts in CMOS analog IC circuit analysis
- Intuitive approach
- Examples
- Summary

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IMPORTANT RELATIONSHIPS FOR CMOS ANALOG IC DESIGN

1.) Square law relationship:

$$i_D = \frac{K'W}{2L}(v_{GS} - V_T)^2$$

2.) Small-signal transconductance formula:

$$g_m = \sqrt{\frac{2K'WI_D}{L}}$$

3.) Small-signal simplification:

$$g_m \approx 10g_{mbs} \approx 100g_{ds}$$

4.) Saturation relationship:

$$V_{DS}(\text{sat}) = \sqrt{\frac{2I_D}{K'(W/L)}}$$

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An Intuitive Method of Small Signal Analysis

Small signal analysis is used so often in analog circuit design that it becomes desirable to find faster ways of performing this important analysis.

Intuitive Analysis (or Schematic Analysis)

Technique:

1.) Identify the transistor(s) that convert the input voltage to current (these transistors are called *transconductance transistors*).

2.) Trace the currents to where they flow into an equivalent resistance to ground.

3.) Multiply this resistance by the current to get the voltage at this node to ground.

4.) Repeat this process until the output is reached.

Simple Example:

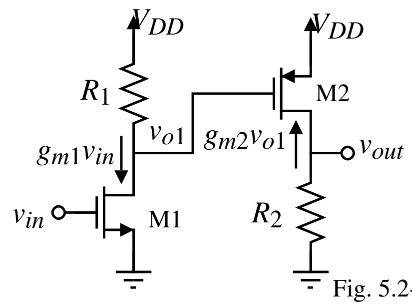

Fig. 5.2-10C

$$v_{o1} = -(g_{m1}v_{in})R_1 \;\rightarrow\; v_{out} = -(g_{m2}v_{o1})R_2 \;\rightarrow\; v_{out} = (g_{m1}R_1g_{m2}R_2)v_{in}$$

Intuitive Analysis of the Current-Mirror Load Differential Amplifier

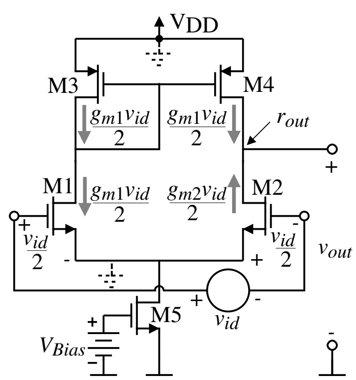

Fig. 5.2-11

1.) $i_1 = 0.5g_{m1}v_{id}$ and $i_2 = -0.5g_{m2}v_{id}$

2.) $i_3 = i_1 = 0.5g_{m1}v_{id}$

3.) $i_4 = i_3 = 0.5g_{m1}v_{id}$

4.) The resistance at the output node, r_{out}, is $r_{ds2}||r_{ds4}$ or $\dfrac{1}{g_{ds2}+g_{ds4}}$

5.) $\therefore\; v_{out} = (0.5g_{m1}v_{id} + 0.5g_{m2}v_{id})r_{out} = \dfrac{g_{m1}v_{in}}{g_{ds2}+g_{ds4}} = \dfrac{g_{m2}v_{in}}{g_{ds2}+g_{ds4}} \Rightarrow \dfrac{v_{out}}{v_{in}} = \dfrac{g_{m1}}{g_{ds2}+g_{ds4}}$

Some Concepts to Help Extend the Intuitive Method of Small-Signal Analysis

1.) Approximate the output resistance of any cascode circuit as

$$R_{out} \approx (g_{m2}r_{ds2})r_{ds1}$$

where M1 is a transistor cascoded by M2.

2.) If there is a resistance, R, in series with the source of the transconductance transistor, let the effective transconductance be

$$g_{m(eff)} = \frac{g_m}{1+g_mR}$$

Proof:

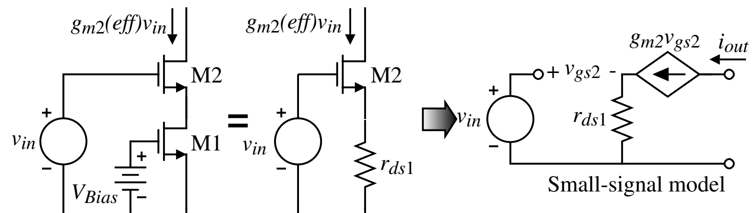

Fig. 5.2-11A

$$\therefore \; v_{gs2} = v_{g2} - v_{s2} = v_{in} - (g_{m2}r_{ds1})v_{gs2} \;\; \Rightarrow \;\; v_{gs2} = \frac{v_{in}}{1+g_{m2}r_{ds1}}$$

Thus, $i_{out} = \dfrac{g_{m2}v_{in}}{1+g_{m2}r_{ds1}} = g_{m2}(eff)\, v_{in}$

Miller Two-Stage Op Amp

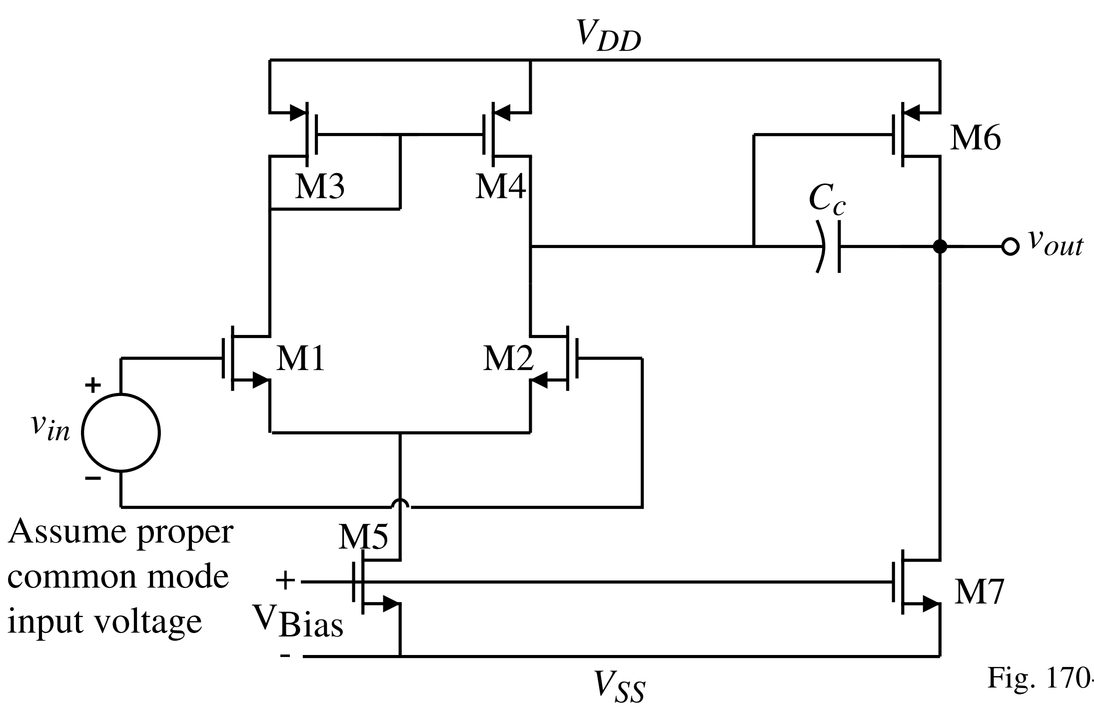

Fig. 170-01

Miller Two-Stage Op Amp

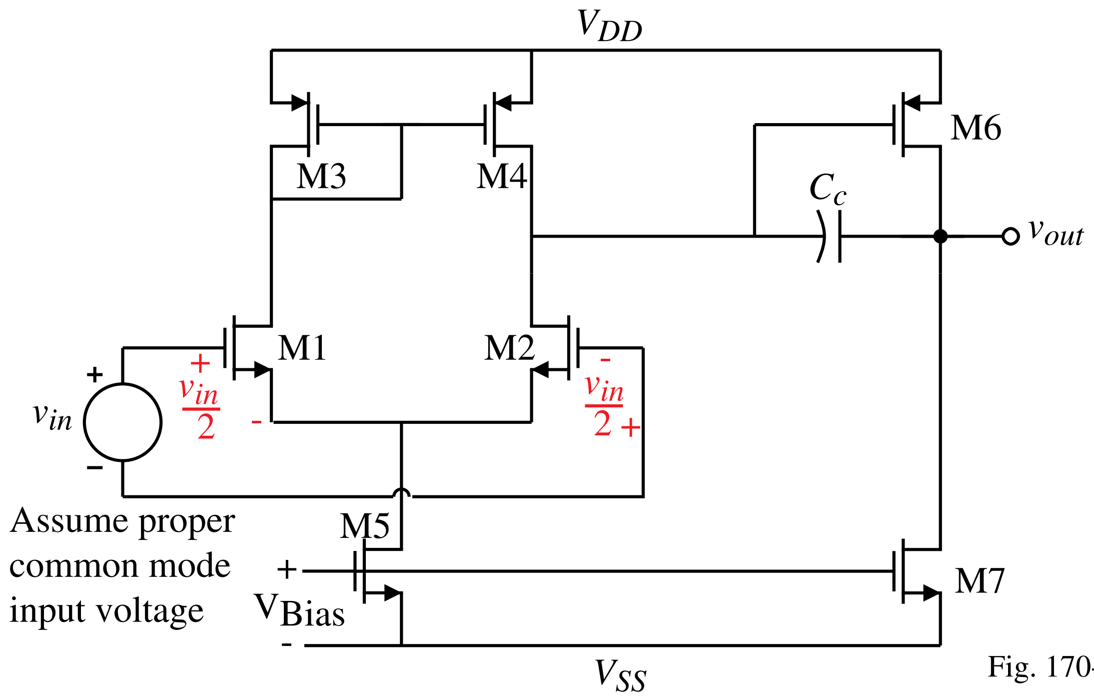

Fig. 170-01

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Miller Two-Stage Op Amp

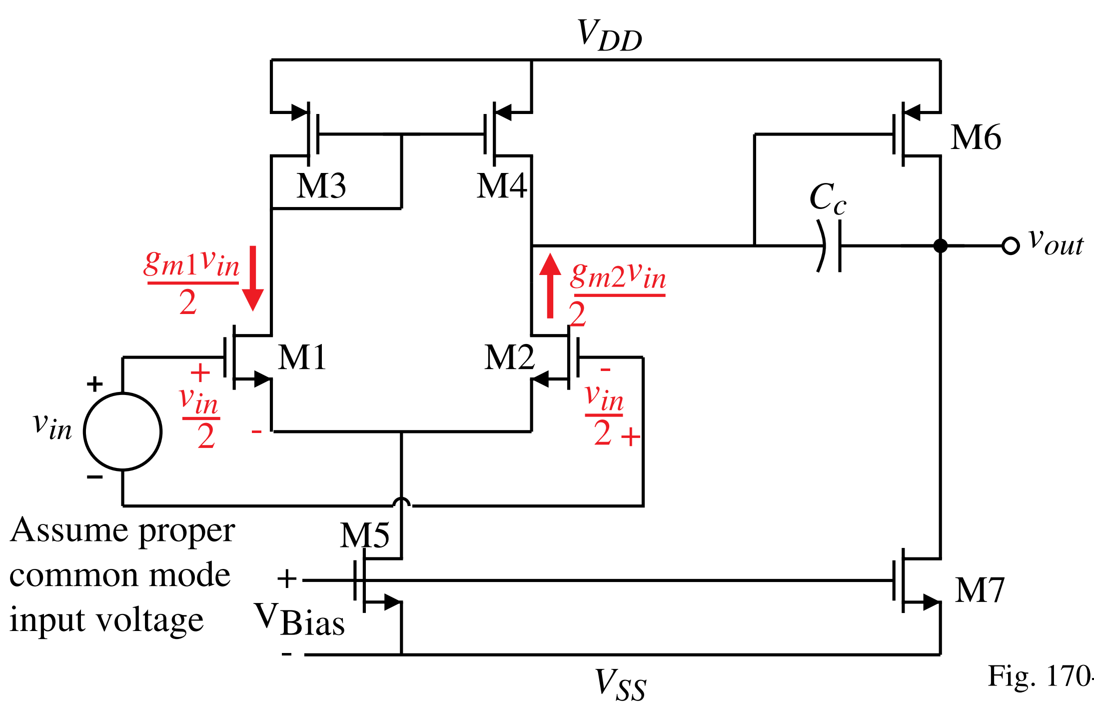

Fig. 170-01

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Miller Two-Stage Op Amp

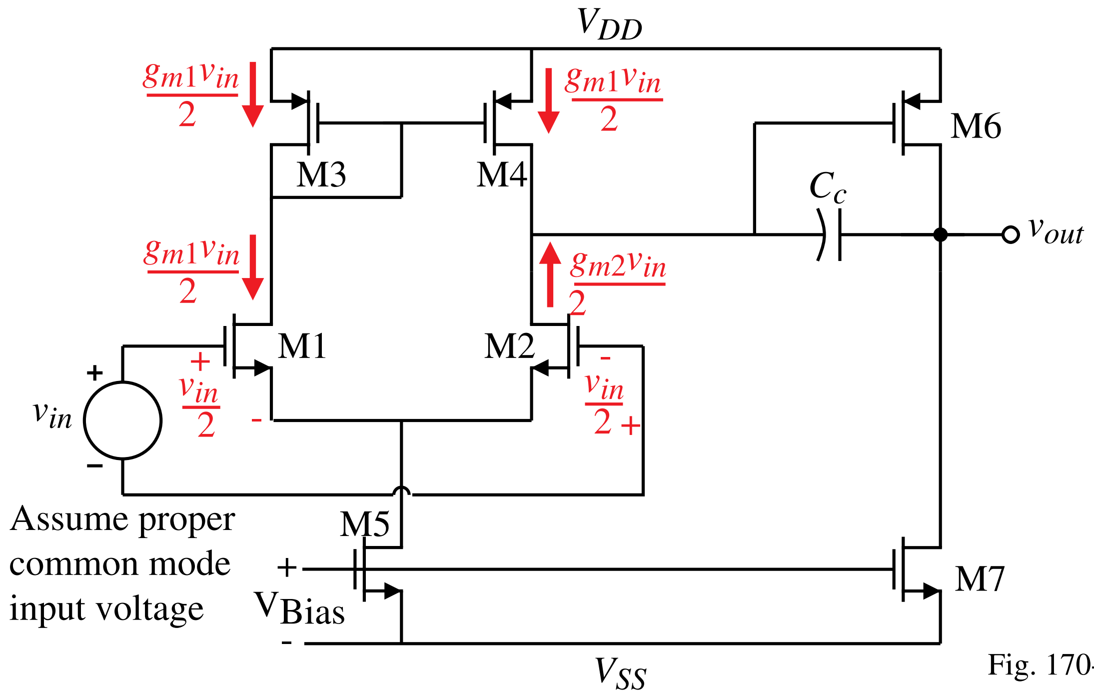

Fig. 170-01

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Miller Two-Stage Op Amp

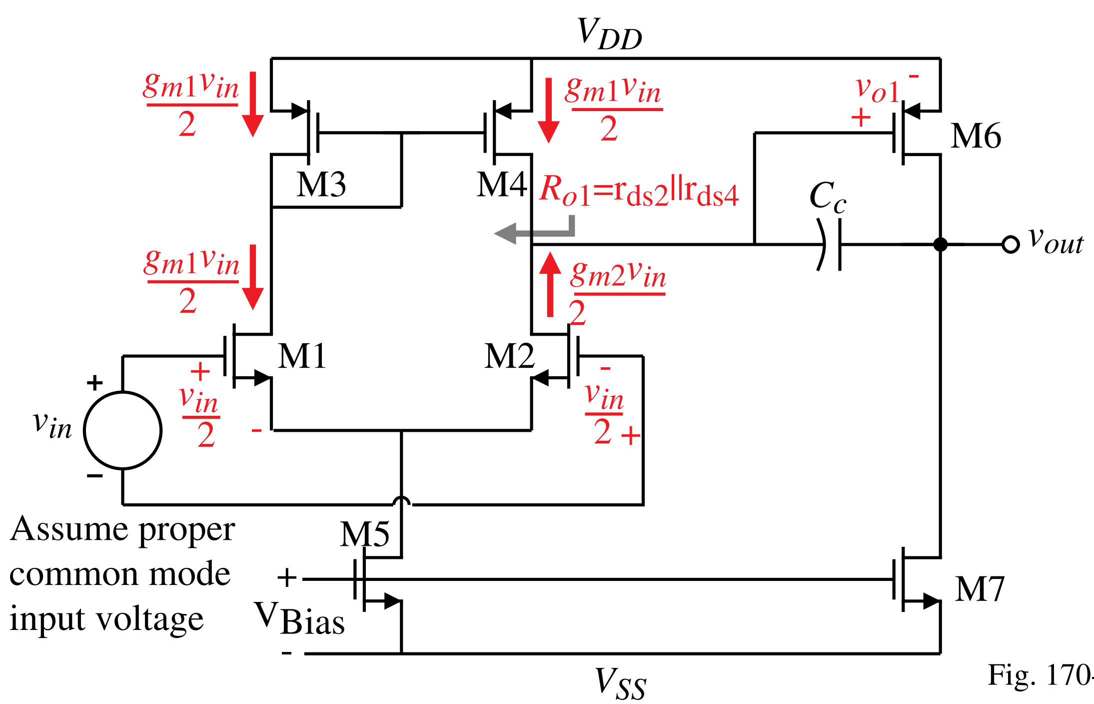

Fig. 170-01

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Miller Two-Stage Op Amp

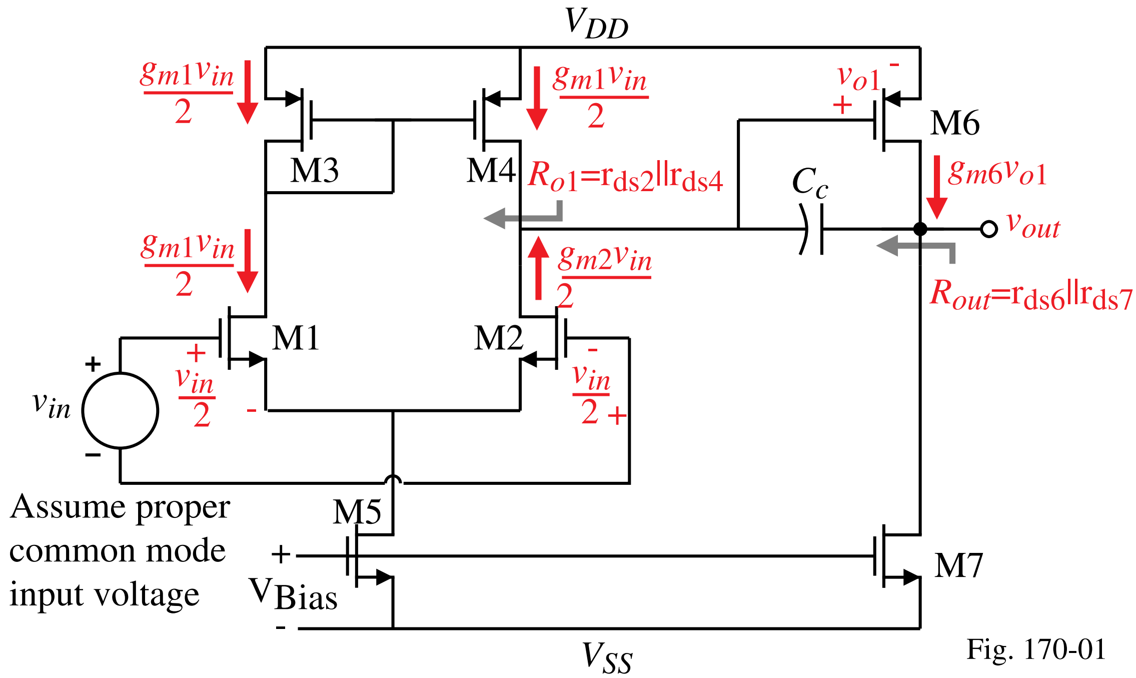

Fig. 170-01

$$\frac{v_{out}}{v_{in}} = \left(\frac{g_{m1}}{g_{ds2}+g_{ds4}}\right)\left(\frac{-g_{m6}}{g_{ds6}+g_{ds7}}\right) = \frac{-g_{m1}g_{m6}}{(g_{ds2}+g_{ds4})(g_{ds6}+g_{ds7})}$$

Folded-Cascode Op Amp

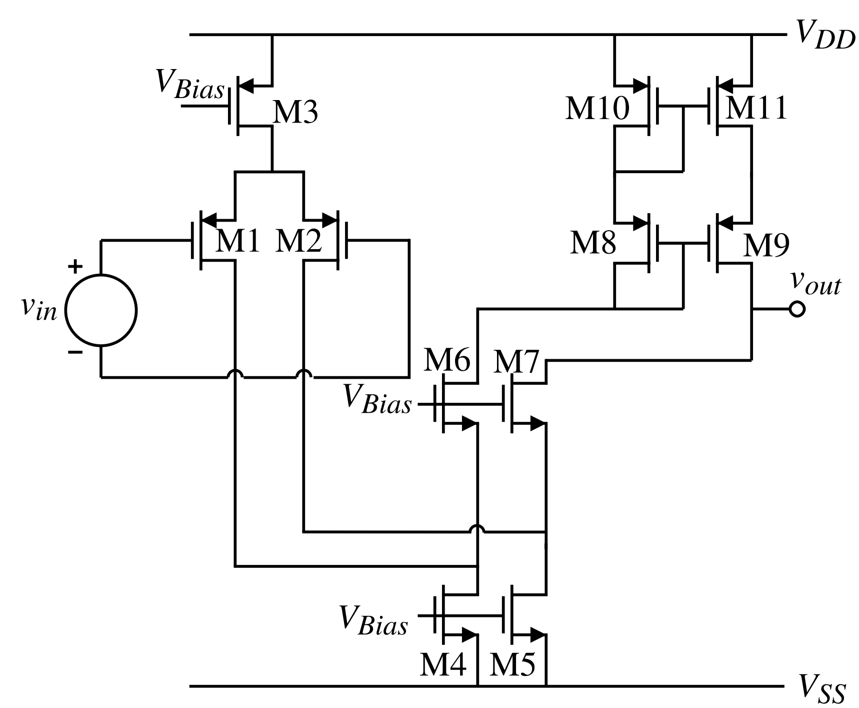

Fig. 170-02

Folded-Cascode Op Amp

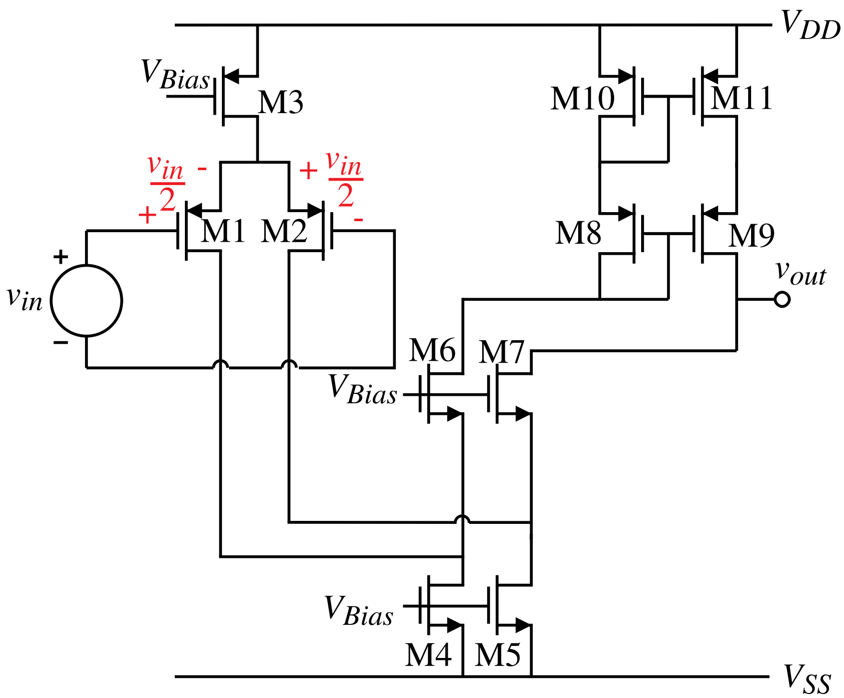

Fig. 170-02

Folded-Cascode Op Amp

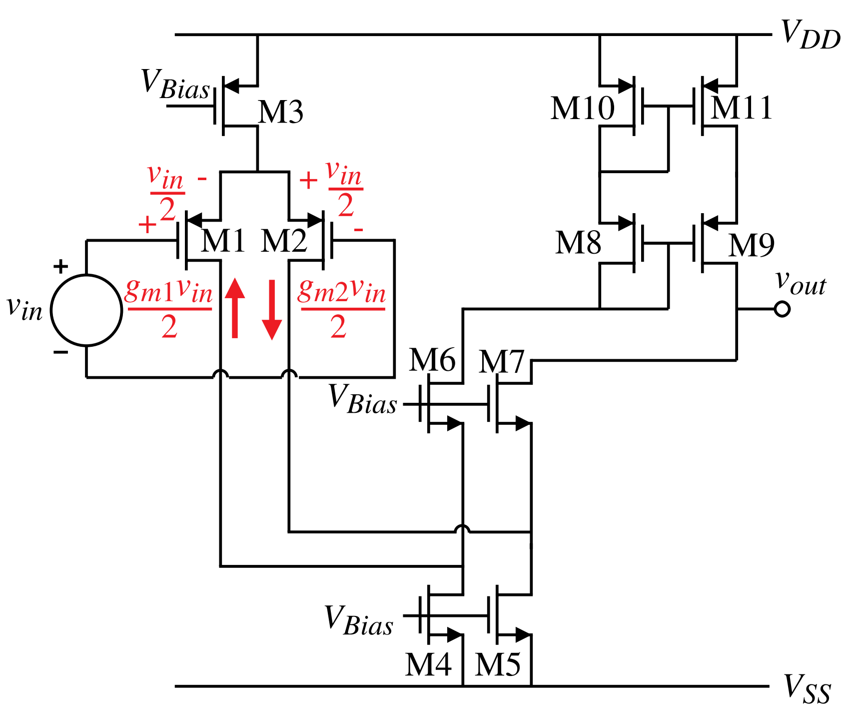

Fig. 170-02

Folded-Cascode Op Amp

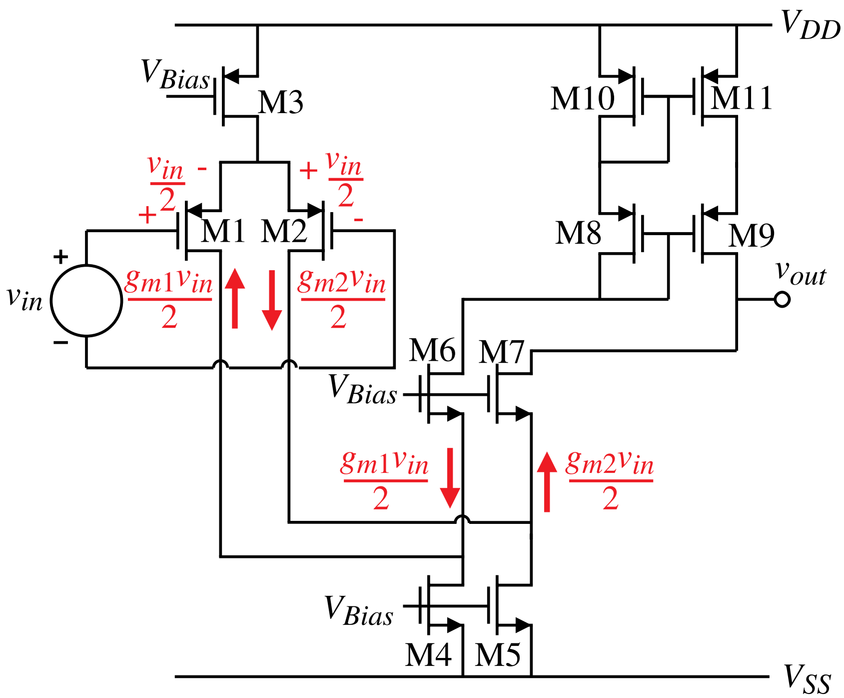

Fig. 170-02

Folded-Cascode Op Amp

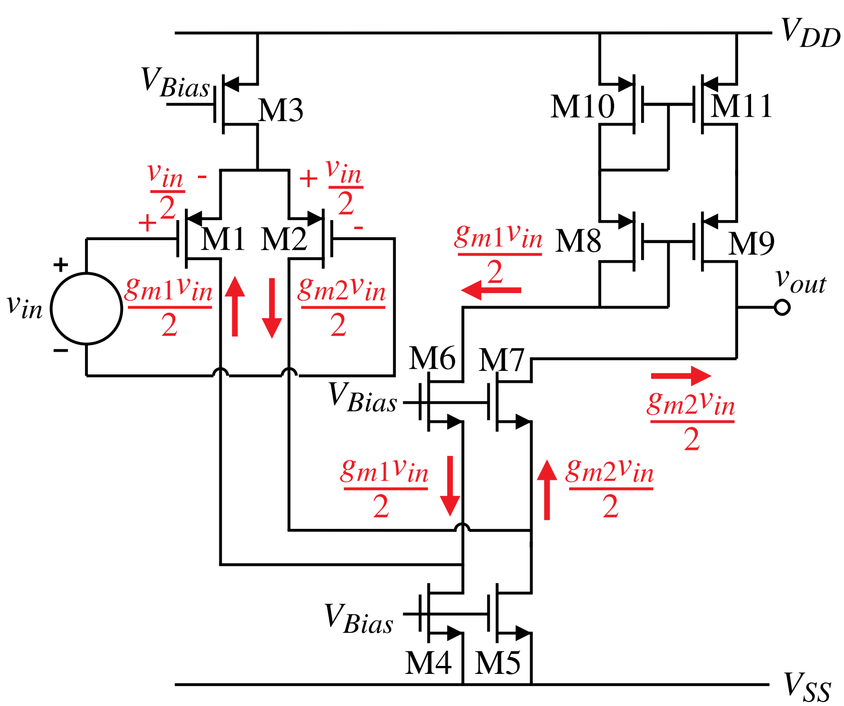

Fig. 170-02

Folded-Cascode Op Amp

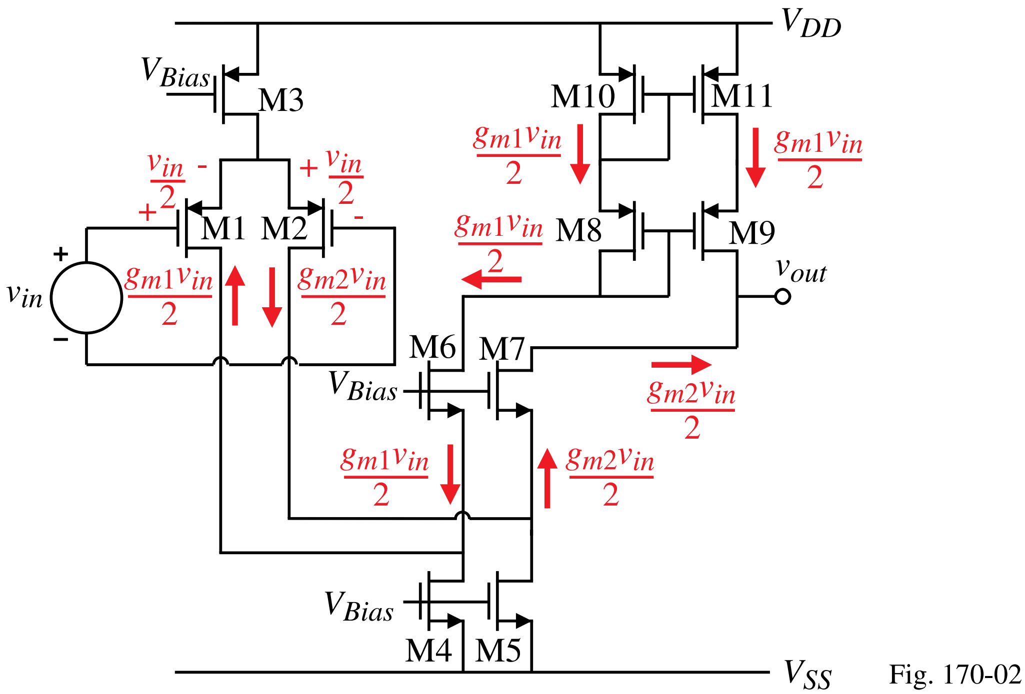

Fig. 170-02

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Folded-Cascode Op Amp

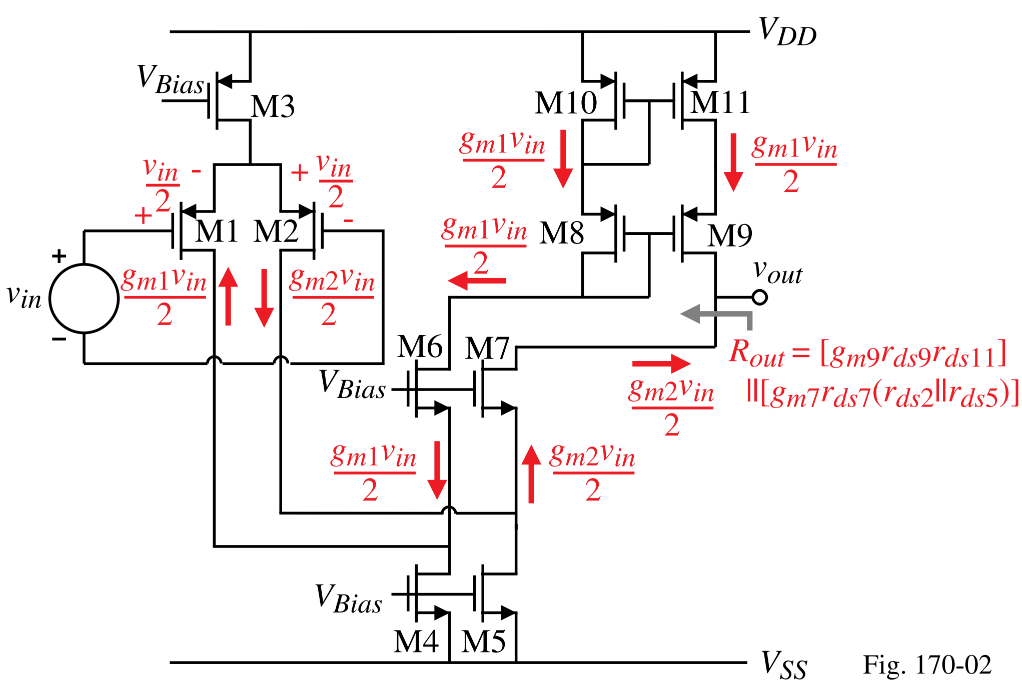

Fig. 170-02

$$\frac{v_{out}}{v_{in}} = \left(\frac{g_{m1}}{2} + \frac{g_{m2}}{2}\right)R_{out} = g_{m1}\{(g_{m9}r_{ds9}r_{ds11})||[g_{m7}r_{ds7}(r_{ds2}||r_{ds5})]\}$$

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SUMMARY

- Intuitive method is quick and simple
- Intuitive method is approximate (misses the unbalance of the folded cascode)
- Intuitive method does not give any information about frequency response
- The intuitive method can be used with BJT circuits assuming β >>1 and including r_π in the resistance calculations

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