NPTEL ONLINE CERTIFICATION COURSES

Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Current mirror circuits

Flow of Discussion (Bottom-up)

—*Building blocks and Models*

- System /Sub-systems (*for specific application*)
  - **Modules** (*performing specific tasks*)
    - **Building blocks** (*having specific characteristics*) **- Bias circuits**
      - Components (*devices/circuit elements*)

- **Week 9 (Course Module 8)**:
  - **Current mirror**
    - **operating principle and analysis,**
  - **Use of current mirror**
    - **as bias circuit and for signal amplification (in CE/CS, CC/CD, CB/CG and**
    - **Differential amplifier).**
  - **Use of current mirror**
    - **as signal mirror (for current mode operation).**

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CONCEPTS COVERED

Concepts Covered:

- **Motivation / need of current mirror**
  - Recapitulation of studied circuits – current biasing element
  - Basic characteristic of current biasing element
  - Signal mirroring circuit in current mode amplifier
- **Basic structure & Operating principle of current mirror**
  - Different versions of current biasing element
  - Current reference-mirror pair transistors
- **Analysis of current mirror**
  - Expression of output current and output resistance
    - BJT and MOSFET
  - Advancement of current mirror
    - BJT and MOSFET
- **Small signal model of current mirror**

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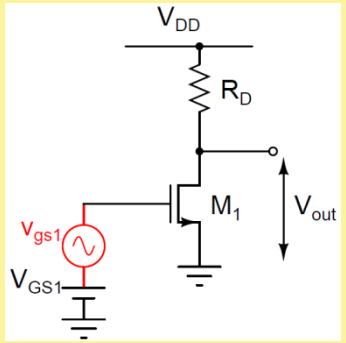
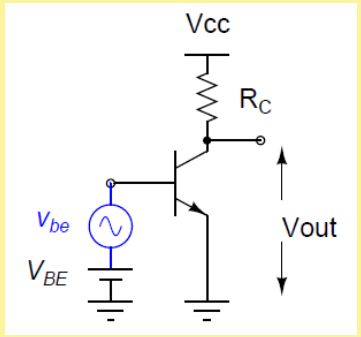
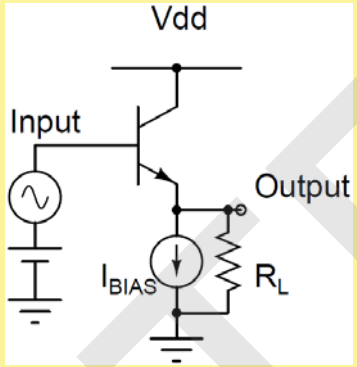
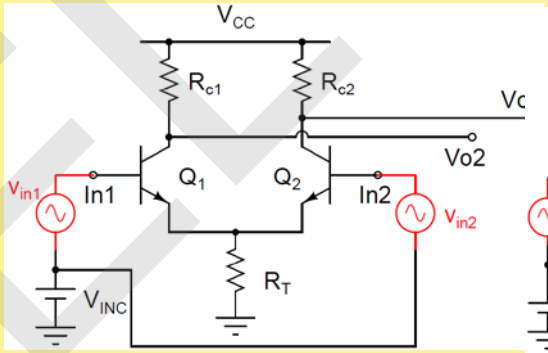
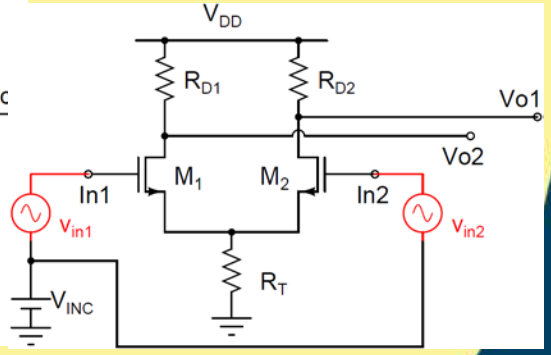
Recapitulations: Amplifiers requiring Current Biasing elements

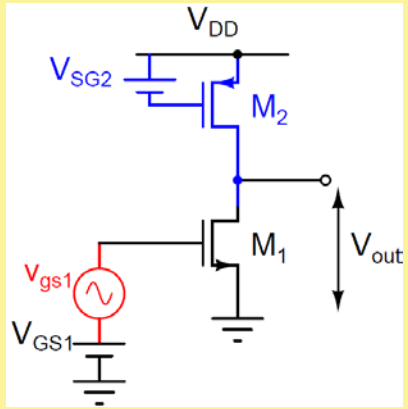


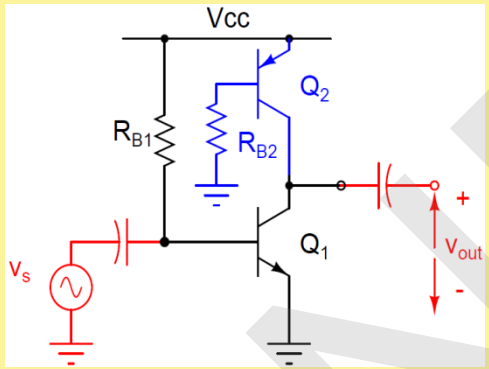


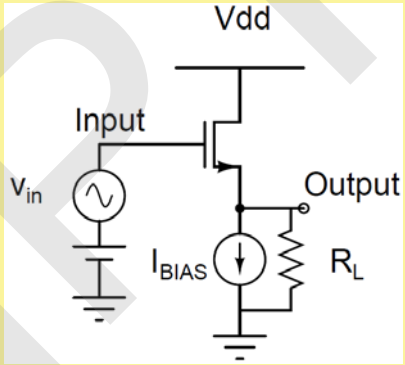












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Basic characteristic required for a Current Biasing element

- **Output impedance should be high** – current should be "independent" on voltage across it
- **Its current should be well defined** (with low variation/uncertainty)
- **Should operate with available supply voltage** – minimum required voltage should be low

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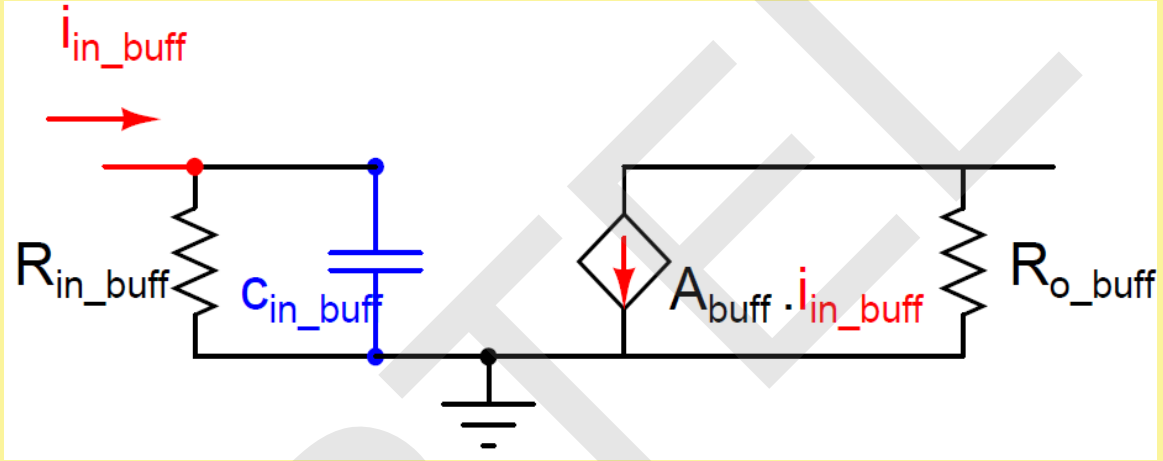
Recapitulation : Necessary features of a Current mode Buffer



- **Output resistance:**
- **Input resistance:**
- **Current gain:**
- ***Leading to Common base and Common gate configurations***
- ***Also, A current mirror works as a current mode buffer***
- ***A current mirror works as a current amplifier as well***

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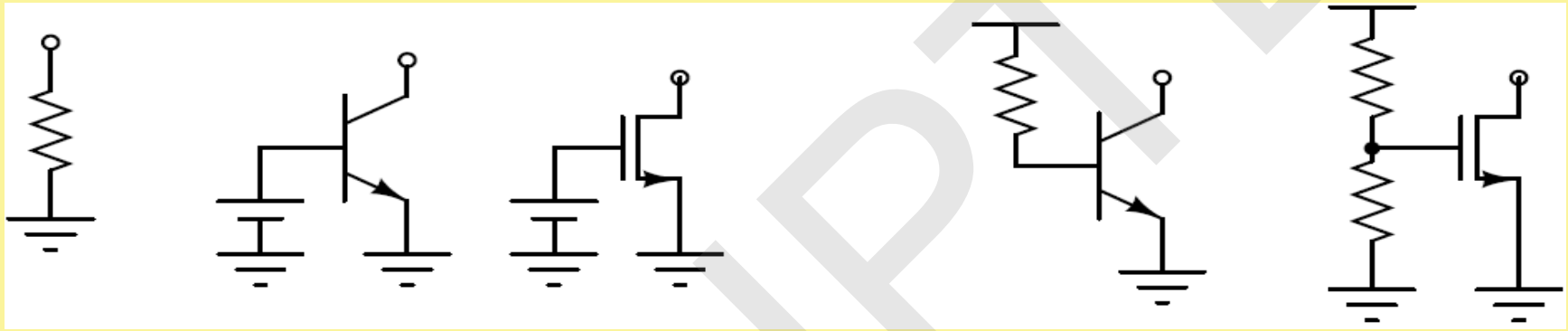
Evolution of Current biasing elements – *leading to current mirror*

- **Basic characteristic required for a Current Biasing element**
  - Output impedance should be high – current should be "independent" on voltage across it
  - Its current should be well defined (with low variation/uncertainty)
  - Should operate with available supply voltage – minimum required voltage should be low



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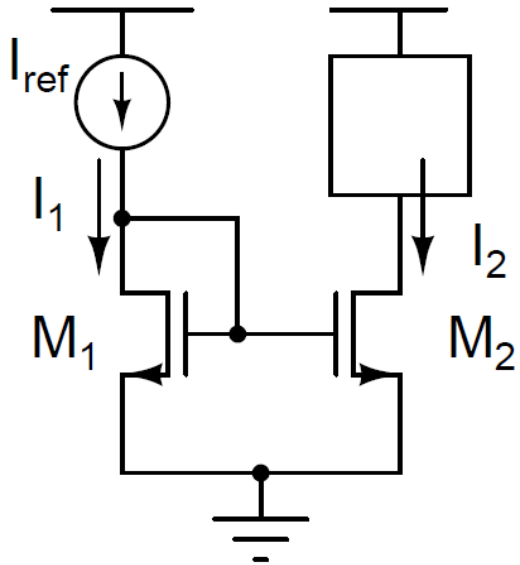
Basic structure and operation of a *current mirror (using MOSFETs)*

- **Basic characteristic required**
  - Output impedance should be high – current should be "independent" on voltage across it
  - Its current should be well defined (with low variation/uncertainty)
  - Should operate with available supply voltage – minimum required voltage should be low



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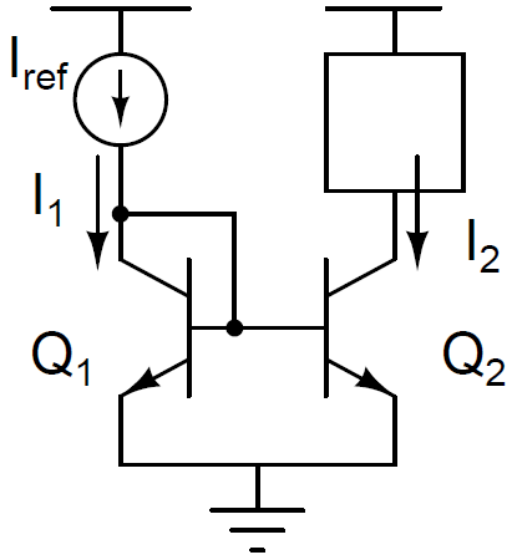
Basic structure and operation of a *current mirror (using BJTs)*

- **Basic characteristic required**
  - **Output impedance should be high – current should be "independent" on voltage across it**
  - **Its current should be well defined (with low variation/uncertainty)**
  - **Should operate with available supply voltage – minimum required voltage should be low**



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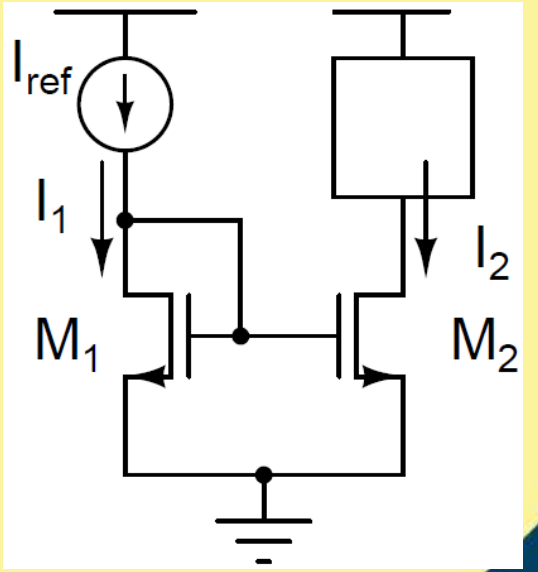
Analysis of a *current mirror (using MOSFETs)*

- **Expression of output current**



$$I_1 = I_{ref} = \frac{K_1}{2}\frac{W_1}{L_1}(V_{GS1} - V_{th1})^2(1 + \lambda_1 V_{DS1})$$

$$I_2 = \frac{K_2}{2}\frac{W_2}{L_2}(V_{GS2} - V_{th2})^2(1 + \lambda_2 V_{DS2})$$

$$I_2 = \frac{W_2}{L_2}.\frac{L_1}{W_1}.I_{ref}\frac{(1 + \lambda_2 V_{DS2})}{(1 + \lambda_1 V_{DS1})} \approx \frac{W_2}{L_2}.\frac{L_1}{W_1}.I_{ref}.\{1 + \lambda(V_{DS2} - V_{DS1})\}$$

$$\approx I_2^* + I_2^*.\lambda.(V_{DS2} - V_{DS1}) \approx I_2^* + \frac{(V_{DS2} - V_{DS1})}{r_{ds2}}$$

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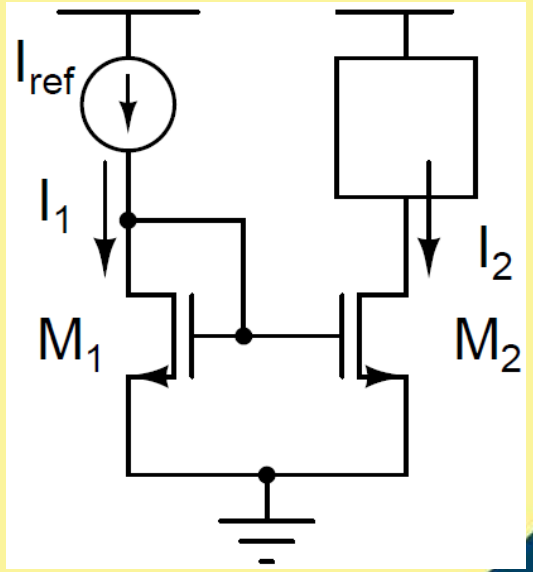
Analysis of a *current mirror (using MOSFETs)* (contd.)

- **Expression of output current – Non-ideality factor**
- **Expression of output resistance**
- **Minimum voltage required across output port of CM**



$$I_2 = \frac{W_2}{L_2}.\frac{L_1}{W_1}.I_{ref}\frac{(1+\lambda_2 V_{DS2})}{(1+\lambda_1 V_{DS1})}$$

$$\approx \frac{W_2}{L_2}.\frac{L_1}{W_1}.I_{ref}.\{1+\lambda(V_{DS2}-V_{DS1})\} \approx I_2^* + \frac{(V_{DS2}-V_{DS1})}{r_{ds2}}$$

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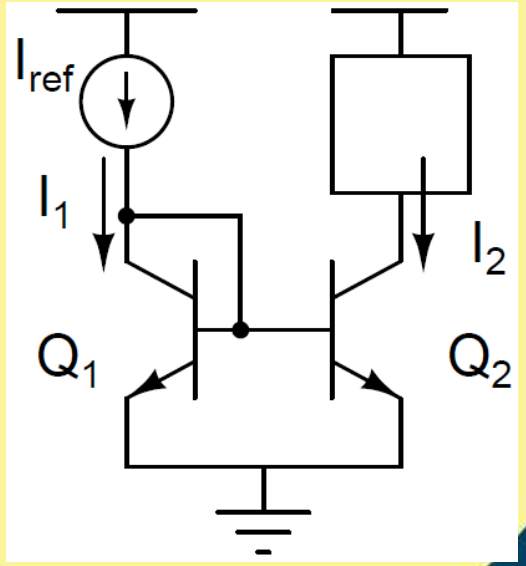
Analysis of a *current mirror (using BJTs)*

- **Expression of output current**



$$I_{C1} = I_{S1}\,.\,e^{\left(\frac{V_{BE}}{V_T}\right)} \times \left(1 + \frac{V_{CE1}}{V_{A1}}\right) \qquad I_{C2} = I_{S2}\,.\,e^{\left(\frac{V_{BE}}{V_T}\right)} \times \left(1 + \frac{V_{CE2}}{V_{A2}}\right)$$

$$I_{C2} = \frac{I_{S2}}{I_{S1}} I_{c1} \times \frac{\left(1 + \frac{V_{CE2}}{V_{A2}}\right)}{\left(1 + \frac{V_{CE1}}{V_{A1}}\right)} \approx \frac{I_{S2}}{I_{S1}} I_{c1} \times \left[1 + \frac{(V_{DS2} - V_{DS1})}{V_A}\right]$$

$$I_{ref} = I_{C1} + I_{B1} + I_{B2} = I_{C1} + \frac{I_{C1}}{\beta_1} + \frac{I_{C2}}{\beta_2} \approx I_{C1} + \frac{I_{C1}}{\beta_1} + \frac{I_{S2}}{I_{S1}} \frac{I_{C1}}{\beta_2}$$

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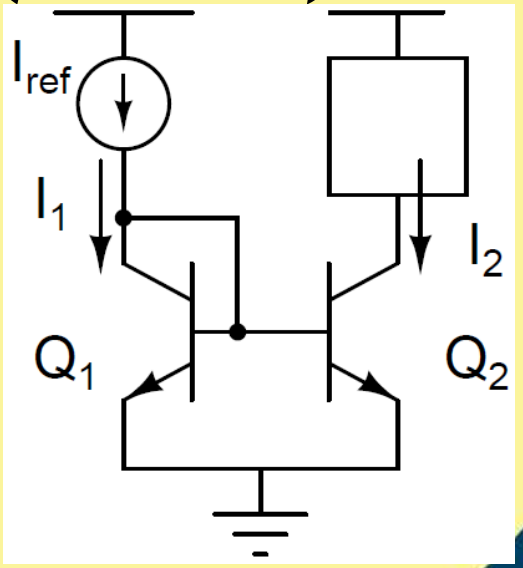
Analysis of a *current mirror (using BJTs)* (contd.)



- **Expression of output current – Non-ideality factor**

$$I_{C2} \approx \frac{I_{S2}}{I_{S1}} I_{c1} \times \left[1 + \frac{(V_{DS2} - V_{DS1})}{V_A}\right] \qquad I_{ref} \approx I_{C1} + \frac{I_{C1}}{\beta_1} + \frac{I_{S2}}{I_{S1}} \frac{I_{C1}}{\beta_2}$$

$$I_{C2} \approx \frac{I_{S2}}{I_{S1}} I_{ref} \times \frac{1}{\left[1 + \frac{1}{\beta_1} + \frac{I_{S2}}{I_{S1}} \frac{1}{\beta_2}\right]} \times \left[1 + \frac{(V_{DS2} - V_{DS1})}{V_A}\right]$$

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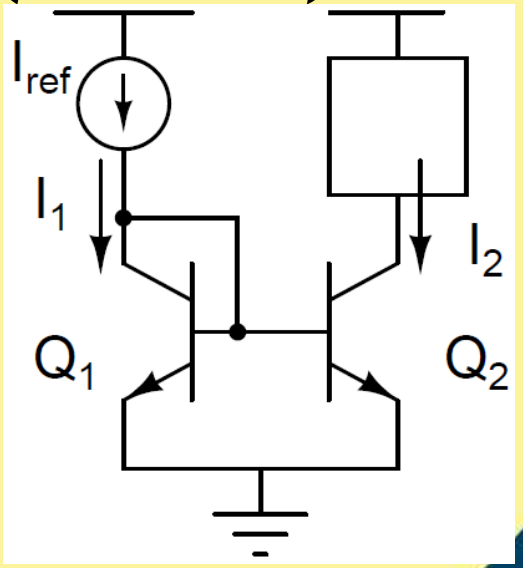
Analysis of a *current mirror (using BJTs)* *(contd.)*

- **Expression of output resistance**
- **Minimum voltage required across output port of CM**



$$I_{C2} \approx \frac{I_{S2}}{I_{S1}} I_{ref} \times \frac{1}{\left[1 + \frac{1}{\beta_1} + \frac{I_{S2}}{I_{S1}} \frac{1}{\beta_2}\right]} \times \left[1 + \frac{(V_{DS2} - V_{DS1})}{V_A}\right]$$

$$\approx I_{C2}^{*} + I_{C2}^{*} \times \frac{(V_{DS2} - V_{DS1})}{V_A} \qquad \approx I_{C2}^{*} + \frac{(V_{DS2} - V_{DS1})}{r_{o2}}$$

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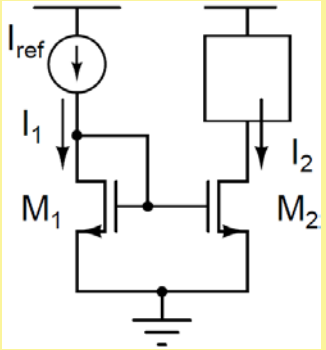
Enhancement of simple current mirror (cascode current mirror)

- Increasing output resistance



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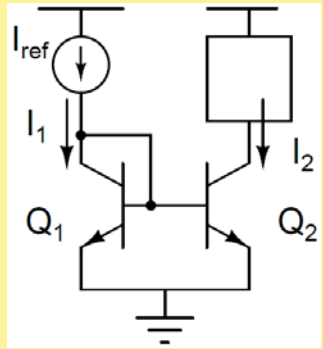
Enhancement of simple current mirror (cascode current mirror)

- Increasing output resistance



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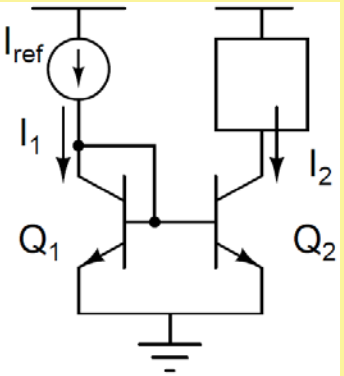
Enhancement of simple current mirror (Beta-helper)

- Increasing current accuracy



$$I_{ref} \approx I_{C1} + \frac{1}{(1+\beta_5)}\left\{\frac{I_{C1}}{\beta_1} + \frac{I_{S2}}{I_{S1}}\frac{I_{C1}}{\beta_2}\right\}$$

$$I_{C2} \approx \frac{I_{S2}}{I_{S1}} I_{ref} \times \frac{1}{\left[1 + \frac{1}{(1+\beta_5)}\left\{\frac{1}{\beta_1} + \frac{I_{S2}}{I_{S1}}\frac{1}{\beta_2}\right\}\right]} \times \left[1 + \frac{(V_{DS2} - V_{DS1})}{V_A}\right]$$

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Conclusion

Conclusion:

- **Motivation / need of using current mirror (CM)**
  - Current biasing element in amplifiers
  - Basic characteristic – output impedance should be high
  - Signal mirroring circuit in current mode amplifier
- **Basic structure & Operating principle**
  - Different versions of current biasing element leading to CM
  - Current reference-mirror pair transistors
- **Analysis of current mirror**
  - Expression of output current
  - Output resistance
  - Advancement of current mirror
- ***Small signal model of current mirror to be discussed***

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Thank you

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Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Usage of Current mirror

Flow of Discussion (Bottom-up)

—*Building blocks and Models*

- System /Sub-systems (*for specific application*)
  - **Modules** (*performing specific tasks*)
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- **Week 9 (Course Module 8)**:
  - Current mirror
    - operating principle and analysis,
  - **Use of current mirror**
    - **as bias circuit and for signal amplification (in CE/CS, CC/CD, CB/CG and**
    - **Differential amplifier).**
  - **Use of current mirror**
    - **as signal mirror (for current mode operation).**

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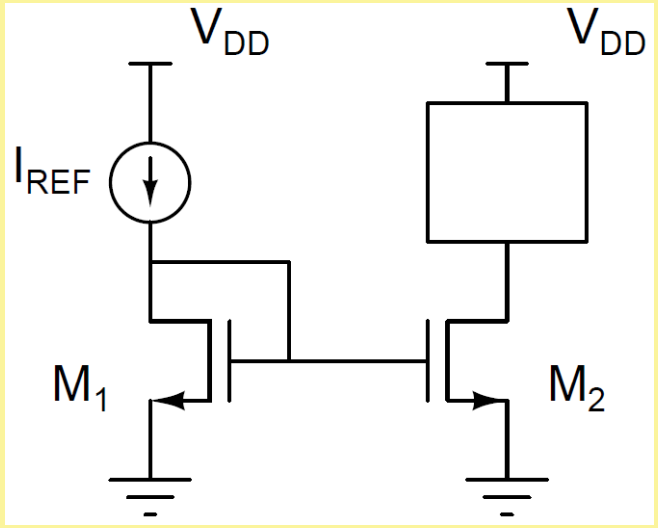
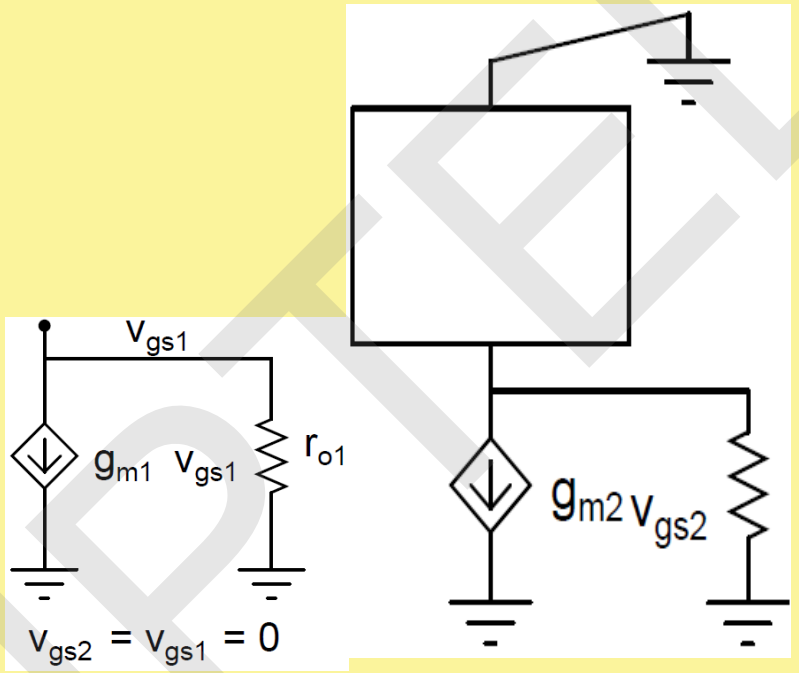
CONCEPTS COVERED

Concepts Covered:

- **Small signal model of current mirror**
  - Under D.C. condition (BJTs and MOSFETs)
  - Carrying current signal (BJT and MOSFETs)
- **Usage of current mirror**
  - As bias element in CE and CS amplifier
  - As bias element in CC and CD amplifier
- **Usage of current mirror in Differential amp.**
  - As bias elements
  - As signal mirroring element

Small signal equivalent circuit of a current mirror (*using MOSFETs*)





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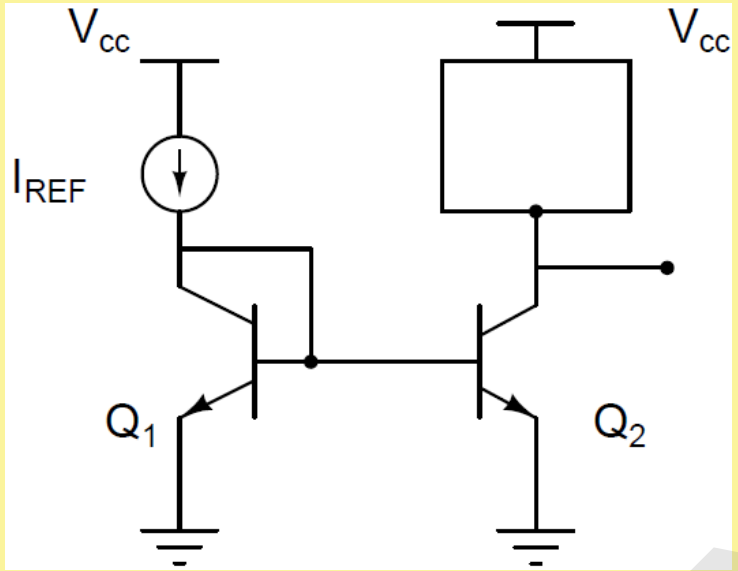
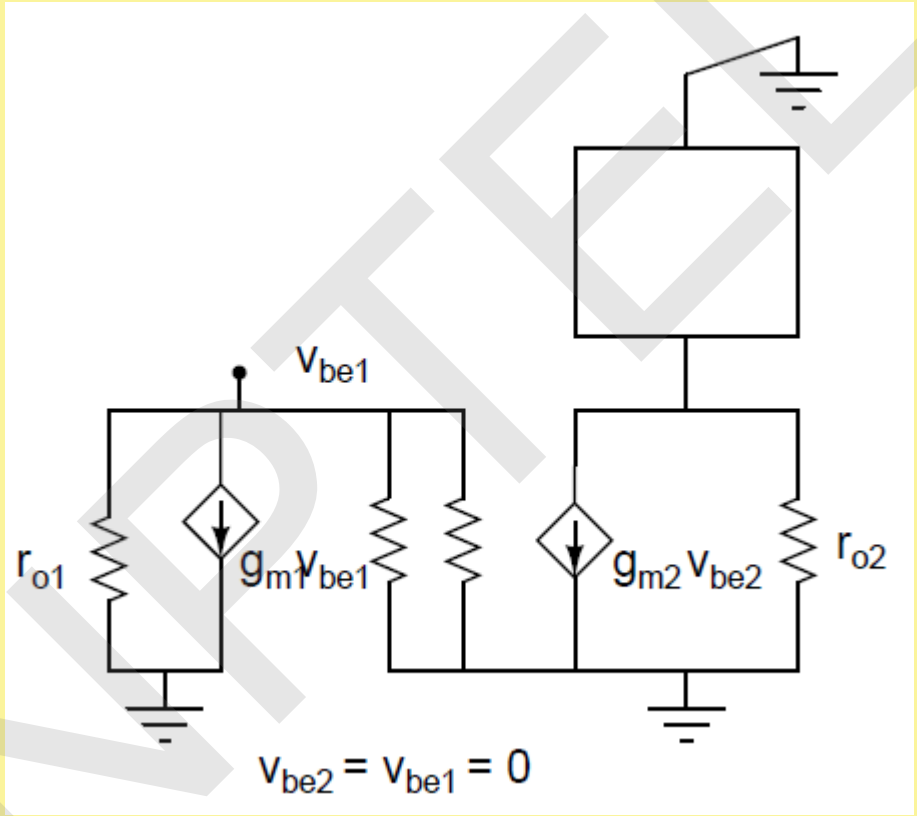
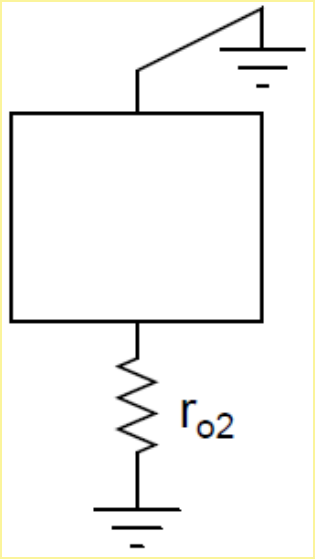
Small signal equivalent circuit of a current mirror (*using BJTs*)







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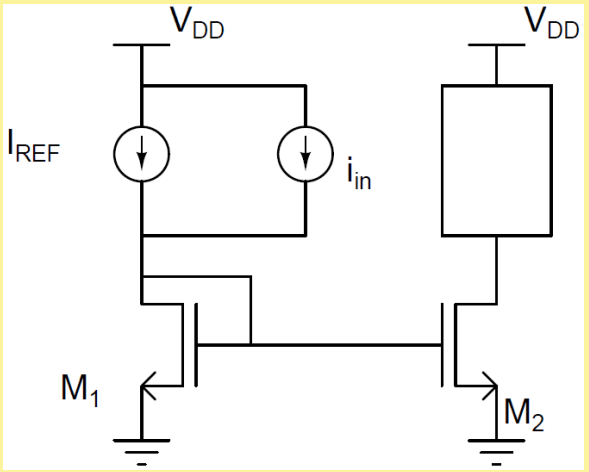
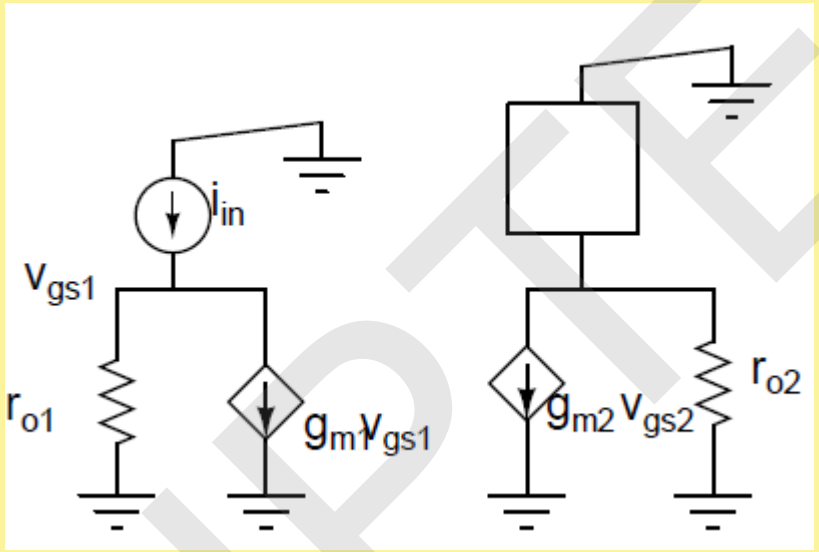
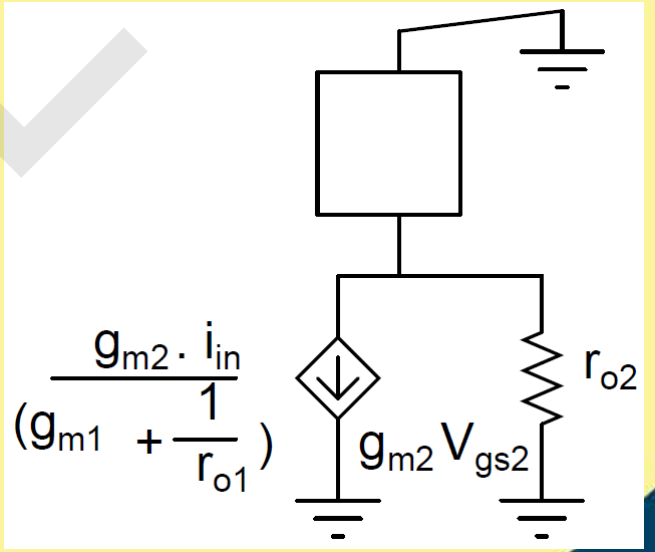
Small signal equiv. circuit of a current mirror (MOSFETs)

having a.c. current signal







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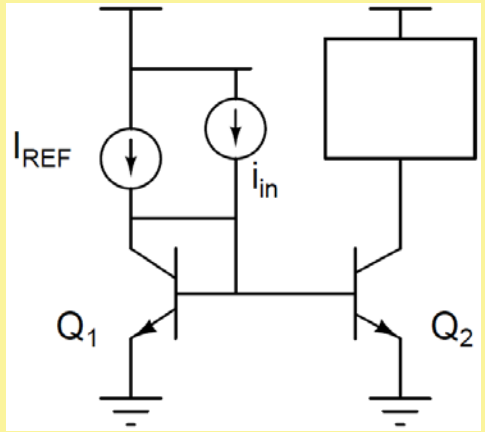
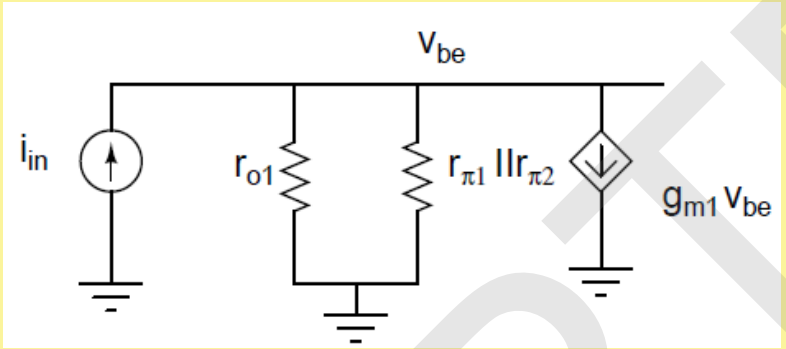
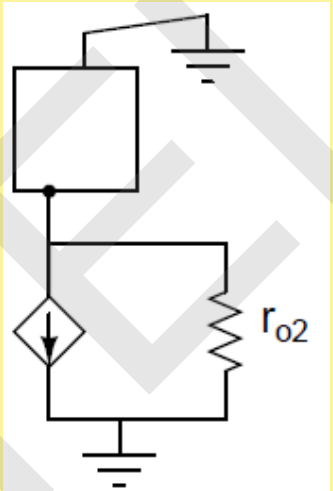
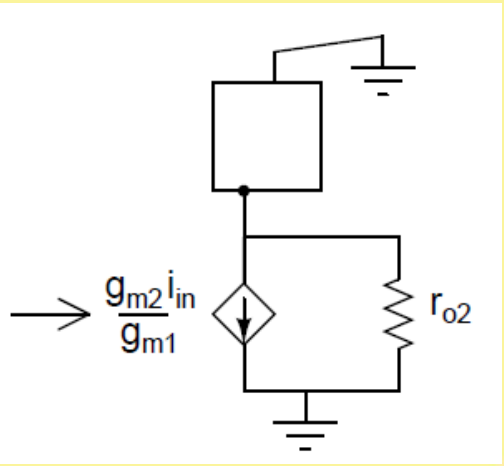
Small signal equiv. circuit of a current mirror (BJTs)

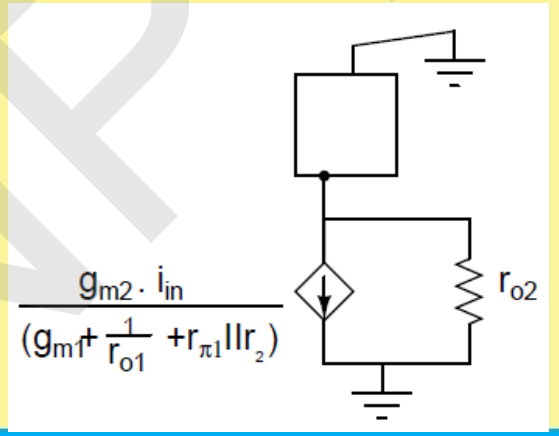
having a.c. current signal











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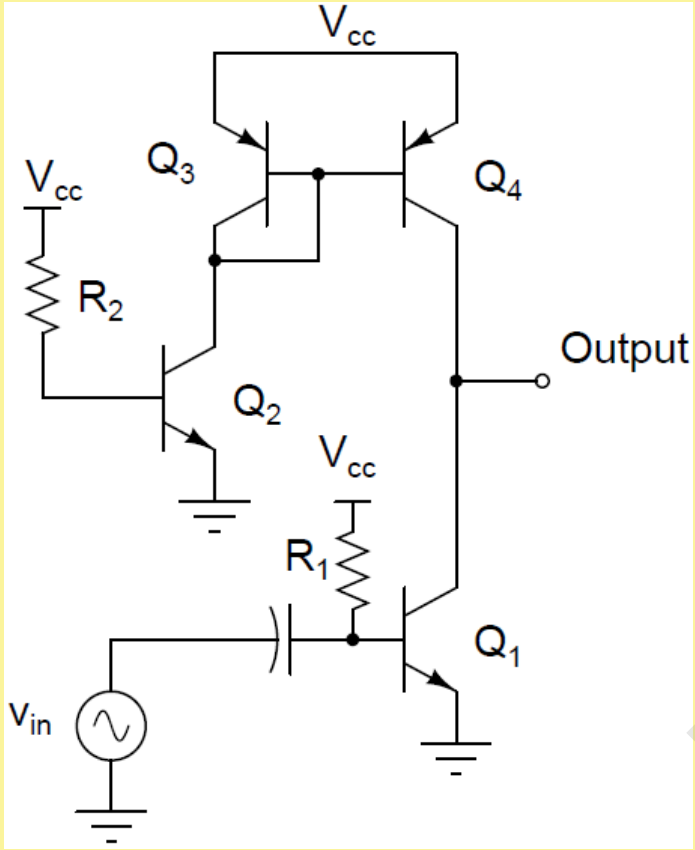
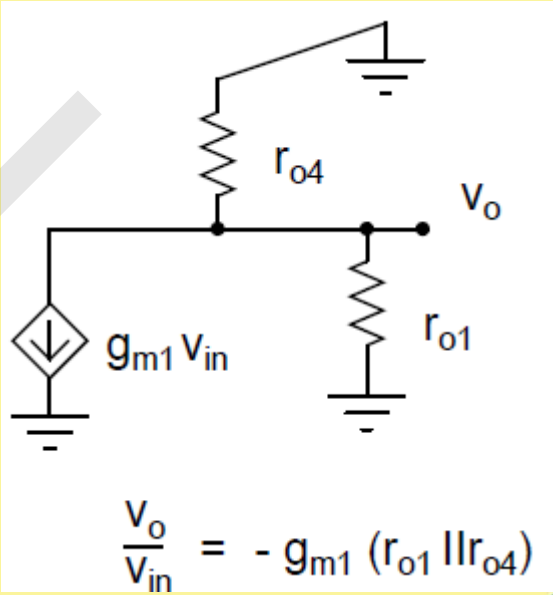
Usage of current mirror in CE amplifier with active load





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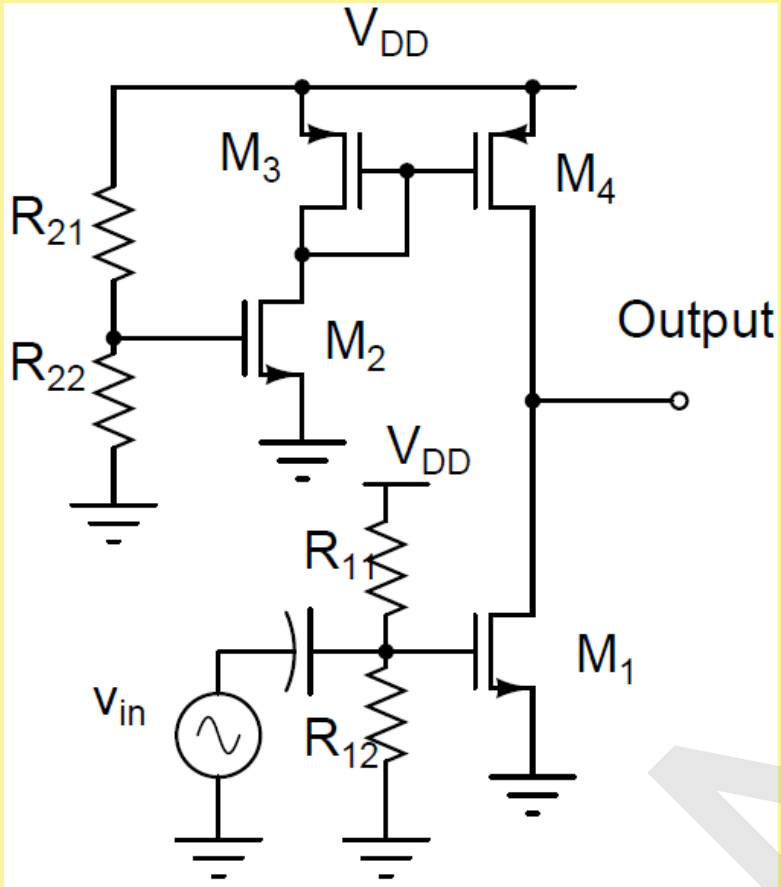
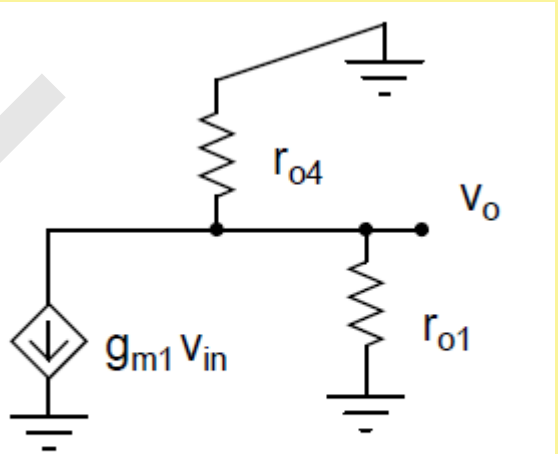
Usage of current mirror in CS amplifier with active load





$$\frac{v_o}{v_{in}} = -g_{m1}(r_{o1} \| r_{o4})$$

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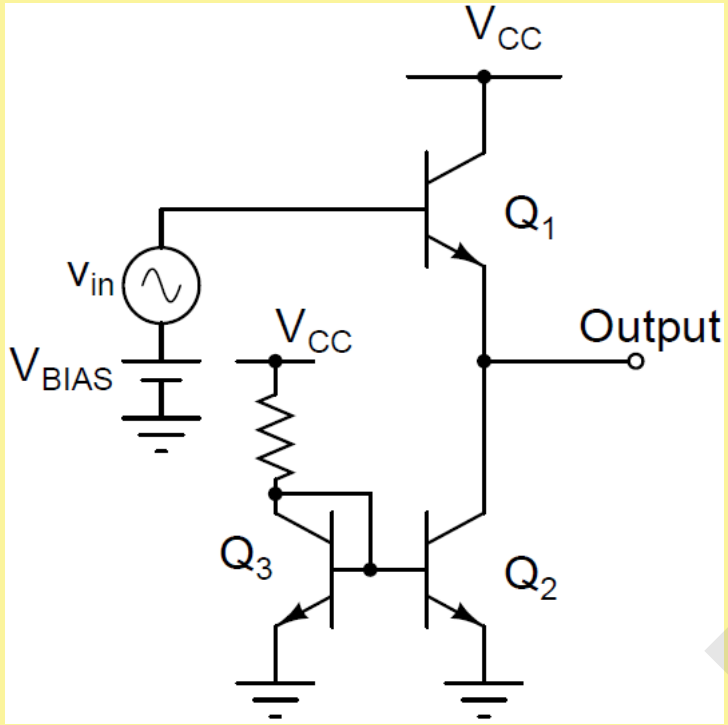
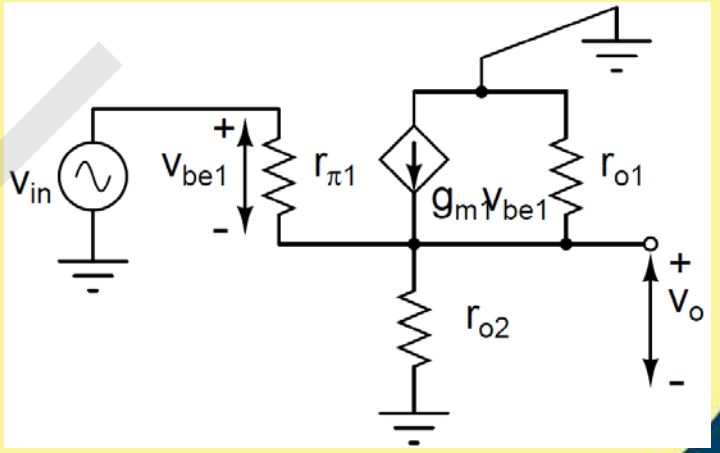
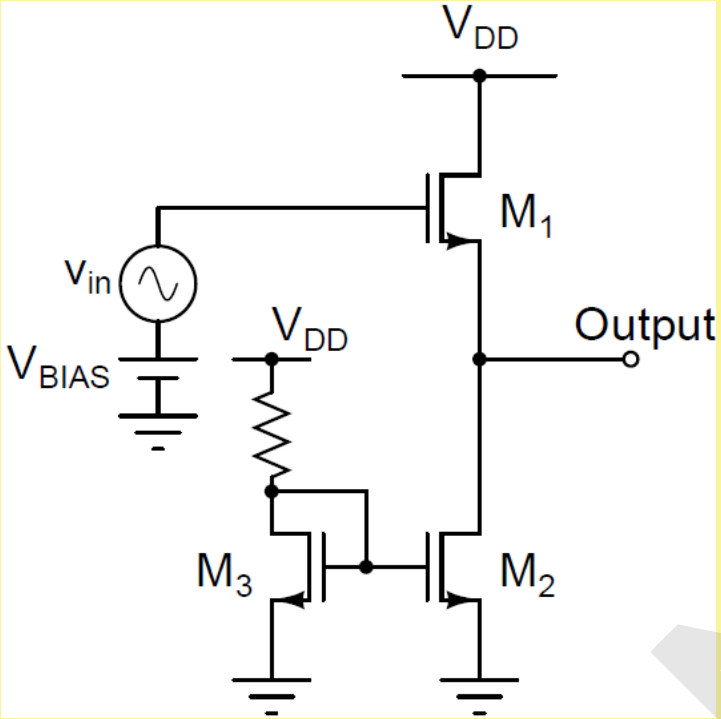
Usage of current mirror in CC amplifier

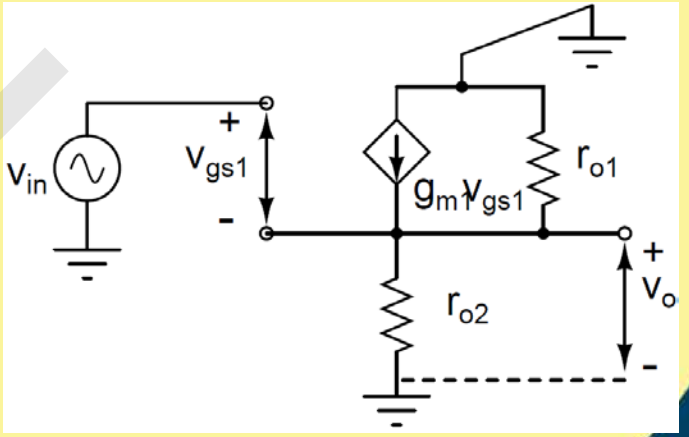




NPTEL

Usage of current mirror in CD amplifier

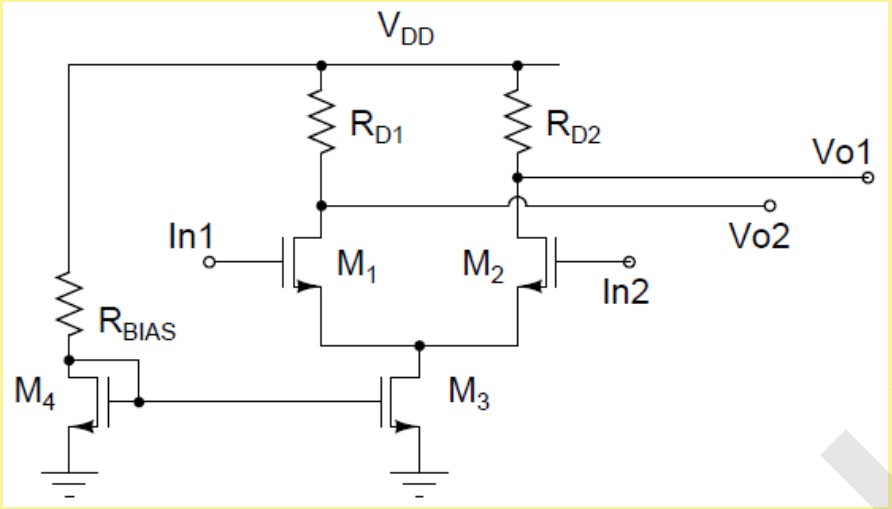


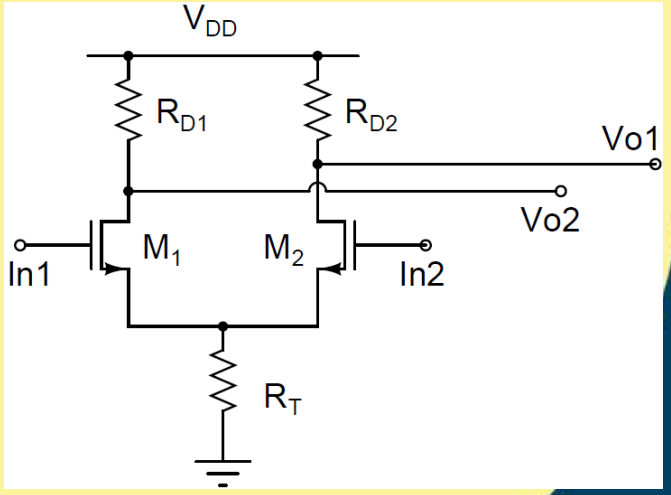


NPTEL

Usage of current mirror in Differential amplifier using MOSFETs

- **Replace Tail resistor to improve common mode gain**

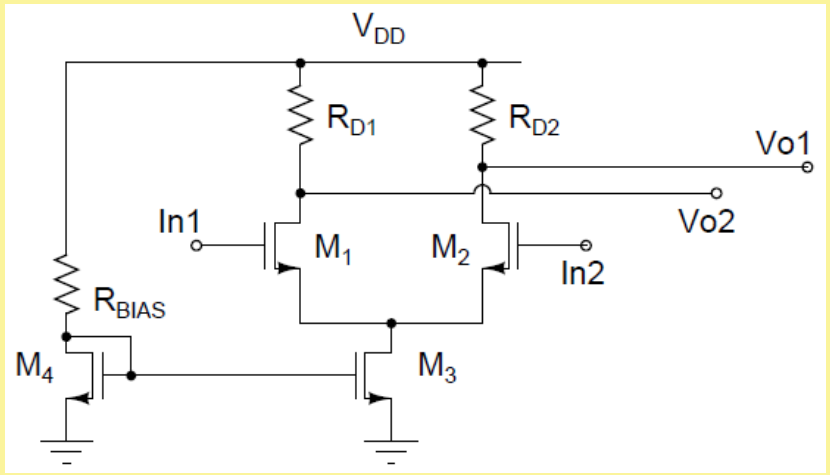


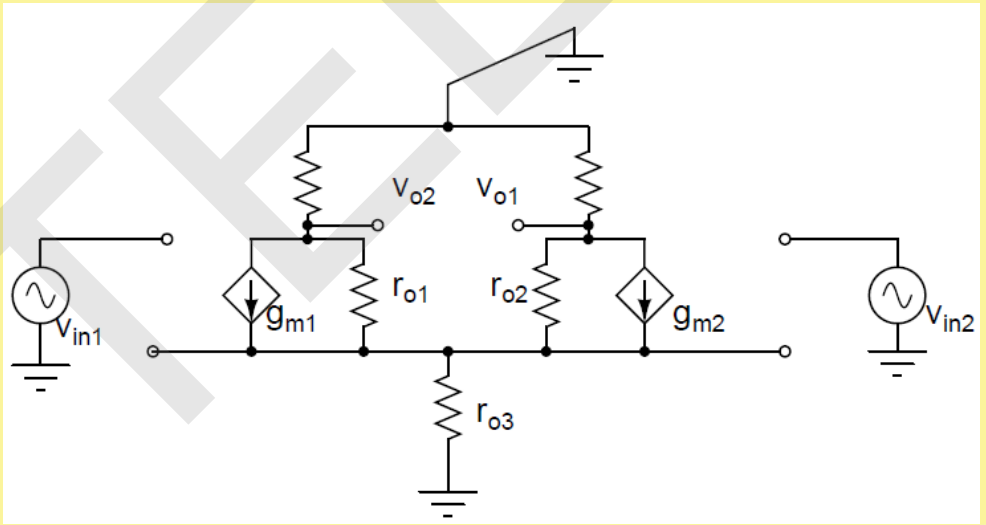


NPTEL

Usage of current mirror in Differential amplifier using MOSFETs

- **Replace Tail resistor to improve common mode gain**

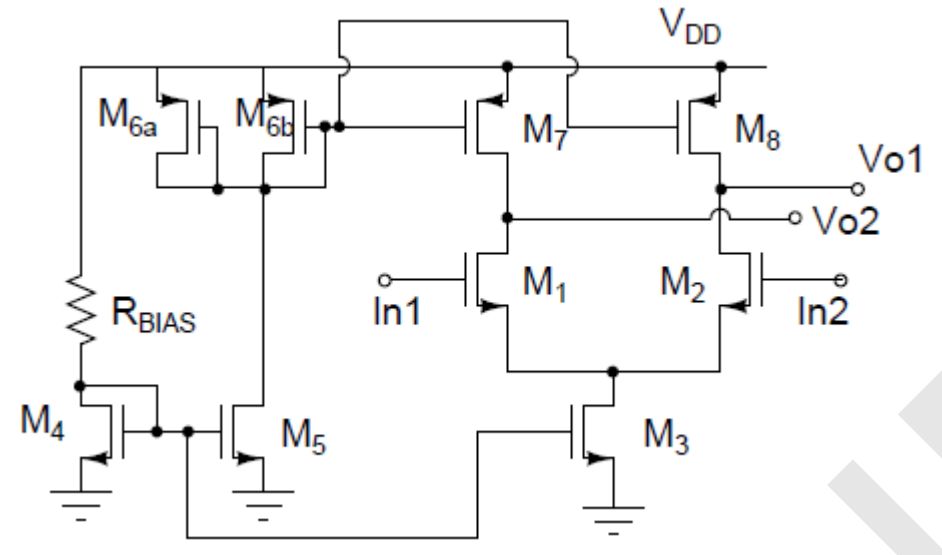


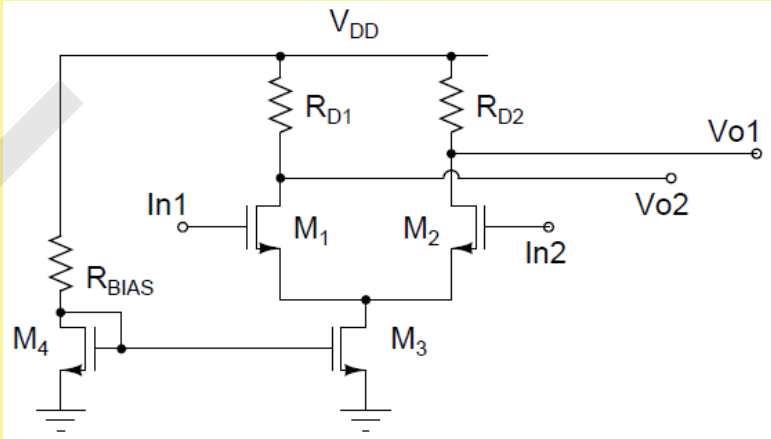


NPTEL

Usage of current mirror in Differential amplifier using MOSFETs *(contd.)*

- **Replace load resistors to improve differential mode gain**

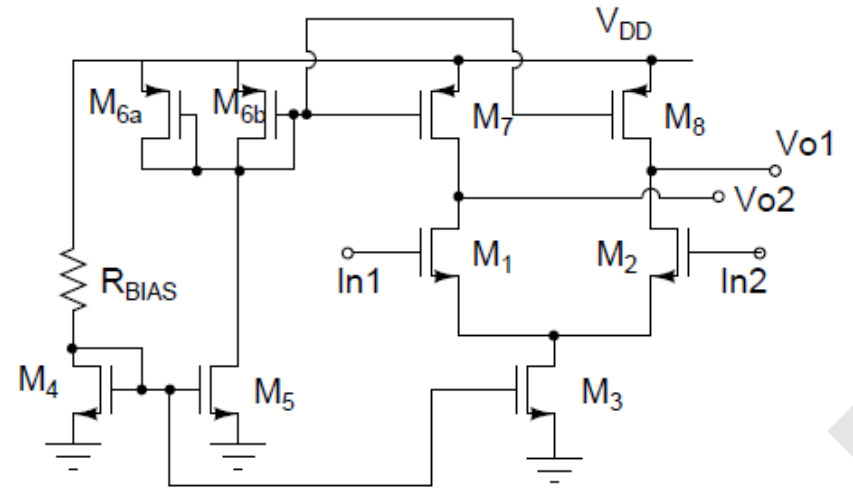


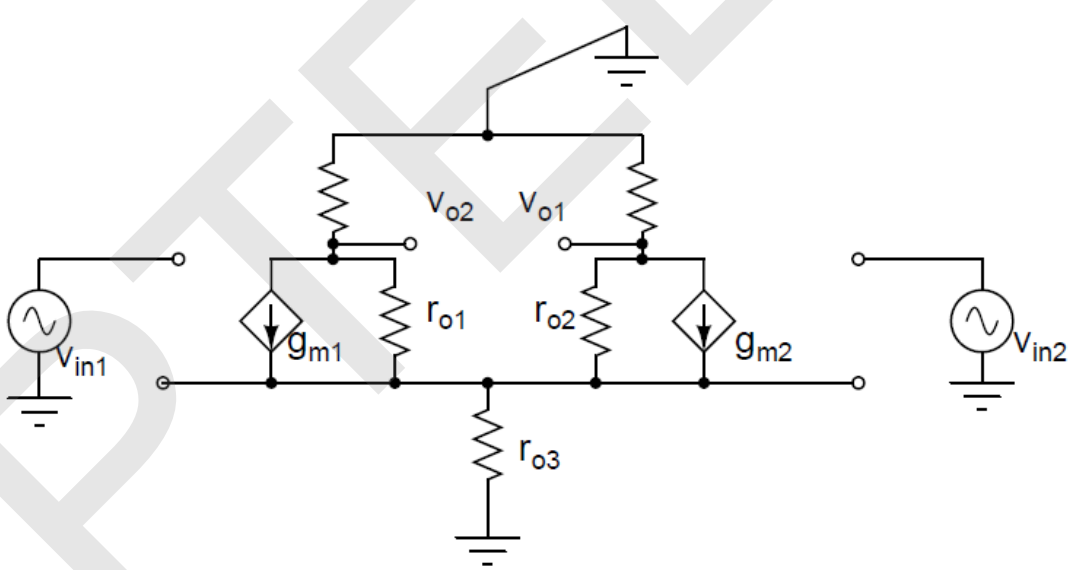


NPTEL

Usage of current mirror in Differential amplifier using MOSFETs *(contd.)*

- **Replace load resistors to improve differential mode gain**





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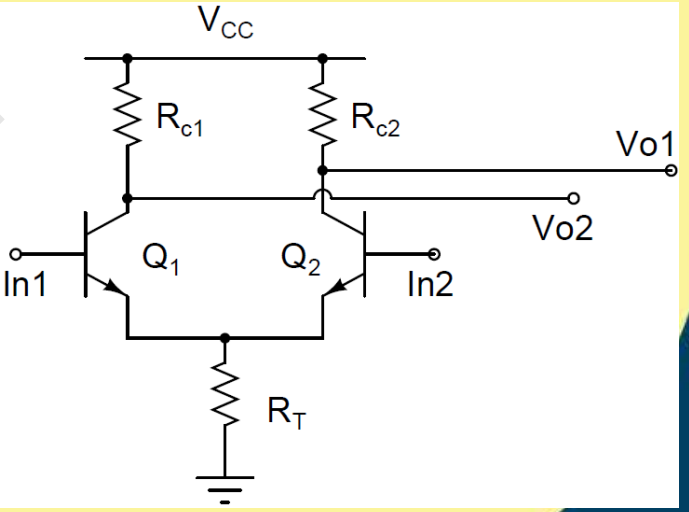
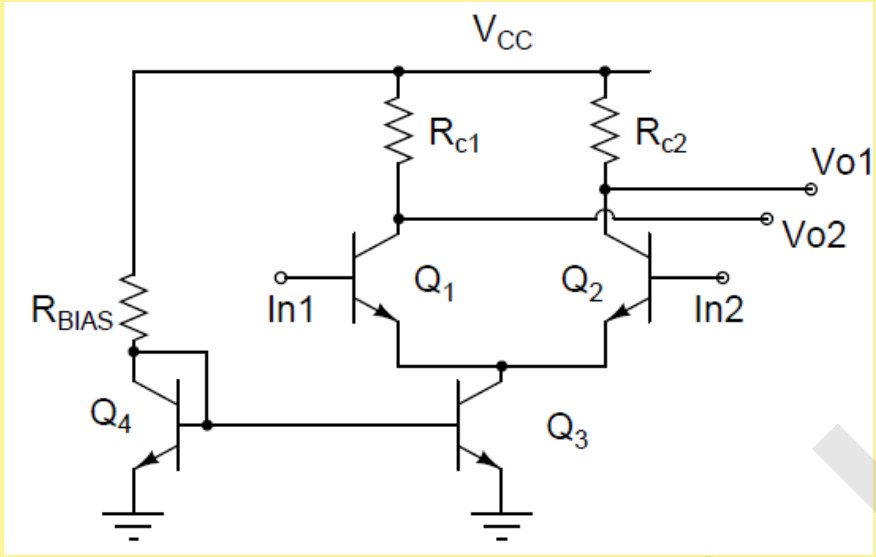
Usage of current mirror in Differential amplifier using BJTs

- **Replace Tail resistor to improve common mode gain**

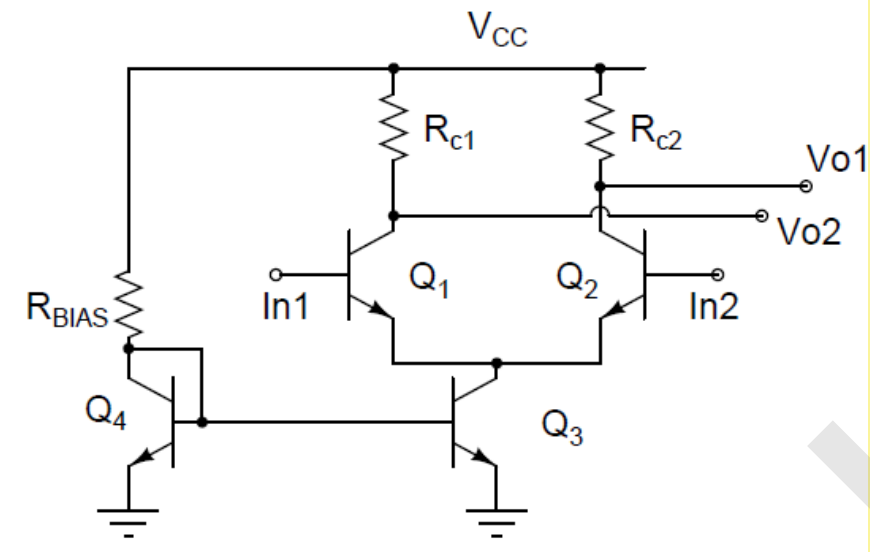


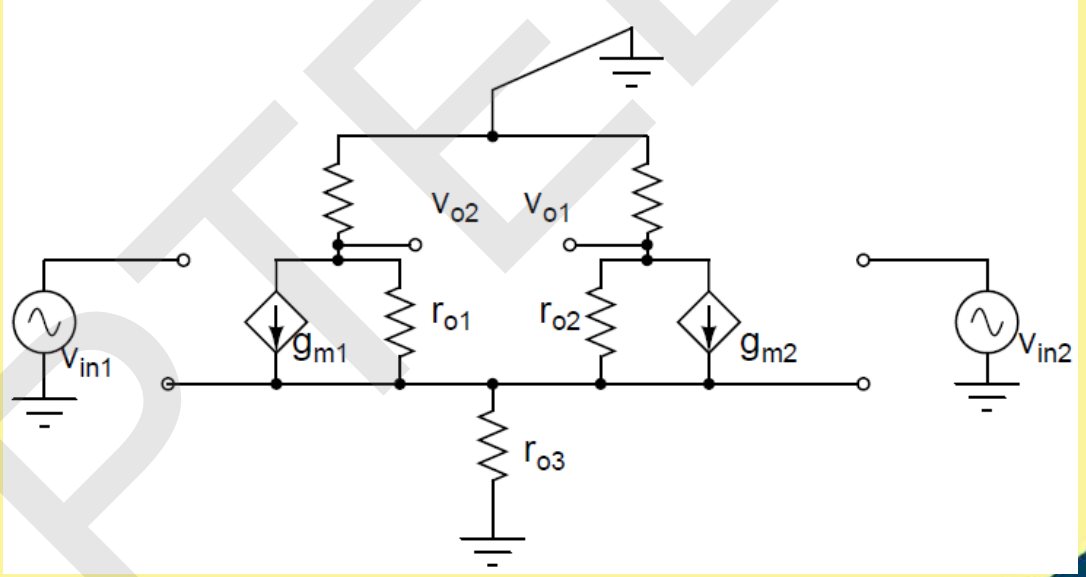


NPTEL

Usage of current mirror in Differential amplifier using BJTs

- **Replace Tail resistor to improve common mode gain**

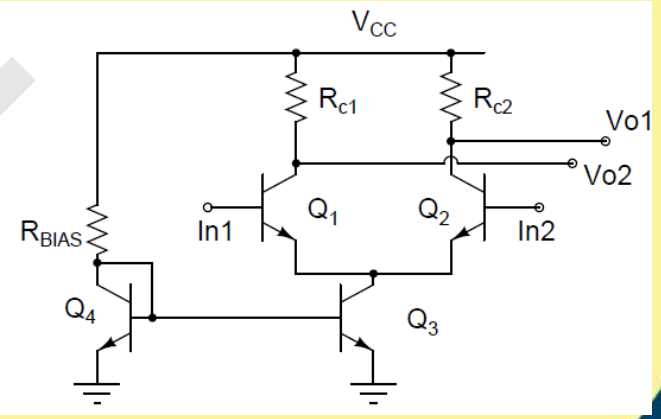


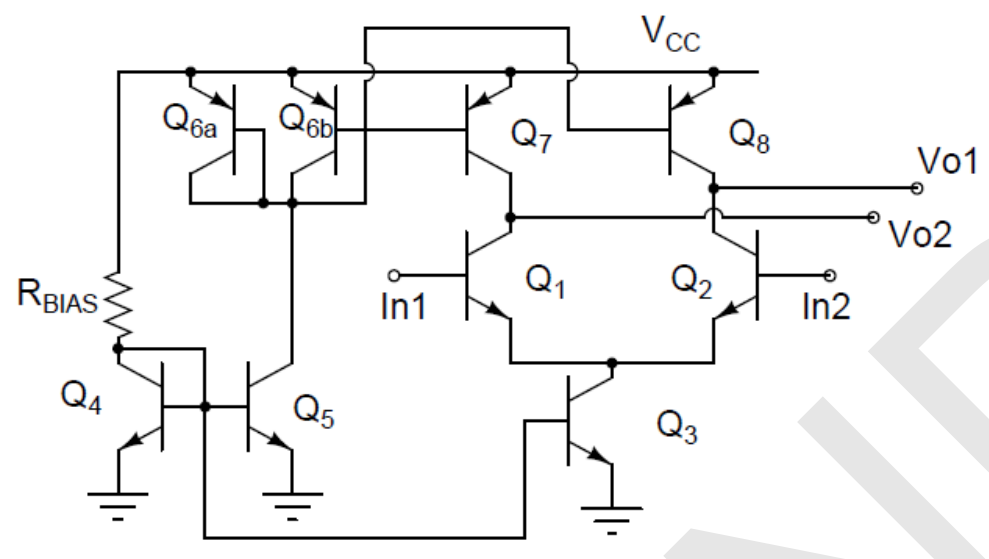


NPTEL

Usage of current mirror in Differential amplifier using BJTs *(contd.)*

- **Replace load resistors to improve differential mode gain**

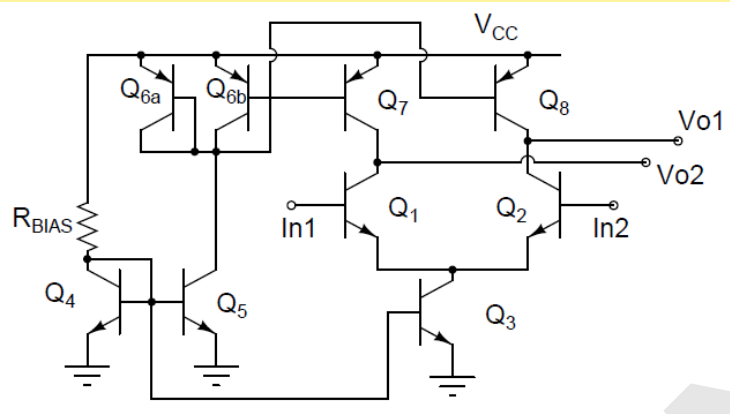


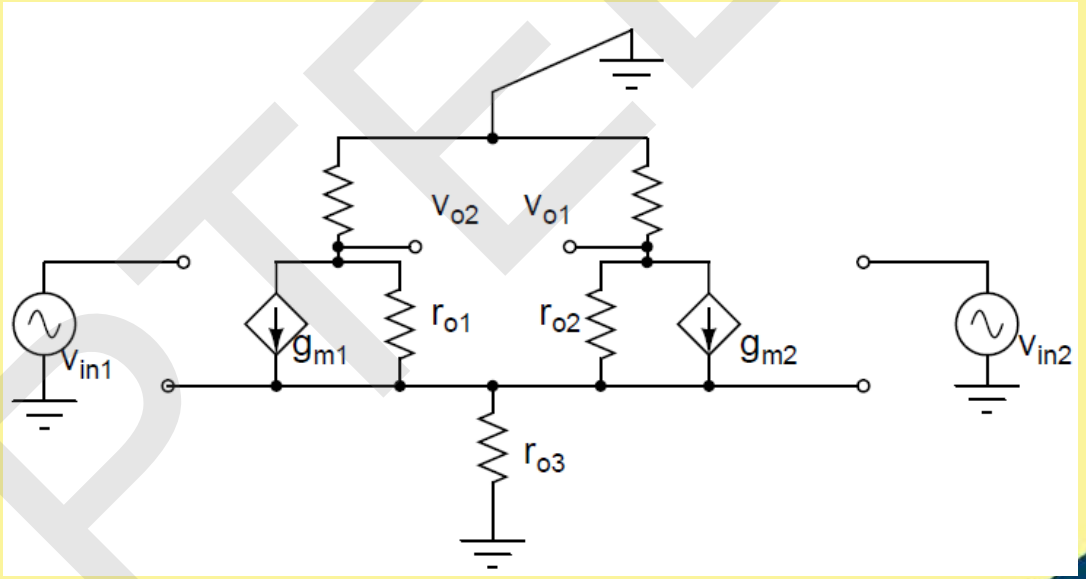


NPTEL

Usage of current mirror in Differential amplifier using BJTs *(contd.)*

- **Replace load resistors to improve differential mode gain**





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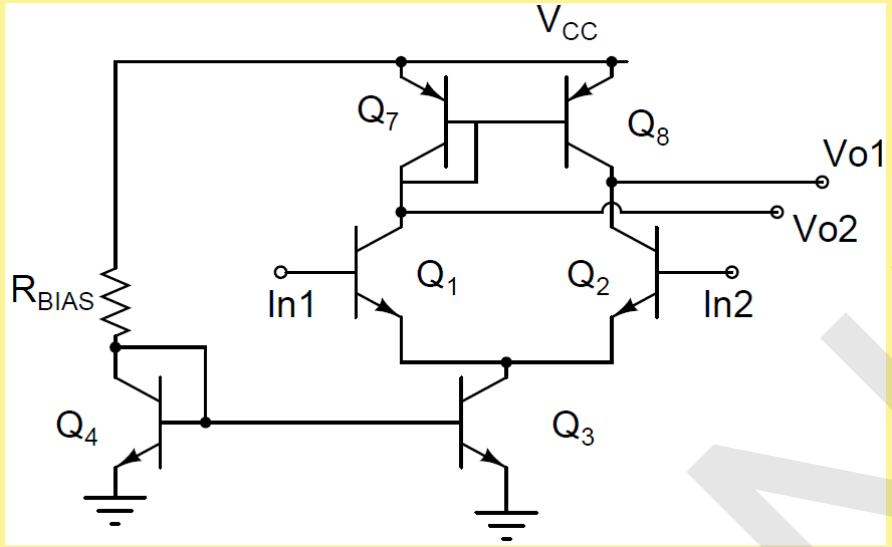
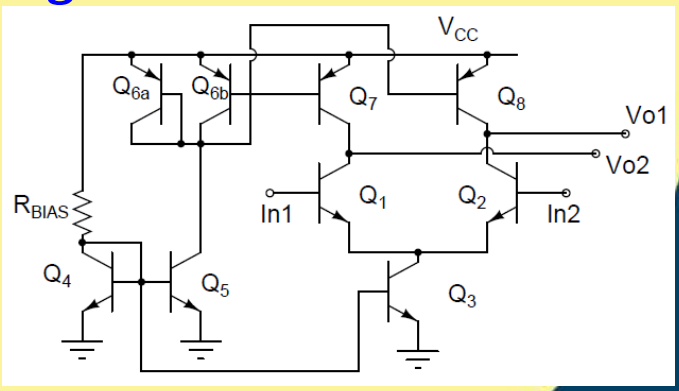
Usage of current mirror in Differential amplifier using BJTs *(contd.)*

- **Replace load to improve differential mode gain and common mode gain**





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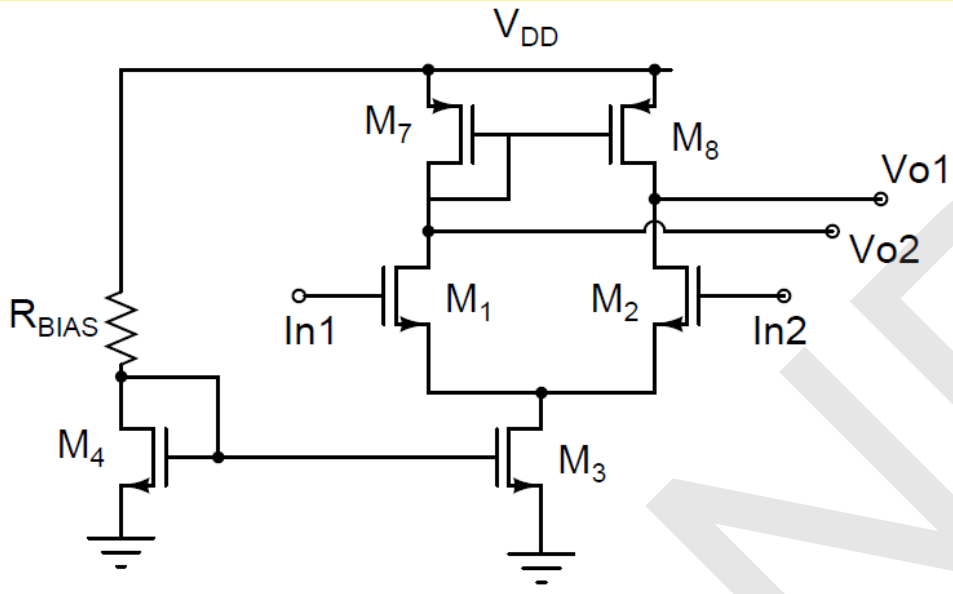
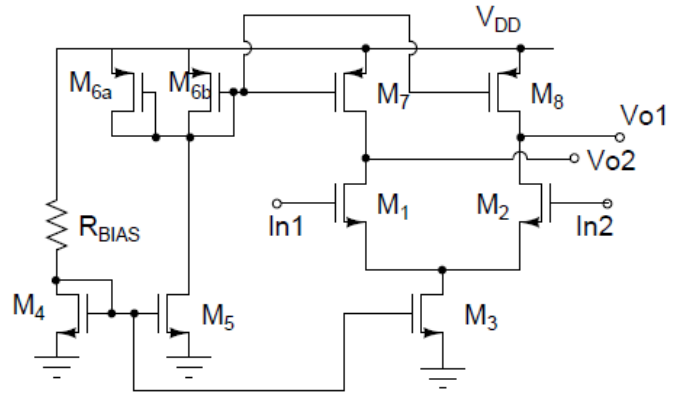
Usage of current mirror in Differential amplifier using BJTs *(contd.)*

- **Replace load to improve differential mode gain and common mode gain**





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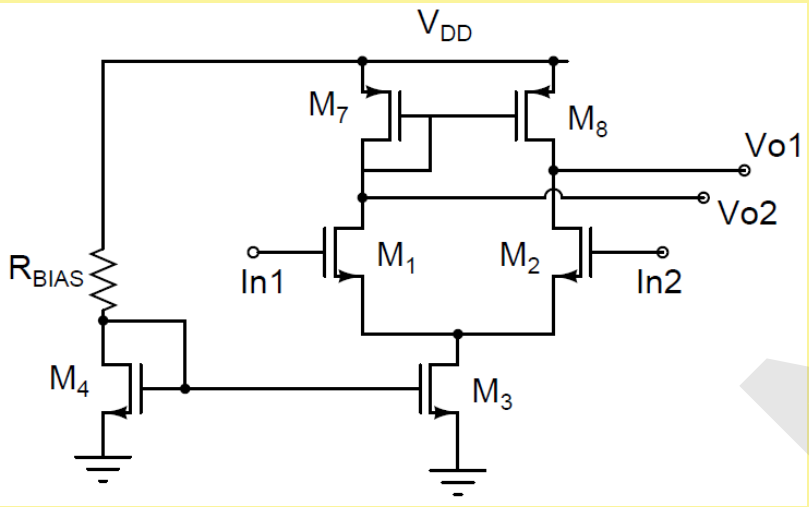
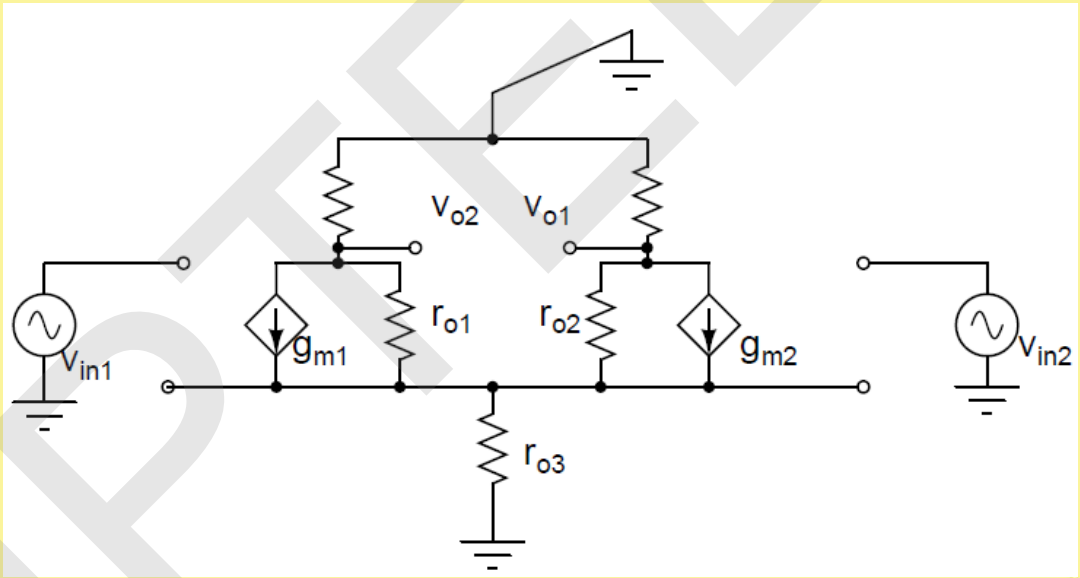
Usage of current mirror in Differential amplifier using BJTs *(contd.)*

- **Replace load to improve differential mode gain and common mode gain**





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Conclusion

Conclusion:

- **Small signal model of current mirror**
  - Under D.C. condition (BJTs and MOSFETs)
  - Carrying current signal (BJT and MOSFETs)
- **Usage of current mirror**
  - As bias element in CE and CS amplifier
  - As bias element in CC and CD amplifier
- **Usage of current mirror in Differential amplifier**
  - As bias elements
  - As signal mirroring element

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Thank you

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Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Numerical examples on Current mirror and its applications

Flow of Discussion (Bottom-up)

—*Building blocks and Models*

- System /Sub-systems (*for specific application*)
  - **Modules** (*performing specific tasks*)
    - **Building blocks** (*having specific characteristics*) **- Bias circuits**
      - Components (*devices/circuit elements*)

- **Week 9 (Course Module 8)**:
  - **Current mirror**
    - **operating principle and analysis,**
  - **Use of current mirror**
    - **as bias circuit and for signal amplification (in CE/CS, CC/CD, CB/CG and**
    - **Differential amplifier).**
  - **Use of current mirror**
    - **as signal mirror (for current mode operation).**

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CONCEPTS COVERED

Concepts Covered:

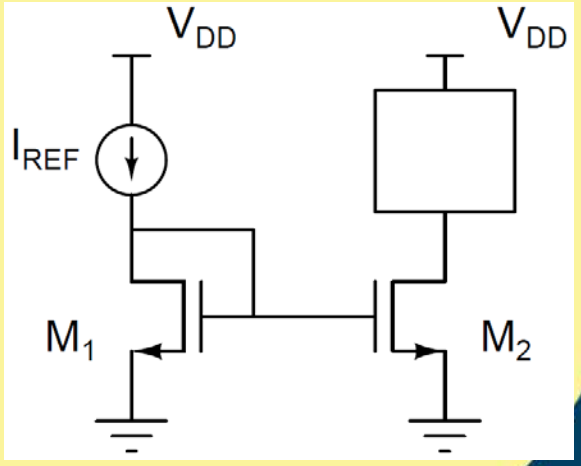
- **Numerical examples on simple current mirror**
  - Using MOSFETs
  - Using BJTs
- **Numerical examples on improvised CM**
  - Using BJTs
  - Using MOSFETs
- **Numerical examples on amplifiers having CM**
  - CE/CS amplifiers
  - Differential amplifiers

Numerical example on simple current mirror (*using MOSFETs*)

- **Example 1:**
- **$(K_n.W1/L1) = 1$ mA/V^2, $(K_n.W2/L2) = 4$ mA/V^2; $V_{th1} = V_{th2} = 1.5$V,**
- **$I_{REF} = 0.5$ mA, $V_{DD} = 12$V**

(i) Considering $\lambda 1 = \lambda 2 \approx 0.0$/V ,

- **Find the values of V_{GS1} and I_{DS2}**
- **Find $V_{DS(min)}$ for proper operation of the circuit**



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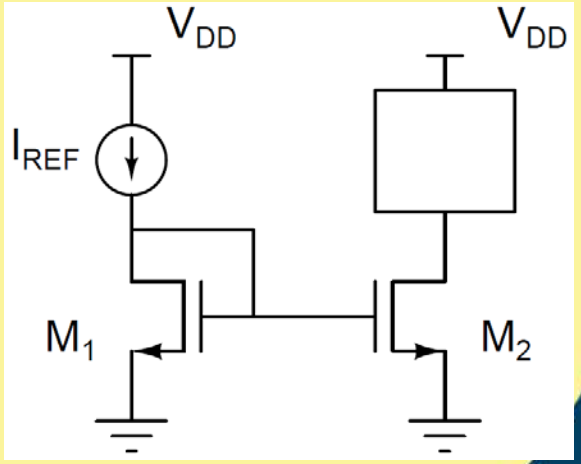
Numerical example on simple current mirror (*using MOSFETs*)

- **Example 1 (contd.):**

- **$(K_n.W1/L1) = 1$ mA/V^2, $(K_n.W2/L2) = 4$ mA/V^2; $V_{th1} = V_{th2} = 1.5$V,**
- **$I_{REF} = 0.5$ mA, $V_{DD} = 12$V**

(ii) Considering $\lambda 1 = \lambda 2 \approx 0.01$ /V ,

- **Find the values of $I_{DS}2$ for VDS2 = 2.5V and 5.5V**
- **Calculate the small signal output resistance of the current mirror**



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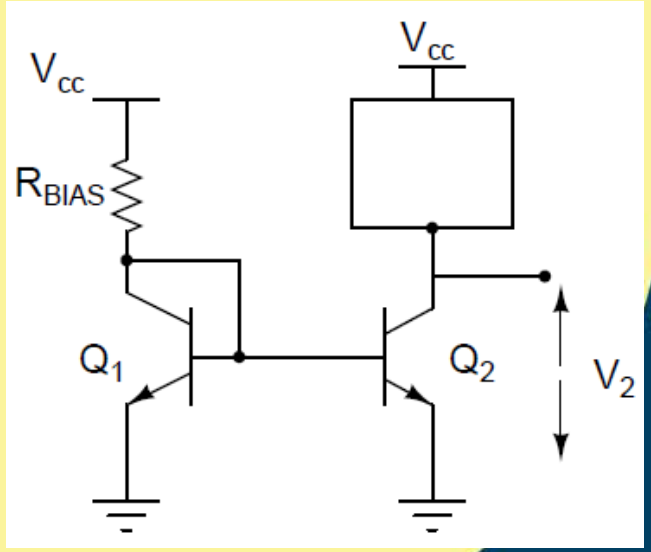
Numerical example on simple current mirror (*using BJTs*)

- **Example 2:**
- Assume that, $V_{BE(on)1} = V_{BE(on)2} \approx 0.6V$,
- $I_{S1} = 9.5 \times 10^{-14}$ Amp, $I_{S2} = 2.85 \times 10^{-13}$ Amp,
- $V_{CC} = 12V$; $R_{BIAS} = 22.8\ k\Omega$

(i) Considering $\beta 1$, $\beta 2$, V_{A1} and V_{A2} are having very high values, calculate I_{C2}. Also, find $V_{2(min)}$ for proper operation of the circuit

(ii) Considering $\beta 1 = 100$, $\beta 2 = 150$ and, V_{A1} and V_{A2} are having very high values, calculate I_{C2}



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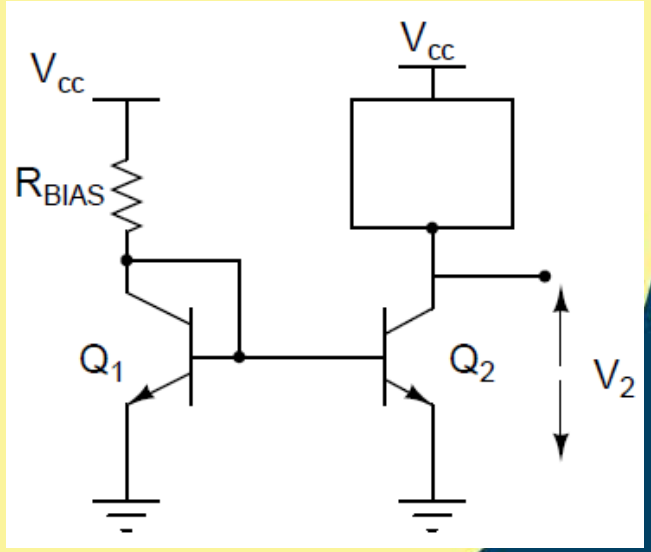
Numerical example on simple current mirror (*using BJTs*)

- **Example 2 (contd.):**
- **Assume that, $V_{BE(on)1} = V_{BE(on)2} \approx 0.6V$,**
- **$I_{S1} = 9.5 \times 10^{(-14)}$ Amp, $I_{S2} = 2.85 \times 10^{(-13)}$ Amp,**
- **$V_{CC} = 12V$; $R_{BIAS} = 22.8\ k\Omega$**

(iii) Considering $\beta 1 = 100$, $\beta 2 = 150$ and, $v_{A1} = 50V$ and $v_{A2} = 100V$,

calculate I_{C2} for V2 = 0.6V and 5.6V.

Also, calculate small signal output resistance



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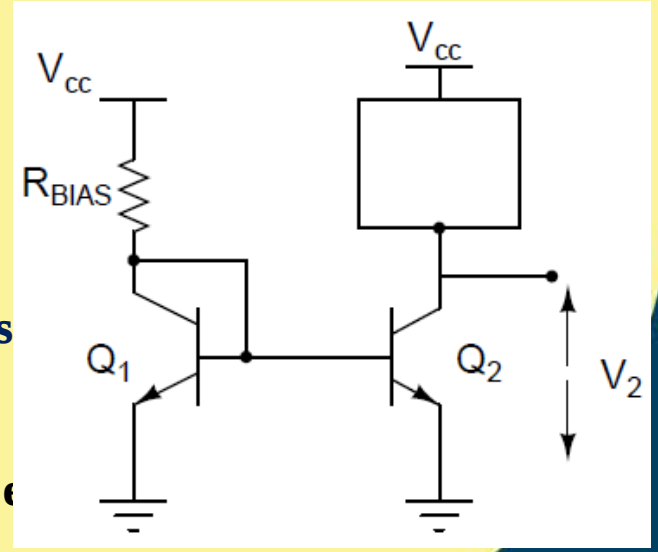
Numerical example on improved current mirror (*using BJTs*)

- **Example 3:**
- Assume that, $V_{BE(on)1} = V_{BE(on)2} \approx 0.6V$,
- $I_{S1} = 9.5 \times 10^{(-14)}$ Amp, $I_{S2} = 2.85 \times 10^{(-13)}$ Amp,
- $V_{CC} = 12V$; $R_{BIAS} = 22.8\ k\Omega$
- Consider $\beta 1 = 100$, $\beta 2 = 150$ and, V_{A1} and V_{A2} are having very high values



(i) Calculate the non-ideality factor due base current loss.

(ii) Add a Beta helper transistor (Q3) in the current mirror for more accurate current mirror ratio.

Also, adjust the value of RBIAS to 21.6 kΩ to keep the reference current same. Calculate the non-ideality factor and then IC2 assuming β3 = 99

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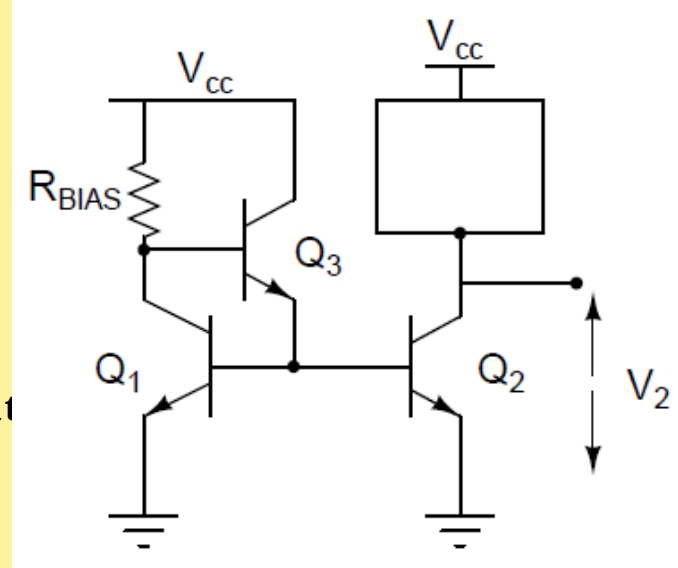
Numerical example on improved current mirror (*using BJTs*)

- **Example 3 (contd.) :**
- **Assume that, $V_{BE(on)1} = V_{BE(on)2} \approx 0.6V$,**
- **$I_{S1} = 9.5 \times 10^{(-14)}$ Amp, $I_{S2} = 2.85 \times 10^{(-13)}$ Amp,**
- **$V_{CC} = 12V$; $R_{BIAS} = 22.8\ k\Omega$**
- **Consider $\beta 1 = 100$, $\beta 2 = 150$ and, V_{A1} and V_{A2} are having very high values,**



(ii) Add a Beta helper transistor (Q3) in the current mirror for more accurate current mirror ratio.

Also, adjust the value of RBIAS to 21.6 kΩ to keep the reference current same.
Calculate the non-ideality factor and then IC2 assuming β3 = 99

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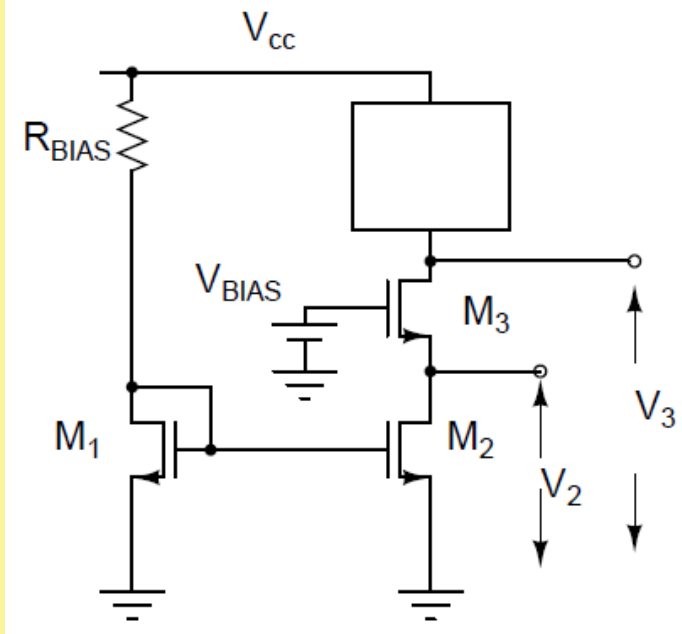
Numerical example on improved current mirror (*using MOSFETs*)



- **Example 4:**
- **$(K_n.W1/L1) = 1$ mA/V^2, $(K_n.W2/L2) = (K_n.W3/L3) = 4$ mA/V^2;**
- **Vth = 1.5V, $\lambda 2 \approx 0.01$/V**
- **R_{BIAS} = 19 kΩ, V_{BIAS} = 5V, V_{DD} = 12V**

(i) Find the values of V_{GS1} and I_{DS1}

(ii) Find the values of V2 and I_{DS2}

[Hint: assume M2 and M3 are in saturation region and $V_{DS2} = V_{DS3}$]

(ii) For V3 = 5V, calculate small signal output resistance. Using this information, calculate I_{DS3} for V3 = 8V

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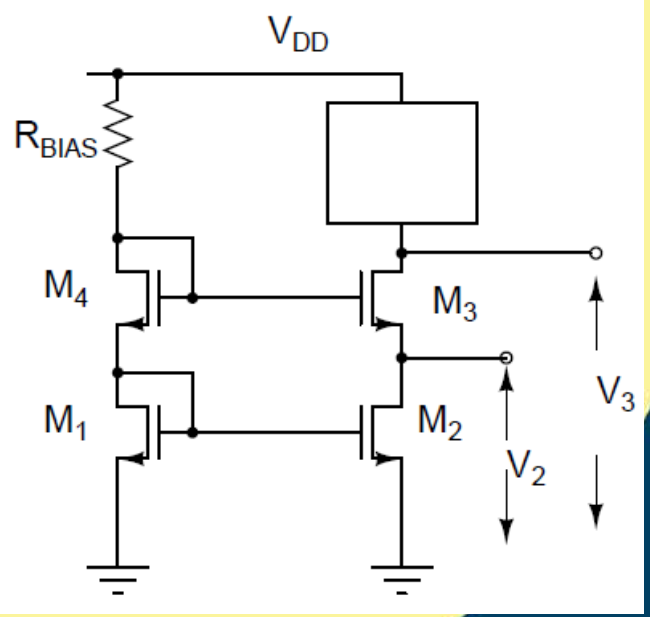
Numerical example on improved current mirror (*using MOSFETs*)

- **Example 5:**
- **$(K_n.W1/L1) = (K_n.W4/L4) = 2$ mA/V^2, $(K_n.W2/L2) = (K_n.W3/L3) = 4$ mA/V^2;**
- **Vth = 1.5V, $\lambda 2 \approx 0.01$/V**
- **V_{DD} = 12V**

(i) Find the values of R_{BIAS} so that the current through this resistor is equal to 1 mA. Use this value of R_{BIAS} for the subsequent parts of this question.

(ii) Find the values of IDS3 and small signal output resistance of the current mirror.

(iii) What is the minimum values of V3 with which the small signal output resistance remain high



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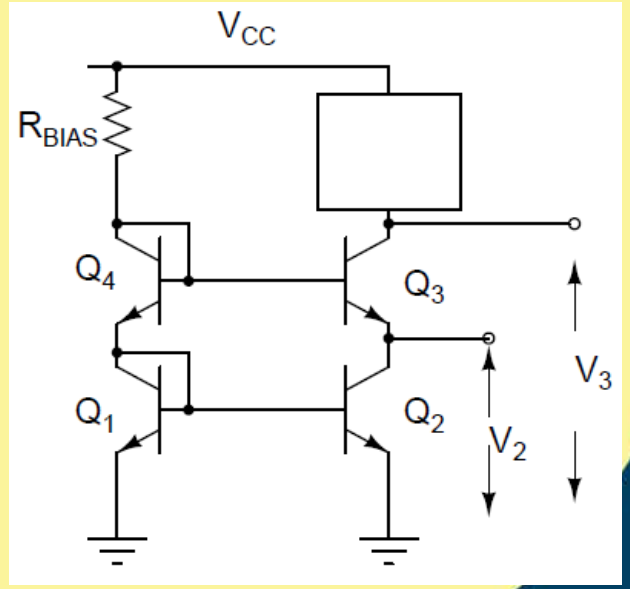
Numerical example on improved current mirror (*using BJTs*)



- **Example 6:**
- **Assume that, $V_{BE(on)i} \approx 0.6V$, βi's are very high and all V_{Ai}'s = 50V**
- **$I_{s1} = I_{s4} = 9.5 \times 10^{(-14)}$ Amp, $I_{s2} = I_{s3} = 1.9 \times 10^{(-13)}$ Amp,**
- **Vcc = 12V**

(i) Find the value of R_{BIAS} so that the current through it is equal to 1 mA.
Use this value of R_{BIAS} for the subsequent parts of this question.

(ii) Find the values of small signal output resistance of the current mirror.
And, calculate I_{C3} for V3 = 1.2V and 5.2V

(iii) What is the minimum values of V3 with which the output resistance remain high

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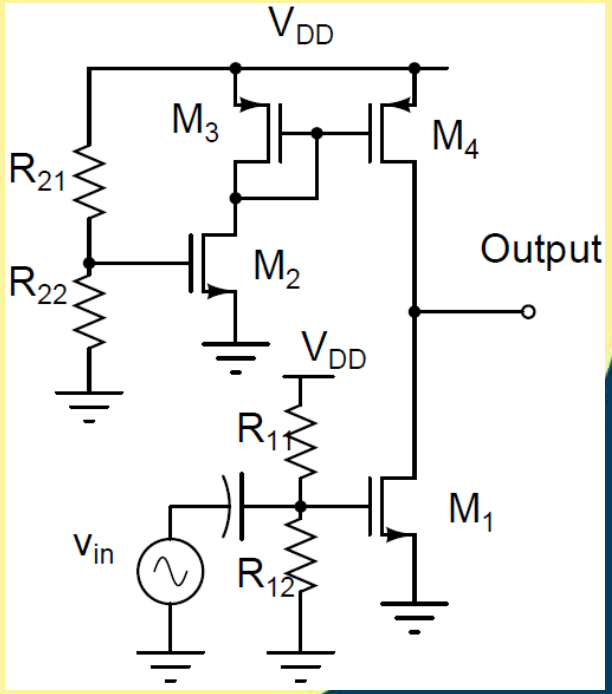
Numerical example on CS amplifier using CM (*using MOSFETs*)



- **Example 7:**
- **$(K_n.W1/L1) = (K_n.W2/L2) = 2$ mA/V^2, $(K_p.W3/L3) = (K_p.W4/L4) = 0.5$ mA/V^2;**
- **Vth = 1.5V, $\lambda 2 \approx 0.01$/V**
- **V_{DD} = 12V**

(i) Find the values of R11/R12 (= R21/R22) ratio so that nominal current of ID1 = 1 mA

Use this value of R11/R12 (= R21/R22) ratio for the subsequent parts of this question.

(ii) Find the values small signal output resistance and voltage gain of the amplifier.

(iii) Find the d.c. output voltage

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Numerical example on CE amplifier using CM(*using BJTs*)

- **Example 8:**

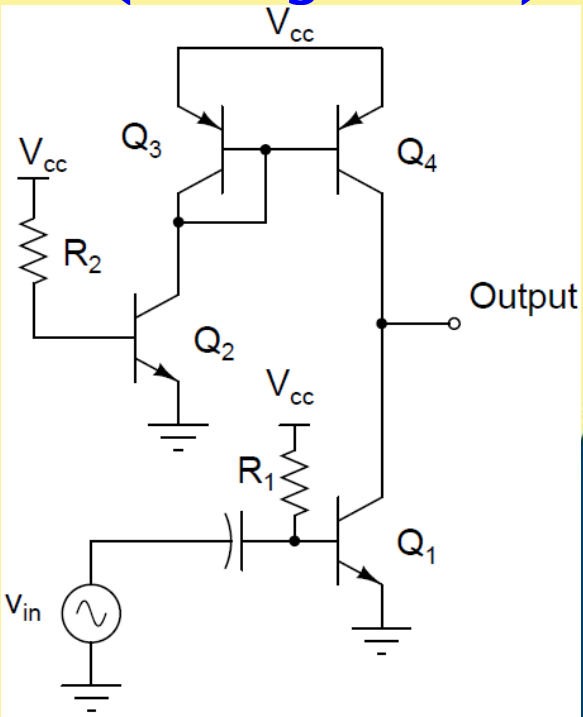
- Assume that, $V_{BE(on)i} \approx 0.6V$ and $V_A = 100V$, $V_T = 26mV$
- $\beta 1 = \beta 2 = 100$, Q1 and Q2 are identical and Q3 and Q4 are identical
- R1 = R2, Vcc = 12V

CASE – I: β3 and β4 are very high

(i) Find the value of R_1 so that nominal value of I_{C1} is equal to 2 mA.
Use this value of R_1 for the subsequent parts of this question.

(ii) Find the values small signal output resistance and voltage gain of the amplifier.

(iii) Find the d.c. output voltage



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Numerical example on CE amplifier using CM (*using BJTs*)

- **Example 8 (contd.):**

- Assume that, $V_{BE(on)i} \approx 0.6V$ and $V_A = 100V$, $V_T = 26mV$
- $\beta 1 = \beta 2 = 100$, Q1 and Q2 are identical and Q3 and Q4 are identical
- R1 = R2, Vcc = 12V

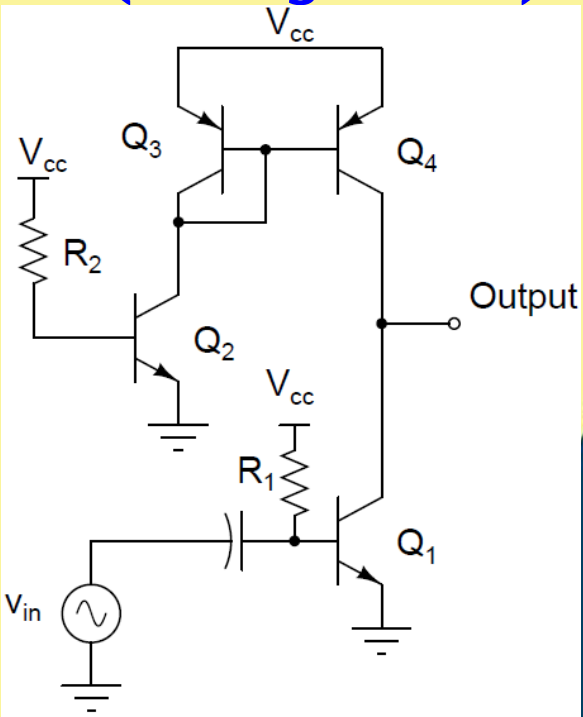
CASE – II: $\beta 3 = \beta 4 = 250$

(i) Find the precise value of I_{C1} and I_{C2} for $V_{CE1} = 11.4V$ and $V_{CE2} = 11.4V$

Find the precise value of I_{C3} and I_{C4} for $V_{CE1} = 11.4V$ and $V_{CE2} = 11.4V$

(ii) Find the non-ideality factor due to base current loss in the current mirror

(iii) Find the d.c. output voltage



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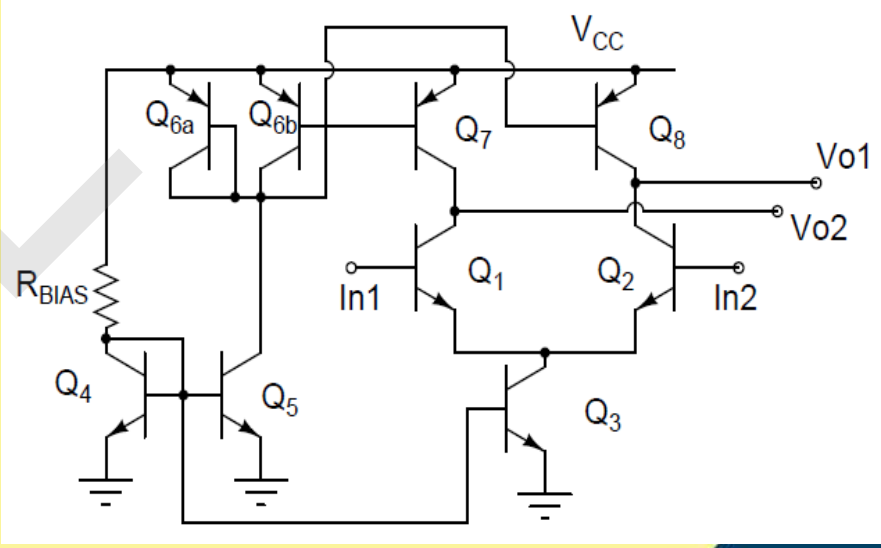
Numerical example on Differential amplifier having CM (*using BJTs*)

- **Example 9:**
- Assume that, $V_{BE(on)i} \approx 0.6V$ and $V_A = 100V$, βi's are very high
- Q1 and Q2 are identical, Q3, Q4 and Q5 are identical,
- Q_{6a}, Q_{6b}, Q_7 and Q_8 are identical
- $R_{BIAS} = 11.4\ k\Omega$, $V_{CC} = 12V$, $V_T = 26mV$

For a "meaningful" input common mode bias

(i) Find d.c. currents through all transistors of the circuit



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Numerical example on Differential amplifier having CM (*using BJTs*)

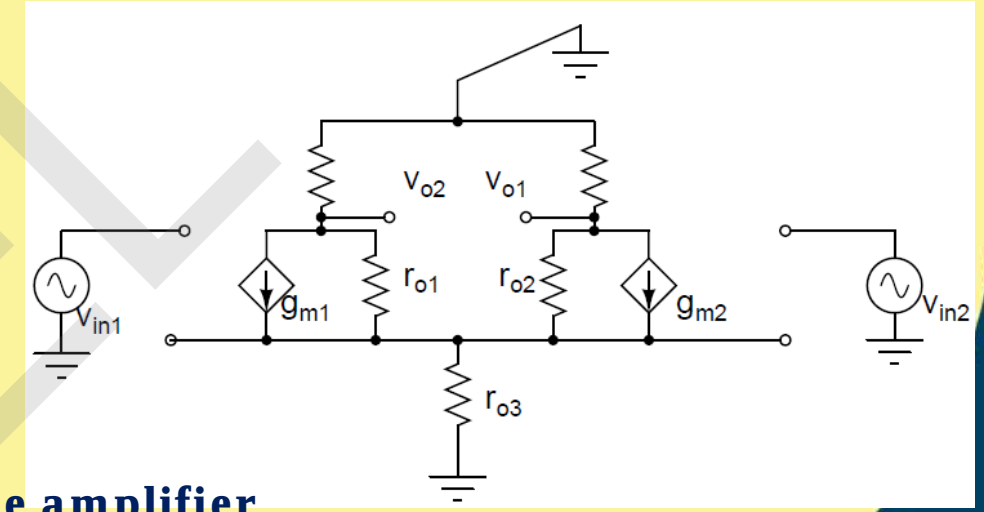
- **Example 9 (contd.):**

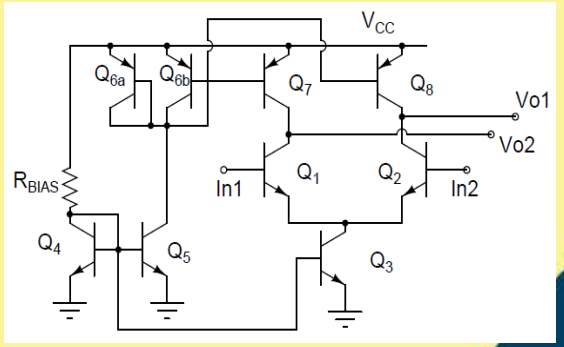
- Assume that, $V_{BE(on)i} \approx 0.6V$ and $V_A = 100V$, βi's are very high
- Q1 and Q2 are identical, Q3, Q4 and Q5 are identical,
- Q_{6a}, Q_{6b}, Q_7 and Q_8 are identical
- $R_{BIAS} = 11.4\ k\Omega$, $V_{CC} = 12V$, $V_T = 26mV$

For a "meaningful" input common mode bias

(i) Find d.c. currents through all transistors of the circuit

(ii) Find the differential mode gain and common mode gain of the amplifier





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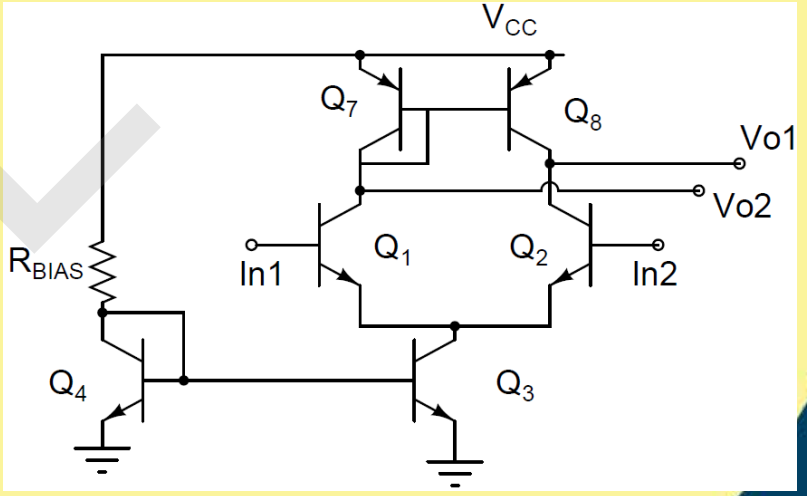
Numerical example on Differential amplifier having CM (*using BJTs*)

- **Example 10:**
- Assume that, $V_{BE(on)i} \approx 0.6V$ and $V_A = 100V$, βi's are very high
- Q1 and Q2 are identical, Q3, Q4 and Q5 are identical,
- Q_7 and Q_8 are identical
- $R_{BIAS} = 11.4\ k\Omega$, $V_{CC} = 12V$, $V_T = 26mV$

For a "meaningful" input common mode bias

(i) Find d.c. currents through all transistors of the circuit



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Numerical example on Differential amplifier having CM (*using BJTs*)

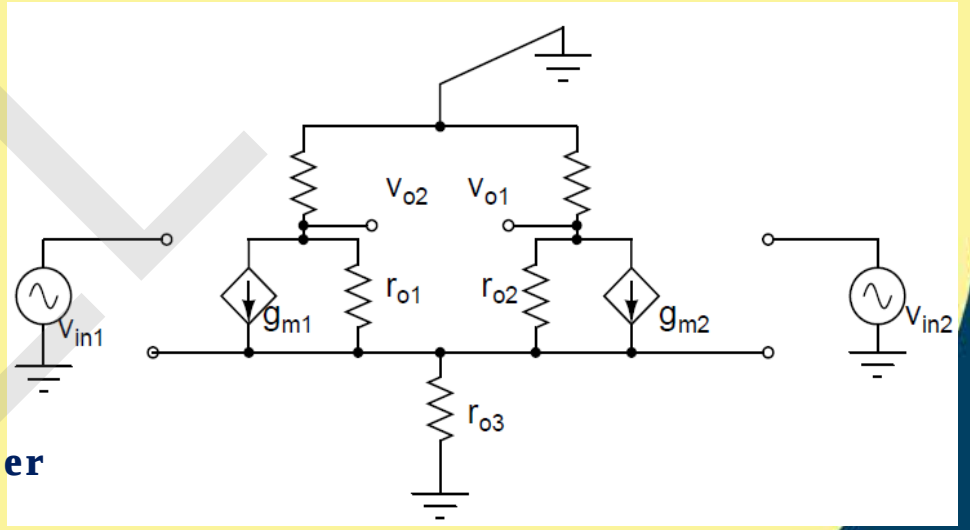
- **Example 10 (contd.) :**

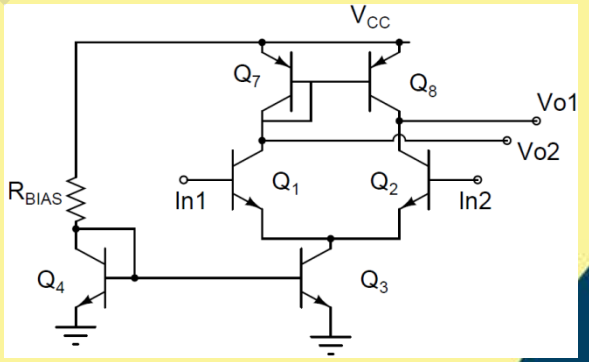
- Assume that, $V_{BE(on)i} \approx 0.6V$ and $V_A = 100V$, βi's are very high
- Q1 and Q2 are identical, Q3, Q4 and Q5 are identical,
- Q7 and Q8 are identical
- $R_{BIAS} = 11.4\ k\Omega$, $V_{CC} = 12V$, $V_T = 26mV$

For a "meaningful" input common mode bias

(i) Find d.c. currents through all transistors of the circuit

(ii) Find the differential mode gain and common mode gain of the amplifier





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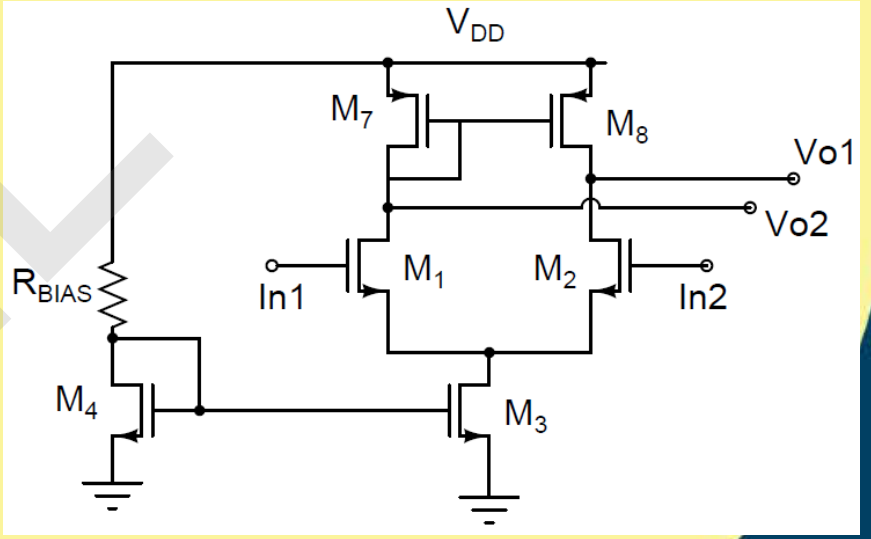
Numerical example on Differential amplifier having CM (*using MOSFETs*)

- **Example 11:**
- **$(K_n.W1/L1) = (K_n.W2/L2) = 2$ mA/V^2,**
- **$(K_n.W3/L3) = (K_n.W4/L4) = 4$ mA/V^2,**
- **$(K_p.W7/L7) = (K_p.W8/L8) = 1$ mA/V^2;**
- **Vth = 1.5V, λi's ≈ 0.01/V , V_{DD} = 12V, R_{BIAS} = 9.5 kΩ,**

For a "meaningful" input common mode bias

(i) Find d.c. currents through all transistors of the circuit



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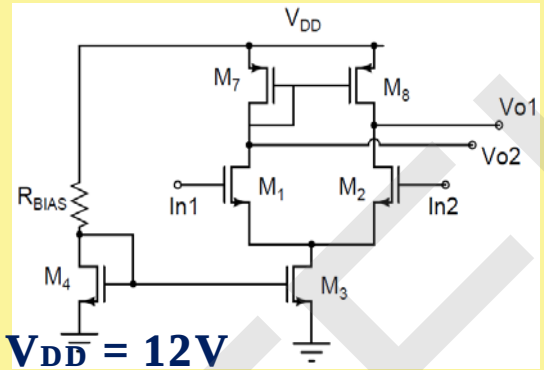
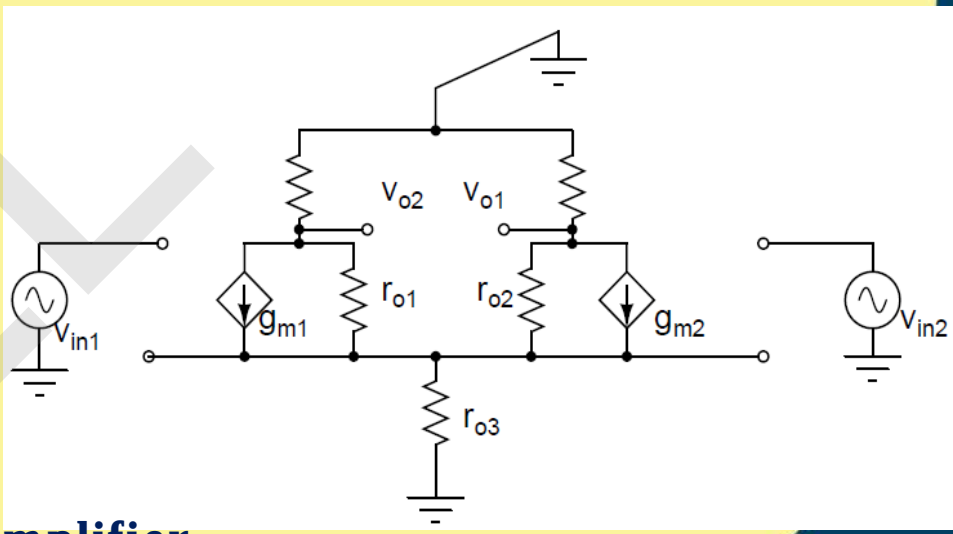
Numerical example on Differential amplifier having CM (*using MOSFETs*)





- **Example 11 (contd.):**
- **$(K_n.W1/L1) = (K_n.W2/L2) = 2$ mA/V^2,**
- **$(K_n.W3/L3) = (K_n.W4/L4) = 4$ mA/V^2,**
- **$(K_p.W7/L7) = (K_p.W8/L8) = 1$ mA/V^2**
- **Vth = 1.5V, λi's ≈ 0.01/V, R_{BIAS} = 9.5 kΩ, V_{DD} = 12V**

For a "meaningful" input common mode bias

(i) Find d.c. currents through all transistors of the circuit

(ii) Find the differential mode gain and common mode gain of the amplifier

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Conclusion

Conclusion:

- **Numerical examples on simple current mirror**
  - Using MOSFETs
  - Using BJTs
- **Numerical examples on improvised CM**
  - Using BJTs
  - Using MOSFETs
- **Numerical examples on amplifiers having CM**
  - CE/CS amplifiers
  - Differential amplifiers

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Thank you