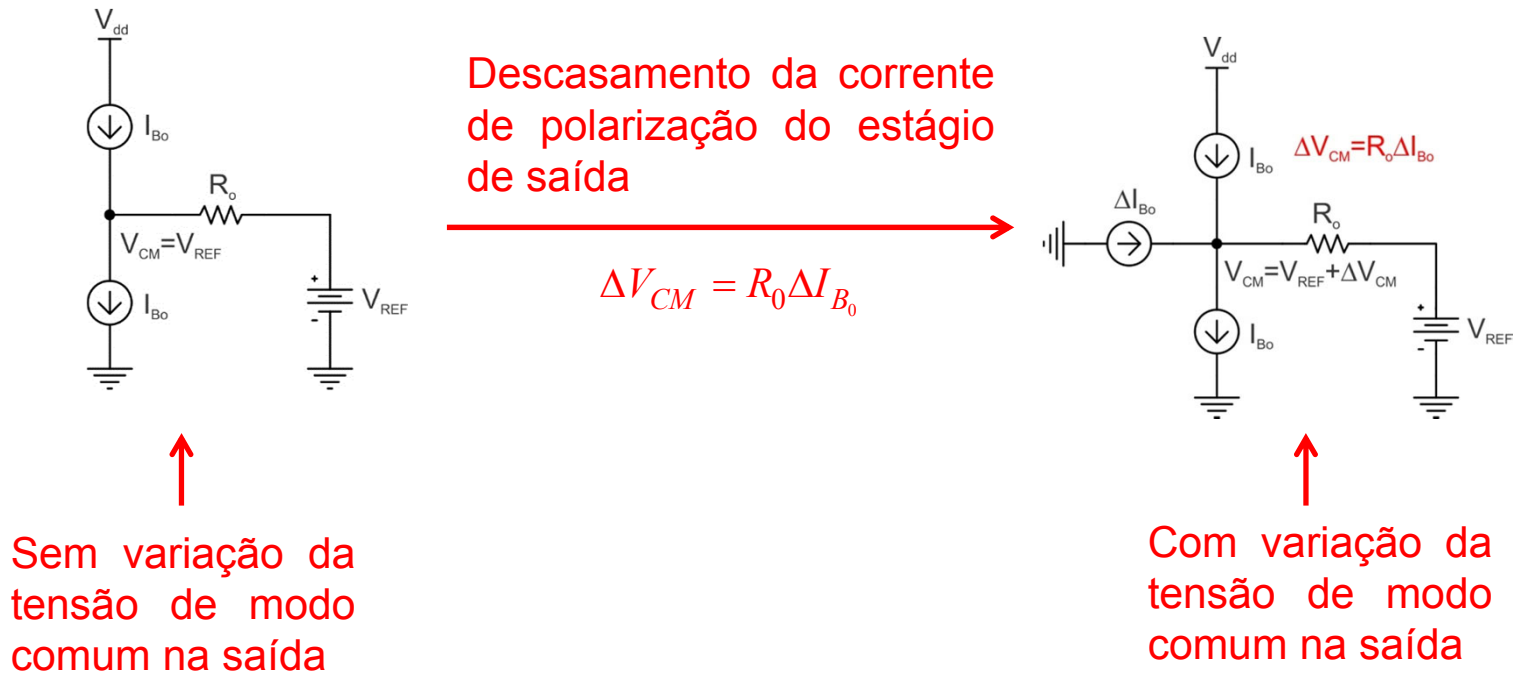


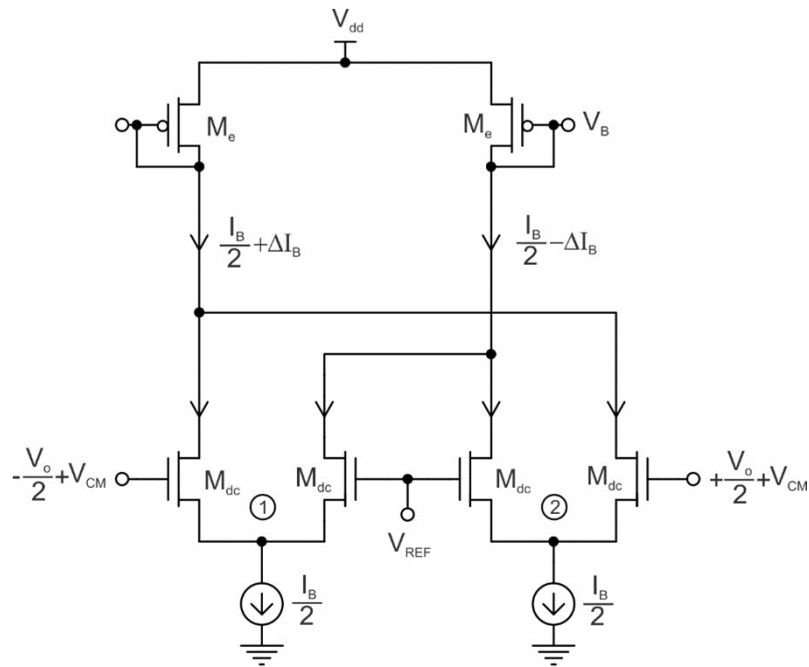
## Realimentação de Modo Comum - CMFB

O OpAmp e OTA fully differential necessitam de um circuito que mantenha a tensão de modo comum de saída em um determinado valor, pois o modo comum de saída é totalmente rejeitado pela entrada diferencial. O desvio da tensão de modo comum é devido ao descasamento das fontes de corrente do estágio de saída.

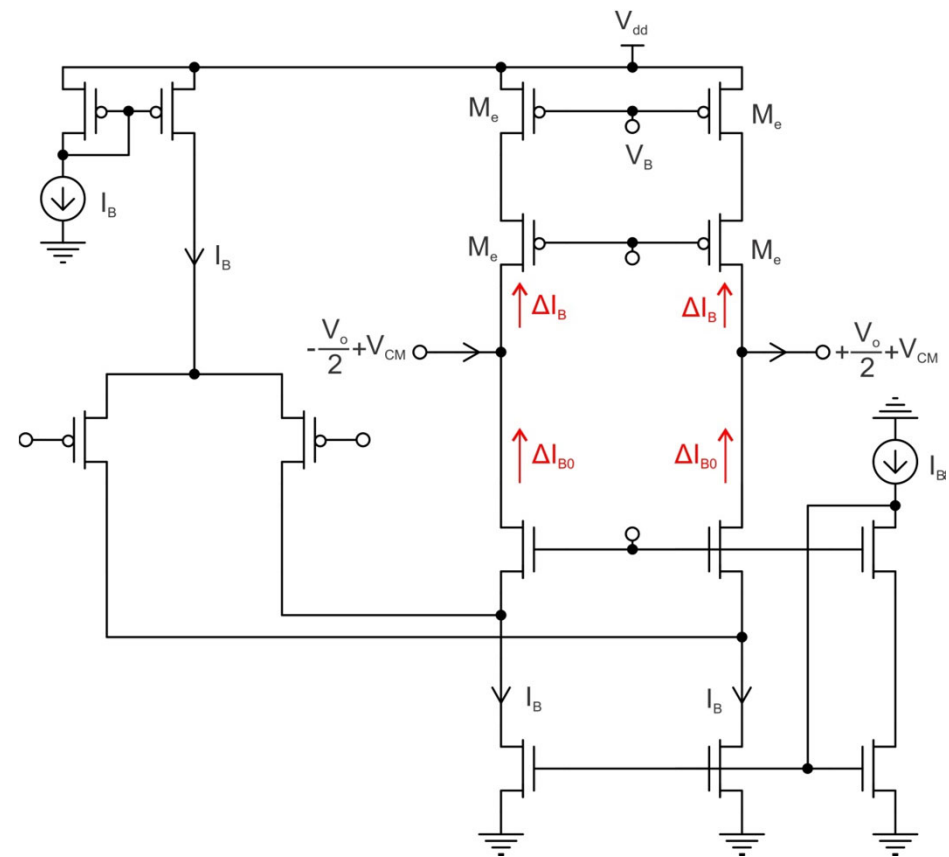


## Detector de Modo Comum com Duplo Diferencial – Princípio de Funcionamento

### Detector de modo comum

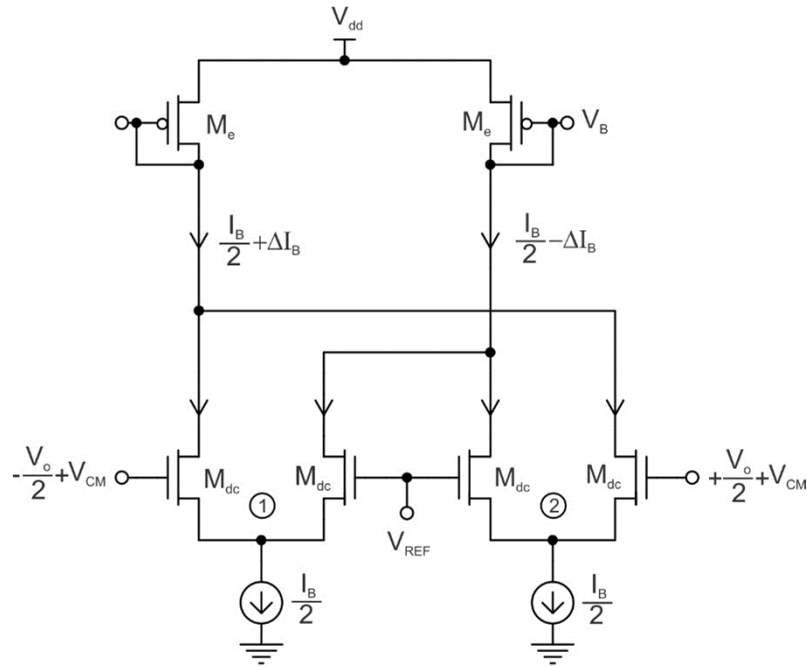


### OTA fully differential - PMOS

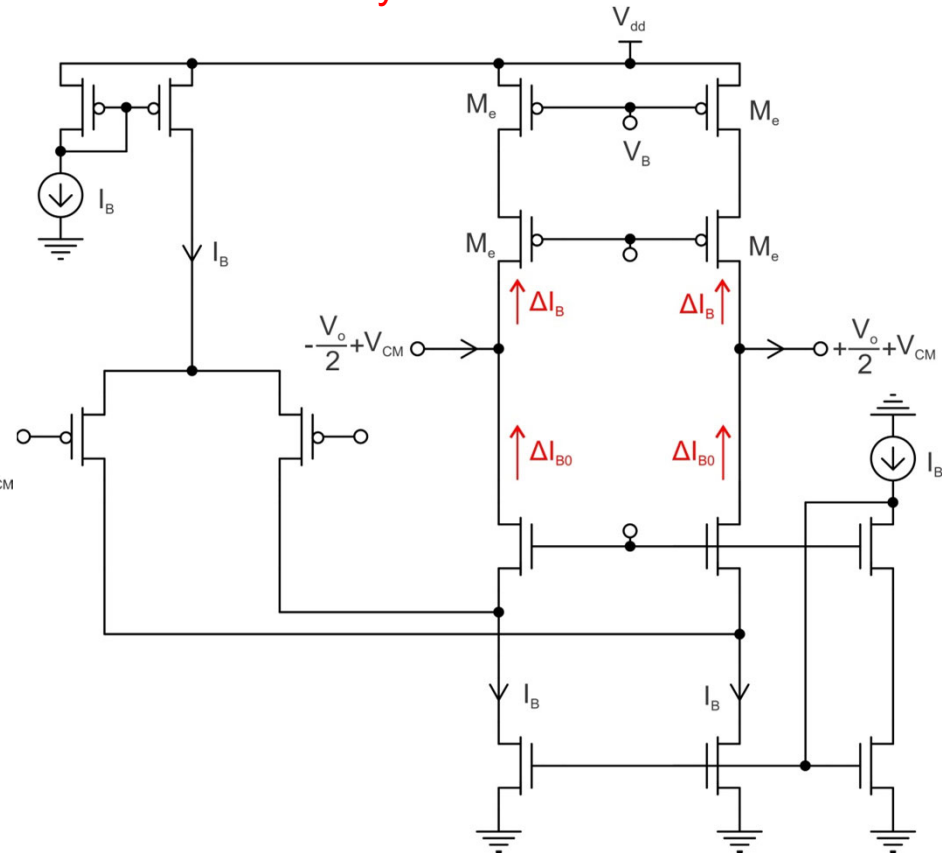


## Detector de Modo Comum com Duplo Diferencial

### Detector de modo comum



### OTA fully differential



### Análise AC de pequenos sinais

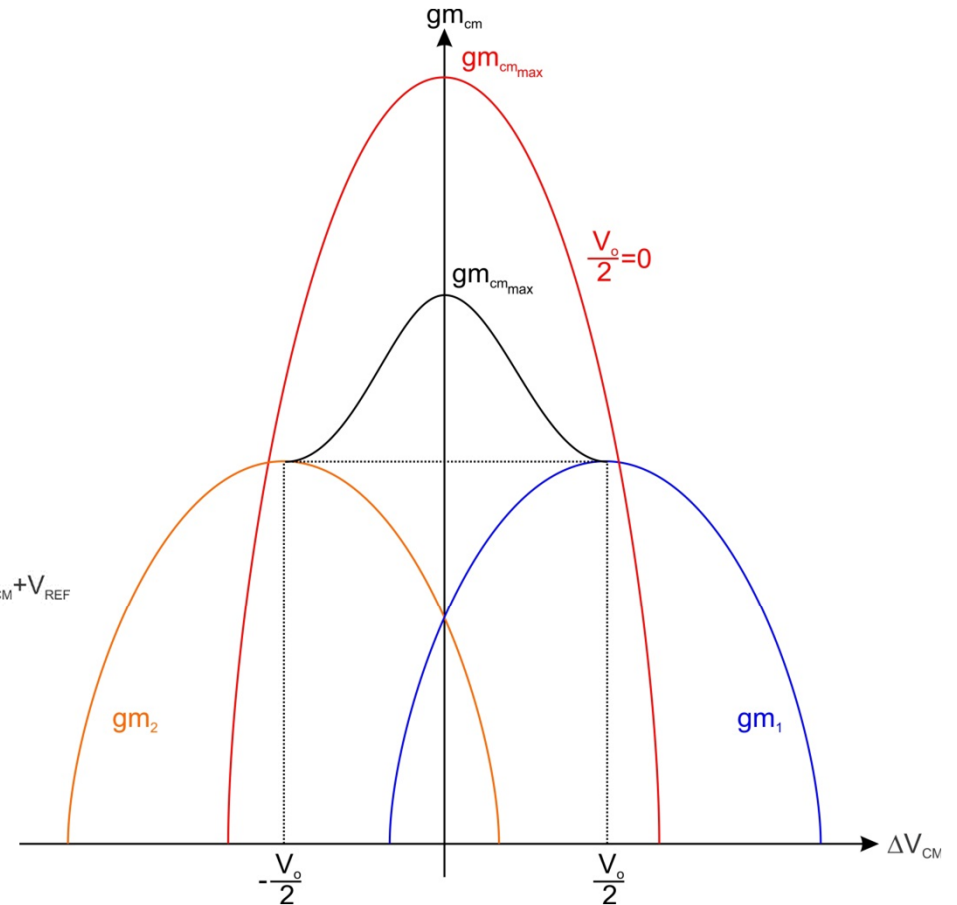
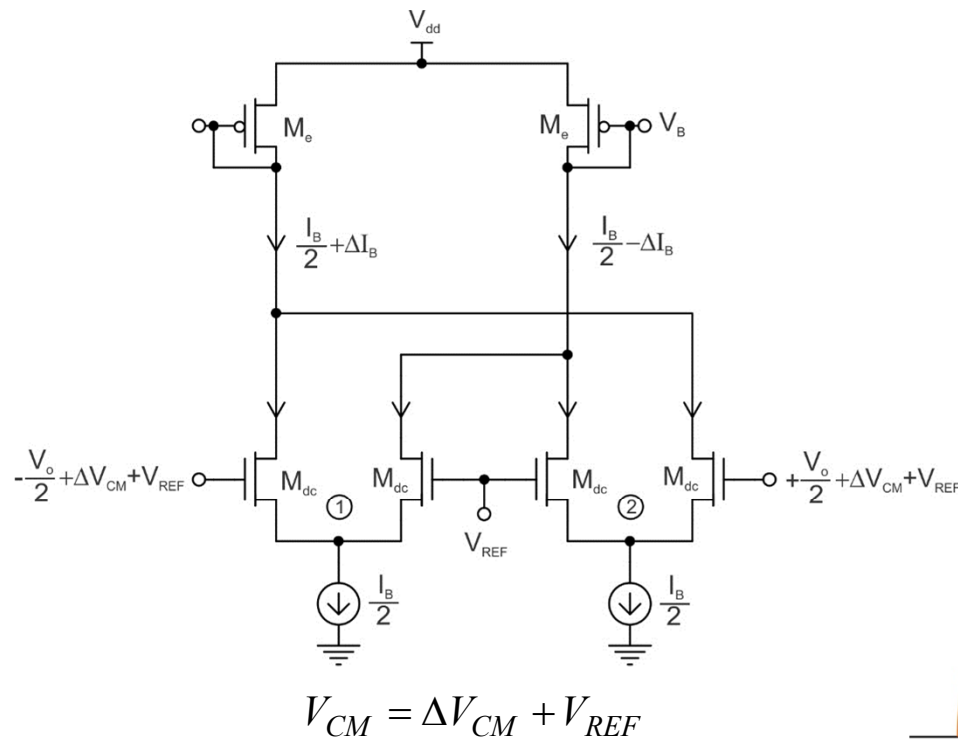
$$gm_1 = gm_2 = gm$$

$$\Delta V_{CM} = V_{CM} - V_{REF} \rightarrow \Delta I_B = gm \left( -\frac{v_0}{2} + \Delta V_{CM} \right) + gm \left( +\frac{v_0}{2} + \Delta V_{CM} \right)$$

$$\Delta I_B = 2gm\Delta V_{CM} \rightarrow gm_{cm} = \frac{\Delta I_B}{\Delta V_{CM}} \rightarrow gm_{cm} = 2gm \rightarrow \Delta I_B = gm_{cm}\Delta V_{CM}$$

$$\Delta V_{CM} = (\Delta I_{B_0} - \Delta I_B) R_0 \rightarrow \Delta V_{CM} = \frac{R_0}{1 + gm_{cm} R_0} \Delta I_{B_0} \xrightarrow{gm_{cm} R_0 \gg 1} \Delta V_{CM} \cong \frac{\Delta I_{B_0}}{gm_{cm}}$$

## Análise de grandes sinais



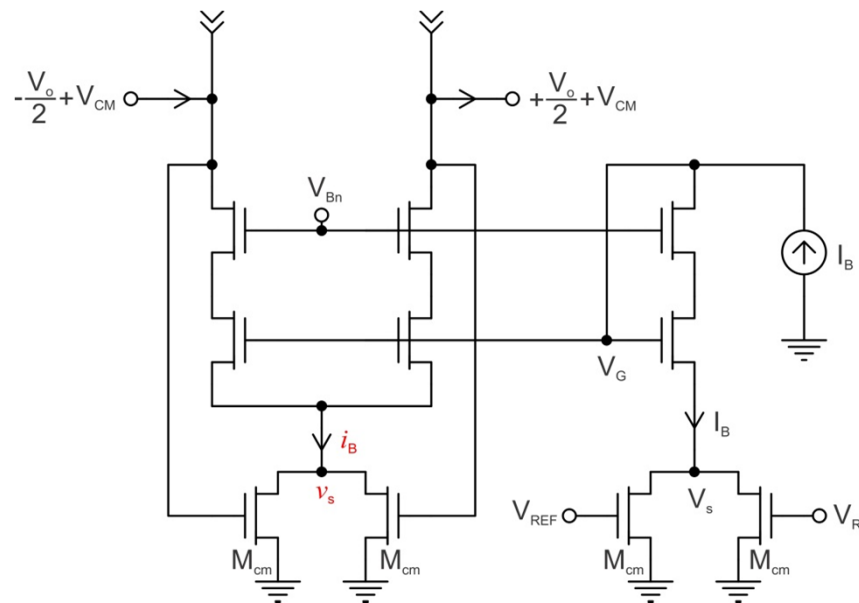
As curvas de transcondutâncias dos pares diferenciais 1 e 2 se deslocam em função da tensão de saída diferencial, alterando o valor de  $gm_{cm}$  na origem. Isto modula a tensão de modo comum na saída.

$$gm_{cm_{max}}(v_0) = gm_1\left(-\frac{v_0}{2}\right) + gm_2\left(\frac{v_0}{2}\right) \rightarrow gm_{cm_{max}}(v_0) = gm\left(-\frac{v_0}{2}\right) + gm\left(\frac{v_0}{2}\right)$$

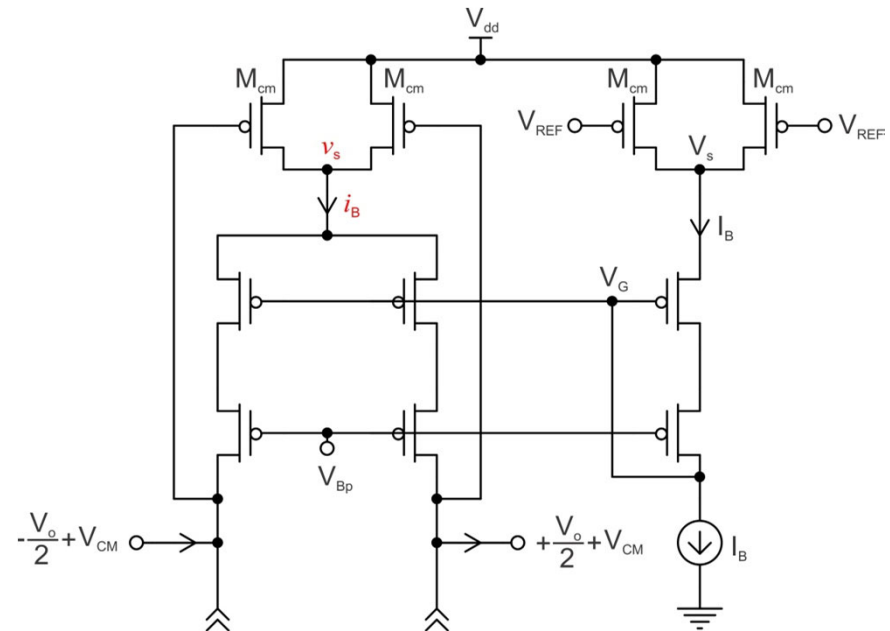
$$\Delta V_{CM} = \frac{R_0}{1 + gm_{cm_{max}}(v_0)R_0} \Delta I_{B_0} \xrightarrow{gm_{cm_{max}}(v_0)R_0 \gg 1} \Delta V_{CM} \cong \frac{\Delta I_{B_0}}{gm_{cm_{max}}(v_0)}$$

### Detector de Modo Comum com Transistor em Triodo

## Versão NMOS



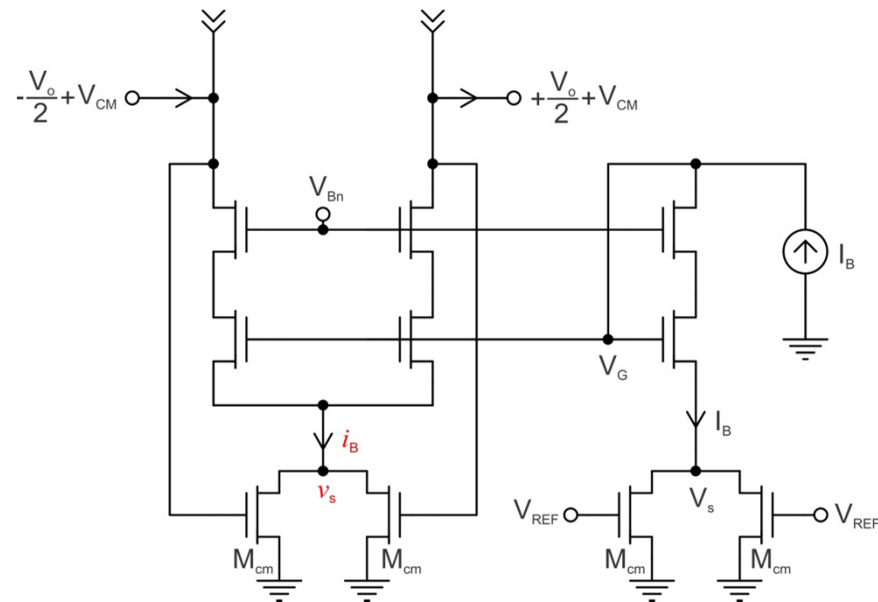
## Versão PMOS



- A tensão  $V_s$  é considerada constante em ambas as implementações
- $V_s$  deve ser tal que os transistores continuem em triodo, apesar da variação de  $V_o$
- Este detector de modo comum limita a excursão de sinal de saída

## Princípio de Funcionamento do Detetor de Modo Comum com Transistor em Triodo

### Versão NMOS



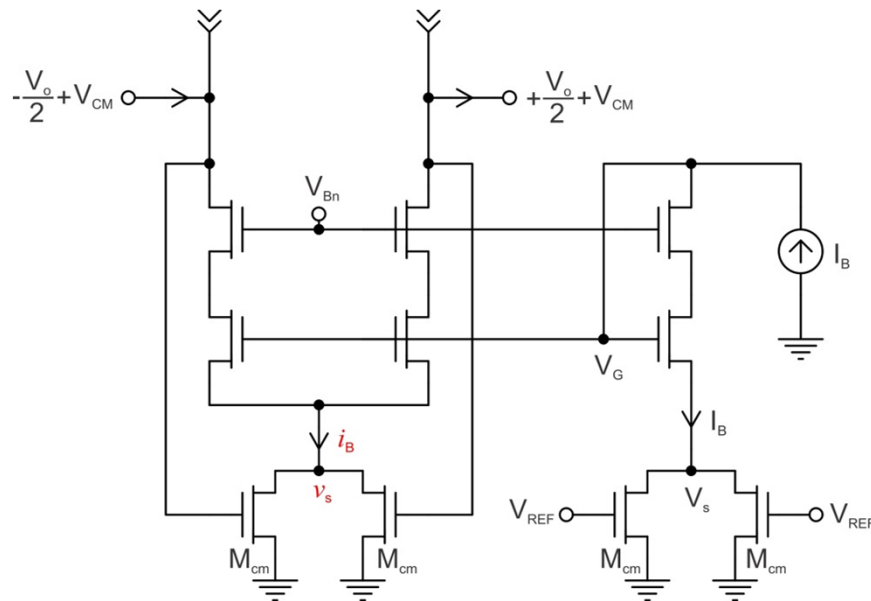
## Análise AC de Pequenos Sinais da Versão NMOS

$$I_B = 2k_p \frac{W_{cm}}{L_{cm}} \left( (V_{REF} - V_T)V_s - \frac{\alpha}{2}V_s^2 \right) \rightarrow \text{Circuito de polarização}$$

$$I_B = \frac{k_p}{2\alpha} \frac{2W}{L} (V_G - V_s - V_T)^2 \rightarrow \text{Circuito de polarização}$$

$$i_B = k_p \frac{W_{cm}}{L_{cm}} \left( \left( \frac{v_0}{2} + V_{CM} - V_T \right) v_s - \frac{\alpha}{2} v_s^2 + \left( -\frac{v_0}{2} + V_{CM} - V_T \right) v_s - \frac{\alpha}{2} v_s^2 \right) \rightarrow \text{Circuito de controle}$$

$$i_B = 2k_p \frac{W_{cm}}{L_{cm}} \left( (V_{CM} - V_T)v_s - \frac{\alpha}{2}v_s^2 \right)$$



### Circuito de controle

$$\frac{i_B}{2} = \frac{k_p}{2\alpha} \frac{W}{L} (V_G - v_s - V_T)^2$$

$$i_B = 2k_p \frac{W_{cm}}{L_{cm}} \left( (V_{CM} - V_T)v_s - \frac{\alpha}{2}v_s^2 \right)$$

## Solução das equações de corrente

$$I_B = 2k_p \frac{W_{cm}}{L_{cm}} \left( (V_{REF} - V_T) V_S - \frac{\alpha}{2} V_S^2 \right) \longrightarrow \beta_{cm} = k_p \frac{W_{cm}}{L_{cm}} \longrightarrow I_B = 2\beta_{cm} \left( (V_{REF} - V_T) V_S - \frac{\alpha}{2} V_S^2 \right)$$

$$I_B = \frac{k_p}{2\alpha} \frac{2W}{L} (V_G - V_s - V_T)^2 \longrightarrow \beta = k_p \frac{W}{L} \longrightarrow I_B = \frac{\beta}{\alpha} (V_G - V_s - V_T)^2$$

$$i_B = 2k_p \frac{W_{cm}}{L_{cm}} \left( (V_{CM} - V_T) v_s - \frac{\alpha}{2} v_s^2 \right) \longrightarrow \beta_{cm} = k_p \frac{W_{cm}}{L_{cm}} \longrightarrow i_B = 2\beta_{cm} \left( (V_{CM} - V_T) v_s - \frac{\alpha}{2} v_s^2 \right)$$

$$\frac{i_B}{2} = \frac{k_p}{2\alpha} \frac{W}{L} (V_G - v_s - V_T)^2 \longrightarrow \beta = k_p \frac{W}{L} \longrightarrow \frac{i_B}{2} = \frac{\beta}{2\alpha} (V_G - v_s - V_T)^2$$

## Circuito de polarização

$$V_G = \frac{\beta_{cm} \left( \alpha \sqrt{2I_B \beta \alpha} + \beta ((\alpha - 1)V_T + V_{REF}) \right) - \beta \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)}}{\alpha \beta \beta_{cm}}$$

$$V_S = \frac{\beta_{cm} (V_{REF} - V_T) - \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)}}{\alpha \beta_{cm}}$$

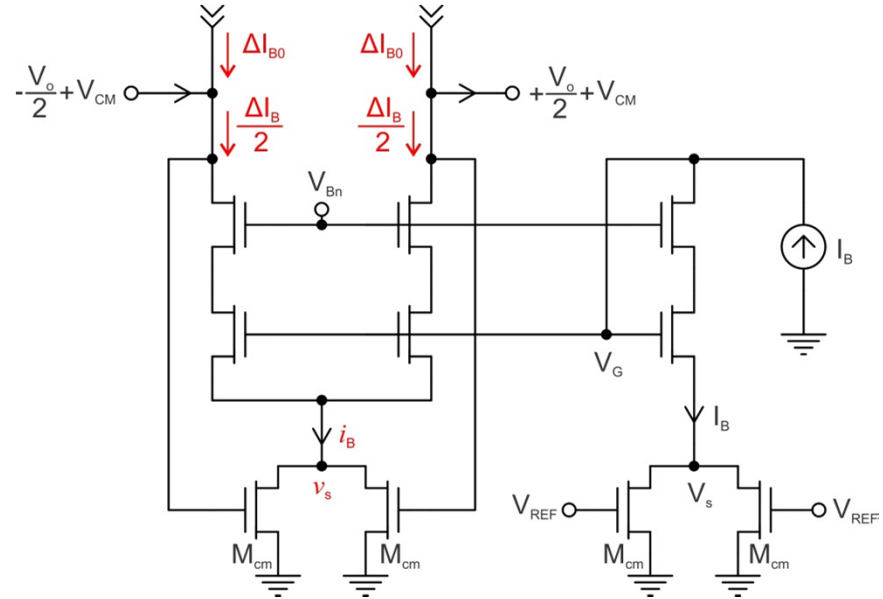


## Determinação de $\Delta V_{CM}$

$$f = \frac{i_B}{2} - \frac{\beta}{2\alpha} (V_G - v_s - V_T)^2 \quad \rightarrow \quad f = 0$$

$$g = i_B - 2\beta \left( (V_{CM} - V_T) v_s - \frac{\alpha}{2} v_s^2 \right) \quad \rightarrow \quad g = 0$$

Estimativa das variações de  $\Delta V_{CM}$  e  $\Delta i_B$  pelas derivadas no ponto de operação



$$\begin{cases} \frac{\partial f}{\partial i_B} \Delta i_B + \frac{\partial f}{\partial V_{CM}} \Delta V_{CM} + \frac{\partial f}{\partial v_s} \Delta v_s = 0 \\ \frac{\partial g}{\partial i_B} \Delta i_B + \frac{\partial g}{\partial V_{CM}} \Delta V_{CM} + \frac{\partial g}{\partial v_s} \Delta v_s = 0 \end{cases} \xrightarrow{\text{Ponto de operação}} \begin{cases} v_s = V_s \\ i_B = I_B \\ V_{CM} = V_{REF} \end{cases}$$

$$\Delta V_{CM} = \left( \Delta I_{B_0} - \frac{\Delta i_B}{2} \right) R_0$$

$$\Delta V_{CM} = \frac{\alpha R_0 \left( \sqrt{2I_B \beta \alpha} + 4\alpha \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right) \Delta I_{B_0}}{\sqrt{2I_B \beta \alpha} \left( (V_{REF} - V_T) \beta_{cm} R_0 + \alpha \right) - \left( R_0 \sqrt{2I_B \beta \alpha} - 4\alpha^2 \right) \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)}}$$

Explorando o limite para o infinito de  $I_B R_0$

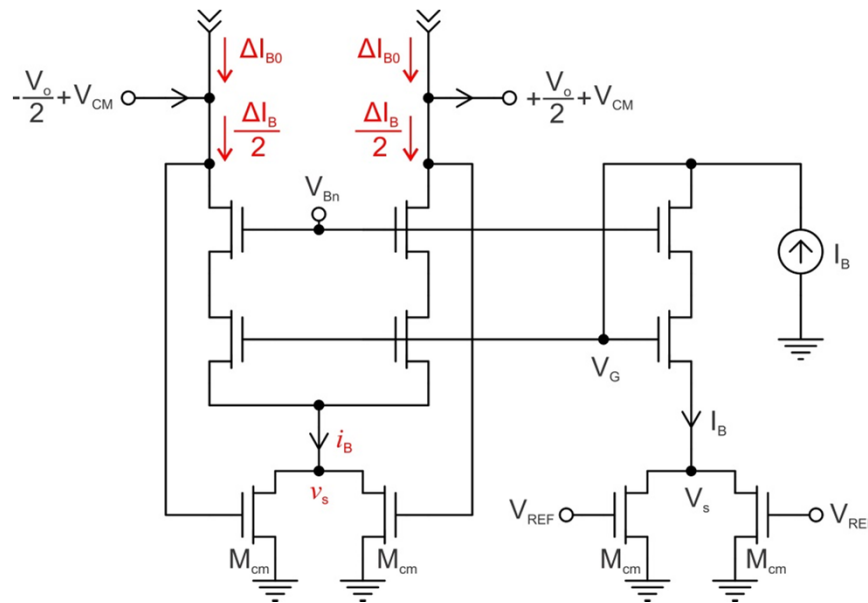
$$I_B R_0 \gg 1 \longrightarrow \eta = I_B R_0 \longrightarrow R_0 = \frac{\eta}{I_B}$$

$$\Delta V_{CM} = \frac{\alpha \eta \left( \sqrt{2I_B \beta \alpha} + 4\alpha \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right) \Delta I_{B_0}}{\sqrt{2I_B \beta \alpha} \left( (V_{REF} - V_T) \beta_{cm} \eta + I_B \alpha \right) - \left( \eta \sqrt{2I_B \beta \alpha} - 4I_B \alpha^2 \right) \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)}}$$

Estimando  $\Delta V_{CM}$  com o limite de  $\eta$  tendendo para o infinito

$$\lim_{\eta \rightarrow \infty} \Delta V_{CM} = \frac{\alpha \left( \sqrt{2I_B \beta \alpha} + 4\alpha \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right) \Delta I_{B_0}}{\sqrt{2I_B \beta \alpha} \left( \beta_{cm} (V_{REF} - V_T) - \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right)}$$

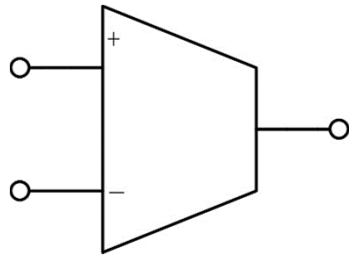
$$\Delta V_{CM} \cong \frac{\alpha \left( \sqrt{2I_B \beta \alpha} + 4\alpha \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right)}{\sqrt{2I_B \beta \alpha} \left( \beta_{cm} (V_{REF} - V_T) - \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right)} \Delta I_{B_0}$$



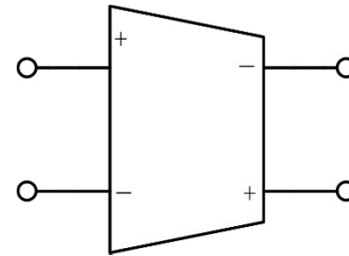
$\Delta I_{B0}$  tem origem no descasamento das fontes de corrente de polarização do estágio de saída em cascode, e é responsável, em grande parte, pela variação da tensão de modo comum na saída.

$$\Delta V_{CM} \cong \frac{\alpha \left( \sqrt{2I_B \beta \alpha} + 4\alpha \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right)}{\sqrt{2I_B \beta \alpha} \left( \beta_{cm} (V_{REF} - V_T) - \sqrt{\beta_{cm} \left( (V_{REF} - V_T)^2 \beta_{cm} - \alpha I_B \right)} \right)} \Delta I_{B0}$$

## *Símbolos do OTA*



*Single ended*



*Fully differential*

**Final deste  
Tópico**