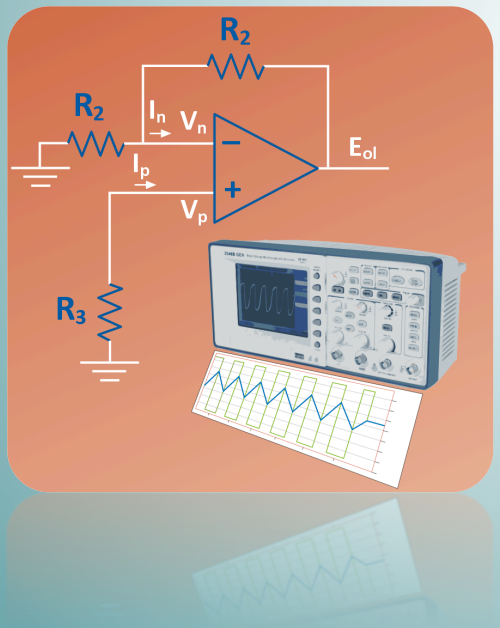
Electrónica Básica

Tema B.4.
El Amplificador Diferencial



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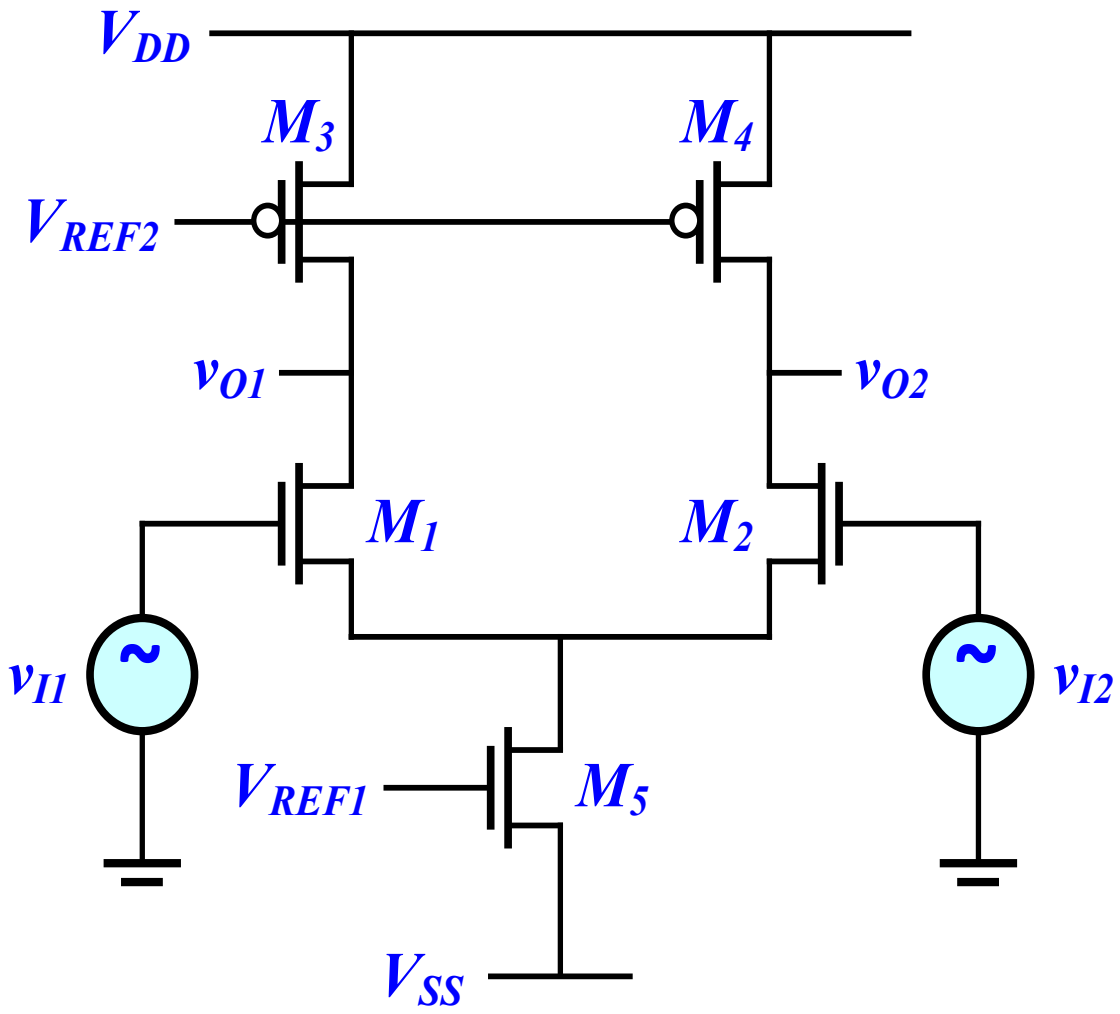
DPTO. DE ELECTRÓNICA Y COMPUTADORES

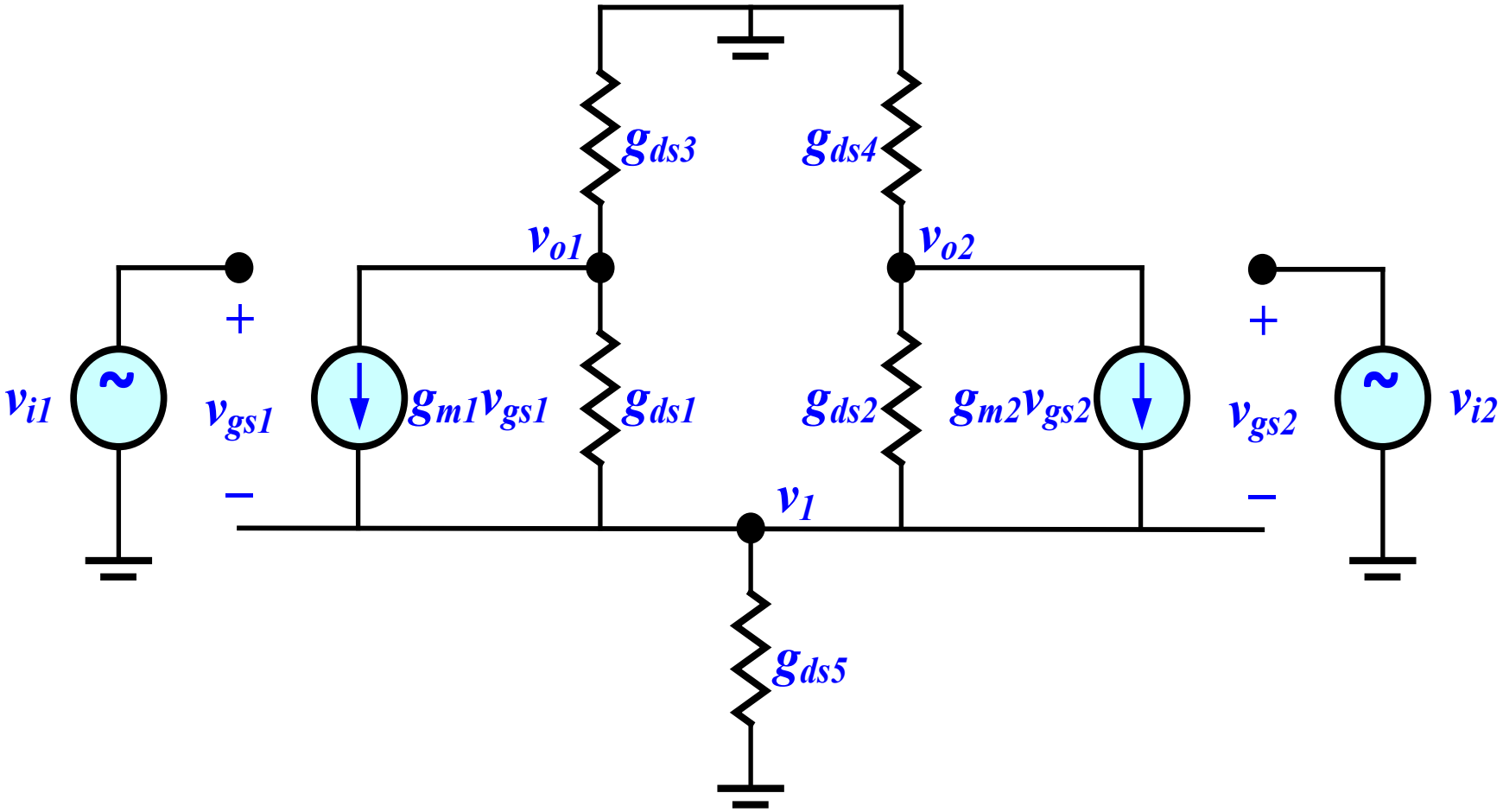
Amplificador Diferencial con Carga Activa

- Esquema de circuito:



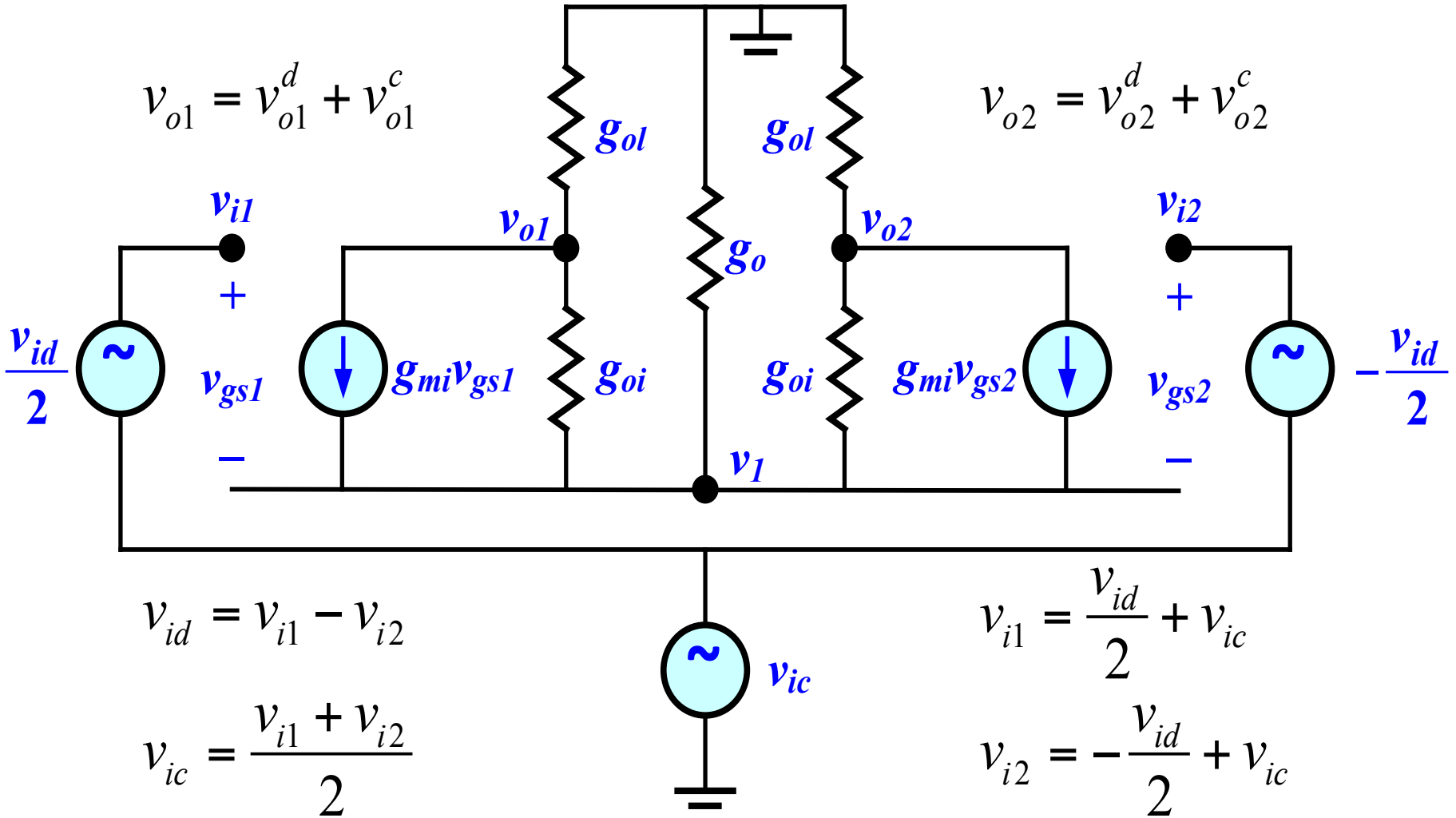
Amplificador Diferencial con Carga Activa

- Circuito equivalente de pequeña señal:



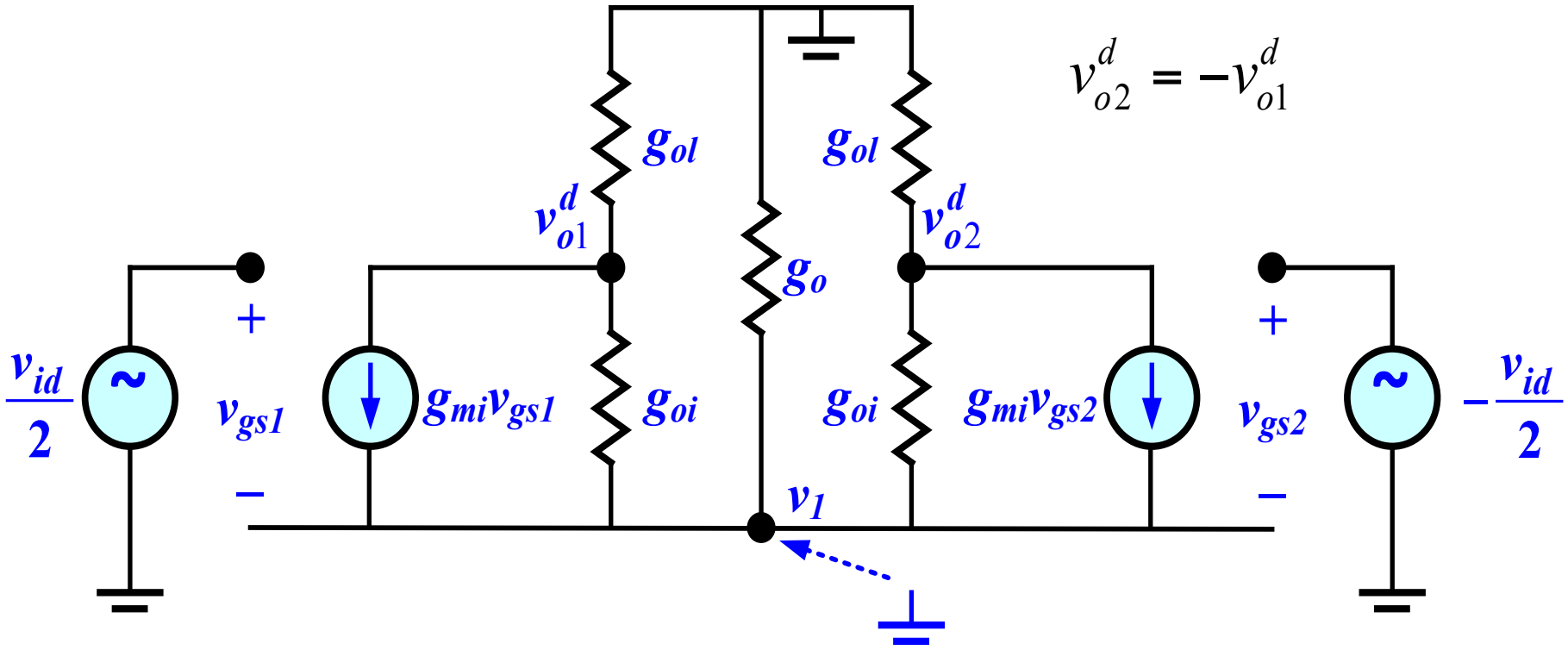
Amplificador Diferencial con Carga Activa

- Circuito equivalente con transistores simétricos:



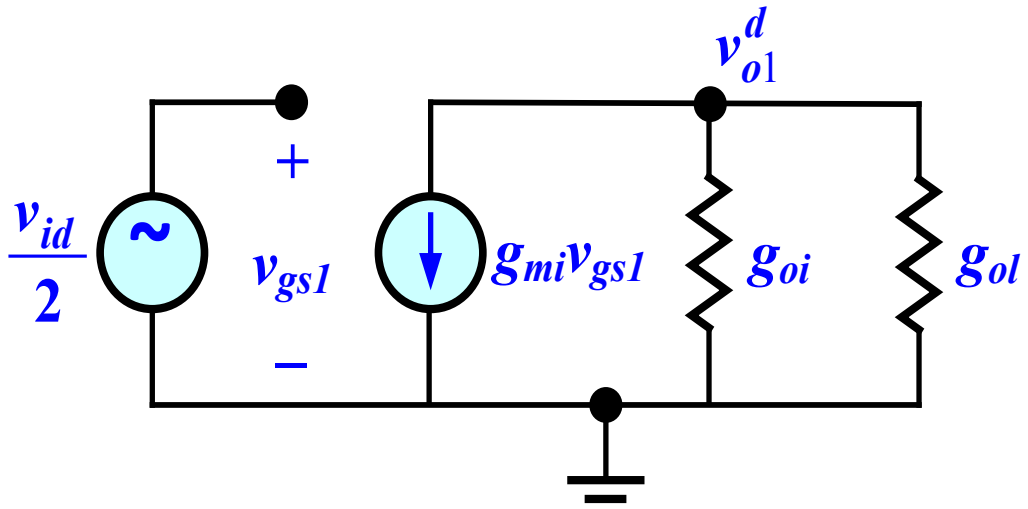
Amplificador Diferencial con Carga Activa

- Análisis en modo diferencia (DM):



Amplificador Diferencial con Carga Activa

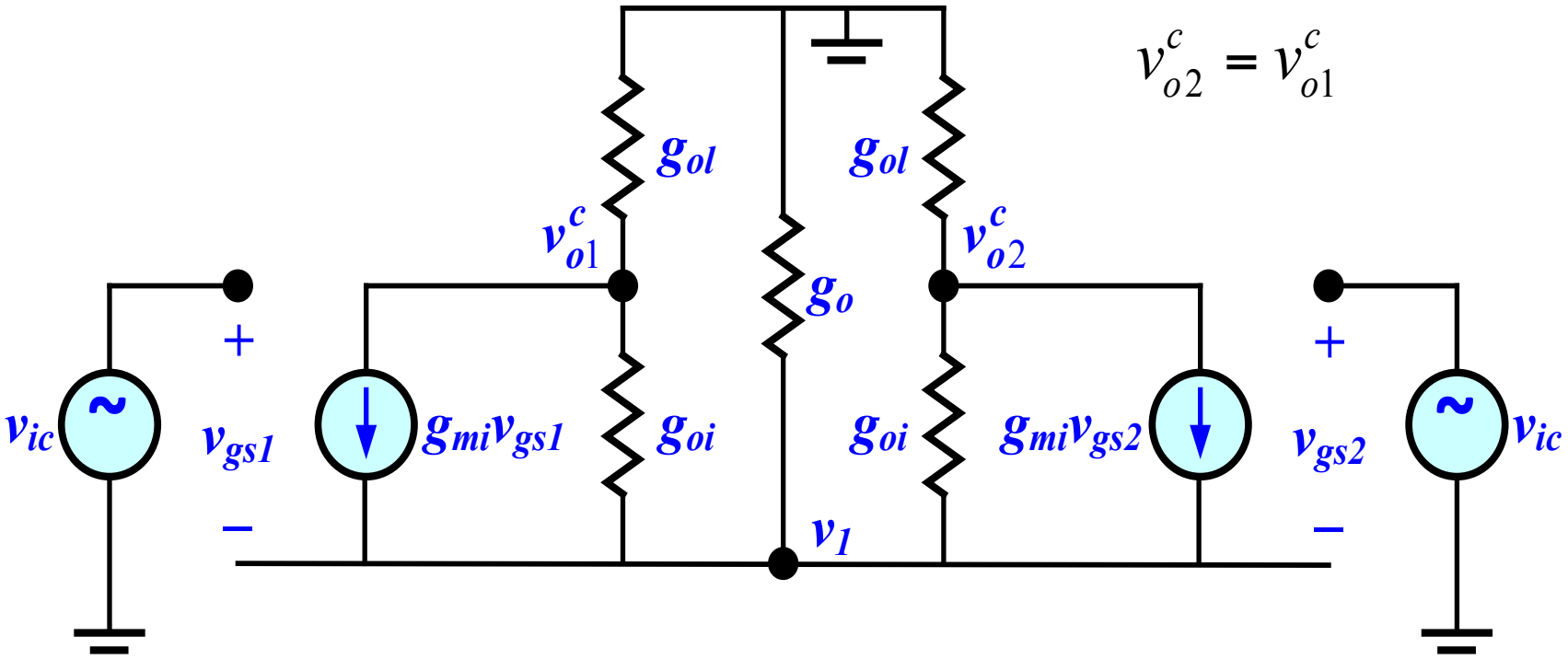
- Circuito equivalente de pequeña señal en DM:



$$v_{o1}^{d} = -\frac{g_{mi}}{\left(g_{ol} + g_{oi}\right)} \frac{v_{id}}{2}$$

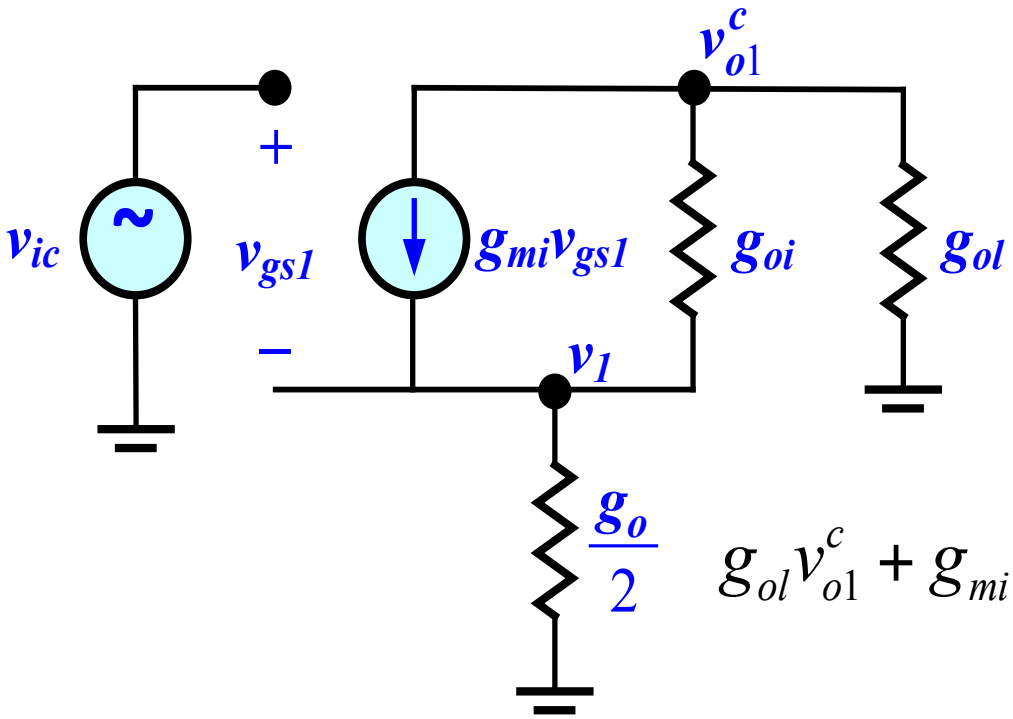
Amplificador Diferencial con Carga Activa

- Análisis en modo común (CM):



Amplificador Diferencial con Carga Activa

- Circuito equivalente de pequeña señal en CM:



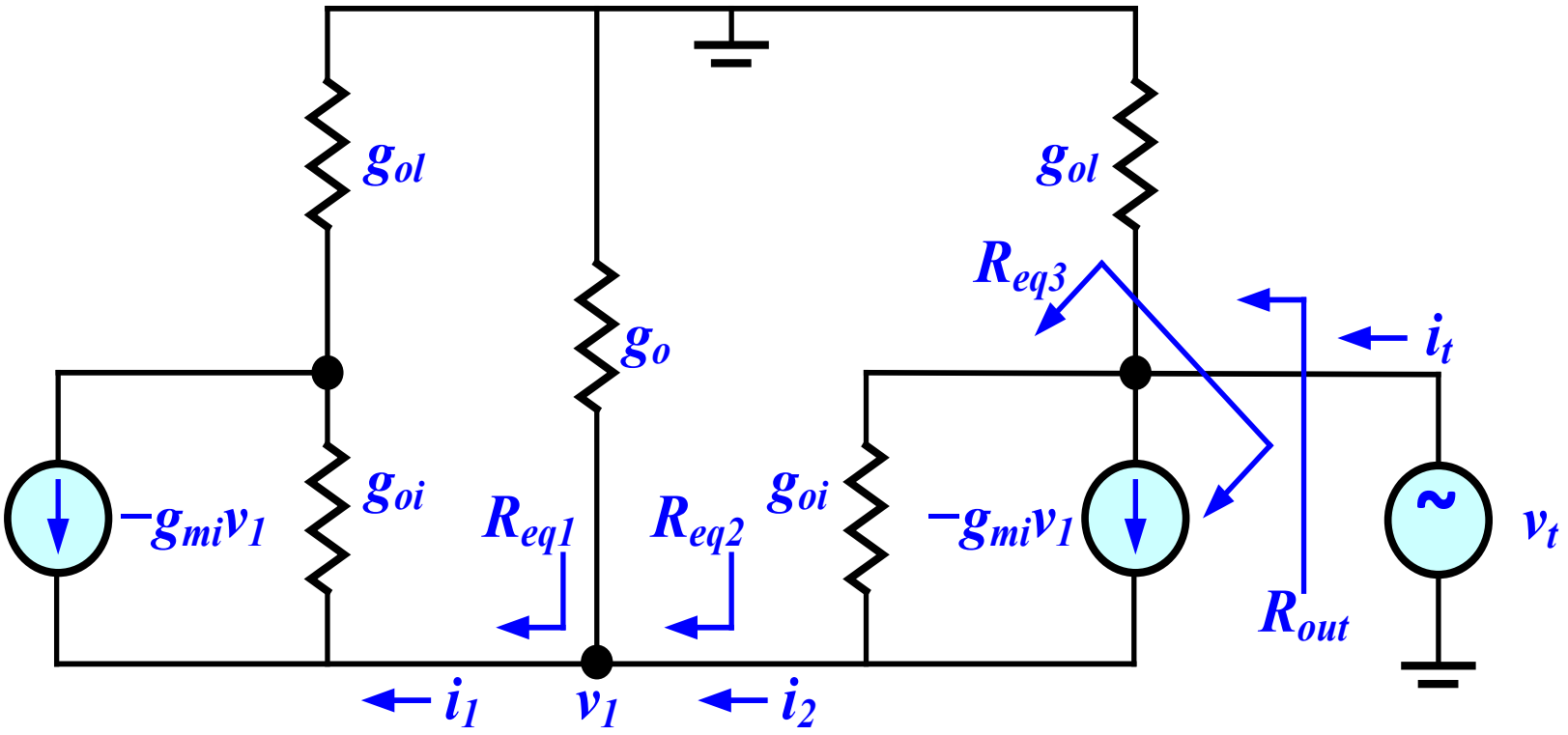
$$\frac{g_o}{2} v_1 = -g_{ol}\, v_{o1}^c$$

$$g_{ol} v_{o1}^c + g_{mi}\left(v_{ic} - v_1\right) + g_{oi}\left(v_{o1}^c - v_1\right) = 0$$

$$\frac{v_{o1}^c}{v_{ic}} = -\frac{g_{mi}\, g_o}{g_{oi}\, g_o + g_{ol}\, g_o + 2g_{ol}\left(g_{mi} + g_{oi}\right)}$$

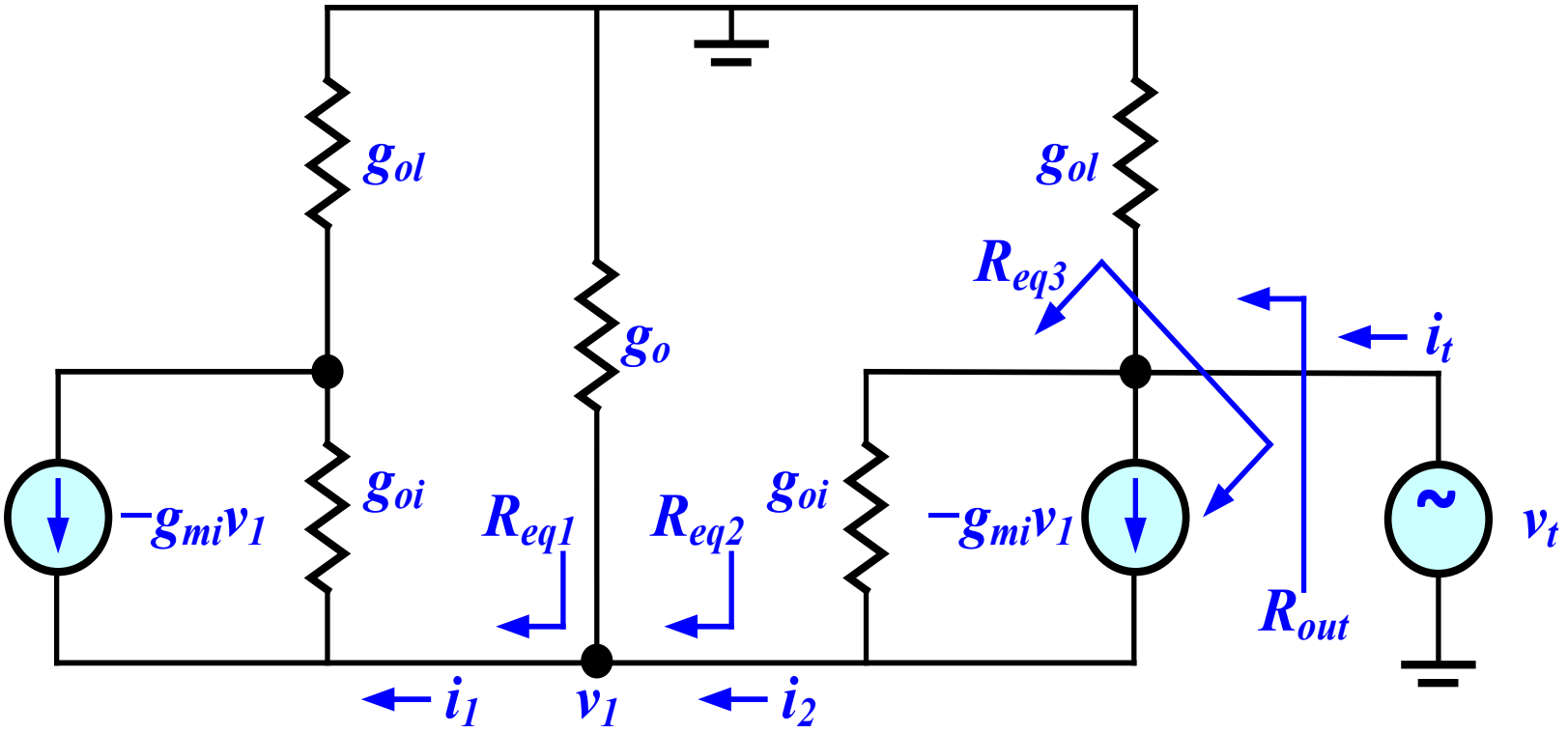
Amplificador Diferencial con Carga Activa

- Resistencia de salida R_{out}:



Amplificador Diferencial con Carga Activa

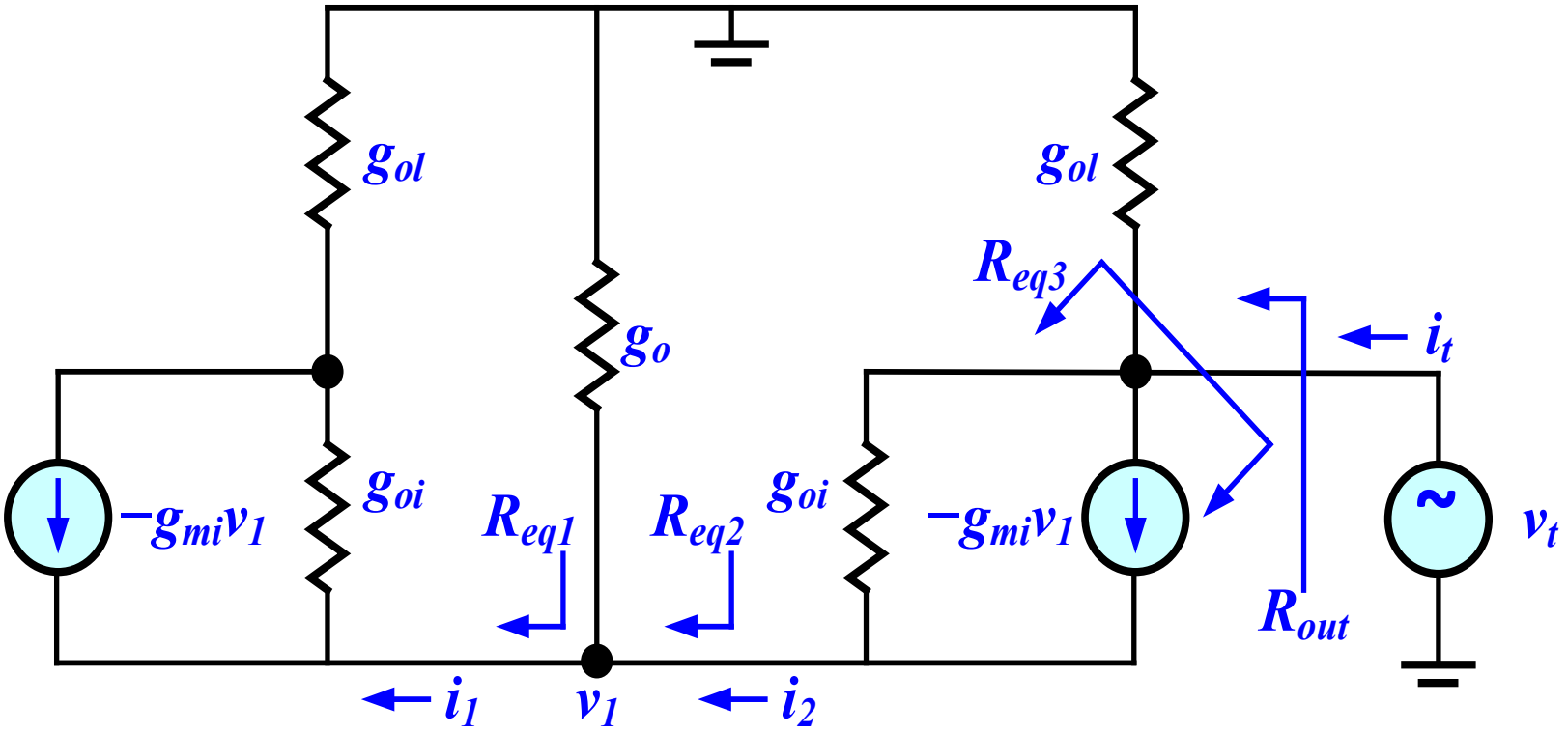
- Cálculo de R_{eq1} :



$$R_{eq1} = \frac{g_{oi} + g_{ol}}{\left(g_{oi} + g_{mi}\right) g_{ol}}$$

Amplificador Diferencial con Carga Activa

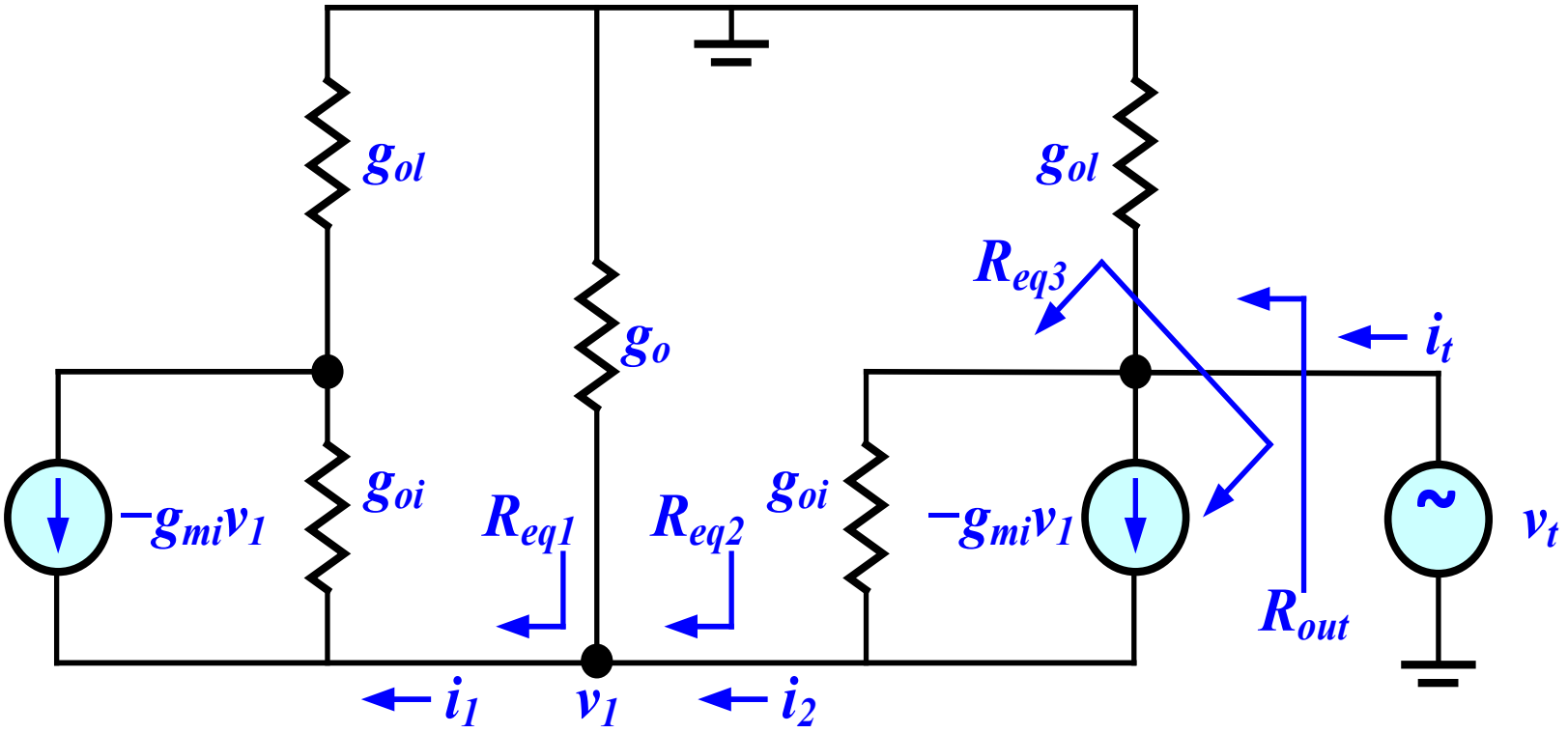
- Cálculo de R_{eq2} :



$$R_{eq2} = g_o^{-1} \,||\, R_{eq1}$$

Amplificador Diferencial con Carga Activa

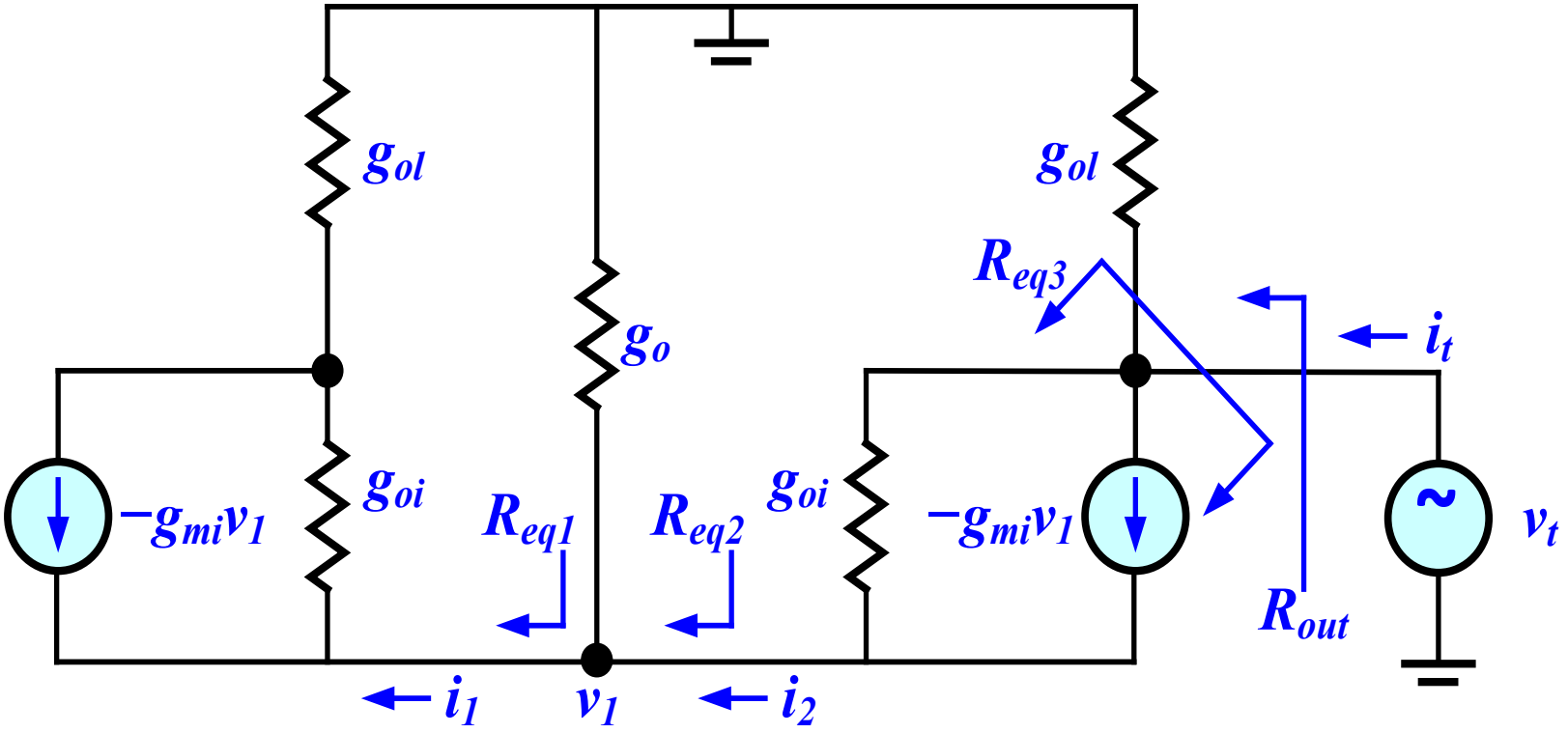
- Cálculo de R_{eq3} :



$$R_{eq3} = R_{eq2} + g_{oi}^{-1}\left(1 + g_{mi}R_{eq2}\right)$$

Amplificador Diferencial con Carga Activa

- Cálculo de R_{out} :



$$R_{out} = g_{ol}^{-1} \,||\, R_{eq3}$$

Amplificador Diferencial con Carga Activa

- Tensiones de salida:

$$v_{o1} = v_{o1}^{d} + v_{o1}^{c}$$

$$v_{o1} = -\frac{g_{mi}}{\left(g_{ol} + g_{oi}\right)}\frac{v_{id}}{2} - \frac{g_{mi}\, g_{o}}{g_{oi}\, g_{o} + g_{ol}\, g_{o} + 2g_{ol}\left(g_{mi} + g_{oi}\right)} v_{ic}$$

$$v_{o2} = v_{o2}^{d} + v_{o2}^{c} = -v_{o1}^{d} + v_{o1}^{c}$$

$$v_{o2} = \frac{g_{mi}}{\left(g_{ol} + g_{oi}\right)}\frac{v_{id}}{2} - \frac{g_{mi}\, g_{o}}{g_{oi}\, g_{o} + g_{ol}\, g_{o} + 2g_{ol}\left(g_{mi} + g_{oi}\right)} v_{ic}$$

Amplificador Diferencial con Carga Activa

- Ganancias DM (A_{dm}) y CM (A_{cm}):

$$v_{od} = v_{o1} - v_{o2} = -\frac{g_{mi}}{\left(g_{ol} + g_{oi}\right)} v_{id}$$

$$A_{dm} = \frac{v_{od}}{v_{id}} = -\frac{g_{mi}}{\left(g_{ol} + g_{oi}\right)}$$

$$v_{oc} = \frac{v_{o1} + v_{o2}}{2} = -\frac{g_{mi}\, g_o}{g_{oi}\, g_o + g_{ol}\, g_o + 2g_{ol}\left(g_{mi} + g_{oi}\right)} v_{ic}$$

$$A_{cm} = \frac{v_{oc}}{v_{ic}} = -\frac{g_{mi}}{g_{oi} + g_{ol} + \dfrac{2g_{ol}\left(g_{mi} + g_{oi}\right)}{g_o}}$$

Amplificador Diferencial con Carga Activa

- Razón de rechazo del modo común (***CMMR***):

$$CMRR = \left| \frac{A_{dm}}{A_{cm}} \right| = 1 + \frac{2g_{ol}\left(g_{mi} + g_{oi}\right)}{g_o\left(g_{ol} + g_{oi}\right)}$$

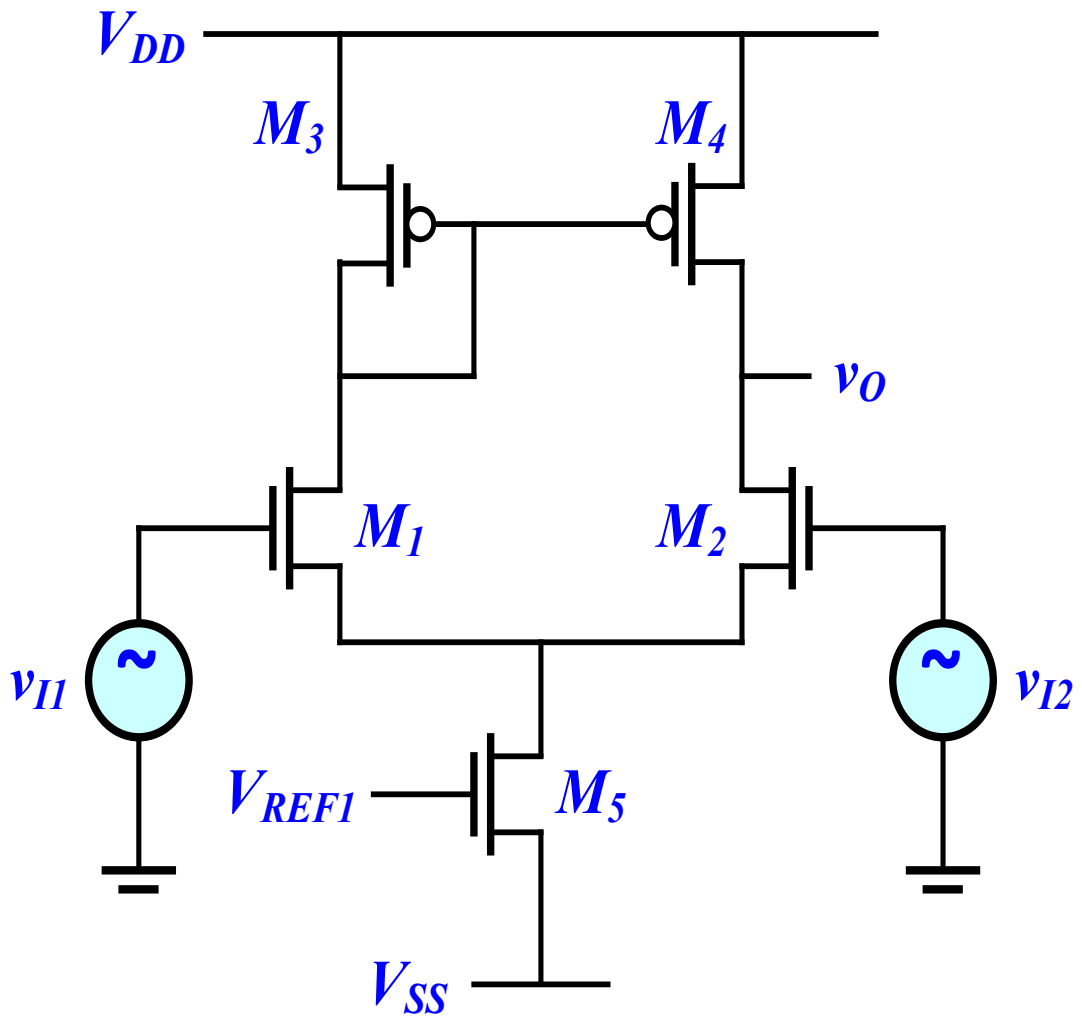
- Tensiones de salida *vs.* tensiones de entrada:

$$v_{o1} = \frac{A_{dm}}{2}\left(v_{i1} - v_{i2}\right) + \frac{A_{cm}}{2}\left(v_{i1} + v_{i2}\right)$$

$$v_{o2} = -\frac{A_{dm}}{2}\left(v_{i1} - v_{i2}\right) + \frac{A_{cm}}{2}\left(v_{i1} + v_{i2}\right)$$

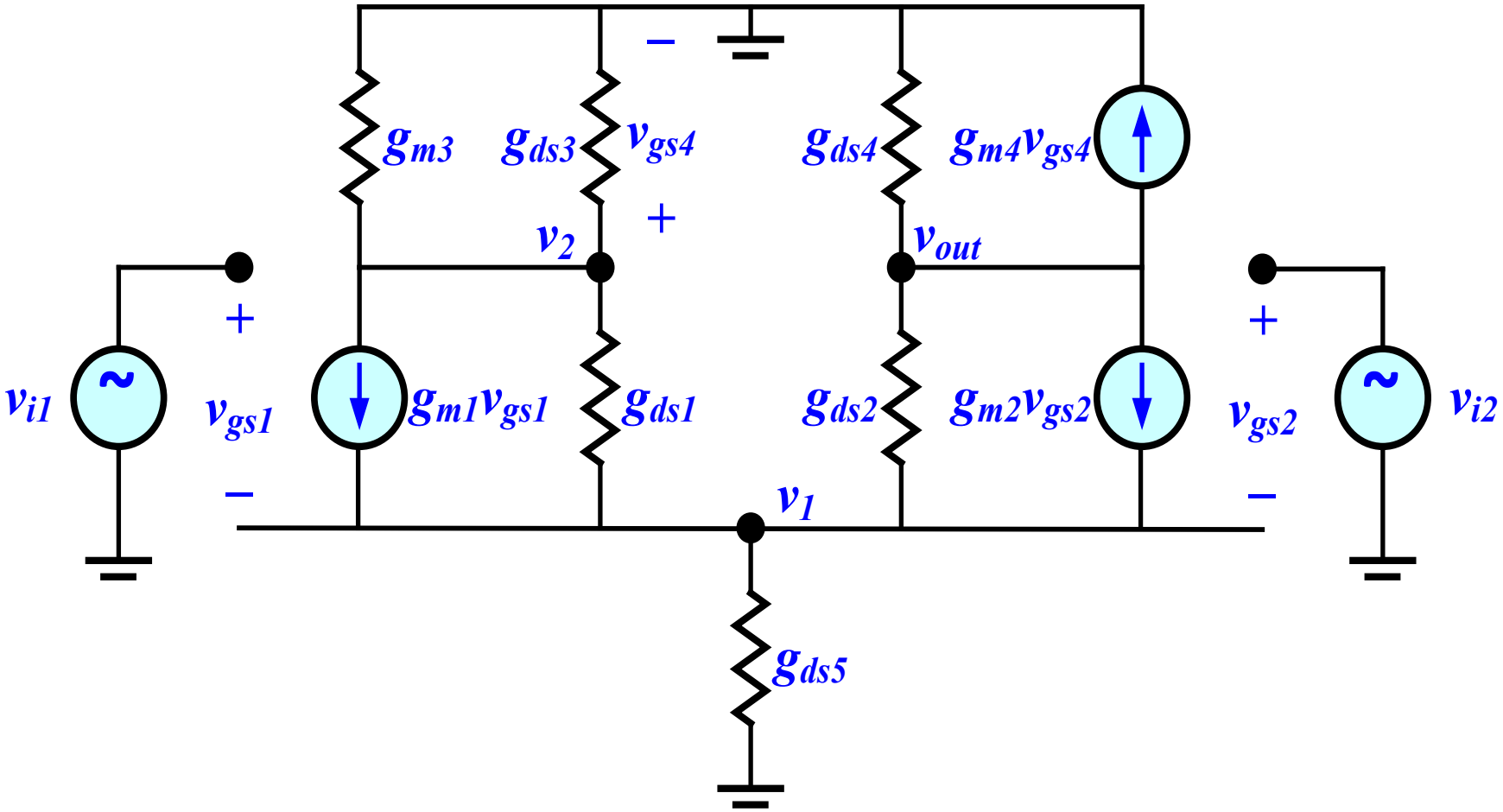
Amplificador Diferencial con Espejo de Corriente

- Esquema de circuito:



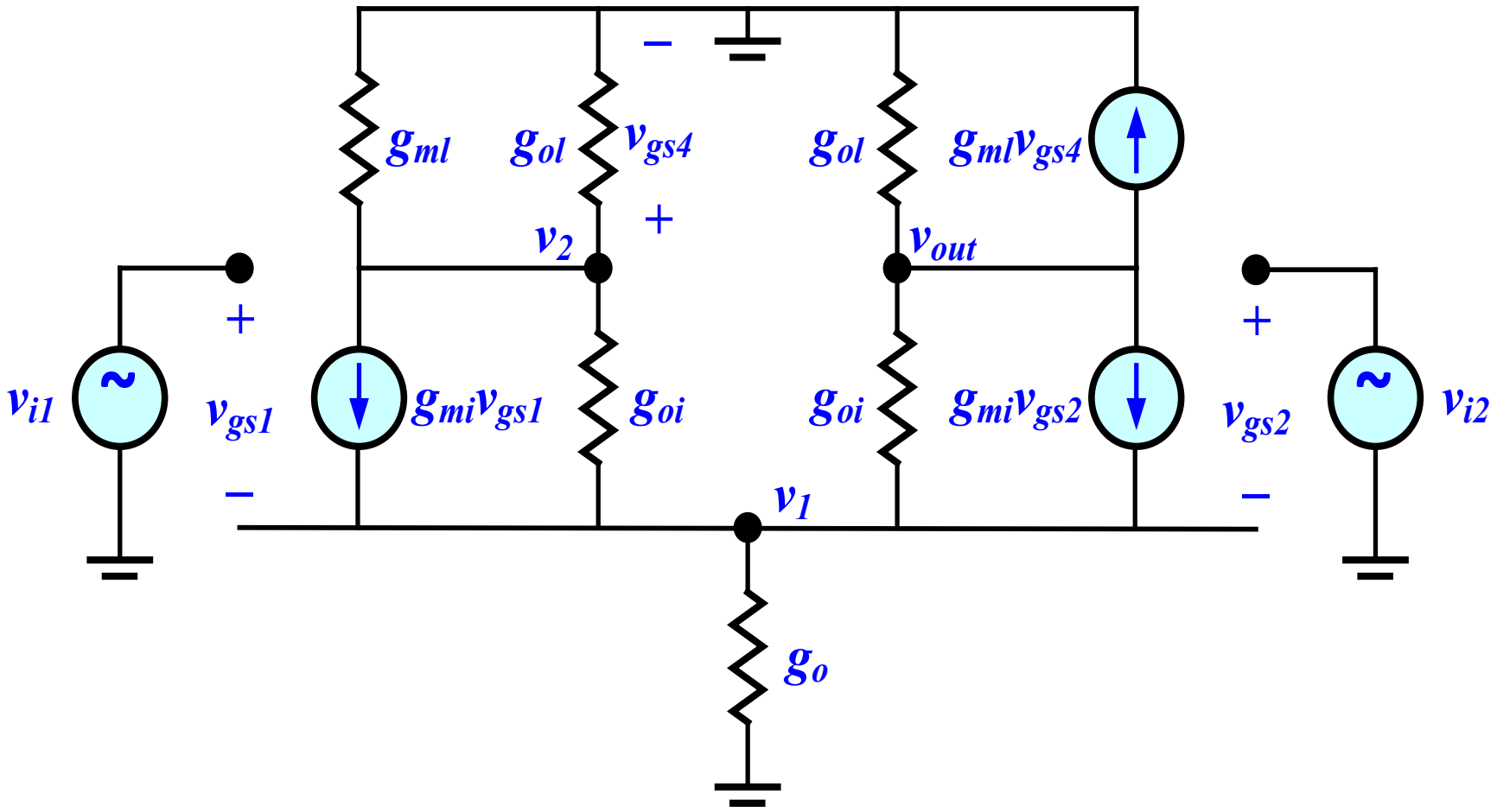
Amplificador Diferencial con Espejo de Corriente

- Circuito equivalente de pequeña señal:



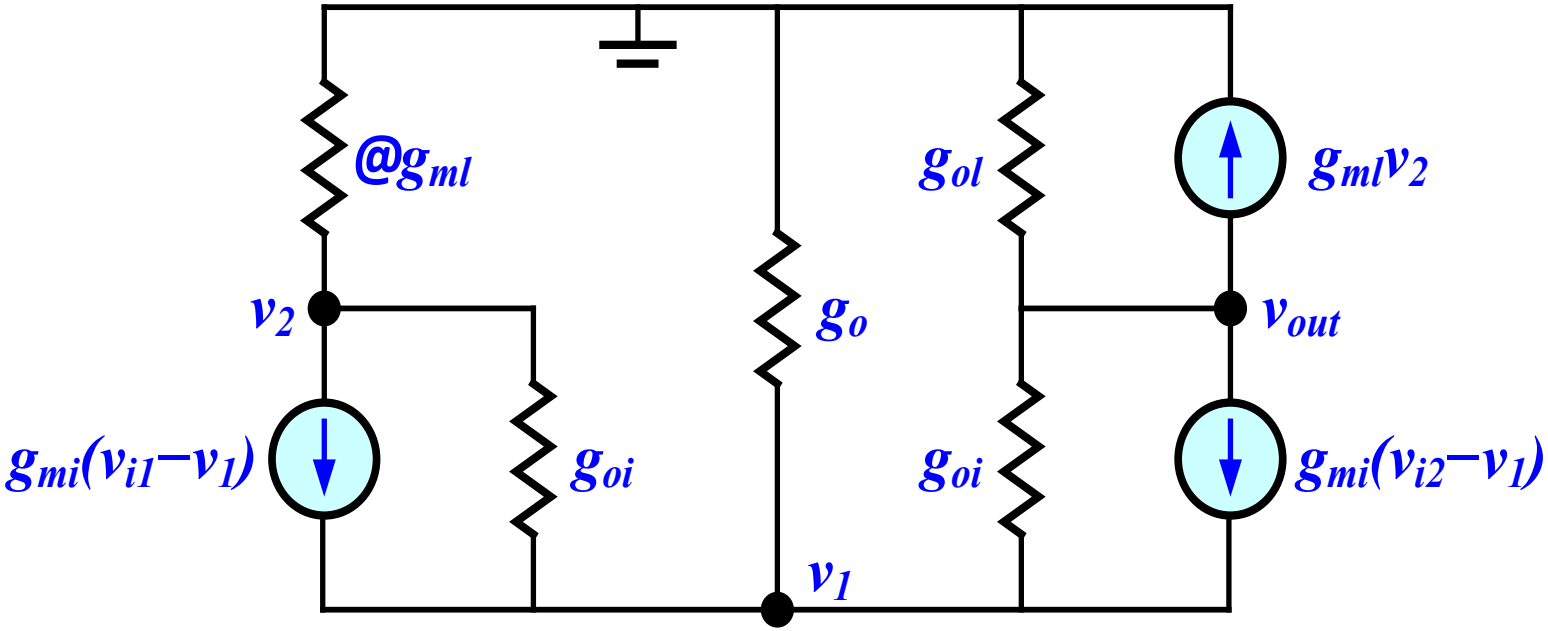
Amplificador Diferencial con Espejo de Corriente

- Circuito equivalente con transistores simétricos:



Amplificador Diferencial con Espejo de Corriente

- Análisis del circuito con transistores simétricos:



$$g_{ml}v_2 + g_{mi}\left(v_{i1} - v_1\right) + g_{oi}\left(v_2 - v_1\right) = 0$$

$$-g_o v_1 + g_{oi}\left(v_2 - v_1\right) + g_{mi}\left(v_{i1} - v_1\right) + g_{oi}\left(v_{out} - v_1\right) + g_{mi}\left(v_{i2} - v_1\right) = 0$$

$$g_{ol}v_{out} + g_{ml}v_2 + g_{oi}\left(v_{out} - v_1\right) + g_{mi}\left(v_{i2} - v_1\right) = 0$$

Amplificador Diferencial con Espejo de Corriente

- Tensión de salida v_{out}:

$$\left(g_{mi}+g_{oi}\right)v_1-\left(g_{ml}+g_{oi}\right)v_2=g_{mi}v_{i1}$$

$$\left(2g_{mi}+2g_{oi}+g_o\right)v_1-g_{oi}v_2-g_{oi}v_{out}=g_{mi}v_{i1}+g_{mi}v_{i2}$$

$$\left(g_{mi}+g_{oi}\right)v_1-g_{ml}v_2-\left(g_{oi}+g_{ol}\right)v_{out}=g_{mi}v_{i2}$$

$$v_{out}=\frac{g_{mi}g_{ml}\left(2\left(g_{mi}+g_{oi}\right)\left(v_{i1}-v_{i2}\right)+g_o\left(v_{i1}-\left(1+\frac{g_{oi}}{g_{ml}}\right)v_{i2}\right)\right)}{\left(g_{mi}+g_{oi}\right)\left(g_{oi}g_{ol}+2g_{ml}\left(g_{oi}+g_{ol}\right)\right)+g_o\left(g_{ml}+g_{oi}\right)\left(g_{oi}+g_{ol}\right)}$$

$$v_{out}=\frac{g_{mi}g_{ml}\left(2\left(g_{mi}+g_{oi}\right)+g_o\left(1+\frac{g_{oi}}{2g_{ml}}\right)\right)\left(v_{i1}-v_{i2}\right)-g_{mi}g_{oi}g_o\frac{\left(v_{i1}+v_{i2}\right)}{2}}{\left(g_{mi}+g_{oi}\right)\left(g_{oi}g_{ol}+2g_{ml}\left(g_{oi}+g_{ol}\right)\right)+g_o\left(g_{ml}+g_{oi}\right)\left(g_{oi}+g_{ol}\right)}$$

Amplificador Diferencial con Espejo de Corriente

- Ganancias DM (A_{dm}) y CM (A_{cm}):

$$v_{out} = A_{dm}\left(v_{i1} - v_{i2}\right) + A_{cm}\frac{\left(v_{i1} + v_{i2}\right)}{2}$$

$$A_{dm} = \frac{g_{mi}g_{ml}\left(2\left(g_{mi} + g_{oi}\right) + g_o\left(1 + \frac{g_{oi}}{2g_{ml}}\right)\right)}{\left(g_{mi} + g_{oi}\right)\left(g_{oi}g_{ol} + 2g_{ml}\left(g_{oi} + g_{ol}\right)\right) + g_o\left(g_{ml} + g_{oi}\right)\left(g_{oi} + g_{ol}\right)}$$

$$A_{cm} = \frac{-g_{mi}g_{oi}g_o}{\left(g_{mi} + g_{oi}\right)\left(g_{oi}g_{ol} + 2g_{ml}\left(g_{oi} + g_{ol}\right)\right) + g_o\left(g_{ml} + g_{oi}\right)\left(g_{oi} + g_{ol}\right)}$$

Amplificador Diferencial con Espejo de Corriente

- Razón de rechazo del modo común (***CMMR***):

$$CMRR = \left|\frac{A_{dm}}{A_{cm}}\right| = \frac{g_{ml}}{g_{oi}g_o}\left(2\left(g_{mi}+g_{oi}\right)+g_o\right)+\frac{1}{2}$$

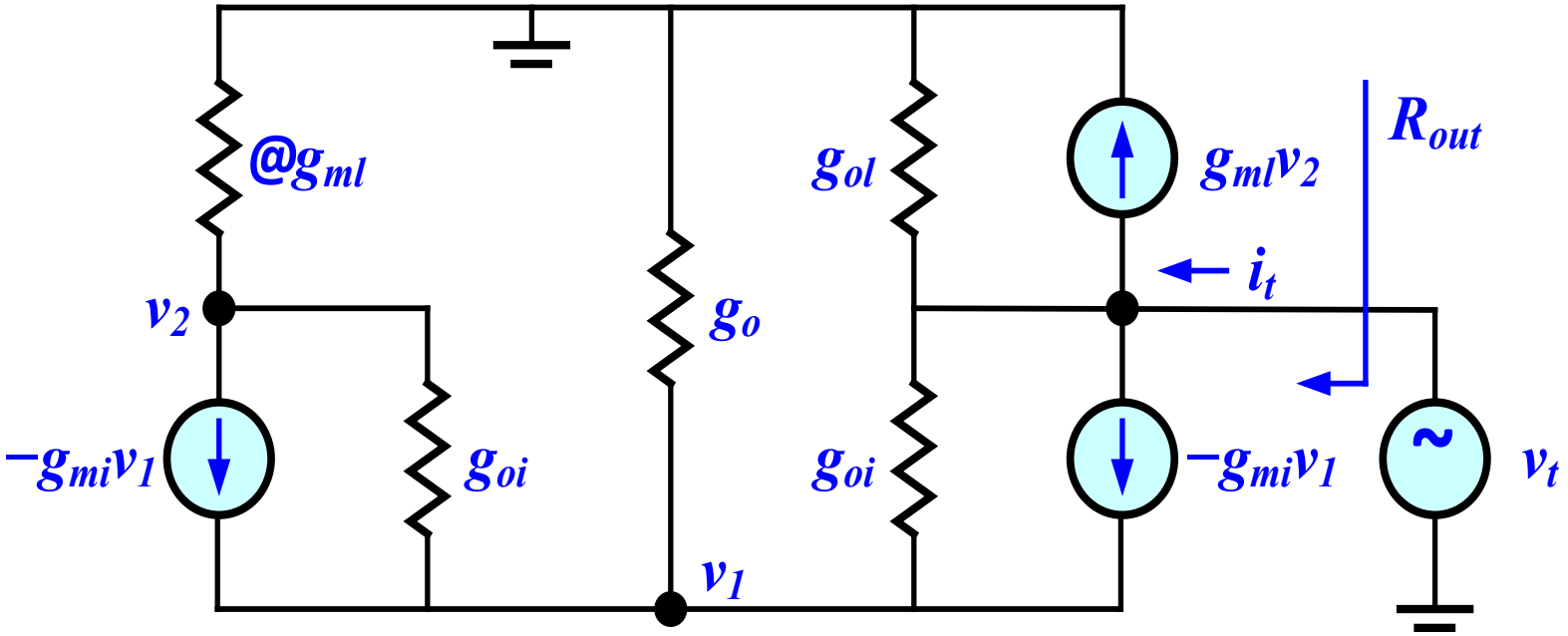
- Expresiones simplificadas: $g_{mi}, g_{ml} >> g_o, g_{oi}, g_{ol}$

$$A_{dm}\ ;\ \frac{g_{mi}}{g_{oi}+g_{ol}} \qquad A_{cm}\ ;\ \frac{-g_o g_{oi}}{2g_{ml}\left(g_{oi}+g_{ol}\right)}$$

$$CMRR\ ;\ \frac{2g_{mi}g_{ml}}{g_o g_{oi}}$$

Amplificador Diferencial con Espejo de Corriente

- Resistencia de salida R_{out}:



$$g_{ml}v_2 - g_{mi}v_1 + g_{oi}\left(v_2 - v_1\right) = 0$$

$$-g_o v_1 + g_{oi}\left(v_2 - v_1\right) - g_{mi}v_1 + g_{oi}\left(v_t - v_1\right) - g_{mi}v_1 = 0$$

$$g_{ol}v_t + g_{ml}v_2 + g_{oi}\left(v_t - v_1\right) - g_{mi}v_1 = i_t$$

Amplificador Diferencial con Espejo de Corriente

- Cálculo de $\boldsymbol{R_{out}}$:

$$\left(g_{mi}+g_{oi}\right)v_1-\left(g_{ml}+g_{oi}\right)v_2=0$$

$$\left(2g_{mi}+2g_{oi}+g_o\right)v_1-g_{oi}v_2-g_{oi}v_t=0$$

$$\left(g_{mi}+g_{oi}\right)v_1-g_{ml}v_2-\left(g_{oi}+g_{ol}\right)v_t=-i_t$$

$$R_{out}=\frac{v_t}{i_t}$$

$$R_{out}=\frac{\left(g_{mi}+g_{oi}\right)\left(2g_{ml}+g_{oi}\right)+g_o\left(g_{ml}+g_{oi}\right)}{\left(g_{mi}+g_{oi}\right)\left(g_{oi}g_{ol}+2g_{ml}\left(g_{oi}+g_{ol}\right)\right)+g_o\left(g_{ml}+g_{oi}\right)\left(g_{oi}+g_{ol}\right)}$$

$$g_{mi},g_{ml}>>g_o,g_{oi},g_{ol}:\quad R_{out}\ ;\ \frac{1}{g_{oi}+g_{ol}}$$