ECEN 326
Electronic Circuits

Feedback

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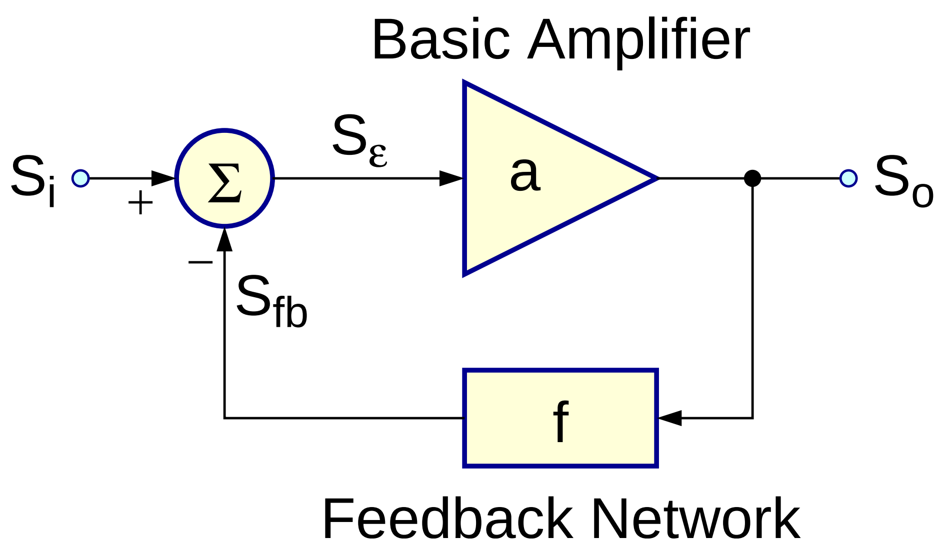
Ideal Feedback Configuration



$$\frac{S_o}{S_i} = A = \frac{a}{1+T} \quad , \quad T = af$$

$$\frac{S_\varepsilon}{S_i} = \frac{1}{1+T} \quad , \quad \frac{S_{fb}}{S_i} = \frac{T}{1+T}$$

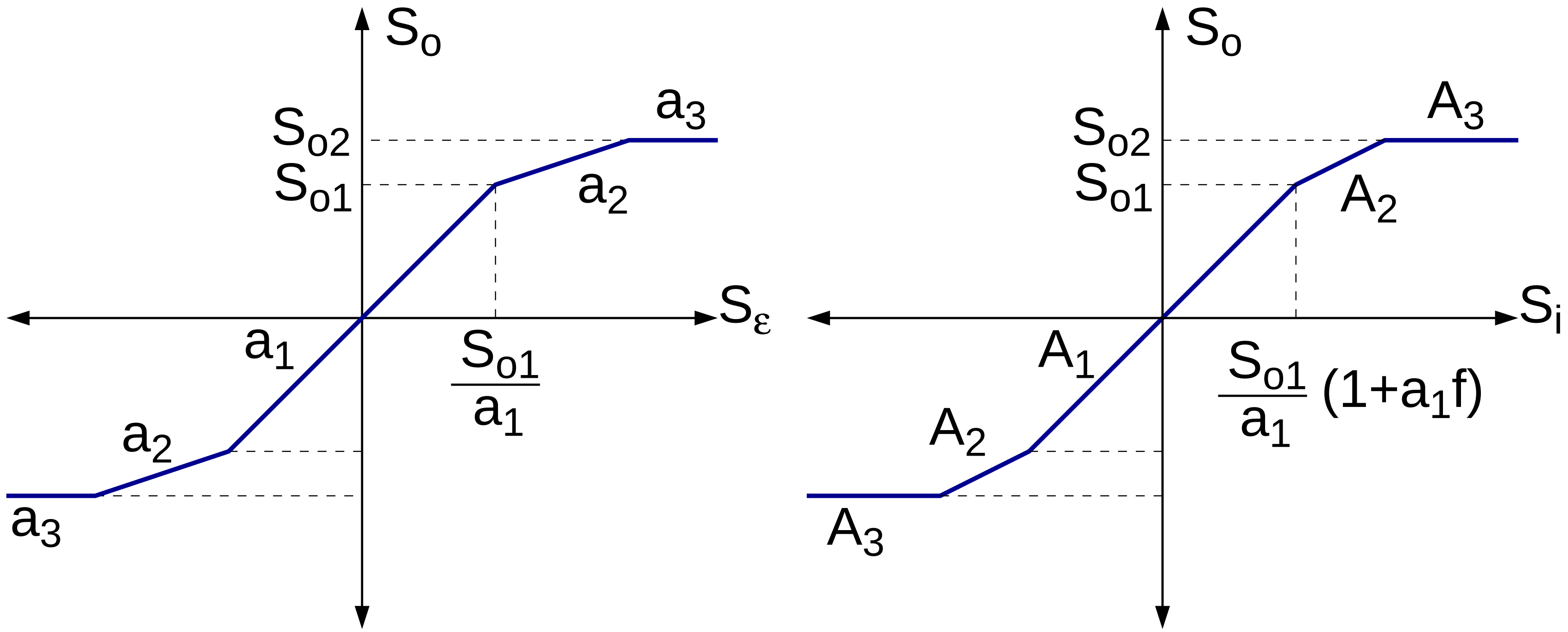
Effect of Feedback

Gain of the basic amplifier (**a**) usually depends on temperature, operating conditions and process parameters.

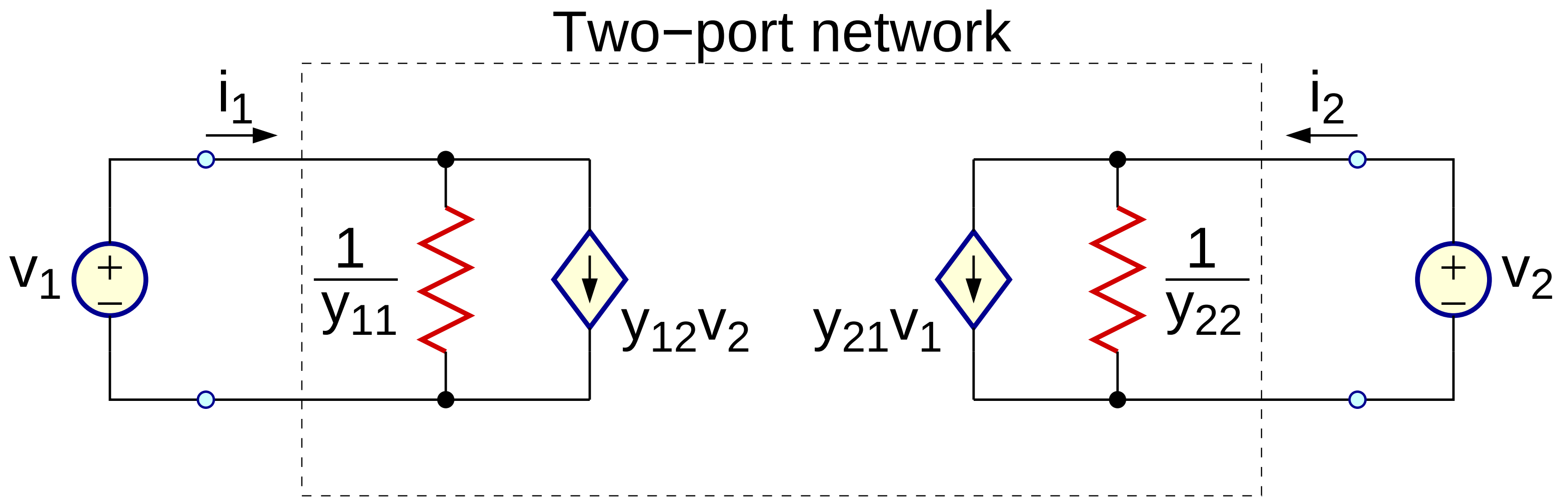
$$\frac{dA}{da} = \frac{(1+af) - af}{(1+af)^2} = \frac{1}{(1+af)^2}$$

$$\delta A = \frac{\delta a}{(1+af)^2} \quad \Rightarrow \quad \frac{\delta A}{A} = \frac{1+af}{a}\frac{\delta a}{(1+af)^2}$$

$$\frac{\delta A}{A} = \frac{\frac{\delta a}{a}}{1+af} = \frac{\frac{\delta a}{a}}{1+T}$$

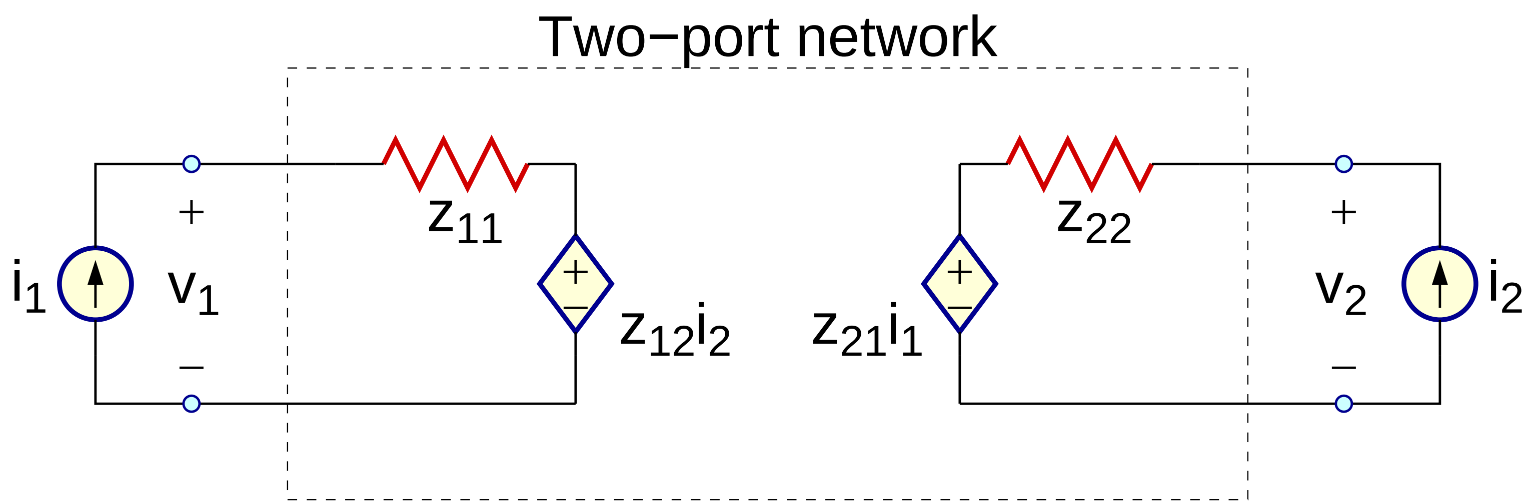


$$\mathbf{A_1 = \frac{a_1}{1 + a_1 f} \approx \frac{1}{f}} \quad , \quad \mathbf{A_2 = \frac{a_2}{1 + a_2 f} \approx \frac{1}{f}}$$



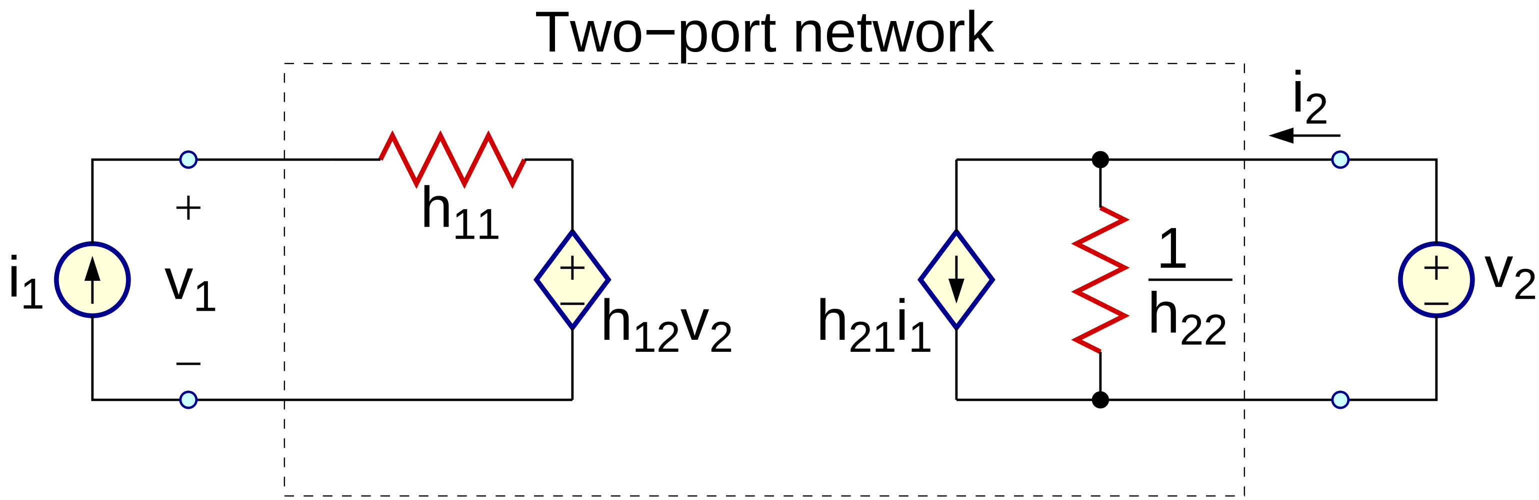
$$i_1 = y_{11}v_1 + y_{12}v_2$$
$$i_2 = y_{21}v_1 + y_{22}v_2$$

$$y_{11} = \left.\frac{i_1}{v_1}\right|_{v_2=0} , \quad y_{12} = \left.\frac{i_1}{v_2}\right|_{v_1=0}$$
$$y_{21} = \left.\frac{i_2}{v_1}\right|_{v_2=0} , \quad y_{22} = \left.\frac{i_2}{v_2}\right|_{v_1=0}$$



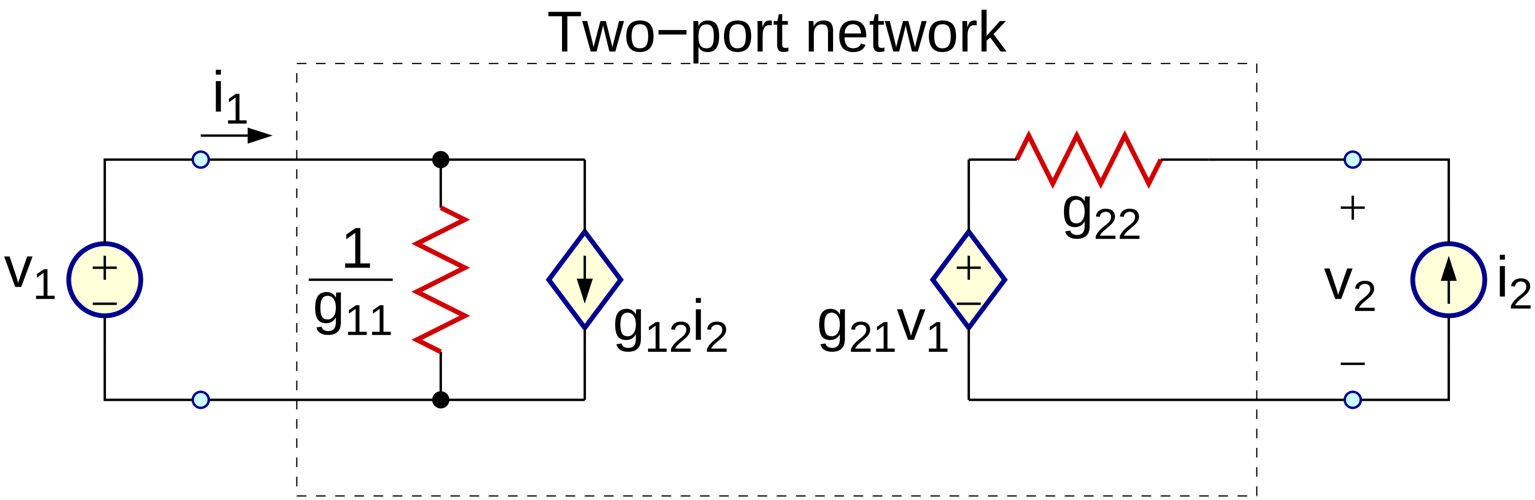
$$v_1 = z_{11} i_1 + z_{12} i_2$$
$$v_2 = z_{21} i_1 + z_{22} i_2$$

$$z_{11} = \left.\frac{v_1}{i_1}\right|_{i_2=0} \quad , \quad z_{12} = \left.\frac{v_1}{i_2}\right|_{i_1=0}$$
$$z_{21} = \left.\frac{v_2}{i_1}\right|_{i_2=0} \quad , \quad z_{22} = \left.\frac{v_2}{i_2}\right|_{i_1=0}$$



$$v_1 = h_{11} i_1 + h_{12} v_2$$
$$i_2 = h_{21} i_1 + h_{22} v_2$$

$$h_{11} = \left.\frac{v_1}{i_1}\right|_{v_2=0} \quad , \quad h_{12} = \left.\frac{v_1}{v_2}\right|_{i_1=0}$$
$$h_{21} = \left.\frac{i_2}{i_1}\right|_{v_2=0} \quad , \quad h_{22} = \left.\frac{i_2}{v_2}\right|_{i_1=0}$$



$$i_1 = g_{11} v_1 + g_{12} i_2$$
$$v_2 = g_{21} v_1 + g_{22} i_2$$

$$g_{11} = \left.\frac{i_1}{v_1}\right|_{i_2=0} \quad , \quad g_{12} = \left.\frac{i_1}{i_2}\right|_{v_1=0}$$

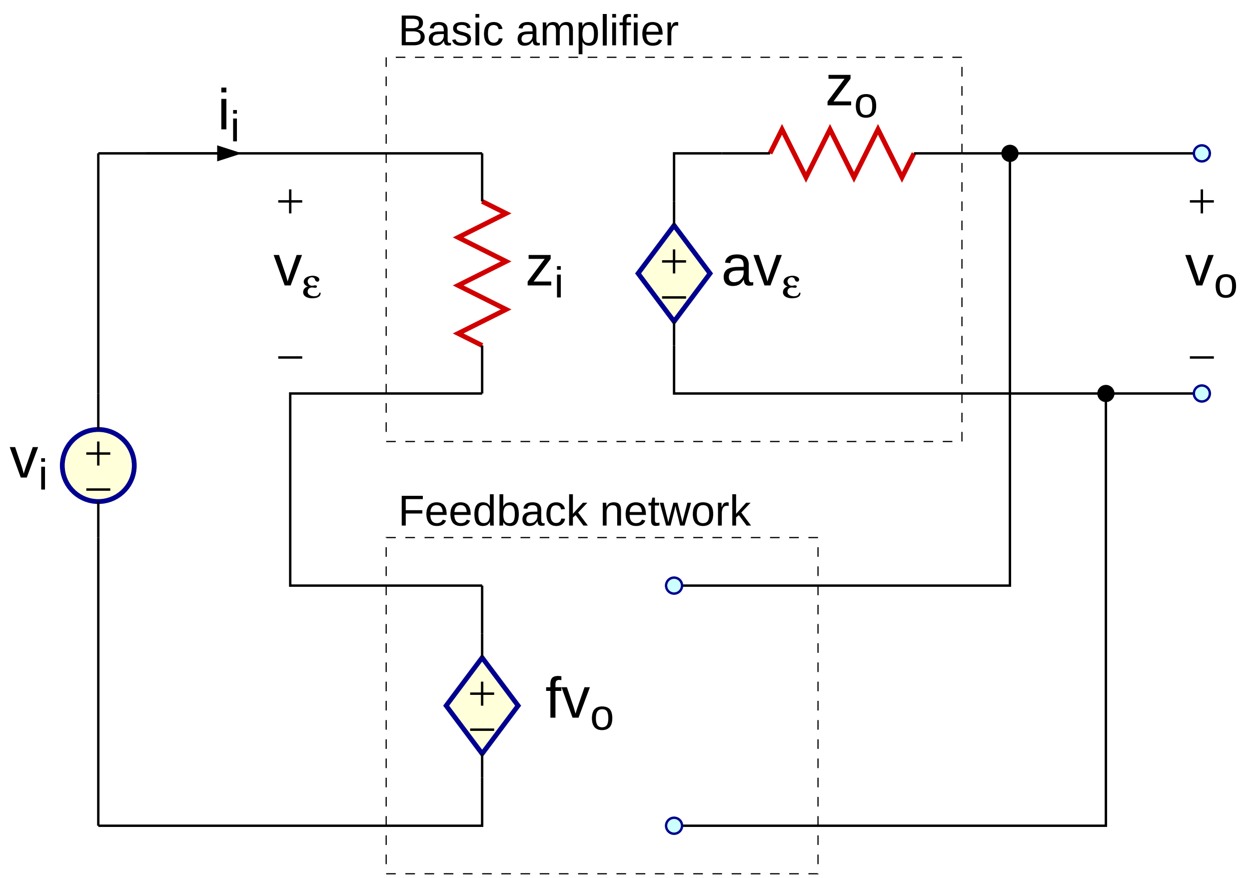
$$g_{21} = \left.\frac{v_2}{v_1}\right|_{i_2=0} \quad , \quad g_{22} = \left.\frac{v_2}{i_2}\right|_{v_1=0}$$

Feedback Configurations

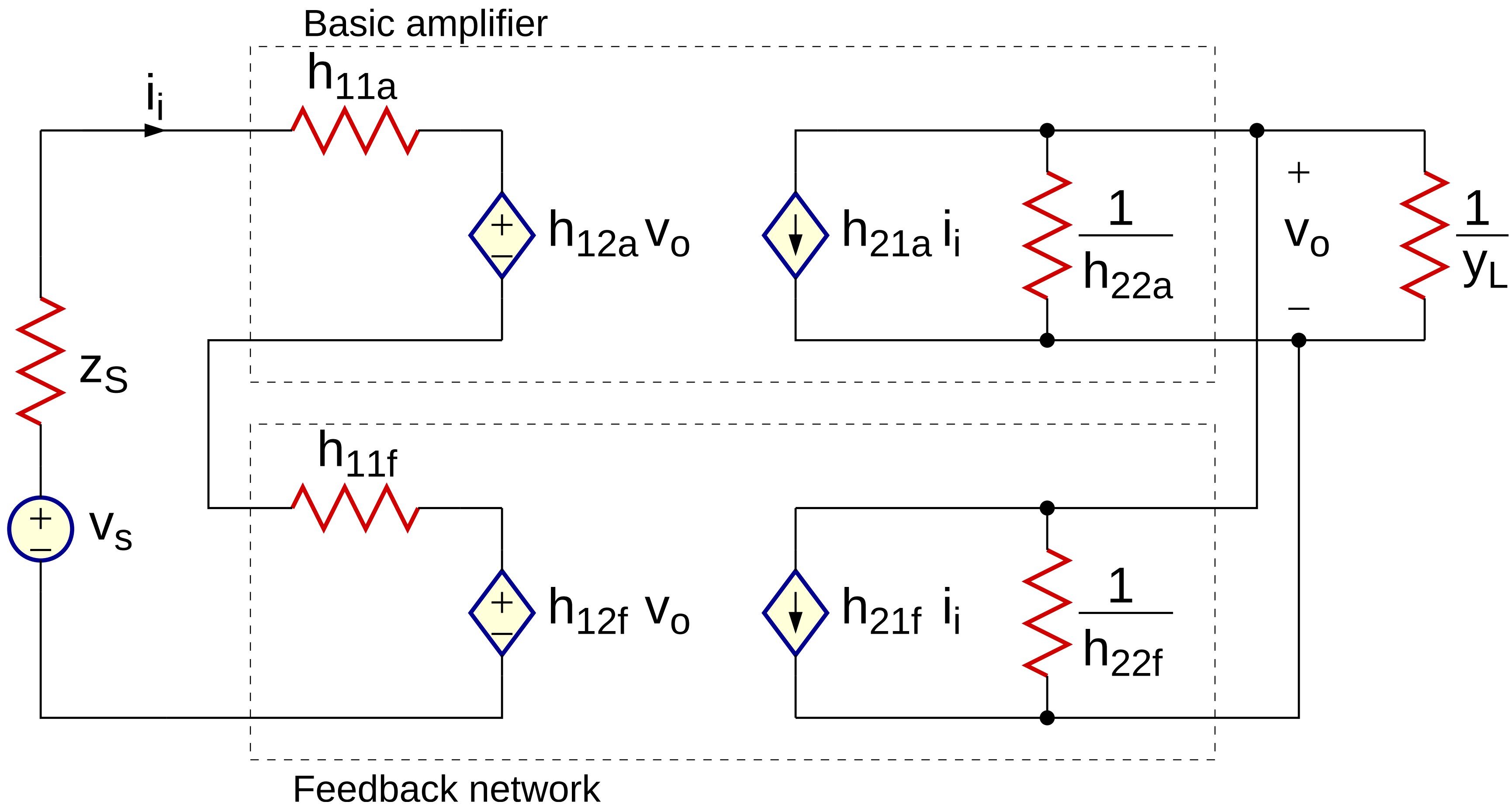
According to whether the output signal $\mathbf{S_o}$ is a current or a voltage and whether the feedback signal $\mathbf{S_{fb}}$ is a current or a voltage, four feedback configurations exist:

- Series-Shunt Feedback
  $\mathbf{S_{fb} = v_{fb}}$ (voltage), $\mathbf{S_o = v_o}$ (voltage)
- Shunt-Shunt Feedback
  $\mathbf{S_{fb} = i_{fb}}$ (current), $\mathbf{S_o = v_o}$ (voltage)
- Shunt-Series Feedback
  $\mathbf{S_{fb} = i_{fb}}$ (current), $\mathbf{S_o = i_o}$ (current)
- Series-Series Feedback
  $\mathbf{S_{fb} = v_{fb}}$ (voltage), $\mathbf{S_o = i_o}$ (current)

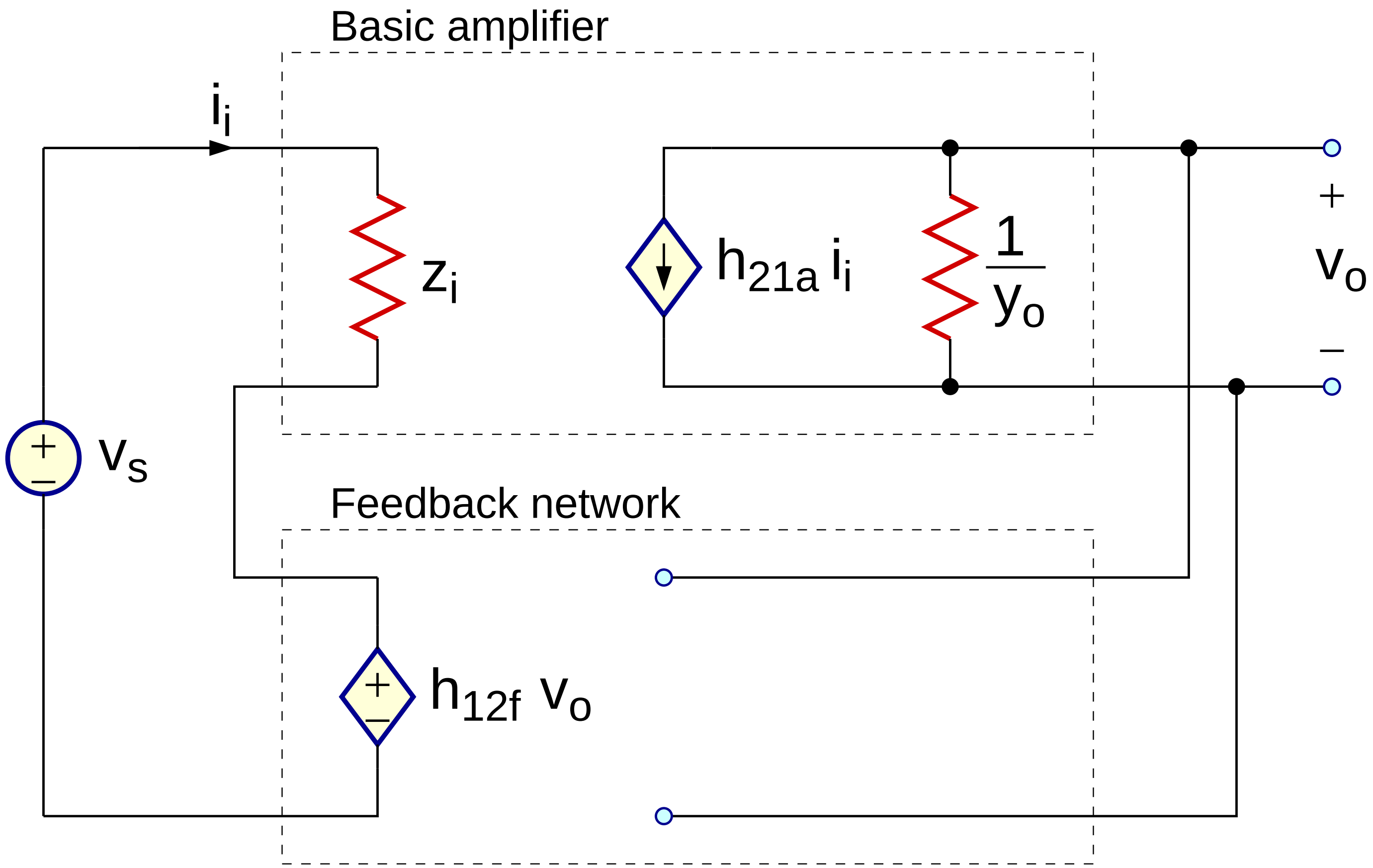
Series-Shunt



$$\frac{v_o}{v_i} = \frac{a}{1 + af} \qquad Z_i = (1 + af)z_i \qquad Z_o = \frac{z_o}{1 + af}$$

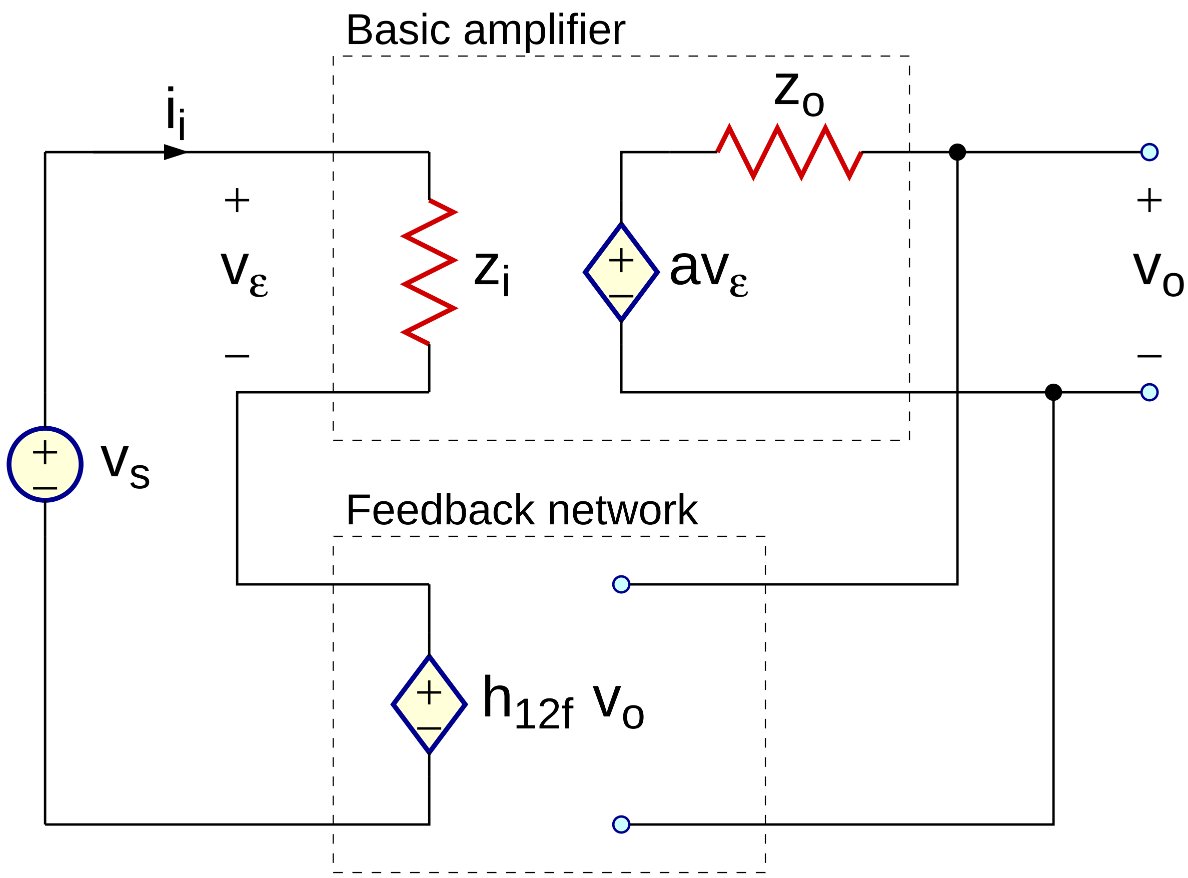


$$|\mathbf{h_{12f}}| \gg |\mathbf{h_{12a}}| \qquad |\mathbf{h_{21a}}| \gg |\mathbf{h_{21f}}|$$

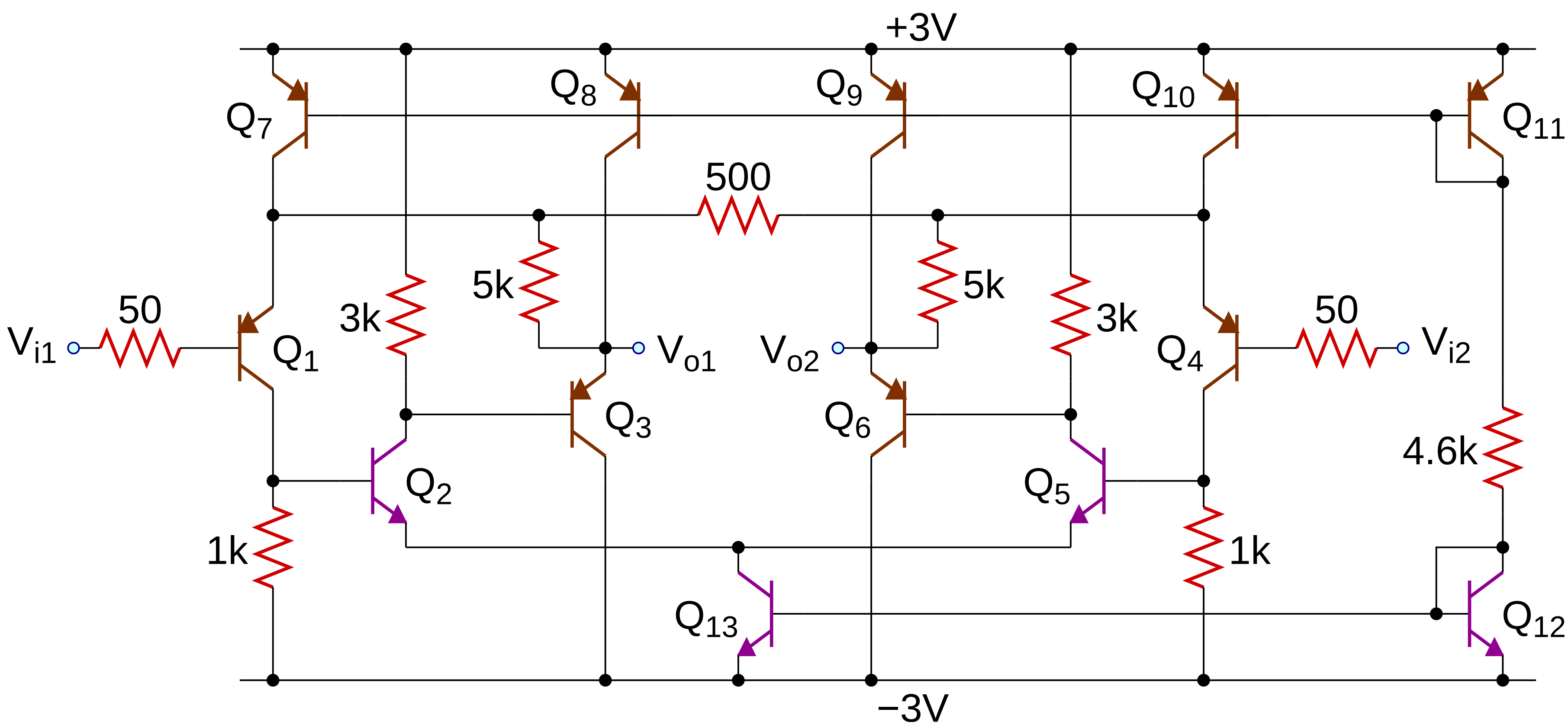


$$z_i = z_S + h_{11a} + h_{11f}$$

$$y_o = y_L + h_{22a} + h_{22f}$$

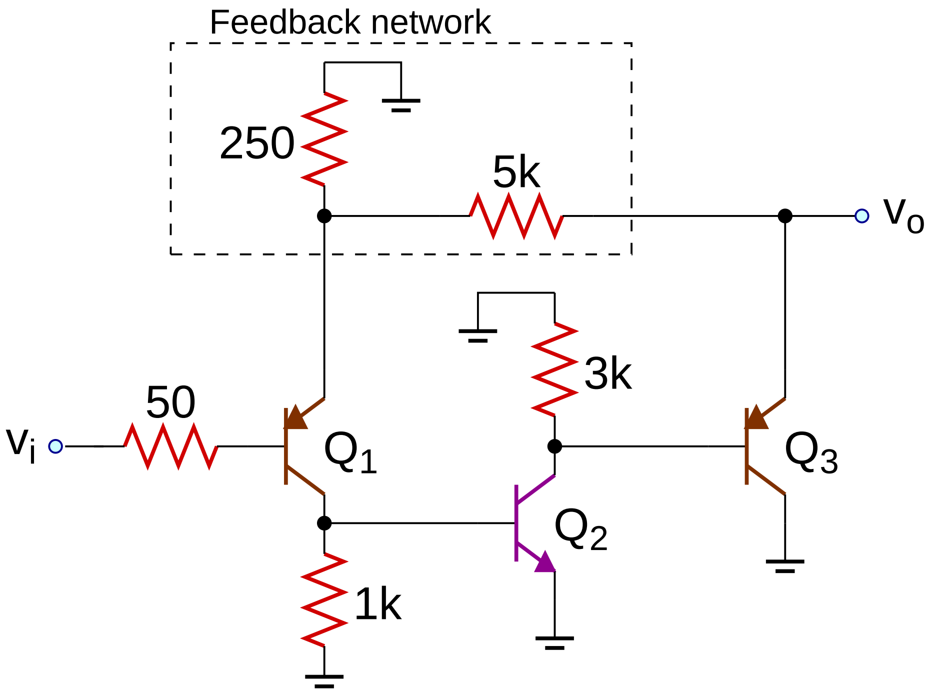


$$a = -\frac{h_{21a}}{z_i y_o} \qquad f = h_{12f} \qquad z_o = \frac{1}{y_o}$$



$$V_{i1,dc} = V_{i2,dc} = 0, \;\; V_A = \infty, \;\; V_T = 25\text{mV}, \;\; \beta = 100$$

Differential-mode AC half circuit:

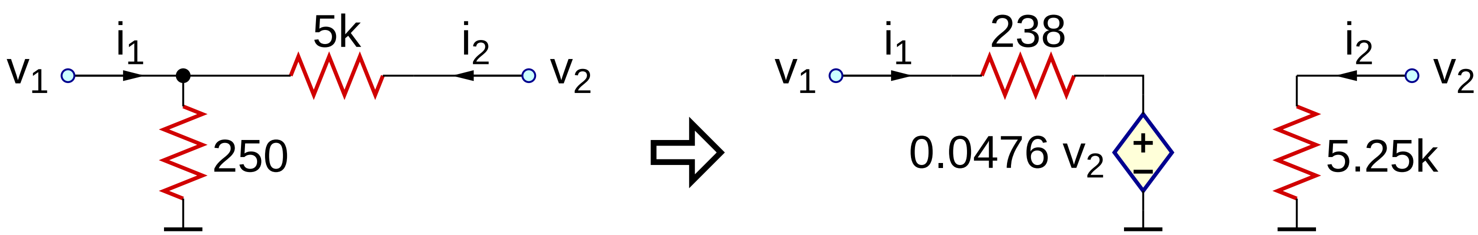


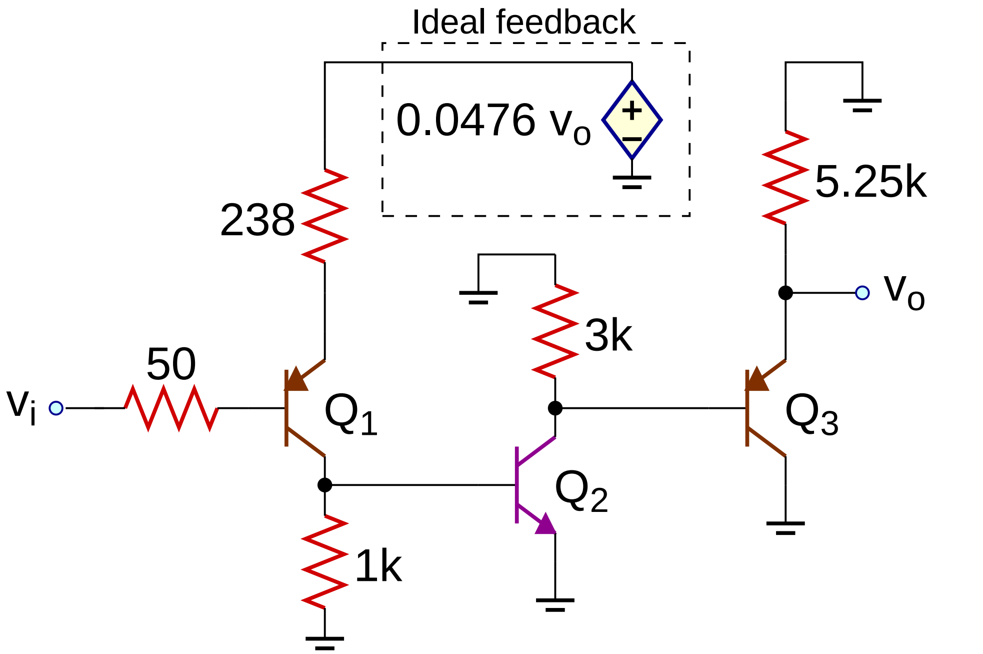
Input: Voltage

Output: Voltage

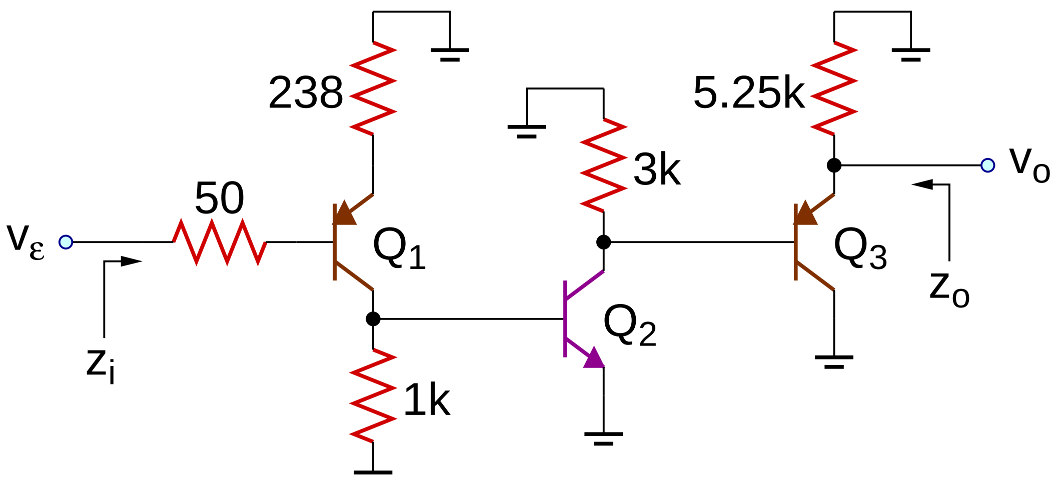
$$I_{C1} = 1.3\ \text{mA}$$
$$I_{C2} = 0.5\ \text{mA}$$
$$I_{C3} = 0.7\ \text{mA}$$

h-parameter representation of the feedback network:





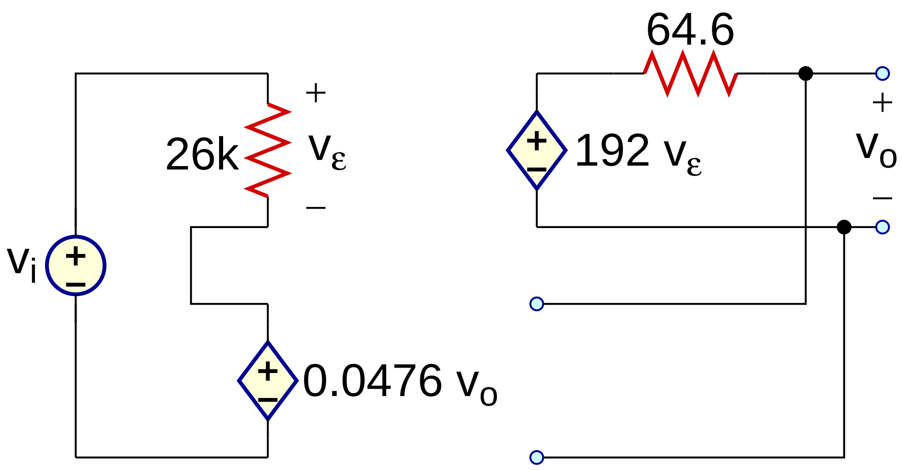
$$f = 0.0476$$



$$a = \frac{v_o}{v_\varepsilon} = 192$$

$$z_i = 26\ \mathrm{k\Omega}$$

$$z_o = 64.6\ \Omega$$

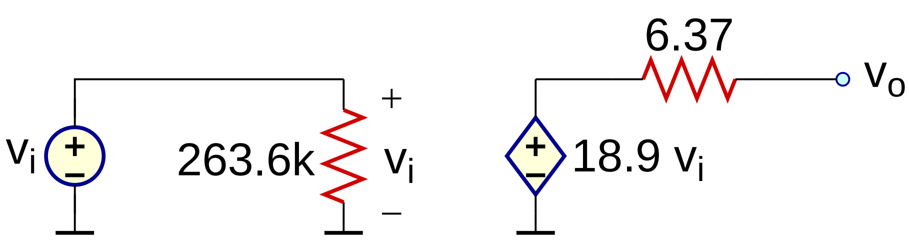


$a = 192$

$f = 0.0476$

$z_i = 26\ \text{k}\Omega$

$z_o = 64.6\ \Omega$



$$A = \frac{v_o}{v_i} = \frac{a}{1+af} = 18.9$$

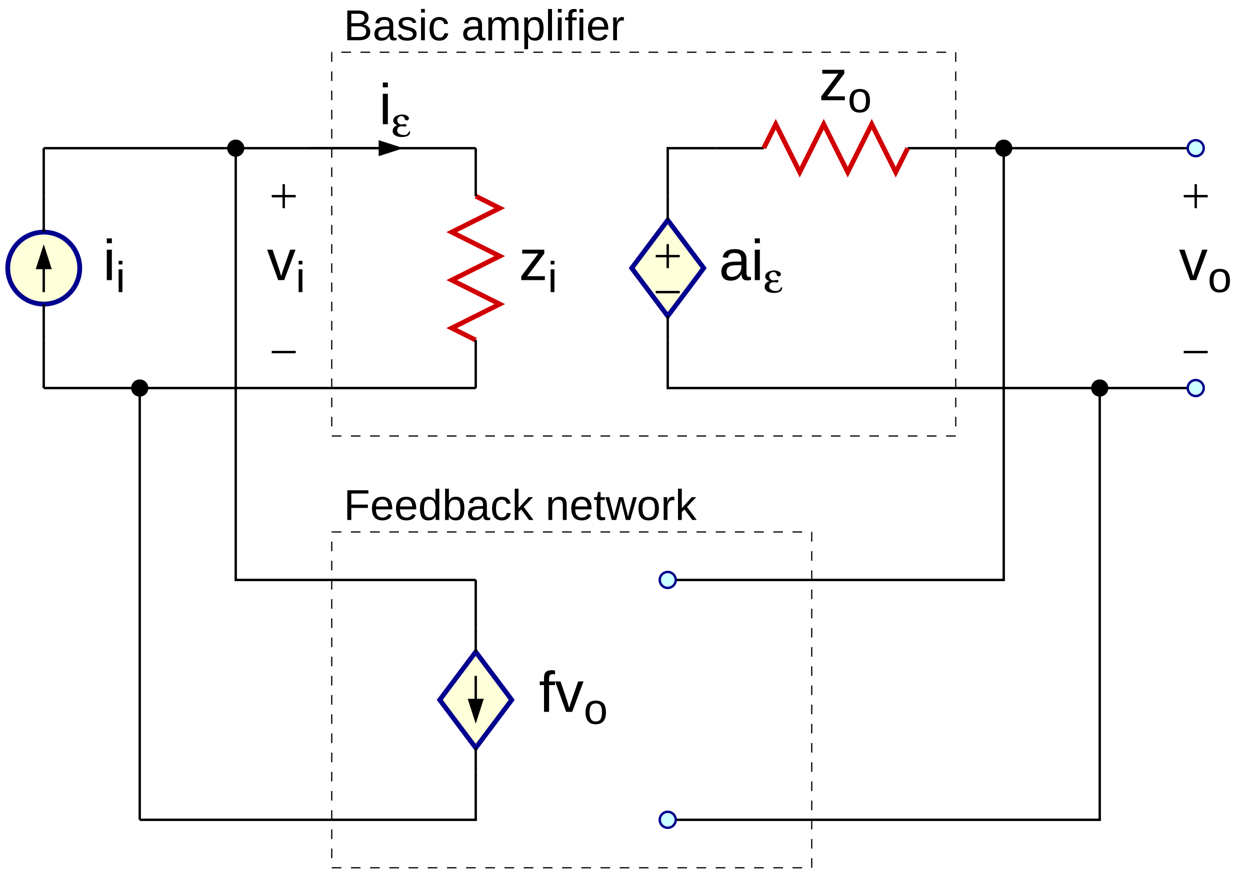
$$Z_i = z_i(1+af) = 263.6\ \text{k}\Omega \qquad Z_o = \frac{z_o}{1+af} = 6.37\ \Omega$$

$$A_{dm} = 18.9$$

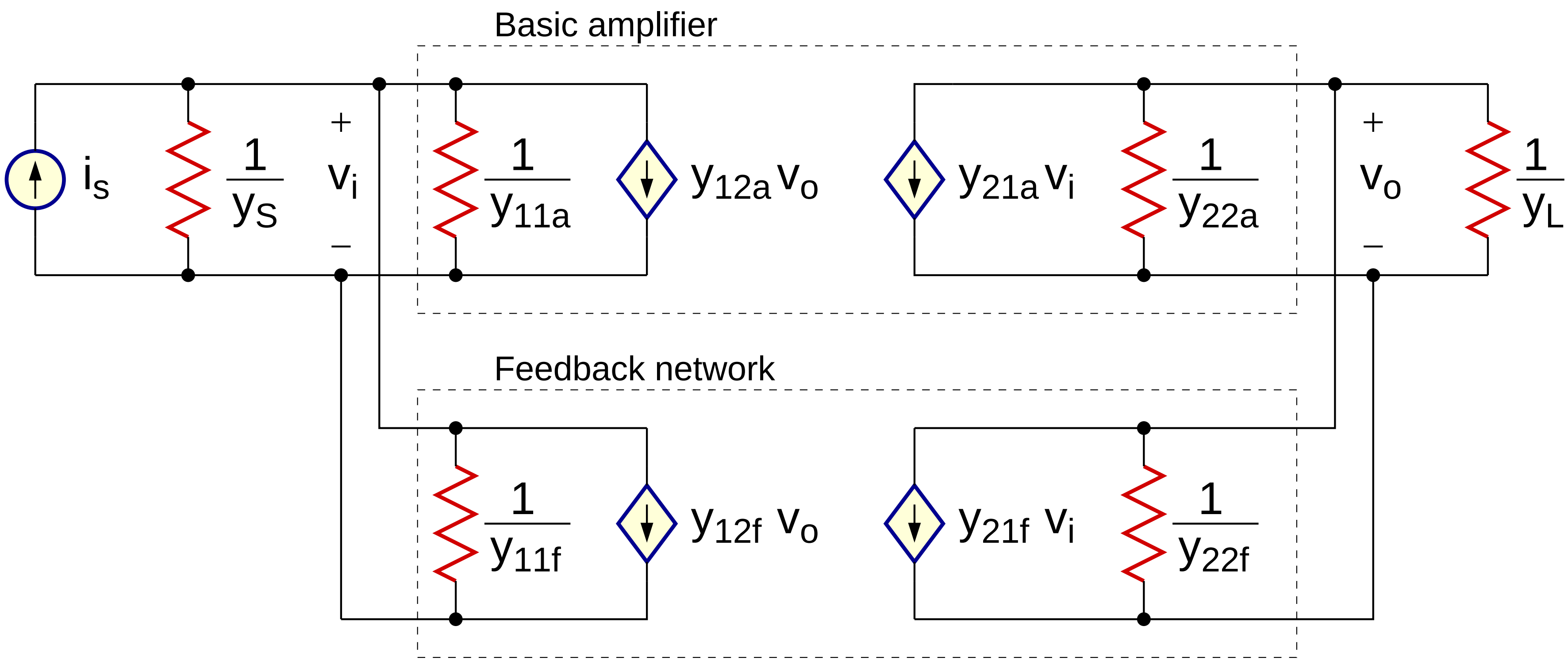
$$R_{id} = 2 \times 263.6\text{k} = 527.2\ \text{k}\Omega$$

$$R_{od} = 2 \times 6.37 = 12.7\ \Omega$$

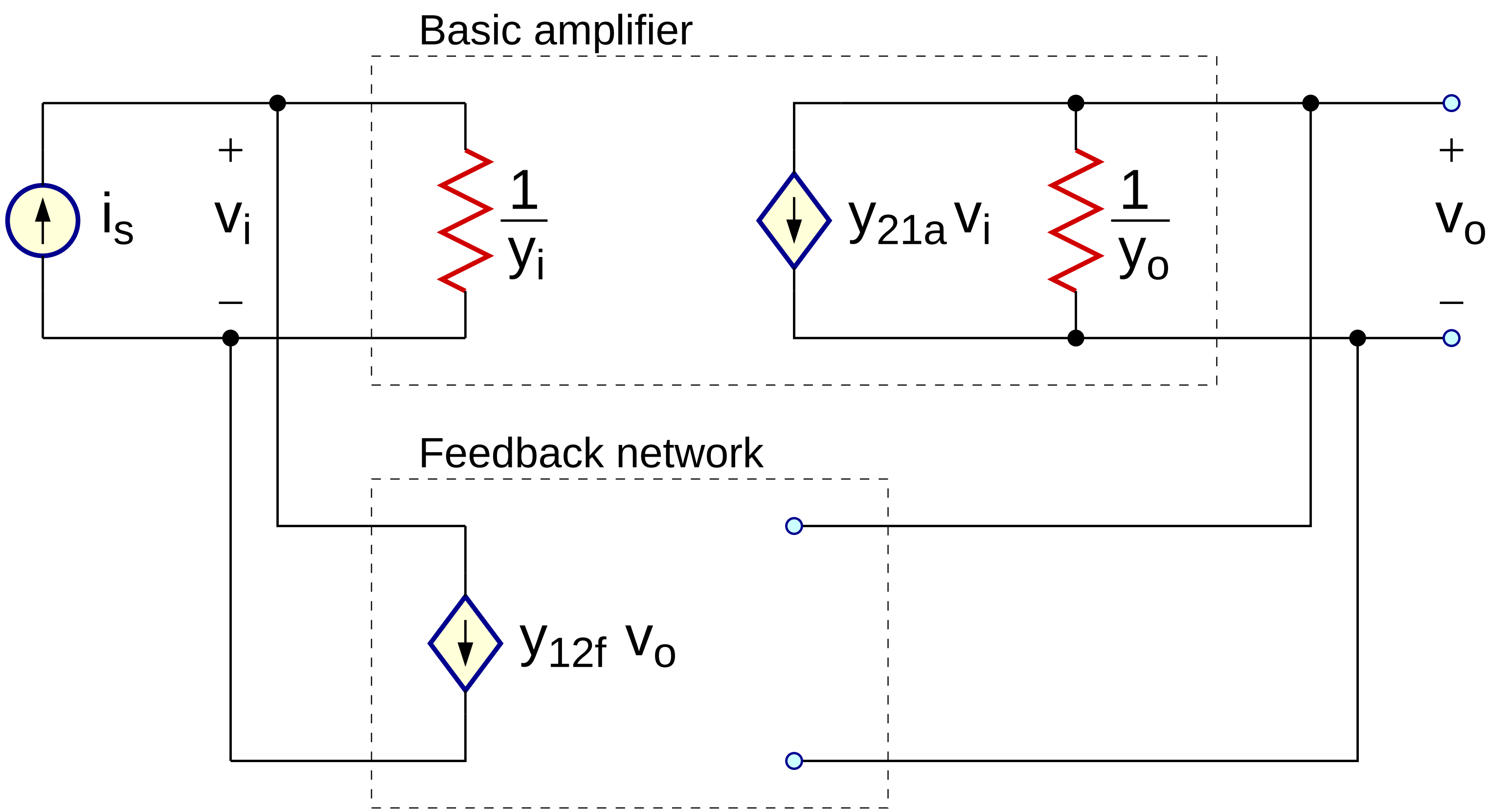
Shunt-Shunt



$$\frac{v_o}{i_i} = \frac{a}{1 + af} \qquad Z_i = \frac{z_i}{1 + af} \qquad Z_o = \frac{z_o}{1 + af}$$

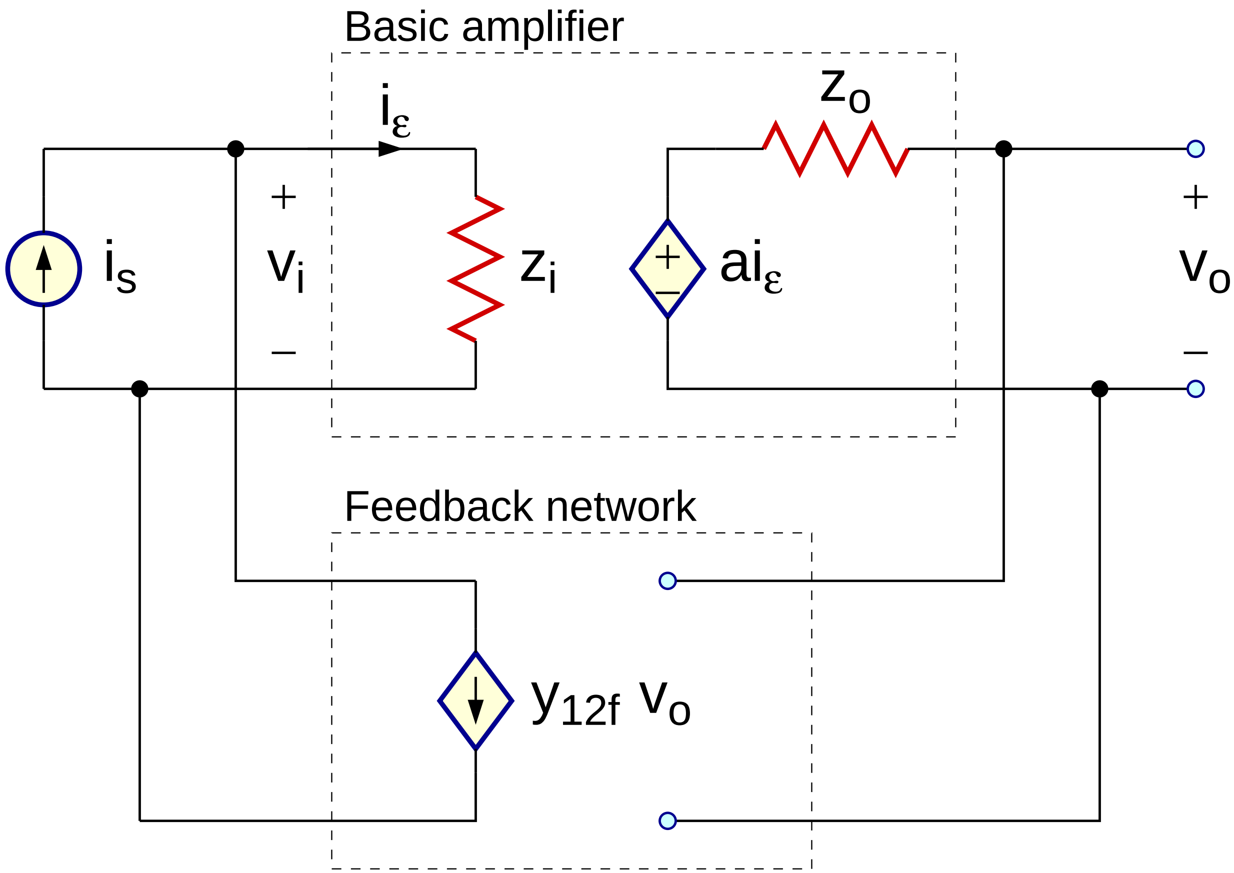


$$|\mathbf{y_{12f}}| \gg |\mathbf{y_{12a}}| \qquad |\mathbf{y_{21a}}| \gg |\mathbf{y_{21f}}|$$

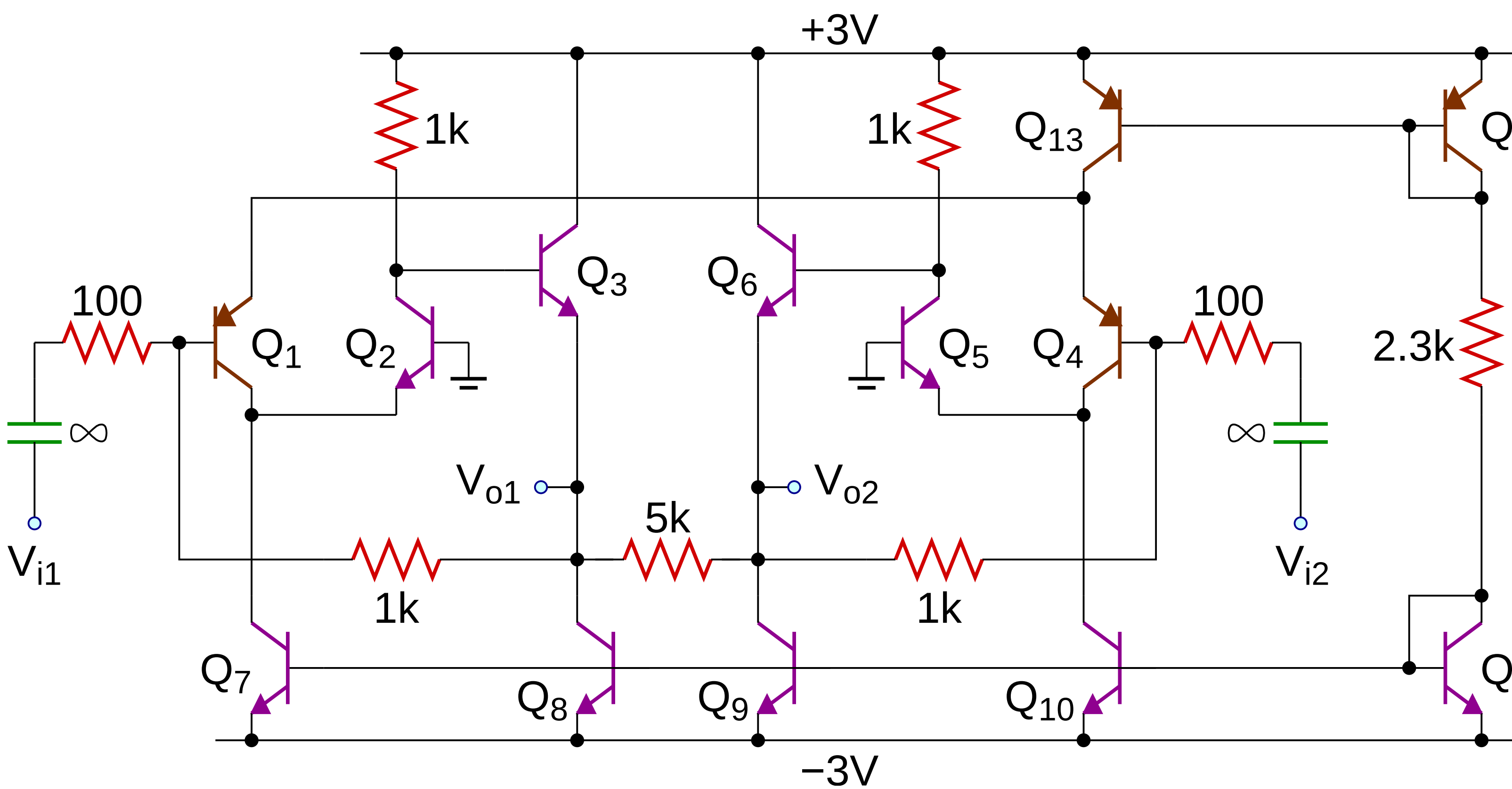


$$y_i = y_S + y_{11a} + y_{11f}$$

$$y_o = y_L + y_{22a} + y_{22f}$$

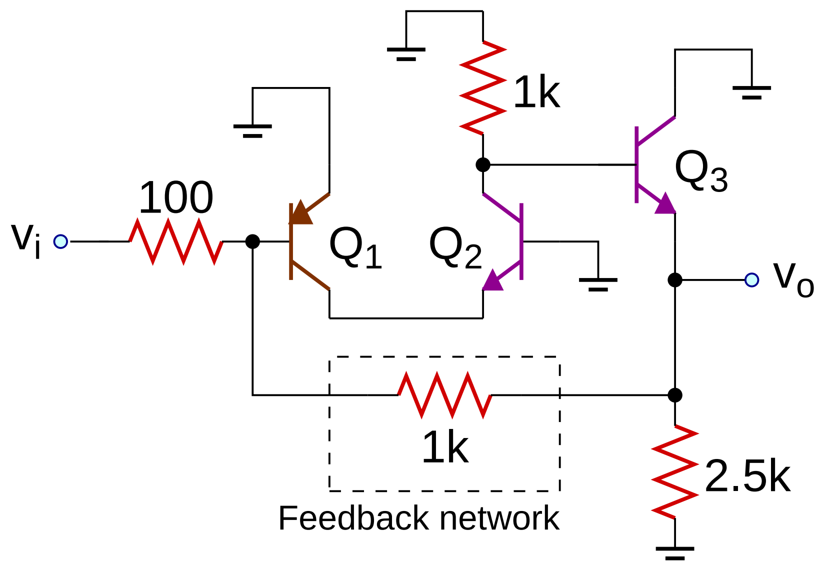


$$a = -\frac{y_{21a}}{y_i y_o} \qquad f = y_{12f} \qquad z_i = \frac{1}{y_i} \qquad z_o = \frac{1}{y_o}$$



$$V_{i1,dc} = V_{i2,dc} = 0, \; V_A = \infty, \; V_T = 25\text{mV}, \; \beta = 100$$

Differential-mode AC half circuit:

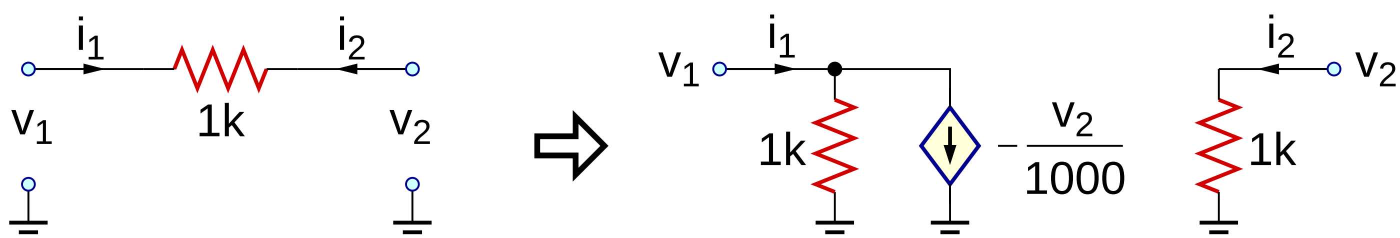


Input: Current

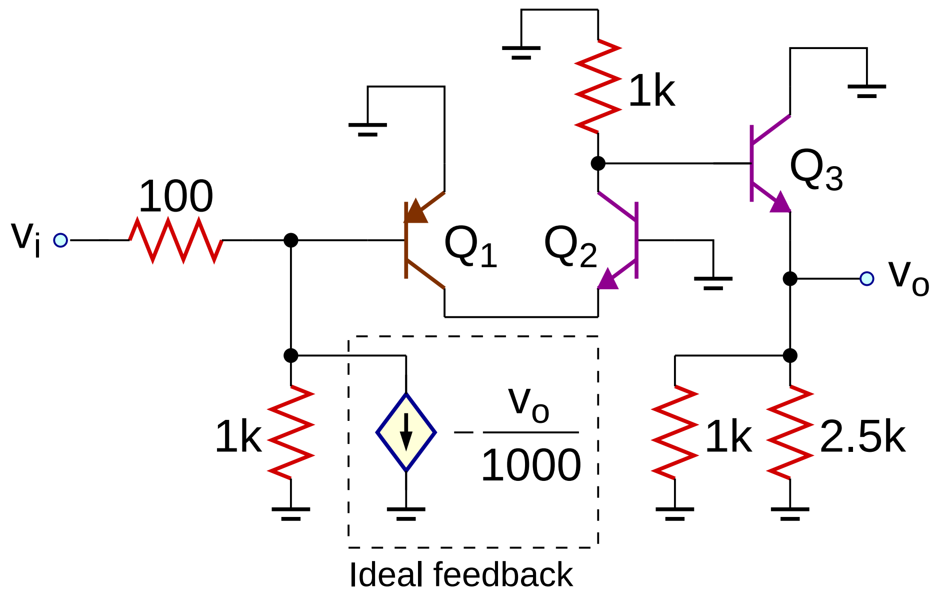
Output: Voltage

$$\mathbf{I_{C1} = 1\ mA}$$
$$\mathbf{I_{C2} = 1\ mA}$$
$$\mathbf{I_{C3} = 2\ mA}$$

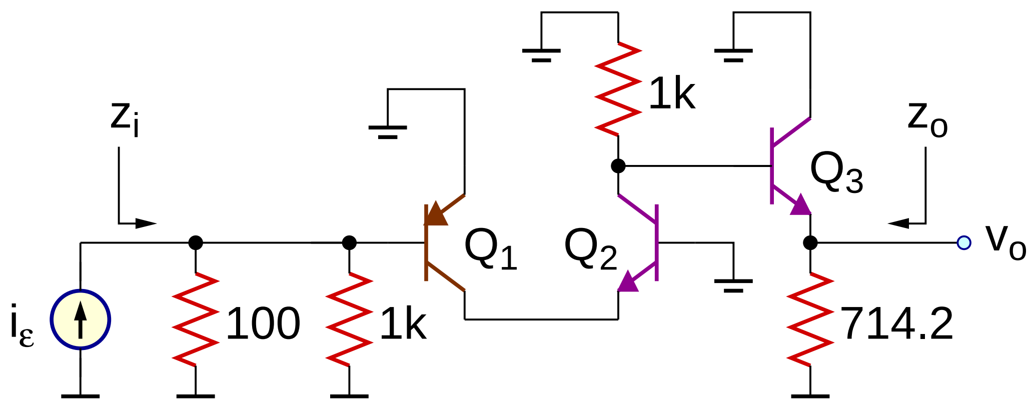
y-parameter representation of the feedback network:



Shunt-Shunt



$$f = -0.001$$

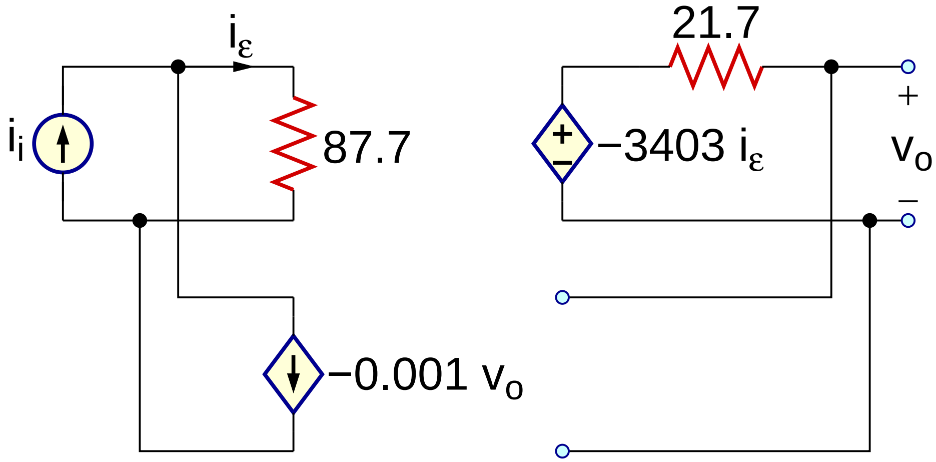


$$a = \frac{v_o}{i_\varepsilon} = -3403$$

$$z_i = 87.7\ \Omega$$

$$z_o = 21.7\ \Omega$$

Shunt-Shunt



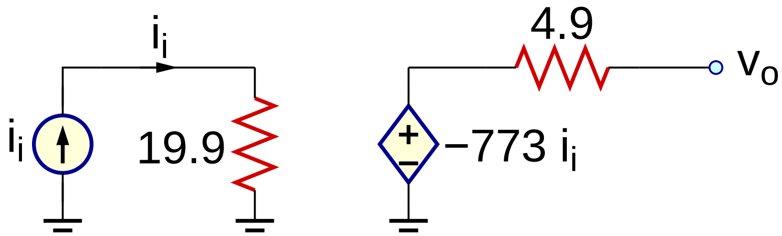
$$i_i = \frac{v_i}{100}$$

$$a = -3403$$

$$f = -0.001$$

$$z_i = 87.7\ \Omega$$

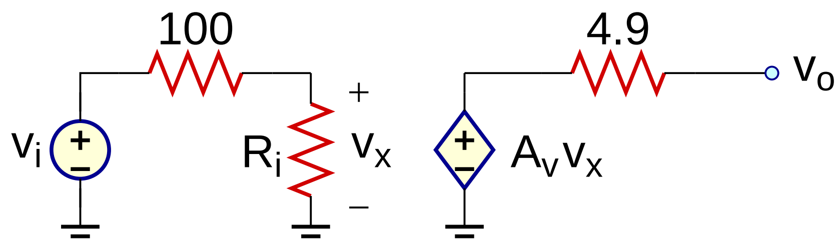
$$z_o = 21.7\ \Omega$$



$$A = \frac{v_o}{i_i} = \frac{a}{1+af} = -773$$

$$Z_i = \frac{z_i}{1+af} = 19.9\ \Omega \qquad Z_o = \frac{z_o}{1+af} = 4.9\ \Omega$$

Voltage-mode equivalent circuit:



$$100 \parallel R_i = Z_i \;\Rightarrow\; \frac{1}{100} + \frac{1}{R_i} = \frac{1}{Z_i} \;\Rightarrow\; R_i = 24.8\ \Omega$$

$$i_i = \frac{v_i}{100}\ ,\ v_o = -773 i_i \;\Rightarrow\; \frac{v_o}{v_i} = -7.73$$

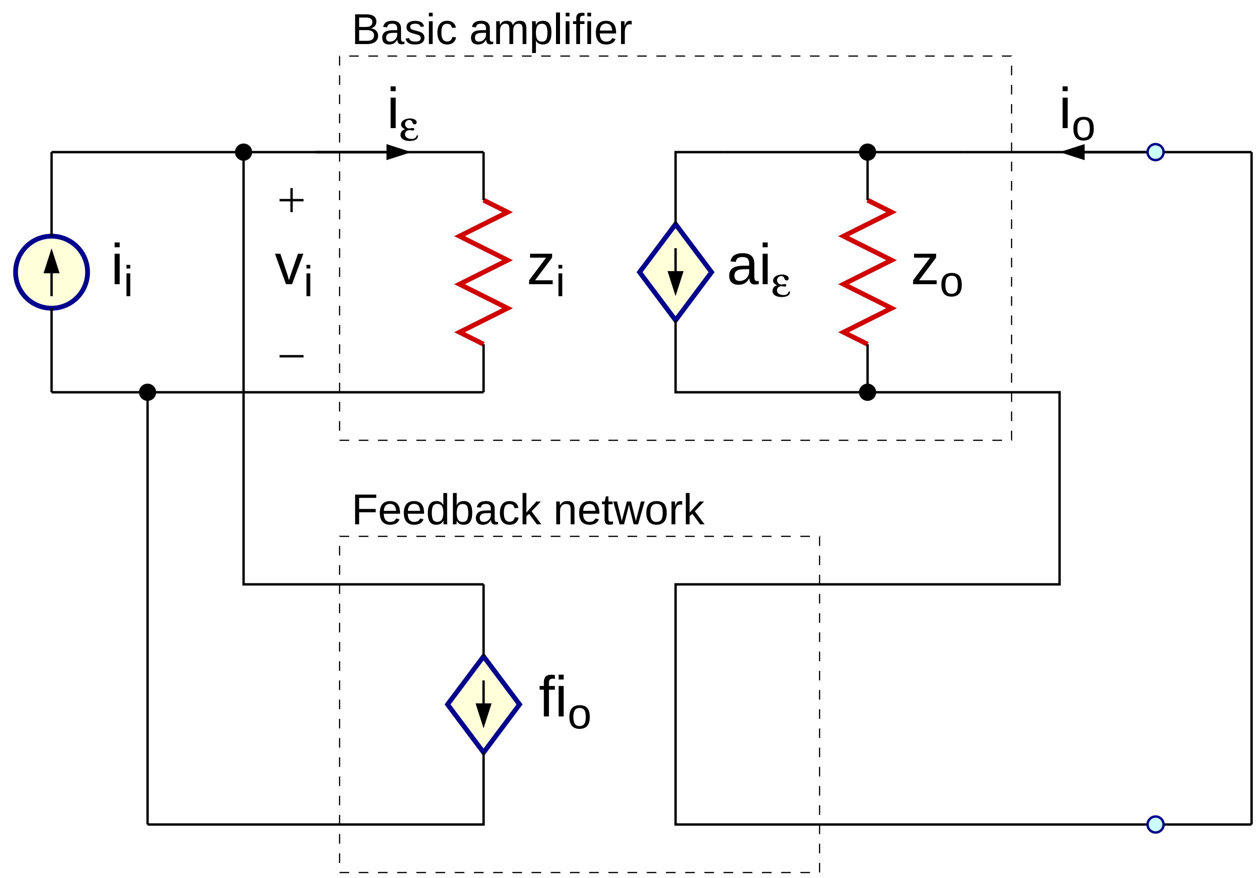
$$v_o = -7.73 v_i = A_v \frac{R_i}{R_i + 100} v_i \;\Rightarrow\; A_v = -38.9$$

$$A_{dm} = -7.73$$

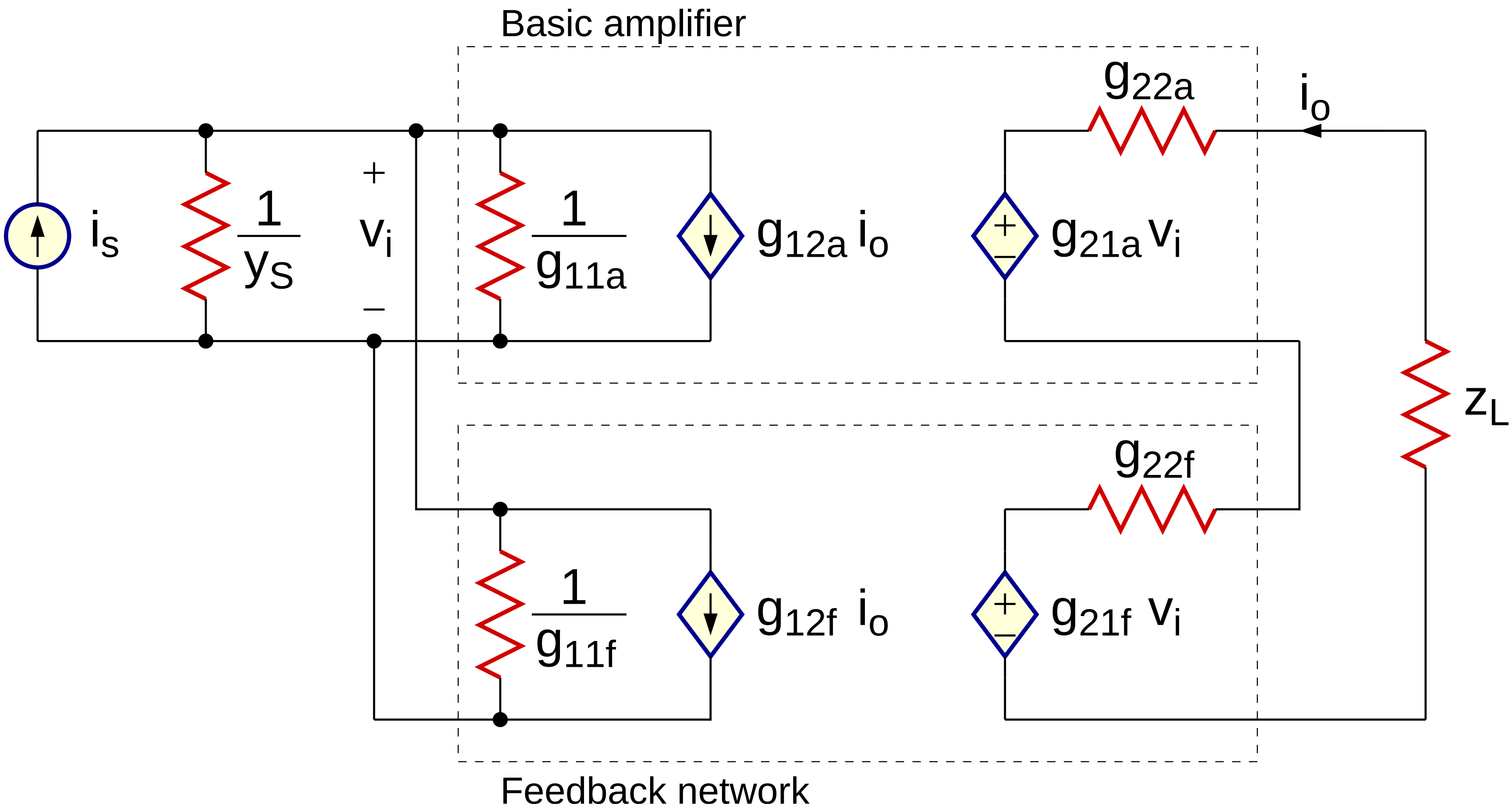
$$R_{id} = 2 \times (100 + 24.8) = 249.6\ \Omega$$

$$R_{od} = 2 \times 4.9 = 9.8\ \Omega$$

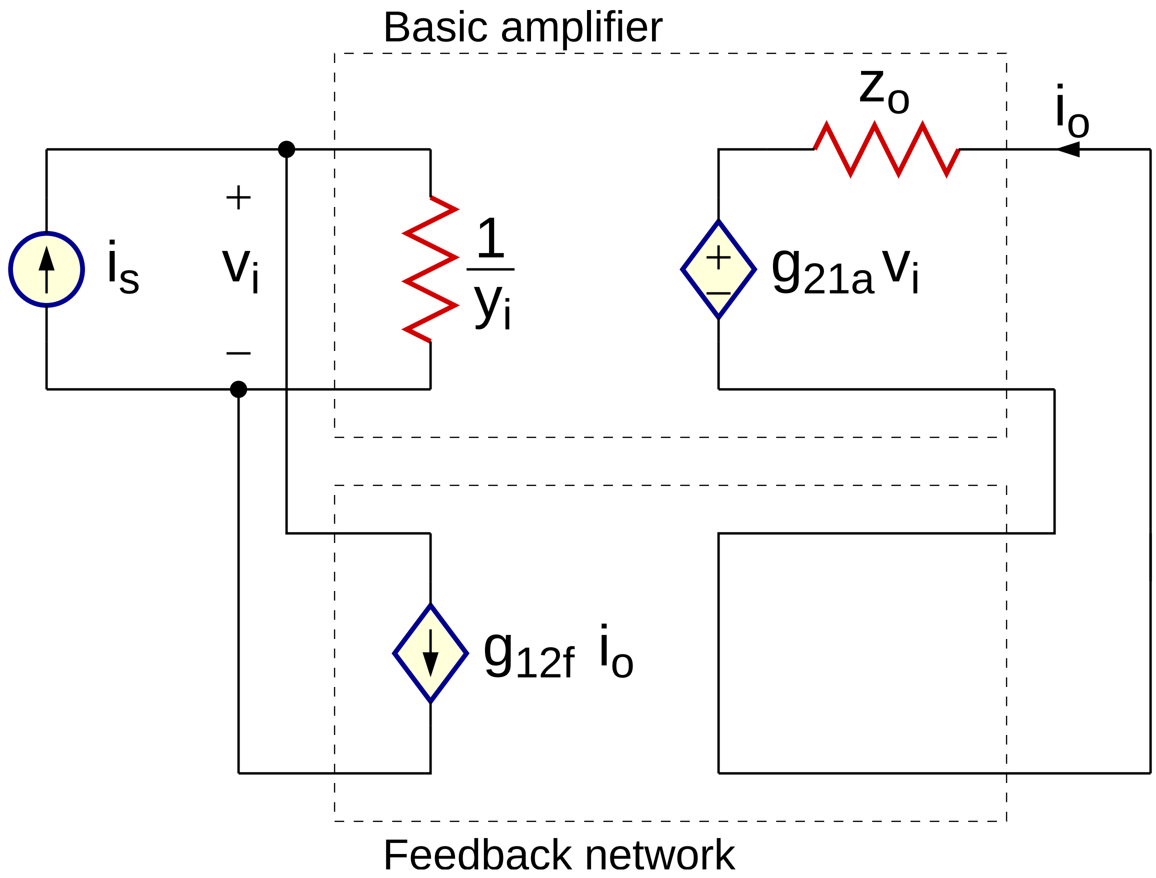
Shunt-Series



$$\frac{i_o}{i_i} = \frac{a}{1+af} \qquad Z_i = \frac{z_i}{1+af} \qquad Z_o = z_o(1+af)$$

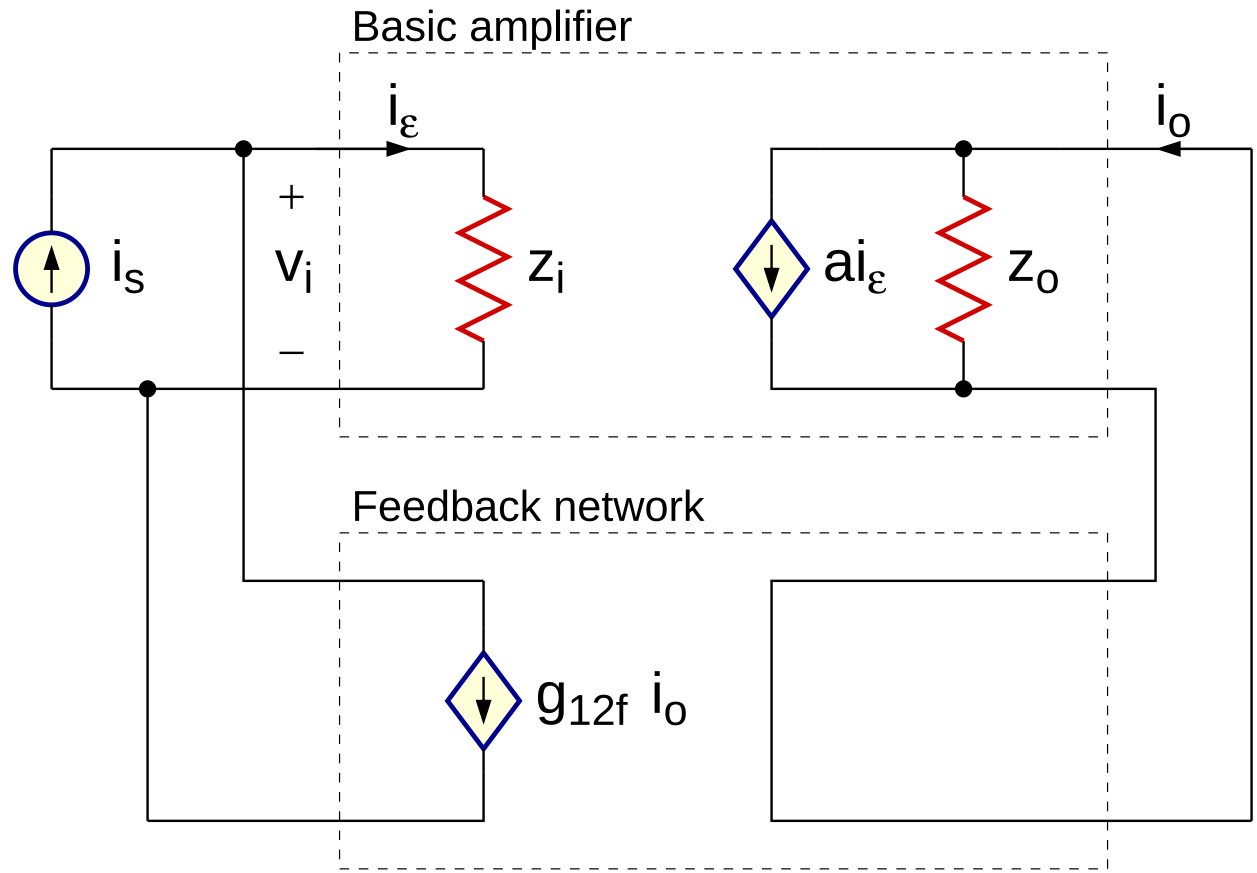


$$|g_{12f}| \gg |g_{12a}| \qquad |g_{21a}| \gg |g_{21f}|$$

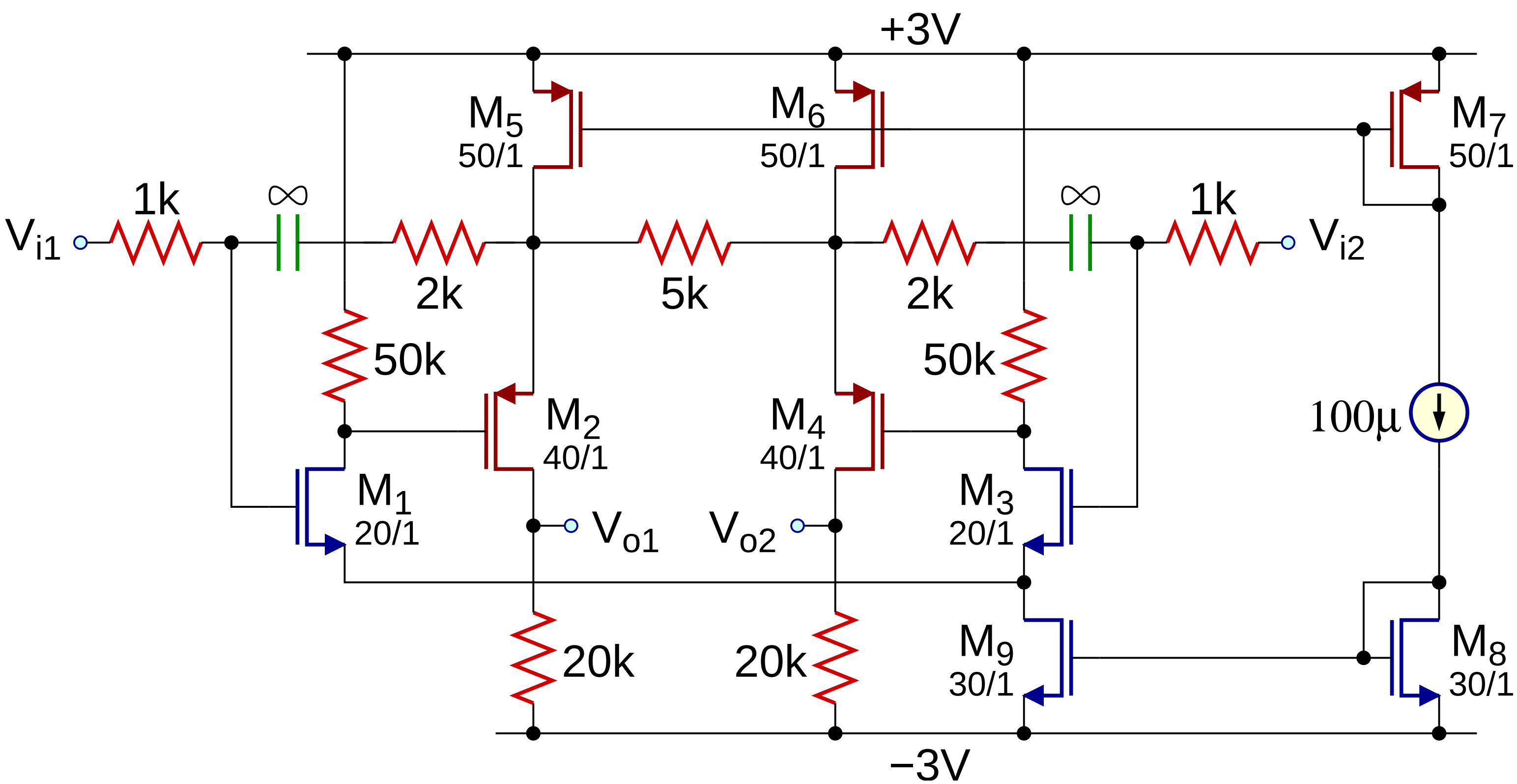


$$\mathbf{y_i = y_S + g_{11a} + g_{11f}}$$

$$\mathbf{z_o = z_L + g_{22a} + g_{22f}}$$



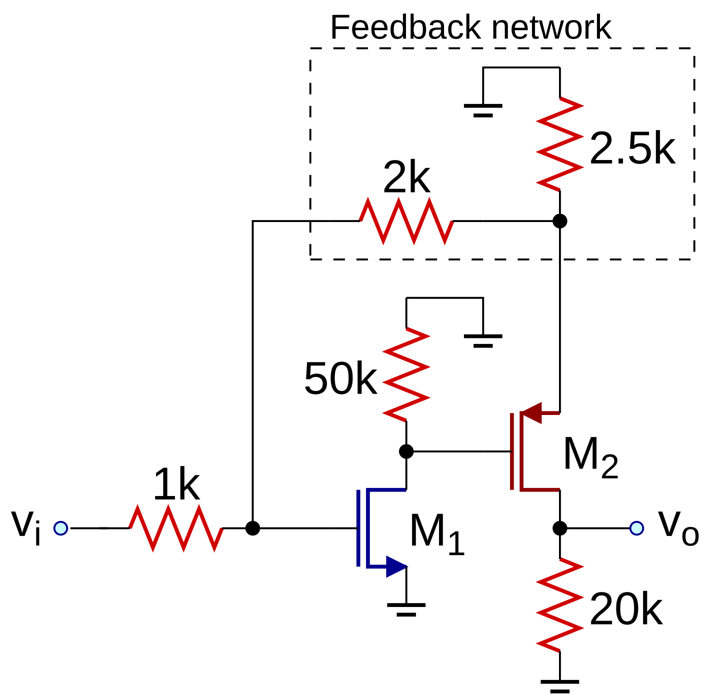
$$a = -\frac{g_{21a}}{y_i z_o} \qquad f = g_{12f} \qquad z_i = \frac{1}{y_i}$$



$$k'_n = 190\ \mu A/V^2,\ k'_p = 110\ \mu A/V^2,\ \lambda_n = \lambda_p = 0$$

$$V_{tn} = 1.5\ V,\ V_{tp} = -1.6\ V,\ \chi = 0$$

Differential-mode AC half circuit:

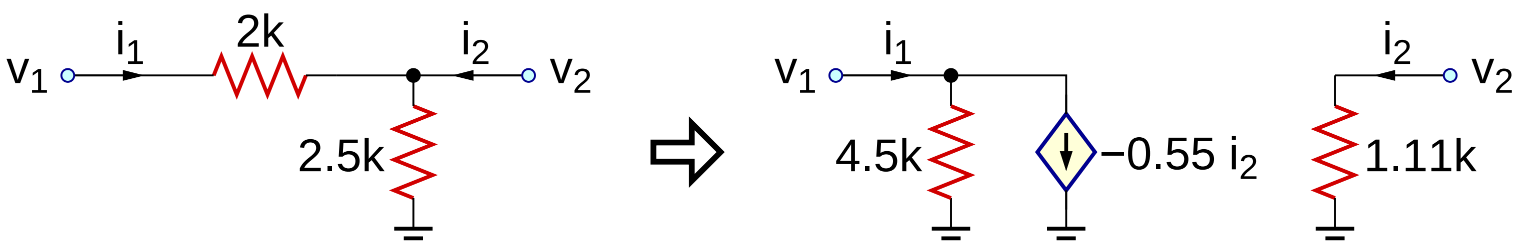


Input: Current

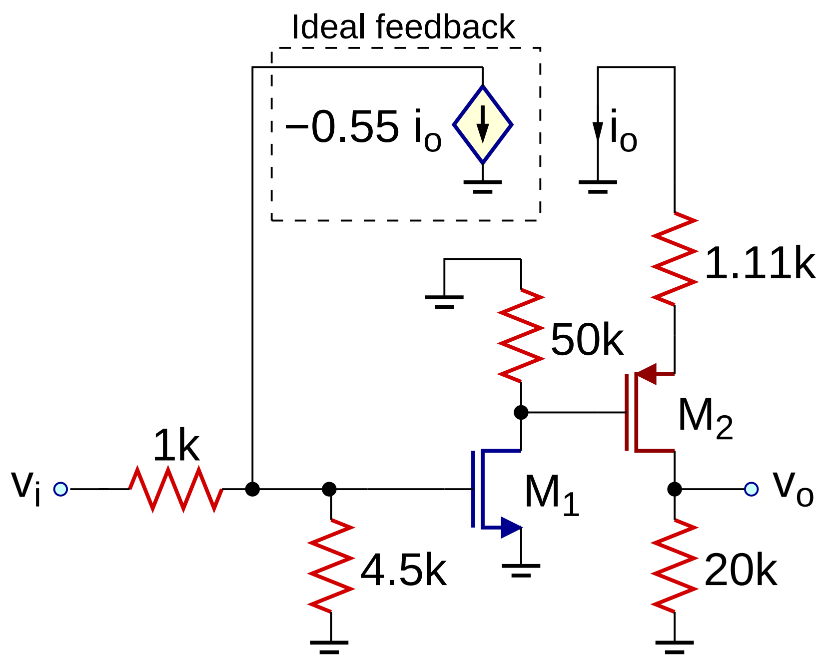
Output: Current

$$\mathbf{I_{D1} = 50\ \mu A}$$
$$\mathbf{I_{D2} = 100\ \mu A}$$

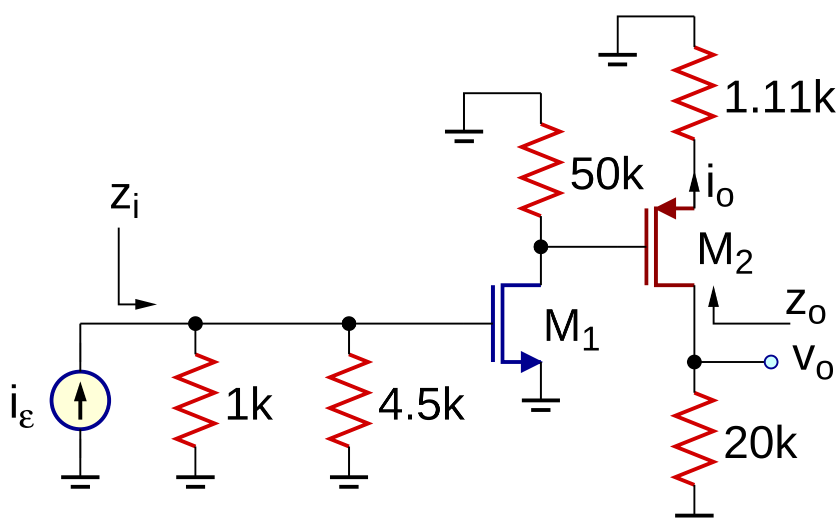
g-parameter representation of the feedback network:



Shunt-Series



$$f = -0.55$$

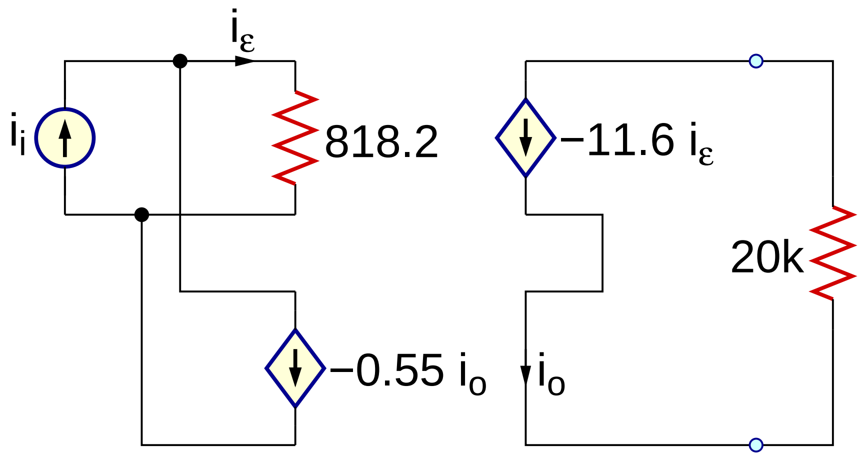


$$a = \frac{i_o}{i_\varepsilon} = -11.6$$

$$z_i = 818.2\ \Omega$$

$$z_o = \infty$$

Shunt-Series



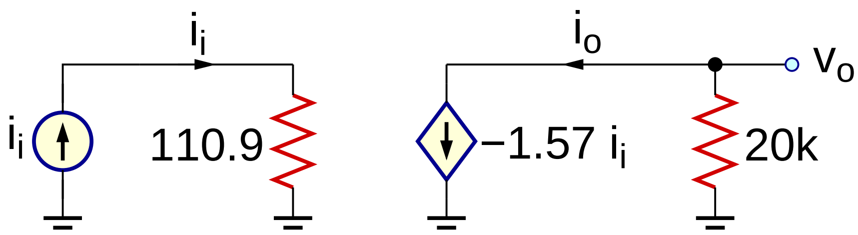
$$i_i = \frac{v_i}{1k}$$

$$a = -11.6$$

$$f = -0.55$$

$$z_i = 818.2\ \Omega$$

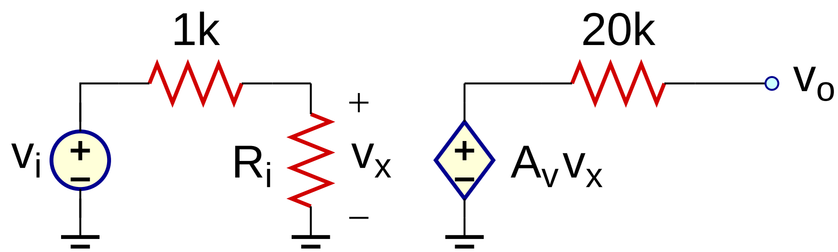
$$z_o = \infty$$



$$A = \frac{i_o}{i_i} = \frac{a}{1+af} = -1.57$$

$$Z_i = \frac{z_i}{1+af} = 110.9\ \Omega \qquad Z_o = \infty$$

Voltage-mode equivalent circuit:



$$1k \parallel R_i = Z_i \;\Rightarrow\; \frac{1}{1k} + \frac{1}{R_i} = \frac{1}{Z_i} \;\Rightarrow\; R_i = 124.7\ \Omega$$

$$i_i = \frac{v_i}{1k},\;\; v_o = -(20k)(-1.57 i_i) \;\Rightarrow\; \frac{v_o}{v_i} = 31.4$$

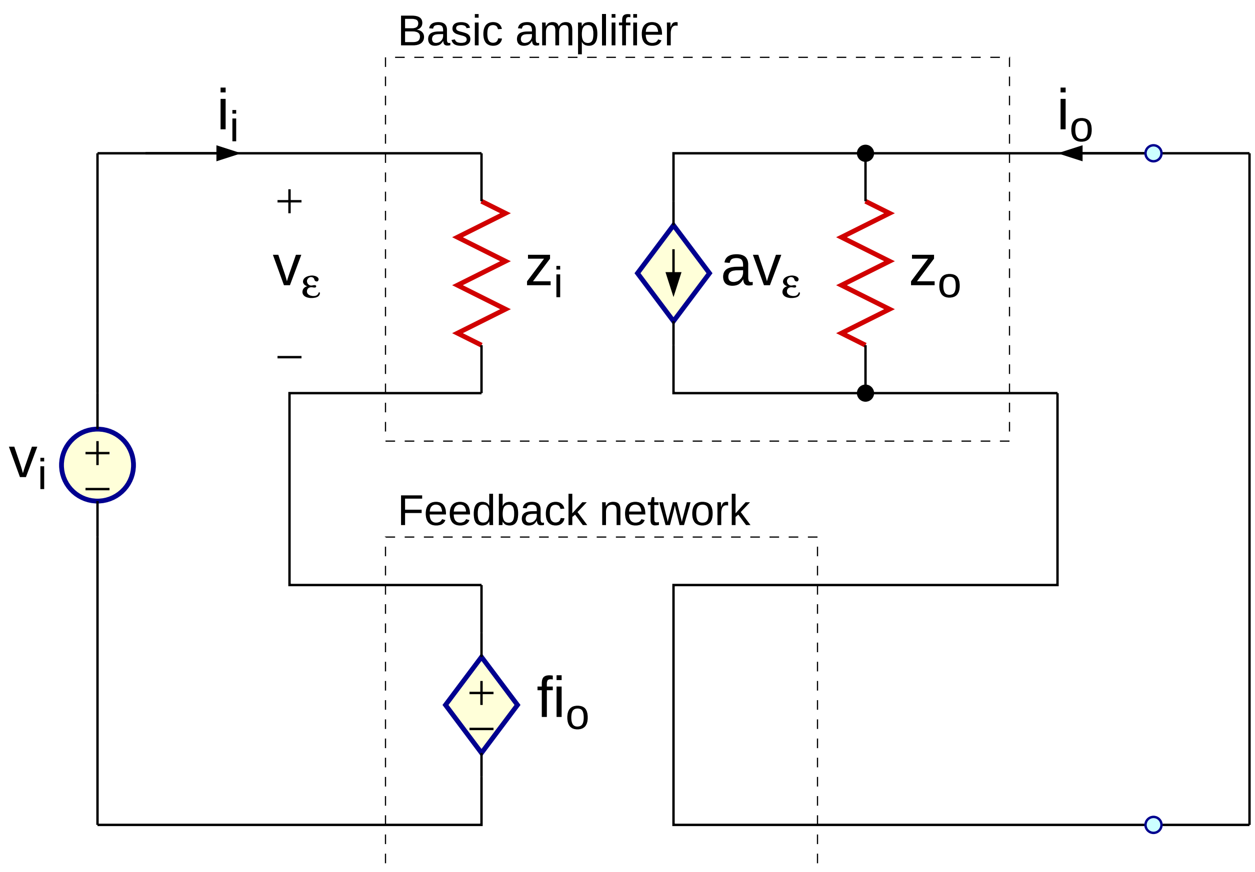
$$v_o = 31.4 v_i = A_v \frac{R_i}{R_i + 1k} v_i \;\Rightarrow\; A_v = 283.2$$

$$A_{dm} = 31.4$$

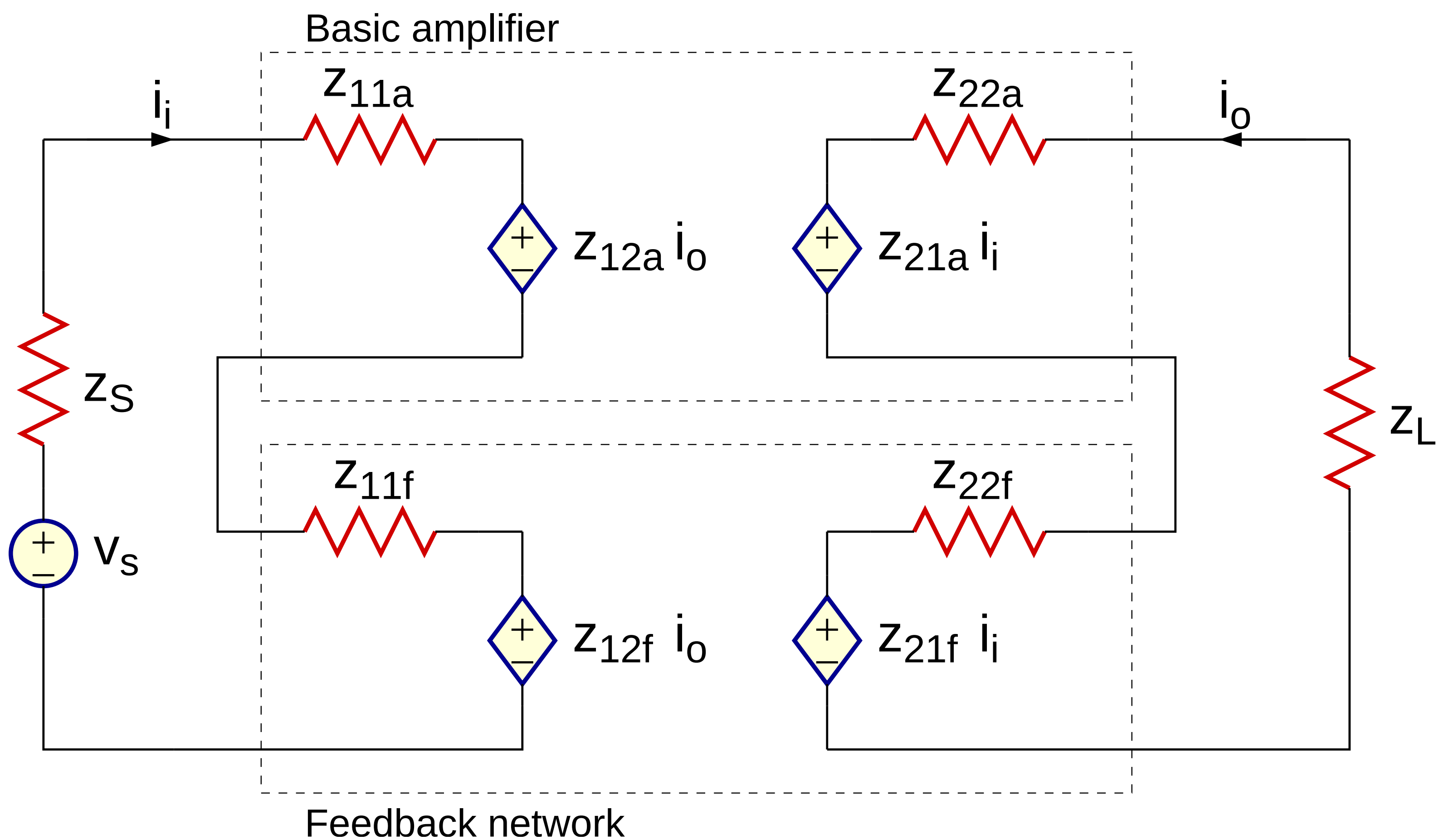
$$R_{id} = 2 \times (1k + 124.7) = 2.25\ k\Omega$$

$$R_{od} = 2 \times 20k = 40\ k\Omega$$

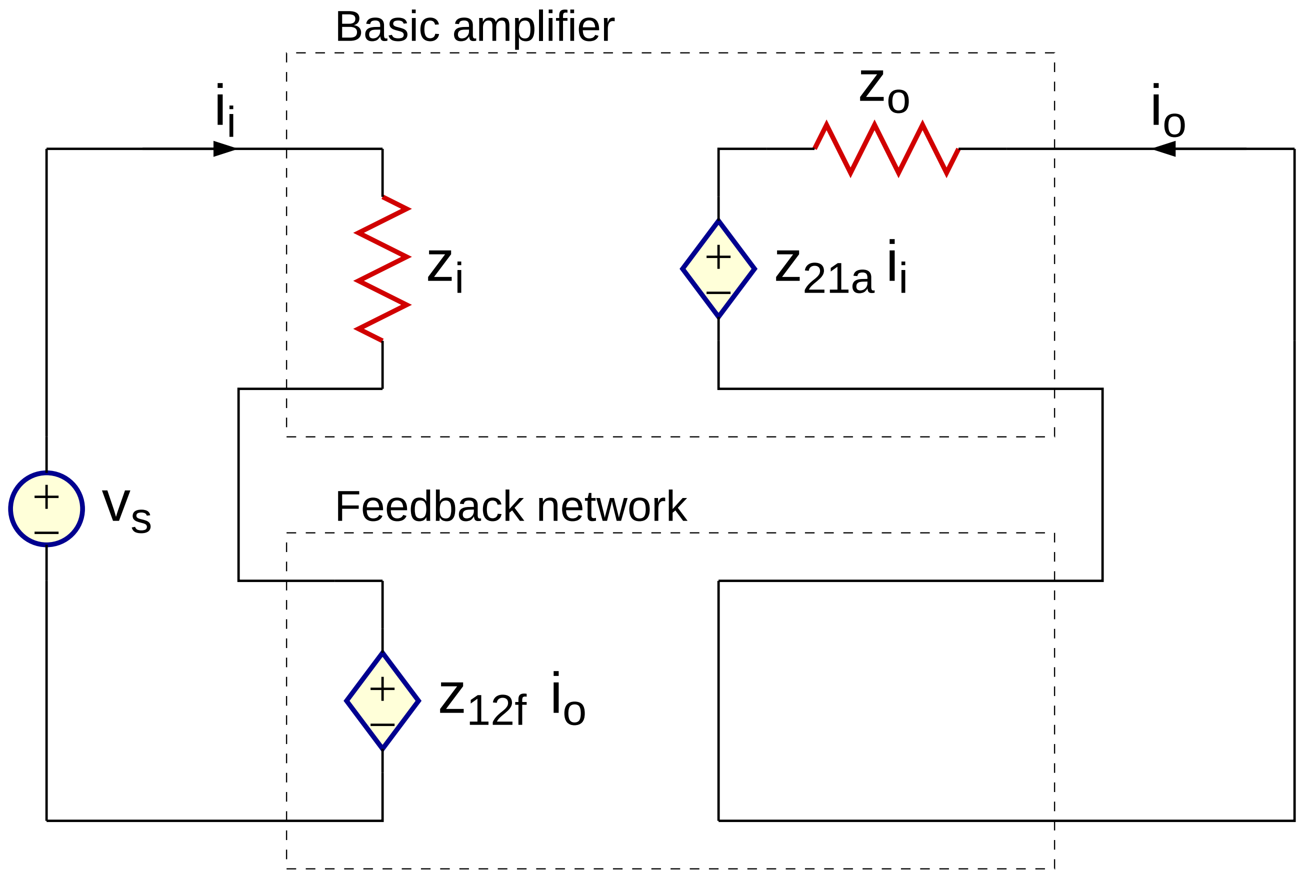
Series-Series



$$\frac{i_o}{v_i} = \frac{a}{1 + af} \qquad Z_i = z_i(1 + af) \qquad Z_o = z_o(1 + af)$$

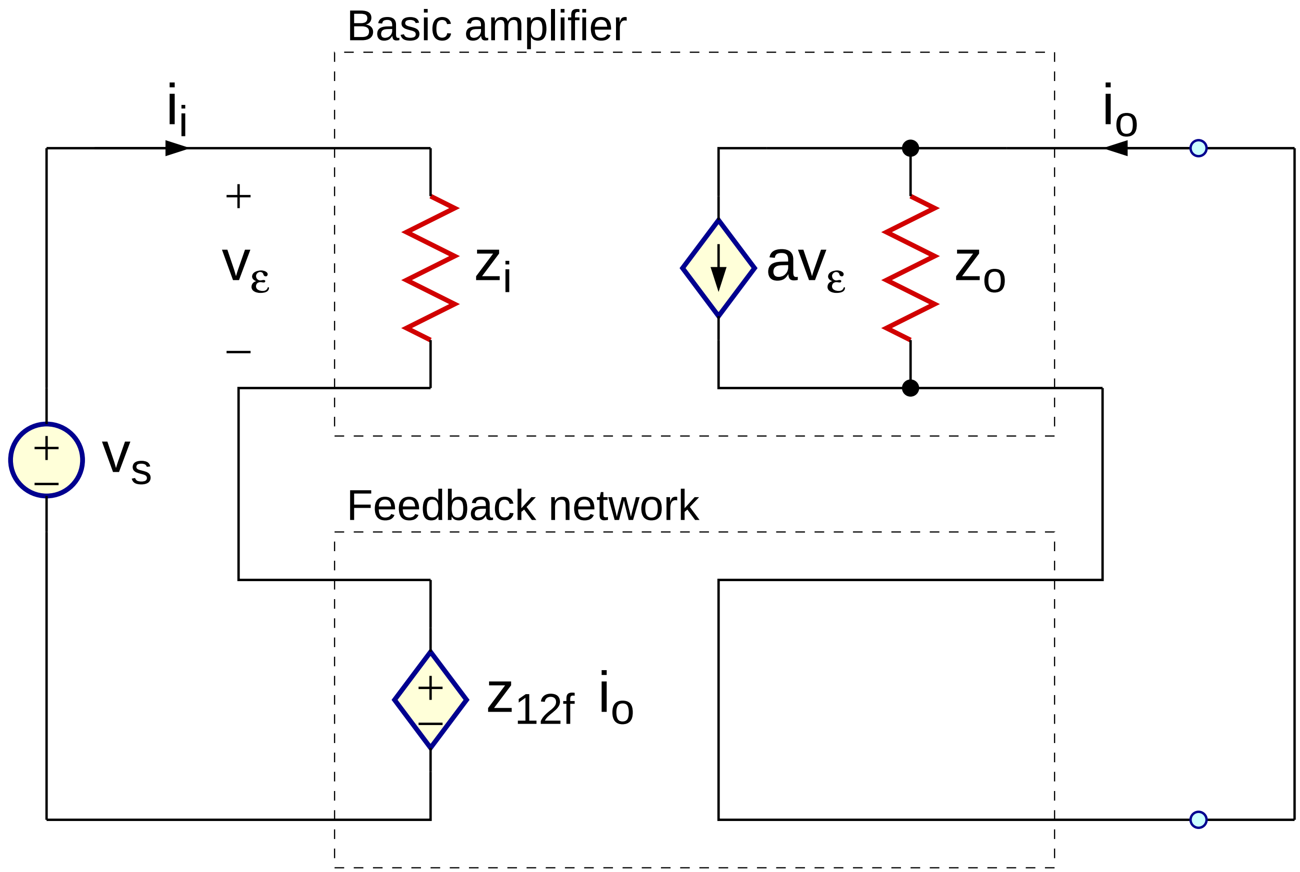


$$|\mathbf{z_{12f}}| \gg |\mathbf{z_{12a}}| \qquad |\mathbf{z_{21a}}| \gg |\mathbf{z_{21f}}|$$

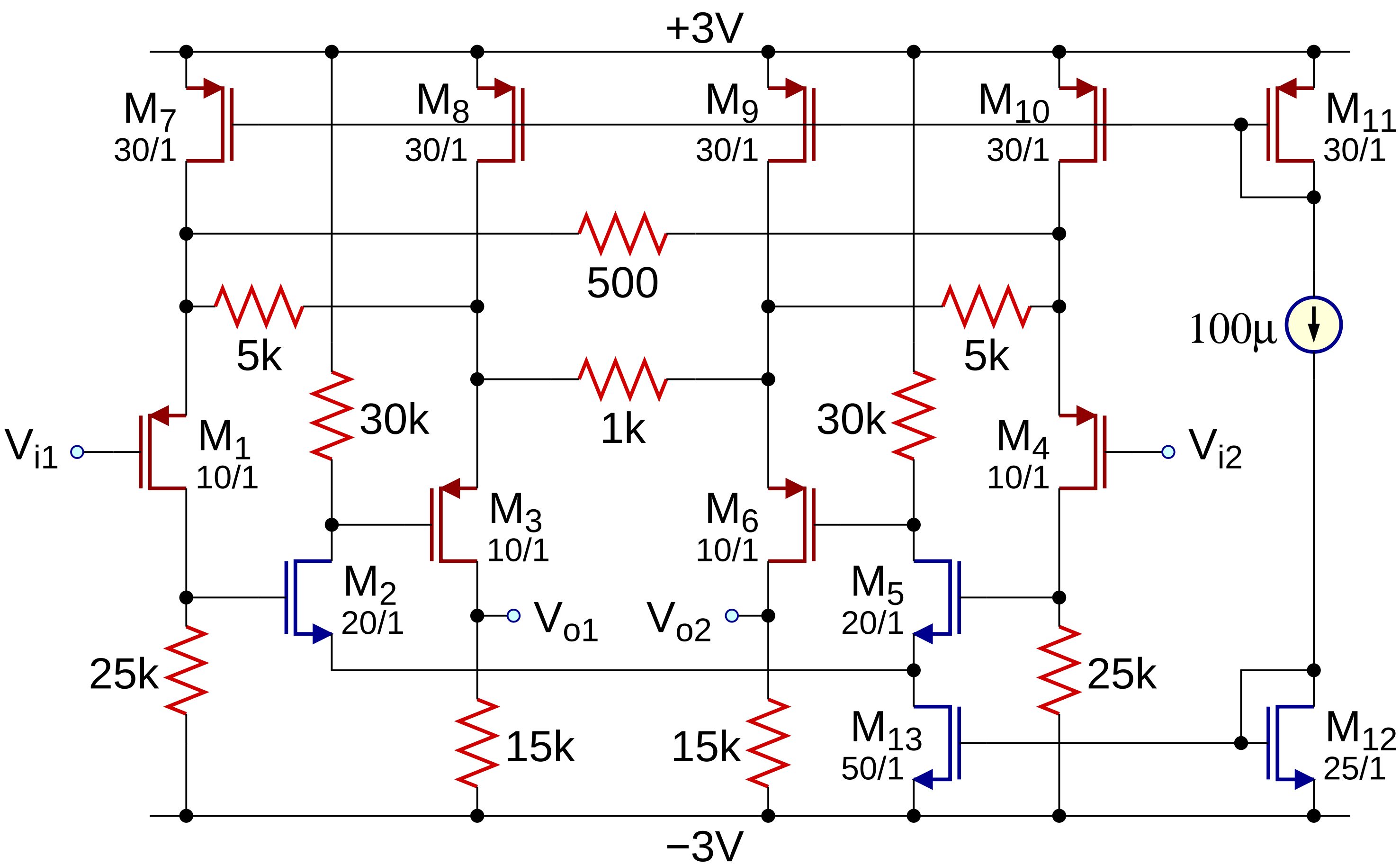


$$z_i = y_S + z_{11a} + z_{11f}$$

$$z_o = z_L + z_{22a} + z_{22f}$$



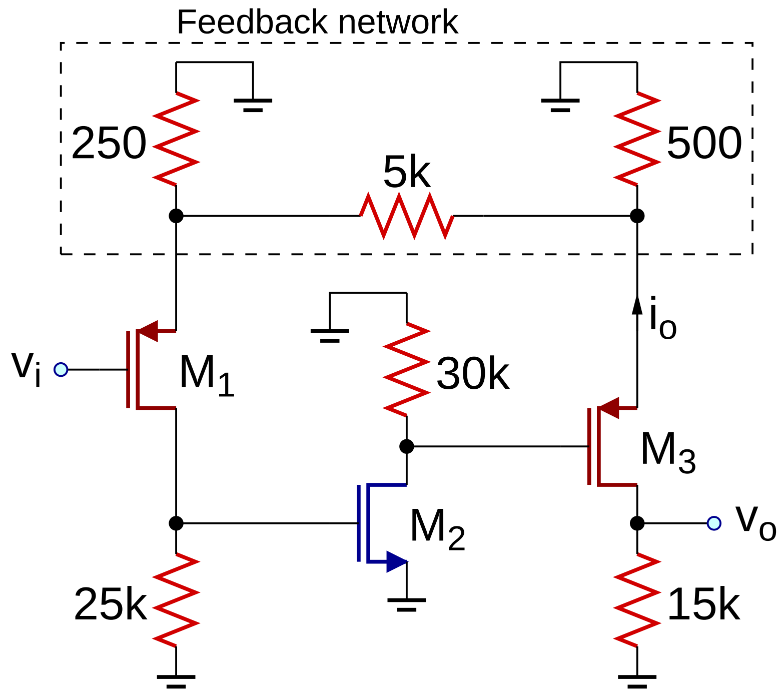
$$a = -\frac{z_{21a}}{z_i z_o} \qquad f = z_{12f}$$



$$k'_n = 190\ \mu A/V^2,\ k'_p = 110\ \mu A/V^2,\ \lambda_n = \lambda_p = 0$$

$$V_{tn} = 1.5\ V,\ V_{tp} = -1.6\ V,\ \chi = 0$$

Differential-mode AC half circuit:

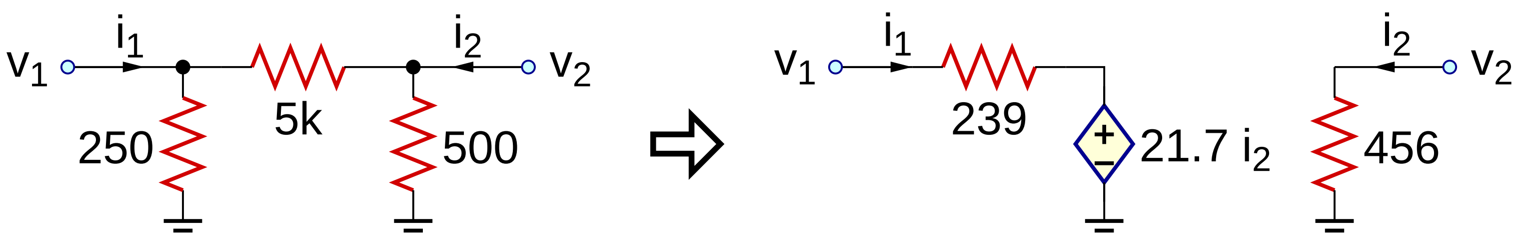


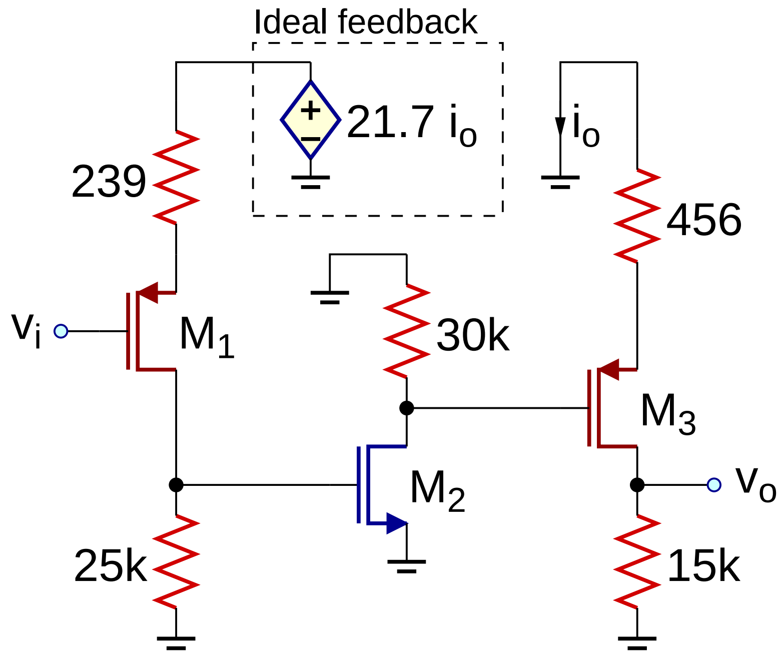
Input: Voltage

Output: Current

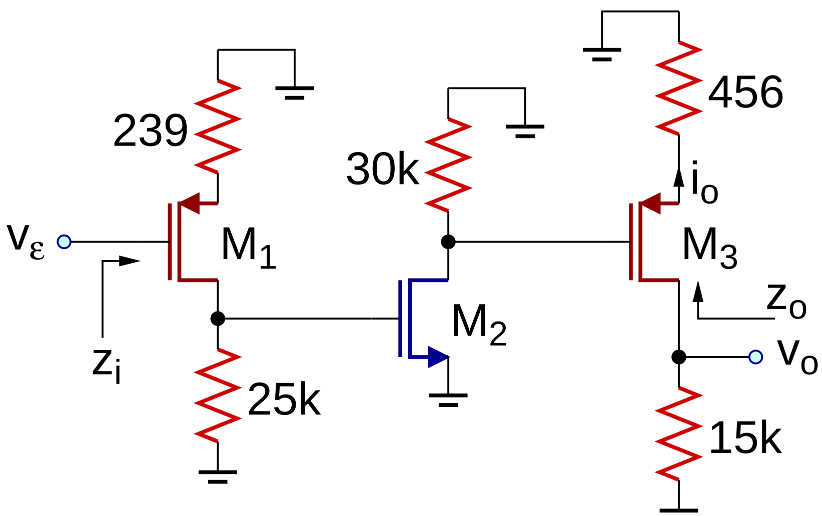
$$\mathbf{I_{D1} = 100\ \mu A}$$
$$\mathbf{I_{D2} = 100\ \mu A}$$
$$\mathbf{I_{D3} = 100\ \mu A}$$

z-parameter representation of the feedback network:





$$f = 21.7$$



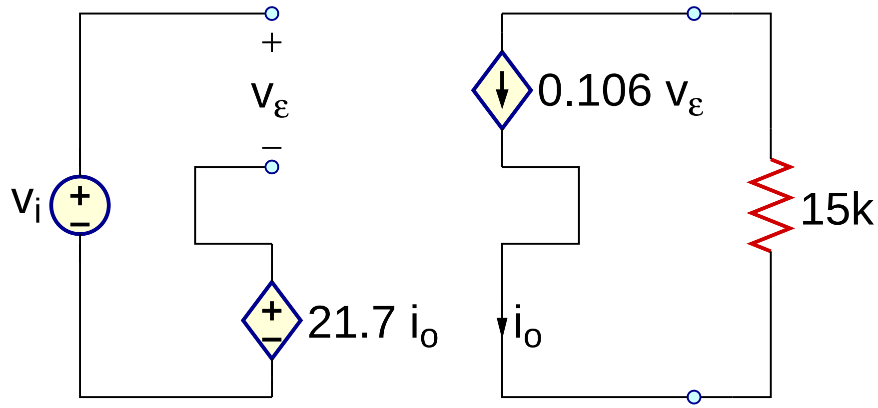
$$a = \frac{i_o}{v_\varepsilon} = 0.106$$

$$z_i = \infty$$

$$z_o = \infty$$

Series-Series

Example

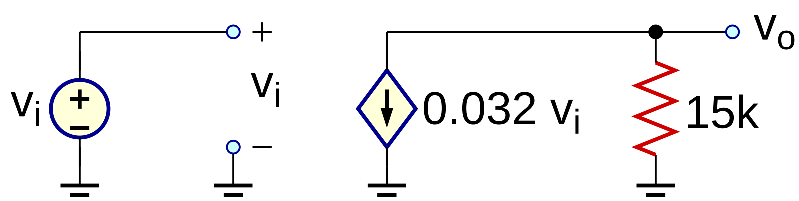


$$a = 0.106$$

$$f = 21.7$$

$$z_i = \infty$$

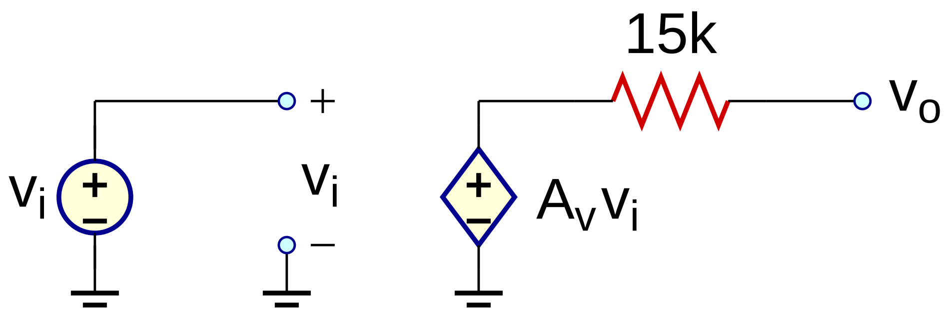
$$z_o = \infty$$



$$A = \frac{i_o}{v_i} = \frac{a}{1+af} = 0.032$$

$$Z_i = \infty \qquad Z_o = \infty$$

Voltage-mode equivalent circuit:



$$\mathbf{v_o = -(15k)(0.032v_i) = A_v v_i \;\Rightarrow\; A_v = -480}$$

$$\mathbf{A_{dm} = -480}$$
$$\mathbf{R_{id} = \infty}$$
$$\mathbf{R_{od} = 2 \times 15k = 30\ k\Omega}$$