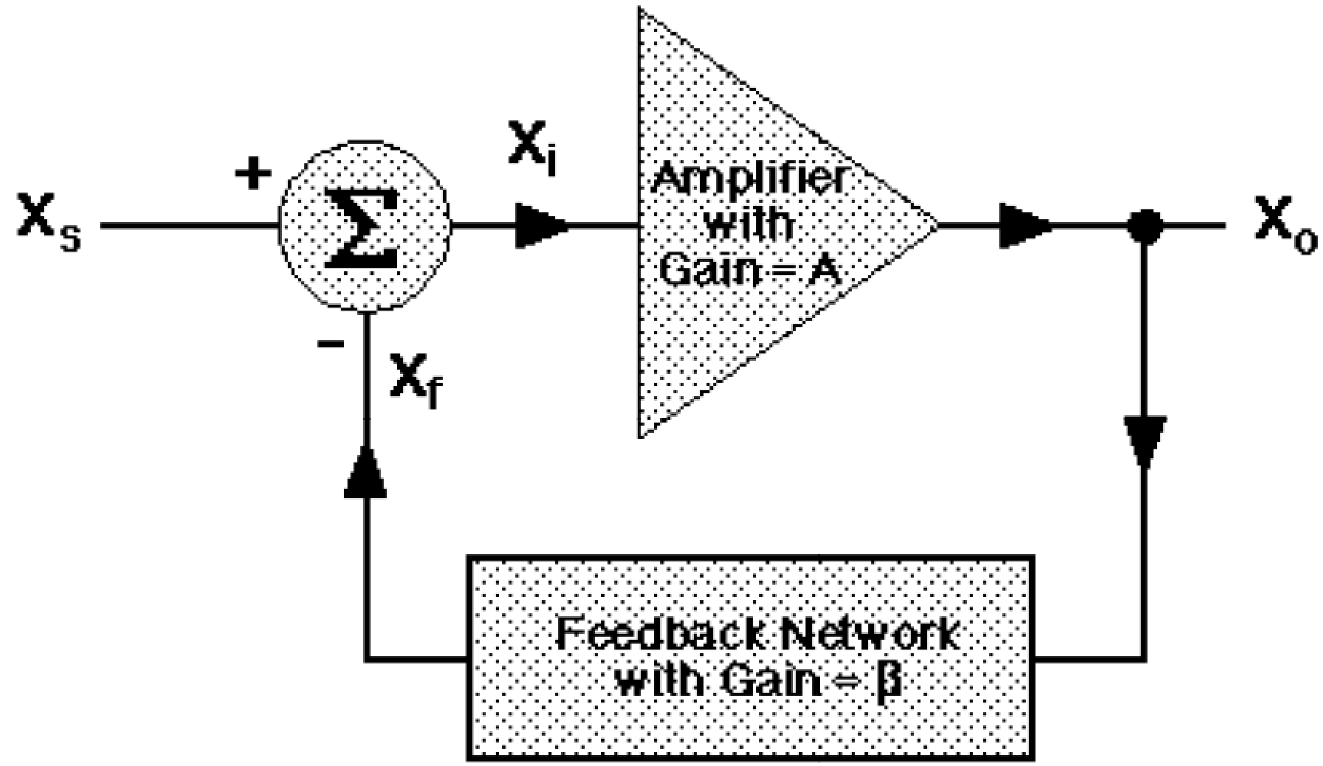
# Basic Electronic Circuits
# (IEC-103)

## Lecture-07

# Feedback

# Basic Block Diagram



# Closed Loop Gain

$$X_i = X_s - X_f = X_s - \beta X_o$$

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**Rearranging**

# Closed Loop Gain

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**But** $X_o = AX_i$

$$\therefore \frac{X_o}{A} = X_s - \beta X_o$$

**Rearranging**

$$\left(\frac{1}{A} + \beta\right) X_o = X_S$$

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$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta} \approx \frac{1}{\beta} \quad \text{(for very large A)}$$

# Closed Loop Bandwidth

**Open loop gain**

$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_H}}$$

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If we use amplifier with negative feedback

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**Open loop gain**

$$A(s) = \frac{A_0}{1 + \dfrac{s}{\omega_H}}$$

**If we use amplifier with negative feedback**

$$A_f(s) = \frac{A(s)}{1 + \beta A(s)}$$

# Closed Loop Bandwidth

$$A_f(s) = \frac{\dfrac{A_0}{1+\beta A_0}}{1+\dfrac{s}{\omega_H(1+\beta A_0)}}$$

# Closed Loop Bandwidth

$$A_f(s) = \frac{\dfrac{A_0}{1+\beta A_0}}{1+\dfrac{s}{\omega_H(1+\beta A_0)}} = \frac{A_{0f}}{1+\dfrac{s}{\omega_{Hf}}}$$

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where

$$\omega_{Hf} = \omega_H(1+\beta A_0)$$

$$A_{0f} = \frac{A_0}{(1+\beta A_0)}$$

# Closed Loop Bandwidth

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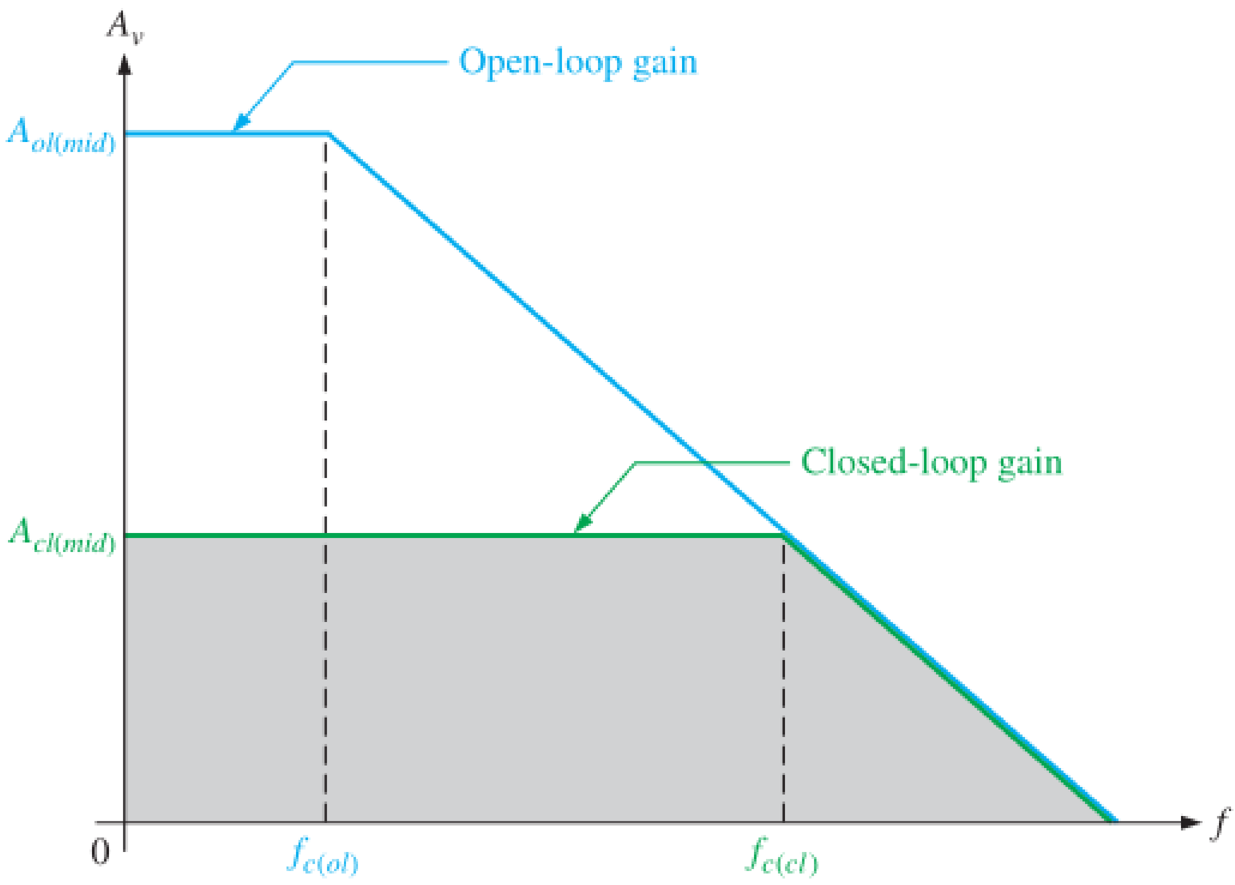
**where**

$$\omega_{Hf} = \omega_H(1+\beta A_0)$$

$$A_{0f} = \frac{A_0}{(1+\beta A_0)}$$

**The cut-off frequency is increased by a factor $(1+A_0\beta)$**

# Closed Loop Bandwidth



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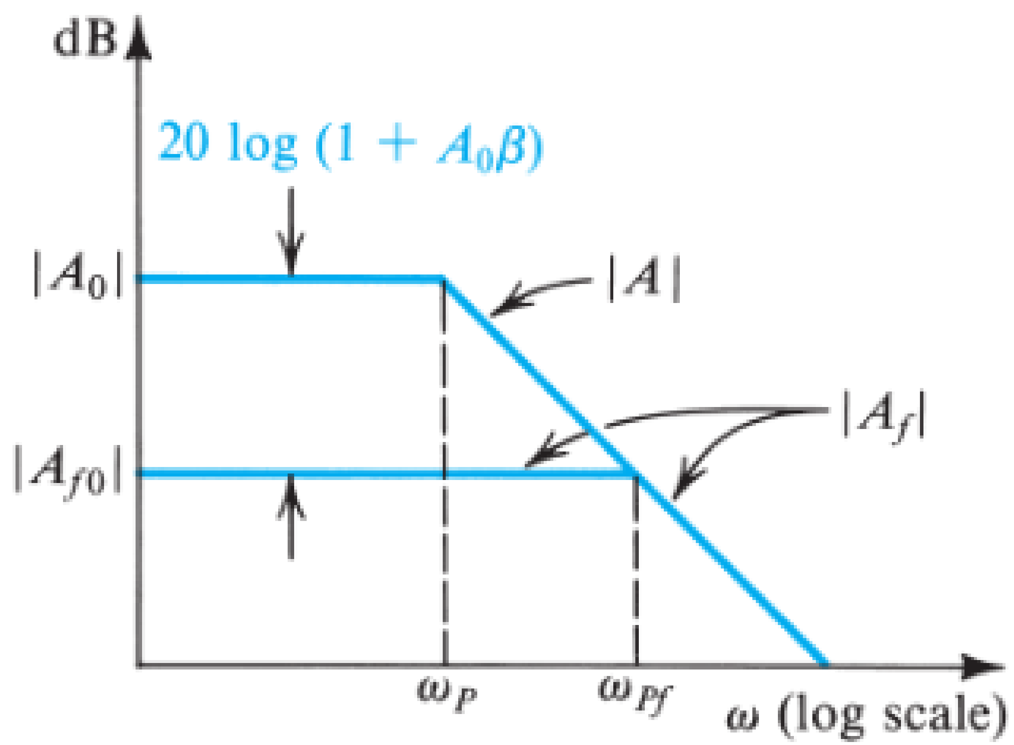

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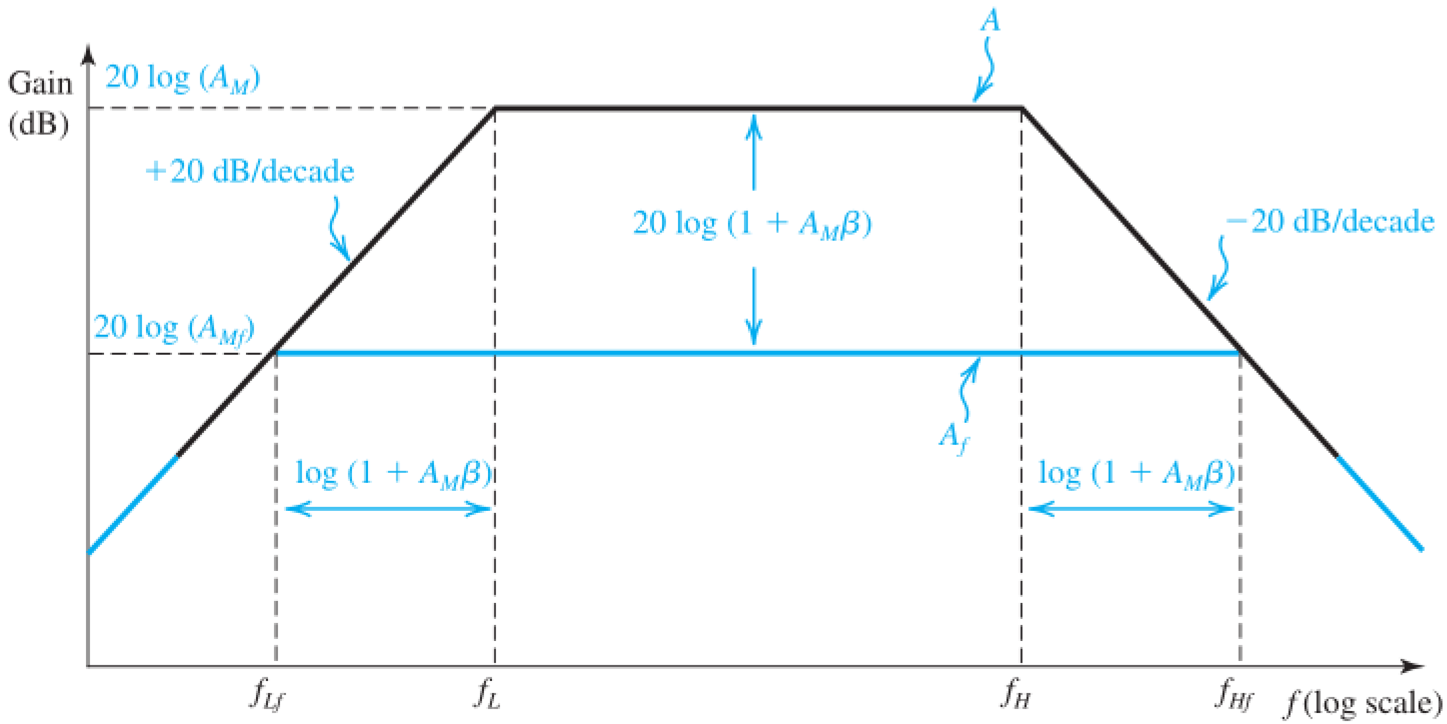


$$f_{Lf} = \frac{f_L}{1 + A_M\beta} \qquad A_{Mf} = \frac{A_M}{1 + A_M\beta} \qquad f_{Hf} = f_H(1 + A_M\beta)$$

# Effect of Negative Feedback on Operational Amplifiers

| | VOLTAGE GAIN | INPUT Z | OUTPUT Z | BANDWIDTH |
|---|---|---|---|---|
| Without negative feedback | $A_{ol}$ is too high for linear amplifier applications | Relatively high | Relatively low | Relatively narrow (because the gain is so high) |
| With negative feedback | $A_{cl}$ is set to desired value by the feedback circuit | Can be increased or reduced to a desired value depending on type of circuit | Can be reduced to a desired value | Significantly wider |

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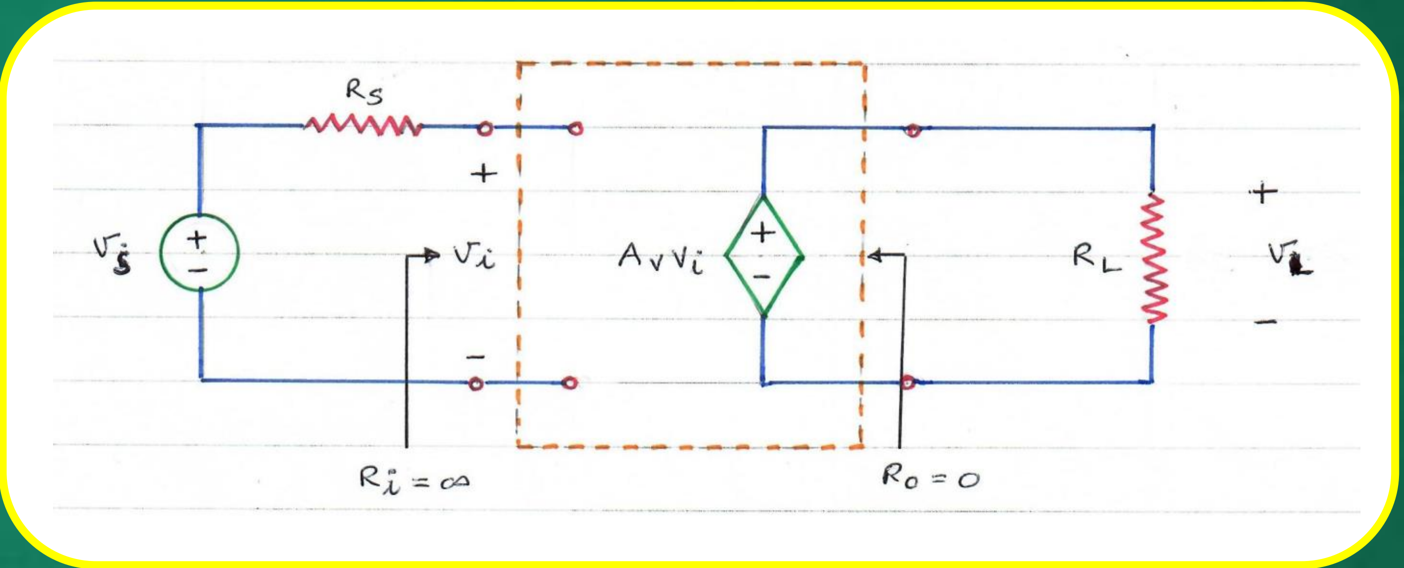
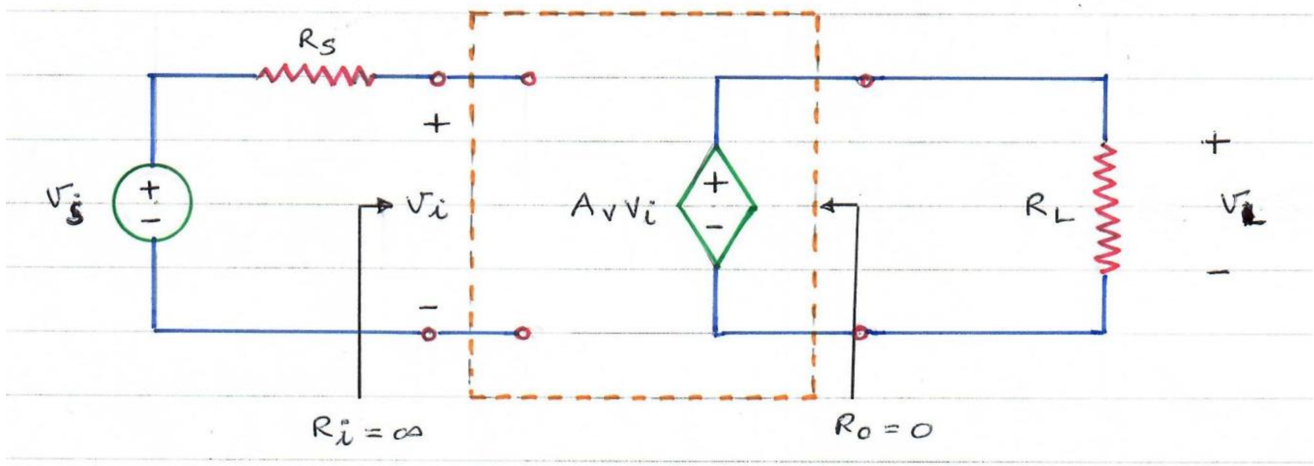
- Current Amplifier (Current-Current)

# Ideal Voltage Amplifier



# Ideal Voltage Amplifier




$$\frac{v_{\mathrm{L}}}{v_s} = A_v$$

# Practical Voltage Amplifier

- Any signal source has finite source resistance $R_s$.
- The amplifier is often asked to drive current in to a load of finite impedance $R_L$ (Ex: $8\ \Omega$ speaker).
- The controlled source is a voltage controlled voltage source (VCVS).
- $A_v$ = Open Circuit Voltage Gain can be found by applying a voltage source with $R_s = 0$ and measuring the open circuit output (no load or $R_L = \infty$).
- Why are input and output impedance important?

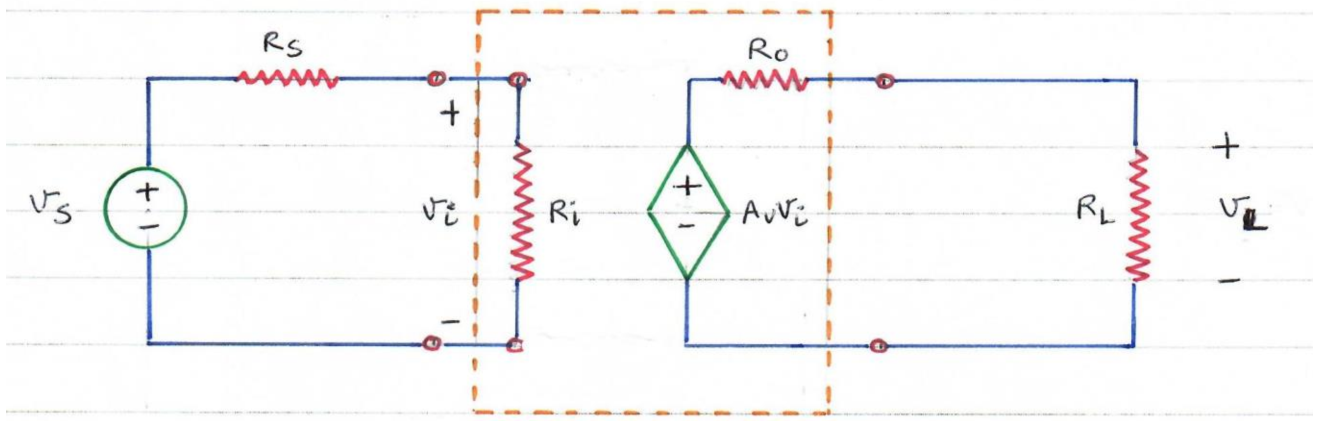
# Practical Voltage Amplifier

- Only voltage $V_{in}$ is amplified to $A_vV_{in}$.

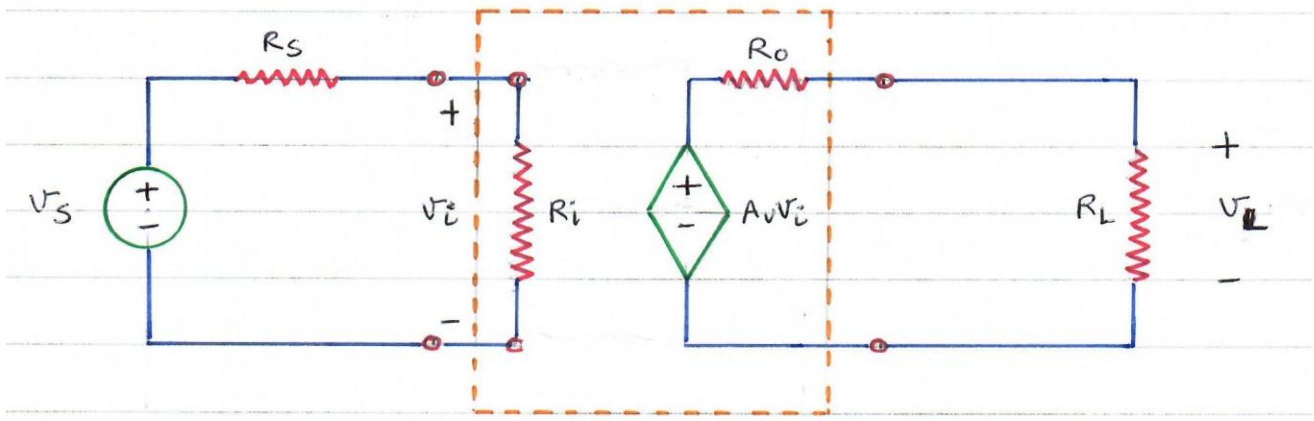
- Since $R_s$ and $R_{in}$ form a voltage divider that determines $V_{in}$, $R_{in}$ should be as large as possible for maximum voltage.

- Since $R_L$ and $R_{out}$ form a voltage divider that determines $V_{out}$, $R_{out}$ should be as small as possible for maximum output voltage.

# Practical Voltage Amplifier

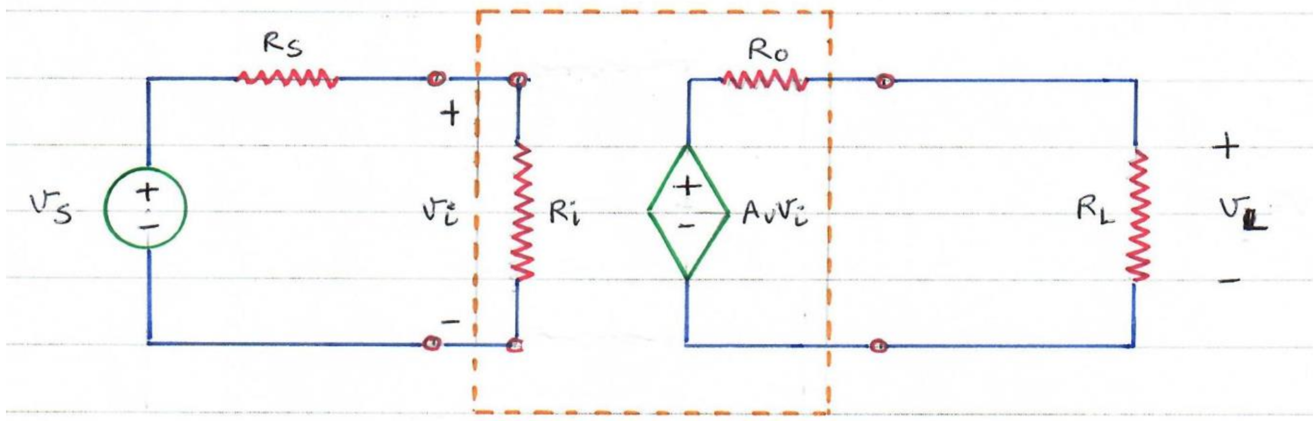


# Practical Voltage Amplifier




$$\frac{v_L}{v_s} = \frac{A_v R_i R_L}{(R_s + R_i)(R_o + R_L)}$$

# Practical Voltage Amplifier

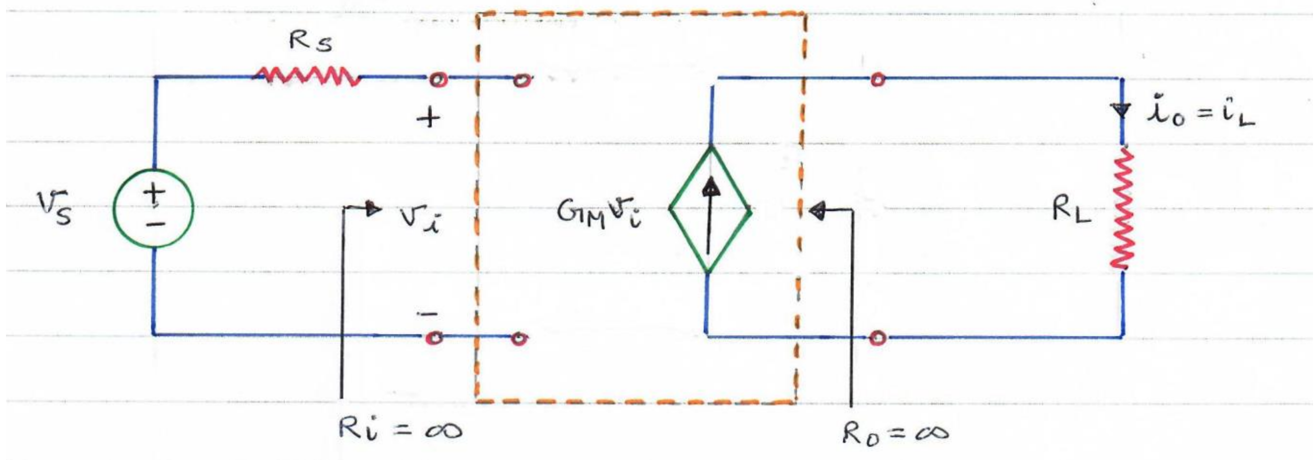



$$\frac{v_L}{v_s} = \frac{A_v R_i R_L}{(R_s + R_i)(R_o + R_L)}$$

$$\frac{v_L}{v_s} = A_v$$

$$if \;\; R_i = \infty \, , R_o = 0$$

# Ideal Transconductance Amplifier



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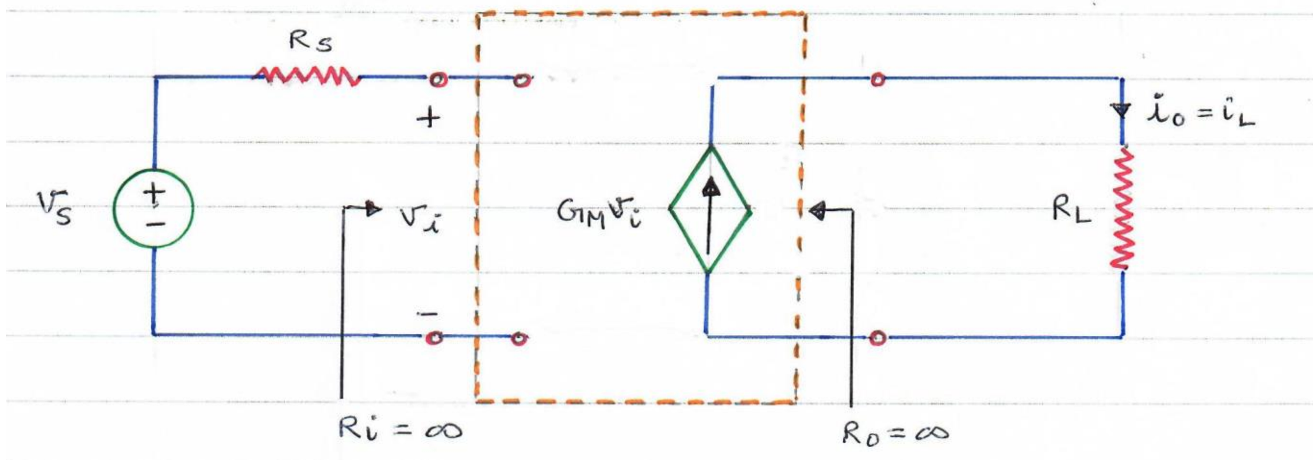
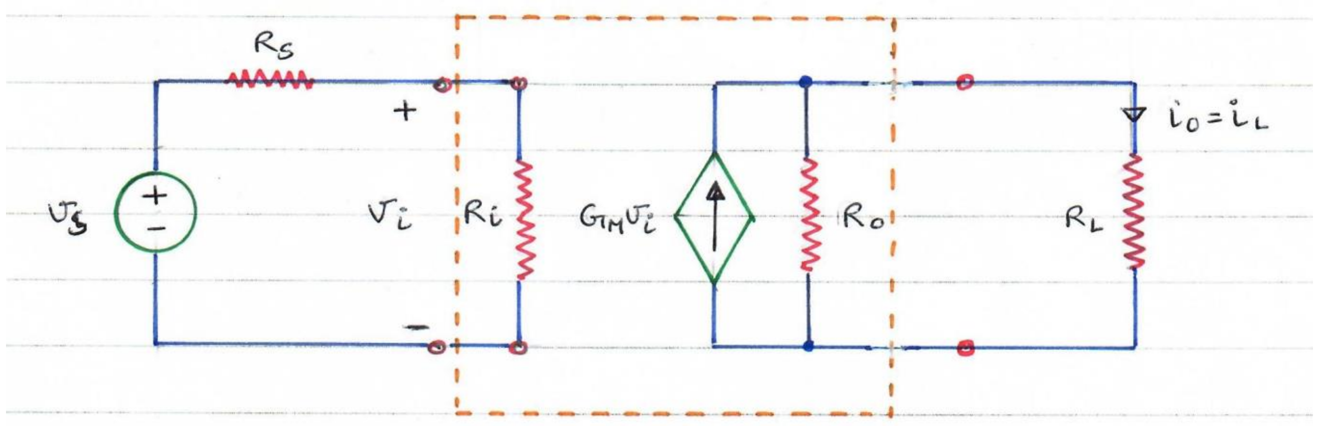



$$\frac{i_L}{v_s} = G_m$$

# Practical Transconductance Amplifier



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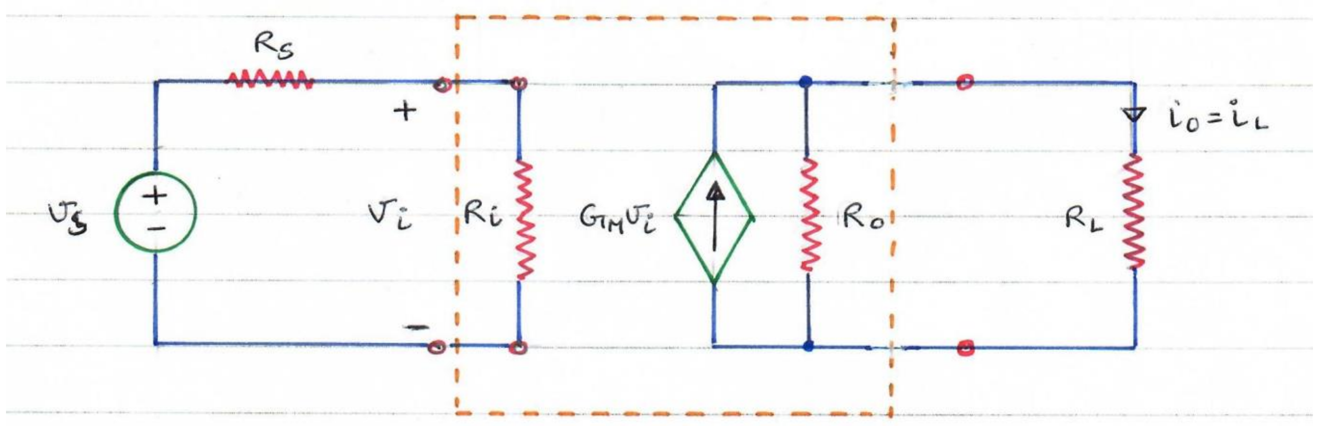
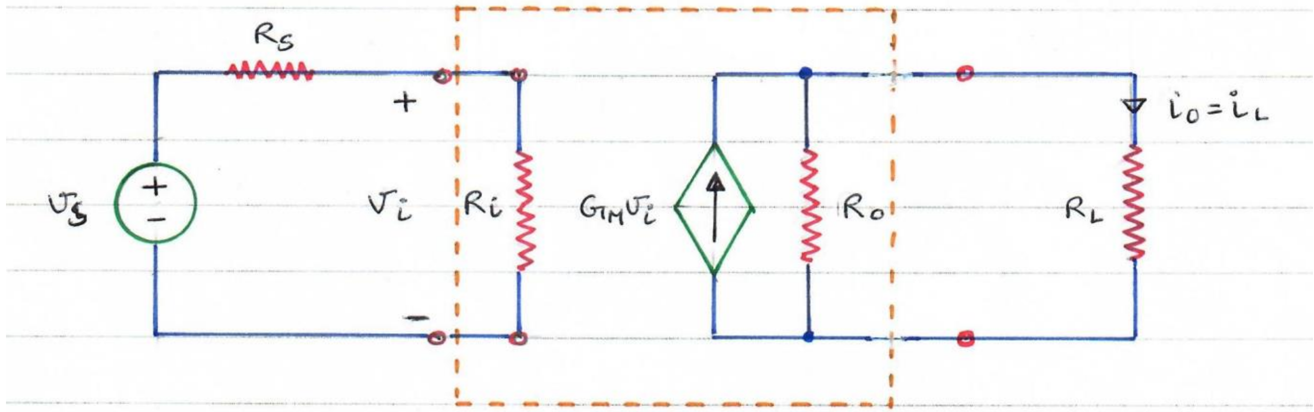



$$\frac{i_L}{v_s} = \frac{G_m R_i R_o}{(R_s + R_i)(R_o + R_L)}$$

# Practical Transconductance Amplifier

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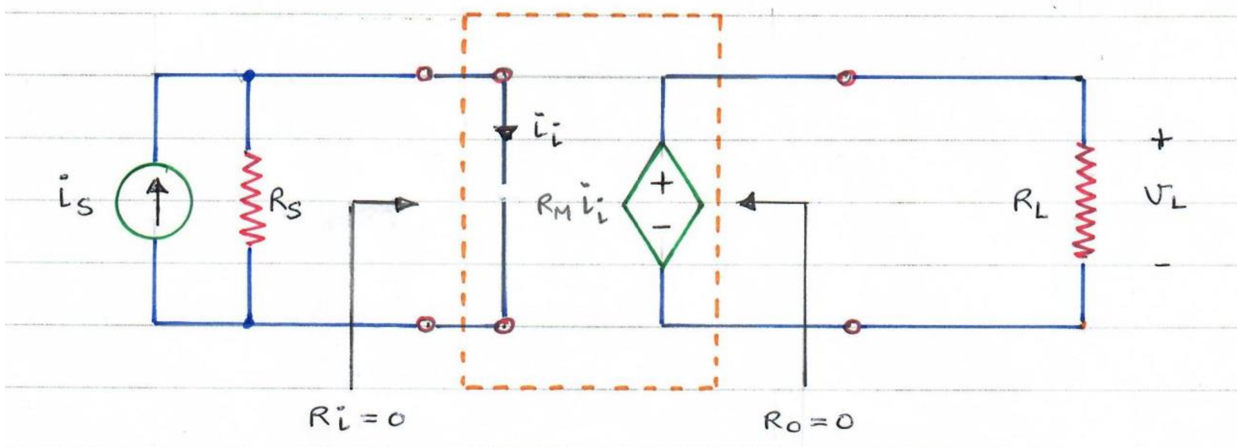
$$\frac{i_L}{v_s} = G_m$$

$$if \;\; R_i = \infty \, , R_o = \infty$$

# Ideal Transresistance Amplifier



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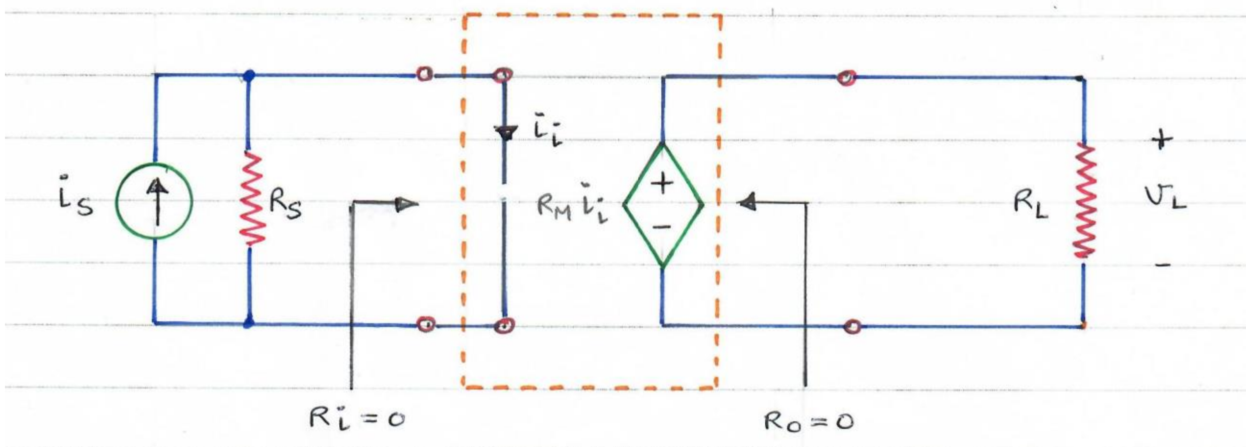
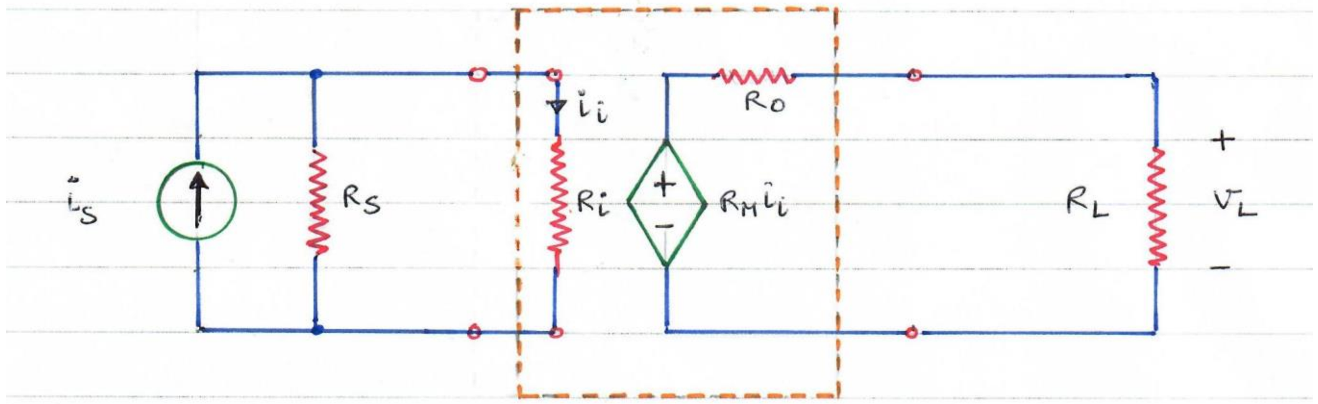



$$\frac{v_L}{i_s} = R_m$$

# Practical Transresistance Amplifier



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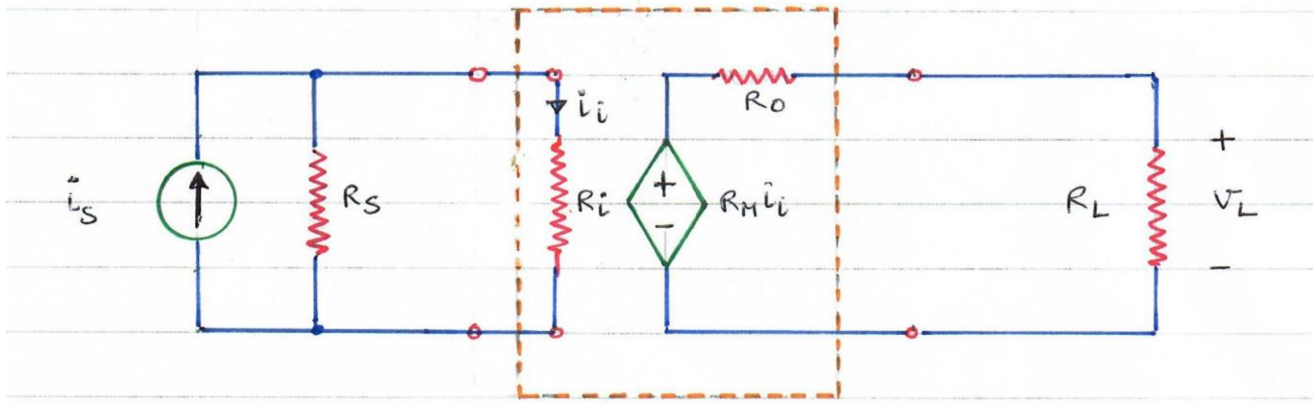
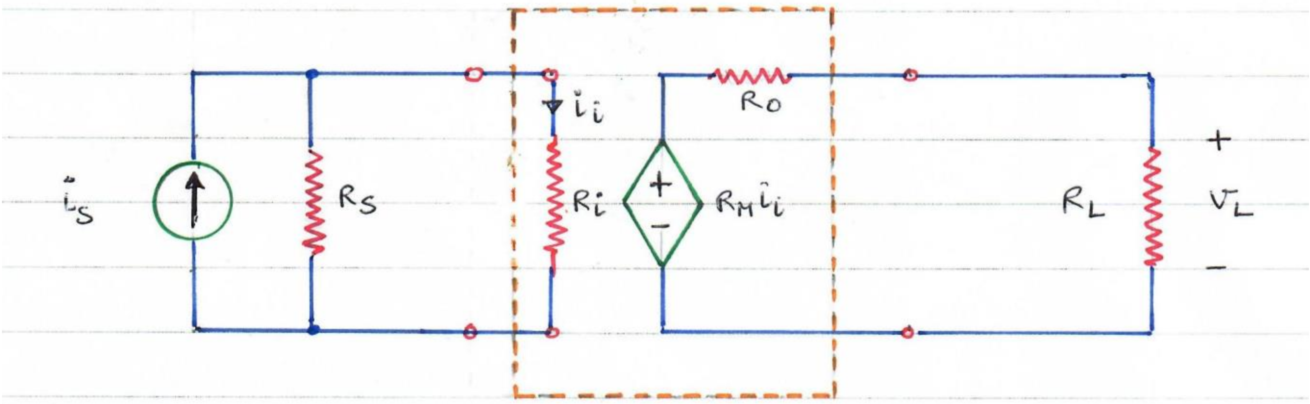



$$\frac{v_L}{i_s} = \frac{R_m R_s R_L}{(R_s + R_i)(R_o + R_L)}$$

# Practical Transresistance Amplifier

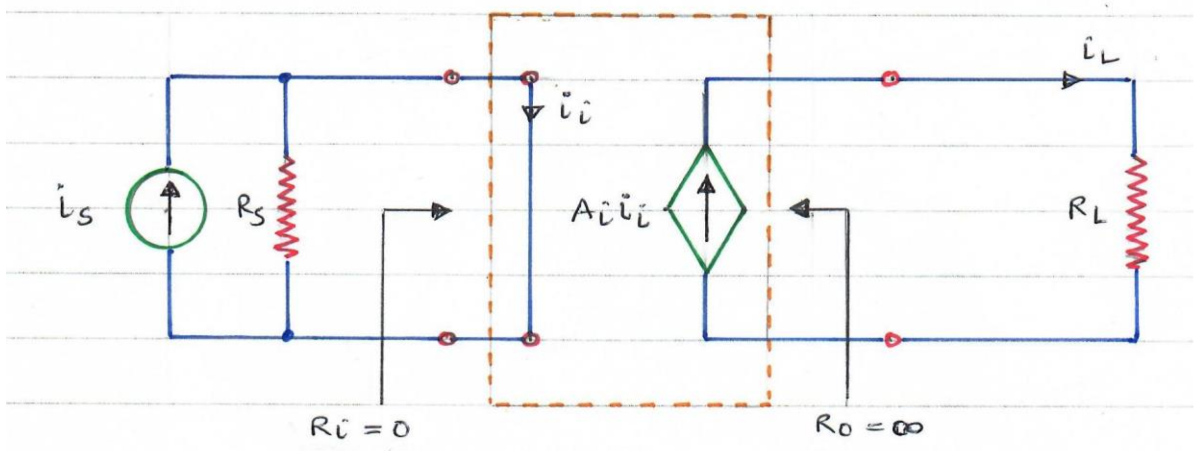



$$\frac{v_L}{i_s} = \frac{R_m R_s R_L}{(R_s + R_i)(R_o + R_L)}$$

$$\frac{v_L}{i_s} = R_m$$

$$if \;\; R_i = 0 \, , R_o = 0$$

# Ideal Current Amplifier



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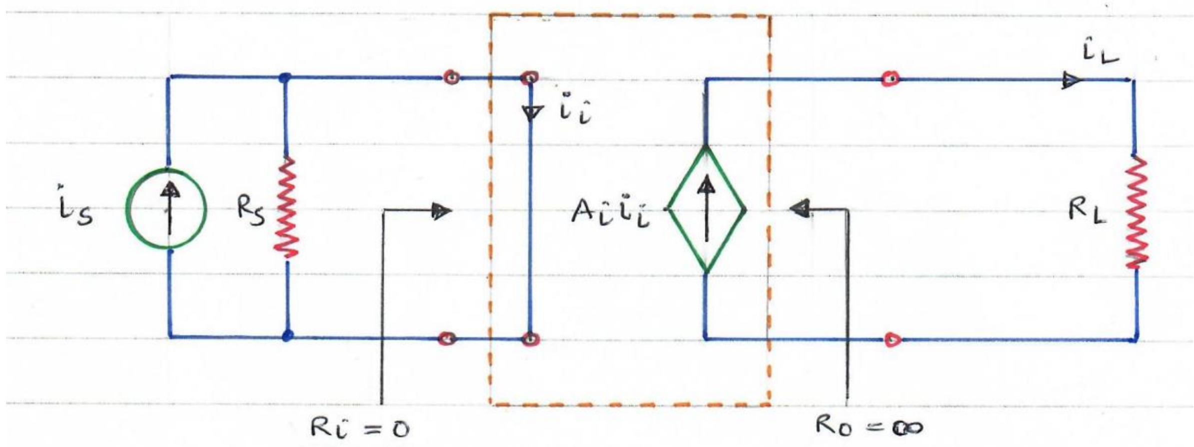
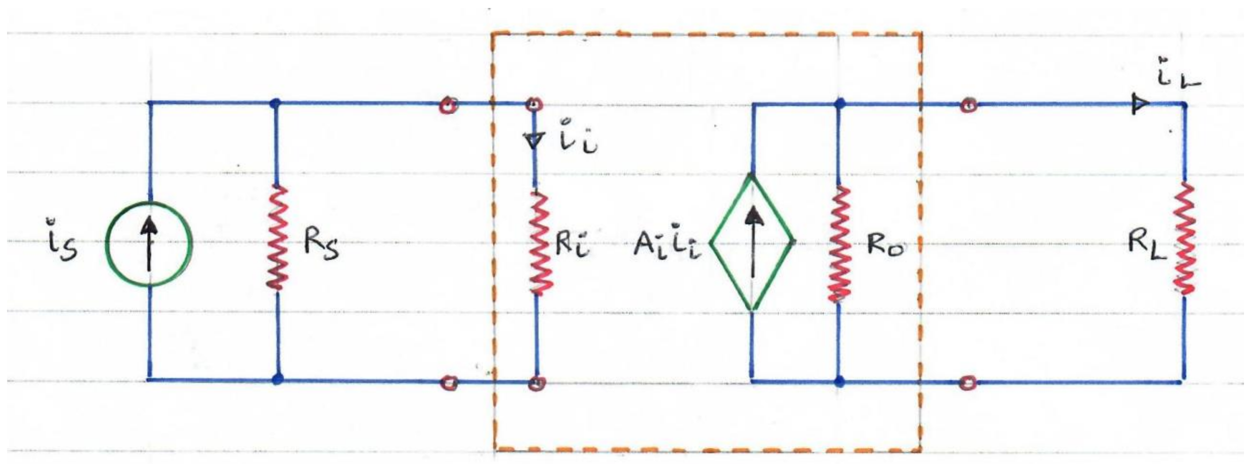



$$\frac{i_L}{i_s} = A_i$$

# Practical Current Amplifier



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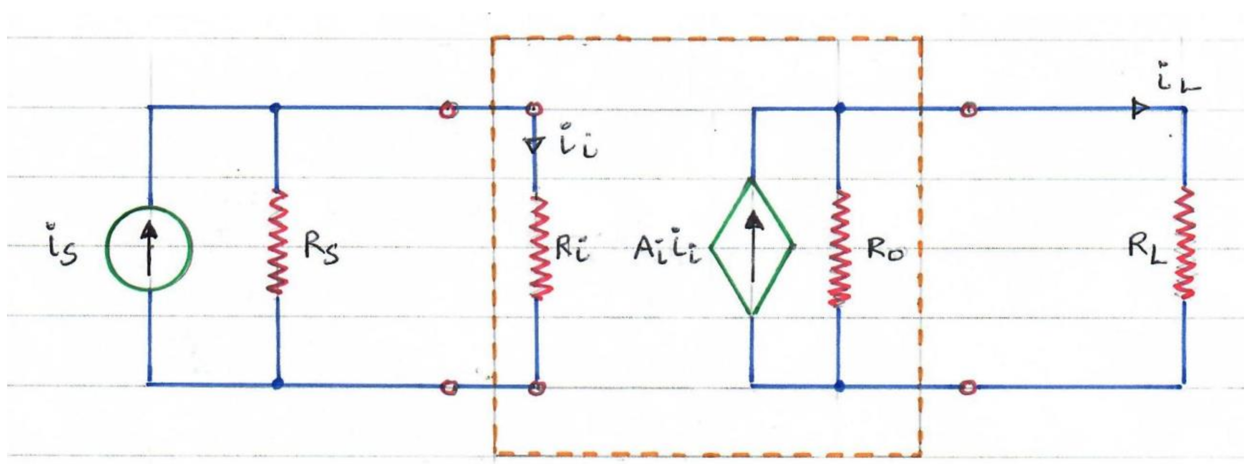
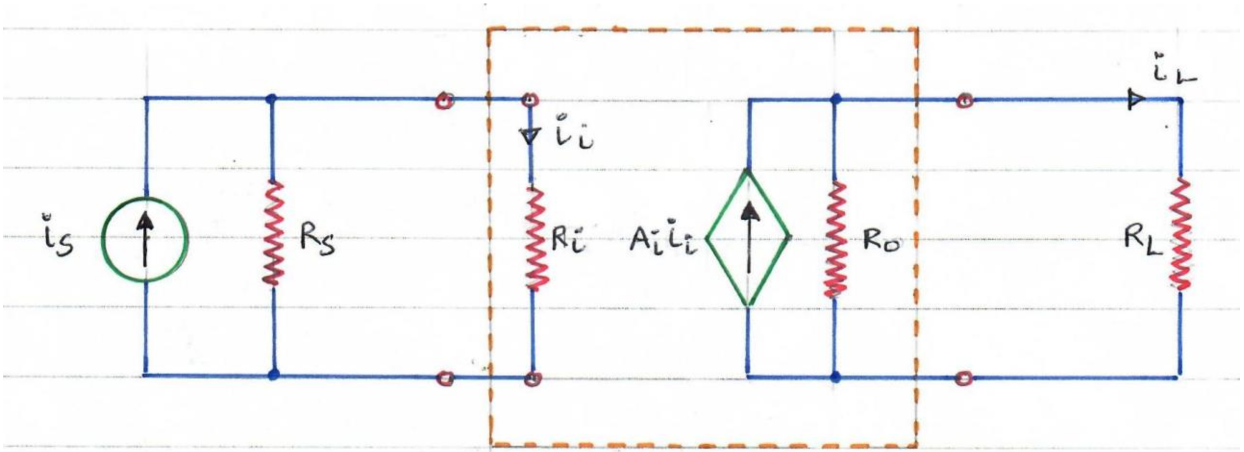



$$\frac{i_L}{i_s} = \frac{A_i R_s R_o}{(R_s + R_i)(R_o + R_L)}$$

# Practical Current Amplifier




$$\frac{i_L}{i_s} = \frac{A_i R_s R_o}{(R_s + R_i)(R_o + R_L)}$$

$$\frac{i_L}{i_s} = A_i$$

$$if \;\; R_i = 0 \, , R_o = \infty$$

# Practical Current Amplifier

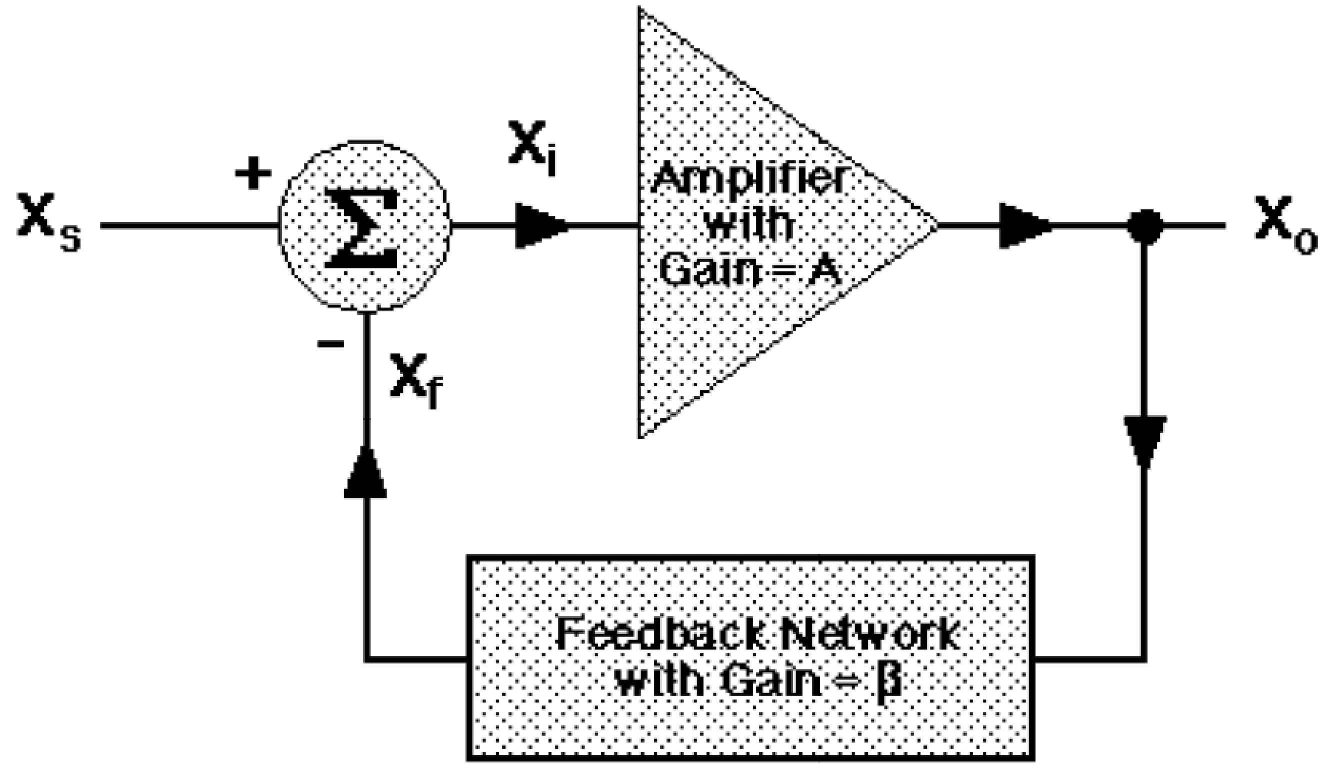
- Only current $i_{in}$ is amplified to $A_i i_{in}$.
- Since $R_s$ and $R_{in}$ form a current divider that determines $i_{in}$, $R_{in}$ should be as small as possible for maximum current.
- Since $R_L$ and $R_{out}$ form a current divider that determines $i_{out}$, $R_{out}$ should be as large as possible for maximum output current.

# Ideal Amplifiers

| Type of Amplifier | Gain Expression | Ideal Input Impedance | Ideal Output Impedance |
|---|---|---|---|
| Voltage | $A_v = V_o/V_s$ Voltage Gain (dimensionless) | $Z_i = \infty$ | $Z_o = 0$ |
| Transconductance | $G_m = I_o/V_s$ Transconductance (Siemens) | $Z_i = \infty$ | $Z_o = \infty$ |
| Transresistance | $R_m = V_o/I_s$ Transresistance (Ohms) | $Z_i = 0$ | $Z_o = 0$ |
| Current | $A_i = I_o/I_s$ Current Gain (dimensionless) | $Z_i = 0$ | $Z_o = \infty$ |

# Feedback Topologies

# Basic Block Diagram



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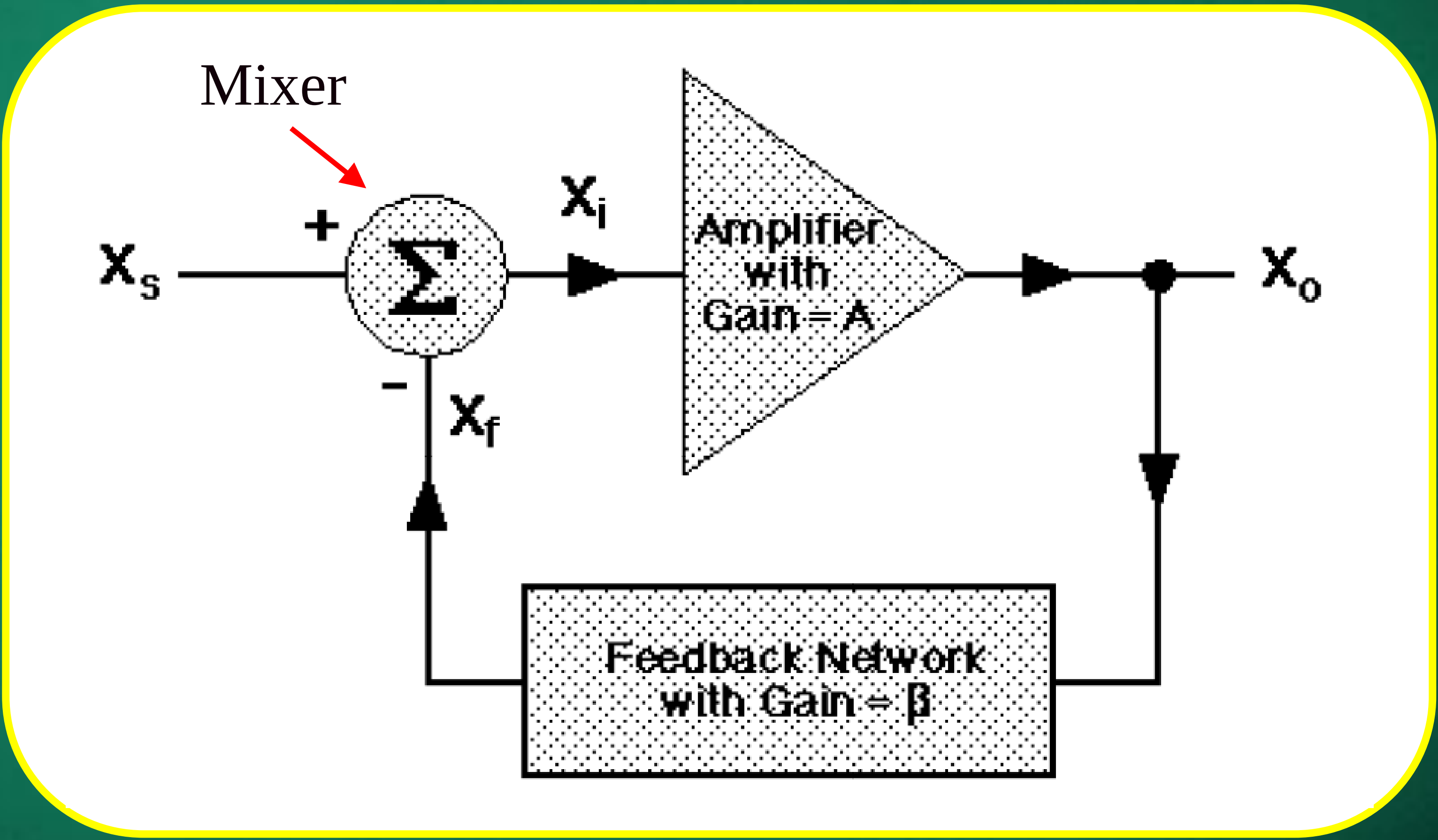

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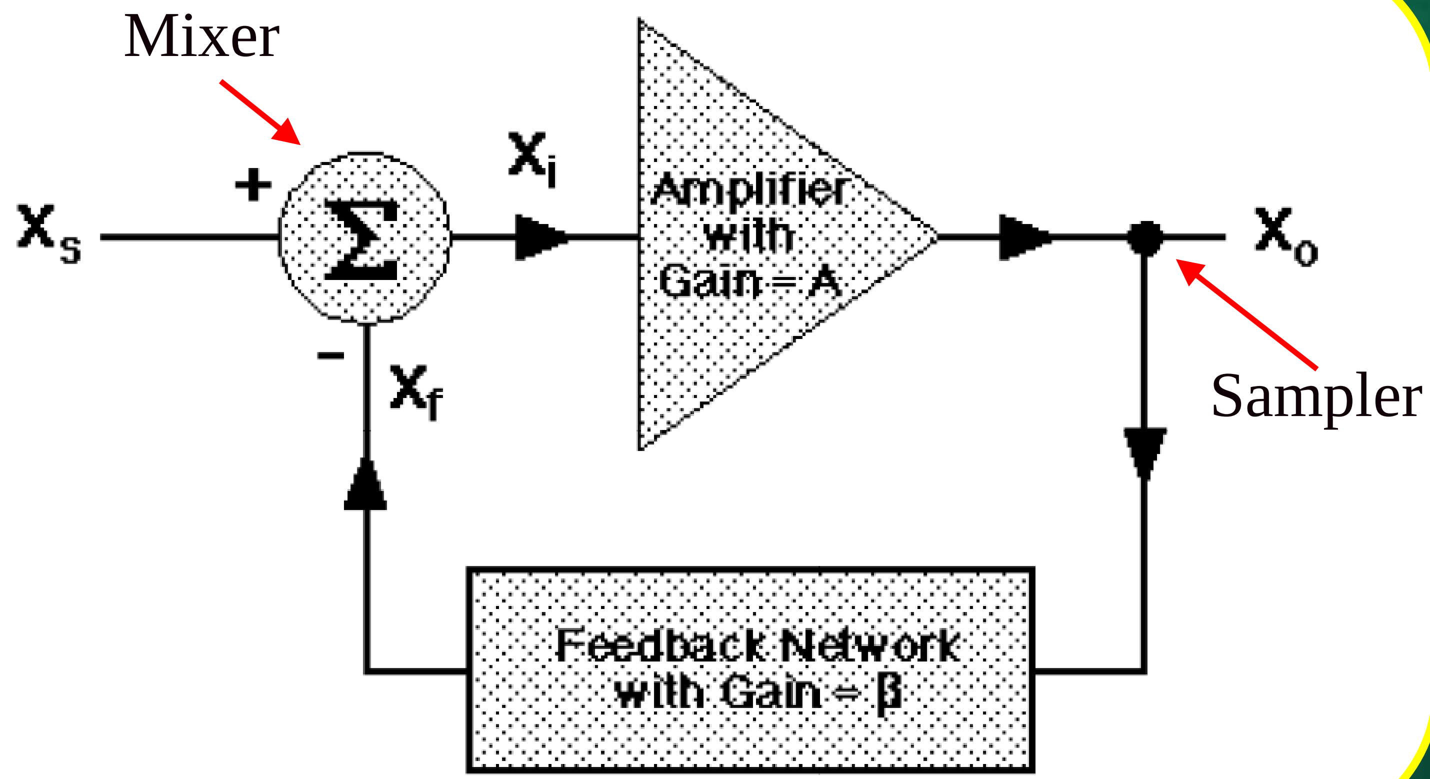
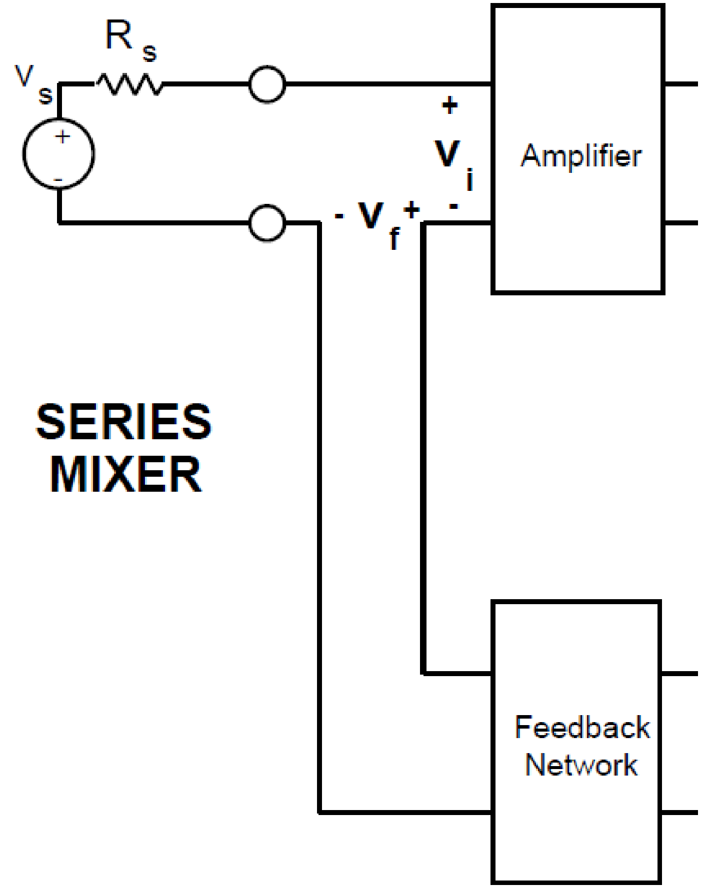
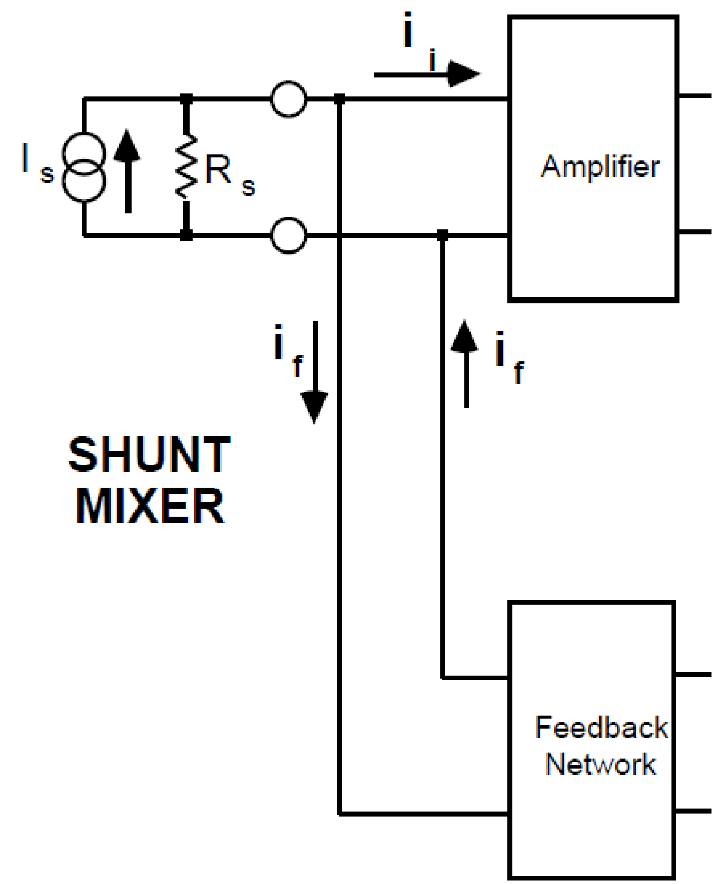


# Types of Mixers

# Series Mixer

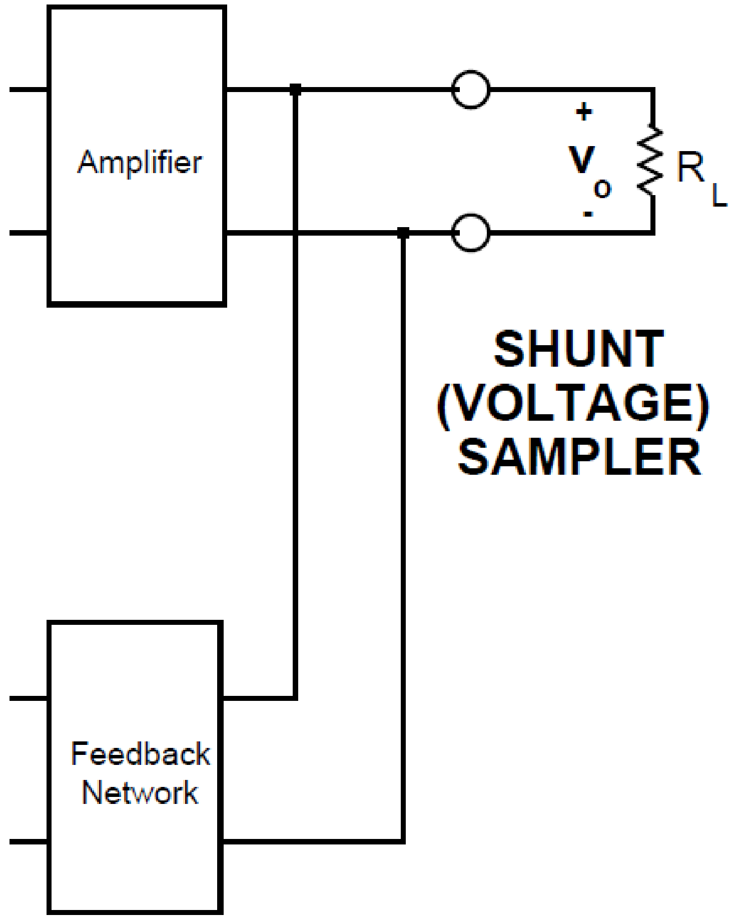


# Shunt Mixer

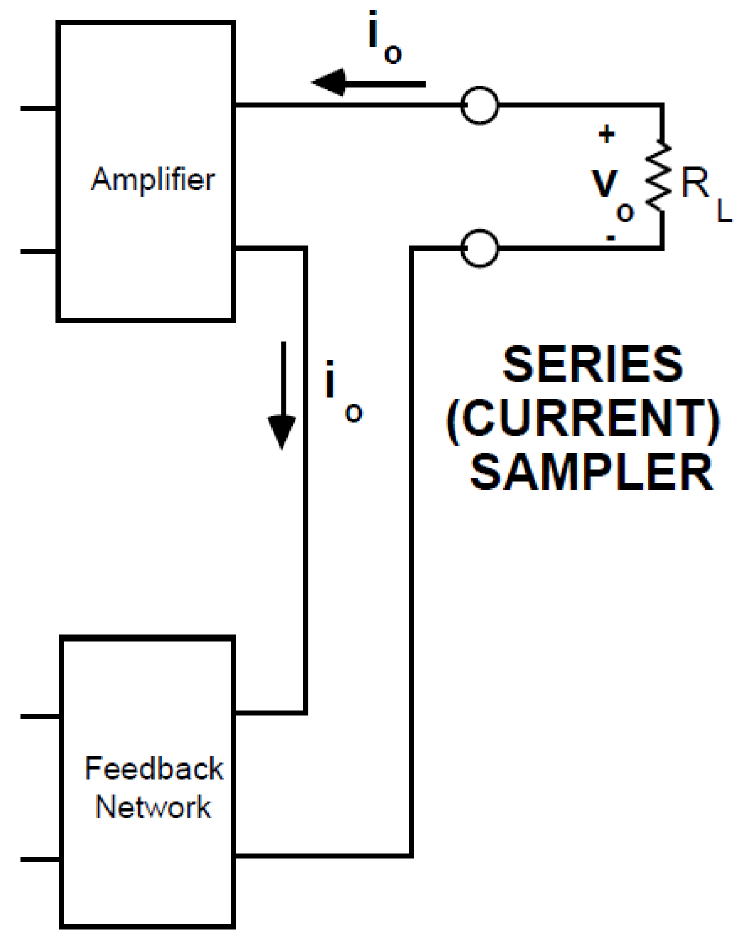


# Types of Samplers

# Shunt Sampler



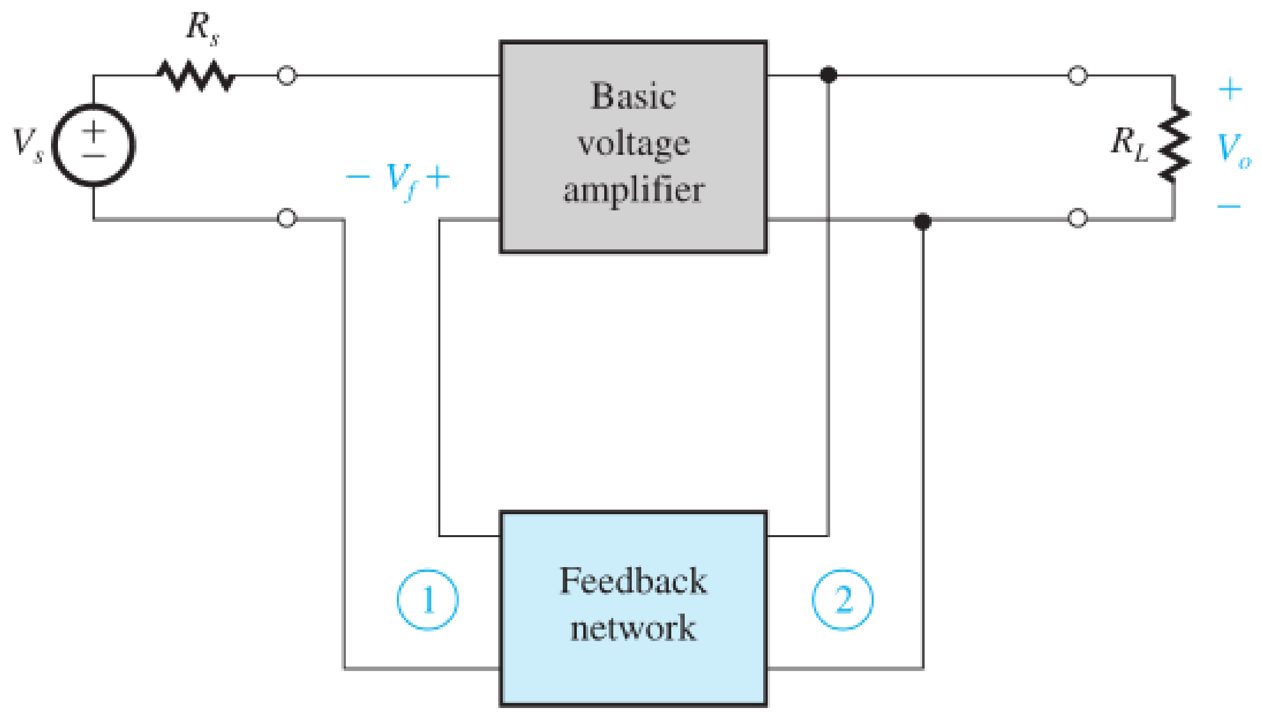
# Series Sampler



# Types of Amplifiers based on Feedback Topology

| | | | |
|---|---|---|---|
| Series-Shunt | Series (voltage) mixing, Shunt (voltage) sampling | V-V | Voltage Amplifier |
| Shunt-Series | Shunt (current) mixing, Series (current) sampling | I-I | Current Amplifier |
| Series-Series | Series (voltage) mixing, Series (current) sampling | V-I | Transconductance Amplifier |
| Shunt-Shunt | Shunt (current) mixing, Shunt (voltage) sampling | I-V | Transresistance Amplifier |

# Series-Shunt Amplifier



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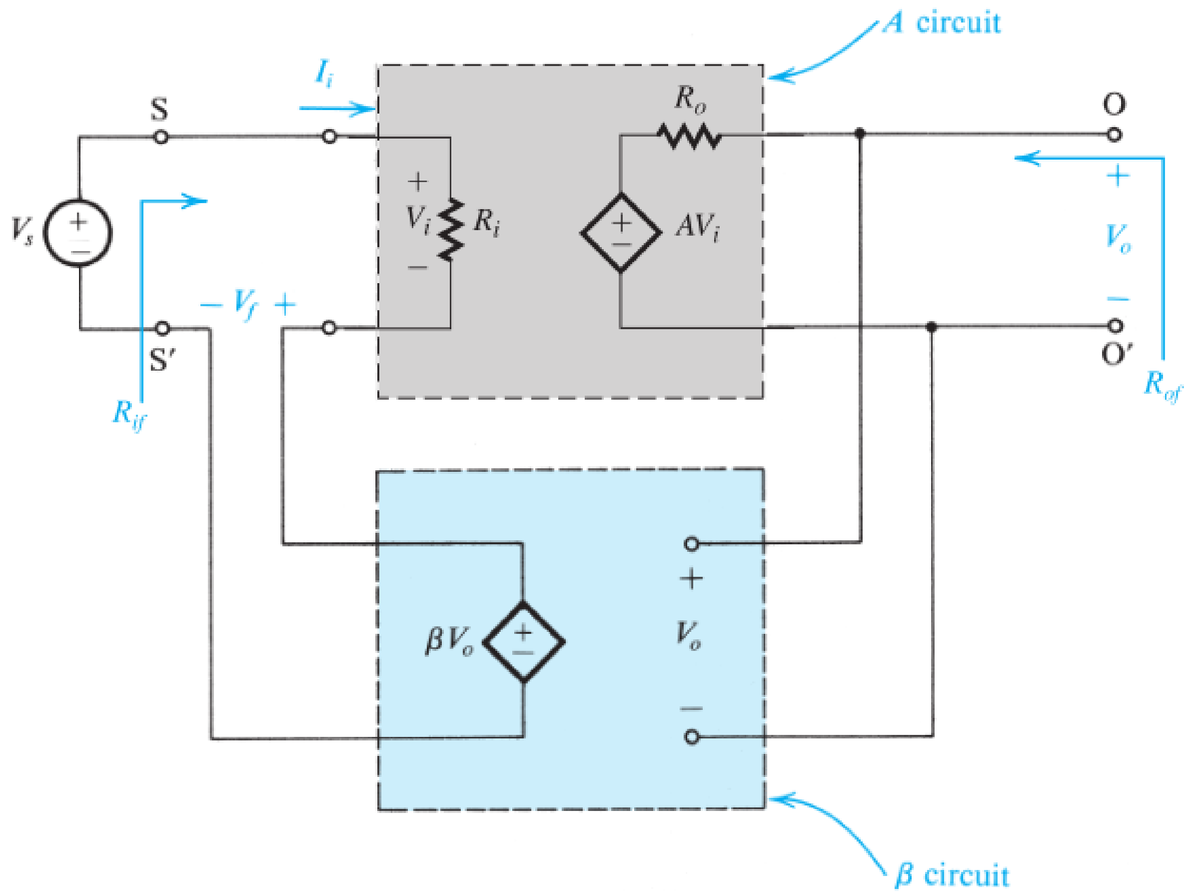
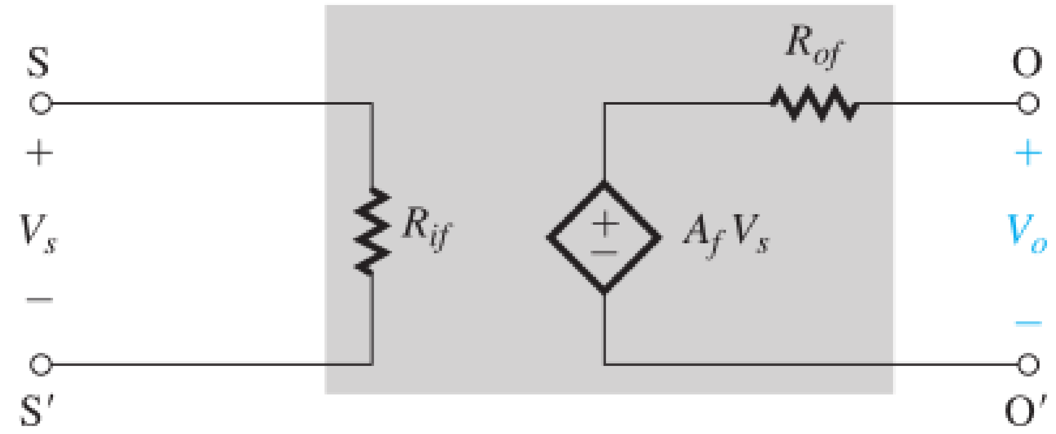


# Series-Shunt Amplifier

## Equivalent Circuit



# Series-Shunt Feedback

**Input Impedance ($R_{if}$)**

# Series-Shunt Feedback

## Input Impedance ($R_{if}$)

$$R_{if} \equiv \frac{V_s}{I_i} = \frac{V_s}{\left(\frac{V_i}{R_i}\right)} = R_i\left(\frac{V_s}{V_i}\right) = R_i\left(\frac{V_i + V_f}{V_i}\right) = R_i\left(\frac{V_i + \beta A V_i}{V_i}\right)$$

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$$\Rightarrow R_{if} = R_i\left(1 + A\beta\right)$$

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$$\Rightarrow R_{if} = R_i(1 + A\beta)$$

$$Z_{if}(s) = Z_{if}(s)[1 + A(s)\beta(s)]$$

# Series-Shunt Feedback

## Input Impedance ($R_{if}$)

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$$\Rightarrow R_{if} = R_i\left(1 + A\beta\right)$$

$$Z_{if}(s) = Z_{if}(s)\left[1 + A(s)\beta(s)\right]$$

True for all series mixing cases.

# Series-Shunt Feedback

## Output Impedance ($R_{of}$)

# Series-Shunt Feedback

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$$R_{of} \equiv \frac{V_t}{I} \Rightarrow I = \frac{V_t - AV_i}{R_o}$$

# Series-Shunt Feedback

**Output Impedance ($R_{of}$)**

$$R_{of} \equiv \frac{V_t}{I} \Rightarrow I = \frac{V_t - AV_i}{R_o}$$

**Disable source input ($V_s = 0$)**

# Series-Shunt Feedback

**Output Impedance ($R_{of}$)**

$$R_{of} \equiv \frac{V_t}{I} \Rightarrow I = \frac{V_t - AV_i}{R_o}$$

**Disable source input ($V_s = 0$)**

$$V_i = -V_f = -\beta V_o = -\beta V_t$$

# Series-Shunt Feedback

## Output Impedance ($R_{of}$)

$$R_{of} \equiv \frac{V_t}{I} \Rightarrow I = \frac{V_t - AV_i}{R_o}$$

## Disable source input ($V_s = 0$)

$$V_i = -V_f = -\beta V_o = -\beta V_t$$

$$I = \frac{V_t - AV_i}{R_o} = \frac{V_t + A\beta\beta_t}{R_o} = \frac{V_t\left(1 + A\beta\right)}{R_o}$$

# Series-Shunt Feedback

$$I = \frac{V_t(1 + A\beta)}{R_o} \Rightarrow \frac{V_t}{I} = R_{of} = \frac{R_o}{(1 + A\beta)}$$

# Series-Shunt Feedback

$$I = \frac{V_t\left(1 + A\beta\right)}{R_o} \Rightarrow \frac{V_t}{I} = R_{of} = \frac{R_o}{\left(1 + A\beta\right)}$$

**Output Impedance ($R_{of}$)**

# Series-Shunt Feedback

$$I = \frac{V_t(1+A\beta)}{R_o} \Rightarrow \frac{V_t}{I} = R_{of} = \frac{R_o}{(1+A\beta)}$$

**Output Impedance ($R_{of}$)**

$$R_{of} = \frac{R_o}{1+A\beta} \text{ or, more generally, } Z_{of}(s) = \frac{Z_o(s)}{1+A(s)\beta(s)}$$

# Series-Shunt Feedback

$$I = \frac{V_t\left(1 + A\beta\right)}{R_o} \Rightarrow \frac{V_t}{I} = R_{of} = \frac{R_o}{\left(1 + A\beta\right)}$$

**Output Impedance ($R_{of}$)**

$$R_{of} = \frac{R_o}{1 + A\beta} \text{ or, more generally, } Z_{of}(s) = \frac{Z_o(s)}{1 + A(s)\beta(s)}$$

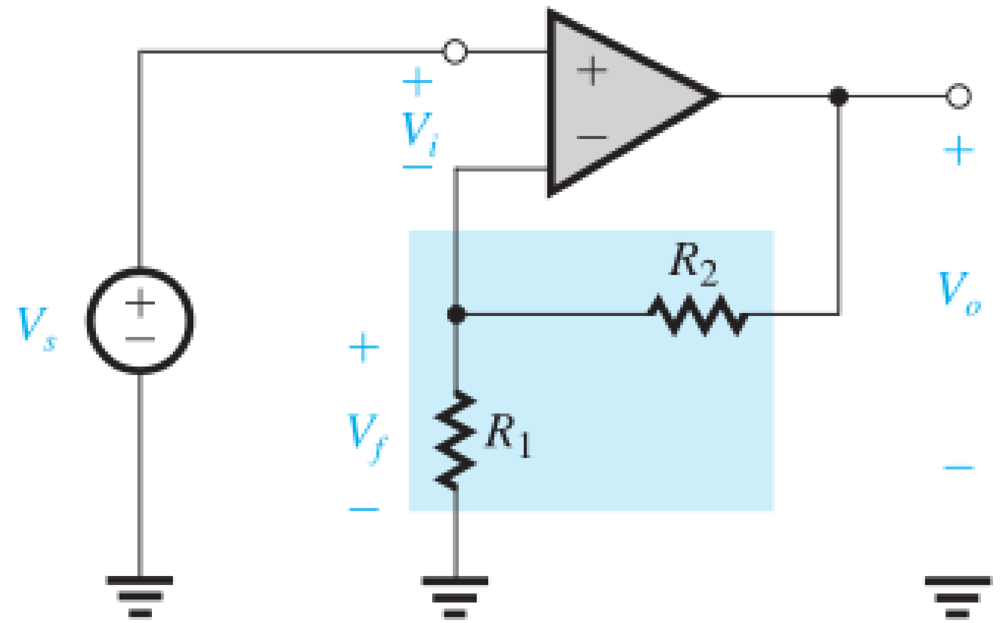
**True for all shunt sampling cases.**

# Series-Shunt Feedback

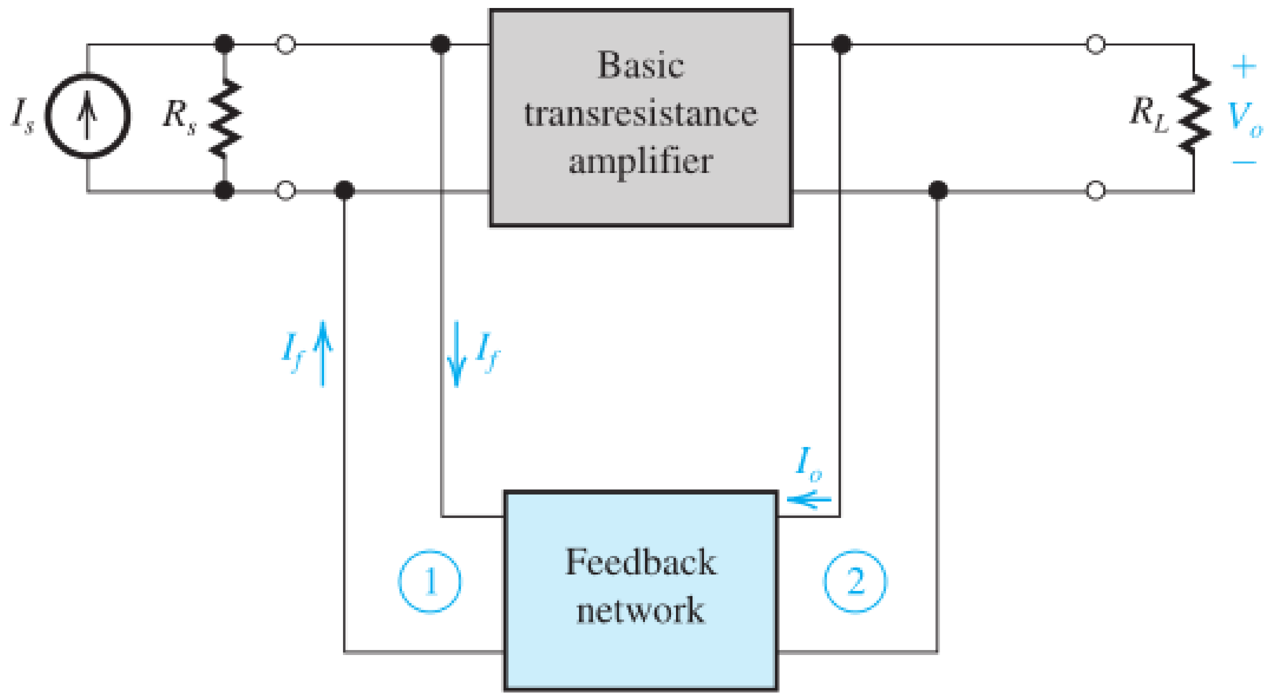
**Closed Loop Gain ($A_f$)**

$$A_f = \frac{A}{1 + A\beta}$$

# Series-Shunt Amplifier



# Shunt-Shunt Amplifier



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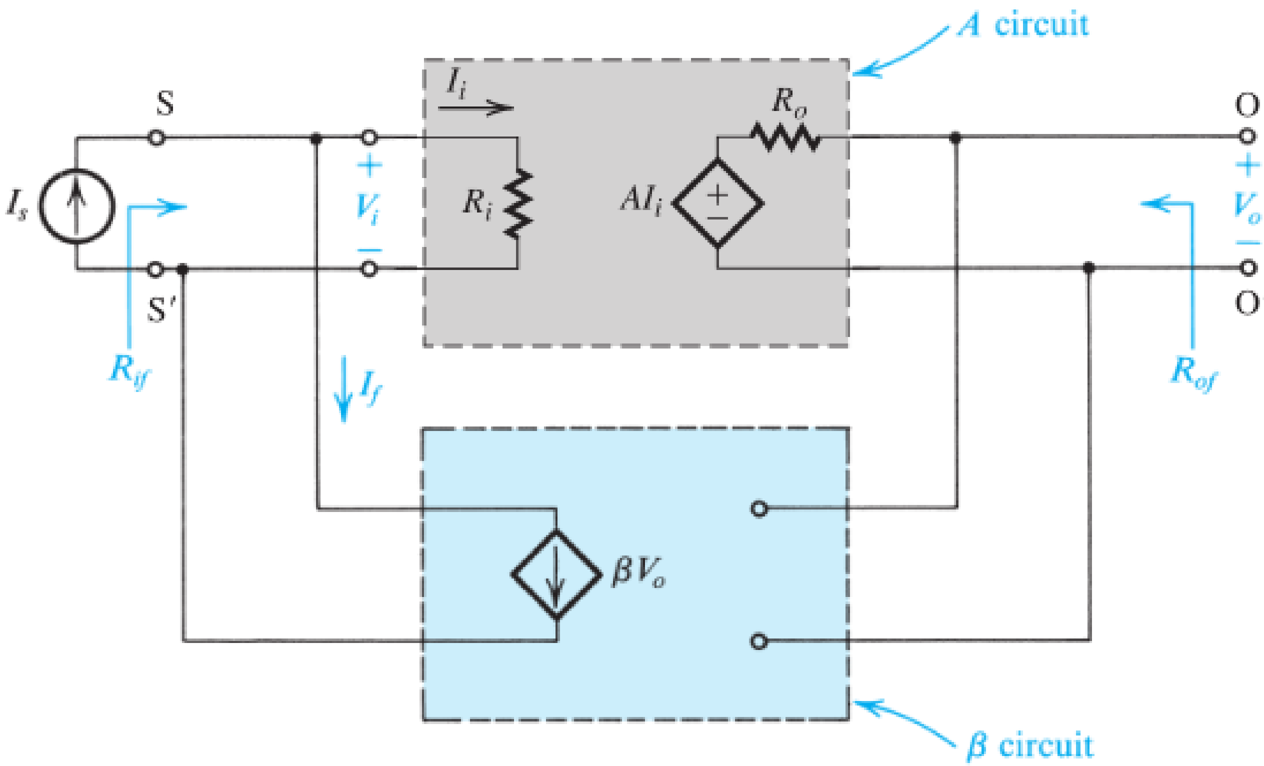

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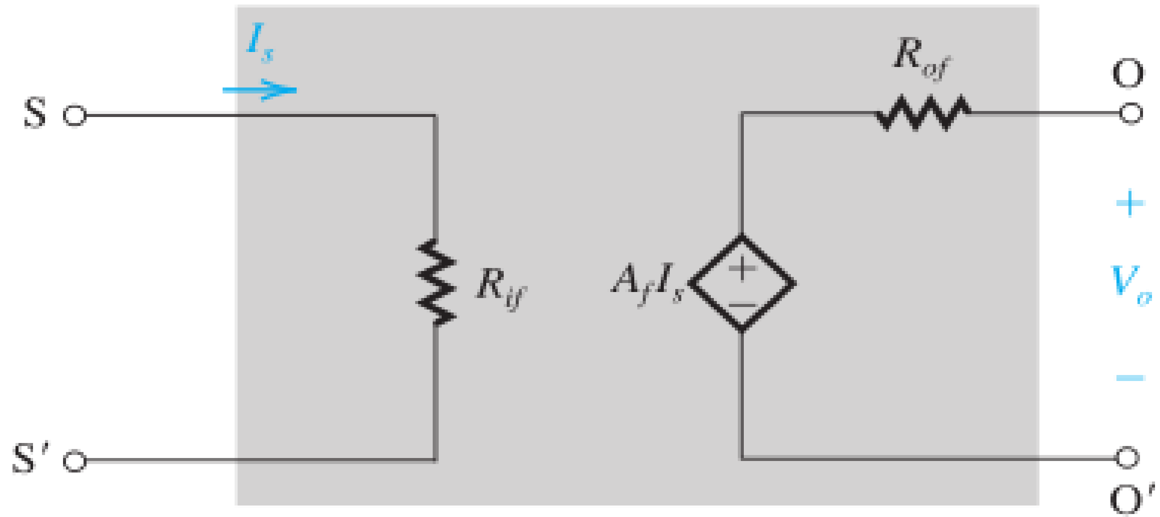

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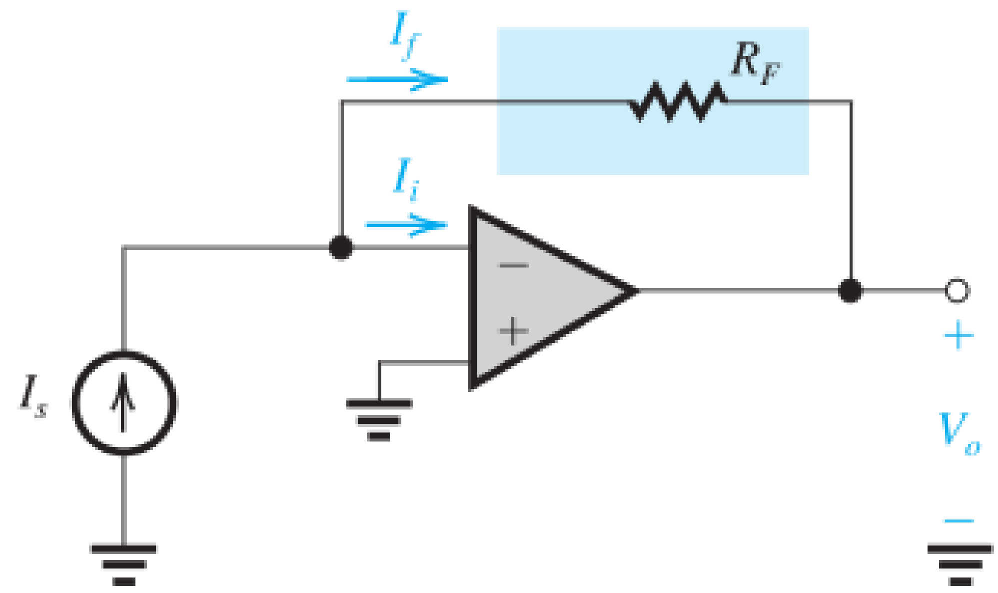

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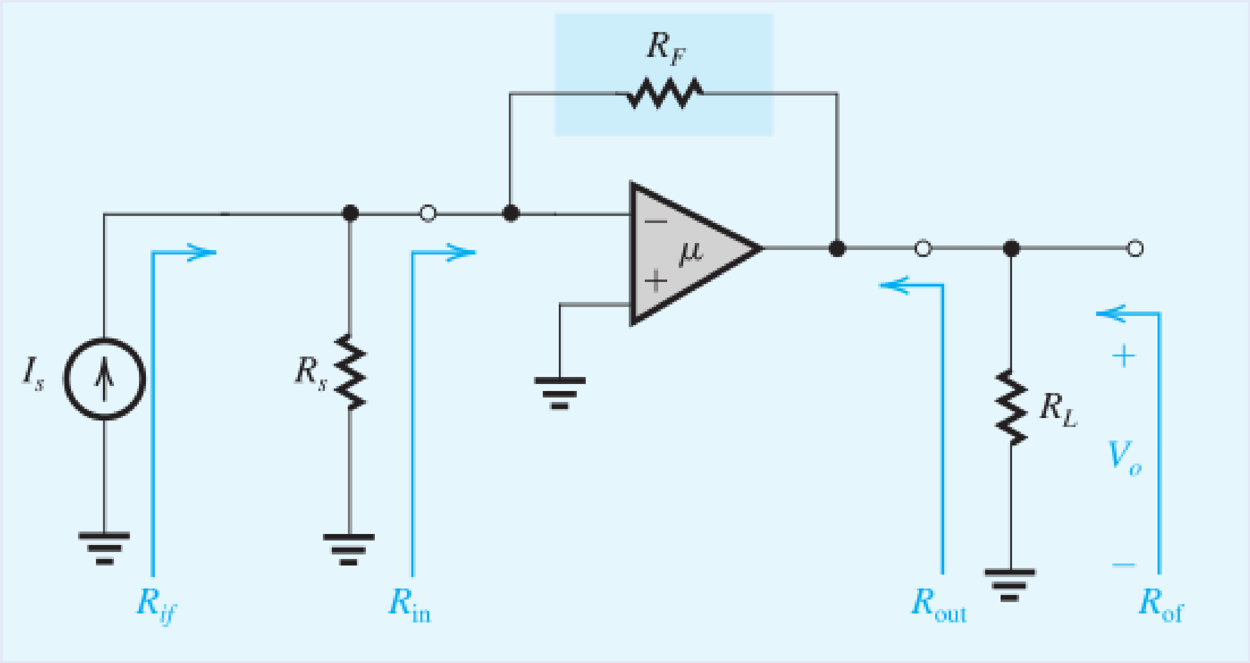
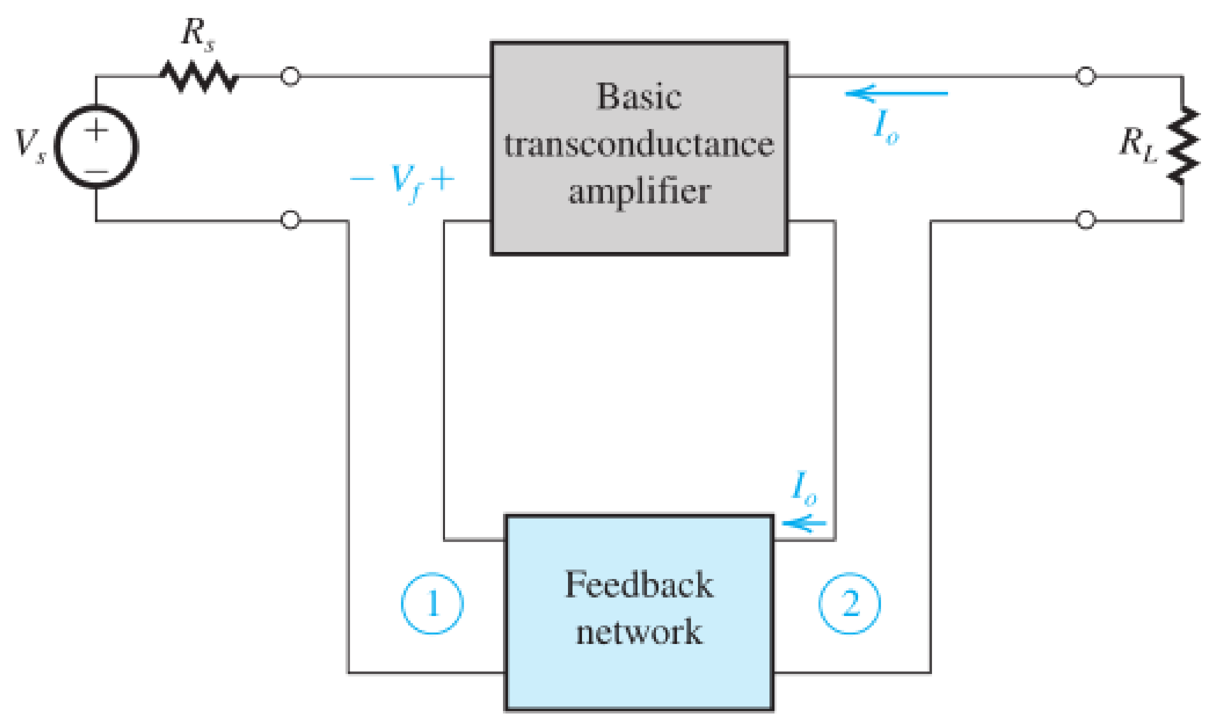
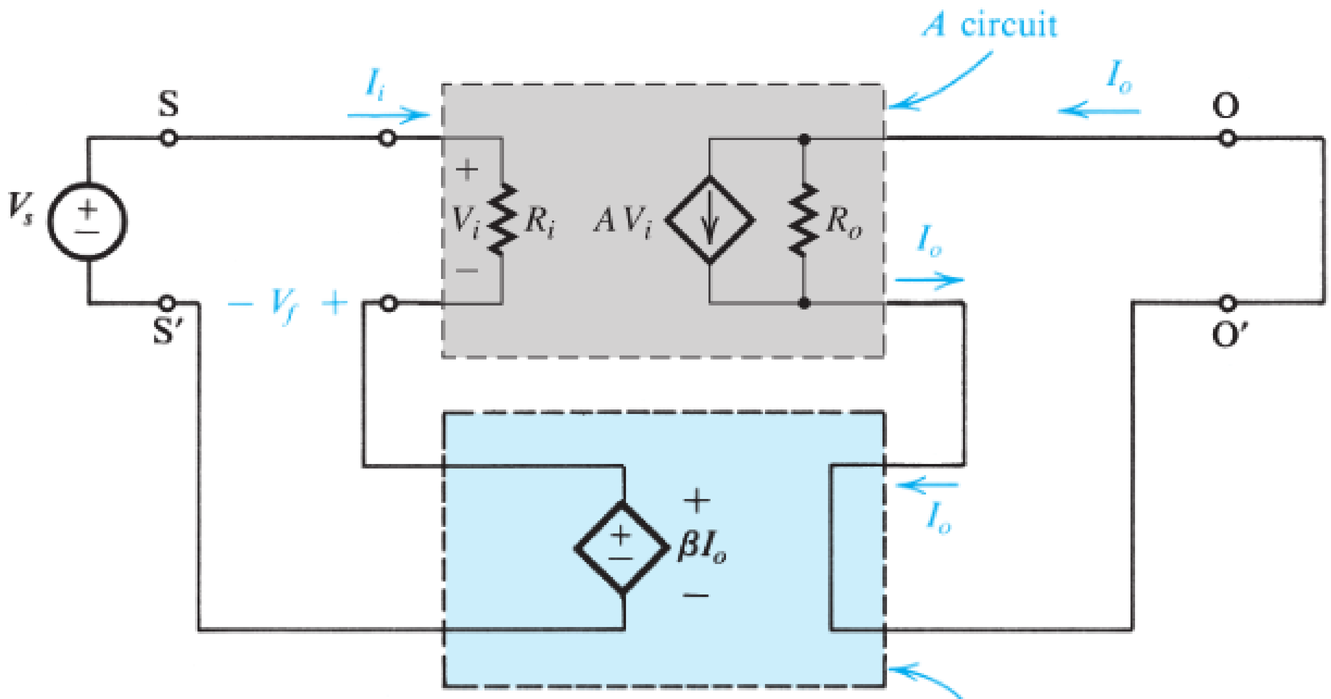


# Series-Series Amplifier

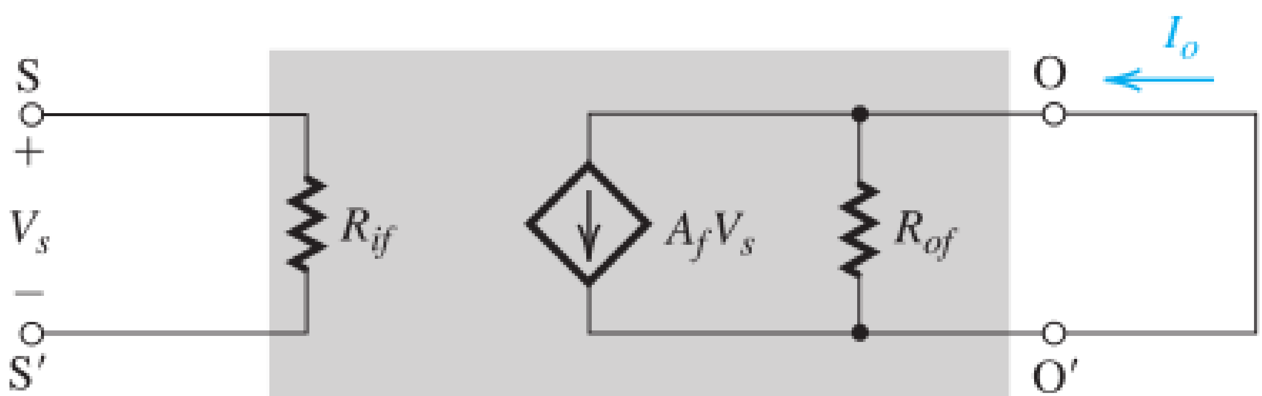


# Series-Series Amplifier

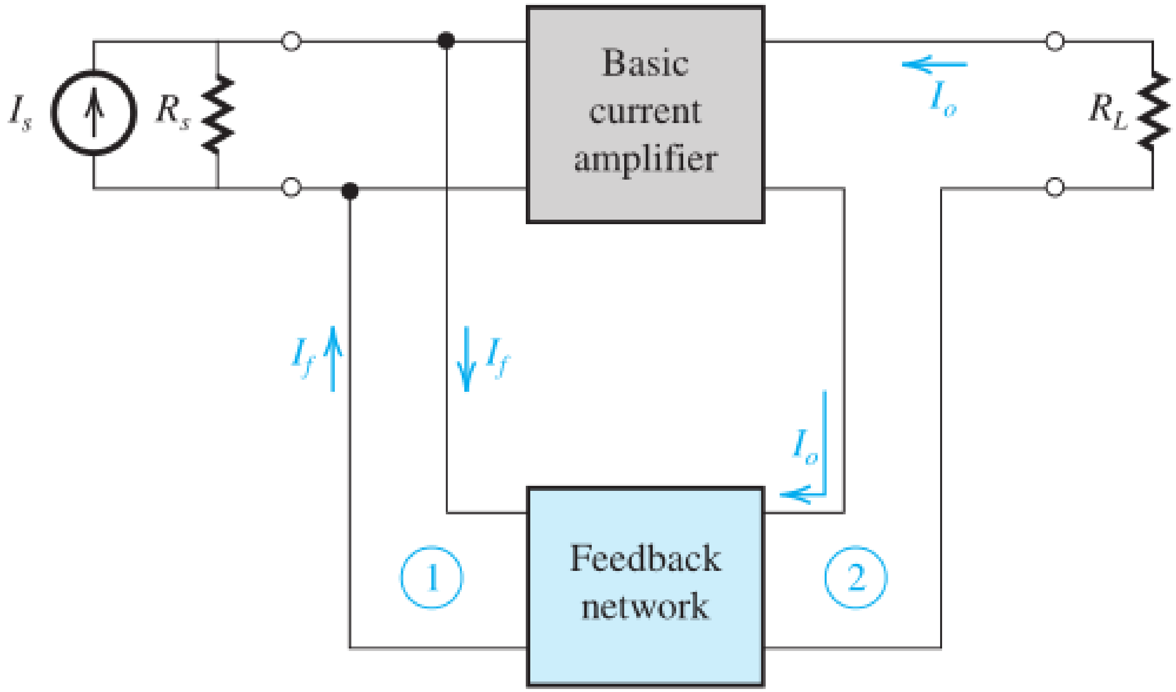



(a)

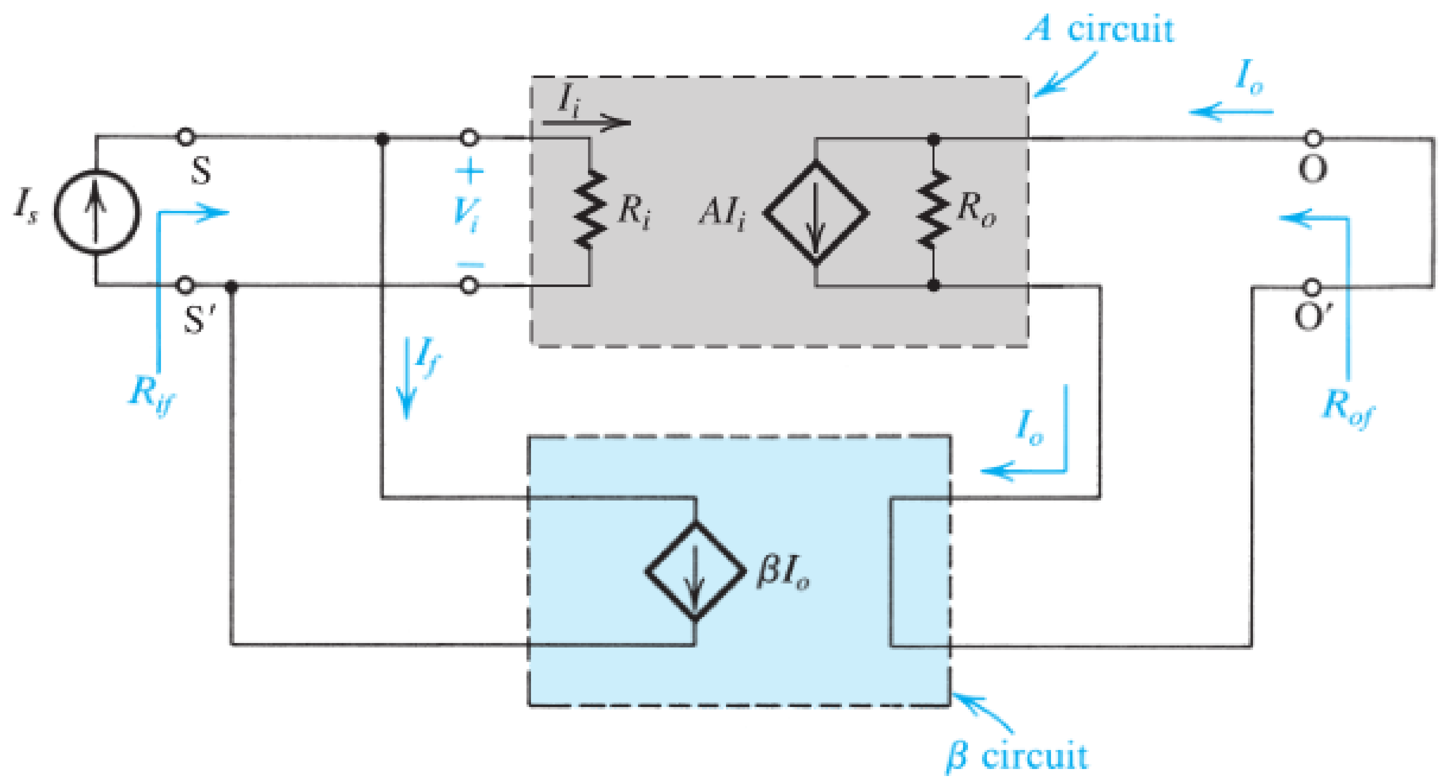
# Series-Series Amplifier



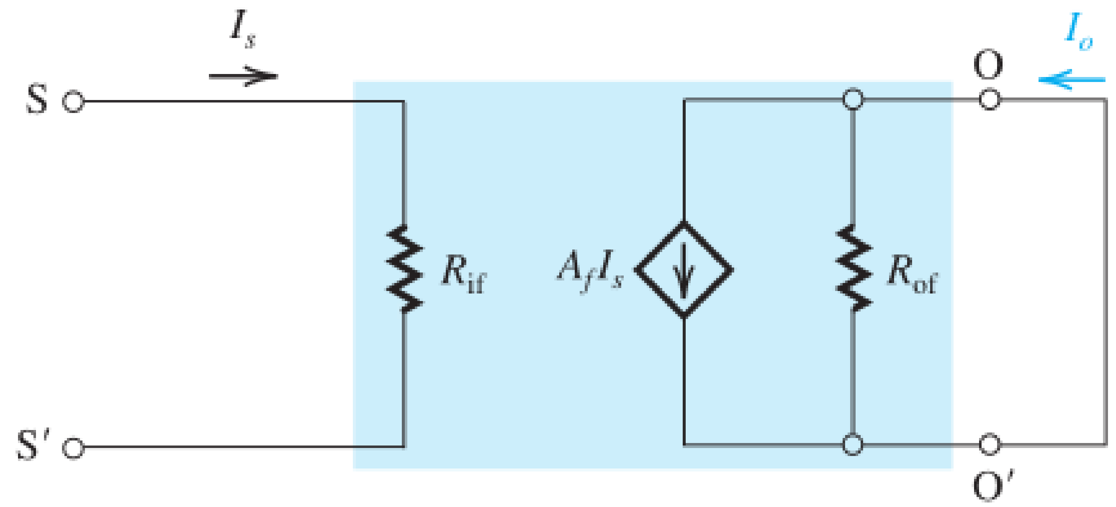
# Shunt-Series Amplifier



# Shunt-Series Amplifier



# Shunt-Series Amplifier

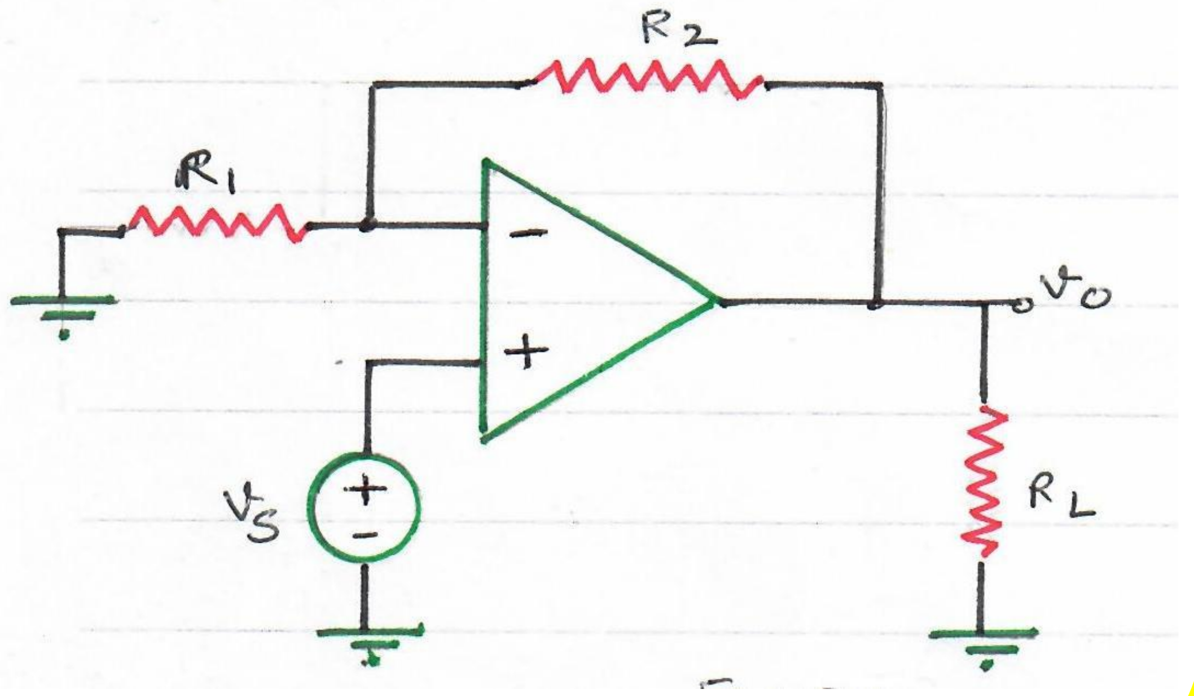


# Feedback Relations

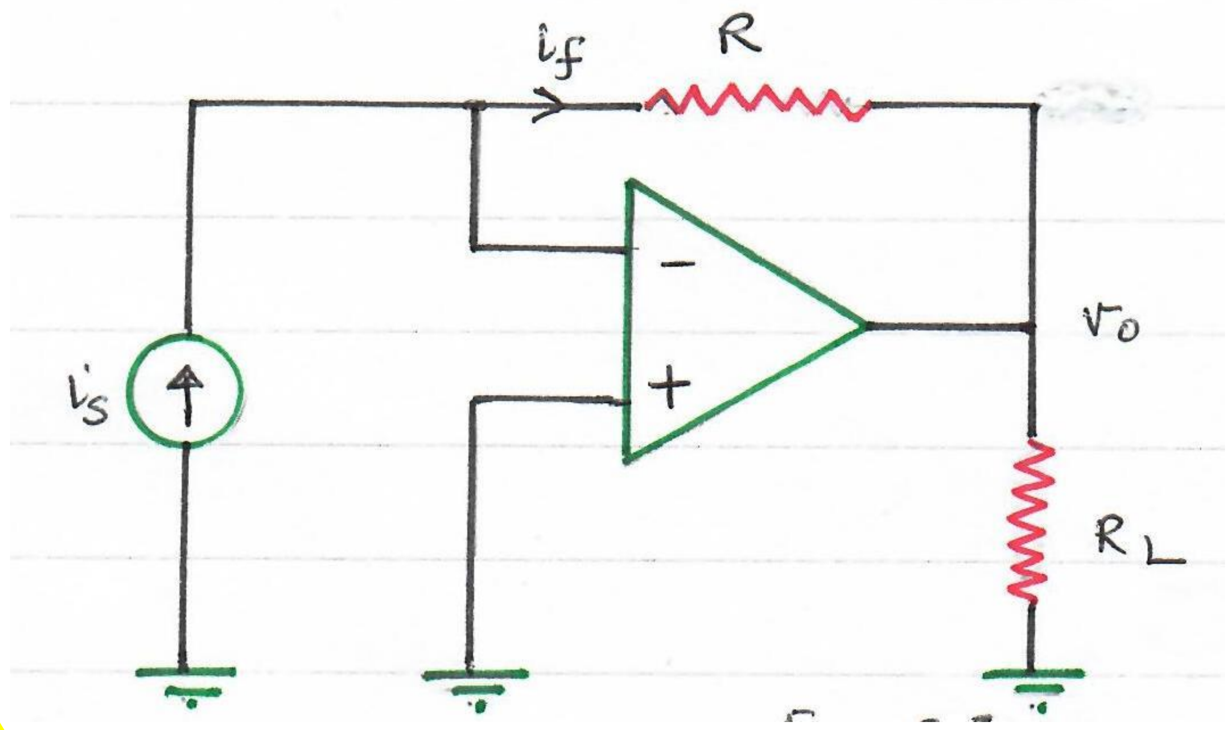
| | Gain | Input Resistance | Output Resistance |
|---|---|---|---|
| Without feedback | $A$ | $R_i$ | $R_o$ |
| Series-shunt<br>$A$ (V/V)<br>$\beta$ (V/V) | $A_f = \dfrac{A}{1 + \beta A}$ | $R_{if} = R_i(1 + \beta A)$ | $R_{of} = \dfrac{R_o}{1 + \beta A}$ |
| Series-series<br>$A$ (A/V or ℧)<br>$\beta$ (V/A or Ω) | $A_f = \dfrac{A}{1 + \beta A}$ | $R_{if} = R_i(1 + \beta A)$ | $R_{of} = R_o(1 + \beta A)$ |
| Shunt-shunt<br>$A$ (V/A or Ω)<br>$\beta$ (A/V or ℧) | $A_f = \dfrac{A}{1 + \beta A}$ | $R_{if} = \dfrac{R_i}{1 + \beta A}$ | $R_{of} = \dfrac{R_o}{1 + \beta A}$ |
| Shunt-series<br>$A$ (A/A)<br>$\beta$ (A/A) | $A_f = \dfrac{A}{1 + \beta A}$ | $R_{if} = \dfrac{R_i}{1 + \beta A}$ | $R_{of} = R_o(1 + \beta A)$ |

# Examples

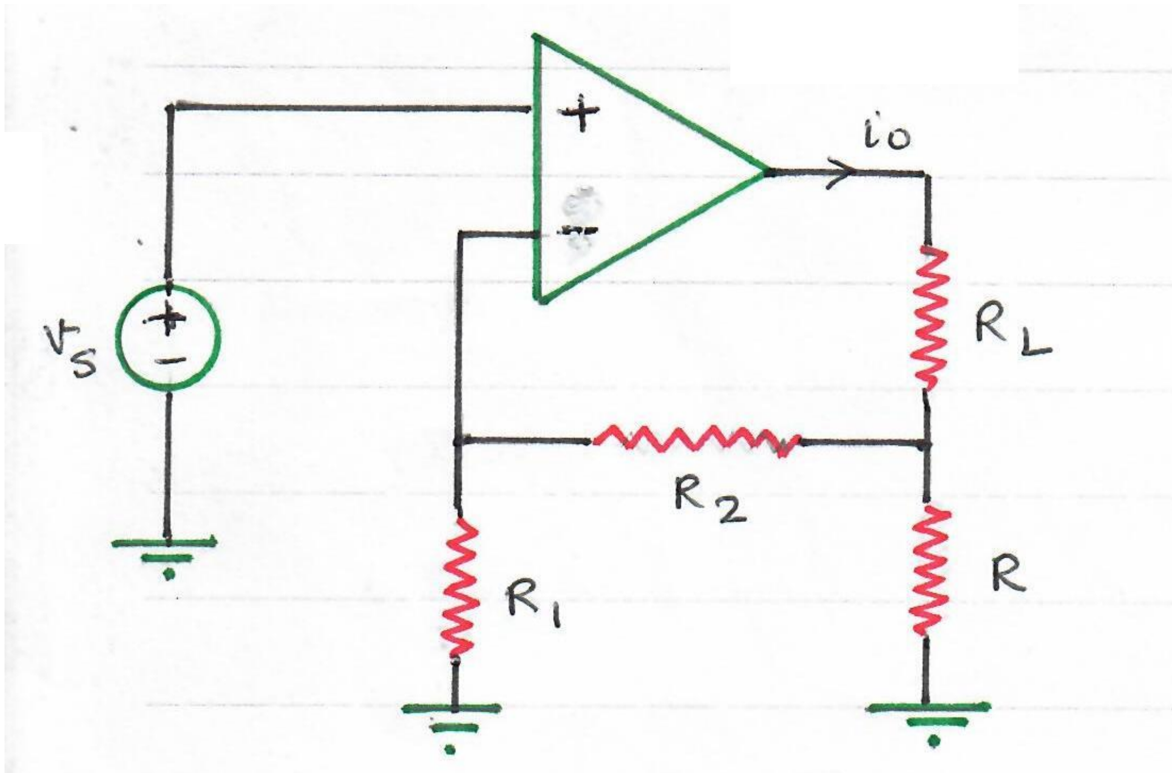
# Identify the Topology



# Identify the Topology



# Identify the Topology



# Identify the Topology