Lecture 6 – Feedback Amplifier Part I

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Outline of this Lecture

- Feedback Amplifier
- Types of Feedback Amplifiers
- Voltage Amplifier
- Transconductance Amplifier

Feedback Amplifier

Introduction

Amplifiers are usually classified into two groups: open-loop amplifiers and closed-loop (feedback) amplifiers

In amplifier design, feedback is usually applied to achieve one or more of the following goals:

- Make the value of the gain less sensitive to variations in the values of circuit components
- Extend the Bandwidth
- Modify the input and output resistances

Feedback Amplifier

Introduction

The basic idea of feedback is to **trade off** gain for other desirable properties.

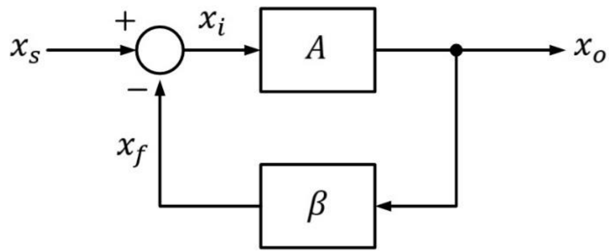
The most important parameter of any feedback amplifier is the **amount of feedback**.

The **amount of feedback** is factor by which the gain is reduced, by which the circuit is desensitized, by which the input resistance of a voltage amplifier is increased, by which the bandwidth is extended, and so on.

Feedback Amplifier

General Feedback Structure

The (−) sign at the bottom input of the summer makes the feedback a **negative** feedback.



The (+) sign at the bottom input of the summer makes the feedback a **positive** feedback.

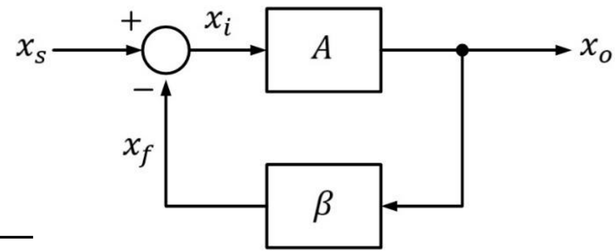
The gain A is the **open-loop gain** of the basic amplifier

The gain β is the **feedback factor**

Feedback Amplifier

General Feedback Structure

The quantities x can represent either a voltage or a current signal



x_s	Supplied signal
x_i	Input signal to the basic amplifier
x_o	Output signal
x_f	Feedback signal

$$x_o = Ax_i$$

$$x_f = \beta x_o$$

$$x_i = x_s - x_f$$

$$x_o/A = x_s - \beta x_o$$

$$x_o(1 + A\beta) = Ax_s$$

The main assumption in the general structure is that the gain A is **completely independent** on β

Feedback Amplifier

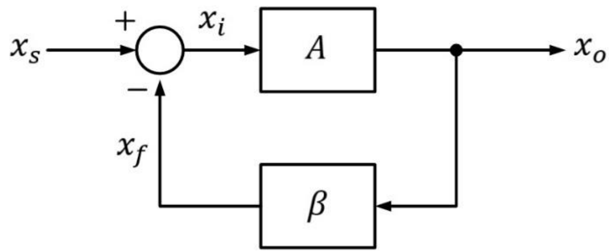
General Feedback Structure

The closed-loop gain of the feedback amplifier A_f, is given by

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

The quantity $A\beta$ is called the **loop gain**

The quantity $1 + A\beta$ is called the **amount of feedback**



$$x_o = Ax_i$$

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Feedback Amplifier

General Feedback Structure

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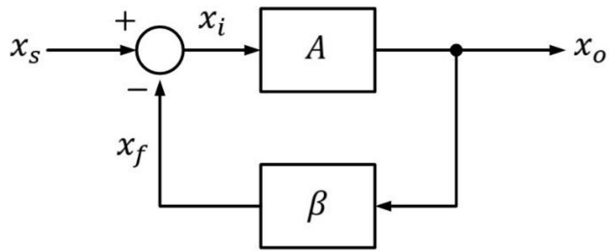


$$A_f = \frac{x_o}{x_i} = \frac{A}{1 + A\beta}$$

If $A\beta \gg 1$

$$A_f \simeq \frac{1}{\beta}$$

When the loop gain is large, the gain of the feedback amplifier is almost **independent** on A.

Feedback Amplifier

Properties of Negative Feedback

Gain Desensitivity

$$A_f = \frac{A}{1 + A\beta} \quad \rightarrow \quad \frac{dA_f}{dA} = \frac{(1)(1 + A\beta) - (\beta)(A)}{(1 + A\beta)^2}$$

$$= \frac{1}{(1 + A\beta)^2} = \frac{A_f / A}{1 + A\beta}$$

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

The percentage change in A_f is **smaller** than the percentage change in A by $1 + A\beta$.

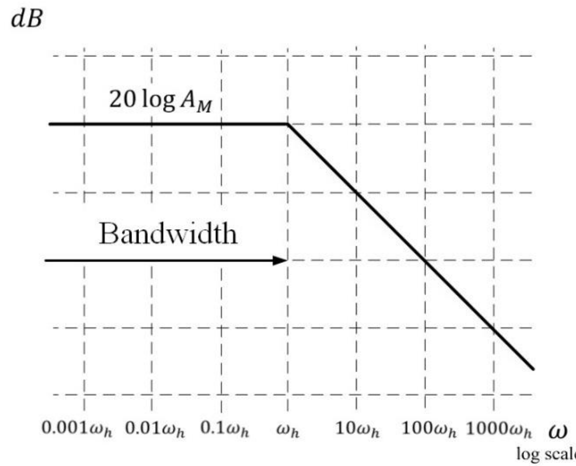
Feedback Amplifier

Properties of Negative Feedback

Bandwidth Extension

Consider an amplifier $A(s)$ whose high-frequency response is characterized by a single pole ω_h

$$A(s) = \frac{A_M}{1 + s/\omega_h}$$



$$BW = \omega_h$$

The bandwidth of the amplifier is defined as the range of the frequency in which the gain do not fall more than $3dB$ from its maximum value

Feedback Amplifier

Properties of Negative Feedback

Bandwidth Extension

Consider an amplifier $A(s)$ whose high-frequency response is characterized by a single pole ω_h

$$A(s) = \frac{A_M}{1 + s/\omega_h} \quad \rightarrow \quad A_f(s) = \frac{A(s)}{1 + \beta A(s)}$$

$$= \frac{A_M/(1 + s/\omega_h)}{1 + \beta\, A_M/(1 + s/\omega_h)}$$

$$= \frac{A_M}{1 + \beta A_M + s/\omega_h}$$

Feedback Amplifier

Properties of Negative Feedback

Bandwidth Extension

Consider an amplifier $A(s)$ whose high-frequency response is characterized by a single pole ω_h

$$A(s) = \frac{A_M}{1 + s/\omega_h} \quad \rightarrow \quad A_f(s) = \frac{A_M/(1 + \beta A_M)}{1 + s/[\omega_h(1 + \beta A_M)]}$$

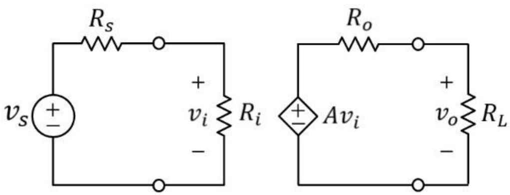
The bandwidth is **increased** by a factor equal to $1 + \beta A_M$ while the midband gain is **decreased** by the same factor

The Gain-Bandwidth product of a single pole amplifier **remains** constant

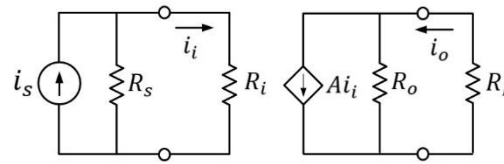
Feedback Amplifier

Amplifier Types

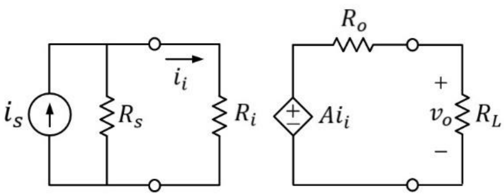
Based on the input signal to be amplified and on the desired form of output signal, amplifiers are classified into four categories:



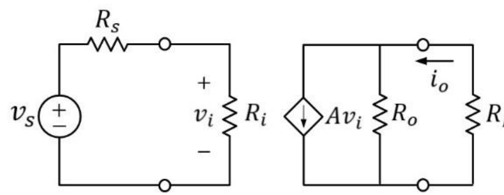
Voltage amplifier



Current amplifier



Transresistance amplifier



Transconductance amplifier

Feedback Amplifier

Feedback Amplifier Types

Based on the input signal to be amplified and on the desired form of output signal, amplifiers are classified into four categories:

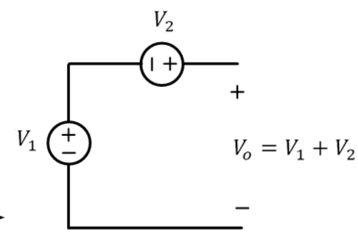
Amplifier Type	Input signal x_s, x_i, x_f	Output signal x_o
Voltage Amplifier	Voltage	Voltage
Current Amplifier	Current	Current
Transconductance Amplifier	Voltage	Current
Transresistance Amplifier	Current	Voltage

Feedback Amplifier

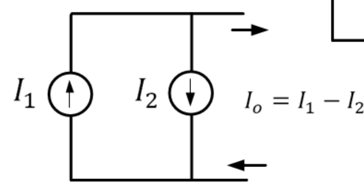
Feedback Amplifier Types

Sampling and Mixing

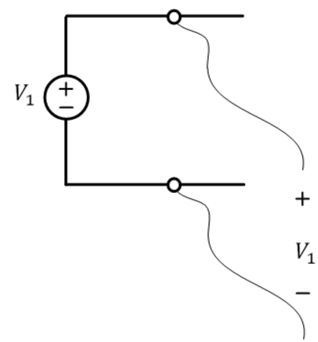
Voltage signals are added or subtracted (mixed) in **series** fashion



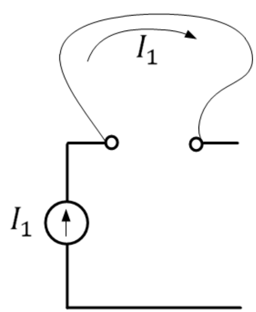
Current signals are mixed in **parallel (shunt)** fashion



Voltage is sampled in a **parallel (shunt)** fashion



Current is sampled in a **series** fashion

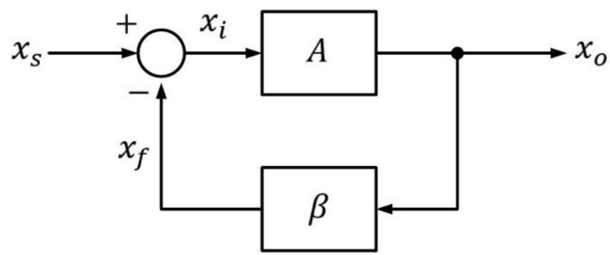


Feedback Amplifier

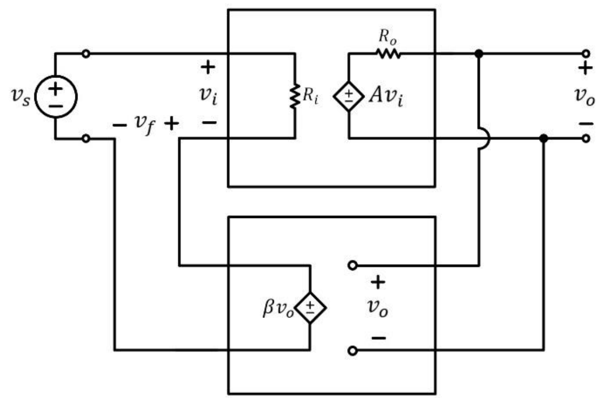
Feedback Amplifier Types

Voltage Amplifier

x_i, x_f and x_o, are voltage signals



The subtraction is done in series fashion and the sampling is done in shunt fashion



This feedback Topology is called **Series-Shunt** feedback

Feedback Amplifier

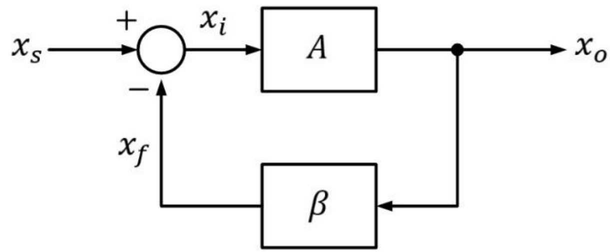
Feedback Amplifier Types

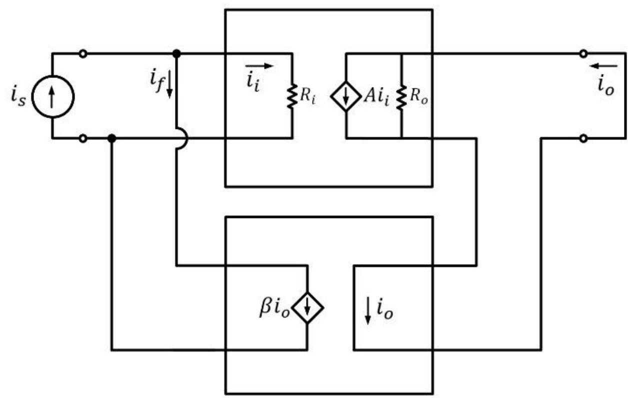
Current Amplifier

x_i, x_f and x_o, are current signals

The subtraction is done in shunt fashion and the sampling is done in series fashion

This feedback Topology is called **Shunt-Series** feedback

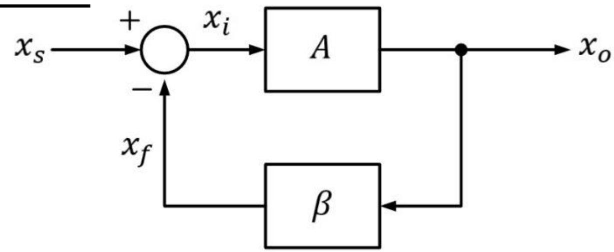




Feedback Amplifier

Feedback Amplifier Types

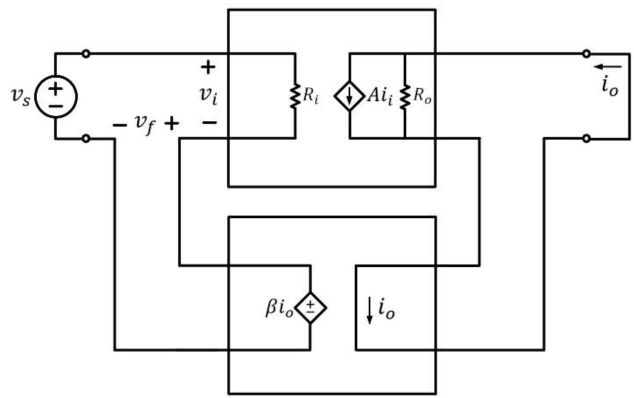
Transconductance Amplifier



x_i, and x_f are voltage signals while x_o is current signal

The subtraction is done in series fashion and the sampling is done in series fashion

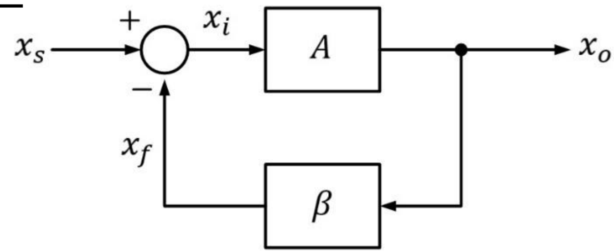
This feedback Topology is called **Series-Series** feedback



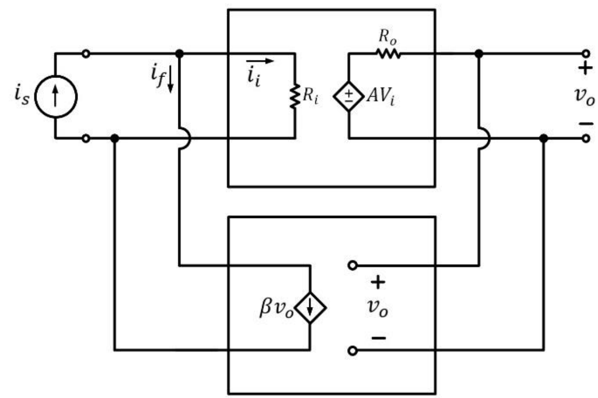
Feedback Amplifier

Feedback Amplifier Types

Transresistance Amplifier



x_i, and x_f are current signals while x_o is voltage signal

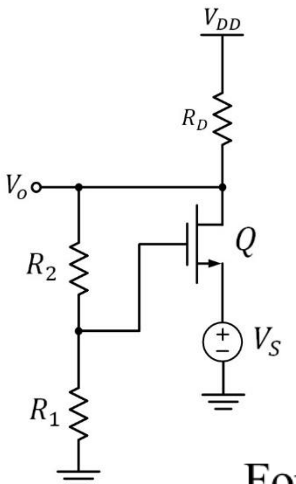


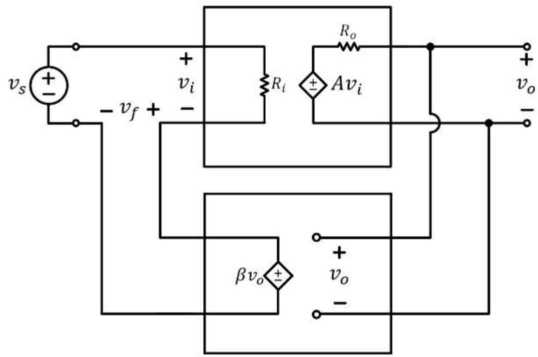
The subtraction is done in shunt fashion and the sampling is done in shunt fashion

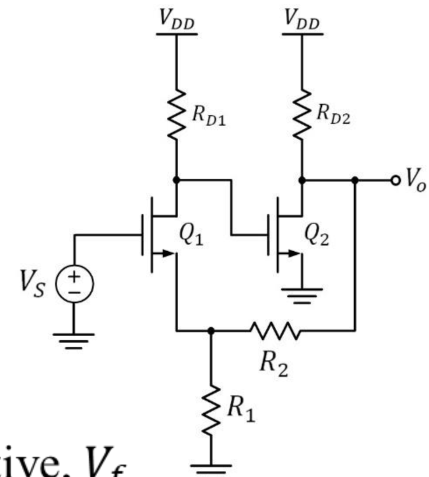
This feedback Topology is called **Shunt-Shunt** feedback

Voltage Amplifier

Series-Shunt Feedback Topology







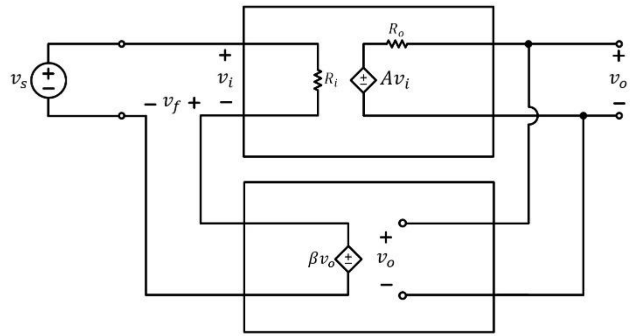
For the feedback to be negative, V_f must be of the **same** polarity as V_s

Voltage Amplifier

Series-Shunt Feedback Topology

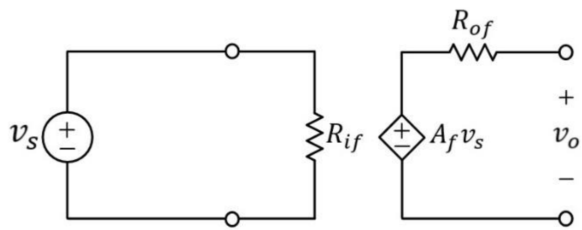
The Ideal Case

In the ideal case, the feedback network has an **infinite** input resistance and **zero** output resistance



The feedback network **does not** load the basic amplifier

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



Voltage Amplifier

Series-Shunt Feedback Topology

The Ideal Case

$$v_f = \beta v_o = A\beta v_i$$

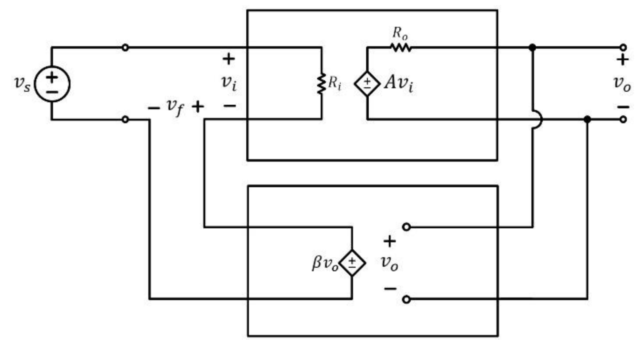
$$v_i = v_s - v_f$$

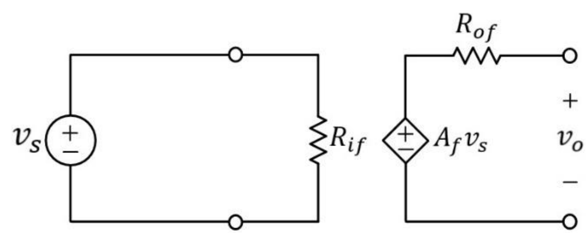
$$v_i = v_s - A\beta v_i$$

$$v_s = v_i(1 + A\beta)$$

$$\frac{v_s}{i_i} = \frac{v_i}{i_i}(1 + A\beta)$$

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





Voltage Amplifier

Series-Shunt Feedback Topology

The Ideal Case

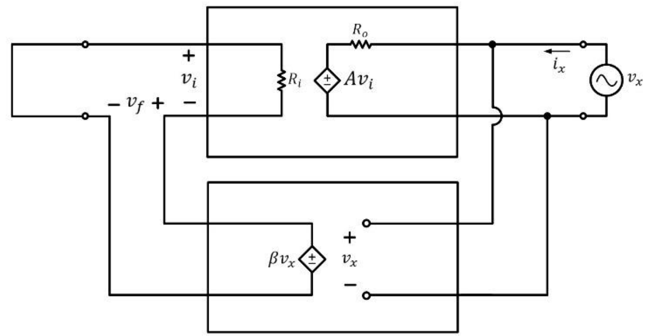
$$i_x = \frac{v_x - Av_i}{R_o}$$

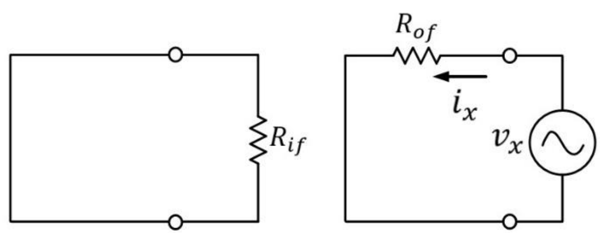
$$v_f = \beta v_x$$

$$v_i = -v_f = -\beta v_x$$

$$i_x = \frac{v_x + A\beta v_x}{R_o} = \frac{v_x(1 + A\beta)}{R_o}$$

$$R_{of} = \frac{v_x}{i_x} = \frac{R_o}{1 + A\beta}$$





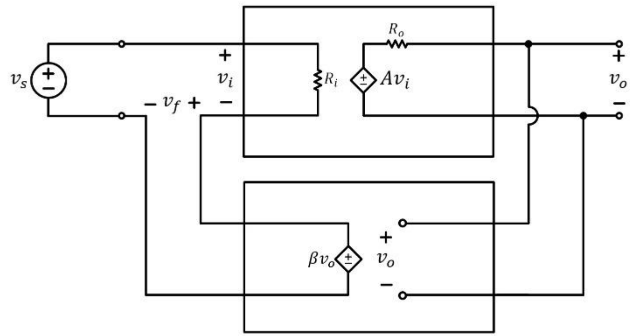
Voltage Amplifier

Series-Shunt Feedback Topology

The Ideal Case

The series-mixing results in an increase in the input resistance by a factor $1 + A\beta$

The shunt sampling at the output results in a decrease in the amplifier output resistance by $1 + A\beta$



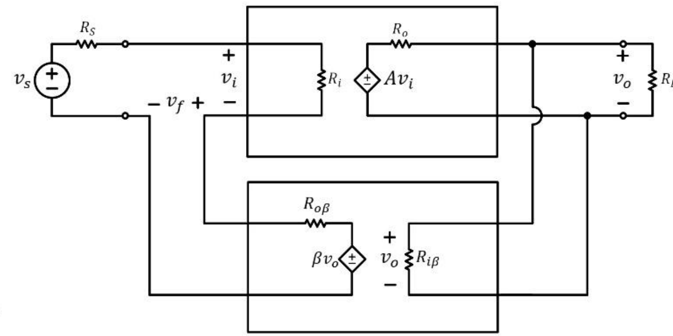
Series connection **always increases** the resistance while parallel (shunt) connection **always decreases** the resistance.

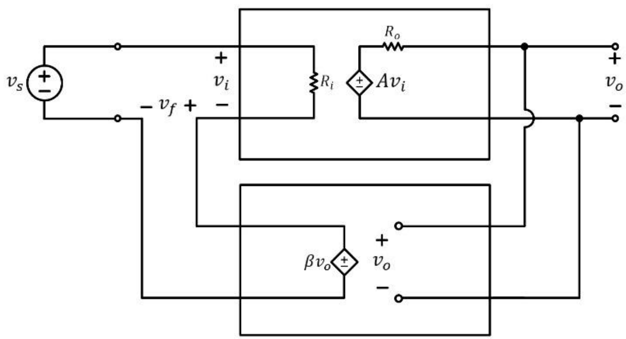
Voltage Amplifier

Series-Shunt Feedback Topology

The Practical Case

In the practical case, the feedback network loads the basic amplifier and affects the values of A, R_i, and R_o.





The finite source and load resistances also affect the values of A, R_i, and R_o.

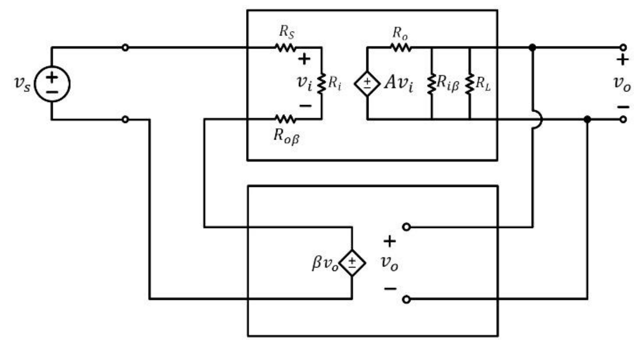
Voltage Amplifier

Series-Shunt Feedback Topology

The Practical Case

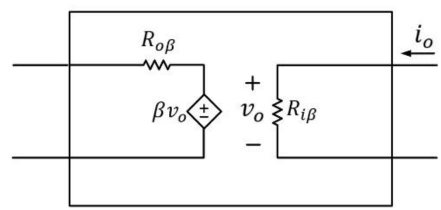
The gain of the feedback network is given by

$$\beta = \left.\frac{v_f}{v_o}\right|_{i_f=0}$$



The input resistance of the feedback network is given by

$$R_{i\beta} = \left.\frac{v_o}{i_o}\right|_{i_f=0}$$



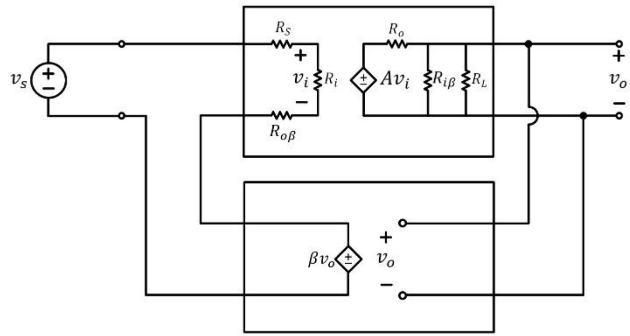
Voltage Amplifier

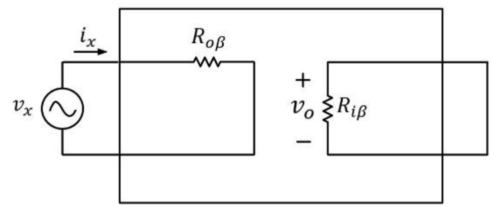
Series-Shunt Feedback Topology

The Practical Case

The output resistance of the feedback network is given by

$$R_{o\beta} = \frac{v_x}{i_x}\bigg|_{v_o=0}$$





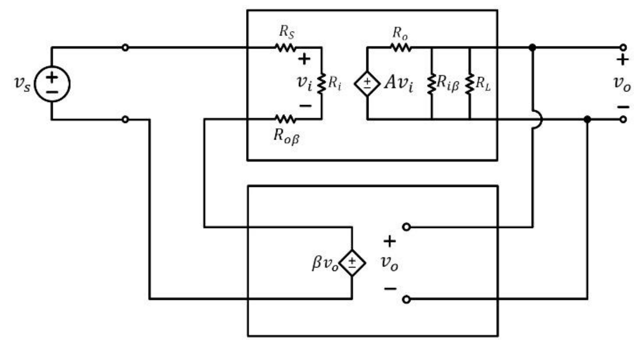
Voltage Amplifier

Series-Shunt Feedback Topology

The Practical Case

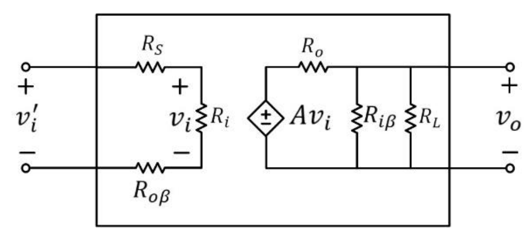
The gain of the modified basic amplifier is given by

$$A_m = \frac{v_o}{v_i'}$$



R_{im} and R_{om} are determined from the modified basic amplifier circuit

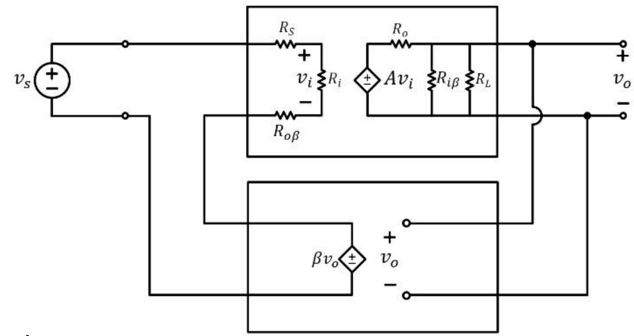
$$R_{im} = \left.\frac{v_i'}{i_i}\right|_{i_o=0} \qquad R_{om} = \left.\frac{v_o}{i_o}\right|_{v_i'=0}$$



Voltage Amplifier

Series-Shunt Feedback Topology

The Practical Case



The overall gain of the feedback amplifier is given by

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

The input resistance with feedback is given by

$$R_{if} = R_{im}(1 + A_m\beta)$$

The output resistance with feedback is given by

$$R_{of} = \frac{R_{om}}{1 + A_m\beta}$$

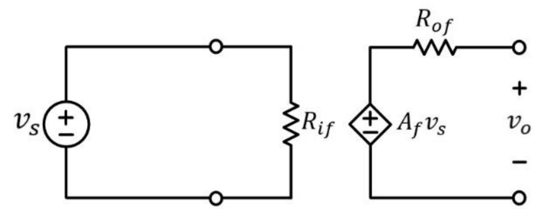
Voltage Amplifier

Series-Shunt Feedback Topology

The Practical Case

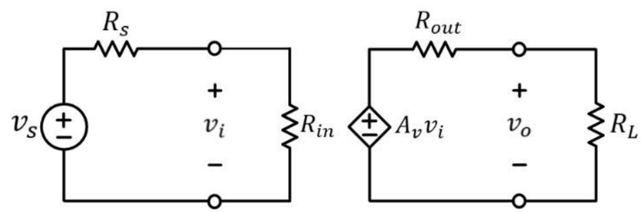
The actual input resistance of the feedback amplifier is given by

$$R_{in} = R_{if} - R_s$$



The actual output resistance of the feedback amplifier is given by

$$R_{out} = 1\Big/\left(\frac{1}{R_{of}} - \frac{1}{R_L}\right)$$



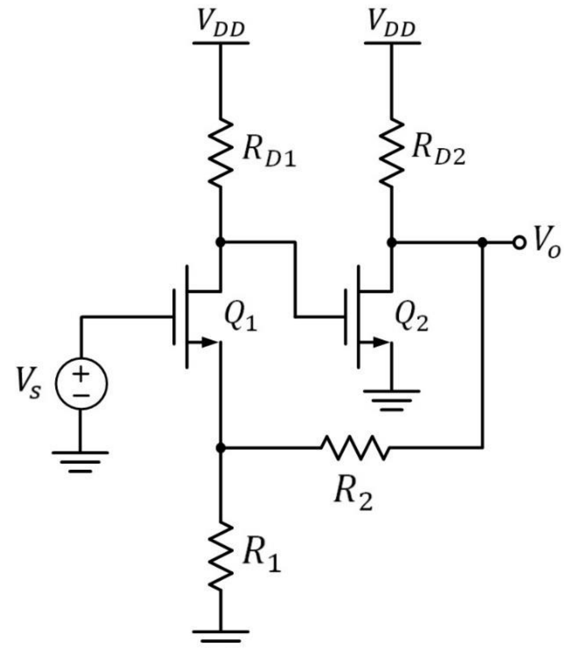
$$R_{of} = R_{out} // R_L$$

Voltage Amplifier

Example (1)

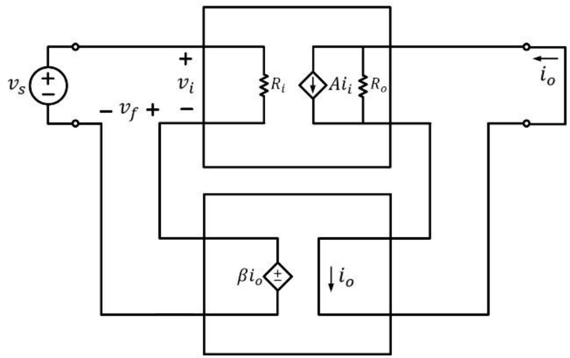
Analyze the shown amplifier obtain its voltage gain, input resistance, and output resistance.

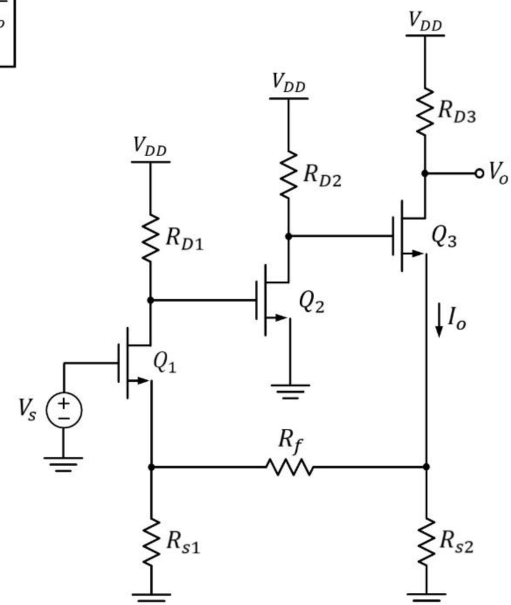
$g_{m1} = g_{m2} = 4mA/V$,
$R_{D1} = R_{D2} = 10K\Omega$,
$R_1 = 1K\Omega, R_2 = 9K\Omega$.
Neglect r_o for Q_1 and Q_2



Transconductance Amplifier

Series-Series Feedback Topology





For the feedback to be negative, v_f must be of the **same** polarity as v_s

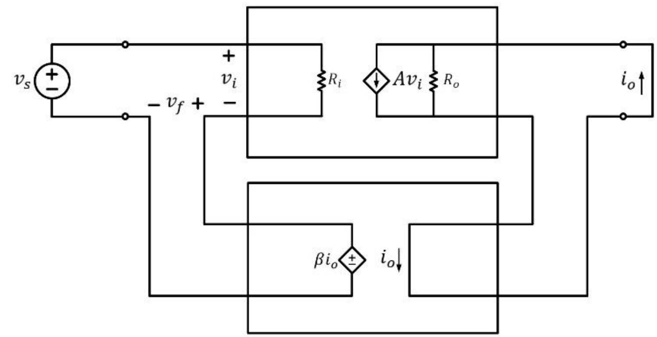
Transconductance Amplifier

Series-Series Feedback Topology

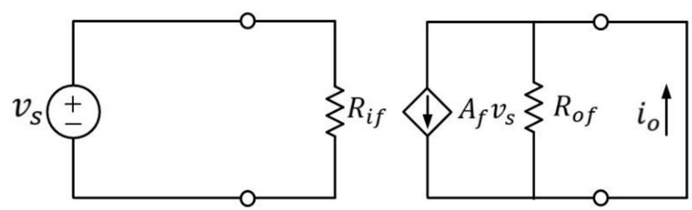
The Ideal Case

In the ideal case, the feedback network has an **zero** input resistance and **zero** output resistance

The feedback network **does not** load the basic amplifier



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



Transconductance Amplifier

Series-Series Feedback Topology

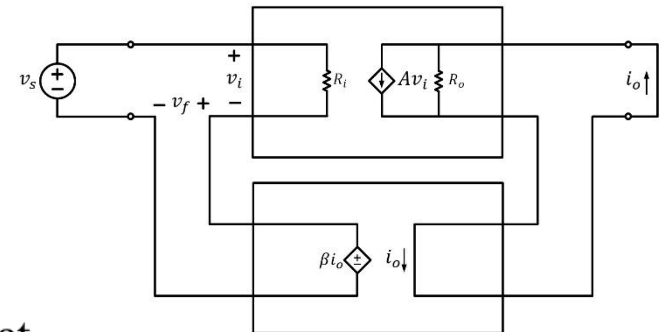
The Ideal Case

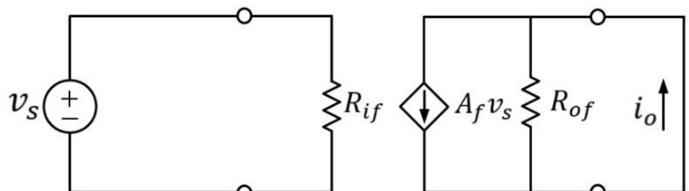
Due to the series connection at the input, the input resistance is given by

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

Due to the series connection at the output, the output resistanc is given by

$$R_{of} = R_o(1 + A\beta)$$



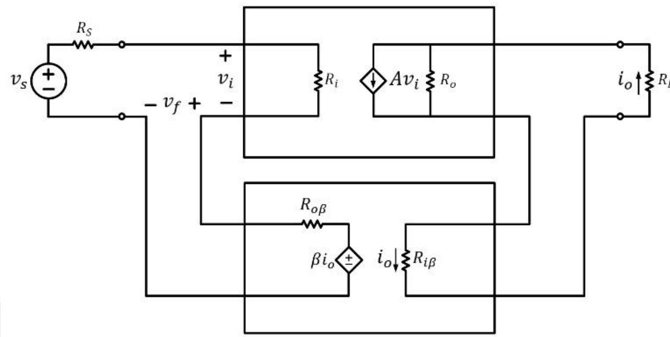


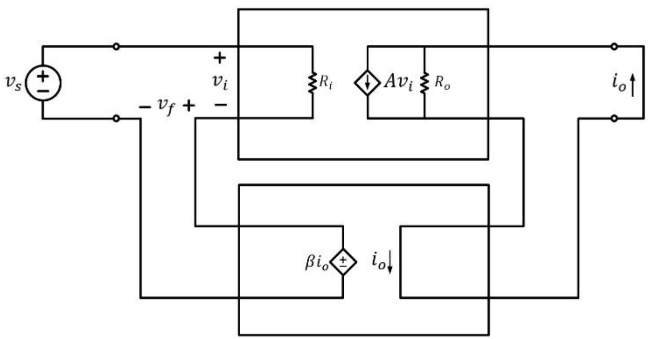
Transconductance Amplifier

Series-Series Feedback Topology

The Practical Case

In the practical case, the feedback network loads the basic amplifier and affects the values of A, R_i, and R_o.





The finite source and load resistances also affect the values of A, R_i, and R_o.

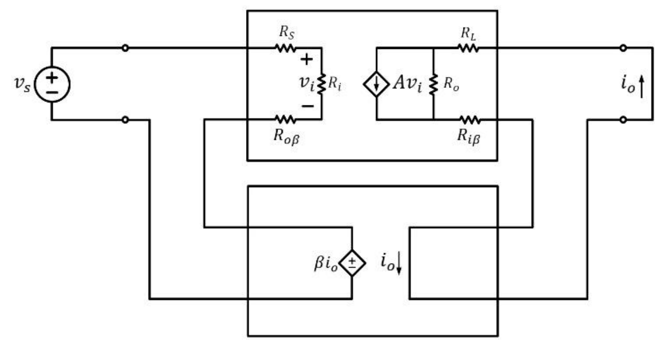
Transconductance Amplifier

Series-Series Feedback Topology

The Practical Case

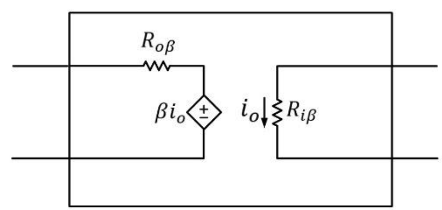
The gain of the feedback network is given by

$$\beta = \left.\frac{v_f}{i_o}\right|_{i_f=0}$$



The input resistance of the feedback network is given by

$$R_{i\beta} = \left.\frac{v_o}{i_o}\right|_{i_f=0}$$



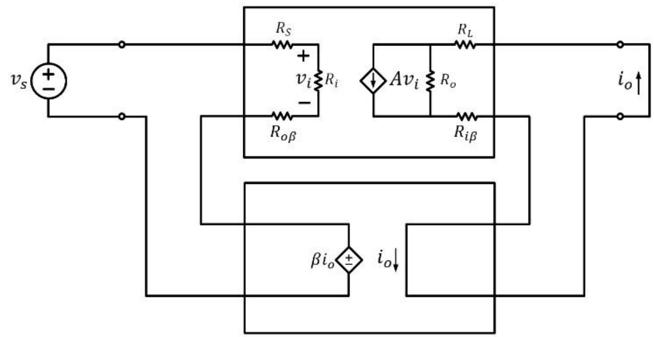
Transconductance Amplifier

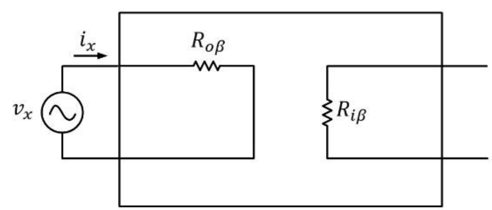
Series-Series Feedback Topology

The Practical Case

The output resistance of the feedback network is given by

$$R_{o\beta} = \left.\frac{v_x}{i_f}\right|_{i_o=0}$$





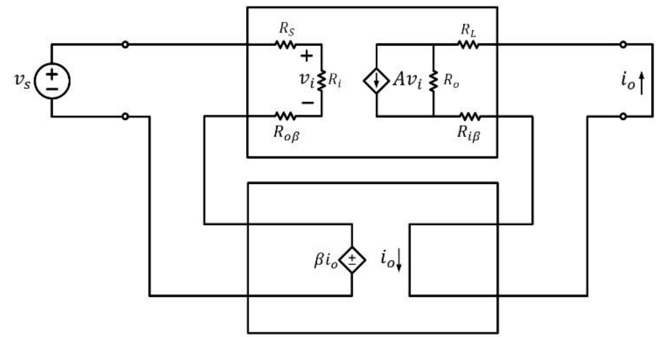
Transconductance Amplifier

Series-Series Feedback Topology

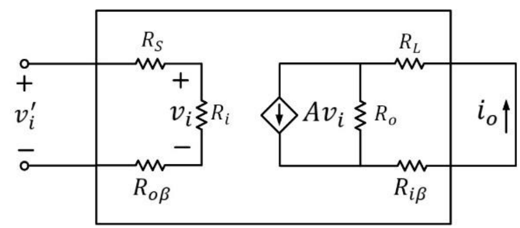
The Practical Case

The gain of the modified basic amplifier is given by

$$A_m = \frac{i_o}{v_i'}$$



R_{im} and R_{om} are determined from the modified basic amplifier circuit

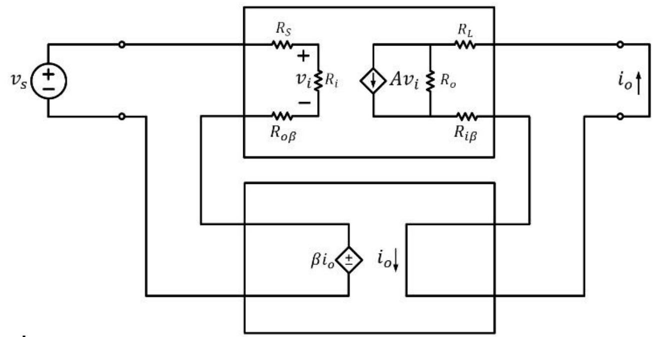


$$R_{im} = \frac{v_i'}{i_i} \qquad R_{om} = \left.\frac{v_o}{i_o}\right|_{v_i'=0}$$

Transconductance Amplifier

Series-Series Feedback Topology

The Practical Case



The overall gain of the feedback amplifier is given by

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

The input resistance with feedback is given by

$$R_{if} = R_{im}(1 + A_m\beta)$$

The output resistance with feedback is given by

$$R_{of} = R_{om}(1 + A_m\beta)$$

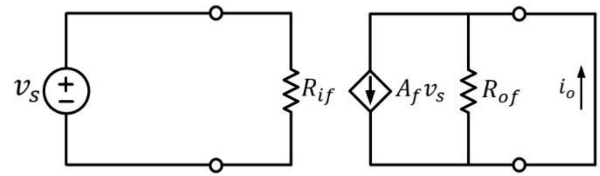
Transconductance Amplifier

Series-Series Feedback Topology

The Practical Case

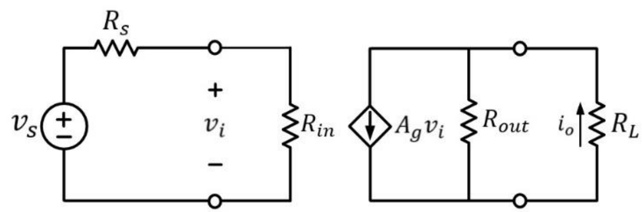
The actual input resistance of the feedback amplifier is given by

$$R_{in} = R_{if} - R_s$$



The actual output resistance of the feedback amplifier is given by

$$R_{out} = R_{of} - R_L$$



$$R_{of} = R_{out} + R_L$$

Transconductance Amplifier

Example (2)

Analyze the shown amplifier obtain its voltage gain, input resistance, and output resistance.