



NPTEL ONLINE CERTIFICATION COURSES

Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Feedback system

Flow of Discussion (Bottom-up)

– Modules

- **System / Sub-systems** (*for specific application*)
 - **Modules** (*performing specific tasks*)
 - **Building blocks** (*having specific characteristics*) - **Bias circuits**
 - **Components** (*devices/circuit elements*)
- **Week 10 (Course Module 9):**
 - **Feedback System: Basic feedback theory**
 - **Four different feedback configurations and their characteristics**
 - **Effects of feedback on frequency response of an amplifier**
 - **Application of feedback in practical circuits**



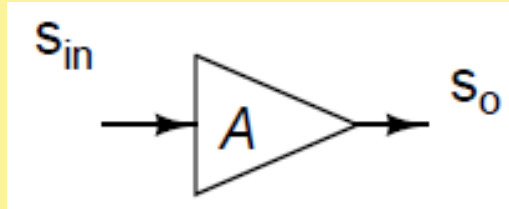
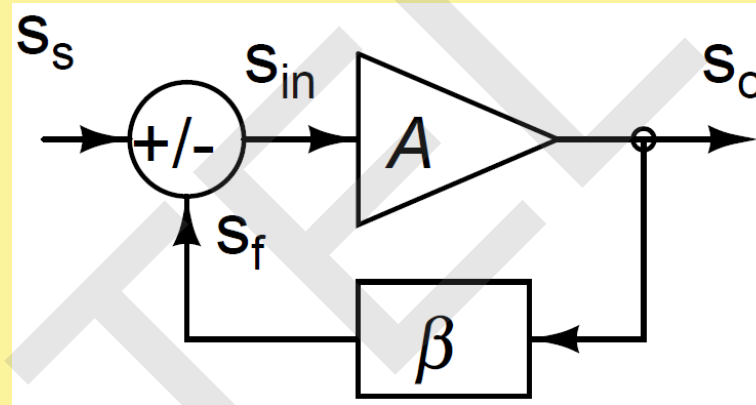
CONCEPTS COVERED

Concepts Covered:

- ☐ Basic concepts of a feedback system
- ☐ Basic types of feedback systems
- ☐ Transfer characteristic of a feedback system
- ☐ Four basic configurations of feedback systems

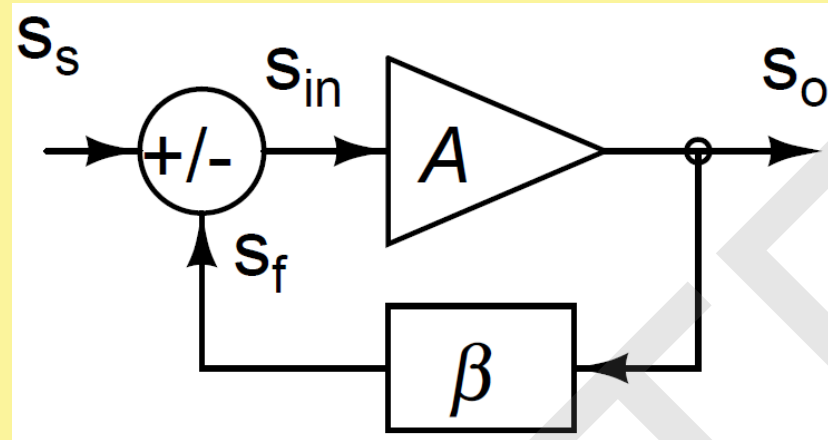


Feedback system: *Basic concepts*



- **Basic model of feedback system consists of**
 - **Forward amplifier**
 - **Feedback path/network**
 - **Signal sampler**
 - **Signal mixer**

Feedback system: *Basic concepts (contd.)*



Types of feedback - **negative** and **positive** :

For a change at a point in the system/circuit if the created effect coming back to the point through the feedback path **negate the original change** then the feedback system is called negative feedback system.

For a change at a point in the system/circuit, if the created effect coming back to the point through the feedback path **aggravate the original change** then the feedback system is called positive feedback system.

Examples of *positive* and *negative* F.B. system

Situation I:

$$S_{in} = S_s + S_f, A > 0 \text{ and } \beta > 0$$

Situation II:

$$S_{in} = S_s + S_f, A < 0 \text{ and } \beta > 0$$

Situation III:

$$S_{in} = S_s - S_f, A > 0 \text{ and } \beta > 0$$

Situation IV:

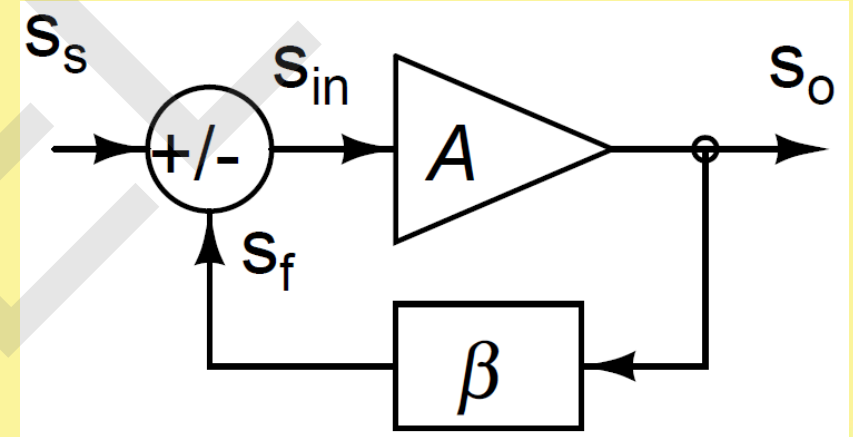
$$S_{in} = S_s - S_f, A < 0 \text{ and } \beta > 0$$

Situation V:

$$S_{in} = -S_s + S_f, A < 0 \text{ and } \beta > 0$$

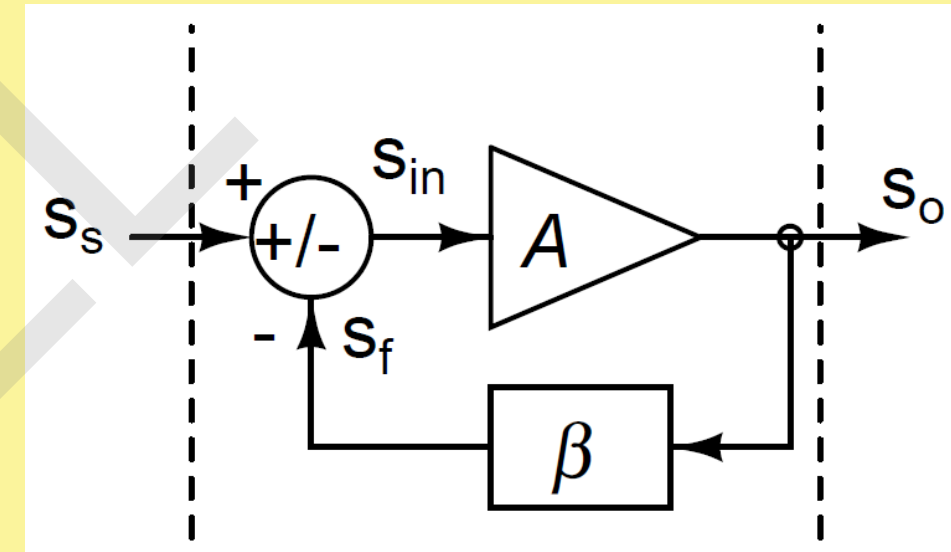
Situation VI:

$$S_{in} = -S_s - S_f, A > 0 \text{ and } \beta > 0$$



Transfer characteristic of a F.B. system

- Input-to-output transfer characteristic / Primary input-to-primary output gain of the F.B. system
- **Loop Gain of the feedback system**
- De-sensitivity factor of a negative feedback system



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

$$L.G. = -\beta \cdot A$$

$$D = (1 + \beta \cdot A)$$



More about model of negative F.B. system

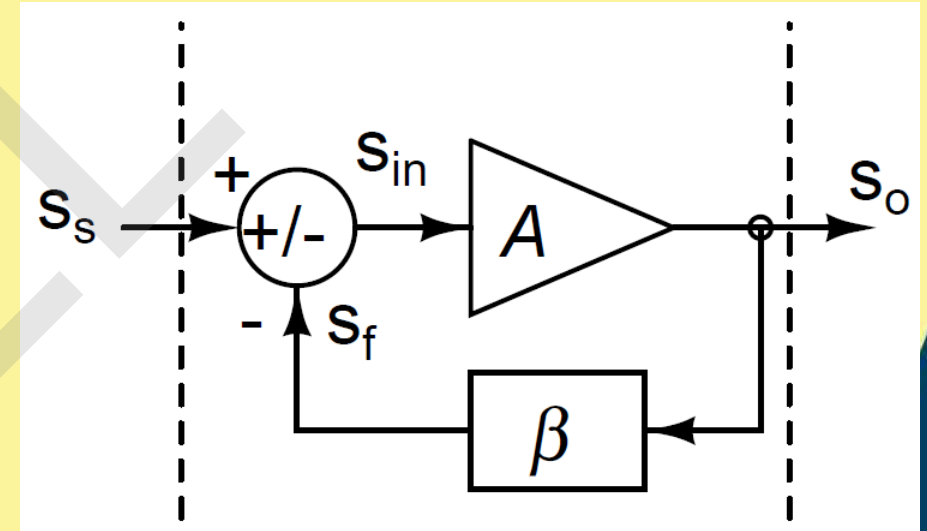
Applicability of the model:

- It is valid for time domain analysis
- It is valid for frequency domain analysis

Cautions on assumption :

- Forward amplifier and feedback path are unidirectional
- Loading effects are ignorable or, considered in the transfer functions of forward amplifier and the

$$A_f = \frac{A'}{(1 + \beta'.A')} \quad L.G. = -\beta'.A' \quad D = (1 + \beta'.A')$$

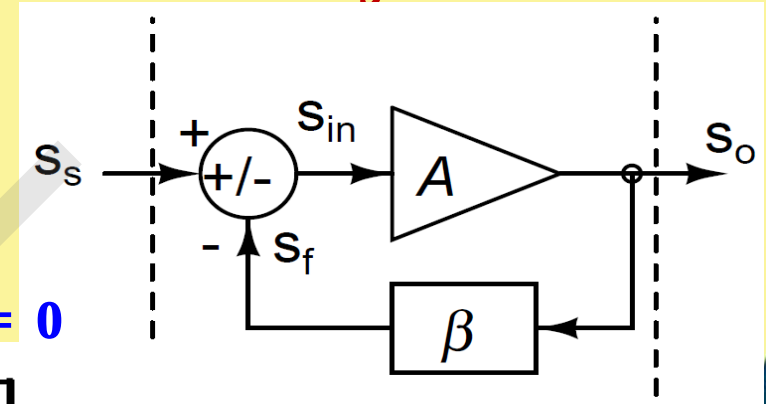
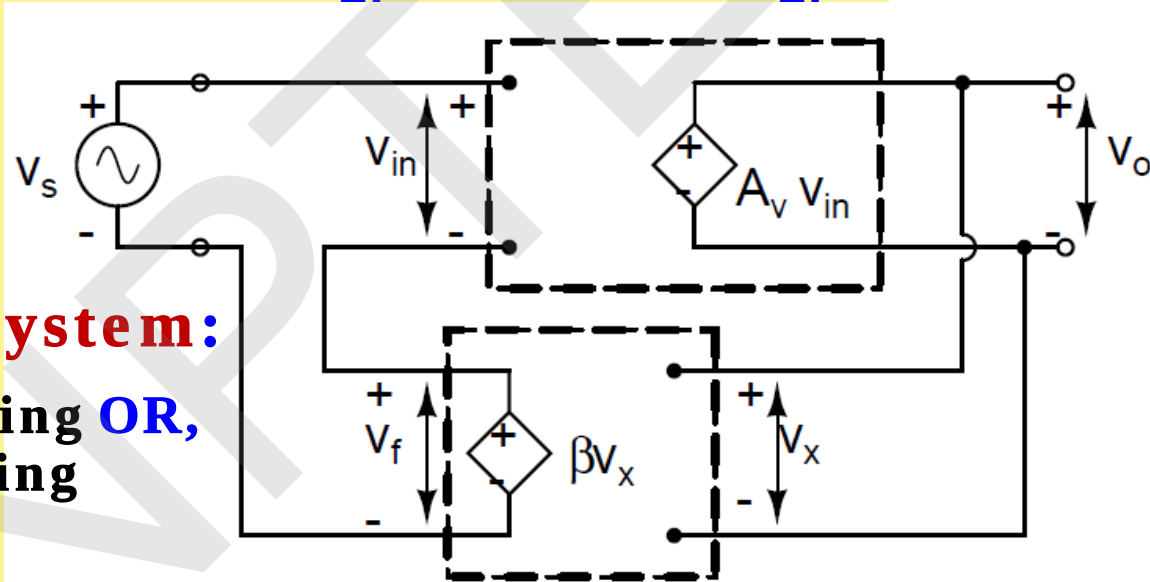


Kinds of signals *we consider* at the input and output ports are voltage or current *leading to four basic configurations*

Four Basic configurations of negative F.B. systems

Case I: Both, Input and output signals are voltages:

- Voltage sampler (at the output port) is a parallel sampler
- Voltage mixer (at the input port) is a series mixer
- Ideal model has, $R_{in} \rightarrow \infty$, $R_{out} = 0$ $R_{in}\beta \rightarrow \infty$ and $R_{out}\beta = 0$



Naming of this feedback system:

Voltage sampling–Voltage mixing **OR**,
Shunt sampling–Series mixing

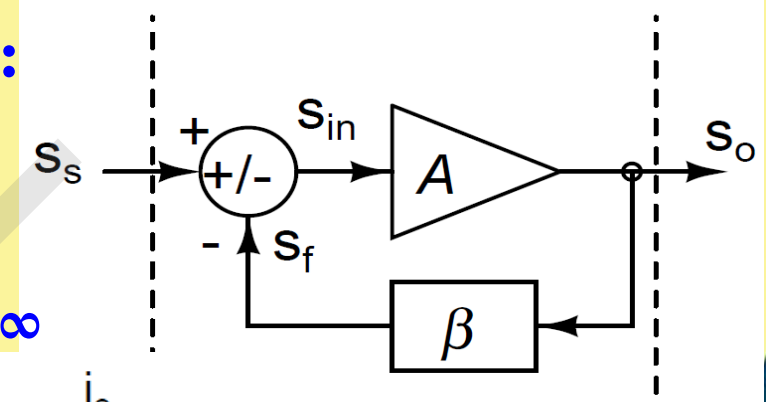
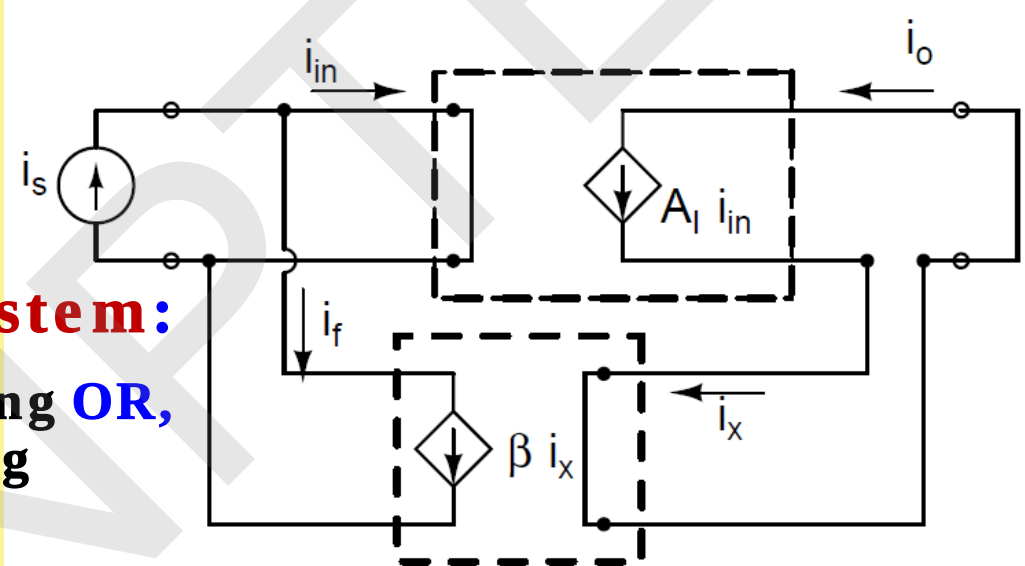
Alternately, Shunt-Series **OR**,
Voltage-Series feedback system



Four Basic configurations of negative F.B. systems (*contd.*)

Case II: Both, Input and output signals are currents:

- Current sampler (at the output port) is a series sampler
- Current mixer (at the input port) is a parallel mixer
- Ideal model has, $R_{in} = 0$, $R_{out} \rightarrow \infty$, $R_{in_\beta} = 0$ and $R_{out_\beta} \rightarrow \infty$



Naming of this feedback system:

Current sampling–Current mixing **OR**,
Series sampling–Shunt mixing

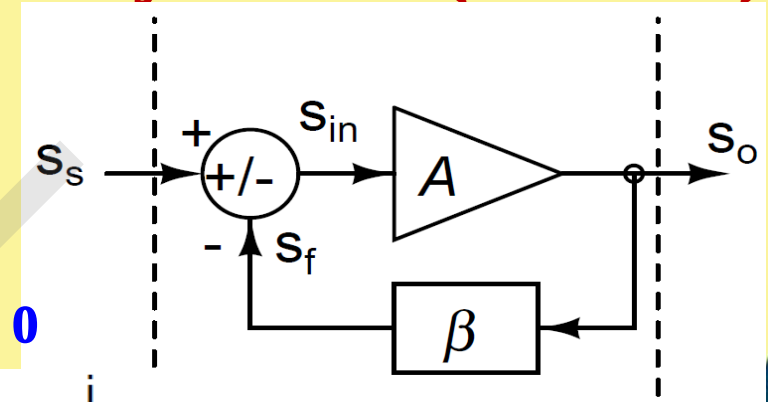
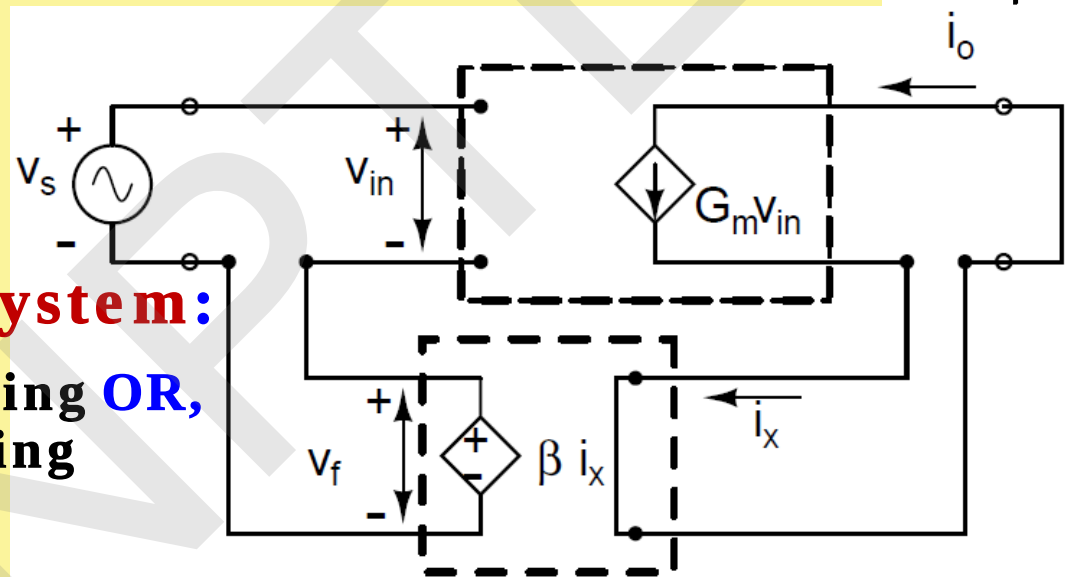
Alternately, Series –Shunt **OR**,
Current-Shunt feedback system



Four Basic configurations of negative F.B. systems (*contd.*)

Case III: Input is voltage and output is current :

- Current sampler (at the output port) is a series sampler
- Voltage mixer (at the input port) is a series mixer
- Ideal model has, $R_{in} \rightarrow \infty$, $R_{out} \rightarrow \infty$, $R_{in_\beta} = 0$ and $R_{out_\beta} = 0$



Naming of this feedback system:

Current sampling–Voltage mixing **OR**,
Series sampling–Series mixing

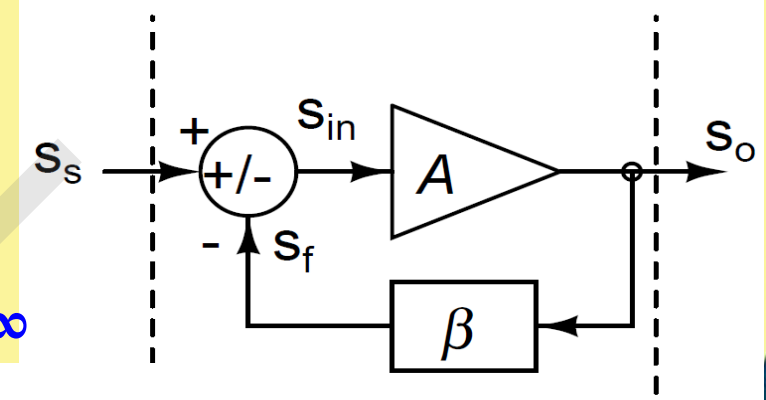
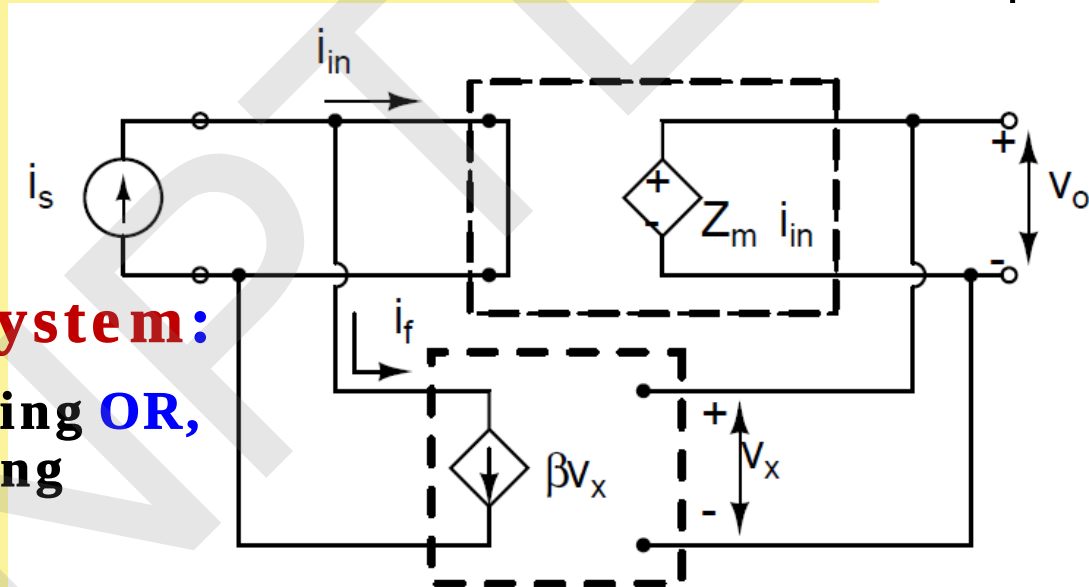
Alternately, Series –Series **OR**,
Current-Series feedback system



Four Basic configurations of negative F.B. systems (*contd.*)

Case IV: Input is current and output is voltage:

- Voltage sampler (at the output port) is a parallel sampler
- Current mixer (at the input port) is a parallel mixer
- Ideal model has, $R_{in} = 0$, $R_{out} = 0$, $R_{in_\beta} \rightarrow \infty$ and $R_{out_\beta} \rightarrow \infty$



Naming of this feedback system:

Voltage sampling–Current mixing **OR**,
Shunt sampling–Shunt mixing

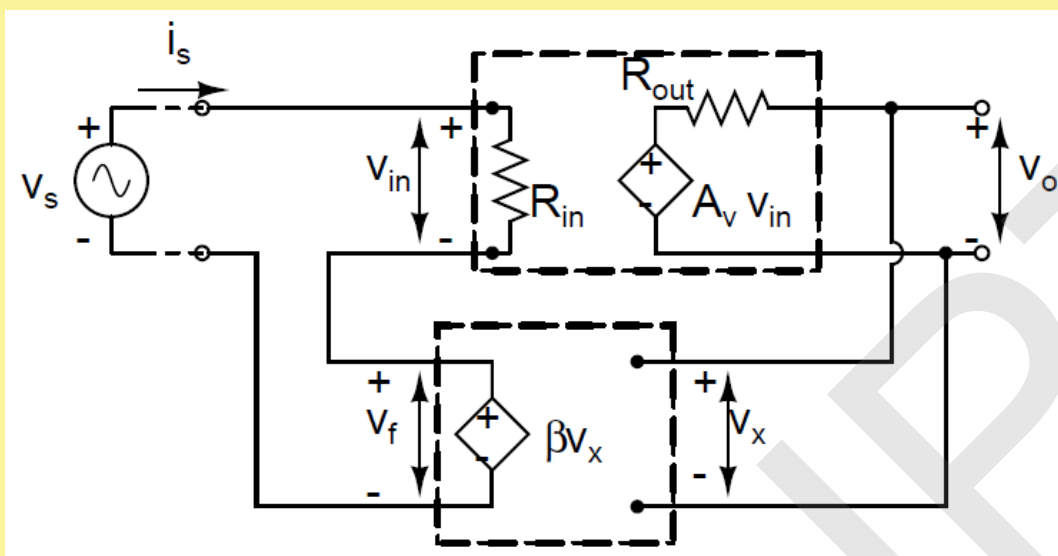
Alternately, Shunt –Shunt **OR**,
Voltage-Shunt feedback system



Change in input Resistance of a voltage amp. due to Feedback

Shunt-Series / Voltage-Series feedback system

With Ideal feedback network ($R_{in_f} \rightarrow \infty$ and $R_{out_f} = 0$): $R_{in_f} = R_{in} \cdot (1 + \beta \cdot A_V)$



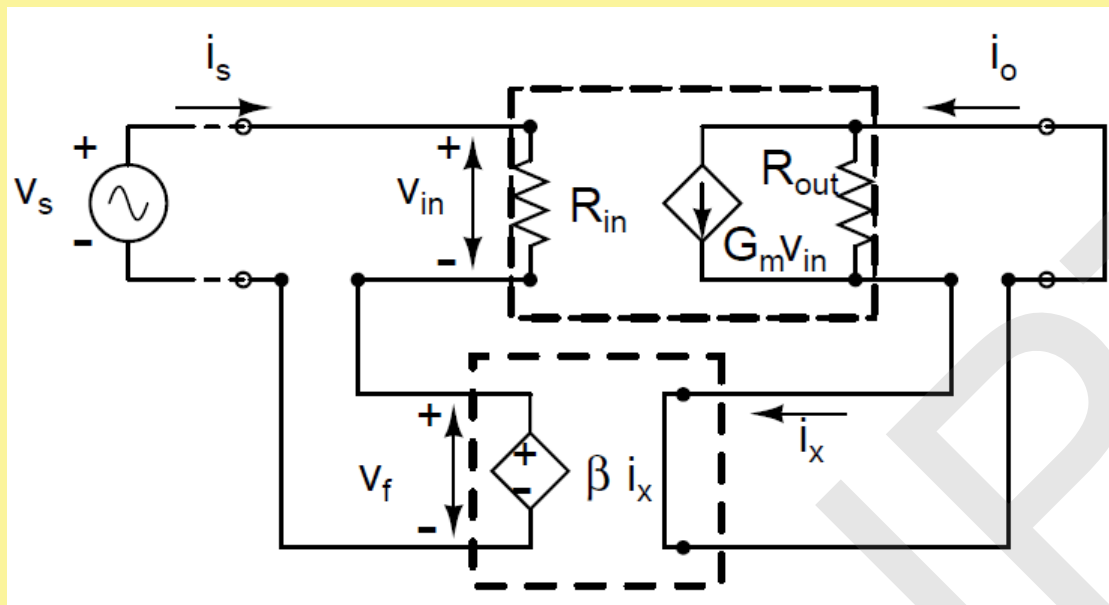
$$R_{in_f} = R_{in} \cdot (1 + \beta \cdot A'_V)$$

$$R_{in_f} = R_{in} \cdot (1 + \beta \cdot A''_V) + R_{out_f}$$

Change in input Resistance of a Trans-conductance amp. due to F.B.

Series-Series / Current-Series feedback system

With Ideal feedback network ($R_{in_f} = 0$ and $R_{out_f} = 0$): $R_{in_f} = R_{in} \cdot (1 + \beta \cdot G_m)$



$$R_{in_f} = R_{in} \cdot (1 + \beta \cdot G'_m)$$

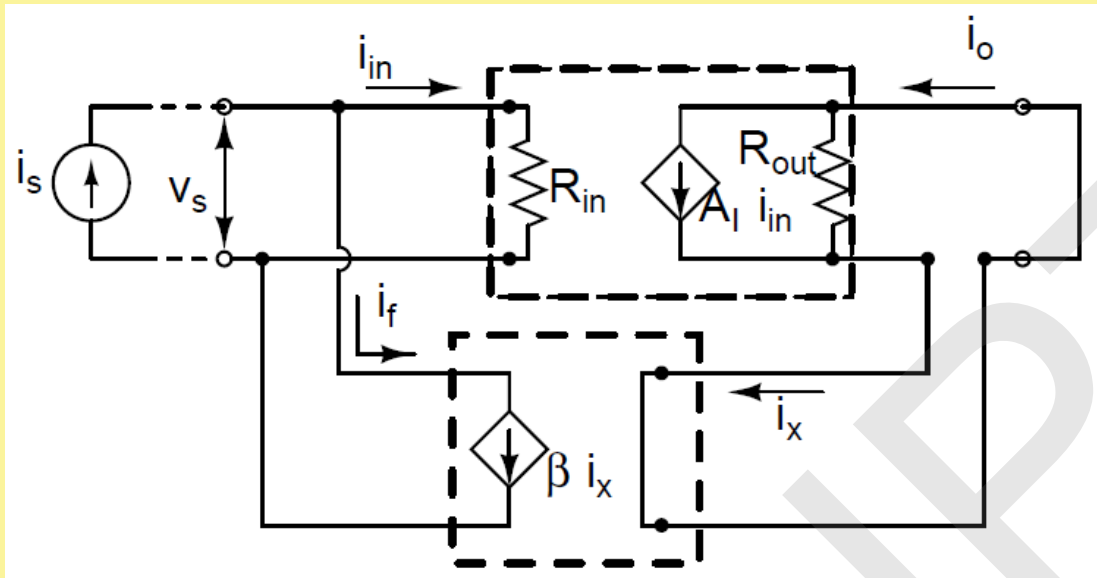
$$R_{in_f} = R_{in} \cdot (1 + \beta \cdot G''_m) + R_{out_f}$$

Change in input Resistance of a current amp. due to F.B.

Series-Shunt/ Current-Shunt feedback system

With Ideal feedback network ($R_{in_f} = 0$ and $R_{out_f} \rightarrow \infty$):

$$R_{in_f} = \frac{R_{in}}{(1 + \beta \cdot A_I)}$$

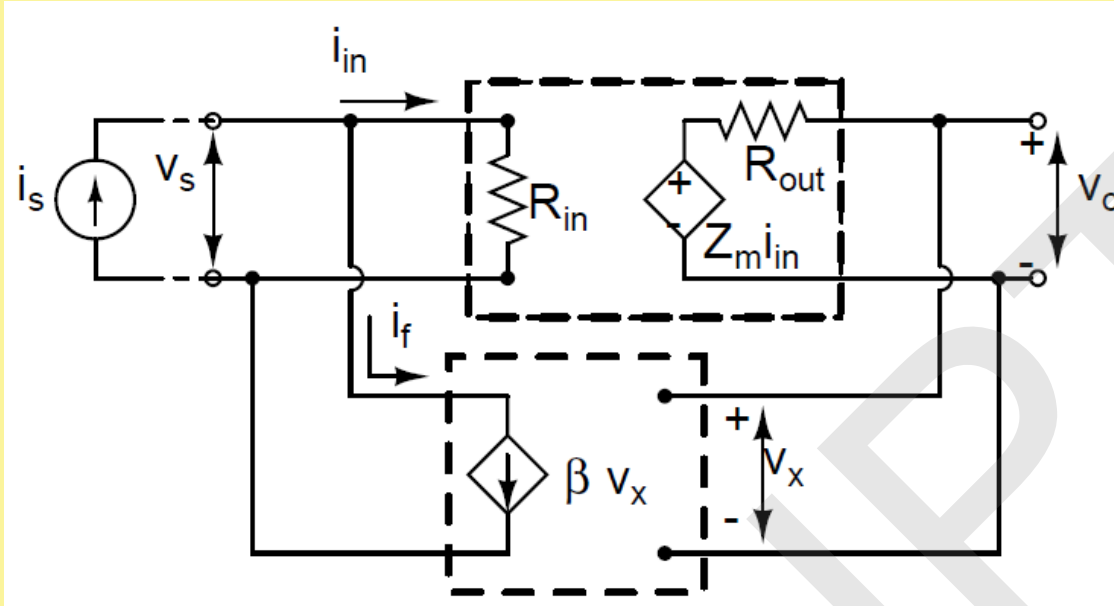


$$R_{in_f} = \frac{R_{in}}{(1 + \beta \cdot A'_I)}$$

$$R_{in_f} = \frac{R_{in}}{(1 + \beta \cdot A''_I)} \parallel R_{out_f}$$

Change in input Resistance of a Trans-impedance amp. due to F.B. Shunt-Shunt/ Voltage-Shunt feedback system

With Ideal feedback network ($R_{in_f} \rightarrow \infty$ and $R_{out_f} \rightarrow \infty$): $R_{in_f} = \frac{R_{in}}{(1 + \beta \cdot Z_m)}$



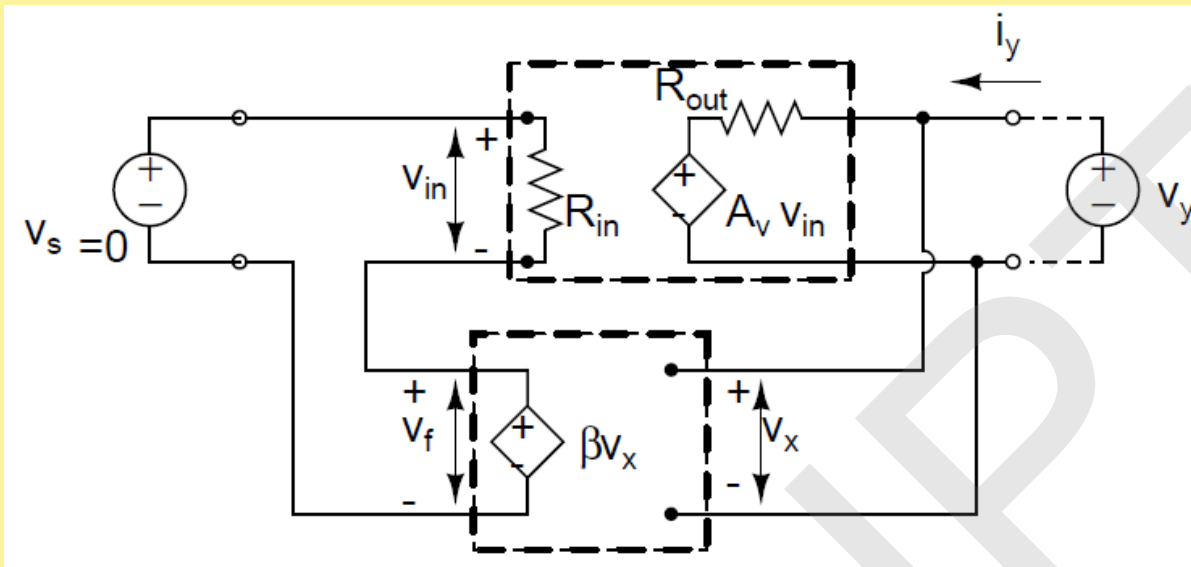
$$R_{in_f} = \frac{R_{in}}{(1 + \beta \cdot Z'_m)}$$

$$R_{in_f} = \frac{R_{in}}{(1 + \beta \cdot Z''_m)} || R_{out_f}$$

Change in output Resistance of a voltage amp. due to Feedback

Shunt-Series / Voltage-Series feedback system

With Ideal feedback network ($R_{in_f} \rightarrow \infty$ and $R_{out_f} = 0$):

$$R_{out_f} = \frac{R_{out}}{(1 + \beta \cdot A_v)}$$


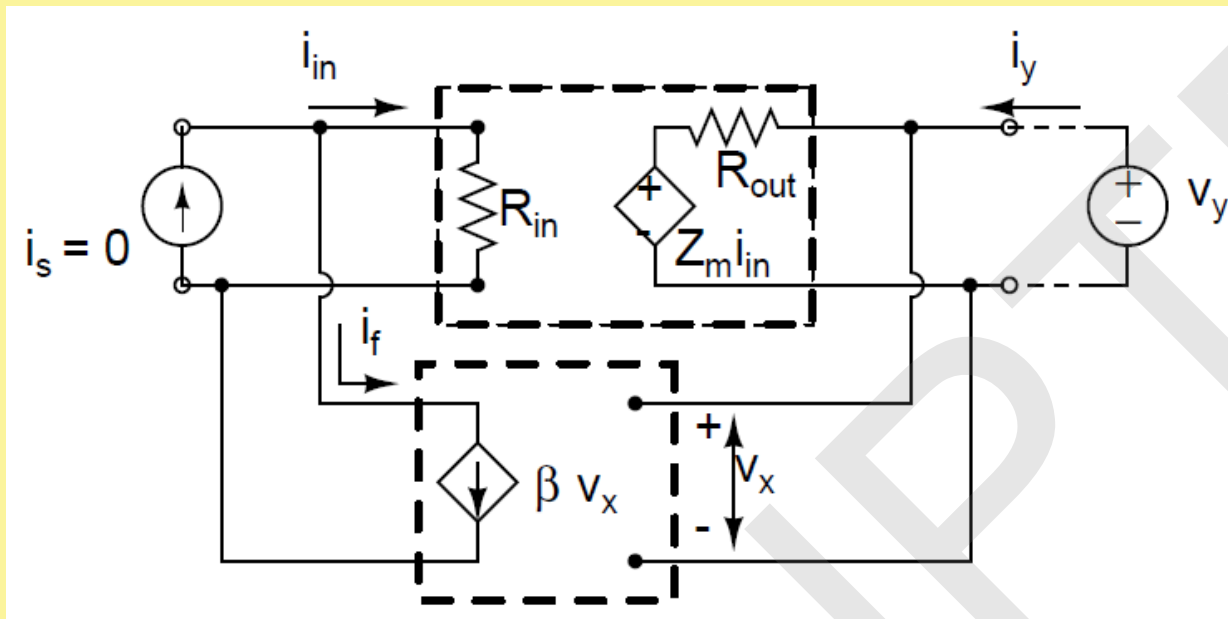
$$R_{out_f} = \frac{R_{out}}{(1 + \beta' \cdot A_v)}$$

$$R_{out_f} = \frac{R_{out}}{(1 + \beta'' \cdot A_v)} \parallel R_{in_f}$$

Change in Output Resistance of a Trans-impedance amp. due to F.B.

Shunt-Shunt/ Voltage-Shunt feedback system

With Ideal feedback network ($R_{in_β} \rightarrow \infty$ and $R_{out_β} \rightarrow \infty$):

$$R_{out_f} = \frac{R_{out}}{(1 + \beta \cdot Z_m)}$$


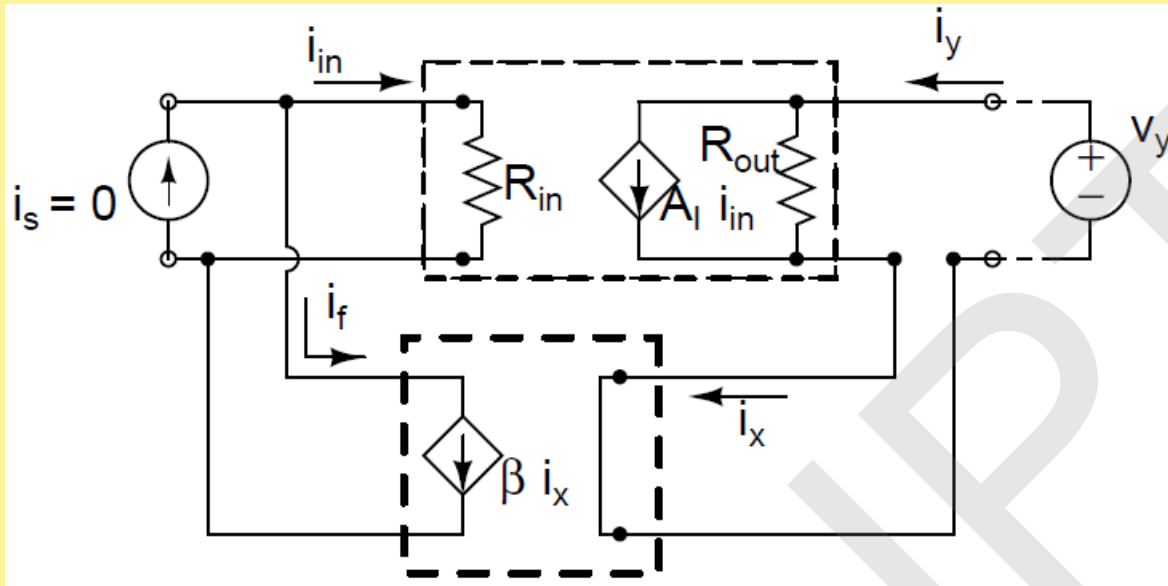
$$R_{out_f} = \frac{R_{out}}{(1 + \beta' \cdot Z_m)}$$

$$R_{out_f} = \frac{R_{out}}{(1 + \beta'' \cdot Z_m)} \parallel R_{in_β}$$

Change in output Resistance of a current amp. due to F.B.

Series-Shunt/ Current-Shunt feedback system

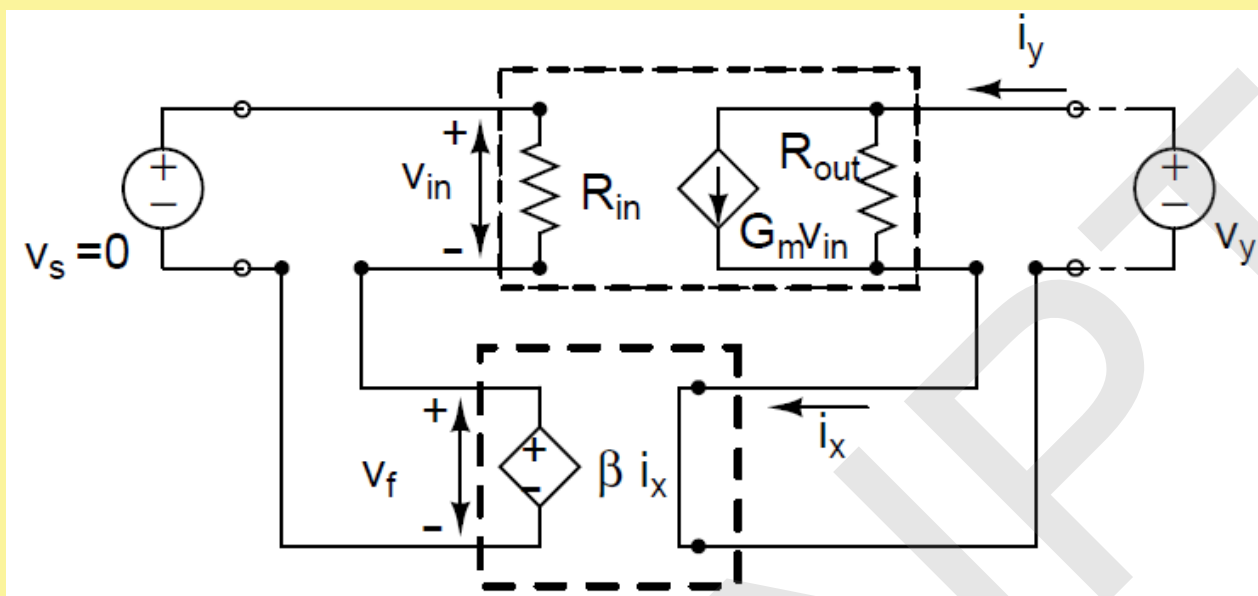
With Ideal feedback network ($R_{in_}\beta = 0$ and $R_{out_}\beta \rightarrow \infty$): $R_{out_f} = R_{out} \cdot (1 + \beta \cdot A_I)$



$$R_{out_f} = R_{out} \cdot (1 + \beta' \cdot A_I) \quad R_{out_f} = R_{out} \cdot (1 + \beta'' \cdot A_I) + R_{in_}\beta$$

Change in output Resistance of a Transconductance amp. due to F.B. Series-Series / Current-Series feedback system

With Ideal feedback network ($R_{in_β} = 0$ and $R_{out_β} = 0$): $R_{out_f} = R_{out} \cdot (1 + β \cdot G_m)$



$$R_{out_f} = R_{out} \cdot (1 + β' \cdot G_m) \quad R_{out_f} = R_{out} \cdot (1 + β'' \cdot G_m) + R_{in_β}$$

Numerical example on voltage amp. having Feedback

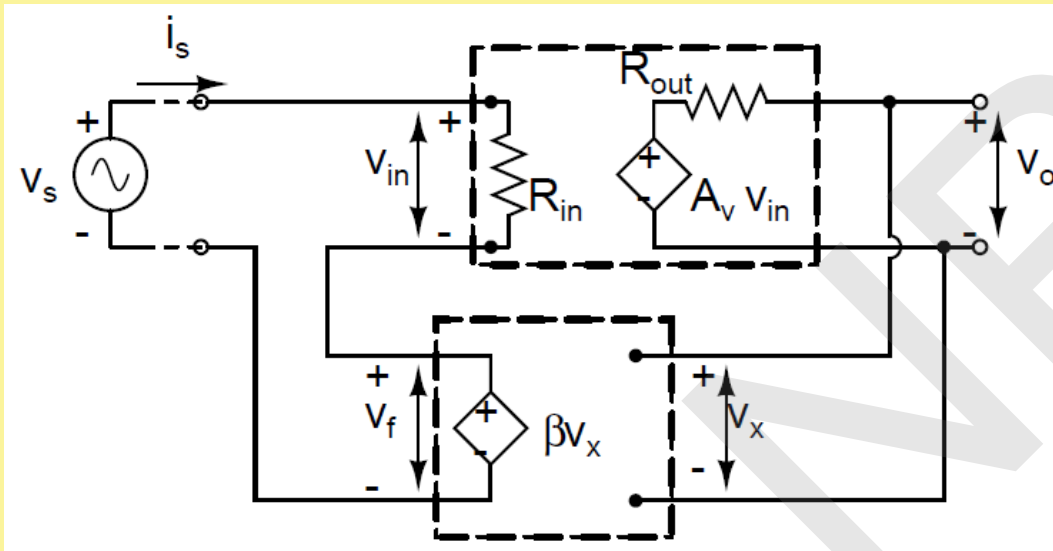
(Shunt-Series / Voltage-Series feedback system)

Given: $R_{in} = 1\text{ k}\Omega$, $R_{out} = 4\text{ k}\Omega$, $A_v = 200$ and $\beta = 0.095$, $V_s = 100\text{ mV}$

Find the values of A_{v_f} , R_{in_f} , R_{out_f} and V_o

Case I: With Ideal feedback network ($R_{in_f} \rightarrow \infty$ and $R_{out_f} = 0$) :

Case II: With Ideal feedback network (but with $R_{in_f} = 200\Omega$ and $R_{out_f} = 1\text{ k}\Omega$)



Numerical example on Trans-conductance amp. having F.B.

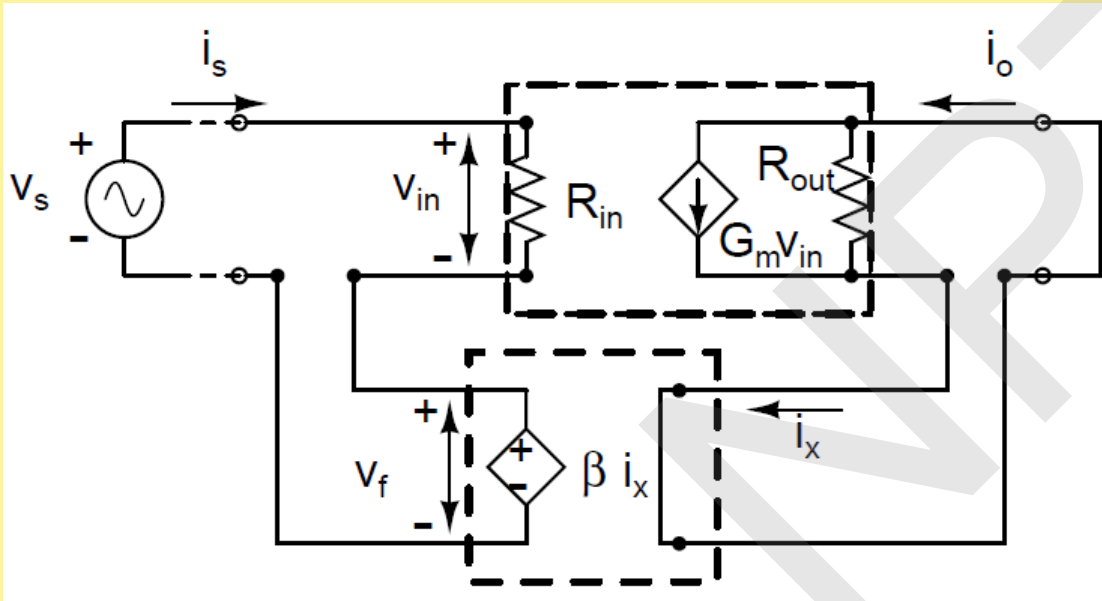
(Series-Series / Current-Series feedback system)

Given: $R_{in} = 1\text{ k}\Omega$, $R_{out} = 4\text{ k}\Omega$, $G_m = 100\text{ mA/V}$ and $\beta = 90\text{ }\Omega$, $V_s = 100\text{ mV}$

Find the values of G_{m_f} , R_{in_f} , R_{out_f} and i_o

Case I: With Ideal feedback network ($R_{in_\beta} = 0\text{ }\Omega$ and $R_{out_\beta} = 0\text{ }\Omega$) :

Case II: With Ideal feedback network (but with $R_{in_\beta} = 100\text{ }\Omega$ and $R_{out_\beta} = 4\text{ k}\Omega$)



Conclusion:

- ❑ Basic concepts of a feedback system
- ❑ Basic types of feedback systems
 - Positive
 - Negative
- ❑ Transfer characteristic of a feedback system
- ❑ Four basic configurations of F.B. sys. and their characteristics
 - Shunt-series / Voltage-series
 - Series-shunt / Current-shunt
 - Shunt-shunt / Voltage-shunt
 - Series-series / Current-series
- ❑ Numerical examples

Conclusion





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*Thank
you*





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Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Effect of Feedback on Frequency response

Flow of Discussion (Bottom-up)

— System /Sub-systems

- **System /Sub-systems** (*for specific application*)
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 - **Building blocks** (*having specific characteristics*) - **Bias circuits**
 - **Components** (*devices/circuit elements*)
- **Week 10 (Course Module 9):**
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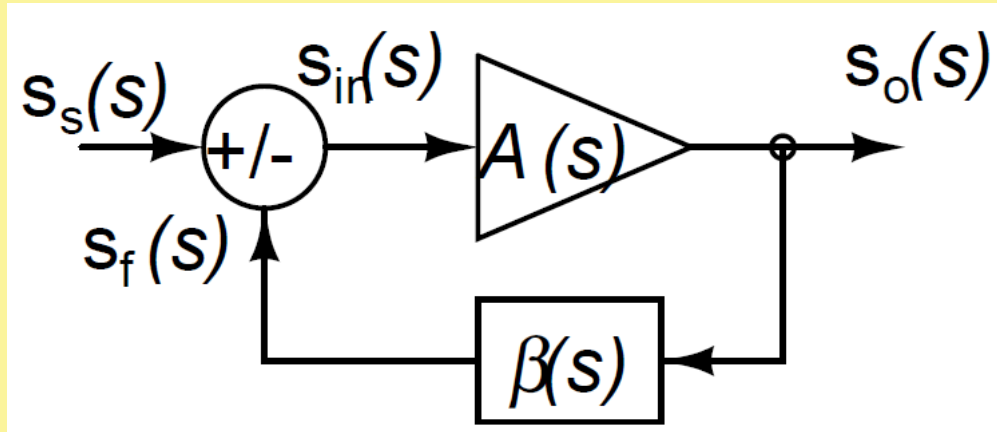
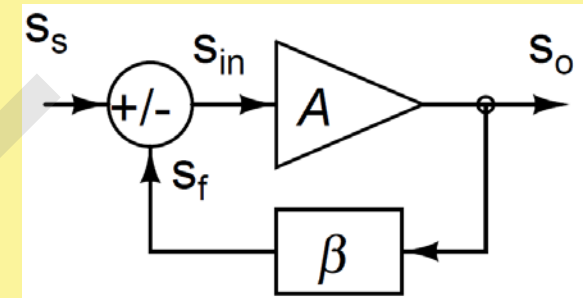
CONCEPTS COVERED

Concepts Covered:

- ☒ Location of poles of a feedback system for different cases of forward amplifier and the feedback network
 - ☐ Single pole
 - ☐ Two poles
 - ☐ Three poles



Feedback system in *Laplace* domain: *Basics*



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

$$-LG(s) = \beta(s).A(s)$$

$$D(s) = \{1 + \beta(s).A(s)\}$$

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

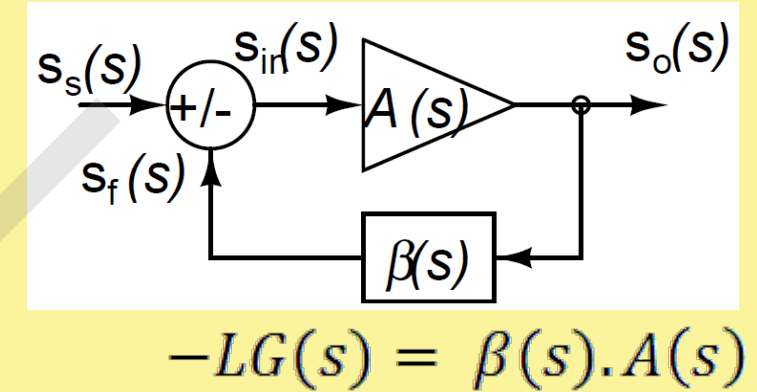
Frequency response of a feedback system

Case I:

- β is independent of frequency
- Negative feedback system for d.c.
- Forward Amplifier has one pole

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

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p}\right)}$$



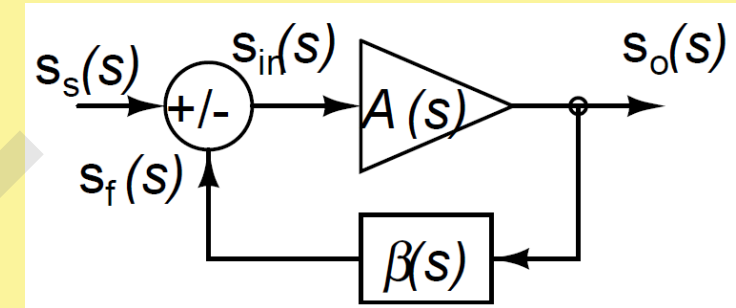
$$A_f(s) = \frac{A_{o_f}}{\left(1 + \frac{s}{p'}\right)} \quad \text{where, } A_{o_f} = \frac{A_o}{(1 + \beta.A_o)} \quad \text{and} \quad p' = p.(1 + \beta.A_o)$$



Frequency response of a feedback system: Case I (contd.)

Gain plots of $A(s) = \frac{A_o}{\left(1 + \frac{s}{p}\right)}$ $-LG(s) = \beta(s).A(s)$

$$A_f(s) = \frac{A(s)}{(1 + \beta(s).A(s))} = \frac{A_{o-f}}{\left(1 + \frac{s}{p'}\right)} \quad \text{where,} \quad A_{o-f} = \frac{A_o}{(1 + \beta.A_o)} \quad \text{and} \\ p' = p.(1 + \beta.A_o)$$



Frequency response of a feedback system: Case I (contd.)

Gain & Phase plots of

$$-LG(s) = \beta(s).A(s)$$

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

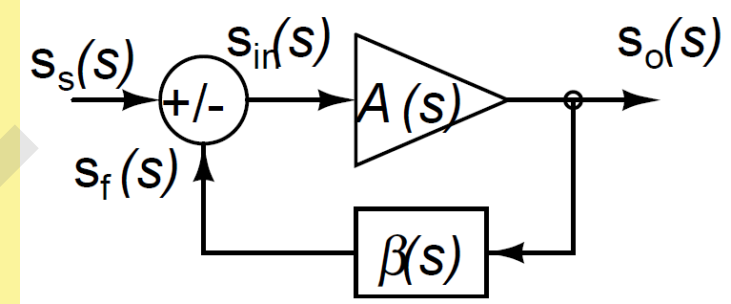
$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p}\right)}$$

$$= \frac{A_{o_f}}{\left(1 + \frac{s}{p'}\right)}$$

where,

$$A_{o_f} = \frac{A_o}{(1 + \beta.A_o)} \quad \text{and}$$

$$p' = p.(1 + \beta.A_o)$$

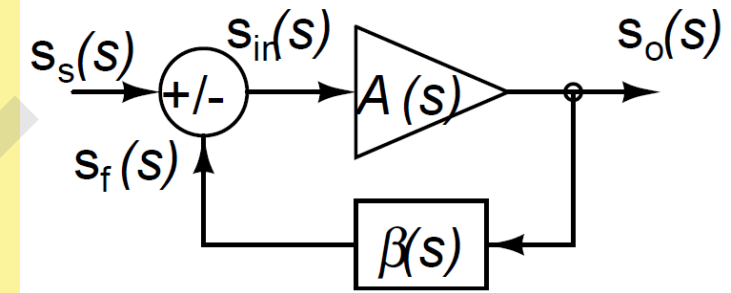


Frequency response of a feedback system

Case II-A:

- Forward Amplifier has two poles
- β is independent of frequency
- Negative feedback system for d.c.
- For $p_2 \gg p_1 \cdot (1 + \beta \cdot A_o)$

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right) \left(1 + \frac{s}{p_2}\right)}$$



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

$$= \frac{A_o}{(1 + \beta \cdot A_o)} \frac{1}{\left(1 + \frac{s}{p_1(1 + \beta \cdot A_o)} + \frac{s}{p_2(1 + \beta \cdot A_o)} + \frac{s^2}{p_1 p_2(1 + \beta \cdot A_o)}\right)}$$

$$\approx \frac{A_{o_f}}{\left(1 + \frac{s}{p_1(1 + \beta \cdot A_o)} + \frac{s}{p_2} + \frac{s^2}{p_1 p_2(1 + \beta \cdot A_o)}\right)}$$

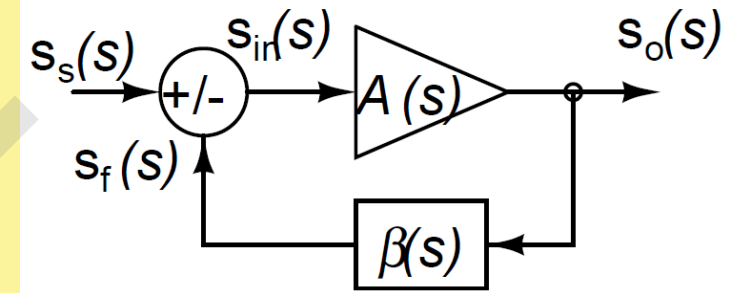


Frequency response of a feedback system

Case II-A(contd.):

- Forward Amplifier has two poles
- β is independent of frequency
- Negative feedback system for d.c.
- For $p_2 \gg p_1 \cdot (1 + \beta \cdot A_o)$

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right) \left(1 + \frac{s}{p_2}\right)}$$



$$A_f(s) = \frac{A(s)}{(1 + \beta(s) \cdot A(s))} \approx \frac{A_{o_f}}{\left(1 + \frac{s}{p_1(1 + \beta \cdot A_o)} + \frac{s}{p_2} + \frac{s^2}{p_1 p_2(1 + \beta \cdot A_o)}\right)}$$

$$A_f(s) = \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right) \left(1 + \frac{s}{p'_2}\right)} \quad \text{where,} \quad A_{o_f} = \frac{A_o}{(1 + \beta \cdot A_o)}$$

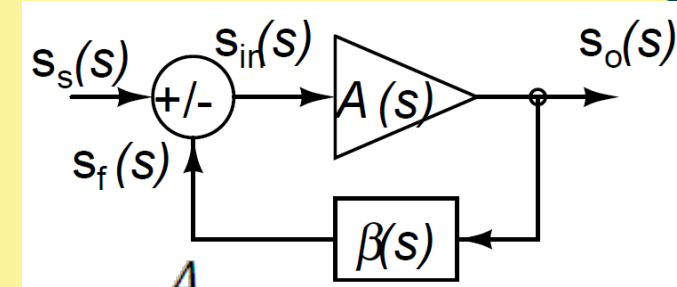
$p'_1 = p_1 \cdot (1 + \beta \cdot A_o) \quad \text{and} \quad p'_2 \approx p_2$

Frequency response of a feedback system: Case II-A (contd.)

Bode' plots of $A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right)\left(1 + \frac{s}{p_2}\right)}$ $-LG(s) = \beta(s).A(s)$

$$A_f(s) = \frac{A(s)}{(1 + \beta(s).A(s))} = \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right)\left(1 + \frac{s}{p'_2}\right)} \quad \text{where,} \quad A_{o_f} = \frac{A_o}{(1 + \beta.A_o)}$$

$$p'_1 = p_1.(1 + \beta.A_o) \quad \text{and} \quad p'_2 \approx p_2$$



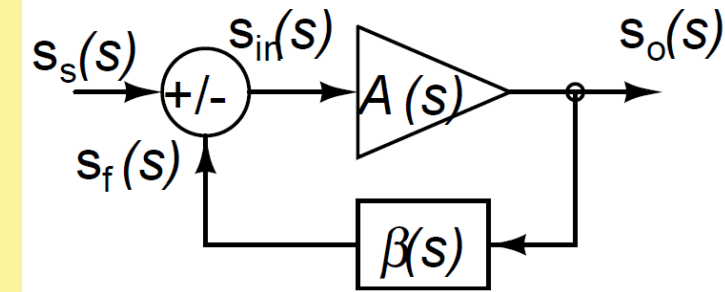
Frequency response of a feedback system

Case II-B:

- Forward Amplifier has two poles
- β is independent of frequency
- Negative feedback system for d.c.

- For $p_2 \gg p_1$ but, $p_2 \sim p_1 \cdot (1 + \beta \cdot A_o)$

$$\begin{aligned}
 A_f(s) &= \frac{A(s)}{(1 + \beta(s) \cdot A(s))} \\
 &= \frac{A_o}{(1 + \beta \cdot A_o)} \frac{1}{\left(1 + \frac{s}{p_1(1 + \beta \cdot A_o)} + \frac{s}{p_2(1 + \beta \cdot A_o)} + \frac{s^2}{p_1 p_2(1 + \beta \cdot A_o)}\right)} \\
 &\approx \frac{A_o}{(1 + \beta \cdot A_o)} \frac{1}{\left(1 + \frac{s}{p_1(1 + \beta \cdot A_o)} + \frac{s^2}{p_1 p_2(1 + \beta \cdot A_o)}\right)}
 \end{aligned}$$



Frequency response of a feedback system

Case II-B (contd.):

- **For** $p_2 \gg p_1$ but, $p_2 \sim p_1 \cdot (1 + \beta \cdot A_o)$

$$A_f(s) \approx \frac{A_{o_f}}{\left(1 + \frac{s}{p_1(1 + \beta \cdot A_o)} + \frac{s^2}{p_1 p_2(1 + \beta \cdot A_o)}\right)} \approx \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right)\left(1 + \frac{s}{p'_2}\right)}$$

where, $A_{o_f} = \frac{A_o}{(1 + \beta \cdot A_o)}$

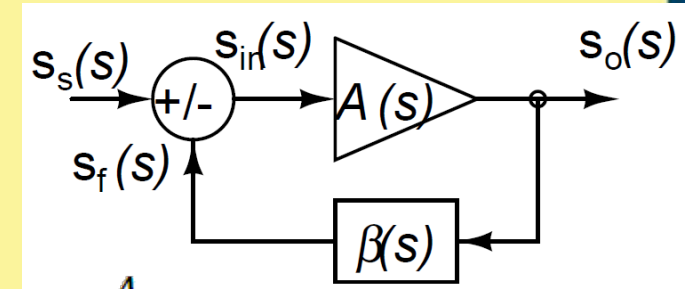
$$p'_1 = 0.5 \times [p_2 - \sqrt{\{p_2^2 - 4p_1 p_2(1 + \beta \cdot A_o)\}}] \text{ and}$$

$$p'_2 = 0.5 \times [p_2 + \sqrt{\{p_2^2 - 4p_1 p_2(1 + \beta \cdot A_o)\}}]$$



Frequency response of a feedback system: Case II-B (contd.)

Gain plots of $A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right)\left(1 + \frac{s}{p_2}\right)}$ $-LG(s) = \beta(s).A(s)$



$$A_f(s) = \frac{A(s)}{(1 + \beta(s).A(s))} = \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right)\left(1 + \frac{s}{p'_2}\right)} \quad \text{where,} \quad A_{o_f} = \frac{A_o}{(1 + \beta.A_o)}$$

$$p'_1 = 0.5 \times [p_2 - \sqrt{\{p_2^2 - 4p_1p_2(1 + \beta.A_o)\}}] \quad \text{and}$$

$$p'_2 = 0.5 \times [p_2 + \sqrt{\{p_2^2 - 4p_1p_2(1 + \beta.A_o)\}}]$$

Frequency response of a feedback system: Case II-B (contd.)

Gain & Phase plots of

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right)\left(1 + \frac{s}{p_2}\right)} \quad -LG(s) = \beta(s).A(s)$$
$$A_f(s) = \frac{A(s)}{(1 + \beta(s).A(s))} = \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right)\left(1 + \frac{s}{p'_2}\right)} \quad \text{where,} \quad A_{o_f} = \frac{A_o}{(1 + \beta.A_o)}$$
$$p'_1 = 0.5 \times [p_2 - \sqrt{\{p_2^2 - 4p_1p_2(1 + \beta.A_o)\}}] \quad \text{and}$$
$$p'_2 = 0.5 \times [p_2 + \sqrt{\{p_2^2 - 4p_1p_2(1 + \beta.A_o)\}}]$$



Comparison of locations of poles for Case II-A and Case II-B

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right)\left(1 + \frac{s}{p_2}\right)} \quad A_f(s) \approx \frac{A_{o-f}}{\left(1 + \frac{s}{p'_1}\right)\left(1 + \frac{s}{p'_2}\right)} \quad \text{where,} \quad A_{o-f} = \frac{A_o}{(1 + \beta \cdot A_o)}$$

Case II-A : $p_2 \gg p_1 \cdot (1 + \beta \cdot A_o)$ $p'_1 = p_1 \cdot (1 + \beta \cdot A_o)$ and $p'_2 \approx p_2$

Case II-B : $p_2 \gg p_1$ but, $p_2 \sim p_1 \cdot (1 + \beta \cdot A_o)$
 $p'_1 = 0.5 \times [p_2 - \sqrt{\{p_2^2 - 4p_1p_2(1 + \beta \cdot A_o)\}}]$ and $p'_2 = 0.5 \times [p_2 + \sqrt{\{p_2^2 - 4p_1p_2(1 + \beta \cdot A_o)\}}]$



Frequency response of a feedback system

Case III:

- Negative feedback system for d.c.
- β has one pole
- Forward Amplifier has one pole

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

$$= \frac{A_o}{(1 + \beta_o A_o) \left(1 + \frac{s}{p_a(1 + \beta_o A_o)} + \frac{s}{p_b(1 + \beta_o A_o)} + \frac{s^2}{p_a p_b(1 + \beta_o A_o)} \right)}$$

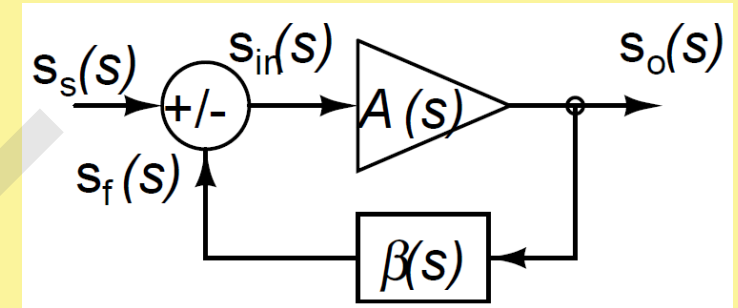
$$A_f(s) \approx \frac{A_{o-f} \left(1 + \frac{s}{p_b} \right)}{\left(1 + \frac{s}{p'_1} \right) \left(1 + \frac{s}{p'_2} \right)}$$

where,

$$A_{o-f} = \frac{A_o}{(1 + \beta_o A_o)}$$

$$\beta(s) = \frac{\beta_o}{\left(1 + \frac{s}{p_b} \right)}$$

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_a} \right)}$$



$$-LG(s) = \beta(s).A(s)$$

Frequency response of a feedback system: Case III (contd.)

Gain plots of

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_a}\right)}$$

$$\beta(s) = \frac{\beta_o}{\left(1 + \frac{s}{p_b}\right)}$$

$$-LG(s) = \beta(s).A(s)$$

$$A_f(s) \approx \frac{A_{o-f} \left(1 + \frac{s}{p_b}\right)}{\left(1 + \frac{s}{p'_1}\right) \left(1 + \frac{s}{p'_2}\right)}$$

where,

$$A_{o-f} = \frac{A_o}{(1 + \beta_o A_o)}$$



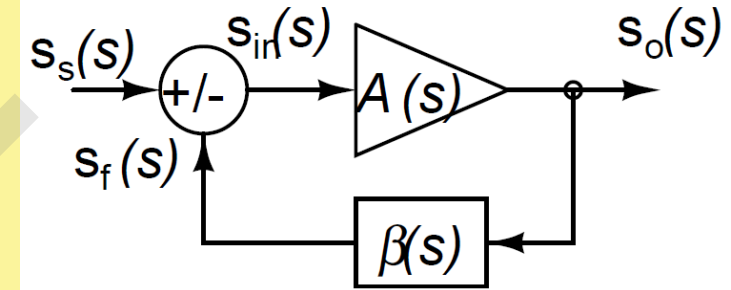
Frequency response of a feedback system

Case IV:

- Forward Amplifier has three poles
- β is independent of frequency
- Negative feedback system for d.c.
- For

$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right) \left(1 + \frac{s}{p_2}\right) \left(1 + \frac{s}{p_3}\right)}$$

$$p_3 > p_2 \gg p_1 \cdot (1 + \beta \cdot A_o)$$



$$A_f(s) \approx \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right) \left(1 + \frac{s}{p'_2}\right) \left(1 + \frac{s}{p'_3}\right)} \quad \text{where,} \quad A_{o_f} = \frac{A_o}{(1 + \beta \cdot A_o)}$$

$$p'_1 = p_1 \cdot (1 + \beta \cdot A_o) \quad p'_2 \approx p_2 \quad \text{and} \quad p'_3 \approx p_3$$

Frequency response of a feedback system

Case IV (contd.):

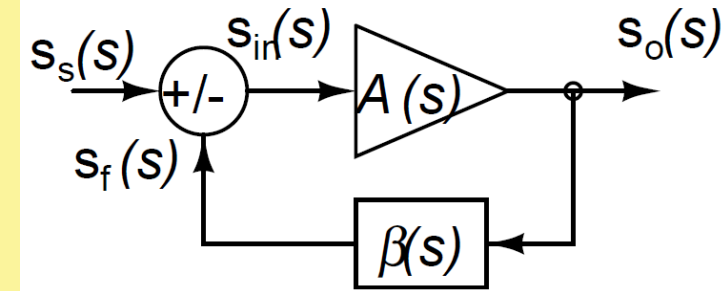
$$A(s) = \frac{A_o}{\left(1 + \frac{s}{p_1}\right) \left(1 + \frac{s}{p_2}\right) \left(1 + \frac{s}{p_3}\right)}$$

$$A_f(s) \approx \frac{A_{o_f}}{\left(1 + \frac{s}{p'_1}\right) \left(1 + \frac{s}{p'_2}\right) \left(1 + \frac{s}{p'_3}\right)}$$

$$p_3 > p_2 \gg p_1 \cdot (1 + \beta \cdot A_o)$$

$$\text{where, } A_{o_f} = \frac{A_o}{(1 + \beta \cdot A_o)}$$

$$p'_1 = p_1 \cdot (1 + \beta \cdot A_o) \quad p'_2 \approx p_2 \quad \text{and} \quad p'_3 \approx p_3$$



Conclusion

Conclusion:

- ☐ Location of poles of a feedback system depends on the location of poles of forward amplifier and feedback network
- ☐ Following cases have been discussed:
 - ☐ Single pole
 - ☐ Two poles
 - ☐ Three poles





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*Thank
you*





NPTEL ONLINE CERTIFICATION COURSES

Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Applications of Feedback in amplifier circuits

Flow of Discussion (Bottom-up)

– Sub-systems/Modules

- **System / Sub-systems** (*for specific application*)
 - **Modules** (*performing specific tasks*)
 - **Building blocks** (*having specific characteristics*) - **Bias circuits**
 - **Components** (*devices/circuit elements*)
- **Week 10 (Course Module 9):**
 - **Feedback System: Basic feedback theory**
 - **Four different feedback configurations and their characteristics**
 - **Effects of feedback on frequency response of an amplifier**
 - **Application of feedback in practical circuits**



CONCEPTS COVERED

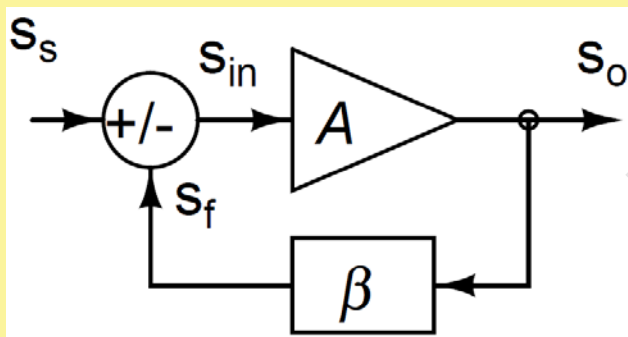
Concepts Covered:

- ☐ **How to apply feedback in BJT amplifiers**
 - ☐ Voltage-shunt (shunt-shunt) F.B.
 - ☐ Current-series (series-series) F.B.
 - ☐ Voltage-series (shunt-series) F.B.
- ☐ **Customization / extension of basic FB model**
- ☐ **Application of feedback in op-amp circuits**
 - ☐ Inverting amplifier
 - ☐ Integrator and Differentiator
 - ☐ Non-inverting amplifier
 - ☐ A circuit with two feedback loops



Summary of effects of negative feedback loop in amplifier

Configuration names	Sin	So	A ↓	Rin ↓	Rout ↓	Unit of β_{FB}
Voltage-Shunt (Shunt-Shunt)	I	V	Z_m	↓	↓	Mho
Current-Shunt (Series-Shunt)	I	I	A_I	↓	↑	-
Voltage-Series (Shunt-Series)	V	V	A_V	↑	↓	-
Current-Series (Series-Series)	V	I	G_m	↑	↑	Ohm

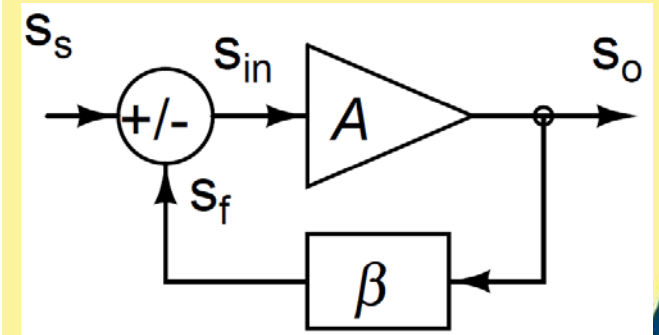


$$A_f = \frac{A}{(1 + \beta \cdot A)}$$

$$D = (1 + \beta \cdot A)$$

Summary of effects of negative feedback loop in amplifier (contd.)

Configuration names	S_{in}	S_o	$A \downarrow$	R_{in}	R_{out}	Unit of β_{FB}
Voltage-Shunt (Shunt-Shunt)	I	V	Z_m	$\downarrow$	$\downarrow$	Mho
Current-Shunt (Series-Shunt)	I	I	A_I	$\downarrow$	$\uparrow$	-
Voltage-Series (Shunt-Series)	V	V	A_v	$\uparrow$	$\downarrow$	-
Current-Series (Series-Series)	V	I	G_m	$\uparrow$	$\uparrow$	Ohm



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

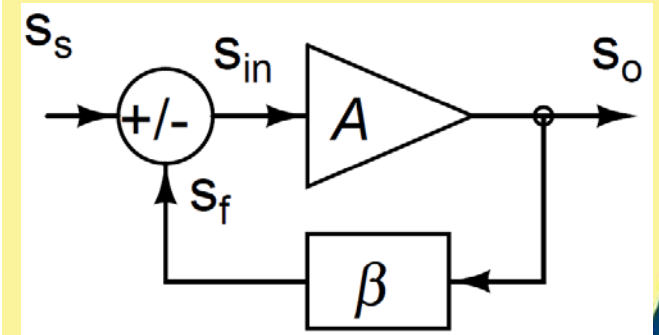
- Which configuration?
- Consequences !

	A_I	A_v	G_m	Z_m
A_I	1	R_{in}/R_{out}	R_{in}	$1/R_{out}$
A_v	R_{out}/R_{in}	1	R_{out}	$1/R_{in}$
G_m	$1/R_{in}$	$1/R_{out}$	1	$1/(R_{in} \cdot R_{out})$
Z_m	R_{out}	R_{in}	$(R_{in} \cdot R_{out})$	1



Procedure to incorporate feedback loop in amplifier

Configuration names	Sin	So	A ↓	Rin ↓	Rout ↓	Unit of β_{FB}
Voltage-Shunt (Shunt-Shunt)	I	V	Z_m	↓	↓	Mho
Current-Shunt (Series-Shunt)	I	I	A_I	↓	↑	-
Voltage-Series (Shunt-Series)	V	V	A_V	↑	↓	-
Current-Series (Series-Series)	V	I	G_m	↑	↑	Ohm



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

• Steps to follow:

- Select the right feedback configuration
- Be aware of consequences
- To make the loop effective and intuitive :
 - Consider the loading effect on “A” (i.e., use A')
 - Find useful range of β_{FB} providing $A'' \approx A'$, $\beta'_{FB} \approx \beta_{FB}$ and $(A' \beta_{FB}) \gg 1$



Procedure to incorporate feedback loop in amplifier (*contd.*)

- To make the loop effective and intuitive :
 - Consider the loading effect on “A” (i.e., use A')
 - Find useful range of β_{FB} providing

$$A'' \approx A' \quad \text{and} \quad \beta'_{FB} \approx \beta_{FB}$$

$$R_{in_ \beta} \gg R_{out} \quad \text{for voltage sampling}$$

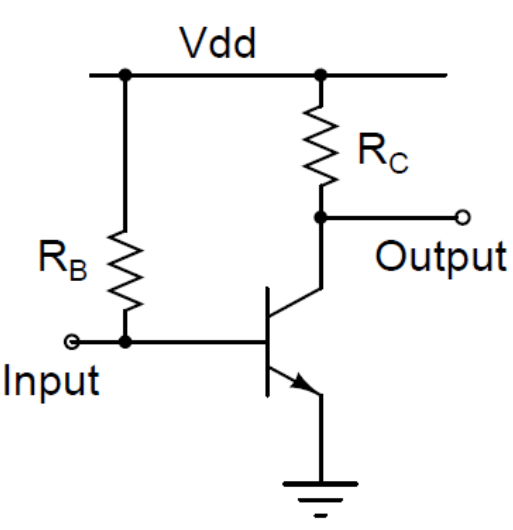
$$R_{out_ \beta} \gg R_{in} \quad \text{for current mixing}$$

and

$$A' \cdot \beta_{FB} \gg 1$$



Application circuit-1



Configuration names	Sin	So	A ↓	Rin ↓	Rout ↓	Unit of β_{FB}
Voltage-Shunt (Shunt-Shunt)	I	V	Z_m	↓	↓	Mho
Current-Shunt (Series-Shunt)	I	I	A_I	↓	↑	-
Voltage-Series (Shunt-Series)	V	V	A_v	↑	↓	-
Current-Series (Series-Series)	V	I	G_m	↑	↑	Ohm

We want stable Z_m defined by feedback network

Feedback configuration: *Voltage-Shunt (Shunt-shunt) feedback*

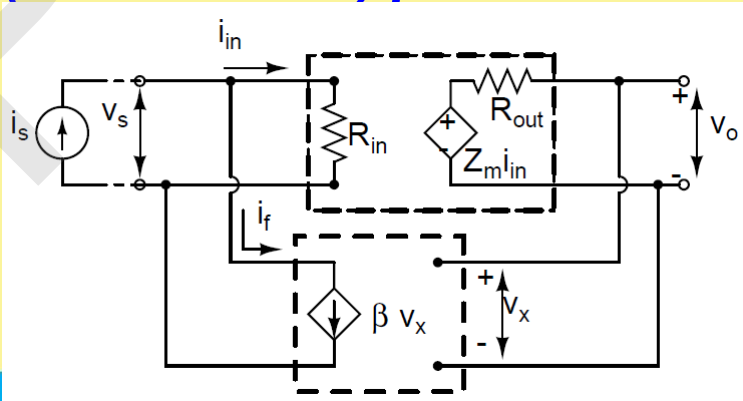
Input signal:

Output signal:

Forward amplifier gain:

T.F. of F.B. Network :

Rin: Rout:



Application circuit-1 (contd.)

Feedback configuration: *Voltage-Shunt (Shunt-shunt) feedback*

S_s :

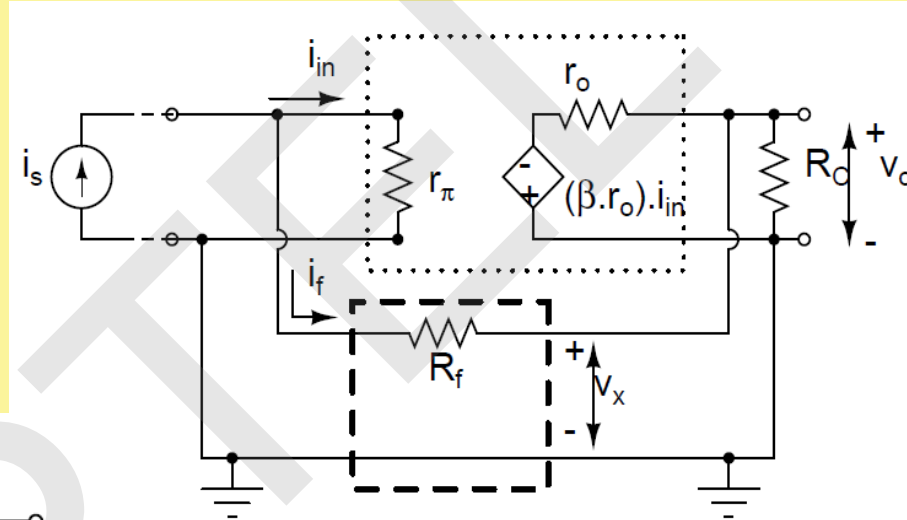
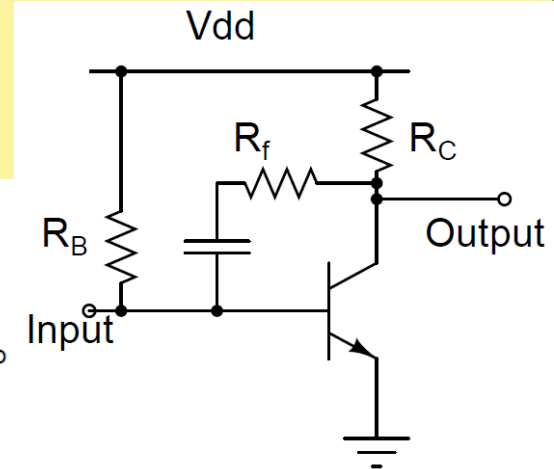
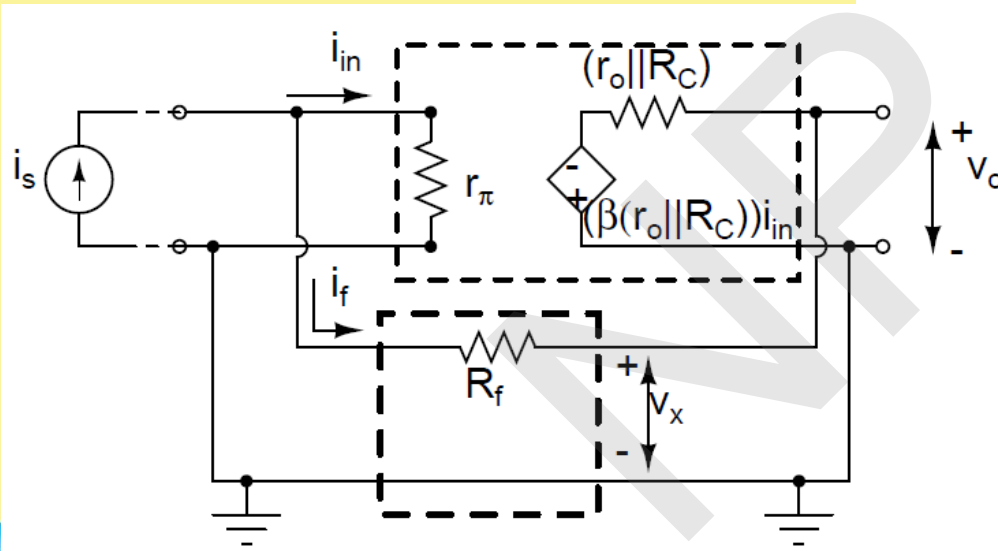
S_o :

A :

β_{FB} :

R_{in} :

R_{out} :



Application circuit-1 (contd.)

Feedback configuration: *Voltage-Shunt (Shunt-shunt) feedback*

A : $Z_m =$

R_{in} =

R_{out} =

$\beta_{FB} = 1/R_f$

Suitable range of R_f

$R_{in_f} \gg R_{out}$

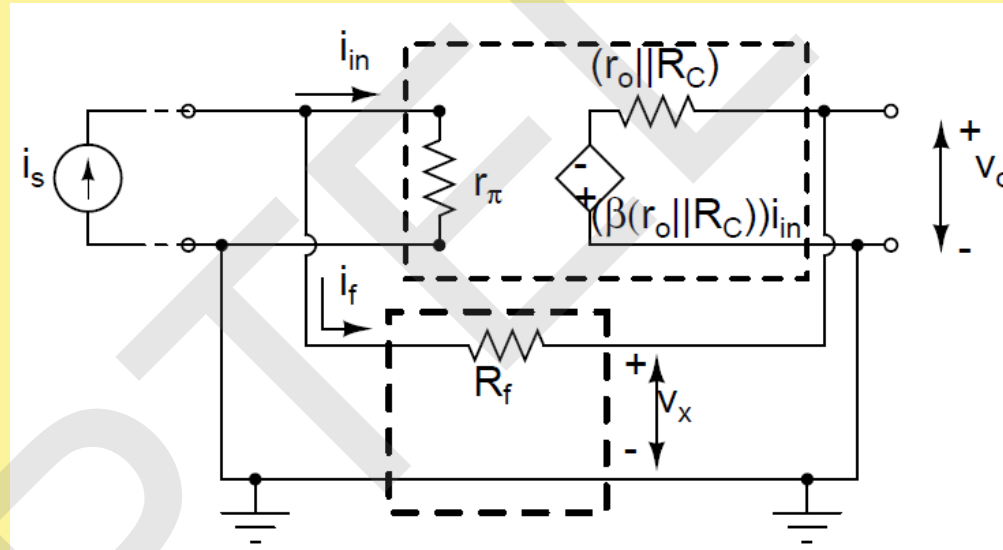
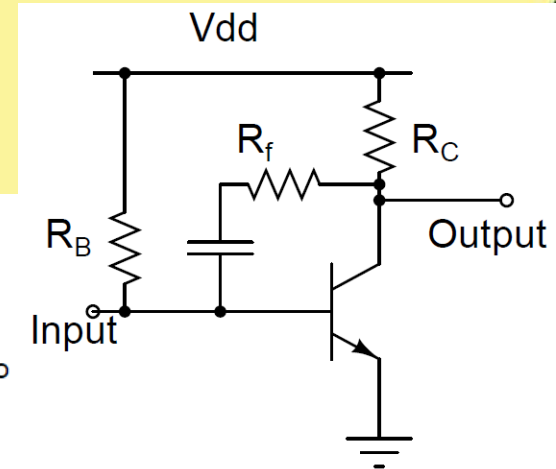
$R_{out_f} \gg R_{in}$

$A' \cdot \beta_{FB} \gg 1$

$A_f: Z_{m_f} =$

$R_{in_f}:$

$R_{out_f}:$



Application circuit-1 (contd.)

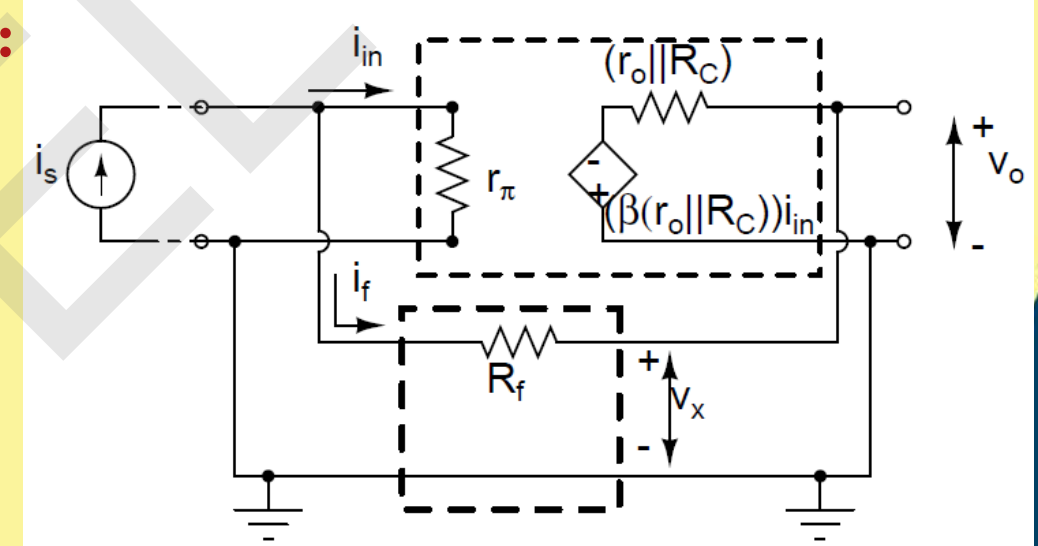
Feedback configuration: *Voltage-Shunt (Shunt-shunt) feedback*

Consequences of the F.B on other parameters:

A_v :

A_i :

G_m :



	A_i	A_v	G_m	Z_m
A_i	1	R_{in}/R_{out}	R_{in}	$1/R_{out}$
A_v	R_{out}/R_{in}	1	R_{out}	$1/R_{in}$
G_m	$1/R_{in}$	$1/R_{out}$	1	$1/(R_{in} \cdot R_{out})$
Z_m	R_{out}	R_{in}	$(R_{in} \cdot R_{out})$	1

Application circuit-1 : Numerical example

Feedback configuration: *Voltage-Shunt (Shunt-shunt) feedback*

$R_C = 5\text{ k}\Omega$; $R_B = 940\text{ k}\Omega$ $V_{DD} = 10\text{ V}$; $V_{BE(on)} = 0.6\text{ V}$; $V_A = 100\text{ V}$, $\beta = 100$

$A : Z_m =$

$R_{in} =$ $R_{out} =$

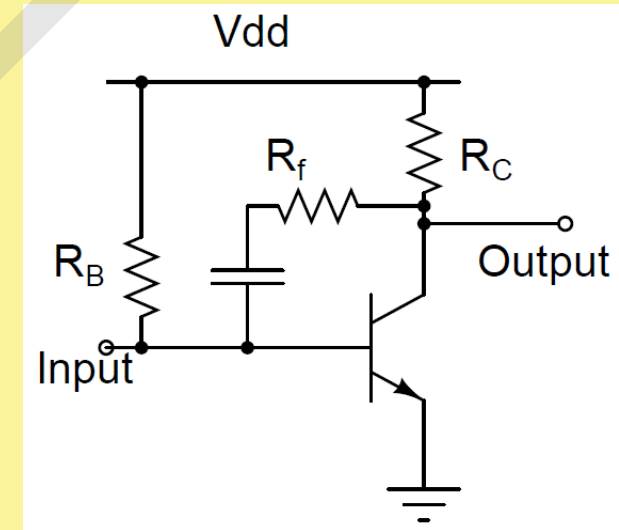
$\beta_{FB} = 1/R_f$

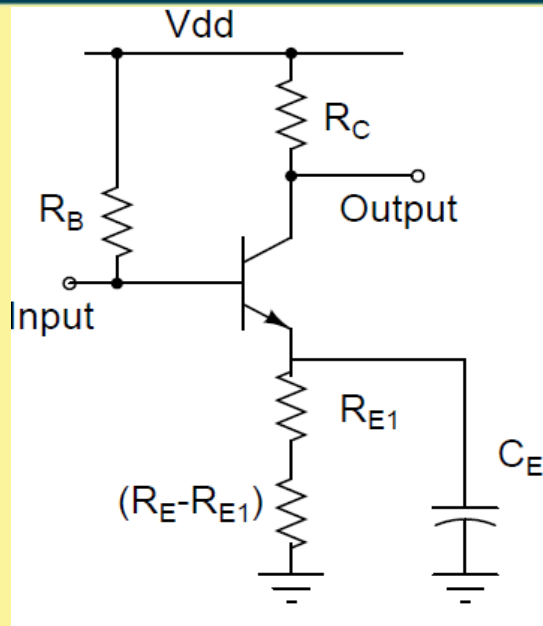
Suitable range of R_f

$A_f : Z_{m_f} =$

$R_{in_f} :$

$R_{out_f} :$





Application circuit-2

Configuration names	Sin	So	A ↓	Rin ↓	Rout ↓	Unit of β_{FB}
Voltage-Shunt (Shunt-Shunt)	I	V	Z_m	↓	↓	Mho
Current-Shunt (Series-Shunt)	I	I	A_I	↓	↑	-
Voltage-Series (Shunt-Series)	V	V	A_v	↑	↓	-
Current-Series (Series-Series)	V	I	G_m	↑	↑	Ohm

We want stable G_m defined by feedback network

Feedback configuration: *Current-Series (Series-Series) feedback*

Input signal:

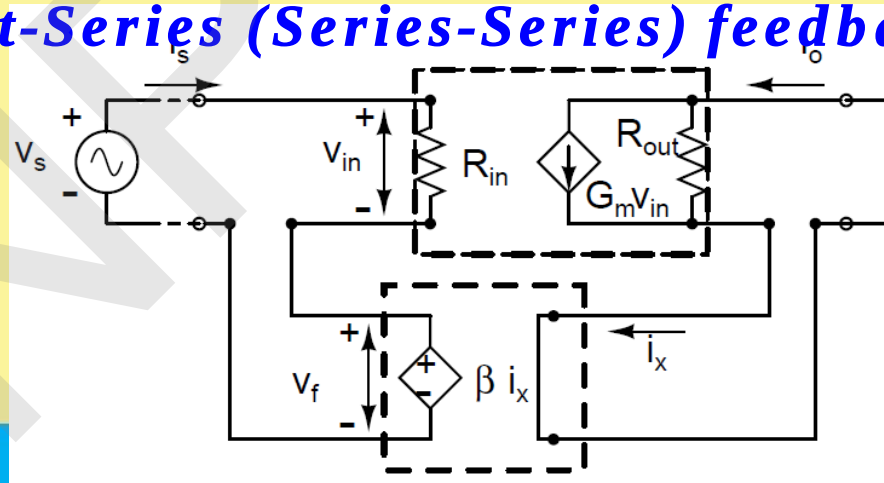
Output signal:

Forward amplifier gain:

T.F. of F.B. Network :

R_{in} :

R_{out} :



Application circuit-2 (contd.)

Feedback configuration: *Current-Series (Series-Series) feedback*

S_s :

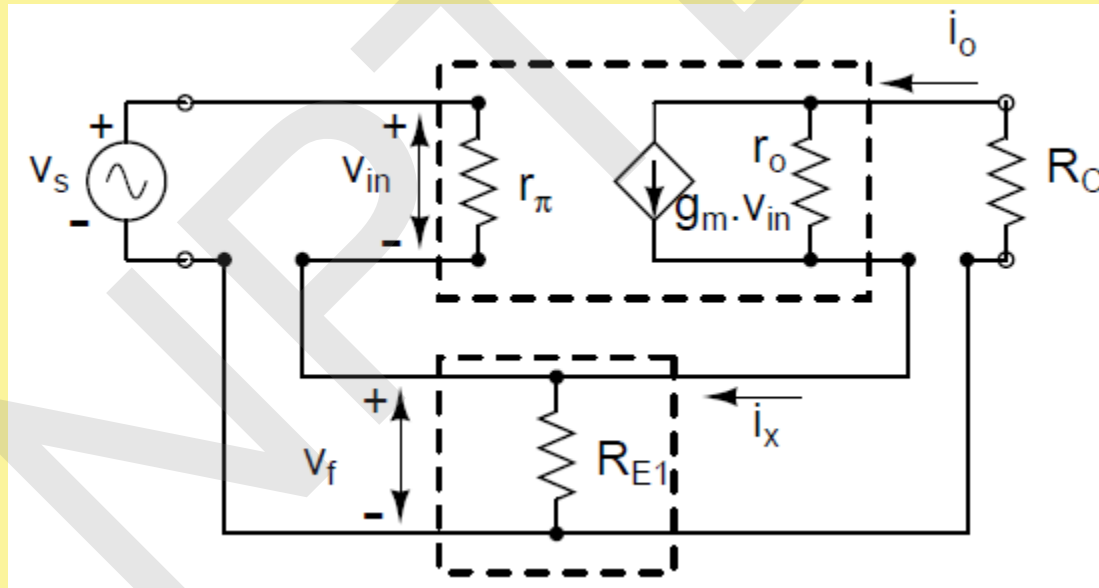
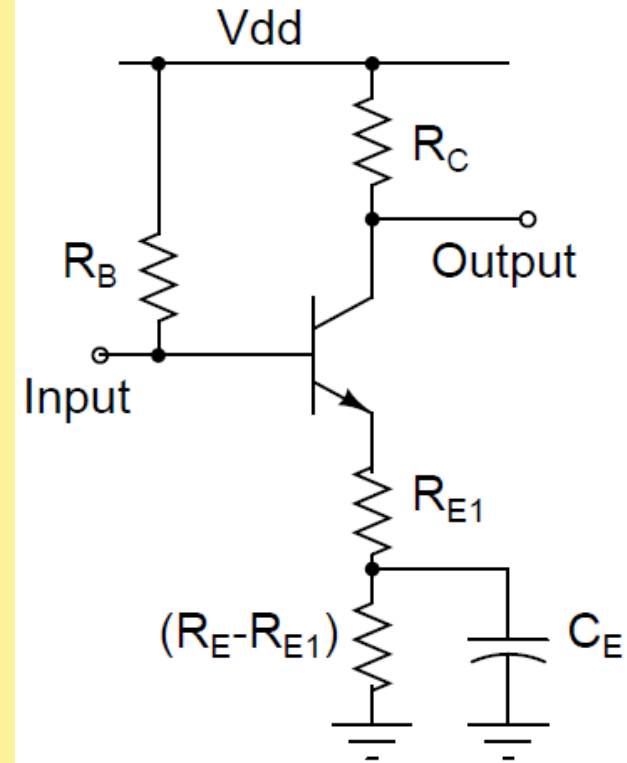
S_o :

A :

β_{FB} :

R_{in} :

R_{out} :



Application circuit-2 (contd.)

Feedback configuration: *Current-Series (Series-Series) feedback*

$$A : G_m =$$

$$R_{in} = \quad R_{out} =$$

$$\beta_{FB} = R_{E1}$$

Suitable range of R_{E1}

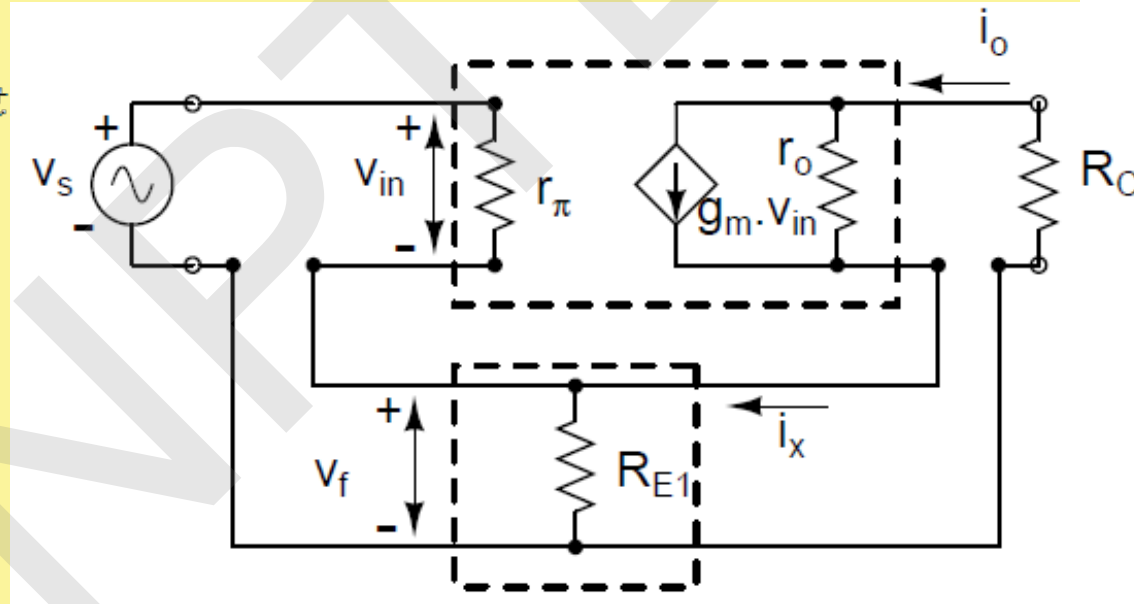
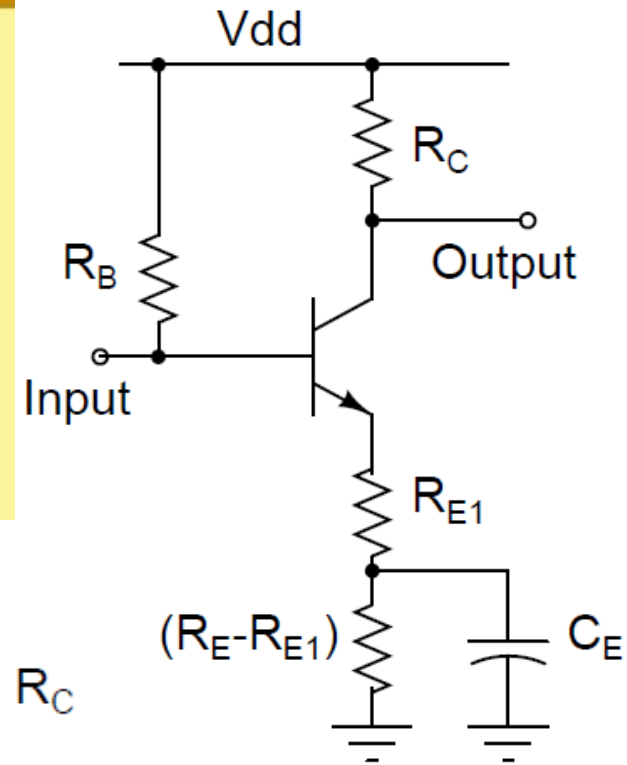
$$R_{out_\beta} \ll R_{in} \quad R_{in_\beta} \ll R_{out}$$

$$A' \cdot \beta_{FB} \gg 1$$

A_f :

R_{in_f} :

R_{out_f} :



Application circuit-2 (contd.)

Feedback configuration: *Current-Series (Series-Series) feedback*

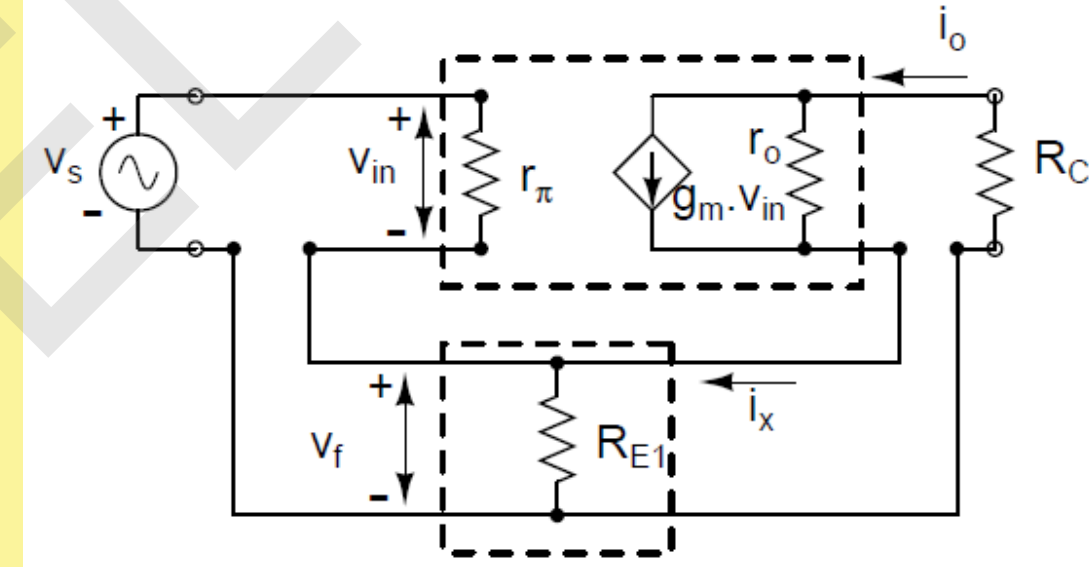
Consequences of the F.B on other parameters:

A_v :

A_i :

Z_m :

	A_i	A_v	G_m	Z_m
A_i	1	R_{in}/R_{out}	R_{in}	$1/R_{out}$
A_v	R_{out}/R_{in}	1	R_{out}	$1/R_{in}$
G_m	$1/R_{in}$	$1/R_{out}$	1	$1/(R_{in}.R_{out})$
Z_m	R_{out}	R_{in}	$(R_{in}.R_{out})$	1



Application circuit-2 : Numerical example

Feedback configuration: *Current-Series (Series-Series) feedback*

$R_C = 5\text{k}\Omega$, $R_B = 840\text{k}\Omega$, $V_{dd} = 10\text{V}$, $R_E = 1\text{k}\Omega$,

$V_{BE(on)} = 0.6\text{V}$, $V_A = 100\text{V}$, $\beta = 100$

A : $G_m =$

$R_{in} =$

$R_{out} =$

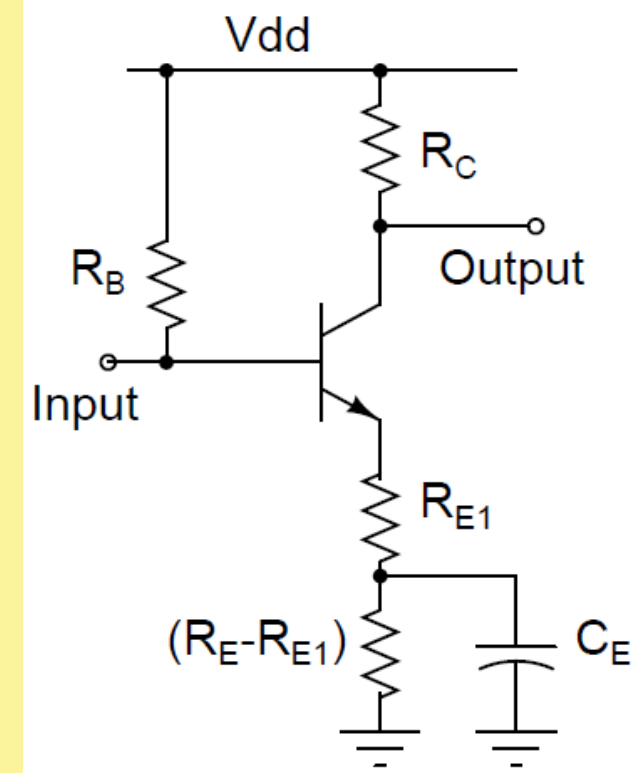
$\beta_{FB} = R_{E1}$

Suitable range of R_{E1}

A_f: $G_{m_f} =$

$R_{in_f} =$

$R_{out_f} =$



Application circuit-2 (contd.)

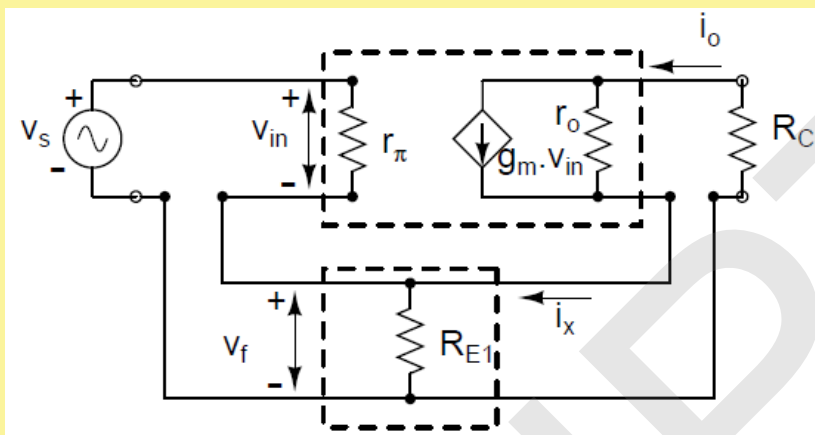
Feedback configuration: *Current-Series (Series-Series) feedback*

Consequences of the F.B on other parameters:

A_v :

A_i :

Z_m :



	A_i	A_v	G_m	Z_m
A_i	1	R_{in}/R_{out}	R_{in}	$1/R_{out}$
A_v	R_{out}/R_{in}	1	R_{out}	$1/R_{in}$
G_m	$1/R_{in}$	$1/R_{out}$	1	$1/(R_{in} \cdot R_{out})$
Z_m	R_{out}	R_{in}	$(R_{in} \cdot R_{out})$	1

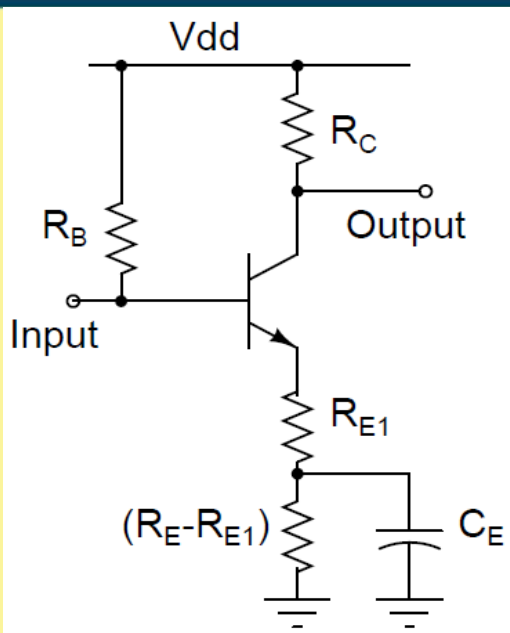
Consequences of the F.B on other parameters (considering R_C):

A_v :

A_i :

Z_m :





Application circuit-3

Configuration names	Sin	So	A ↓	Rin ↓	Rout ↓	Unit of β_{FB}
Voltage-Shunt (Shunt-Shunt)	I	V	Z_m	↓	↓	Mho
Current-Shunt (Series-Shunt)	I	I	A_I	↓	↑	-
Voltage-Series (Shunt-Series)	V	V	A_v	↑	↓	-
Current-Series (Series-Series)	V	I	G_m	↑	↑	Ohm

We want stable A_v defined by feedback network

Feedback configuration: **Voltage-Series (Shunt-Series) feedback**

Input signal:

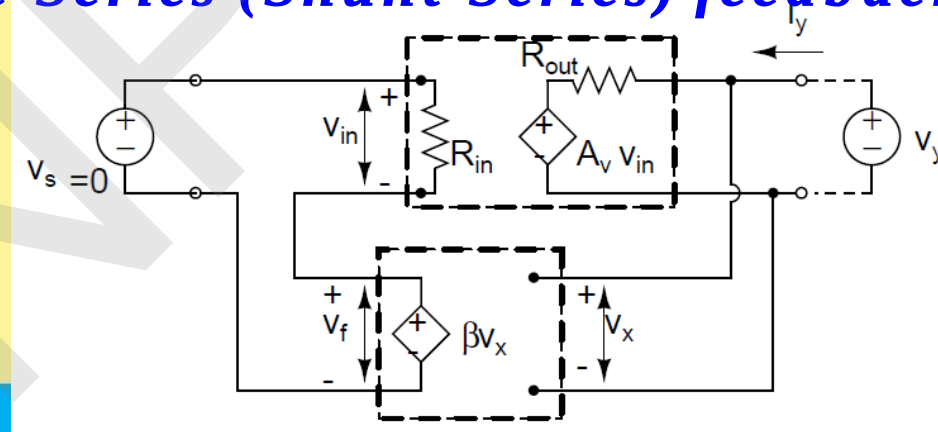
Output signal:

Forward amplifier gain:

T.F. of F.B. Network :

Rin:

Rout:



Application circuit-3 (contd.)

Feedback configuration: *Voltage-Series (Shunt-Series) feedback*

S_s :

S_o :

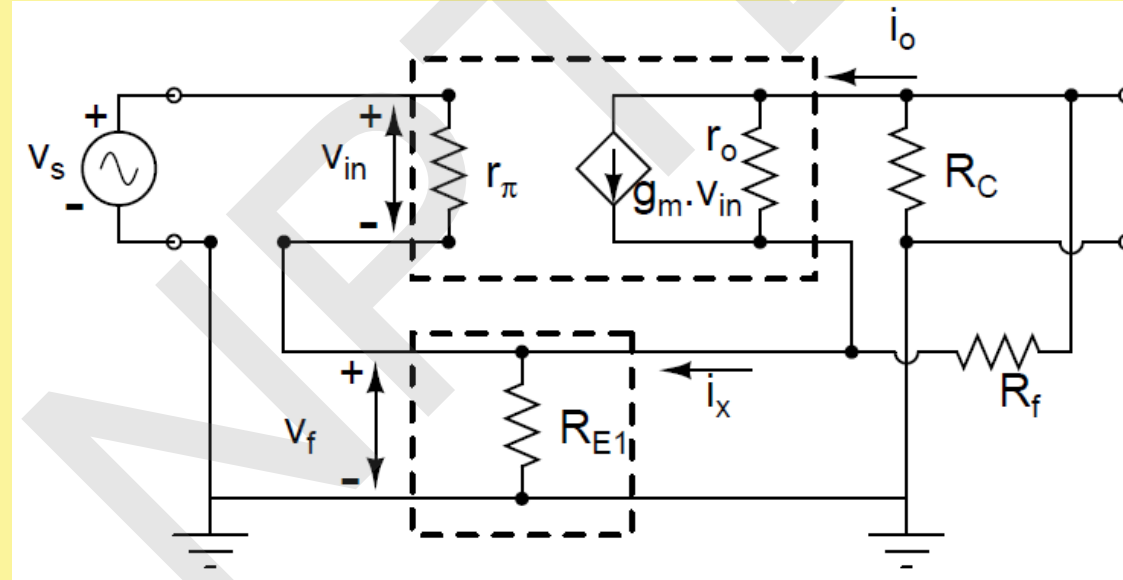
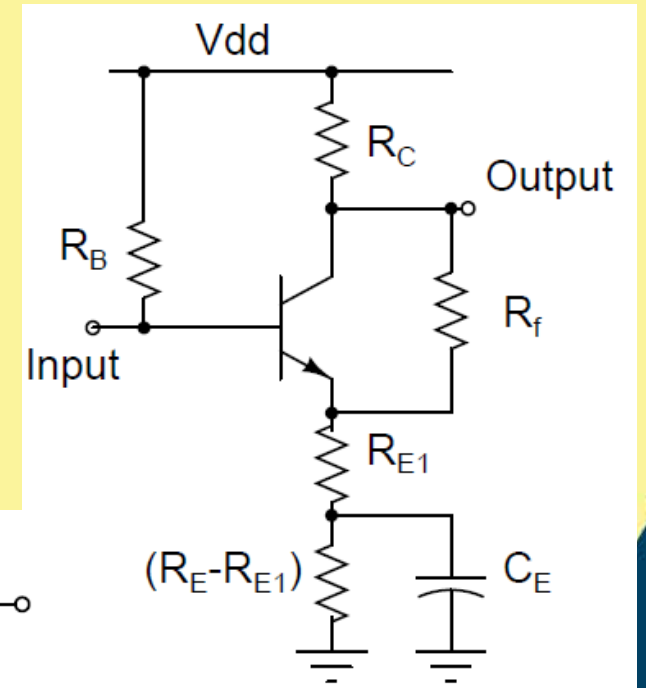
A :

β_{FB} :

R_{in} :

R_{out} :

It is a positive feedback !



Application circuit-3 (contd.)

Feedback configuration: *Voltage-Series (Shunt-Series) feedback*

S_s :

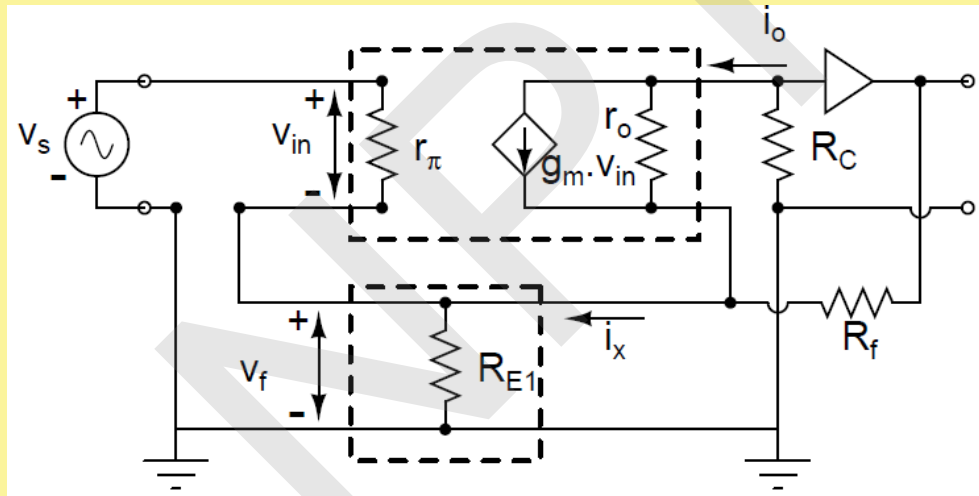
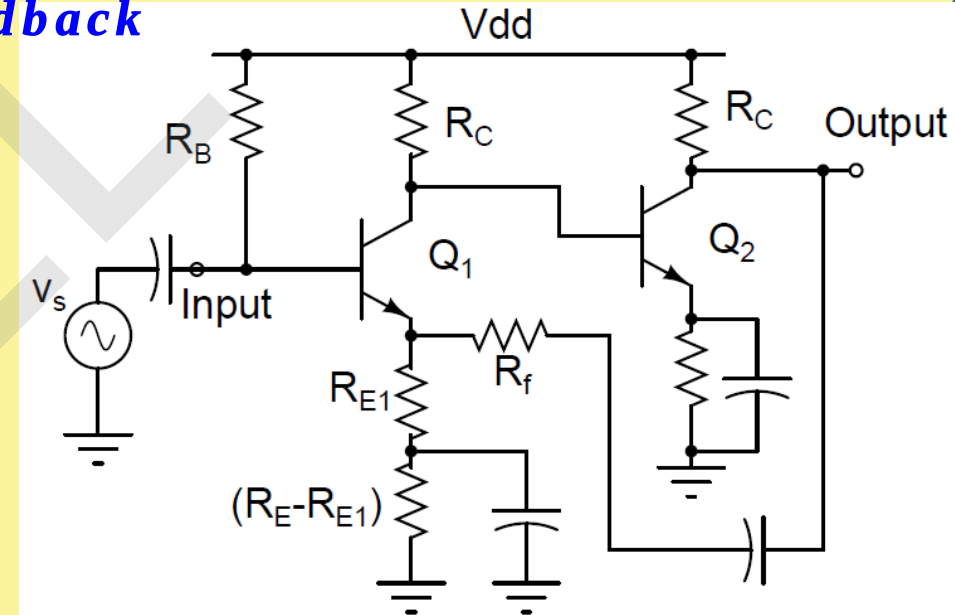
S_o :

A :

β_{FB} :

R_{in} :

R_{out} :



Application circuit-3 (contd.)

Feedback configuration: *Voltage-Series (Shunt-Series) feedback*

$$A : A_v =$$

$$R_{in} = \quad R_{out} =$$

$$\beta_{FB} = R_{E1} / (R_f + R_{E1})$$

Suitable range of R_{E1}

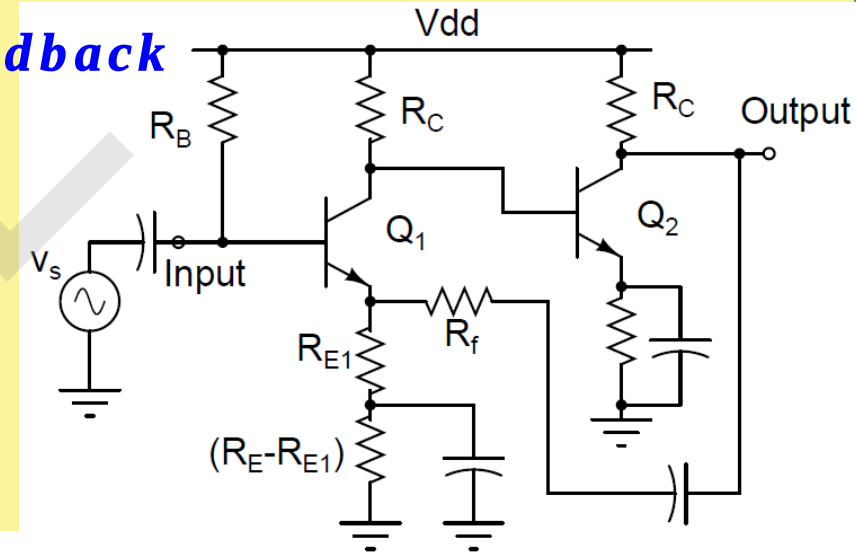
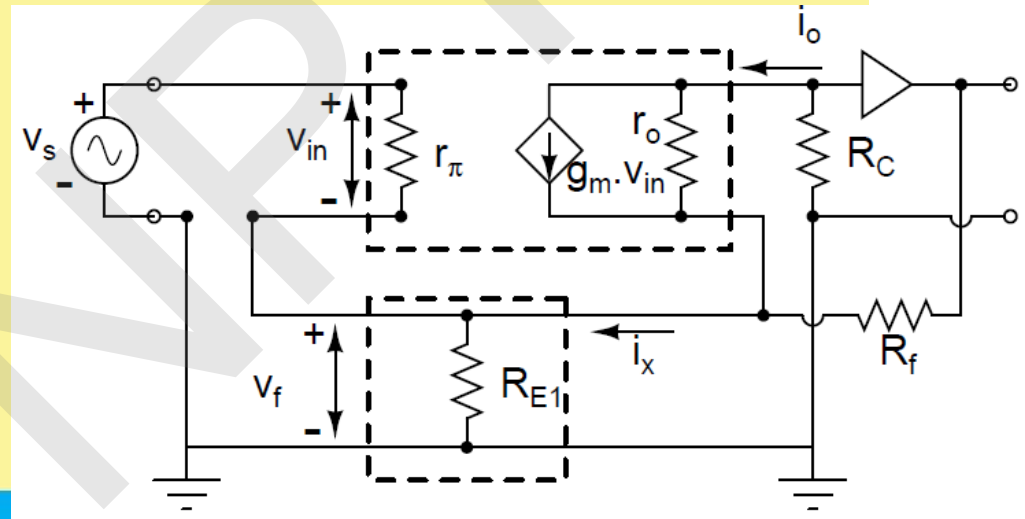
$$R_{out_\beta} \ll R_{in} \quad R_{in_\beta} \gg R_{out}$$

$$A' \cdot \beta_{FB} \gg 1$$

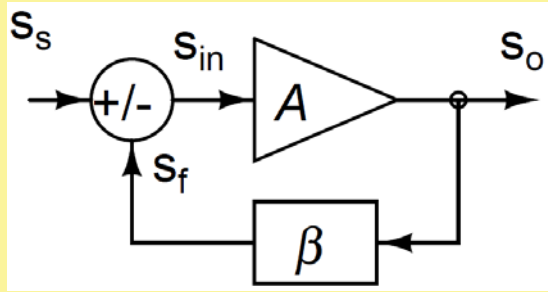
A_f :

R_{in_f} :

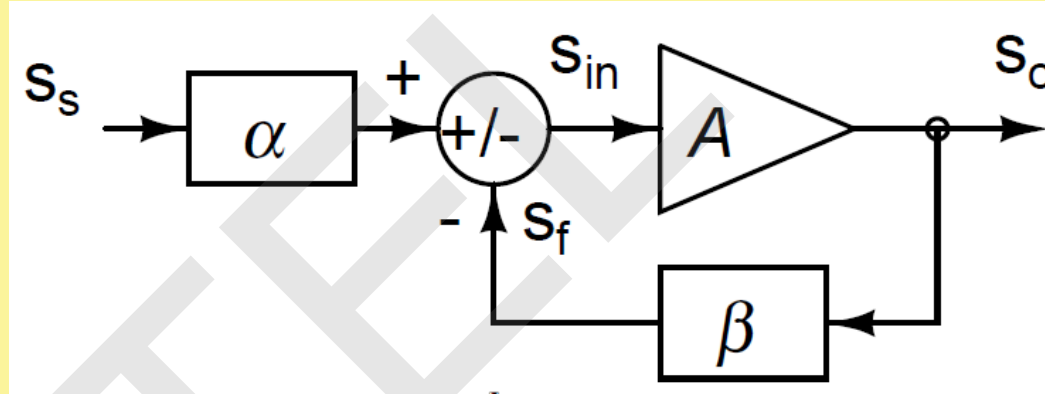
R_{out_f} :



Feedback system with pre-stage: *Basic concepts*



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

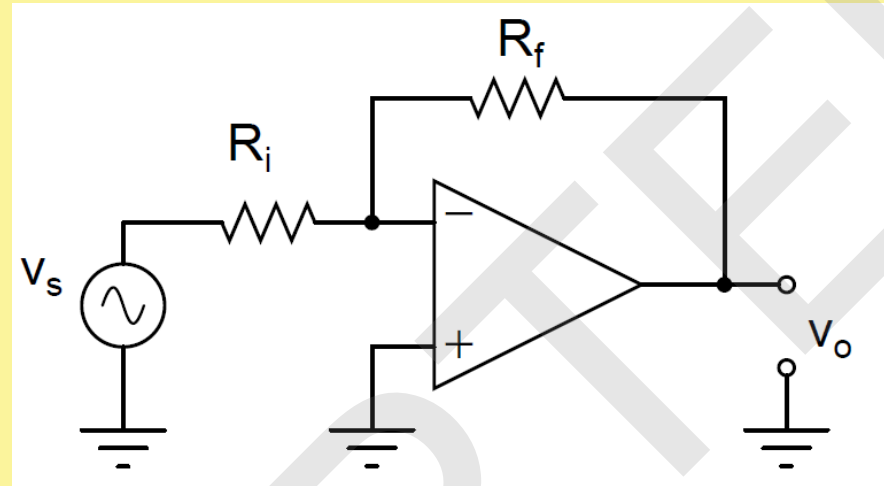
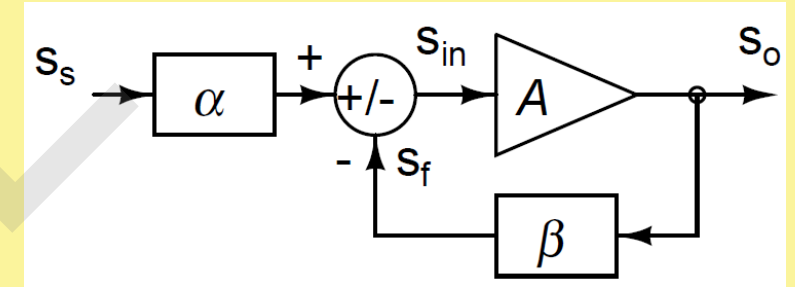


$$A_f = \frac{\alpha \cdot A}{(1 + \beta \cdot A)}$$

- **Basic model of feedback system consists of**
 - **Forward amplifier**
 - **Feedback path/network**
 - **Signal sampler**
 - **Signal mixer**
 - **Pre-stage (Alpha block)**

Feedback system using operational amplifier (Op-Amp)

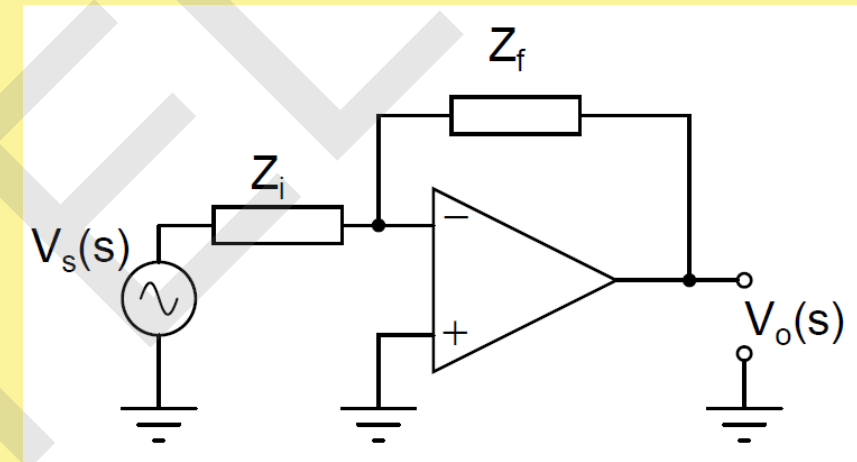
Inverting amplifier:



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

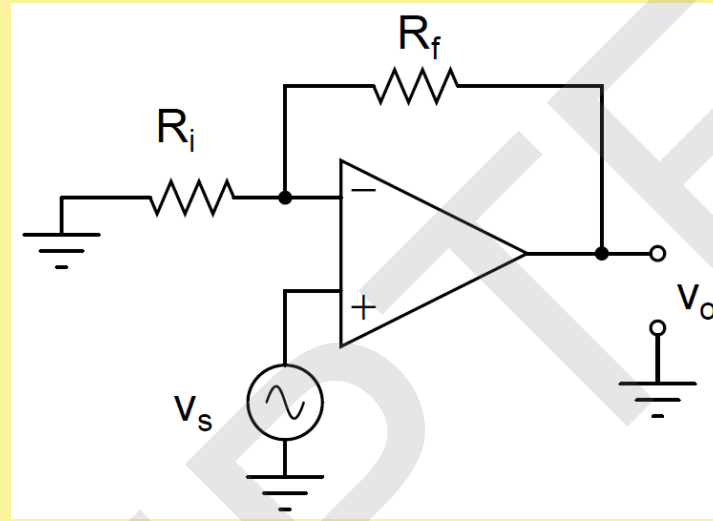
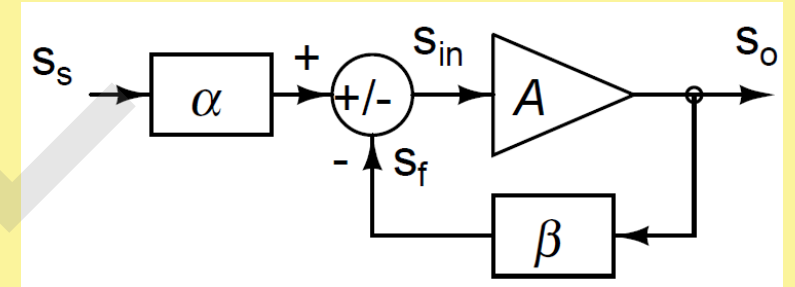
Feedback system using Op-Amp (contd.)

Integrator and Differentiator:



Feedback system using Op-Amp (contd.)

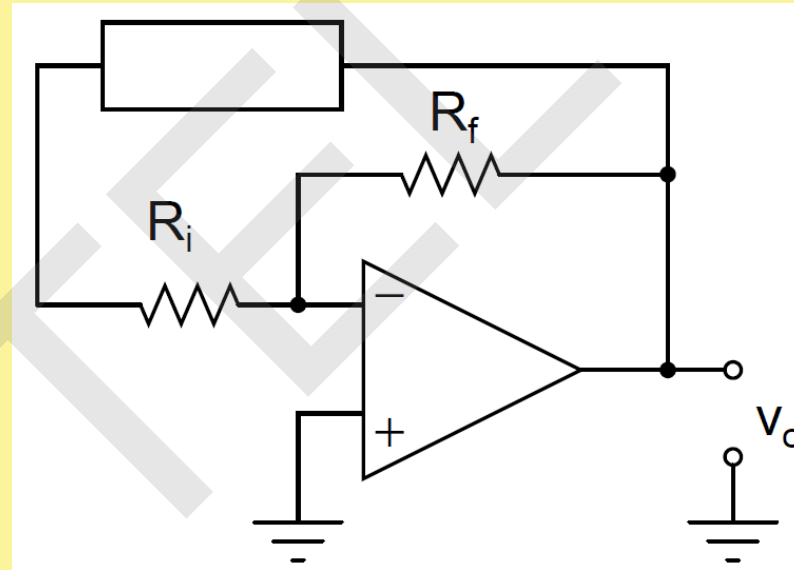
Non-inverting amplifier:



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

Feedback system using Op-Amp (contd.)

Two loop system :



Conclusion

Conclusion:

- ❑ **Application of feedback in BJT amplifiers**
 - ❑ Voltage-shunt (shunt-shunt) F.B.
 - ❑ Current-series (series-series) F.B.
 - ❑ Voltage-series (shunt-series) F.B.
- ❑ **Simple extension of basic FB model**
- ❑ **Application of feedback in op-amp circuits**
 - ❑ Inverting amplifier
 - ❑ Integrator and Differentiator
 - ❑ Non-inverting amplifier
 - ❑ A circuit with two feedback loops





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*Thank
you*

