7. Feedback amplifiers and OPAMP 15 Lectures

(a) Effects of Positive and Negative Feedback. Voltage series, current series, voltage shunt and current shunt feedback and uses for specific amplifiers. Estimation of Input Impedance, Output Impedance, Gain, Stability, Distortion and Noise for voltage series feedback

(b) Operational Amplifiers (Black Box approach): Characteristics of an Ideal and Practical Op-Amp. (IC 741) Open-loop and Closed-loop voltage Gain. Frequency Response. CMRR. Slew Rate and concept of Virtual ground.

(c) Application of OPAMP: D.C. Application: • Inverting and non-inverting amplifiers • Inverting and non-inverting Adder • Differentiator as Subtractor • Logarithmic & anti logarithmic amplifiers • Error amplifier – Comparator – Schmidt Trigger A.C. Application: • Differentiator • Integrator

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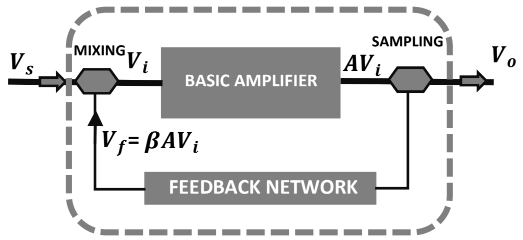
Amplifier is an electronic device which increases the strength of the signal given to it as input.

The process of injecting a fraction of output energy of some device back to the input is known as **Feedback**. It has been found that feedback is very useful in reducing noise and making the amplifier operation stable.

Principle of Feedback Amplifier

A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**. The feedback circuit usually consists of resistors, inductors and capacitors. The concept of feedback amplifier can be understood from the following figure.



Let and the input of the basic Amplifier (without feedback) be V_i. Let the gain of the amplifier (without feedback) be A and the gain of the feedback network is β .

Let the input signal (with feedback) be V_s overall gain (with feedback) of The amplifier be A_f and overall output voltage (with feedback) be V_O.

$V_i = V_s + V_f = V_s + \beta V_O$ Again, $V_O = AV_i = A(V_s + \beta V_O)$

Then $V_O(1 - A\beta) = AV_s$ then $A_f = \frac{V_O}{V_s} = \frac{A}{(1-A\beta)}$. Hence $\boxed{\boldsymbol{A_f = \frac{A}{(1-A\beta)}}}$

<u>N.B:</u> A, β, A_f are in general complex. When $|A_f| > |A|$ then overall gain increased due to feedback, called positive/ regenerative feedback when $|A_f| < |A|$ then overall gain decreased due to feedback, called negative/ degenerative feedback.

Depending upon whether the feedback signal **aids** or **opposes** the input signal, there are two types of feedbacks used.

<u>Positive feedback: -</u> The feedback in which the feedback energy i.e., either voltage or current is **in phase** with the input signal and thus aids the input signal, is called as **Positive feedback** ***(this concept is used in oscillators)*.**

Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as

1. Increasing distortion.
2. Instability.

It is because of these disadvantages the positive feedback is not recommended for the amplifiers. If the positive feedback is sufficiently large, it leads to oscillations, by which oscillator circuits are formed. This concept will be discussed in OSCILLATORS chapter.

Negative feedback: -The feedback in which the feedback energy i.e., either voltage or current is **out of phase** with the input and thus opposes it, is called as **negative feedback**.

Though the **gain** of negative feedback amplifier is **reduced**, there are many advantages of negative feedback such as

1. Stability of gain is improved
2. Reduction in distortion
3. Reduction in noise
4. Increase in input impedance
5. Decrease in output impedance
6. Increase in the range of frequency uniform application/ increase in bandwidth.

It is because of these advantages negative feedback is frequently employed in amplifiers.

Note that: we know that an inverting amplifier introduce a 180° phase change, whereas in noninverting amplifier introduce 0° phase change. That's why for an inviting positive feedback amplifier, the feedback network introduces another 180° phase change, so that overall phase becomes 0° or 360°. But for a non-inviting negative feedback amplifier, the feedback network introduces no phase change, so that overall phase becomes 180°. Similarly, for in noninverting positive feedback amplifier, the feedback network introduces no phase change. But for a non-inviting negative feedback amplifier, the feedback network introduce 180° phase change, so that overall phase becomes 180°.

What are the Types of amplifiers?

There are four types of amplifiers based on input signal fed to it and the output signal extracted from it. They are

1. Voltage amplifier
2. Current amplifier
3. Trans conductance amplifier
4. Trans resistance amplifier

Define voltage gain, current gain, Trans-conductance, Trans-resistance?

1. **Voltage gain** of an amplifier is defined as ratio of output voltage to input voltage fed to amplifier. It is unit less and is denoted by A_V, Voltage gain $A_V = \frac{V_o}{V_i}$
2. **Current gain** of an amplifier is defined as ratio of output current to input current fed to amplifier. It is unit less and is denoted by A_I, Voltage gain $A_I = \frac{I_o}{I_i}$
3. **Trans-conductance** (for transfer conductance), also infrequently called mutual conductance, is the electrical characteristic relating the current through the output of a device to the input voltage of a device. Conductance is the reciprocal of resistance. Trans-admittance (or transfer admittance) is the AC equivalent of trans-conductance.

Trans-conductance of an amplifier is defined as ratio of output current to input voltage fed to amplifier. It is specified in units of mhos (or) Siemens and is denoted by g_m, Trans-conductance $G_m = \frac{I_o}{V_i}$

4. **Trans-resistance** (for transfer resistance), also infrequently referred to as mutual resistance, is the dual of trans-conductance. It is the electrical characteristic relating the voltage across the output of a device to the current through the input of a device. Trans-impedance (or, transfer impedance) is the AC equivalent of trans-resistance, and is the dual of trans-admittance.

Trans-resistance of an amplifier is defined as ratio of output voltage to input current fed to amplifier. It is specified in units of ohms and is denoted by r_m, Trans-conductance $R_m = \frac{V_o}{I_i}$

What are the Ideal input and output resistances of various amplifiers?

Parameter/Type of amplifier	Voltage amplifier	Current amplifier	Trans-conductance amplifier	Trans-resistance amplifier
Input resistance	∞	**0**	∞	**0**
Output resistance	**0**	∞	∞	**0**

What is an Audio amplifier?

Audio amplifiers are electronic power amplifiers used to amplify low intensity audio signals to a level suitable to drive loud speakers. The audio frequencies are in the range 20 Hz to 20,000 Hz. Normally Class AB power amplifiers are used to do audio amplification. Phase distortion will not create much problem in audio amplifiers.

What is a Video amplifier?

These amplifiers are used to amplify video signals. These amplifiers have varying bandwidths based on the type of filter used at each point. Typically, a low-pass amplifier will be having a bandwidth in the range from 2 to 10 MHz Some of the applications are in television receivers, cathode-ray-tube computer terminals, and pulse amplifiers. The phase distortion is of prime concern in video amplifiers; hence extra elements are added to nullify distortion.

What is Power amplifier?

A power amplifier stage is an amplifier optimized to deliver high output power. Special attention has to be paid in designing such amplifiers as the power dissipation across the junction raises its temperature and eventually destroys it. In practice we can observe that the power transistors are bulky in nature to handle high powers as high surface area leads to high heat removing capacity.

Classification of Feedback Systems

Thus far we have seen the way in which the output signal is "fed back" to the input terminal, and for feedback systems this can be of either, **Positive Feedback** or **Negative Feedback**. But the manner in which the output signal is measured and introduced into the input circuit can be very different leading to four basic classifications of feedback.

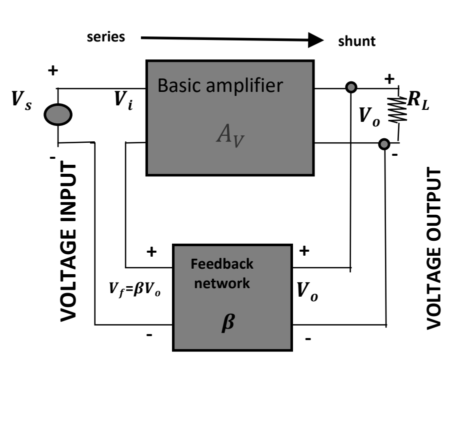
Based on the input quantity being amplified, and on the desired output condition, the input and output variables can be modelled as either a voltage or a current. As a result, there are four basic classifications of single-loop feedback system in which the output signal is fed back to the input and these are:

1. **Series-Shunt Configuration** – Voltage in and Voltage out or *Voltage Controlled Voltage Source* (VCVS).
2. **Shunt-Series Configuration** – Current in and Current out or *Current Controlled Current Source* (CCCS).
3. **Series-Series Configuration** – Voltage in and Current out or *Voltage Controlled Current Source* (VCCS).
4. **Shunt-Shunt Configuration** – Current in and Voltage out or *Current Controlled Voltage Source* (CCVS).

These names come from the way that the feedback network connects between the input and output stages as shown.

Series-Shunt Feedback Systems

Series-Shunt Feedback, also known as **voltage series feedback**, operates as a voltage-voltage controlled feedback system. The error voltage fed back from the feedback network is in *series* with the input. The voltage which is fed back from the output being proportional to the output voltage, V_O as it is parallel, or shunt connected.



For the series-shunt connection, the configuration is defined as the output voltage, V_O to the input voltage, V_S . Most inverting and non-inverting operational amplifier circuits operate with series-shunt feedback producing what is known as a "voltage amplifier". As a voltage amplifier the ideal input resistance, R_{in} is very large, and the ideal output resistance, R_{out} is very small.

Then the "series-shunt feedback configuration" works as a true voltage amplifier as the input signal is a voltage and the output signal is a voltage, so the transfer gain is given as: $A_V = \frac{V_O}{V_S}$.

Note that this quantity is dimensionless as its units are volts/volts.

Overall gain, input resistance and output resistance calculation Series-Shunt Feedback Systems

Overall gain:-

Suppose A_V, β, A_{Vf} are gain without feedback, feedback factor and gain with feedback and let all the parameters are real.

$V_O = A_V V_i = A_V(V_s \pm V_f) = A_V(V_s \pm \beta V_O)$ [$as\ V_f = \beta V_O$ & taking '+' sign and '-' sign for positive and negative feedback]

Then $V_O(1 \mp A_V\beta) = A_V V_s$ then $A_{Vf} = \frac{V_O}{V_s} = \frac{A_V}{(1\mp A_V\beta)}$. Hence $\boxed{\boldsymbol{A_{Vf} = \frac{A_V}{(1\mp A_V\beta)}}}$**..................(i)**

Note that in equation (i) '-'sign for positive feedback and '+' sign for negative feedback.

Input resistance:-

$R_{if} = \frac{V_S}{I_S} = \frac{V_S}{I_i}$ ....(ii) [as input is in series] again $R_i = \frac{V_i}{I_i} = \frac{V_O}{A_V I_i}$ then $I_i = \frac{V_O}{A_V R_i}$

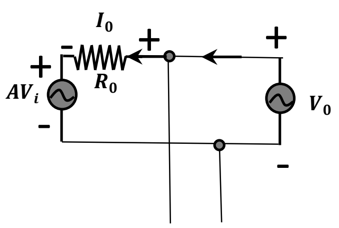
Hence from equation (ii) $R_{if} = \frac{V_S}{I_i} = \frac{V_S A_V R_i}{V_O} = \frac{(1\mp A_V\beta)}{A_V} A_V R_i = R_i(1 \mp A_V\beta)$. Hence $\boxed{R_{if} = R_i(1 \mp A_V\beta)}$..............(iii)

Note that in equation (iii) '-'sign for positive feedback and '+' sign for negative feedback.

Output resistance:-

The output impedance is defined as the ratio of output voltage and output current when <u>input is short circuited</u> and <u>load is disconnected and output is driven by a test source</u> V_o

$R_{of}\big|_{V_s=0} = \frac{V_o}{I_o}$ Now from output circuit $V_o = I_o R_o + A_V V_i$

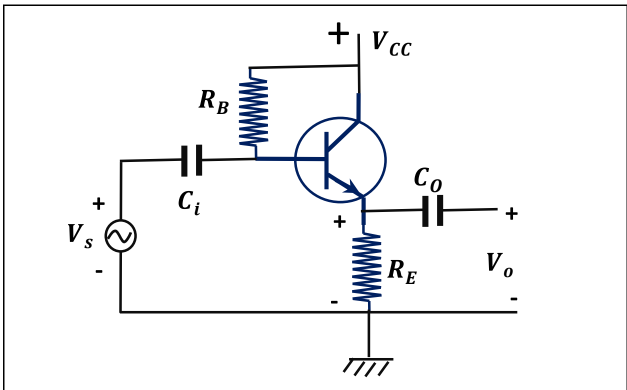


where R_o = output resistance without feedback

then $I_o R_o = V_o - A_V V_i$ Again from input circuit $V_i = (0 \pm V_f)$

Then $I_o R_o = V_o \mp A_V V_f = V_o \mp A_V \beta V_O = V_O(1 \mp A_V\beta)$

$R_{of}\big|_{V_s=0} = \frac{V_o}{I_o} = \frac{V_O R_O}{V_O(1\mp A_V\beta)}$. Then $\boxed{R_{of}\big|_{V_s=0} = \frac{R_O}{(1\mp A_V\beta)}}$.

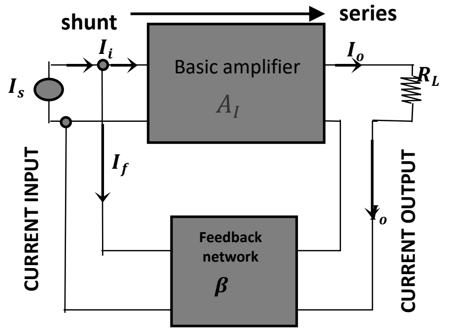


<u>**Practical series shunt feedback circuit: -**</u> The emitter follower circuit is an example of series shunt or voltage series feedback circuit. The output voltage V_o taken across R_L totally feedback to the input, which act in series with the input voltage.

Here $\beta = \frac{V_f}{V_o} = 1$

Shunt-Series Feedback Systems

Shunt-Series Feedback, also known as *shunt current feedback*, operates as a current-current controlled feedback system. The feedback signal is proportional to the output current, I_O flowing in the load. The feedback signal is fed back in parallel or *shunt* with the input as shown.



For the shunt-series connection, the configuration is defined as the output current, I_O to the input current, I_S. In the shunt-series feedback configuration the signal fed back is in parallel with the input signal and as such it is the currents, not the voltages that add.

This parallel shunt feedback connection will not normally affect the voltage gain of the system, since for a voltage output a voltage input is required. Also, the series connection at the output increases output resistance, R_{out} while the shunt connection at the input decreases the input resistance, R_{in}.

Then the "shunt-series feedback configuration" works as a true current amplifier as the input signal is a current and the output signal is a current, so the transfer gain is given as: $A_I = \frac{I_O}{I_S}$. Note that this quantity is dimensionless as its units are amp/amp.

Overall gain, input resistance and output resistance calculation Shunt-Series Feedback Systems

Overall gain:-

Suppose A_I, β, A_{If} are gain without feedback, feedback factor and gain with feedback and let all the parameters are real

$I_O = A_I I_i = A_I(I_s \pm I_f) = A_I(I_s \pm \beta I_O)$ [$as\ I_f = \beta I_O$ & taking '+' sign and '-' sign for positive and negative feedback]

Then $I_O(1 \mp A_I\beta) = A_I I_s$ then $A_{If} = \frac{I_O}{I_s} = \frac{A_I}{(1\mp A_I\beta)}$. Hence $\boxed{\boldsymbol{A_{If} = \frac{A_I}{(1\mp A_I\beta)}}}$**………………..(i)**

Note that in equation (i) '-'sign for positive feedback and '+' sign for negative feedback.

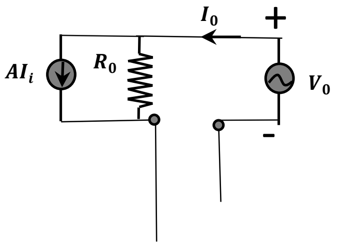
Input resistance:-

$R_{if} = \frac{V_s}{I_s} = \frac{V_i}{I_s}$ [as input is in shunt] $= \frac{I_i R_i}{I_s}$ [as $R_i = \frac{V_i}{I_i}$] $= \frac{I_O}{A_I}\frac{R_i}{I_s} = \frac{A_I}{(1\mp A_I\beta)}\frac{R_i}{A_I} = \frac{R_i}{(1\mp A_I\beta)}$ Hence $\boxed{R_{if} = \frac{R_i}{(1\mp A_I\beta)}}$……………(iii)

Note that in equation (iii) '- 'sign for positive feedback and '+' sign for negative feedback.

Output resistance: -

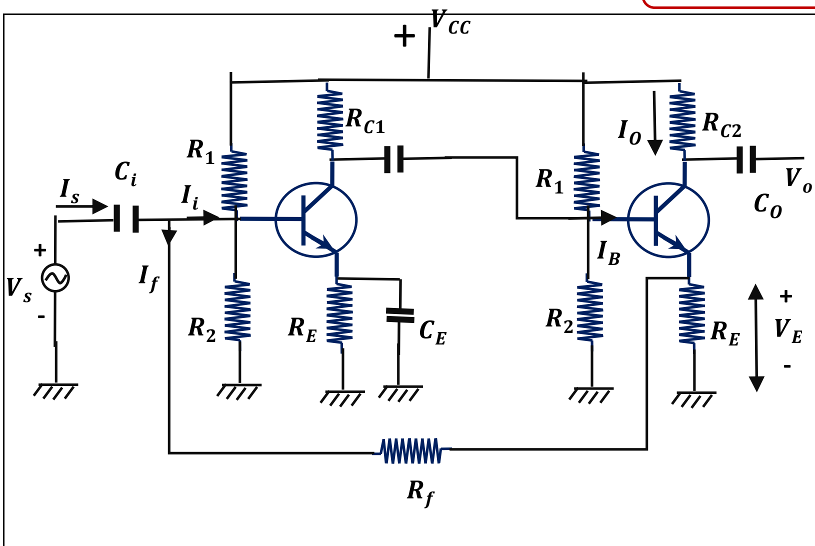
The output impedance is defined as the ratio of output voltage and output current when <u>input is short circuited</u> and <u>load is disconnected and output is driven by a test source</u> V_o that means $R_{of}\big|_{V_s=0} = \frac{V_o}{I_o}$



Now from output circuit $I_o = \frac{V_o}{R_o} + A_I I_i$ where R_o = output resistance without feedback

Again from input circuit $I_i = (0 \pm I_f)$ Then $I_o = \frac{V_o}{R_o} \pm A_I I_f = \frac{V_o}{R_o} \pm A_I\beta I_O$ [$as\ I_f = \beta I_O$]

$\frac{V_o}{R_o} = I_o(1 \mp A_I\beta)$ then, $R_{of}\big|_{V_s=0} = \frac{V_o}{I_O} = \frac{R_O I_O(1\mp A_I\beta)}{I_O}$. Then $\boxed{R_{of}\big|_{V_s=0} = R_o(1 \mp A_I\beta).}$



Practical shunt series feedback circuit: -

Here feedback current $I_f = \frac{(V_S - V_E)}{R_f} = -\frac{V_E}{R_f}$

Taking $V_S < V_E$

Now $V_E = (I_o + I_B + I_f)R_E \approx (I_o + I_f)R_E$

Hence $I_f = -\frac{(I_o+I_f)R_E}{R_f} = -\frac{(I_o)R_E}{R_f} - \frac{(I_f)R_E}{R_f}$

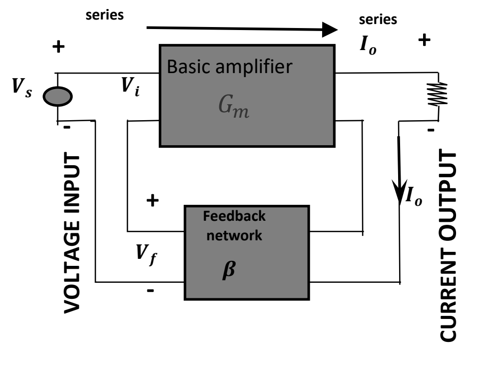
Or, $I_f\left(1 + \frac{R_E}{R_f}\right) = -\frac{I_o R_E}{R_f}$

Hence $I_f = -\left(\frac{R_E}{R_E+R_f}\right) I_o$

Hence $\beta = \frac{I_f}{I_O} = -\left(\frac{R_E}{R_E+R_f}\right)$

Series-Series Feedback Systems

Series-Series Feedback Systems, also known as *series current feedback*, operates as a voltage-current controlled feedback system. In the series current configuration, the feedback error signal is in *series* with the input and is proportional to the load current, I_O. Actually, this type of feedback converts the current signal into a voltage which is actually fed back and it is this voltage which is subtracted from the input.



For the series-series connection, the configuration is defined as the output current, I_O to the input voltage, V_S. Because the output current, I_O of the series connection is fed back as a voltage, this increases both the input and output impedances of the system. Therefore, the circuit works best as a trans-conductance amplifier with the ideal input resistance, R_{in} being very large, and the ideal output resistance, R_{out} is also very large.

Then the "series-series feedback configuration" functions as trans-conductance type amplifier system as the input signal is a voltage and the output signal is a current. for a series-series feedback circuit the transfer gain is given as: $G_m = \frac{I_O}{V_S}$.

Overall gain, input resistance and output resistance calculation Series -Series Feedback Systems

Overall gain:-

Suppose G_m, β, G_{mf} are gain without feedback, feedback factor and gain with feedback and let all the parameters are real

$I_O = G_m V_i == G_m(V_s \pm V_f) = G_m(V_s \pm \beta I_O)$ [$as\ V_f = \beta I_O$ & taking '+' sign and '-' sign for positive and negative feedback]

Then $I_O(1 \mp G_m\beta) = G_m V_s$ then $G_{mf} = \frac{I_O}{V_S} = \frac{G_m}{(1 \mp G_m\beta)}$. Hence $\boxed{G_{mf} = \frac{G_m}{(1 \mp G_m\beta)}}$ **………………..(i)**

Note that in equation (i) '-'sign for positive feedback and '+' sign for negative feedback.

Input resistance:-

$R_{if} = \frac{V_S}{I_S} = \frac{V_S}{I_i}$ ……………(ii) [as input is in series] again $R_i = \frac{V_i}{I_i} = \frac{I_O}{G_m\, I_i}$ then $I_i = \frac{I_O}{G_m R_i}$

Hence from equation (ii) $R_{if} = \frac{V_S}{I_i} = \frac{V_S G_m R_i}{I_O} = \frac{(1 \mp G_m\beta)}{G_m} G_m R_i = R_i(1 \mp G_m\beta)$. Hence $\boxed{R_{if} = R_i(1 \mp G_m\beta)}$……………(iii)

Note that in equation (iii) '-'sign for positive feedback and '+' sign for negative feedback.

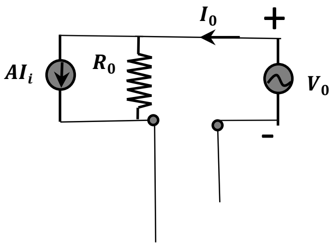
$R_{if} = \frac{V_S}{I_S} = \frac{V_i}{I_S} = \frac{I_i R_i}{I_S} = \frac{I_O}{A}\frac{R_i}{I_S} = \frac{A}{(1 \mp A\beta)}\frac{R_i}{A} = \frac{R_i}{(1 \mp A\beta)}$ ……………(ii) [as input is in shunt] again $R_i = \frac{V_i}{I_i} =$

Hence $\boxed{R_{if} = \frac{R_i}{(1 \mp A\beta)}}$…………….(iii)

Note that in equation (iii) '-'sign for positive feedback and '+' sign for negative feedback.

Output resistance:-

The output impedance is defined as the ratio of output voltage and output current when <u>input is short circuited</u> and <u>load is disconnected and output is driven by a test source</u> V_o



$R_{of}\big|_{V_S=0} = \frac{V_O}{I_O}$ Now from output circuit $I_o = \frac{V_O}{R_O} + G_m I_i$

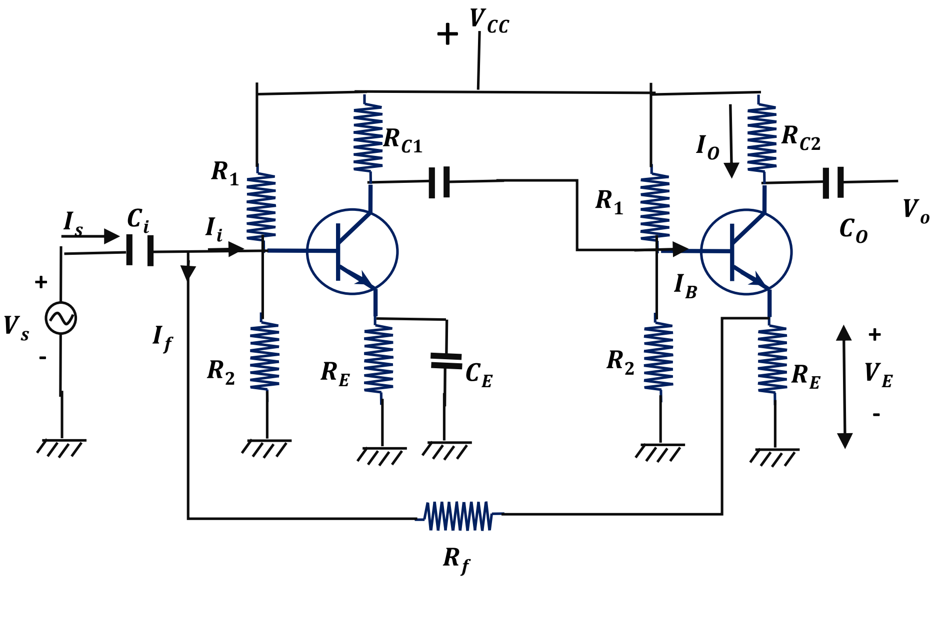
where R_o = output resistance without feedback

then $I_o = \frac{V_O}{R_O} + G_m I_i$ Again from input circuit $V_i = (0 \pm I_f)$

Then $I_o = \frac{V_O}{R_O} \pm G_m I_f = \frac{V_O}{R_O} \pm G_m \beta I_O$

$\frac{V_O}{R_O} = I_o(1 \mp G_m\beta)$

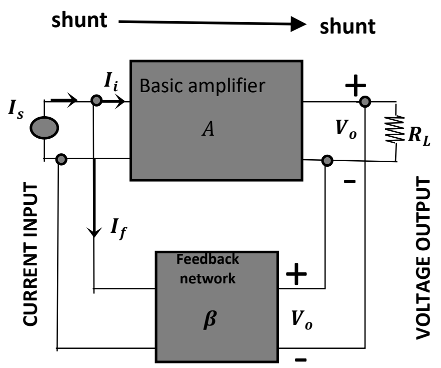
$R_{of}\big|_{V_S=0} = \frac{V_O}{I_O} = \frac{R_O I_O(1 \mp G_m\beta)}{I_O}$. Then $\boxed{R_{of}\big|_{V_S=0} = R_o(1 \mp G_m\beta).}$

	**<u>Practical shunt series feedback circuit: -</u>**

<u>Shunt-Shunt Feedback Systems</u>

Shunt-Shunt Feedback Systems, also known as *shunt voltage feedback*, operates as a current-voltage controlled feedback system. In the shunt-shunt feedback configuration the signal fed back is in parallel with the input signal. The output voltage is sensed and the current is subtracted from the input current in shunt, and as such it is the currents, not the voltages that subtract.

Shunt-Shunt Feedback System

	For the shunt-shunt connection, the configuration is defined as the output voltage, V_O to the input current, I_S. As the output voltage is fed back as a current to a current-driven input port, the shunt connections at both the input and output terminals reduce the input and output impedance. therefore, the system works best as a trans-resistance system with the ideal input resistance, R_{in} being very small, and the ideal output resistance, R_{out} also being very small. Then the shunt voltage configuration works as trans-resistance type voltage amplifier as the input signal is a current and the output signal is a voltage, so the transfer gain is given as: $R_m = \frac{V_O}{I_S}$.

Feedback Systems Summary

We have seen that a **Feedback System** is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system, and depending on the type of feedback used, the feedback signal which is mixed with the systems input signal, can be either a voltage or a current.

Feedback will always change the performance of a system and feedback arrangements can be either positive (regenerative) or negative (degenerative) type feedback systems. If the feedback loop around the system produces a loop-gain which is negative, the feedback is said to be negative or degenerative with the main effect of the negative feedback is in reducing the systems gain.

If however the gain around the loop is positive, the system is said to have positive feedback or regenerative feedback. The effect of positive feedback is to increase the gain which can cause a system to become unstable and oscillate especially if GH = -1.

We have also seen that block-diagrams can be used to demonstrate the various types of feedback systems. In the block diagrams above, the input and output variables can be modelled as either a voltage or a current and as such there are four combinations of inputs and outputs that represent the possible types of feedback, namely: Series Voltage Feedback, Shunt Voltage Feedback, Series Current Feedback and Shunt Current Feedback.

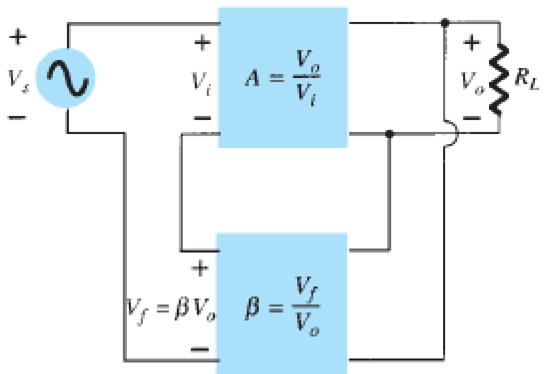
The names for these different types of feedback systems are derived from the way that the feedback network connects between the input and output stages either in parallel (shunt) or series.

In the next tutorial about Feedback Systems, we will look at the effects of *Negative Feedback* on a system and see how it can be used to improve a control systems stability.

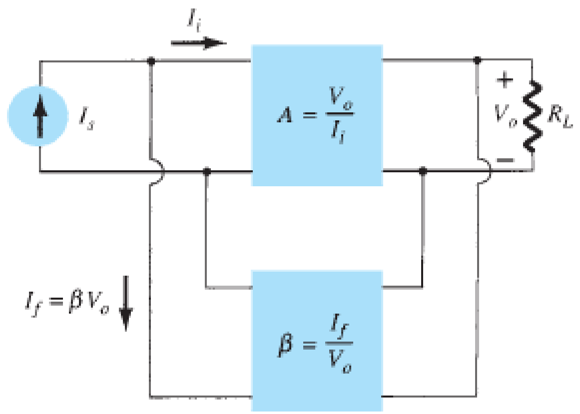
There are four basic ways of connecting the feedback signal. Both voltage and current can be feedback to the input either in series or parallel. Specifically, there can be

1. Voltage Series Feedback, 2. Voltage Shunt feedback, 3. Current Series Feedback, 4. Current Shunt negative feedback

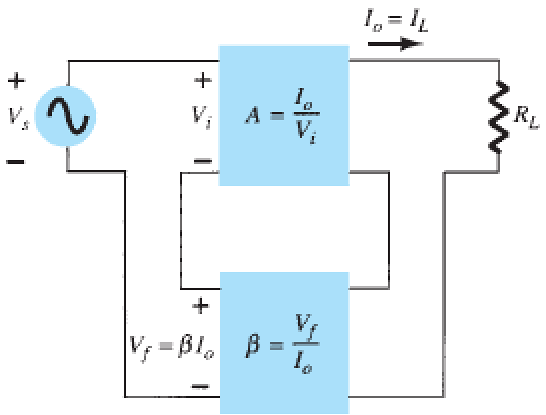
1. Voltage Series Feedback: In this type a part of output voltage fed back in series with the input signal, resulting in overall gain reduction. It reduces the output impedance and increase the input resistance.



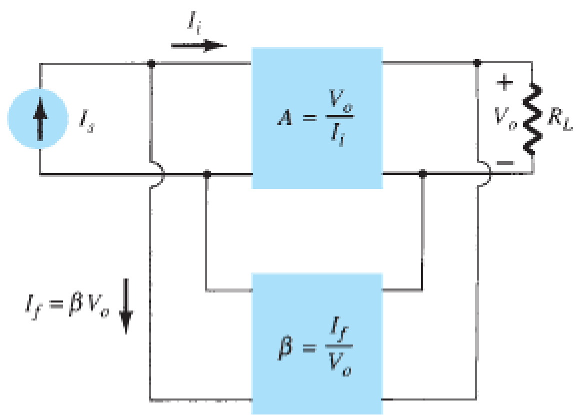
1. Voltage Shunt feedback: In this type a part of output voltage fedback in shunt (parallel) with an input signal.The voltage-shunt feedback provides a stabilised overall gain and decrease both input and output resistance.



1. Current Series Feedback: In current series feedback a voltage is develop which is proportional to the output current. This is called current feedback even though it is a voltage that substracted from the input voltage.Because of the series connection at the input and output,the input and output resistance get increased.This type of amplifier is called transconductance amplifier.



Current Shunt negative feedback:It is called as series derived,shunt fed feedback.The shunt connection at the input reduces the input impedance and series connection at the output increases the output impedance.



The input and output impedance for each type is given by following table.

Voltage-Series	Current-Series	Voltage-Shunt	Current-Shunt
Z_{if} $Z_i(1 + \beta A)$ (increased)	$Z_i(1 + \beta A)$ (increased)	$\dfrac{Z_i}{1 + \beta A}$ (decreased)	$\dfrac{Z_i}{1 + \beta A}$ (decreased)
Z_{of} $\dfrac{Z_o}{1 + \beta A}$ (decreased)	$Z_o(1 + \beta A)$ (increased)	$\dfrac{Z_o}{1 + \beta A}$ (decreased)	$Z_o(1 + \beta A)$ (increased)

The feedback factor for each configuration is shown in the each figure