Analog Circuits

Day-11

Feedback Amplifiers

Introduction of Feedback Amplifiers:

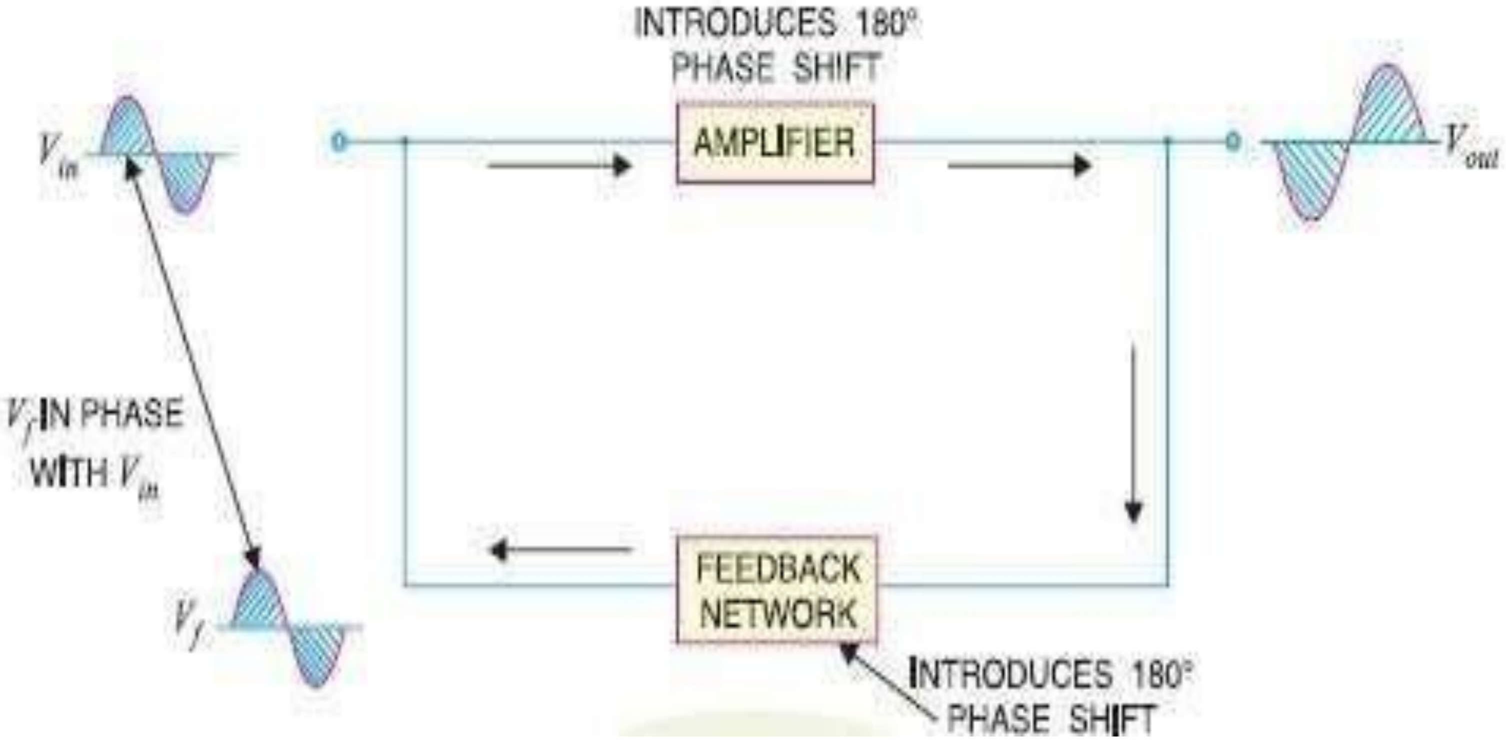
The phenomenon of feeding a portion of the output signal back to the input circuit is known as feedback. The effect results in a dependence between the output and the input and an effective control can be obtained in the working of the circuit. Feedback is of two types.

- Positive Feedback
- Negative Feedback

Positive or regenerate feedback:

- In positive feedback, the feedback energy (voltage or currents), is in phase with the input signal and thus aids it. Positive feedback increases gain of the amplifier also increases distortion, noise and instability.
- Because of these disadvantages, positive feedback is seldom employed in amplifiers. But the positive feedback is used in oscillators.

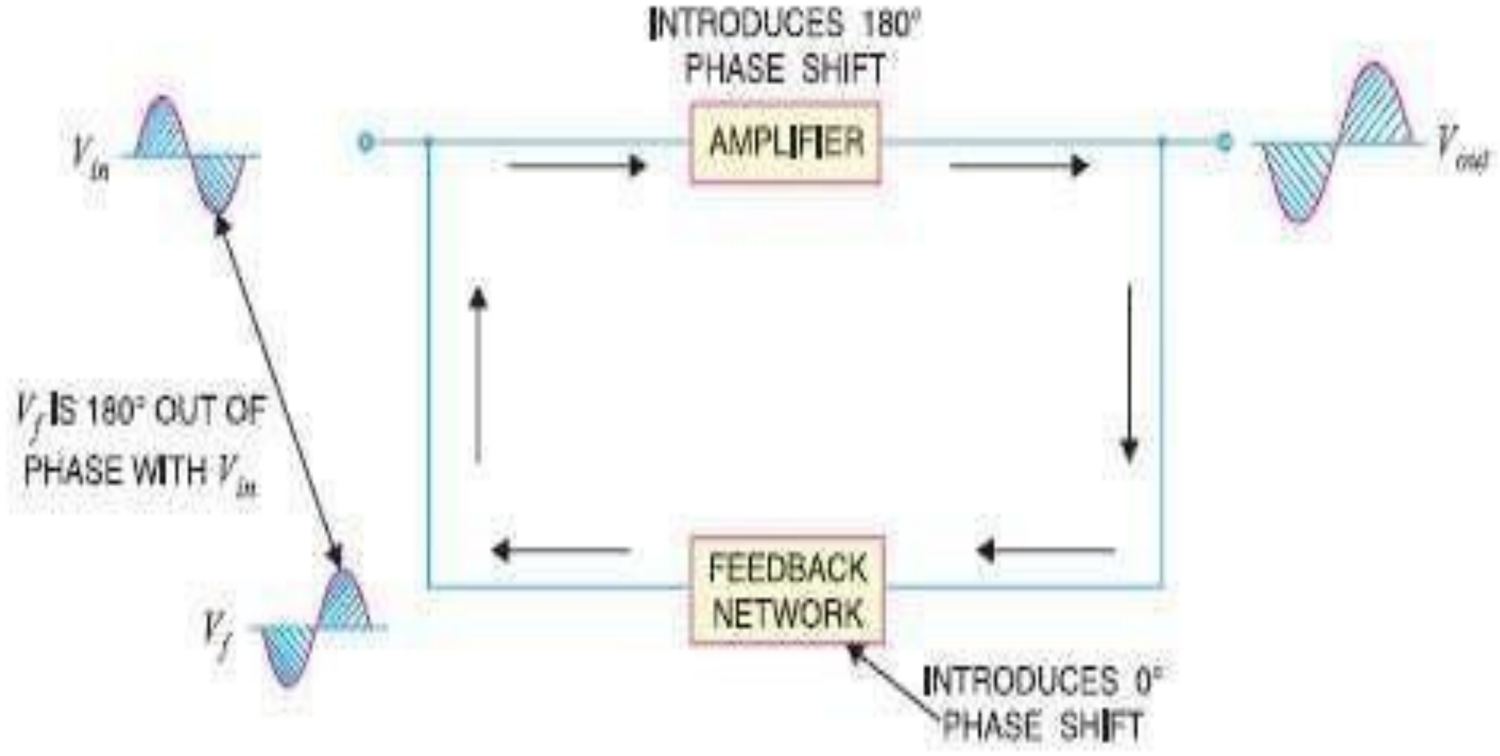
Positive Feedback



Negative or Degenerate feedback:

- In negative feedback, the feedback energy (voltage or current), is out of phase with the input signal and thus opposes it.
- Negative feedback reduces gain of the amplifier. It also reduce distortion, noise and instability.
- This feedback increases bandwidth and improves input and output impedances.
- Due to these advantages, the negative feedback is frequently used in amplifiers.

Negative Feedback

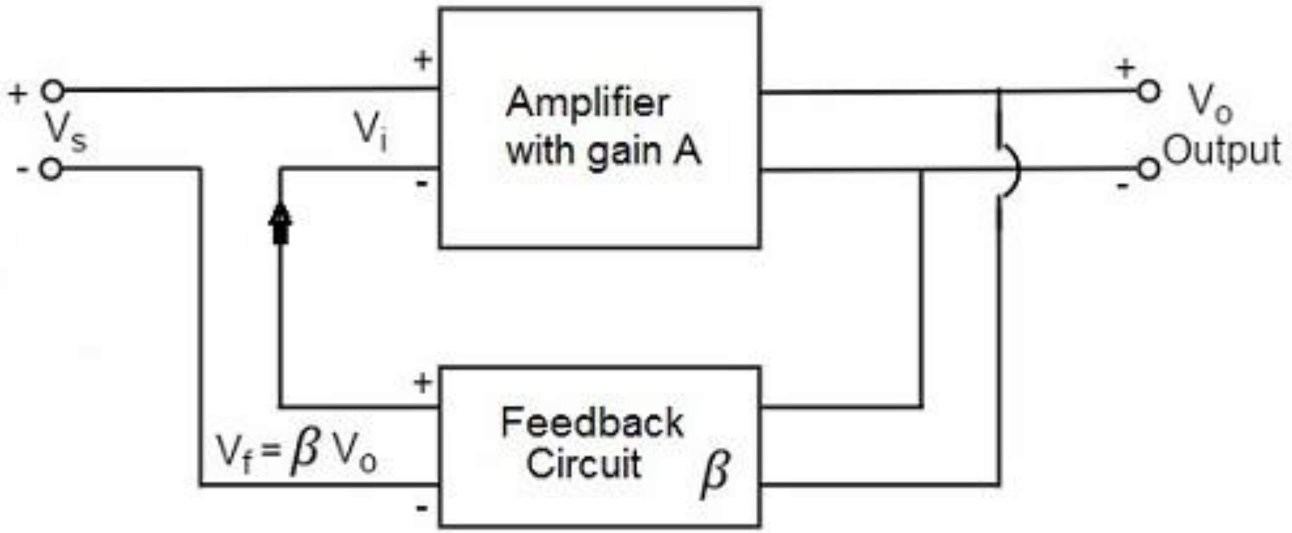


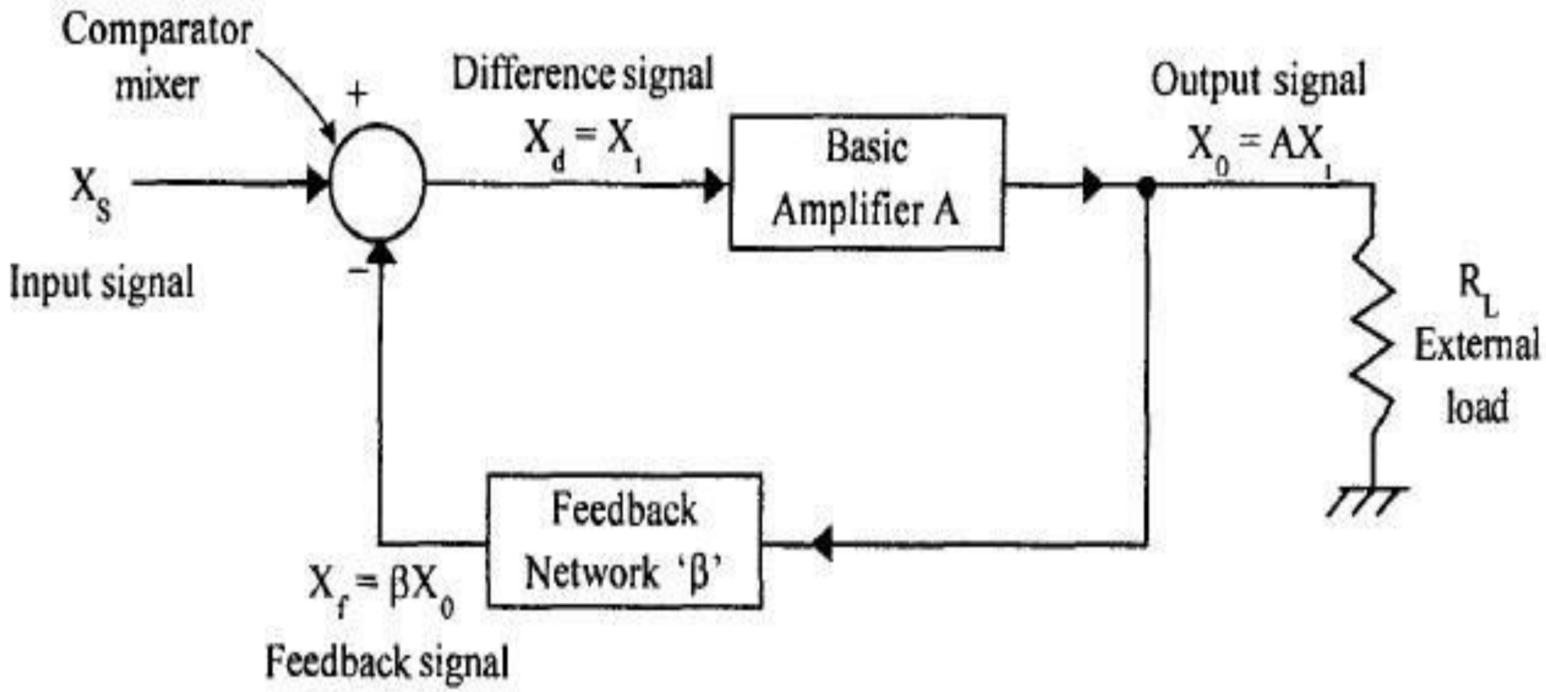
Comparison Between Positive and Negative Feed Back:

S.No.	Negative Feedback	Positive Feedback
1.	Feedback energy is out phase with their input signal	Feedback energy is in phase with the input signal.
2.	Gain of the amplifier decreases	Gain of the amplifier increases
3.	Gain stability increases	Gain stability decreases
4.	Noise and distortion decreases.	Noise and distribution increases.
5.	Increase the band width	Decreases bandwidth
6.	Used in amplifiers	Used in Oscillators

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. The concept of feedback amplifier can be understood from the following figure.





Generalized feedback amplifier

In the above figure, the gain of the amplifier is represented as A. The gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i. The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is subtracted for negative feedback, from the signal voltage V_s. Now,

$$\mathbf{V_i = V_s - V_f = V_s - \beta V_o}$$

The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.

The output V_o must be equal to the input voltage (V_s - βV_o) multiplied by the gain A of the amplifier.
Hence,

$$(Vs - \beta Vo)A = Vo$$

$$AVs - A\beta Vo = Vo$$

$$AVs = Vo(1 + A\beta)$$

$$Vo/Vs = A/(1 + A\beta)$$

Therefore, the gain of the amplifier with feedback is given by

$$A_f = A/(1 + A\beta)$$

Effect of negative feedback on amplifier performance:

The effect of negative feedback on an amplifier is considered in relation to gain, gain stability, distortion, noise, input/output impedance and bandwidth and gain-bandwidth product.

Gain:

The gain of the amplifier with feedback is given by

$$A_f = A/(1+A\beta)$$

Hence, gain decreases with feedback.

Gain Stability:

An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations,

$$\mathbf{A_f = A/(1+A\beta)}$$

For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product **Aβ** much greater than unity. Therefore, in the above relation, '1' can be neglected as compared to **Aβ** and the expression becomes

$$\mathbf{A_f = A/(1+A\beta) = 1/\beta}$$

It may be seen that the gain now depends only upon feedback fraction, **β,** i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.

Distortion:

A power amplifier will have non-linear distortion because of large signal variations. The negative feedback reduces the nonlinear distortion. It can be proved mathematically that:

$$\mathbf{D_f = D/(1+A\beta)}$$

Where D = distortion in amplifier without feedback

D_f = distortion in amplifier with negative feedback

It is clear that by applying negative feedback, the distortion is reduced by a factor **(1+Aβ)**

Noise :

There are numbers of sources of noise in an amplifier. The noise *N* can be reduced by the factor of **(1+Aβ),** in a similar manner to non-linear distortion, so that the noise with feedback is given by

$$\mathbf{N_f = N/(1+A\beta)}$$

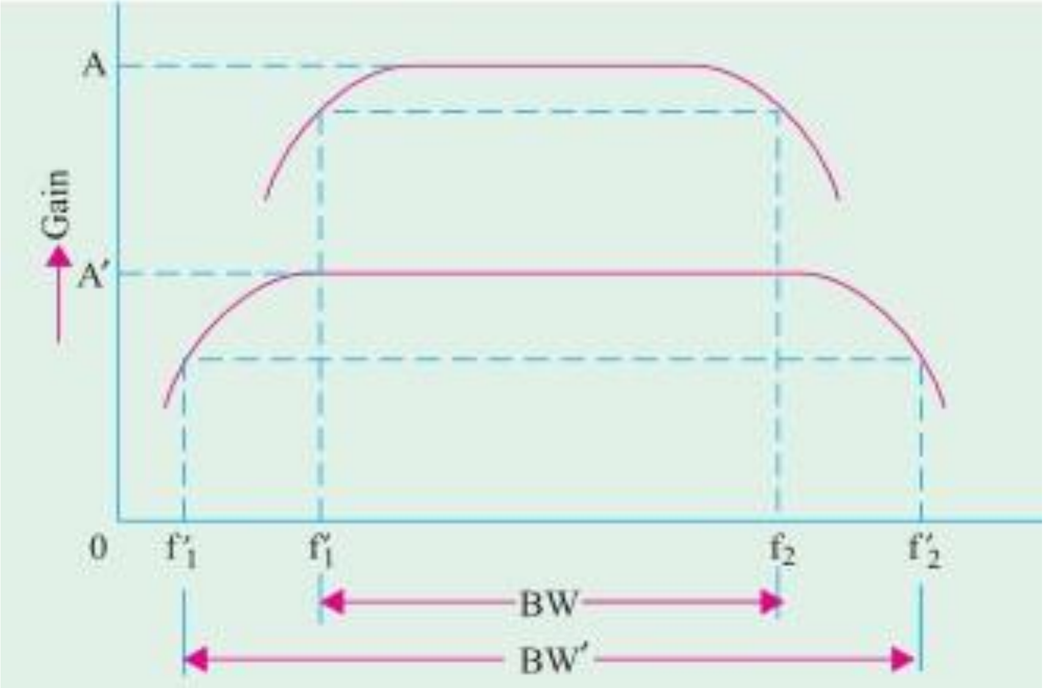
However, if it is necessary to increase the gain to its original level by the addition of another stage, it is quite possible that the overall system will be noisier that it was at the start. If the increase in gain can be accomplished by the adjustment of circuit parameters, a definite reduction in noise will result from the use of negative feedback.

Input / Output Impedance :

The input and output impedances will also improve by a factor of

(1+Aβ), based on feedback connection type.

Bandwidth and Gain-bandwidth Product:



$$f_{hf} = f_h\,(1+A\beta)$$

$$f_{lf} = f_l\,/(1+A\beta)$$

Bandwidth and Gain-bandwidth Product

Each of higher and lower cut-off frequencies will improve by a factor of **(1+Aβ).** However, gain-bandwidth product remains constant.

An important piece of information that can be obtained from a frequency response curve is the bandwidth of the amplifier. This refers to the ‘band’ of frequencies for which the amplifier has a useful gain. Outside this useful band, the gain of the amplifier is considered to be insufficient compared with the gain at the centre of the bandwidth. The bandwidth specified for the voltage amplifiers is the range of frequencies for which the amplifiers gain is greater than 0.707 of the maximum gain Alternatively, decibels are used to indicate gain, the ratio of output to input voltage. The useful bandwidth would be described as extending to those frequencies at which the gain is -3db down compared to the gain at the mid-band frequency.

Feedback in Emitter Follower Amplifier:

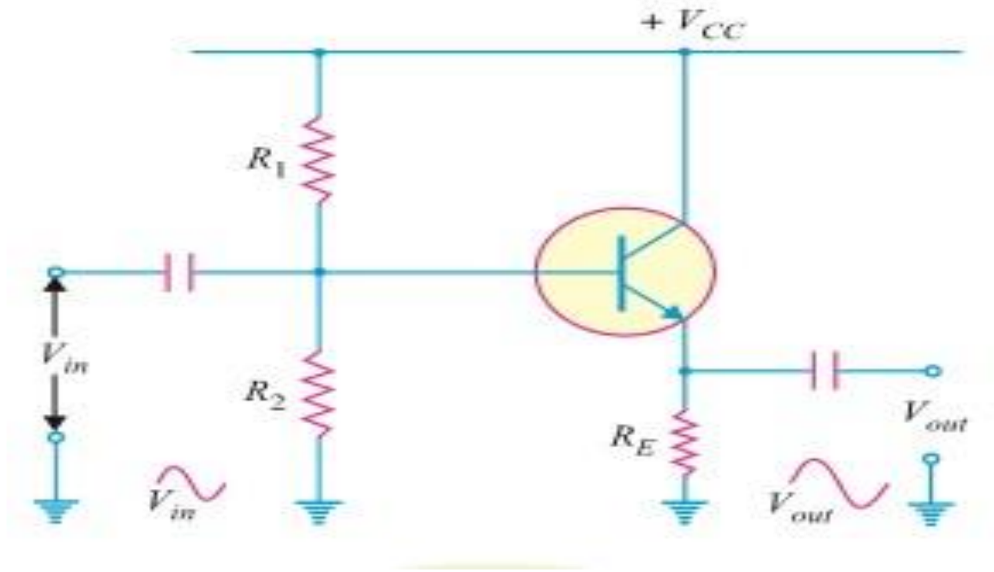


Diagram of an emitter follower

Operation:

For the emitter follower, the input voltage is applied at base and the resulting a.c. emitter current produces an output voltage ($I_e R_E$) across the emitter resistance. This voltage opposes the input voltage, thus providing negative feedback (Voltage series). It is called emitter follower because the output voltage follows the input voltage.

The major characteristics of the emitter follower are:

The voltage gain of an emitter follower is close to 1.

Relatively high current gain and power gain.

High input impedance and low output impedance.

Input and output ac voltages are in phase.

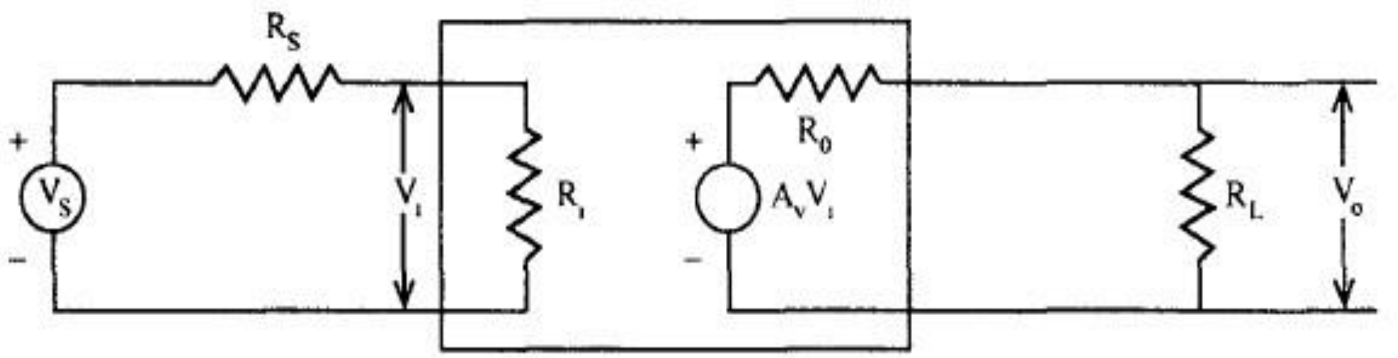
Classification of Basic Amplifiers:

Amplifiers can be classified broadly as,

- Voltage amplifiers.
- Current amplifiers.
- Transconductance amplifiers.
- Transresistance amplifiers.

Voltage Amplifier:

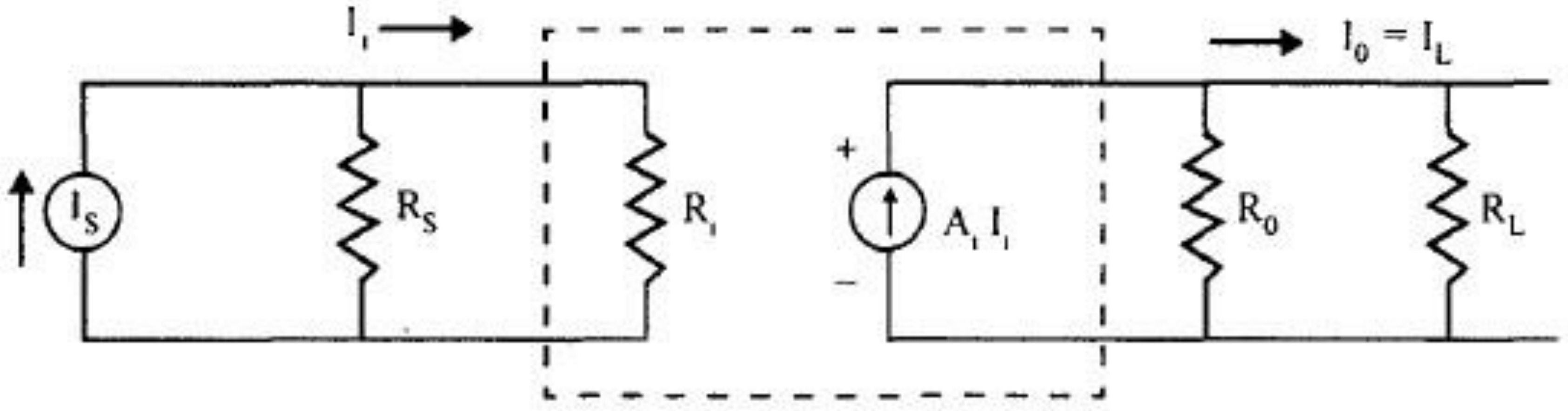
Ri >> Rs and Ro << RL



Equivalent circuit of voltage amplifier.

Current Amplifier:

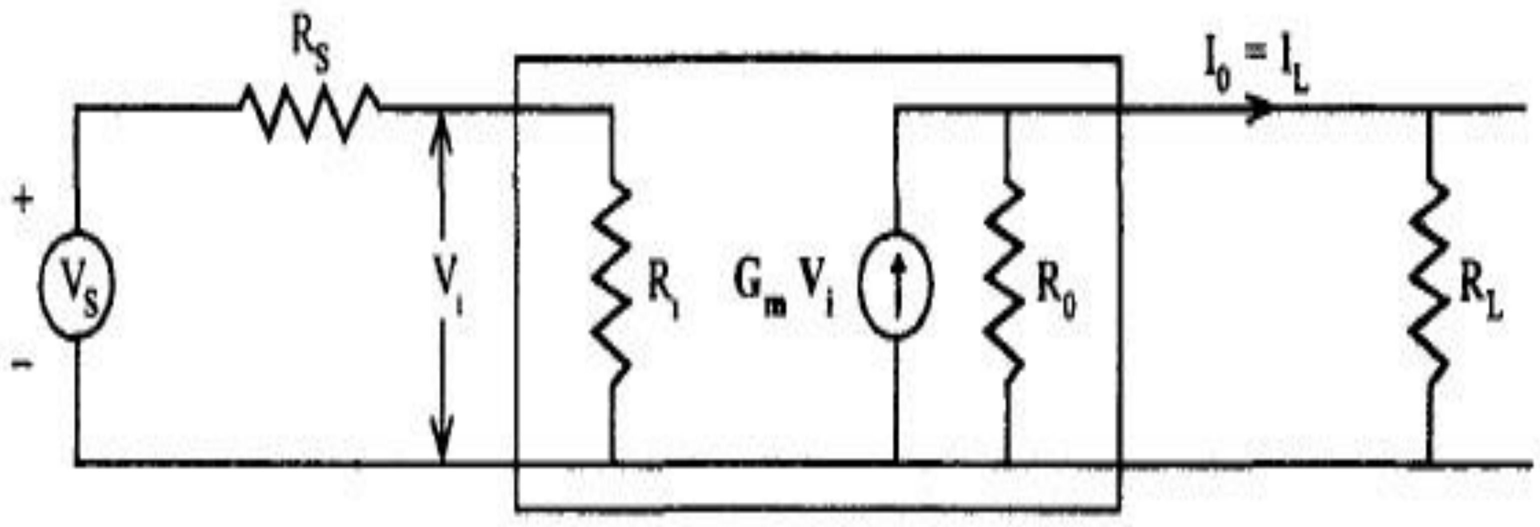
Ri << Rs and Ro >> RL



Equivalent circuit for current amplifier

Transconductance Amplifier:

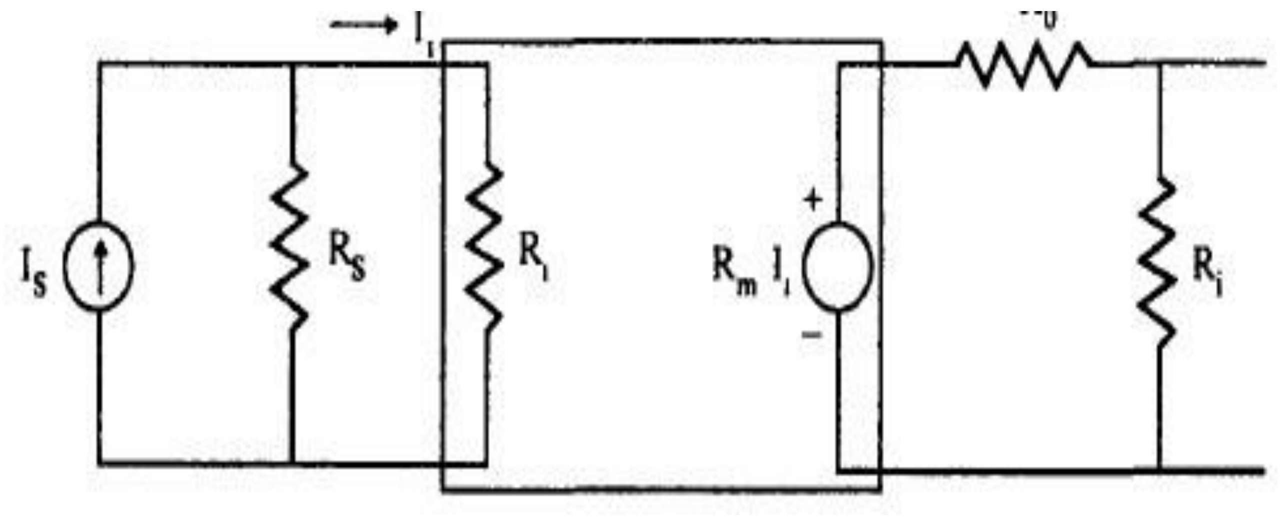
Ri >> Rs and Ro >> RL



Equivalent circuit for transconductance amplifier

Transresistance Amplifier:

Ri << Rs and Ro << RL



Equivalent circuit for transresistance amplifier

Summary:

Sl. No.	Type	Input	Output	Ri	Ro
1	Voltage Amplifier	Voltage	Voltage	High	Low
2	Current Amplifier	Current	Current	Low	High
3	Transconductance Amplifier	Voltage	Current	High	High
4	Transresistance Amplifier	Current	Voltage	Low	Low

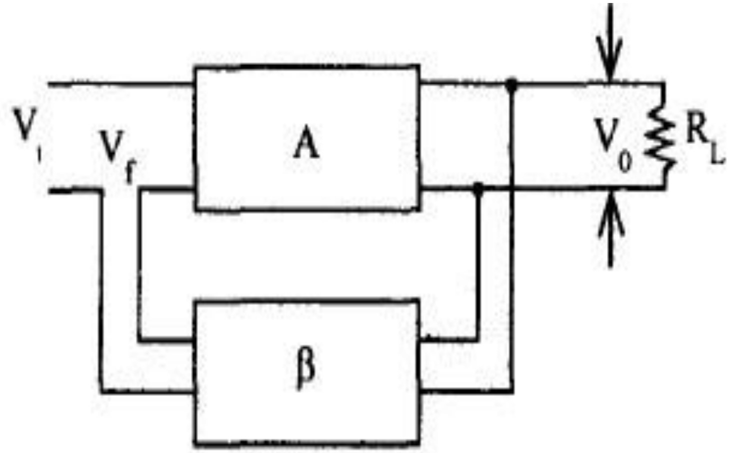
Classification of Feedback Amplifiers:

There are four types of feedback,

- Voltage series feedback.
- Voltage shunt feedback.
- Current shunt feedback.
- Current series feedback

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

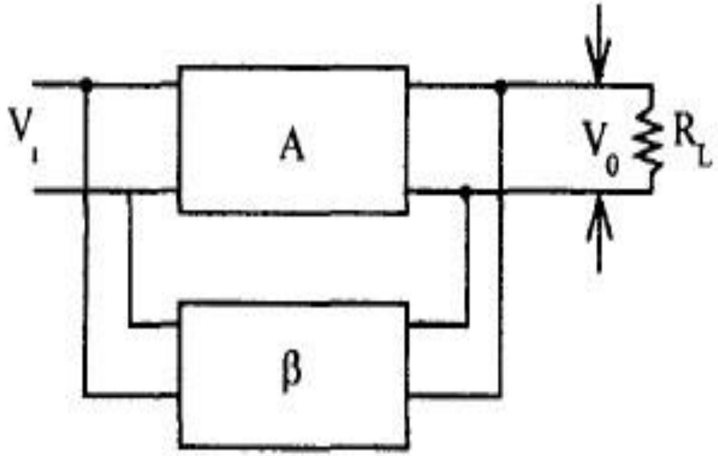
$$R_{of} = R_o\,/\,(1+A\beta)$$



Voltage series feedback.

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

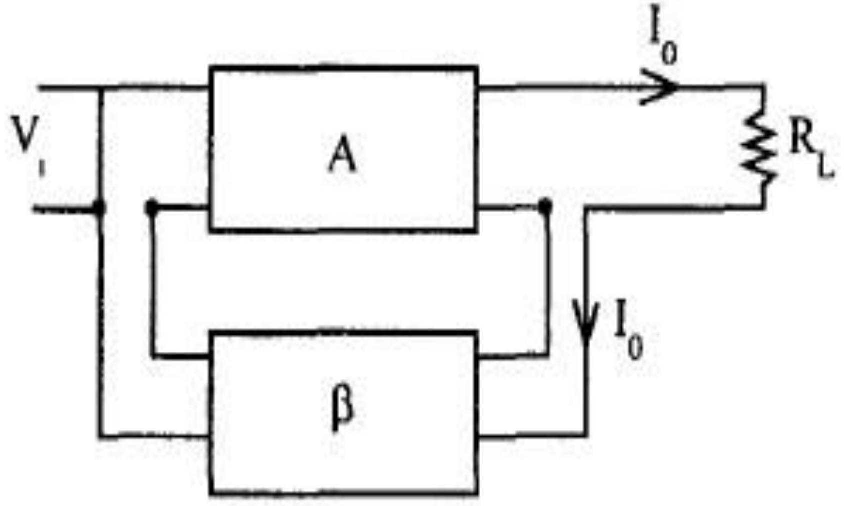
$$R_{of} = R_o\,/\,(1+A\beta)$$



Voltage shunt Feedback

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

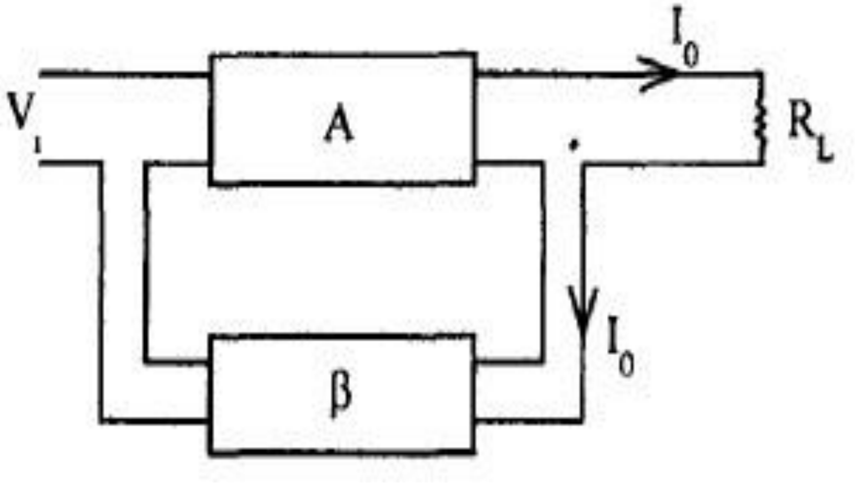
$R_{of} = R_o (1+A\beta)$



Current Shunt Feedback

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

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



Current Series Feedback

Effect of feedback on Input Resistance:

Voltage shunt Feedback

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

Current Shunt Feedback

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

Voltage series feedback.

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

Current series Feedback

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

Effect of feedback on Output Resistance:

Voltage shunt Feedback

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

Current Shunt Feedback

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

Voltage series feedback.

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

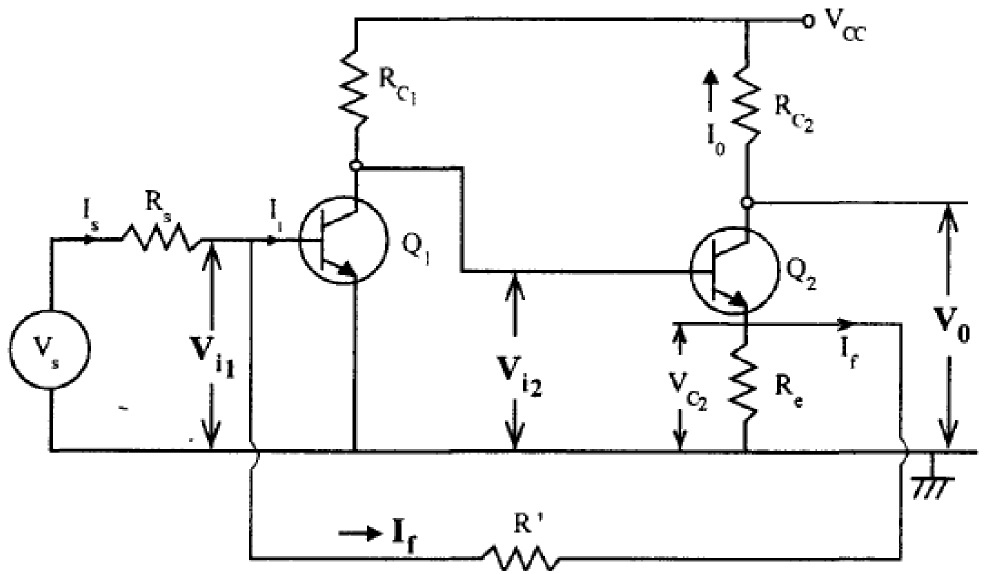
Current series Feedback

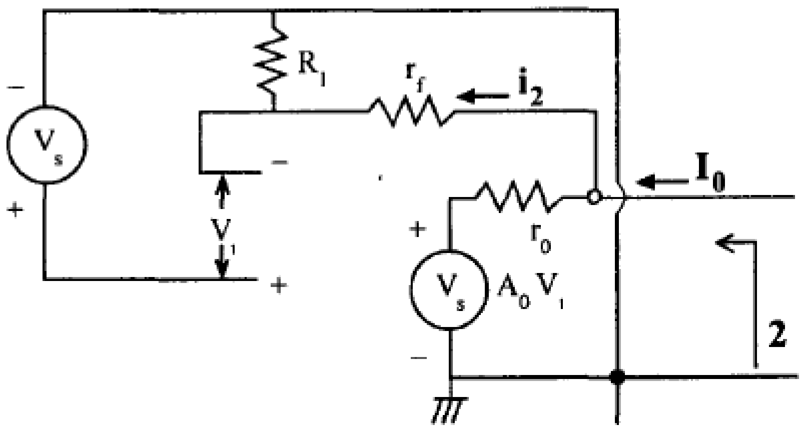
$$R_{of} = R_o (1+A\beta)$$

Summary:

Sl. No.	Type	Rif	Rof
1	Voltage Shunt Feedback Amplifier	$R_{if} = R_i / (1+A\beta)$	$R_{of} = R_o / (1+A\beta)$
2	Current Shunt Feedback Amplifier	$R_{if} = R_i / (1+A\beta)$	$R_{of} = R_o (1+A\beta)$
3	Voltage Series Feedback Amplifier	$R_{if} = R_i (1+A\beta)$	$R_{of} = R_o / (1+A\beta)$
4	Current Series Feedback Amplifier	$R_{if} = R_i (1+A\beta)$	$R_{of} = R_o (1+A\beta)$

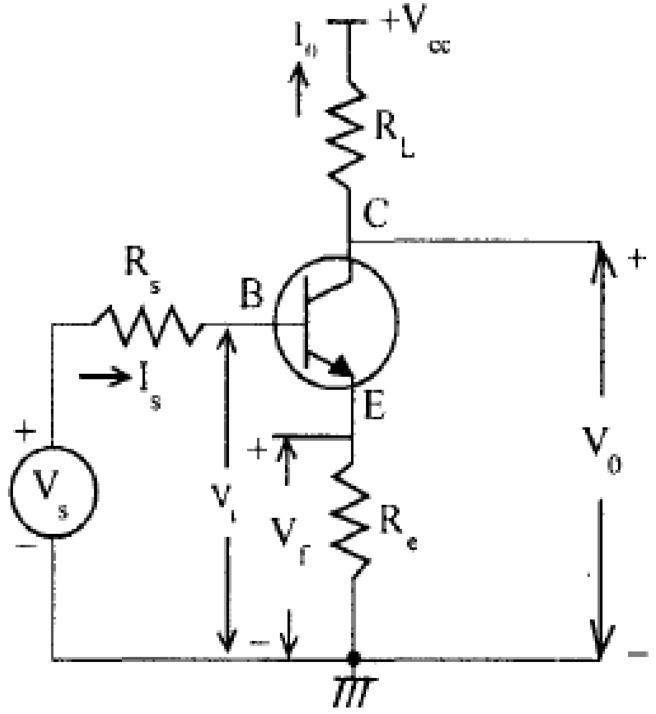
Current shunt feedback.



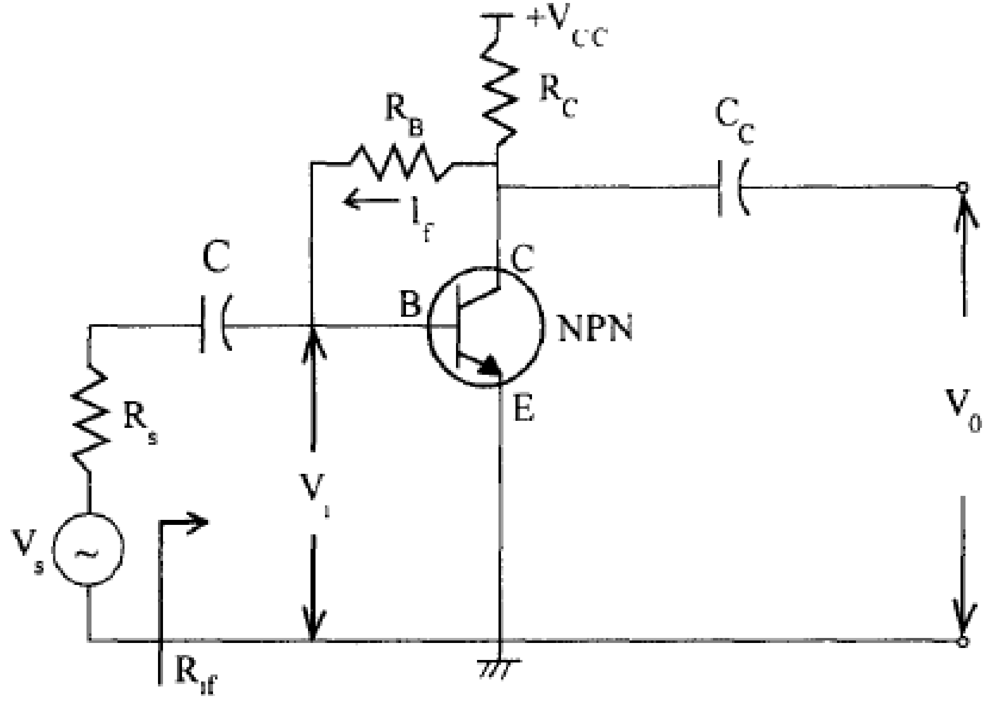


Equivalent circuit.

Current Series Feedback



Voltage Shunt Feedback



GATE Questions and Solutions

7.02. If the input impedance & voltage gain of a open loop voltage series feedback amplifier are $3k\Omega$ & 100, and the feedback factor is $\frac{1}{50}$, then the input impedance of closed loop configuration is ________

(A) $9k\Omega$
(B) $6k\Omega$
(C) $3k\Omega$
(D) $12k\Omega$

Sol. $A = 100, R_{in} = 3k\Omega$

$R_{inf} = R_{in}(1 + A\beta)$

$= 3k\Omega\left(1 + 100\,\frac{1}{50}\right)$

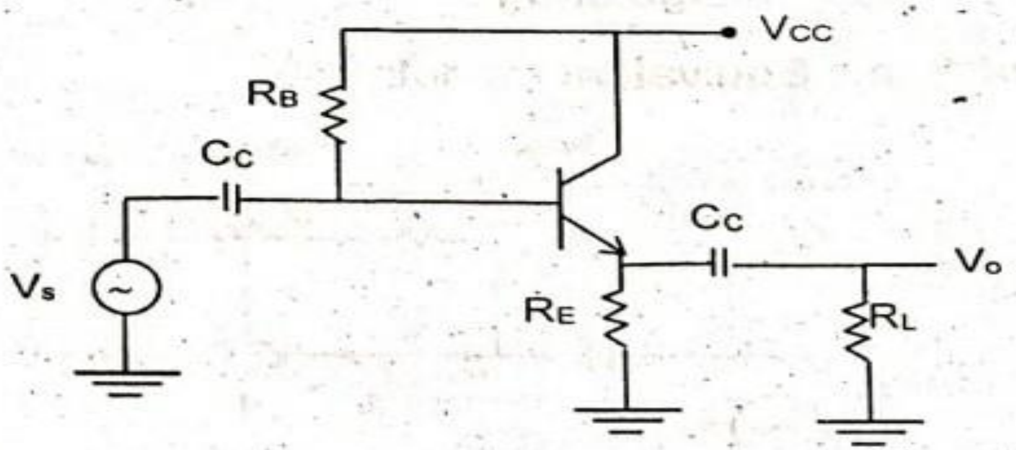
$R_{inf} = 9k\Omega$ Choice (A)

Note: Voltage – series feedback

(i) $R_{inf} = R_{in}(1 + A\beta)$

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

7.03. Find the type of the feedback in the given circuit



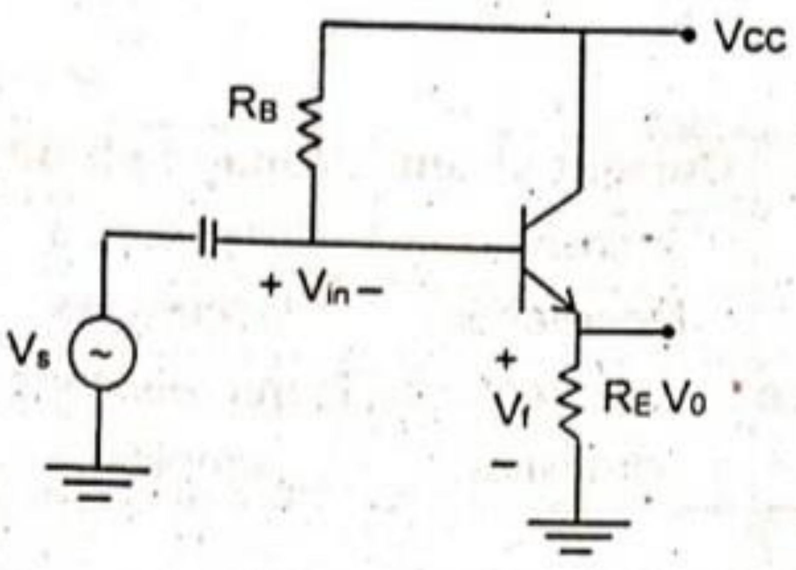
(A) Current – series

(B) Voltage shunt

(C) Voltage series

(D) Current shunt

Sol. a.c equivalent circuit:



Input – series connection

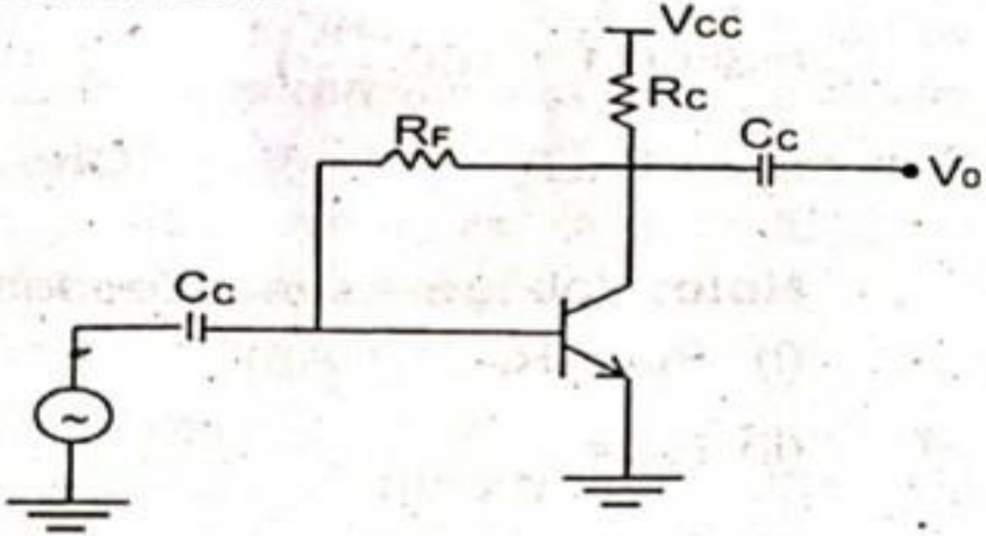
Output – shunt connection

∴ Voltage series feedback

Choice (C)

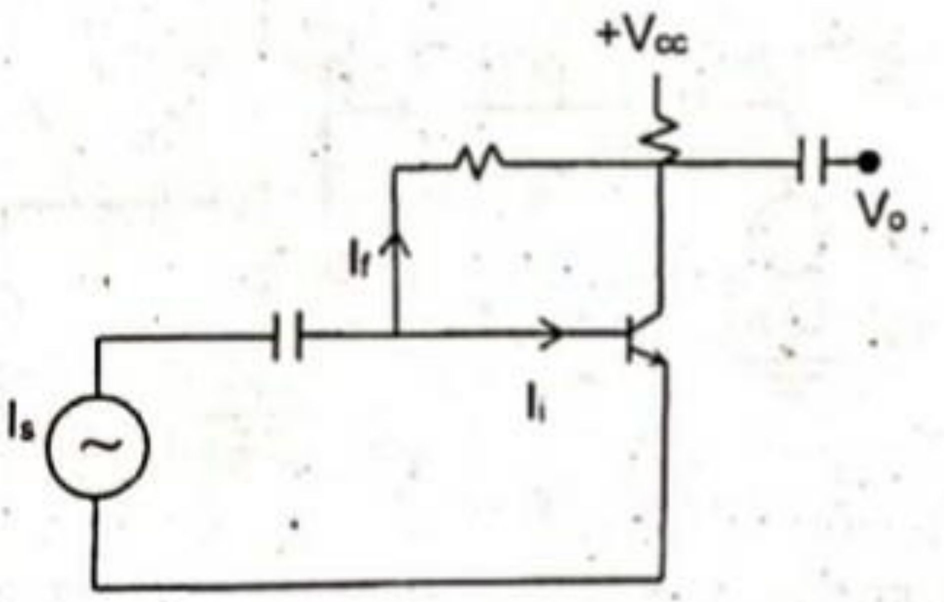
Choice (C)

7.04. Find the type of the feedback in the given circuit.



(A) Voltage – series
(B) Current – series
(C) Current shunt
(D) Voltage shunt

Sol. a.c Equivalent model:



Input:– shunt connection

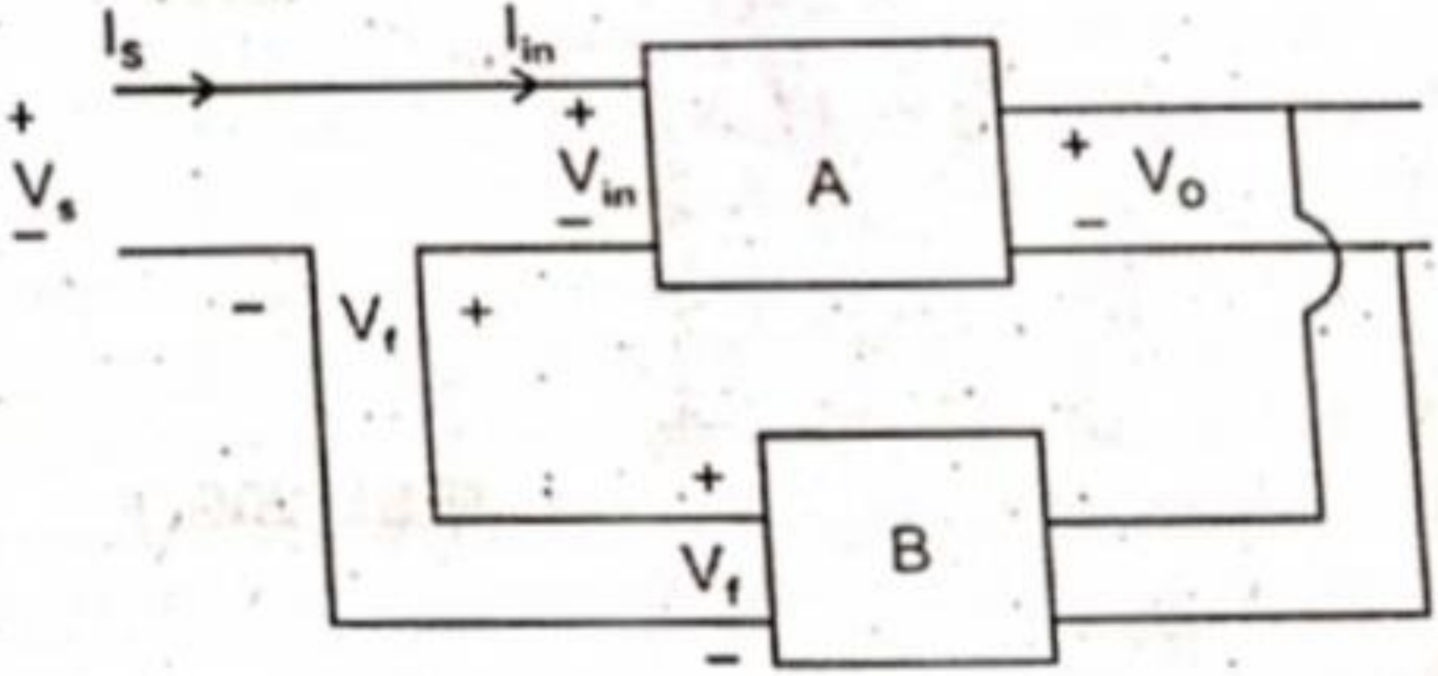
Output:– shunt connection

∴ Voltage shut feedback.

Choice (D)

7.13. What are the effects of negative voltage series feedback on the characteristics of an amplifier? Derive an expression for input resistance of such an amplifier with feedback in terms of input resistance without feedback and feedback factor.

Sol.



Effects of negative voltage series feedback on the characteristics of an Amplifier:

(i) Input impedance increases:

$$R_{inf} = \frac{V_s}{I_s} = \frac{V_{in}[1 + A\beta]}{I_{in}} = R_{in}[1 + A\beta]$$

$$\therefore V_{in} = V_s - V_f \Rightarrow V_{in} = V_s - \beta A V_{in}$$

$$V_s = [1 + A\beta] V_{in}$$

$I_s = I_{in}$ since series at the input

(ii) Similarly output impedance decreases

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

(iii) Voltage gain decreases

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

(iv) Lower cut off frequency decreases

$$f_L^1 = \frac{f_L}{1 + A\beta}$$

(v) Upper cut off frequency increases

$$f_H^1 = f_H [1 + A\beta]$$

(vi) Bandwidth increases

$$B_w^1 = B_w [1 + A\beta]$$

(vii) Distortion decreases

$$D_1 = \frac{D}{1 + A\beta}$$

(viii) Stability increases.

1. Voltage series feedback (also called series shunt feedback) results in

(GATE 2004)

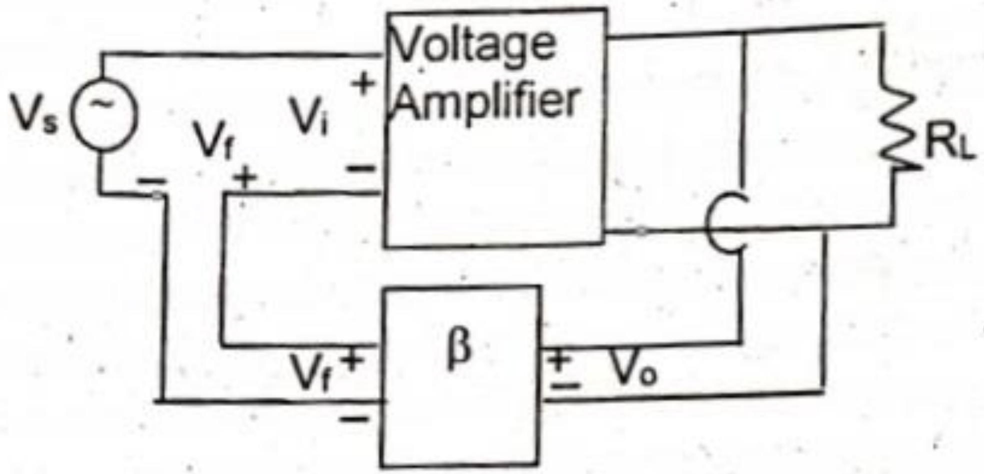
(A) increase in both input and output impedance

(B) Decrease in both input and output impedance

(C) Increase in input impedance and decrease in output impedance

(D) Decrease in input impedance and increase in output impedance

1. Voltage series feedback



In voltage series feed back input impedance is increases and output resistance is decreases.

Choice (C)

4. The effect of current shunt feedback in an amplifier is to (GATE 2005)

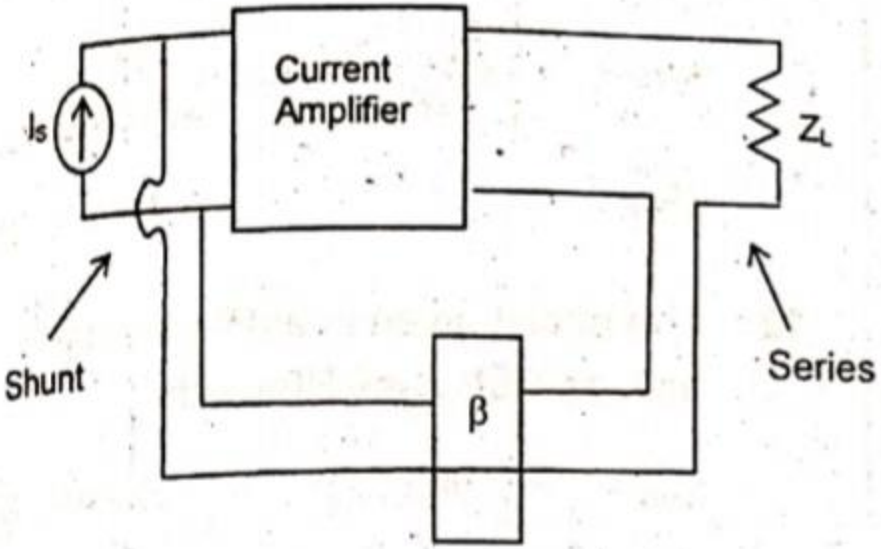
(A) increase the input resistance and decrease the output resistance

(B) increase both input and output resistance

(C) decreases both input and output resistance

(D) decrease the input resistance and increase the output resistance.

4. The effect of current stunt feed back in an amplifier is to decrease input resistance and increase output resistance.



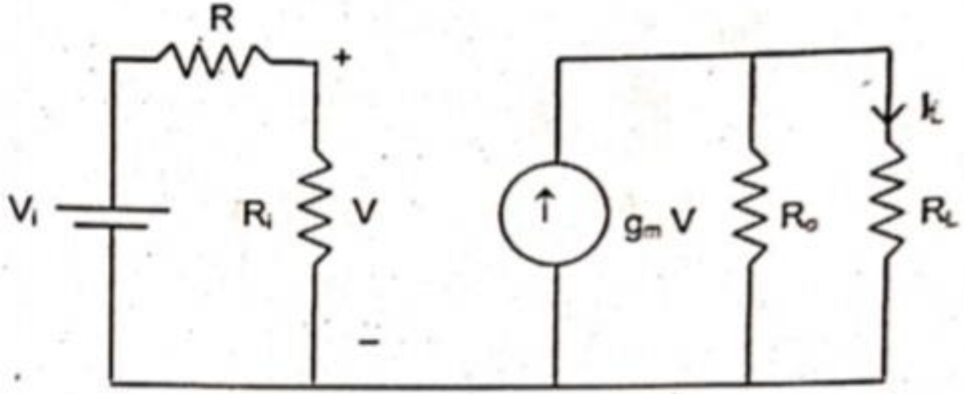
Choice (D)

6. The input impedance (Z_i) and the output impedance (Z_0) of an ideal trans conductance (Voltage controlled current source) amplifier are (GATE 2006)

(A) $Z_i = 0, Z_0 = 0$ (B) $Z_i = 0, Z_0 = \infty$

(C) $Z_i = \infty, Z_0 = 0$ (D) $Z_i = \infty, Z_0 = \infty$

6. For Transconductance amplifier $Z_i = \infty$, $Z_0 = \infty$



Transconductance amplifier

Choice (D)

7. In a transconductance amplifier, it is desirable to have **(GATE 2007)**

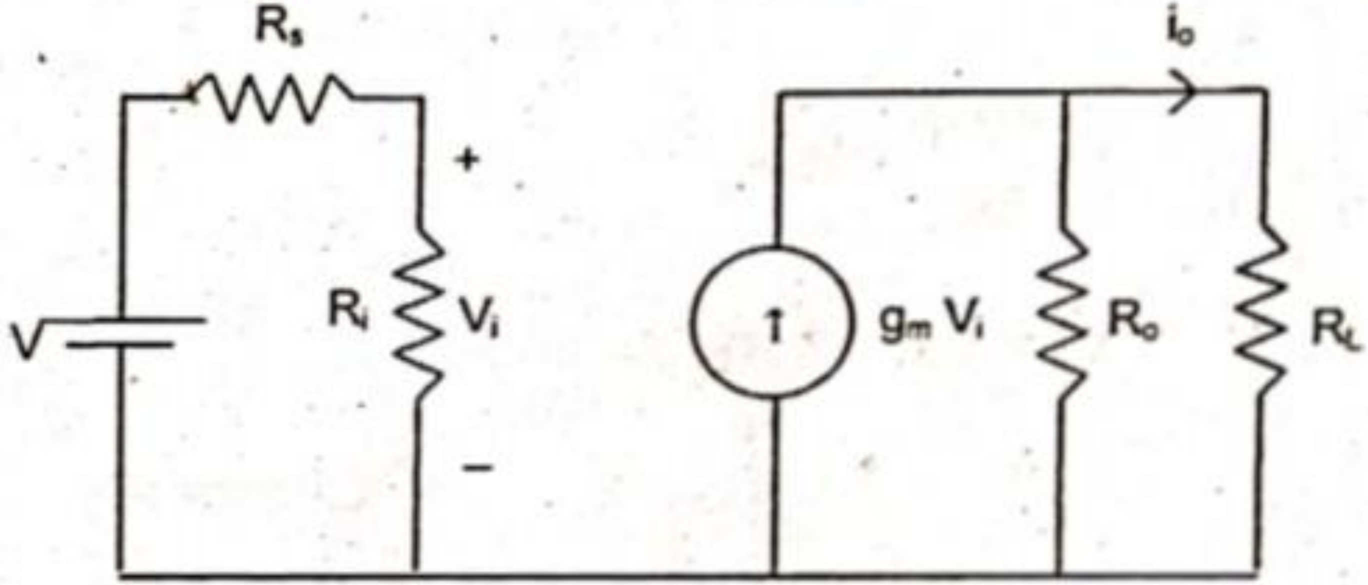
(A) a large input resistance and a large output resistance

(B) a large input resistance and a small output resistance

(C) a small input resistance and a large output resistance

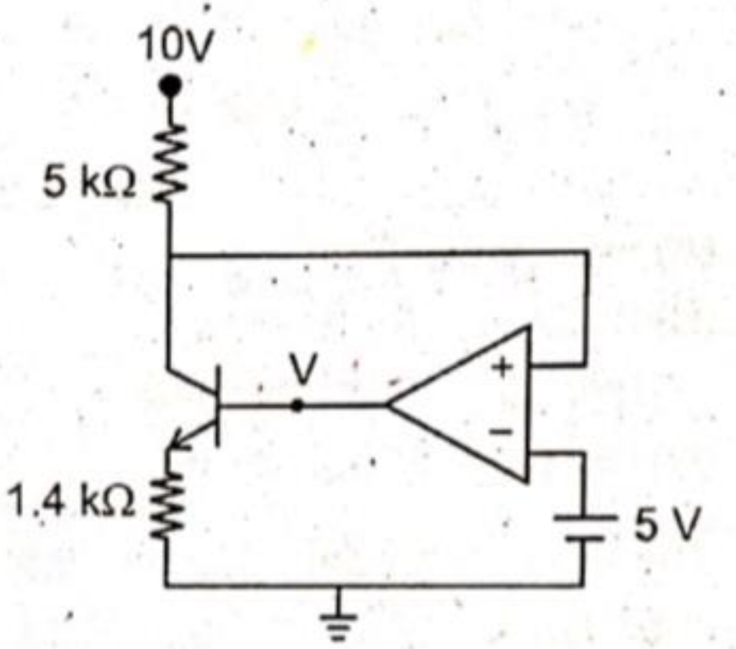
(D) a small input resistance and a small output resistance

7. For transconductance amplifier $R_i >> R_S$ and $R_O >> R_L$ i.e., a large input resistance and a large output.



Choice (A)

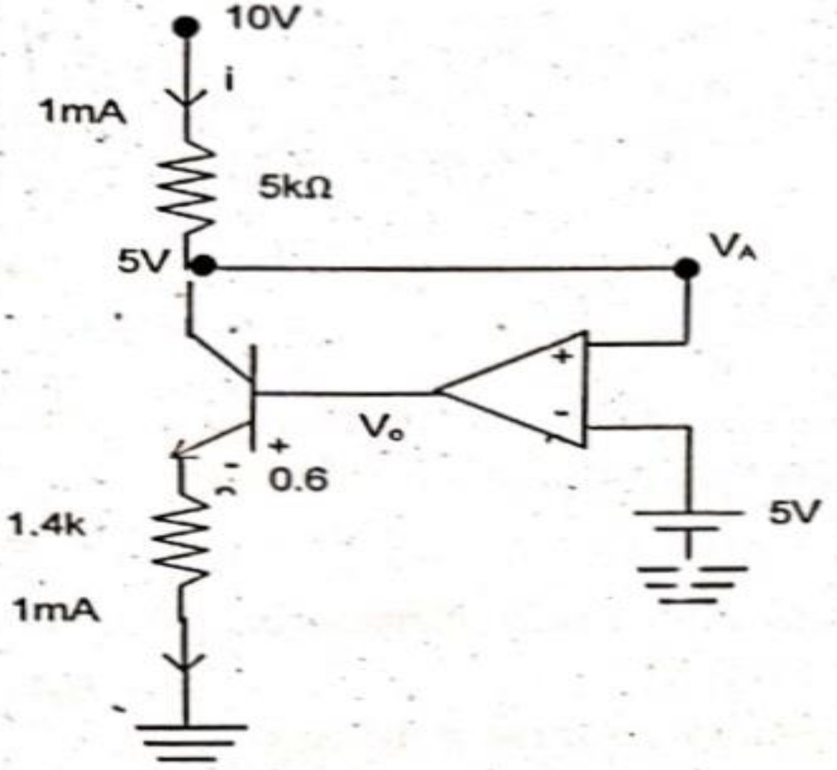
9. In the circuit shown below, the op-amp is ideal, the transistor has $V_{BE} = 0.6V$ and $\beta = 150$. Decide whether the feedback in the circuit is positive or negative and determine the voltage V at the output of the op-amp



(GATE 2009)

(A) Positive feedback, V=10 V
(B) Positive feedback, V=0 V
(C) Negative feedback, V=5 V
(D) Negative feedback, V=2 V

9.

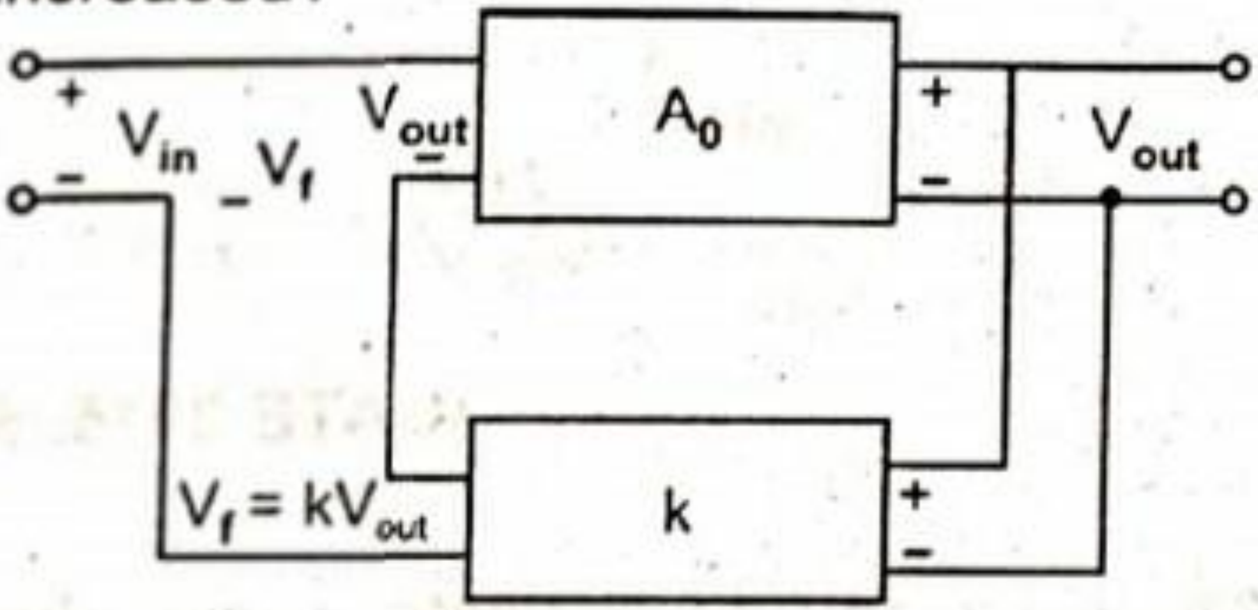


$$i = \frac{10-5}{5k\Omega} = 1mA$$

$V_o = 0.6 + 1.4k\Omega \times 1mA$

$= 2V$ Choice (D)

13. In a voltage-voltage feedback as shown below, which one of the following statements is TRUE if the gain k is increased?



(GATE 2013)

(A) The input impedance increases and output impedance decreases

(B) The input impedance increases and output impedance also increases

(C) The input impedance decreases and output impedance also decreases

(D) The input impedance decreases and output impedance increases

13. The input impedance increases and output impedance decreases.

Choice (A)

14. A good current buffer has

(GATE 2014, Set-1)

(A) low input impedance and low output impedance

(B) low input impedance and high output impedance

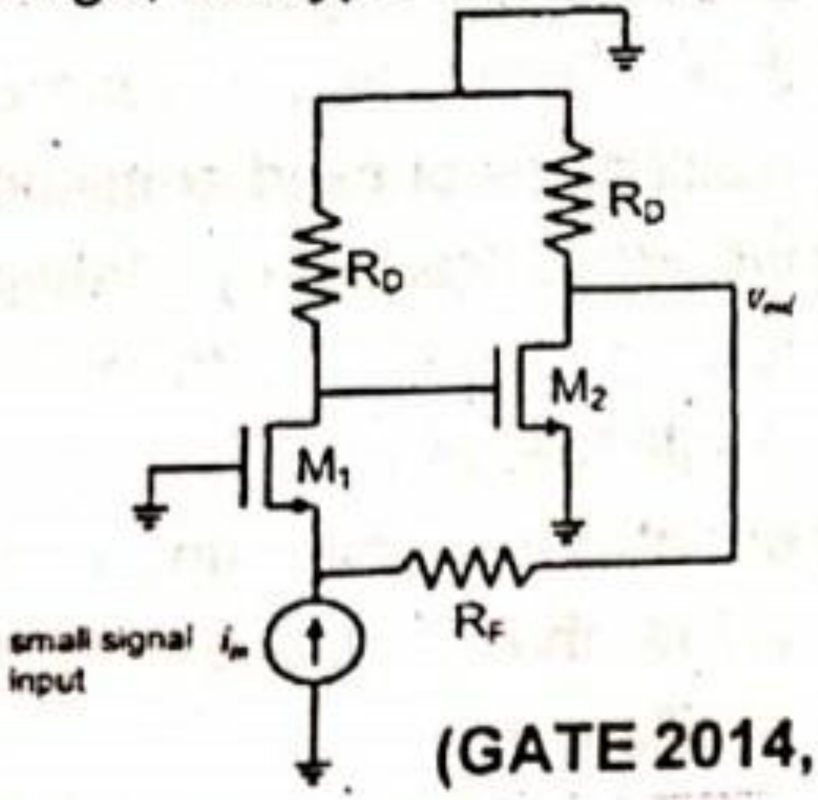
(C) high input impedance and low output impedance

(D) high input impedance and high output impedance

14. Current buffer has low input impedance and high output impedance.

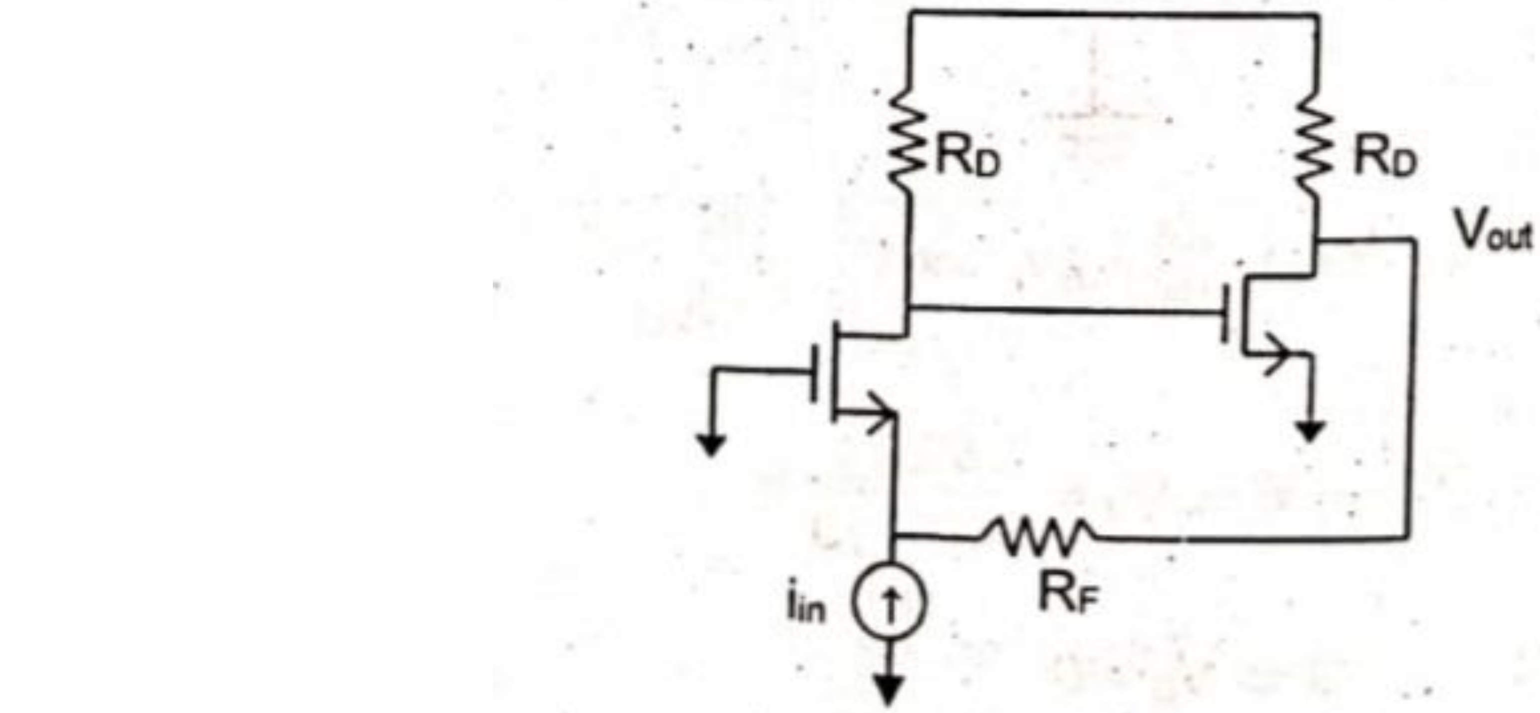
Choice (B)

15. In the ac equivalent circuit shown in the figure if i_{in} is the input current and R_F is very large, the type of feedback is



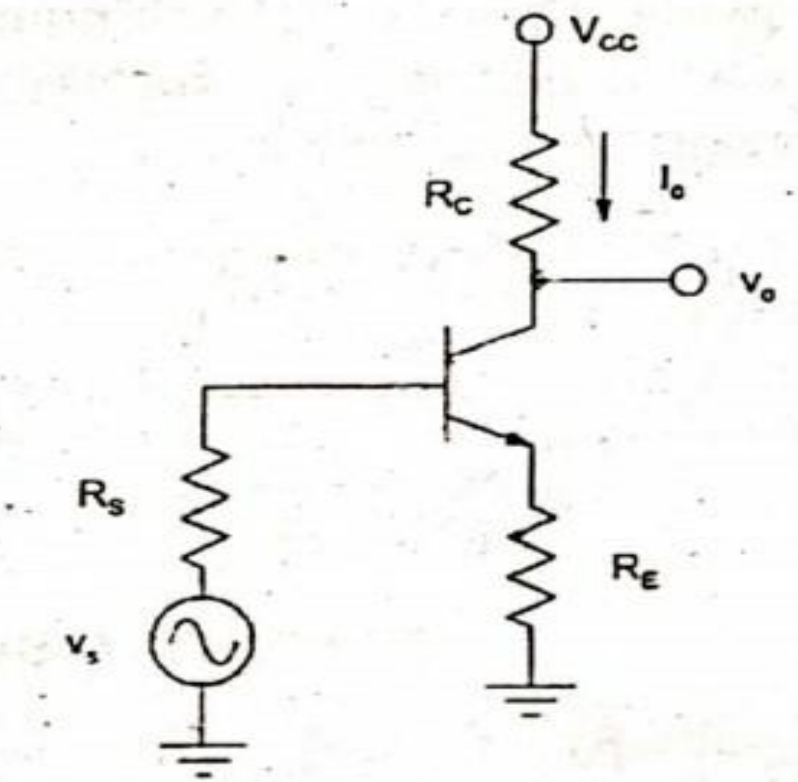
(GATE 2014, Set-1)

15. Feedback signal is shunt to input current source and output voltage is $(V_o) \alpha V_f$. So given feedback is voltage – current feedback.



Choice (B)

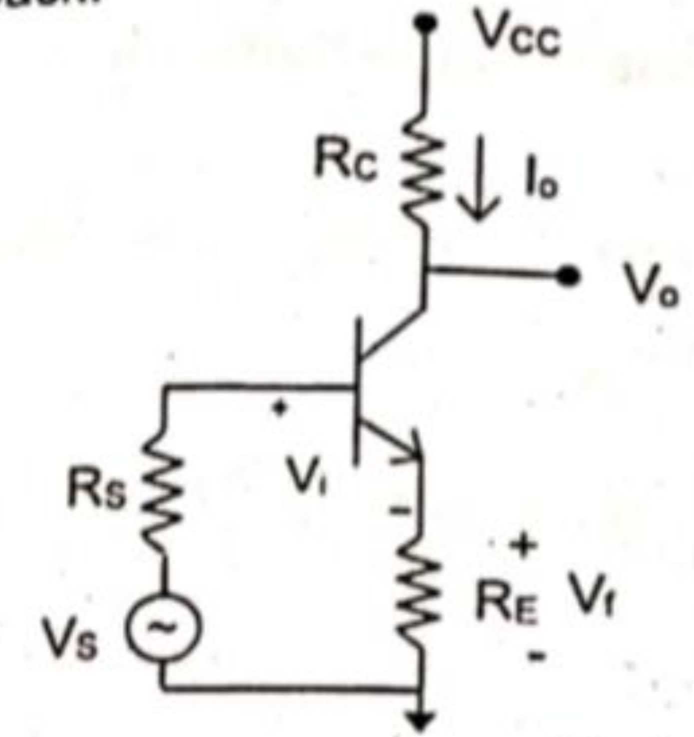
17. The feedback topology in the amplifier circuit (the base bias circuit is not shown for simplicity) in the figure is



(GATE 2014, Set-2)

(A) Voltage shunt feedback
(B) Current series feedback
(C) Current shunt feedback
(D) Voltage series feedback

17. Feedback voltage $V_f \alpha I_o$ and V_f series with source voltage so it is current series feedback.



Choice (B)

18. The desirable characteristics of a transconductance amplifier are

(GATE 2014, Set-3)

(A) high input resistance and high output resistance

(B) high input resistance and low output resistance

(C) low input resistance and high output resistance

(D) low input resistance and low output resistance

18. Characteristics of a transconductance amplifier are high input resistance and high output resistance.

Choice (A)

24. A good transconductance amplifier should have **(GATE 2017, Set-1)**

(A) high input resistance and low output resistance

(B) low input resistance and high output resistance

(C) high input and output resistances

(D) low input and output resistances

24. For a transconductance amplifier, input and out put resistance is high and output resistance is also high. The transconductance amplifier can also be called voltage controlled current source, i.e. VCCS. An amplifiers is VC when input resistance is high, and an amplifies is CS when output resistance is high.

Choice (C)

14. Match the following

Types of FeedbackAmplifier		Input Resist.		Output resist.
A	Voltage-series	1	Increases	Increases
B	Voltage-shunt	2	Decreases	Increases
C	Current-series	3	Decreases	Decreases
D	Current-shunt	4	Increases	Decreases

1.

A	4
B	3
C	1
D	2

2.

A	3
B	4
C	1
D	2

3.

A	1
B	2
C	3
D	4

4.

A	1
B	2
C	4
D	3

Sol: Trick to remember

The first term shows how the feedback is taken

Voltage is measured in parallel (by voltmeter) - Hence 1st term voltage means, the parallel connection at the output

Current is measured in series - Hence 1st term current means series connection at the output.

Series connection increases resistance.

Parallel connection decreases resistance .

Configuration	Output Connection	Input Connection	Output Resistance	Input resistance
Voltage Series	Shunt	Series	Decrease	Increase
Voltage Shunt	Shunt	Shunt	Decrease	Decrease
Current Series	Series	Series	Increase	Increase
Current Shunt	Series	Shunt	Increase	Decrease

Answer: 1

End of Presentation