Analog Electronic Circuits-BEE303

Module 3: Multistage Amplifiers & Feedback Amplifiers

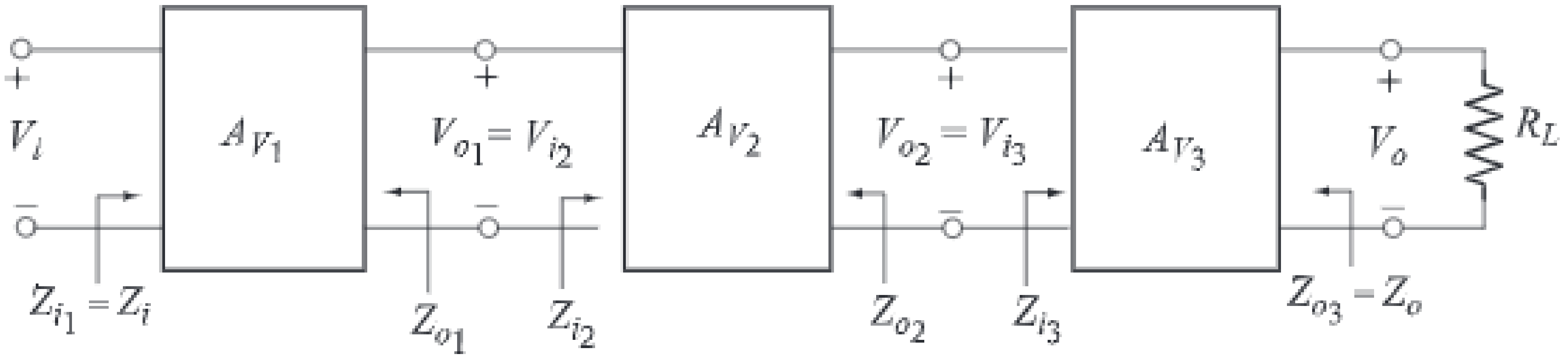
Module III

- **Multistage amplifiers:** **Cascade and cascode connections, Darlington circuits, analysis and design.**
- **Feedback amplifiers:** **Feedback concept, different types, practical feedback circuits, analysis and design of feedback circuits.**

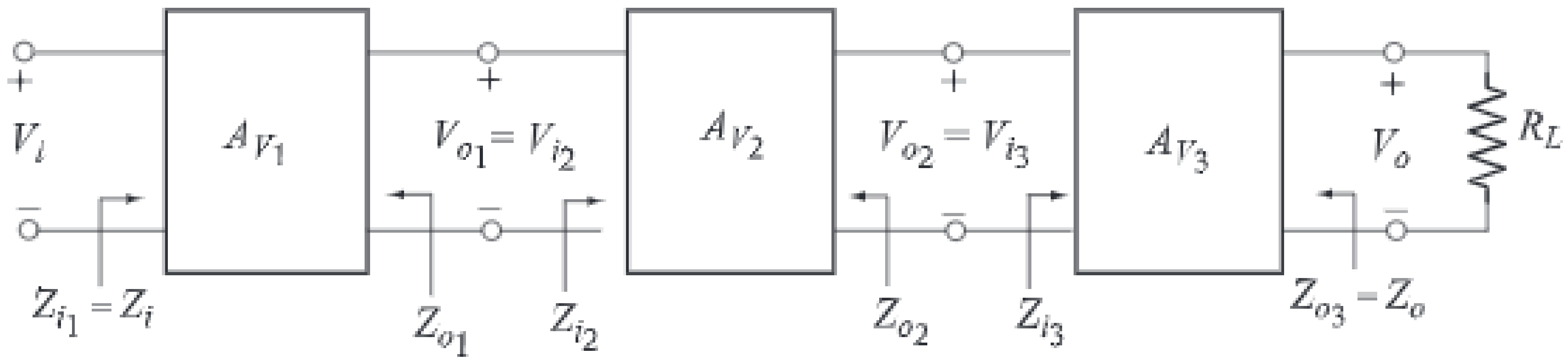
Multistage Amplifiers: Cascade Connection

When the amplification from a single stage amplifier is not sufficient for a particular purpose or when the input or output impedance is not of suitable magnitude for the intended application, two or more stages are connected in series.

The output of one stage is connected as input to the other stage.



Multistage Amplifiers: Cascade Connection



For the cascaded system, the input impedance is that of first stage and output impedance is that of last stage.

$$Z_i = Z_{i1} \quad \text{and} \quad Z_O = Z_{O3}$$

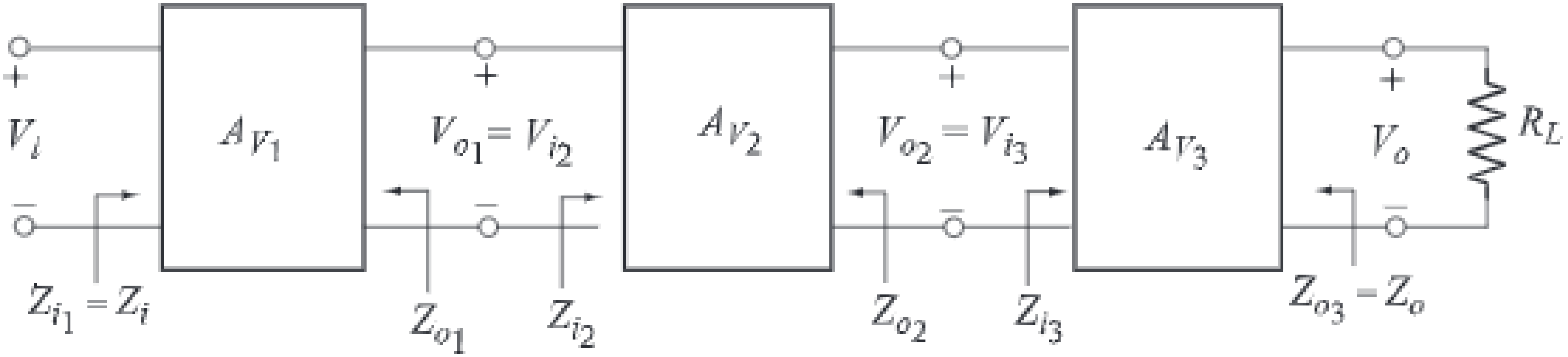
The output of one stage is connected as input to the other stage.

$$V_{i2} = V_{O1} \quad \text{and} \quad V_{i3} = V_{O2}$$

A total overall voltage gain of the cascading amplifier is:

$$A_{VT} = \frac{V_O}{V_I}$$

Multistage Amplifiers: Cascade Connection



A total overall voltage gain of the cascading amplifier is:

$$A_{VT} = \frac{V_O}{V_I}$$

$$A_{VT} = \frac{V_O}{V_{i3}} * \frac{V_{i3}}{V_{i2}} * \frac{V_{i2}}{V_I}$$

$V_{i2} = V_{O1}$ and $V_{i3} = V_{O2}$

$$A_{VT} = \frac{V_O}{V_{i3}} * \frac{V_{O2}}{V_{i2}} * \frac{V_{O1}}{V_I}$$

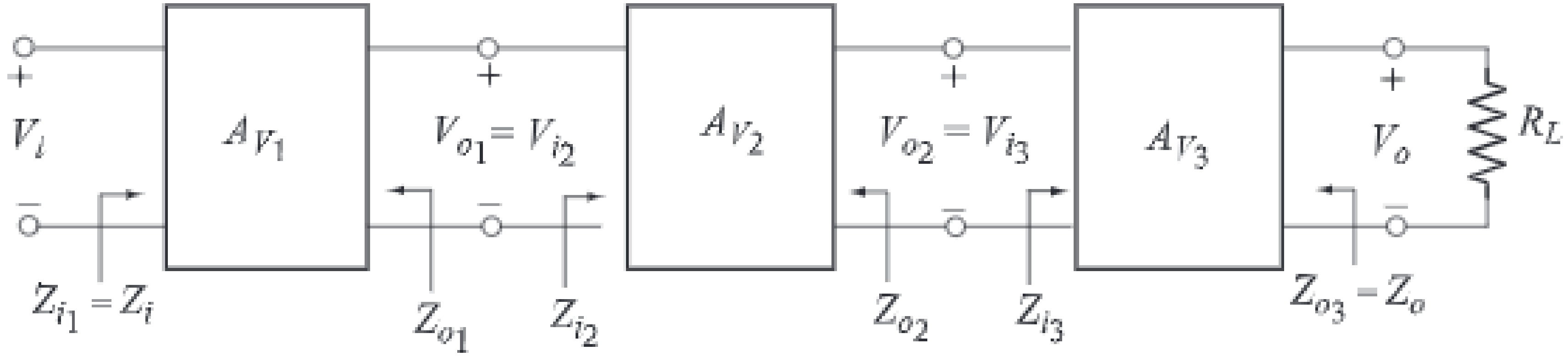
$$A_{VT} = A_{V3} * AV_2 * AV_1$$

$$A_{VT} = AV_1 * AV_2 * AV_3$$

For n-cascaded amplifier stages,

$$A_{VT} = AV_1 * AV_2 * AV_3 ------ -AVn$$

Multistage Amplifiers: Cascade Connection



A total overall current of the cascading amplifier is:

$$A_{IT} = -AVT * \frac{Z_{i1}}{R_L}$$

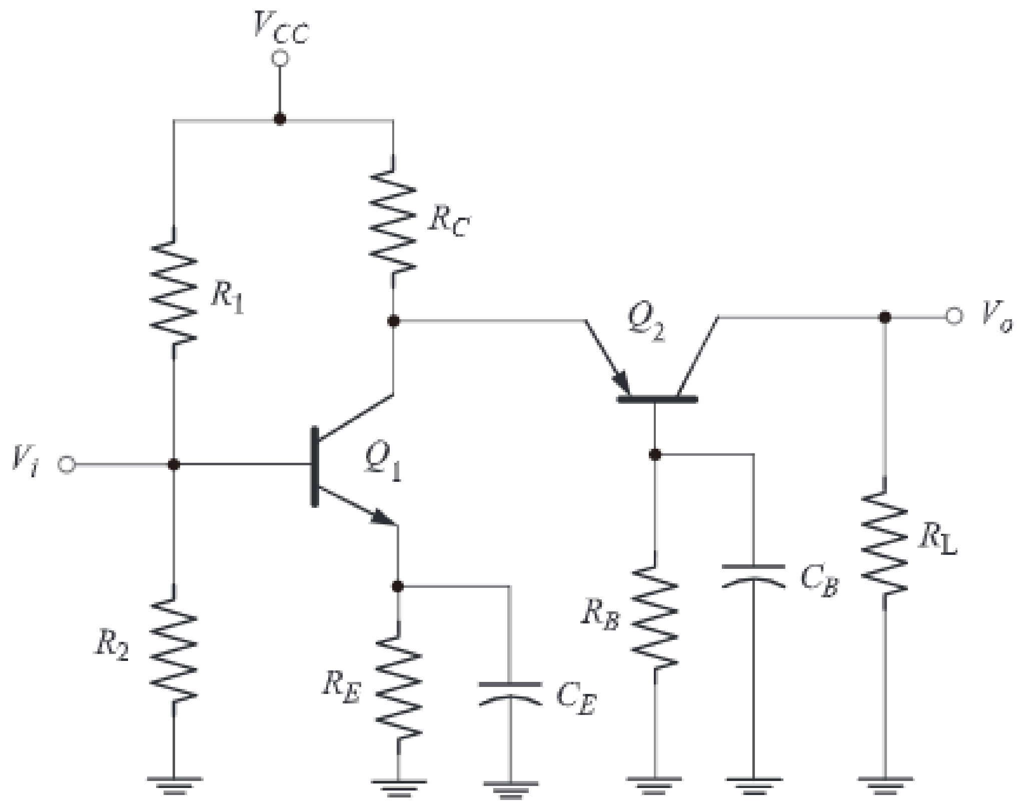
Multistage Amplifiers: Cascode Connection

In this connection the output of Common Emitter (CE) stage drives the input of Common Base (CB) stage.

1. **Low input capacitance**
2. **High input impedance (provided by CE)**
3. **High output impedance (provided by CB)**
4. **Excellent high frequency response**

The voltage gain of CE stage is very low.

R_B is used to limit the bias current of Q_2.



Cascade Connection: Solved Examples

1. For the cascaded arrangement shown below, determine

a. The loaded voltage gain of each stage

b. The total gain of the system, A_V and A_{VS}

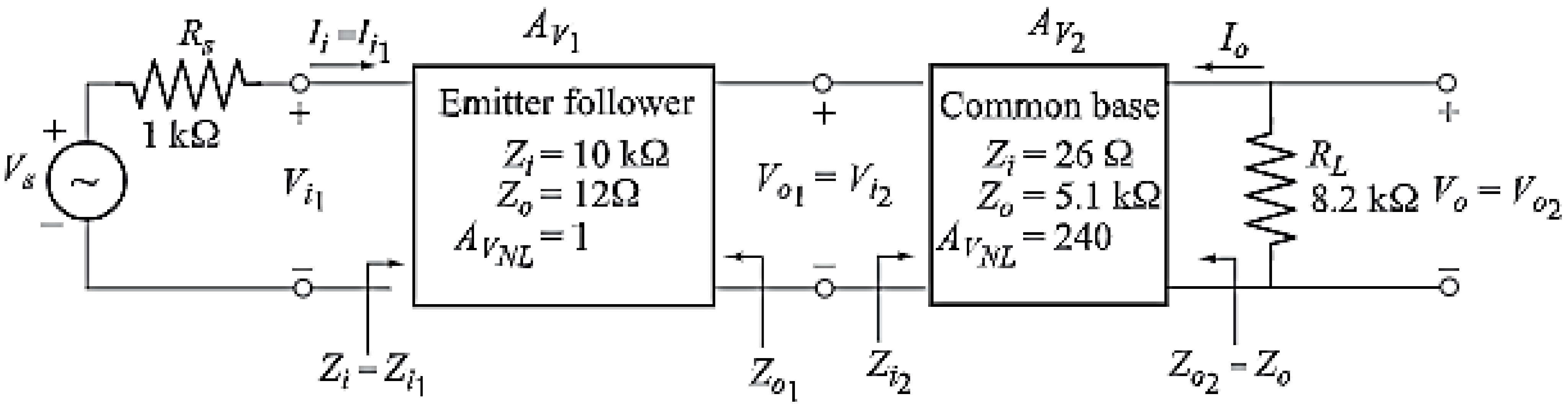
c. The total current gain of the system

Given:

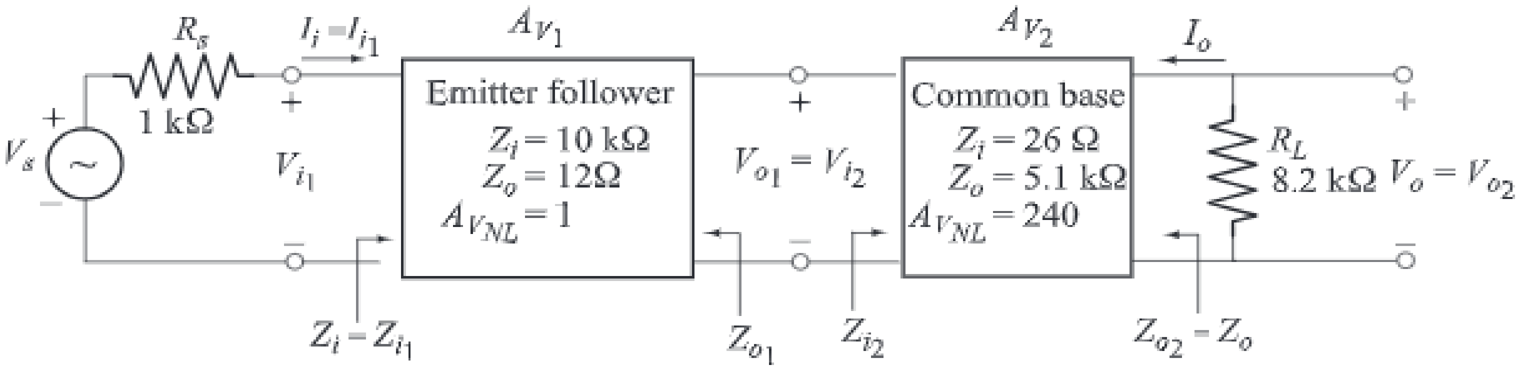
Stage 1: Z_i = 10kΩ, Z_O = 12Ω, A_{VNL} = 1

Stage 2: Z_i = 26Ω, Z_O = 5.1kΩ, A_{VNL} = 240

R_S = 1kΩ, R_L = 8.2kΩ



Cascade Connection: Solved Examples



a. The loaded gain of each stage

For the emitter follower stage the load is Z_{i2}.

$$A_{V1} = \frac{V_{O1}}{V_{i1}} = \frac{Z_{i2}}{Z_{i2} + Z_{O1}} A_{VNL}$$

$$A_{V1} = \frac{26}{26+12} * 1 = 0.684$$

$$A_{V2} = \frac{V_{O2}}{V_{i2}} = \frac{R_L}{R_L + Z_{O2}} A_{VNL}$$

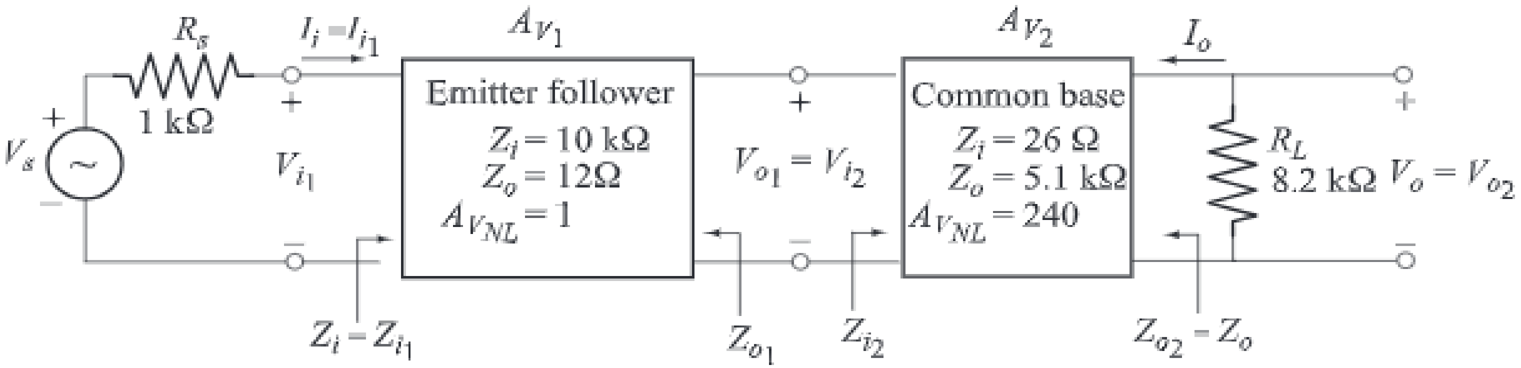
$$A_{V2} = \frac{8.2k}{8.2k + 5.1k} * 240 = 147.97$$

b. Total voltage gain

$$A_{VT} = AV_1 * AV_2$$

$$A_{VT} = 0.684 * 147.97 = 101.20$$

Cascade Connection: Solved Examples



$$A_{VS} = \frac{Z_{i1}}{Z_{i1} + R_S} A_{VT}$$

$$A_{VS} = \frac{10k}{10k + 1k} * 101.20 = 92$$

c. Total current gain

$$A_{IT} = -AVT * \frac{Z_{i1}}{R_L}$$

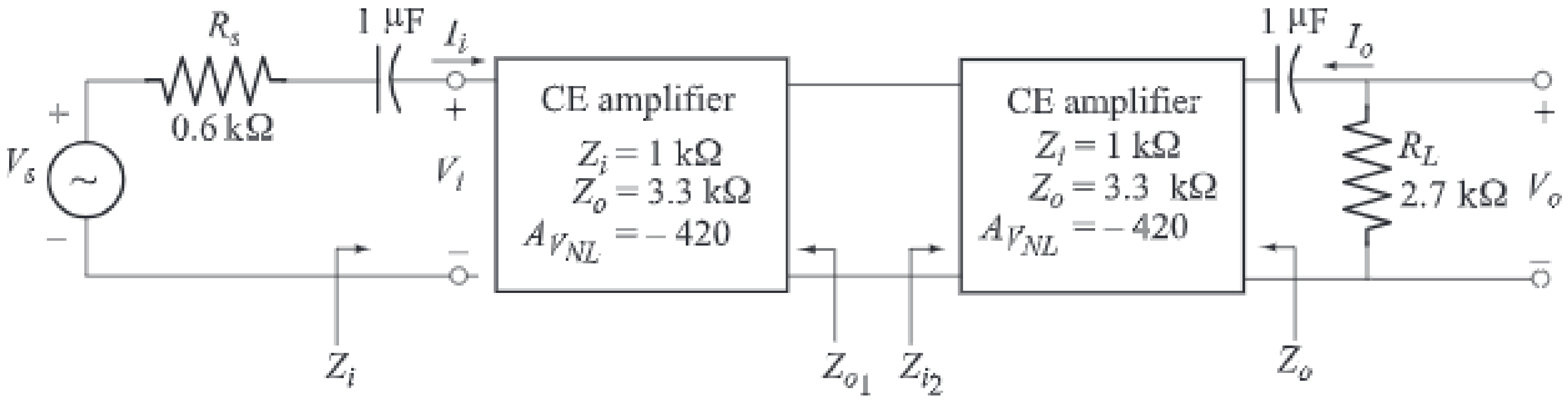
$$A_{IT} = -(101.20) * \frac{10k}{8.2k} = -123.41$$

Cascade Connection: Solved Examples

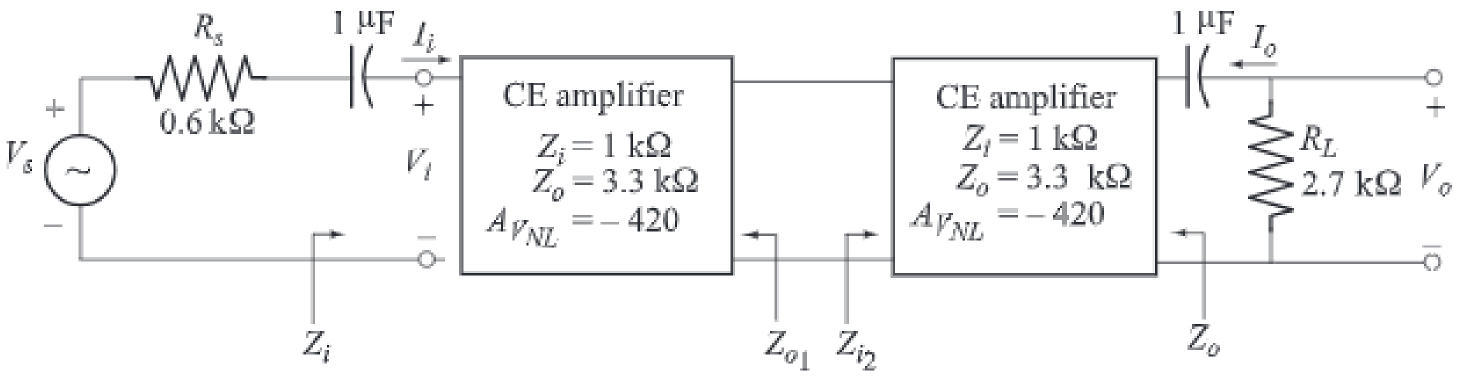
1. For the cascaded arrangement shown below, determine

a. The loaded voltage gain of each stage
b. The total gain of the system, A_V and A_{VS}
c. The current gain of each stage
d. The total current gain

Given:
Stage 1: Z_i = 1kΩ, Z_O = 3.3kΩ, A_{VNL} = -420
Stage 2: Z_i = 1kΩ, Z_O = 3.3kΩ, A_{VNL} = -420
R_S = 0.6kΩ, R_L = 2.7kΩ



Cascade Connection: Solved Examples



a. The loaded gain of each stage

For the emitter follower stage the load is Z_{i2}.

$$A_{V1} = \frac{V_{O1}}{V_{i1}} = \frac{Z_{i2}}{Z_{i2} + Z_{O1}} A_{VNL}$$

$$A_{V1} = \frac{1k}{1k + 3.3k} * -420 = -97.67$$

$$A_{V2} = \frac{V_{O2}}{V_{i2}} = \frac{R_L}{R_L + Z_{O2}} A_{VNL}$$

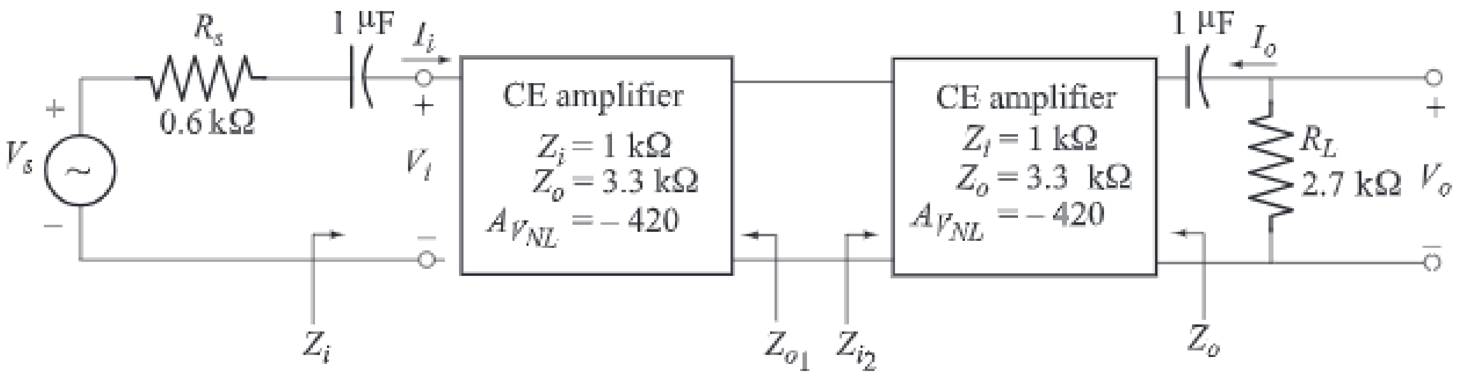
$$A_{V2} = \frac{2.7k}{2.7k + 3.3k} * -420 = -189$$

b. Total voltage gain

$$A_{VT} = AV_1 * AV_2$$

$$A_{VT} = -97.67 * -189 = 18.45 * 103$$

Cascade Connection: Solved Examples



$$A_{VS} = \frac{Z_{i1}}{Z_{i1} + R_S} A_{VT}$$

$$A_{VS} = \frac{1k}{1k + 0.6k} * 18.45 * 10^3 = 11.53 * 10^3$$

c. Current gain of each stage

$$A_{I1} = -AV_1 * \frac{Z_{i1}}{Z_{i2}}$$

$$A_{I1} = -(-97.67) * \frac{1k}{1k} = 97.67$$

$$A_{I2} = -AV_2 * \frac{Z_{i2}}{R_L} = -(-189) * \frac{1k}{2.7k} = 70$$

$$A_{iT} = Ai_1 * Ai_2 = 97.67 * 70 = 6.84 * 10^3$$

Darlington Amplifier

β_1 = Current gain of Q_1

β_2 = Current gain of Q_2

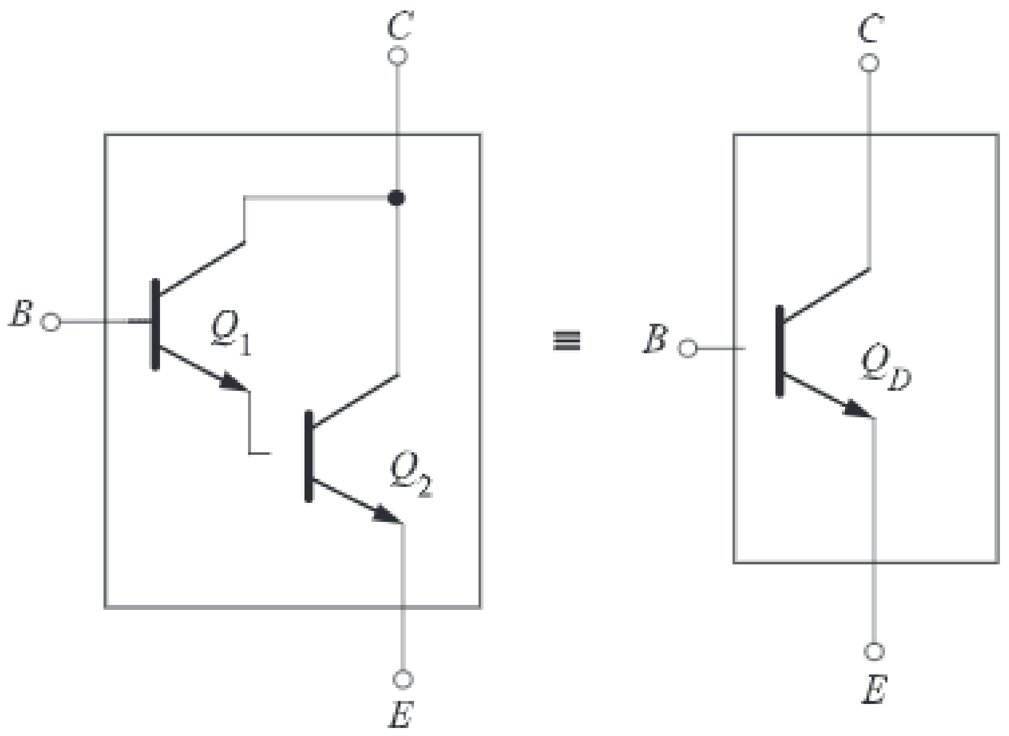
The current gain of Darlington Transistor:

$$\beta_D = \beta_1 * \beta_2$$

If $\beta_1 = \beta_2 = \beta$

$$\beta_D = \beta^2$$

A Darlington connection acts as single transistor with a **large current gain**.



Darlington Amplifier: DC Bias

Applying KVL to the base circuit we get;

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{BE} = V_{BE1} + V_{BE2}$$

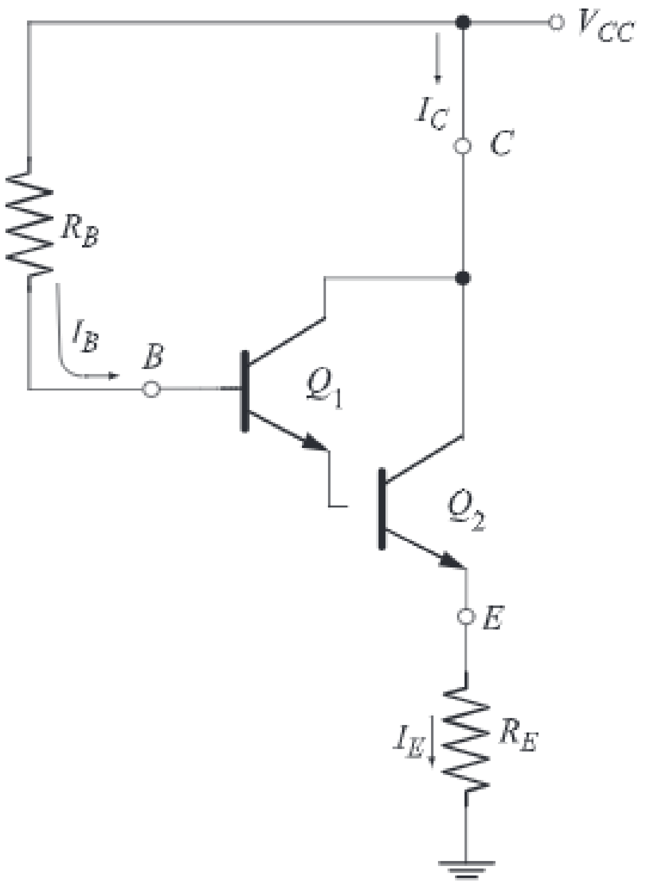
$$I_E = (1+\beta_D) I_B \approx \beta_D I_B$$

$$I_B R_B = V_{CC} - V_{BE} - I_E R_E$$

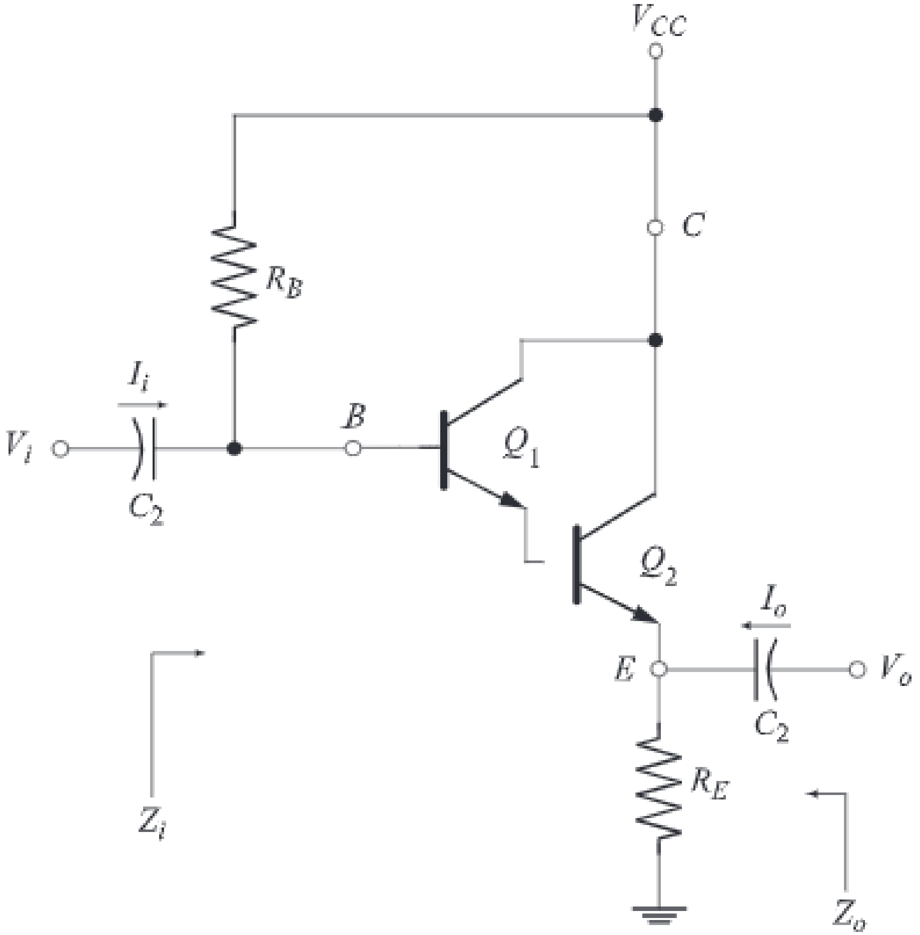
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta_D) R_E}$$

$$V_E = I_E * R_E$$

$$V_B = V_{BE} + V_E$$

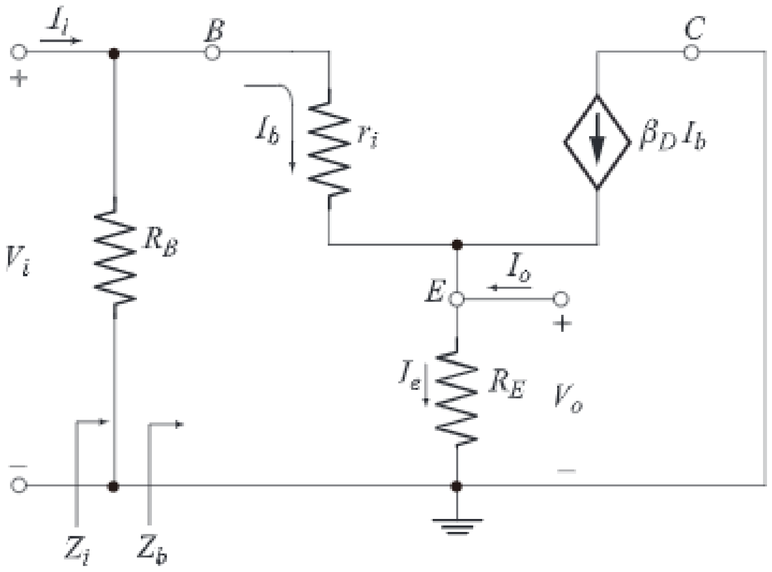


Darlington Emitter Follower



The Darlington transistor is replaced by

1. **Input resistance r_i between base and emitter.**
2. **Controlled current source between collector and emitter terminals.**



AC equivalent circuit

Darlington Emitter Follower

AC Input Impedance (Z_I):

Applying KVL to the circuit we get;

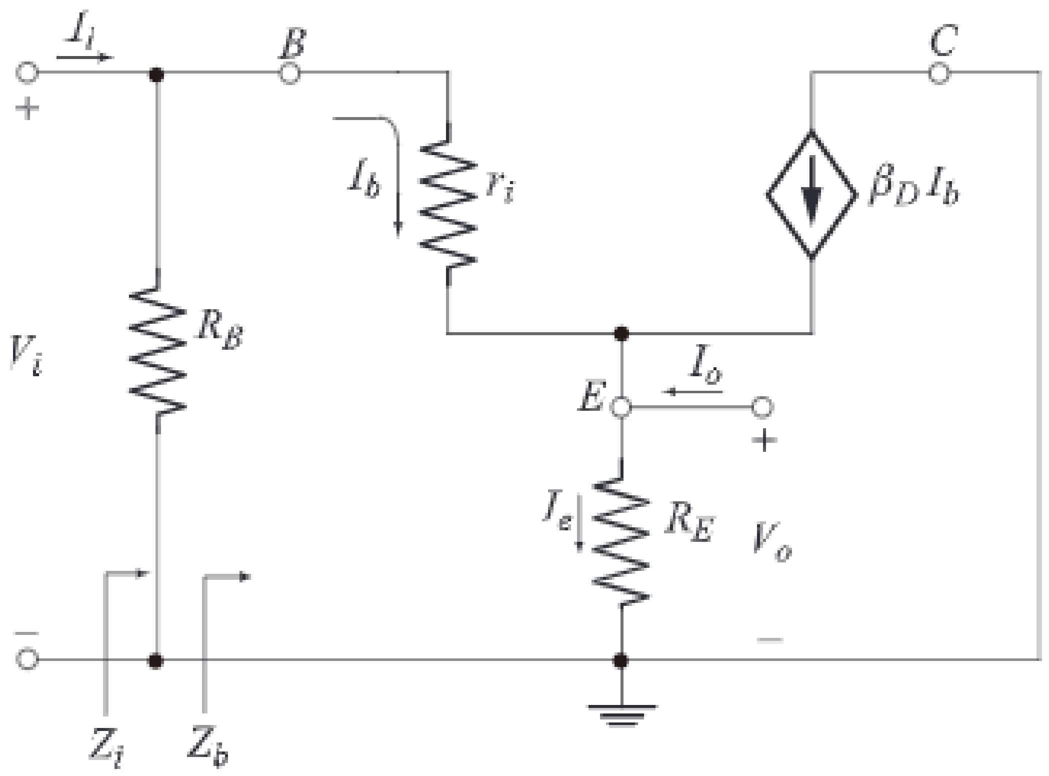
$$V_I = I_b r_i + I_e R_E$$

$$I_e = (1+\beta_D)I_b$$

$$V_I = I_b r_i + (1+\beta_D)I_b R_E$$

$$Z_b = \frac{V_I}{I_b} = r_i + (1+\beta_D)R_E \approx \beta_D R_E$$

$$Z_I = \frac{V_I}{I_I} = R_B \| Z_b$$



AC equivalent circuit

Darlington Emitter Follower

AC Current Gain (A_I):

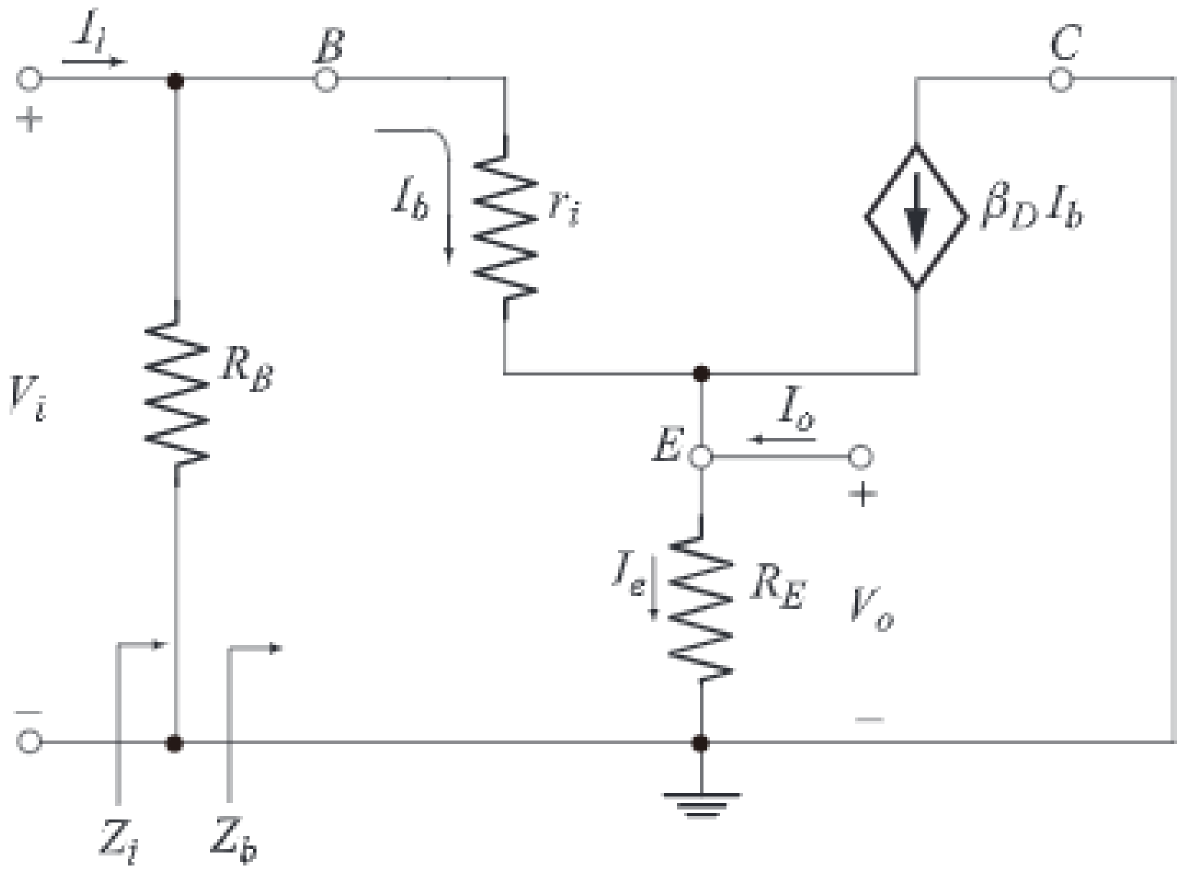
$$A_I = \frac{I_O}{I_I} = \frac{I_O}{I_b} * \frac{I_b}{I_I}$$

$$I_O = I_e$$

$$A_I = \frac{I_e}{I_I} = \frac{I_e}{I_b} * \frac{I_b}{I_I}$$

$$I_e = (1+\beta_D)I_b \approx \beta_D I_b$$

$$\frac{I_e}{I_b} = \beta_D$$



AC equivalent circuit

Darlington Emitter Follower

AC Current Gain (A_I):

Applying KCL to the circuit we get;

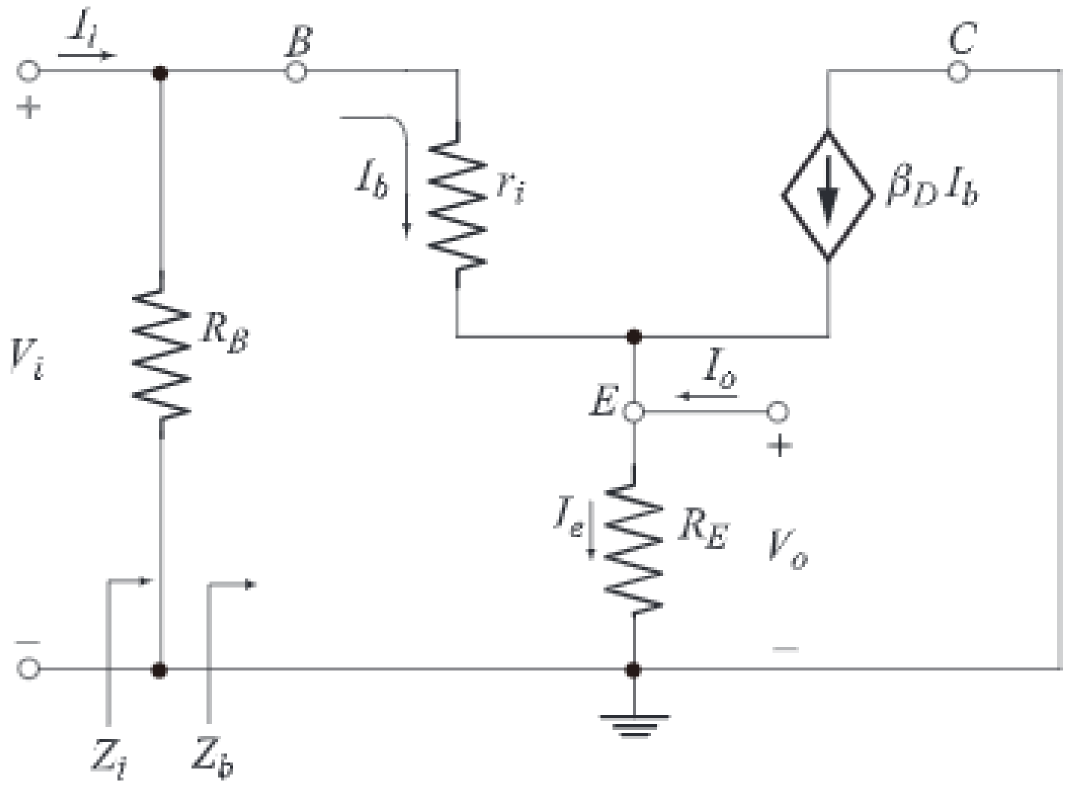
$$I_I = \frac{V_I}{R_B} + I_b$$

$$V_i = I_b Z_b$$

$$I_I = \frac{I_b Z_b}{R_B} + I_b = [\frac{Z_b}{R_B} + 1] * I_b$$

$$I_I = [\frac{Z_b + R_B}{R_B}] * I_b$$

$$\frac{I_b}{I_I} = \frac{R_B}{Z_b + R_B}$$



AC equivalent circuit

$$A_I = \frac{\beta_D R_B}{Z_b + R_B} = \frac{\beta_D R_B}{\beta_D R_E + R_B}$$

Darlington Emitter Follower

AC Voltage Gain (A_V):

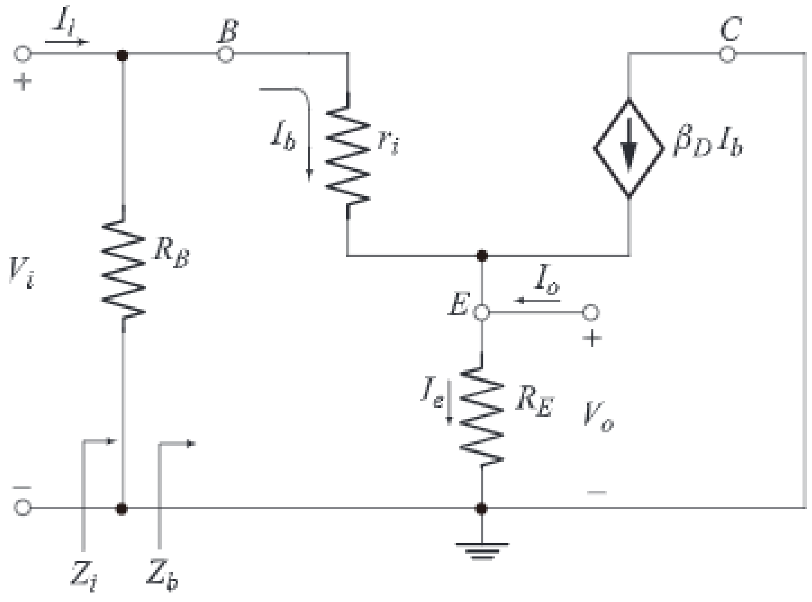
$$V_O = I_e R_E$$

$$V_O = (1+\beta_D) I_b R_E$$

$$V_I = I_b[r_i + (1+\beta_D)R_E]$$

$$A_V = \frac{V_O}{V_I} = \frac{(1+\beta_D)IbRE}{I_b[ri + (1+\beta_D)RE]}$$

$$A_V = \frac{V_O}{V_I} = \frac{(1+\beta_D)RE}{[ri + (1+\beta_D)RE]} \approx 1$$



AC equivalent circuit

Darlington Emitter Follower

AC Output Impedance (Z_O):

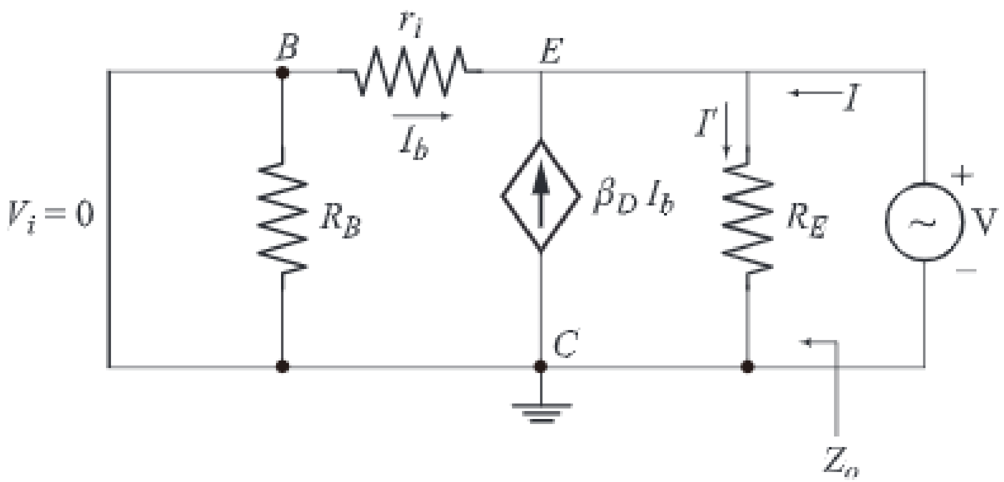
Applying KCL to the circuit we get;

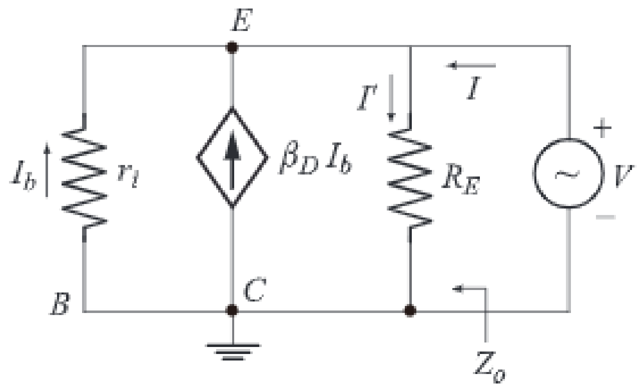
$$I_b + \beta_D I_b - I^I + I = 0$$

$$I_b = \frac{-V}{r_i} \quad \text{and} \quad I^I = \frac{V}{R_E}$$

$$\frac{-V}{r_i} + \beta_D \frac{-V}{r_i} - \frac{V}{R_E} + I = 0$$

$$\left[\frac{1}{r_i} + \frac{\beta_D}{r_i} + \frac{1}{R_E}\right] V = I$$





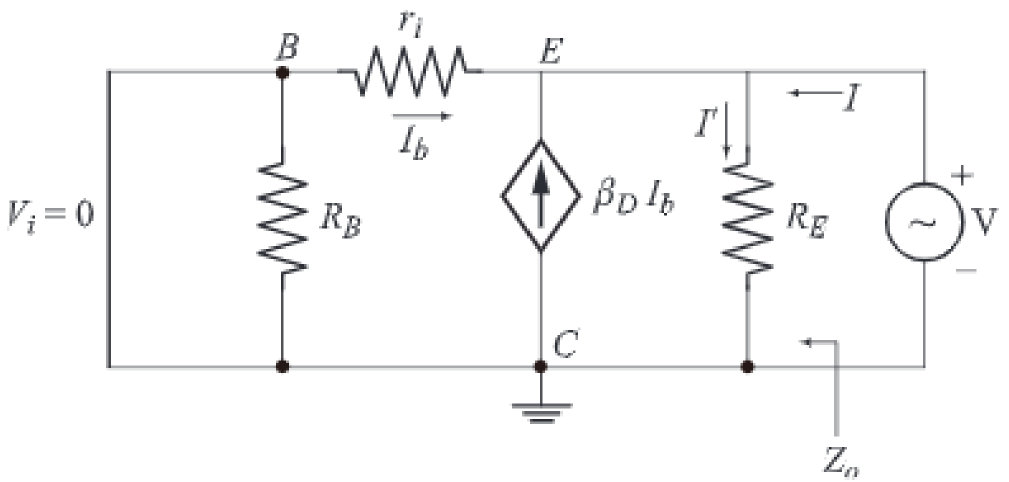
Darlington Emitter Follower

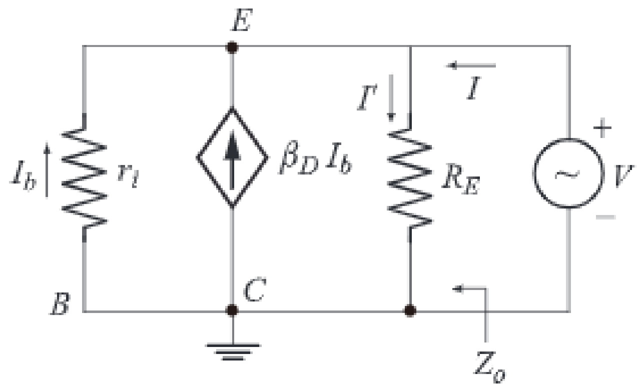
AC Output Impedance (Z_O):

$$Z_O = \frac{V}{I} = \frac{1}{\left[\frac{1}{r_i} + \frac{\beta_D}{r_i} + \frac{1}{R_E}\right]}$$

$$Z_O = \frac{V}{I} = \frac{1}{\left[\frac{1}{r_i} + \frac{1}{r_i/\beta_D} + \frac{1}{R_E}\right]}$$

$$Z_O = \left[r_i \| R_E \| \frac{r_i}{\beta_D}\right] \approx \frac{r_i}{\beta_D}$$





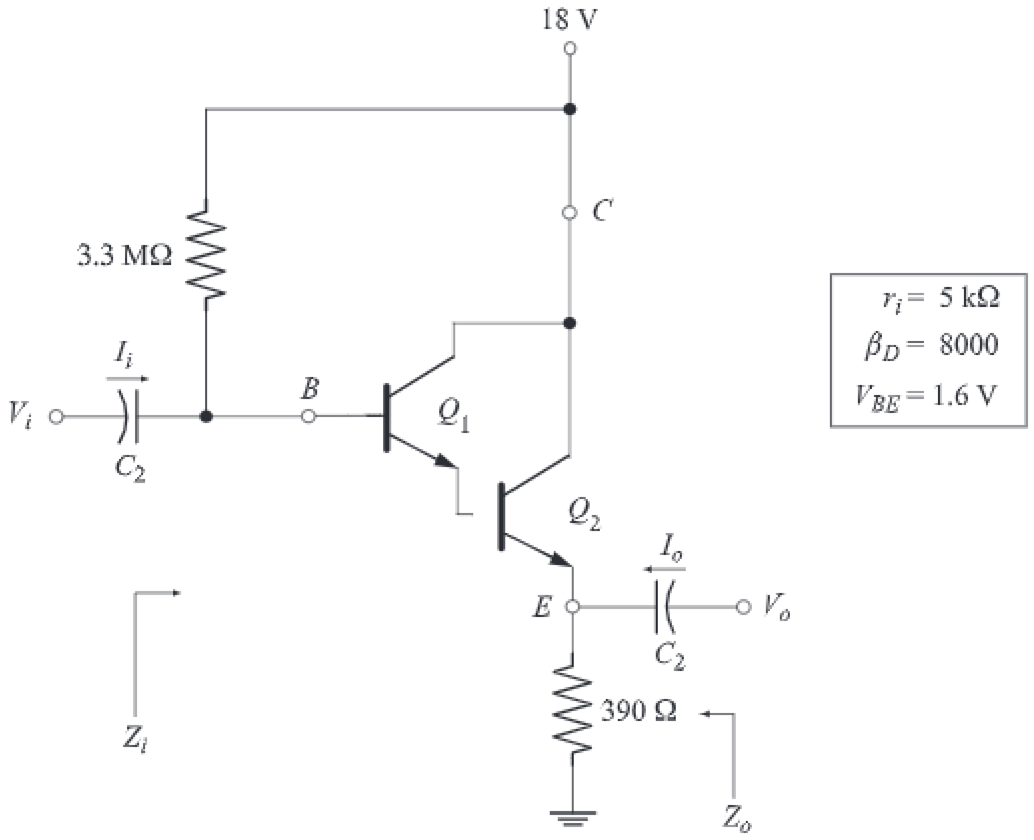
Darlington Emitter Follower

For the Darlington emitter-follower shown below:

(a) Calculate the dc bias voltages V_B, V_E, V_C and currents I_B and I_C.

(b) Calculate the input and output impedances.

(c) Determine the voltage and current gains.



Darlington Emitter Follower

(a)

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta_D R_E}$$

$$= \frac{18\,\text{V} - 1.6\,\text{V}}{3.3\,\text{M}\Omega + (8000)(390\,\Omega)} = 2.55\,\mu\text{A}$$

$$I_E = I_{E_2} \approx I_{C_2} = \beta_D I_B$$

$$= (8000)\,(2.55\,\mu\text{A}) = 20.4\,\text{mA}$$

$$V_E = I_E R_E = (20.4\,\text{mA})\,(390\,\Omega) = 7.96\,\text{V}$$

$$V_B = V_{BE} + V_E = 1.6\,\text{V} + 7.96\,\text{V} = 9.56\,\text{V}$$

Since the collector is directly tied to V_{CC}, the collector voltage equals the dc supply voltage V_{CC}.

$$\therefore \quad V_C = V_{CC} = 18\,\text{V}$$

Darlington Emitter Follower

(b)

$$Z_b = r_i + (1 + \beta_D)\, R_E$$
$$= 5\ \text{k}\Omega + (8001)\,(390\ \Omega) = 3.13\ \text{M}\Omega$$
$$Z_i = R_B \,||\, Z_b = 3.3\ \text{M}\Omega \,||\, 3.13\ \text{M}\Omega = 1.6\ \text{M}\Omega$$
$$Z_o = r_i \,||\, R_E \,||\, \frac{r_i}{\beta_D}$$
$$= 5\ \text{k}\Omega \,||\, 390\ \Omega \,||\, \frac{5\text{k}\Omega}{8000} = 0.625\ \Omega$$

Darlington Emitter Follower

(c)

$$A_V = \frac{R_E(1+\beta_D)}{r_i + R_E(1+\beta_D)}$$

$$= \frac{(390\,\Omega)(8001)}{5\,\text{k}\Omega + (390\,\Omega)(8001)} = 0.998$$

$$A_I = \frac{\beta_D R_B}{R_B + \beta_D R_E}$$

$$= \frac{(8000)(3.3\,\text{M}\Omega)}{3.3\,\text{M}\Omega + (8000)(390\,\Omega)} = 4112.15$$

(d)

$$V_o = A_V V_i = (0.998)\,(120\text{ mV})$$

$$= 119.76\text{ mV}$$

ATME College of Engineering

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Analog Electronic Circuits – BEE303

Module-III: Feedback Amplifiers

FEEDBACK AMPLIFIERS

- A feedback amplifier is one in which a fraction of the amplifier output is fed back to the input circuit. This partial dependence of amplifier output on its input helps to control the output. A feedback amplifier consists of two parts:
- **Positive feedback:** If the feedback voltage (or current) is so applied as to increase the input voltage (i.e. it is in phase with it), then it is called positive feedback. Other names for it are : regenerative or direct feedback.
- **Negative feedback:** If the feedback voltage (or current) is so applied as to reduce the amplifier input (i.e. it is 180° out of phase with it), then it is called negative feedback. Other names for it are : degenerative or inverse feedback.

Feedback Amplifiers

Advantages of Negative feedback:

1. Negative feedback stabilizes transfer gain.
2. Reduces Non-linear distortion by a factor, $1 + \beta A$.
3. Noise output is reduced by a factor, $1 + \beta A$.
4. Negative feedback reduces frequency distortion.
5. Voltage amplifier generally have high input resistance and low output resistance. Negative feedback further increases the input resistance and further decreases the output resistance.
6. Improves frequency response of the amplifier.

ADVANTAGES OF NEGATIVE FEEDBACK

- Higher fidelity i.e. more linear operation
- Highly stabilized gain
- Increased bandwidth i.e. improved frequency response
- Less amplitude distortion
- Less harmonic distortion
- Less frequency distortion
- Less phase distortion
- Reduced noise
- Input and output impedances can be modified as desired

Disadvantages of positive feed back

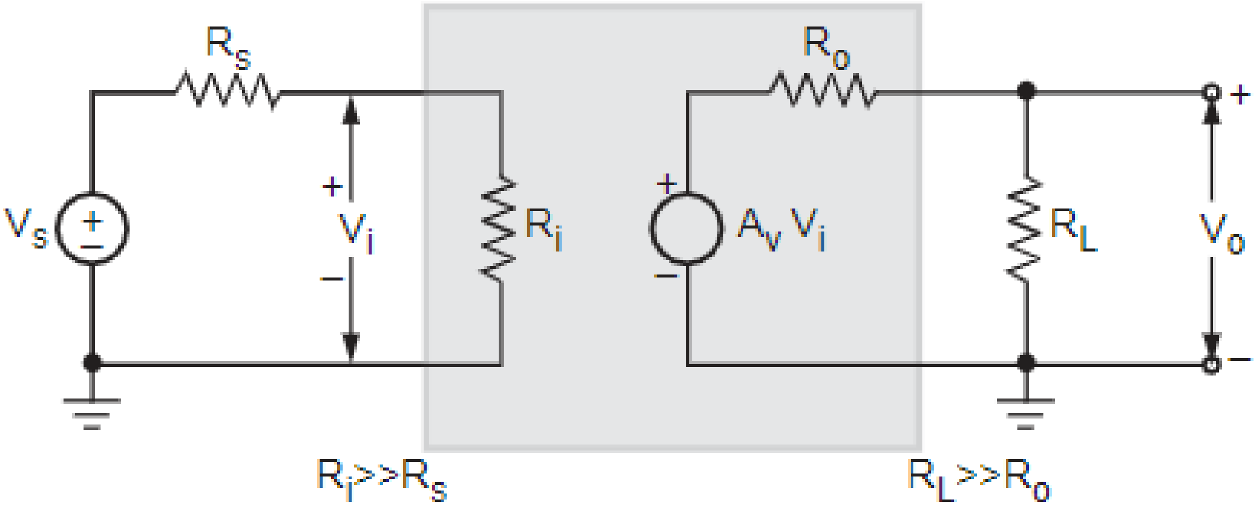
- Increases the distortion.
- Increases the noise.
- Poor stability.

Due to these features:

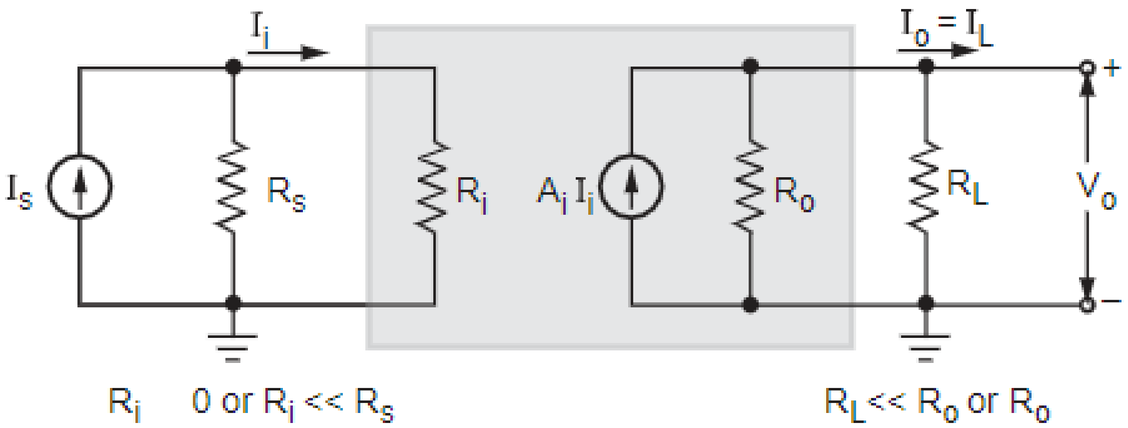
- it is seldom used in amplifiers.
- it is used in oscillators.

Feedback Amplifiers

Voltage Amplifier



Current Amplifier



$R_I >> R_S$ and $R_L >> R_O$

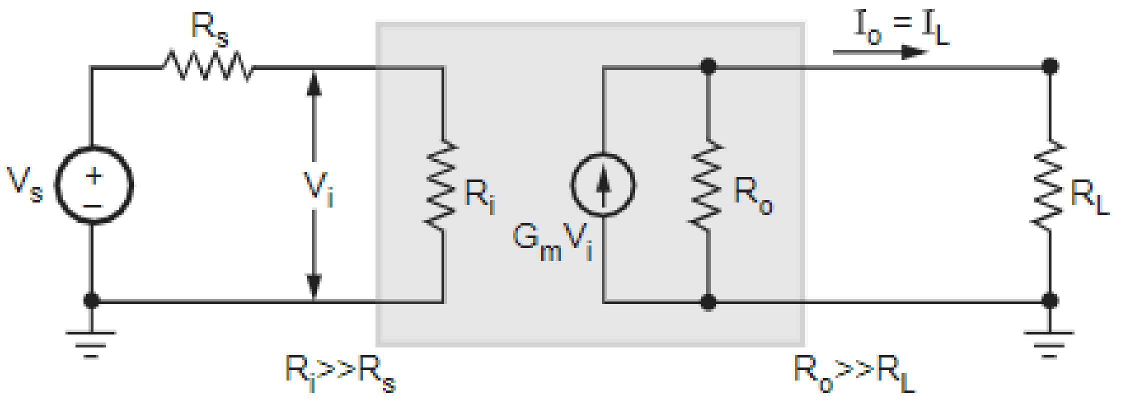
For Ideal Case: R_I = Infinite and R_O = Zero
Output voltage is proportional to the input voltage.

$R_I << R_S$ and $R_L << R_O$

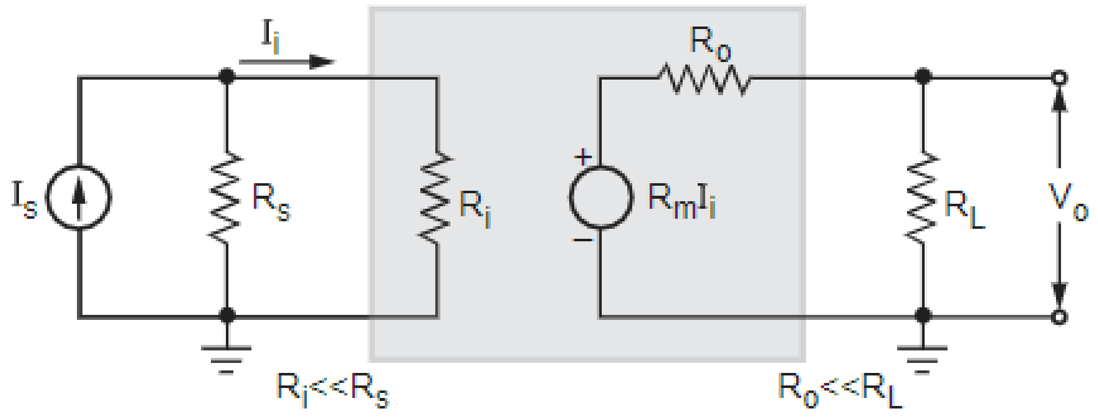
For Ideal Case: R_I = Zero and R_O = Infinite
Output current is proportional to input current.

Feedback Amplifiers

Transconductance Amplifier



Transresistance Amplifier



$R_I >> R_S$ and $R_L << R_O$

For Ideal Case: R_I = Infinite and R_O = Infinite
Output current is proportional to the input voltage.

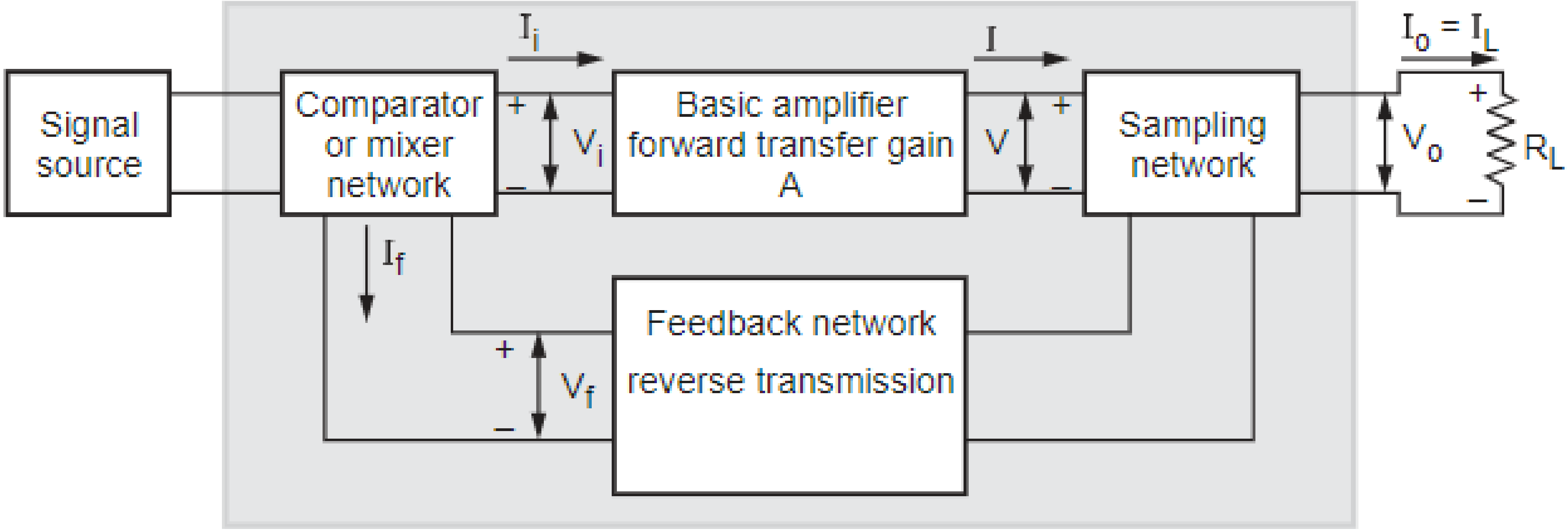
$R_I << R_S$ and $R_O << R_L$

For Ideal Case: R_I = Zero and R_O = Zero
Output voltage is proportional to input current.

Feedback Amplifier

The amplifier in which a part of output is sampled fed back to the input of the amplifier is called feedback amplifier.

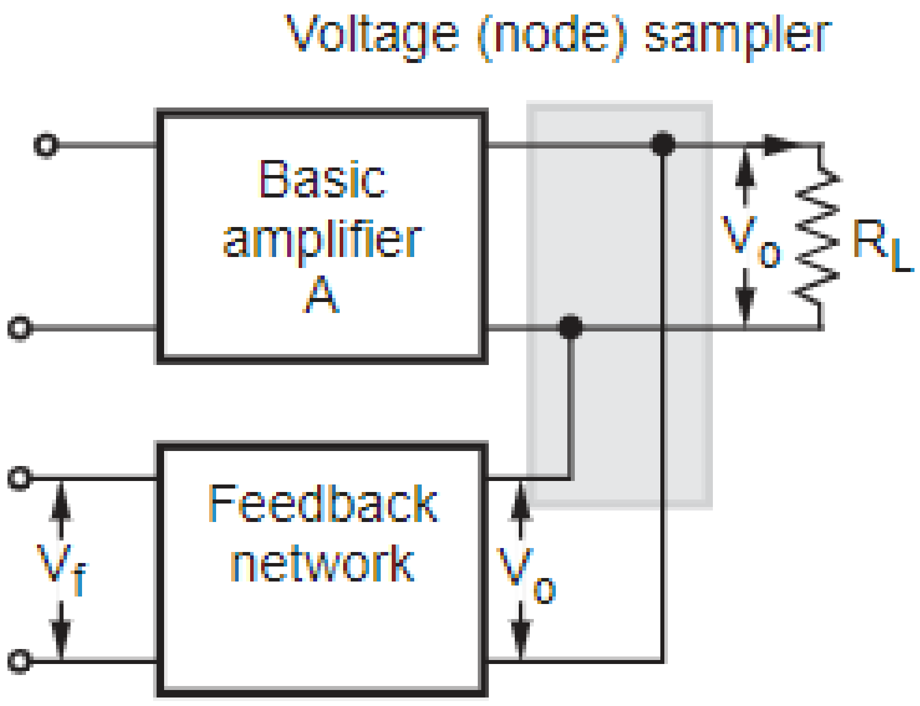
When input and a part of output signal are in phase, is called positive feedback.
When input and a part of signal are in out of phase, is called negative feedback.



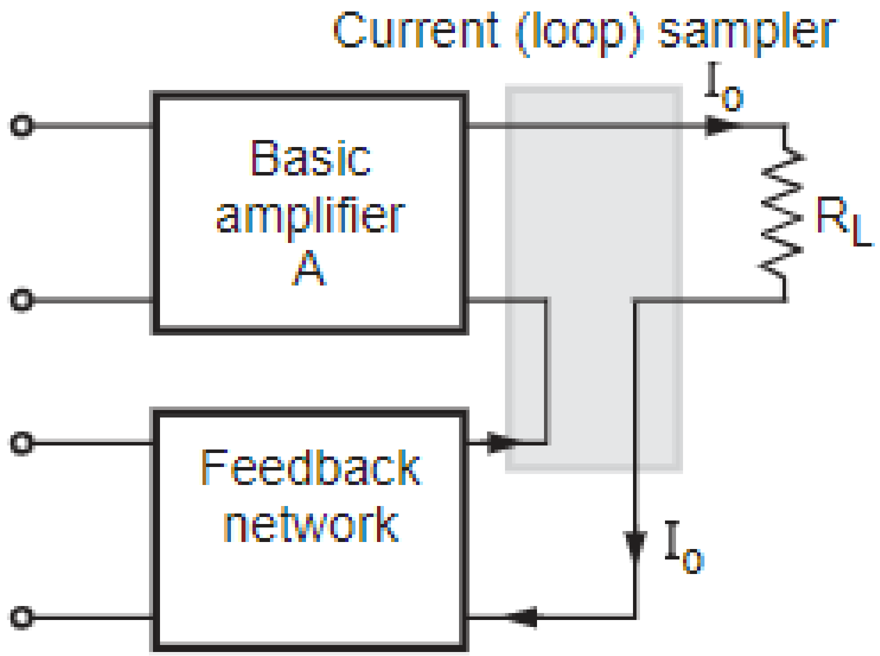
Feedback Structure

Sampling Network:

- The output voltage is sampled by connecting feedback network in shunt across the output.
- The output current is sampled by connecting feedback network in series with the output.



(a) Voltage or node sampling

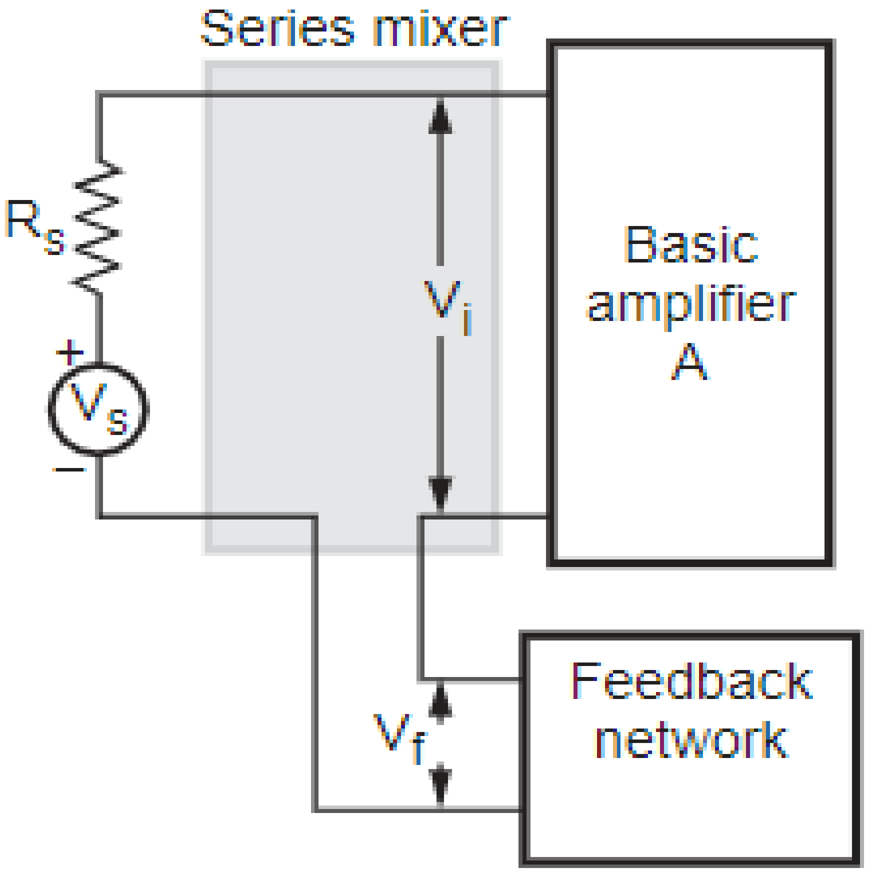


(b) Current or loop sampling

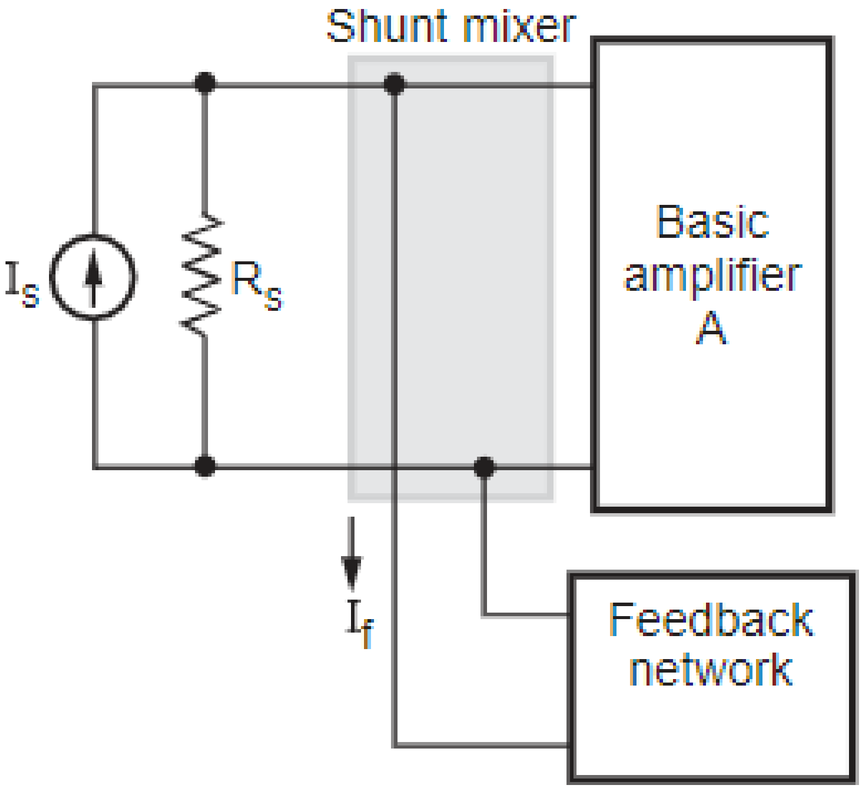
Feedback Structure

Mixer Network:

-

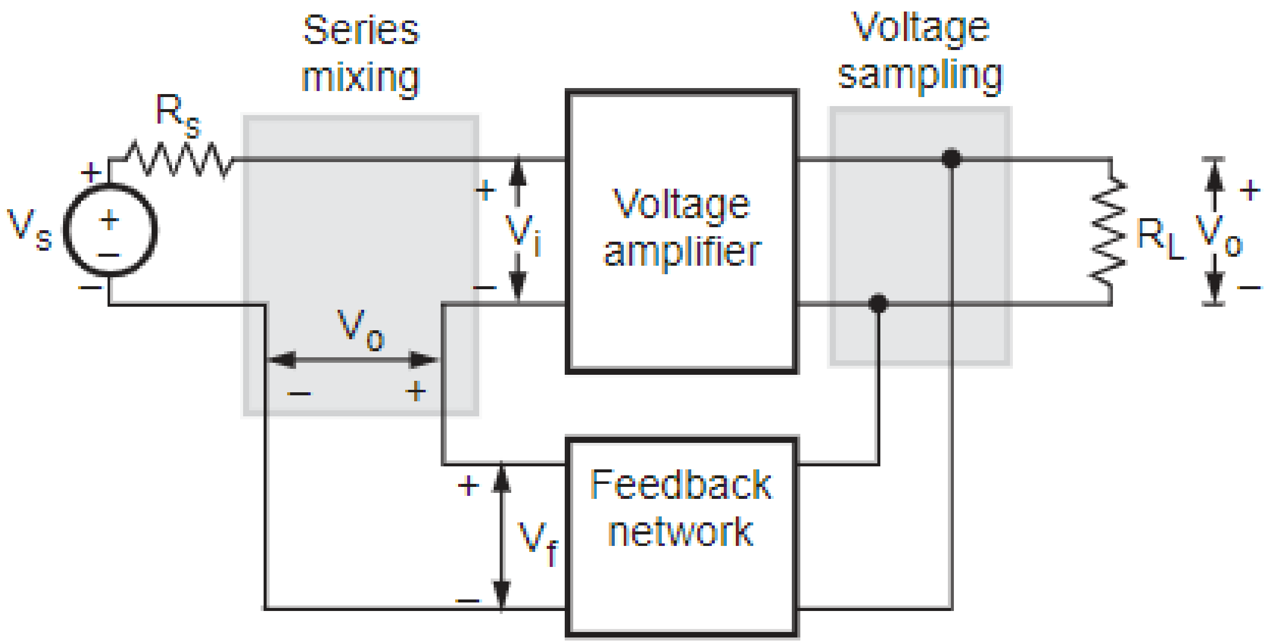


(a) Series mixing

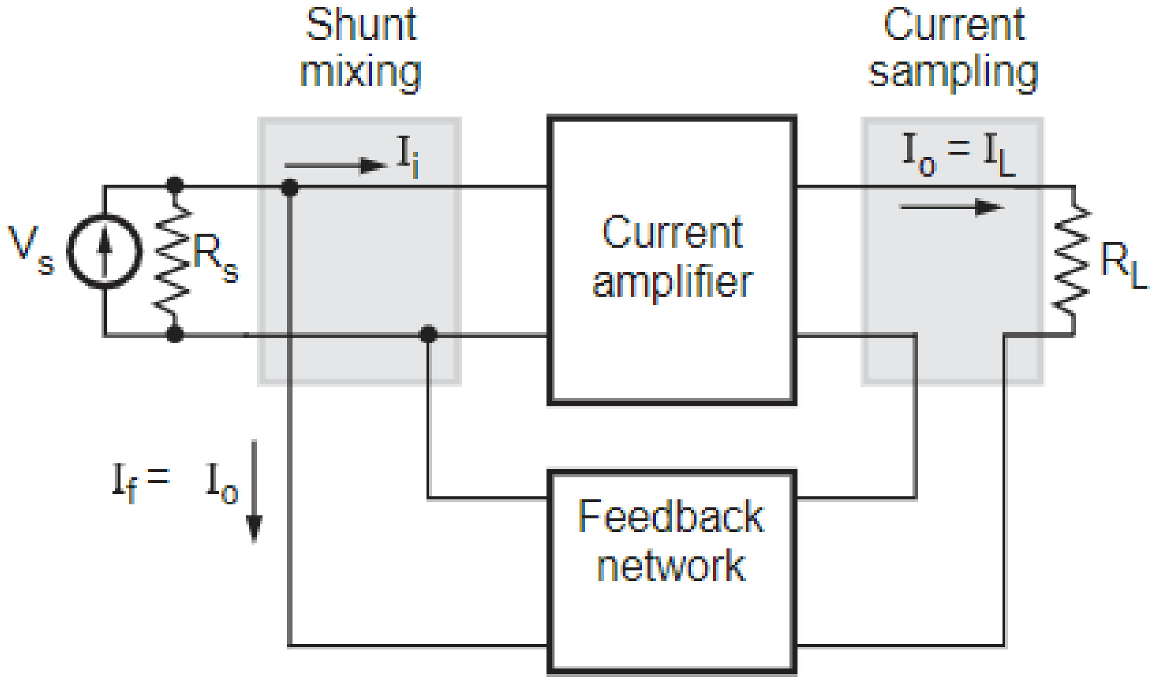


(b) Shunt mixing

Basic Feedback Topologies

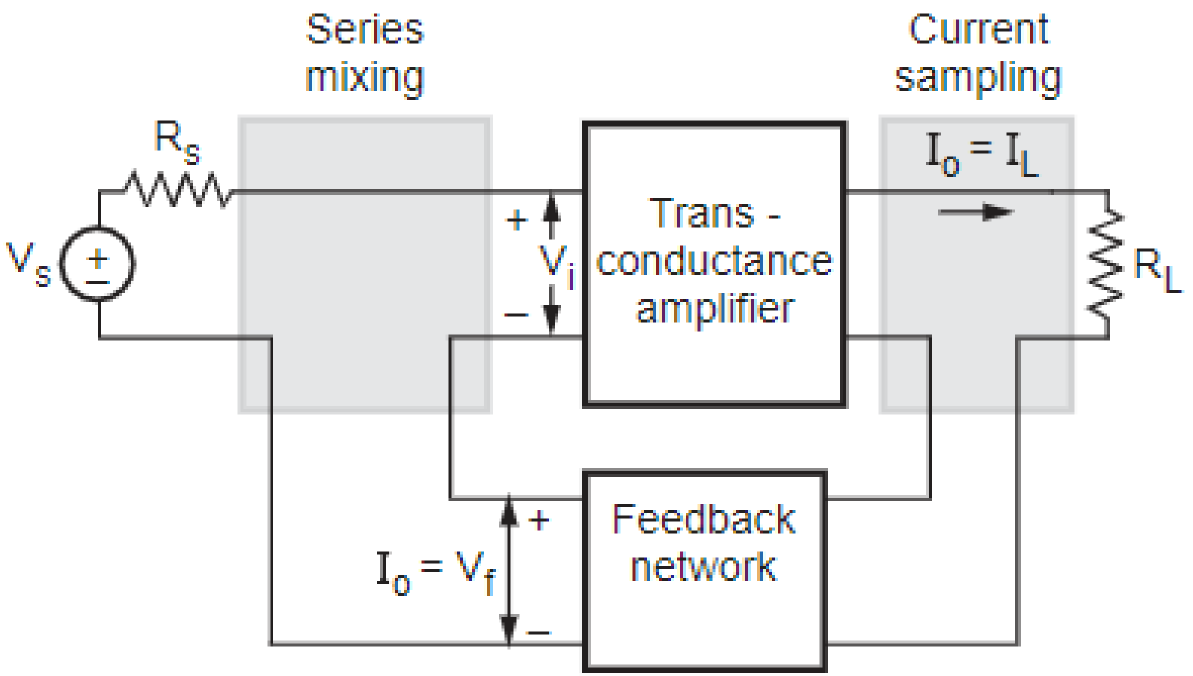


Voltage amplifier with voltage series feedback

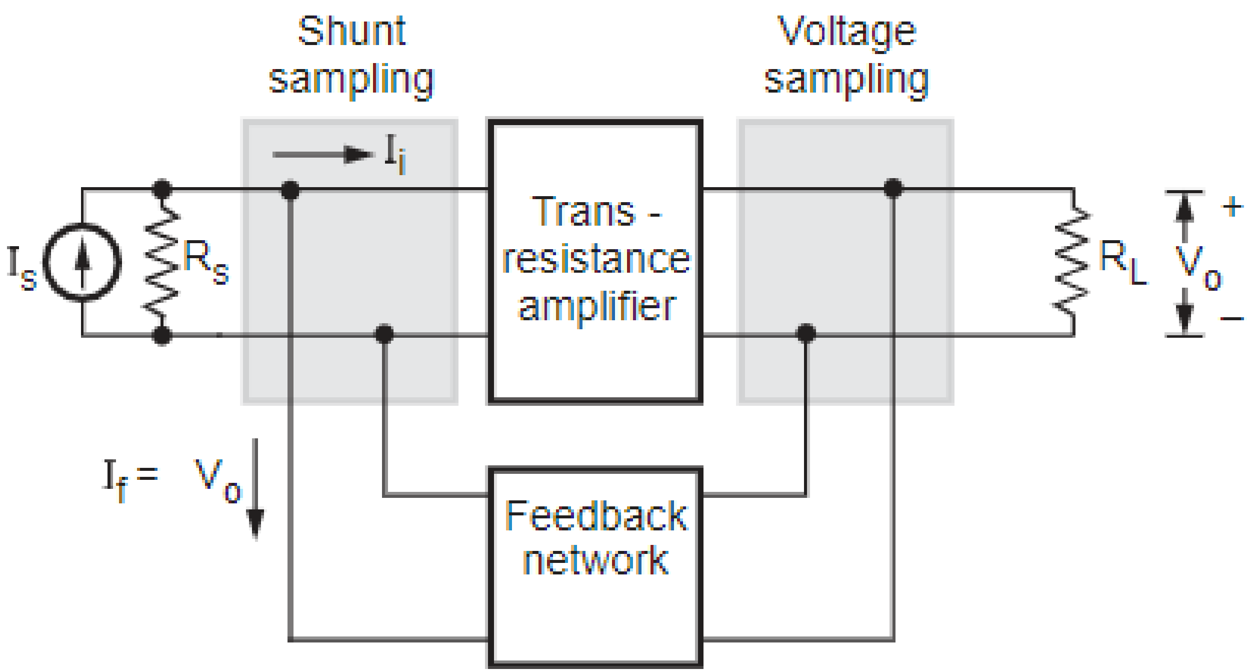


Current amplifier with current shunt feedback

Basic Feedback Topologies

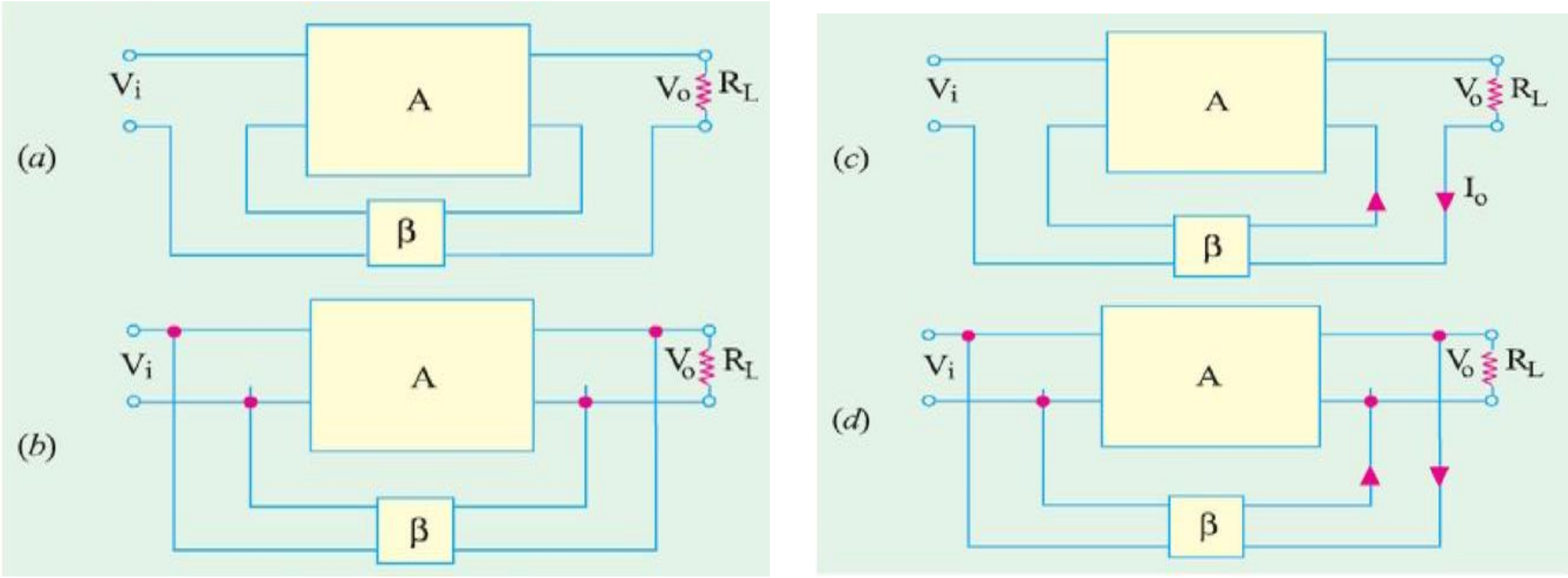


Trans-conductance amplifier with current series feedback

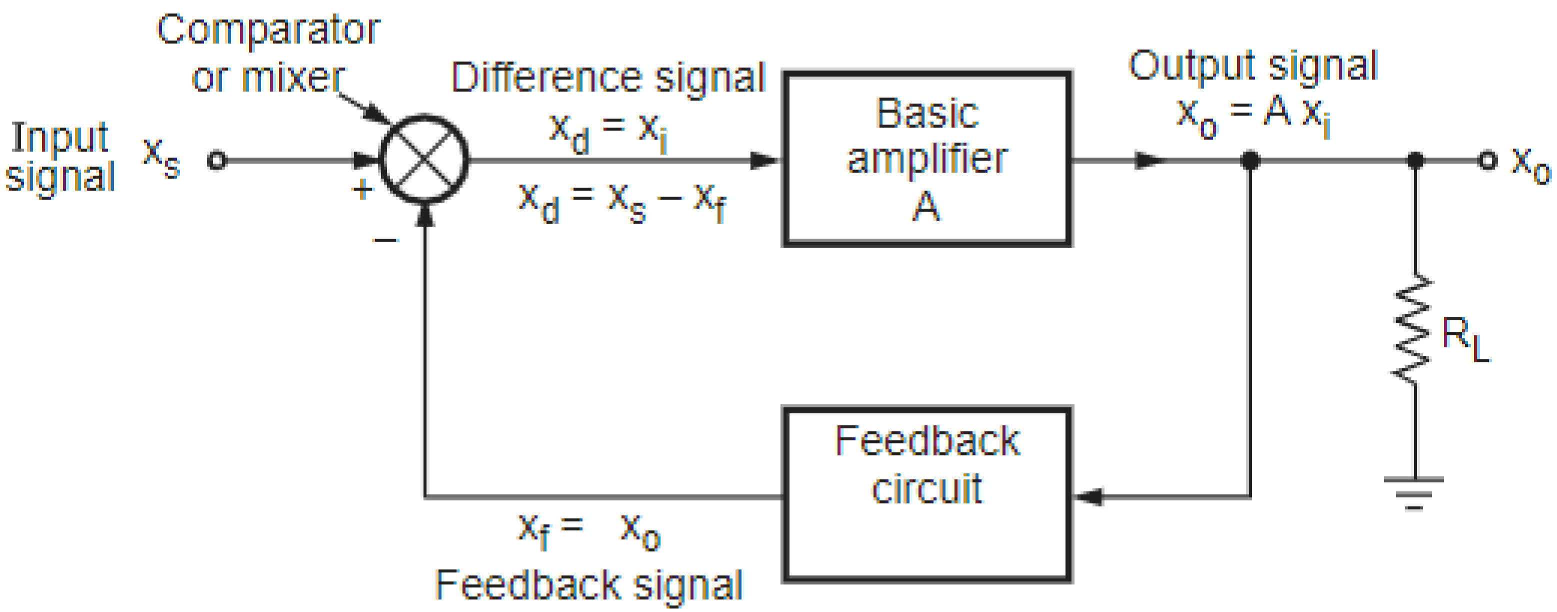


Trans-resistance amplifier with voltage shunt feedback

FORMS OF NEGATIVE FEEDBACK



Gain with Feedback



$$A = \frac{X_o}{X_I} \quad \text{and } A_f = \frac{X_o}{X_s}$$

Where,

X_O = Output voltage or output current.

X_I = Input voltage or input current.

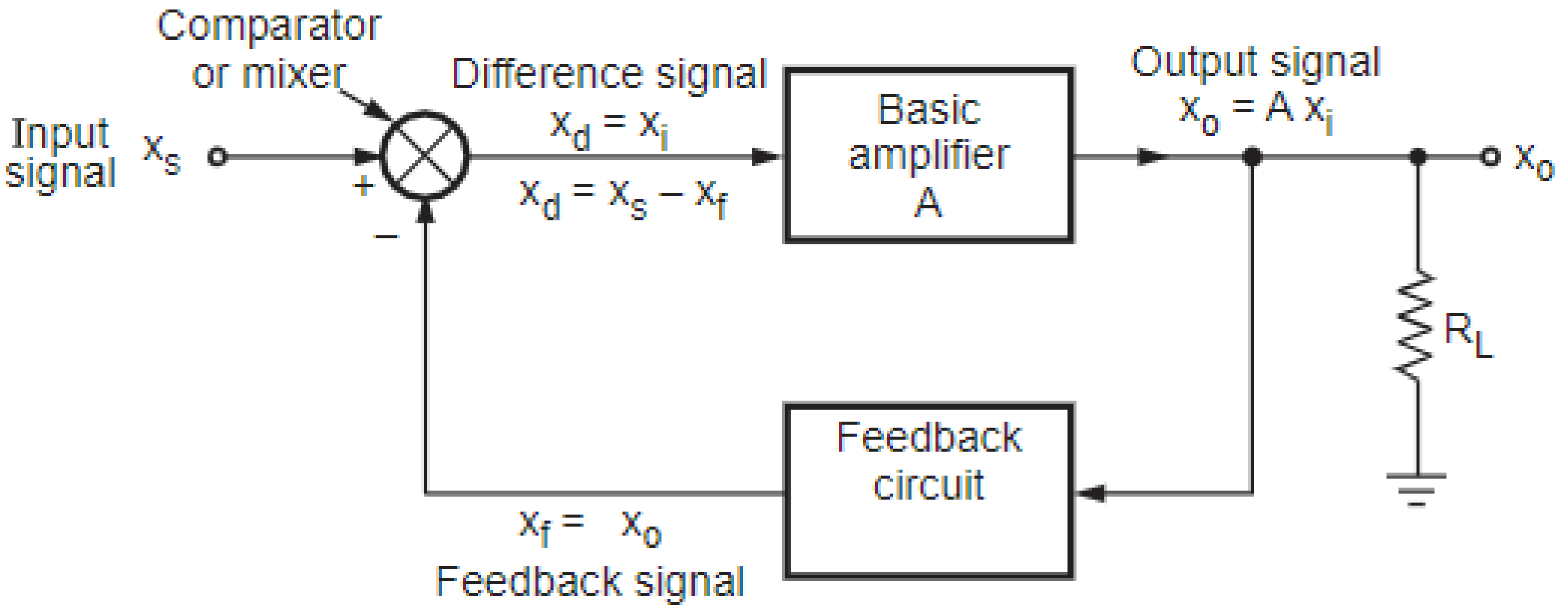
X_S = Source voltage or source current.

$$X_I = X_S - X_f$$

X_f = feedback voltage or feedback current.

$$A_f = \frac{X_O}{X_S} = \frac{X_O}{X_I + Xf}$$

Gain with Feedback



$$A_f = \frac{X_O}{X_S} = \frac{X_O}{X_I + Xf}$$

$$A_f = \frac{X_O/XI}{1 + Xf/XI}$$

$$A_f = \frac{A}{1 + \left[\frac{X_f}{X_O} * \frac{X_O}{X_I}\right]}$$

$$A_f = \frac{A}{1 + [\beta\, A]}$$

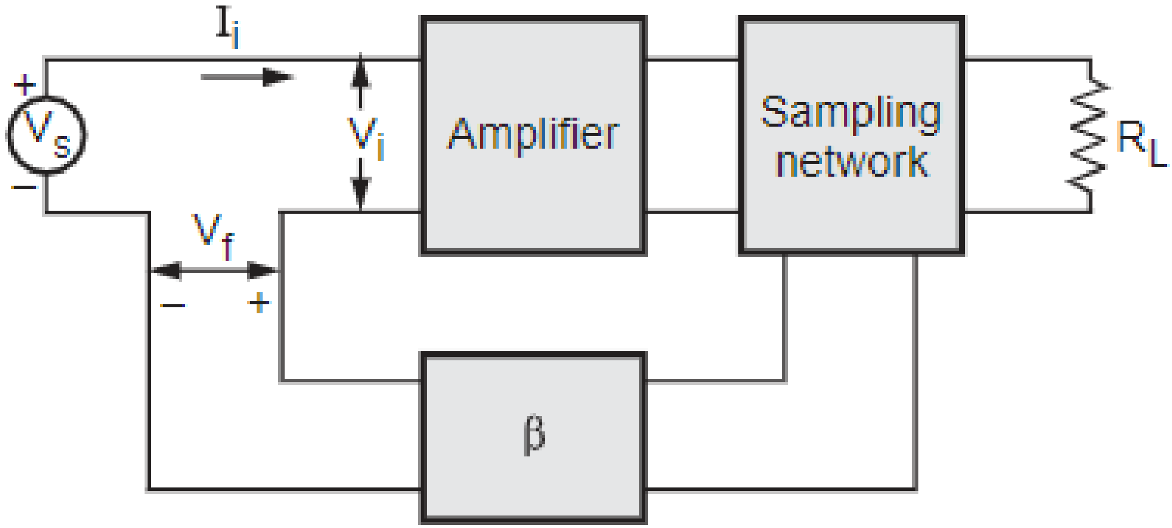
β is a Feedback Factor

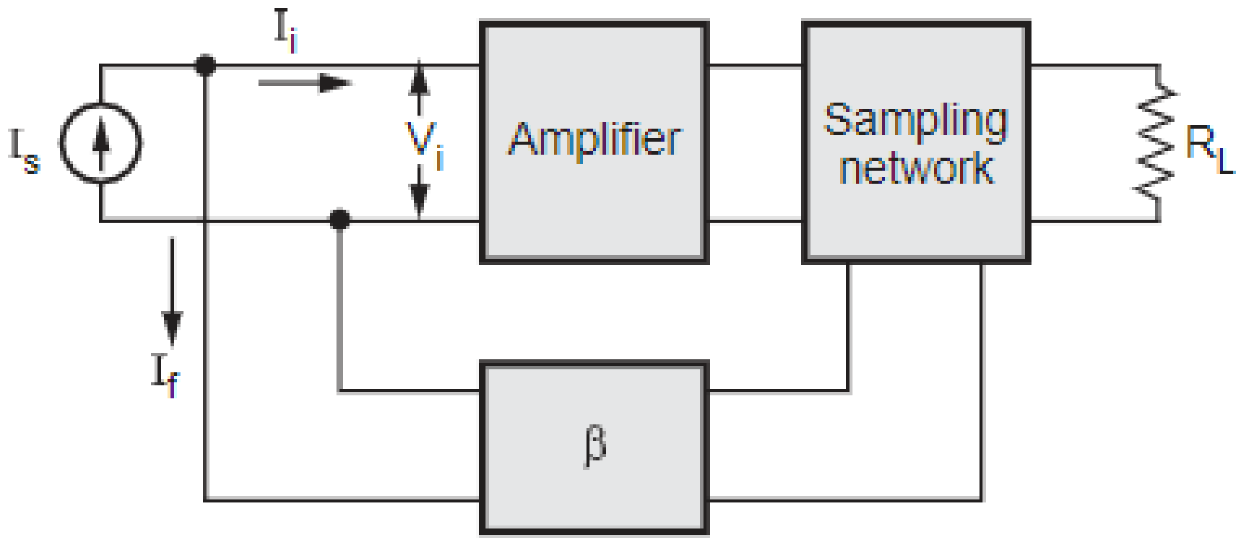
Effect of Feedback on Input Resistance

Voltage Amplifier:

If feedback signal is added in series with the input signal, it increases the input resistance.

If feedback signal is added in shunt with the input signal, it decreases the input resistance.





Input resistance of Voltage Series Feedback amplifier

Input resistance with feedback:

$$R_{if} = \frac{V_S}{I_i} \qquad (1)$$

Obtain Expression for Vs

Applying KVL to the input side we get;

$$V_S - I_iR_i - V_f = 0$$

$$V_S = I_iR_i + V_f = I_iR_i + \beta V_O \qquad (2)$$

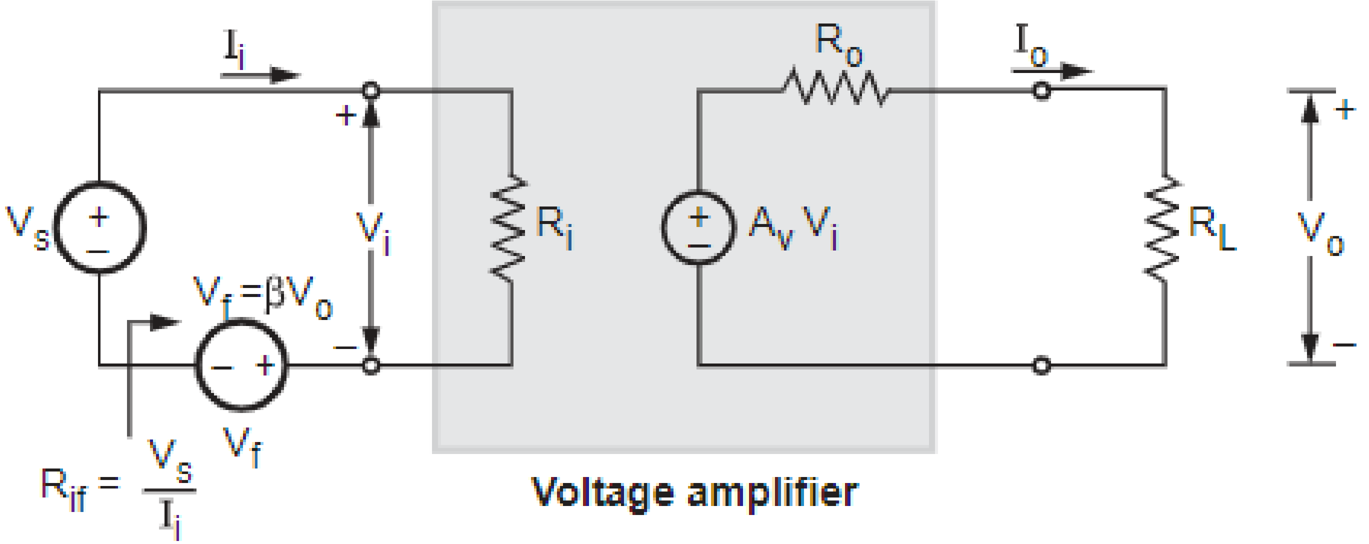
Obtain Expression for Vo in terms of Ii

The output voltage is given by;

$$V_O = \frac{A_v V_i R_L}{R_O + R_L} = A_V V_i$$

Where, $A_V = \frac{A_v R_L}{R_O + R_L}$

$$V_O = A_V I_i R_i \qquad (3)$$



Obtain Expression for R_{if}

Substitute Eq.(3) in Eq.(2)

$$V_S = I_iR_i + \beta V_O = I_iR_i + \beta A_V I_i R_i$$

$$R_{if} = \frac{V_S}{I_i} = R_i + \beta A_V R_i$$

$$R_{if} = \frac{V_S}{I_i} = R_i\,[1 + \beta A_V]$$

Input resistance of Current Series Feedback Amplifier

Input resistance with feedback:

$$R_{if} = \frac{V_S}{I_i} \qquad (1)$$

Obtain Expression for Vs

Applying KVL to the input side we get;

$$V_S - I_iR_i - V_f = 0$$

$$V_S = I_iR_i + V_f = I_iR_i + \beta I_O \qquad (2)$$

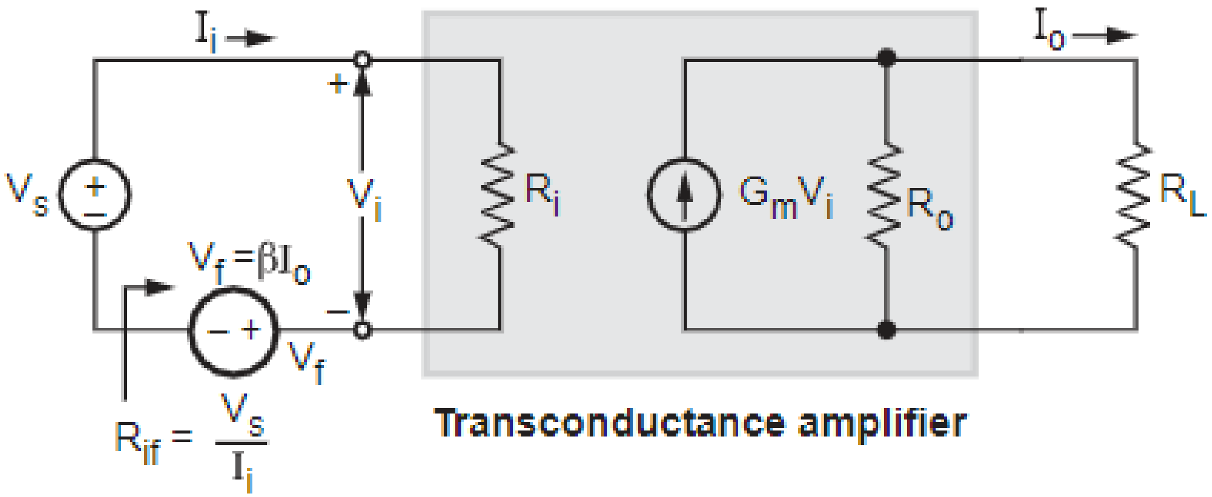
Obtain Expression for Io in terms of Vi

The output current is given by;

$$I_O = \frac{G_mV_iR_O}{R_O + R_L} = G_MV_i$$

Where, $G_M = \frac{G_mR_O}{R_O+R_L}$

$$I_O = G_MI_iR_i \qquad (3)$$



Obtain Expression for R_{if}

Substitute Eq.(3) in Eq.(2)

$$V_S = I_iR_i + \beta I_O = I_iR_i + \beta\, G_MI_iR_i$$

$$R_{if} = \frac{V_S}{I_i} = R_i + \beta\, G_MR_i$$

$$R_{if} = \frac{V_S}{I_i} = R_i\,[1+ \beta\, G_M]$$

Input resistance of Current Shunt Feedback Amplifier

Input resistance with feedback:

$$R_{if} = \frac{V_I}{I_S} \qquad (1)$$

Obtain Expression for Is

Applying KCL to the input side we get;

$$I_S = I_i + I_f$$

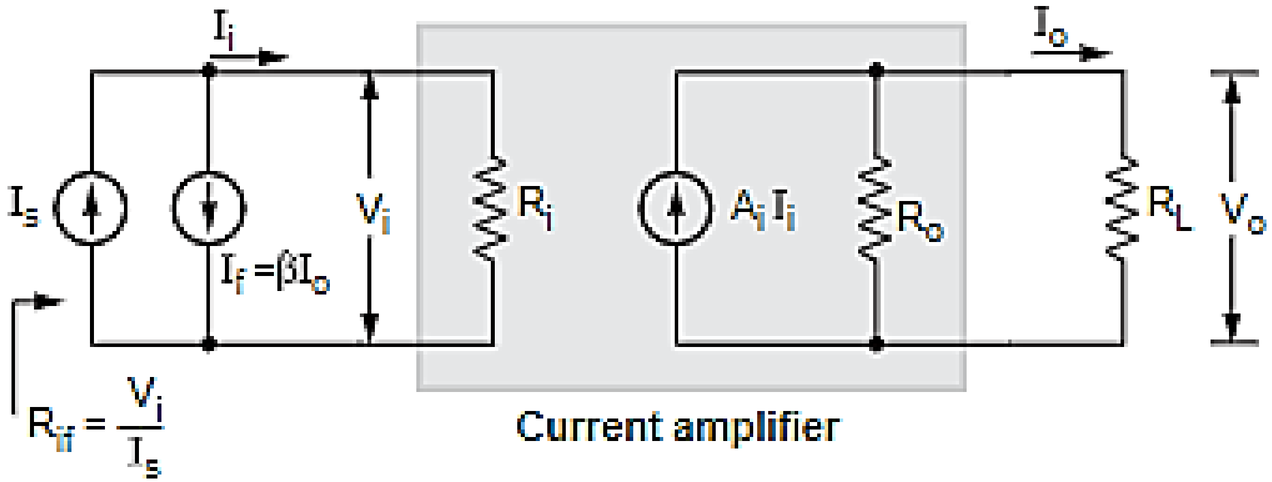
$$I_S = I_i + \beta I_O \qquad (2)$$

Obtain Expression for Io in terms of Ii

The output current is given by;

$$I_O = \frac{A_i I_i R_O}{R_O + R_L} = A_I I_i \qquad (3)$$

Where, $A_I = \dfrac{A_i R_O}{R_O + R_L}$



Obtain Expression for R_{if}

Substitute Eq.(3) in Eq.(2)

$$I_S = I_i + \beta I_O = I_i + \beta A_I I_i = I_i\,[1 + \beta A_I]$$

$$R_{if} = \frac{V_I}{I_S} = \frac{V_I}{I_i(1 + \beta A_I)}$$

$$R_{if} = \frac{V_I}{I_S} = \frac{R_I}{(1 + \beta A_I)}$$

Input resistance of Voltage Shunt Feedback Amplifier

Input resistance with feedback:

$$R_{if} = \frac{V_I}{I_S} \qquad (1)$$

Obtain Expression for Is

Applying KCL to the input side we get;

$$I_S = I_i + I_f$$

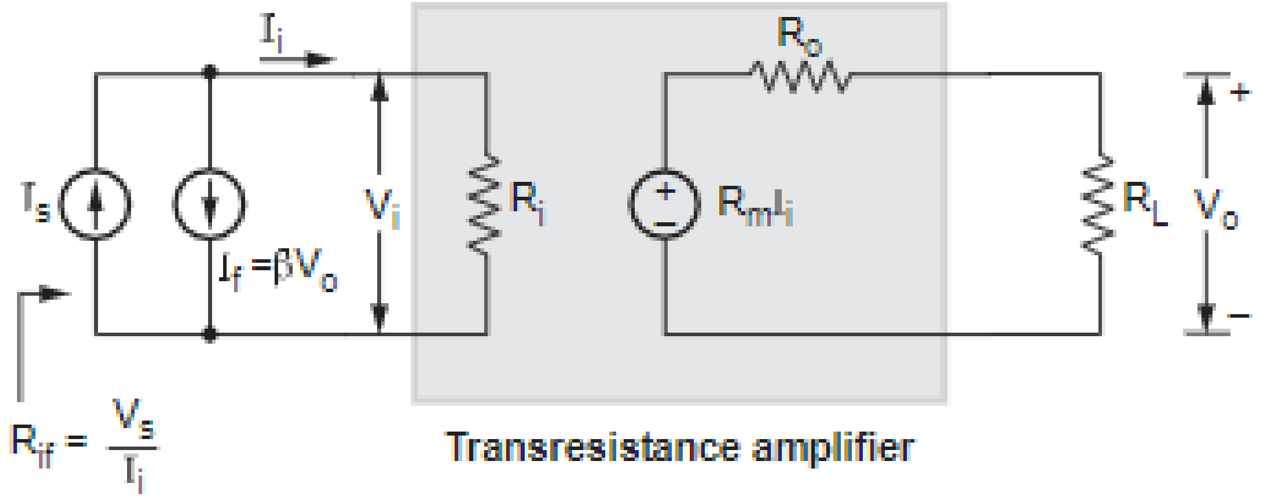
$$I_S = I_i + \beta V_O \qquad (2)$$

Obtain Expression for Vo in terms of Ii

The output voltage is given by;

$$V_O = \frac{R_m I_i R_O}{R_O + R_L} = R_M I_i \quad (3)$$

Where, $R_M = \frac{R_m R_O}{R_O + R_L}$



Obtain Expression for R_{if}

Substitute Eq.(3) in Eq.(2)

$$I_S = I_i + \beta I_O = I_i + \beta R_M I_i = I_i\,[1 + \beta R_M]$$

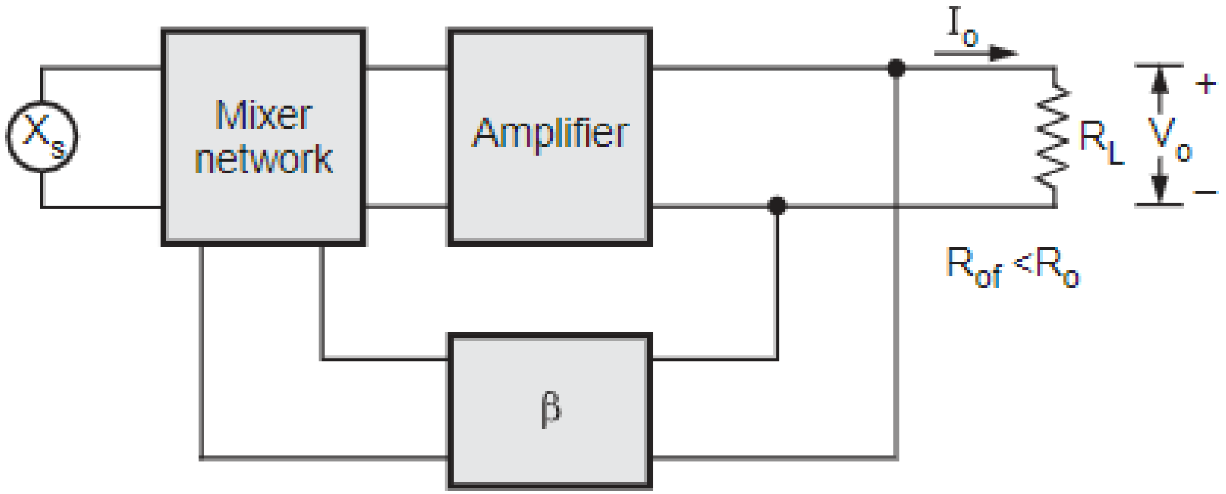
$$R_{if} = \frac{V_I}{I_S} = \frac{V_I}{I_i(1 + \beta R_M)}$$

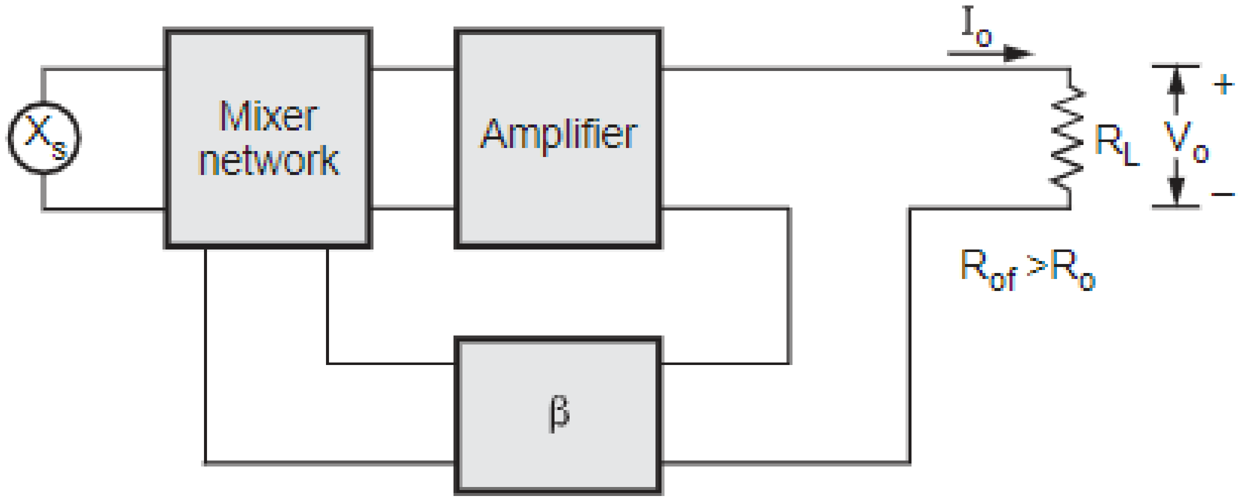
$$R_{if} = \frac{V_I}{I_S} = \frac{R_I}{(1 + \beta R_M)}$$

Effect of Feedback on Output Resistance

The negative feedback signal which samples the output voltage, it decreases the output resistance.

The negative feedback signal which samples the output current, it increases the output resistance.





Output resistance of Voltage Series Feedback

Output resistance with feedback:

1.Obtain Expression for I in Terms of V.

Applying KVL to the output side we get;

$$A_V V_I + IR_O - V = 0$$

$$I = \frac{V - A_v V_i}{R_O}$$

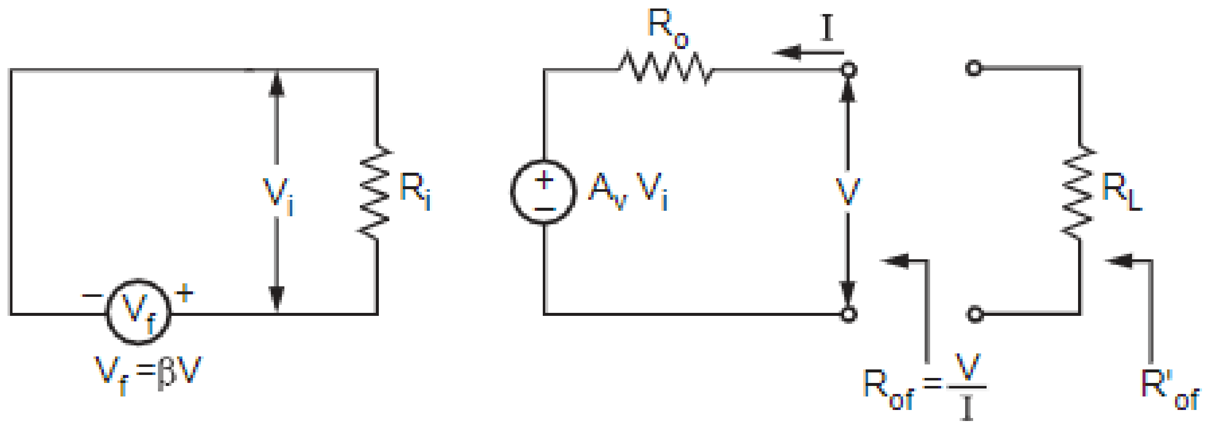
The input voltage is given as;

$$V_i = - V_f = - \beta V$$

$$I = \frac{V + \beta A_v V}{R_O} = \frac{V(1 + \beta A_V)}{R_O}$$

2. Obtain Expression for R_{Of}

$$R_{Of} = \frac{V}{I} = \frac{R_O}{1 + \beta A_V}$$



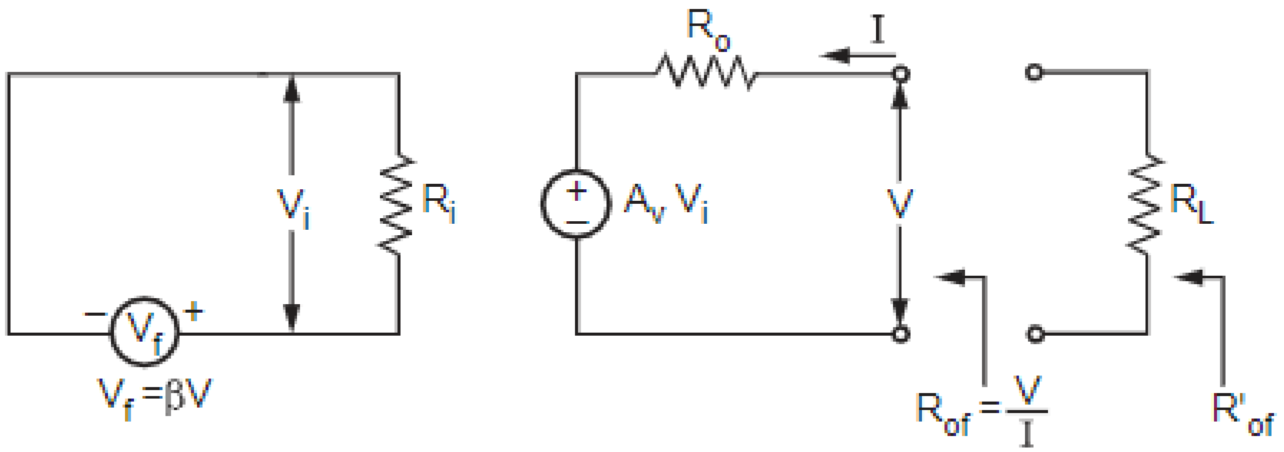
Draw the Equivalent Circuit with Vs = 0 & RL disconnected

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$

Output resistance of Voltage Series Feedback

3. Obtain Expression for R'_{Of}

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$



$$\frac{\left(\frac{R_o}{1+\beta A_v}\right) \times R_L}{\frac{R_o}{(1+\beta A_v)} + R_L}$$

$$= \frac{R_o R_L}{R_o + R_L(1+\beta A_v)} = \frac{R_o R_L}{R_o + R_L + \beta A_v R_L}$$

$$R'_{of} = \frac{R'_o}{1+\beta A_V}$$

$$R'_{of} = \frac{\frac{R_o R_L}{R_o + R_L}}{1 + \frac{\beta A_v R_L}{R_o + R_L}}$$

$$\because R'_o = \frac{R_o R_L}{R_o + R_L} \text{ and } A_V = \frac{A_v R_L}{R_o + R_L}$$

Output resistance of Voltage Shunt Feedback

Output resistance with feedback:

1.Obtain Expression for I in Terms of V

Applying KVL to the output side we get;

$$R_m I_i + I R_O - V = 0$$

$$I = \frac{V - RmIi}{R_O}$$

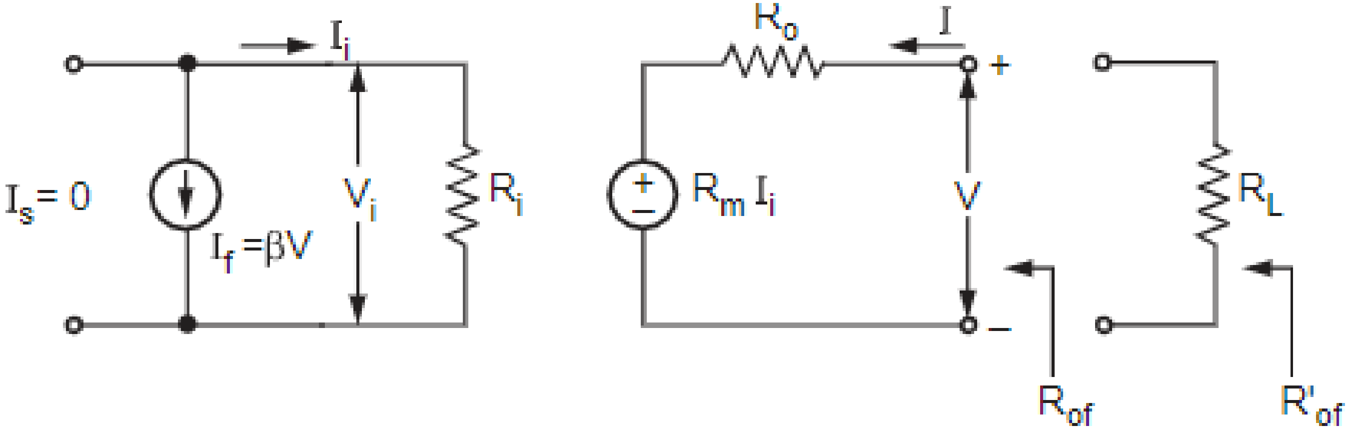
The input current is given as;

$$I_i = -I_f = -\beta V$$

$$I = \frac{V + \beta R_m V}{R_O} = \frac{V(1 + \beta R_m)}{R_O}$$

2. Obtain Expression for R_{Of}

$$R_{Of} = \frac{V}{I} = \frac{R_O}{1 + \beta R_m}$$



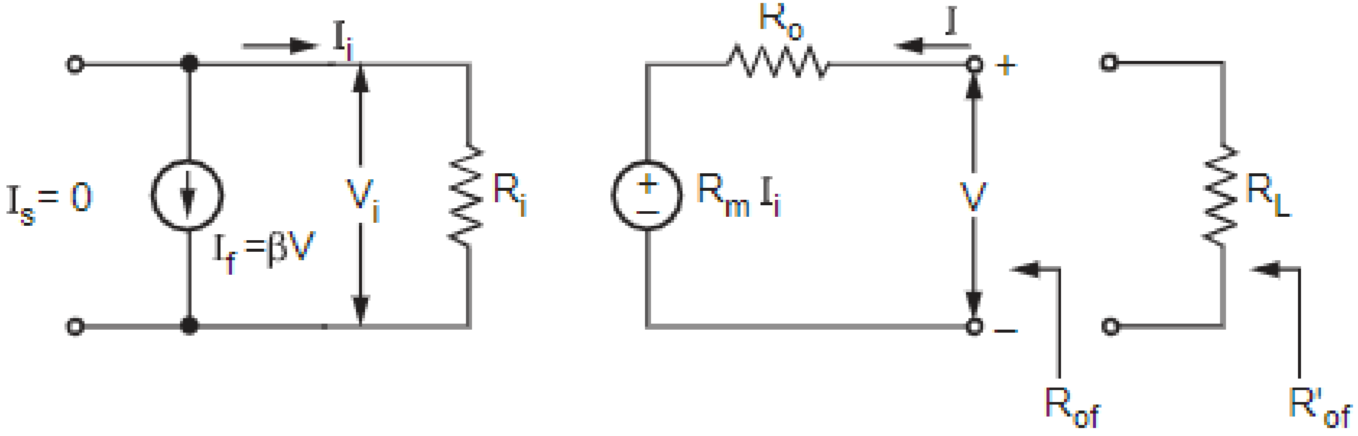
Draw the Equivalent Circuit with Is = 0 & RL disconnected

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$

Output resistance of Voltage Shunt Feedback

3. Obtain Expression for R'_{Of}

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$



$$= \frac{\dfrac{R_o \times R_L}{1 + R_m \beta}}{\dfrac{R_o}{1 + R_m \beta} + R_L} = \frac{R_o R_L}{R_o + R_L (1 + R_m \beta)}$$

$$R'_{of} = \frac{R'_o}{1 + \beta R_M}$$

$$R'_{of} = \frac{\dfrac{R_o R_L}{R_o + R_L}}{1 + \dfrac{\beta R_m R_L}{R_o + R_L}}$$

where $R'_o = \dfrac{R_L \times R_{of}}{R_L + R_{of}}$ and $R_M = \dfrac{R_m R_L}{(R_o + R_L)}$

Output resistance of Current Series Feedback

Output resistance with feedback:

1.Obtain Expression for I in Terms of V

Applying KCL to the output side we get;

$$I = \frac{V}{R_O} - GmVi$$

The input voltage is given as;

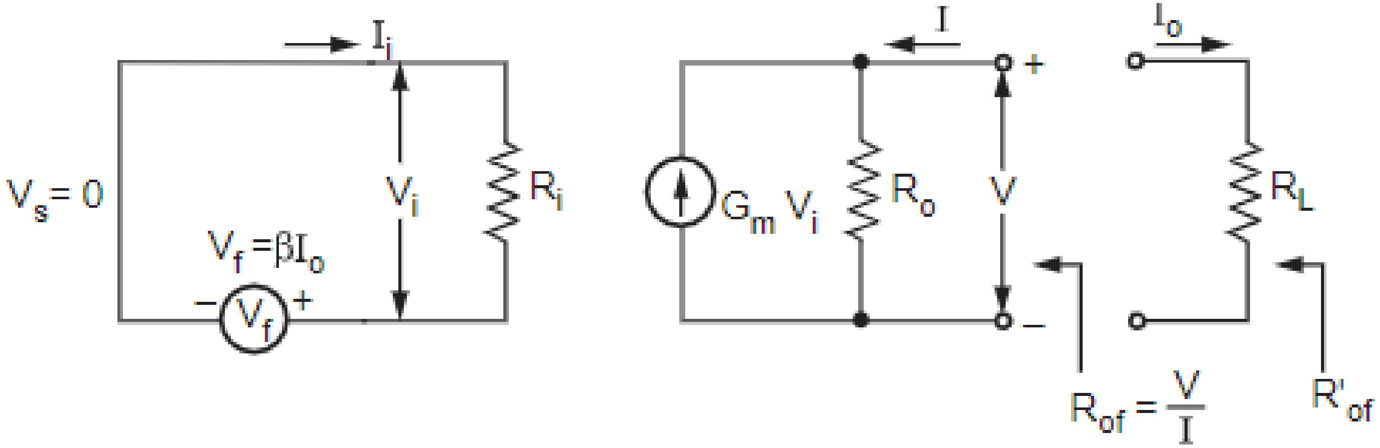
$$V_i = - V_f = - \beta I_o = \beta I$$

$$I = \frac{V}{R_O} - Gm\beta I$$

$$\frac{V}{R_O} = I + G_m\beta I$$

2. Obtain Expression for R_{Of}

$$R_{Of} = \frac{V}{I} = R_O(1 + \beta G_m)$$



Draw the Equivalent Circuit with Vs = 0 & RL disconnected

$$R_{of}^1 = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$

Output resistance of Current Series Feedback

3. Obtain Expression for R'_{Of}

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$

$$R'_{of} = R_{of} \parallel R_L = \frac{R_{of} \times R_L}{R_{of} + R_L} = \frac{R_o (1+\beta G_m) R_L}{R_o (1+\beta G_m) + R_L} = \frac{R_o R_L (1+\beta G_m)}{R_o + R_L + \beta G_m R_o}$$

$$R'_{of} = \frac{\dfrac{R_L R_o (1+\beta G_m)}{R_o + R_L}}{1 + \dfrac{\beta G_m R_o}{R_o + R_L}}$$

$$R'_{of} = \frac{R'_o (1+\beta G_m)}{1+\beta G_M}$$

$$R'_o = \frac{R_o R_L}{R_o + R_L} \quad \text{and } G_M = \frac{G_m R_o}{R_o + R_L}$$

Output resistance of Current Shunt Feedback

Output resistance with feedback:

1.Obtain Expression for I in Terms of V

Applying KCL to the output side we get;

$$I = \frac{V}{R_O} - AiIi$$

The input current is given as;

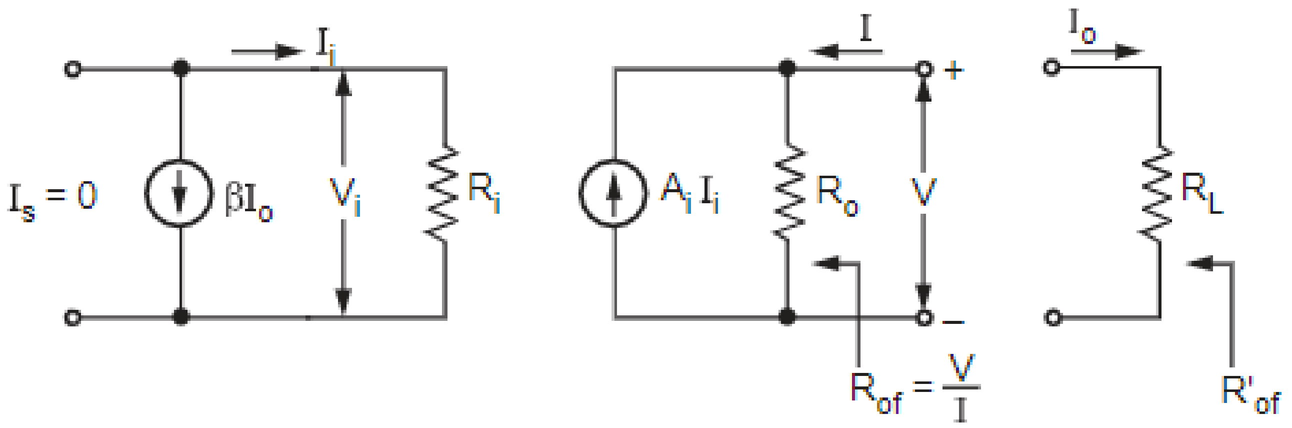
$$I_i = - I_f = - \beta I_o = \beta I$$

$$I = \frac{V}{R_O} - Ai\beta I$$

$$\frac{V}{R_O} = I + Ai\beta I$$

2. Obtain Expression for R_{Of}

$$R_{Of} = \frac{V}{I} = R_O(1 + \beta A_i)$$

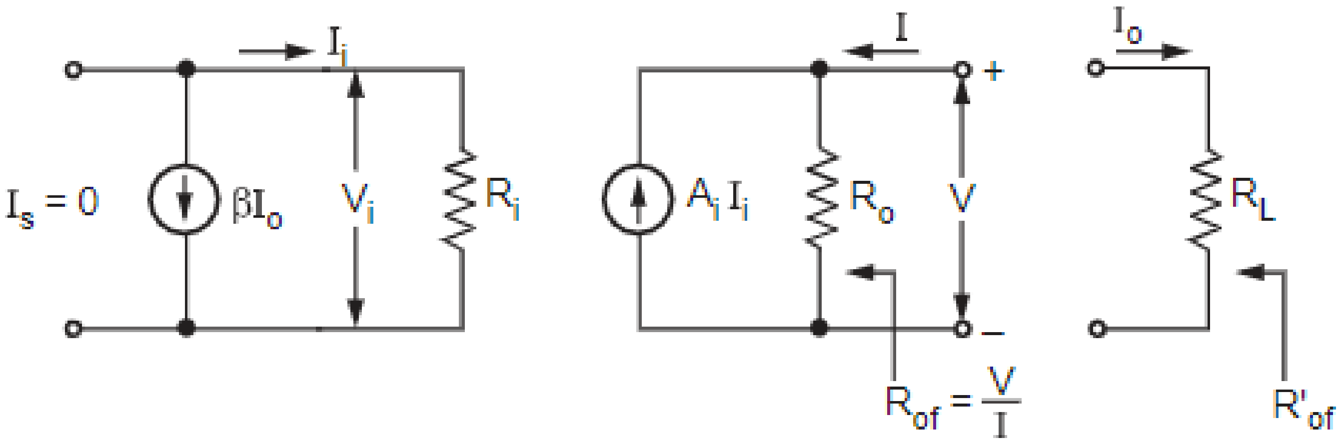


$$R_{of}^1 = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$

Output resistance of Current Shunt Feedback

3. Obtain Expression for R'_{Of}

$$R_{of}^{1} = R_{of} \parallel R_L = \frac{R_{Of} * RL}{R_{of} + R_L}$$



$$R'_{of} = R_{of} \parallel R_L = \frac{R_{of} \times R_L}{R_{of} + R_L} = \frac{R_o\,(1+\beta A_i)\,R_L}{R_o\,(1+\beta A_i) + R_L} = \frac{R_o\,R_L\,(1+\beta A_i)}{R_o + R_L + \beta A_i\,R_o}$$

$$R'_{of} = \frac{\dfrac{R_o\,R_L\,(1+\beta A_i)}{R_o + R_L}}{1 + \dfrac{\beta A_i\,R_o}{R_o + R_L}}$$

$$\boxed{R'_{of} = \frac{R'_o\,(1+\beta A_i)}{(1+\beta A_I)}}$$

$$R'_o = \frac{R_o\,R_L}{R_o + R_L} \quad \text{and} \quad A_I = \frac{A_i\,R_o}{R_o + R_L}$$

Table summarizes the effect of negative feedback on amplifier.

Parameter	Voltage series	Current series	Current shunt	Voltage shunt
Gain with feedback	$A_{vf} = \frac{A_v}{1+\beta A_v}$ decreases	$G_{mf} = \frac{G_m}{1+\beta G_m}$ decreases	$A_{if} = \frac{A_i}{1+\beta A_i}$ decreases	$R_{mf} = \frac{R_m}{1+\beta R_{mf}}$ decreases
Stability	Improves	Improves	Improves	Improves
Frequency response	Improves	Improves	Improves	Improves
Frequency distortion	Reduces	Reduces	Reduces	Reduces
Noise and Nonlinear distortion	Reduces	Reduces	Reduces	Reduces
Input resistance	$R_{if} = R_i(1+\beta A_V)$ increases	$R_{if} = R_i(1+\beta G_M)$ increases	$R_{if} = \frac{R_i}{1+\beta A_I}$ decreases	$R_{if} = \frac{R_i}{1+\beta R_M}$ decreases
Output resistance	$R_{of} = \frac{R_o}{1+\beta A_v}$ decreases	$R_{of} = R_o(1+\beta G_m)$ increases	$R_{of} = R_o(1+\beta A_i)$ increases	$R_{of} = \frac{R_o}{1+\beta R_m}$ decreases

Characteristics	Type of Feedback			
	Voltage series	Voltage shunt	Current series	Current shunt
Voltage gain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Harmonic Distortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases
Input Resistance	Increases	Decreases	Increases	Decreases
Output Resistance	Decreases	Decreases	Increases	Increases

Feedback Amplifiers: Solved Examples

1. Determine the voltage gain, input and output impedance with feedback for voltage series having $A = -100$, $R_i = 10k\Omega$ and $R_O = 20k\Omega$ for feedback $\beta = -0.1$.

1. Voltage Gain with feedback

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

$$A_f = \frac{-100}{1 + (-0.1)(-100)} = -9.09$$

2. Input resistance with feedback

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

$$R_{if} = 10k\,(1 + (-0.1)(-100))$$

$$R_{if} = 110\ k\Omega$$

3. Output resistance with feedback

$$R_{Of} = \frac{R_O}{1 + \beta A_V}$$

$$R_{Of} = \frac{20k}{1 + (-0.1)(-100)} = 1.818k\Omega$$

Feedback Amplifiers: Solved Examples

2. An amplifier with negative feedback has a voltage gain of 120. It is found that without feedback an input signal of 60 mV is required to produce a particular output, whereas with feedback the input signal must be 0.5V to get the same output. Find A_V and β.

Given: A_{vf} = 120

$$A_V = \frac{V_O}{V_S} = \frac{V_O}{60mV}$$

$$A_{Vf} = \frac{V_O}{0.5}$$

$V_O = A_{vf} * 0.5 = 120 * 0.5 = 60V$

$$A_V = \frac{V_O}{V_S} = \frac{V_O}{60mV} = \frac{60}{60mV} = 1000$$

$$A_{Vf} = \frac{A_V}{1 + \beta A_V}$$

$$120 = \frac{1000}{1 + \beta * 1000}$$

β = 0.00733

Feedback Amplifiers: Solved Examples

3. An amplifier has a voltage gain of 4000. Its input impedance is 2kΩ and output impedance is 60kΩ. Calculate the voltage gain, input and output impedance of the circuit if 5%of the feedback is fed in the form of series negative voltage feedback.

1. Voltage Gain with feedback

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

$$A_f = \frac{4000}{1+(0.05)(4000)} = 19.9$$

2. Input resistance with feedback

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

$$R_{if} = 2k\,(1+(0.05)(4000))$$

$$R_{if} = 402\ k\Omega$$

3. Output resistance with feedback

$$R_{Of} = \frac{R_O}{1+\beta A_V}$$

$$R_{Of} = \frac{60k}{1+(0.05)(4000)} = 298.5\Omega$$

THANK YOU