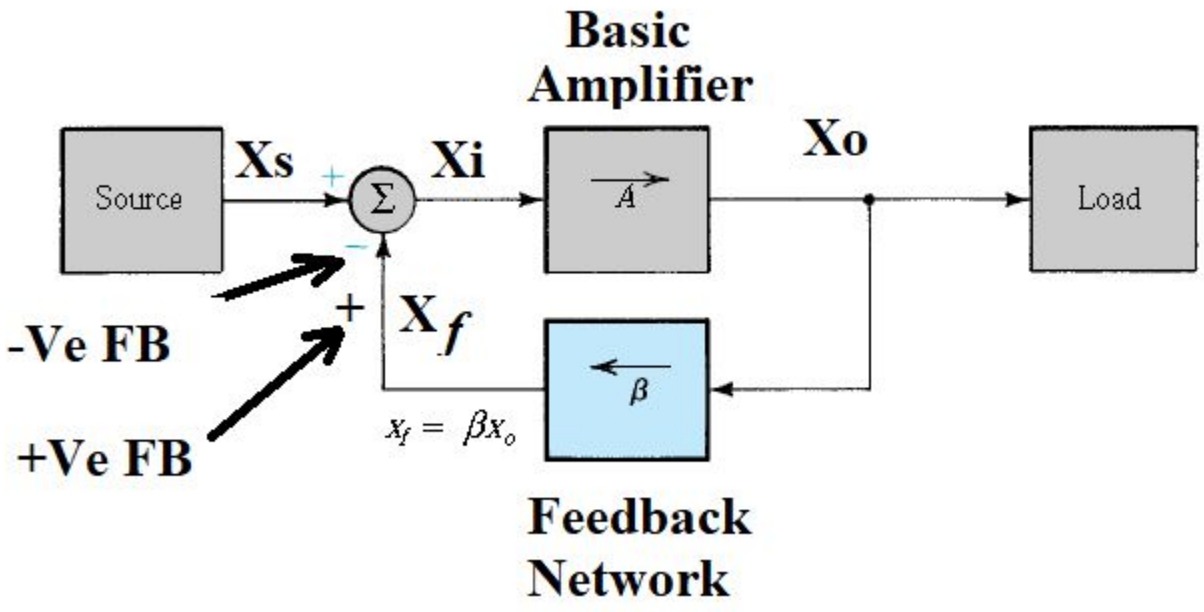
Lecture (2)
Feedback Amplifiers

Definition of Feedback

- A small part of the output signal is fed-back to the input signal to be Added to it (positive Feedback) or Subtracted from it (negative feedback).

Types of Feedback



- **Positive Feedback:**

  Used to build Oscillators.

- **Negative feedback:**

  Used to build Stable amplifier gain.

$$A_f = \frac{A}{1+A\beta} \qquad \text{-ve FB}$$

$$A_f = \frac{A}{1-A\beta} \qquad \text{+ve FB}$$

A : The Amplifier Gain

β : The feedback factor

A_f: The Feedback gain

(gain after FB, closed loop gain)

Advantages of Negative Feedback

1. Desensitize the gain:

Make the value of the gain less sensitive to variations in the values of circuit components, such as might be caused by changes in temperature.

2. Reduce nonlinear distortion:

Make the output proportional to the input (in other words, make the gain constant, independent of signal level).

3. Reduce the effect of noise:

Minimize the contribution to the output of unwanted electric signals generated, either by the circuit components themselves, or by extraneous interference.

4. Control the input and output resistances:

Raise or lower the input and output resistances by the selection of an appropriate feedback topology.

5. Extend the bandwidth of the amplifier.

Disadvantages of Negative Feedback

- **Reduce the amplifier Gain.**

Negative Feedback Amplifiers

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

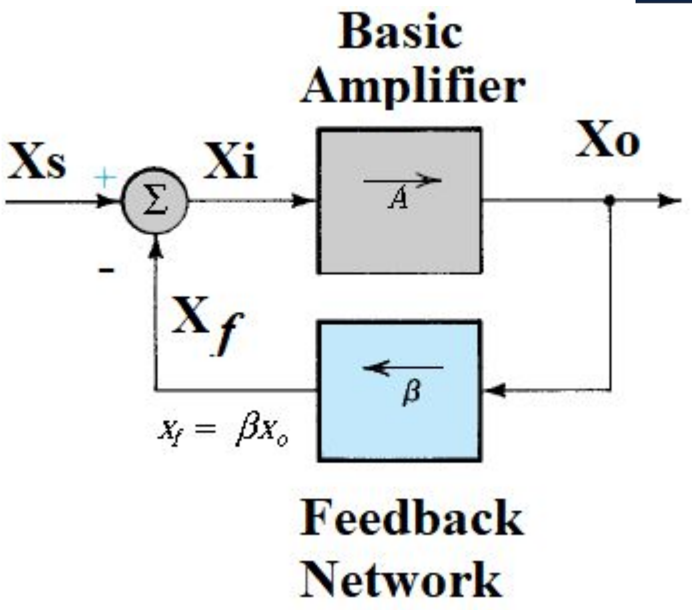
- Xs: The signal source (input of the circuit)
- Xi : The amplifier input
- Xo : The amplifier output
- *Xf* : The feedback signal

$$A = \frac{X_o}{X_i}$$

$$\beta = \frac{X_f}{X_o}$$

$$A = \frac{X_o}{X_i}$$

$$A_f = \frac{X_o}{X_s} = \frac{A}{1+A\beta} \approx \frac{1}{\beta}$$



Amplifier gain A → Very high
Feedback factor β < 1
Then,

$$A\beta >> 1$$

The feedback gain A_f is nearly independent of the amplifier gain A

Some Properties of Negative Feedback

Gain Desensitivity:

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

Then, $\frac{dA_f}{A_f} = \frac{dA}{(1+A\beta)^2} \text{ X } \frac{1+A\beta}{A} = \frac{1}{1+A\beta}\,\frac{dA}{A} \longrightarrow \frac{dA_f}{A_f} = \frac{1}{1+A\beta}\,\frac{dA}{A}$

Gain Sensitivity (S)

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

Gain Desensitivity (D)

$$\boxed{D = 1/S = 1 + A\beta}$$

dA_f : Amount of change of the feedback gain.

A_f : The feedback gain.

$\frac{dA_f}{A_f}$: Percentage change in the feedback gain.

A : Amplifier gain (open-loop gain without FB).

dA : Amount of change of the amplifier gain.

$\frac{dA}{A}$: Percentage change in the amplifier (open-loop) gain.

Example

A designer is required to achieve a closed loop gain of 25 ± 1 % v/v using a basic amplifier whose gain variations is ± 10 %. What is the nominal values of the amplifier gain A and the feedback factor β.

Solution:

$* \; A_f = 25 \pm 1\%$

$\therefore \; \frac{\Delta A_f}{A_f} = \pm 1\% = \pm 0.01$

$* \; \frac{\Delta A}{A} = \pm \frac{10}{100} = \pm 0.1$

$S = \frac{\Delta A_f}{A_f} \Big/ \frac{\Delta A}{A} = \frac{1}{1 + A\beta}$

$\therefore \; \frac{0.01}{0.1} = \frac{1}{1 + A\beta}$

$\therefore \; \boxed{1 + A\beta = 10}$

$* \; A_f = 25 = \frac{A}{1 + A\beta} \rightarrow 25 = \frac{A}{10}$

$\boxed{A = 250}$

$* \; 1 + A\beta = 10$

$\beta = \frac{9}{A} = \frac{9}{250} = 0.036$

Example

An amplifier with a nominal gain A = 1000 V/V exhibits a gain change of 10% as the temperature changes from 25 °C to 75 °C. It is required to constrain the change to 0.1 % by applying negative feedback. Calculate the largest closed loop gain possible (A_f) .

Solution:

* $A = 1000$, $\frac{\Delta A}{A} = \frac{10}{100} = 0.1$

* Required $\frac{\Delta A_f}{A_f} = \frac{0.1}{100} = 0.001$

Sensitivity $S = \frac{\Delta A_f / A_f}{\Delta A / A} = \frac{1}{1 + A\beta}$

$\therefore \frac{0.001}{0.1} = \frac{1}{1 + A\beta}$

$\therefore \boxed{1 + A\beta = 100}$

$\therefore A_f =$ closed Loop gain $= \frac{A}{1 + A\beta}$

$\therefore A_f = \frac{1000}{100}$

$\boxed{A_f = 10}$ #

Types of Amplifiers

1. Voltage Amplifier (Series-Shunt FB)

$X_i = V_i, X_o = V_o, X_f = V_f, X_s = V_s$

$A = \frac{X_o}{X_i} = \frac{V_o}{V_i}$, $\beta = \frac{X_f}{X_o} = \frac{V_f}{V_o}$

$$A_f = \frac{X_o}{X_s} = \frac{V_o}{V_s} = \frac{A}{1 + A\beta}$$

- Feedback input resistance (R_{if})

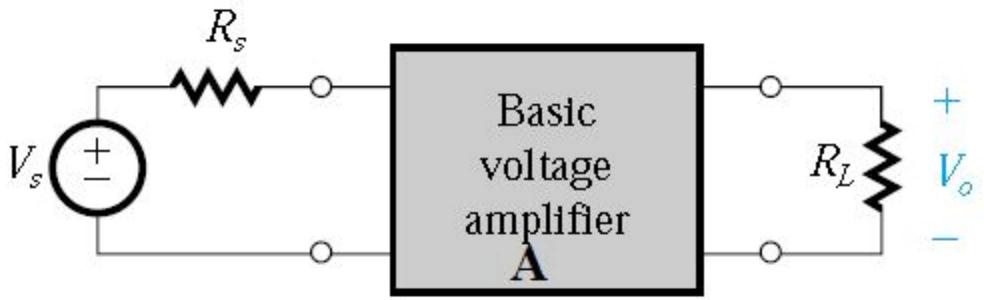
  $R_{if} = R_i\,(1 + A\beta\,)$

- Feedback output resistance (R_{of})

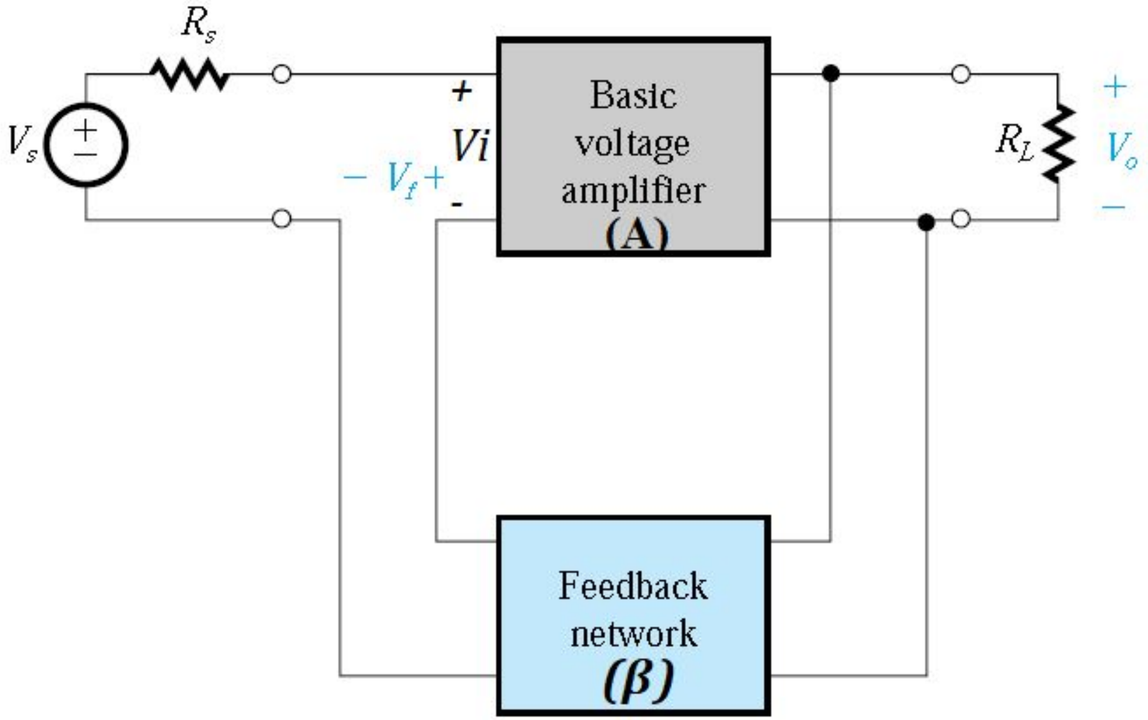
  $R_{of} = \frac{R_o}{1+A\beta}$

R_i input resistance without feedback

R_o output resistance without feedback



Open-Loop

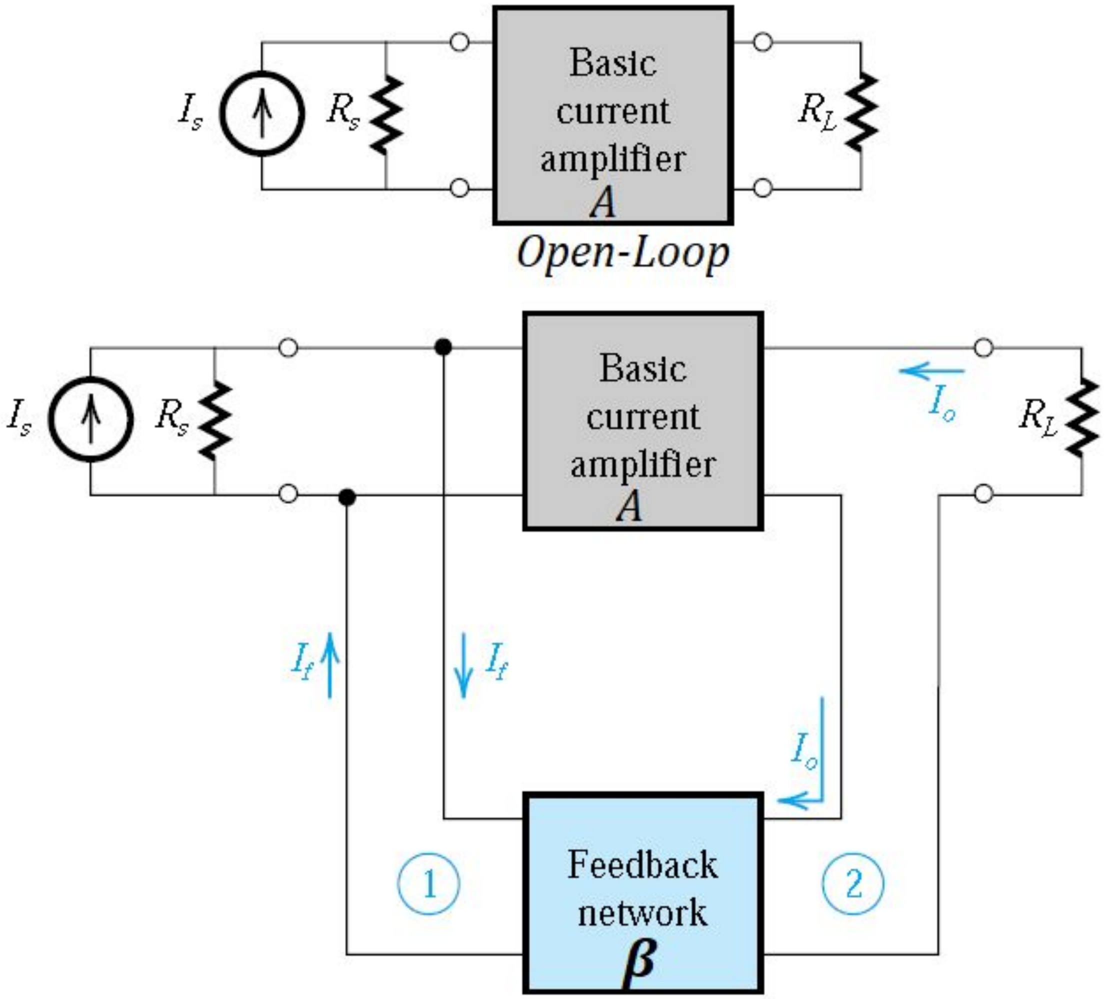


2. Current Amplifier (Shunt-Series FB)

$$X_i = I_i, X_o = I_o, X_f = I_f, X_s = I_s$$

$$A = \frac{X_o}{X_i} = \frac{I_o}{I_i}, \qquad \beta = \frac{X_f}{X_o} = \frac{I_f}{I_o}$$

$$A_f = \frac{X_o}{X_s} = \frac{I_o}{I_s} = \frac{A}{1 + A\beta}$$



- Feedback input resistance (R_{if})

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

- Feedback output resistance (R_{of})

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

R_i input resistance without feedback

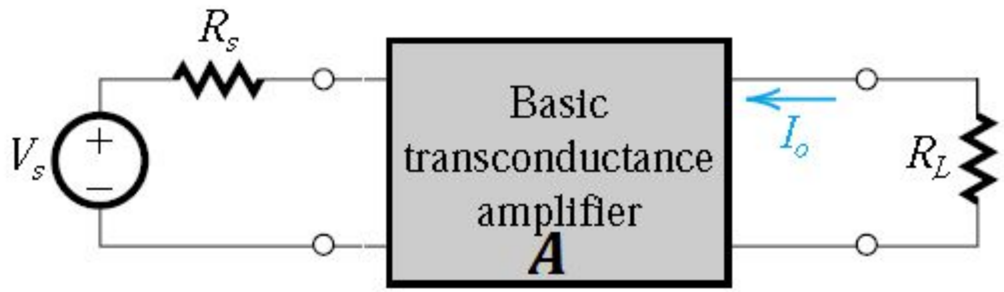
R_o output resistance without feedback

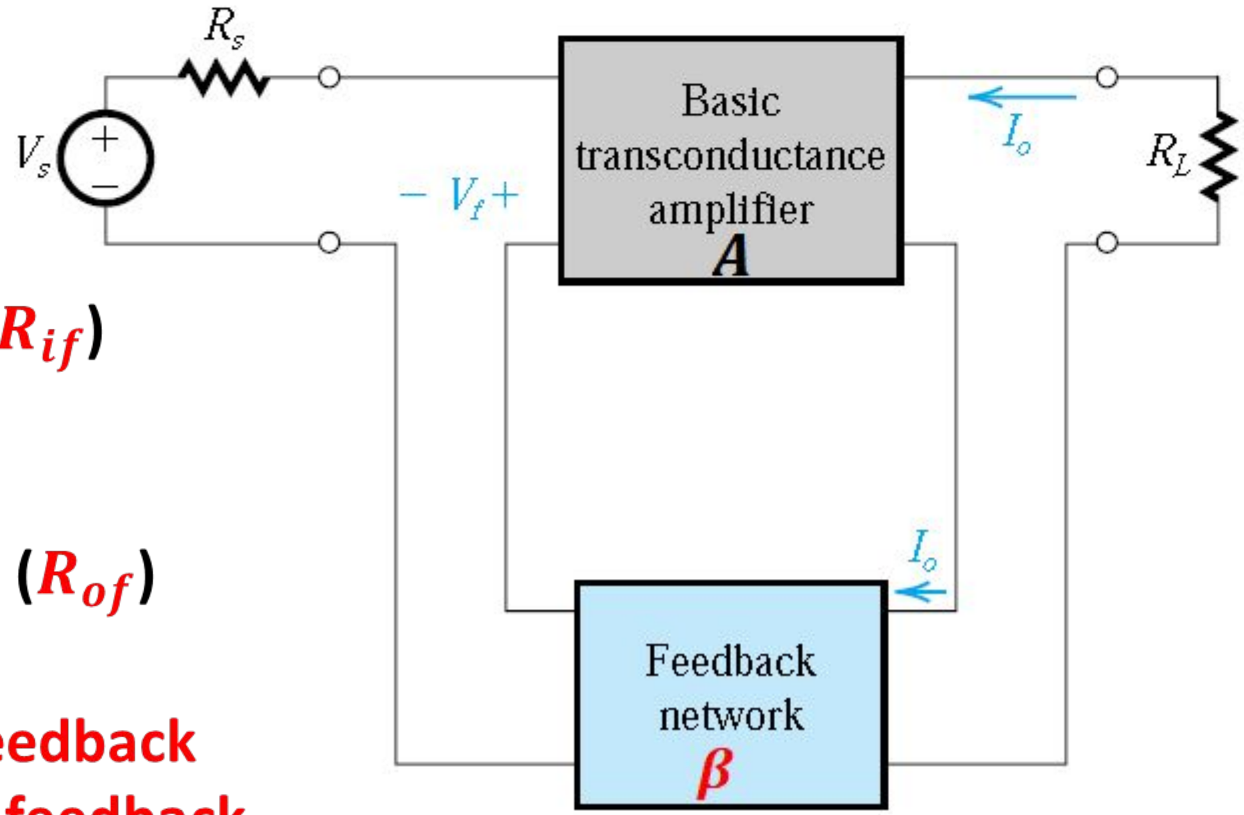
3. Trans-conductance Amplifier (Series-Series FB)

$$X_i = V_i, X_o = I_o, X_f = V_f, X_s = V_s$$

$$A = \frac{X_o}{X_i} = \frac{I_o}{V_i}, \qquad \beta = \frac{X_f}{X_o} = \frac{V_f}{I_o}$$

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





- Feedback input resistance (R_{if})

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

- Feedback output resistance (R_{of})

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

R_i input resistance without feedback

R_o output resistance without feedback

4. Trans-Resistance Amplifier (Shunt-Shunt FB)

$$X_i = I_i, X_o = V_o, X_f = I_f, X_s = I_s$$

$$A = \frac{X_o}{X_i} = \frac{V_o}{I_i}, \qquad \beta = \frac{X_f}{X_o} = \frac{I_f}{V_o}$$

$$A_f = \frac{X_o}{X_s} = \frac{V_o}{I_s} = \frac{A}{1 + A\beta}$$

- ❑ Feedback input resistance (R_{if})

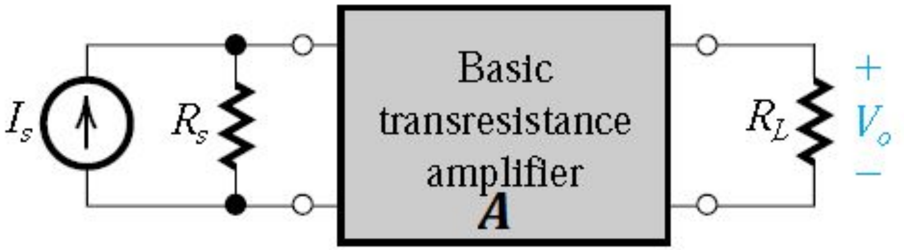
$$R_{if} = \frac{R_i}{1+A\beta}$$

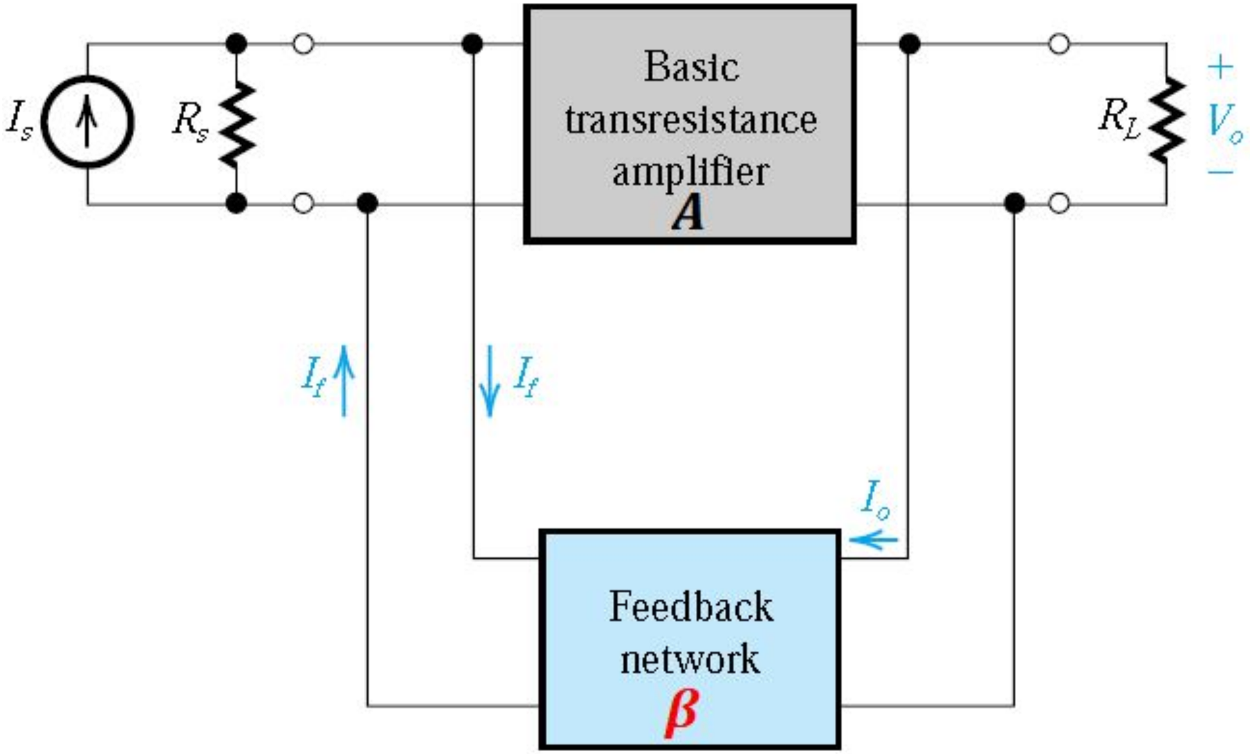
- ❑ Feedback output resistance (R_{of})

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

R_i input resistance without feedback

R_o output resistance without feedback

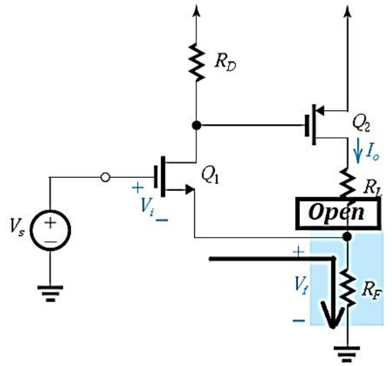


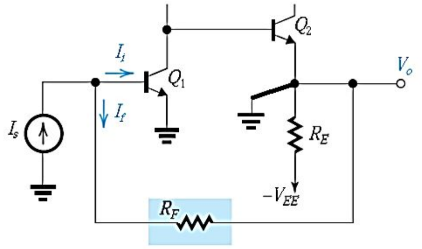


Analysis of the Feedback Amplifier Circuits

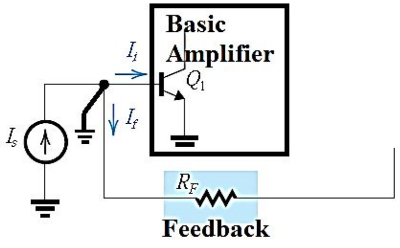
Steps:

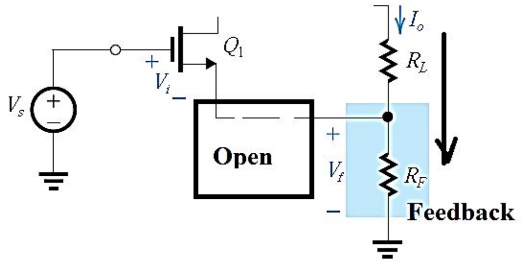
1. **Draw the input Circuit Without Feedback (Cancel the output)**
   Output topology **Shunt** → Out = 0 (short Vo =0)
   Output topology **Series** → Out = Open (Io = 0)





2. **Draw the Output Circuit Without Feedback (Cancel the Input)**
   Input topology **Shunt** → Input of amplifier = 0 (short input)
   Input topology **Series** → Input of amplifier = Open
   And calculate the feedback factor β





3. **Draw the Total circuit without feedback (Input and output)**
4. **Draw the Small signal model and analyze the circuit and find:**

- **Open Loop gain** $A = \frac{X_o}{X_s}$ **(and you had calculated β in step 2)**
- **The open-loop input resistance** R_i
- **The open-loop output resistance** R_o

5. **The Feedback gain is then** $A_f = \frac{A}{1+A\beta}$
6. **Calculate R_{if} and R_{of} according to the topology.**

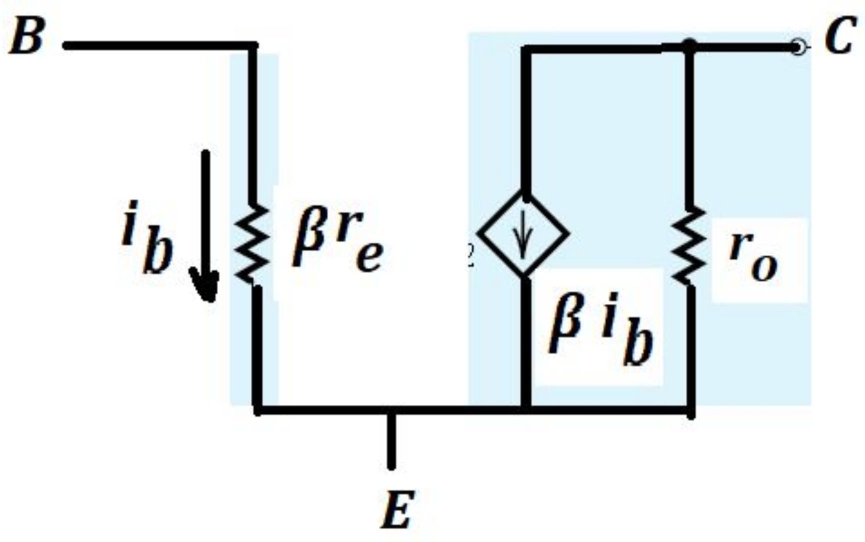
Small Signal AC Model

1. BJT Model

- $r_e = \frac{r_\pi}{\beta} = \frac{V_T}{I_C}$

V_T = 0.025 V at room temp.

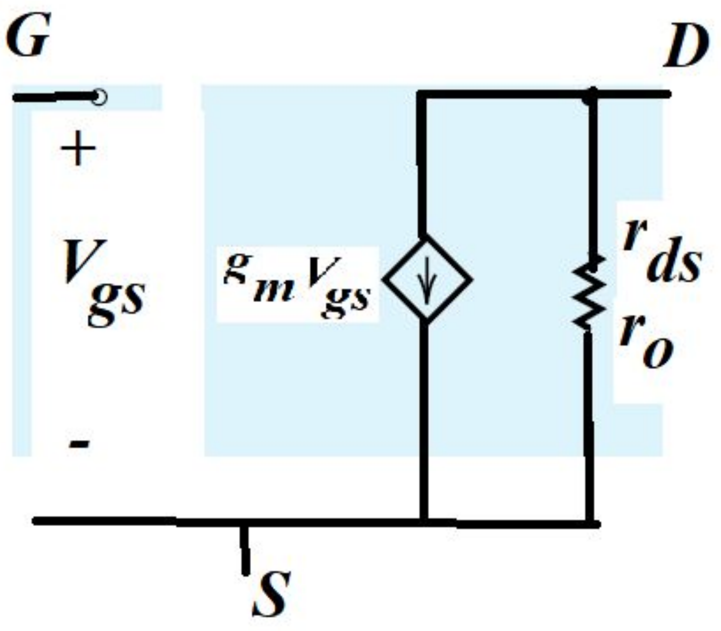
- $r_o = \frac{V_A}{I_C}$



2. MOSFET Model

- $g_m = \sqrt{2\,KI_D}$

- $r_o = r_{ds} = \frac{V_A}{I_D}$



Feedback Topologies

1. **Series-Series Feedback:**

   Input= Voltage (Vs) □ Voltage Source

   Output = Current (Io) □ Amp.out is a Current Source

2. **Series-Shunt Feedback:**

   Input= Voltage (Vs) □ Voltage Source

   Output = Voltage(Vo) □ Amp.out is a Voltage Source

3. **Shunt-Series Feedback:**

   Input= Current (Is) □ Current Source

   Output = Current (Io) □ Amp.out is a Current Source

4. **Shunt-Shunt Feedback:**

   Input= Current (Is) □ Current Source

   Output = Voltage (Vo) □ Amp.out is a Voltage Source

Series Input □ Voltage
Shunt Input □ Current

Series Out □ Current
Shunt Out □ Voltage

Input and Output Resistances (R_{in} and R_{out})

- **R_{in} The input resistance excluding Rs**

  - Series Input topology → $R_{in} = R_{if} - R_s$

  - Shunt Input Topology → $R_{in} = \frac{1}{\frac{1}{Rif} - \frac{1}{Rs}}$

- **R_{out} The Output resistance excluding R_L**

  - Series Output topology → $R_{out} = R_{of} - R_L$

  - Shunt Output Topology → $R_{out} = \frac{1}{\frac{1}{Rof} - \frac{1}{RL}}$

Example Series-Shunt

The circuit shown in Figure represents a Series-Shunt Feedback amplifier circuit. Analyze the circuit and Calculate:

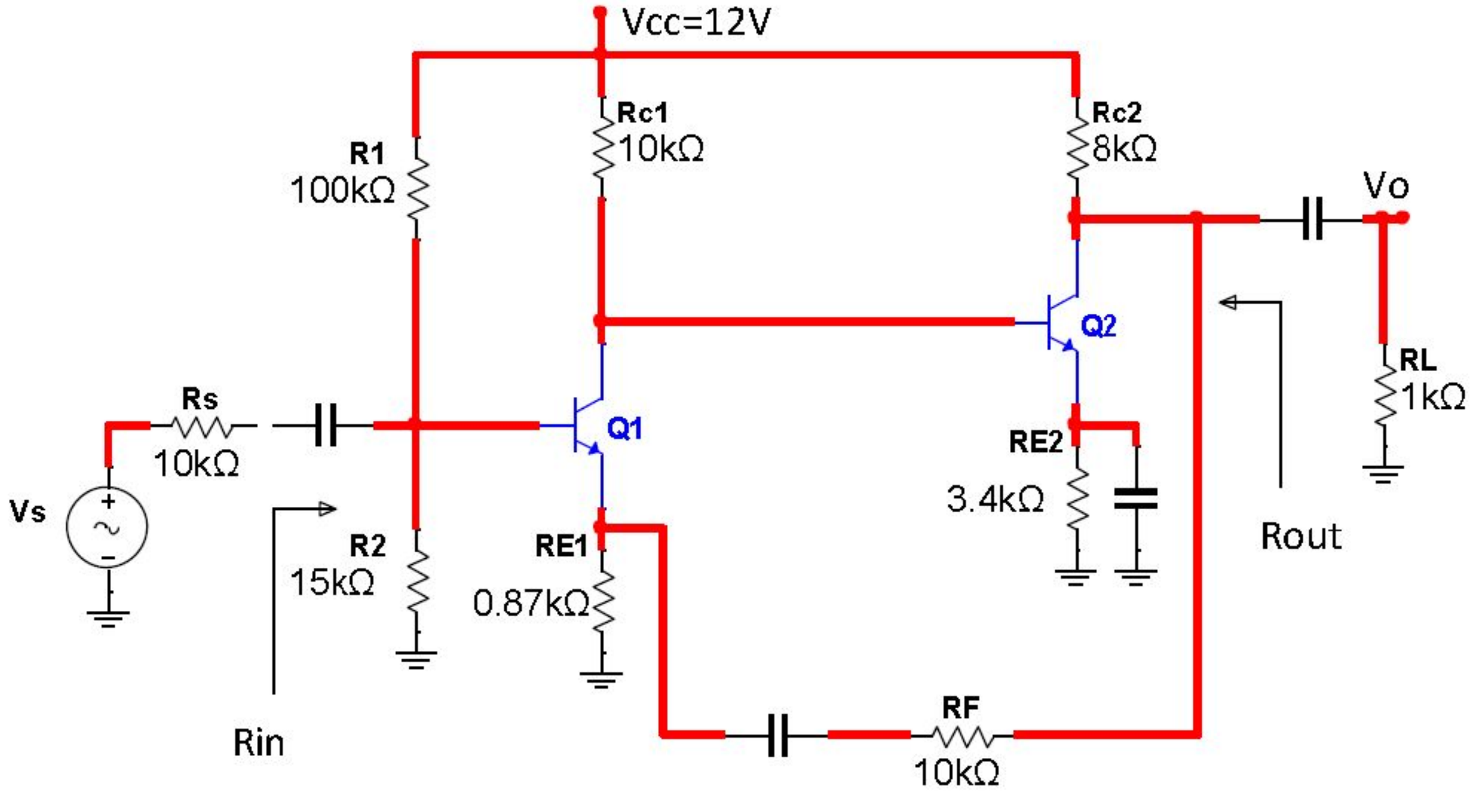
a. The feedback factor β and the open loop gain A.

b. The feedback gain A_f.

c. The feedback input and output resistances (R_{if} and R_{of}).

d. R_{in} and R_{out}.

Given: $\beta_1 = \beta_2 = 100$, $r_{e1} = 26\ \Omega$, $r_{e2} = 68\ \Omega$, $r_{o1} = 100k\ \Omega$ and $r_{o2} = 261.54k\ \Omega$.



Solution:

(a) The feedback factor β and the open loop gain A.

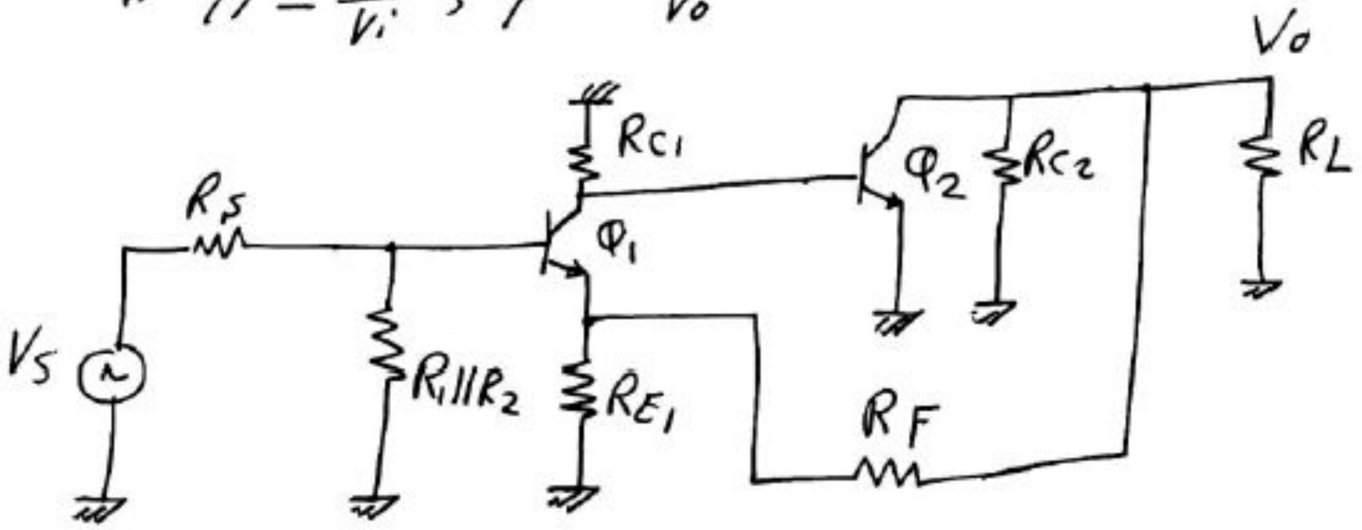
Topology:-

Input → series

output → shunt

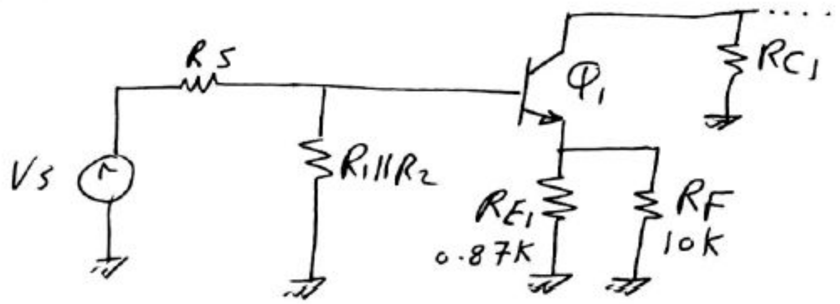
∴ series — shunt Feedback

∴ $A = \frac{V_o}{V_i}$, $\beta = \frac{V_F}{V_o}$



* Input Circuit without Feedback :-

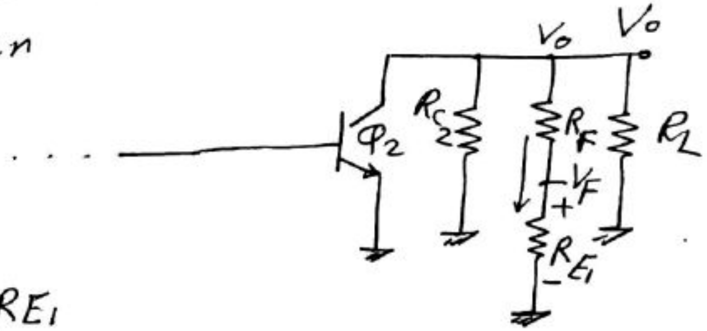
o/P → short ($V_o = 0$)



let $R_X = R_{E1} \parallel R_F = 0.8K$

* output circuit without Feedback

I/P → open



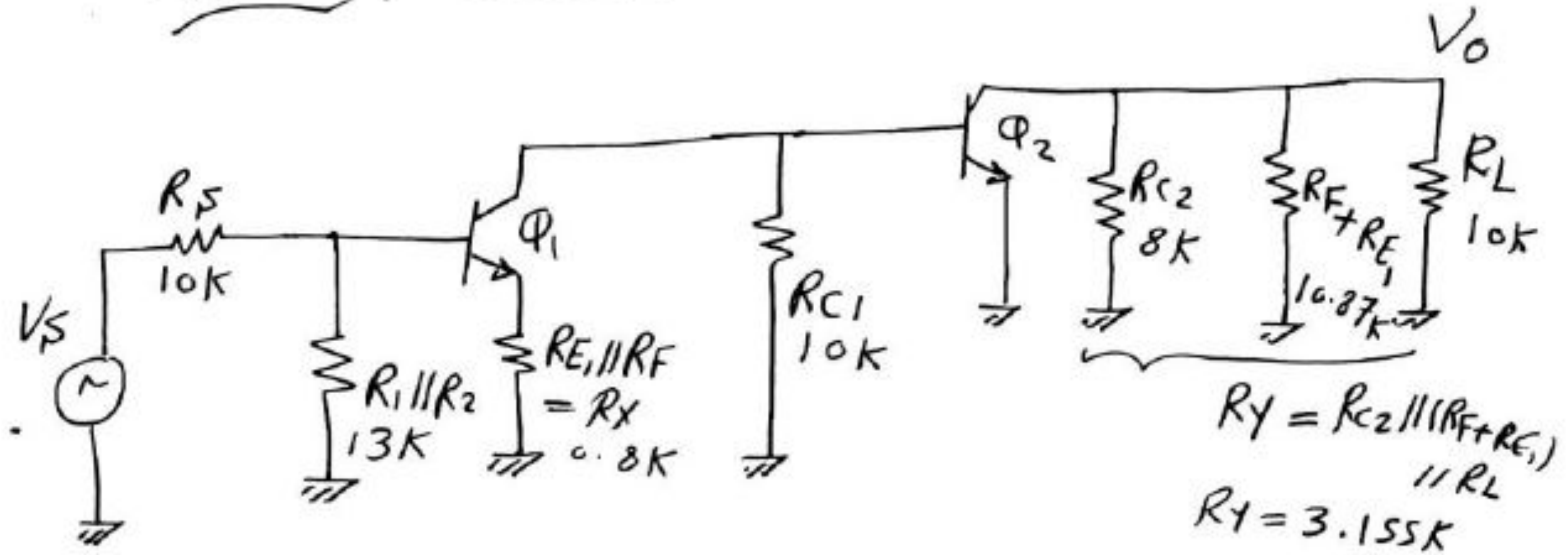
$$\beta = \frac{V_F}{V_o}$$

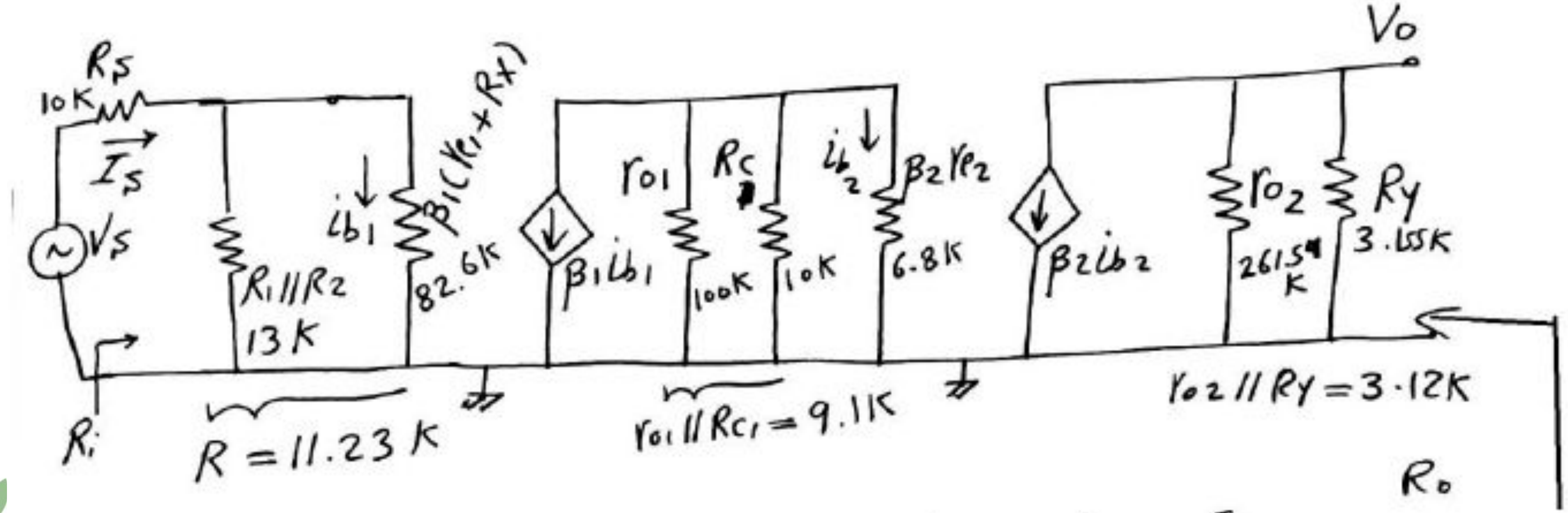
$$* \; V_f = \frac{V_o}{R_F + R_{E1}} \cdot R_{E1}$$

$$\therefore \; \beta = \frac{V_F}{V_o} = \frac{R_{E1}}{R_F + R_{E1}} = \frac{0.87}{10 + 0.87}$$

$$\beta = 0.08$$

Total Circuit without F.B





$$A = \frac{V_o}{V_S} = \frac{V_o}{i_{b2}} \times \frac{i_{b2}}{i_{b1}} \times \frac{i_{b1}}{I_S} \times \frac{I_S}{V_S}$$

$$* \quad V_o = -\beta_2 i_{b2} (r_{o2} \parallel R_Y)$$

$$\therefore \boxed{\frac{V_o}{i_{b2}} = -\beta_2 (r_{o2} \parallel R_Y) = -311.74}$$

$$* \quad i_{b2} = -\beta_1 i_{b1} \frac{(r_{o1} \parallel R_{C1})}{(r_{o1} \parallel R_{C1}) + \beta_2 r_{e2}}$$

$$\therefore \boxed{\frac{i_{b2}}{i_{b1}} = -\beta_1 \frac{r_{o1} \parallel R_{C1}}{r_{o1} \parallel R_{C1} + \beta_2 r_{e2}} = -57.233}$$

$$* \quad i_{b1} = I_s \frac{R_1 \parallel R_2}{(R_1 \parallel R_2) + \beta_1 (r_{e1} + R_X)}$$

$$\boxed{\frac{i_{b1}}{I_s} = \frac{R_1 \parallel R_2}{(R_1 \parallel R_2) + \beta_1 (r_{e1} + R_X)} \cong 0.136}$$

$$* \quad I_s = \frac{V_s}{R_s + (R_1 \| R_2 \| \beta_1(re_1 + R_x))}$$

$$\frac{I_s}{V_s} = \frac{1}{R_s + [R_1 \| R_2 \| \beta_1(re_1 + R_x)]} = 0.0471$$

$$\therefore \quad A = \frac{V_o}{V_s} = (-311.74)(-57.233)(0.136)(0.0471)$$

$$A \cong 114.3 \quad , \quad \beta = 0.08$$

$$* \quad 1 + A\beta = 10.144$$

b. The feedback gain A_f.

$$A_{vf} = \frac{V_o}{V_s} = \frac{A}{1+A\beta} = \frac{114.3}{10.144} = 11.2677$$

Feedback gain.

c. The feedback input and output resistances (R_{if} and R_{of}).

* $R_i = R_s + [R_1 \| R_2 \| \beta_1 (r_{e1} + R_x)]$

$$\boxed{R_i = 21.23\ k\Omega}$$

* $R_{if} = R_i (1 + A\beta) = 21.23 \times 10.144$

$R_{if} = 215.36\ k\Omega$

* $R_o = R_y \| r_{o2} = 3.12\ k\Omega$

* $R_{of} = \frac{R_o}{1 + A\beta} = \frac{3.12}{10.144}$

$R_{of} = 0.3076\ k\Omega = 307.6\ \Omega$

d. R_{in} and R_{out}.

$$* \; R_{in} = R_{if} - R_s = 205.36\,K\Omega$$

$$R_{out} = \frac{1}{\frac{1}{R_{of}} - \frac{1}{R_L}} = \frac{1}{\frac{1}{0.3076} - \frac{1}{10}}$$

$$R_{out} = 0.31736\,K\Omega = 317.36\,\Omega$$