Analog IC Design : 2022-23
Lecture 10
Feedback

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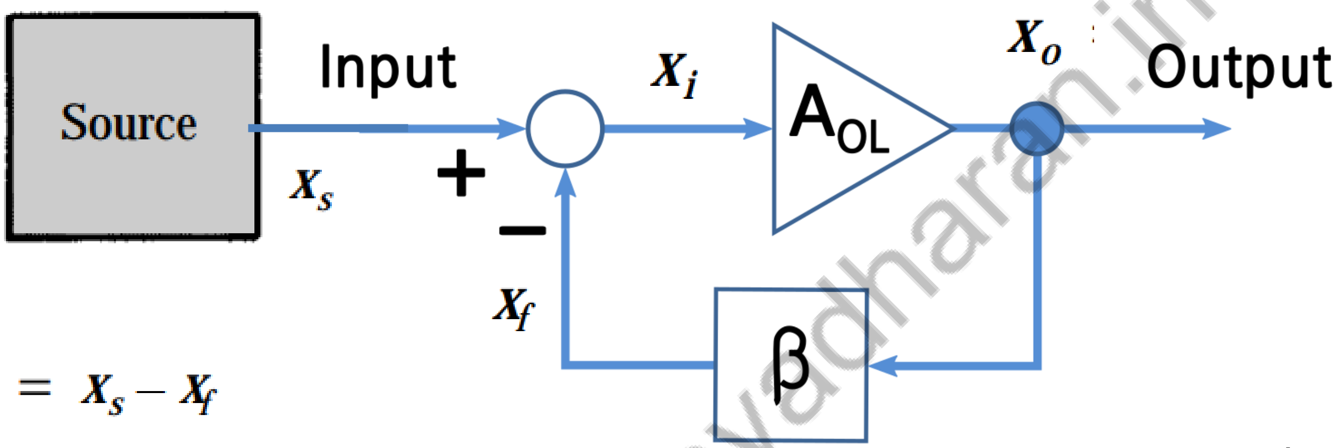
Negative Feedback



$$X_i = X_s - X_f$$

$$X_f = \beta X_o$$

$$X_o = A X_i$$

$$x_0 = A x_S - A x_f$$

$$x_0 = A x_S - A\beta x_0$$

$$x_0 = \frac{A x_S}{1 + A\beta}$$

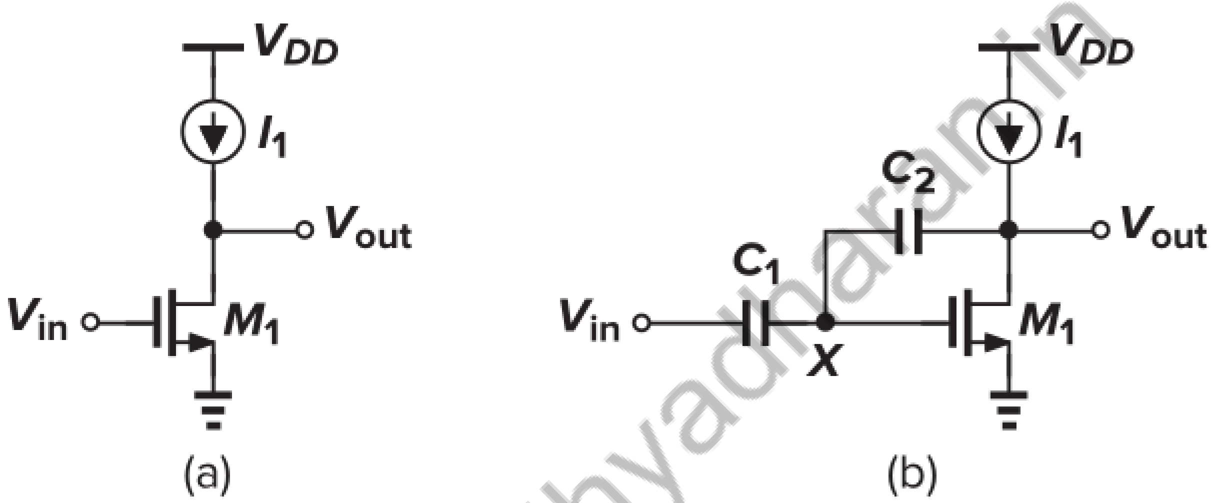
$$\textit{Closed loop gain } A_f = \frac{x_0}{x_s} = \frac{A}{1 + A\beta}$$

$A\beta$ is called the **loop gain and is generally >> 1**

$$A_f \approx \frac{1}{\beta}$$

The feedback network usually consists of passive components, which are accurate, and hence the overall gain will have very little dependence on the gain of the basic amplifier, A, a desirable property because the gain A is usually a function of many manufacturing and application parameters, some of which might have wide tolerances.

Gain Desensitization



(a) Simple common-source stage; (b) circuit of (a) with feedback.

$$V_{out}/V_X = -g_{m1}r_{O1}$$

$$(V_{out} - V_X)C_2s = (V_X - V_{in})C_1s$$

$$\frac{V_{out}}{V_{in}} = -\frac{1}{\left(1 + \frac{1}{g_{m1}r_{O1}}\right)\frac{C_2}{C_1} + \frac{1}{g_{m1}r_{O1}}}$$

$$\frac{V_{out}}{V_{in}} = -\frac{C_1}{C_2}$$

Advantages of Negative Feedback

Gain Desensitivity

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

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

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

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

Bandwidth Extension

$$A(s) = \frac{A_M}{1 + s/\omega_H}$$

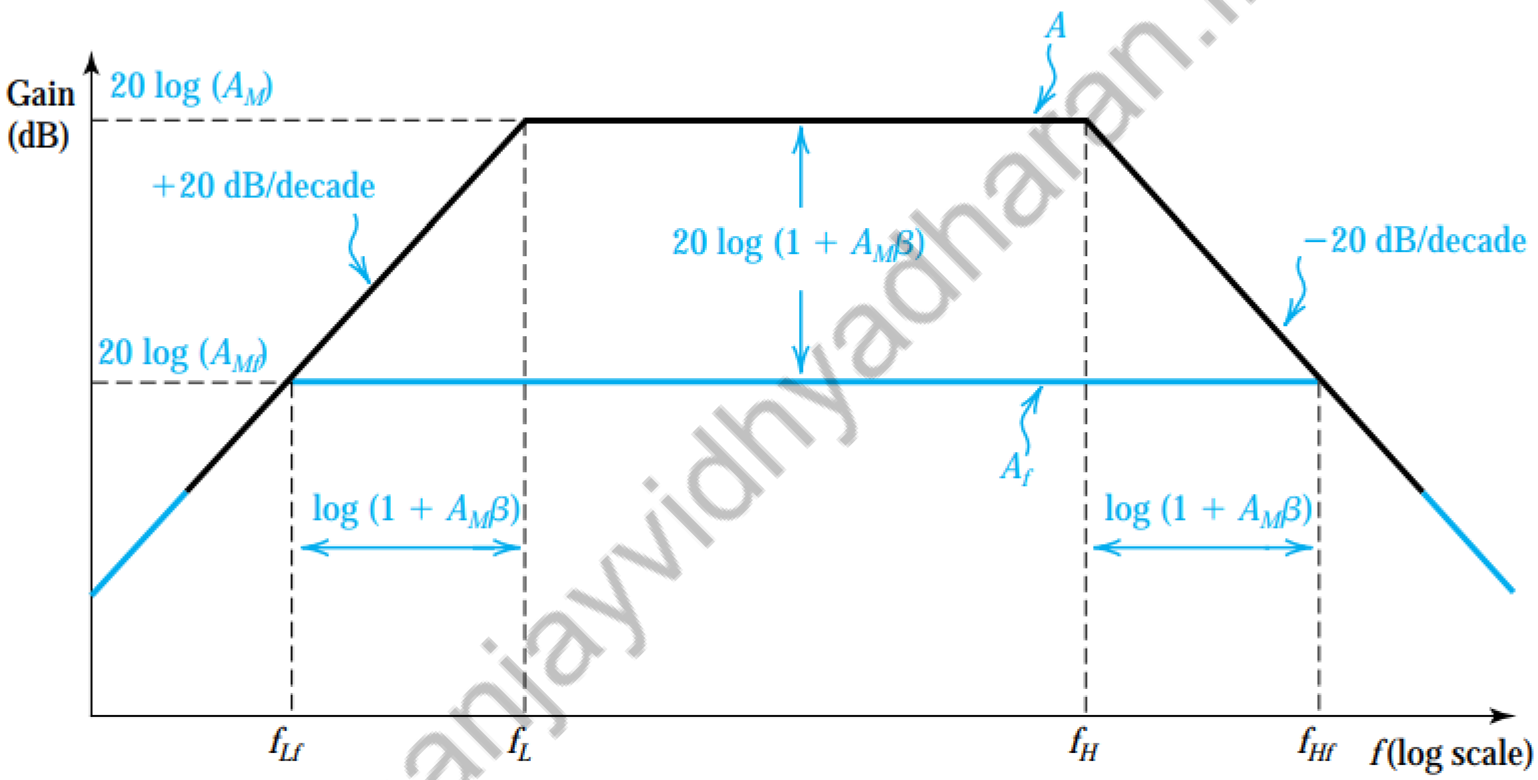
$$A_f(s) = \frac{A(s)}{1 + \beta A(s)}$$

$$A_f(s) = \frac{\frac{A_M}{1 + {}^{s}/_{\omega_H}}}{1 + \frac{\beta A_M}{1 + {}^{s}/_{\omega_H}}}$$

$$A_f(s) = \frac{A_M}{1 + \beta A_M + {}^{s}/_{\omega_H}}$$

$$A_f(s) = \frac{A_M/(1 + A_M\beta)}{1 + s/\omega_H(1 + A_M\beta)}$$

Advantages of Negative Feedback

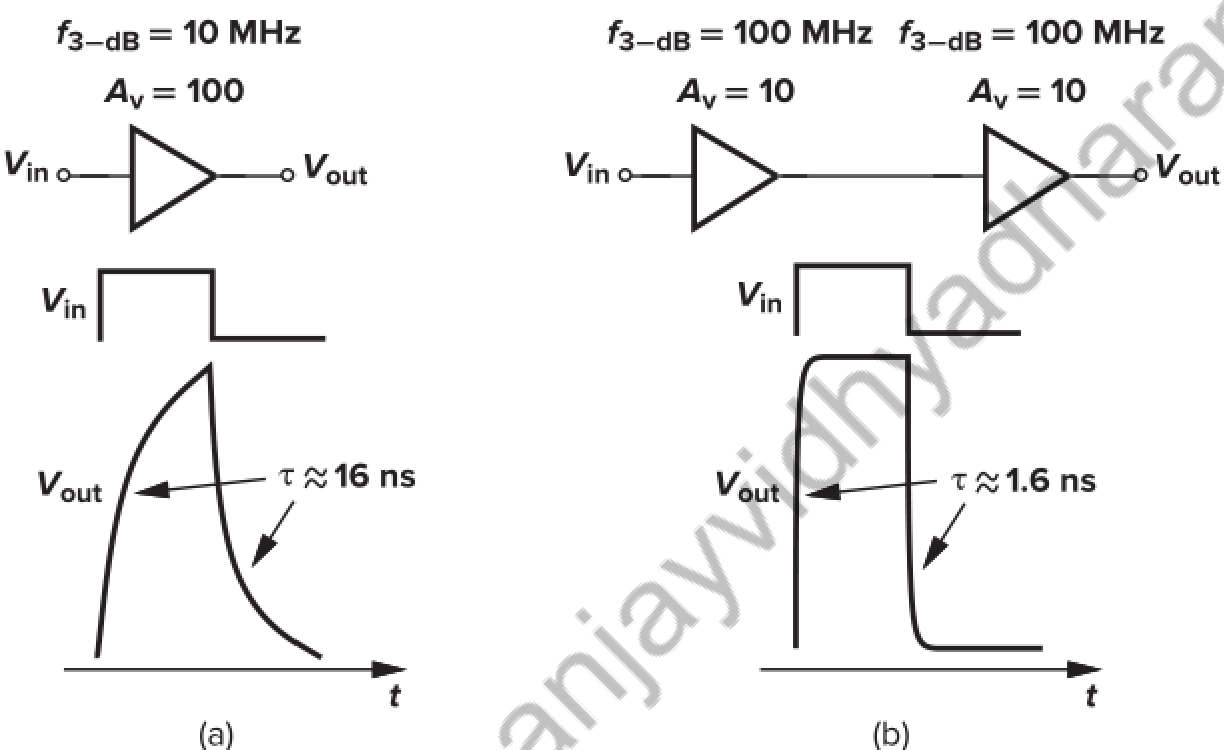


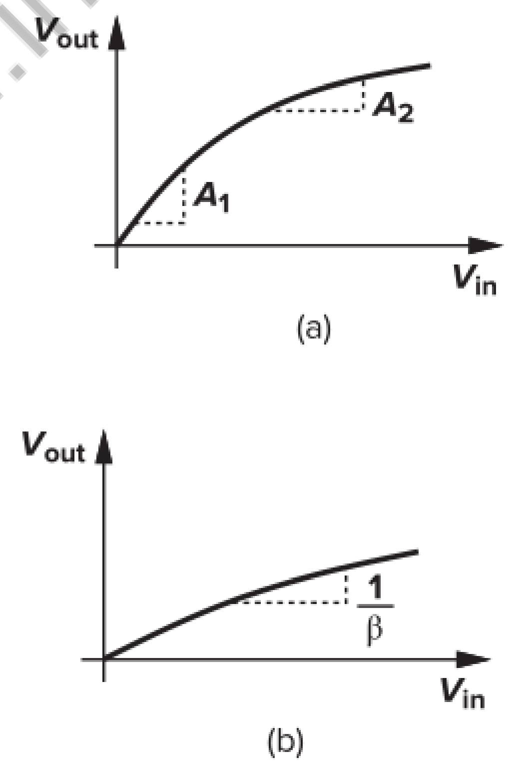
$$f_{Lf} = \frac{f_L}{1 + A_M\beta}$$

$$A_{Mf} = \frac{A_M}{1 + A_M\beta}$$

$$f_{Hf} = f_H(1 + A_M\beta)$$

Advantages of Negative Feedback

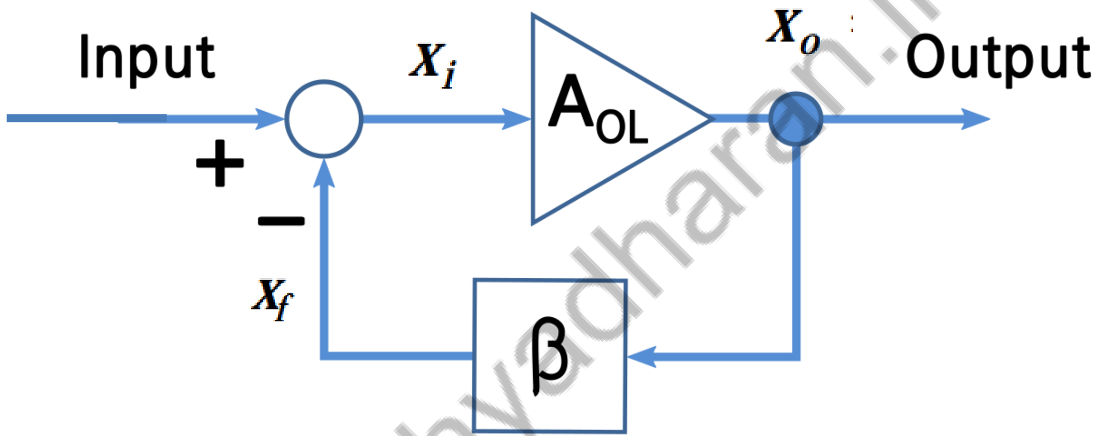




Amplification of a 20-MHz square wave by (a) a 10-MHz amplifier and (b) a cascade of two 100-MHz feedback amplifiers.

Advantages of Negative Feedback

Noise Reduction



With Feedback

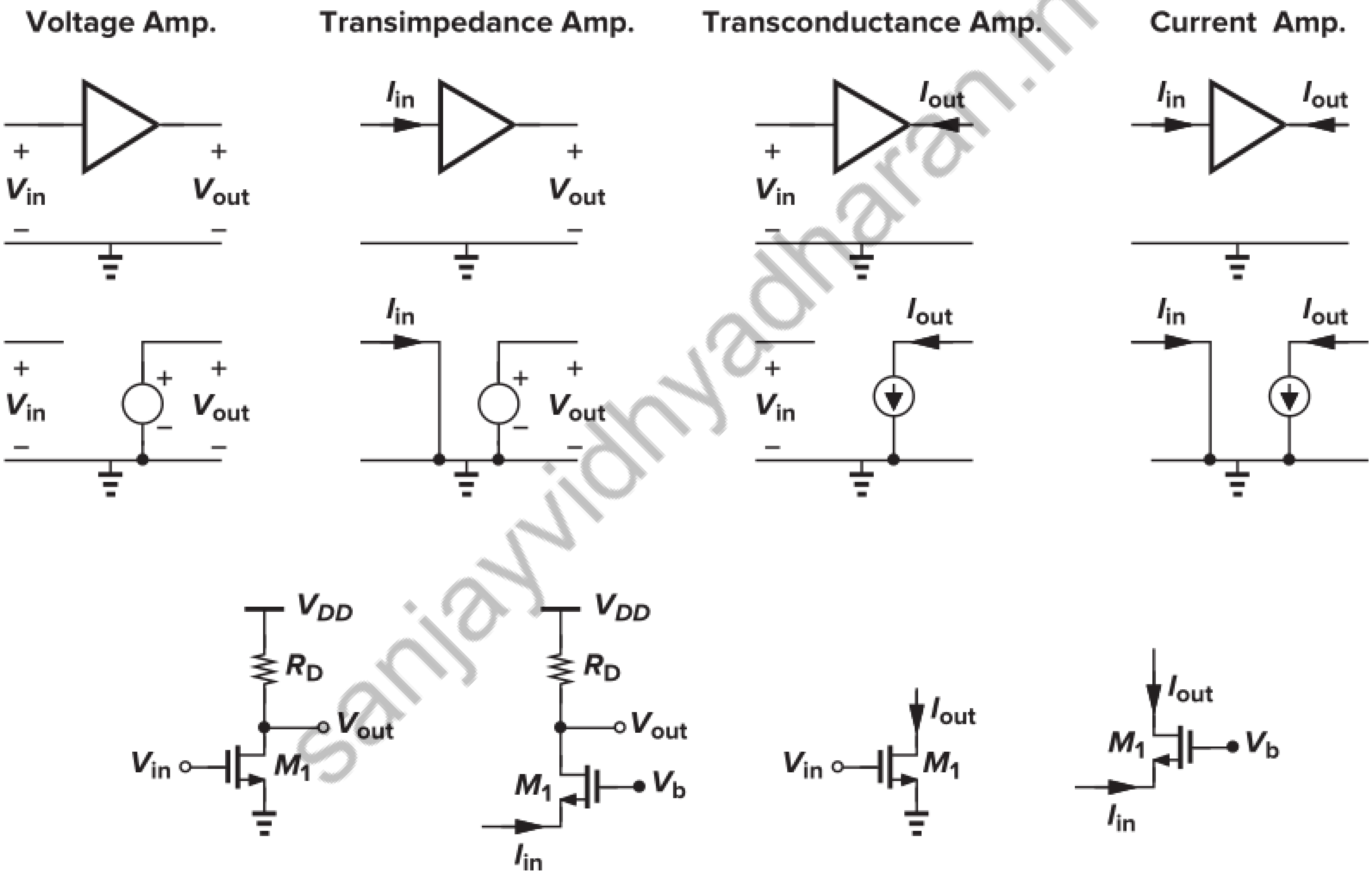
$$N_{out\_f} = A(N_{in} - \beta N_{out_f}) + N_{amp}$$

$$N_{out\_f} = \frac{AN_{in}}{1 + A\beta} + \frac{N_{amp}}{1 + A\beta}$$

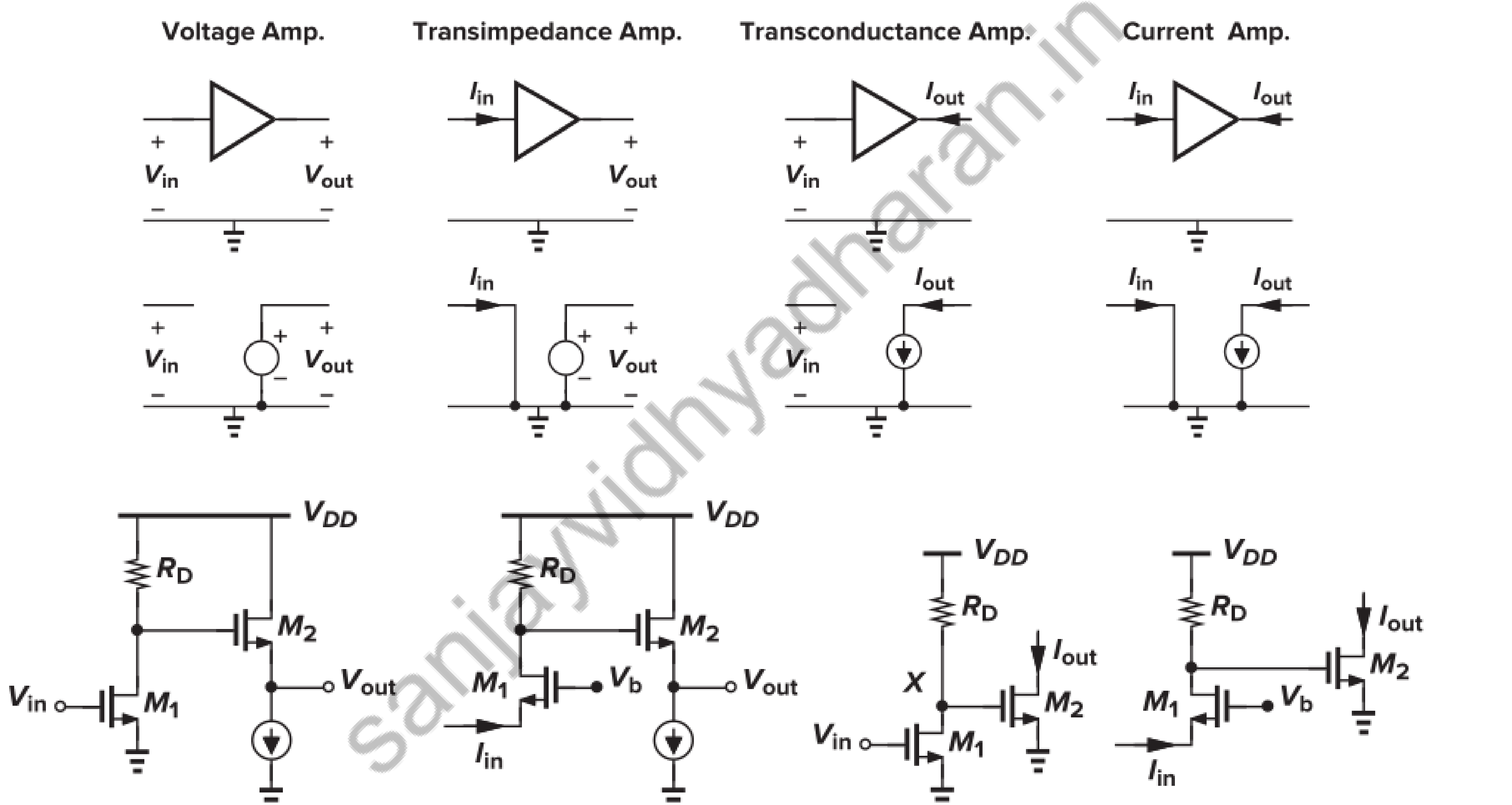
Without Feedback

$$N_{out} = AN_{in} + N_{amp}$$

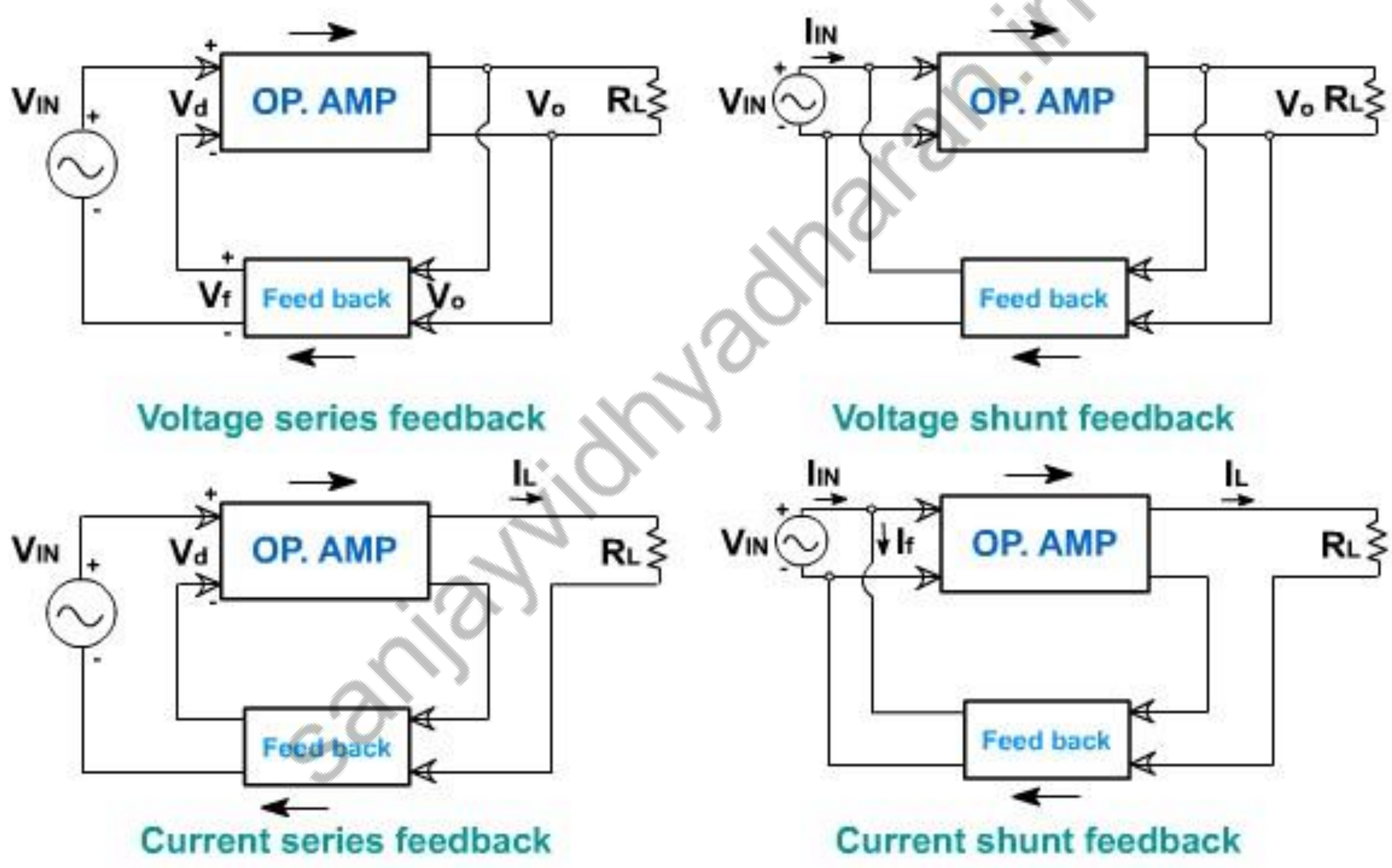
Types of Amplifiers



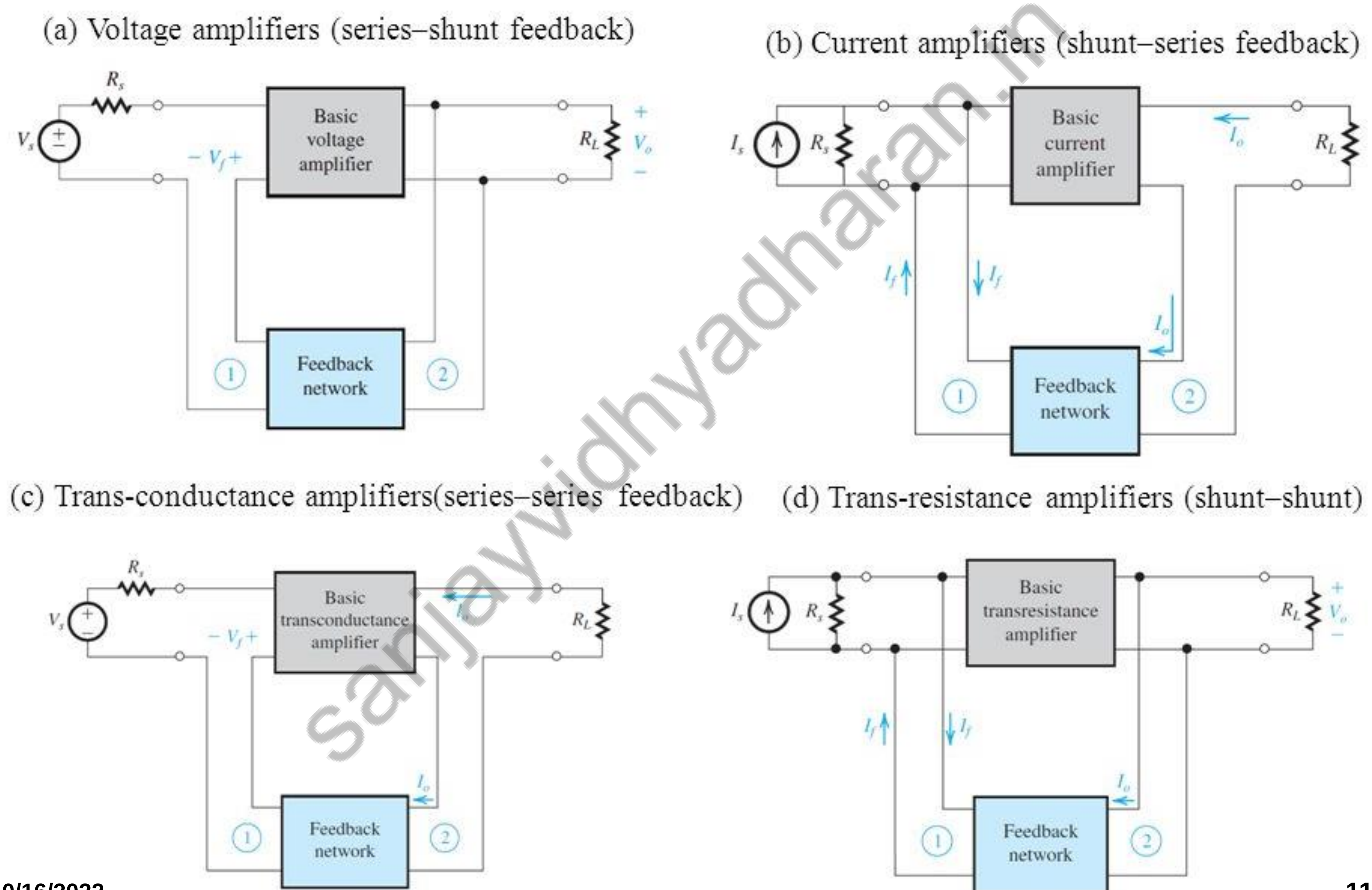
Types of Amplifiers



Basic Feedback Topologies



Basic Feedback Topologies



Series-Shunt Feedback Amplifier (Voltage-Voltage Feedback)

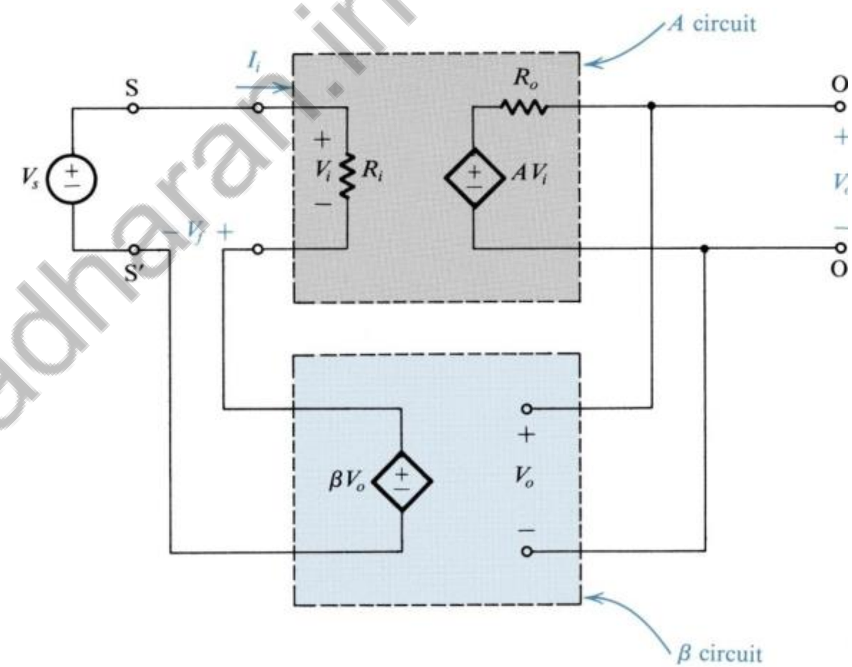
$$V_f = \beta V_o$$

$$V_i = V_s - V_f$$

$$V_o = A(V_s - \beta V_o)$$

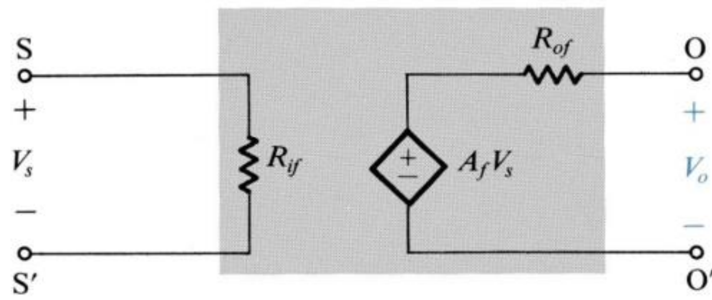
$$A_f \equiv \frac{V_o}{V_s} = \frac{A}{1+\beta A}$$

$$R_{if} = \frac{V_s}{I_i} = \frac{V_s}{V_i/R_i} = R_i \frac{V_s}{V_i} = R_i \frac{V_i + \beta A V_i}{V_i} = R_i(1 + A\beta)$$



$$V_o = I_o R_0 - \beta A V_o$$

$$\frac{V_o}{I_o} = R_{0f} = \frac{R_0}{1+\beta A}$$

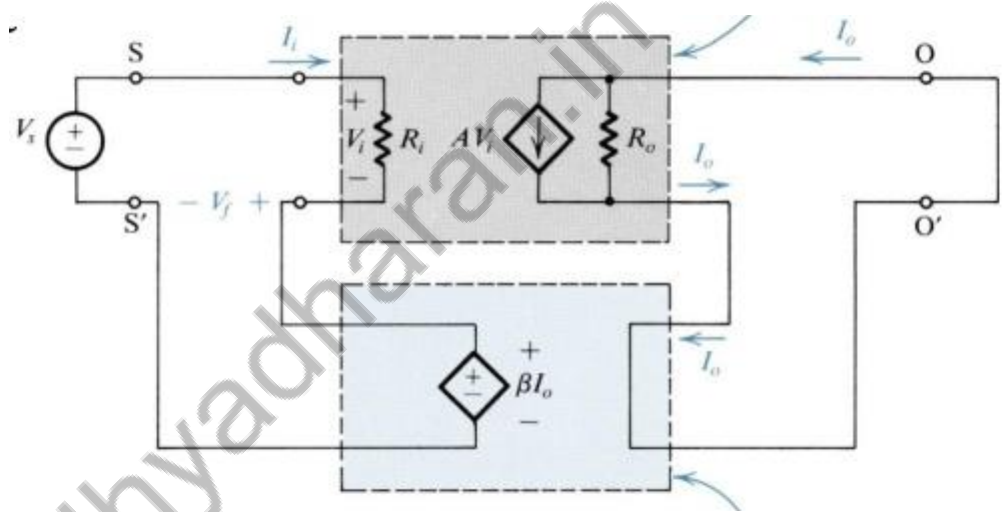


β, A, A_f have no unit

Loop gain has no unit

Series-Series Feedback Amplifier (Current-Voltage Feedback)

$$I_0 = G_M\ V_i = G_M\ (V_s\ + \beta I_0)$$



$$\frac{I_0}{V_s} = G_{Mf}\ = \frac{G_M}{1 + \beta G_M}$$

$$V_s = I_i\ R_i + \beta I_0$$

$$V_s = I_i\ R_i + \frac{\beta G_M\ V_s}{1 + \beta G_M}$$

$$\frac{V_s}{I_i} = R_{if} = (1 + \beta G_M\ )\ R_i$$

$$I_{tst} = \frac{V_{tst}}{R_0} - \beta G_M\ I_{tst}$$

$$R_{of}\ = \frac{V_{tst}}{I_{tst}} = R_0(1 + \beta G_M\ )$$

$G_{M,}\ G_{Mf}$ *transconductance*: $^{A}/_{V}$

$\boldsymbol{\beta}$ *Resistance*: *Ohms* *Loop gain has no unit*

Shunt-Shunt Feedback Amplifier (Voltage-Current Feedback)

$$V_0 = R_M\ I_i = R_M\ (I_s\ + \beta V_0)$$

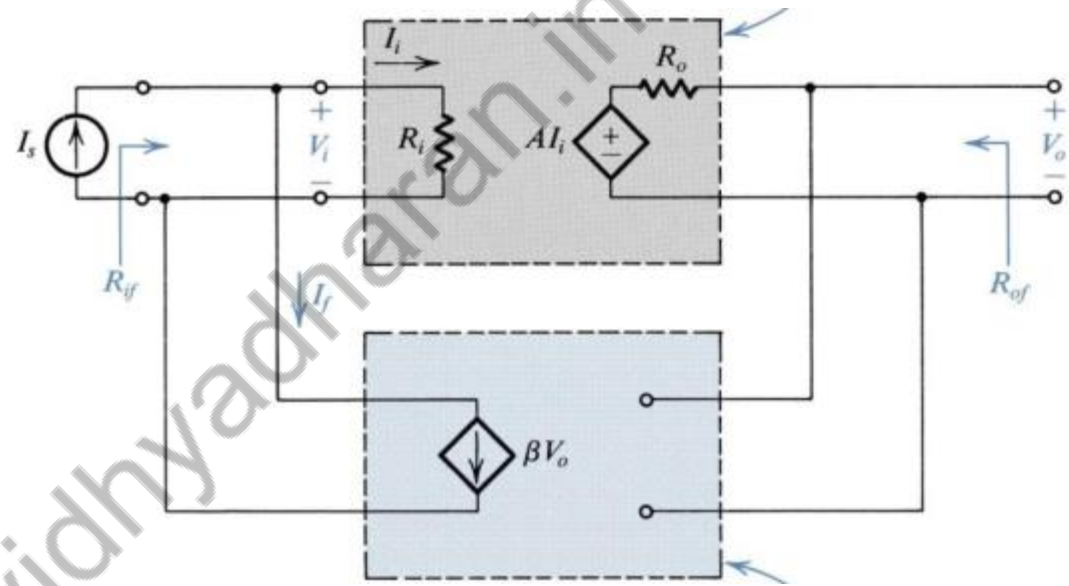
$$\frac{V_0}{I_s} = R_{Mf}\ = \frac{R_M}{1+\beta R_M}$$

$$I_s = I_f\ + \frac{V_i}{R_i}$$

$$I_s = \beta R_M\ I_i + \frac{V_i}{R_i}$$

$$I_s = \beta R_M\ \frac{V_i}{R_i} + \frac{V_i}{R_i}$$

$$\frac{V_i}{I_s} = R_{if} = \frac{R_i}{1+\beta R_M}$$



$$V_o = I_o R_0\ - \beta R_M\ V_o$$

$$\frac{V_o}{I_o} = R_{0f}\ = \frac{R_0}{1+R_M\ A}$$

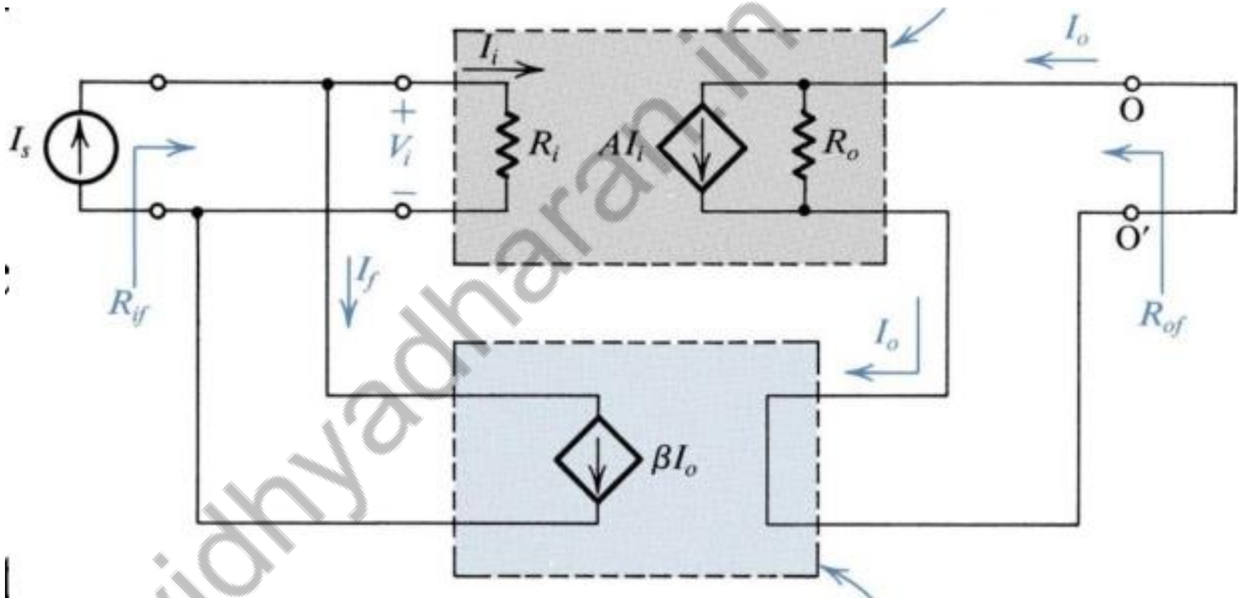
$R_{M,}\ R_{Mf}$ *transresistance*: Ohms

$\boldsymbol{\beta}$ *transconductance*: A/V

Loop gain has no unit

Shunt-Series Feedback Amplifier (Current-Current Feedback)

$$\frac{I_0}{I_s} = A_{If} = \frac{A_I}{1 + \beta A_I}$$



$$\frac{V_i}{I_s} = R_{if} = \frac{R_i}{1 + \beta A_I}$$

$$R_{of} = \frac{V_{tst}}{I_{tst}} = \frac{R_0}{1+\beta A_I}$$

β, A_I, A_{If} have no unit

Loop gain has no unit

Analysis of Feedback Amplifiers

To find the input circuit:

1. Set $V_o = 0$ for voltage sampling. In other words, short the output node.
2. Set $I_o = 0$ for current sampling. In other words, open the output loop.

To find the output circuit:

1. Set $V_i = 0$ for shunt comparison. In other words, short the input node.
2. Set $I_i = 0$ for series comparison. In other words, open the input loop.

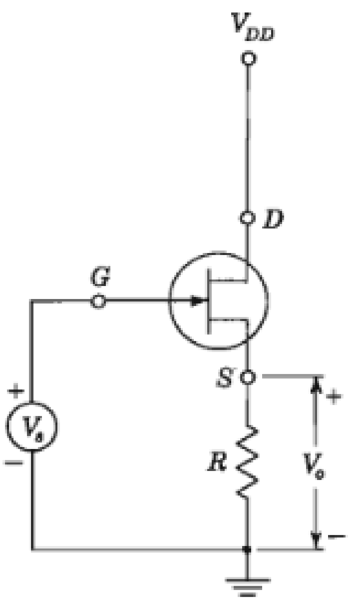
These procedures ensure that the feedback is reduced to zero without altering the loading on the basic amplifier.

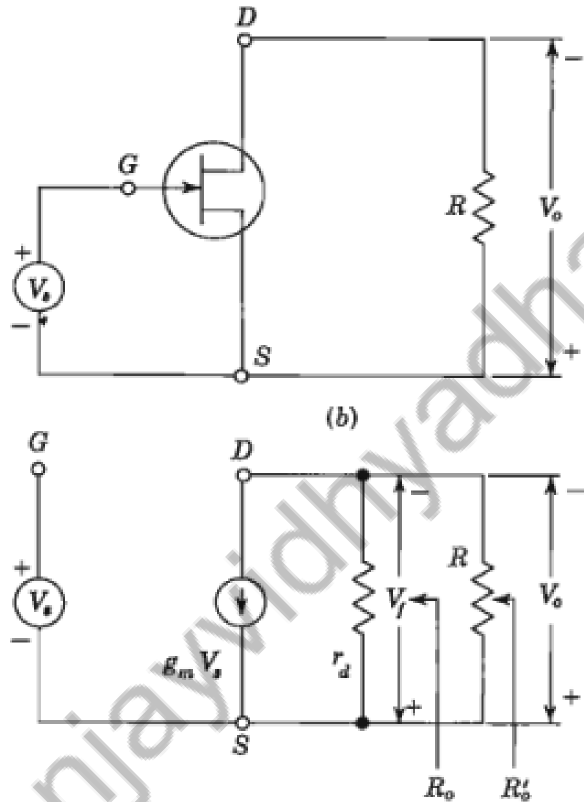
Analysis of Feedback Amplifiers

The complete analysis of a feedback amplifier is obtained by carrying out the following steps:

1. Identify the topology. (*a*) Is the feedback signal X_f a voltage or a current? In other words, is X_f applied in series or in shunt with the external excitation? (*b*) Is the sampled signal X_o a voltage or a current? In other words, is the sampled signal taken at the output node or from the output loop?
2. Draw the basic amplifier circuit without feedback, following the rules listed above.
3. Use a Thévenin's source if X_f is a voltage and a Norton's source if X_f is a current.
4. Replace each active device by the proper model (for example, the hybrid-Π model for a transistor at high frequencies or the h-parameter model at low frequencies).
5. Indicate X_f and X_o on the circuit obtained by carrying out steps 2, 3, and 4. Evaluate $\beta = X_f/X_o$.
6. Evaluate A by applying KVL and KCL to the equivalent circuit obtained after step 4.
7. From A and β, find D, A_f, R_{if}, R_{of}, and R'_{of}.

Example - 1 Source Follower





$$A_V = \frac{V_o}{V_i} = \frac{g_m V_s r_d R}{(r_d + R) V_s} = \frac{\mu R}{r_d + R}$$

where $\mu = g_m r_d$

$$D = 1 + \beta A_V = 1 + \frac{\mu R}{r_d + R} = \frac{r_d + (1 + \mu)R}{r_d + R}$$

$$A_{Vf} = \frac{A_V}{D} = \frac{\mu R}{r_d + (1 + \mu)R}$$

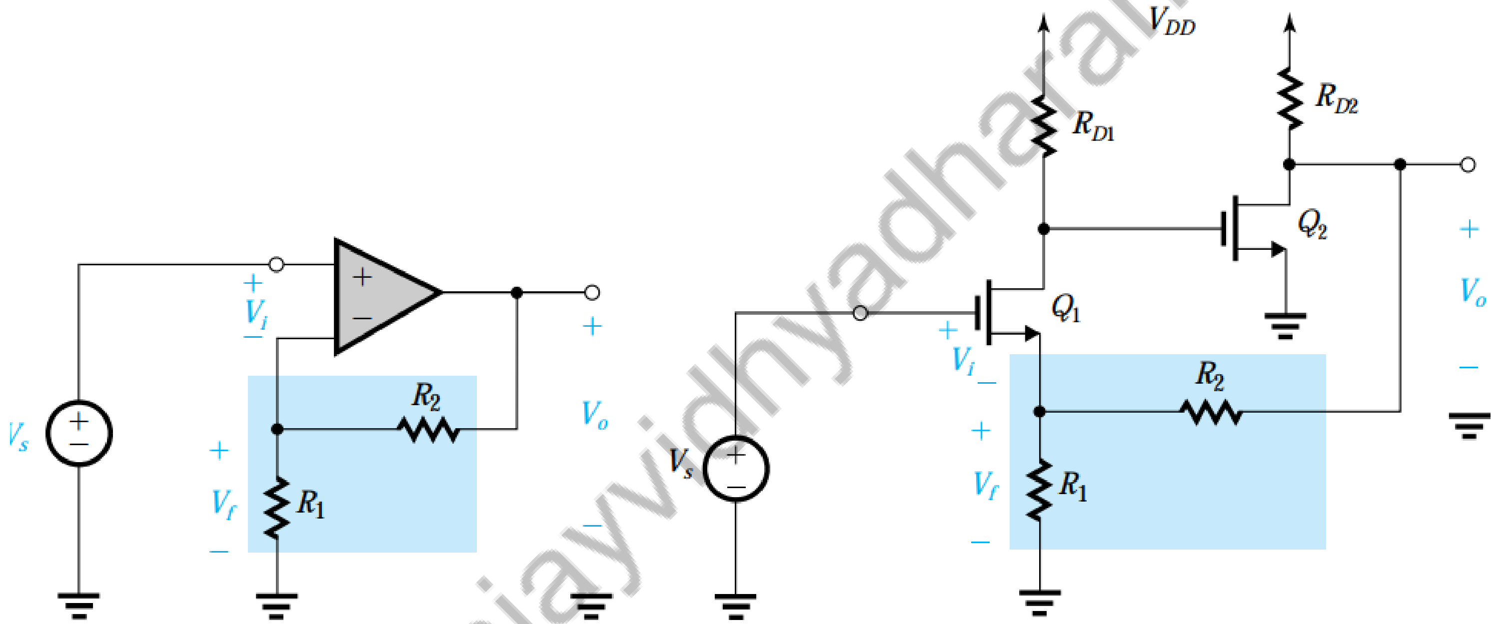
Since $R_i = \infty$, then

$$R_{if} = R_i D = \infty$$

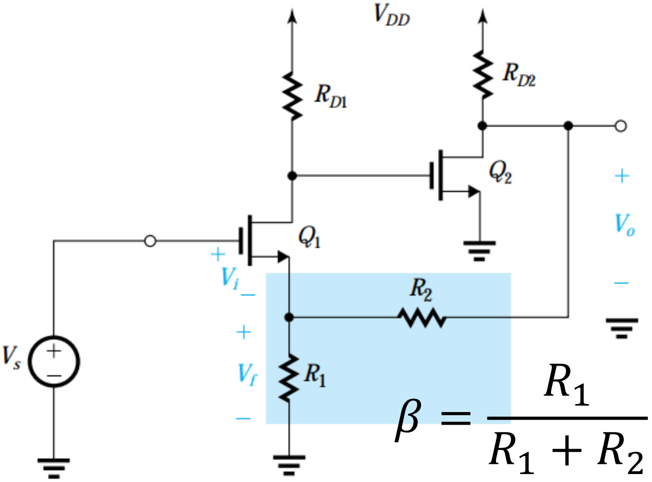
$$R'_{of} = \frac{R'_o}{D} = \frac{R r_d}{R + r_d} \frac{r_d + R}{r_d + (\mu + 1)R} = \frac{R r_d}{r_d + (\mu + 1)R}$$

We must now draw the basic amplifier without feedback. To find the input circuit, set $V_o = 0$, and hence V_s appears directly between G and S. To find the output circuit, set $I_i = 0$ (the input loop is opened), and hence R appears only in the output loop. Following these rules we obtain Fig. 13-12b.

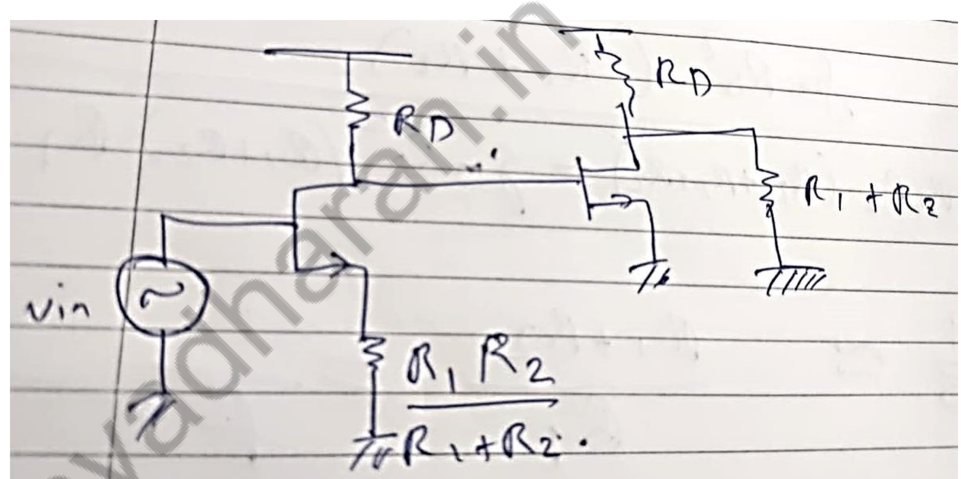
Example - 2



Example - 2



$$\beta = \frac{R_1}{R_1 + R_2}$$

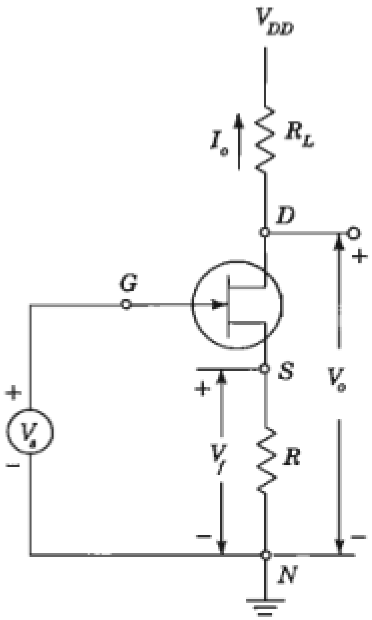


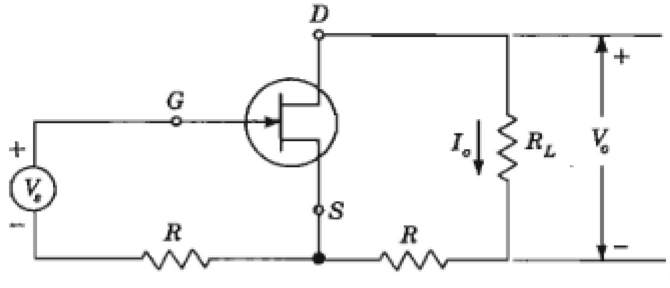
$$G_1 = \frac{R_D(R_1 + R_2)}{R_1 R_2} \qquad G_2 = \frac{g_{m2} R_D (R_1 + R_2)}{R_D + R_1 + R_2} \qquad A_0 = \frac{g_{m2} R_D^2 (R_1 + R_2)^2}{R_1 R_2 (R_D + R_1 + R_2)}$$

$$\beta A_0 = \frac{g_{m2} R_D^2 (R_1 + R_2) R_1}{R_1 R_2 (R_D + R_1 + R_2)} \qquad 1 + \beta A_0 = \frac{R_1 R_2 (R_D + R_1 + R_2) + g_{m2} R_D^2 (R_1 + R_2) R_1}{R_1 R_2 (R_D + R_1 + R_2)}$$

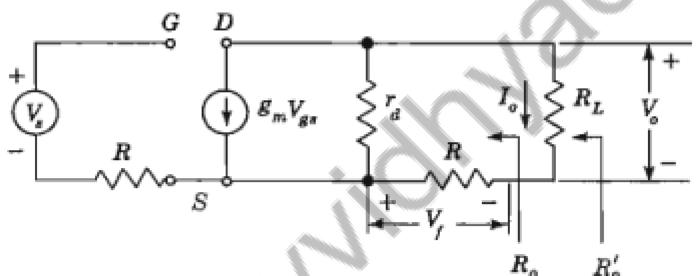
$$A_f = \frac{A_0}{1 + \beta A_0} = \frac{g_{m2} R_D^2 (R_1 + R_2)^2}{R_1 R_2 (R_D + R_1 + R_2) + g_{m2} R_D^2 (R_1 + R_2) R_1} \approx \frac{R_1 + R_2}{R_1} = \frac{1}{\beta}$$

Example - 3





(b)



Since $R_i = \infty$, then

$$R_{if} = R_i D = \infty$$

$$R_o = r_d + R$$

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

$$= (r_d + R)\frac{r_d + (\mu + 1)R}{r_d + R} =$$

$$= r_d + (\mu + 1)R$$

$$G_M = \frac{I_o}{V_i} = \frac{I_o}{V_s} = \frac{-g_m r_d}{r_d + R_L + R}$$

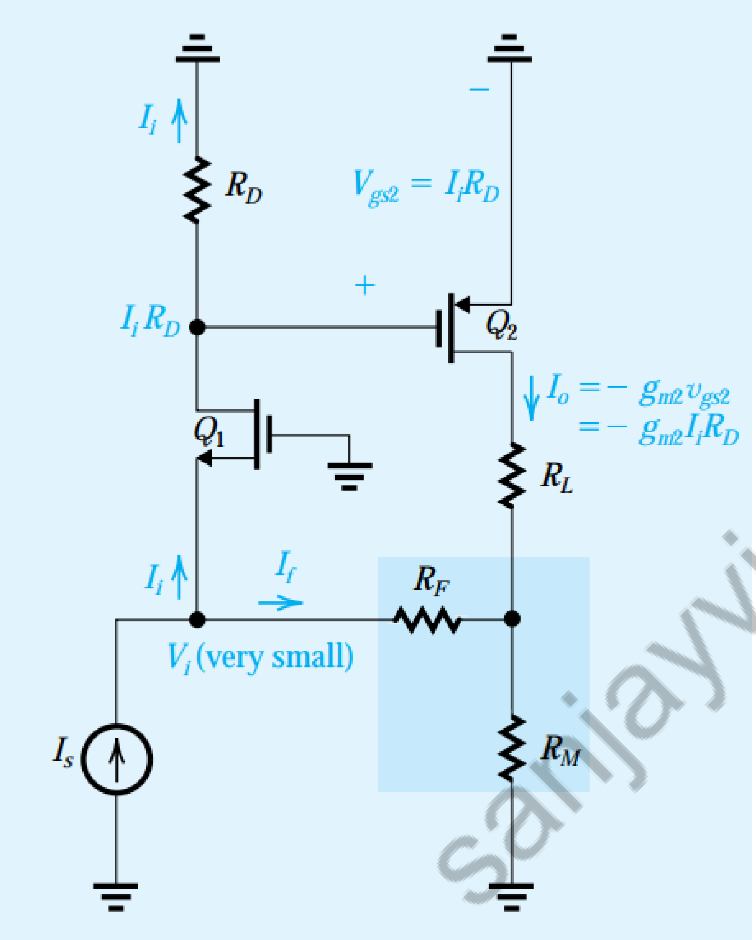
$$= \frac{-\mu}{r_d + R_L + R}$$

$$\beta = \frac{V_f}{I_o} = -R$$

$$D = 1 + \beta G_M = 1 + \frac{\mu R}{r_d + R_L + R} = \frac{r_d + R_L + (\mu + 1)R}{r_d + R_L + R}$$

$$G_{Mf} = \frac{G_M}{D} = \frac{-\mu}{r_d + R_L + (\mu + 1)R}$$

Example - 4



$$I_o = -g_{m2} R_D I_i$$

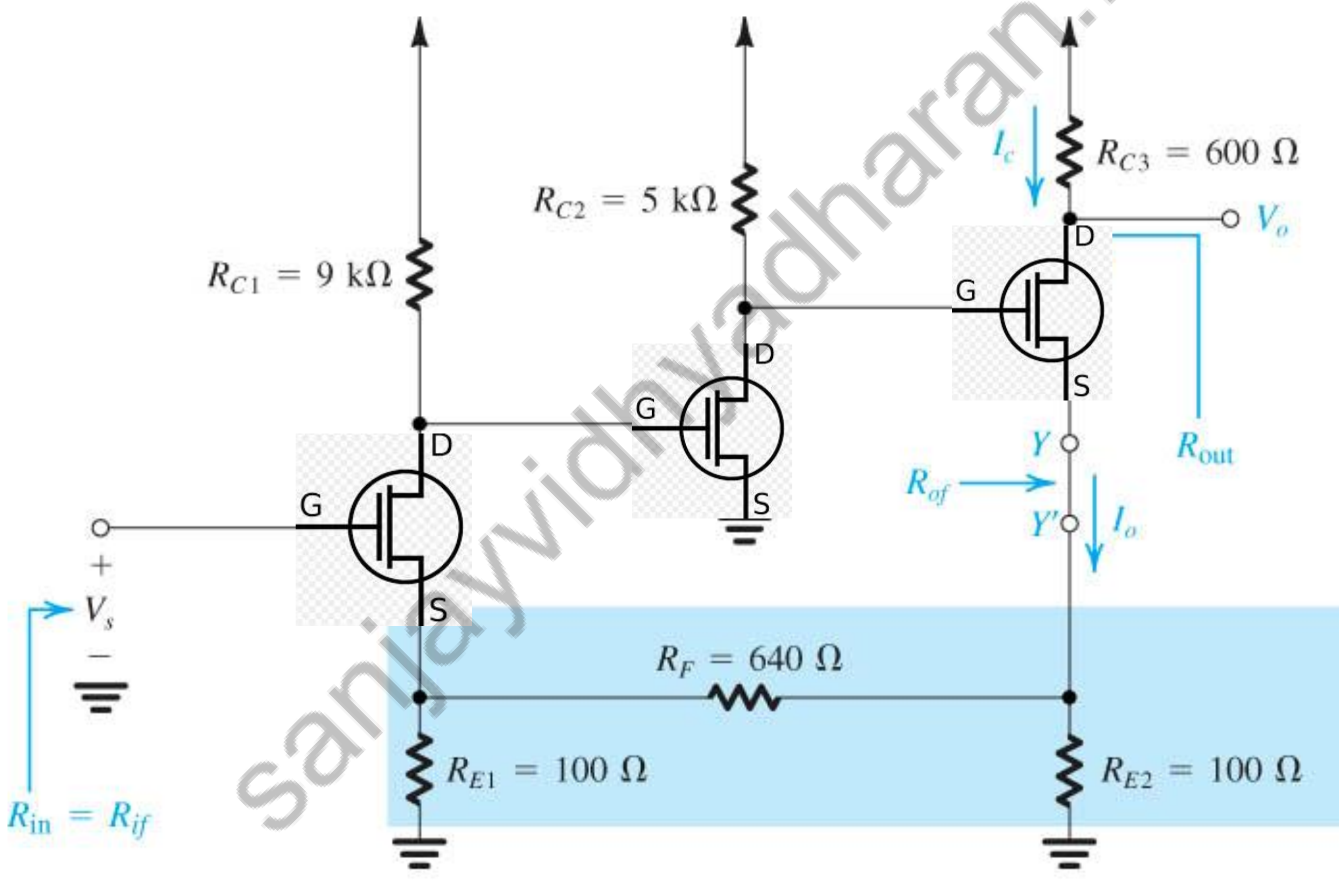
$$A \equiv \frac{I_o}{I_i} = -g_{m2} R_D$$

$$\beta \equiv \frac{I_f}{I_o} \simeq -\frac{R_M}{R_F + R_M}$$

$$A_f \equiv \frac{I_o}{I_s} = -\frac{g_{m2} R_D}{1 + g_{m2} R_D \Big/ \left(1 + \frac{R_F}{R_M}\right)}$$

$$I_i = \frac{(R_F + R_M) I_s}{R_F + R_M + \frac{1}{g_{m1}}}$$

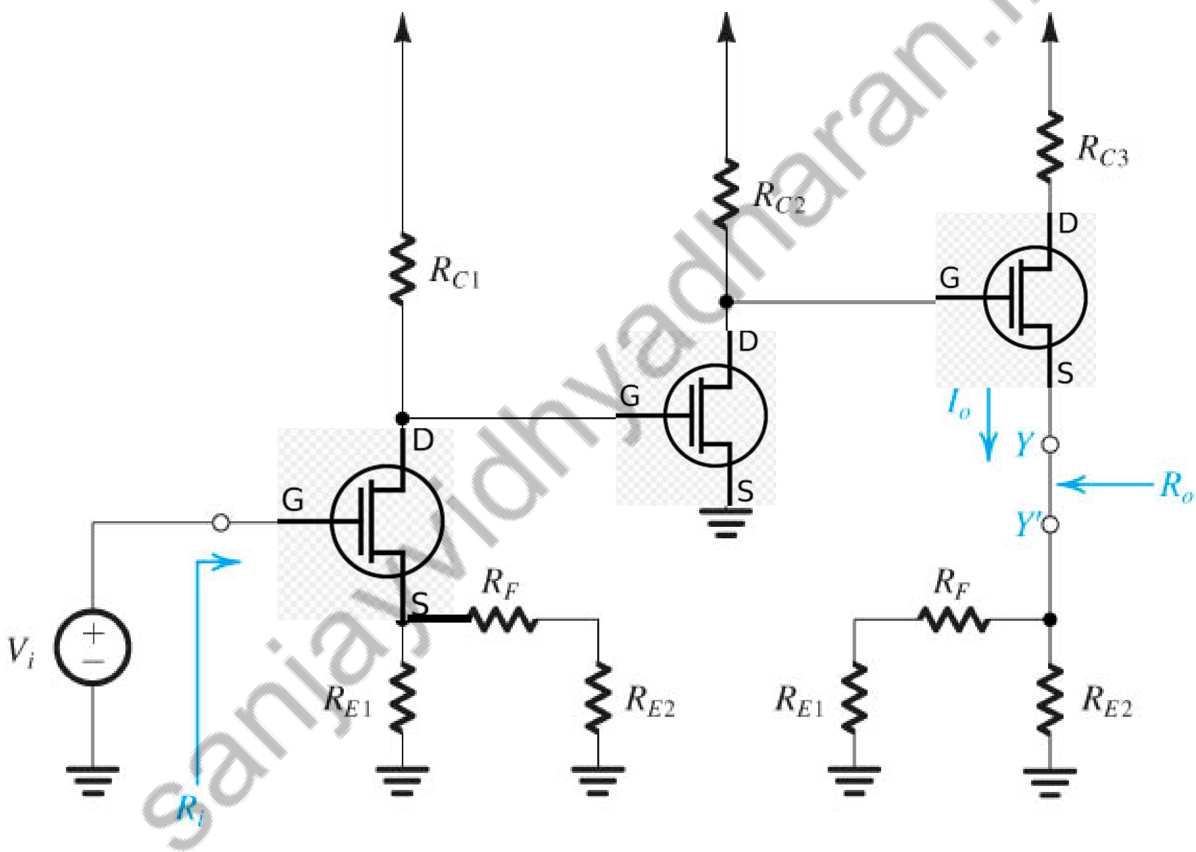
Example - 5



$R_{C1} = 9\ k\Omega$
$R_{C2} = 5\ k\Omega$
$R_{C3} = 600\ \Omega$
I_c
V_o
D
G
S
R_{out}
Y
Y'
R_{of}
I_o
+
V_s
−
$R_F = 640\ \Omega$
$R_{E1} = 100\ \Omega$
$R_{E2} = 100\ \Omega$
$R_{in} = R_{if}$

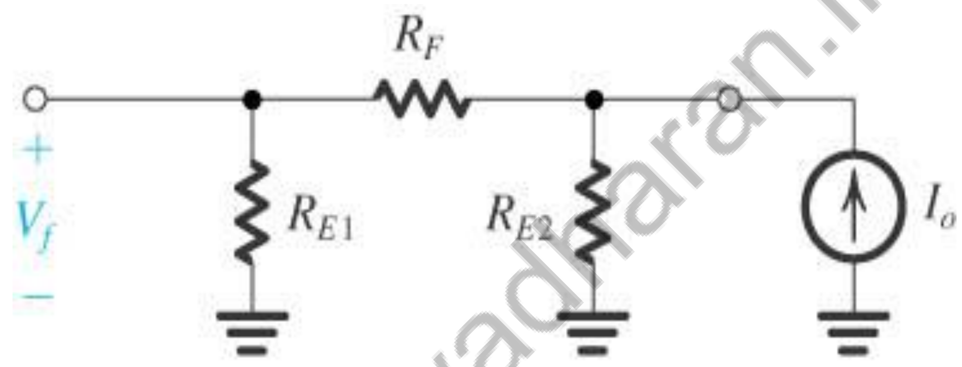
(a)

Example - 5



(b)

Example - 5



(c)

$$\beta \equiv \frac{V_f}{I_o} = \frac{R_{E2}}{R_{E2} + R_F + R_{E1}} \times R_{E1}$$

Thankyou