Analysis of Feedback Amplifier

1. Basic Amplifier is **Unilateral**, but the Gain is evaluated with loading of (i) feedback network (ii) Source & Load Resistance

2. Feedback network too is **Unilateral**. Essentially we say there is no or very little feed forward case

Analysis steps: -
(a) Identify Topology - What is type of Feedback (Sensing) and how it mixes with the Input.
You have a **Series Mixing** if in the input circuit, there is a circuit component \( C \) which is in series with \( V_s \). Then

\[ X_f = V_f \text{ is Feedback Signal} \]

You have **Shunt Mixing at Input Circuit**, if there is a connection between 'Input Node' (Base or Gate) and the output circuit, then

\[ X_f = I_f \text{ current feedback} \]

We also test for Sampling now:
(i) Set $V_o = 0 \ (R_{\text{load}} = 0)$. If now $X_f$ becomes "zero", then Sampling is Voltage kind
This is called Shunt Sampling

(ii) Set $I_o = 0 \ (R_L \to \infty)$, then if $X_f = 0$, then we have Current Sampling or Series Sampling

Step (a) Find Input Circuit by
Setting $V_0 = 0$ (Shunt Amplifying)
$I_0 = 0$ (Series Amplifying)

Step (b) Find Output Circuit by
Setting $V_c = 0$ for Current Mixing (Shunt)
or $I_c = 0$ for Voltage Mixing (Series)
Then get $A_{OL}$ from this Circuit.

c) Evaluate $\beta$ for the topology $= \frac{x_f}{x_0}$

d) Get $A_{OL}\beta = T$ for the Amplifier

e) Evaluate $A_{CL} = A_f$ for the Amplifier

f) Evaluate $R_{ip}$ and $R_{op}$ for the Amplifier
Since $R_E$ is common between input & output circuit, this amplifier is a voltage amplifier.

Circuit without feedback:

Input Circuit: $V_o = 0$

Output Circuit: Set $V_c = 0$ (current sampling) & $i_i = 0$ (voltage sampling).

If we make $V_c = 0$, there is dependent source in the output.

We have circuit with only load resistance $R_E$. 

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Course Name: Analog Circuits
Lecture No. 18
Instructor's Name: Prof. A. N. Chandorkar
Example of Source/Emitter Follower

If we make \( V_0 = 0 \), \( V_f = 0 \) then the input has serious mixing and shunt sampling. 

\[ \therefore \text{It is a Series-Shunt Amplifier} \]
For Shunt Sampling

\[
R_{of} = \frac{R_o}{1+T} \quad \text{and} \quad R_o = V_o \text{ for our Voltage Amplifier.}
\]

\[
\frac{V_o}{1 + \frac{\beta R_o E}{R_n + R_s}} = \frac{V_o (R_n + R_s)}{R_n + R_s + \beta R_o E}
\]

\[
\frac{R_s + R_n}{\beta} = \frac{2\lambda}{10^6} = 2\mu\text{n}
\]
Shunt-Shunt Amplifier

\[ i_i = i_s - i_f \]

Since 'Input Circuit node' is connected to 'output' node through \( R_f \), then feedback has Shunt Mixing.

If we make \( V_o = 0 \), then there is no feedback.

Hence we have Shunt Sampling.
Hence Amplification without Feedback has eq. circuit as

\[
\frac{1}{R_{\text{odf}}} = \frac{1}{r_0} + \frac{1}{R_f} + \frac{1}{r_0}
\]

\[
A_{OL} = \frac{V_0^*}{V_{in}} = \frac{V_0^*}{V_{in}} \cdot \frac{V_{in}}{I_s} = -g_m R_{\text{odf}} \cdot R_f
\]

\[
\frac{R_s^*}{R_s} = R_f \quad \& \quad R_0^* = R_{\text{odf}}
\]

Feedback factor \( \beta = \frac{V_f^*}{V_0^*} = \frac{1}{R_f} \)
\[ A_{CL} = \frac{V_o}{I_s} = \frac{A_{OL}}{1 + A_{OL} B} \]

\[ = - \frac{g_m R_{oDF} \cdot R_f}{1 + g_m R_{oDF} \cdot R_f \cdot \frac{1}{R_f}} \]

\[ = - R_f \quad \text{if} \quad g_m R_{oDF} \gg 1 \]

Voltage Gain

\[ A_{VCL} = \frac{V_o}{V_{in}} = \frac{V_o}{I_s} \cdot \frac{I_s}{V_{in}} = A_{CL} \cdot \frac{1}{R_f} \]

\[ = - \frac{g_m R_{oDF} \cdot R_f}{1 + g_m R_{oDF} \cdot \frac{1}{R_f}} \]

\[ = - \frac{g_m R_{oDF}}{1 + g_m R_{oDF}} \]
ac equivalent circuit is

open loop amplifier will then be:

@ input circuit: we set $V_o = 0$ (shunt sampling), then

(b) output circuit: we set $V_{in} = 0$
Hence Amplifier without Feedback has the Circuit

\[ V_{II} = \frac{\gamma_{II}}{\gamma_{II} + R_s} V_s \]

\[ R_{OE} = \infty \times RE \]

\[ A_{OL} = \frac{V_o}{V_s} = \frac{\gamma_{II}}{\gamma_{II} + R_s} \cdot g_m R_{OE} \]
\[ \beta = \frac{V_s}{V_o} = 1 \]

\[ \therefore T = A_{OL} \beta = \frac{g_m \beta}{\gamma + R_s} = \frac{\beta \text{ROE}}{\gamma + R_s} \]

Then Feedback Gain \( A_{CL} = A_f \)

\[ = \frac{A_{OL}}{1 + T} = \frac{\beta \text{ROE}}{1 + \frac{\beta \text{ROE}}{\gamma + R_s}} \]

\[ = \frac{\beta \text{ROE}}{\gamma + R_s + \beta \text{ROE}} \]

\[ R_{IF} = (1 + T) R_i \]

\[ \therefore R_{IF} = \gamma \frac{1 + \frac{\beta \text{ROE}}{(\gamma + R_s)}}{\gamma + R_s + \beta \text{ROE}} \]

We have \( R_c = \gamma \)

\[ = \gamma + \frac{\gamma}{\gamma + R_s} \cdot \beta \text{ROE} = \gamma + \beta \text{ROE} \]
\[ R_f = \frac{V_{in}}{I_S} = \frac{R_f}{1 + g_m R_o D_f R_f / R_f} \]

\[ = \frac{R_f}{1 + g_m R_o D_f} \]

\[ \therefore A_{vel} = - \frac{g_m R_o D_f R_f}{1 + g_m R_o D_f} \cdot \frac{1 + g_m R_o D_f}{R_f} \]

\[ = - g_m R_o D_f \]
Stability

\[ A_{CL} = \frac{A_{OL}}{1+T} \]

If \( T > 0 \) (time), we have negative feedback.
Then \( A_{CL}(s) < A_{OL}(s) \) and feedback stabilizes \( A_{CL}(s) \).

If \( T < 0 \), we have positive feedback, then
\[ A_{CL}(s) > A_{OL}(s) \] This leads to instability

Even without signal, small noise at input is amplified and
positive feedback increases input to amplifier, thus increasing
output further. In a typical case the system may oscillate.

We can find stability condition in negative feedback amplifier
by observing Bode's plots for closed loop gain transfer function.
Phase Margin & Gain Margin

\[ \phi_M = \angle T(j\omega_0) + 180^\circ \]

\[ GM = -20 \log T(j\omega_0) \]
Stability in Feedback Amplifiers

\[ A_{CL}(s) = \frac{A_{OL}(s)}{1 + T(s)} \]

We see that 'Zeros' of \((1 + T(s))\) are poles of \(A_{CL}(s)\), and any poles of \(A_{OL}(s)\) are not common to \(T(s)\).

We assume \(A_{OL}\) makes system stable, then on \(S\)-plane (\(S+j\omega\) plane) then poles of \(A_{OL}\) will be on the Left Half Plane.

Typical:

\[ A_{CL}(s) = \frac{A_{\infty}}{1 + \frac{a_s s}{1 + T_0} + \frac{a_2 s^2}{1 + T_0} + \frac{a_3 s^3}{1 + T_0}} \]
Generalized Expressions for T.F.A Stabilty

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

$$\omega_0 \quad s = j\omega$$

$$A_{cl}(j\omega) = \frac{A(j\omega)}{1 + A(j\omega)\beta(j\omega)}$$

The loop gain \( T = A(j\omega)\beta(j\omega) \) is a complex fn.

$$T(j\omega) = A(j\omega)\beta(j\omega)$$

$$= |A(j\omega)\beta(j\omega)| e^{j\phi(j\omega)} \quad \text{Amplitude & Phase}$$

If \( \phi(j\omega) = 180^\circ \) for a frequency, \( T(j\omega) = \text{Negative Real No.} \)

Thus \( A_{cl} \) will increase as \( \omega \).
If $|T(\omega)| = 1$ at $\omega = \omega_1$,

then $A_{cl} = \frac{A(s)}{s} = 0$.

Hence, amplifier becomes Oscillator.
Compensation

1. Miller Compensation & Pole Splitting

\[ \omega_{p1} = \frac{1}{9mR_2C_fR_1} \]

\[ \omega_{p2} = \frac{9mC_f}{C_1(C_2 + C_f(C_1+C_2))} \]

Without Feedback:

\[ \omega_{p1} = \frac{1}{R_1C_1} \]

\[ \omega_{p2} = \frac{1}{R_2C_2} \]

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