1. Multi-stage Amplifier Topologies

\[ x_5 \rightarrow [A_1] \rightarrow A_2 \rightarrow \cdots \rightarrow [A_n] \rightarrow x_0 \]

- Feedback arrangements are basically:
  - Local Feedback
  - Global Feedback

Local Feedback

To simplify we assume \( A_1 = A_2 = \cdots = A_n = A_{OL} \) and \( B_1 = B_2 = \cdots = B_n = B_L \)

Global Feedback

Under the above assumptions, global feedback is more difficult to stabilize even when

\[ A_{OL} = \frac{A_{CLMB}}{1 + \frac{s}{\omega_p}} \]

is a single pole dynamic system

Local feedback, in the same conditions, has no stability issues.
Sensitivity of the closed loop gain:

\[ A_{FL} = \frac{A_{ol}}{(1 + P_l A_{ol})^N} \quad \text{for local feedback} \]

\[ A_{FG} = \frac{A_{N}}{1 + P_g A_{N}} \quad \text{for global feedback} \]

For a fair comparison, we need to assume that \( A_{FG} = A_{FL} \Rightarrow \)

\[ (1 + P_l A_{ol})^N = 1 + P_g A_{N} \]

Sensitivity is defined as

\[ S_A = \frac{\partial A}{\partial A} \cdot \frac{A}{A_F} \]

we could also consider

\[ S_B = \frac{\partial A}{\partial B} \cdot \frac{B}{A_F} = - \frac{A_{ol}^2}{(1 + P_{ol} A_{ol})^2} \cdot \frac{B}{A_{ol}} (1 + P_{ol} A_{ol}) = - \frac{A_{ol} B}{1 + A_{ol} B} \]

\[ A_F = \frac{A_{ol}}{1 + P_{ol} A_{ol}} \]

\[ S_B^n = 1 \quad \text{any time } A_{ol} B \gg 1 \quad \text{(the typical case)} \]

Any error or tolerance or drift that modifies \( B \), modifies \( A_F \) by the same amount (only the sign is opposite).

**Therefore:** \( B \)-networks must be implemented with very stable components, with low tolerance.

Let's go back to \( S_{AF} \)

\[ S_{AFl} = N \cdot \frac{A_{ol}^N}{(1 + P_l A_{ol})^{N-1}} \cdot \frac{1 + P_l A_{ol} - P_l A_{ol}^2}{(1 + P_l A_{ol})^2} \cdot \frac{A_{ol}}{A_{FL}} = N \cdot \frac{A_{ol}^N}{(1 + P_l A_{ol})^{N-1}} \cdot \frac{(1 + P_l A_{ol})^N}{A_{ol}^N} \]

\[ = N \cdot \frac{1}{1 + P_l A_{ol}} \]
\[ S_{AG} = \frac{N A_a^{n+1} (1 + B_g A_a^n) - N B_c A_a^{n+1}}{(1 + B_g A_a^n)^2} \cdot \frac{A_a (1 + B_g A_a^n)}{A_a^n} \]
\[ = \frac{N A_a^{n+1} + N B_c A_a^{n+1} - N B_c A_a^{n+1}}{(1 + B_g A_a^n) A_a^{n+1}} = \frac{N}{1 + B_g A_a^n} = \left( \frac{N}{1 + B_g A_a^n} \right)^n \]

\[ S_{A_E} = \left( S_{A_{fl}} \right)^N \cdot \frac{1}{N^{n-1}} \ll S_{A_E} \]
\[ < 1 \quad < 1 \]

**Global Feedback is Very Advantageous** (in terms of sensitivity, it is less advantageous in terms of stability)

Because there's no clear winner, both solutions are used, often at the same time.

**Block Diagrams of Feedback Amplifiers**

(relationship between feedback theory and control system theory)

From this circuit, we can immediately derive a block diagram where loading effects and scale factors are taken into account.

\[ x_s = k_s u_s \]
\[ u_i = \frac{n_i}{n_i + r_i} \]
\[ A_i = \frac{a_i}{a_i + r_i} \]
\[ u_0 = \frac{a_0}{a_0 + r_0} \]
\[ A_c = a_i A_0 a_o \]

**Equivalent Circuit** of a voltage amplifier with feedback
It is then possible to interconnect block diagrams to treat complex amplifier organizations such as:

- Cascade organization
- Nested loop organization
- Intertwined loop organization

But care must be taken to account for loading effects.

1. **Cascade**

2. **Nested Loop**

3. **Intertwined**

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**1. Cascade**

These must be calculated considering the loading effects.

**2. Nested Loop**

We need to take into account loading effects here.

**3. Intertwined**

We need to take loading effects into account.
In general terms, the bandwidth widening property holds but care must be taken before applying such property to any amplifier.

Consider this example:

$$R_s$$

![Circuit diagram]

Single pole raised at

$$\omega_p = \frac{1}{RC}$$

which obviously does not depend on $$T$$ or $$1+T = 1+A$$

The reason the pole does not depend on $$T$$ is that it is placed outside the feedback loop. Actually, the pole is located inside $$\mu_s$$.

Let's consider another example:

$$R_s$$

![Circuit diagram]

Again, the pole does not depend on $$T$$

Indeed, $$C_s$$ "sees" the same resistance $$R_s + R_G$$ no matter the value of $$T$$.

Using feedback theory, we can calculate $$A$$ and $$\beta$$ exactly. Therefore, we can also find $$T = 3a_R$$.

Once we have $$T$$, we can use Nyquist theorem and
Discuss the amplifier stability.

But we can also shape the B-network to enhance the amplifier's stability margins (phase margin and/or gain margin).

This is caused by compensation of an amplifier. This will be the object of next lessons.

**Example**

CE amplifier with self-bias

\[
\begin{align*}
\text{Small signal equivalent circuit at mid-band} \\
\text{1. Find } A_0 &= \frac{V_o}{V_i} \text{, } R_{in} \text{ and } R_{out} \\
\text{2. Discuss the pole location} \\
\text{3. Draw the amplifier block diagram.}
\end{align*}
\]