**Bode Plots: Some Typical Cases**

![Bode Plot Diagram]

1. **#1** 10 dB
2. **#2** -40 dB

**In this case**, if additional poles and zeros are placed at a distance from \( \omega_0 \)

\[ \text{PM} = 90^\circ \]

The loop is stable with a large margin.

**The minimum phase margin** in this case can be as low as 20 dB.

The system is "formally" stable but with very small PM, the time response is lightly damped and shows persistent oscillations. => Compensation is needed.

To compensate the amplifier, we can modify the B-network in different ways:

1. **WE CAN PLACE A ZERO IN \( T \) AT \( \omega = \omega_0 \) BECAUSE B-NETWORKS ARE PASSIVE (MOST OF THE TIMES), WE HAVE ALSO AN ADDITIONAL POLE (AT HIGH FREQUENCY)**

With compensation, \( \text{PM} \leftarrow \text{PM} + 45^\circ \) after \( \text{BEFORE} \) zero effect

2. **WE CAN PLACE BOTH ZERO AND POLE AT APPROPRIATE FREQUENCIES IMPLEMENTING A LEAD-LAG COMPENSATION OR ZERO-POLE COMPENSATION**.

\[ \text{PM} \text{ IS IMPROVED MORE OR LESS DEPENDING ON WHERE WE PLACE } \omega_0 \text{ AND } \omega_0. \]

Typical design choice is to have

\[ \frac{\omega_p}{\omega_0} = \frac{\omega_0}{\omega_0} = 4 \quad \Rightarrow \quad \text{PM} \leftarrow \text{PM} + 60^\circ \]

**After Before**
To solve the problem the Opamp is internally compensated by intentionally reducing \(\omega_p^2\) (strongly).

This way phase margin can be improved to minimum 45°.

\[
\frac{\omega_c}{\omega_p} = \frac{R_2}{R_1R_2} < 1
\]

If the Opamp is unity gain stable, this configuration yields a target signal attenuation but no stability issues.

Let's analyse some Opamp configurations where there can be stability problems even when the Opamp is internally compensated, unity gain stable.

**Time Differentiator**

If the Opamp is ideal we know that

\[
A_n = \frac{\omega_c}{\omega_p} = -\frac{RC}{s}
\]

But what can we say when \(A_{ol}\) is:

\[
A_{ol} = \frac{A_{ol0}}{1 + \frac{s}{\omega_c}}
\]

Internally compensated, unity gain stable Opamp.

The most straightforward way to analyse the problem is
To use **direct loop inspection**

\[
T = -\frac{N_e}{V_e} = -\left( -\frac{A_0 \varphi}{1 + \frac{s}{\omega_0}} \cdot \frac{1}{s \omega C} \right) = \frac{A_0 \varphi}{1 + \frac{s}{\omega_0}} \cdot \frac{1}{1 + s \omega C}
\]

Once we have \(T\) we can discuss stability, \(A_0(s), B(s)\)

\[
|A_0| \text{dB} \quad |B| \text{dB} \quad |T| \text{dB} \quad \omega_0 \quad \omega_C \quad \omega_{EC} \quad \omega_{CR}
\]

\[
\angle T @ \omega = \omega_{CR} \approx \varphi
\]

**Conclusion:** The circuit needs to be compensated.

A different way of looking at this stability issues is to use Bode plots of \(A_0\) and \(1/B\), why?

Because considering frequencies where \(|T| > 1\) we see that

\[
A_T = A_{wn} = \frac{A_0}{1 + T} = \frac{A_0}{1 + B A_0} \uparrow \frac{1}{B} \quad \text{The target frequency response}
\]

\(|T| > 1\)

So it is normally easier to plot \(1/B\) instead of \(B\), as the former is specified by design.
On this type of plot, we can define:

Closing Ratio: Difference between the slope of $A_{cl}$ and that of $1/\beta$ for $\omega < \omega_{cr}$ and

Opening Ratio: Difference between the slope of $1/\beta$ and that of $A_{cl}$ for $\omega > \omega_{cr}$

In this case, closing ratio is $-20 - (+20) = -40$ dB/dec

and the opening ratio is $+20 - (-20) = +40$ dB/dec.

Both indicate small PM values can be expected.

Another analytical approach is to use feedback theory based on that:

Feedback topology is voltage sensing - current mixing.

So this is a trans-resistance amplifier.

The B-network is the circuit part connecting the output node (where we measure voltage) to the input node (where we mix currents). So it is resistor $R$.

$$Z_i = \frac{N_1}{i_1} |_{U_0 = 0} = R$$

$$Z_{o_i} = \frac{N_0}{i_2} = R$$

$$\delta = \frac{i_2}{V_o} |_{U_0 = 0} = -\frac{1}{R}$$

Nonlinear model of the input.