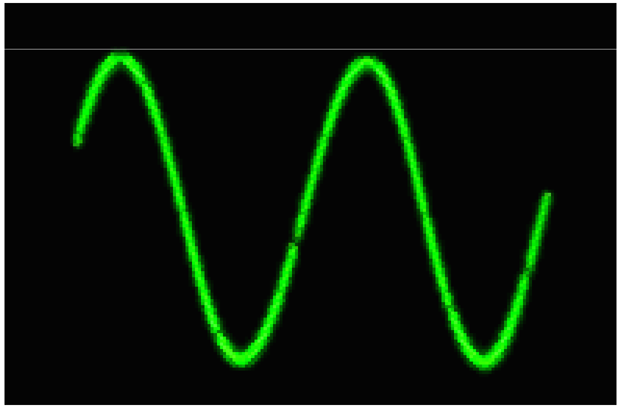
(Analog) Electronics II

Lesson II
Stability of Feedback Amplifiers



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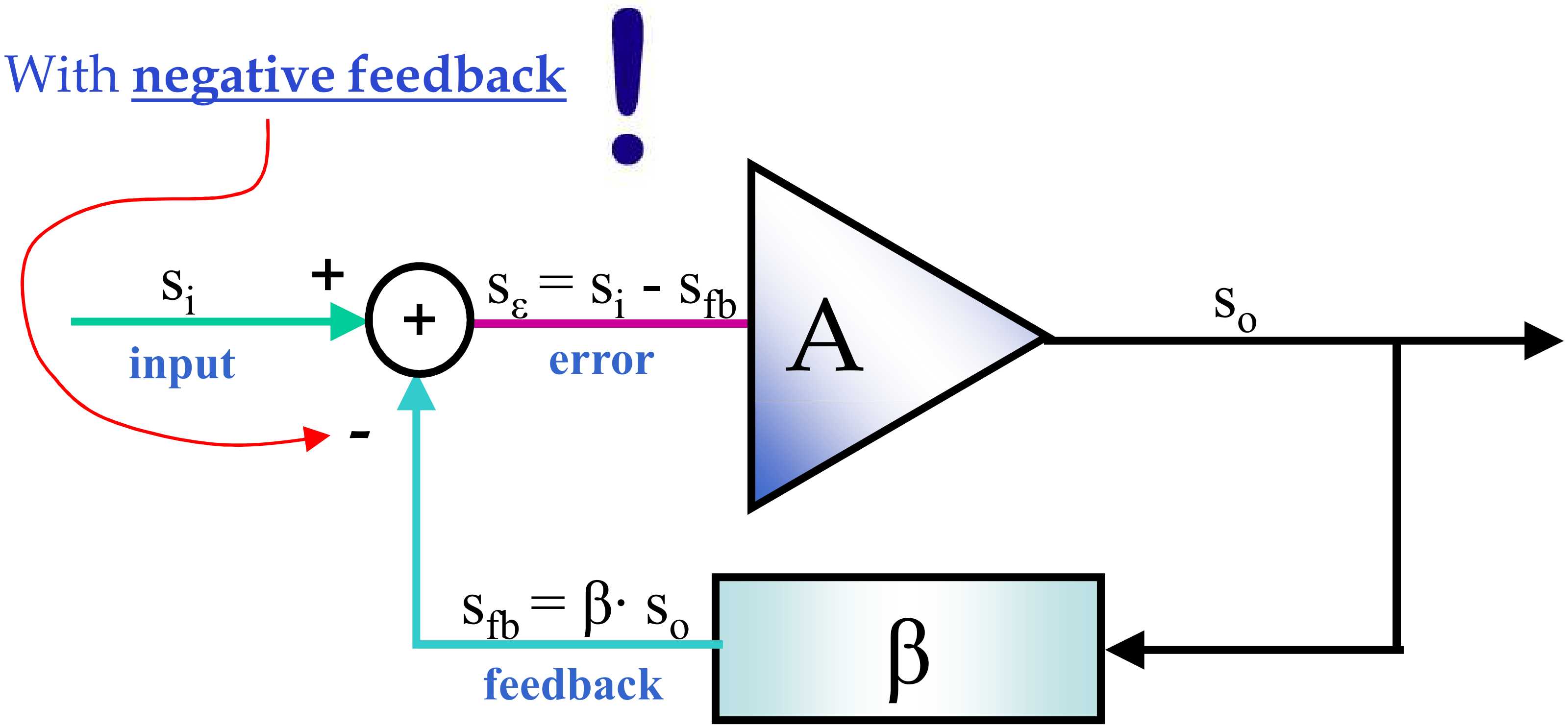
Ideal Configuration of a Feedback Amplifier



$$A = \frac{a}{1 + a\,f}$$

What happens with the frequency response?

$$A(s) = \frac{a(s)}{1 + a(s)f(s)}$$

How can we explore the effect of feedback on the frequency response of the amplifier?

Does feedback affect it anyway?

Why did we use feedback anyway?

At the cost of **GAIN REDUCTION**, we obtain

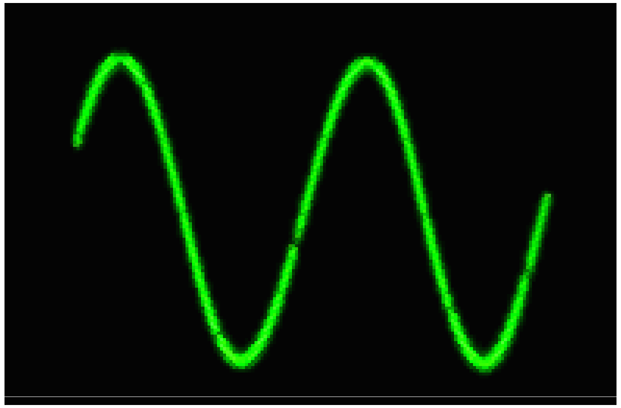
An amplifier closer to ideal characteristics:

- Insensitivity against active component parameter dispersion.
- Linear Gain
- Input/Output Inpedances

However, the circuit has tendency toward . . . . .

OSCILLATION.

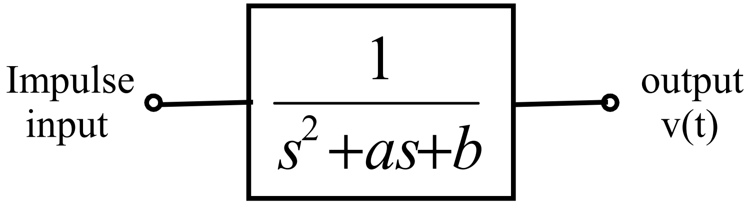
Oscillation ??????????



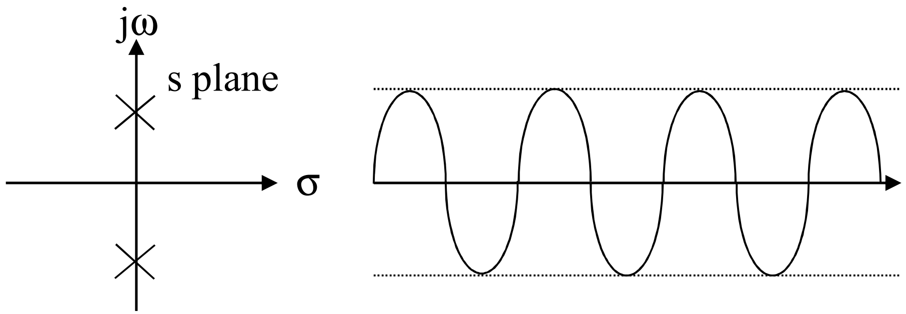
What frequency?

What amplitude?

Why?



$$s = \sigma_\circ \pm j\omega$$



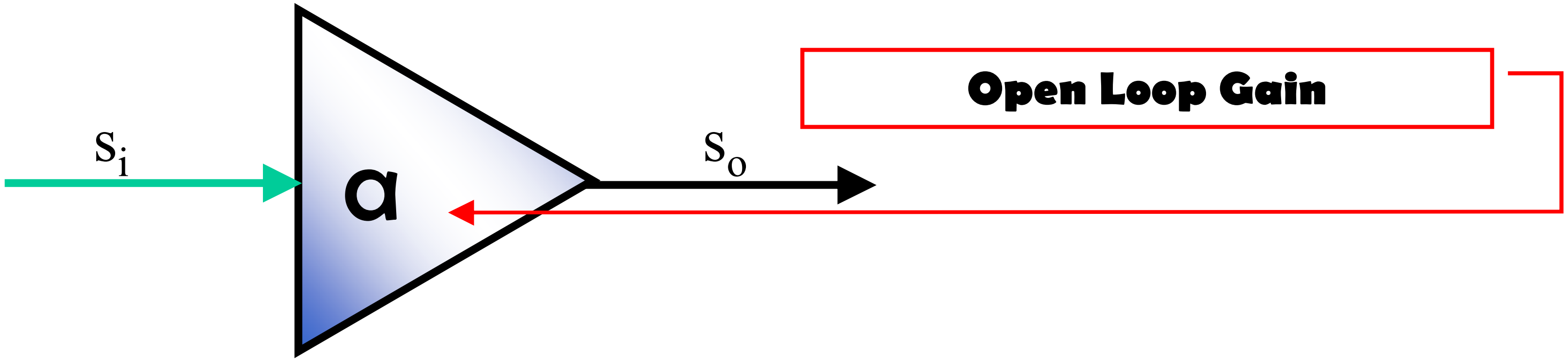
$$\upsilon(t) = e^{\sigma_\circ t}[e^{j\omega_n t} + e^{-j\omega_n t}] = 2e^{\sigma_\circ t}\cos(\omega_n t)$$

Feedback, Poles and Stability

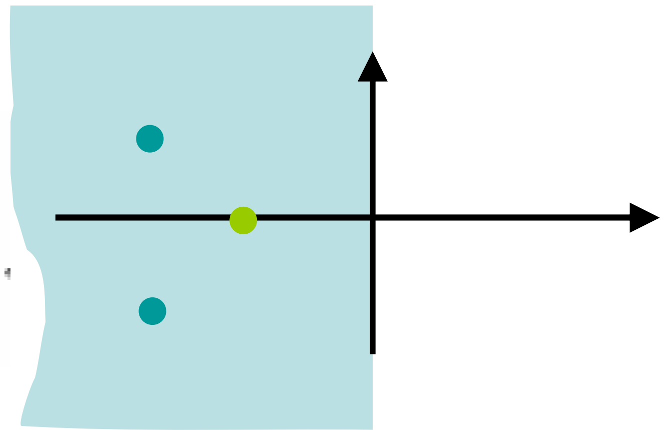
1. One pole system

2. Two pole system

3. More than two poles



$$A(s) = \frac{K}{\left(1 - \frac{s}{p_1}\right)\left(1 - \frac{s}{p_2}\right)\cdots\left(1 - \frac{s}{p_n}\right)}$$



Open loop amplifiers are always STABLE systems

Case 1. $A(s)$ has one pole

Frequency Domain

Gray-Meyer

$$a(s) = \frac{K}{1 - \frac{s}{p_1}}$$

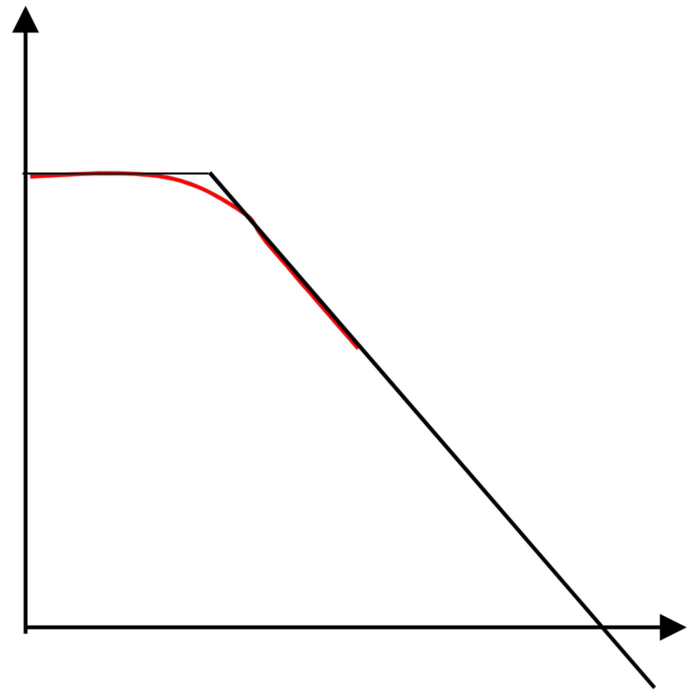
Sedra-Smith

$$a(s) = \frac{A_0}{1 + \frac{s}{\omega_P}}$$

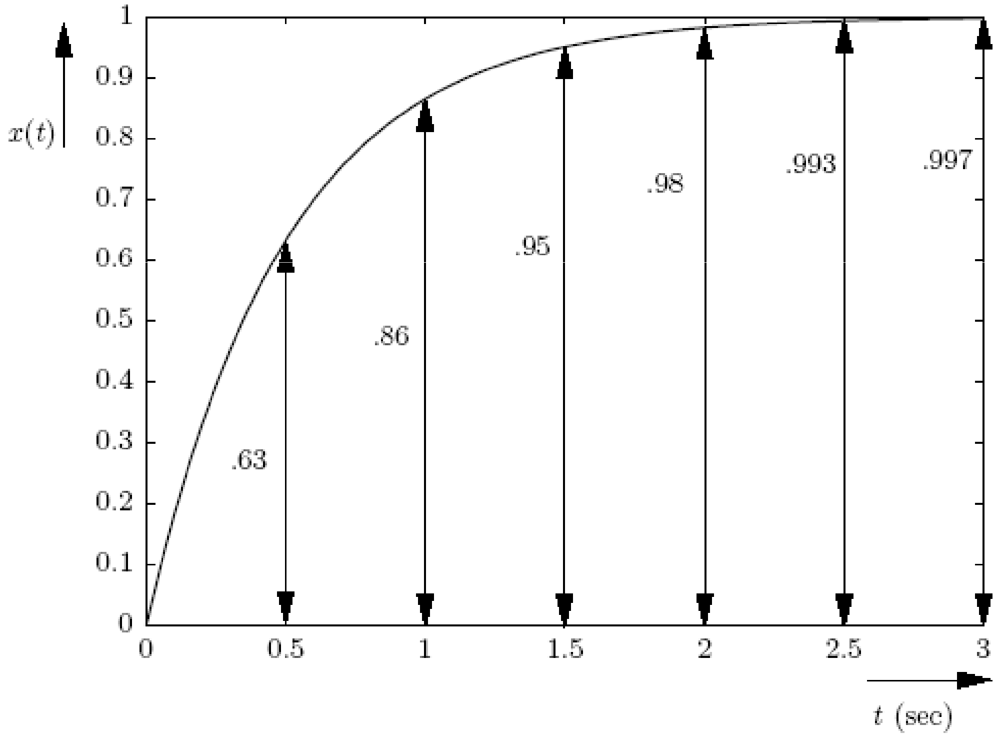
Time Domain

$$v_{out} + \frac{1}{\omega_P}\frac{dv_{out}}{dt} = A_0 v_{in}$$

Frequency Domain

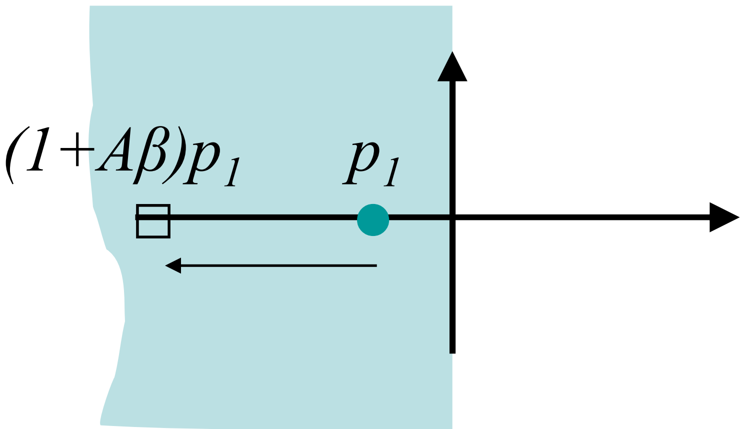


Time Domain



Feedback, Poles and Stability

$$A(s) = \frac{K}{1+Kf} \frac{1}{1 - \dfrac{s}{p_1(1+Kf)}}$$

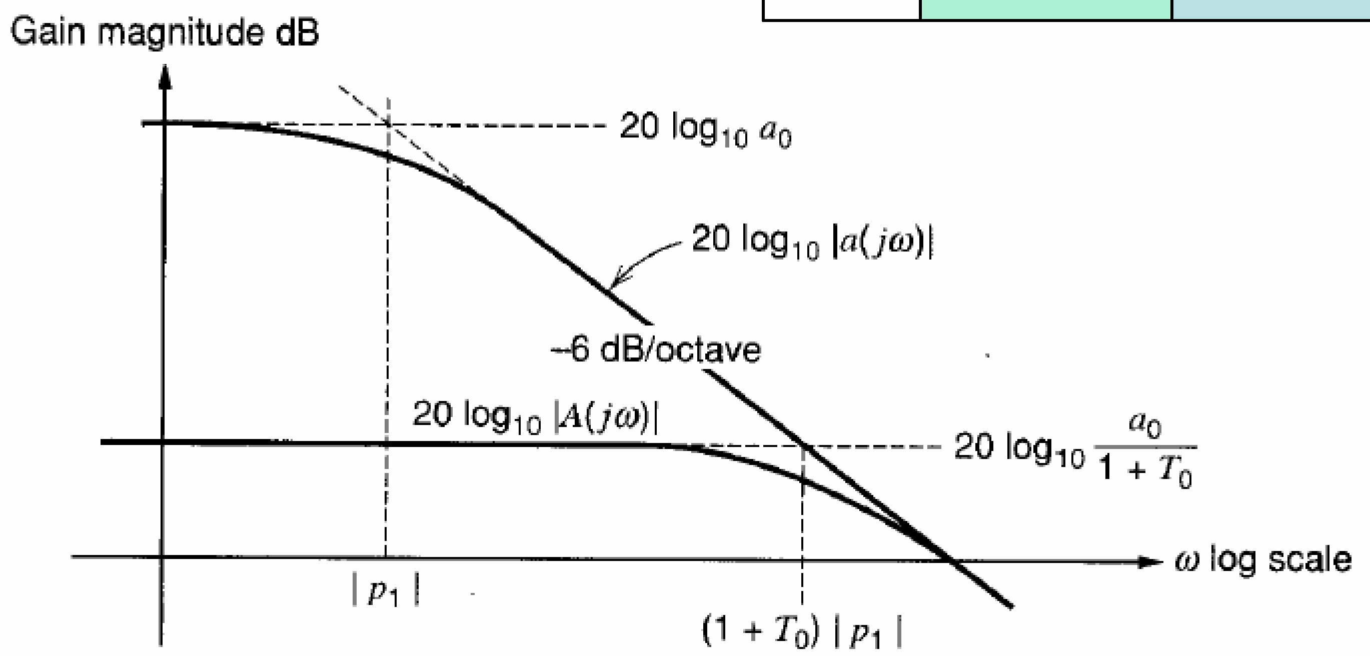


unconditionally STABLE

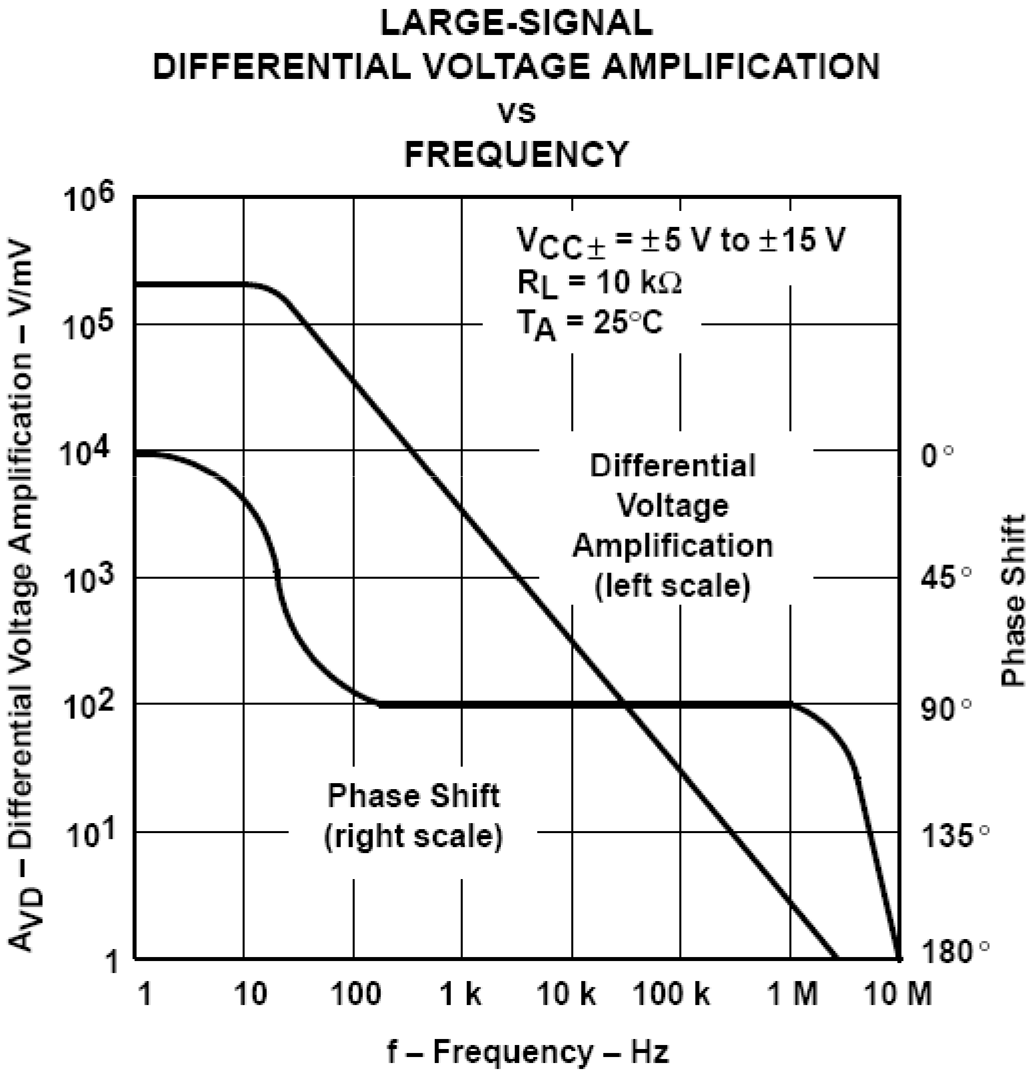
Gain x Bandwidth Product

$$A(s)=\frac{K}{1+K\,f}\,\frac{1}{1-\dfrac{1}{p_1(1+K\,f)}}$$

	Basic	Feedback
GAIN	K	$\frac{K}{1+K\,f}$
BW	p_1	$p_1(1+K\,f)$



Feedback, Poles and Stability

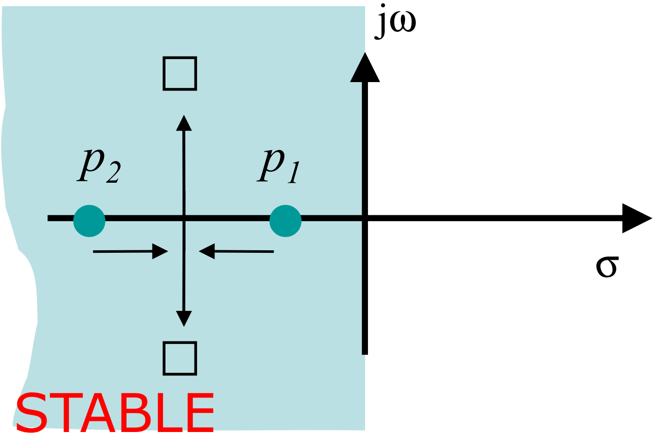


Feedback, Poles and Stability

Hints on what happens with higher order systems

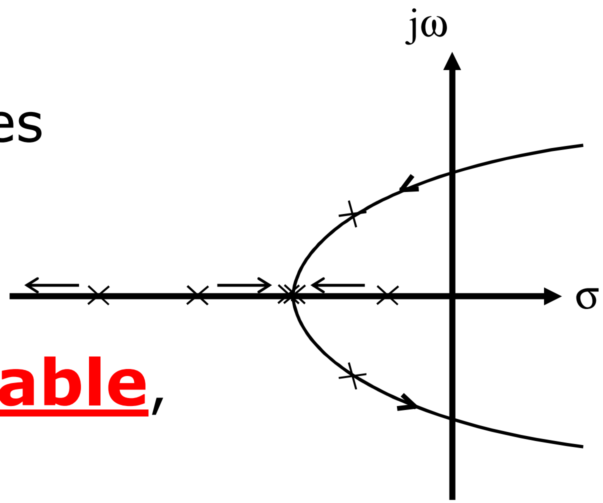
Case 2. $a(s)$ has two poles

$$A(s) = \frac{K}{\left(1 - \frac{s}{p_1}\right)\left(1 - \frac{s}{p_2}\right)}.$$



unconditionally STABLE

Case 3. $a(s)$ more than two poles



System can become **unstable**, depending on f strength.

Origin of the instability

Origin of the instability

IF <u>feedback</u> can turn our system unstable . . .

. . . . means that poles of $a(s)$ are not the poles of $A(s)$

$$A(s) = \frac{a(s)}{1 + a(s) f(s)} \Rightarrow 1 + \underbrace{a(s)f}_{L(s)} = 0$$

characteristic equation

$$A(j\omega) = \frac{a(j\omega)}{1 + a(j\omega) f} \Rightarrow 1 + a(j\omega)f = 0$$

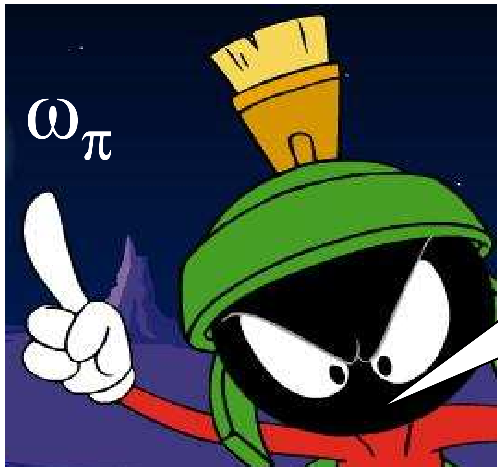
$$1 + |a(j\omega)f| e^{j\phi(\omega)} = 0$$

Origin of the instability

¿What happens when $\phi = \pi$?

- $|\, a(\omega_{\pi} f \,|\, e^{j\pi} = -\,|\, a(\omega_{\pi}) f \,|$
- $$A(j\omega) = \frac{a(j\omega)}{1 - |a(j\omega)|\, f}$$

What is significant here?



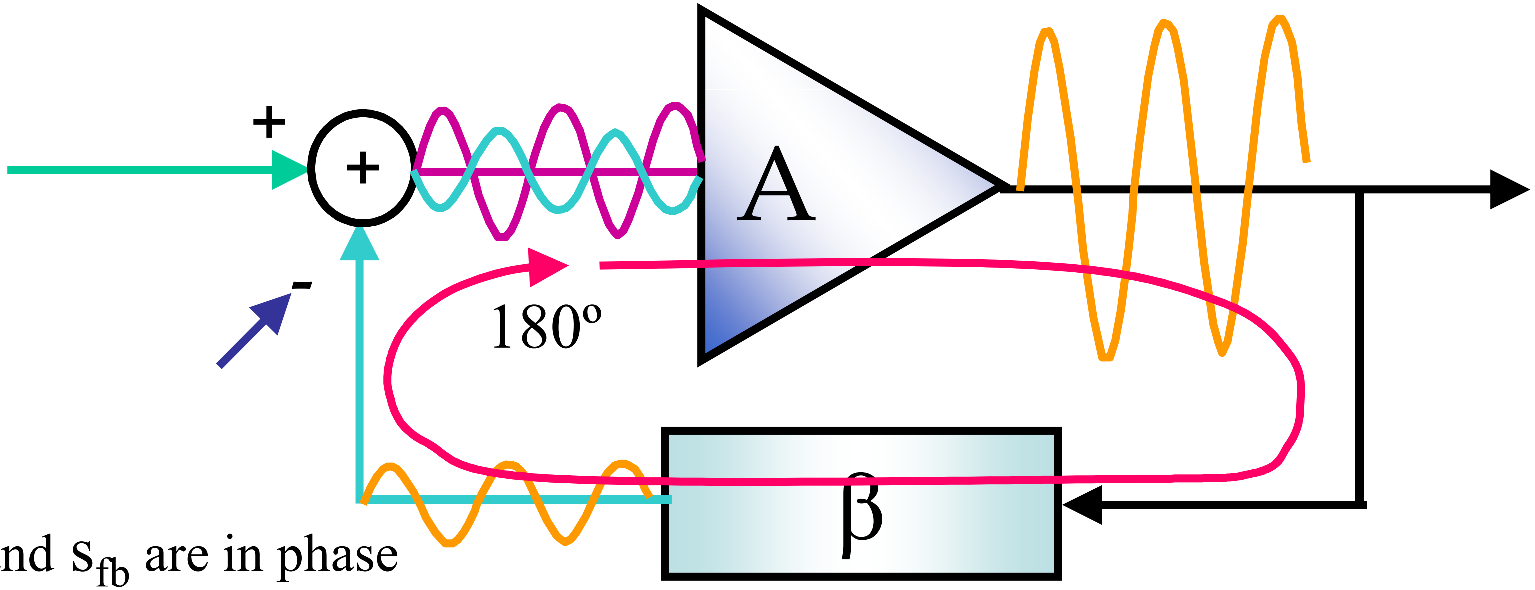
Be careful
with it !!!!

Origin of the instability

Phase change in the loop gain ***Aβ*** has influence in the type of feedback of the amplifier :

- ***β < 1***

- ***Aβ is always positive***

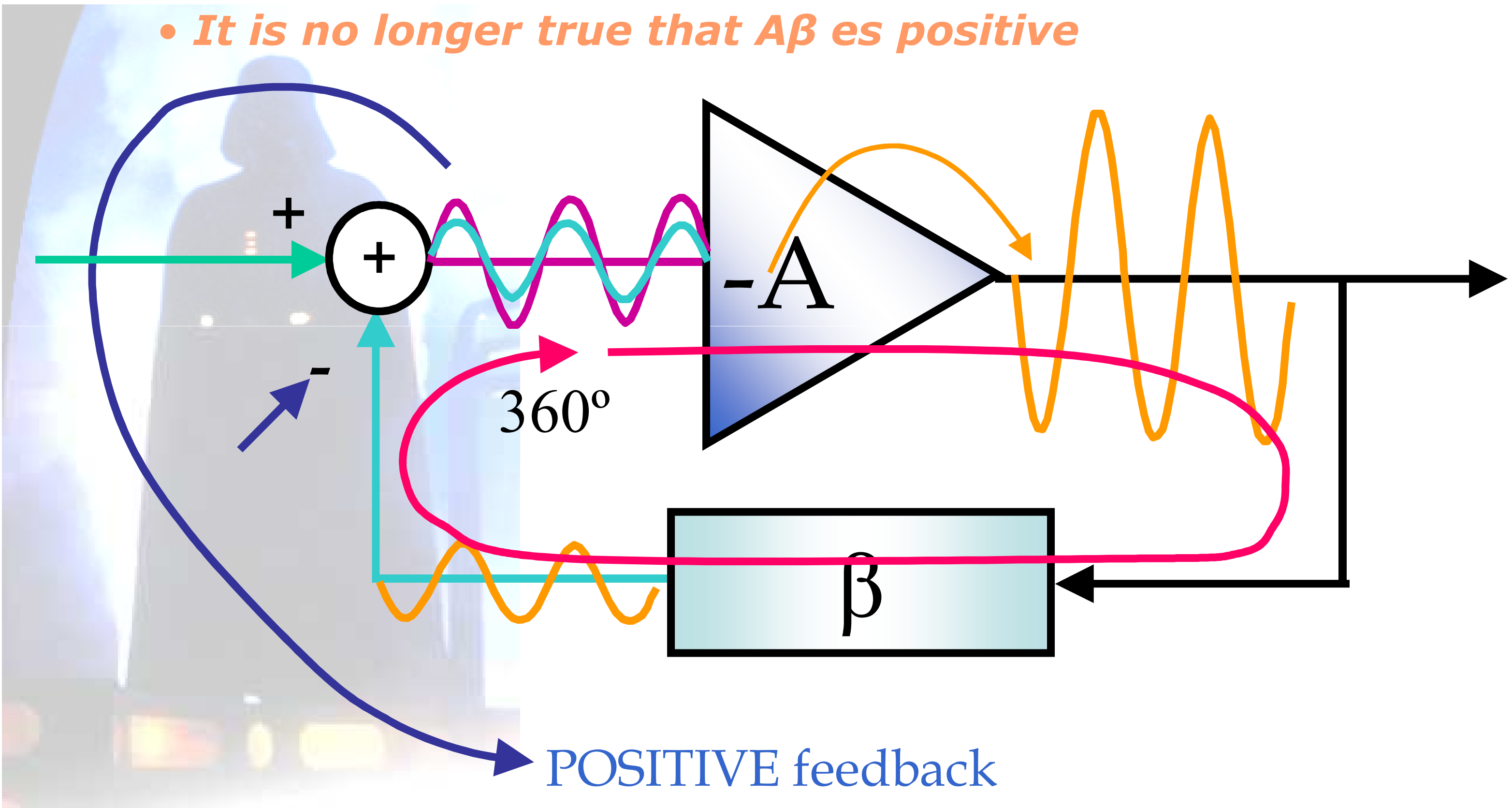


s_ε and s_{fb} are in phase

. . . . . thus the comparator SUBSTRACTS

Origin of the instability

At ω_{π} :



Origin of the instability

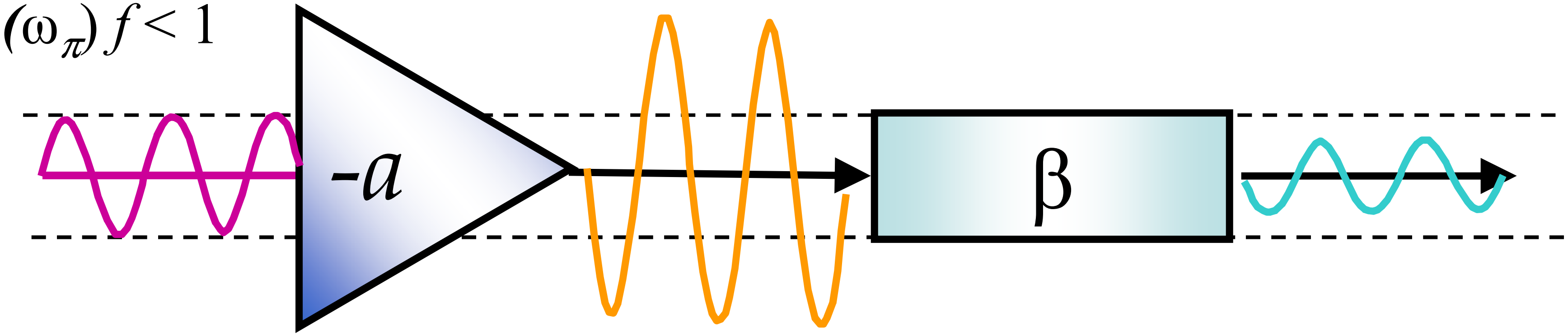
- We have clear out the **OSCILATION FREQUENCY**.

- How about the conditions for oscillation,

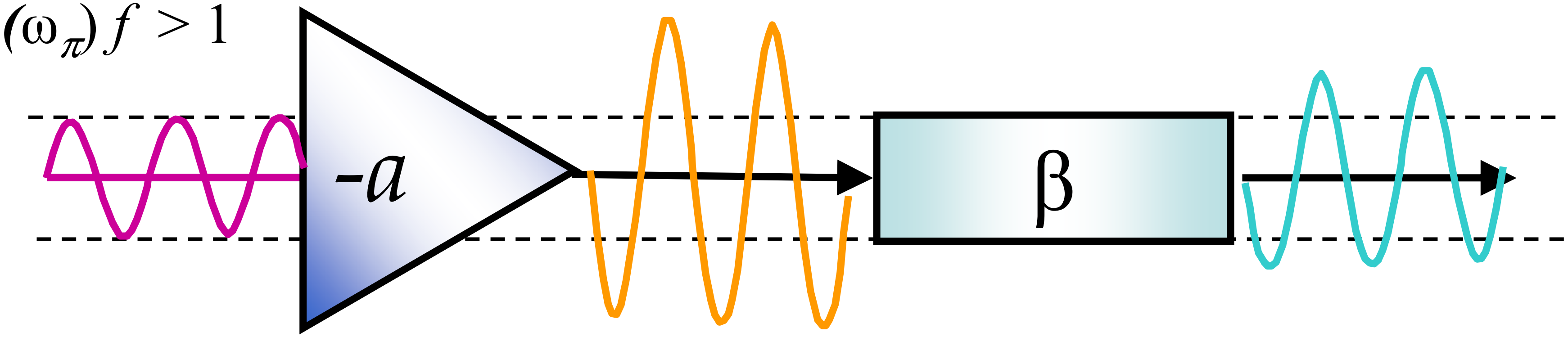
  . . . Why does it depend on f?

Origin of the instability

$a(\omega_\pi) f < 1$



$a(\omega_\pi) f > 1$



Tools to analyze the stability of feedback amplifiers

The secret is within the LOOP GAIN, $a(s)\,f$

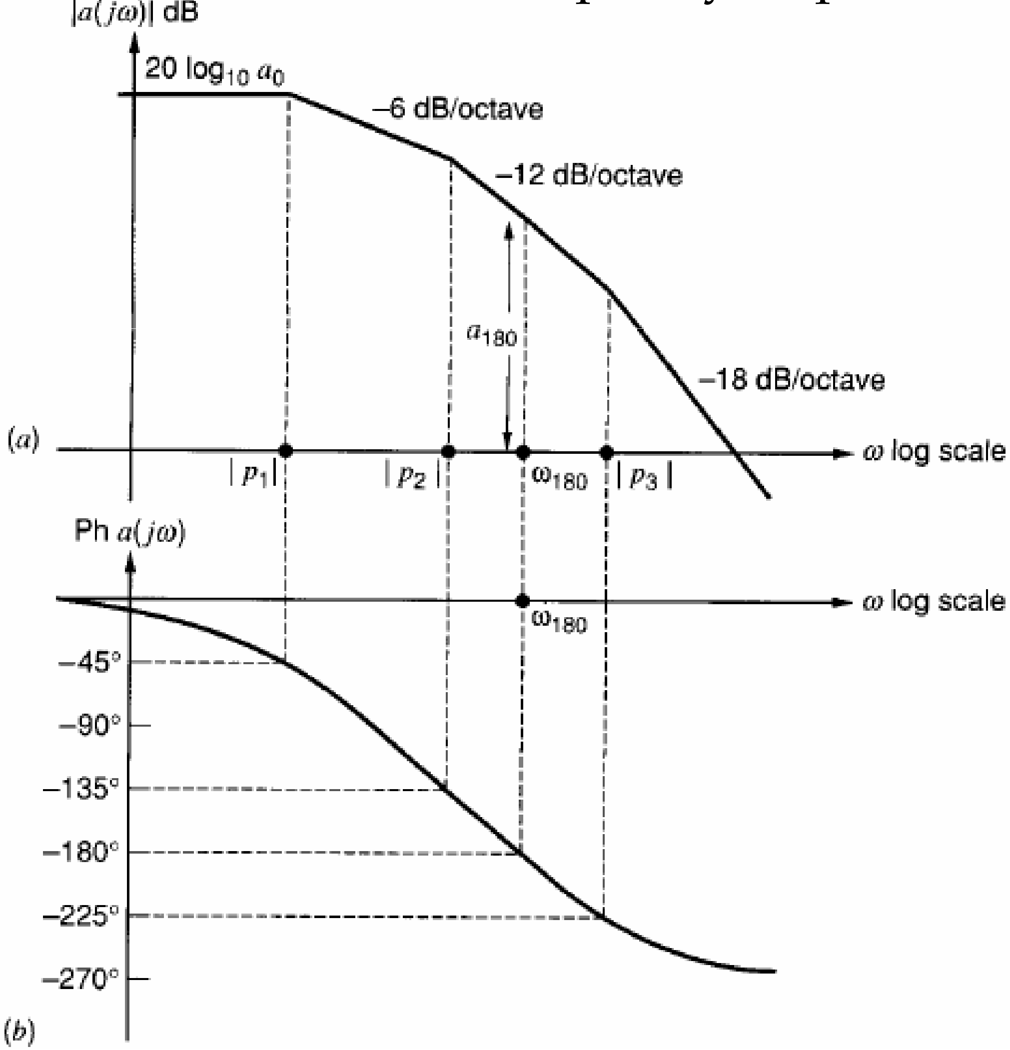
$$a(j\omega)\,f$$

$$|\,a(j\omega)\,f\,|\;e^{j\phi(\omega)}$$

ω_π $\quad$ $a(\omega_\pi)\,f > 1$

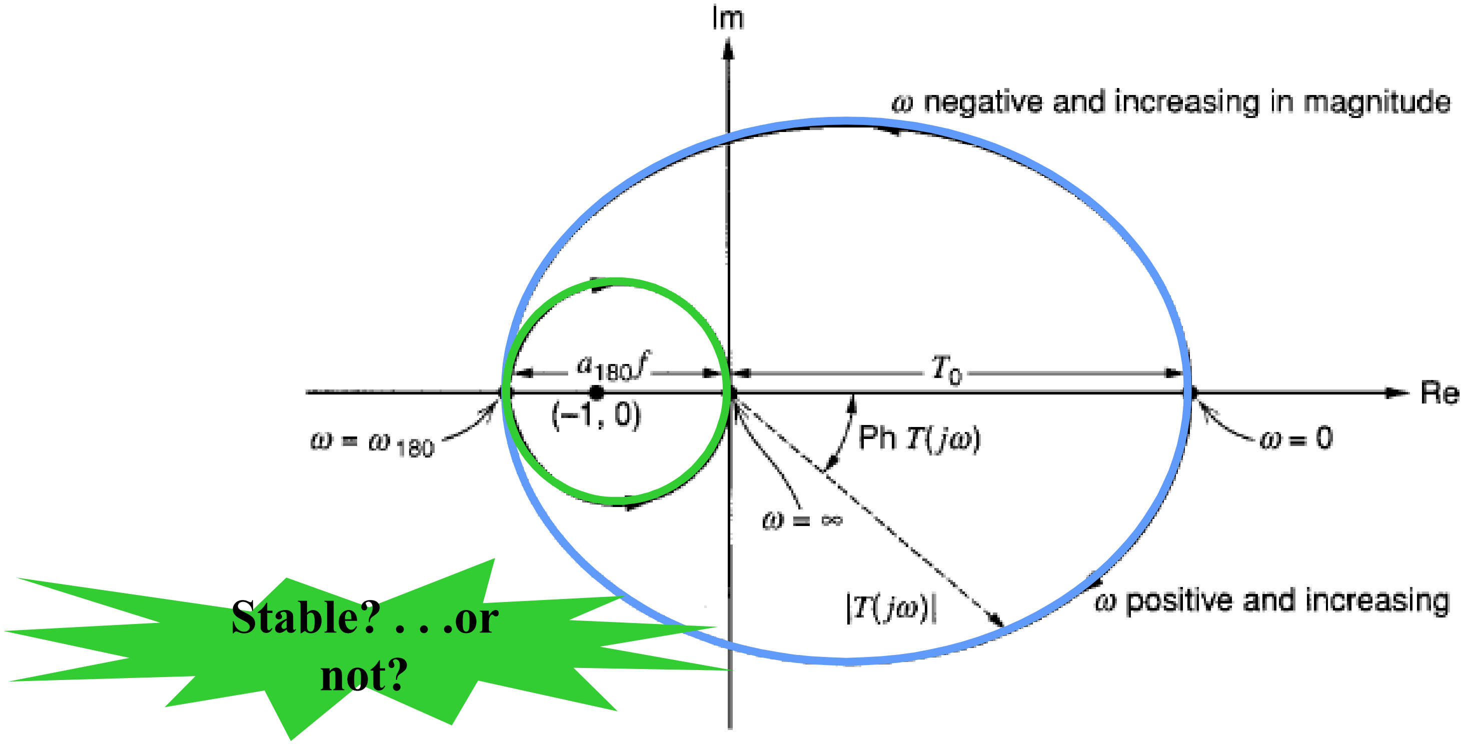
Starting point

. . . . The frequency response of the BASIC AMPLIFIER

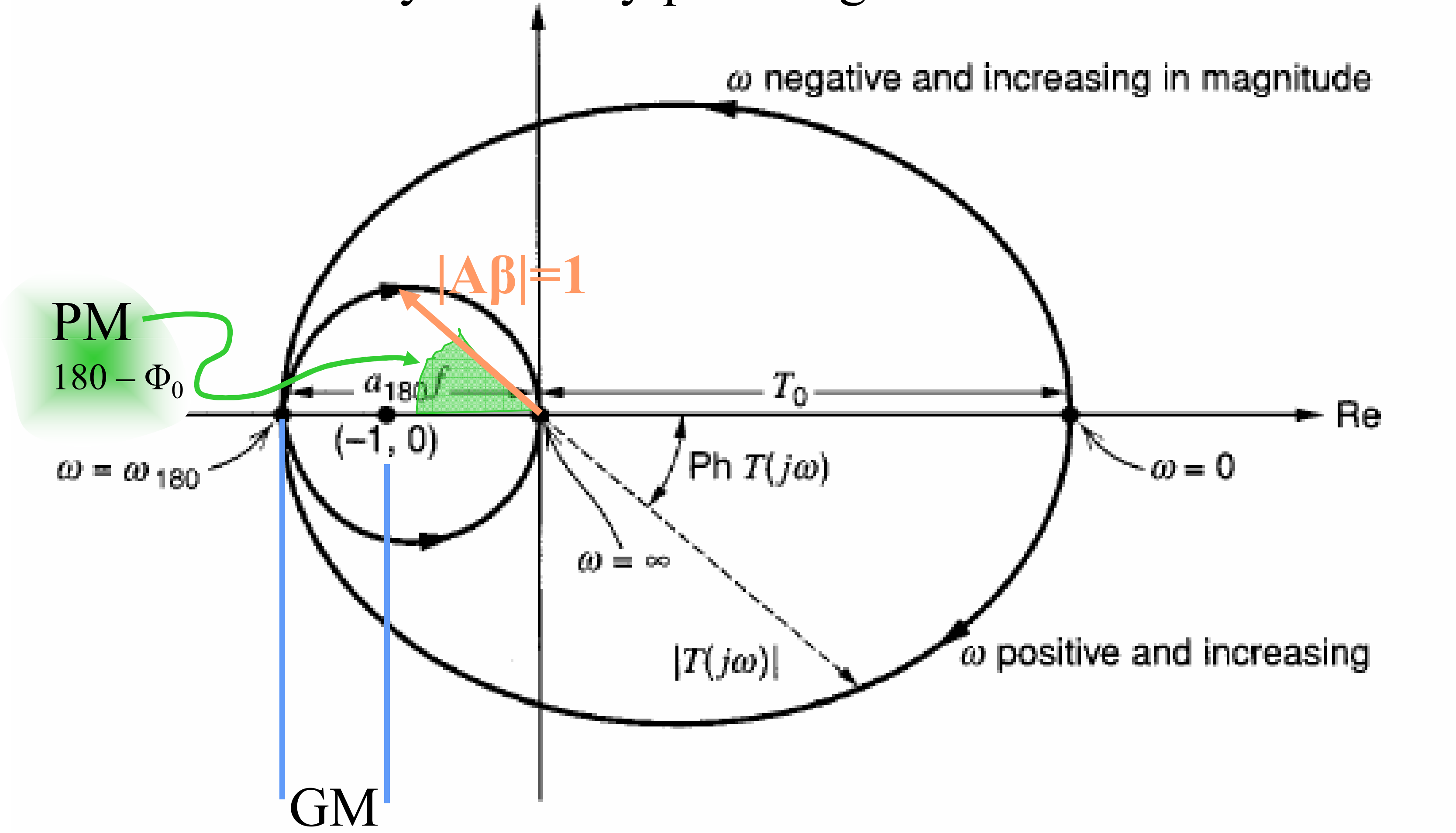


Nyquist diagram

Polar representation of $a(j\omega)f$



Criteria for stability in the Nyquist diagram



$a(j\omega)f$ in the Bode plot

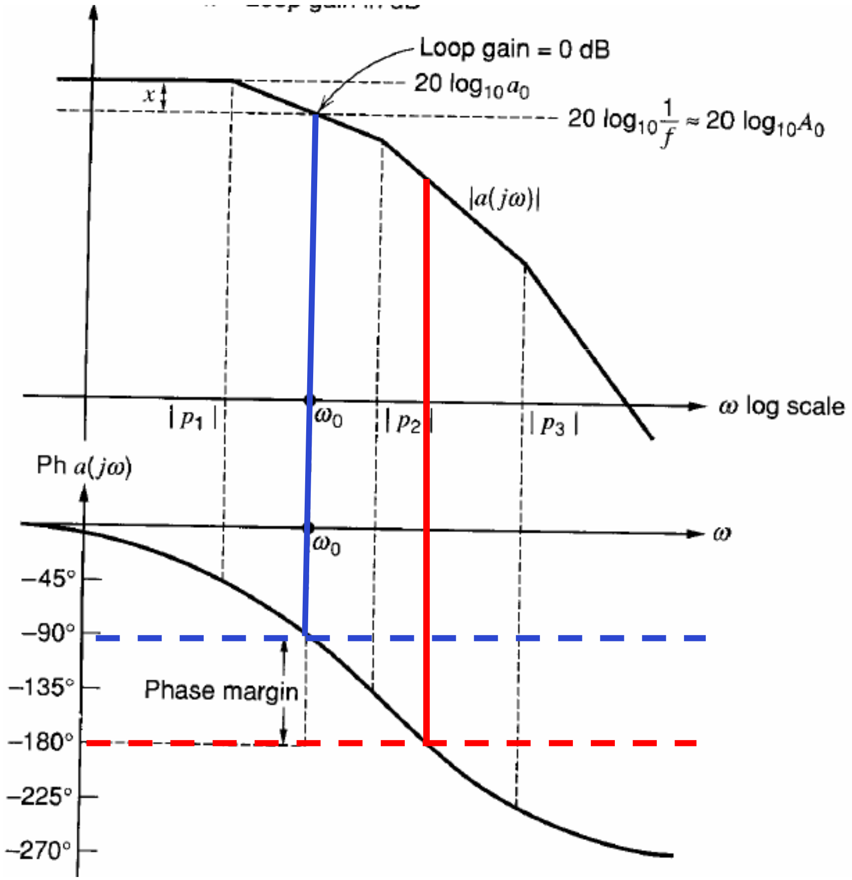
$$20\log_{10}(a(j\omega)f) = 20\log_{10}[a(j\omega)] + 20\log_{10}[f] =$$

$$= 20\log_{10}[a(j\omega)] - 20\log_{10}[1/f] =$$

$$= 20\log_{10}[a(j\omega)] - 20\log_{10}(A)$$

(feedback network is resistive and presents a flat frequency response)

Two basic reference frequencies,



	f_0	f_π
a(f)	a_0	a_π
Φ(f)	Φ_0	Φ_π

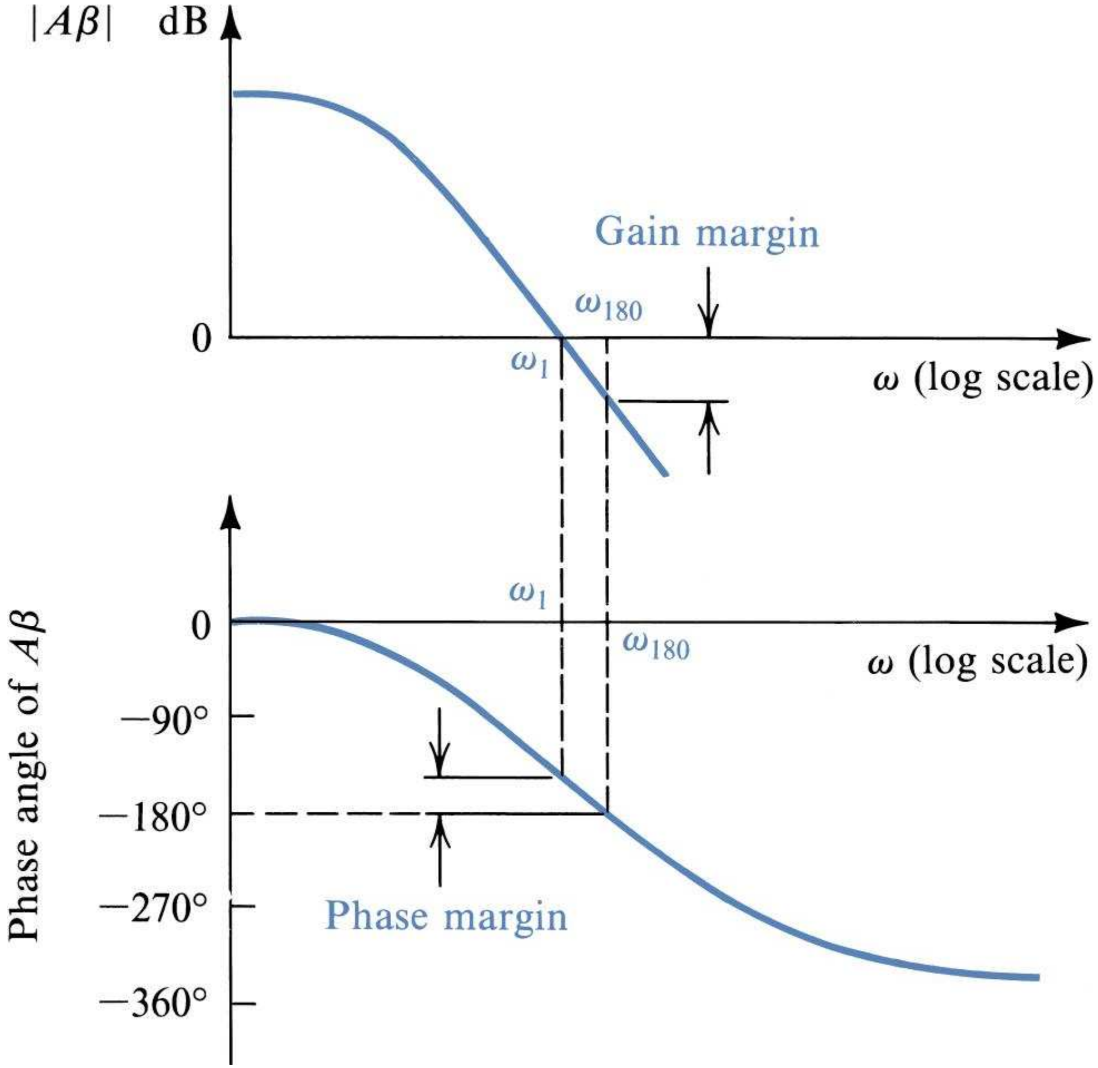
donde, $a_0 = A\ (=1/f\ )$

$\Phi_\pi = -180$

PM = 180º + Φ_0

GM = G - a_π

Tools to analyze the stability . . .



The importance of the Phase Margin,

For ω_0

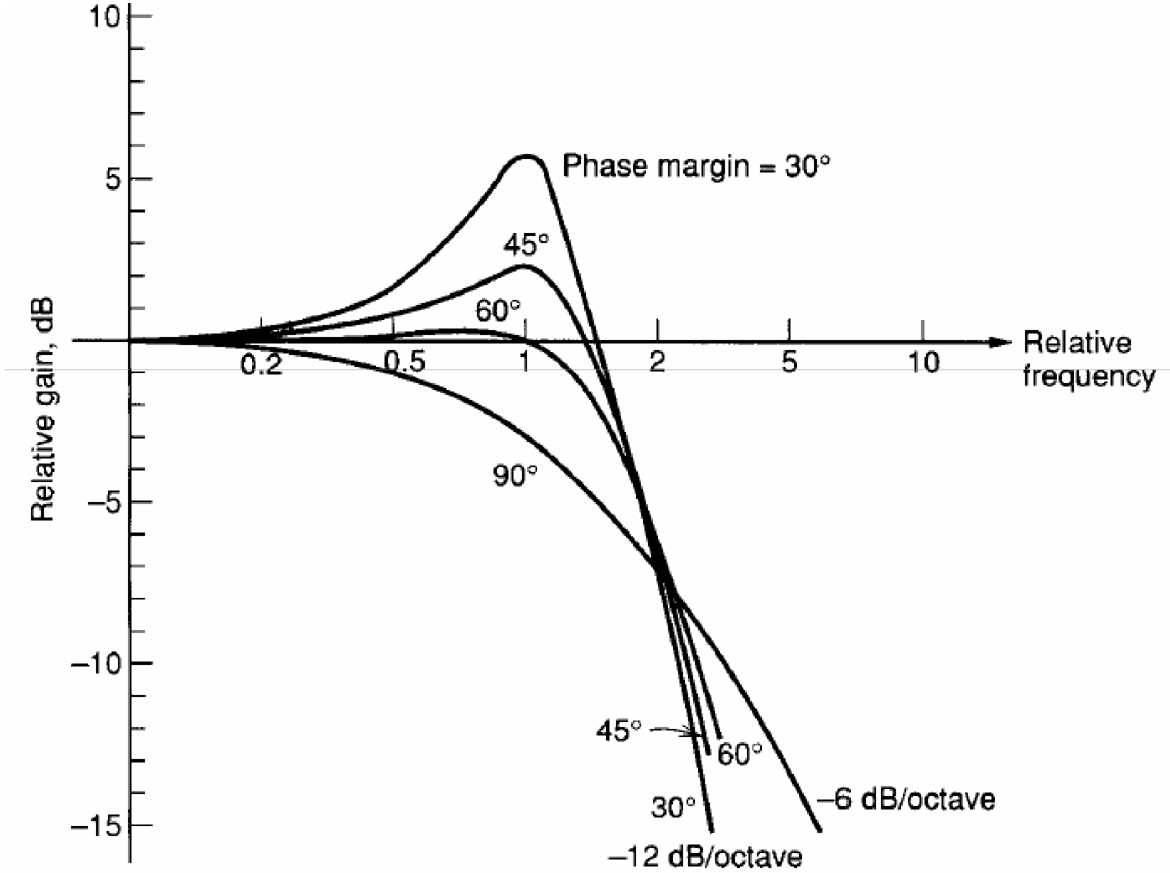
$$A_f(j\omega_0) = \frac{a(j\omega_0)}{1 + a(j\omega_0) f}$$

$$= \frac{(1/f)\, e^{-j\theta_0}}{1 + e^{-j\theta_0}}$$

en las que

$$\theta_0 = 180 - PM$$

$$\left| A_f(j\omega_0) \right| = \frac{(1/f)}{\left| 1 + e^{-j\theta_0} \right|}$$



Compensation

Tools to control the gain/phase margins

Modify the BASIC AMPLIFIER freq. response *a(s)*, by:

- DOMINANT POLE:

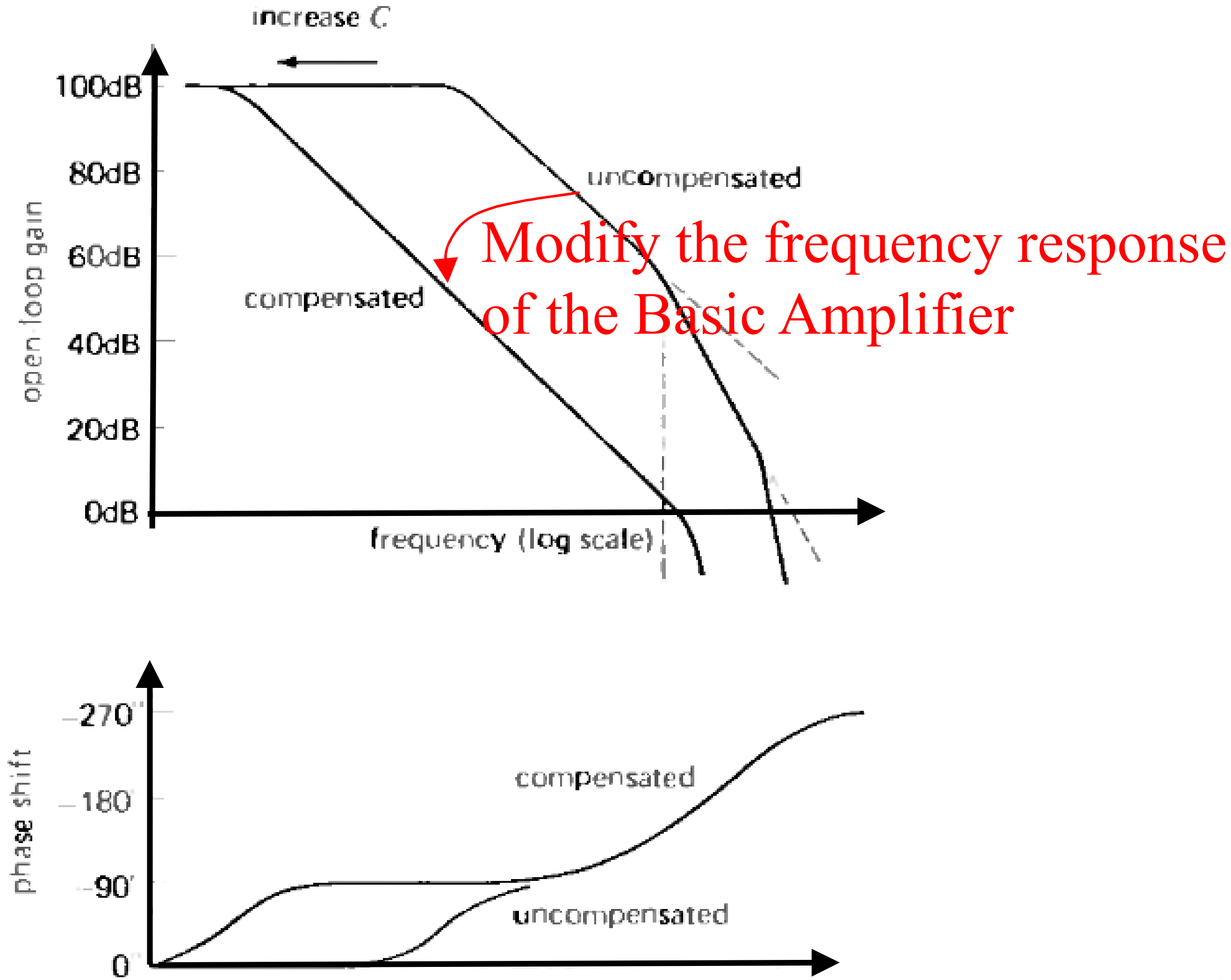
  Place a new pole at LF

- POLE-ZERO:

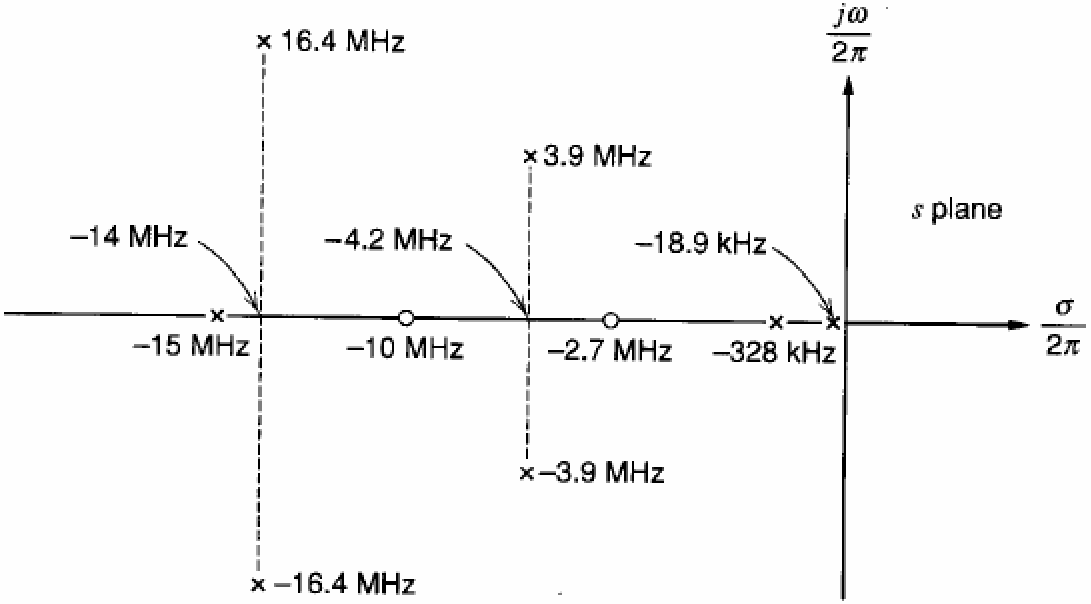
  Place a new pole at LF and cancel lowest frequency pole of basic amplifier with a new zero.

AIM: Keep the phase change in the loop below -180º at all frequencies where the loop gain is greater that unity (UNITY GAIN COMPENSATION)

Compensation



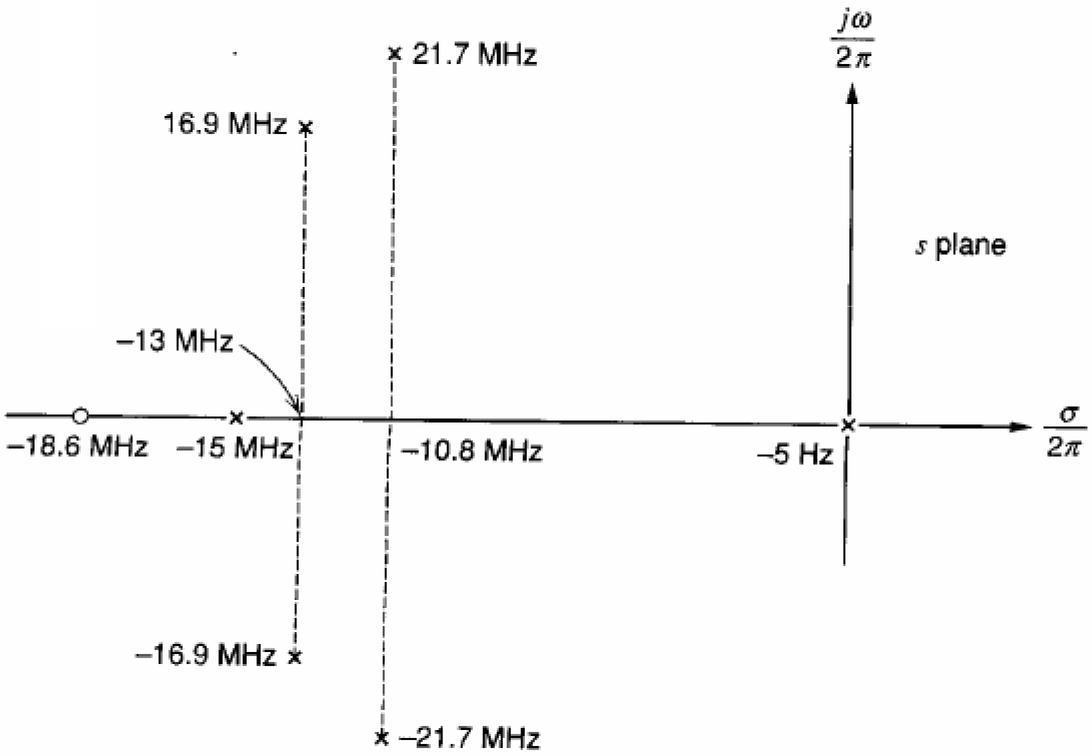
OP AMP 741 before . . . .



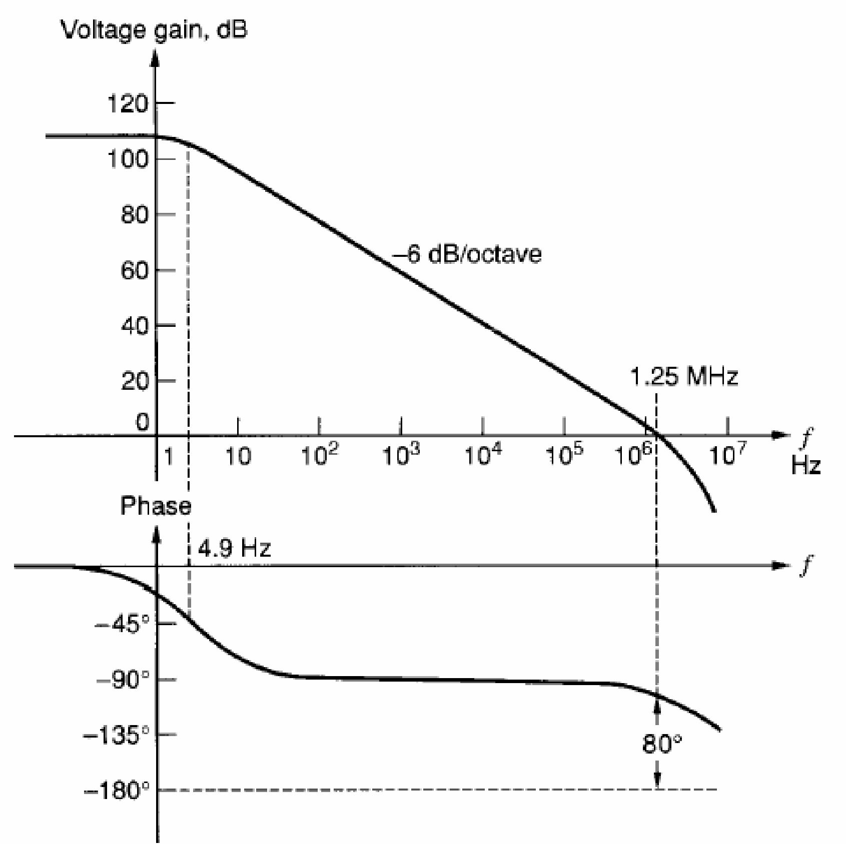
$A_{DC} = 120$ dB

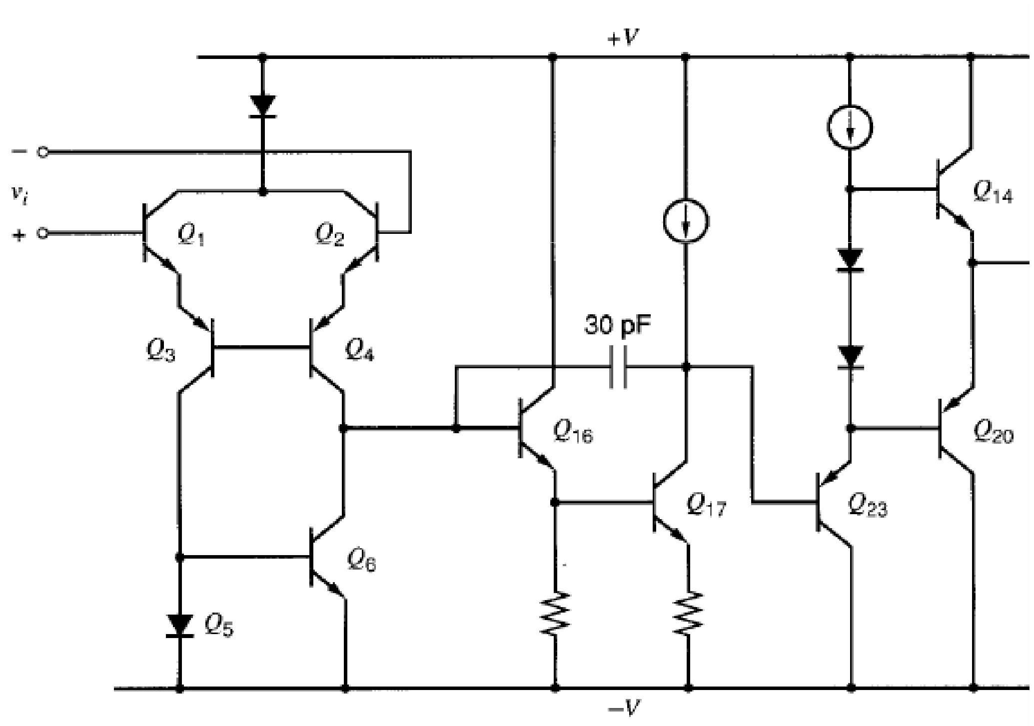
Compensation

. . . . and after compensation



Compensation





Compensation