Frequency Compensation

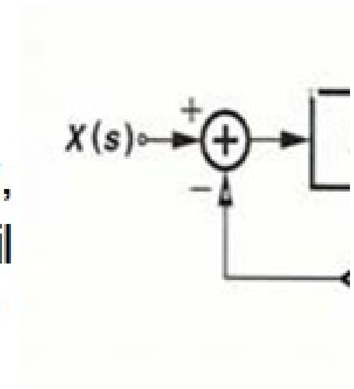
INTRODUCTION

In this lecture, we deal with the stability and frequency compensation of linear feedback systems to the extent necessary to understand design issues of analog feedback circuits. Beginning with a review of stability criteria and the concept of phase margin, we study frequency compensation, introducing various techniques suited to different op amp topologies. We also analyze the impact of frequency compensation on the slew rate of two- stage op amps.

BASIC NEGATIVE-FEEDBACK SYSTEM

- General considerations

☐ Close-loop transfer function: $\frac{Y}{X}(s) = \frac{H(s)}{1+\beta H(s)}$



if $\beta H(s = j\omega 1) = -1$, the gain goes to infinity, and the circuit can amplify is own noise until it eventually begins to oscillate at frequency $\omega 1$.

☐ Barkhausen's Criteria:

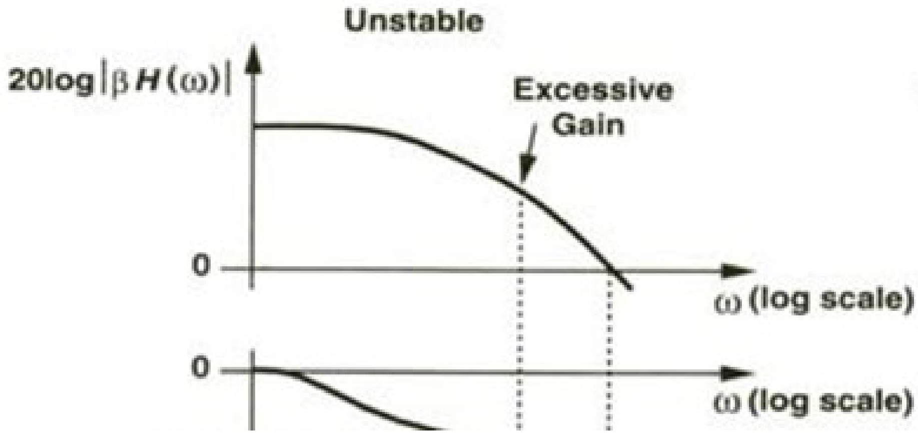
$$|\beta H(s = j\omega 1)| = 1$$
$$\angle \beta H(s = j\omega 1) = -180^\circ .$$

The total phase shift around the loop at ω_1 is 360° becaus feedback itself introduces 180° of phase shift. The 360° ph

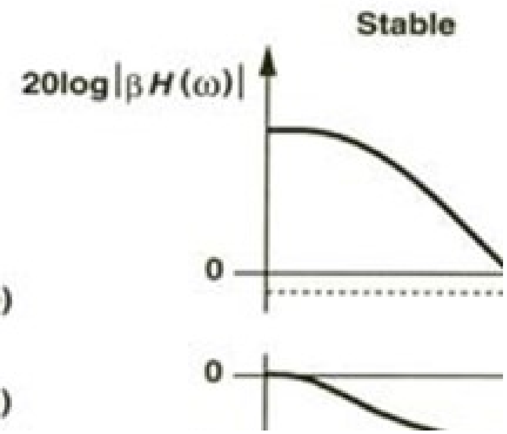
Bode Plot

- A negative feedback system may oscillate at $\omega 1$ if
  (1) the phase shift around the loop at this frequency is so mu
  feedback becomes *positive*.
  (2) the loop gain is still enough to allow signal buildup.

Unstable system



Stable sy

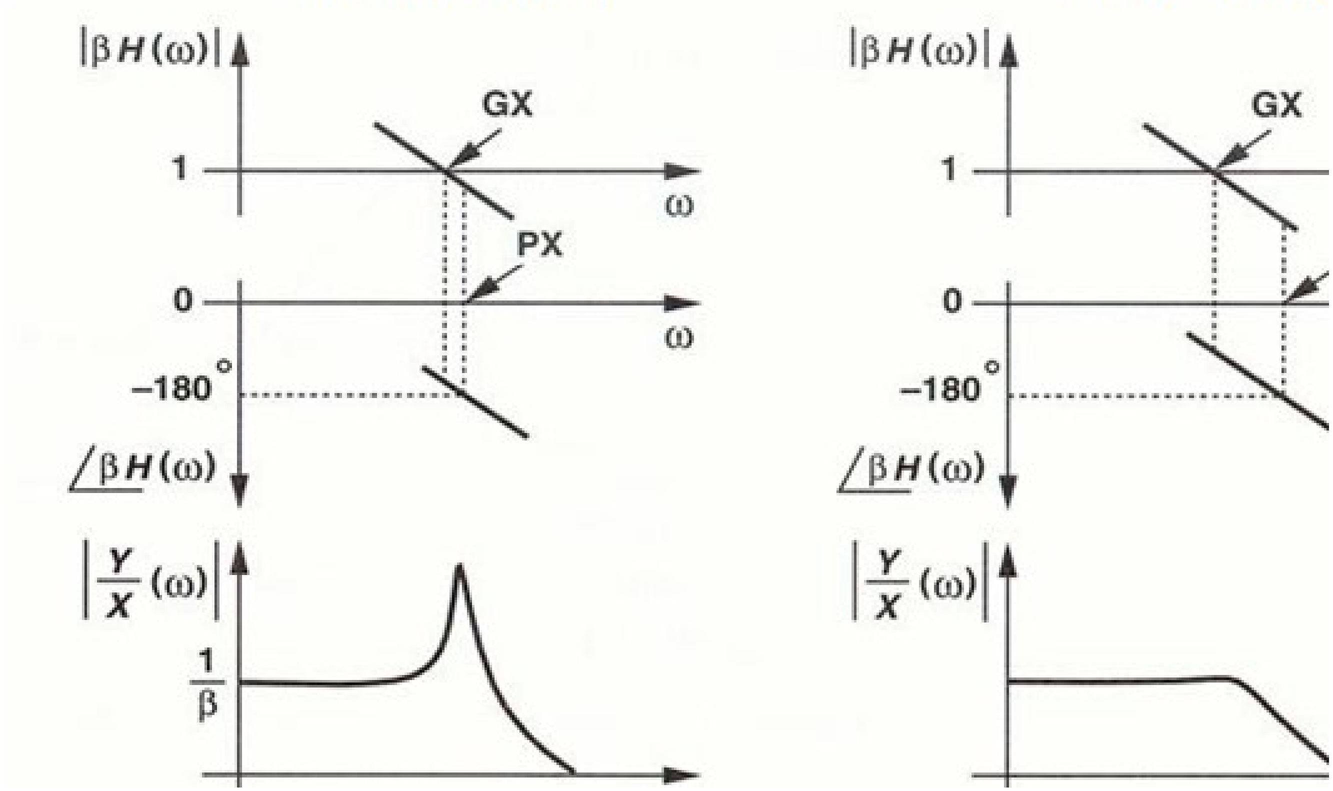


Phase margin

- Close-loop frequency and time response

Small margin

Large marg



Phase margin (cont'd)

- *Phase margin* (PM) is defined as

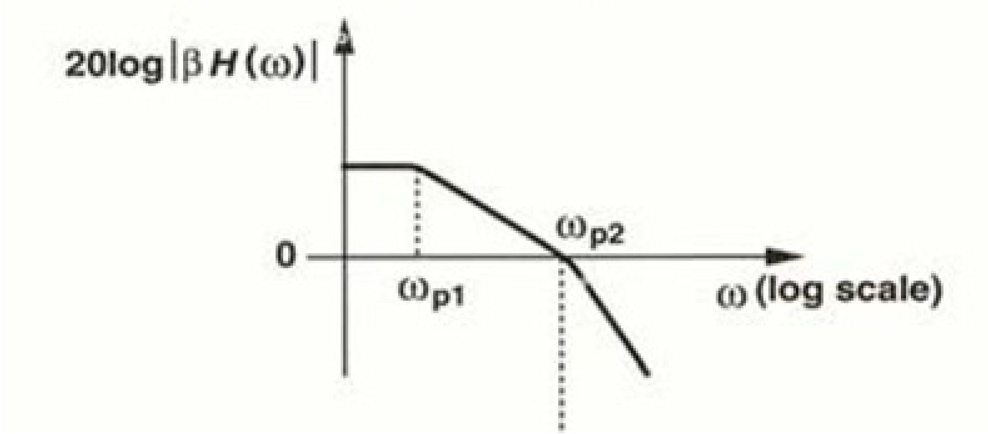
$$PM = 180^{\circ} + \angle \beta H(\omega = \omega_1)$$

where ω_1 is the gain crossover frequency.

- Example

A two-pole feedback system is designed such that $|\beta H(\omega = \omega$

$|\omega_{P1}| << |\omega_{P2}|$.



Since $\angle \beta H$ reache

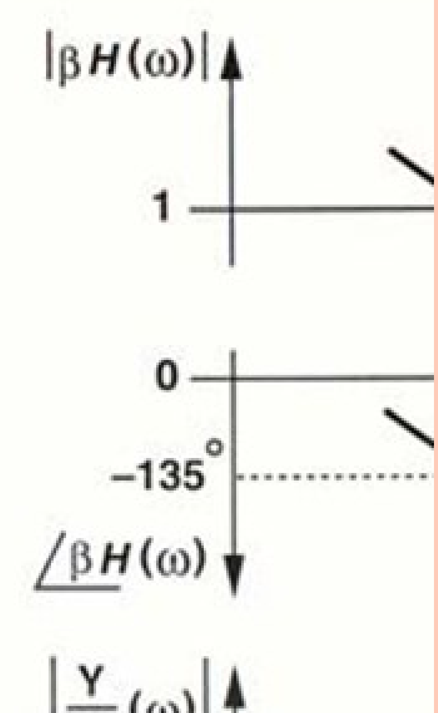
How much phase margin is adequate?

- For $PM = 45°$, at the gain crossover frequency $\angle \beta H(\omega_1) = -13$
$|\beta H(\omega_1)| = 1$, yielding $\frac{Y}{X} = \frac{H(j\omega_1)}{1 + 1\cdot\exp(-j135°)} = \frac{H(j\omega_1)}{0.29 - 0.71j}$

It follows that $\left|\frac{Y}{X}\right| = \frac{1}{\beta}\cdot\frac{1}{|0.29 - 0.71j|} \approx \frac{1.3}{\beta}$

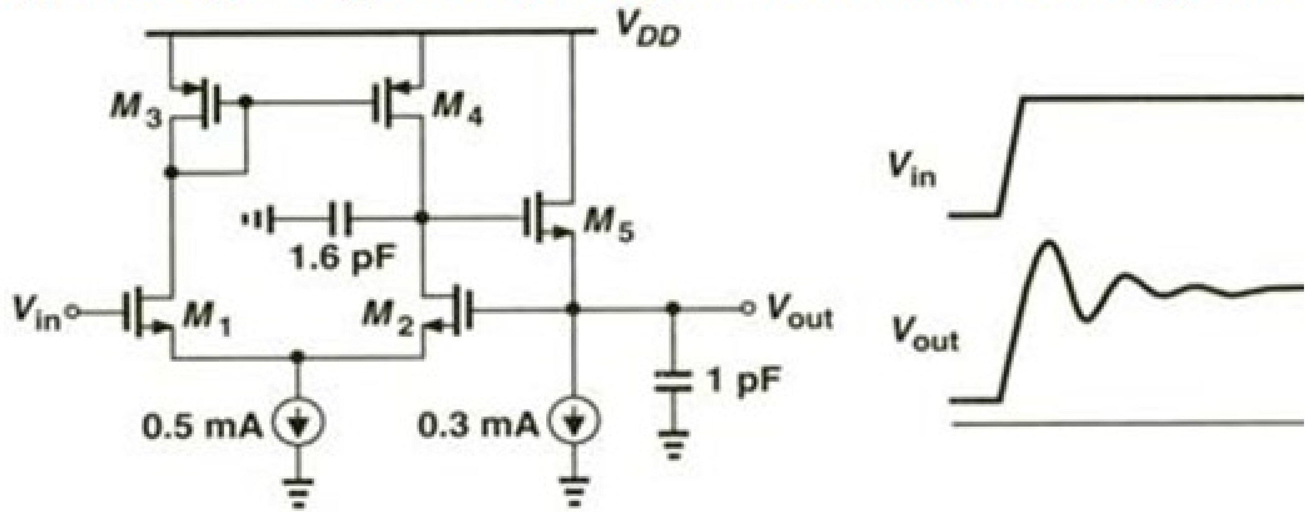
The frequency response of the feedback system suffers from a 30% peak at $\omega = \omega_1$.

- Close-loop frequency response for 45° phase margin:



How much phase margin is adequate? (cont'd)

- Example:
  Unity-gain buffer: $PM \approx 65^{o}$, unity-gain frequency = 150 MHz.
  However, the large-signal step response suffers from signific



- The large-signal step response of feedback amplifiers is n
  slewing but also because of the nonlinear behavior result
  excursions in the bias voltages and currents of the a
  excursions in fact cause the pole and zero frequencies to v