9.5. Regulator design

Typical specifications:

- Effect of load current variations on output voltage regulation

  This is a limit on the maximum allowable output impedance

- Effect of input voltage variations on the output voltage regulation

  This limits the maximum allowable line-to-output transfer function

- Transient response time

  This requires a sufficiently high crossover frequency

- Overshoot and ringing

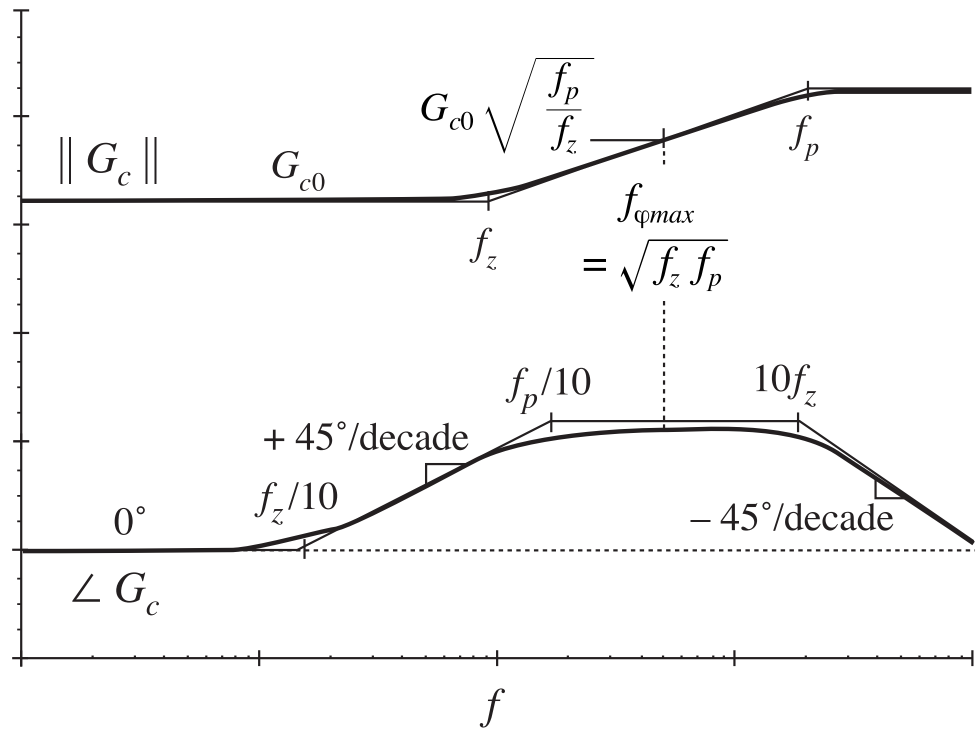
  An adequate phase margin must be obtained

The regulator design problem: add compensator network $G_c(s)$ to modify $T(s)$ such that all specifications are met.

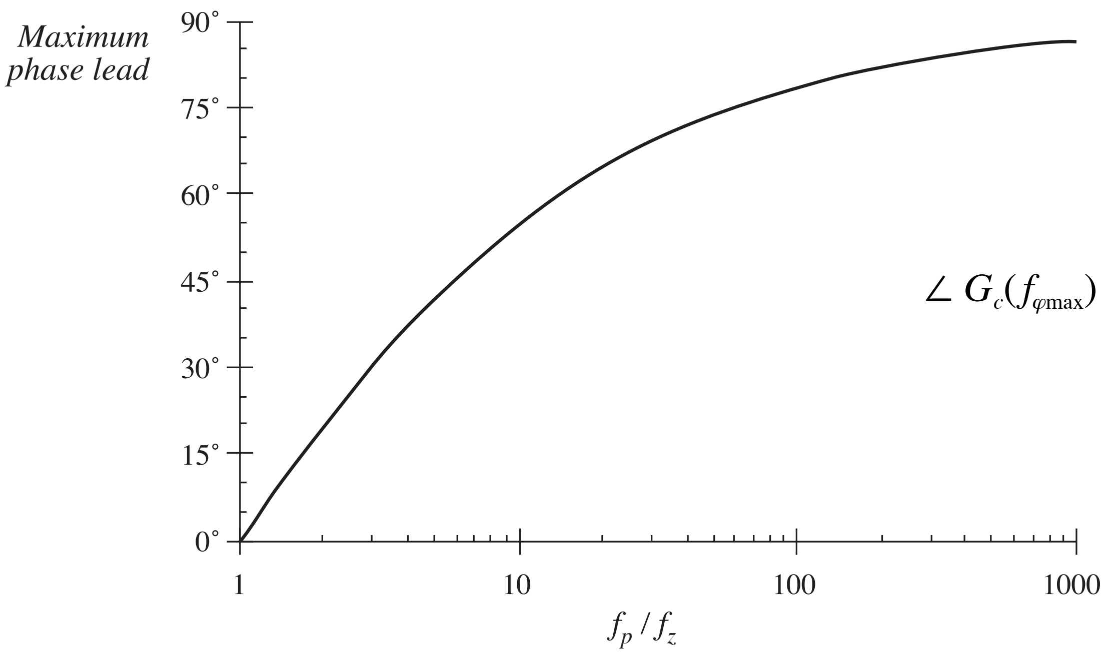
9.5.1. Lead (PD) compensator

$$G_c(s) = G_{c0} \frac{\left(1 + \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{\omega_p}\right)}$$

Improves phase margin



Lead compensator: maximum phase lead



$$f_{\varphi max} = \sqrt{f_z f_p}$$

$$\angle\, G_c(f_{\varphi max}) = \tan^{-1}\left(\frac{\sqrt{\frac{f_p}{f_z}} - \sqrt{\frac{f_z}{f_p}}}{2}\right)$$

$$\frac{f_p}{f_z} = \frac{1 + \sin\left(\theta\right)}{1 - \sin\left(\theta\right)}$$

Lead compensator design

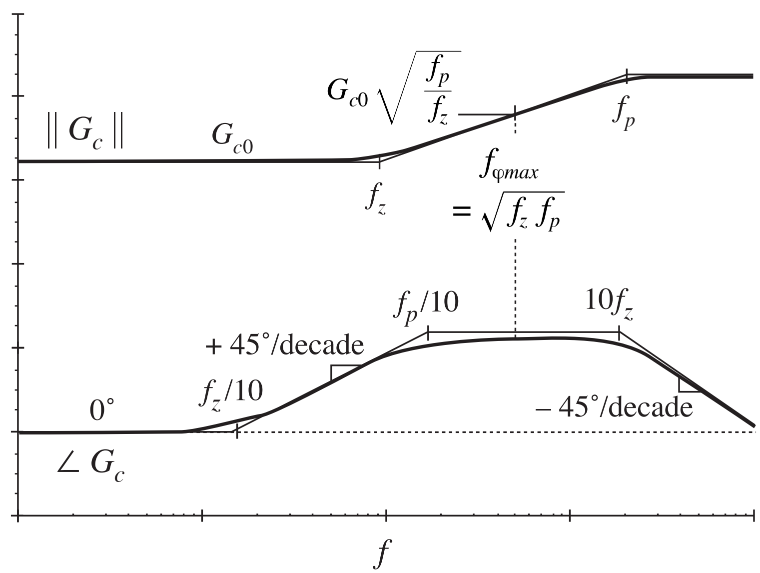
To optimally obtain a compensator phase lead of θ at frequency f_c, the pole and zero frequencies should be chosen as follows:

$$f_z = f_c \sqrt{\frac{1 - \sin(\theta)}{1 + \sin(\theta)}}$$

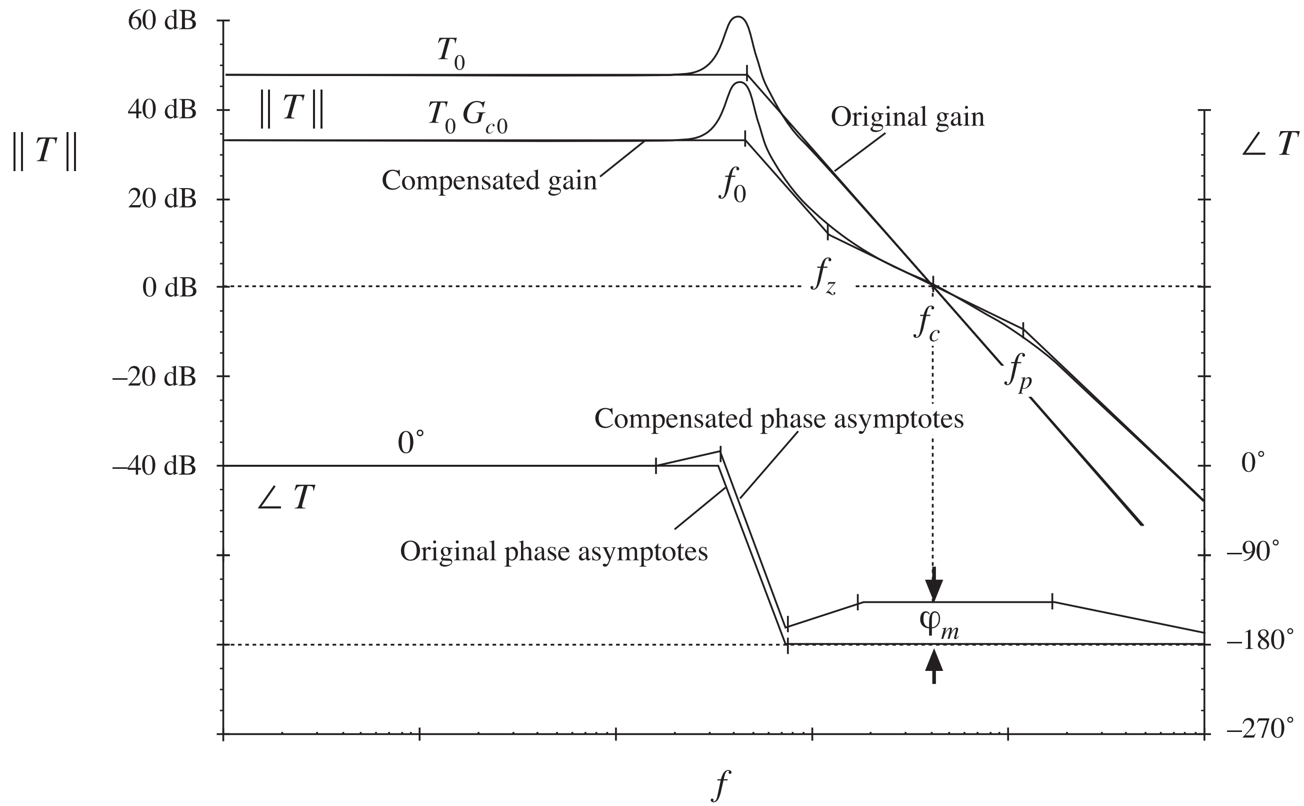
$$f_p = f_c \sqrt{\frac{1 + \sin(\theta)}{1 - \sin(\theta)}}$$

If it is desired that the magnitude of the compensator gain at f_c be unity, then G_{c0} should be chosen as

$$G_{c0} = \sqrt{\frac{f_z}{f_p}}$$



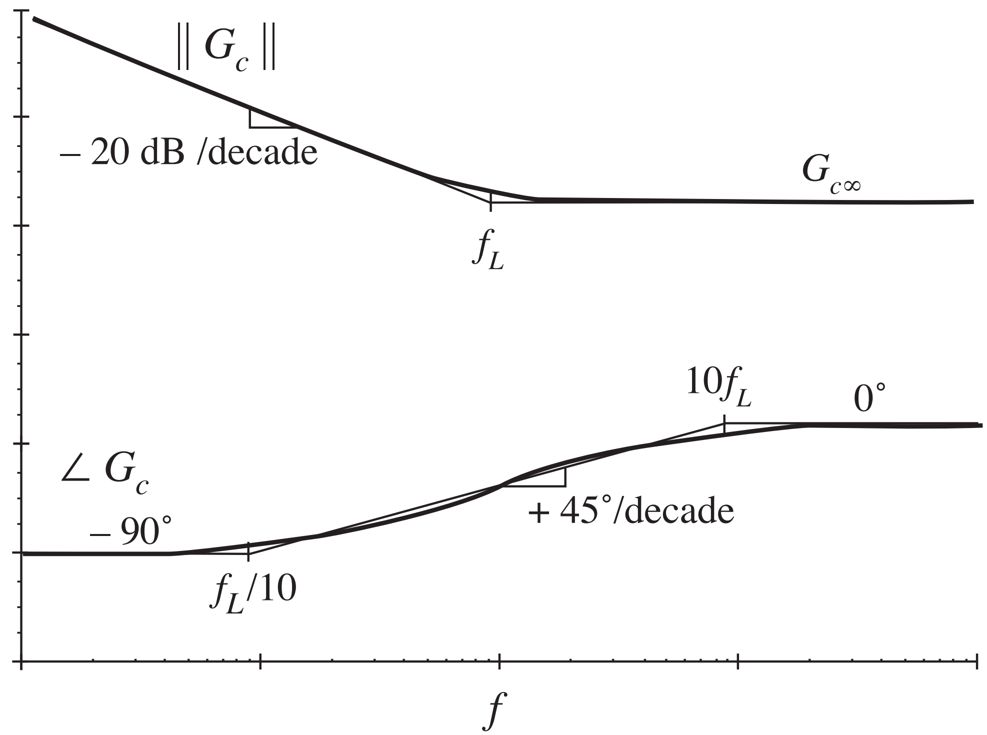
Example: lead compensation



9.5.2. Lag (PI) compensation

$$G_c(s) = G_{c\infty}\left(1 + \frac{\omega_L}{s}\right)$$

Improves low-frequency loop gain and regulation



Example: lag compensation

original (uncompensated) loop gain is

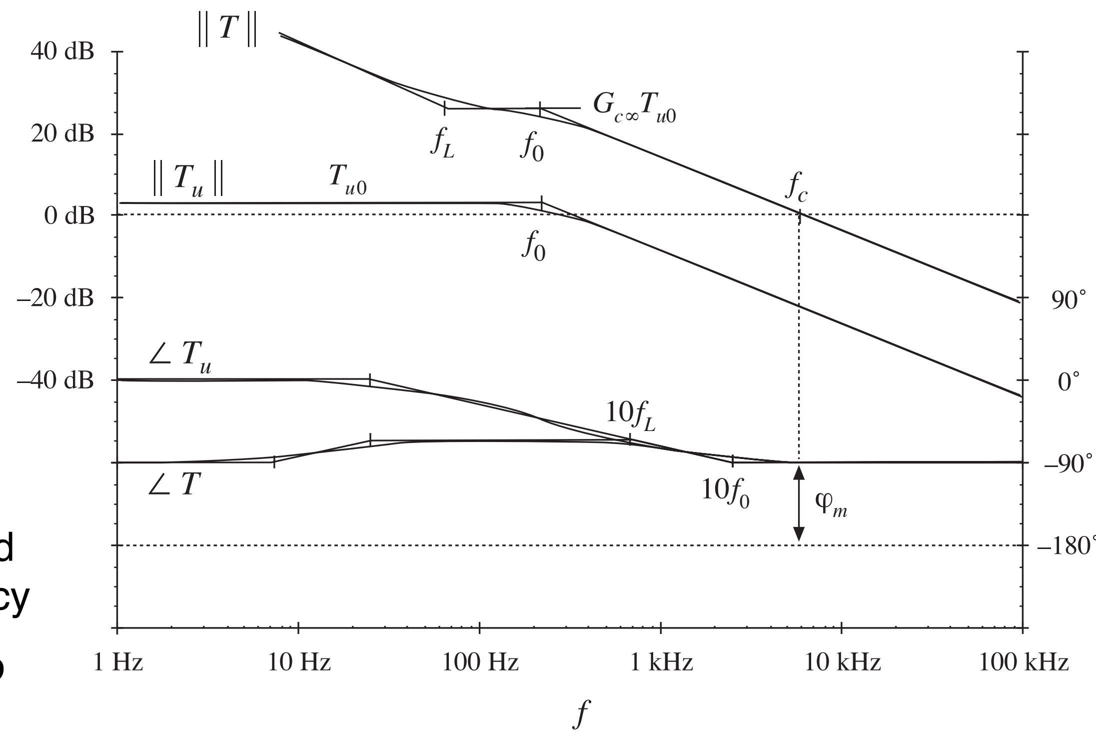
$$T_u(s) = \frac{T_{u0}}{\left(1 + \frac{s}{\omega_0}\right)}$$

compensator:

$$G_c(s) = G_{c\infty}\left(1 + \frac{\omega_L}{s}\right)$$

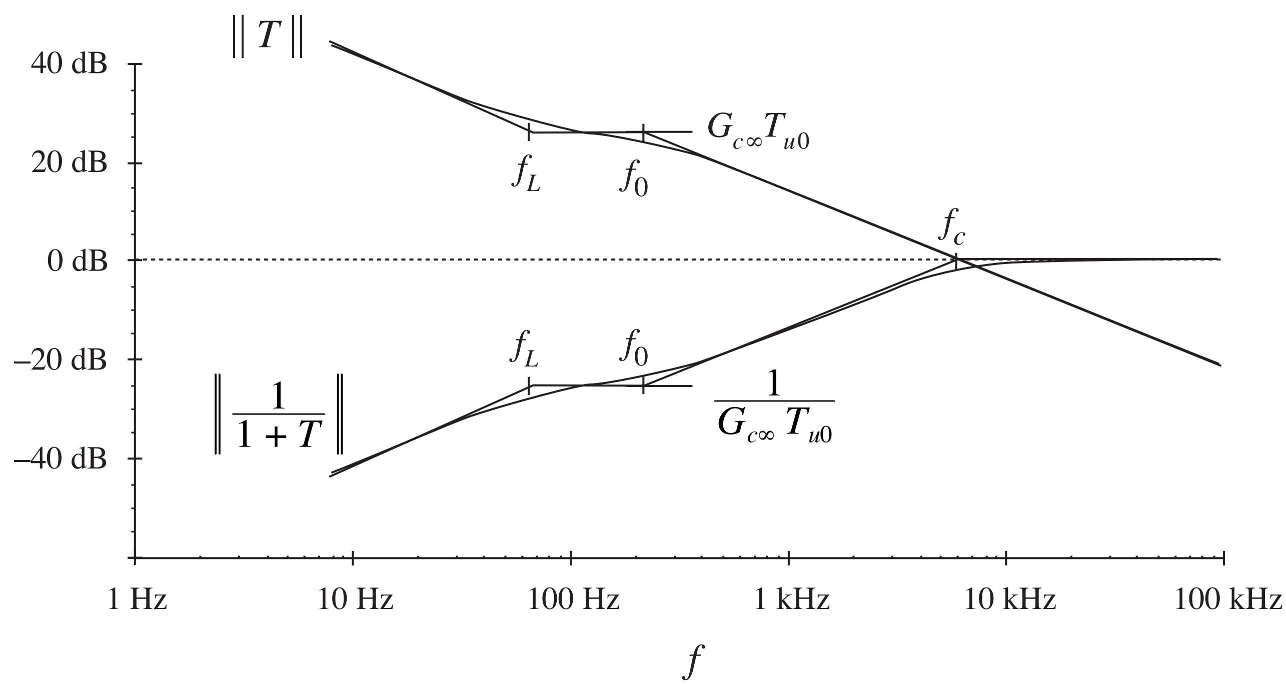
Design strategy: choose

- $G_{c\infty}$ to obtain desired crossover frequency
- ω_L sufficiently low to maintain adequate phase margin



Example, continued

Construction of $1/(1+T)$*, lag compensator example:*



9.5.3. Combined (PID) compensator

$$G_c(s) = G_{cm} \frac{\left(1 + \frac{\omega_L}{s}\right)\left(1 + \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{\omega_{p1}}\right)\left(1 + \frac{s}{\omega_{p2}}\right)}$$