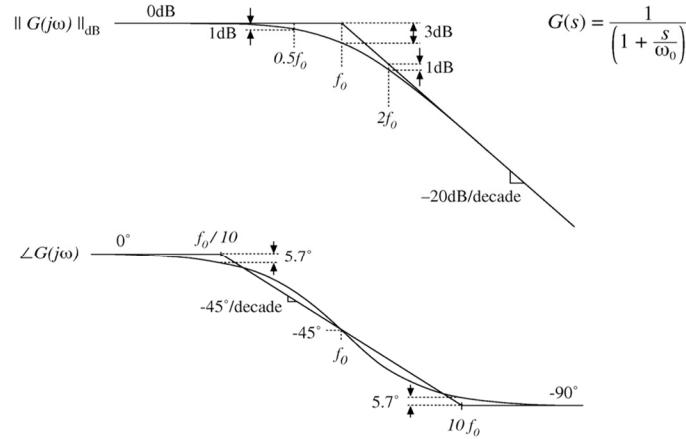


Summary: Single Real Pole



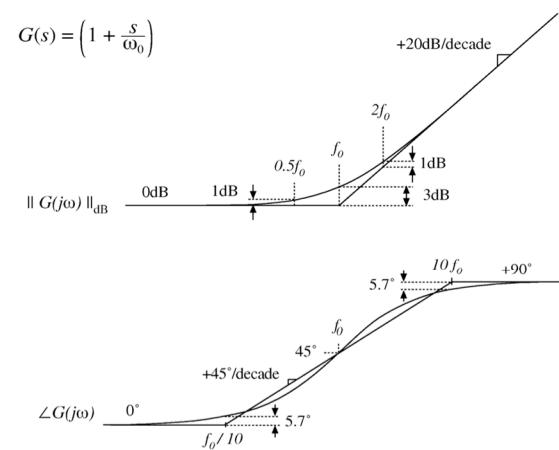
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Bode Plot: Real Zero



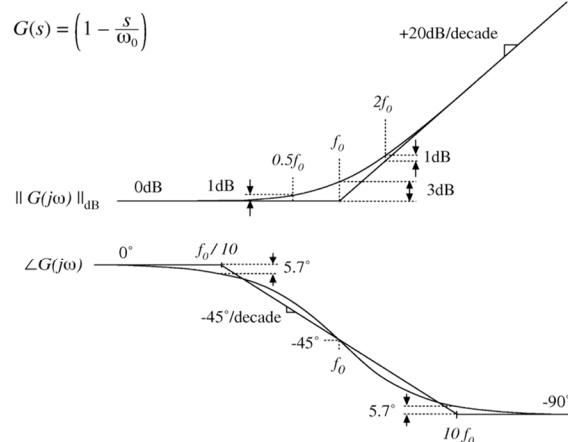
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RHP Zero



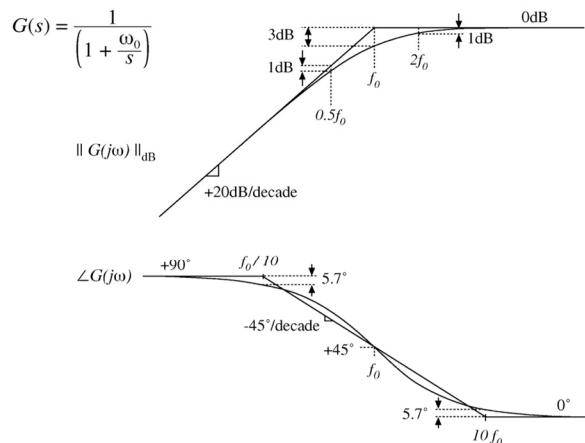
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Inverted Pole



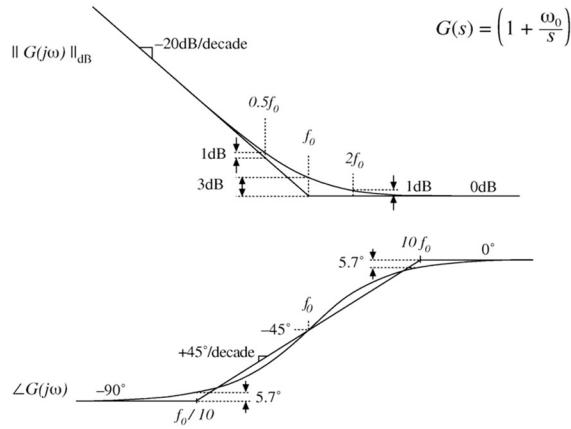
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Inverted Zero



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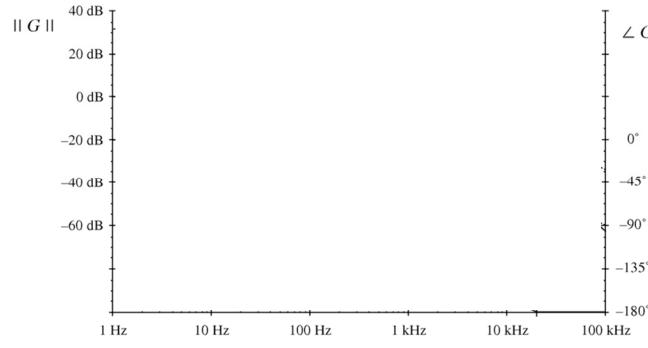
Multiplying Transfer Functions



Example 1

$$G(s) = \frac{G_0}{\left(1 + \frac{s}{\omega_1}\right)\left(1 + \frac{s}{\omega_2}\right)}$$

with $G_0 = 40 \Rightarrow 32 \text{ dB}$, $f_1 = \omega_1/2\pi = 100 \text{ Hz}$, $f_2 = \omega_2/2\pi = 2 \text{ kHz}$



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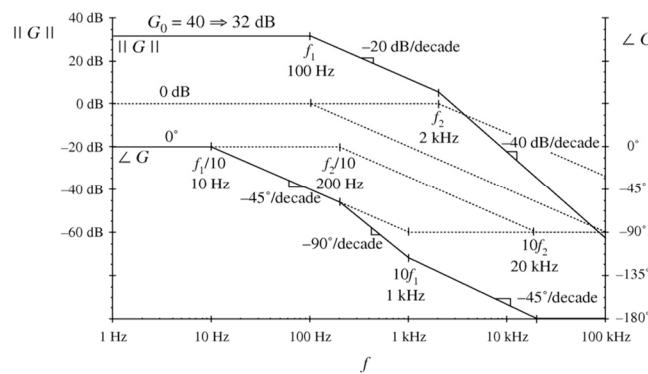
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Example 1

$$G(s) = \frac{G_0}{\left(1 + \frac{s}{\omega_1}\right)\left(1 + \frac{s}{\omega_2}\right)}$$

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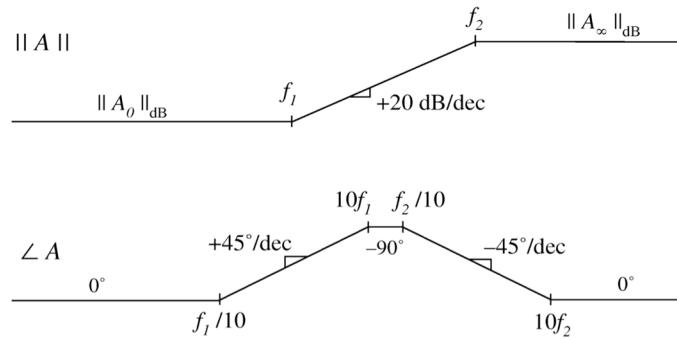
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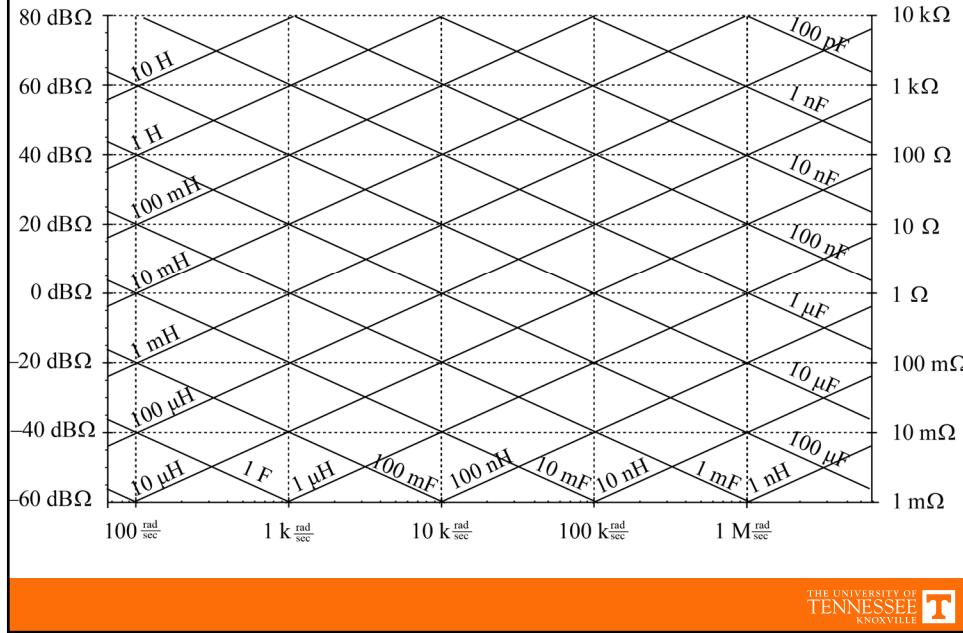


Example 2

Determine the transfer function $A(s)$ corresponding to the following asymptotes:



Graphical Construction



Standard Form for Complex Poles

$$G(s) = \frac{1}{1 + 2\xi \frac{s}{\omega_0} + \left(\frac{s}{\omega_0}\right)^2} \quad \text{or} \quad G(s) = \frac{1}{1 + \frac{s}{Q\omega_0} + \left(\frac{s}{\omega_0}\right)^2}$$

- When the coefficients of s are real and positive, then the parameters ζ , ω_0 , and Q are also real and positive
 - The parameters ζ , ω_0 , and Q are found by equating the coefficients of s
 - The parameter ω_0 is the angular corner frequency, and we can define $f_0 = \omega_0/2\pi$
 - The parameter ζ is called the *damping factor*. ζ controls the shape of the exact curve in the vicinity of $f=f_0$. The roots are complex when $\zeta < 1$.
 - In the alternative form, the parameter Q is called the *quality factor*. Q also controls the shape of the exact curve in the vicinity of $f=f_0$. The roots are complex when $Q > 0.5$.

The Q Factor

In a second-order system, ζ and Q are related according to

$$Q = \frac{1}{2\zeta}$$

Q is a measure of the dissipation in the system. A more general definition of Q , for sinusoidal excitation of a passive element or system is

$$Q = 2\pi \frac{(\text{peak stored energy})}{(\text{energy dissipated per cycle})}$$

For a second-order passive system, the two equations above are equivalent. We will see that Q has a simple interpretation in the Bode diagrams of second-order transfer functions.

Magnitude Asymptotes

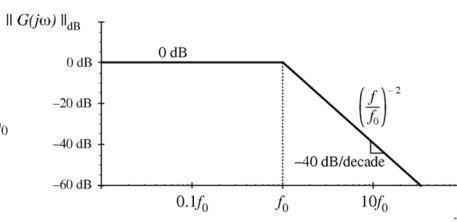
In the form $G(s) = \frac{1}{1 + \frac{s}{Q\omega_0} + \left(\frac{s}{\omega_0}\right)^2}$

let $s = j\omega$ and find magnitude: $\|G(j\omega)\| = \sqrt{\left(1 - \left(\frac{\omega}{\omega_0}\right)^2\right)^2 + \frac{1}{Q^2} \left(\frac{\omega}{\omega_0}\right)^2}$

Asymptotes are

$$\|G\| \rightarrow 1 \quad \text{for } \omega \ll \omega_0$$

$$\|G\| \rightarrow \left(\frac{f}{f_0}\right)^{-2} \quad \text{for } \omega \gg \omega_0$$



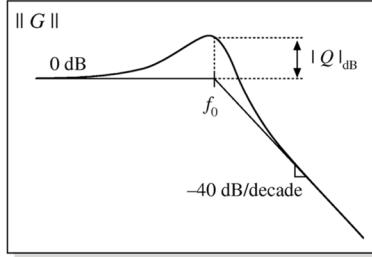
Exact Magnitude Curve

$$\|G(j\omega)\| = \sqrt{\left(1 - \left(\frac{\omega}{\omega_0}\right)^2\right)^2 + \frac{1}{Q^2} \left(\frac{\omega}{\omega_0}\right)^2}$$

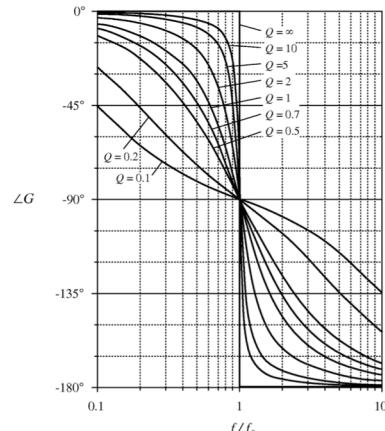
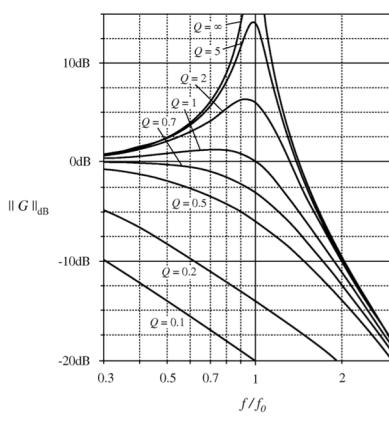
At $\omega = \omega_0$, the exact magnitude is

$$\|G(j\omega_0)\| = Q \quad \text{or, in dB:} \quad \|G(j\omega_0)\|_{\text{dB}} = |Q|_{\text{dB}}$$

The exact curve has magnitude Q at $f = f_0$. The deviation of the exact curve from the asymptotes is $|Q|_{\text{dB}}$

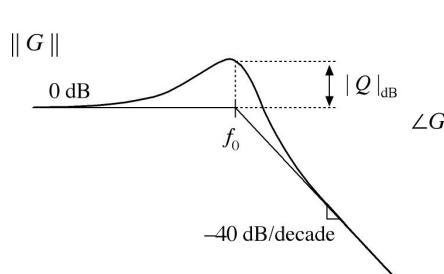


Curves for Varying Q

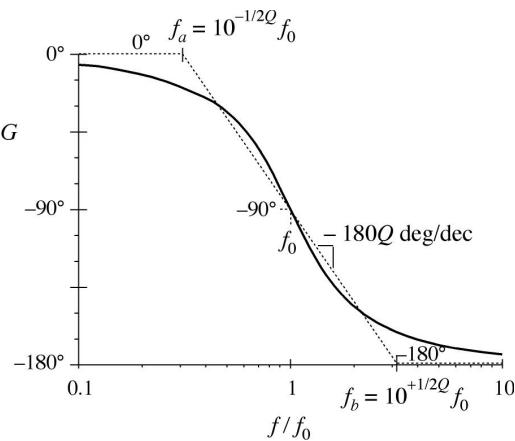


Summary: Asymptotes for Complex Poles

Magnitude

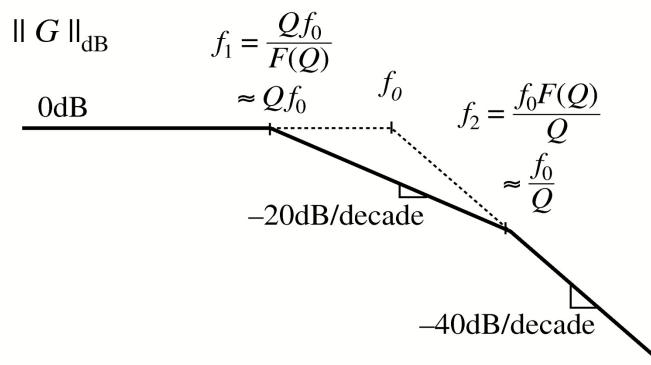


Phase



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The Low-Q Approximation



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