Chapter 1-21

1.65

for (a) \[ V_o = V_i \left( \frac{1/SC}{1/SC + R} \right) \]
\[ \frac{V_0}{V_i} = \frac{1}{1 + SCR} \]
where \( k = 1 \)
\( \omega_0 = \frac{1}{RC} \) from table 1.2 it is low pass.

for (b) \[ V_o = V_i \left( \frac{R}{R + \frac{1}{SC}} \right) \]
\[ \frac{V_0}{V_i} = \frac{SRC}{1 + SCR} \]
\[ \frac{V_0}{V_i} = \frac{S}{S + \frac{1}{RC}} \]
where \( k = 1 \)
\( \omega_0 = \frac{1}{RC} \) from table 1.2 it is high pass.

1.66

\[ V_i = V_o \left( \frac{R_1}{sC} \right) \]
\[ \frac{V_i}{V_o} = \frac{R_1}{R_2 + \frac{1}{sC} + R_2} \]
\[ \frac{V_i}{V_o} = \frac{R_1}{1 + sC} \times R \]
\[ \omega_0 = \frac{1}{RC} \]
\[ f_0 = \frac{1}{2\pi \sqrt{L C}} \]
\[ \frac{1}{2\pi \times 10^{-3} \times 0.1 \times 10^{-3} \times 0.1 \times 10^{-3}} = 31.8 \text{ Hz} \]
\[ |T(j\omega_0)| = K \]
\[ \frac{1}{10 + 40} \sqrt{2} = 0.57 \text{ V/V} \]

1.67 Using the voltage-divider rule.

\[ T(s) = \frac{V_o}{V_i} = \frac{R_2}{R_2 + R_1 + \frac{1}{sC}} \]
\[ T(s) = \left( \frac{R_3}{R_1 + R_2} \left( \frac{R_3}{R_2 + R_3} \right) \right) \]
\[ \frac{1}{1 + sC} \]
where is from Table 1.2 is of the high-pass type with
\[ K = \frac{R_3}{R_1 + R_2} \]
\( \omega_0 = \frac{1}{C(R_1 + R_2)} \)

As a further verification that this is a high-pass network and \( T(s) \) is a high-pass transfer function, we assume as \( s \to 0 \), \( T(s) \to 0 \); and as \( s \to \infty \), \( T(s) \to \infty \). Also, from the circuit observe as \( s \to \infty \), \( 1/\sqrt{C} \to 0 \) and \( V_o/V_i \to R_2/(R_1 + R_2) \). Now, for
\[ R_1 = 10 \text{ k\Omega}, R_2 = 40 \text{ k\Omega}, \text{ and } C = 0.1 \text{ \mu F} \]
\[ f_0 = \frac{1}{2\pi \sqrt{L C}} = \frac{1}{2\pi \times 10^{-3} \times 0.1 \times 10^{-3} \times 0.1 \times 10^{-3}} = 31.8 \text{ Hz} \]
\[ |T(j\omega_0)| = K \]
\[ \frac{1}{10 + 40} \sqrt{2} = 0.57 \text{ V/V} \]

1.68 Using the voltage divider rule.

\[ V_o = \frac{V_o}{V_i} \left( \frac{R_3}{sC} \right) \]
\[ R_3 + \frac{R_1}{sC} + R_3 \]
\[ R_3 + \frac{R_1}{(1 + sC)} \]
\[ \frac{V_o}{V_i} = \frac{R_3}{R_3 + \frac{R_1}{sC} + R_3} \]
\[ \frac{V_o}{V_i} = \frac{R_3}{1 + sC} \times R \]
\[ \omega_0 = \frac{1}{RC} \]
\[ f_0 = \frac{1}{2\pi \sqrt{L C}} = \frac{1}{2\pi \times 10^{-3} \times 0.1 \times 10^{-3} \times 0.1 \times 10^{-3}} = 31.8 \text{ Hz} \]
\[ |T(j\omega_0)| = K \]
\[ \frac{1}{10 + 40} \sqrt{2} = 0.57 \text{ V/V} \]
\[ V_o = \frac{R_L}{V_s} = \frac{R_L}{R_L + R_s} \]

\[ = \frac{R_L}{R_L + R_s} + \frac{1}{sC} \]

which is of the high-pass STC type (see Table 1.2) with

\[ K = \frac{R_L}{R_L + R_s} \quad \omega_0 = \frac{1}{C(R_L + R_s)} \]

For \( f_o \leq 10 \text{ Hz} \)

\[ \frac{1}{2\pi C(R_L + R_s)} \leq 10 \]

\[ \Rightarrow C \geq \frac{1}{2\pi \times 10(20 + 5) \times 10^3} \]

Thus, the smallest value of \( C \) that will do the job is \( C = 0.64 \mu F \).

1.69 The given measured data indicate that this amplifier has a low-pass STC frequency response with a low-frequency gain of 40 dB, and a 3-dB frequency of 10 Hz. From our knowledge of the Bode plots for low-pass STC networks (Figure 1.23a) we can complete the Table entries and sketch the amplifier frequency response.

\[ f(\text{Hz}) \quad |T(\text{dB})| \quad |\angle T(\degree)| \]

| f(\text{Hz}) | |T(\text{dB})| |\angle T(\degree)| |
|-----------|-----------|----------------|
| 0         | 40        | 0              |
| 100       | 40        | 0              |
| 1000      | 40        | 0              |
| 10^3      | 37        | -45^\circ      |
| 10^4      | 20        | -90^\circ      |
| 10^6      | 0         | -90^\circ      |

1.70 From our knowledge of the Bode plots of STC low-pass and high-pass networks we see that this amplifier has a mid-band gain of 40 dB, a low-frequency response of the high-pass STC type with \( f_{\text{in}} = 10^2 \text{ Hz} \), and a high-frequency response of the low-pass STC type with \( f_{\text{in}} = 10^6 \text{ Hz} \). We thus can sketch the amplifier frequency response and complete the table entries as follows:

\[ f(\text{Hz}) \quad |T(\text{dB})| \quad 30 \quad 40 \quad 40 \quad 37 \quad 20 \quad 0 \]

1.71 Since the overall transfer function is that of three identical STC LP circuits in cascade (but with no loading effects since the buffer amplifiers have input and zero output resistances) the overall gain will drop by 3 dB below the value at dc at the frequency for which the gain of each STC circuit is 1 dB down. This frequency is found as follows: The transfer function of each STC circuit is

\[ T(s) = \frac{1}{1 + \frac{s}{\omega_0}} \]

where

\[ \omega_0 = 1 / CR \]

Thus,

\[ |T(j\omega)| = \frac{1}{\sqrt{1 + \frac{\omega^2}{\omega_0^2}}} \]

\[ 20 \log \frac{1}{\sqrt{1 + \frac{\omega_1dB}{\omega_0}}} = -1 \]

\[ \Rightarrow \frac{\omega_{1dB}}{\omega_0} = 10^{0.1} \]

\[ \omega_{1dB} = 0.51 \omega_0 \]

\[ \omega_{1dB} = 0.51 / CR \]
c) \(1 + \frac{R_2}{R_1} = 2 \text{ V/V}, \ f_{3db} = 10 \text{ kHz}\)
\[f_r = 10 \text{ MHz} \times 2 = 20 \text{ MHz}\]

d) \(-\frac{R_2}{R_1} = -2 \text{ V/V}, \ f_{3db} = 10 \text{ kHz}\)
\[f_r = 10 \text{ MHz}(1 + 2) = 30 \text{ MHz}\]

e) \(-\frac{R_2}{R_1} = -1000 \text{ V/V}, \ f_{3db} = 20 \text{ kHz}\)
\[f_r = 20 \text{ kHz}(1 + 100) = 20.02 \text{ MHz}\]

f) \(1 + \frac{R_2}{R_1} = 1 \text{ V/V}, \ f_{3db} = 1 \text{ MHz}\)
\[f_r = 1 \text{ MHz} \times 1 = 1 \text{ MHz}\]

g) \(-\frac{R_2}{R_1} = -1, \ f_{3db} = 1 \text{ MHz}\)
\[f_r = 1 \text{ MHz}(1 + 1) = 2 \text{ MHz}\]

2.114

Gain = \(1 + \frac{R_2}{R_1} = 96 \text{ V/V}\)
\[f_{3db} = 8 \text{ kHz}\]
\[f_r = 96 \times 8 = 768 \text{ kHz}\]
for \(f_{3db} = 24 \text{ kHz}\)
Gain = \(\frac{768}{24} = 32 \text{ V/V}\)

2.115

\[f_{3db} = f_r = 1 \text{ MHz}\]

\[|G| = \frac{1}{\sqrt{1 + \left(\frac{f}{f_{3db}}\right)^2}} = \frac{1}{\sqrt{1 + f^2}} f_{3db} \text{ MHz}\]

\[|G| = 0.99 \Rightarrow f = 0.142 \text{ MHz}\]
The follower behaves like a low-pass STC circuit with a time constant \(\tau = \frac{1}{2\pi \times 10^6} = \frac{1}{2\pi} \mu s\)
\[t_r = 2.20 = 0.35 \mu s \text{ (Refer to Appendix F)}\]

2.116

\(1 + \frac{R_2}{R_1} = 10 \text{ V/V, } R_1 = 1 \text{ kO, } R_2 = 9 \text{ kO}\)

If we consider \(5\tau\) the time that it takes for the output voltage to reach 99% of its final value, then:
\[5\tau = 100 \text{ ns} \Rightarrow \tau = 20 \text{ ns}\]

\(\tau = \frac{1}{w_{3db}} \Rightarrow w_{3db} = 50 \times 10^6 \Rightarrow f_{3db} = 7.96 \text{ MHz}\)
\[f_r = (1 + \frac{R_2}{R_1})f_{3db} = 10 \times 7.96 = 79.6 \text{ MHz}\]

2.117

a) Assume two identical stages, each with a gain function:
\[G = \frac{G_o}{1 + \frac{w}{w_1}} = \frac{G_o}{1 + j\omega f_1}\]
\[G = \frac{G_o}{\sqrt{1 + \left(\frac{f}{f_1}\right)^2}}\]

The overall gain of the cascade is
\[G^2 = \frac{G_o^2}{\sqrt{1 + \left(\frac{f}{f_1}\right)^2}}\]

The gain will drop by 3db when:
\[1 + \left(\frac{f_{3db}}{f_1}\right)^2 = \sqrt{2}, \text{ Note } 3db = 20\log\sqrt{2}\]
\[f_{3db} = F_1\sqrt{2} - 1\]

2.118

\[f_r = 100 \times 5 = 500 \text{ MHz if single op-amp is used.} \]

with op-amp that has only \(f_r = 40 \text{ MHz}\), the possible closed 100 p gain at 5 MHz is:
\[|A| = \frac{40}{5} = 8 \text{ V/V}\]

To obtain an overall gain of 100, three such amplifier cascaded, would be required. Now, if each of the 3 stages, has a low-frequency (d) closed loop gain K, then its 3-db frequency will \(\frac{40}{k} \text{ MHz}\).
16.18
(a) \( f_p = 3.4 \text{ kHz} \)
\( A_{\text{peak}} = 1 \text{ dB} \Rightarrow t = 0.5088 \)
\( f_s = 4 \text{ kHz} \) \( A_{\text{min}} = 35 \text{ dB} \)
\( \omega_s / \omega_p = 1.176 \)

Using Eq (16.22):
\[ A(\omega_s) = 10 \log \left[ 1 + i^2 \cosh^2 \left( N \cosh^{-1} \left( \frac{\omega_s}{\omega_p} \right) \right) \right] \]
& trying different values for \( N \)
\( A(\omega_s) \)
8 \( 28.8 \text{ dB} \)
9 \( 33.9 \text{ dB} \)
10 \( 38.98 \text{ dB} \)

:. Use \( N = 10 \)

Excess attenuation \( = 39 - 35 = 4 \text{ dB} \)
(b) Poles are given by:
\[ P_k = -\omega_p \sin \left( \frac{2k - 1}{N} \cdot \frac{\pi}{2} \right) \sinh \left( \frac{1}{N} \sinh^{-1} \left( \frac{1}{t} \right) \right) \]
\[ + j\omega_p \cos \left( \frac{2k - 1}{N} \cdot \frac{\pi}{2} \right) \cosh \left( \frac{1}{N} \sinh^{-1} \left( \frac{1}{t} \right) \right) \]
for \( k = 1, 2, ..., N \).

Since \( t = 0.5088 \) and \( N = 10 \)
\( \sinh \left( 1 / N \sinh^{-1} \left( 1 / t \right) \right) = 0.1433 \)
\( \cosh \left( 1 / N \sinh^{-1} \left( 1 / t \right) \right) = 1.010 \)

:. \( P_1 = \omega_p \left[ -0.1433 \sin \left( \frac{\pi}{20} \right) + j1.010 \cos \left( \frac{\pi}{20} \right) \right] \)
\[ = \omega_p (-0.0224 + j0.9978) \]
\( P_2 = \omega_p (-0.0650 + j0.9000) \)
\( P_3 = \omega_p (-0.1013 + j0.7143) \)
\( P_4 = \omega_p (-0.1277 + j0.4586) \)
\( P_5 = \omega_p (-0.1415 + j0.1580) \)

Now it should be realized that the remaining poles are complex conjugates of the above.
pole-pair \( P_1 \) & \( P_1^* \) give a factor:
\[ S^2 + 2(0.0224)\omega_p S + \omega_p^2(0.0224^2 + 0.9978^2) \]
\[ = S^2 + 0.0448 \omega_p S + 1.023 \omega_p^2 \]
i.e. this factor is from \( (S - P_1)(S - P_1^*) \).
\( P_{2\text{yield}}: S^2 + 0.130 \omega_p S + 0.902 \omega_p^2 \)
\( P_{3\text{yield}}: S^2 + 0.203 \omega_p S + 0.721 \omega_p^2 \)
\( P_{4\text{yield}}: S^2 + 0.255 \omega_p S + 0.476 \omega_p^2 \)
\( P_{5\text{yield}}: S^2 + 0.283 \omega_p S + 0.212 \omega_p^2 \)

Now \( T(S) \) is given by
\[ T(S) = \frac{k \omega_p^{10}}{E S^2 (S - P_1)(S - P_1^*) \cdots (S - P_2)(S - P_2^*)} \]
where the second order terms of the denominator are given above.
k is the dc gain
\[ k = \frac{1}{1 + t^2} = 0.8913 \]
\( \omega_p = 2\pi \times 3400 \)

16.19 \( f_o = 10 \text{ kHz} \)
DC gain \( = -R_2/R_1 = -10 \)
\( R_{in} = 10 \text{ k} \Omega \)

\[ R_{in} = R_1 = 10 \text{ k} \Omega \]
DC gain \( = -R_2/R_1 = -10 \)
\( R_2 = 10R_1 = 100 \text{ k} \Omega \)
\[ R_2C = 1/W_o \]
\[ C = \frac{1}{W_o R_2} = \frac{1}{2\pi 10^4 \times 100 \times 10^3} \]
\[ = 0.159 \text{ nF} \]

16.20 \( f_o = 100 \text{ KHz} \)
\( R_1(\infty) = 100 \text{ k} \Omega \)
\[ |T(\infty)| = 1 \]

\[ R_{in} = R_1 = 100 \text{ k} \Omega \]
\[ |T(\infty)| = R_2/R_1 = 1 \]
\( R_2 = R_1 = 100 \text{ k} \Omega \)
\[ CR_1 = 1/W_o \]
\[ C = \frac{1}{W_o R_1} = \frac{1}{2\pi 100 \times 10^4 \times 100 \times 10^3} \]
\[ = 15.9 \text{ nF} \]
16.21 Use general first-order circuit:

Zero at 1 kHz; Pole at 100 kHz

\(-|T(0)| = 1; \quad R_i(O) = 1 \, \text{k}\Omega\)

Thus: \(R_i(\text{DC}) = R_i = 1 \, \text{k}\Omega\)

\(T(\text{DC}) = -R_i/R_1 = -1\)

\(R_2 = R_1 = 1 \, \text{k}\Omega\)

For a pole at 100 kHz

\(C_2R_2 = 1/W_0 \Rightarrow C_2 = \frac{1}{2\pi f_0 R_2}\)

= 1.59 nF

For the circuit \(T(s) = \frac{a_0 s + a_o}{s + W_0}\)

Thus the Zero at \(-a_0/a_1 = -2\pi \times 10^3\)

\(C_1R_1 = a_0/a_0\)

\(C_1 = \frac{1}{2\pi \times 10^3 R_1}\)

= 159 nF

High freq gain = \(-\frac{C_1}{C_2} = -100\)

= 40 dB

\(|T| (\text{dB})\)

1 kHz 100 kHz f(log)

16.22

\(V_1 = \frac{1/C}{1/S C + R_1} V_i\)

\(= \frac{1}{1 + S\tau} V_i \quad \tau = R_C\)

\(V_+ = V_-\) due to virtual short between terminals

\(\therefore I_i = \left(V_i - \frac{1}{1 + S\tau} V_i\right)\frac{1}{R_1}\)

\(V_O = V_2 - I_i R_1\)

\(= \frac{V_i}{1 + S\tau} \left(1 - \frac{V_i}{1 + S\tau}\right)\frac{R_1}{R_i}\)

\(V_O = \frac{1 - (1 + S\tau)}{1 + S\tau} = \frac{1 - S\tau}{1 + S\tau}\)

16.23

At +ve terminal

\(V_1 = \frac{1/C}{1/S C + R_1} V_i\)

\(= \frac{1}{1 + S\tau} V_i \quad \tau = R_C\)

\(V_+ = V_-\) due to virtual short between terminals

\(\therefore I_i = \left(V_i - \frac{1}{1 + S\tau} V_i\right)\frac{1}{R_1}\)

\(V_O = V_2 - I_i R_1\)

\(= \frac{V_i}{1 + S\tau} \left(1 - \frac{V_i}{1 + S\tau}\right)\frac{R_1}{R_i}\)

\(V_O = \frac{1 - (1 + S\tau)}{1 + S\tau} = \frac{1 - S\tau}{1 + S\tau}\)
\( \phi(\omega) = 180^\circ + \tan^{-1}\left( \frac{\omega}{-\omega_o} \right) - \tan^{-1}\left( \frac{\omega}{\omega_o} \right) \)

Sub: \( \tan\left( \frac{\omega}{-\omega_o} \right) = 180^\circ - \tan^{-1}\left( \frac{\omega}{\omega_o} \right) \)

\( \Rightarrow \phi(\omega) = -2\tan(\omega/\omega_o) \)

Now \( \phi = -120^\circ \) at \( \omega = 2\pi 60 \)

\(-120^\circ = -2\tan(WRC) \)

\(-60 = -\tan^{-1}(2\pi 60 \times R \times 10^{-6}) \)

\( R = 4.59 \, k\Omega \)

\( R \), can be arbitrarily chosen use \( R_1 = 10 \, k\Omega \)

16.28

![Diagram](attachment:diagram.png)

**Natural Modes:**

\(- \frac{1}{2} \pm j\frac{\sqrt{3}}{2} \)

\( \omega_o = \sqrt{\frac{1}{2} + \left( \frac{\sqrt{3}}{2} \right)^2} = 51.0 \)

\( \frac{\omega_o}{2Q} = 1 \Rightarrow \frac{\omega_o}{Q} = 1 \)

\[ T(s) = \frac{a_2s^2}{s^2 + \frac{\omega_o}{Q} + \omega_o^2} = \frac{a_2s^2}{s^2 + s + 1} \]

\[ |T(j\omega)| = a_2 = 1 \]

\[ \therefore T(s) = \frac{s^2}{s^2 + s + 1} \quad Q = 1 \]

16.29

For a 2nd-order bandpass

\[ T(S) = \frac{a_1S}{S^2 + \frac{\omega_o}{Q} + \omega_o^2} \]

\[ T(j\omega) = \frac{j\omega a_1}{(\omega_o^2 - \omega^2) + j\omega a_1 \omega_o} \]

\[ |T(j\omega)| = \frac{aW}{\sqrt{\left( \omega_o^2 - \omega^2 \right)^2 + \left( \omega a_1 \omega_o \right)^2}} \]

Part (a):

\[ |T(j\omega_1)| = |T(j\omega_2)| \]

\[ aW_1 \]

\[ = aW_2 \]

\[ \omega_o^2 \left[ \frac{(\omega_o^2 - \omega_1^2)^2 + \left( \omega a_1 \omega_o \right)^2}{Q} \right] \]

\[ = \omega_o^2 \left[ \omega_1^2 \omega_o^2 - \omega_1^4 \right]^2 + \left( \omega a_1 \omega_o \right)^2 \]

\[ \omega_1^2(\omega_o^2 - 2\omega_2\omega_o^2 + \omega_2^2) = \omega_2^2(\omega_o^2 - 2\omega_2\omega_o^2 + \omega_1^2) \]

\[ \omega_1^2\omega_o^2 + \omega_2^2\omega_o^2 = \omega_2^2\omega_o^2 + \omega_1^2\omega_o^2 \]

\[ \omega_1^2 - \omega_2^2 = \omega_2^2 - \omega_1^2 \]

\[ \omega_2^2 - \omega_1^2 \]

\[ \omega_1^2 = \omega_1 \omega_2 \quad Q.E.D. \]

(b) For Fig. 16.4:

\( \omega_{Pr} = 8100 \, \text{rad/s} \)

\( \omega_{Pr} = 10000 \, \text{rad/s} \)

\( A_{max} = 1 \, \text{dB} \)

\( \omega_o = (8100)(10000) \)

\( \omega_o = 9000 \, \text{rad/s} \)

\[ |T(j\omega_{Pr})| = |T(j\omega_{pr})| = 10^{-1/20} \]

\[ = 0.8913 \]

\[ |T(j\omega_0)| = \frac{\omega_o a_1}{\sqrt{(\omega_o^2 - \omega_0^2)^2 + \left( \frac{\omega_o}{Q} \right)^2}} = 1 \]

\[ \Rightarrow \frac{\omega_o a_1}{\omega_o/Q} = 1 \]

\[ \therefore \frac{Qa_1}{\omega_o} = 1 \Rightarrow a_1 = \frac{\omega_o}{Q} \]

\[ |T(j0.9\omega_o)|^2 = |T(j0.9\omega_o)|^2 = 0.8913^2 \]
\[
\frac{(\omega_0/\xi)^2(0.9\omega_0)^2}{(\omega_0^2 - (0.9\omega_0)^2)^2 + \left(\frac{(0.9\omega_0)}{\xi}\right)^2} = 0.8913^2
\]

\[
\frac{\left(\frac{\omega_0}{\xi}, (0.9\omega_0)^2\right)^2}{\xi^2} = 0.8913^2\left[(\omega_0^2 - (0.9\omega_0)^2)^2 + \left(\frac{(0.9\omega_0)}{\xi}\right)^2\right]
\]

\[
\frac{0.81\omega_0^2}{\xi^2} = 0.8913^2\left[W_0^2(1 - 0.81)^2 + \frac{0.81\omega_0^2}{\xi^2}\right]
\]

\[
\frac{0.81\omega_0^2}{\xi^2}(1 - 0.8913^2) = 0.8913^2\omega_0^2 \times (1 - 0.81)^2
\]

\[\text{SUB} \omega_0 = 9000 \text{ gives} \]

\[Q = 2.41\]

Now \(Q_1 = \frac{\omega_0}{\xi} = 0.415\omega_0\)

\[. T(S) = \frac{0.415\omega_0 S}{S^2 + 0.415\omega_0 S + \omega_0^2}\]

IF \(W_S = 3000 \text{ rad/s}\)

\[|T(j3000)| = \frac{0.415\omega_0(3000)}{\sqrt{(W_S^2 - 3000^2)^2 + (\omega_0 3000 \times 0.415)^2}} = 0.1537\]

\[. A_{\text{min}} = -20\log(0.1537) = 16.3\text{ dB}\]

Now \(\omega_{s1} \text{ and } \omega_{s2}\) are geometrically symmetrical about \(\omega_0\):

\[\omega_{s1} = \omega_0 \]

\[\omega_{s2} = \frac{9000^2}{3000} = 27000 \text{ rad/s}\]

\[Q \leq 2\]

\[Q = 1.005\]

\[. T(S) = \frac{a_2}{\omega_0^2} = \frac{1}{-\text{DC Gain}}\]

\[Q_2 = 1\]

\[T(S) = \frac{S^2 + (2\pi 60)^2}{S^2 + S^{2\pi 60} + (2\pi 60)^2}\]

\[T(S) = \frac{S + 1.421 \times 10^5}{S^2 + 375.1s + 1.421 \times 10^5}\]

\[16.31\]

FOR ALL PASS:

\[T(S) = \frac{Q^2 S^2 - S W_0/Q + \omega_0^2}{S^2 + S W_0/\xi + \omega_0^2}\]

If Zero frequency < pole frequency

\[T(S) = \frac{Q^2 S^2 - S W_0/\xi + \omega_0^2}{S^2 + S W_0/\xi + \omega_0^2} \omega_n < \omega_0\]

At DC: \(|T| = \frac{\omega_n}{\omega_0}\) where \(\frac{\omega_n}{\omega_0} < 1\)

\[A_{\text{min}} = -20\log(0.1537) = 16.3\text{ dB}\]

IF Zero frequency > pole frequency then \(\omega_n > \omega_0\)

At DC: \(|T| = Q^2 \frac{\omega_n}{\omega_0}\) where \(\frac{\omega_n}{\omega_0} > 1\)

\[16.32\]

From exercise 16.15

\[Q = \frac{\frac{\omega_0}{\xi}}{\sqrt{10^{Q/10}} - 1}\]

\[\omega_0 = 2\pi(60) \text{ BW} = 2\pi 6 \text{ A} = 20\text{dB}

\[= 1.005\]

\[T(S) = \frac{a_2}{\omega_0} \frac{S^2 + \omega_0^2}{S^2 + S^{2\pi 60} + \omega_0^2}\]

\[|T(0)| = \frac{a_2}{\omega_0^2} = 1 \text{ << DC Gain}\]

\[Q_2 = 1\]

\[T(S) = \frac{S^2 + (2\pi 60)^2}{S^2 + S^{2\pi 60} + (2\pi 60)^2}\]

\[\text{If } Q_1 > Q_0\]

\[|T(j\omega_0)| = \frac{Q_2 Q_0}{Q_1} < Q_2\]