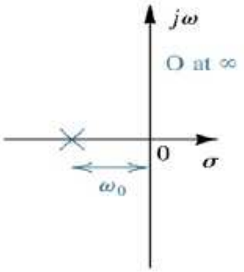
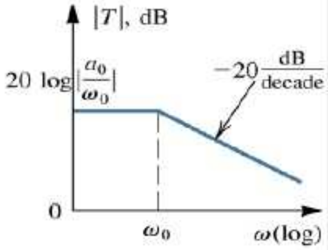
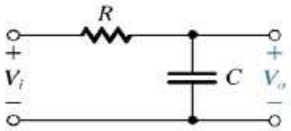
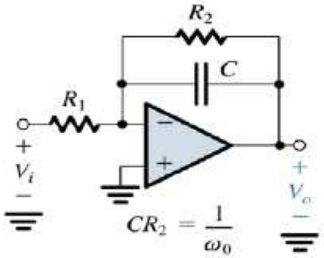
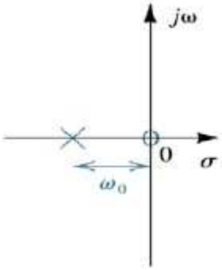
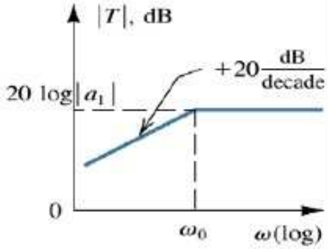
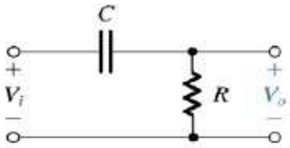
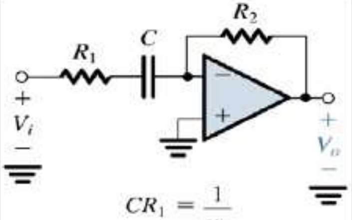
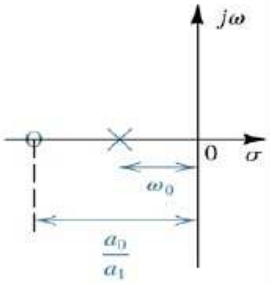
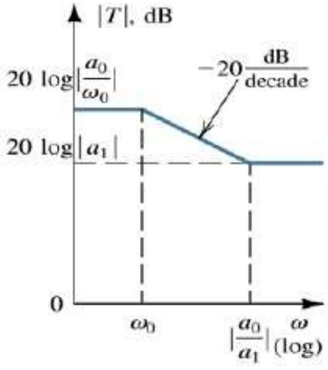
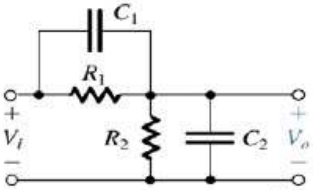
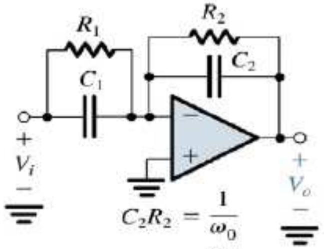
| Filter Type and $T(s)$ | $s$-Plane Singularities | Bode Plot for $\|T\|$ | Passive Realization | Op Amp-RC Realization |
|---|---|---|---|---|
| (a) Low-Pass (LP)<br>$T(s) = \frac{a_0}{s+\omega_0}$ |  |  |  <br>$CR = \frac{1}{\omega_0}$<br>dc gain = 1 |  <br>$CR_2 = \frac{1}{\omega_0}$<br>dc gain $= -\frac{R_2}{R_1}$ |
| (b) High-Pass (HP)<br>$T(s) = \frac{a_1 s}{s+\omega_0}$ |  |  |  <br>$CR = \frac{1}{\omega_0}$<br>High-frequency gain = 1 |  <br>$CR_1 = \frac{1}{\omega_0}$<br>High-frequency gain $= -\frac{R_2}{R_1}$ |
| (c) General<br>$T(s) = \frac{a_1 s + a_0}{s+\omega_0}$ |  |  |  <br>$(C_1 + C_2)(R_1 // R_2) = \frac{1}{\omega_0}$<br>$C_1R_1 = \frac{a_0}{a_1}$<br>dc gain $= \frac{R_2}{R_1 + R_2}$<br>HF gain $= \frac{C_1}{C_1 + C_2}$ |  <br>$C_2R_2 = \frac{1}{\omega_0}$<br>$C_1R_1 = \frac{a_1}{a_0}$<br>dc gain $= -\frac{R_2}{R_1}$<br>HF gain $= -\frac{C_1}{C_2}$ |

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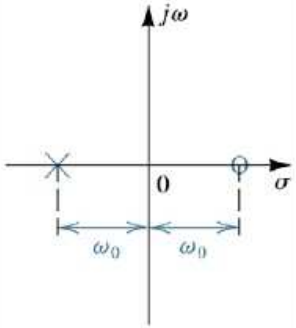
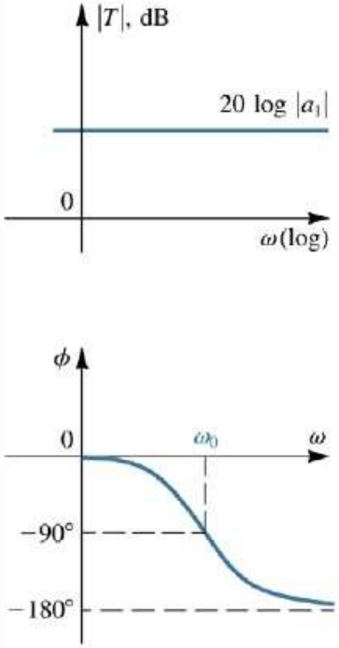
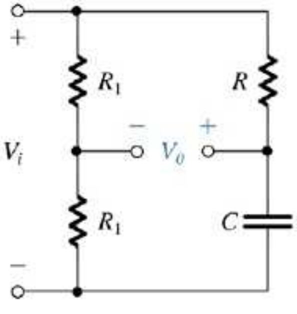
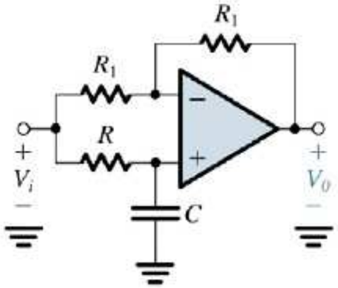
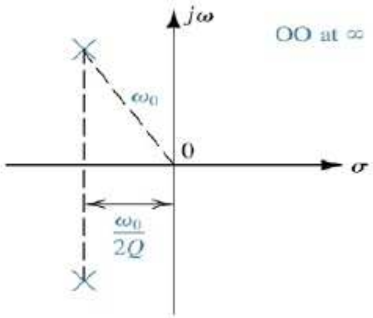
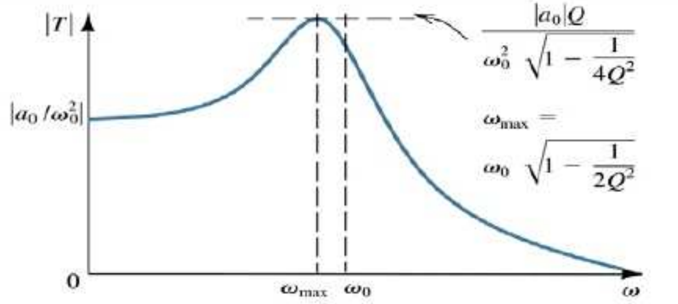
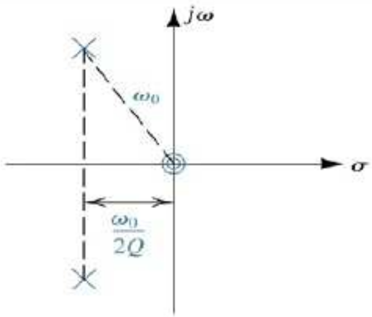
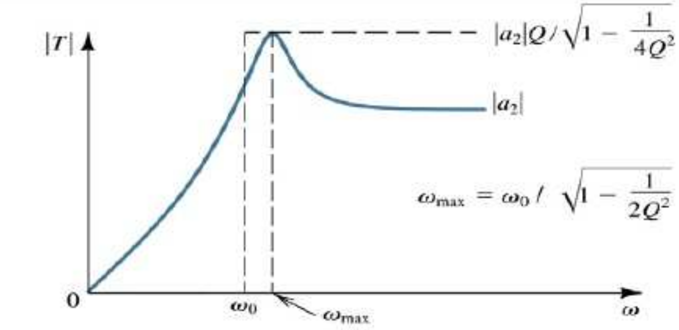
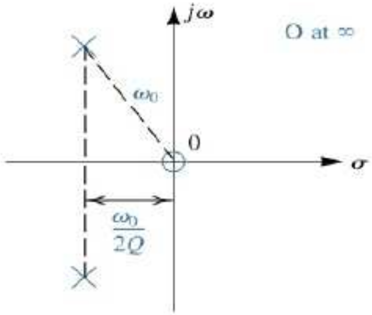
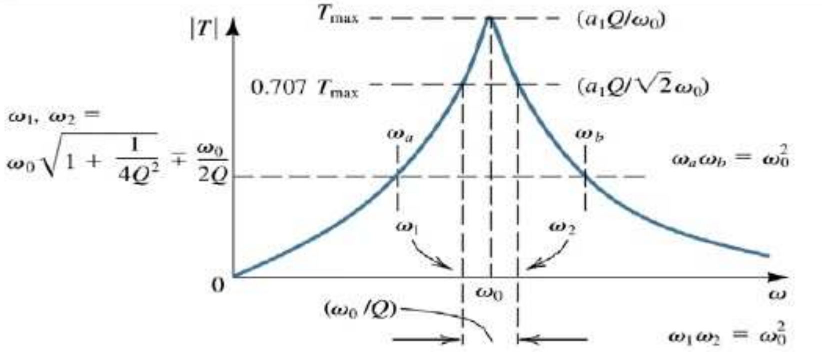
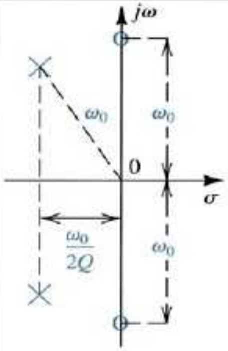
| $T(s)$ | Singularities | $\lvert T\rvert$ and $\phi$ | Passive Realization | Op Amp-RC Realization |
|---|---|---|---|---|
| $T(s) = -a_1\frac{s-\omega_0}{s+\omega_0}$<br>$a_1 > 0$ |  |  |  <br>$CR = 1/\omega_0$<br>Flat gain $(a_1) = 0.5$ |  <br>$CR = 1/\omega_0$<br>Flat gain $(a_1) = 1$ |

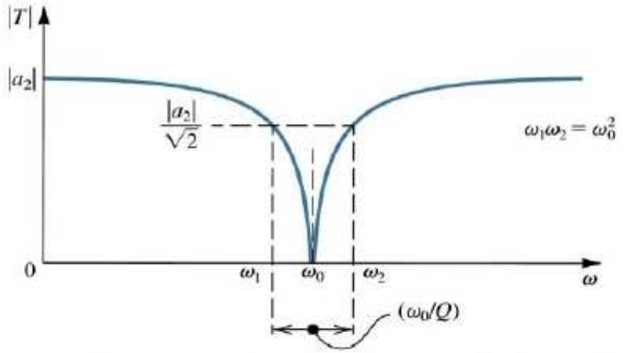
| Filter Type and $T(s)$ | $s$-Plane Singularities | $\|T\|$ |
|---|---|---|
| (a) Low-Pass<br>(LP)<br>$T(s) = \dfrac{a_0}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$<br>dc gain $= \dfrac{a_0}{\omega_0^2}$ |  |  |
| (b) High-Pass<br>(HP)<br>$T(s) = \dfrac{a_2 s^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$<br>High-frequency gain<br>$= a_2$ |  |  |
| (c) Bandpass (BP)<br>$T(s) = \dfrac{a_1 s}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$<br>Center-frequency gain<br>$= \dfrac{a_1 Q}{\omega_0}$ |  |  |

(d) Notch

$$T(s) = a_2 \frac{s^2 + \omega_0^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$$

dc gain = high-frequency gain = $a_2$





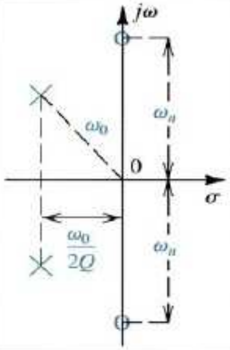
(e) Low-Pass Notch (LPN)

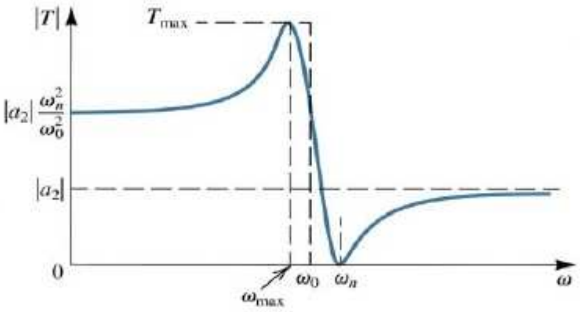
$$T(s) = a_2 \frac{s^2 + \omega_n^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$$

$\omega_n \geqslant \omega_0$

dc gain $= a_2 \dfrac{\omega_n^2}{\omega_0^2}$

high-frequency gain = $a_2$





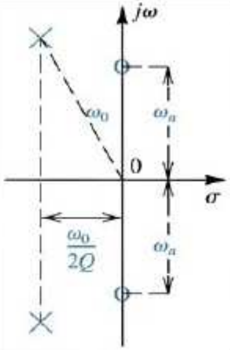
(f) High-Pass Notch (HPN)

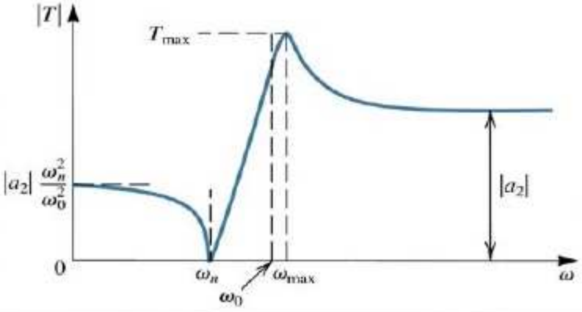
$$T(s) = a_2 \frac{s^2 + \omega_n^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$$

$\omega_n \leqslant \omega_0$

dc gain $= a_2 \dfrac{\omega_n^2}{\omega_0^2}$

high-frequency gain = $a_2$





$$\omega_{\max} = \omega_0 \sqrt{\frac{\left(\dfrac{\omega_n^2}{\omega_0^2}\right)\left(1 - \dfrac{1}{2Q^2}\right) - 1}{\dfrac{\omega_n^2}{\omega_0^2} + \dfrac{1}{2Q^2} - 1}}$$

$$T_{\max} = \frac{|a_2| \qquad |\omega_n^2 - \omega_{\max}^2|}{\sqrt{(\omega_0^2 - \omega_{\max}^2)^2 + \left(\dfrac{\omega_0}{Q}\right)^2 \omega_{\max}^2}}$$

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(g) All-Pass<br>(AP)

$$T(s) = a_2 \frac{s^2 - s\,\frac{\omega_0}{Q} + \omega_0^2}{s^2 + s\,\frac{\omega_0}{Q} + \omega_0^2}$$

Flat gain = $a_2$

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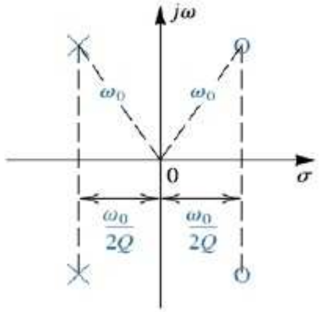

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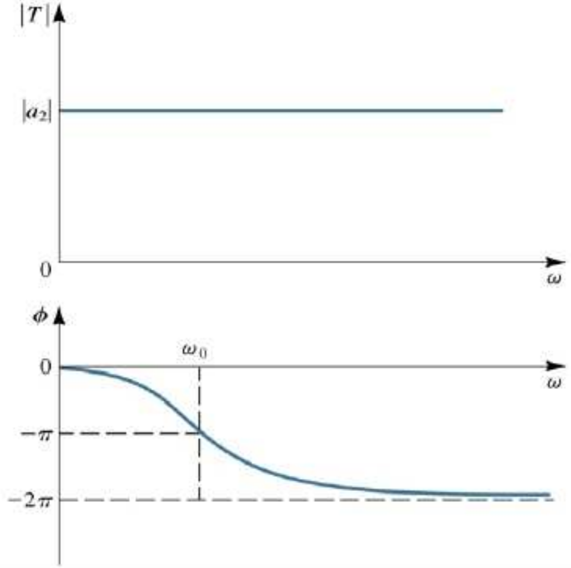

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