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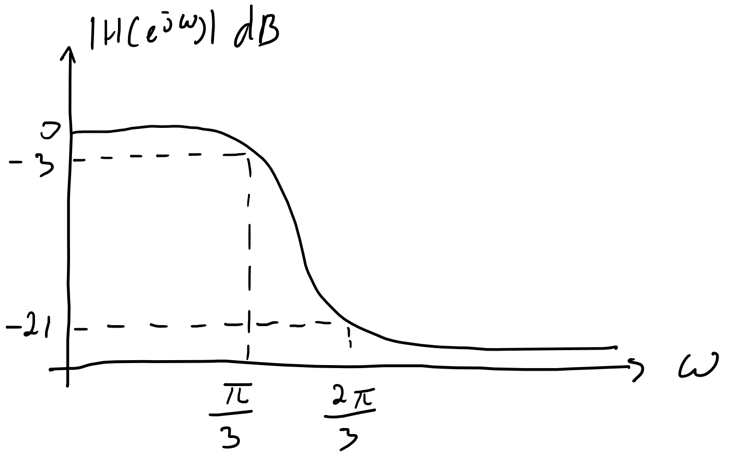
1. $f_p = 2\ kHz$ $\qquad R_p = -3\ dB$

$f_s = 4\ kHz$ $\qquad R_s = -21\ dB$

$F_s = 12\ kHz$

a. $\omega_p = \dfrac{2\pi f_p}{F_s} = \dfrac{2\pi \cdot 2\ kHz}{12\ kHz} = \dfrac{\pi}{3}$ rad/sampel

$\omega_s = \dfrac{2\pi f_s}{F_s} = \dfrac{2\pi \cdot 4\ kHz}{12\ kHz} = \dfrac{2\pi}{3}$ rad/sampel

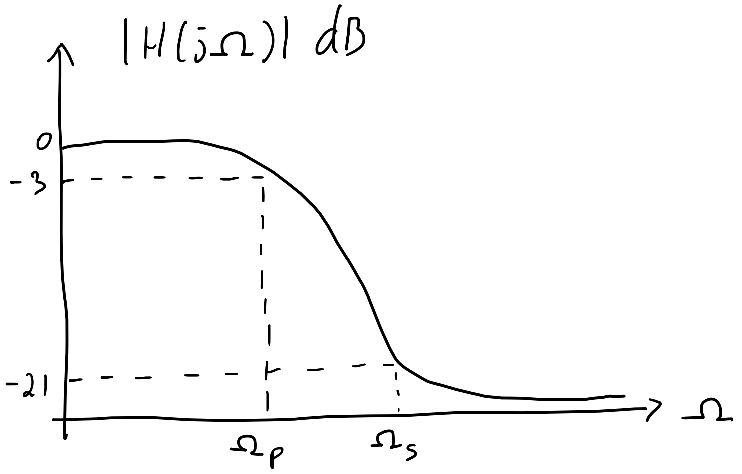


b. $T = \dfrac{1}{F_s} = \dfrac{1}{12\ kHz} = \dfrac{1}{12\times10^3}$; $F_s = \dfrac{1}{T}$

$\Omega_p = \dfrac{2}{T}\tan\left(\dfrac{\omega_p}{2}\right) = 2.12\times10^3 \tan\left(\dfrac{\pi}{3}\cdot\dfrac{1}{2}\right) = 13.856,41$ rad/s

$\Omega_s = \dfrac{2}{T}\tan\left(\dfrac{\omega_s}{2}\right) = 2.12\times10^3 \tan\left(\dfrac{\cancel{2}\pi}{3}\cdot\dfrac{1}{\cancel{2}}\right) = 41.569,22$ rad/s

c.



$\Omega_p = 13.856,41$ rad/s

$\Omega_s = 41.569,22$ rad/s

d. Berdasarkan no. c filter yang digunakan adalah LPF

$$\Omega_c = \frac{\Omega_s}{\Omega_p} = \frac{41.569,22}{13.856,41} = 3$$

$$n = \left\lceil \frac{\log\left[\frac{10^{-\frac{R_p}{10}} - 1}{10^{-\frac{R_s}{10}} - 1}\right]}{2\log\left(\frac{1}{\Omega_c}\right)} \right\rceil = \left\lceil \frac{\log\left[\frac{10^{0,3} - 1}{10^{2,1} - 1}\right]}{2\log\left(\frac{1}{3}\right)} \right\rceil = \lceil 2,19 \rceil = 3$$

Karena tanpa ripple, gunakan filter Butterworth

$$H_3(s) = \frac{1}{s^3 + 2s^2 + 2s + 1}$$

e. LPF : $s \rightarrow \frac{s}{\Omega_p}$

$$H(s)\Big|_{s \to \frac{s}{\Omega_p}} = \frac{1}{\left(\frac{s}{\Omega_p}\right)^3 + 2\left(\frac{s}{\Omega_p}\right)^2 + 2 \cdot \frac{s}{\Omega_p} + 1}$$

$$= \frac{\Omega_p^3}{s^3 + 2s^2\Omega_p + 2s\,\Omega_p^2 + \Omega_p^3}$$

$$= \frac{13.856,41^3}{s^3 + 2s^2(13.856,41) + 2s(13.856,41)^2 + 13.856,41^3}$$

$$= \frac{2,7 \times 10^{12}}{s^3 + 27712,82\,s^2 + 3,8 \times 10^8\,s + 2,7 \times 10^{12}}$$

f.

$$H(z) = H(s)\Big|_{s \to 2F_s\left(\frac{1-z^{-1}}{1+z^{-1}}\right)}$$

$$= \frac{\left(2F_s \frac{\sqrt{3}}{3}\right)^3}{\left(2F_s \frac{1-z^{-1}}{1+z^{-1}}\right)^3 + 2 \cdot 2F_s \frac{\sqrt{3}}{3}\left(2F_s \frac{1-z^{-1}}{1+z^{-1}}\right)^2 + 2\left(2F_s \frac{\sqrt{3}}{3}\right)^2 \cdot \left(2F_s \frac{1-z^{-1}}{1+z^{-1}}\right) + \left(2F_s \frac{\sqrt{3}}{3}\right)^3}$$

$$= \frac{\left(\frac{\sqrt{3}}{3}\right)^3}{\left(\frac{1-z^{-1}}{1+z^{-1}}\right)^3 + 2\frac{\sqrt{3}}{3}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)^2 + 2\left(\frac{\sqrt{3}}{3}\right)^2 \cdot \frac{1-z^{-1}}{1+z^{-1}} + \left(\frac{\sqrt{3}}{3}\right)^3}$$

$$= \frac{(1+z^{-1})^3 \cdot 0{,}6^3}{(1-z^{-1})^3 + 2 \cdot 0{,}6\,(1-z^{-1})^2 (1+z^{-1}) + 2\,0{,}6^2 \cdot (1-z^{-1})(1+z^{-1})^2 + (1+z)^3\,0{,}6^3}$$

$$H(z) = \frac{27z^{-3} + 81z^{-2} + 81z^{-1} + 27}{-38z^{-3} + 216z^{-2} - 354z^{-1} + 392}$$

g. $n = 3$

h. $$H(z) = \frac{Y(z)}{X(z)}$$