Part I. Introduction

“The poles of a system (those closest to the imaginary axis in the s-plane) give rise to the longest lasting terms in the transient response of the system. Then those poles are called dominant poles.”

Figure 1 shows the natural modes of a Chebyshev filter for $n = 4$.

Some basic equations are showing below:

$$k_p = \sqrt{10^{\alpha_p/10} - 1} \quad \text{or} \quad \alpha_p = 10 \log(1 + k_p^2)$$

$$a = \frac{1}{k_p} + \sqrt{\frac{1}{k_p^2} + 1}$$

Then, for each pole, the real part is:
\[
\Sigma_k = -\sin\left(\frac{2k - 1}{n} \pi \right) \frac{1}{2} \left( a^{1/n} - a^{-1/n} \right) \quad k = 1, 2, \ldots , \Box
\]
and the imaginary part is:
\[
\Omega_k = \cos\left(\frac{2k - 1}{n} \pi \right) \frac{1}{2} \left( a^{1/n} + a^{-1/n} \right) \quad k = 1, 2, \ldots , \Box
\]
and then:
\[
S_k = \Sigma_k + j\Omega_k \quad k = 1, 2, \ldots , \Box
\]

In this project, \( n \) equals to 5. Another useful equation is:
\[
Q_p = \frac{|S_k|}{2 \times |Re[S_k]|} \quad k = 1, 2, \ldots , \Box
\]

**Part II. Question 1**—plot the pole \( Q(Q_p) \) of the dominant pole of a fifth-order Chebyshev filter as a function of \( \alpha_p \)

*Figure 2. Poles locations.*
Figure 2 shows the poles locations if we let passband loss equals to 0.1, 0.25, and 0.5dB. From this figure we can see, larger passband loss, the locations are closer to the origin.

If we assume that the range of passband loss is 0 to 1dB, then, we can draw $Q_p$ as a function of $\alpha_p$ for every pole. As shown in figure 3, the green curve is when $k$ equals to 3, which refers to the pole most far away from the origin. The red and yellow curve represent when $k$ equals to 2 and 4 respectively. The reason why these two curves are the same is the locations for pole $S_2$ and $S_4$ are symmetrical with respect to the $\Sigma$ axis. Same conditions for $S_1$ (blue curve) and $S_5$ (cyan curve).
Figure 4 indicates $Q_p$ as a function of $\alpha_p$ for the dominant pole. Again, in this figure, it is assuming that the range for $\alpha_p$ is from 0 to 1dB.

**Part III. Question 2—find the largest passband loss if $Q_p < 5$, $Q_p < 3$, and $Q_p < 1$**

- If $Q_p < 5$ hold, the largest $\alpha_p = 0.7dB$.
- If $Q_p < 3$ hold, the largest $\alpha_p = 0.05dB$.
- If $Q_p < 1$ hold, there is no valid value for $\alpha_p$.

In this project, I assumed $\alpha_p$ is varying from 0 to 1dB, and the changing step was 0.01dB. If I use smaller changing step, the result could be more accurate.