$h(t)$ is impulse response of LTI system; $H(s)$ is Laplace transform of $h(t)$.

$$H(j\omega) = |H(j\omega)|e^{j\phi(\omega)}; \quad T_d(\omega) = -\frac{d\phi(\omega)}{d\omega}; \quad |H(j\omega)|_{dB} = 20\log|H(j\omega)|; \quad H(s) = \frac{a_ms^m + \ldots + a_0}{s^N + b_{n-1}s + \ldots + b_0}$$

$$|H(j\omega)|^2 = H(s)H(-s)|_{\omega=j\omega} = H(j\omega)H(-j\omega); \quad \text{General Lowpass} \quad |H(j\omega)|^2 = \frac{A_0^2}{1 + F(\omega^2)};$$

**Butterworth:**

$$F(\omega) = \varepsilon^{2(\frac{\omega}{\omega_p})^{2N}}; \quad A_{\max} = 20\log\sqrt{1 + \varepsilon^2}; \quad A_{\min} \leq 10\log\left[1 + \varepsilon^2(\frac{\omega}{\omega_p})^{2N}\right]$$

Poles lie on circle of radius $\omega_p\left(\frac{1}{\varepsilon}\right)^{\frac{1}{N}}$ spaced apart by $\frac{\pi}{N}$ with first half angle from $j\omega$ axis

**Chebyshev:** (for $\omega_p = 1$) $F(\omega) = \varepsilon^{2(\frac{\omega}{\omega_p})^{2N}}; \quad C_N(\omega) = \cos(N\cos^{-1}(\omega)) \leq 1$

$$\begin{align*}
C_N(\omega) = \cosh(N\cosh^{-1}(\omega)) \leq 1; \quad C_{N+1}(\omega) = 2\omega C_N(\omega) - C_{N-1}(\omega); \\
A_{\max} = 20\log\sqrt{1 + \varepsilon^2}; \quad A_{\min} \leq 10\log[1 + \varepsilon^2\cosh^2(N\cosh^{-1}(\omega_p/\omega_p))] \end{align*}$$

**Second-order polynomial:**

$$s^2 + \left(\frac{\omega_0}{Q}\right)s + \omega_0^2; \quad \text{for } Q > 0.5, \text{ poles complex at radius } \omega_0 \text{ and real part is } -\frac{\omega_0}{2Q}$$

**Lowpass and highpass:** peaking occurs if $Q > 1/\sqrt{2}$ and $\omega_{\max} = \omega_0\sqrt{1 - 1/(2Q^2)}$

**Bandpass:** for complex poles, peak occurs at $\omega_0$ and has 3dB bandwidth of $\omega_0/Q$

**LCR:** $\omega_0 = 1/\sqrt{L}\bar{C}; \quad Q = \omega_0CR$

**KHN Biquad:** $RC = \frac{1}{\omega_0^2}; \quad 2\left(\frac{R_1 || R_2}{R_3} + R_3\right) = \frac{1}{Q}; \quad 2\left(\frac{R_2 || R_3}{R_1} + R_1\right) = k$

**Tow-Thomas Biquad:** $RC = \frac{1}{\omega_0^2}; \quad \text{damping resistor is } QR; \text{ numerator is } -s^2(\frac{C}{C}) + s\left(\frac{1}{C}\right)(\frac{1}{R_1} - \frac{R}{RR_3}) + \frac{1}{RR_2C^2}$