# Digital Signal Processing

## Low-Pass Filter (LPF)

LPF is used for filtering noise frequency, bypassing the frequency below the frequency cut-off (Fc) and attenuating the frequency above the frequency cut-off. The applications include anti-aliasing, reconstruction, and speech processing, often used in audio amplifiers, equalizers, and speakers. However, simple RC LPF or first-order LPF is the simplest and often used. Simple passive RC LPF can be easily made by connecting in series a single resistor with a single capacitor as shown in Figure 1. ([(646) IIR Filters - Theory and Implementation (STM32) - Phil's Lab #32 - YouTube](https://www.youtube.com/watch?v=QRMe02kzVkA&ab_channel=Phil%E2%80%99sLab))

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| Figure RC filter circuit | The RC Filter can be calculated using this equation:  Where:  fc = Frequency cut-off (Hz)  R = Resistance (Ω)  C = Capacitance (F) |

Instead of designing RC Filter by hardware, we can design RC Filter by software. We can use a simple Infinite Impulse Response Filter (IIR) in the discrete-time. It can be calculated using this equation:

Or

Where:

= fs = Time sampling / Frequency sampling

RC = fc = Time constant / Frequency cut-off

Xi = Input

Yi = Current output

Yi-1 = Previous output

We know that:

Hence, we can simplify our formula as:

The filter output also can be calculated using the frequency manner. Besides the RC Filters, there are also other LPF:

* Butterworth – Produces the best output response with no ripple in the pass band or stop band, resulting in a flat filter response but at the expense of a relatively wide transition band. This filter is mostly used for communications or control systems. ([Butterworth Filter Design with a Low Pass Butterworth (electronics-tutorials.ws)](https://www.electronics-tutorials.ws/filter/filter_8.html))
* Chebyshev Produces an aburpt/sharp cut-off and steep roll-off, allowing it to remove noise frequency quickly. Chebyshev also has variation amplitude in the pass-band. Examples of applications include medical equipment, EEG, and radar systems. ([What is a Chebyshev filter? (collimator.ai)](https://www.collimator.ai/reference-guides/what-is-a-chebyshev-filter))
* Elliptic/Cauer approximation - Compared to Chebyshev, Elliptic has a sharper stopband cut-off, worsening the transient response. This filter is suitable for Power Amplifier (PA), which is good at rejecting the harmonics in PA. ([What is an Elliptic / Cauer Filter - the Basics » Electronics Notes (electronics-notes.com)](https://www.electronics-notes.com/articles/radio/rf-filters/what-is-elliptical-cauer-filter-basics.php))
* Bessel – Optimized for maximally flat delay time (constant delay), which has the linear phase response and excellent transient response but at the expense of flatness in the pass-band and rate of roll-off. ([MT-204.pdf (analog.com)](https://www.analog.com/media/en/training-seminars/tutorials/MT-204.pdf))

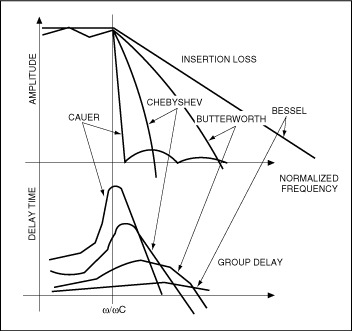


Figure Comparison between LPF