Time constants and filters

For each periodic electrical biosignal, there is a certain frequency band that is specific to it and in which it is usually sensed and evaluated. This means that such a signal has a frequency spectrum limited by finite values, i.e. that such a signal can be decomposed into the sum of a finite number of harmonic functions without losing the information carried by the signal. Noise understood as an unwanted admixture to a useful signal usually leads to worse processing and interpretation of the signal. Using knowledge of the frequency spectrum of the signal and noise, unwanted noise can be suppressed and thus ideally improve the quality of the overall signal.

Frequency filters

Frequency filters are filters that suppress part of the frequency spectrum of the passing signal. Ideally, it would completely suppress the unwanted part of the spectrum and not affect the desirable part at all, but this state cannot be achieved.

Transfer filter

To mathematically describe the behavior of a filter, its transmission can be used. The **transmission** of filter *A* is defined as follows:

$$A = \frac{U_2}{U_1}$$

where U_1 is the voltage at the filter input and U_2 is the corresponding voltage at the filter output. Assuming that the given filter is linear in the sense that the filter parameters are independent of the input voltage, one can conceptually set the input voltage equal to one and such a transfer will describe the behavior of the filter at any voltage. From a somewhat more complicated theory, it follows that from the assumption of linearity of the filter, for any periodic signal, its change after passing through the filter can be determined by intersecting the responses to individual harmonics. For that reason, it is useful to use the transmission as a function of frequency:

$$A(f) = \frac{u_2(t)}{u_1(t)}$$

where $u_1(t)$ is the voltage at the input (harmonic with frequency *f*, unity amplitude and zero phase shift) and $u_2(t)$ is the voltage at the output (harmonic with frequency *f* for the linear filter). In technical practice, the phase shift must also be taken into account, which is most often realized using complex phasors.

Frequency filter types

Low pass filter

A low-pass filter (low-pass) passes, i.e. does not suppress, only those frequencies in the signal spectrum that are lower than **the cut-off frequency** f_0. Conversely, frequencies that are higher than f_0 will not pass through. For the transfer of an ideal low-pass filter, the following should apply:

$$A(f) = \begin{cases} 1, & f \le f_0 \\ 0, & f > f_0 \end{cases}$$

High \-pass filter

The high-pass filter (high-pass filter) is actually an addition to the supplemental filter type. The ideal transfer function is:

$$A(f) = \begin{cases} 0, & f \le f_0 \\ 1, & f > f_0 \end{cases}$$

Band-pass

A band-pass filter only passes those frequency components of the signal that are between the cut-off frequencies (in the frequency band), and filters out the other frequencies. The cutoff frequencies are denoted by f_1 and f_2. For the ideal transmission of a band-pass filter:

$$A(f) = \begin{cases} 1, & f_1 \le f \le f_2 \\ 0, & \text{otherwise} \end{cases}$$

Band Retention

A band-stop (notch filter) is the exact opposite of a band-pass filter. It passes everything except the band located between the cutoff frequencies *f 1* and *f 2*.

$$A(f) = \begin{cases} 0, & f_1 \le f \le f_2 \\ 1, & \text{otherwise} \end{cases}$$

Implementation of filters

Custom filters can be implemented in several ways:

- passive electrical filters,
- active electrical filters,
- digital filters.

Passive electrical filters are the simplest way to implement filters. It is a series-parallel connection of capacitors, resistors and in some applications even coils. A filter is easy to describe by methods from elementary electrical circuit analysis and is usually easy to design. The disadvantage is that it is difficult to implement really high-quality filters and that the transmission on such a filter is always less than one, i.e. the signal is always more or less attenuated.

Active electrical filters are made up of passive filters supplemented with active elements, in usual applications with operational amplifiers. For example, feedback can already be used in such filters, filters can work with much weaker signals and much better filter quality can be achieved. On the other hand, filters require a high-quality power supply, usually symmetrical, their design is more difficult, and active filters for very high frequencies are more difficult to implement.

Digital filters are based on the digitization of the signal and the subsequent processing of the spectrum of the digitized signal by mathematical operations in the computer. The advantage is that it is also possible to implement filters that would be impossible to build practically and in principle, the disadvantage is the limitation of analog-to-digital conversion.

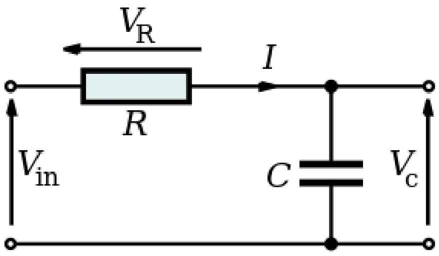
In practice, all three groups of filters are used in cooperation according to a specific technical task.

Passive electrical filters

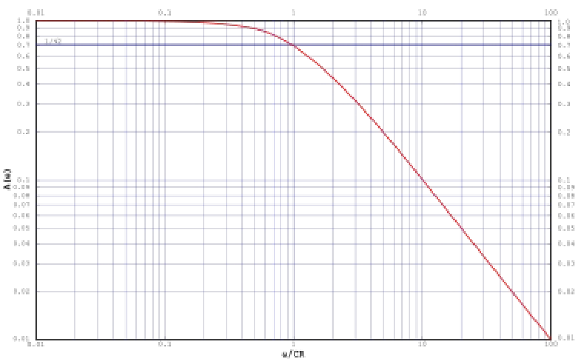
The basic elements for passive electrical elements are capacitor (C), inductor (L) and resistor (R), in practice realized by capacitor, coil and resistor. The basic blocks are cells formed by a pair of elements connected in series or in parallel. So we distinguish series and parallel cells RC, RL and LC. Filters of the upper or lower type can be realized from RC and RL elements. complements the filter, LC elements can be used to create a band pass and a band stop.

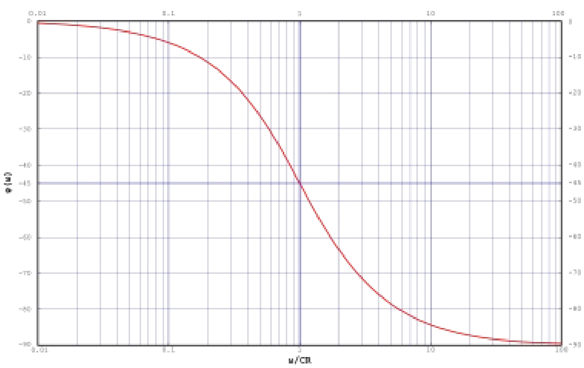
Lower filter realized by series RC cell

The electrical diagram of the low-pass filter is shown in the following figure:



The transfer function of this filter is more complex because the ratio of the electrical resistance of the resistor and the capacitance of the capacitor does not change stepwise depending on the frequency. In addition, there is a phase shift. The transfer characteristics for amplitude and for phase are in the following figures:





Several significant values characterizing the filter can (in general) be defined in the amplitude characteristic. The **cut-off frequency** is determined as the frequency value at which the transmission drops by 3&dB. Another significant value is the **rate of decline** of transmission in the right part of the graph, usually called the **slope**. The greater this drop, the better the filter, because it better separates the frequencies it is supposed to pass from the frequencies it is supposed to suppress. The steepness is constant for a certain type of filter regardless of the specific values of the elements used, it is actually a property of the mathematical description. Here we are talking about the **order of the filter**, the more complicated the filter is to connect and therefore the more complicated the description, the higher order the filter can be. Mathematically, the order of the filter is actually the number of so-called poles including the multiplicity of the transfer function of the filter, i.e. the RC filter is a filter of the 1st order.

An RC cell has a defined **time constant** τ. This is related to the behavior of the RC cell as a so-called integration cell, i.e. practically mainly with the charging of the capacitor C during a step change in the voltage at the input of the cell. Since the ideal capacitor follows an exponential and theoretically approaches the steady-state value only asymptotically v, the charging rate is defined as reaching a certain value that corresponds to 63% of the steady-state value. This choice is given by theoretical considerations, thanks to which the time constant can be determined very easily as:

$$\tau = RC$$

The time constant chosen in this way is also related to the cut-off frequency:

$$f_0 = \frac{1}{2\pi\tau}$$

Thus, the cutoff frequency is determined by the relation:

$$f_0 = \frac{1}{2\pi RC}$$

High pass realized by a series RC cell

The implementation of the high-pass filter is similar to the implementation of the low-pass filter, only the positions of the resistor and capacitor are reversed in the connection. The properties of such a filter are similar.

Bandpasses and holdups

Passive filters of the bandpass or holdup type are usually implemented using an inductor and a capacitor, usually in conjunction with a resistor. Usually, it is a matter of using the fact that by connecting an inductor and a capacitor, a resonant circuit is created, which has a maximum impedance at the resonant frequency, or admissions.

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Literature

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- Petr Heřman: Biosignály z pohledu biofyziky
- ORSÁG, Petr – PUNČOCHÁŘ, Josef. *Teoretická elektrotechnika II* [online] . 1. edition. Ostrava : FEI VŠB-TUO, 2011. 308 pp. Available from <http://mi21.vsb.cz/sites/mi21.vsb.cz/files/unit/teoreticka_elektrotechnika.pdf>. ISBN ..