

# Qucs

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## A Tutorial

### Active Filters Design with Qucs and Qucsactivefilter

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# Introduction

The purpose of this manual is to explain bases of active filter design methods using **qucs-activefilter** tool. You can start **qucs-activefilter** by clicking in the Qucs main menu *Tools->Active Filters*. Qucsactivefilter provides easy and powerful tool for manipulations with active filters. Qucsactivefilter can operate only active filters. For passive filter use Qucsfilter instead. Basic explanations about active filters could be found here: [https://en.wikipedia.org/wiki/Active\\_filter](https://en.wikipedia.org/wiki/Active_filter) Qucsfilter builds active filters circuits based on RC-components and operational amplifier (opamp). Qucsactivefilter uses ideal opamps. It uses 1-3 opamps per filter section. The number of opamps depends on selected approximation type, filter type and topology.

## Interface description

The main window of this tool is shown in the Figure 1

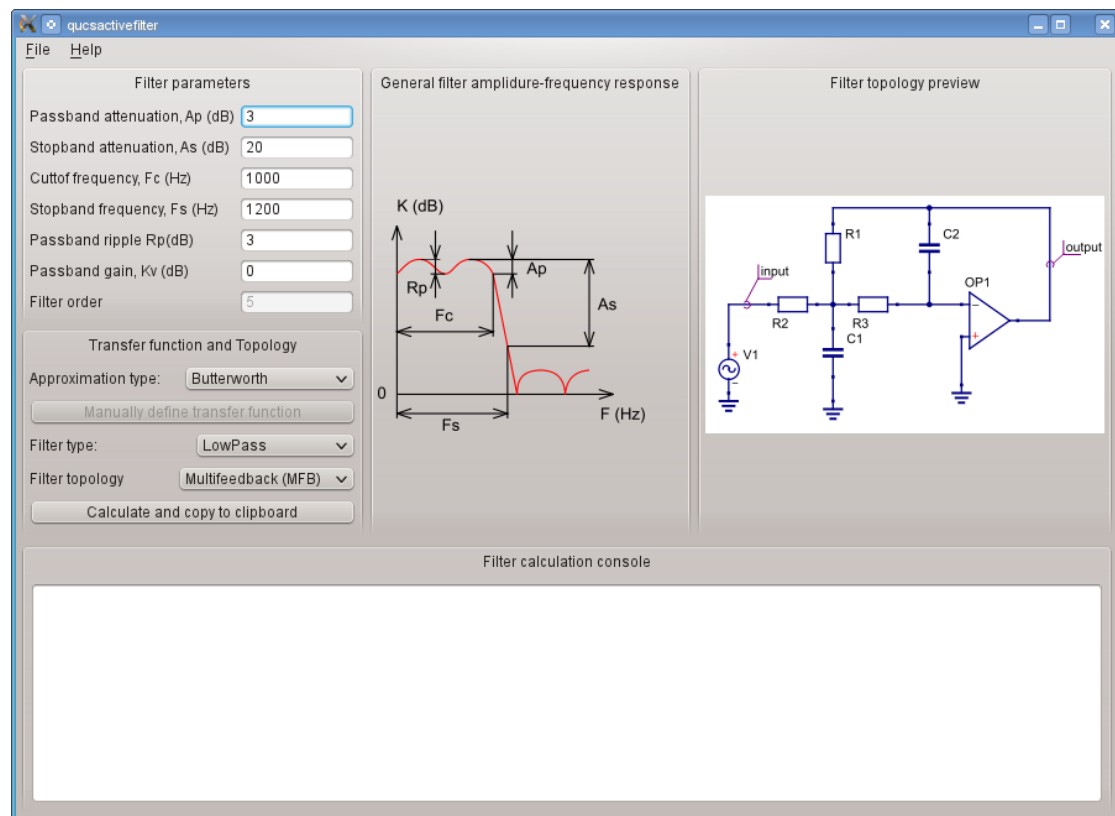


Figure 1: Qucs-Activefilter main window

Main windows contains five groups of controls:

1. Filter parameters input fields (left part of the window). You should filter frequency response parameters here. These parameters are shown on the frequency response preview. This part of the window also contains *Calculate and copy to clipboard* push button.
2. Filter frequency response preview (middle part of the window).
3. Filter topology preview (right part of the window). You can see common form of the filter section topology here.
4. Calculation console. Filter order, poles/zeros list and part list are printed here if filter calculation is successful. Part list contains RC-elements values for each section of the filter.
5. Menu bar. You can access *File->Exit* and get short *Help* here.

## Filter transfer function

Active filters are characterized by transfer function in frequency domain. Common form of the filter transfer function is given here:

$$H(s) = \frac{b_ms^m + b_{m-1}s^{m-1} + \dots + b_2s^2 + b_1s + b_0}{a_ns^n + a_{n-1}s^{n-1} + \dots + a_2s^2 + a_1s + a_0} \quad (1)$$

Filter order  $N$  is:

$$N = \max(m, n) \quad (2)$$

Filter order determines the number of filter sections and filter circuit complexity. Active filter consists of  $k = N/2$  2-nd order section and  $k = N\%2$  1-st order sections.

Zeros of the transfer function are roots of numerator. Poles are the roots of denominator. We need to know filter transfer function to determine components (resistors and capacitors — RC) values of the active filter circuit.

Qucsactivefilter uses user-defined filter parameters in frequency domain to determine filter order, transfer function and RC-elements value for each section of the filter.

Qucsactivefilter uses filter design algorithms provided by [D. Johnson, J. Johnson, H. Moore A handbook of active filters — Prentice-Hall, Inc, Engewood Cliffs., N.J.07632, USA, — 1980].

## Filters parameters explanation

We need to define following four groups of parameters to calculate active filter:

1. Frequency response approximation type. Butterworth, Chebyshev, Inverse Chebyshev, Cauer (Elliptic) and Bessel filters are available.
2. Frequency response parameters: filter gain and bandwidth.
3. Filter topology. Sallen-Key, Mutifeedback (MFB) and Cauer topologies are available.
4. Filter type. Low-pass, high-pass, band-pass and band-stop filters are available.

All of these parameters are presented in the left side of Qucsactivefilter main window.

Different filter topologies have different number of opamps, resistors and capacitors per section. Sallen-Key and MFB topologies are the most suitable for Chebyshev and Butterworth filters.

Frequency response parameters differ for various filter types (low-pass, high-pass, band-pass, band-stop) and approximations.

Frequency response of low-pass and high-pass filters has following parameters:

1. Cutoff frequency  $F_c$
2. Passband attenuation  $A_p$
3. Passband ripple  $R_p$  (for Chebyshev and Cauer filters only)
4. Stopband attenuation  $A_s$
5. Stopband frequency  $F_s$
6. Passband gain  $K$

Qucsactivefilter estimates filter order automatically for Chebyshev, Butterworth and Cauer filter. Minimal order that provides required frequency domain parameter is used. You don't need define filter order manually for these approximations. filtersOrder could not be determined automatically for Bessel filter. You should define filter order for the Bessel filters manually.

Frequencies should be defined in Hertz (Hz). Attenuation and ripple should be defined in decibels (dB).

Frequency response of band-pass and band-stop filters has following parameters:

1. Upper cutoff frequency  $F_u$
2. Lower cutoff frequency  $F_l$
3. Transient bandwidth  $TW$  is gap between pass band and stop band.
4. Passband ripple  $R_p$  (for Chebyshev and Cauer filters only)
5. Stopband attenuation  $A_s$
6. Passband gain  $K$

Only Chebyshev, inverse Chebyshev and Cauer filters have ripple in pass band. Butterworth and Bessel have no. Cauer filter has ripple in stop band too. Qucs-activefilter suggests that stop band ripple less than stopband attenuation. All of these parameters you can see in frequency response preview in the middle part of the Qucsactivefilter main window.

## Filter design example

For example, consider Chebyshev low-pass filter with following parameters:

1. Cutoff frequency: 2 kHz;
2. Passband ripple: 2 dB;
3. Stopband frequency: 2.2 kHz
4. Stopband attenuation: 20 dB
5. Passband gain: 0 dB

At first step we need to put these parameters into corresponding input fields. in the left part of the main window. Then we need to select Chebyshev approximation in the *Approximation type* combo box, select Sallen-Key topology in *Filter topology* combo box and select low-pass filter in *Filter type* combo box. The next figure presents main window with filled input fields for our example.

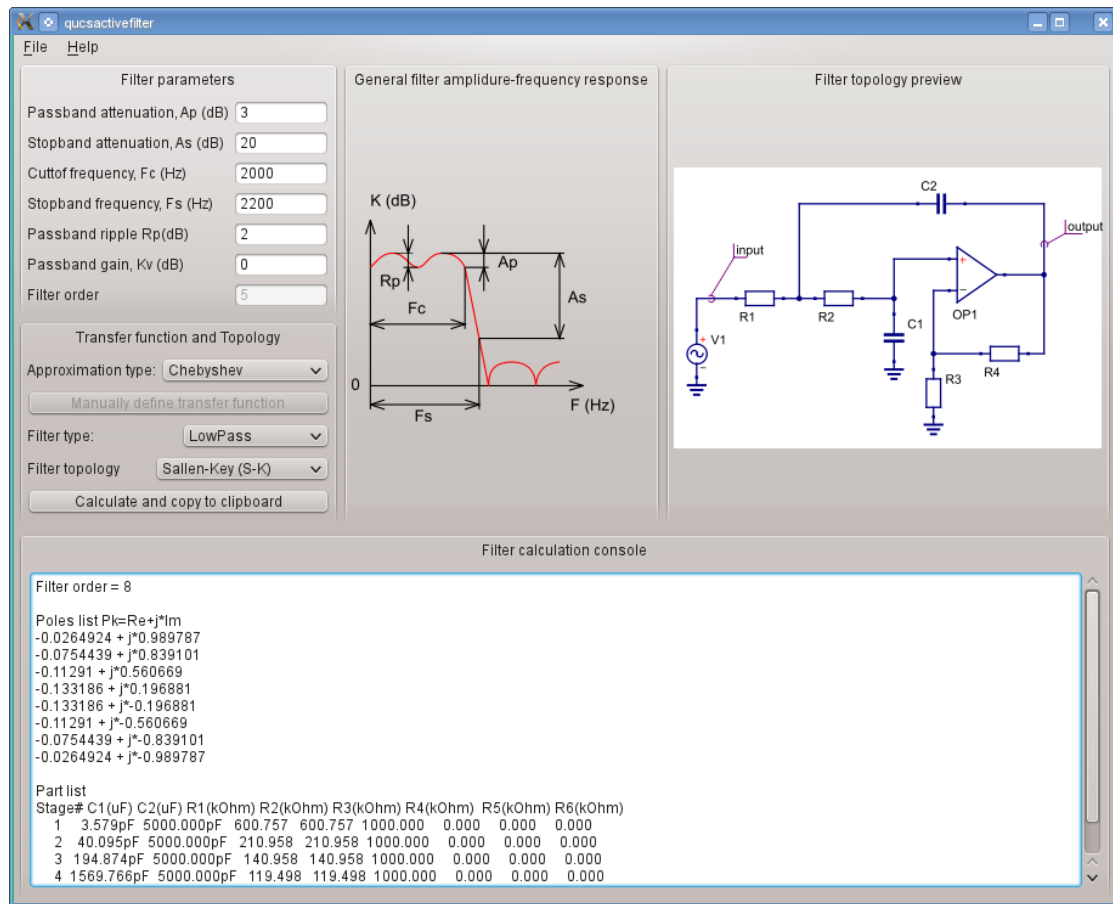


Figure 2: Sallen-Key low-pass filter design example with Qucsactivefilter

As all input fields are filled, we can press *Calculate and copy to clipboard* button. After this button is clicked, we can see calculation results (transfer function poles and zeros list and part list) in the bottom part of the main window. Filter is calculated successfully. If there was errors during filter calculation, calculation process is aborted and warning message box appears. You should change frequency response parameters and/or filter topology in such case.

You can use components values from the part list for active filter simulation with external circuit simulation program.

Now filter schematic is in the system clipboard. We can switch back to the Qucs schematic window and press  $\text{Ctrl} + V$  or *Edit->Paste*. Filter schematic appears (Fig. 3)

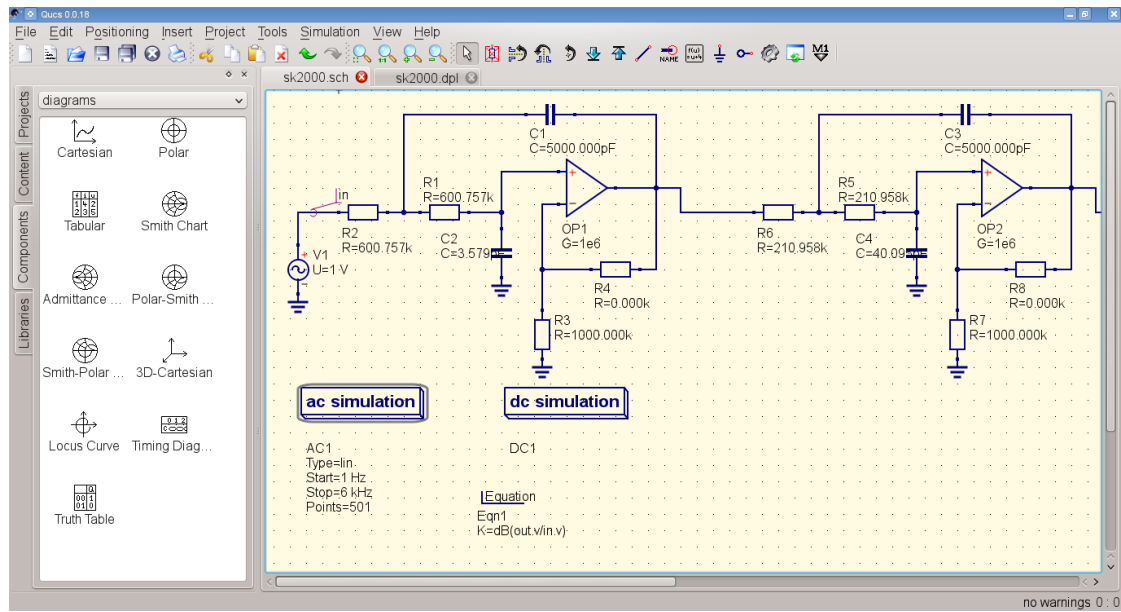


Figure 3: Sallen-Key filter schematic in Qucs

This schematic already contains AC and DC simulations and equation for the filter gain calculation ( $K$  parameter). We can press F2 and simulate it. Simulation completes and we can switch to the display page and place Cartesian plot on it. If we place  $K$  graph on this plot, we can see frequency response of the filter (Fig.4). This frequency response meets all required parameters.

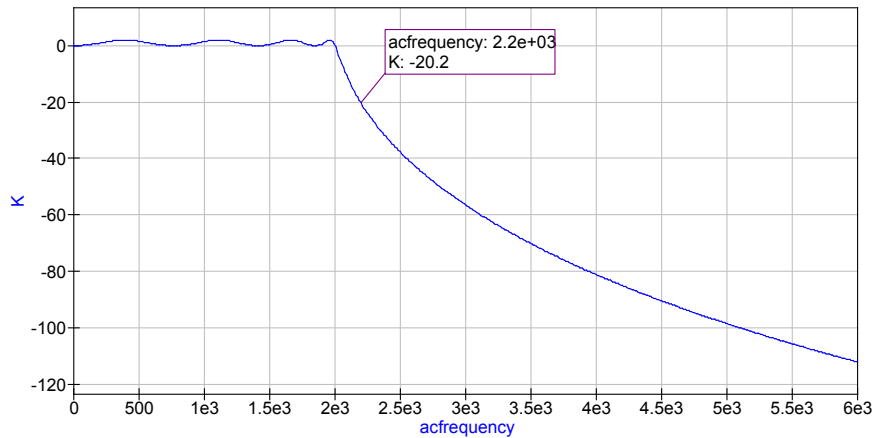


Figure 4: Filter simulation results (frequency response)

## Manual transfer function definition

Using Qucsactivefilter you can define numerator and denominator coefficients manually. It's need to select *User defined* transfer function in *Approximation type* combo box. *Manually define transfer function* button becomes available. Transfer function setup dialog (Fig.5) appears after the click on this button.

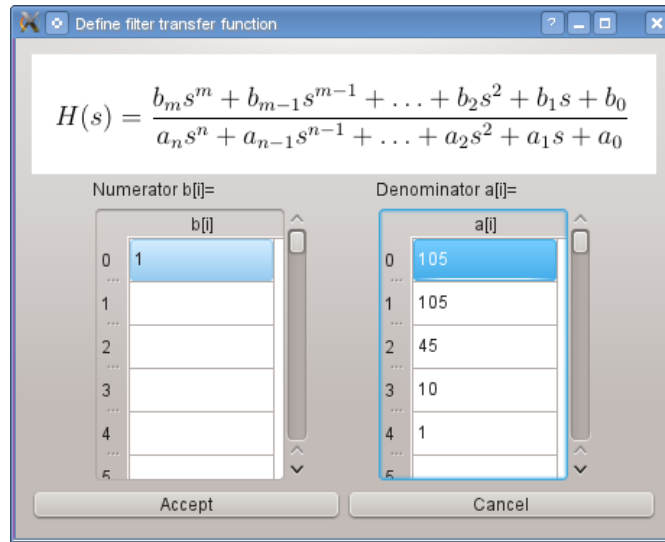


Figure 5: Manual transfer function definition

You can fill two columns of the table and define numerator ( $a_i$ ) and denominator ( $b_i$ ) transfer function coefficients. Then you can press *Accept* button and calculate active filter with given topology.

Presented example (Fig.5) implements the following transfer function:

$$H(s) = \frac{1}{s^4 + 10s^3 + 45s^2 + 105s + 105} \quad (3)$$

This transfer function implements 4th-order Bessel filter.

## Conclusion

Qucsactivefilter tool was considered. You can easy design active filter with this tool and Qucs. Report about any bugs for Qucsactivefilter to Vadim Kuznetsov (E-mail: [ra3xdh@gmail.com](mailto:ra3xdh@gmail.com)).