

# FILTERD: ANALOG FILTER DESIGN LABORATORY FOR TEACHING AND RESEARCH

Jan Chojcan<sup>1</sup>, Jacek Izydorczyk<sup>2</sup>, Adam Dustor<sup>3</sup>

**Abstract** — *FilterD is a software for analog filter design and investigation, which has proved to be effective for both educational and practical design purposes. It is used in undergraduate engineering courses, in graduate study and general research. The programme is easily extendable, i.e. it is possible to use computed filter data for non-standard computations as the system is implemented in Mathcad math-programming language. FilterD can compute low-pass, high-pass, band-pass and band-reject active and passive filters. It is possible to use Butterworth, Chebyshev, Bessel and Caue approximations of ideal filter. FilterD has been in use for four years. It is in the everyday use for undergraduate and graduate filter design course, as a design tool for many dissertation projects and have been downloaded by about 80k professional users by WWW net.*

**Index Terms** — *filter design, Mathcad application, analog filters, filter realisations.*

## INTRODUCTION

Filter design is a well-known domain of science. There are many methods of filter design, however most of them require a lot of complicated calculations. It is no wonder that many engineers tried to implement these methods as a software application to ease and speed up the design stage. The reason for this is quite obvious, the calculations required to design an analog filter of high order are so complicated and long that it is impractical to do it manually. Although there are tables of filter coefficients, more versatile approach to filter design requires the stand-alone application that can compute filter parameters for any entry filter values. FilterD is an example of such application but additionally it helps its users to understand how filters are designed which is its great educational virtue.

FilterD is a programme requiring the use of Mathcad, which is a very popular multifeatured and powerful scientific computational programme with a wide range of features. Actually FilterD is a set of worksheets that run under the shell of the Mathcad. Originally it was written to provide a multifeatured versatile design utility for the realization of active and passive analog filters. FilterD can compute low-pass filters, high-pass filters, band-pass filters and band-reject filters. For all filter types it is possible to use Butterworth and Chebyshev approximations. For low-pass filters Caue (elliptic) approximation is available. At the

beginning of design it is necessary to determine the parameters of designed filter, i.e. pass-band and stop-band frequencies and attenuations. For example for low-pass filter it is required to specify two frequencies and two attenuations. In case of band-pass and band-reject filters four frequencies and two attenuations are required. Approximations of ideal filters are computed based on either a Butterworth or Chebyshev prototype. In both cases required filter orders are displayed. FilterD can plot amplitude response of a filter (either linear or logarithmic), phase, group delay, normalized pole-zero diagram and step function response. The great advantage of this application is the fact that it not only computes coefficients of filter transfer function but also physical realisations both passive and active. Active realisations are provided for cascaded biquads and parallel-connected biquads. Passive realisations are provided for lossless ladders with a single resistor at the input or output, with two equal-valued resistors and with two unequal-valued resistors. For this latter case the maximum permitted ratio of resistors is displayed. As all calculations use Mathcad, all of the equations used during design procedure are displayed and available for the user, which helps to understand how the filter is designed.

## Technical information

FilterD is a collection of Mathcad worksheets for analog filter design and it can be easily obtained from [http://www.iele.polsl.gliwice.pl/projektant\\_filtrow/](http://www.iele.polsl.gliwice.pl/projektant_filtrow/) or from <http://www.mathsoft.com/mathcad/library/world.html>. The programme is copyrighted and may be freely used and distributed by individuals as long as no charge is made. All other rights, including commercial usage, are reserved by the author. The programme is distributed as a "FilterD.zip" file that contains the "FilterD" folder which should be copied into the root directory of the C: drive. The resulting filter structure should have "secrets" as a subdirectory of "FilterD". The "FilterD" folder contains a setup.txt installation manual and a filters.mcd Mathcad file that consists of links to the individual .mcd files hidden in the "secrets" subdirectory. As some of the files have long names they may not be handled properly by MSDOS versions of unzipping utilities.

FilterD works under version of Mathcad 6.0 Professional Edition and higher. Unfortunately it cannot be run on any of the Standard Editions of Mathcad. For those

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who do not have a copy of Mathcad it is suggested to obtain a free copy of Mathcad Explorer from the Mathcad website. Although it does not allow to save data to disk but permits to design all types of filters except the Cauer ones.

### APPLICATION EXAMPLE

To understand how FilterD works an example of filter design is presented. At first filters.mcd Mathcad file should be run and then it is possible to choose one of five filter types as it can be seen in Figure 1.

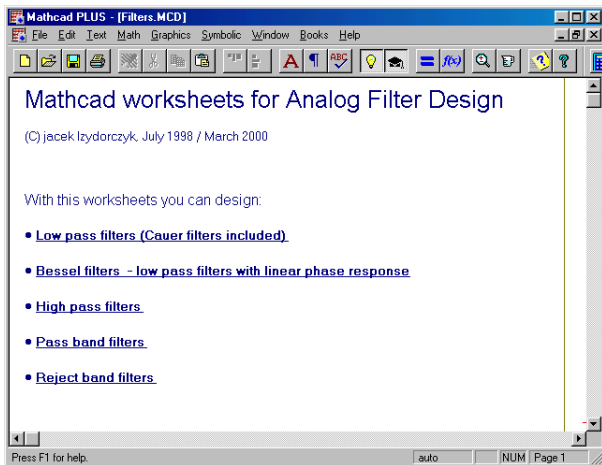


FIGURE 1  
MAIN FILTERD WINDOW.

If for example low-pass filter is designed then the first option should be chosen. Input specifications for this filter with a passband edge of 10 kHz and a stopband edge of 12 kHz and with a passband ripple of 2 dB are shown in Figure 2. The minimum stopband attenuation is 35 dB. Subsequently it is possible to choose the type of approximation either Butterworth or Chebyshev if the required order of filter is too high for low-pass filters Cauer approximation is available. To meet these specifications a 24<sup>th</sup> (for Butterworth) or 9<sup>th</sup> (for Chebyshev) order filter is required. The amplitude response for a Chebyshev approximation is shown in Figure 3. FilterD computes also phase response, group delay shown in Figure 4, normalized pole-zero plot on Gauss plane in Figure 5 and step function response in Figure 6. After all previously mentioned calculations it is possible to choose physical implementation of filter in Figure 7. FilterD can compute six different filter implementations, four passive LC ladders, i.e. terminated at the input, at the output, terminated at both ends and matched and terminated at both ends as well as two active: parallel and cascaded. For all implementations values of capacitors and inductors are displayed as a row vector. Calculated passive implementations are shown in Figures 8,9,10,11 whereas active filters in Figure 12.

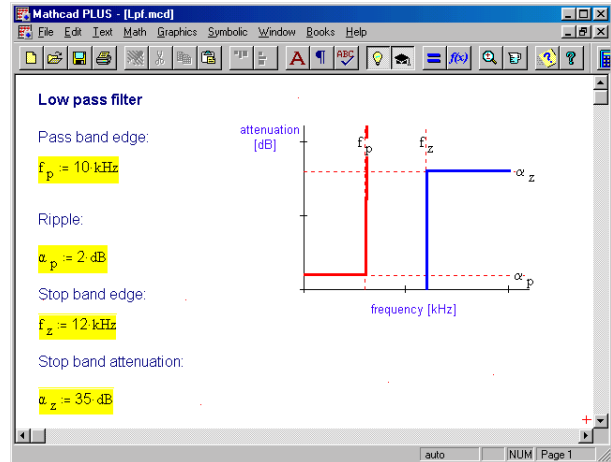


FIGURE 2  
INPUT SPECIFICATIONS FOR A LOW-PASS FILTER.

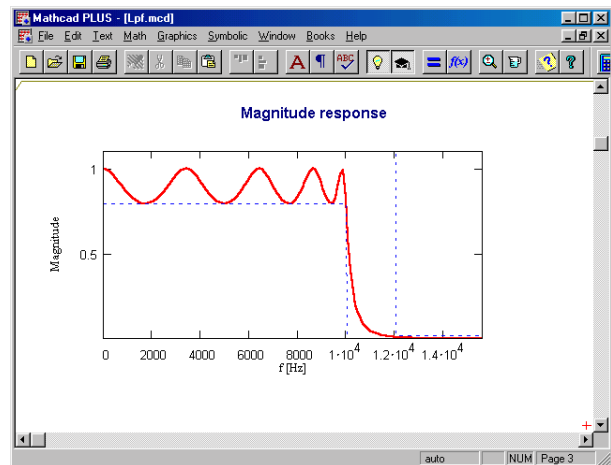


FIGURE 3  
AMPLITUDE RESPONSE FOR CHEBYSHEV APPROXIMATION.

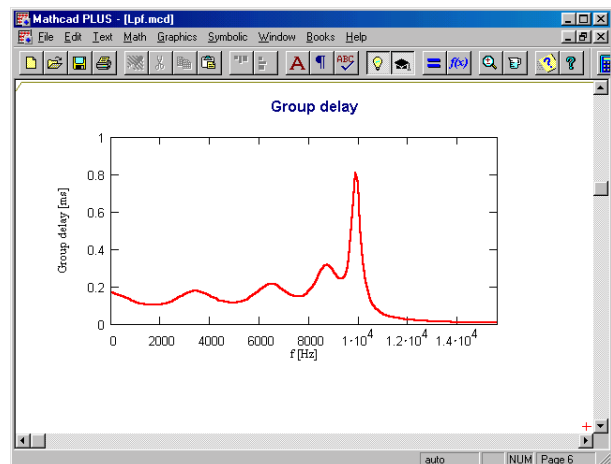


FIGURE 4  
GROUP DELAY OF DESIGNED FILTER.

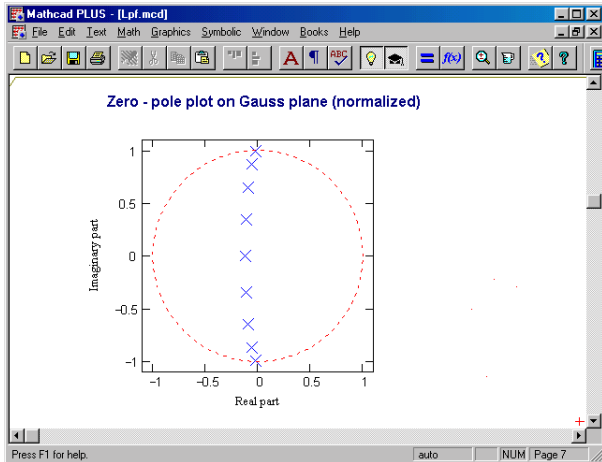


FIGURE. 5  
NORMALIZED POLES AND ZEROS OF TRANSFER FUNCTION.

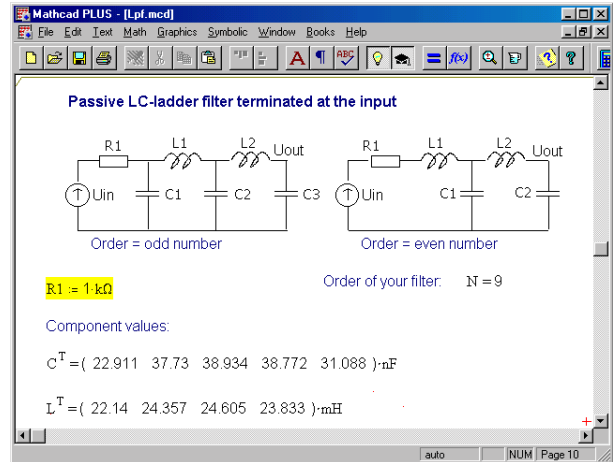


FIGURE. 8  
PASSIVE LC-LADDER TERMINATED AT THE INPUT.

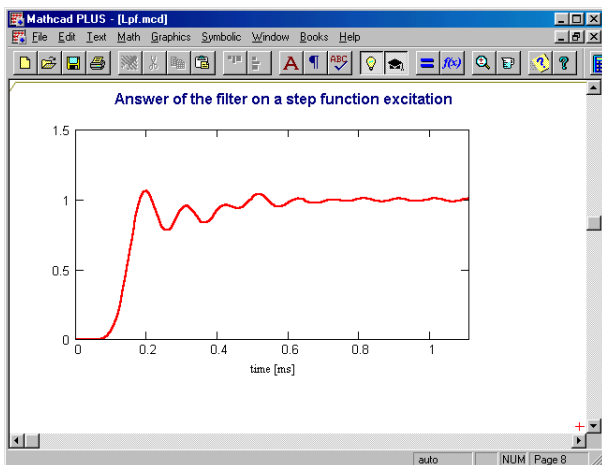


FIGURE. 6  
STEP FUNCTION RESPONSE FOR DESIGNED FILTER.

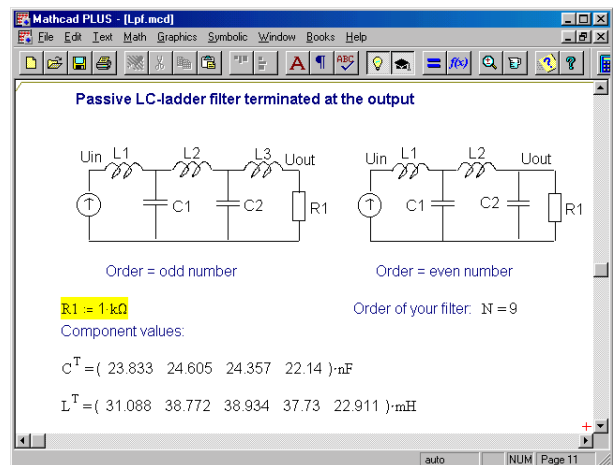


FIGURE. 9  
PASSIVE LC-LADDER TERMINATED AT THE OUTPUT.

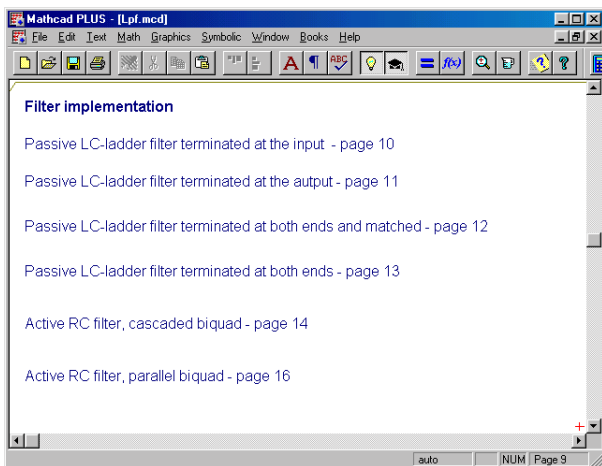


FIGURE. 7  
FILTER IMPLEMENTATIONS.

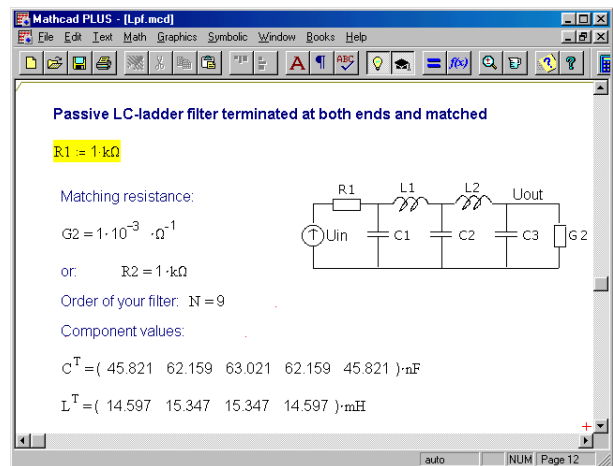


FIGURE. 10  
PASSIVE LC-LADDER TERMINATED AT BOTH ENDS AND MATCHED.

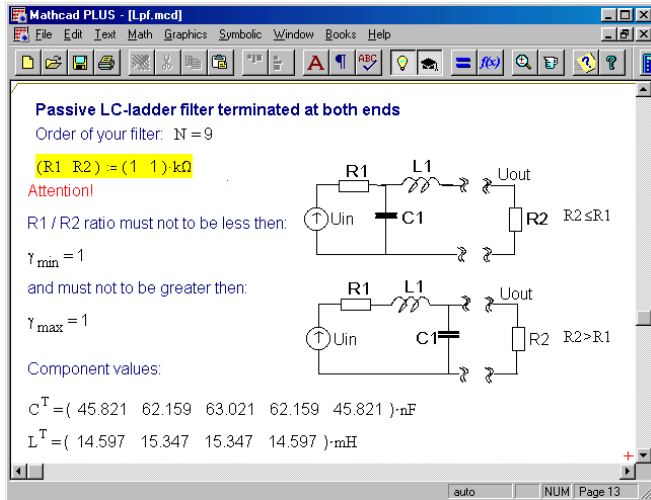


FIGURE. 11  
PASSIVE LC-LADDER TERMINATED AT BOTH ENDS.

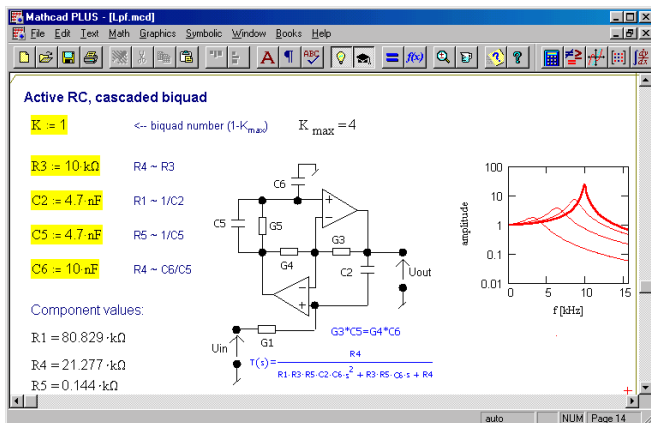


FIGURE. 12  
ONE OF THE FOUR CASCADED STRUCTURES FOR THE ACTIVE RC REALIZATION.

### COMPUTER-AIDED DESIGN OF ELECTRONIC CIRCUITS

Institute of Electronics of the Silesian University of Technology gives lectures on computer-aided design of electronic circuits. During this course students are taught how to design and first of all simulate electronic circuits. To pass this course they have to do three projects. The first is an implementation and full analysis, by means of SPICE programme, Ebers-Moll model of bipolar transistor. The second is an analysis of transistor Schmidt trigger. The third finally is a full design of analog active RC filter. Students have to not only compute transfer function of filter and values of individual elements but they also have to check by Monte Carlo method influence of each element on amplitude and phase response. Tolerance of resistors is 5% whereas tolerance of capacitors is 10%.

Students are encouraged to design the whole filter in Mathcad environment. As calculations of such filter are quite complicated most of them make use of FilterD, which is a software tool specially designed to support analog filter design. As all equations are available in FilterD, student can not only feed filter specifications but also see how it is designed. After filter design, students have to check an influence of nonideal operational amplifier on filter parameters.

Described course finishes with an exam but students who decided to do such filter in practice and its parameters met initial specifications are excused from this exam. One of constructed filters is shown in Figure 14.

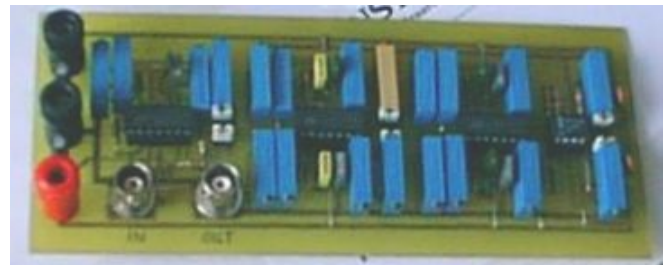


FIGURE. 13  
PRACTICAL IMPLEMENTATION OF ANALOG ACTIVE FILTER DESIGNED BY FILTERD.

### SUMMARY

Presented set of Mathcad worksheets has great educational virtues as all calculations and used equations are readily available. Its construction enables simple enhancement and implementation of other analog filters just by adding Mathcad worksheet with a new set of design formulas.

One of its educational applications in the Institute of Electronics of the Silesian University of Technology is to help students during computer-aided design of electronic circuits course where students are obliged to design active filters.

As FilterD is dedicated to analog filter design it seemed necessary to create another application in order to design digital filters. Such programme, which is also a set of Mathcad worksheets but only in Polish, is available from [http://www.iele.polsl.gliwice.pl/projektant\\_filtrow/Projektant%20Fitrow%20Cyfrowych.htm](http://www.iele.polsl.gliwice.pl/projektant_filtrow/Projektant%20Fitrow%20Cyfrowych.htm).

### REFERENCES

- [1] Izydorczyk J., Płonka G., Tyma G., "Teoria sygnałów", Wydawnictwo Helion, Gliwice, 1999.