Teaching Support of Electric Filters by Syntfil Package

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Abstract: This paper is a presentation of a system for analog filters design. The system consists of a special package Syntfil created in Maple™ environment. The package contains functions for solving particular tasks in the complete design procedure of electric filters. The package is designed to use in mathematical program Maple. However it is possible to use the package directly in MATLAB® using Extended Symbolic Math Toolbox in addition. A system of WWW interface for filter design based on Syntfil package is presented in the next part of the article. The WWW interface uses the above mentioned software. The system is proposed for education and research in Czech Technical University.

Key-Words: Analog Filter Design, Maple, MATLAB, Magnitude Approximation.

1 Introduction

Syntfil package [1, 5, 6, 4] is a good combination of a design system with suitable mathematical program. This combination gives possibility to follow results of separate design steps and in addition to treat them mathematically which is necessary for high-quality teaching software. The package was created in Maple programming language and originally destined for usage in Maple environment.

Users of MATLAB program can use Syntfil package directly in MATLAB too, due to Extended Symbolic Math MATLAB in addition. This toolbox incorporate symbolic computation of Maple engine into the numeric environmet of MATLAB. The computational engine underlying the toolboxes is the kernel of Maple, a system developed primarily at the University of Waterloo, Canada. These versions of the Symbolic Math Toolboxes are designed to work with MATLAB 6 or greater and Maple 8. There are two toolboxes: The basic Symbolic Math Toolbox is a collection of more than 100 MATLAB functions that provide access to the Maple kernel using a syntax and style that is a natural extension of the MATLAB language. The basic toolbox also allows you to access functions in the Maple linear algebra package. The Extended Symbolic Math Toolbox augments this functionality to include access to all nongraphics Maple packages, Maple programming features, and user-defined procedures as Syntfil package is. Engineers and teachers can use Syntfil package for complete analog filter design in both environments – Maple and MATLAB.

It is possible to run Maple in graphical or text mode in many platforms (Unix, Linux, Microsoft Windows, MacOs, ...). The text mode additionally enables "scripting mode" what is very advantageous for easy cooperation with external programs. An interface application have been made for using this design system in the internet environment [3]. It allows to use the system on computers with arbitrary operation systems, without any special software installation. The system can be used on every authorized computer with internet connection.

2 The Syntfil Package

The package contains functions for solving particular tasks in the complete design procedure of electrical filters. These functions allow computation of filter magnitude approximation, consecutive synthesis of filter electrical circuit and analysis of designed filter structure. The package includes:

- Set of functions for solving approximation tasks: normalization and computation of Butterworth, Chebyshev, Cauer (types A, B and C) and Inverse Chebyshev (types A and B) approximations, i.e. computation of gain and characteristic function.

- Set of functions for LC filter synthesis according to calculated gain and characteristic functions: computation of chain matrix from gain and characteristic function for a chosen filter termination, realization of LC ladder filter from chain matrix, transformation of LC ladder structure of normalized lowpass filter (NLP) to lowpass (LP), highpass (HP), bandpass (BP) or band-rejection (BS).

- Set of functions for cascade design of active RC (ARC) filters: NLP pole-zero frequency transformation, biquadratic functions forming (pole-zero pairing), determination of biquad cascading order, calculation of gain distribution and realization of particular biquads.

- Functions for resulting filter structures analysis including of Q-factors of inductors for LC ladders and DC open-loop gain and unity-gain frequency of operational amplifiers for ARC filters.

3 WWW Interface

User interface is based on WWW (client-server conception). The computation and interface program runs on the server and a user uses an arbitrary graphic client ⇒ standard WWW browser (Internet Explorer, Mozilla, Opera etc.) for results displaying only. This principle is illustrated on the flow-chart, figure 1.

The server runs under operation system Linux. The design of filters is solved using the above mentioned Syntfil package in the mathematical program MAPLE. The interface between MAPLE and WWW is built up on scripts in PHP. According to client requests the results are presented by dynamically created WWW pages. These pages are provided to the client by means of HTTP server Apache.

4 An Example of a Filter Design

Syntfil package can be used for seminar support, which is advantageous in comparison with single-purpose programs. Using the package, particular results of design can be mathematically treated and verified, directly in Maple worksheet environment. By this way, students get excellent tool for filter problem understanding. Students derive benefit frequently from the www application for solving semestral works. The application enables simple filter design using the Syntfil package without the necessity of any special software installation and demands no familiarity with MAPLE software.

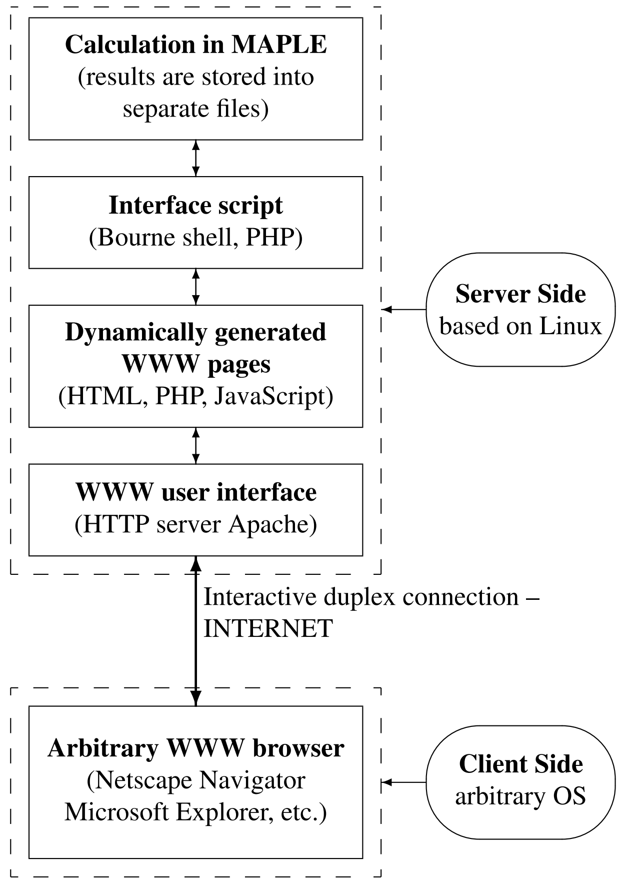


Figure 1: Principle of www application

The usage of the Syntfil package is presented firstly on a filter design in MAPLE environment. It is a design of a Chebyshev bandpass filter with following specification: $f_{-s} = 500\,\text{Hz}$, $f_{-p} = 1\,\text{kHz}$, $f_p = 2\,\text{kHz}$ and $f_s = 4000\,\text{Hz}$, $a_p = 3\,\text{dB}$ and $a_s = 20\,\text{dB}$. The same design is next illustrated using the internet application and finally using MATLAB environment.

Using the www application is illustrated on figure 2, where filter specification is set. The results of LC ladder filter synthesis for required magnitude approximation and filter termination is on figure 4. Analysis of the filter frequency responses is shown on figure **??**.

Commented listing of MAPLE worksheet follows (precise syntax of commands and computing abilities of Syntfil package are described in package help).

Activation of the SYNTFIL library:

```
> with(syntfil):
```

Input parameters of BP filter. Transformation to NLP.

```
> f_s,f_p,fp,fs:=500,1000,2000,4000:
> ap,as:=3,20:
> x:=BP2NLP(f_s,f_p,fp,fs,ap,as);
```

$$x := 3.500000000,\ 3,\ 20$$

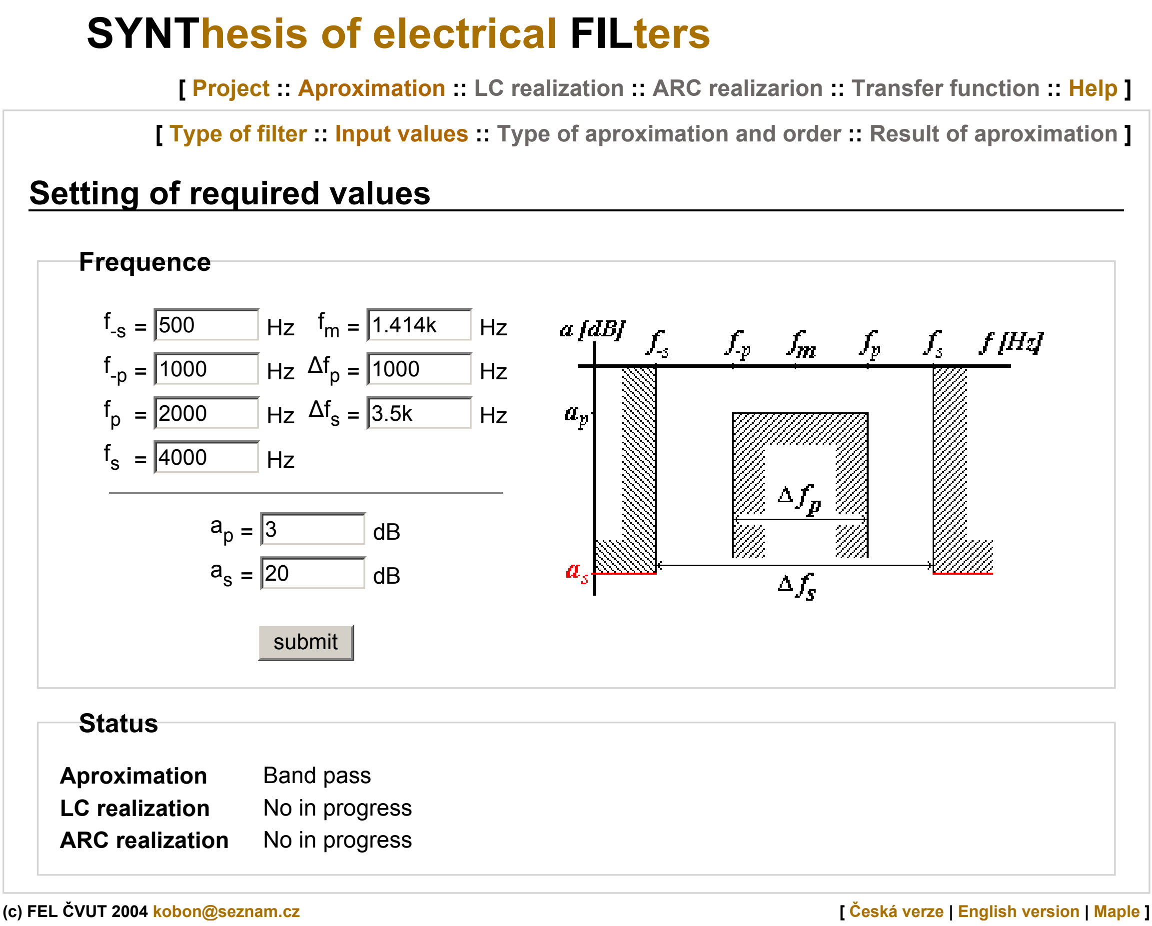


Figure 2: Setting of filter specification

Computation of the transfer function order for chosen type of transformation.

```
> xo:=ChebyshevNLPOrder(x);
```

$$xo := 2,\ 3.500000000,\ 3$$

Computation of power transfer ratio and characteristic function for Chebyshev approximation.

```
> g,p:=Chebyshev(xo,s);
```

$$g,\ p := 1.995256690\, s^2 + 1.286740343\, s + 1.412537542,$$
$$1.995256690\, s^2 + 0.9976283448$$

Synthesis of LC ladder structure. Termination of the filter on both sides – common, value of the resistor on source side R1=1, dropping from source side – front, Π ladder structure and filter parameters - g, p.

```
> elm:=DroppNLP(common,1,front,PI,g,p);
```

$$elm := \mathrm{table}([$$
$$1 = \mathrm{table}([Z = \frac{1}{s\,C1},\ orientation = shunt,$$
$$elements = \{C1 = 3.101258\}]),$$
$$2 = \mathrm{table}([Z = s\,L1,\ orientation = direct,$$
$$elements = \{L1 = 0.5338804\}]),$$
$$R1 = 1,\ R2 = 0.1721496,$$
$$type = LC\_NLP\_common])$$

Calculation of real elements for required bandpass LC ladder.

```
> R0:=100:
> elmbp:=ElemsBP(elm,R0,f_p,fp);
```

$$elemsbp := \mathrm{table}([$$
$$1 = \mathrm{table}([Z = \frac{1}{s\,C1 + \frac{1}{s\,L1}},\ orientation = shunt,$$
$$elements = \{C1 = 0.4935805\, 10^{-5},$$
$$L1 = 0.002565974\}]),$$
$$2 = \mathrm{table}([Z = s\,L1 + \frac{1}{s\,C1},\ orientation = direct,$$
$$elements = \{L1 = 0.008496970,$$
$$C1 = 0.1490549\, 10^{-5}\}]),$$
$$R1 = 100,\ R2 = 17.21496,$$
$$type = LC\_BP\_common])$$

Calculation of LC ladder transfer function.

```
> MakeH(elemsbp);
```

$$1.000000000\, s^2 / (0.5054044691\, 10^{-7}\, s^4 +$$
$$0.0002047910954\, s^3 + 9.393565023\, s^2$$
$$+ 16169.65678\, s + 0.3150783358\, 10^9)$$

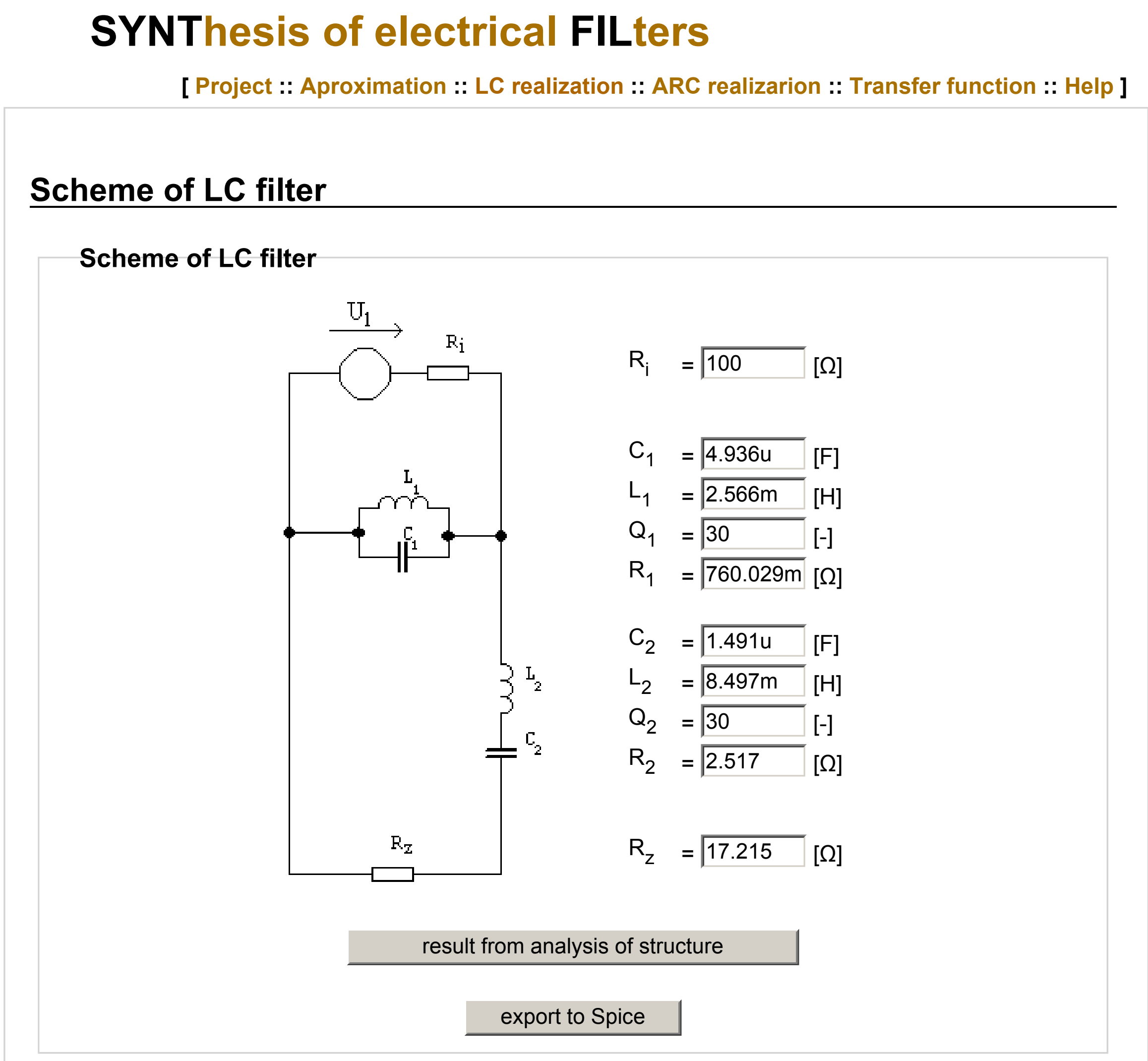


Figure 3: Resulting LC filter structure

Computation of transfer function poles.

```
> Gc,poles:=ChebyshevPoles(xo);
```

$$Gc,\ poles := 1.995256690,$$
$$[-0.3224498255 + 0.7771575702\,I,$$
$$-0.3224498255 - 0.7771575702\,I]$$

Computing of cascade parameters of the filter (ω_0, and Q of the particular biquadratic transfers functions – biquads).

```
> str:=NLP2BP(f_p,fp,Gc,poles);
```

$$str := \text{table}([$$
$$1 = \text{table}([Q = 4.550337,\ omega\_0 = 6762.652]),$$
$$2 = \text{table}([Q = 4.550337,\ omega\_0 = 11675.42]),$$
$$H0 = 5.188699, type = cascade\_BP])$$

Cascade filter structure synthesis – gain distribution and synthesis of particular biquads. Detailed description of ARCSynt function and schemes of used biquads are mentioned in Syntfil help.

```
> params:=table([C1=1e-8,h0=1]):
```

```
> strbp:=ARCSynt(str,params);
```

$$strbp := \text{table}([$$
$$1 = \text{table}([C2 = 0.1\,10^{-7},\ A0 = \infty,\ ft = \infty,\ R = 0,$$
$$R12 = 1665.043,\ R3 = \infty,\ R2 = 134572.6,$$
$$C1 = 0.1\,10^{-7},\ R11 = 67286.29, type = BP1]),$$
$$2 = \text{table}([C2 = 0.1\,10^{-7},\ A0 = \infty,\ ft = \infty,\ R = 0,$$
$$R12 = 1075.952,\ R3 = \infty,\ R2 = 77947.27,$$
$$C1 = 0.1\,10^{-7},\ R11 = 7511.254, type = BP1]),$$
$$type = ARC])$$

Calculation of ARC filter transfer function.

```
> h:=MakeH(strbp,s);
```

$$h := 0.10489565\,10^{-5}\,s^2/$$
$$((0.90548900\,10^{-6}\,s^2 + 0.0013457258\,s + 41.411144)$$
$$(0.58548173\,10^{-7}\,s^2 + 0.00015022508\,s + 7.9810268))$$

Simplification and normalization of rational expression – transfer function.

```
> 1/sort(normal(expand(1/h)));
```

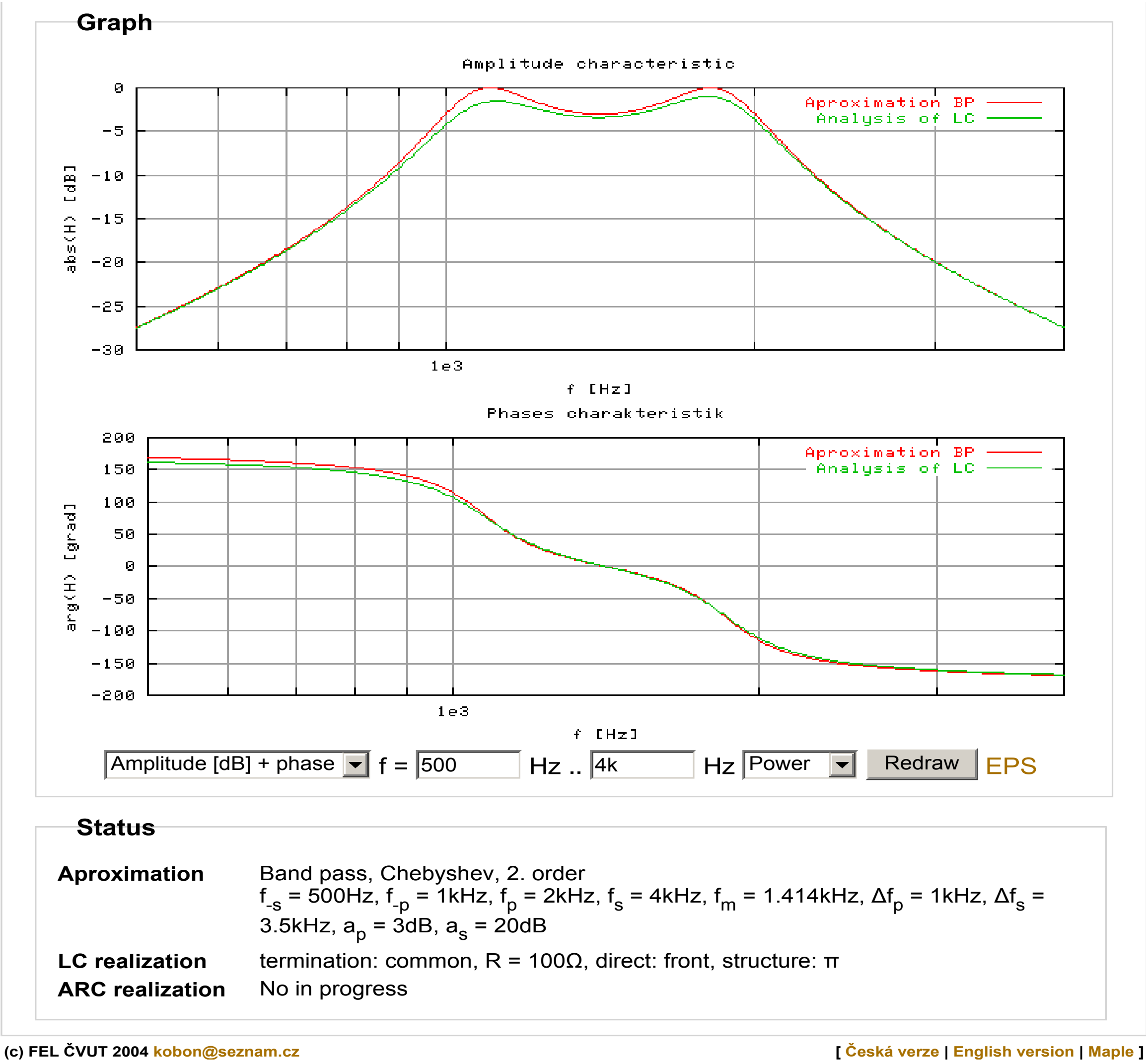
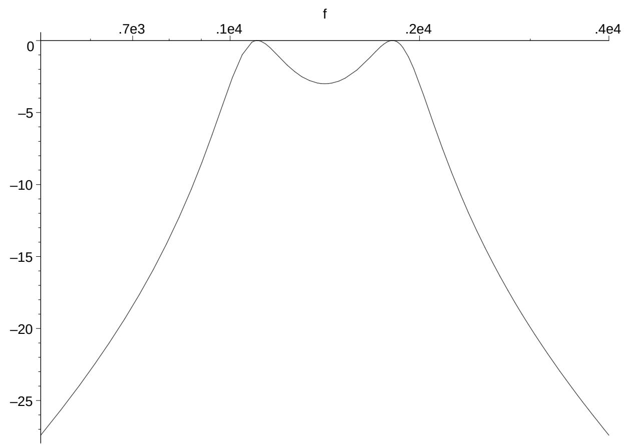


Figure 4: Frequency responses of ideal and real LC filter

$$s^2/(0.505404424\,10^{-7}\,s^4 + 0.000204791086\,s^3 + 9.3935643\,s^2 + 16169.656\,s + 0.315078308\,10^9)$$

Plot of magnitude frequency response.

```
> plots[semilogplot](MagnitudeHdB(h)
>  (2*Pi*f),f=500..4000);
```



The usage of the Syntfil package in MATLAB environment is presented on the same filter design. Listing of input file MATLAB commands follow.

```
DIGITS(10)
maple('with(syntfil)');
f_p = 1000;
fp = 2000;
x = maple('BP2NLP',500,f_p,fp,...
                           4000,3,20)
xo = maple('ChebyshevNLPOrder',x)
pol = maple('Chebyshev',xo,'s')
ELEMS = maple('DroppNLP','common',...
                 1,'front','PI',pol);
elems = strrep(ELEMS,'TABLE','table');
maple('evalf',elems,4)
R=100;
ELEMSBP = maple('ElemsBP',elems,...
                           R,f_p,fp);
elemsbp = strrep(ELEMSBP,'TABLE',...
                           'table');
```

```
maple('evalf',elemsbp,4)
poles = maple('ChebyshevPoles',xo)
STR = maple('NLP2BP',f_p,fp,poles);
str = strrep(STR,'TABLE','table');
STRBP = maple('ARCSynt',str,...
  'table([C1=1e-8,h0=1])');
strbp = strrep(STRBP,'TABLE','table');
maple('evalf',strbp,4)
h = maple('MakeH',strbp,'s')
ah = maple('MagnitudeHdB',h);
ezplot(maple(ah,'2*Pi*f'),[500,4000])
title 'MagnitudeHdB'
```

5 Conclusion

The Syntfil package includes all necessary tools for complex design of analog electrical filters. The package is drawn up in the view of filter design teaching at our university. Using the package, particular results of design can be mathematically treated and verified, directly in Maple worksheet environment. It is necessary for high-quality teaching software. This system is well structured and transparent but on the other hand it is less suitable for the routine work on design. It was the reason for the creation of new WWW interface which enables simple filter design using the Syntfil package without the necessity of any special software installation.

The package can be used in original environment of Maple, for which it was designed. It is also possible to use the package directly in MATLAB using Extended Symbolic Math Toolbox. MATLAB users can also derive benefit from the package by this way. Maple command outputs are interpreted in MATLAB as a string format. They should be converted first for direct processing in MATLAB environment. The interface tool (m-files) is now being prepared to provide this conversion. Syntfil utilization in MATLAB environment will be more user friendly using this interface.

Syntfil package is further being developed and extended about new functions. Syntfil package will be soon offered through MapleConnect™ program [2]. Light version of the package is available on requests by email to authors.

Acknowledgement

Development of new version of the www application was supported by grant of Ministry of Education, Youth and Sports No. 1N04075.Maple, MapleConnect are trademarks of Waterloo Maple Inc.MATLAB is a registered trademark of The MathWorks, Inc.All other trademarks are property of their respective owners.

References

[1] Bičák J., Hospodka, J.: *Syntfil – Synthesis of Electric Filters in Maple*, Proceedings of Maple Summer Workshop MWS 2004. Waterloo ON, Canada.

[2] http://webstore.maplesoft.com/
http://www.maplesoft.com/mapleconnect/

[3] Bičák J., Hospodka, J.: *Design of Electric Filters in Maple and through WWW*, Malta 2001, ICECS 2001 Proceedings, Vol. 3, pp. 1619–1622, ISBN 0-7803-7058-9.

[4] Bičák J., Hospodka J.: *Using Syntfil Package in MATLAB for Analog Filter Design*, Proceedings of the Digital Communications '04, Žilina: EDIS-vydavatelstvo ŽU, 2004, p. 25-29. ISBN 80-8070-165-2.

[5] Hospodka, J.: *Cascade Realization of Electrical Filters Using Syntfil Package*, Proceedings of the Digital Communications '03, Žilina: EDIS-vydavatelstvo ŽU, 2003, p. 25-29. ISBN 80-8070-165-2.

[6] Bičák, J.: *Cauer Approximation and Elliptic Integrals in Program Maple*, Proceedings of the Polish-Hungarian-Czech Workshop on Circuit Theory, Signal Processing, and Applications, Prague CTU, 2003, p. 1-6, ISBN 80-01-02825-9.