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MICROCOMPUTER BASED FILTER SYNTHESIS AND SIMULATION

Bogdan M. Wilamowski
University of Wyoming
Department of Electrical Engineering
Laramie, WY 82071-3295

ABSTRACT

A software called FILTERS is a teaching-aid for analog and digital filter synthesis. The software makes the solution of the filter approximation problem, which is traditionally carried out by means of tables and nomograms [1]-[3], easier and faster. The program demonstrates synthesis with various basic approaches such as Butterworth, Chebyshev, Inverse Chebyshev, Cauer and Thompson. Circuit implementation can be done using library of operational amplifier based first and second order stages. The program also has many additional options such as computation of complex and real roots, decomposition of polynomial ratios into partial-fractions or continued-fractions and many others. An important program feature is that after circuit synthesis, the SPICE input files can be automatically generated.

Software called FILTERS is a teaching-aid for analog and digital filter synthesis and is used as a teaching tool in both undergraduate and graduate courses. The program FILTERS is very easy to use, is highly interactive, and contains window graphics capabilities to give the student insight into synthesis of active analog filters and analog prototypes for digital filter design. FILTERS makes the solution of the filter approximation problem, which is traditionally carried out by means of tables and nomograms [1]-[3], easier and faster. The program demonstrates synthesis with various basic approaches such as Butterworth, Chebyshev, Inverse Chebyshev, Cauer and Thompson. Currently available software [4][5] has very limited circuit implementation. The program also has many additional options such as computation of complex and real roots, decomposition of polynomial ratios into partial-fractions or continued-fractions and many others which are appreciated by students when synthesis is compared to using "paper and pencil design".

The aim of the program is to develop better filter design intuition, and to accelerate the learning process. The program is capable of handling two fundamental problems in circuit synthesis: the approximation problem and the circuit implementation problem. Active circuit synthesis requires multiple trial-and-error steps with various methods of approximations and various practical circuit implementations. Traditional strategy with tables and nomograms may require several hours of "paper and pencil design" to check one possible approach. A detailed discussion of this material in class will not leave enough time to cover other important topics.

Classical approximation algorithms such as Butterworth, Chebyshev, Inverse Chebyshev, Cauer and Thompson was implemented. In the case of the Cauer elliptic filters, an algorithm using series expansions given by Antoniou [6] was used. For filter transformation from lowpass to bandpass and bandstop, the Geffe algorithm was utilized.

The software was developed to meet two goals:

1. to illustrate lectures using a IBM XT/AT compatible microcomputer with a Sharp QA-25 overhead PC-projector.
2. to allow use by students for homework and lab assignments running it on the IBM XT/AT type microcomputers in our computer-aided engineering laboratory.

In order to meet the first goal, a supporting graphical package was developed so that not only circuit parameters but also all possible circuit characteristics of interest can be graphically visualized. In order to meet the second goal, a program was developed menu driven utilizing a fully interactive multiple windows technique. There is no manual for this software, but after a short introduction students are able to use program based on the menus and the screen explanations

For the undergraduate level, the program was developed in such a way that students quickly understand the basic linear circuit behavior. They may observe transient and frequency circuit responses from which they gain understanding of the principles of the Laplace transformation. The program demonstrates the effects of zero and pole locations on the transfer function of a linear system in terms of the magnitude, phase and group delay frequency responses and the transient response for unit step and Dirac delta excitation.

More advanced synthesis is used in graduate courses. The program demonstrates synthesis with various basic approaches such as Butterworth, Chebyshev, Inverse Chebyshev, Cauer and Thompson. Based on the "brick wall" specification, filter order and then the lowpass prototype can be found. As the next step various filter transformations, lowpass to highpass, lowpass to bandpass and lowpass to bandstop, can be exercised. As a result, the numerator and denominator polynomials and the zero and pole locations of the transfer function are given. Also single and biquad forms, omegas, Qs, and frequency scaling factors are computed as well. After synthesis the frequency and transient responses can be plotted on the screen. Figures 1 to 4 shows the bandstop prototype frequency and transient responses for the filter with four different synthesis approaches. Figures 5 to 8 shows band bandpass prototype magnitude and phase frequency responses for the filter with four different synthesis approaches.

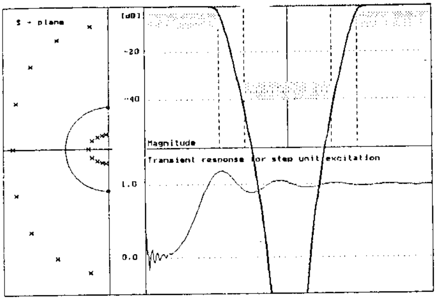

Fig. 1. Pole-zero locations, magnitude as function of frequency and transient response for the Butterworth 18 order bandstop filter with attenuation 40dB/3dB, w_c=10000Hz, bw_s=15000Hz, bw_p=26667Hz;

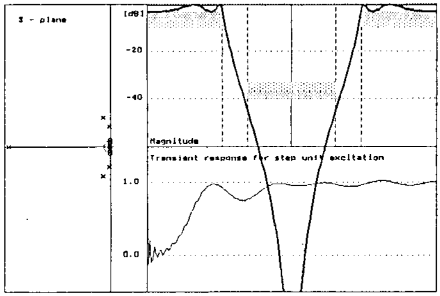

Fig. 2. Pole-zero locations, magnitude as function of frequency and transient response for the Chebyshev 10 order bandstop filter with attenuation 40dB/3dB, w_c=10000Hz, bw_s=15000Hz, bw_p=26667Hz;

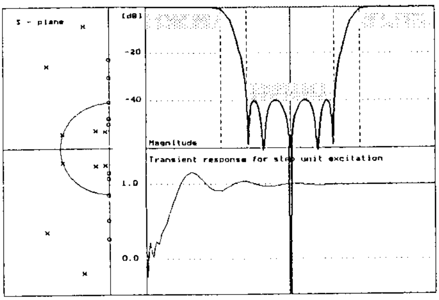

Fig. 3. Pole-zero locations, magnitude as function of frequency and transient response for the Inverse Chebyshev 10 order bandstop filter with attenuation 40dB/3dB, w_c=10000Hz, bw_s=15000Hz, bw_p=26667Hz;

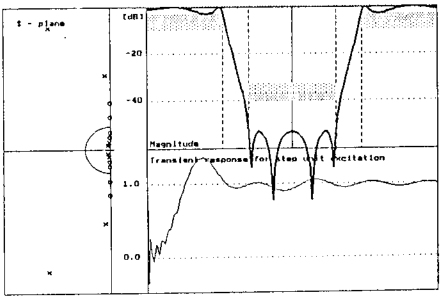

Fig. 4. Pole-zero locations, magnitude as function of frequency and transient response for the Cauer elliptic 8 order bandstop filter with attenuation 40dB/3dB, w_c=10000Hz, bw_s=15000Hz, bw_p=26667Hz;

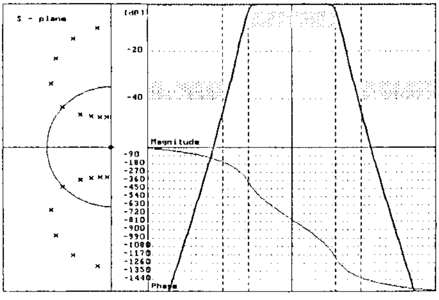

Fig. 5. Pole-zero locations, magnitude and phase as function of frequency for the Butterworth 18 order bandpass filter with attenuation 3dB/40dB, w_c=10000Hz, bw_p=15000Hz, bw_s=26667Hz;

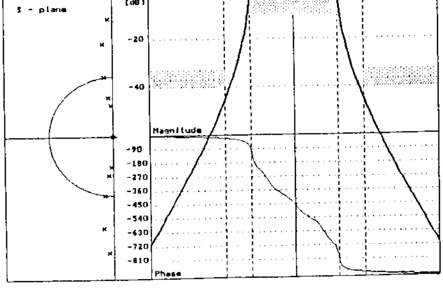

Fig. 6. Pole-zero locations, magnitude and phase as function of frequency for the Chebyshev 10 order bandpass filter with attenuation 3dB/40dB, w_c=10000Hz, bw_p=15000Hz, bw_s=26667Hz;

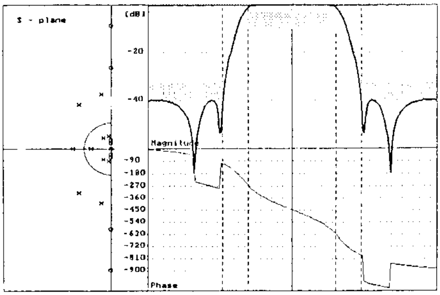

Fig. 7. Pole-zero locations, magnitude and phase as function of frequency the Inverse Chebyshev 10 order bandpass filter with attenuation 3dB/40dB, w_c=10000Hz, bw_p=15000Hz, bw_s=26667Hz;

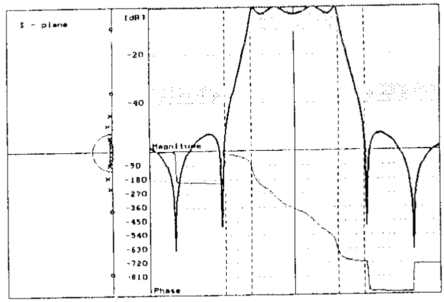

Fig. 8. Pole-zero locations, magnitude and phase as function of frequency for the Cauer elliptic 8 order bandpass filter with attenuation 3dB/40dB, w_c=10000 Hz, bw_p=15000Hz, bw_s=26667 Hz;

Magnitude, phase and group delay frequency responses are directly computed from the transfer function. The transient response is computed as the sum of inverse Laplace transformations for decomposed partial-fractions of the transfer function. It can be done for both step and Dirac delta excitation.

Practical circuit implementation can be done using cascade filter realization. Various first order and second order biquad subcircuits such as Tow-Thomas, Sallen-Key, Delyiannis-Friend and notch type circuits can be chosen by the students. For circuit description in most commercially available programs, symbolic notation is used. With this form a large circuit can be described, but circuit diagrams can not be visualized. The software FILTERS was developed so that practical circuit diagrams can be drawn on the screen for better student perception. Since practical circuits are too large to be drawn on the screen as a whole, the unique combination of block diagram and circuit diagram was developed using a multiple window approach. For example Fig. 9 and 10 illustrate practical implementation of Chebyshev bandpass filter which characteristics were presented in figure 6. By moving the highlighted area through the block diagram in the other window, a detailed circuit diagram of each block is displayed. Another program option is to look through various practical circuit implementations of the highlighted block.

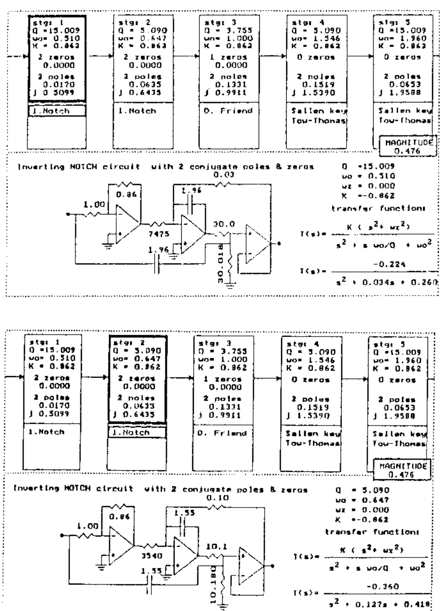

Fig. 9. First and second stage circuit implementation for the Chebyshev bandpass filter specified in Fig. 6

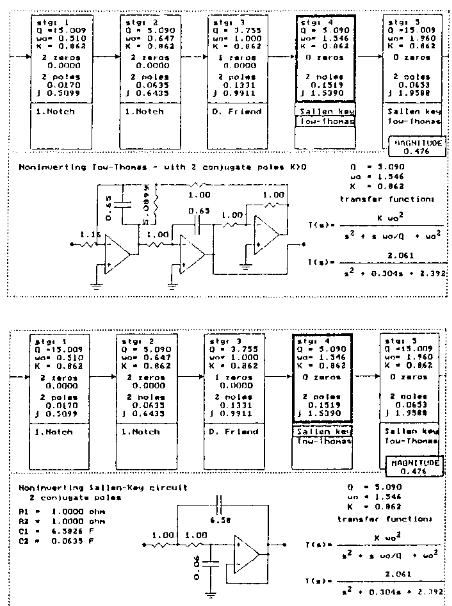

Fig. 10. Alternative fourth stage circuit implementation for the Chebyshev bandpass filter specified in Fig. 6

The Thomson type synthesis is also possible. Figures 11 and 12 shows the magnitude and delay characteristics of two Thompson type delay filters.

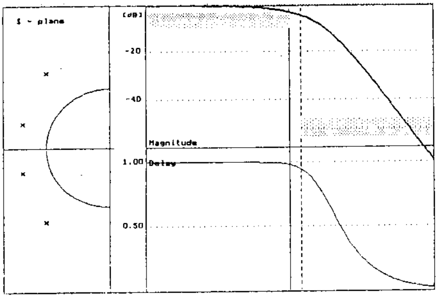

Fig. 11. Pole-zero locations, magnitude and delay as function of frequency for the Thompson delay 4 order lowpass filter with w_c=1000 rad/s

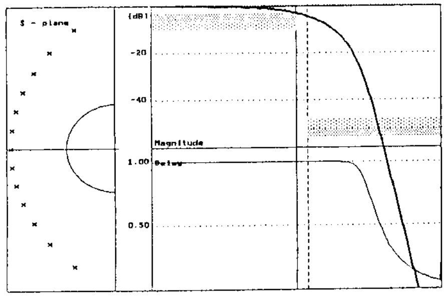

Fig. 12. Pole-zero locations, magnitude and delay as function of frequency for the Thompson delay 13 order lowpass filter with w_c=1000 rad/s

The program FILTERS has a few additional options which can be very useful in homework assignments. For any given polynomial up to degree 22 (limited by screen size) it can:

1. Compute all complex and real roots.
2. Extract automatically all single real factors and all biquad factors.
3. Calculate the derivative polynomial using a symbolic approach.
4. For a given value of s calculate the complex value of the polynomial, magnitude and phase.

For two polynomials it can:

1. Add and subtract them
2. Multiply one by the other.
3. Divide one by the other.
4. Decompose the ratio of polynomials into a sum of partial-fractions (Foster input impedance synthesis).
5. Decompose the ratio of polynomials into the continued-fraction (Cauer input impedance synthesis of the ladder network).

An important program feature is that after circuit synthesis, the SPICE input files can be automatically generated and students may verify their design by this well known and reliable computer tool. The program was written in PASCAL and it has about 6000 lines of source code and works with IBM XT/AT compatibles and was successfully tested on various graphical adapters such as Hercules, CGA and EGA. In order to enhance easy student perception, program menus with multiple windows were developed with convenient choosing either by moving a highlighted bar through the window or by characters from the keyboard. In order to improve the I/O communication, an input data window editor was developed. The window concept was implemented in both text and graphical modes. The multiple window approach allows for simultaneous observation of pole and zero location, with various frequency and transient responses. For practical circuit implementation, the multiple window concept allows for simultaneous observation of the block diagram and circuit diagrams of highlighted blocks.

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