Analog Filter Group Delay Optimization. Efficiency Evaluation of Optimization Methods.

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Abstract: - A lot of methods for analog filter group delay optimization have been developed. In the article an original approach to the evaluation of the optimization methods is presented. Our approach is based on the original representation of the optimization results in a polar space. In that space there are very interesting spirals indicating the optimization efficiency directly and clearly. This approach can be also used for evaluation of other optimized parameters and functions. The contribution contains a few practice examples of evaluation. The described approach extends the classical evaluation methods. Polar portraits of optimization results provide generalized view of optimization process.

Key-Words: - Analog filters, group delay, optimization, evaluation, polar space,

1 Introduction

Many publications have been written about the analog filter group delay optimization. Various methods are used to optimize the filter group delay. Some of them work with standard approximations (Bessel, Thomson). The most often used optimization idea is to use an all-pass network connected in cascade behind the filter. A basic optimization objective is to design the optimal order and coefficients of an all-pass network transfer function [1], [3], [8] and [12].

A few techniques are used to design the optimal all-pass network. Some of them use simple iterative methods [15] the other ones are based on sophisticated approaches, e.g. genetic and evolutionary algorithms, see [2], [6], [7], [9] and [12].

The optimization algorithms are still needed. Group delay equalizers are used in many electronic devices, e.g. video filters, TV and Radio signal transmission, ADC and DAC networks [15], [16], [17] and [18], etc. Similar optimization algorithms are also used in case of digital filters at present [11].

An optimized group delay ripple is the most often required optimization result. If the optimization algorithm is launched then there is a problem to compare achieved results. Several all-pass network orders and also optimized filters can be used. Then there are a lot of optimization results and we can compare them and choose the best of them. A good evaluation of optimization results is important especially in case of using more algorithms. We often need more then only simple numeral result but also so-called trends analysis.

2 Basic evaluation idea

A basic optimization task is to find the optimal order and optimal coefficients of the correction all-pass network transfer function. The all-pass network transfer function is divided into the first and second-order sections because of later active RC realization see Fig.1 and [4].

Our evaluation approach is based on these following features:

- Simple visual results of comparison and evaluation,
- Simple comparison in case of multiple optimizations,
- Simple evaluation in case of comparative optimizations using more algorithms,
- Evaluation of trends,
- Qualitative and quantitative evaluation,
- Evaluation of distance from optimization optimum.

If classical evaluation methods are used many comparative numbers or graphs (bar graphs) must be presented. Our evaluation approach offers to put all needed data together within one graph.

Commonly used evaluation graphs display only one or two resulting series. Our approach offers generalized view of optimization evaluation.

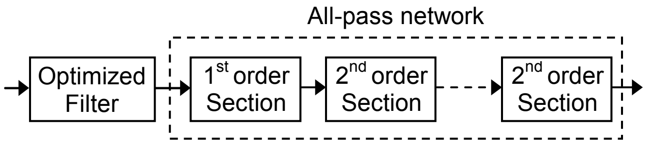

Fig.1. Basic idea of group delay optimization.

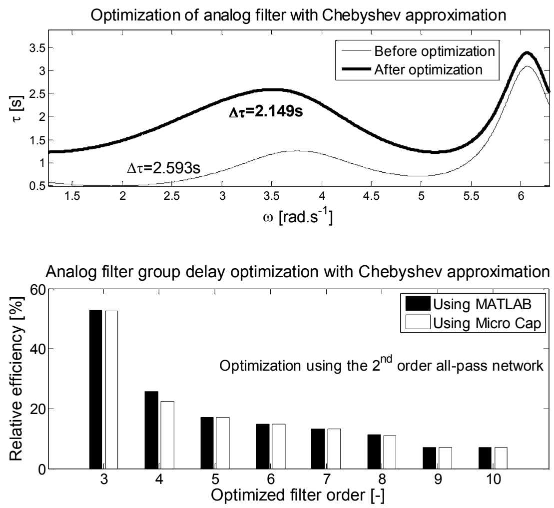

Fig.2. Typical types of optimization evaluation.

The bar graphs are typical types of graphs together with graphical output of algorithm, see Fig.2. The optimization must be carried out repeatedly to get the bar graph, of course. The bar graph shows the results in case of double optimization using the MATLAB® and Micro-Cap, see [13], [14] and [15]. Similar result presentation is unsuitable in case of multiple optimizations.

If we optimize the analog filters with more orders it is more suitable to display all results in the polar space. The same situations occur also for comparative optimization.

3 Polar spaces

The polar space is defined over the optimization results in case of multiple optimizations. Let us consider two vectors as the optimization results: *VekPolar* is the vector of the optimized filter orders and *Cheby_Allpass2* is the vector of the optimal group delay ripples.

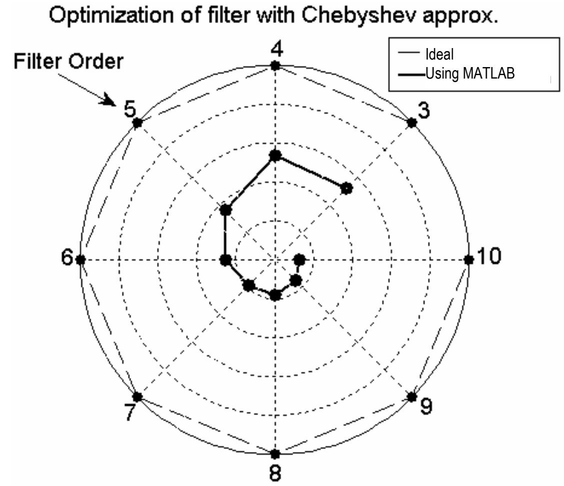

Fig.3. Simple polar space.

If we create a suitable polar graph with mentioned testing vectors then we obtain very interesting space. The simple polar space is shown in Fig.3. The origin of the coordinate system indicates the optimized filter. This origin means that the optimization efficiency is 0%. The perimeter of the polar space has the efficiency 100%. It means that the group delay ripple is 0s (ideal state). Each vertex of the octagon indicates concrete optimized filter order (from 3 to 10). The most important result is a spiral inside the polar space. There are optimization results. Each dot indicates a concrete value of the group delay ripple obtaining using algorithm. A distance between output dots and the origin of the coordinate system indicates the relative optimization efficiency. As you can see the optimization of the higher-order filter is more complicated. It means that there is lower optimization efficiency (higher group delay ripple).

The polar spaces are accessible thanks to an intuitive command *polar* in the MATLAB environment [10] and [14]. We can write simple expression as follows:

```
h=polar(VekPolar,Cheby_Allpass2,‘k‘);
set(h,’LineWidth’,4,’MarkerSize’,4);
L=legend('Ideal','Using Matlab');
set(L,‘Ideal‘,‘Using MATLAB‘);
```

There are a few other parameters to set the polar space well. A main advantage of the polar spaces is especially in case of multiple optimizations, as mentioned above. These cases are presented in next chapter.

We can summarize the main advantages of the polar representation:

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- Easy creation of spaces (MATLAB environment),
- Intuitive evaluation of the optimization results,
- Number of space vertexes is given by number of solved cases.

The polar space presented in Fig.3 can by modified. The 3D graph can be created. Then the spiral will rise as a three-dimensional helix. Such 3D graph is too complicated.

4 Examples of practical optimizations

The polar spaces are used to evaluate many multiple and comparative optimizations. Let us consider the optimized analog filters with orders from 3 to 10. There are these typical utilizations:

- Optimizations with constant all-pass order,
- Optimizations with given optimization algorithm,
- Comparative optimizations with various algorithms,
- Optimizations with given filter approximations, etc.

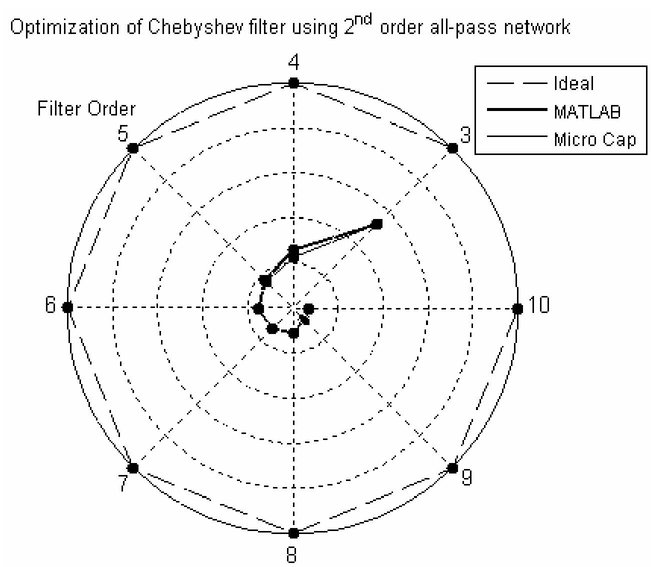

Fig.4. Optimization with constant all-pass order.

Two practical examples of optimizations with constant all-pass network order are shown in Fig.4 and Fig.5.

Both Fig.4 and Fig.5 are extreme cases. Two kind of analog filters are optimized using the second and fourth-order all-pass networks. You can see that the filters with Butterworth approximation have better optimization efficiency (spirals are near the circle perimeter) [4]. There are two spirals in the figures but they are almost coinciding.

The optimizations for variable the all-pass network order are shown if Fig.6 and Fig.7. The polar space from Fig.6 was created using the MATLAB system and the Fig.7 was obtained using the Micro-Cap, see [15].

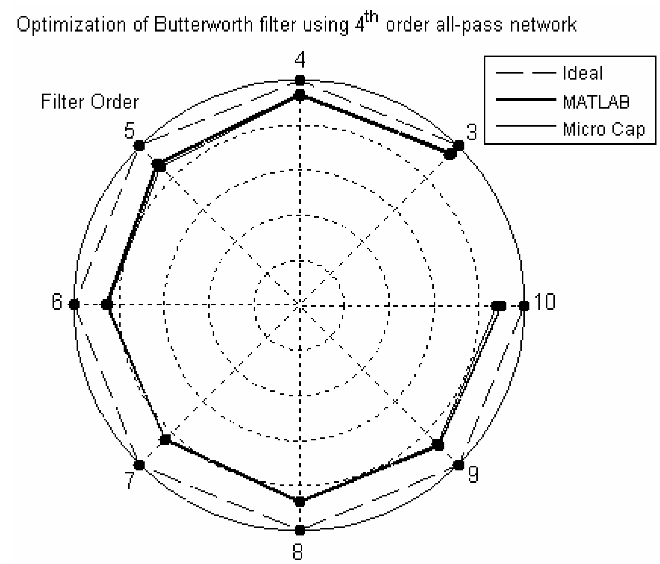

Fig.5. Next optimization with constant all-pass order.

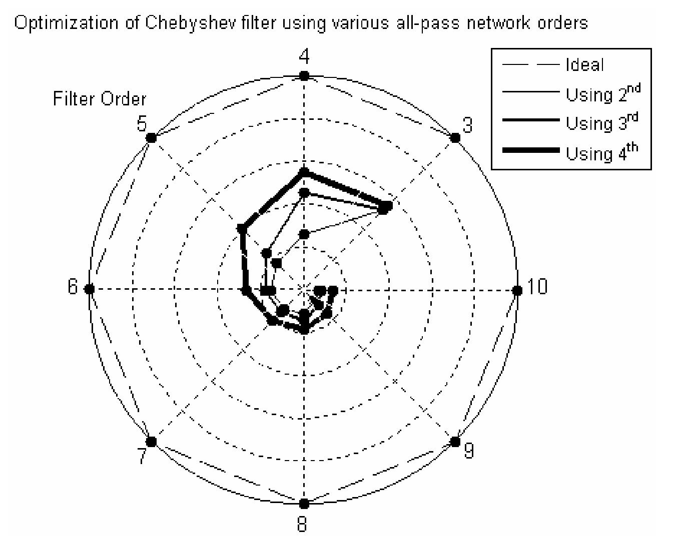

Fig.6. Optimization with various all-pass network orders.

We had these two optimization algorithms. The MATLAB oriented algorithm was developed in our department.

The second algorithm is embedded in the Micro-Cap simulator. It is based on the well known Powell's method, see [5]. It is evident that the higher-order all-pass networks provide better optimization results. Let us repeat that the origin of the coordinate system indicates the optimized filter.

The polar representation evokes a radar display. Many comparative optimizations were carried out during our development. We used the Micro-Cap as professional comparative algorithm. A testing scheme is shown in Fig.8.

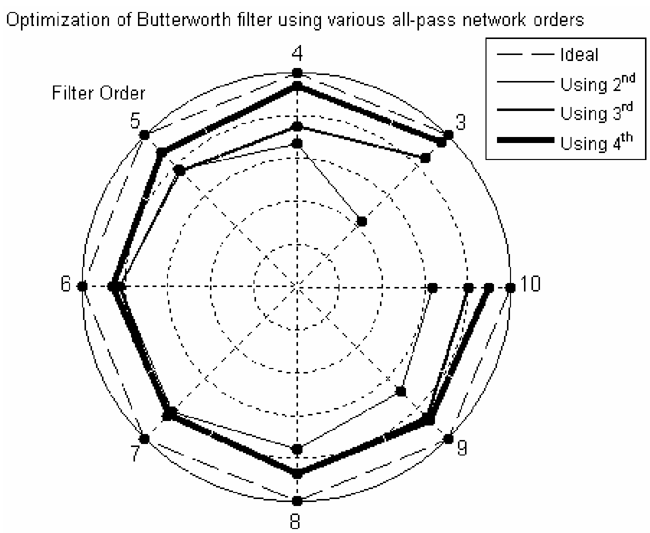

Fig.7. Optimization with various all-pass network orders.

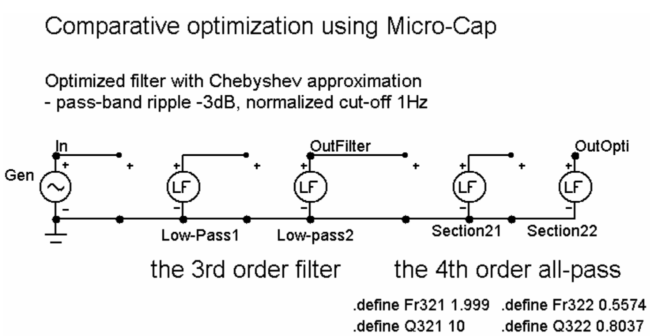

Fig.8. Comparative optimization in Micro-Cap.

There are the third-order optimized analog filter and the fourth-order optimal all-pass network. Both networks are defined using so-called Laplace *LFVofV* sources as two sections. The optimal transfer function coefficients are defined using command *.define*. These values were found using the optimization algorithm.

The results of the optimization are shown in Fig.9. The graphs were obtained by launching of the scheme shown in Fig.8.

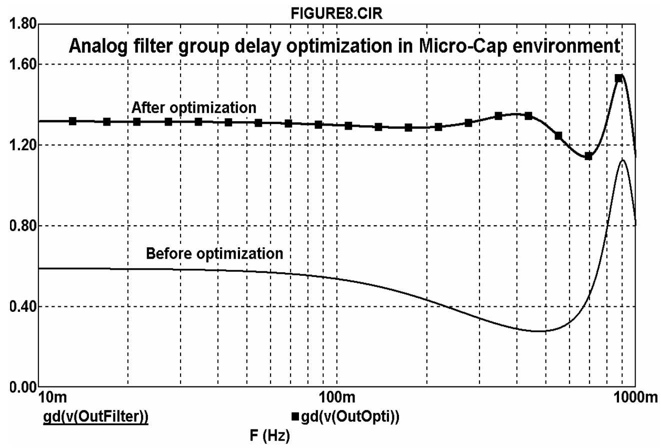

Fig.9. Group delay optimization in Micro-Cap.

5 Conclusion

The original method was introduced to evaluate the results of the analog filter group delay optimization. The method is based on a definition of the polar spaces. The results of the group delay optimization are portrayed in the polar space. The polar spaces are accessible in the MATLAB environment thanks to the command *polar*. Described evaluation method is suitable for multiple optimizations. It can be used for other types of optimizations (not only group delay). The polar portraits also enable the trends analysis. The method substitutes current evaluation methods. Efficiency of the proposed evaluation method was verified using a lot of optimizations. Our original method is independent on concrete type of the optimization algorithm or technique. The method can be used to compare a lot of optimization results (more optimization algorithms and methods, selection of optimum, etc.).

The presented evaluation approach can be also applied in case of measured group delay. It is a general-purpose approach how to evaluate the multiply optimization results.

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