IPASJ International Journal of Mechanical Engineering (IIJME)
Web Site: http://www.ipasj.org/IIJME/IIJME.htm
A Publisher for Research Motivation ....
Email:editoriijme@ipasj.org
Volume 5, Issue 6, June 2017
ISSN 2321-6441

PRACTICE UTILIZATION OF ALGORITHMS FOR ANALOG FILTER GROUP DELAY OPTIMIZATION

Mr. Manohar Parikar

College of Engineering, Pune

ABSTRACT

This contribution deals with an application of three different algorithms which optimize a group delay of analog filters. One of them is a part of the professional circuit simulator Micro Cap 7 and the others two original algorithms are developed in the MATLAB environment. An all-pass network is used to optimize the group delay of an arbitrary analog filter. Introduced algorithms look for an optimal order and optimal coefficients of an all-pass network transfer function. Theoretical foundations are introduced and all algorithms are tested using the optimization of testing analog filter. The optimization is always run three times because the second, third and fourth-order allpass network is used. An equalization of the original group delay is a main objective of these optimizations. All outputs of all algorithms are critically evaluated and also described.

1. INTRODUCTION

Analog filters belong to the most widely used dynamic systems. A design, analysis and optimization of the filters have been developing for a long time. Results of the development have been widely published in many countries; see [2], [5], [9], [12] and [17]. Standard design and realization methods are mastered at present. Development works are currently oriented to various areas, e.g. currentmode networks, monolithic integration, multi-criteria design using neural networks or evolutionary algorithms [7] and [18]. New network structures have been found. They use modern active elements and they also extend a usable frequency bandwidth [3], [22]. It is a well-known fact that required magnitude frequency response of the analog filter is a basic design criterion. Selective properties of the filter are concentrated in the response, see [5], [17]. It is necessary to consider also other frequency responses, e.g. a group delay. The group delay response of the analog filter can create so-called linear distortion of the processed signal in a pass-band together with the magnitude response [17], [20]. An optimal course of the analog filter group delay response is rigorously required in some areas of electronics, e.g. in video signal processing or during the TV signal transmission [13]. A lot of integrated circuit producers include group delay equalizers directly into their chips [25], [26]. In the past, many special papers were published about the group delay optimization [8], [10], [20]. Our main idea was to develop simply applicable, fast and robust algorithms. Both described original algorithms are used for personal computers (PC) and they were developed in the MATLAB environment [21]. The results of the algorithms are compared with the algorithm which is integrated in the Micro Cap 7, see [24]. All outputs of our algorithms are practically usable.

2. BASIC OPTIMIZATION IDEA

The analog filter designed using the magnitude frequency response requirements often has an unsuitable course of the group delay response. There is a big ripple at a limit of the pass-band. To optimize the group delay response and to keep the optimal magnitude response are the main objectives of the optimization task. It can be realized using the all-pass network which is connected behind the optimized analog filter. The all-pass magnitude frequency response is constant. That is why the optimization task is oriented to its phase properties.

To optimize the analog filter group delay means to find the suitable order and coefficients of the all-pass network transfer function. The group delay of the all-pass network is added with the group delay of the analog filter.

A designer can specify a few restrictive conditions or requirements to the optimization outputs are realizable. The main optimization result often is to reduce the analog filter group delay ripple. There can be other requirements, e.g. concrete distribution of the group delay along the frequency axis or the all-pass order maximum value given. A mean value of the total group delay response rises during the optimization, because both of the circuits, the analog filter and the all-pass network are connected in cascade, see Fig. 1. It is necessary to explore this effect but there are no problems in many practice applications.

2.1 The First and Second-Order All-Pass Networks

Let us repeat that the all-pass networks are linear dynamic systems having the constant magnitude frequency response. Their phase properties are specified during the optimization. The main optimization result is the transfer function in a semi-symbolic form. It is suitable to decompose the filter transfer function into the first and secondorder sections, because of possible later cascade ARC realization. Then a cut-off or resonant frequency and a Qfactor of each section are the typical outputs of the algorithm [17],.

If we design the first-order all-pass network then we optimize one parameter $\omega 0$. There are two parameters: the Q-factor and ωr in case of the second-order all-pass network design. An optimization space has a high and variable dimension in a general case.

3. Optimization Algorithms

In this chapter three optimization algorithms are described. The description is oriented especially to their practice utilization and comparison. The first two algorithms are the original functions, the third one is a comparative method used in the Micro Cap 7. The calculation of the all-pass network group delay course is simple because of equations (2) and (5).

3.1 Original Optimized Analog Filter

All three optimization algorithms were tested by using one common analog filter. It was the fifth-order lowpass filter designed by the Chebyshev approximation. There was the 3dB ripple in the pass-band. The transfer function coefficients can be obtained by several possibilities, e.g. using the tables of active ARC realization or by a direct design using the computer.

3.2 Initial Optimization Requirements

The main objective of all optimization algorithms is to reduce the initial group delay ripple $\Delta\tau$ of the testing fifth-order analog filter. The algorithms will look for optimal values of f0, fr and Q of all the first and second-order sections. The second, third and fourth-order all-pass networks will be used for this task. It could be predicted that the resulting group delay ripple will be decreased.

3.3 Required Outputs

The analog filter group delay course will be optimized by using the three all-pass networks mentioned above. The group delay with the reduced ripple will be the main output for each used all-pass network. Both ripples in percents, initial and resulting will be compared. The user specifies how many percents it is necessary to reduce the ripple.
3.4 Simple Iterative Algorithm The first introduced algorithm is based on simple iterative approach with respect to the analog filter properties. The initial group delay course (simulated or measured), the analog filter transfer function and user requirements are the possible input parameters.

3.4. Objective Function of Optimization

The initial values of the all-pass network parameters can be set according to various criteria, e.g. as a centre of a parameter interval or according to the ARC normalized filter coefficients. The initial values of f0, fr and Q are set. Then a new group delay course is calculated and also compared with required result. If the user main requirement is not fulfilled then sensitivity of variables f0, fr and Q is determined by using a little change of them. After it a new vector of mentioned parameters is set and the optimization continues with the new values. The new values are set by using a step set before.

3.4.1 Testing of the Algorithm

The described algorithm was widely tested. The results of the optimization are shown in Fig. 4, 5, 6. The resulting optimal coefficients of the all-pass networks transfer function are grouped in Tab. 2. The results are valid for the normalized frequency axis 1 Hz. A few algorithm properties can be controlled by using some initial settings, e.g. speed and accuracy. The algorithm works with the values of f0, fr and Q. These sections coefficients have a concrete physical meaning. The algorithm can automatically change the all-pass network order during the optimization. The whole algorithm consists of one m-file.

The evolution algorithms showed themselves very efficient in the area of the design and optimization of the electrical circuits and systems [4], [14], [15], [23]. The new unconventional methods for the design of the group delay equalizers, which utilize the evolutionary algorithms, were presented in the papers [14], [23]. The main advantage of the evolution based methods is that the methods do not need to determine an initial estimation of the unknown searched variables to ensure convergence of the algorithm. The next advantage is that the evolution-based methods are more robust against convergence to the local extremes in comparison with the design procedures based on classical numerical methods [1], [16], [21].

4. SUMMARY OF OPTIMIZATION RESULTS

The achieved reduction of the analog filter group delay course is well-arranged in Tab. 8. The optimization algorithms mentioned above are described. The second, third and fourth-order all-pass networks were used to optimize the analog filter. The evolutionary algorithm was used twice and these two cases are marked Evol1 and Evol2. The Evol2 algorithm includes an equi-ripple correction. A number in each cell indicates reduction in percents. An ideal case of the reduction is 100 %. It means the original group delay course is optimized into the constant course.

The algorithms Iteration and Evol1 provide comparable results, as we can see in Tab. 8. The Micro Cap 7 offers the worst results. However, these results depend on current bounds of the optimization parameters. The main disadvantage of the Micro-Cap optimization algorithm is a very long calculation time. It could be possible to compare many other parameters of used algorithms, e.g. setting possibilities, speed etc. This contribution is oriented to direct application and a comparison of ones.

REFERENCES

[1]. POWELL, M. J. D. An efficient method for finding the minimum of a function of several variables without calculating derivatives. Computer Journal, 1964, no. 7, p. 155-162.
[2]. SHAUMAN, R., GHAUSI, M. S., LAKER, K. R. Design of Analog Filters. Prentice Hall, New Jersey, 1990.
[3]. HUYNEN, I., VANHOENACKER-JANVIER, D., VANDER VORST, A. Spectral domain form of new variational expression for very fast calculation of multilayered lossy planar line parameters. IEEE Transactions on Microwave Theory and Techniques, 1994, vol. 42, no. 11, p. 2099-2106.
[4]. STORN, R. Differential evolution design of an IIR-filter with requirements for magnitude and group delay. Technical Report TR- 95-026, ICSI, May 1995.
[5]. TAYLOR, F. J., WILLIAMS, A. B. Electronic Filter Design Handbook. McGraw-Hill, 1995.
[6]. NELDER, J. A., MEAD, R. A simplex method for function minimalization. Computer Journal, 1964, vol. 7, pp. 308–313.
[7]. MICHALEWICZ, Z. Genetic Algorithms + Data Structures = Evolution Programs. 3rd ed. Berlin, Heidelberg, New York: SpringerVerlag, 1996.
[8]. SCULTETY, L. Zero group delay networks. In. Proc. of the ECCTD’97. Budapest (Hungary), September 1997, p. 589-593.
[9]. MARTINEK, P., BOREŠ, P., MATZNER, I. Electric filters. ČVUT Prague, 1998. ISBN 80-01-01591-2 (in Czech).
[10]. CARVALHO, D. B., FILHO, S. N., SEARA, R. Design of phase equalizers using phase delay characteristic. In Proc. of the ISCAS'98, Monterey (USA), 1998.
[11]. LAGARIAS, J. C., REEDS, J. A., WRIGHT, M. H., WRIGHT, P. E. Convergence properties of the Nelder-Mead Simplex Method in low dimensions. SIAM Journal of Optimization, 1998, vol. 9, no. 1, p. 112-147.
[12]. WANG, S., WANG, F., DEVABHAKTUNI, V. K., ZHANG, Q. J. A hybrid neural and circuit-based model structure for microwave modeling. In Proceedings of the 29th European Microwave Conference. Munich (Germany), 1999, p. 174 - 177.
[13]. GREGORA, P., VIT, V. Television Techniques. Devices for TV Signal Transmission. Prague: BEN Technical Literature, 2000 (in Czech).
[14]. ŽIŠKA, P., LAIPERT, M. Analog group delay equalizers design based on evolutionary algorithm. Radioengineering, 2006, vol. 15, no. 1, p. 1-5, ISSN 1210-2512.
[15]. MARTINEK, P., VONDRAŠ, J. New approach to filters and group delay equaliser transfer function design. In ICECS 2001 - The 8th IEEE International Conference on Electronics, Circuits and Systems. St. Julian’s: ICECS 2001, 2001, vol. 1, p. 157-160.