THE METHOD OF SPIRAL DESIGN MODEL FOR THE AUTOMATED DESIGN OF ANALOG IP-CORES IN COMPUTING

МЕТОД СПИРАЛЕВИДНОЙ МОДЕЛИ ПРОЕКТИРОВАНИЯ ДЛЯ АВТОМАТИЗАЦИИ РАЗРАБОТКИ АНАЛОГОВЫХ IP-БЛОКОВ В ВЫЧИСЛИТЕЛЬНЫХ СИСТЕМАХ

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Abstract: *The systematic approach of complex technical devices design allows not only to design new devices and objects, but also to automate the design process. This article discusses the seven-layer spiral design model, which can be used to simplify the design process of complex devices in areas of mechanical engineering and computer engineering. The spiral model in this work is used for automation of analog IP-cores design; in particular, the windows application that implements the automated design system of analog low-pass filters was developed. The application allows user to design the filter scheme in automated mode after inputting the parameters. The proposed method has certain benefits compared to the known automated design methods for the specific object classes.*

Keywords: AUTOMATED DESIGN, SEVEN-LAYER SPIRAL DESIGN MODEL, IP-CORES, LOW-PASS FILTERS

1. Introduction

In modern mechanical engineering, as in other industrial branches, the period of production update is getting shorter and more and more complex technical objects have been designed. One of the most important stages in manufacturing of such objects is design stage. At this very stage of development of the object its general configuration is determined and many mistakes in the object development could be prevented. Therefore sustained interest in methodology and methods of design is observed.

2. Methods of technical objects design. Systematic approach

There are several approaches for technical objects design. One of design methodologies is the system design. It assumes sequential stage by stage design of a device. Dividing the design process into stages and aspects allows: firstly, using concurrent design methods, and secondly, organizing existing data and forming new knowledge. Concurrent design makes it possible for a large development team to elaborate a new device. Main principles of systematic approach are practical usefulness, unity of the components and variability in time.

Modern design processes of technical objects in most cases are computer-aided. Very seldom it is possible to make these processes fully automatic. Structuring of design process by applying systematic approach allows creation of computer-aided design (CAD) systems, which simplify and accelerate development of new devices and moreover allow receiving products of optimal quality at the output.

CAD facilities (such as Matlab Simulink, Actel, Altera, Cadence and many others) usually follow some design flows [1]. In most of such systems modelling and design of end product are automated but the stage of structuring is given to a developer. At this stage the developer is supposed to build up the model of designed object from component blocks suggested by the system. The developer chooses one or another decision using his own ideas of optimality and later checks how it fits the demanded characteristics. The design flows for objects in such CAD systems are quite difficult and in most cases include textual or graphical setting of object structure and subsequent modelling, synthesis and debugging of this object at various levels [2].

There are also several methodologies based on design models used for software development. They include iterative [3], waterfall [4] and other models of development. Each of these models has its advantages and drawbacks, and is used or was used till recently in software development. Design stages are clearly described in these models. However, methodologies based on them are mainly used for development of software and not for technical objects.

Specific design flows exist for several types of objects. Various models are used depending on the object. They differ in set of stages and objective of design. Statement of objectives allows choosing criteria connected with them. There are several design models for electronic analog components [5], digital elements [6], video systems [7, 8], software packages [9]. One of the most full (detailed) design models is spiral model [10]. It can be used in design of various devices, including objects of mechanical engineering.

3. Seven-layer spiral model methodology

Contracting spiral model of design is most fully described by Lypar Ju. I. [10] (see Fig.1). It uses objective approach where design of object is leaded through spiral-like route from objectives towards the final structure of object and its parameters.

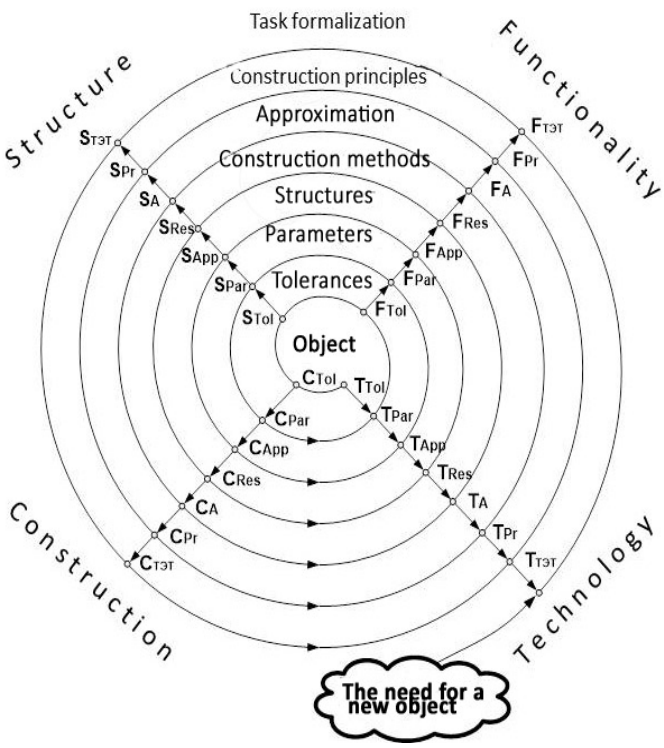

Fig.1. *Spiral model of objects design. Titles of seven stages are given in the upper middle part of the picture, four aspects are shown in the corners*

The model includes seven levels (or stages) of design for every aspect of design: technological, functional, structural and constructional. At each stage a subset of the most effective decisions is selected from a number of suggested decisions with the help of a choice function, which determines the optimal configuration of the object. Spiral model in a compact way describes a huge diversity of structure variants of designed object and variants of its functionality. This scheme gives no practical limitations to application field and component composition of technical object. Therefore this design methodology can be considered rather general and can be used in development of many technical objects and devices, either simple or complex.

The stages of spiral design model go in the following order: stage of setting of requirements that designed object should meet (S_{TET}); stage of synthesis of construction principles (S_{Pr}); stage of approximation of desired configuration and characteristics of the object (S_{App}); stage of synthesis of construction ways (S_{Res}); stage of structure synthesis (S_{App}); stage of structure elements parameters calculation (S_{Par}); stage of tolerances (S_{Tol}). Each stage has a feedback, movement towards and backwards along design stages is also possible. Consequently the model is sustainable to any changes at any design stage and if it becomes necessary to include such changes there is no need to start design process from the beginning.

Result of design in one or another aspect is a composition of functions of choice at all stages (1). The resulting set should include effective solution describing the designed technical object realized in the most optimal way.

$$\Pi = S_{Tol} \circ S_{Par} \circ S_{App} \circ S_{Res} \circ S_{A} \circ S_{Pr} \circ S_{TET} \qquad (1)$$

At each turn of the spiral the following tasks are solved.

Work on functional aspect (F) of designed object means analysis of technical, technological, exploitation, economical and ecological requirements to devices and subsystems (briefly TET). In most cases at the first stage there is lack of data for solving all the tasks. Therefore at each new stage system analysis of results of previous stages is done and additional requirements are formulated for new stages. The complex of those requirements forms a choice function for the next stage.

Structural aspect (S) includes synthesis of structures relevant to stages. Solutions at this stage can be not numerical most of the time, they can partly be put on inventive level. Therefore the problem of searching for subsets of optimal solutions from the set of existing solutions has to be solved. In other words, the key of this aspect is not to list all of possible structural decisions, but to isolate and structure subsets of solutions that meet choice functions of every design stage according to principles of systematic approach.

Work on constructional aspect (C) includes allocation of subsystems, components and elements and connection layout. It should be done in such a way that minimizes parasitic influence of corresponding objects on each other. In this aspect methods of optimization are widely used and CAD systems have programs for this purpose.

In the frames of work on technological aspect (T) elements of the components, subsystems and the whole system are designed at physical level. As a rule CAD system of this aspect is the first to be developed for it sets parameters of all used elements, but their allocation and other peculiarities are given during work on the previous aspects.

Spiral model scheme gives clear demonstration of all stages of the technical object design process according to systematic design approach and its principles. Such detailed and at the same time clear and easy understandable scheme can help simplifying the automation of design process at least at the structural aspect of design. Comparison of the described spiral model methodology with some other design methods mentioned earlier is done in table 1.

Table 1: *Comparison of spiral model with other design models and design flows*

Characteristics	Clarity	Generality	Applicability
Specific design flows	+	–	+
Design flows of CAD systems (Altera, Simulink)	–	+	+
Software design models (e.g., iterative, waterfall models)	+	–	±
Spiral design model	+	+	+

Methodology based on spiral design model has clarity, generality and applicability. In design of technical objects this features can give advantage over other existing methodologies.

4. Practical use of the spiral model methodology in filter design

Based on spiral model methodology, an application for a design system of analog IP-cores, named Design IP [11], was developed. IP-cores are the reusable units of logic, cell or chip layout design, which are the intellectual property of the designer, so IP in IP-cores stands for “Intellectual Property”. IP-cores have made a huge impact on system-on-chip design, that is why analog IP-cores are an essential part of modern portable computing systems, but the automation of the analog IP-cores is so far less developed than the digital IP-cores automation. This is why the goal of developing an application for digital IP-cores automated design was set in the present work.

The goal was to develop an automated design system which allows user to design one of the simplest IP-cores - low-pass analog filter circuitries - in automated mode. Now the first stage of the work is done. It includes development of an application for design system for passive filters of low orders. The Filter Wiz Pro [12] system was taken as a prototype of developed system.

Design process in the developed application goes step-by-step; each step corresponds to one of the stages of spiral design model. The user controls design process by inputting object parameters and observing the solutions that program suggests for each stage, choosing the most suitable solution for the specific object according to optimality criteria provided by the program. At each stage the user can go back at any number of the stages and change his choice or the input parameters. Changes will be set and applied, and the result of the next design stage will be different, considering the changes.

Design IP system was developed using C# programming language in Visual Studio environment. It was made as a Windows Form application. In the main form (window) of the application the object of design is chosen, its parameters are input and the scheme of design progress is shown step-by-step. Each tab corresponds to one of the spiral model design stages applied to analog filter design. The user progresses from the left to the right, moving forwards and backwards between the tabs when necessary.

Let’s observe the working process of the application. The circuity and its parameters can be saved in the end, and the recently saved circuitries for the specific filter of certain order can be shown to user when the user restarts the program. The appropriate window is opened by pressing the button "Existing solutions". On Fig.2 the main window of the application is presented.

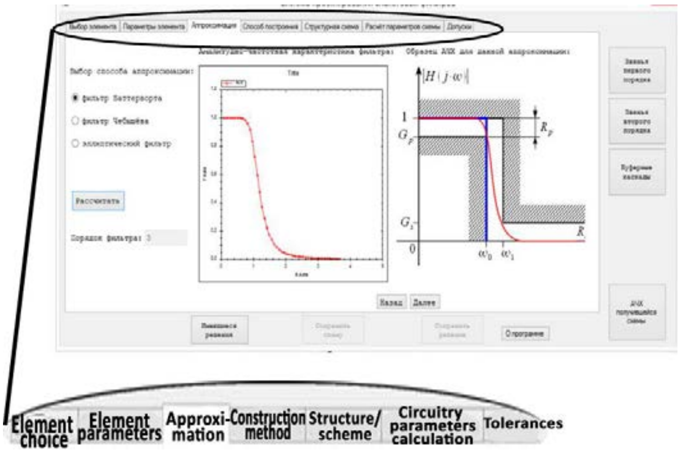

Fig.2. *Main window of Design IP system. Titles of tabs (translated from Russian) are given in the bubble below*

At the "Designed element choice" stage the user decides which type of filter to make. By default, only the choice of the low-pass filter is implemented. However, types of filters that can be done based on it are mentioned too, such as high-pass filter, band-pass filter, band-stop filter.

At the "Element parameters" stage the input of filter parameters is made. For filter design the parameters that measure filter bandwidth and transmittance are needed, such as passband frequency, stopband frequency, passband attenuation and stopband attenuation. A picture is provided for the user to show clearly how these parameters are graphically described. Also, the value of load resistance is being input at this stage, which will be later needed for the filter circuitry parameters calculation. Fig. 3 demonstrates the tab of this stage.

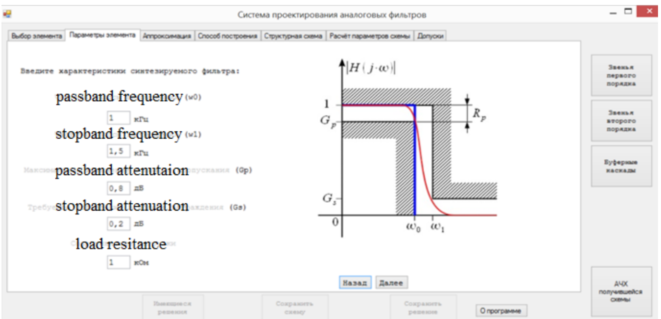

Fig.3. *"Element parameters" stage of Design IP system. Parameters are input in the textboxes by user*

At the "Approximation" stage the user observes the result of calculation of filter amplitude-frequency response and filter order is calculated according to a chosen approximation method (Chebyshev [13], Butterworth [14] or elliptic [15]). Also the window contains the example of amplitude-frequency response of filter for the particular approximation for comparison. Fig. 2 shows the result of Butterworth filter approximation, where the calculated filter order is equal to five. Also on this stage the transfer function of the filter is determined by calculating its zeros and poles according to the chosen approximation method.

At the "Choosing construction methods" stage the choice of the construction method for circuitry is done. By default, only chain connection of passive units is implemented. This stage also provides the choice of the low-order units, which are combined into a filter of higher order. Units are chosen form the menu on the right side of the application window.

At "Structure" stage the picture of filter circuitry is combined, using the units that user had chosen. It is shown to the user and the user is able to save it as an image file.

On the next stage, "Circuitry parameters calculation", calculation of such parameters as capacitances, inductances, resistances, is done. Calculation is fulfilled using knowledge of filter zeros and poles, which were determined earlier in the program at the "Approximation" stage, and using the formulas from the program database for calculations of parameters for different units. Current version of the program only implements calculation of Butterworth filters. Fig. 4 shows the stage of parameters calculation for Butterworth filter with order equal to five.

Fig.4. *"Circuitry parameters calculation" stage of Design IP system. Explanation of parameters for the first, second and third unit of the filter is given below*

On the final "Tolerances" stage user chooses the row of standard values of capacitances, inductances and resistances, according to which the nominal values for the circuitry elements parameters are calculated. Several rows are provided; each of them has a different number of values so that the user would choose optimal tolerance value, which characterizes the difference between nominal value and the calculated value.

As a result of the program use, the nominal values of parameters are successfully received according to user's choice. Also on this stage user can see the plot amplitude-frequency response of the filter, by which he can esteem the transmittance qualities of the deigned filter.

The developed application allows user to develop analog low-pass filters in automated mode, progressing step-by-step through separate stages of design, and receive the filter circuitry with nominal values of its parameters as the output.

5. Conclusions

This paper observes the design methodology based on spiral design model. The advantages of this methodology, such as generality and clarity, allow using it for the automated design of technical objects and devices.

As an example of practical use of this method, a windows form application was developed. It implements step-by-step design of analog IP-cores. The design process is based on stages of spiral model. The use of the application was demonstrated: based on the input filter parameters, the circuitry of the filter with the parameters of its elements was developed in automated mode. This application may serve as an illustration of the systematic approach to design in general and also be an example of usage of the spiral model based methodology for design automation in particular. Further development of this application can include widening of types of designed objects by applying new schemes and new methods for design of separate parts of the object, for example, methods of directed graphs for unit synthesis [16].

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