A PRACTICAL APPROACH TO DESIGN AND MODELING DIGITALLY PROGRAMMABLE ANALOG CIRCUITS

Ivailo Milanov Pandiev[1], Peter Ivanov Yakimov[2], Doycho Dimitrov Doychev[3], Todor Georgiev Todorov[4], Veselin Yanev Stanchev[5]

Department of Electronics, Technical University of Sofia, Kliment Ohridski Street No 8, 1000 Sofia, Bulgaria, e-mail: [1]ipandiev@tu-sofia.bg, [2]pij@tu-sofia.bg, [3]dddoychev@tu-sofia.bg, [4]ttodorov@tu-sofia.bg, [5]vstanchev@tu-sofia.bg

In this paper, practical approaches to design and macromodeling digitally programmable analog circuits are described. The proposed design approaches are based on the design methods for analog circuits, the procedures for performing simulation projects and the general methodology for building Web-based client/server applications. Those methods are complete framework, which includes all activities, intermediate products, design procedures and relations between them, necessary for design and realization of a concrete electronic circuit and a relevant simulation macromodel. The design approaches are applicable to a broad class of circuits that amplify and convert analog signals under digital control codes, such as programmable gain amplifiers (PGAs), in-amps, sample-and- hold amplifiers (SHAs), digitally programmable active (RC and SC) filters and oscillators.

Keywords: digitally programmable analog circuits, design methodology, analog circuit macromodeling method.

1. INTRODUCTION

The wide application of electronics within industry, ecology, transport and life are a reason to design various analog and digital circuits with small size, weight and power consumption. The significant mean for enhances of electronics have mixed (analog/ digital) circuits and in particular, digitally programmable analog circuits. They are realized as specialized integrated circuits (IC), with analog and digital functions joined together on the same chip or as discrete electronic circuits, which consist of basically operational amplifiers, digital controlling circuits, common RLC components, CMOS analog switches, multiplexers and digital potentiometers.

The design of analog and digital electronic circuits relies heavily on insight gained from hand calculations based on first-order models [1 – 3]. However, many important details of circuit behavior, such as precise gain, DC offsets, distortion and noise depend on second-order device characteristics cannot be included in hand calculation. The simulation analysis is a standard tool for verifying detailed circuit behavior beyond the scope of hand analysis. The core of each simulation program is libraries with models/macromodels for analog and digital components. In the literature, related with the simulation modeling, there are a number of models for analog ICs and macromodeling methods [6-10]. In this paper we present specific practical approaches to design and modeling digitally programmable analog circuits.

2. A Practical Approach to Design Digitally Programmable Analog Circuits

In this section is presented a specific practical approach for digitally programmable analog circuits design. The proposed design approach is based on the methods for analog circuits design and the methodology for building Web-based client/server applications, given in [1 – 5]. The design approach diagram is shown in Fig. 1. This approach is a framework, which includes all activities, intermediate products, design procedures and relations between them, necessary for design and realization of a concrete digitally programmable analog circuit. The practical approach presented here is based on a Top-Down analysis approach. Generally, design and realization of digitally programmable analog circuit can be resumed in six main phases (activities), which is performing in a linear fashion: (1) circuit specification; (2) schematic design; (3) experimental and simulation testing; (4) circuit verification; (5) layout design; (6) prototype fabricate and documentation. Despite the fact that these have been shown in a linear fashion, moving from circuit specification to schematic design and so on, additional phases such as optimization and modification, aim to demonstrate the iterative nature of the process. For example, experimentation may identify some additional issues, which alter the circuit and require further circuit building before experimentation continues. The design approach must always start with a project definition and move towards prototype fabricate and documentation. The schematic design phase is highlights of the proposed practical approach. In this phase analog circuit strategy for realization is chosen and a method for realization of the digital circuit is selected. The schematic of the digital circuit, necessary for programming the dynamic parameters (gain, pole frequency, centre frequency, bandwidth, quality factor, duty cycle etc.), strongly depends on the structure of the analog electronic circuit. Also, the mode of switching the dynamic parameters it's increasingly important for the structure of the digital circuit. The schematic design complete with simulation and experimental testing. However, some of the analog and digital integrated circuits do not have simulation macromodels, the connections related with simulation testing are marked in gray. The verification check is performed by comparison analysis between experimental results and the technical specification parameters. The design approach finishes with layout design of the circuit as a PCB or monolithic integrated circuit and preparing of a prototype with technical documentation, including main electrical and constructive parameters.

3. A Metothodology for Analog Circuit Macromodeling

Based on the design procedures for performing simulation projects and the methodology for building Web-based applications [4 – 8], in this section is presented a specific methodology for analog circuit macromodeling. The proposed methodology, shown in Fig. 2, includes all activities, intermediate products, design procedures and relations between them, necessary for developing a concrete simulation macromodel. Generally the methodology consists five main phases (activities), which is performing in a linear fashion. The names of those phases are: (1) formulation the problem (2) collect data and construct conceptual model, (3) build the model, (4) simulation and operational validation and finally (5) document and present simulation results.

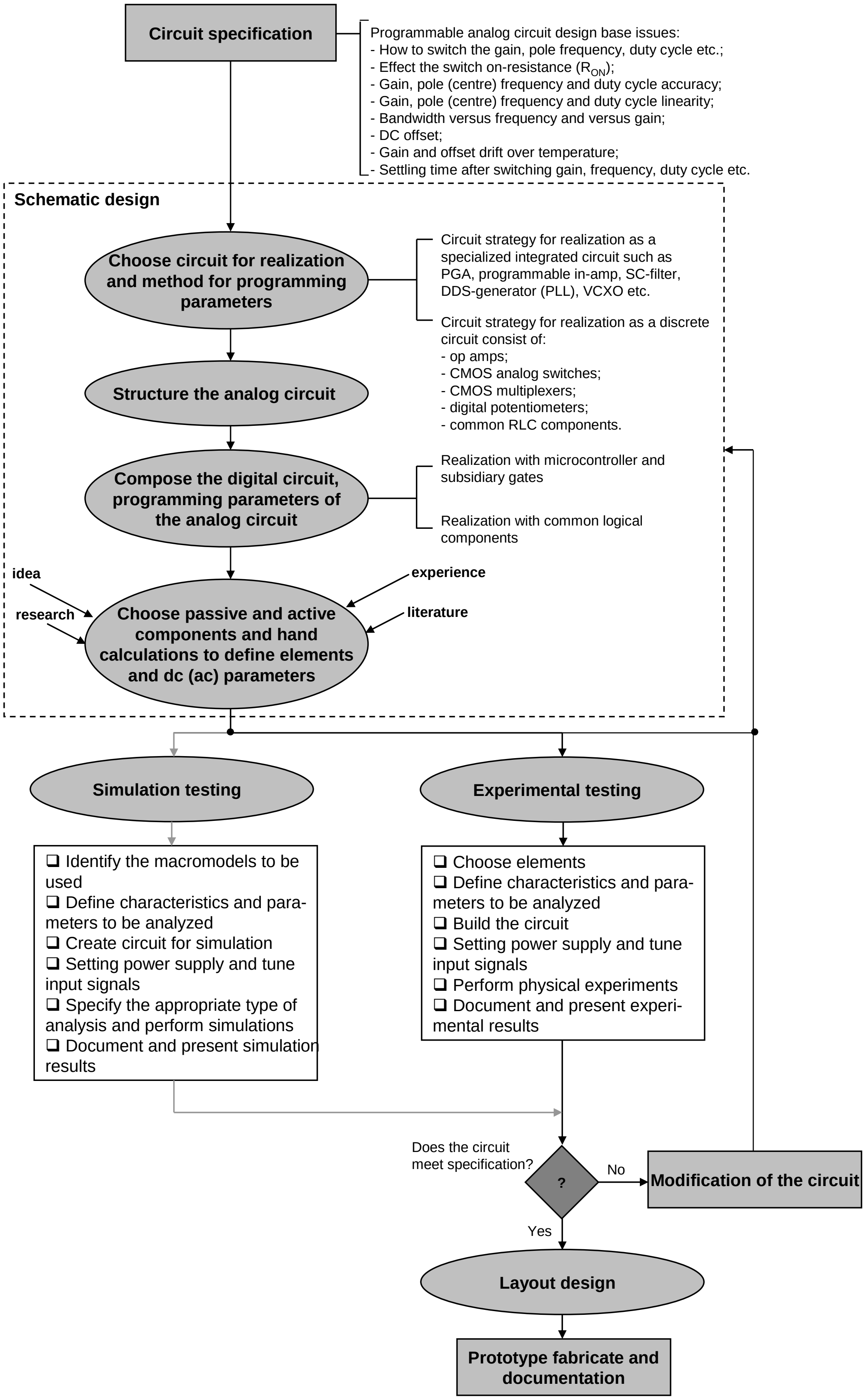

Fig. 1. A practical approach to design digitally programmable analog circuit.

Each phases of the methodology can be split into smaller steps, which are performed as an iterative pattern. In using the methodology to develop a valid simulation macromodel, several version of a macromodel are usually developed during the modeling process prior to obtaining a satisfactory valid macromodel.

The methodology presented in this section can be split into two parts: real environment (real world) with related activities and intermediate products and simulation environment (simulation world) with activities and products. We first discuss the activities (phases), related with the real world. The *problem entity* includes description of the structure and the behavior of the modeled analog IC. *Electrical characteristics and parameters* are obtained by physical experiments on the real device (IC). *System theories* describes the electrical characteristics of the supposed macromodel and possibility its behavior. In fact the electrical characteristics of the macromodel are a small part from all characteristics of the actual analog IC. System theories are developed by *abstracting* what has been observed from the real device and by *hypothesizing* from electrical characteristics and parameters of the device.

Now we discuss the simulation environment, which shows a macromodel development process. The *conceptual macromodel* by the simulation environment part is the mathematical, logical and/or verbal representation of the actual device developed for the objectives of a particular simulation project. The *simulation macromodel specification* is a written detailed description of the software design and specification for programming the conceptual macromodel on a particular computer system. The *computerized simulation macromodel* is the conceptual model implementing on a computer. The conceptual macromodel is developed through an analysis and modeling phase and computerized simulation macromodel is developed through a computer programming and implementation phase. Finally the *simulation results and data* are the graphical and numerical data and results from simulation experiments conducted on the computerized macromodel.

The macromodel verification and validation during model iteration are performed. The purpose of *verification* is to guarantee the correct behavior of each element in the developed model. In this process each element is tested in turn to ensure that, firstly, they behave in the manner intended by the macromodel code, and secondly, that their behavior is representative of the actual device. Verification is effectively a "micro" check of the developed macromodel. The purpose of *validation* is to guarantee the correct degree of accuracy by checking that overall behavior of the macromodel is representative of the actual device. Model validation can be seen as a "macro" check of the simulation. The methodology, shown in Fig. 2, includes model verification and validation at various phases. *Conceptual model verification* is defined as determining that the theories and assumptions underlying the conceptual macromodel are consistent with those in the system theories and that the model representation of the real device is "reasonable" for the intended purpose of the simulation model. *Specification verification* is defined as assuring that the simulation macromodel specification for programming the conceptual macromodel on the specified computer system is satisfactory. *Computerized model verification* is defined as assuring that the computerized macromodel has been implemented according to the specification. Ultimately *operational validation* is defined as a process of comparing the performance of the macromodel with the real analog integrated circuit (real system). During the validation is tested the overall macromodel accuracy and its ability to meet the simulation project's objectives.

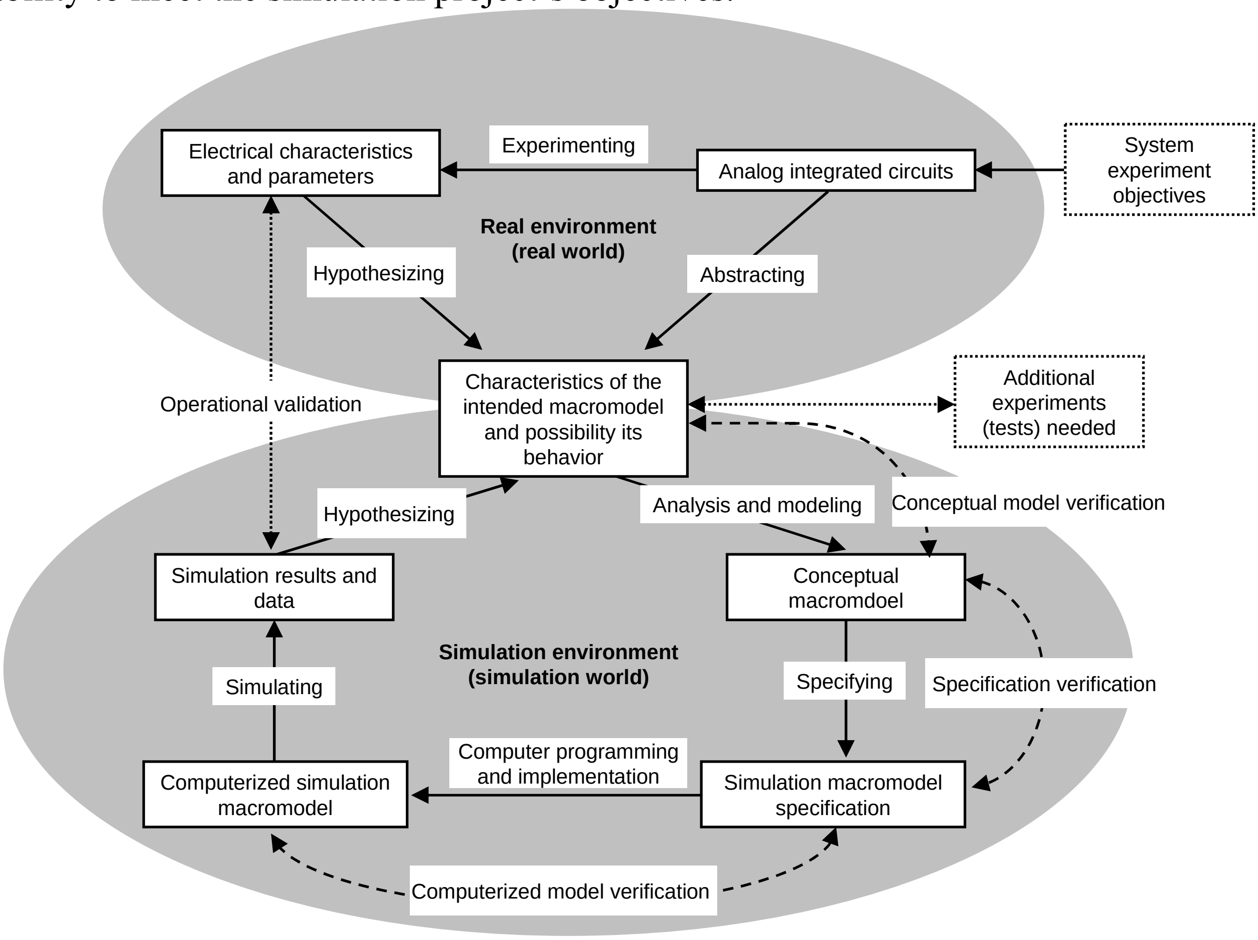

Fig. 2. A methodology for analog circuit macromodeling.

The essential phase (activity) within the proposed methodology is macromodel building (computerizing and implementing) and documenting. The procedure of electrical model building and documenting is shown in Fig. 3. Generally the procedure consists six main steps (activities), which is performing in a linear fashion. The names of those steps are: (1) *partition the structure* of the IC into *n*-th functional blocks (stages) $i = \overline{1, n}$, (2) *define the most important elements* of the stages, (3) *modeling separate stage* (with index *i*), (4) *cascade structure synthesis* (generate equivalent circuit), (5) *simulation testing* of the created macromodel and (6) *document and present the simulation results*.

The aim of macromodeling is to obtain a circuit model of an IC or a portion of an IC, which has a significantly reduced complexity to provicle for smaller, less costly simulation time, or to permit the simulation of larger IC's or IC systems for the same time and cost. The first and second step of the design procedure, presented in Fig. 3, is to partition the structure of the IC into functional blocks (stages) and define within the most important groups elements. Those groups of elements have to be represented in the equivalent circuit of the intended macromodel.

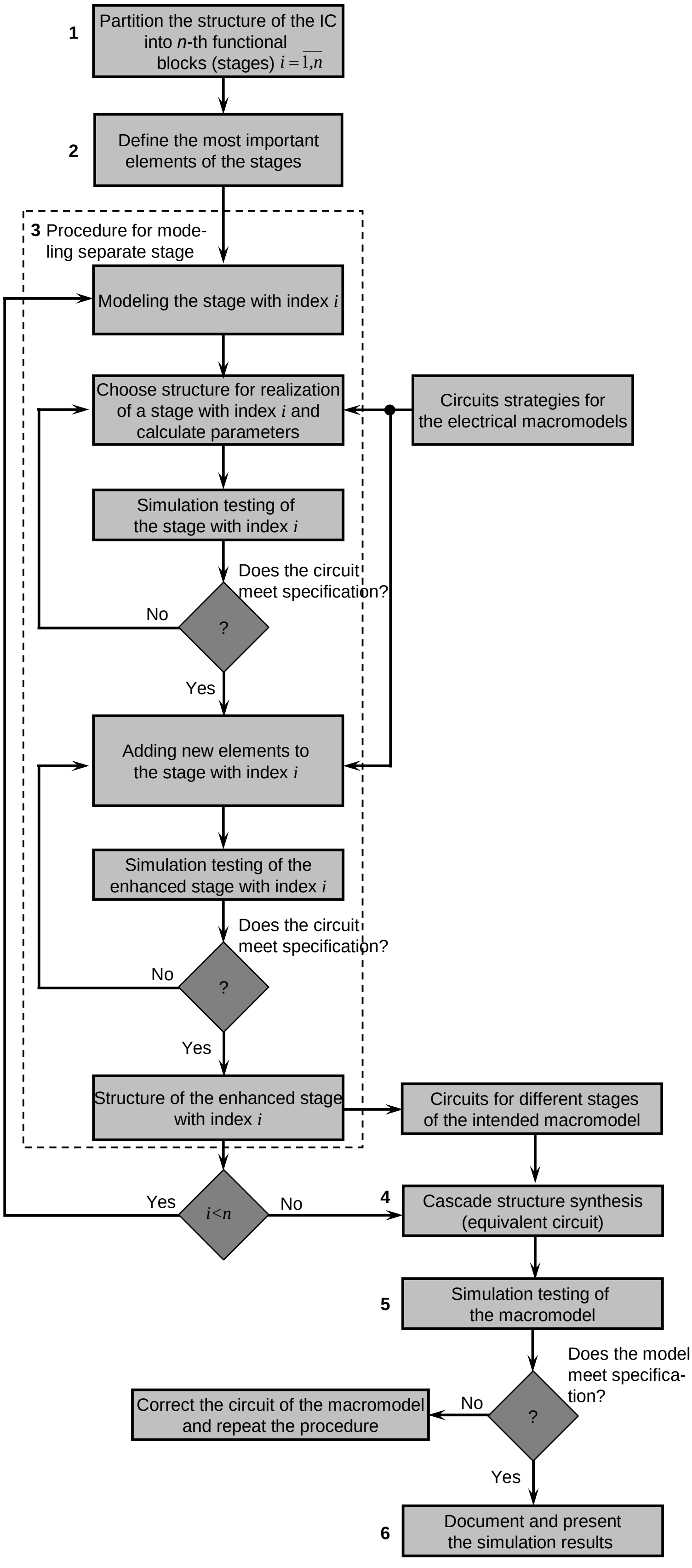

Fig. 3. Model building and documenting procedure.

The third step is a design procedure for modeling stage with indexes *i*. In the most of modeled IC the stage with index $i=1$ is the input stage, which defines the input impedance, the CMRR, the PSRR, the gain (for the op amps), the input offset voltage and current, noise voltage/ current spectral density, etc. The macromodeling of single stages are developed by using two basic modeling techniques: *simplification and build-up*. In the *simplification technique*, representative portion of IC are simplified by using simple ideal (passive and active) elements to replace numerous real elements. Thus, the final model using this approach bears a strong resemblance to the real circuit and simulates basic dc and ac parameters of the real device. In the *build-up technique*, a circuit configuration composed of ideal elements is proposed to meet certain external circuit specifications without necessarily resembling a portion of an actual circuit configuration. The build-up technique is employed in the development of the second order effects such as the poles and zeros of the frequency response, CMRR versus frequency, PSRR, noise, maximum output voltage swing, maximum output currents, etc. The design procedure of each functional block (stage) complete with verification. When all stages from the structure of the IC are modeled (step 4) the complete equivalent circuit of the macromodel is composed. For the obtained macromodel simulation testing (step 5) within EDA environment is performed. The validation procedure is implemented by comparison the new macromodel with the real system or by comparison with other existing validated model. Finally the documentation (step 6) for the macromodel should include the conceptual model (critical for future reuse of the model) created before model building, a detailed description of the circuit netlist (computer program) and the simulation results. The final presentation for the macromodel should include animations and a discussion of the model building and validation process to promote model credibility.

4. CONCLUSIONS

This paper presented the following achievements of the team of the developers:

- Development of the practical approach to design digitally programmable analog circuits;
- Development of the methodology for analog circuit macromodeling. The proposed methodology is based on the procedures for performing simulation projects and the general methodology for building Web-based client/server applications;
- The created practical approaches can be useful for design and modeling of various electronic circuits such as programmable gain amplifiers, in-amps, programmable active filters, SHAs, programmable oscillators, etc.

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