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MODELING OF MULTIDOMAIN AUTOMATIC CONTROL SYSTEMS IN ECAD

На підставі аналізу існуючих підходів у проектуванні та моделюванні автоматичних систем регулювання та мехатронних систем зроблено висновок про застосовність програм ECAD для наскрізного проектування мультидоменних систем на всіх рівнях абстракції. Теоретичні висновки підтверджено виконанням практичних завдань у програмі MC11 й узагальнено у вигляді методики наскрізного проектування в середовищі ECAD.

Ключові слова: *мехатронна система; САР; мультидоменна система; наскрізне проектування; ECAD; методика.*

Based on the analysis of existing approaches in the design and simulation of automatic control systems and mechatronic systems, it concluded that ECAD programs can be used for through designing multi-domain systems at all levels of abstraction, from conceptual models at the macro-level to the physical models at the micro-level. The theoretical conclusions are confirmed by the decision of practical example in the program MC 11 and summarized in the form of methodology of through-design of multi-domain systems in ECAD.

Key words: *mechatronic systems; automatic control systems; multi-domain systems; through-design; ECAD, modeling methodology*

Problem formulation. Automatic regulation and control systems (ACS) are multi-domain systems and composed of subsystems with different physical properties, synergistic combination of which provides a new quality. Mechatronic systems (MS) are variations of ACS and consist of mechanical actuator, which driven by digital and mixed-signal electronics subsystems [1]. MS have been successfully used in the Electronic Climate Control (ECC) in cars, for example [2]. These systems are synthesized the macro-level by using tools such as neural networks, Bond Graphs and Finite State Machines methods [2; 3].The software for such modeling are programs of Computer Aided Engineering (CAE) and Computer Algebra System (CAS) [1; 3]. Example of ECC model in CAS/CAE-System MatLab/Simulink/Stateflow existing now [4].

During the through-design different programs must be used at each hierarchical level:

– on macro-level: First study the behavior of the system as a whole (like a single unit), then synthesized the structure of the system and its parameters are determined. At this level usually used CAE and CAS programs.

– on micro-level: the system is divided into subsystems, each of them studied in object-oriented software. At this level are used different CAD programs (Computer-Aided Design).

Technology of design, which automated at all levels of abstraction (through-design), called Virtual Manufacturing (VM). CAD is one part of the whole Digital Product Development (DPD) activity within the Product Lifecycle Management (PLM) processes, and as such is used together with other tools, which are either integrated modules or stand-alone products, such as CAS, CAE and Computer-Aided Manufacturing (CAM), including instructions to Computer Numerical Control (CNC) machines [5]. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing [3; 5].

CAD is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design in many fields. Its use in designing electronic systems is known as "Electronic design automation", or EDA. EDA is also referred to as "Electronic Computer-Aided Design" (ECAD). Everything made by the electronics industry results from designers using EDA tools and services. In mechanical design it is known as "Mechanical design automation" (MDA) or MCAD, which includes the process of 3D solid state modeling (Finite element analysis) and creating a technical drawing [6].

When ACS are modeled at the system (macro) level abstraction, can used causal approach, which represent ACS system like composition of units, connected by the principle of causation. Using of the causal approach requires abstraction from the real functional and structural schemes of designed system and from physical properties of its subsystems, which may belong to different domains (mechanical, electronic, etc). At micro-level usually used a-causal approach, based on systems of equations (algebraic or differential) of physical models (inside single domain). Therefore, the specialist, who designs ACS at all layers of abstraction, should not only know perfectly causal and a-causal (physical) approaches to modeling and related software, but also be able to provide error-free communication of information during the transition between different simulation programs while changing levels of abstraction. Thus, through-design of ACS requires develop methodological support for harmonizing the various approaches and tools of simulation, or adaptation software for design in single environment.

We examine how useful are programs CAS, CAE and ECAD for ACS/MS modeling. Suitability of different programs presented in table 1.

Obviously, only ECAD programs usually have a direct link with the CAM. High level of mathematical support of these programs (instruments of Behavioral Simulation) allows us to recommend them for research the systems at the macro level too.

Purpose of the article is to develop methods and models for analyzing causal schemes of multi-domain system in the environment with a-causal principles of simulation for through-design at all levels of abstraction in electron domain programs (ECAD).

Main material. Let us consider advantages ECAD for ACS/MS modeling:

– Physical and accurate models for devices of electronic domain;

– Advanced analysis tools in the time and frequency domains;

– Availability of specific tools for controllers modeling;

– Ability to analyze nonlinear circuits not only in stationary and small-signal modes;

– Analysis of the ACS taking into account the physical properties of the blocks/devices;

– Implantation in Virtual Manufacturing, design "from conception to realization" with CAM-data generation;

– Ability to transition between levels: from system-structural to functional-schematic;

– Possibility of aggregative systems simulation, based on models for subsystems of different levels of abstraction (diacoptics principle);

– Powerful demos (MC11, OrCAD); universality of mathematical basis (SPICE).

Table 1

Useful CAS, CAE and ECAD for ACS/MS modeling

Criteria	Programs		
	CAS	CAE	EDA/ECAD
Approach	Causal, formal		A-causal, physical
Abstraction	High (macro)		Low (micro)
Object orientation	No. Focusing on multi-domain systems		Yes. Focusing on single-domain systems
Libraries of models	Formal models of ACS blocks Formal high-level causal type models and macromodels, abstracted from the physical processes in object, sorted by belonging to a certain domain		Physical models of elements from single domain. Models of elements from another domains (including ACS blocks) obtained by physical analogies method
Possibilities for synthesis and analysis of ACS	Tools for system synthesis and analysis based on State Machine, High-level programming languages; Samples of MS	Tools for synthesis and analysis based on BG languages, neural Networks; Powerful Linear Systems Editor (LSE); Samples of MS	Possibility of Emulation; quasi-causal approach; Instruments for behavioral modeling, (VHDL-AMS language); Samples of MS; Models of PWM, PLD and several types of microcontrollers (sorted by manufacturers);
	Formal models for PLD, controllers PID – regulators		
Algorithms of simulation	Large collection of Explicit and Implicit algorithms	Several Explicit Implicit algorithms	Implicit algorithms of simulation for nonlinear stiff systems
	Interpretation approach		Compilation approach
Algorithms of optimization	Large collection of optimization methods	Several methods of optimization, for LSE parameters including	Special algorithms of parameters optimization for nonlinear stiff systems
Connection with CAM	No	No	Yes (in Professional Versions); partially in Demo Versions

Although, on the other hand:

– Absence of methology/techniques using the quasi-causal approach to design ACS;

– Lack of a developed library of non-electronic devices, mechatronic systems, etc.;

– Some models of motors and actuators – without feedback;

– Limited number of optimization and stimulation algorithms, compared to CAS and CAE.

It is clear from these observations, that ECAD – is more convenient software (environment) for the through-design. Many of the EDA companies acquire small companies with software or other technology that can be adapted to their core business [7]. This trend is helped by the tendency of software companies to design tools as accessories that fit naturally into a larger vendor’s suite of programs on digital circuitry, many new tools incorporate analog design, and mixed systems. In table 2 features and benefits ECAD for ACS/MS modeling presented.

Table 2

Comparison of ECAD programs

Company-Manufacturer (capitalization)	Program for quasi-causal ACS/MS modeling	MCAD Cooperation	Price	Power of Demo	Through design
Synopsys ($5,8 billion)	Saber HSPICE	–	High	Low	–/+
Cadence ($4,5 billion)	OrCAD	–	High	High	+
Mentor Graphics ($2,4 billion)	Mentor SystemVision MCAD Co-Designer	+	High	Low	+
Altium	PCAD (AltiumDesigner) CircuitMaker	+	Mid dle	Middle	+
National Instruments	NI Multisim	–	Low	Middle	+/–
Labcenter Electronics	Proteus	–	Low	Middle	+
Spectrum Software	MicroCap	–	Low	High	–/+

ECAD-program SystemVision (Mentor Graphics®) [8] leverages the power and flexibility of VHDL-AMS (Hardware Description Language for mixed-signal systems), the IEEE standard language for modeling multi-domain and analog-mixed-signal system behavior at multiple levels of design abstraction [9]. It has large library of VHDL-AMS models, ranging from electronic components to motors, digital gates to hydraulic pumps, thermal to magnetic blocks. SystemVision also supports direct use of standard SPICE models (universal mathematical base for ECAD) [10]. ECAD/MCAD Design Data Integration help to transfer accurate design data inter CAD tools for electrical and mechanical designs.

Cooperation Programs and Libraries of element's models, during multi-domain simulation of ACS in Mentor SystemVision ptesented on fig. 1 [8; 10]. However, the price of the complete set of these programs is too high.

A good alternative for the purpose of students teaching or for small-scale manufacturing is the product of Spectrum Software – MicroCap, especially in 11 versions (MC11), with new features [11]. The technical advancements in MC11 for ACS simulation:

- open Libraries (more than 32,000 models) and Editors of models, shapes, circuits, packages;
- tools with transfer function (Laplace, Fourier, z-transform);
- simulation base on PSpice, SPICE3, HSPICE TM solvers, and models, which associated with these solvers for adequate simulation of nonlinear stiff systems;
- Periodic Steady State, Sensitivity and FFT-Analysis;
- Stability analysis for linear systems;
- AMS behavioral non-electronic devices modeling;
- New Optimization Algorithms;
- Package, Shape, Component Editors and Multi-page hierarchical schematic editor;
- LAN version for collaborative projects and threading techniques, multiple CPUs are employed to reduce simulation time.

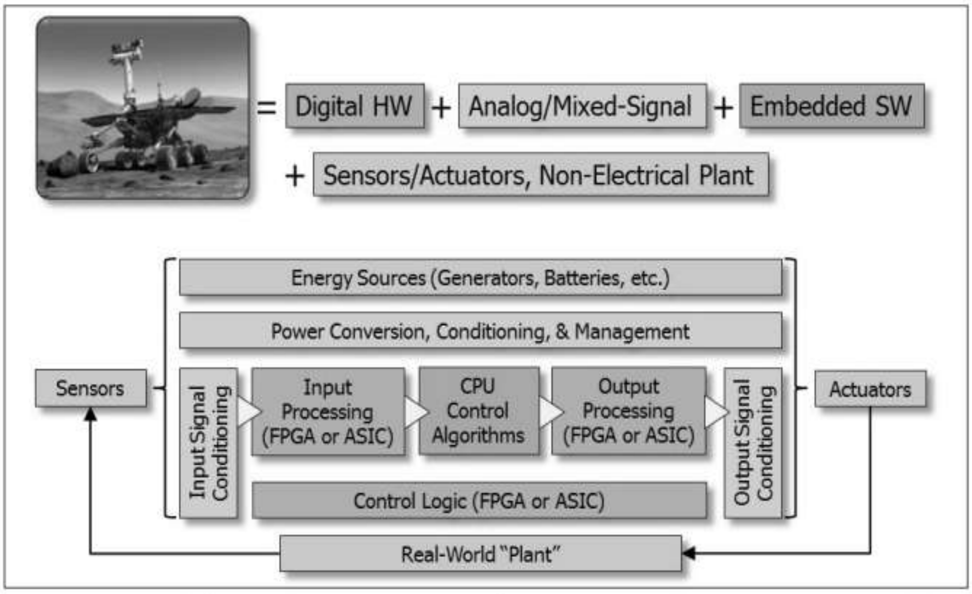
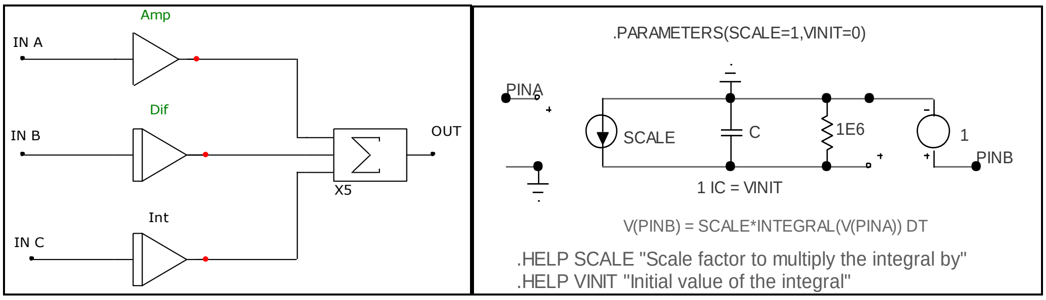


Fig. 1. Multi-domain simulation of ACS in Mentor SystemVision

Blocs from MC11 Library of Macros, which can be used for building schemes of ACS: Modulators (AM, FSK, PSK, PWM, etc); generators (Noise, VCO, Monostable, etc.); transfer functions (ABS, Clip, AMP, Resonant, Slip, Schmitt etc.); Blocks with mathematical operations (Dif, Div, Int, Sum, Sub etc.); Delay Blocks and other tools. So, MC11 can be used for simulation at all levels of abstraction and we can use it for development environment to design, integrate, verify and optimize multi-discipline designs, consisting of digital, analog and mixed-signal electronics, control algorithms and software, sensors, actuators and mechanical plant. It is only necessary to learn how to use the tools that the program provides for this purpose.

We examined possibilities of MC11 for the analysis of the trajectory generator, which is some kind of ACS. It consists of: ideal trajectory generator (pattern), switching device, emulator of disturbances and PID-regulator. The aim of regulator is to define a trajectory similar to ideal pattern, regardless of external disturbances. Macromodel of PID regulator for MC9 program (fig. 2, a) consist of "adder", which allows you to scale signals on each channel, "proportional block" (AMP – amplifier to improve stability), "integrator" (INT block to improve accuracy) and "differentiator" (DIF block with improved dynamic properties).

Model of Integrator block obtained by analogy principle, and based on properties of RC-circuit (fig. 2, b). Causality in it given by voltage-controlled sources (current/voltage), which provides galvanic isolation between output and input circuits. This scheme illustrated quasi-causal approach in modeling. Distortion emulated by special Behavioral-elements: programmable depended sources and RLC components (B-elements), in which we can programmated behave of unit, device or even whole system. It's found, that usage of universal functional-logic behavioral macromodels allows simplifying the simulation algorithm for AMS and MS. Well, B-elements give to us unique flexibility when modeling ACS and MS in ECAD.



a b

Fig. 2. Structure of macromodels: a) PID-regulator; b) Integrator

Transient Analysis of ACS before and after regulation presented on fig. 3.

Fig. 3. Transient Analysis of ACS: a) before regulation; b) after regulation

According to the results of the work, can be identified key stages of complex systems modeling in ECAD, which can form in a methodical sequence:

– collecting available information about the object of study and the requirements for it;

– description of system structure and connections between elements, input and output variables of blocs and the system as a whole in selected software for simulation at macro-level;

– choosing algorithms and principles for each of the structural elements of the system;

– determining the values of model parameters (identification/parameterization of models);

– after simulation, tuning parameters and evaluation of the adequacy the model blocks;

– comparison the results of simulation with the characteristics of real system (verification);

– complete system model analysis (engineering), to optimize system parameters;

– researching subsystems at micro-level, optimizing and preparing data for CAM.

Conclusions and further researches directions. At the macro level multi-domain systems can be modeled in ECAD by structural schemes, which based on composition of B-elements, or by the method of block-schemes. System-level model can also be described by the language VHDL-AMS [12]. At the micro level multi-domain system modeled by the diakoptics principles: subsystem of control and power electronics can be researched by functional and principal schemes (physical a-causal modeling), but the behavior of non-electronic devices must be emulated by B-elements (quasi-causal modeling). In other words, ECAD program – it's a Virtual Lab for designing and analyzing not only for electronic mixed-signal systems, but also for thermal, mechanical, and hydraulic multi-domain systems or any combination of these and other mechatronic system technologies. Accordingly ECAD support design of ACS and MS at all layers of abstraction: from conceptual model through detailed implementation, therefore, we recommended it for through-design, even in Demo-versions.

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