MŰEGYETEM 1782
Faculty of Electrical Engineering and Informatics
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Synthesis of Systems build Programmable Analog Circuits

Ph.D. Thesis

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1 Introduction

The cooperation of the analog and digital circuits and the embedded controllers as well as their industrial use and technical application have always been in the focus of my interest both in my engineering and teaching background.

In reconfigurable systems the effectiveness and quality of the analog circuit system can be maintained and modified by circuit or by changing the single element values.

There are further advantages of the programmable analog circuit applications; more compact, more reliable, more flexible systems can be produced with better performance. It is especially beneficial if for programming we modify the function of a programmable analog circuit either giving a new topology or a new component parameter using the flexibility of the microcontroller.

In my dissertation my aim is to introduce the analog systems, to examine their application possibilities and to reveal the ways of their innovative use. Among the application possibilities the various applications of the configurable and reconfigurable circuits, the realization of the robust analog circuits, circuit systems are concerned. The realization of the cooperation between the embedded microcontrollers and the programmable analog circuits, its expansion in the manufacturer recommendations and the application ways not mentioned in the application samples are also in the focus of my investigation.

1.1 The programmable analog circuits

The programmable analog circuit (Field-Programmable Analog Array (FPAA)), as a new component and a new technology appeared some twenty-five years ago. As a result of the continuous development, these devices programmed on a digital surface make an analog circuit topology with component parameters also given as programmable.

FPAAs can be used for the realization of different functional units, circuits, circuit elements. These circuits can be used effectively in applications where the low electric power, the lower development and component cost, the effective electronic CAD possibility are important.

The advantage of FPAAs in the field of faster and more economical circuit planning is significant. It is beneficial in self-developing circuit applications [SANTINI][1] [STOICA] [KEYMUELEN], in neural networks [LEE] [GULAG], in signal conditioning [KLEIN], in filters [EMBABI] [EMBABI-ALL], in fuzzy controls [PIERZCHALA] and high-frequency applications [GAUDET] [GULAG]. According to other approaches FPAAs serve the linear and non-linear implemen-

[1] References in the dissertation

tation of the analog system and the scalability of the application to be realized [BRATT] [OTH] [RAY]. Yet the above mentioned advantages are not obvious since it is very difficult to make a user-friendly FPAA and environment [HALL] [HALL-2004].

It has been suggested that the mixed-signalled architecture should be constructed duplicated, thus this circuit will be suitable for the realization of configurable, self-learning processes, algorithms by reprogramming occurring in the background [REISER].

The vast majority of FPAA applications allows the user to use the analog circuit in accordance with the required function taking advantage of the reconfiguration possibility. A further advantage of FPAAs is the simple embedding in bigger hybrid and digital systems.

The developments aim at meeting the big analog processing requirements in the field of high integrated FPAA devices in which there are too complex programmable applications: high-order filters (Fourier-processor), adaptive filter systems, vector-multiplier, matrix-multiplier [HALL-2004].

In multi-value logics [PIERZCHALA], in neural networks, in mixed-signal processor digital and analog circuits [MARTIN] in which the traditional microprocessor is integrated onto a silicon chip with low-performance analog circuit elements, further applications are offered. The smaller geometrical size, the fewer outputs, the cheaper mounting, the specifically smaller dissipation falling on of one volume unit are among the advantages.

Developments to be realized in the field of programmable analog circuits are as follows: speed, accuracy, digital noise, analog noise, performance, resource allocation possibility (capacity of FPAAs, component-level configurability), source usability, effective architectures, development environment services, macros, simulation, dynamic reprogramming [YOSHIZAVA] [EDWARD] [MÜLLER] [BAINS].

Research into the applications of programmable analog circuits, the spread of their application possibilities are to be solved.

2 The general interpretation of the technical problem

The second chapter of the dissertation describes the development of the analog circuits and their application possibilities, their basic operation and structure. Several times, in order to make the terminology unambiguous I introduce the functional units, their operation, their realization and application possibilities.

The FPAAs fall into two main categories according to their basic operation:

the discrete type and the real-time type. We can select from the two basic principles according to the application through buying the appropriate device or through configuring.

The polemic of „analog or digital" in this case leads to the „analog and digital" compromise.

The most recent programmable analog circuit developments, the higher number of configurable blocks, the higher frequency, the lower performance needs require more complex and special devices. These development environments need versatile computer-assistance having bigger and bigger interfaces with other simulation and electronic CAD programs. Reconfigurability reconfigurability support either via doubled memory or via a cooperative microcontroller architecture is considered as an important issue in development and research.

The described basic types are considered as milestones; their development, the quality of their development prove: The programmable analog circuits are beneficial, their advantage against other technologies is significant, and they are more and more widespread. The possibility of dynamic reprogramming is supported and solvable in most FPAAs. The application-related and circuit-theoretical realizations offer further possibilities. Considering the application and the market share of the individual products we can claim that the connected discrete FPAAs are the most widespread.

The reconfigurability of the circuits according to circuit multi-functionality and adaptivity is a more or less applied technique at present. Using this technique more suitable electronic solutions can be found, which are more adaptable under changed circumstances and for new application needs. When using traditional discrete circuit-theoretical elements and components, mostly the parametrical reconfiguration is the typical realization.

With conventional circuit elements, obvious restrictions and technical constraints the realization of the topological reconfiguration is possible, however, this process is not in use due to the apparent difficulties.

The parametrical and topological reconfiguration provide significant advantages in certain applications, the expensive circuit realization, however, restricts the application fields.

Reconfiguration further increases the adaptivity of an analog circuit, extends the application frameworks.

The robust analog circuit solutions provide a consistent, continuously high level operation, which is scalable and modified in a wide range. The safety, effectiveness of the analog circuit system can be increased, the performance input, the maintenance and repair cost can be reduced.

The on-operation testing of the robust system can be realized, the incorrect signal levels can be eliminated. The significance of the noise as error source can be reduced, the occasional over controlling errors can be eliminated.

The various controlling processes and system topologies can provide a solution in case of predictable and non-predictable errors.

The quality of the robust systems can be further increased if the analog system connects to the embedded controller on a digital surface, which is able to change not only the topology of the system, but also the circuit function of each part unit. The above mentioned features underpin the use of the programmable analog circuits in the robust analog systems.

3 The objective of dissertation

In part 2.2 after the description of the development and operation of the analog circuits I revealed such application fields where, I suppose, the previously introduced programmable circuits can be used successfully. In the following part I intend to show the possible application fields where the programmable analog circuits offer further advantages, innovative solutions.

In part 2.3 based on the programmable analog circuit operations and possibilities I intend to find new application solutions which could be realized with difficulty, complicatedly and expensively with the traditional analog circuits. This part is the reinterpretation of the classical circuit solutions and the introduction of new ones where otherwise certain processes could be realized only with difficulty or in no way with the traditional component set.

1. Aim: The transfer function modifying use of the programmable analog circuits in hybrid circuits.

I examine the possibility of how the programmable analog circuits can be used in hybrid circuits to modify the tranfer characteristics. The digital transfer characteristics modified with the analog values and the analog transfer feature are also involved. For this realization I intend to use the programmable analog circuits either as a forward or backward branch.

2. Aim: The use of the programmable analog circuits in reconfigurable circuits

I examine the applicability of the programmable analog circuits in the programmable systems described in chapter 3. I look for application fields where the advantages given by configurability and reconfigurability are important and through which a system containing a programmable analog circuit results in a new operation quality.

I search for solutions to the cooperation of the embedded microcontroller and the programmable analog circuit highlighting the advantages of the cooperation and the exploitation of circuit flexibility.

3. Aim: The applicability of the programmable circuits in robust systems

I work up processes in which exploiting the configuration and reconfiguration possibilities of the programmable analog circuits the robust electronic systems described in chapter 4. can be realized more economically and in a simple way.

I emphasize further possibilities and advantages of the cooperation of the embedded microcontroller and the programmable analog circuits.

4. Aim: Realization of self-organizing systems with programmable analog circuits

I examine the advantages coming from the interaction of a system containing the programmable analog circuits and the configuration process and I make suggestions on their optimal realization.

I examine the construction possibilities of bigger systems and their advantages.

5. Aim: The introduction of the practical application

Due to space constraints, reflecting to the above objectives, some practical applications illustrate the operation-ability of the suggested solutions, the usability and advantage of the described issues.

4 New scientific results, theses

1. Thesis [P1, P9, P13]

I developed a process which makes it possible that the programmable analog circuits in hybrid electronic systems can be used as a system element defining a transfer factor which can modify digital values, or as a device defining a digital logic function which can be modified with analog quantities, they should be placed in the forward or in the backward branches.

1.1. Sub thesis *I verify that by using the parallel digital inputs of a microcontroller depending on the input binary values the programmable analog circuit is reconfigurable, thus making the optimal transmission function between the analog inputs and outputs (1 figure).*

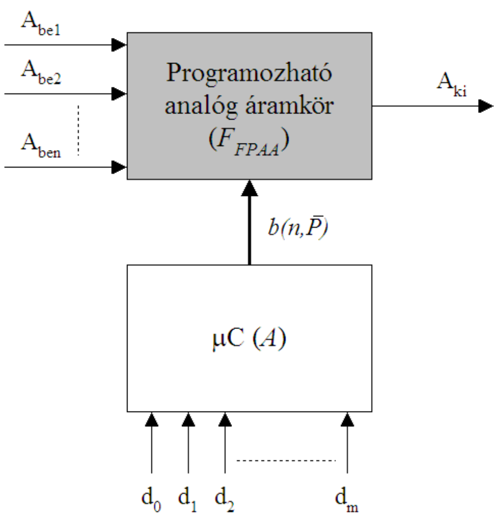

Figure 1: Controlling the circuit function of the programmable analog circuit with digital function.

1.2. Sub thesis *I worked up a new process with the help of which a programmable analog circuit can be attached to a digital feedback network constructing a digital-analog converter — analog inputs, and analog outputs — analog-digital converter signal route configuration (2 figure).*

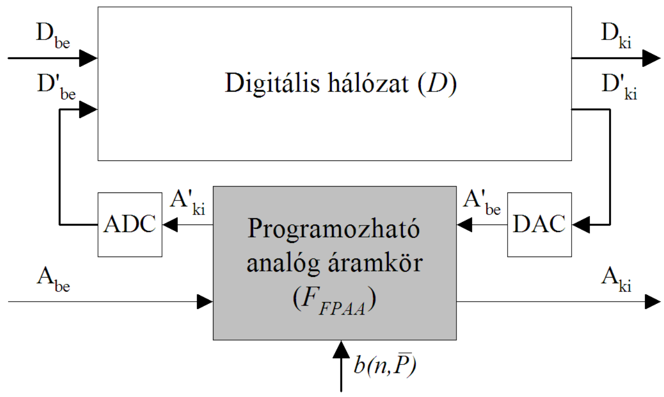

Figure 2: Feedback digital network through the outputs and inputs of the programmable analog circuit.

1.3. Sub thesis *I extended the above described to the virtual combination network constructed in the microcontroller where the feedback can be realized by changing and reconfiguring the circuit function of the programmable analog circuit using the configuration input, the analog output, the analog-digital transfer signal route (3 figure).*

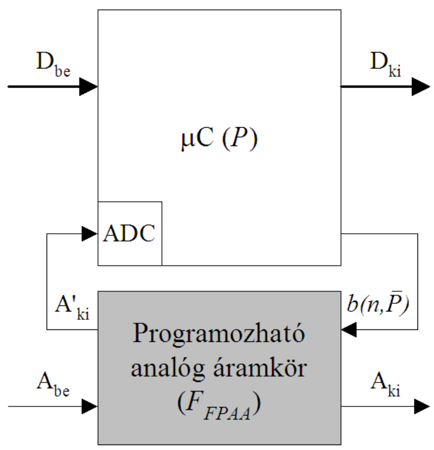

Figure 3: Feedback cooperation of the programmable analog circuit and the microcontroller.

2. Thesis [P2–7, P9]

I worked up processes with the help of which the application possibilities can be extended significantly taking into consideration the system attachment characteristics of the programmable analog circuits.

2.1. Sub thesis *I made an architecture from the programmable analog circuits, microcontrollers in which circuit functions can be changed without a system disturbance which does not exceed a given volume (4 figure).*

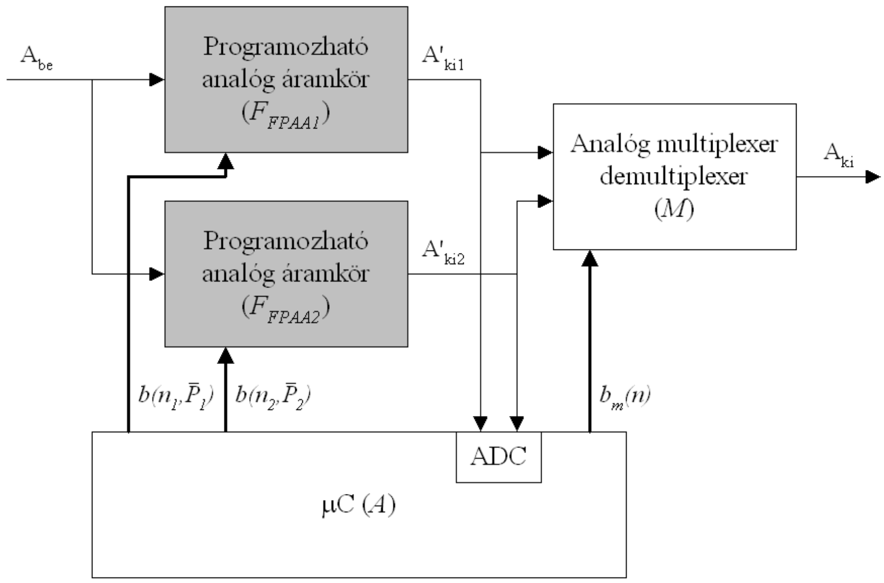

Figure 4: Circuit function change with microcontroller and programmable analog circuits.

2.2. Sub thesis *I worked up a system-construction principle in which, with the help of a microcontroller, by watching the internal conditions of the programmable analog circuits their circuit parameters can be adjust in a wide range. (5 figure).*

2.3. Sub thesis *I worked up a new system construction in which the programmable analog circuit, as a coprocessor, according to its actually configurable configuration, can overtake analog signal processing tasks, which results in speed increase (6 figure).*

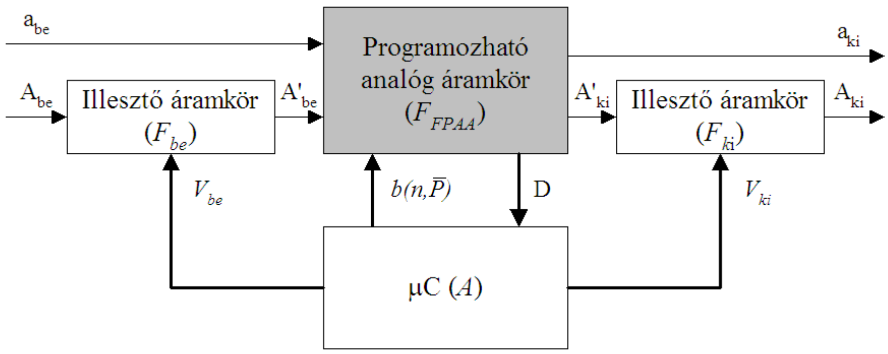

Figure 5: The programmable analog circuit with output and input attachment circuits in a microcontroller environment.

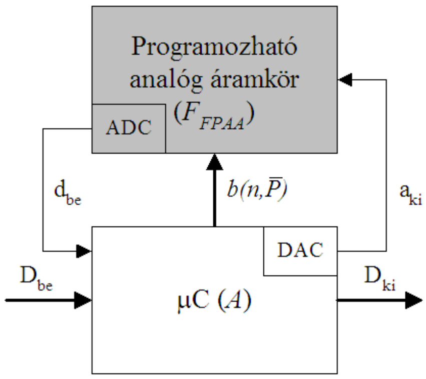

Figure 6: The programmable analog array as an analog signal processor cooperating with a microcontroller.

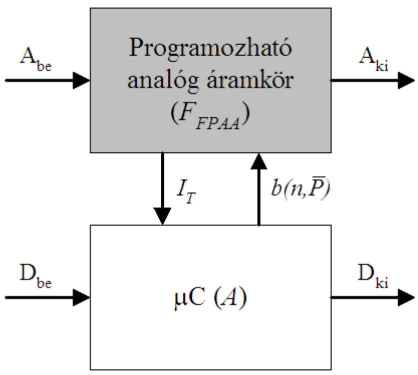

Figure 7: Connecting the microcontroller and the analog circuit with interrupt.

2.4. Sub thesis *I worked up a connection of the microcontroller and the analog circuit in which the change of the parameters of the circuit point assignable in a configurable way is able to generate the termination of the program requiring reconfiguration (7 figure).*

3. Thesis [P9–17]

I worked up processes which result in robust electronically solutions by an appropriate connection of the programmable analog circuits and by applying reconfiguration.

3.1. Sub thesis *I worked up a process in which through the cooperation of the programmable analog circuit and the microprocessor a characteristic prediction can be realized (8 figure).*

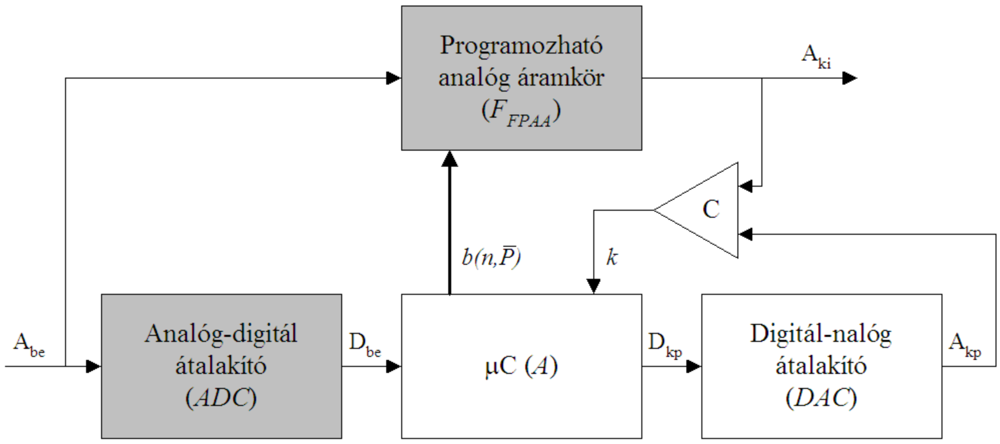

Figure 8: Making robust electronic circuits with a characteristic prediction.

3.2. Sub thesis *Using the microprocessor and the programmable analog circuit I worked up a system-construction principle which realizes predictive configuration (9 figure).*

3.3. Sub thesis *Using programmable analog circuits and a microcontroller I constructed a new, robustness supporting error-masking process which is based on monitoring the state changes of the internal circuit features made by configuration (10 figure).*

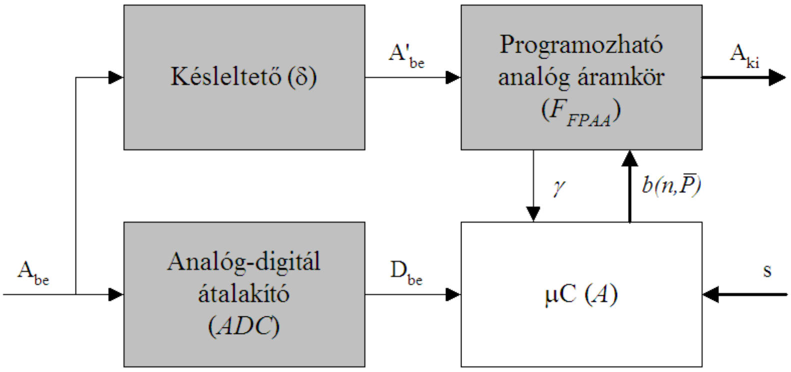

Figure 9: Constructing a robust electronic circuit with predictive control.

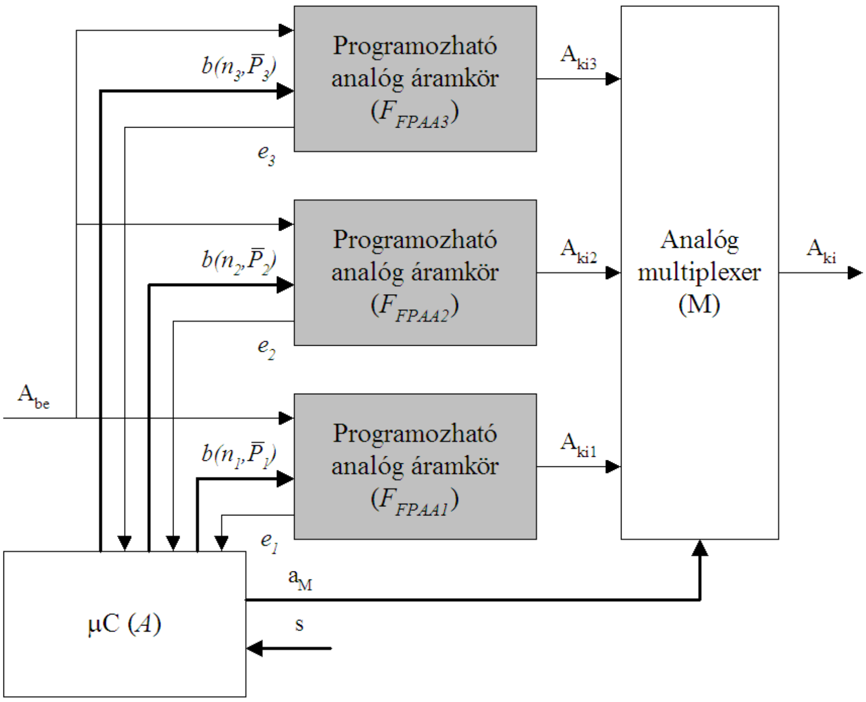

Figure 10: Majority voting principle error masking with programmable analog circuits and microcontroller.

3.4. Sub thesis *I worked up a system construction which depending on the output features provides the self-organization of a robust system by reconfiguring the programmable analog circuit (11 figure).*

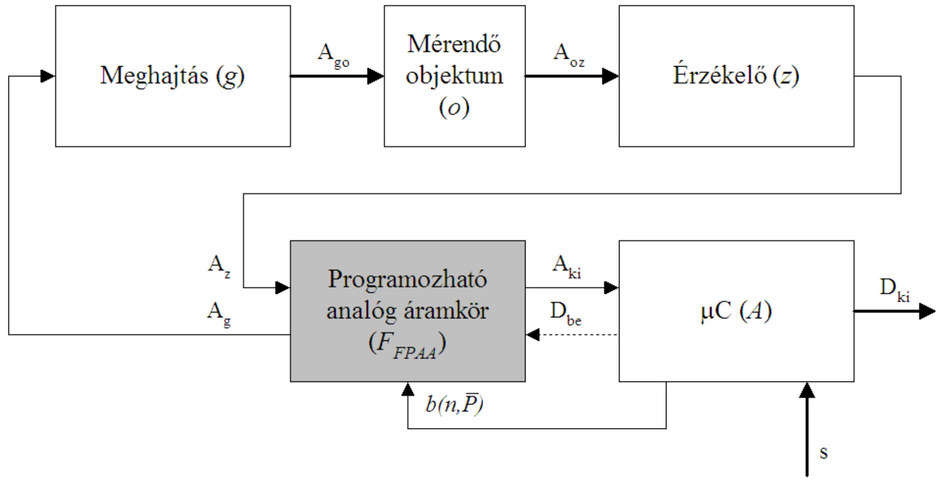

Figure 11: Constructing a self-adjust analog robust system in a measurement equipment.

4. Thesis [P9, P18–19]

I worked up a new system technical structure in which by the proper construction of the algorithm of the embedded microcontroller self-organizing, self-developing, self-learning functions can be realized in an adaptive way.

4.1. Sub thesis *By combining the previously defined database introduced for the dynamic and static configuration and the previously defined process, introducing a constraint feature I worked up a new algorithm for the reconfiguration of the programmable analog circuits.*

4.2. Sub thesis *I worked up a new process in which the redundant system constructed from the programmable analog circuits and the microcontroller makes possible to form, to measure and modify the inactive transmission function by which the database of the circuit functions can continuously be expanded and updated. (12 figure)*

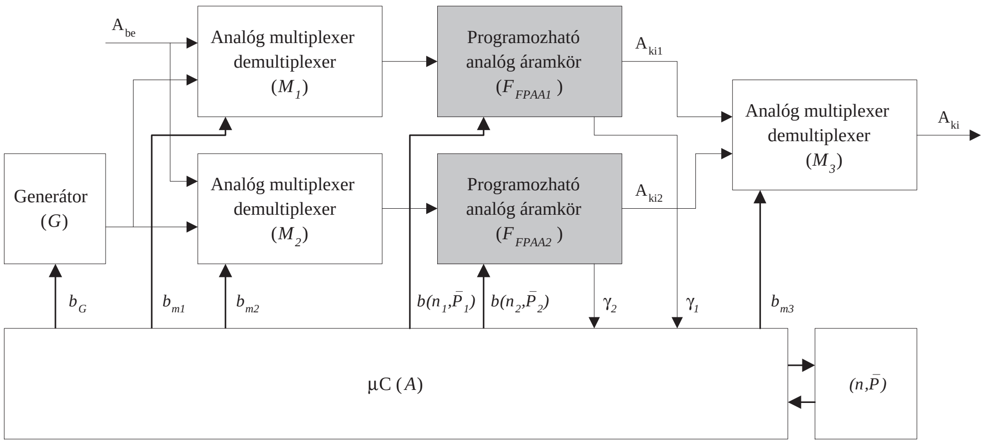

Figure 12: Measuring the transfer characteristics of the programmable analog circuit with a microcontroller in the background.

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