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Transformation of the Acoustic Amplifier into a Modular Structure

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The modular concept of device construction is most often based on the results of economic analyses. It allows lowering both manufacturing and design costs. It also improves their operating characteristics, in particular their repairability. It also happens that the modular structure of a consumer product is used to strengthen its market position. The authors of the article faced such a situation. The management of a company producing audiophile equipment decided to offer its potential customers an acoustic amplifier in which the user would be able to replace the preamplifiers himself, depending on the requirements related to the input signal. This type of modularity is known as "component swapping." Before commencing the development of the structure, detailed analyses of the benefits and potential risks related to the individual stages of the product's life cycle were carried out: design, production and operation. On this basis, the "Divaldi" company, the manufacturer of the equipment, developed assumptions regarding the designed amplifier. In particular, it was considered that the modular system would be built by modifying the existing, successful design of the INT-02 amplifier. The modification will enable easy replacement of the two preamplifier sections. Users will have a choice of classic preamplifiers: line and phono, as well as modules integrated with an analogue-to-digital converter and a module with a Bluetooth receiver. A low-volume production was assumed from previously manufactured and stored components: the base and typical preamplifier sections. As for the exploitation stage, the possibility of self-replacement of modules by the user has been adopted. Based on these assumptions, the concept of an amplifier with two identical pockets was proposed, enabling the simultaneous installation and use of two preamplifier sect ions. Detailed requirements for interfaces between the modules and the base unit were formulated: mechanical and electrical. A review of the available types of signal connectors led to the selection of the PCIe connector as the one that best meets the technical and economic criteria. From the mechanical side, it was proposed to use sliding guides, guaranteeing proper positioning of the modules in the pockets of the base. After selecting and approving the solutions, constructions of the mechanical components of the system were developed, creating a new standard: frame, module pockets and preamplifier module. The successful implementation of the amplifier's modularity became the basis for formulating proposals for further modifications of the design to meet the growing requirements of users who expect more and more possibilities to adapt the structure and interfaces of devices to their own needs.

Keywords: *modularity, acoustic amplifier, customization*

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Introduction

The Role of Modularity in the Construction of Devices and Other Products

The modular design of the devices is of great importance, e.g., for the economics of their production, ease of use or susceptibility to maintenance services. The most popular modular devices that we deal with in everyday life are e.g. personal computers, food processors, some gardening tools and machines, and motor vehicles to some extent. The modularity of products means such standardization that allows modification of their function or appearance by means of relatively easily replaceable units. As in the case of other standards, also when using modularity, many benefits are obtained in the organization of production, storage or service of products. Also, like any standardization, modularity is not without specific disadvantages, in particular, stopping the development of some product features for the duration of the "validity" of the adopted standard, i.e., most often for at least a few years.

It happens that the modular concept of the product is used to improve its market image, i.e., to increase its attractiveness compared to other competing products of the same type. An interesting example of such an approach may be the market of toys for children. Toys are not only supposed to give a child pleasure, but often also help them understand the world around them. A well-known example of combining a toy with the idea of modularity are LEGO bricks. These building blocks, being modules, have a standardized, simple mechanical interface and an ever-growing number of variations, dimensions and functions. Thanks to this, they allow children to create various compositions while teaching them shapes, recreating what they see and their own creativity. By adding new types of blocks to the offer, the number of possible implementations using this simple system is constantly growing, and blocks from a dozen or so years ago will still work with freshly designed modules (Figure 1). With this modular approach, LEGO has to some extent revolutionized the toy market.

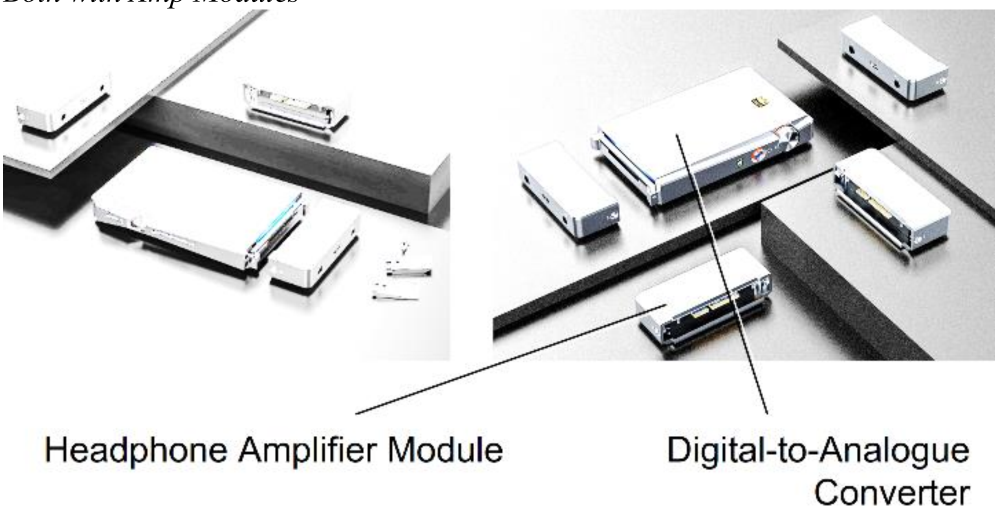
Figure 1. *Fragments of LEGO Ads: a) from 1981, b) from 2023*

Source: LEGO 1981, LEGO 2023.

Modularity in Audiophile Equipment

Manufacturers of audiophile equipment, as well as manufacturers of other expensive market products, try to beat competing companies by offering their customers solutions that are both aesthetically attractive and best suited to their needs in terms of functionality. Thus, they compete in the field of design, technical parameters and available functions. When it is difficult to offer new attractive features in the above-mentioned ranges, then you can consider changing the usable concept of the device, offering customers easy modification of its functions through the use of a modular structure. An example of such a solution is shown in Figure 2. These are two Fiio products - the X7 mk2 file player (Fiio 2016) and the Q5s analogue-to-digital converter (Fiio 2017).

Figure 2. *Fiio X7 Mark II Digital Audio Player (left) and Fi-io Q5s DAC (right). Both with Amp Modules*



Source: Fiio 2016, Fiio 2017.

DIVALDI, a Polish manufacturer of audiophile equipment, has also decided to follow this path. A typical set of devices used by listeners to play music and other sound forms is shown schematically in Figure 3. The dynamic development of this equipment is dictated, on the one hand, by the tendency to fill the space with sound, and on the other hand by the increasing number of sources, and at the same time the types of sound signal that must be transformed and then amplified to the level required by the loudspeakers. The preamplifier shown in the diagram, whose task is to adapt the signal parameters to the requirements of the power amplifier, can be a stand-alone device, can be built into the sound source, or can be a component of the main amplifier (Figure 4). The management of the company decided to offer users of audio systems a power amplifier equipped with replaceable preamplifier modules.

Figure 3. *Schematic Diagram of the Audio System*

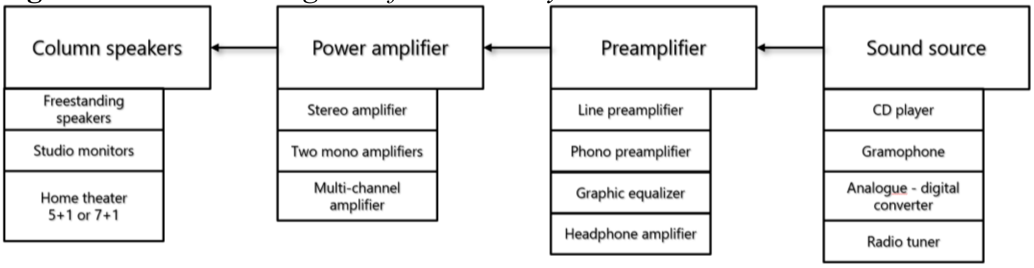
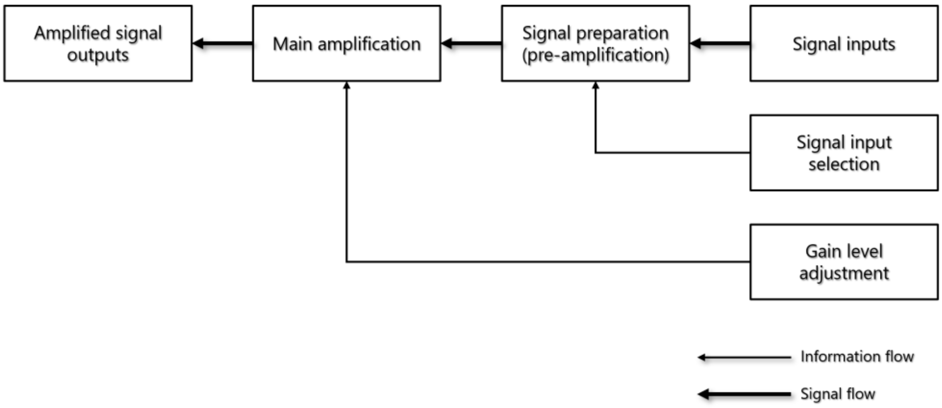


Figure 4. *Functional Block diagram of an Integrated Acoustic Amplifier*



Taking into account the favourable technical parameters as well as the visual attractiveness of the offered products, DIVALDI decided that the new, modular power amplifier should be built by modifying the existing, integrated amplifier INT-02 (Figure 5), which had already been positively received by the market.

Figure 5. *Integrated Amplifier INT-02 Accepted for Modernization - View from the Front Panel*

Objective and Scope of the Project

The aim of the work described in this article was to develop a construction of a modular acoustic amplifier that would meet the manufacturer's requirements, and in particular enable easy replacement of preamplifier modules by the user. At the same time, it was planned to offer the recipients classic preamplifier modules: line and phono, as well as modules additionally equipped with an analogue-to-digital converter, a Bluetooth receiver, and even vacuum tubes. Each module will have appropriate connectors for signal inputs: pairs of RCA, XLR, USB or antenna connectors for modules with wireless communication. The power supply of the module will be provided by the amplifier, i.e., the basic module. It was allowed to offer more than one model of selected modules, to design a module "on request" according to detailed customer requirements, and to design new modules in the future. Such extensive development plans forced the need to provide a universal base for all preamplifier modules, in particular the adoption of such size restrictions that in the future will not become an obstacle to the implementation of new preamplifier design e.g., due to the dimensions of electronic components.

Work began with a review of literature sources on the construction of modular structures, hoping to obtain methodological guidelines to support the implementation of the project. The results of the review were used at the stage of formulating technical assumptions for the amplifier. The construction works were carried out based on the well-known methodology of designing mechatronic devices adapted to the needs of the project. The discussion on the obtained results concerns, above all, effective methods of proceeding in the design of modular systems.

Literature Review

Modular devices are characterized by quite unique standardization in a certain area of the product life cycle. Due to this cycle, we distinguish 3 stages of modularity: modularity in production, modularity in design and modularity in use (Baldwin and Clark 1994). The role of modularity in production is to optimize the number of parts used, e.g., by reducing the variety of fasteners in products or e.g. the base of materials used for the production of parts. Modularity in designing is aimed at creating a design structure capable of quickly introducing changes or corrections with as little impact on other parts of the device as possible. The creation of such a structure takes place through its decomposition at the conceptual stage and the creation of appropriate interfaces between the structures. Modularity in use allows modification, replacement or adjustment of auxiliary functions during its use by the customer. The selection of components is made by the user and he also decides about the possible expansion of the system and the purchase of additional modules, if any. The development of environmental sciences has also resulted in the development of an additional stage: modularity in product recall. The following issues are considered here: design for the environment (Li et al. 2008), design for disassembly, design for recycling (Campagnolo and Camuffo 2010). Each of the above-mentioned stages carries specific limitations adopted in the name of a certain goal resulting from economic, market, ideological or utility factors. These constraints have the benefit of streamlining the process, using predetermined structures and procedures that simplify the process or allow the project to be left open for expansion or evolution.

The modular structure of many devices is of great importance for the economics of their production, susceptibility to maintenance services, but also, as mentioned earlier, for the position of the product on the market. Currently, we can often encounter modularity as an element that distinguishes a given structure from others offered. Typically this is accomplished by the assumption of modularity in use. If the end user is to choose a function from a palette available when he needs it, then the constructor is only supposed to provide an interface that allows combining modules in the configuration chosen by the user. This trend has developed in different stages of new product development: from marketing to design to technology (Fettermann and Echeveste 2014). Shifting the burden of adapting the device's functions to a specific user allows to simplify the conceptual design process due to the needs of the market. On the other hand, it makes it more difficult due to the greater workload of the research and development department and a wider scope of work on product design. Due to the difficulties in measuring the efficiency of the R&D department, it is also difficult to measure the competitiveness of such a solution (Clark and Fujimoto 1992). Of course, every company cares about the most efficient design process possible, and here modularity should be adjusted to the priorities in a given product family by making a profit and loss account that will show the sense and profitability of modularization in a given area (Clark and Fujimoto 1991a, Baldwin and Clark 2000).

Other stages of modularity are less obvious at first glance. Sometimes they reveal themselves in the common components used. Modularity in design can be recognized after the use of previously created modules in new products, which reduces the cost of their production, and at the same time shortens the process of constructing the product (Campagnolo and Camuffo 2010). Cost reduction is also achieved by reducing the variety of, for example, fasteners, which enhances the scale effect within the assumptions of large-series production. This has become commonplace in the automotive industry, where the most efficient ways to manage a product have been worked on for years (Clark and Fujimoto, 1991b).

Modularity has many aspects that need to be considered at the stage of creating design assumptions: from the principles of product design using the features of modularity (Baldwin and Clark 2000), through the goals of modularity, the effects of -carry modularity (Baldwin and Clark 1994), at what stage of product design it should be applied (Campagnolo and Camuffo 2010), to types of modularity, types of modules and stages modularity (Huang and Kusiak 1998, Kusiak and Huang 1996). These assumptions always start with the correct product decomposition (Huang and Kusiak 1998, Kusiak and Larson 1995). Each of these publications emphasizes a different aspect of modularity, and at the same time each of them defines the activities of the designer who was given the task of modularizing the structure. In industrial practice, the most common task is to transform an existing structure into a modular structure in order to obtain a specific, measurable benefit related to improving the efficiency of both the production process and the design process, as well as the relationship between them (Kuwashima and Fujimoto 2013, Awwad and Akroush 2016). Modularity is strongly associated with the product life cycle and sustainable development (Ma and Kremer 2015, Halstenberg et al. 2015), and also brings measurable benefits and costs associated with it (Campagnolo and Camuffo 2010). One of the distinguishing features that has been strongly emphasized in many studies is the definition of the interface between modules, which, due to the limitations it builds, significantly affects further work (Ulrich 1992, Ulrich and Tung 1991).

In the case of the described project, it was assumed that the amplifier should allow the user to install and later use two selected preamplifiers. According to the publication (Kusiak and Huang 1996), this type of modularity of devices is called "interchangeability of modules" (Figure 6). Basically, we distinguish 3 types of cooperation between modules: interchangeability of modules is when auxiliary modules work with bases (basic modules) within one product family and each subsequent module works with existing bases; sharing modules - occurs when modules can go to other product families and modules from other families can create new families of modular products by creating a new set; bus modularity (Figure 7) - is used when a module with two or more interfaces can be matched to any number of basic modules. It allows the number and location of the basic components to be changed, whereas the previous methods only allow for the variability of the basic modules.

Figure 6. *Modularity of Component Exchange (left) and Representation of Modularity of Component Sharing (right): F_i – i-th Basic Module, M_i – i-th Auxiliary Module (Huang and Kusiak 1998)*

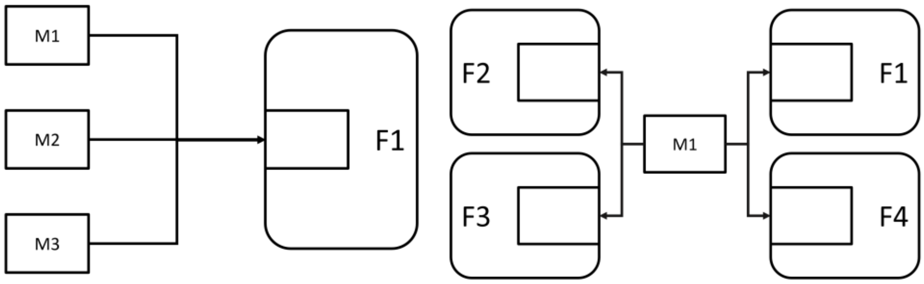
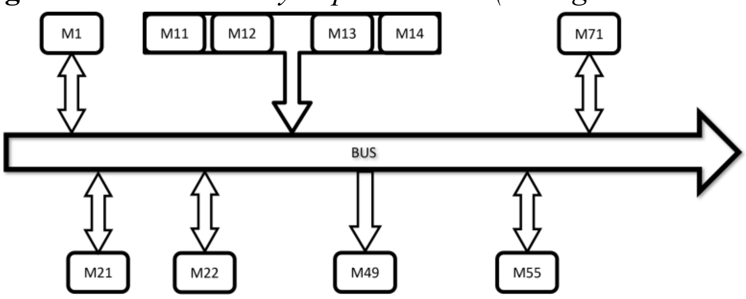


Figure 7. *Bus Modularity Representation (Huang and Kusiak 1998)*



Implementation Method and Course of the Project

The review of literature sources did not give contractors a full answer to the question about the algorithm for designing modular systems, but it provided valuable information systematizing the issues of building such systems. In this situation, the authors decided to use a well-known and proven in many projects algorithm for designing mechatronic devices (Mellal 2018), adapting it on an ongoing basis to the specificity of the task undertaken. According to this algorithm, a typical design of a mechatronic device can be closed in a six-stage cycle, which has the following form:

1. Determining the user's needs - the result of which are e.g., system structure and list of interfaces.
2. System function analysis - leading to the identification of the necessary executive and measurement systems along with technical requirements.
3. Development of executive and measurement systems - ending with proposals of technical solutions for individual functional systems.
4. Development of subsystems of the device: mechanical, electronic and software - which results in technical documentation of the subsystems.
5. Supervision over the execution of the prototype - under which structural corrections are introduced.
6. Running the prototype - with possible improvements to the system.

The article presents the most important results of the work carried out in the first four stages of the cycle, preceding the execution and implementation phase.

Assumptions for the Product Life Cycle

Guided by publications on the life cycle of modular products (Campagnolo and Camuffo 2010), before developing the amplifier, an attempt was made to collect the assumptions made by the manufacturer for the new construction in relation to the individual stages of the product's life. The most important intentions formulated by representatives of DIVALDI are presented below.

Design Phase

The project was to be implemented as a modification of the existing design of the INT-02 integrated amplifier. The modification was to enable easy replacement of the preamplifier section by the user. During the design process, it was important to ensure the use of standard signal connectors to ensure easy availability of manufacturer's parts and documentation.

Production Phase

The company established a small-lot production of the amplifier. It was assumed that semi-finished products from which ready-made modules will be assembled will be stored in the warehouses. Production planning will take place according to the number of incoming orders. Ultimately, the most popular configurations should be available in stores on an ongoing basis, and the production of less popular modules will be organized according to needs and sales.

Testing Phase

The manufactured sub-assembly will be tested prior to assembly by measuring the ratings. If all parameters meet the strict standards set by the company, the subassembly goes to the finished product. The finished product is also checked with measuring equipment to ensure the highest quality. When this test passes, the device is checked in a ready-made reference audio system, where a subjective assessment is made through listening by a designated, qualified employee of the company. This ensures that the product leaving the plant is of the highest quality.

Storage Phase

Due to the requirement to supply stores with the most popular configurations so that they are always on the shelf in stores, the warehouse will contain several pieces of each module and base.

Distribution Phase

Distribution will be carried out by the DIVALDI online store and stationary audio equipment stores around the world. In each store, the most popular modules and the amplifier base will be on the shelf. When buying a product, the customer purchases a base and selects the number of modules he needs. He knows the price of the base and each of the modules. In the store, in addition to the most popular modules, you can order less popular modules that will be delivered to the store for the customer. The user can also order a special module with specific parameters by directly contacting the company.

Use Phase

By replacing the module, the user adjusts the function of the device to his needs. This operation can only be performed when the device is turned off. After placing it in the device, the module is immediately ready for operation. The assembly of the module can be carried out by the user strictly according to the instruction manual. The assembly of the modules is to be possible only in one fixed position, and it must not require the use of additional tools.

Disposal and Servicing Phase

The service of the device will be carried out by DIVALDI. Under the warranty, the product will be picked up from the customer by a courier and delivered to the company, repaired there, and a new one will be sent back to the customer right away to shorten the user's waiting time for the module as much as possible. Repaired modules, free from defects, re-checked by quality control will be sent for resale.

Recycling Phase

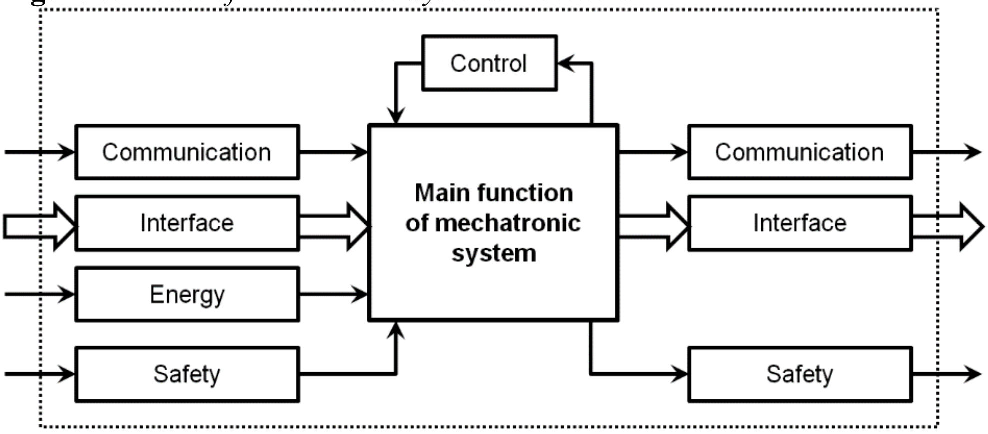
Damaged or worn modules returning to the plant will be inspected, then worn components will be replaced or their components used in new modules while maintaining the highest product quality. Any deviation from the nominal parameters disqualifies the product.

Work on the amplifier was carried out following the well-known and proven in earlier projects algorithm for designing mechatronic devices (Mellal 2018), which was continuously adapted to the specifics of the task undertaken.

Development of Technical and Operational Assumptions

According to Buur (1990), a convenient model of a mechatronic device that allows for the formulation of basic design assumptions is the function diagram shown in Figure 8.

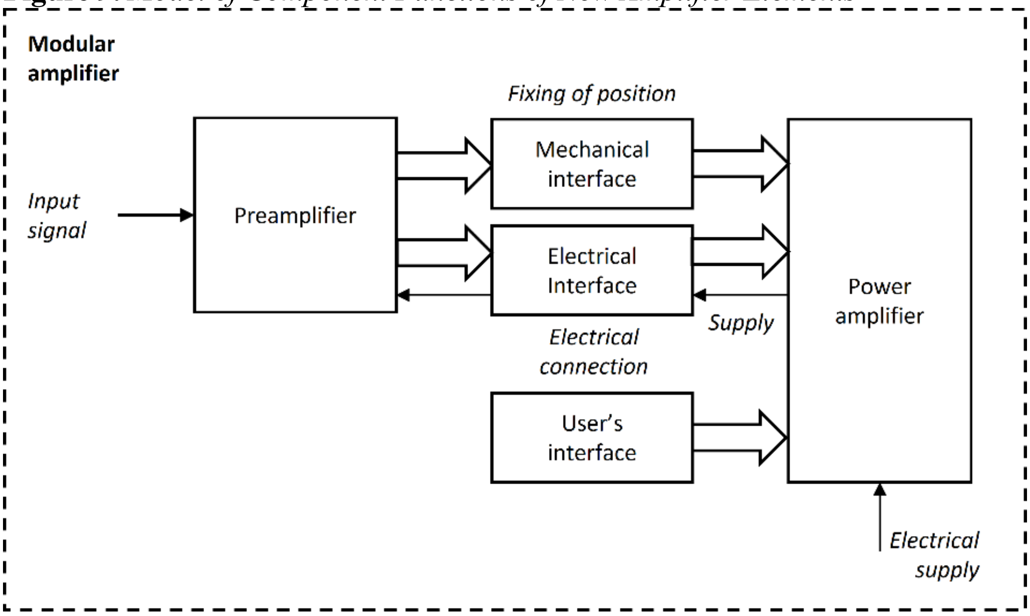
Figure 8. *Model of Mechatronic Systems Functions*



Source: Buur 1990.

Without limiting the application of the above diagram only to mechatronic devices, it can also be referred to in the analysed case. Then, the undertaken project concerns two electronic devices with strictly defined main functions: a preamplifier and a power amplifier, for which an interface with new characteristics is being developed (Figure 9).

Figure 9. *Model of Component Functions of New Amplifier Elements*



Mechanical Features

From the point of view of the implemented project, the individual components of the amplifier must fulfil specific mechanical functions, which are presented below.

Preamplifier

The mechanical functions of the preamplifier consist in its ability to be enclosed within certain dimensions of the electronic preamplifier circuits. In addition, it must be equipped with an input signal receiving system: contact or radio.

Power amplifier

From the operational side, it was assumed that the amplifier should allow the user to install and use two selected preamplifiers without the need to interfere with the mechanical structure of the basic module.

Mechanical interface

The mechanical interface is to guarantee the proper location of the preamplifiers in the basic module, including the implementation of electrical connections, and to protect them against accidental disconnection. The interface is also intended to allow the exchange of modules if the user deems it necessary.

Electrical interface

Its role is to ensure a reliable electrical connection between the leads of the electronic circuits of the preamplifier and the power amplifier, as well as a loss-free supply of the voltage supplying the preamplifier from the amplifier.

User interface

There is a potentiometer in the front panel, which is connected directly to the main amplifier and is used to adjust the sound level. There is also an input selector for the user to select the active pre-amplifier.

The functional requirements included the exclusion of the need to use tools when installing modules, as well as the approximate installation time not exceeding 5 minutes.

Operational strategy

As part of the project, it was assumed that the amplifier should allow the replacement of preamplifiers without any maintenance during the entire period of operation, while the permissible number of module replacement operations should not be less than 50.

Operating environment

The operating environment of the mechanical and electrical interfaces is the interior of the power amplifier, which had to be characterized, especially in terms of the temperatures inside it. This factor has a significant impact on the selection of functional components as well as on the mechanical design. The maximum temperature that can be expected inside the amplifier is 60°C.

System structure

This is where information is gathered concerning, on the one hand, the components that make up a given system, on the other hand, suggested or required technologies for their production, and finally their design form and ergonomics, which are particularly important in the case of market products. The management of DIVALDI has accepted the design concept according to which the preamplifiers will be in the form of drawers placed in the amplifier sockets by sliding them from the rear panel. The rear wall of the module contains signal connectors and, when inserted, forms an integral part of the amplifier's back plate.

The operational concept of the amplifier is illustrated in Figure 10.

Functional Analysis

As in the case of other projects, the algorithms for adapting the amplifier to the customer's needs implemented by the user himself were used to carry out a functional analysis of the constructed interface. The algorithms include: installing one preamplifier, installing two preamplifiers, and replacing the preamplifier. The algorithm for installing one preamplifier is shown in Table 1. In the case of a mechatronic device, the result of the functional analysis is a list of controlled executive systems and measurement systems necessary to perform its main function. When the considered device does not contain controlled mechanical systems, its functional analysis boils down to specifying the assemblies that will be used in performing manual activities. The assemblies identified in this way (Table 1) were included in the block diagram of the modified amplifier (Figure 11).

Figure 10. *Usable Structure of the Designed Amplifier*

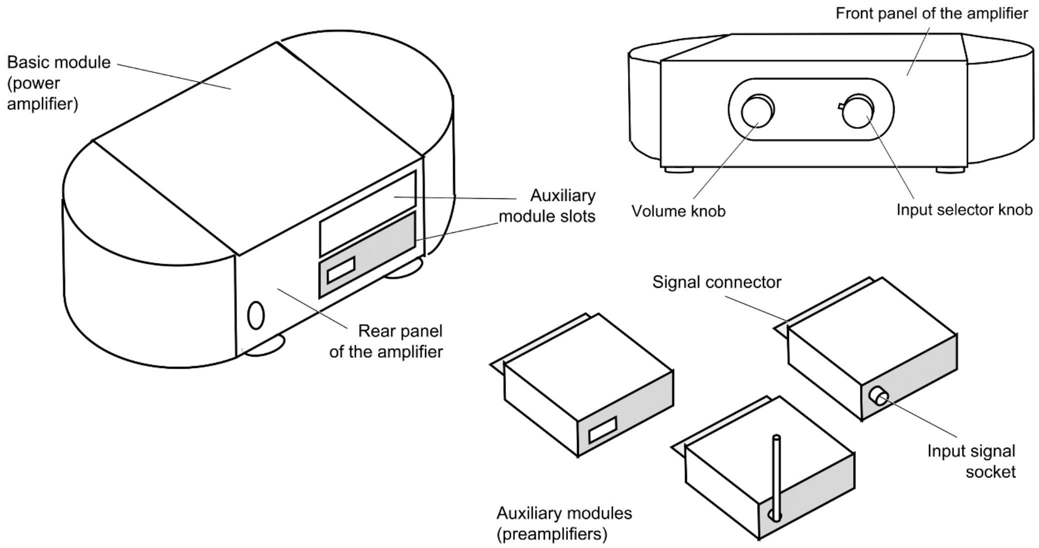
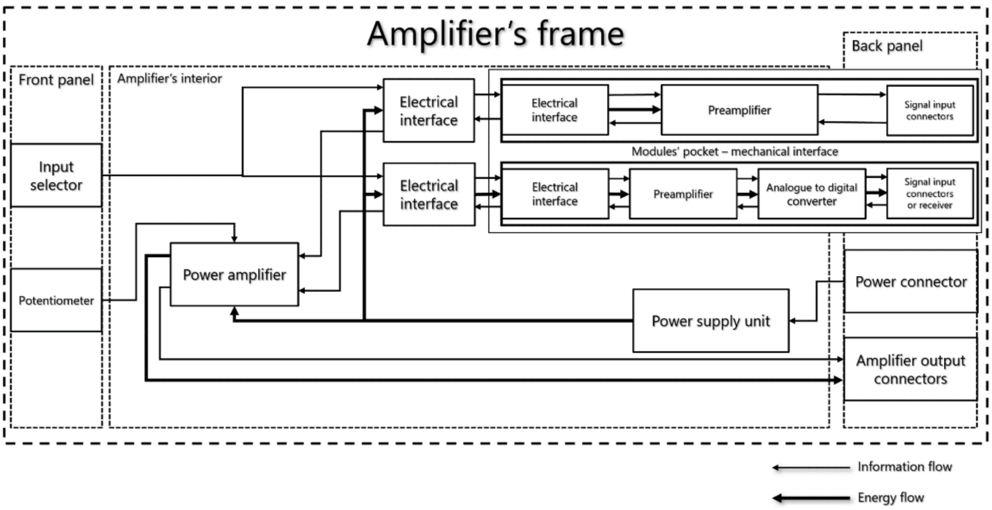


Table 1. *Single Preamplifier Installation Algorithm by the User*

No	Operation	Subassembly
1.	Disconnect the amplifier from the mains power supply.	1. Power switch/power cord
2.	Remove the selected preamplifier from the packaging and, if necessary, unlock the connector	
3.	Inserting the preamplifier into the amplifier's socket while connecting the signal contacts	3.1. Guide assembly 3.2. Contact assembly
4.	Mechanical fixing of the preamplifier module.	4. Module locking assembly
5.	Checking the correctness of assembly.	5. Module mounting indicator
6.	Unpacking the replacement module	
7.	Placing the replacement module in the second slot	7. Module positioning assembly
8.	Retaining the replacement module	8. Module locking assembly
9.	Installation correctness check	9. Module mounting indicator
10.	Mains power on	10. Power switch/power cord
11.	Source selection	11. Selector
12.	Volume setting	12. Rotary potentiometer

Based on the functional diagram, 3 main mechanical components can be distinguished, which also act as a housing and their electronic and signal components: front panel with signal input selector and potentiometer, rear panel with signal input connectors, column output connectors and power connector, the frame of the amplifier, consisting of a sheet metal construction and electronic components of the amplifier attached to it. The radiators together with the sheet metal body form a frame and partly function as a housing. The functional analysis stage was completed by formulating detailed technical requirements for each of the developed and modified assemblies.

Figure 11. *Functional Block Diagram of the INT-02 MODULAR AMPLIFIER*



Development of Functional Modules

Basic Module - Modification of the INT-02 Amplifier

Individual functional blocks were synthesized into modules and their assembly base. On this basis and using a multi-row model of the arrangement of objects inside the amplifier (Heragu and Kusiak 1991), a place for placing the amplifier modules was proposed as in Figure 12. Figure 13 shows the modified configuration of the rear panel of the amplifier.

Figure 12. *Suggested Location of Module Pockets in the Amplifier (top view)*

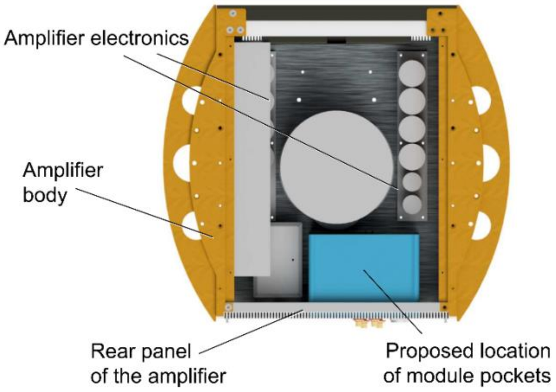
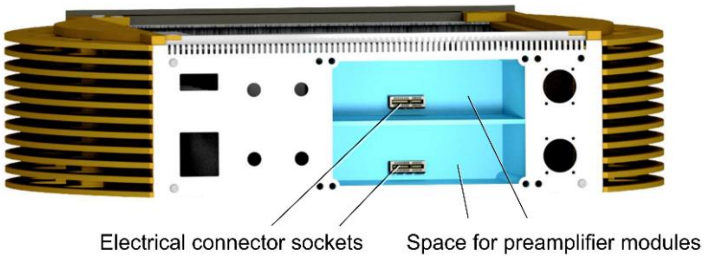


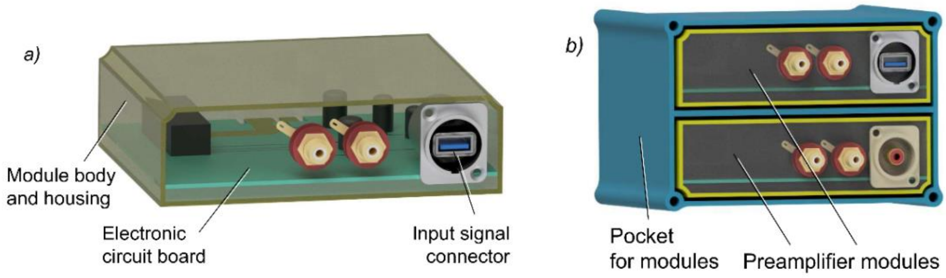
Figure 13. *View of the Rear Panel of the Amplifier before Inserting the Auxiliary Modules*



Auxiliary Modules – Preamplifiers

It was decided to implement the preamplifier modules in the form of cuboids (Figure 14a) strictly filling the space provided in the amplifier pocket (Figure 14b). The electronic circuits of the preamplifier must fit inside the module, and electrical connectors and guides must fit on its external surfaces.

Figure 14. *The Proposed Shape of Auxiliary Modules (a) and Their Location in the Amplifier Pocket (b)*



The adopted spatial configuration of the amplifier was consulted and approved by *DIVALDI*.

Electrical Connection

With the help of the connector, the signal prepared by the preamplifier is included for further amplification. This signal should be transmitted with as little interference as possible. Experts have suggested using connectors that typically carry high-frequency digital signals and have gigabit data rates. Following this path, it was decided to use an edge connector, often used in digital electronics devices, computers, measuring equipment, expansion cards or memories. These connectors carry signals with frequencies of the order of 1 GHz, and sometimes even more. Equally important are the transmitted power signals, and the power of these signals reaches up to 30 W of continuous load. Not every connector is able to accept so much power continuously. The design advantage is the fact that most of them implement one part of the connector in the form of contact pads directly on the board. Other implementations rely on a connector with such functionality, which we solder into the board. Thanks to this, we can make a connection by moving the socket and plug, which implements the assumption of guiding the connector to be inserted using a mechanical interface.

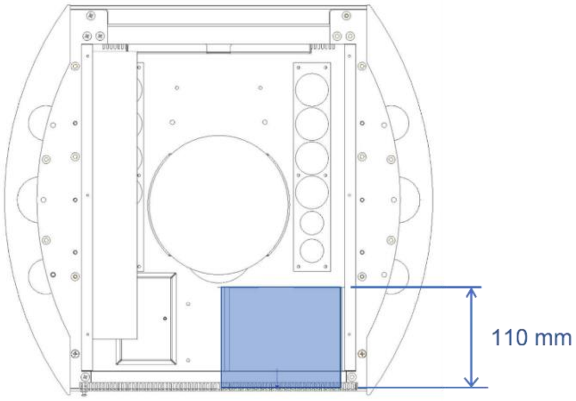
Guide

The mechanical interface has the task of positioning the module in the pocket, guiding it in the pocket when inserting, positioning it relative to the electrical interface, and fixing it in the pocket. A typical assembly that can perform these functions are guides. Trading guides consist of a trolley and a rail. Due to the small loads that occur between the module and the pocket when installing the preamplifier, it was decided to use a sliding guide.

Design of the Amplifier

On the basis of the previously conducted analysis, commercial parts were selected, and then a solid model of the module and the cooperating pocket was developed, which were oriented in the model of the acoustic amplifier supplied by the company. The project involved modification of the frame plate of the current amplifier design, creating space on the back plate (Figure 15) and developing the structure of the module pocket and the module itself.

Figure 15. *Determination of Pocket Depth*



Selection of Commercial Components

The required high quality, availability and multitude of types of edge connectors decided on the choice of edge connectors from the global manufacturer of Molex connectors. Due to the above requirements, the following types of edge connectors were taken into consideration for further comparative analysis: PCI Express, Sliver Card Connector, SATA, SAS SCSI, EdgeLock, Edge-Line, EdgeMate. Then, each of the connectors was analysed due to the parameters offered and the functionality it brings. The results of the analysis are presented in a summary table (Table 2), in which the most important features of each joint from the functional point of view were distinguished and assessed using a point scale.

Table 2. *Evaluation of Technical Properties of Joints with Scoring (Excerpt)*

c	Advantages	pts	Disadvantages	pts	cost	pts	Σ
PCI	- 8Gb/s data transmission - 36 signal lines - max 50VDC - the second connector is a board – Gold plated - Huge popularity	5	- Low resistance to the number of insertion and removal cycles: 50 - max 1.1A per line, so you have to run the power supply in parallel through several lines - assembly perpendicular to the receiving board	6	Minimum: 1 pc. 1 item: PLN 6.20	5	16
Silver Edge	- 32Gb/s data transmission - 140 signal lines - Higher durability: 200 cycles - mounting to the side of the board - gold plating of contacts - good fixing to the board	7	- low maximum voltage 29V; (on the border)	5	Parallel: Min.: 4,800pcs. 1 item PLN 23.28 Perpendicular: Min.: 16,800 pcs. 1 pc.: PLN 5.94	1	13
SATA	- 6Gb/s data transmission - High current 1.5 A per line, so we only divide the power supply into 2 lines, - max 30VDC perfectly fits the requirements, - high endurance of 500 cycles	3	- need to purchase both male and female connector	3	Minimum: 1 pc. 1 pair: PLN 8.44	4	10
SAS SCSI	- Data transmission 6Gb/s - max 30 VDC ideally suited to the requirements - high durability of 500 cycles - more lines (29) than SATA	4	- the need to purchase both male and female connectors, - max current 1.5 A per line, so we only divide the power supply into 2 lines,	4	Minimum: 2500 1 item: PLN 16.81	2	10
edgelock	- double crimp bracket with embossed contact pads as protection against slipping out - max current 3A - max 125VDC - the connector does not need a second plate, it has wires to be stretched to the devices	2	- the need to make a hole and fixing fields in the plate - the need to develop a mechanism to open the safety catch - no possibility of attaching to the plate - no data on adaptation to very small high-frequency signals - the connector is more suitable for power transmission than audio signals	2	Min.: 1pc: 1 piece: PLN 2.93	6	10

On this basis, taking into account the economic advantages - greater popularity and over 12 times lower cost - it was decided to choose the PCIe connector. The author notes that the use of the Edge-Line ESP Power Plus connector is limited to the proprietary connector of one manufacturer, which in the future may cause problems with spare parts and the need for re-analysis in order to change the interface in new products.

On this basis, a set of features of each of the solutions is presented below. Three models of commercial guides were presented, the dimensions of which were initially qualified as possible for application between the pocket and the module. The results were compiled in a Table 3 on the basis of which the solution was selected.

Table 3. *List of Features of the Considered Commercial Guides*

Solutions	Advantages	Disadvantages	Cost
Igus drylin® N (low profile)	- Commercial solution - The *iglidur ® insert* is electrical insulator	- trolleys not adapted to multiple assembly and disassembly of the guide without special treatment of the guide - a fixed insert makes it difficult to remove the play	Trolley: PLN 11.05 Guide: PLN 88.90
Igus drylin ® T (miniature) Carriage: TW-04-07 Guide TS-04-07	- Commercial solution - The *iglidur ® insert* is electrical insulator	- trolleys not adapted to multiple assembly and disassembly of the guide without special treatment of the guide - a fixed insert makes it difficult to remove the play	Trolley: PLN 107.75 Guide: PLN 119.35/m
Pacific Bearing Mini Rail MR7	- Commercial solution - the ability to work at different temperatures - ceramic coating	- trolleys not adapted to multiple assembly and disassembly of the guide - no play clearance - the largest shopping trolley	Trolley: PLN 92.80 Guide: PLN 228.60/m
Sliding guide (plastic shell)	- can be built into the pocket and the module - huge compactness - a bearing shell with an electrical insulator - the bearing shell can be entirely made of plastic or it can be made of steel and covered with a plastic tape - the possibility of additionally designing clearance clearance	- own project - time devoted to the preparation of technical documentation - searching for the manufacturer of the part in the material of the cup	on order;

The considerations contained in the table above led to the conclusion that due to the similarities between the individual commercial guides, the choice is not made between four and two solutions - a commercial solution and the development of own construction. Both the carriages and the guides are of similar dimensions, so the constructor should choose them based on different properties. When choosing commercial guides, the size of the trolley and the guide may be a problem. It will not allow for the maximum use of available space by limiting the possibilities of integrating solutions.

On this basis, it was decided to develop our own way of carrying the module in the pocket. Optimal use of the available space, which determines the maximum dimensions of the module's electronics system. In the future, this may be a threshold condition for creating new systems, so the designer's task is to provide as much space as possible, and it is also important, as in the case of the electrical interface, that the in-house design is resistant to the risk of being withdrawn from production by a third party.

Design Development

The pocket is located in the back part, on the right side. This caused the connectors in this place to be shifted to the left. The space for the previous solution of classic preamplifiers has been removed. The pocket is attached to the amplifier frame plate with rivets (Figure 16). Two printed circuit boards with fixed PCIe connector mounting holes were attached directly to the bay (Figure 17). The electrical leads of the connector are adapted to be threaded through the plate.

In the pocket, unlike the module, there is no need for a high-quality design form, as it will be hidden in the amplifier behind the back plate. The pocket will not be exposed to falls due to the user's inattention, so there is no need to provide it with increased stiffness and impact resistance. On this basis, it was decided to choose a sheet metal structure that would ensure the correct positioning of the module before connecting to the electrical interface at low manufacturing costs.

Figure 16. *Pocket for Modules Fixed Inside the Amplifier*

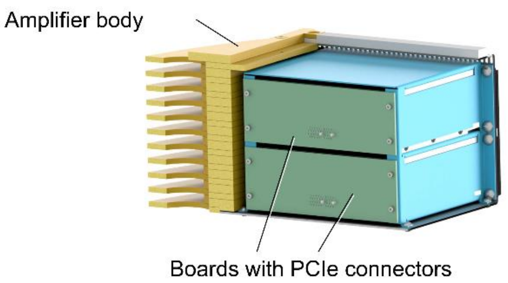
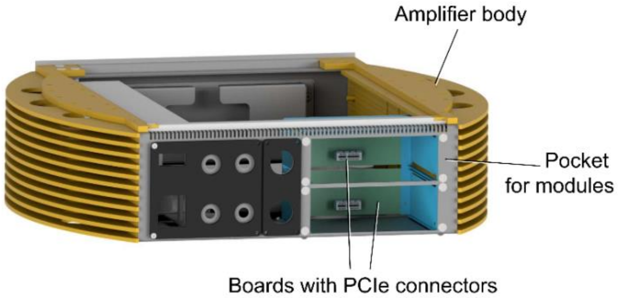


Figure 17. *Rear View of the Amplifier - Printed Circuit Boards (marked green) with PCIe Connectors Located on them are Visible in the Pocket*

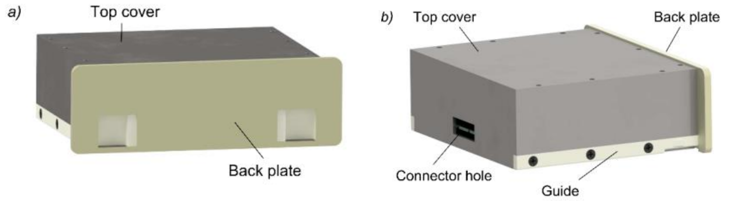


The pocket is a sheet metal structure attached to the frame with rivets. It is attached to the rear panel with conical rivets, thanks to which they do not protrude beyond the outline of the amplifier and do not constitute an obstacle to the installation of modules.

The body of the module will carry mainly loads from the mass of electronics and transport loads during the distribution process. Due to the loads mainly coming from the electronics system, which can be assumed to be in the order of hundreds of grams, it should be as light as possible. Then such a module will load its weight on the module pocket and the guide. Another requirement is the electromagnetic isolation of the module from the environment and the appropriate stiffness of the modules so that it works properly in the guide. The material of choice is either steel alloys or aluminium alloys in the 7075 family.

As part of the construction of the module body, a monolithic structure of a sheet metal, milled or cast body was considered. In order to implement a rigid structure, it was decided to make the body, which also serves as a housing, from milled duralumin elements. Input signal connectors are attached to the rear panel. The top cover eliminates the user's direct access to the electronic circuits (Figure 18). The modules were guided by elements made of sheet metal. The pocket has rectangular holes for latches that position and hold the module, preventing it from sliding out on its own.

Figure 18. *Mechanical Structure of the Preamplifier Module: a) Rear View, B) Front View*



Inside the module, closed with the top cover, there is a printed circuit board with the maximum possible overall dimensions. There is an edge connector on the board that is designed for a PCIe connector that slides through the hole. Mirror guides, made of Teflon, constitute a friction pair with a pocket made of steel sheet. The guides have latches that are deflected by the slats (Figure 19). An undercut was made in the leaves to allow them to be pulled back with the fingers of the hand (Figure 20).

Figure 19. *View of the Module after Removing the Back plate and Cover*

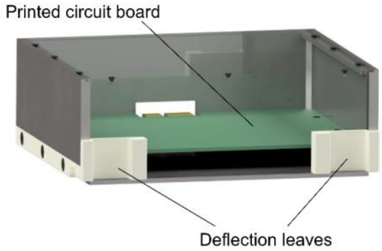
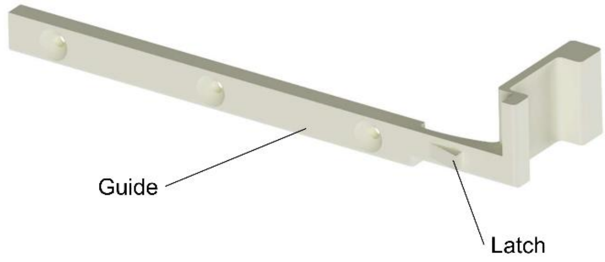


Figure 20. *Left Guide with a Latch*



Discussion

The described work is an important part of the design of the modular acoustic amplifier. As a result, documentation of the mechanical structure of the device was created, which ensures the possibility of easy installation and replacement of preamplifier modules. This documentation defines a kind of standard adopted by DIVALDI, which can be used in the subsequent years of production and development of the INT-02 amplifier.

The implementation of the construction study was preceded by a broad review of sources devoted to the design of modular systems. Thanks to this, it was possible to formulation by DIVALDI of the most important assumptions regarding the amplifier in the context of individual phases of the product's life. At the same time, it was noticed that an effective way of obtaining the necessary information from the contracting authority is to familiarize him with particular issues of modularity in a sequential manner. Thanks to this, it is easier for a company that has not carried out similar projects so far to make decisions regarding the further course of the project. At the same time, a review of publications showed the lack of an unambiguous algorithm for building modular structures (Gershenson et al. 2003). For this reason, after formulating the key assumptions, the authors decided to base further work on the methodology of designing mechatronic devices known to them, which guarantees the correct fulfilment of the adopted technical and operational assumptions. This methodology is a convenient tool for teams constructing technical structures including mechanics, electronics and software. Due to the adopted manual nature of the activities performed when operating the modular amplifier, this methodology was somewhat simplified, because there were no software components in the project, and electronic issues were reduced only to the use of a signal connector and the issue of signal shielding.

The issues of building modular systems are presented in the available literature by many specialists, however, often guided by different points of view. For this reason, it is difficult to combine these issues into a logical arrangement, allowing for the effective conduct of development projects. The authors had the opportunity to learn about these difficulties on the example of the described design of a modular amplifier. In this way, they gained some experience in combining the economic, management and engineering aspects of modularity, which is a strong impulse for them to undertake research on the principles of conducting such projects.

Conclusions

The analyses carried out during the project and the construction work performed are the basis for formulating conclusions regarding both the amplifier design itself and the methodology of proceeding in the construction of modular systems.

1. The design of the modular acoustic amplifier has set an internal standard covering the geometry and spatial configuration of the elements that make up the auxiliary modules. If approved by the Company's management, this standard will be in force for a longer period of time, probably for at least several years. During this time, the modules, both basic and auxiliary, will undergo natural developmental changes. For this reason, it is important that the adopted restrictions do not hamper this development. It seems that one of the ways to eliminate potential threats in this area should be to develop electronic structures of all currently planned preamplifiers to confirm that each of the developed boards will fit in the space provided for it in the auxiliary module and will be able to function properly in it.
2. Analysing the developed structure, it can be seen that it has the potential for expansion not only as part of further improvements of the interface pocket - preamplifier module, but also in the basic module itself. One of the possible directions of development of the design is the implementation of the front panel of the amplifier as another module, which, depending on the version, would extend the functionality of the entire amplifier or adapt the user interface to its needs, including stylistic needs.
3. Modular constructions, like other constructions, are created either as a result of the company's internal development work, or are commissioned to specialized design units. In both cases, decisions regarding the adopted standard are most often made by the company's management and are validation of the project. The specificity of modularity and the serious consequences that result from it indicate that those who decide on the scope and shape of the limitations introduced by modularity should have some knowledge of various aspects of modular constructions. On this basis, the authors suggest that projects of this kind should include some kind of training on modularity, or even workshops for the management of the companies concerned. Such action may increase the awareness of those responsible as to the consequences of their decisions.
4. The authors are convinced that the available knowledge on the construction of modular systems and their own experience in this field may be the beginning of work on an algorithm or a set of algorithms for project management of such systems. In the initial phase, it is planned to develop a detailed description of already implemented projects, including the one presented in this article. The target algorithm can then be created as a result of its further improvement. In these works, the technique of process modelling (Zakarian and Kusiak 2000) and their simulation using Petri nets (Kusiak and Yang 1993) or fuzzy graphs (Li et al.

2008) are expected to be used. This may also require modelling data from previously designed processes and determining the impact of the results of the analysis of such data on further actions (Kusiak et al. 1997). A clear, proven algorithm should not only increase the efficiency of the projects carried out, but also reduce the risk of making significant mistakes, especially at the stage of formulating assumptions.

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