BULGARIAN ACADEMY OF SCIENCES
INSTITUTE OF INFORMATION AND
COMMUNICATION TECHNOLOGIES

INTELLIGENT METHODS OF RESEARCH AND IMPLEMENTATION OF HARDWARE SOLUTIONS

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ABSTRACT

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Professional area: **5.3. Communication and computer technology**
PhD programme: **02.21.04. Computer systems, complexes and networks**

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INTRO

A common form of formalization in the field of artificial intelligence is the system, which includes a set of interacting components that function together to achieve a certain goal. An information system is a construct that encompasses all forms of gathering, storing, retrieving, processing and disseminating information. A distributed system is a complex of connected computers and devices that work together as a single information system, but are located in different physical locations. This type of system is used to solve complex tasks and process large volumes of information, with different components sharing work and resources.

With the development of modern technologies, wider prospects for innovation in the field of distributed systems for wireless collection, transmission and management of information flows are opening up. The current PhD thesis is aimed at the design and development of technical (hardware and software) tools that play a key role in the implementation of such systems.

Distributed systems for wireless collection, transmission, and management of information flows are essential to modern society, where fast and reliable data exchange is essential for various sectors such as industry, transportation, healthcare, and others. Despite the technical challenges, these systems provide the ability to collect and analyze information in real time, leading to improved efficiency, optimization of resources and the ability to innovate.

The presented PhD thesis explores key aspects of the technical design and development of components and devices involved in the realization of these systems. The focus is on architectural solutions, communication protocols, sensors and software platforms that are essential to the functionality and reliability of the systems.

In the research and development process, existing approaches and technologies will be analyzed. In addition new and innovative methods for improving the technical aspects of distributed systems will be presented. Through detailed documented experiments and practical tests, a reliable basis for the realization and optimization of

these systems in real conditions will be built.

The topic of design and development of technical means for distributed systems for wireless collection, transmission and management of information flows is highly topical, due to the growing dependence on technologies that facilitate communication and data management in diverse fields. These advances have the potential to change the way businesses operate, infrastructure and even people's behavior.

Several key aspets highlight the relevance of this topic:

1. **Internet of things (IoT) and Industry 4.0:** The ever-widening implementation of IoT and Industry 4.0 is changing the way devices and systems communicate and exchange information. Distributed wireless data collection systems are at the heart of these advances, allowing devices to connect and exchange data in real time.

2. **Smart cities and infratructure:** The development of smart cities and infrastructure requires the integration of multiple systems and devices for monitoring, management and optimization. Wireless data collection systems are a key technology that enables cities to be more efficient and sustainable.

3. **Healthcare and handheld devices:** Distributed data collection systems also have great potential in healthcare. Wearable devices and sensors can collect data on people's health and provide valuable information for healthcare.

4. **Wireless communication and connectivity:** The development of new wireless technologies such as 5G and LoRa enables faster data exchange and greater range. This opens up new possibilities for collecting and managing information from various remote points.

5. **Information safety and security:** As network infrastructure and communications grow, questions arise about data security and protection against malicious attacks. Research into technical means and methods to protect information becomes critical.

Distributed systems for wireless collection and management of information flows are based on a combination of different technologies, including radio frequency identification (RFID) and artificial intelligence (AI).

Combining neural networks and radio frequency identification can be used to process and analyze data that is collected by RFID technologies. For example, neural networks can be used to analyze data from RFID tags to predict trends in customer behavior, to optimize logistics processes, or to identify data anomalies.

The combination of these technologies can be implemented through the use of distributed systems and cloud resources. Data processing from RFID tags and sensors can be done locally at the point of data collection or on cloud servers where neural networks can analyze and predict events. This approach can lead to more efficient solutions and optimized processes in various areas.

The current PhD thesis aims to **research and implement hardware solutions using modern methods from the field of intelligent systems**.

To achieve this goal, the following tasks have been formulated:

1. To conduct a critical analysis of the possibility of applying intelligen methods for research and implementation of hardware solutions.

2. To analyze the possible connections and interactions between two key technologies - radio frequency identification and neural networks.

3. To explore ways to integrate these technologies to achieve intelligent and efficient solutions for collecting, processing and managing information flows.

4. To conduct an analysis of the opportunities and challenges that arise with the implementation of radio frequency identification and neural networks in distributed systems.

5. To analyze how the incorporation of wireless technologies can enhance the intelligence and functionality of a distributed system by adding additional capabilities for communication and data analysis.

6. To present original hardware solutions for collecting, processing and managing information flows.

The PhD thesis is structured in an introduction, three chapters, a conclusion, accompanied by a declaration of originality of the obtained results and a bibliography.

In the Introduction, the object and subject of the PhD thesis are defined. The relevance of the topic and the motivation for conducting the research are briefly described. The goal of the research work and the tasks to achieve it are set.

Chapter 1 presents the fundamental theoretical concepts related to distributed systems for wireless collection, transmission and management of information flows. It focuses on a specific technology for radio frequency identification (RFID) and the means of its implementation, as a distributed system for wireless collection, transfer and management of information flows. Signal analysis is performed, a hardware solution in the CADSTAR environment and simulations in the MATLAB environment are provided for wireless communication in noisy environments.

Chapter 2 presents theoretical concepts and methods of artificial intelligence. It focuses on the implementation of a distributed system for wireless collection, transmission and management of information flows with Neural Networks (NN). An analysis of a communication network with one-way data transmission, from the input layer to the output layer, without feedback loops, as well as simulations in the MATLAB programming environment for wireless transmission of messages in a noisy environment, was carried out.

Chapter 3 describes the specific research tasks that have been carried out in order to analyze and evaluate the proposed Radio Frequency Identification (RFID) and Neural Network (NN) technologies for their inclusion in distributed systems operation algorithms. The results of the simulation studies that were performed to investigate various aspects of the system are presented. In addition to the conducted research, original hardware solutions of devices for collecting, processing and managing information flows are also presented.

The PhD thesis ends with a Conclusion summarizing the results obtained from the conducted research.

The achieved results of the analysis of the research carried out in the current PhD thesis are presented in the scientific journals – „Problems of Engineering Cybernetics and Robotics” and „Engineering Sciences”, as well as in the proccedings of the 10-th IEEE International Conference on Intelligent Systems - IS '20.

CHAPTER ONE

RADIO FREQUENCY IDENTIFICATION METHODS

1.1. Radiofrequency identification – a brief history.

Radio-Frequency IDentification (RFID) is one of the methods of automatic identification and data collection for automatic remote identification of objects through radio frequency communication.

The Near Field Communication (NFC) technology was created in 2002. It is the result of a joint effort by the Sony and Philips companies, which created NFC as a standard for near-field wireless communication between devices. NFC technology uses radio frequency communication and is based on RFID, but with a shorter range and greater ability for two-way communication between devices

1.2. Main approaches of the radiofrequency identification.

RFID technology is based on radio frequency communication between a specially made identifier (label, tag, card, key fob, sticker, etc.) and a reading device. Each identifier contains a chip with a recorded unique number and an antenna.

1.3. Principles of the working of the hardware components of an RFID system.

An identifier, also called a tag, transponder or label, containing an antenna and an integrated circuit with memory, is placed on the object intended for control. The reader (Reader), also called the controller, periodically emits in short time intervals (usually 50 ms) electromagnetic waves with a fixed frequency, which reach the antenna of the identifier. They trigger it for a set time (usually 20 ms), during which it sends back a modulated signal with the necessary object data, which in turn can be transmitted to a nearby or remote computer, (Fig. 1).

According to international standards, there are four ranges for radio frequency identification. (Fig. 2).

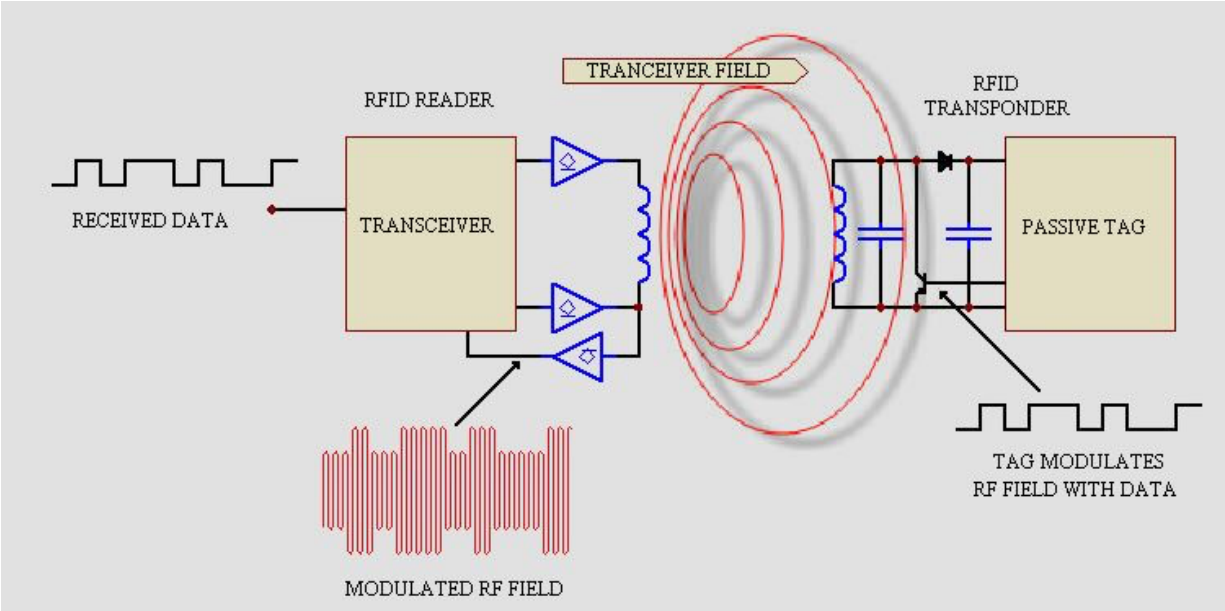

Fig. 1. RFID system

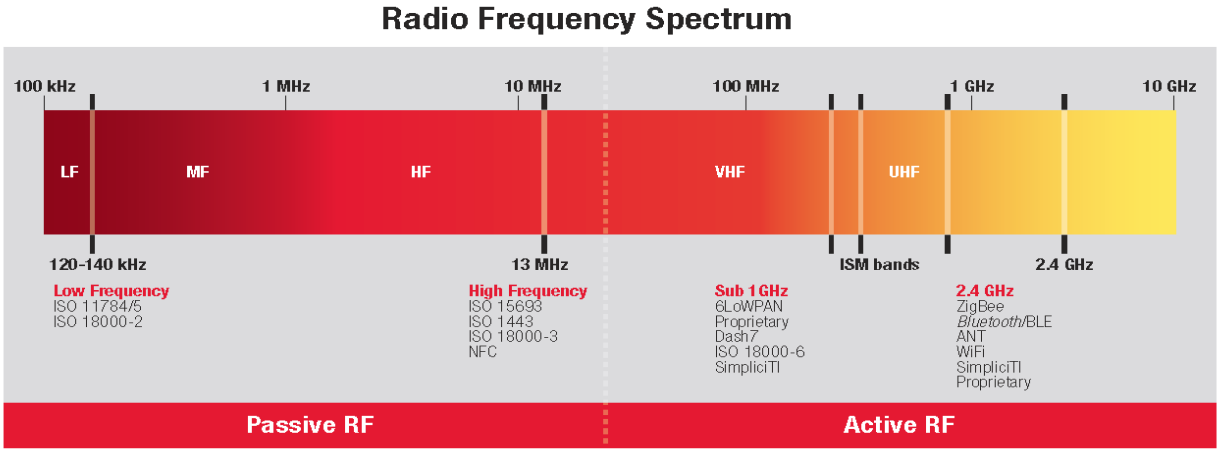

Fig. 2. RFID frequency fields

1.4. Hardware components of an RFID system.

- **RFID identifiers**

Identifiers are also called transponders, and tags. RFID identifiers can be classified according to their power supply as passive (Fig. 3) without their own power supply and active (Fig. 4) with their own power supply (battery).

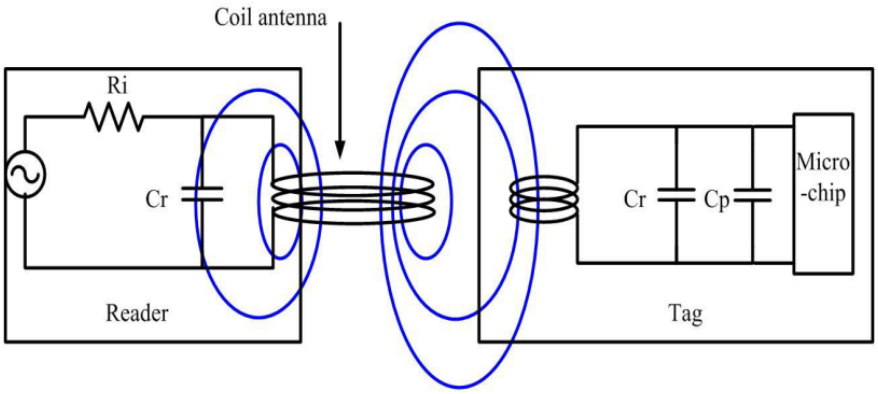

Fig. 3. Passive RFID identificator

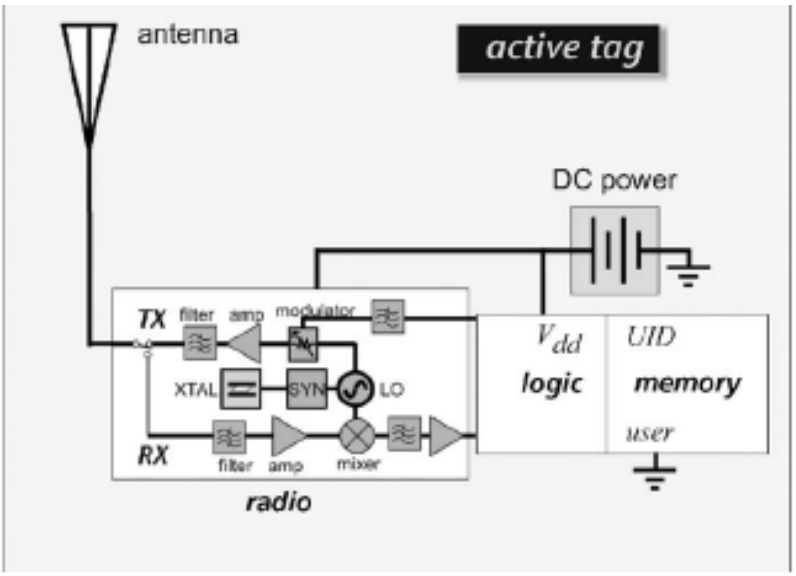

Fig. 4. Active RFID identificator

Passive identifiers do not have their own power supply. The required current is induced in the antenna by receiving a radio frequency signal providing the required voltage for the integrated circuits. The distance at which the data can be read is from a few millimeters to a meter.

- **RFID Reader**

A reading device contains an antenna, a controller for encoding/decoding the channel and memory, (Fig. 5).

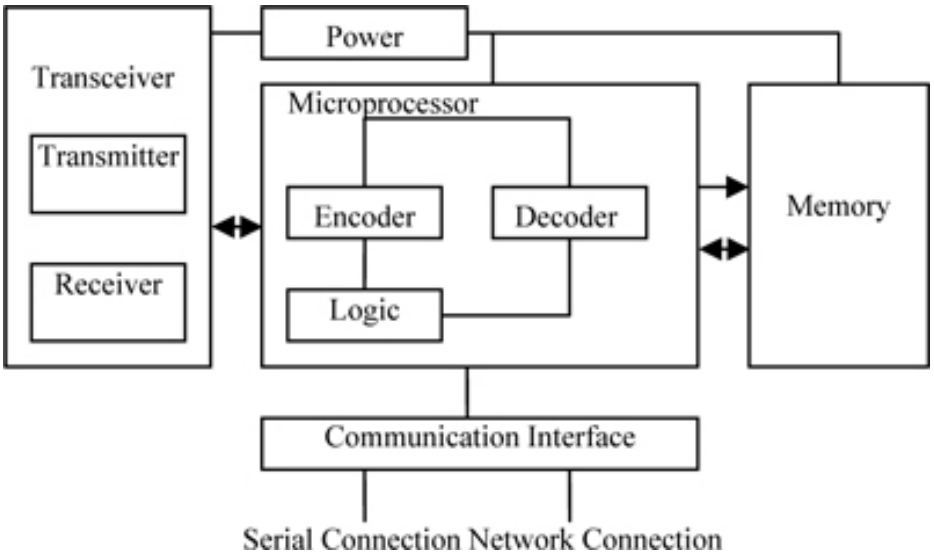

Fig. 5. RFID reader

- Antenna for RFID

A radio frequency identification (RFID) antenna is a specially designed antenna that serves to transmit and receive radio signals in the RFID system. This antenna is an important part of the RFID technology and allows the communication between the RFID reader and the RFID tags. The methods for channel encoding can be found on Fig. 6:

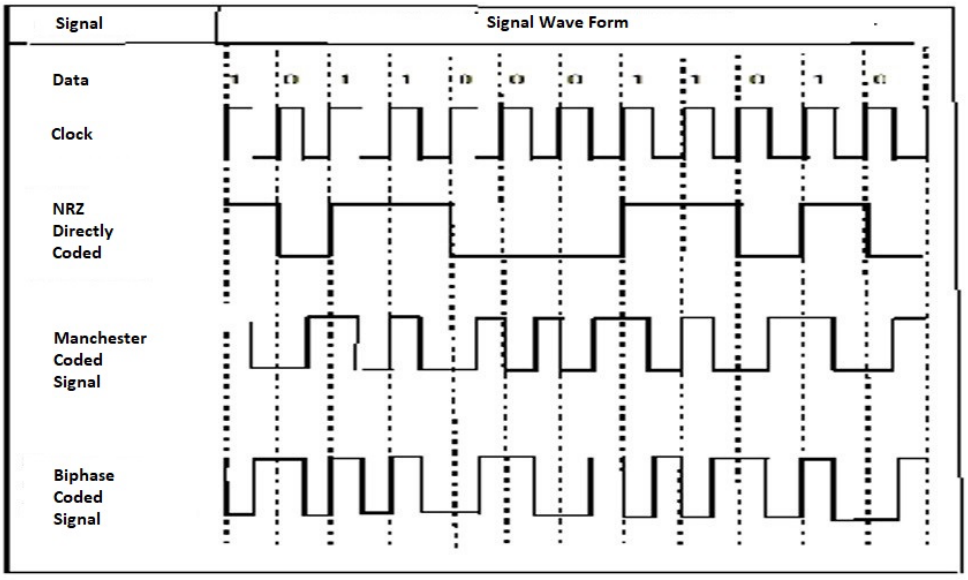

Fig. 6. Channel encoding methods

1.5. Data modulation.

Transmitting data over the air, or across the space separating two components that exchange information, requires that it be represented as a changing field or wave. This transformation is called modulation.

1.6. Data demodulation.

Demodulation of the amplituded modulated signal is performed to recover the original information signal. In the case of envelope separation, the goal is to extract the low-frequency information signal from the modulated signal.

1.7. Hardware implementation of an NFC reader.

Near Field Communication (NFC) is a set of communication protocols and interface based on RFID technology. NFC is the hottest technology trend taking hold worldwide. NFC is monitored by the "NFC Forum", which is an organization of 150 companies that work together to develop the technology.

1.8. NFC reader.

A preselected microcontroller executing a user program performs digital processing of the data in the reader**.**

In the PhD thesis, the object of consideration is the construction of a filter for filtering high-frequency harmonics, as well as a filter for filtering white Gaussian noise. An approach for finding the values of the passive and active elements in the circuit from the point of view of the automatic control theory (ATC) is presented for a specific study of an oscillating unit.

The mathematical model is implemented in the MATLAB program environment for the transmission characteristic of a Chebyshev filter, and the optimal values for the components of the circuit diagram are determined.

1.9. Calculating an RFID antenna.

Two antennas with different parameters are the object of research in this PhD thesis. They are implemented as flexible printed circuit boards. The copper layer is

placed between two layers of polyamide insulation so that it remains in the neutral bend line of the board.

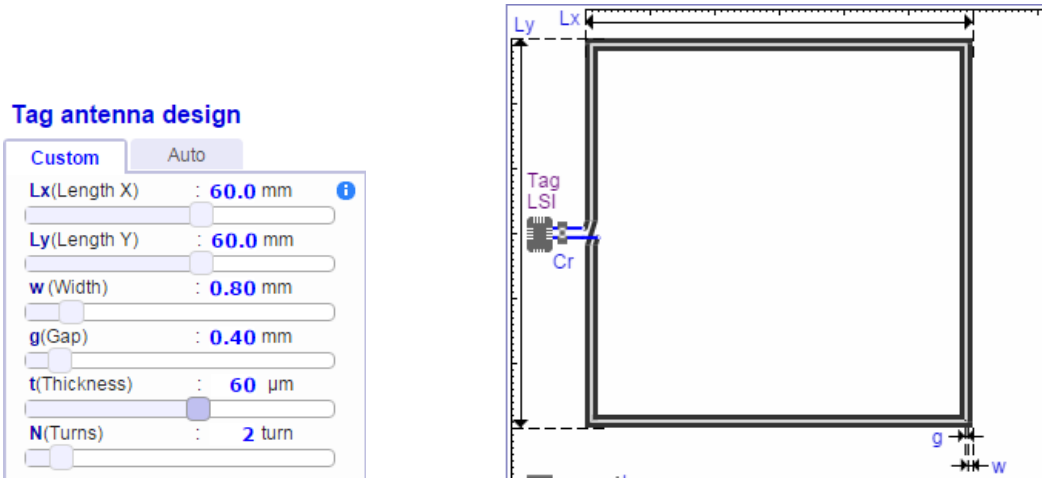

Fig. 15 a. Antenna 1

The matching block together with the EMC filter transform the impedance of the antenna. The results of the calculations are visualized using a Smith chart. In Smith chart terms, one can move the load impedance to the center of the Smith chart where the reflection coefficient is zero. The circles denote the active (real) part of the antenna impedance, and the arcs the reactive (imaginary) part.

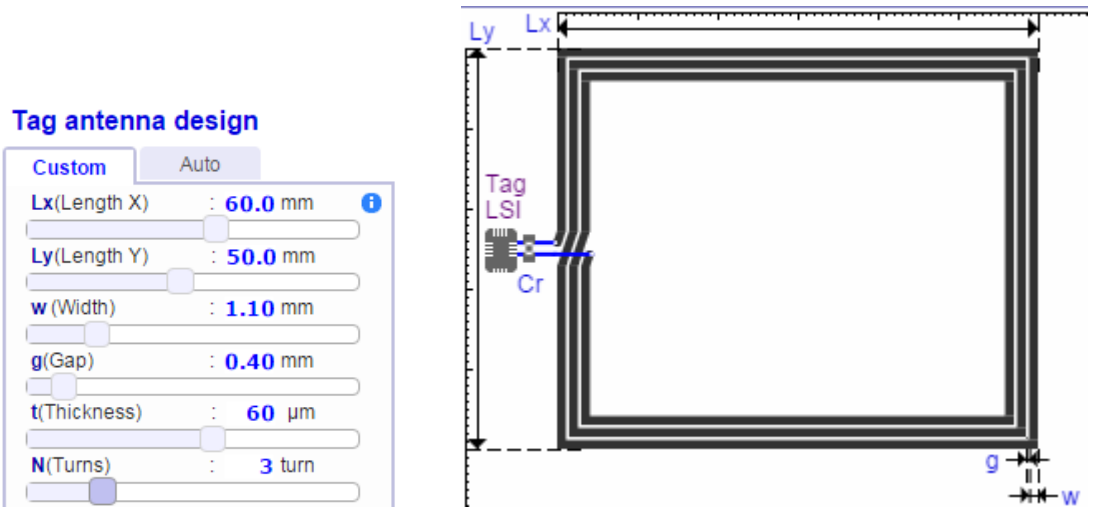

Fig. 15 б. Antenna 2

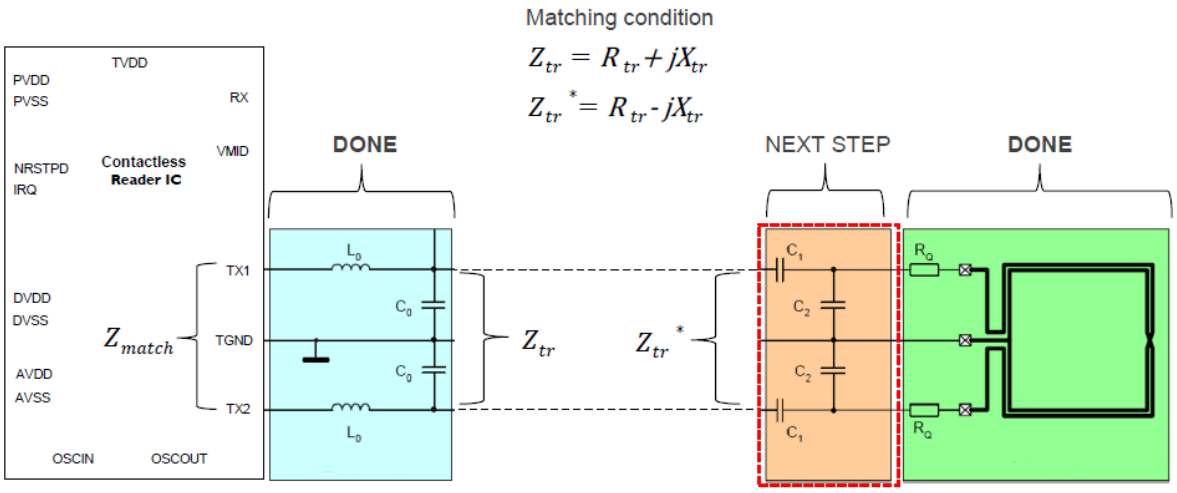

Fig. 17Aligning block of CLRC663

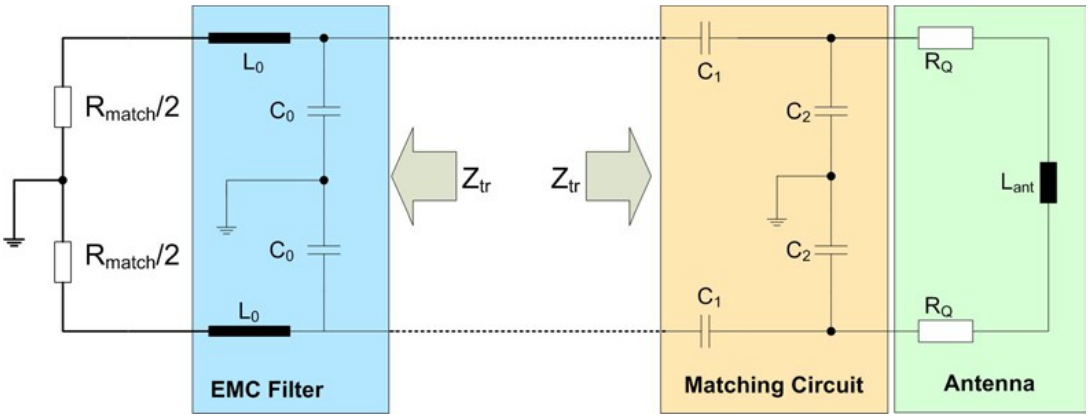

Fig. 18. Aligning block with EMC filter

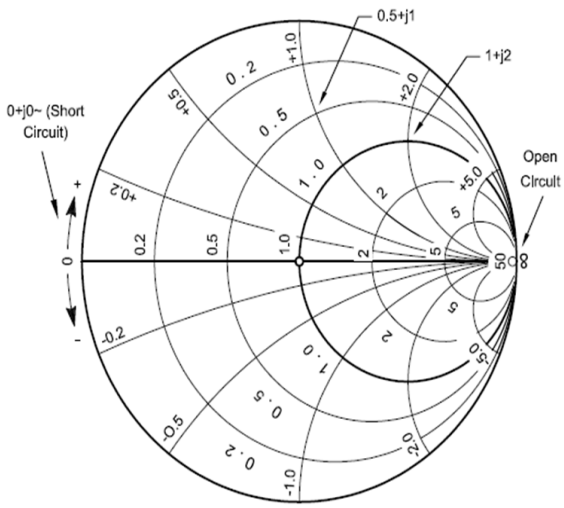

Fig. 19. Smith diagram

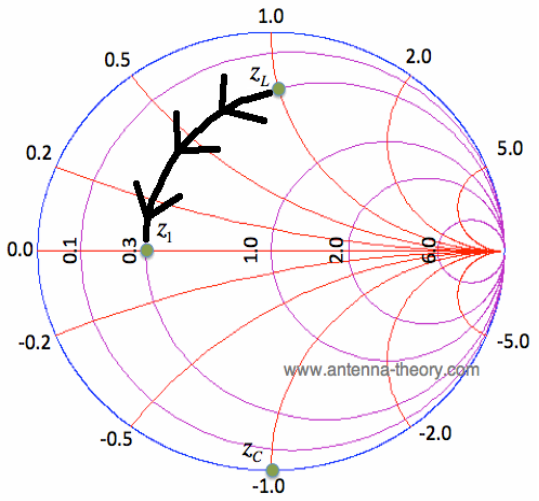

Fig. 20. Reflection coefficient

CHAPTER TWO

INTELLIGENT METHODS FOR RADIO FREQUENCY IDENTIFICATION

In the late 1980s and early 1990s, the popularity of applications of classical artificial intelligence methods in industry reached its peak. As the number of implementations increases, it moves from the stage of pioneering enthusiasm, characterized by showing the workability of the basic ideas and methods, to the stage of analysis of the main three aspects of the application of artificial intelligence - methodological, infrastructural and related to people . A number of difficulties and shortcomings of classical artificial intelligence are manifested. These methodological, infrastructural, and human-related difficulties have limited the wide application of AI in a number of areas over the past 15 years.

Despite the high scientific level of theoretical works on AI, which increasingly move to rigorous mathematical proofs and rely on reliable experimental data rather than intuition, classical artificial intelligence, especially in its applied field, faces serious competition in the face of what has emerged in recent years a new direction. It has adopted the name "Computational Intelligence". It attempts to overcome some of the shortcomings of classical artificial intelligence.

2.3. Main aspects of computer intelligence.

Machine Learning, ML

Artificial Intelligence, AI

Natural Language Processing, NLP

Computer Vision, CV

Robotics

Self-learning and Autonomy

Neural networks are one of the main training methods in computational intelligence. The obtained knowledge in neural networks is represented by the numerical values of the weights in the structural connections.

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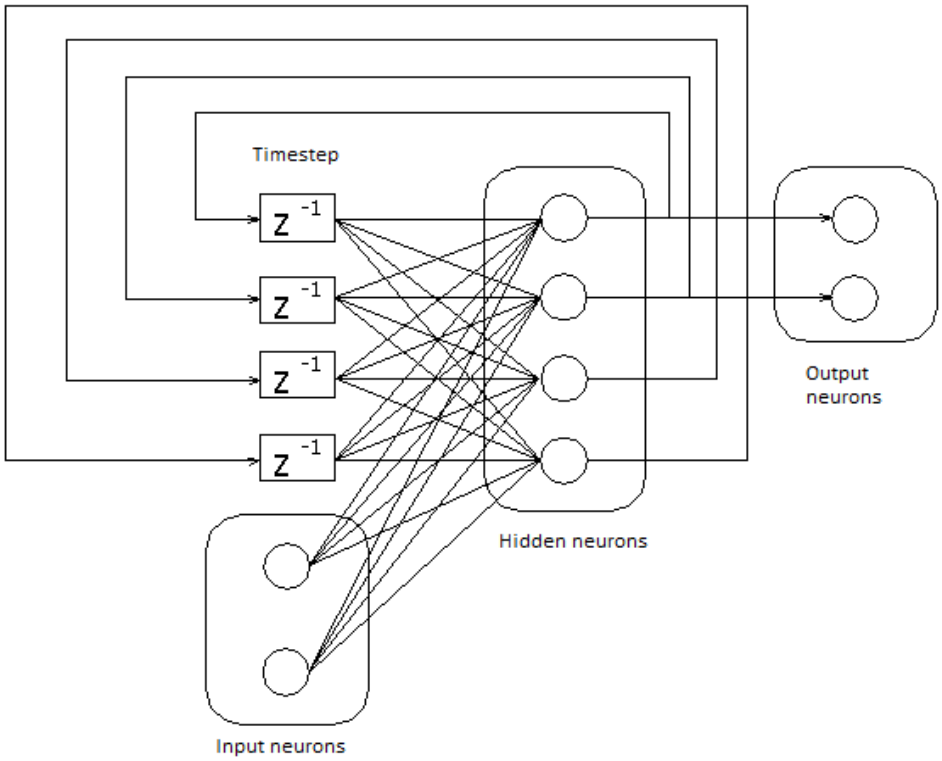


Fig. 29. Recurrent neural network

2.8. Synthesis of an RFID technology and neural networks as a distributed system for wireless collection and manipulation of information streams.

2.8.1. Methodology and plan synthesis.

Generating a modulating signal.

Adding noise.

Creating a neural network.

Training the network.

Decode network output.

Calculation of root mean square error.

Preview the results.

2.8.2. Firmware implementation.

Selection of input and target data for the neural network.

Choosing an Architecture for a Neural Network.

Selection of Neural Network Training.

Decoding the predicted outputs.

2.8.3. Hardware implementation.

This PhD thesis uses HDL Coder, a tool provided by MathWorks that automatically converts MATLAB and Simulink models into VHDL or Verilog code.

Decoding the RFID data: A neural network code is used to filter and decode the data from the amplituded modulated signal. It is programmed in XC3S550A with Xilinx Vivado.

Processing of data: After the data is decoded, the necessary operations are performed to process the data to be visualized on a display or printer. This may include data formatting, error handling, and other manipulations

Output to a display or printer: Software or hardware-built modules in the FPGA are used to manage communication with the visual or printing devices. This can be via standard interfaces such as HDMI, VGA or USB serial port SPI.

CHAPTER THREE

EXPERIMENTAL RESULTS OF THE APPLICATION OF INTELLIGENT METHODS FOR RESEARCH AND IMPLEMENTATION OF HARDWARE SOLUTIONS

3.1. Filtering of an amplituded modulated signal.

In publication [3*], various stages of the performed frequency analysis, time analysis, signal modulation and signal filtering are described. The object of the research are methods of noise suppression by filtering. A periodic sinusoidal signal in the time domain is presented in Fig. 30. A periodic sinusoidal signal in the frequency domain is presented in Fig. 31.

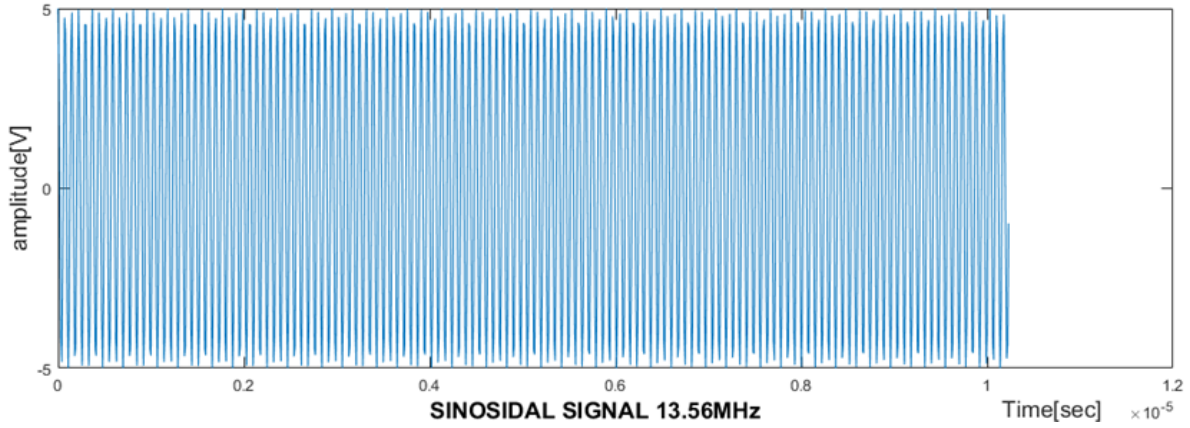


Fig. 30. Sinusoidal signal in time

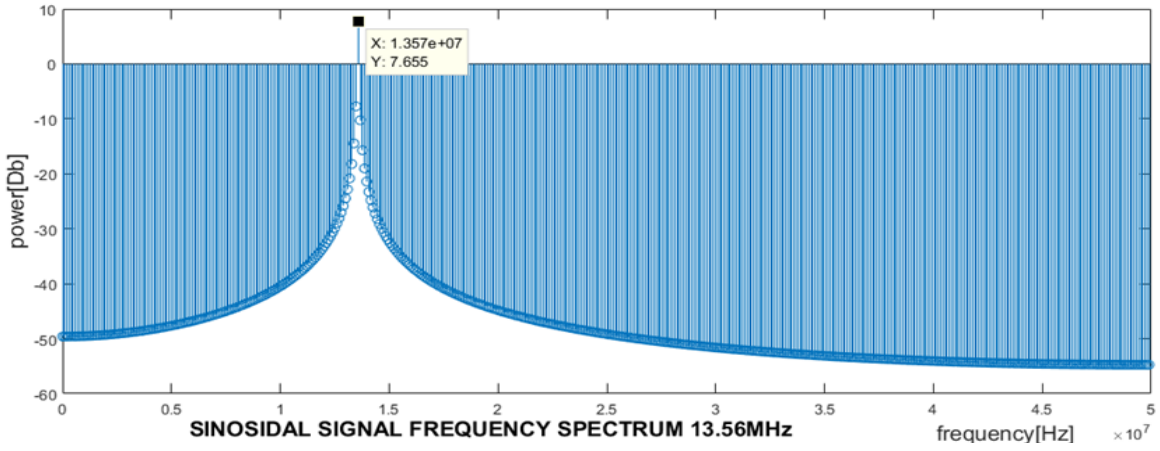


Fig. 31. Sinusoidal signal in frequency

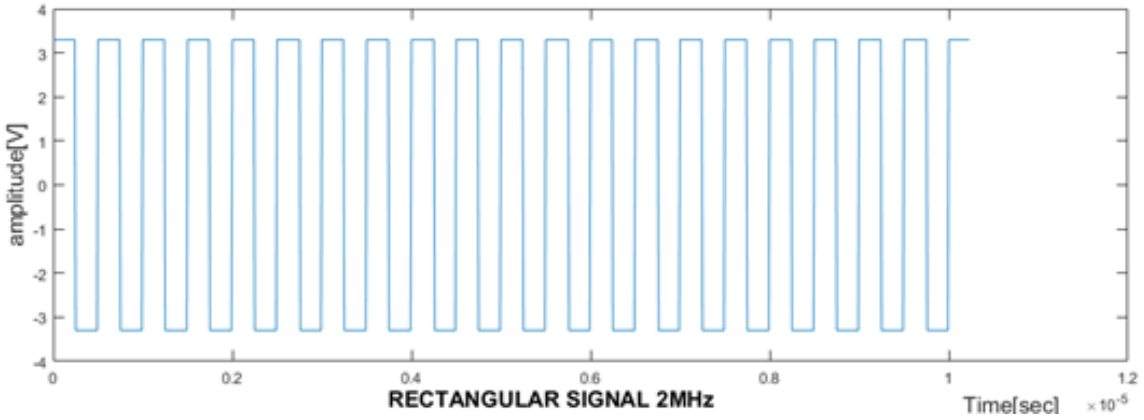


Fig. 32. Rectangular signal in tiime

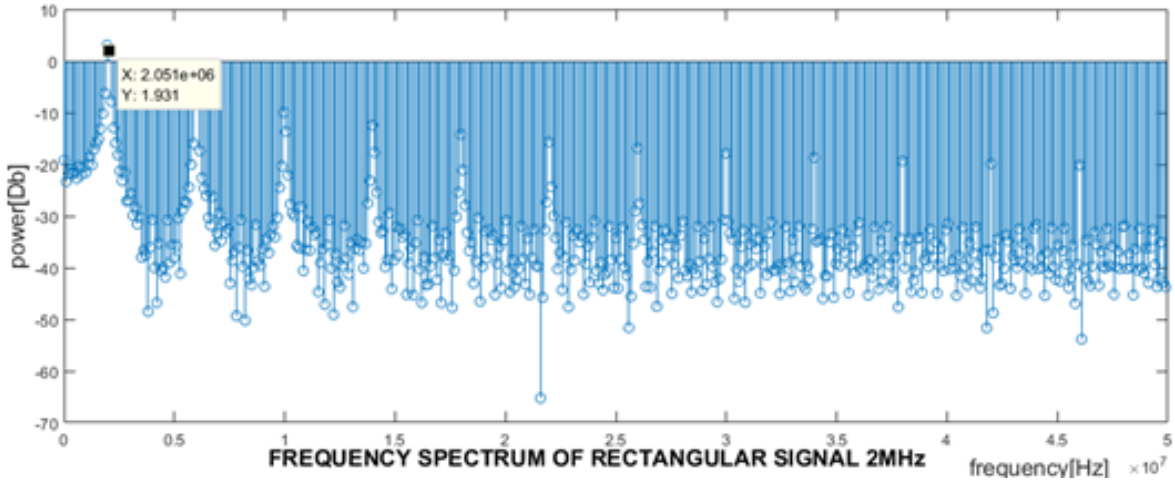


Fig. 33. Rectangular signal in frequency

A periodic rectangular signal in the time domain is shown in Fig. 32. A periodic rectangular signal in the frequency domain is shown in Fig. 33. An amplitude modulated signal in the time domain is shown in Fig. 34.

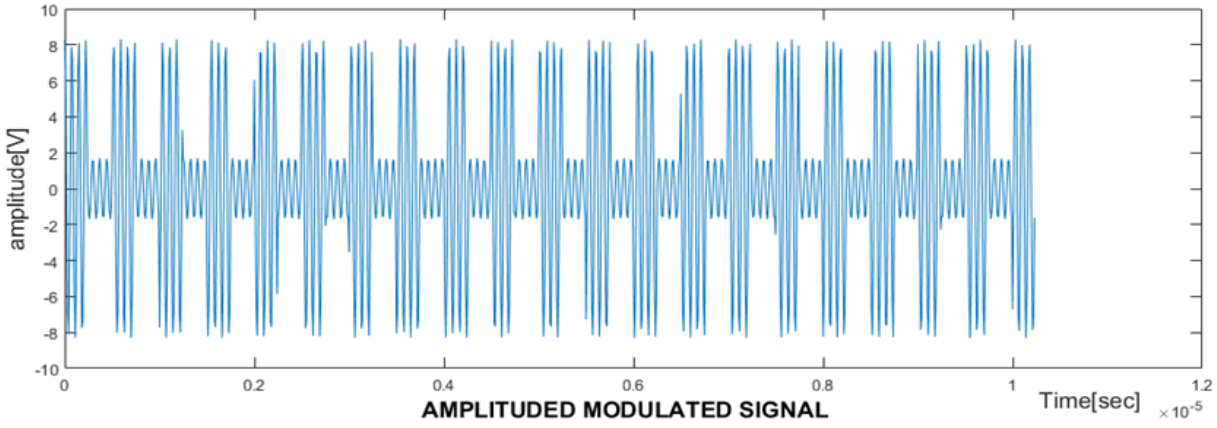


Fig. 34. Amplituded modulated signal

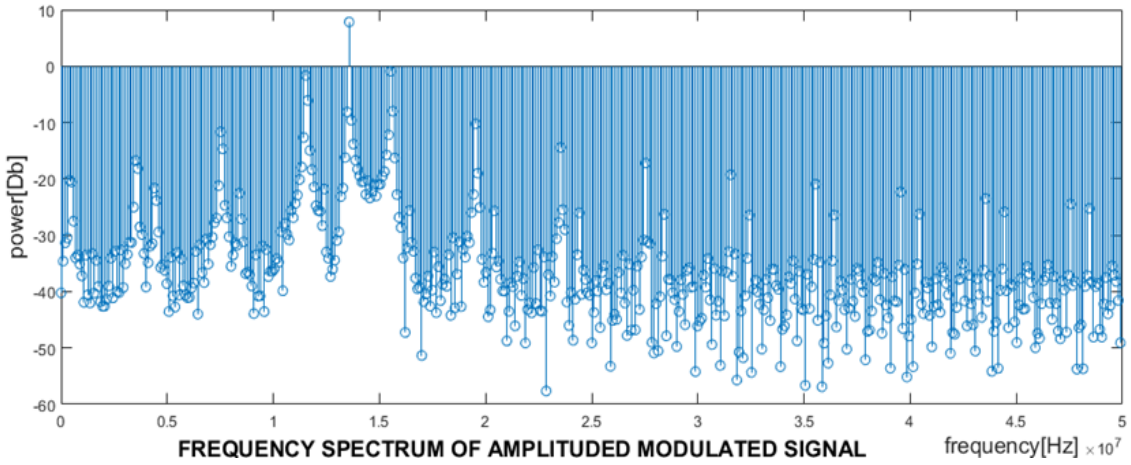


Fig. 35. Frequency spectrum of an amplituded modulated signal

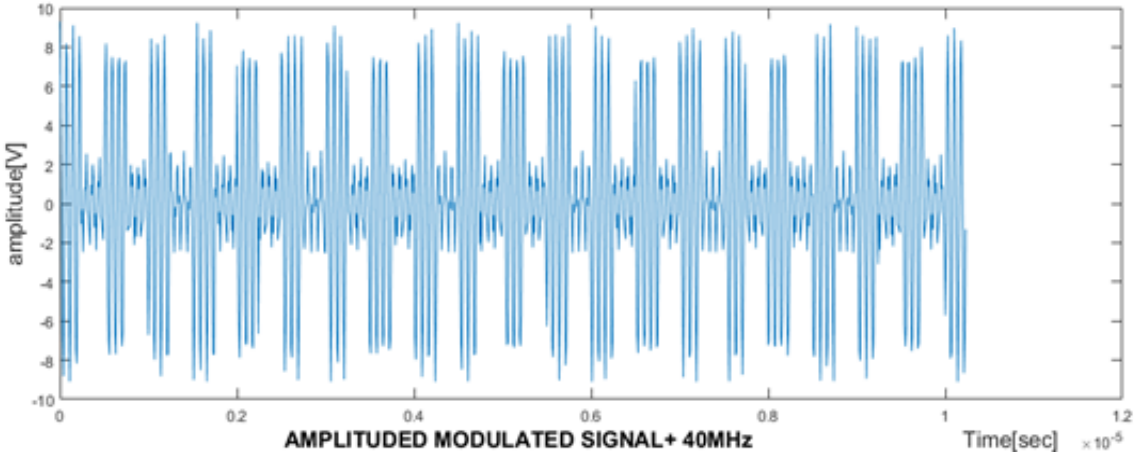


Fig. 36. Amplituded modulated signal

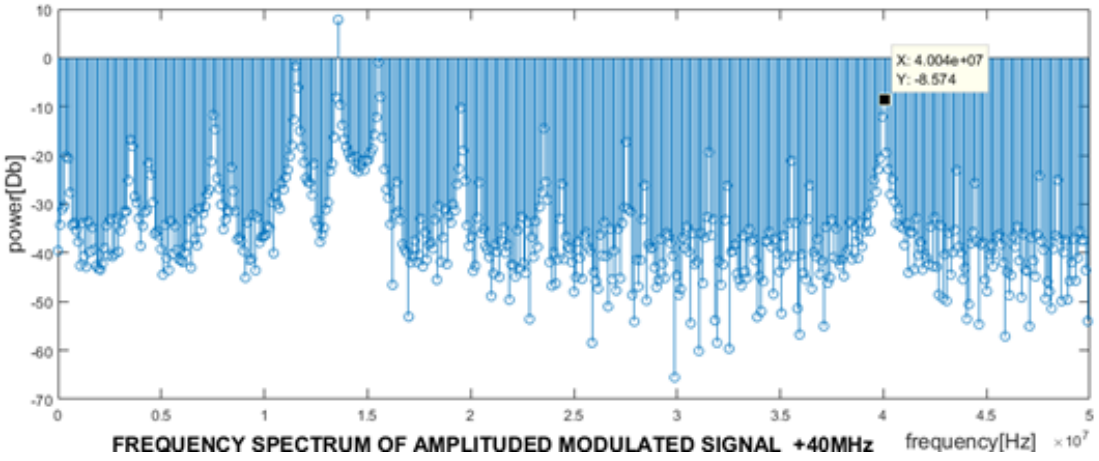


Fig. 37. Frequency spectrum of an amplituded modulated signal

The frequency spectrum of an amplituded modulated signal is shown in Fig. 35. An amplituded modulated periodic sinusoidal signal is presented in Fig. 36. A frequency spectrum of an amplituded modulated periodic sinusoidal signal is presented in Fig. 37.

The transfer function is calculated after using Kirchhoff's voltage law and summing the values of the circuit parameters, which are presented in Table 1. In Fig. 39 shows the result of filtering the signal in the frequency domain.

n	f_s	*T*	ξ	*Pol*	*k*	*R*	*L*	*C*
-	MHz	s	-	-	-	Ω	nH	pF
2	14.520	1.0961e-08	0.1602	Complex conjugate -1.4613 ± 9.0051i	0.3162	4	150	800

Table 1. Results for the metrics of the passive elements of the circuit of the filter

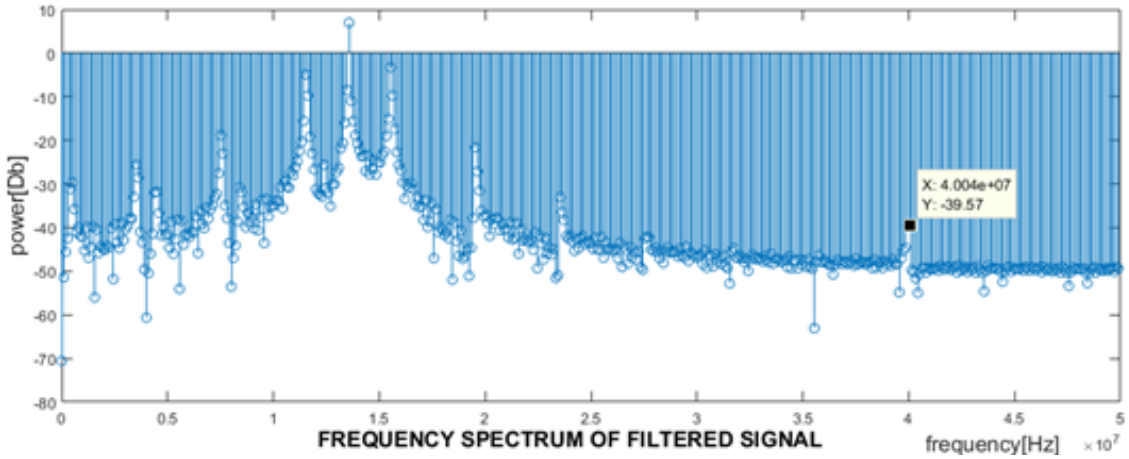


Fig. 39. Frequency spectrum of the filtered signal

From the obtained experimental results, it is clearly seen that the power of the useless signal to us is 40 MHz and has decreased by approximately 30 dB, which means that the used passive filter is effective in removing high frequency signals from the spectrum of the useful signal.

3.2. Tecniques for wireless collection, transmission and manipulation of information streams.

The papers [2*, 4*] present the results of the analysis of problems in the processing of wireless information. A hardware implementation of distributed systems for wireless collection, transfer and manipulation of information flows is described. The main stages of this process (encoding, modulation and filtering of the signal) have been studied thoroughly, according to EMC standards. In addition, this paper shows the calculation results of the RFID antenna parameters.

Digital manipulation of the data in the reader is performed by a pre-selected microcontroller (selected due to the functional specifications of the system) that runs the user application. The microcontroller communicates with a dedicated integrated circuit CLRC66302HN, through a serial peripheral interface (SPI).

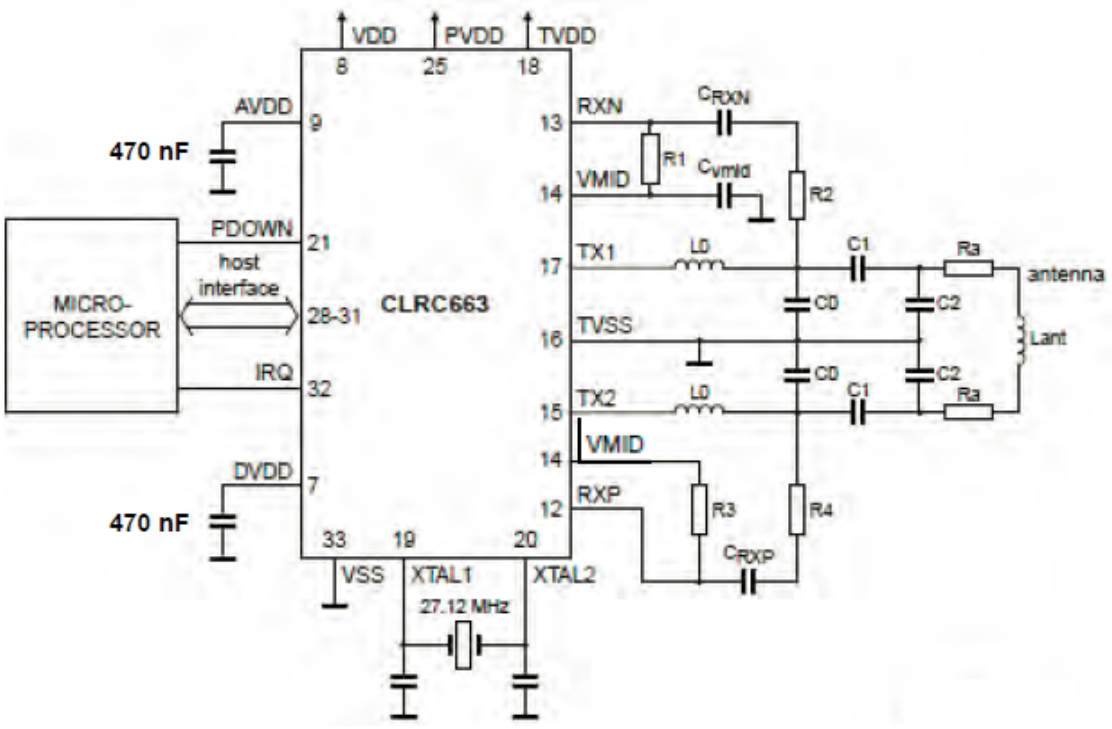


Fig. 40. NFC reader

The NFC reader circuit shown in Fig. 40, includes a microcontroller, a CLRC66302HN integrated circuit, an analog low-pass filter, and an analog impedance matching circuit between it and the rest of the system. The parameters of an NFC antenna are shown on table two below:

a	*b*	*h*	*r*	*Q*	*N*	*L*	*C*	*R*	f_0
cm	cm	cm	cm	-	num	μH	pF	Ω	MHz
14.14	0, 5	0,5	50	25	2	1,2	117	4	13.56

Table 2. Results of the metric parameters of an NFC antenna

The quality factor Q describes the energy stored in the antenna. When the Q-factor is high, the antenna needs more time to respond to the modulation, but radiates more power. Q=25 is the standard value for NFC antennas. In case of symmetrical alignment, optimal signal shape and read and write distance defined in the requirements according to the EMV Co standard are achieved (Fig. 41).

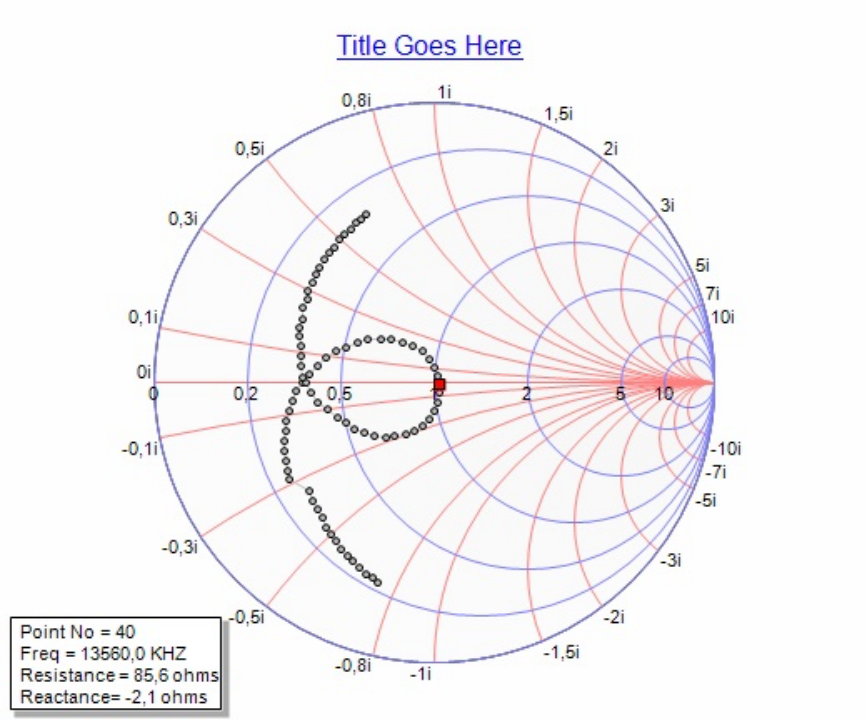


Fig. 41. Smith diagram for the symmetric alignment of the impedance of the antenna

3.3. Intelligent methods in the techniques for wireless collection, transmission and manipulation of information streams.

Hardware Description Language Coder (HDL) is a tool provided by MathWorks that enables the automatic generation of hardware description language code from MATLAB or Simulink models. The obtained results of the analysis are presented in an article [5*]. An example structure of a multilayer perceptron is shown in Fig. 43.

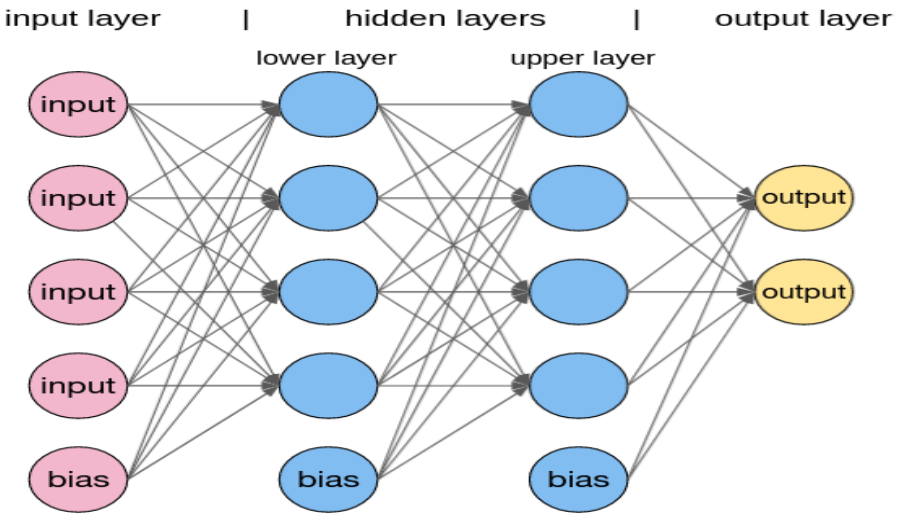
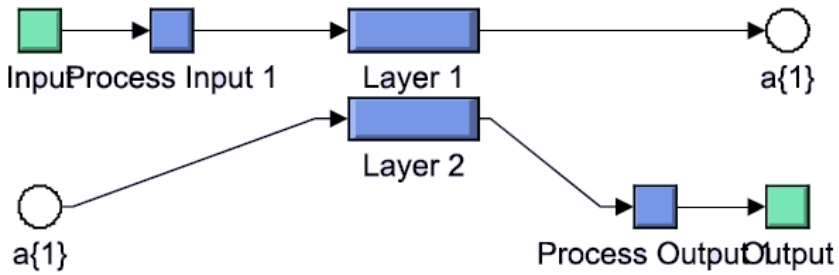
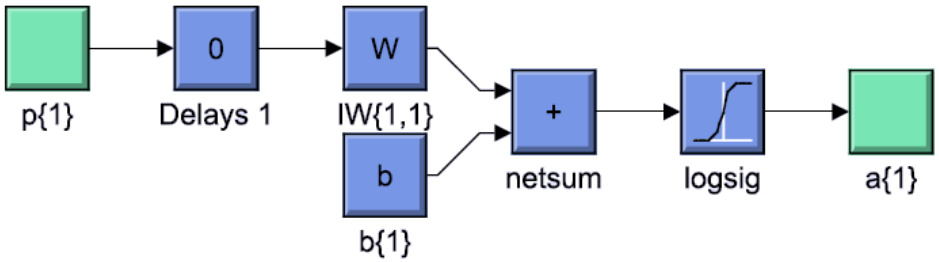


Fig. 43. Multilayer perceptron structure

The hypothesis in the paper is that neural networks, such as MLP, can be used to filter out noise in amplituded modulated signals. Noise filtering is a common task in signal processing, and neural networks can be a powerful tool to accomplish this task. One possible neural network architecture for noise filtering is shown in Fig. 44.



Layer 1:



Layer 2:

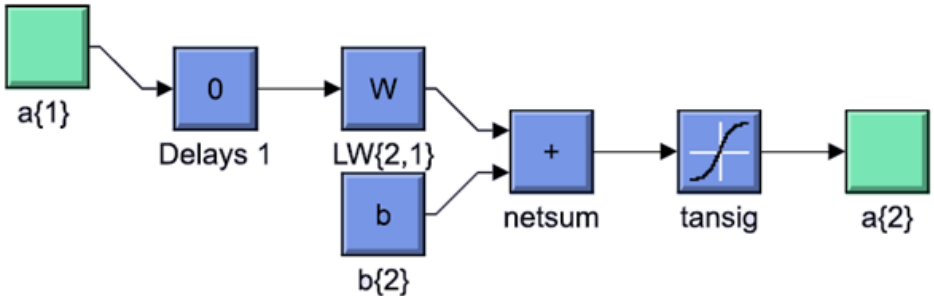


Fig. 44. Neural network architecture

The HDL code generated by HDL Coder can be used in a synthesis and deployment environment such as Xilinx Vivado or Intel Quartus. This process involves compiling VHDL code, creating networks of logic elements, specifying timing constraints, and generating physical configuration files (bit streams) for programming a digital device, such as the FPGA shown in Fig. 45.

Fig. 45. FPGA device

HDL encoder and FPGA modules such as AMD Artix™ 7 50T-2I, TE0714-04-52I-7-B provide the means to transform MLP and other digital systems into real

hardware solutions. This enables fast execution and efficient use of FPGA resources. The combination of multilayer perceptron, HDL encoder and FPGA modules offers a wide range of tools and capabilities for developing complex digital systems and solving various tasks in the field of machine learning and data processing.

3.4. Amplitude modulation and demodulation of wireless transfer of data with a neural network.

In article [5*] the results obtained in the application of amplitude modulation and demodulation with the use of a neural network are presented. The article presents a complete process of amplitude modulation and demodulation using a neural network in the MATLAB programming environment. The presented results and decoded network output demonstrate the effectiveness of the proposed implementation.

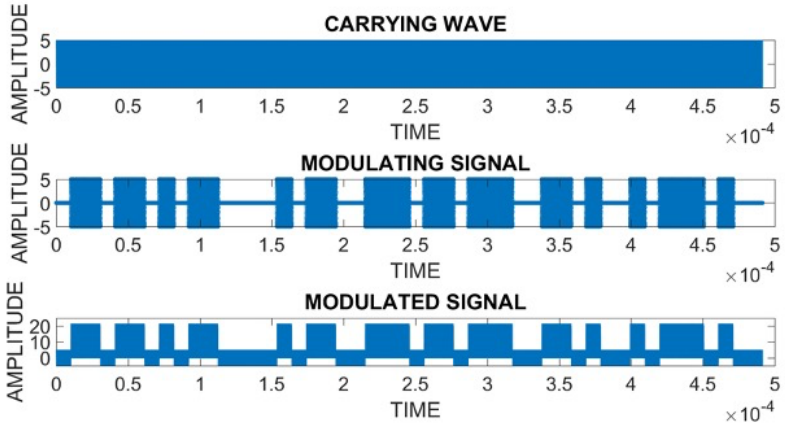


Fig. 46. Amplitude modulation

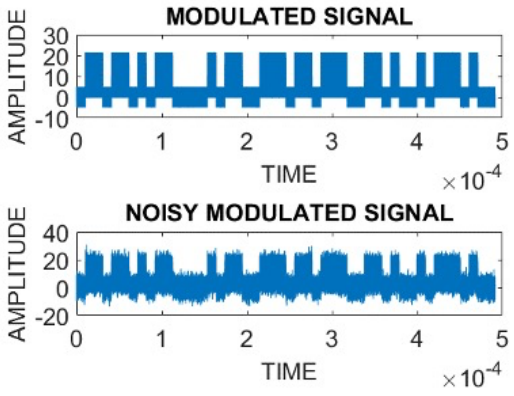


Fig. 47. Noisy modulation of the signal

In Fig. 46 shows the results of the modulation process, showing the carrier signal, the modulating signal and the modulated signal. In Fig. 47 presents the results of the noise process of the modulated signal. The obtained results for real modulated signal, noise modulated signal and neural network output signal are shown in Fig. 48.

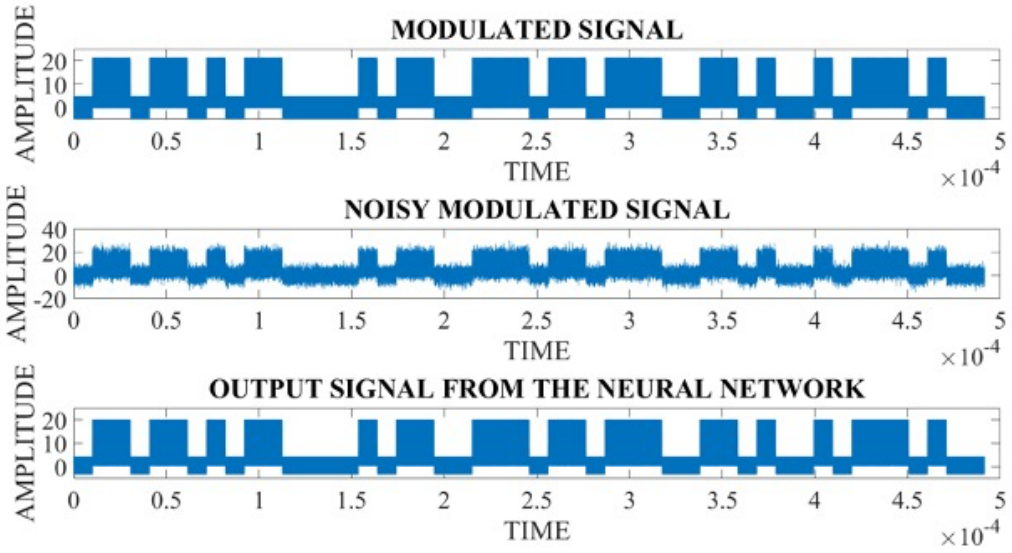


Fig. 48. Output signal of the neural network

This paper presents the basic idea and implementation of wireless data transmission and decoding using neural networks. When developing applications in practice, further optimizations and improvements can be made based on specific requirements and conditions. It is possible to convert the MATLAB code presented in the article to VHDL or Verilog for implementation on programmable logic integrated circuits (FPGA).

3.5. A new generation of wireless networks.

The article [1*] describes the method of signal transmission - Handoff (HO) in different generations of networks. Horizontal Handoff (HHO) and Vertical Handoff (VHO) are considered. The article examines the challenge - Sixth Generation Global Networks.

On Fig. 49 the mobile communication evolution is described.

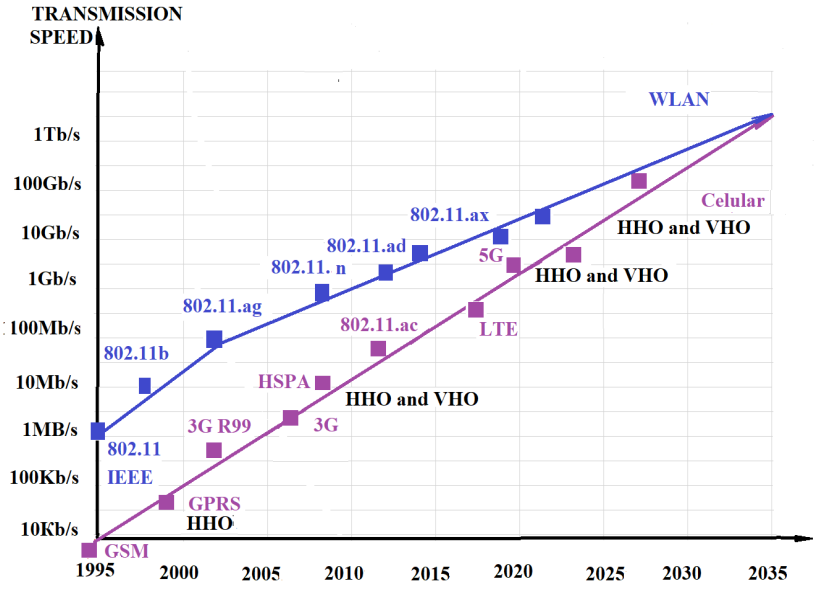


Fig. 49. Mobile communication evolution

The 6G mobile system for global coverage will integrate 5G wireless mobile system and satellite network. Telecommunications satellite is used to broadcast voice, data, internet and video; earth imaging satellite networks are for gathering weather and environmental information; and the navigation satellite network is for Global Positioning System (GPS), (Fig. 50).

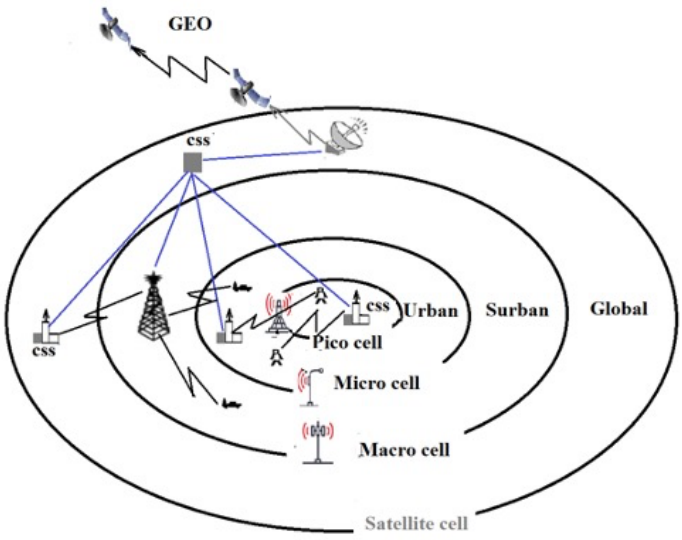


Fig. 50. 6G mobile system

Mobility management is a priority issue in modern mobile networks. The challenge for all networks is to transmit data without loss. The process of handing over a signal when changing a cell or reducing the signal during an active user connection is known in the literature as Handoff (HO), (Fig. 51).

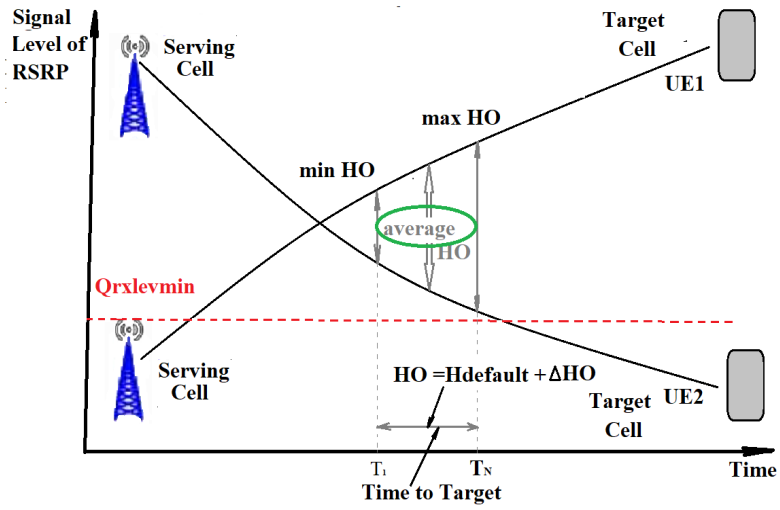


Fig. 51. Handoff (HO)

The development of future wireless networks will lead to an ultra-density of the type and number of base stations, as well as the number of users and the applications they use. The dense, dynamic and multi-layered network architecture requires the development of new mobility management mechanisms adapting to the characteristics of the new generation of networks.

3.6. Implementing hardware solutions.

- POS terminal

A POS terminal is a device that is used to process payments with bank cards or other electronic payment methods. These devices are common in stores, restaurants, gas stations and other commercial establishments where customers can make purchases and pay with credit or debit cards, smartphones, contactless payment chips and other electronic payment methods.

The following Figures present the individual modules of the developed circuit shown in Fig. 52.

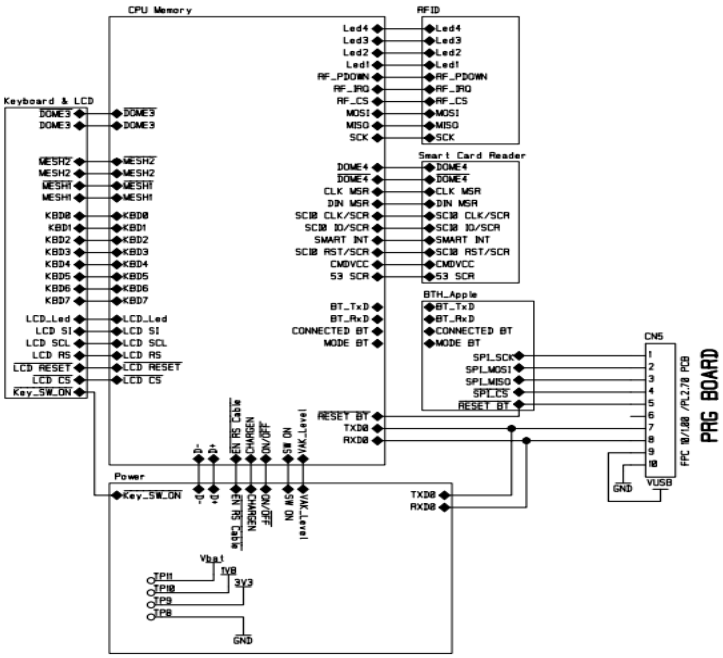


Fig. 52. POS terminal circuit

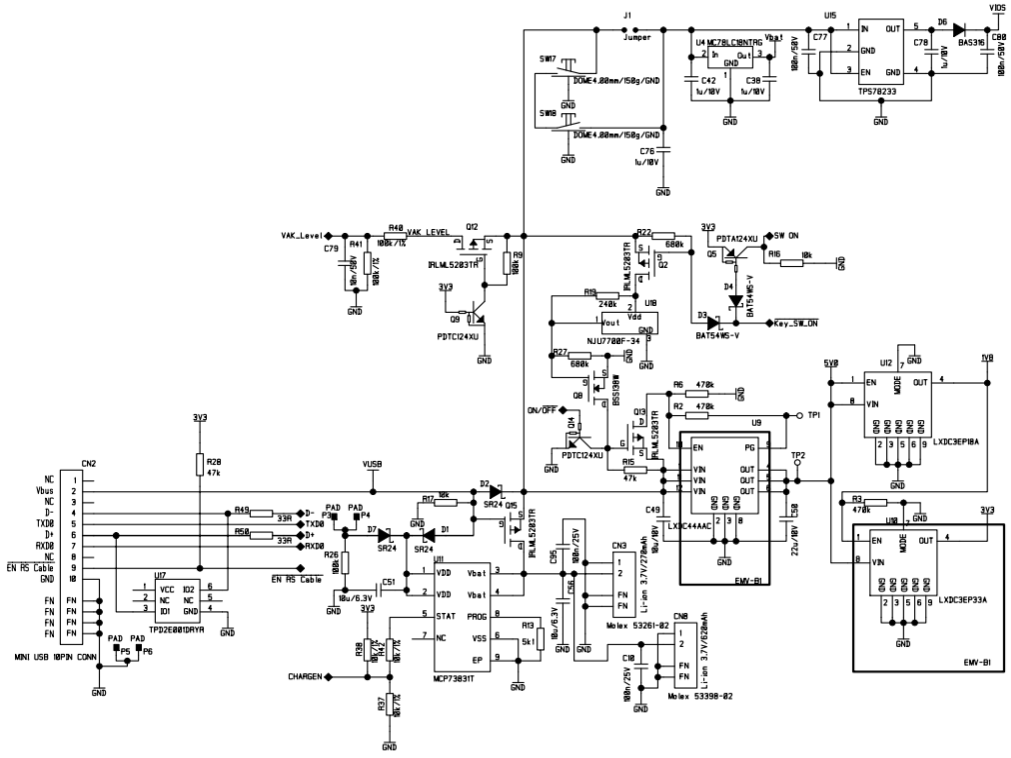


Fig. 53. Power block

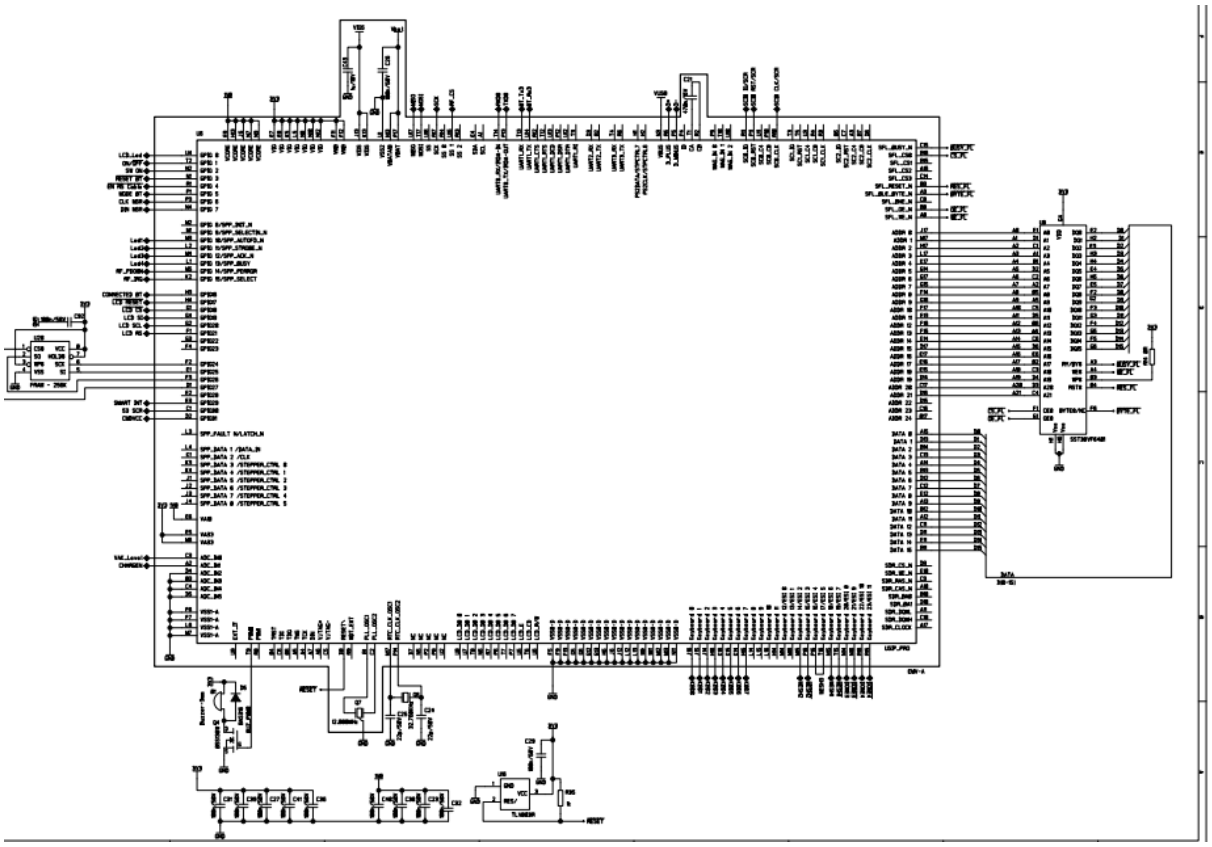


Fig. 54. Data processing microcontroller

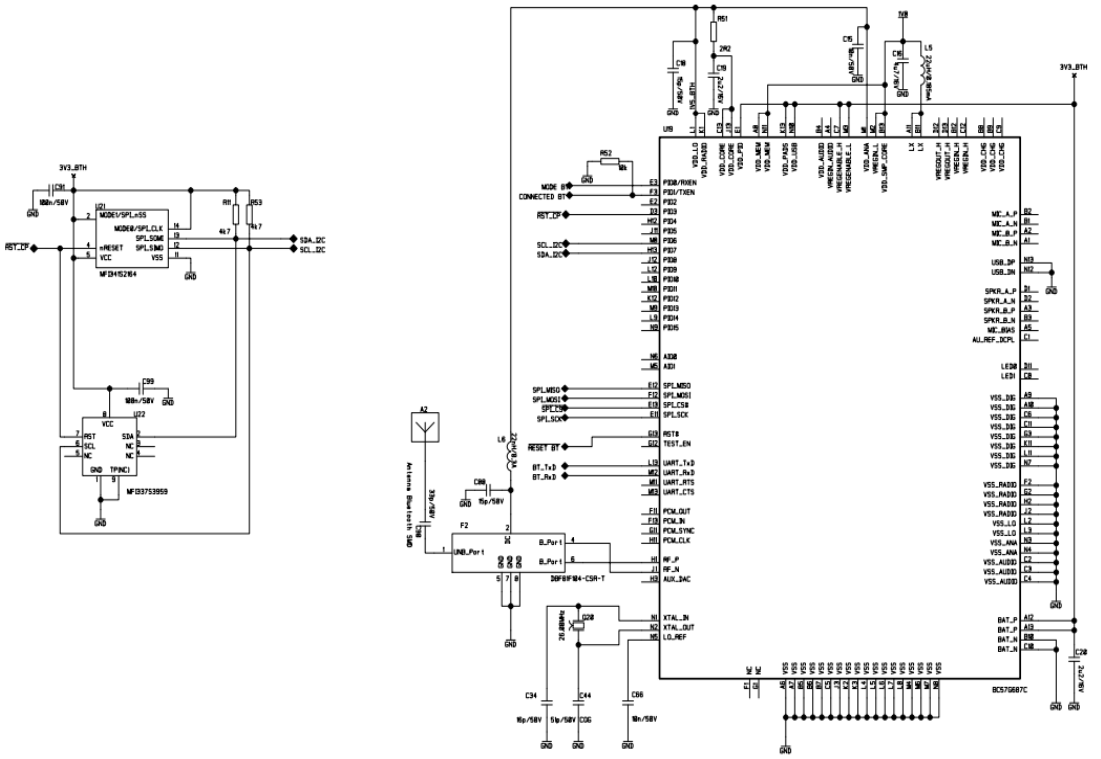


Fig. 55. Bluetooth connection block to an APPLE device

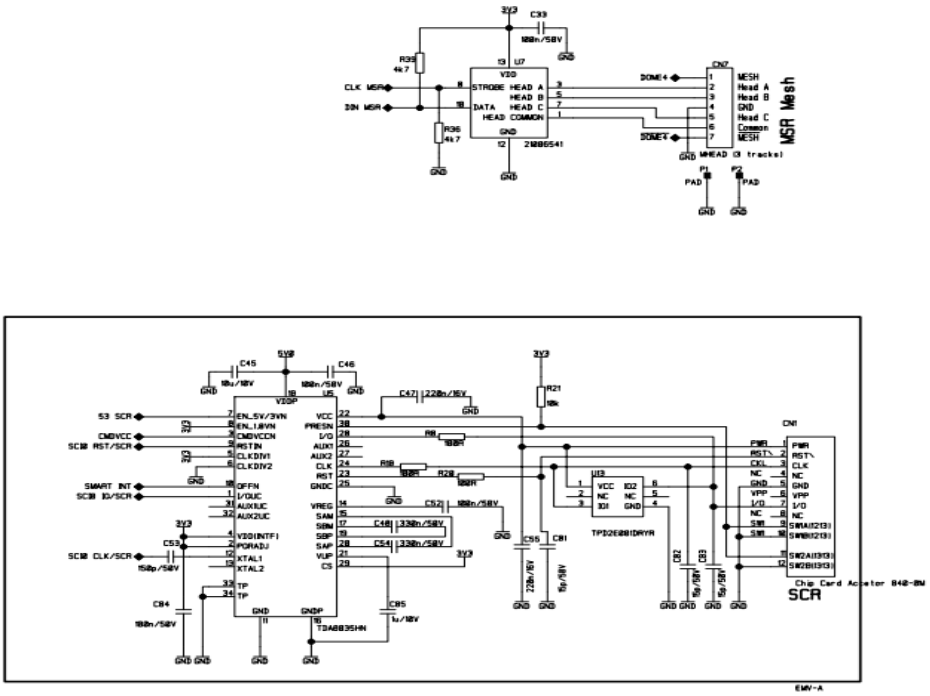


Fig. 56. Block for contact reading of credit cards

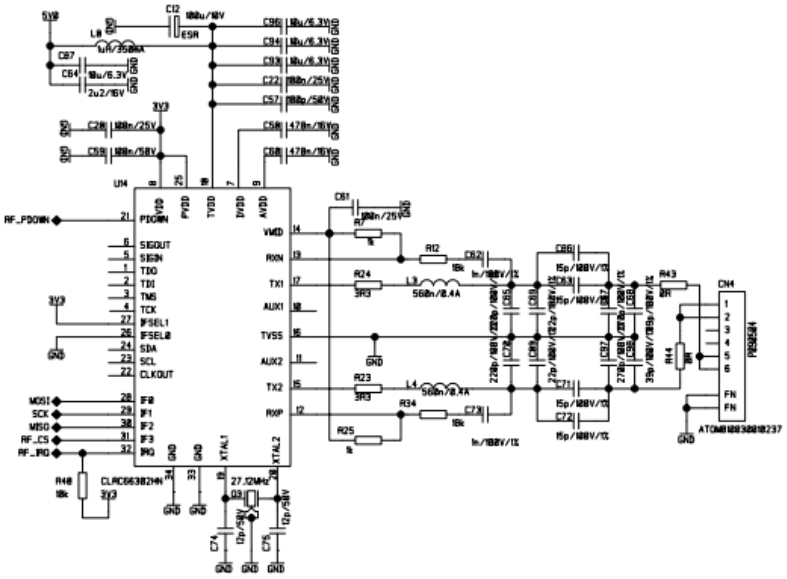


Fig. 57. Block for contact reading of credit cards (RFID, NFC)

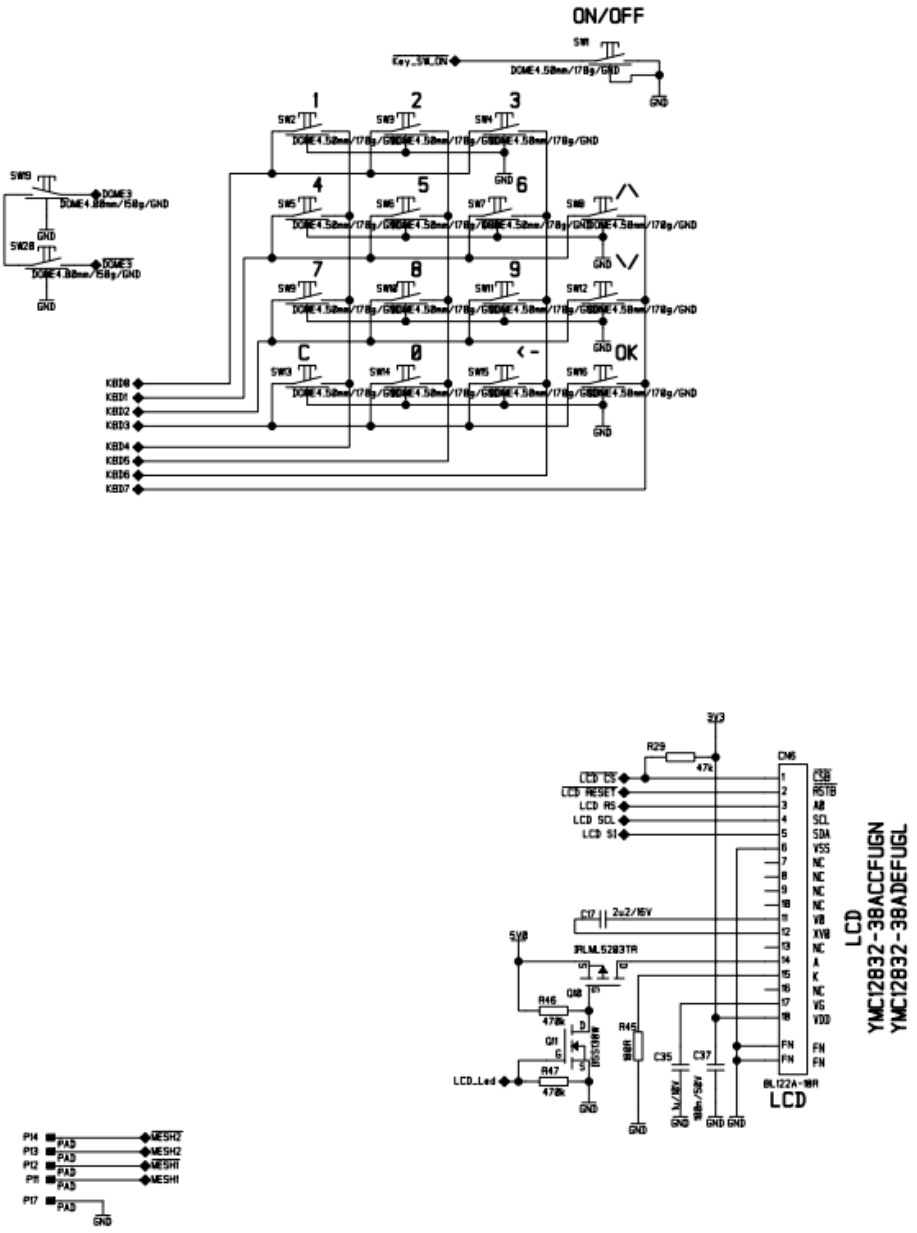


Fig. 58. LCD and manual data entry transaction block

- Wireless card reader

A circuit diagram has been developed, which includes the following modules (Fig. 59):

- power block;

- data processing microcontroller;

- block for connection with an audio smart device;

- Wireless card reader block.

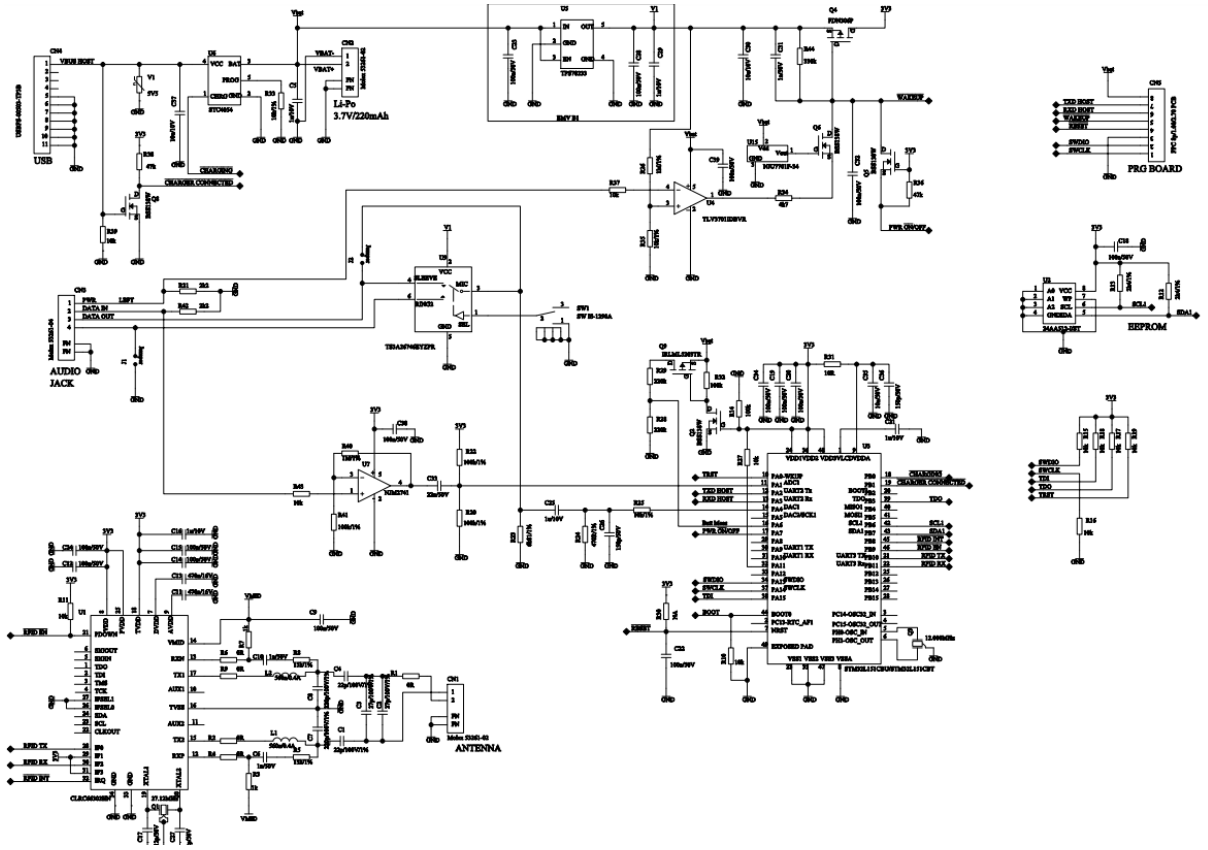


Fig. 59. Electric circuit of a wireless smart card reader

SUMMARY

The PhD thesis is dedicated to the application of innovative, intelligent methods for research and implementation of hardware solutions in the context of distributed systems for wireless collection, transfer and management of information flows. The possible connections and interactions between two technologies - radio frequency identification (RFID) and neural networks (NN) are analyzed, as well as the potential advantages of their inclusion in communication systems. A rationale is presented on how these two technologies complement each other, providing intelligent solutions and opportunities for process optimization. The challenges that arise with the implementation of radio frequency identification and neural networks in distributed systems are described in order to achieve intelligent and efficient solutions for the collection, processing and management of information flows. The present PhD thesis also examines how the incorporation of Wi-Fi technologies can enhance the intelligence and functionality of a distributed system by adding additional capabilities for communication and data analysis.

The research methodology in the PhD thesis includes the use of a numerical and experimental approach. The numerical approach was used in the implementation of the algorithms by means of computer calculation. The experimental approach was used in the creation of the hardware applications.

The aim of this PhD thesis is to research and implement hardware solutions using modern methods from the field of intelligent systems. To achieve the set goal, six scientific tasks have been formulated. In the process of solving them, original results were obtained related to the research of modern intelligent methods for the implementation of hardware solutions of distributed systems for wireless collection, transmission and management of information flows.

As a result of the conducted research, presented in this PhD thesis, the following scientific-applied and applied results were achieved:

1. A critical analysis of the possibility of applying intelligent methods for the analysis and implementation of hardware solutions was carried out.

2. The possible connections and interactions between two key technologies - radio frequency identification and neural networks are analyzed.

3. The ways to integrate these technologies have been investigated to achieve intelligent and effective solutions to collect, process and manage information flows.

4. An analysis of the opportunities and challenges that arise with the implementation of radio frequency identification and neural networks in distributed systems is carried out.

5. It is analyzed how the incorporation of wireless technologies can enhance the intelligence and functionality of a distributed system by adding additional capabilities for communication and data analysis.

6. Original hardware solutions for collecting, processing and managing information flows are presented.

The achieved results of the analysis of the research carried out in the current PhD thesis are presented in the scientific journals – „Problems of Engineering Cybernetics and Robotics" and „Engineering Sciences", as well as in the proccedings of the 10-th IEEE International Conference on Intelligent Systems - IS '20.

The PhD thesis is structured in an introduction, three chapters and a conclusion, accompanied by a declaration of originality of the obtained results and a bibliography.

The PhD thesis was supported by the Bulgarian Ministry of Education and Science under the National Research Program **"Smart crop production", Grant agreement No D01-65/19.03.2021** approved by Decision of the Ministry Council №866/26.11.2020.

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1. Otsetova-Dudin E., **Markov K.**, Mobility Factor in New Generations Wireless Networks. Proceedings of the 10-th International Conference on Intelligent Systems - IS'20, Varna, Bulgaria, IEEE Xplore, ISBN:978-1-7281-5456-5, ISSN:1541-1672, DOI:10.1109/IS48319.2020.9199970, pp. 601-605, 2020.

2. **Markov K.,** Planning and Developing Techniques in Working | Within Distributed Systems for Wireless Gathering, Transferring and Manipulation of Information Streams, Part I. Problems of Engineering Cybernetics and Robotics, 75, Prof. Marin Drinov Academic Publishing House, ISSN:0204-9848, DOI:10.7546/PECR.75.21.07, pp. 59-70, 2021.

3. **Markov K.**, Designing of Technical Tools for Distributed Systems for Wireless Gathering, Transferring and Management of Information. Problems of Engineering Cybernetics and Robotics, 76, Prof. Marin Drinov Academic Publishing House, ISSN:2738-7356, DOI:10.7546/PECR.76.21.02, pp. 25-38, 2021.

4. **Markov K.**, Planning and Developing Techniques in Working with Distributed Systems for Wireless Gathering, Transferring and Manipulation of Information Streams, Part II. Engineering Sciences, LIX, 2, Prof. Marin Drinov Academic Publishing House, ISSN:1312-5702(Print), ISSN:2603-3542(Online), DOI:10.7546/EngSci.LIX.22.02.05, pp. 53-68, 2022.

5. **Markov K.**, Multilayer Perceptron with Backpropagation, HDL Coder, and FPGA Technology: An Integrated Approach for Efficient Neural Network Implementation. Problems of Engineering Cybernetics and Robotics, 80, Prof. Marin Drinov Academic Publishing House, ISSN:2738-7356, DOI:10.7546/PECR.80.23.02, pp. 13-22, 2023.

6. **Markov K.**, Wireless Data Transmission and Neural Networks: Using Amplitude Modulation and Demodulation. Problems of Engineering Cybernetics and Robotics, 80, Prof. Marin Drinov Academic Publishing House, ISSN:2738-7356, DOI:10.7546/PECR.80.23.03, pp. 23-32, 2023.