REVIEW

By PhD Eng. Nevena Stoyanova Mileva – Professor at Plovdiv University "Paisii Hilendarski"

of a dissertation on the award of the educational and scientific degree **"Doctor"**

by: field of higher education 5. Technical sciences

professional field 5.3 *Communication and computer engineering*

doctoral program *"Automation of areas of the non-material sphere (medicine, education, science, administrative activity, etc.)"*

Author: Tihomir Tihomirov Lovchaliev

Topic: Design and automated testing of the parameters of 5G antennas

Scientific supervisor: Assoc. Prof. Nadezhda Miteva Kafadarova, PhD, Plovdiv University "Paisii Hilendarski".

1. General description of the materials submitted

By Order No RD-21-720 of 02.04.2024 of the Rector of Plovdiv University "Paisii Hilendarski" (PU) I was appointed a member of the scientific jury under a procedure for the defence of a dissertation on the topic "Design and automated testing of the parameters of 5G antennas" for acquiring the educational and scientific degree "Doctor" in the field of higher education 5. Technical sciences, professional field 5.3 Communication and computer engineering, doctoral program "Automation of areas of the non-material sphere (medicine, education, science, administrative activity, etc.)". The author of the dissertation is Tihomir Tihomirov Lovchaliev – full-time PhD student at the Department of Electronics, Communications and Information Technologies, supervised by Assoc. Prof. PhD Nadezhda Miteva Kafadarova from Plovdiv University "Paisii Hilendarski".

The set of paper materials presented by Tihomir Lovchaliev is in accordance with Article 36 (1) of the Regulations for the Development of the Academic Staff of Plovdiv University and includes the following documents:

- a request to the Rector of Plovdiv University for disclosure of the procedure for the defence of a dissertation;

- CV in European format;

- minutes of the Department Council related to reporting readiness for opening the procedure and preliminary discussion of the dissertation;

- dissertation;

- autoabstract;

- a list of scientific publications on the topic of the dissertation;

- copies of scientific publications;

- a declaration of originality and authenticity of the attached documents;

2. Brief biographical data for the PhD student

Tihomir Lovchaliev was born in 1992 and completed his secondary education at the Professional High School of Electrical Engineering and Electronics in 2011. In 2015 he received a bachelor's degree in Information Physics and Communications, and in 2018 he acquired a master's degree in Telematics at Plovdiv University "Paisii Hilendarski". Since 2016 until now he is Head of the Help Desk – South Sector at the National Revenue Agency, Plovdiv, with main activities and responsibilities – organizing, administering and optimizing workstations for the whole of southern Bulgaria.

On 01/03/2020 he was enrolled as a full-time PhD student at the Department of Electronics, Communications and Information Technologies at Plovdiv University "Paisii Hilendarski" with supervisor Assoc. Prof. PhD Nadezhda Kafadarova and in March 2023 he is charged with the right of defence.

3. Relevance of the topic and appropriateness of the objectives and tasks set

The topic of the dissertation related to the design and study of the characteristics of antennas for 5G mobile communications is particularly relevant due to several key factors. 5G technology promises significantly faster data speeds and lower latency, which opens doors to the development of new communication services and applications such as virtual reality, the Internet of Things, smart city and more. To realize these capabilities, antennas are needed that can provide the quality communication sought. Optimized antennas can provide better coverage and stability of the connection, which is essential for maintaining high speeds and quality of service in 5G networks. Also, proper antenna design can help reduce network propagation costs, such as improving radio coverage and optimizing base station allocation. On the other hand, 5G antennas must be designed with a view to compatibility and minimizing interference with other existing or future wireless networks, which is an important aspect of providing a quality and reliable service to users.

The aim of the dissertation is related to the design of antennas for 5G and the development of an innovative system for automated study of the radiation pattern diagrams of various antennas in laboratory conditions. To achieve the goal, the PhD student has formulated eight research tasks that fully meet the requirements for the correct conduct of scientific research. On this basis, I appreciate

the topic as very relevant in the context of the rapid development of mobile technologies and the resulting requirements for optimising the antennas used and their characteristics. I accept the main aim and tasks as adequately formulated.

4. Knowledge of the problem

The PhD student Tihomir Tihomirov Lovchaliev shows skill for creative research and purposeful assessment of rich literary material. In his dissertation, he cited 74 literary sources, many of which have been published in the last 10 years. The literature review focuses on cellular mobile communication systems with an emphasis on 5G-related scenarios and services. Different types of antennas for mobile applications, their main characteristics, approaches to their measurement and sources of error are discussed. The review is sufficiently detailed, the doctoral student demonstrates the necessary scientific competence and sufficient depth in the knowledge of the topic that he has applied in the formulation of the aim and the resulting tasks.

5. Methodology of the study

The chosen research methodology is consistent with the set goal and the tasks of the dissertation study. The PhD student has applied modern methods, software and tools in the design of antennas and in the development of the innovative laboratory system for the study of directional pattern diagrams of antennas.

Based on the review of modern approaches to the study of antenna parameters for mobile applications made in Chapter One, an active prototype of a system for the study of antennas for 5G antennas was designed and developed. After experiments, the shortcomings and critical locations of the prototype were systematized and analysed. As a next logical step of the methodology of the study is the development of an active system for studying the directivity pattern of antennas, as well as a methodology for conducting research using the system. To verify the system's operability, experiments were again carried out, the results and analyses of which are placed in the Fifth Chapter. The Sixth Chapter describes the algorithm that the doctoral student used in the design and manufacture of a patch antenna for 5G, as well as the results of the study of its radiation characteristics using the author's system.

6. Characterization and evaluation of the dissertation work

The dissertation work has a volume of 156 pages – it consists of abbreviations used, introduction, six chapters, conclusions, contributions, a list of publications on the dissertation and used literature. The dissertation work is logically structured to fully solve the tasks set and to achieve accurately and effectively the purpose of the study.

The introduction aims to substantiate the topicality of the dissertation problem.

The first chapter presents a detailed analysis of cellular mobile communication systems with a focus on 5G technologies as well as the scenarios and services they provide. Within the analysis, different types of antennas that are used for mobile applications are considered, focusing on their main characteristics, measurement methods and sources of possible errors. In this chapter, Tihomir Lovchaliev describes a sufficiently extensive and thorough radiation pattern diagram as one of the most important characteristics of RF antennas, which gives an idea of the directivity of their radiation and which is the focus of this dissertation.

In Chapter Two, the PhD student has examined in detail the process of designing and manufacturing the current prototype of the antenna research system for 5G mobile communications. An in-depth analysis of the individual modules and functional nodes from which it is built has been made. As a consequence of this analysis, a decision was made on the necessary modules to be included in the designed system such as: transmitting module with antenna, measuring module to which the tested antenna is connected, positioning system, data recording and processing module. The movement of the antenna and the measurement of the signal are synchronized with specially developed by the PhD student software. In this chapter results of a test measurement of the directional action diagram of a dipole antenna operating at 2.5 GHz are presented, which are given graphically in polar and Cartesian coordinates. The developed prototype of the automated testing system presented in the dissertation is original and effective in its kind, proving the high engineering expertise of the author.

Based on the developed prototype of the antenna testing system and after a critical analysis of its shortcomings, an operating system with improved characteristics was created. Optimization of basic functional assemblies and use of new components to improve the performance of the system and expand its capabilities has been carried out. Here again the correct engineering thinking and systematic scientific approach of the PhD student Tihomir Lovchaliev in setting and solving engineering tasks is visible.

The dissertation, in the Third Chapter, presents an innovative approach to the development of an acting system for the study of a directivity model of antennas by developing an author's electromechanical functional assembly. This approach aims to solve the main drawback in many of the existing systems for the study of antenna directivity related to the twisting of the connecting coaxial cables in the rotational movement of the antenna and the stationary positioning of the measuring equipment. The author presents detailed principle schemes of the individual nodes of the mechanical part of the system, which contributes to the clarity and comprehensibility of the proposed

model. The engineering approach and analysis of technical challenges are well founded and shows a high level of technical competence of the author.

The measurement system is controlled by specialized software that was developed by the doctoral student for the purpose of the study and installed on a personal computer. This software plays a key role in the implementation of the user interface and in the synchronization of the actions of the different executive modules that are involved in the process of building the system. The software was developed entirely using the Python programming language along with appropriate libraries, demonstrating the PhD student's good command of this language. To improve the quality of measurements and eliminate unwanted noise, Tihomir Lovchaliev applies the Savitzky-Golay filter for digital signal filtering. In the user interface there is provided the possibility to change filter's main parameters, which are: window size and polynomial line.

The development of specialized software, especially when it is adapted to the needs of a particular measurement system, is an indicator of a high level of engineering skills and competence on the part of the author of the work. The use of Python contributes to the flexibility and efficiency of software, while providing a wide range of opportunities for extension and integration with other technologies.

Chapter Four presents in detail the methodology for conducting the study of antennas with the help of the developed system. This methodology can be successfully used in conducting research on antennas, as well as laboratory exercises in telecommunications with students.

Chapter Five presents an algorithm for the initialization of the system when conducting measurements, as well as results of measurements on the radiation patterns of different types of antennas for 5G. To study the operability and efficiency of the developed system, numerous measurements of the radiation patterns in the E and H plane of different types of antennas were conducted. The results of all measurements remain close to those theoretically defined for the antennas studied. In tabular form, the main elements of the radiation patterns of the antennas in the E plane and the H plane, respectively, are presented.

Chapter Six presents results from the design and measurement of a patch antenna for 5G. Its radiation pattern was simulated using the specialized software ANSYS HFSS and verified using the author's measurement system.

7. Contributions and relevance of development to science and practice

I accept the scientific and applied contributions formulated in the dissertation. The aim and the tasks set in the dissertation are fully fulfilled. The results of the conducted research have an applied and scientific-applied nature.

In the dissertation, the PhD student has presented a detailed critical analysis of cellular mobile communication systems, various types of antennas involved in their construction, focusing on their main characteristics, measurement methods and sources of possible errors. The analysis is focused on modern approaches to the study of antenna parameters for mobile applications.

An operating prototype of the antenna testing system for 5G mobile communications has been designed and manufactured, which consists of modules and functional assemblies, some of which have been developed by the PhD student for the purposes of the dissertation, as well as author's software. A critical analysis of the shortcomings and limitations of the prototype is made, which serves as a starting point in the creation of a unique operating system with improved characteristics. Optimization of basic functional nodes was carried out, as well as a proprietary electromechanical functional module was developed, which prevents the twisting of the connecting cable between the investigated rotating antenna and the spectrum analyser. New components have been used which improve the performance of the system and extend its capabilities. The author's specialized software has been optimized, which has a user interface and with which the actions of the system's executive mechanisms are synchronized, signal filtering is performed, the obtained results are visualized in digital and graphic form (in Cartesian and polar coordinate systems), a database is created from the values of the signal power received by the investigated antenna depending on its angular position.

The functionality of the system has been proven by conducting numerous studies of different types of 5G antennas. Their radiation pattern diagrams have been built and the basic parameters of these diagrams have been determined, which are consistent with the known theoretical radiation patterns of these antennas.

A patch antenna for 5G was designed and manufactured. Its radiative characteristics were simulated using the ANSYS HFSS specialized software and verified by the developed innovative measuring system.

8. Assessment of publications on the dissertation

The main results of the dissertation study are presented in 6 (six) publications in specialized editions.

In two of the publications, which are in Bulgarian and are published in a collection of scientific works of the Union of Scientists in Bulgaria - Plovdiv, the PhD student is the only author. The other 4 publications are in English, in which the PhD student is a co-author (in 1 publication with two authors, in 2 publications with three authors and in 1 publication with four authors) and have been reported at international conferences. Two of these publications are in editions referenced

in SCOPUS (International Scientific Conference "Electronics ET2022, Sozopol), and the other two are in editions included in Google Scholar (ICERI21 and SOCIOINT22).

The review of the publications shows that the necessary publicity of the results of the research done in the dissertation is ensured. Their number is sufficient and complies with the accepted requirements.

9. Personal participation of the doctoral student

After carefully acquainting myself with the dissertation and publications of PhD student Tihomir Lovchaliev, I can confidently state that the results of the research included in the dissertation were obtained entirely with his participation. The PhD student demonstrates accumulated scientific and practical experience, in-depth engineering thinking and a systematic scientific approach to setting and solving engineering tasks.

10. Autoabstract

The autoabstract is made in accordance with the requirements of the Law on The Development of The Academic Staff in The Republic of Bulgaria, Regulations for Implementation of The Law on The Development of The Academic Staff in The Republic of Bulgaria and the relevant Regulations of Plovdiv University "Paisii Hilendarski". It is in a volume of 32 pages and presents in a concise and informative form the content of the dissertation.

The autoabstract is very well structured, with excellently executed illustrations of figures, graphs and schemes. It accurately and clearly outlines the aim and tasks of the dissertation, the results of the conducted scientific research, the critical analyses of the results and the conclusions obtained.

11. Critical remarks and recommendations

I don't have any critical remarks on my presented dissertation. I have certain recommendations that are wishful thinking and do not diminish my assessment of the high quality of the dissertation study conducted.

My recommendations are as follows:

- Although the individual parts of the software developed by the doctoral student are well described and explained in the text of the dissertation, I recommend that the entire source code be presented in the dissertation as a separate appendix.

- For future research work and to expand the capabilities of the system, it is good to construct a shielding Faraday cage in which to accommodate the measuring system.

- In my opinion, contribution 4 and contribution 5 could be combined into one.

12. Personal impressions

I know Tihomir Lovchaliev as a student in Bachelor's degree in Information Physics and Communications and then in the Master's degree in Telematics. He has always made an impression of a purposeful, inquisitive, hardworking and modest young man. After graduating as a Master, Tihomir Lovchaliev was and continues to be a part-time lecturer at the ECIT Department in disciplines such as Wireless Communication Systems, "Computer networks", etc. The knowledge gained in the field of wireless communications, mobile communications and computer engineering as a student, and then in the process of working as a lecturer, has served as a solid foundation in the development of the dissertation. Tihomir Lovchaliev has further developed and applied these theoretical and practical knowledge and skills in solving research tasks and achieving scientific and applied results.

13. Recommendations for future use of dissertation contributions and results

Work should continue towards expanding the capabilities of the antenna research system, to be used both in future research work and in the training of students in the relevant telecommunications disciplines.

Given the extremely current field of mobile telecommunications, to which the development is directed, as well as the great potential of opportunities offered by the system described in the dissertation work, I recommend that research in this field be continued and promoted in journals, if possible with an impact factor.

CONCLUSION

The dissertation ***paper contains scientific-applied and applied results that represent an original contribution to science*** and **meet all** the requirements(s) of the Law on The Development of The Academic Staff in The Republic Of Bulgaria, Regulations for Implementation of The Law on The Development of The Academic Staff in The Republic of Bulgaria and the relevant Regulations of Plovdiv University "Paisii Hilendarski".

The dissertation work shows that the PhD student Tihomir Tihomir Lovchaliev **has** in-depth theoretical knowledge and professional skills in the scientific specialty "Automation of areas of the non-material sphere (medicine, education, science, administrative activity, etc.)" by **demonstrating** qualities and skills for independent scientific research.

Due to the above, I confidently give my ***positive assessment*** of the conducted research, presented by the dissertation reviewed, autoabstract, achieved results and contributions, and ***I pro-***

pose to the honorable scientific jury to award the educational and scientific degree "Doctor" to Tihomir Tihomir Lovchaliev in the field of higher education: 5. Technical Sciences, professional field 5.3. Communication and computer engineering, doctoral program "Automation of areas of the non-material sphere (medicine, education, science, administrative activity, etc.)".

Plovdiv, 15.05.2024   Reviewer: ....
                                                                              (signature)
                                                            Prof. PhD Nevena Mileva
                                                            (*ac. d., n. st., name, surname*)