POSTGRADUATE DOCTORAL STUDY

FORM D5A-OCJ

**APPLICATION FOR INITIATING THE PROCEDURE FOR ASSESSMENT AND DEFENSE OF THE DOCTORAL THESIS**

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| **First name and last name of the student:** | Ante Kapetanović |
| **First name and last name of the supervisor:** | Prof Dragan Poljak, PhD |
| **Postgraduate doctoral study:** | Electrical engineering and information technology |
| **Scientific field/discipline:\*** | Electrical engineering/electronics |
| **Title of doctoral thesis (Croatian):** | Napredna tehnika određivanja prostorno usrednjenih dozimetrijskih veličina na zakrivljenim površinama |
| **Title of doctoral thesis (English):** | Advanced Technique for Assessment of Spatially Averaged Dosimetric Quantities on Nonplanar Surfaces |
| **Language of thesis:** | English |
| **Date of accepting the doctoral thesis proposal:** | 24.4.2023 |

I hereby declare that I have fulfilled all the requirements for initiating the procedure for assessment and defence of doctoral thesis, including publication of papers in the area of doctoral research (list enclosed) and I hereby declare that I have produced the doctoral thesis on my own.

The doctoral thesis was formatted and prepared in accordance with the instructions for preparing the text of the doctoral thesis.

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| **Approval of the supervisor:**  (supervisor gives approval for initiating the procedure mentor for assessment and defence of doctoral thesis) |
| I agree with the initiation of the procedure for assessment and defense of the doctoral thesis of candidate Ante Kapetanović, mag.ing. |
| **Opinion of the supervisor:**  (supervisor gives opinion on conducted research and achieved scientific contribution, recommended approx. 4000 -7000 words) |
| **Overview of the contents of the doctoral thesis**  Doctoral dissertation of candidate Ante Kapetanović is written in English and titled Advanced Technique for Assessment of Spatially Averaged Dosimetric Quantities on Nonplanar Surfaces.  The dissertation contains a total of 147 pages, 15 figures, 3 tables and 145 bibliographic units, and is written according to the "Scandinavian model" and contains the title page, bibliographic data, summary in English and Croatian, place reserved for acknowledgements, table of contents, list of tables, a list of figures, a list of abbreviations, the central part of the dissertation text and finally a CV.  The central part of the dissertation based on a set of published works consists of an introduction in which the motivation is stated, then the research goals and hypothesis, scientific methods and contribution, and then a list of published works on which the scientific contribution of the thesis is based, and finally an overview of the organization of the dissertation.  An overview of the scientific contribution is presented through the works on which the dissertation is based, where the contribution of the doctoral student is also defined for each individual published paper. In the last part, there is a conclusion in which the main solutions and guidelines for possible further research work are stated.  After the conclusion, the literature used in the dissertation is listed. The papers on which the dissertation is based are listed in Appendix A, B, C, and D.  The central part of the dissertation text is organized by chapters as follows:   1. INTRODUCTION    1. Motivation    2. Hypothesis    3. Scientific Method and Contribution    4. Published Papers    5. Outline 2. BASIC ASPECTS OF EXPOSURE TO ELECTROMAGNETIC FIELDS    1. A Primer on Electromagnetic Fields    2. Principles of Non-Ionizing Radiation Effects on Tissue    3. Radio Frequency Electromagnetic Radiation Protection       1. Brief History of Exposure Limits       2. Scientific Basis for Limiting Exposure       3. Basic Restrictions       4. Exposure Reference Levels 3. GOVERNING EQUATIONS AT GIGAHERTZ RANGE    1. Specific Absorption Rate    2. Transition to Area-Averaged Dosimetric Quantities       1. Absorbed/Epithelial Power Density       2. Equivalence of Absorbed/Epithelial Power Density Definitions    3. Incident Power Density    4. State of Research 4. AVERAGING POWER DENSITY ON NONPLANAR SURFACES    1. Normal Estimation on the Evaluation Surface       1. Normal Estimation on Nonplanar Canonical Surfaces       2. Normal Estimation on Nonplanar Anatomical Surfaces    2. Construction of the Averaging Area    3. Spatial Averaging of Power Density 5. PUBLISHED PAPERS    1. Assessment of Incident Power Density on Spherical Head Model up to 100 GHz       1. Abstract       2. Impact Statement       3. Author Contributions       4. Supplementary Materials    2. Machine Learning-Assisted Antenna Modeling for Realistic Assessment of Incident Power Density on Nonplanar Surfaces above 6 GHz       1. Abstract       2. Impact Statement       3. Author Contributions       4. Supplementary Materials    3. Area-Averaged Transmitted and Absorbed Power Density on a Realistic Ear Model       1. Abstract       2. Impact Statement       3. Author Contributions       4. Supplementary Materials    4. On the Applicability of Numerical Quadrature for Double Surface Integrals at 5G Frequencies       1. Abstract       2. Impact Statement       3. Author Contributions 6. CONCLUDING REMARKS 7. BIBLIOGRAPHY 8. APPENDIX A 9. APPENDIX B 10. APPENDIX C 11. APPENDIX D   **Overview of the contents of doctoral thesis per chapters**  The motivation and hypothesis of the dissertation as well as the list of published papers are presented in the introductory part of the dissertation within the first chapter. In situations when the wavelength of the incident field onto the human body is comparable to the radius of curvature of the the exposed body part, the flat surface represents a rough approximation and potentially leads to underestimation of the area-average dosimetric quantities. The basic assumption is therefore that the application of curved models necessarily leads to more accurate spatially averaged power density values. In practical exposure scenarios, the fingers, outer ear and head are at the greatest risk from surface overheating. Thus, the corresponding cylindrical or spherical models are imposed as the most appropriate. However, considering that complex surface geometries such as that of the external ear cannot be adequately described by canonical curved models, there is a need to use tissue-equivalent anatomical models. The mathematical description of the curvature of the surface of anatomical models is possible exclusively using a precise numerical estimate of the normal unit vectors on the surface. Averaging the power density is then achieved by parametrizing the surface in a two-dimensional integration space and using a numerical approach to approximate surface integrals of the vector field. The second hypothesis is, therefore, that the spatial distribution of normal vectors on the surface of anatomical models conditioned by morphological irregularities, asymmetries and eventual deformities of the observed tissue significantly affects the absorption of incident electromagnetic fields significantly. Consequently, the values of the averaged power density can potentially be drastically greater compared to flat models, but also comapred to curved models of symmetric geometry, depending on the antenna position, polarization of the incident field and the area of the integration domain. Final hypothesis is that by applying hybrid methods based on the principles of machine learning combined with the traditional numerical methods, the automatic detection of hot spot regions is indirectly realized in an efficient way. This region is characterized as a limited region of greatest temperature increase.  In the second chapter entitled: Basic Aspects of Exposure to Electromagnetic Fields, an overview of the basics of interaction between radio-frequency electromagnetic fields and the human body is provided. Starting from the first principles expressed in terms of Maxwell's equations, this chapter provides a detailed description of non-ionizing radiation, which forms the basis for determining human exposure limits. Furthermore, the scientific methodology used to derive the limits of human exposure to radio frequency fields in the range from 6 to 300 GHz is presented.  In the third chapter, entitled Governing Equations at Gigahertz Range, a more detailed investigation of mathematical formulations related to spatially averaged dosimetric quantities is carried out, relying on Poynting's theorem, which describes the general law of energy conservation in electrodynamics. Special attention is given to a specific exposure scenario characterized as local, stationary and within the range of 6 to 300 GHz, where the primary outcome of the interaction of electromagnetic fields and the human body is manifested as an increase in skin surface temperature. Finally, this chapter provides an overview of the current state of research, with a focus on computational procedures used to estimate the power density of wireless devices in close proximity to the human body.  In the fourth chapter titled: Averaging Power Density on Nonplanar Surfaces, the candidate delves deeper into the techniques needed to accurately assess the spatially averaged power density on curved evaluation surfaces. In this chapter, the main contributions presented through a scientific description of the used methodology are systematically defined:   * Development of adequate curved and anatomical models of human body parts based on available literature. Two types of curved models of human body parts are described: canonical and anatomical models. Canonical models in the form of a sphere or cylinder provide an efficient approximation of body parts such as the head, eye, fingers, which are often exposed during practical exposure scenarios. On the other hand, anatomical models are developed in order to achieve compatibility with the majority of the population using the expected values of the dimensions of the modeled body part, its structure and anatomy, and the values of the dielectric parameters of interest. * Estimation of normals on integration surfaces of curved parts of the human body. For canonical curved model geometries, the estimation of normals is performed directly using analytical expressions in the appropriate coordinate system (spherical or cylindrical coordinate system based on the ISO 80000-2:2019 convention). On the other hand, in anatomical models, the integration surface is mathematically described as a two-dimensional Riemannian manifold in three-dimensional Euclidean space. There is a separate tangential plane at all points of the observed surface. The direction at any point perpendicular to the corresponding tangential plane contains a normal and a unit normal vector of arbitrary orientation. The curvature of the surface at the observed point can then be described using two planes that contain the normal vector and which are characterized by the largest and smallest curvature of the curve obtained as the intersection of these planes and the control surface. Any regular and smooth (differentiable) surface can be locally expressed as a graph of a bivariate "height function" with respect to any z-direction that does not belong to the mentioned tangential space. Determination of the z-direction is achieved by transforming the original coordinate system using principal component analysis, and the normal vector is realized as a vector product of the partial derivative of the parametrized surface by tangential components. * Efficient spatial averaging of power on surfaces of arbitrary shape. Area integration is performed on the basis of the described calculation of normals, and it is realized in such a way that it does not take into account the positional connections between the points of the calculation of the electromagnetic field. When computing the absorbed field, it is necessary to define the distribution of the normal component of the field over the surface, which, in a mathematical sense, is determined by the scalar product of the vector field of unit normals and complex electromagnetic components. The area integral of the vector field can then be approximated using any two-dimensional quadrature since the field (normalized with respect to the area) passes through the parametric surface.   The published works that serve as the basis of this dissertation are listed in the fifth chapter. Each paper is accompanied by summaries, impact statements and recognition of the contributions of individual authors. For ease of reference, the full text of each published paper can be found in the appendices. Although each of the published papers can be taken as a separate scientific research, these works as a whole make a contribution to numerical dosimetry in terms of the comutation of spatially averaged dosimetric quantities. Rigorous mathematical formulations are used in order to achieve the high-fidelity results, which are compatible with the formulations available in the latest edition of IEEE standards and ICNIRP guidelines for safety levels with regard to human exposure to electromagnetic fields up to 300 GHz. Finally, the last chapter, Concluding Remarks, includes a general discussion, conclusions drawn from the research (original scientific contribution) and indicates the direction of potential future research.  **Original scientific contribution and conclusion**  The main scientific contribution achieved within this dissertation is based on the realization of an efficient technique and the corresponding computer tool for efficient averaging of dosimetric quantities on the surface of curved parts of the human body exposed to electromagnetic fields above 6 GHz.  In addition to the development of an efficient method for averaging the incident and absorbed fields that does not depend on the numerical method used for exposure simulations, the influence of the geometric characteristics of the tissue surface, its morphological characteristics, curvature and geometry of the averaging area is also quantified.  In this way, the foundations for the development of reference models equivalent to exposed tissue in future guidelines and standards for limiting exposure to electromagnetic fields up to 300 GHz are provided.  The main contributions of the dissertation are as follows:   * A set of new realistic models of the human body parts exposed to radiation fields above 6 GHz that replace the traditional flat models represented in the literature for the purpose of better approximation of curved parts of the human body whose radius of curvature is comparable to the wavelength of the incident field. The models are represented as a homogeneous/layered spherical and cylindrical model of the head and a homogeneous/layered anatomical model of the external ear. The ear is chosen due to its morphological complexity due to the complex convex-concave structure of the tissue, which results in an inhomogeneous distribution of the absorbed field, in contrast to the flat, spherical and cylindrical model. Also, the outer ear is the most exposed part of the body during practical exposure scenarios. * An algorithm for the automatic detection of the so-called hot spots region, which represents a limited bounded region of the highest temperature increase compared to the ambient temperature outside the influence of the electromagnetic field. This technique is based on the iterative application of principal component analysis or factor analysis using either a curved model of simple geometry or an anatomical model transformed into a point cloud. The algorithm takes as an input a model represented as a set of three-dimensional coordinates, where each coordinate represents one point on the surface of the model, and thus ensures compatibility with any method (numerical or analytical) used for the assessment of the electromagnetic field and associated interactions. * Calculation of the average absorbed and incident electromagnetic power density using rigorous mathematical definitions based on the area integration of the power density vector flux through a control surface of arbitrary shape. Since the basic part of the integrand function of the area integral is the differential element of the integration domain, it is necessary to determine the distribution of normal vectors on the surface of the model. The contribution of this doctoral dissertation is the development of an advanced, efficient numerical technique for evaluating the surface integral of scalar and vector fields, completely independent of the original electromagnetic method.   The application of the research results carried out within the proposed doctoral dissertation confirms the validity of the absorbed power density as a fundamental limitation for the assessment of temperature rise for local exposure of curved body parts above 6 GHz in a steady state. In addition, an insight into the efficiency of curved and anatomical models for electromagnetic dosimetry at high frequencies is achieved as a basis for future discussions and activities of Working Group 7 under IEEE/ICES (International Committee for) Electromagnetic Safety TC (Technical Committee) 95 SC 6 for electromagnetic dosimetry modeling. Finally, this dissertation represents a kind of starting point for the discussion on the realization of curved models as references in future editions of ICNIRP (International Commission of Nonionizing Radiation Protection) guidelines and IEEE standards for limiting human exposure to radio frequency electromagnetic fields up to 300 GHz.  The research presented in this doctoral thesis makes a significant contribution to the understanding of the problem of human exposure to electromagnetic fields of high frequencies in the field of millimeter waves and contributes to the development of new dosimetric models adapted to the context of future wireless communication technologies. |
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*Signature of the supervisor*

Split, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*Enclosed:*

1. *Doctoral thesis in electronic and printed format (six copies)*
2. *List of published scientific papers in the area of doctoral thesis*

*As necessary, significant contributions in other scientific field/discipline may be included.*

**LIST OF SCIENTIFIC PAPERS PUBLISHED BY THE CANDIDATE IN THE AREA OF DOCTORAL THESIS**

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| **Scientific papers, A category** |

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| --- | --- |
| Authors | **Kapetanović, A.**, Poljak, D. |
| Title of the paper | Machine learning-assisted antenna modelling for realistic assessment of incident power density on non-planar surfaces above 6 GHz |
| Journal | Radiation Protection Dosimetry |
| Issue, pages, year of publication | 199(8-9), 826-834, 2023 |
| Bibliographic databases | Current Contents/Engineering, Google Scholar, SCOPUS, Science Citation Index... |
| Impact factor | 1.053 |

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| --- | --- |
| Authors | **Kapetanović, A.**, Sacco, G., Poljak, D., Zhadobov, M. |
| Title of the paper | Area-Averaged Transmitted and Absorbed Power Density on Realistic Body Parts |
| Journal | IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology |
| Issue, pages, year of publication | 7(1), 39-45, 2023 |
| Bibliographic databases | Current Contents/Engineering, Google Scholar, SCOPUS, Science Citation Index... |
| Impact factor | 3.00 |

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| --- | --- |
| Authors | **Kapetanović, A.**, Poljak, D. |
| Title of the paper | Assessment of Incident Power Density on Spherical Head Model up to 100 GHz |
| Journal | IEEE Transactions on Electromagnetic Compatibility |
| Issue, pages, year of publication | 64, 1296-1303, 2022 |
| Bibliographic databases | Current Contents/Engineering, Google Scholar, SCOPUS, Science Citation Index... |
| Impact factor | 2.036 |

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| --- | --- |
| Authors | **Kapetanović, A.**, Šušnjara, A., Poljak, D. |
| Title of the paper | Stochastic analysis of the electromagnetic induction effect on a neuron’s action potential dynamics |
| Journal | Nonlinear Dynamics |
| Issue, pages, year of publication | 105, 3585-602, 2021 |
| Bibliographic databases | Current Contents/Engineering, Google Scholar, SCOPUS, Science Citation Index... |
| Impact factor | 5.022 |

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| --- | --- |
| Authors | Cvetković, M., **Kapetanović, A.**, Poljak, D., Dodig, H. |
| Title of the paper | On the Applicability of Numerical Quadrature for Double Surface Integrals at 5G Frequencies |
| Journal | Journal of communications software and systems |
| Issue, pages, year of publication | 18:42-53, 2022 |
| Bibliographic databases | Scopus, EBSCO, INSPEC, CrossRef, Google Scholar and DOAJ |
| Impact factor | 1.26 |

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| **Scientific papers, D category** |

|  |  |
| --- | --- |
| Authors | **Kapetanović, A.**, Poljak, D., Li, K. |
| Title of the paper | Standardized Benchmark Dataset for Localized Exposure to a Realistic Source at 10-90 GHz |
| Title of conference proceedings | Proceedings of BioEM 2023, Numerical dosimetry |
| Pages (from-to) | 1-6 |
| Name of the conference | BioEM 2023 |
| Date of conference | 18-23.6.2023, Oxford, UK |

|  |  |
| --- | --- |
| Authors | **Kapetanović, A.**, Šušnjara, A., Poljak, D., Russo, M. |
| Title of the paper | Stochastic-Deterministic Electromagnetic Modeling of Human Head Exposure to Microsoft HoloLens |
| Title of conference proceedings | Special Session on Environmental Electromagnetic Compatibility (EEMC) |
| Pages (from-to) | 1-6 |
| Name of the conference | 30th International Conference on Software, Telecommunications and Computer Networks, SoftCOM 2022 |
| Date of conference | 22-24.9.2022, Split, Croatia |

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| --- | --- |
| Authors | **Kapetanović, A.**, Sacco, G., Poljak, D., Zhadobov, M. |
| Title of the paper | Novel procedure for spatial averaging of absorbed power density on realistic body models at millimeter waves |
| Title of conference proceedings | BioEM proceedings |
| Pages (from-to) | 242-8 |
| Name of the conference | BioEM 2022 |
| Date of conference | 19-24.6.2022, Nagoya, Japan (virtual) |

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| --- | --- |
| Authors | **Kapetanović, A.**, Poljak, D. |
| Title of the paper | Machine learning-assisted antenna modeling for realistic assessment of human exposure reference levels above 6 GHz |
| Title of conference proceedings | IEEE and ICNIRP and Hot Topics EMF |
| Pages (from-to) | 1 (abstract) |
| Name of the conference | 6th European Congress on Radiation Protection |
| Date of conference | 30.5-3.6.2022, Budapest, Hungary |

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| --- | --- |
| Authors | **Kapetanović, A.**, Sacco, G., Poljak, D., Zhadobov, M. |
| Title of the paper | Assessment of Area-Average Absorbed Power Density on Realistic Tissue Models at mmWaves |
| Title of conference proceedings | Facing challenges in electromagnetic dosimetry at mm waves and THz |
| Pages (from-to) | 153-5 |
| Name of the conference | IEEE International Microwave Biomedical Conference (IMBioC 2022) |
| Date of conference | 16-18.5.2022, Suzhou, China in a hybrid mode |

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| --- | --- |
| Authors | Cvetković, M.; Poljak, D.; **Kapetanović, A.**; Dodig, H. |
| Title of the paper | Study on the Suitability of Numerical Integration at 5G Frequencies Using Unit Cube Test |
| Title of conference proceedings | Special Session on Environmental Electromagnetic Compatibility (EEMC) |
| Pages (from-to) | 1-6 |
| Name of the conference | 29th International Conference on Software, Telecommunications and Computer Networks, SoftCOM 2021 |
| Date of conference | 23-25.9.2021 |

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| --- | --- |
| Authors | Cvetković, M.; Poljak, D.; **Kapetanović, A.**; Dodig, H. |
| Title of the paper | Selecting Optimal Numerical Integration Rules for Double Surface Integrals on Triangular Domains |
| Title of conference proceedings | Computation of Electromagnetic Fields |
| Pages (from-to) | 38-41 |
| Name of the conference | 15th International Conference on Applied Electromagnetics, PEC 2021 |
| Date of conference | 30.8-1.9.2021 |

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| --- | --- |
| Authors | Cvetković, M.; Poljak, D.; **Kapetanović, A.**; Dodig, H. |
| Title of the paper | Unit Cube Test for Double Surface Integrals in Frequency Domain Integral Equation Formulations |
| Title of conference proceedings | Engineering Modeling |
| Pages (from-to) | 1-6 |
| Name of the conference | 6th International Conference on Smart and Sustainable Technologies, SpliTech 2021 |
| Date of conference | 8-11.9.2021 |

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| Authors | **Kapetanović, A.**; Poljak, D. |
| Title of the paper | Application of Automatic Differentiation in Electromagnetic Dosimetry – Assessment of the Absorbed Power Density in the mmWave Frequency Spectrum |
| Title of conference proceedings | Engineering Modeling |
| Pages (from-to) | 1-6 |
| Name of the conference | 6th International Conference on Smart and Sustainable Technologies, SpliTech 2021 |
| Date of conference | 8-11.9.2021 |

**LIST OF ALL PUBLISHED WORKS OF APPLICANTS IN THE FIELD OF THE PROPOSED TOPIC OF THE THESIS**

Scientific papers published in journals

1. **Kapetanović, A.** & Poljak D. (2023) „Machine learning-assisted antenna modelling for realistic assessment of incident power density on non-planar surfaces above 6 GHz,” *Radiation Protection Dosimetry*, 199(8-9), 826-834, doi: 10.1093/rpd/ncad114
2. **Kapetanović, A.**, Sacco, G., Poljak, D. & Zhadobov, M. (2022) “Area-averaged transmitted and absorbed power density on a realistic ear model,” *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, 7(1), 39-45, doi: 10.1109/jerm.2022.3225380
3. **Kapetanović, A.** & Poljak, D. (2022) “Assessment of Incident Power Density on Spherical Head Model up to 100 GHz,” *IEEE Transactions on Electromagnetic Compatibility,* 64(5), 1296-1303, doi: 10.1109/temc.2022.3183071
4. Cvetković, M., Poljak, D., **Kapetanović, A.** & Dodig, H. (2022) “On the Applicability of Numerical Quadrature for Double Surface Integrals at 5G Frequencies,” *Journal of communications software and systems*, 18(14), 42-53, doi: 10.24138/jcomss-2021-0183
5. **Kapetanović, A.**, Šušnjara, A. & Poljak, D. (2021) “Stochastic analysis of the electromagnetic induction effect on a neuron’s action potential dynamics,” *Nonlinear dynamics*, 105, 3585-3602 doi: 10.1007/s11071-021-06762-z

Scientific papers published in conference proceedings

1. **Kapetanović, A.**, Poljak, D. & Li, K. (2023) „Standardized benchmark dataset for localized exposure to a realisitic source at 10-90 GHz” In proceedings of BioEM2023, Oxford, UK,
2. **Kapetanović, A.**, Šušnjara, A., Poljak, D. & Russo, M. (2022) “Stochastic-deterministic electromagnetic modeling of human head exposure to Microsoft HoloLens,” In proceedings of 2022 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Hrvatska, 1-5 doi: 10.23919/SoftCOM55329.2022.9911431.
3. **Kapetanović, A.**, Sacco, G., Poljak, D. & Zhadobov, M. (2022) “Assessment of area-average absorbed power density on realistic tissue models at mmWaves,” In proceedings of 2022 IEEE MTT-S International Microwave Biomedical Conference (IMBioC), Sozhou, Kina, 153-155, doi: 10.1109/imbioc52515.2022.9790150
4. **Kapetanović, A.** & Poljak, D. (2021) “Application of automatic differentiation in electromagnetic dosimetry: Assessment of the absorbed power density in the mmWave frequency spectrum,” In proceedings of 2021 International Conference on Smart and Sustainable Technologies (SpliTech), Bol, Hrvatska, 1-6, doi: 10.23919/SpliTech52315.2021.9566429
5. Cvetković, M., Poljak, D., **Kapetanović, A.** & Dodig, H. (2021) “Selecting optimal numerical integration rules for double surface integrals on triangular domains,” In proceedings of 2021 International Conference on Applied Electromagnetics (PEC), Niš, Srbija, 38-41
6. **Kapetanović, A.**; Poljak, D. (2021) „Efficient procedures in assessment of incident power density on non-planar tissue models under electromagnetic exposure in mmWave spectrum,” In proceedings of 2021 International Conference on Telecommunications (ConTEL), Zagreb, Croatia, 9-10
7. Cvetković, M., Poljak, D., **Kapetanović, A.** & Dodig, H. (2021) “Unit cube test for double surface integrals in frequency domain integral equation formulations,” In proceedings of 2021 International Conference on Smart and Sustainable Technologies (SpliTech), Split, Croatia, 1-6, doi: 10.23919/SpliTech52315.2021.9566347
8. Cvetković, M., Poljak, D., **Kapetanović, A.** & Dodig, H. (2021) “Study on the suitability of numerical integration at 5G frequencies using unit cube test,” In proceedings of 2021 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Croatia, 1-6, doi: 10.23919/SoftCOM52868.2021.9559114
9. **Kapetanović, A.**, Šušnjara, A. & Poljak, D. (2020) “Numerical solution and uncertainty quantification of bioheat transfer equation using neural network approach,” In proceedings of 2020 International Conference on Smart and Sustainable Technologies (SpliTech), Bol, Croatia, 1-6, doi: 10.23919/SpliTech49282.2020.9243733

**CONFIRMATION OF THE SUPERVISOR THAT THE APPLICANT'S PUBLISHED PAPERS ARE ALIGNED WITH THE FIELD OF DOCTORAL THESIS RESEARCH**

I confirm that the papers that applicant Ante Kapetanović, a student of the postgraduate doctoral study in Electrical Engineering and Information Technology, listed in the attached list of scientific papers and the attached list of all published papers, belong to the field of doctoral thesis research.

**Supervisor**

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Prof Dragan Poljak, PhD