BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

Opponent Review of Doctoral Dissertation

Applicant: Dominika Warmowska

Title of Dissertation: Terahertz Antenna Arrays for Communications

Opponent: Prof. Miroslav Joler, Ph.D.

Opponent's Department: University of Rijeka, Faculty of Engineering, Rijeka, Croatia

In accordance with the Study and Examination Rules of BUT, in his/her review the opponent will mainly comment on:
a) the topicality of the dissertation,
b) whether the dissertation achieved its given objective,
c) the problem-solving procedure and the results of the dissertation along with the concrete contribution of the doctoral student,
d) the significance for practical application or the progress in the field,
e) formal and language qualities of the dissertation,
f) whether the dissertation fulfils the conditions of Section 47 (4) of the Act,
g) whether the student proved his/her creative abilities in the given research field and whether the work does or does not comply with the standard requirements placed on the dissertations in the given field. The review is not valid without this conclusion.
It is necessary to add a concise commentary to each of the points below.

Ad a) Topicality of the dissertation

The topic of the dissertation is very topical.
Comment:
Terahertz antenna arrays are very interesting, up-and-coming topic in the context of future communications, due to the growing need for lower latency, wider bandwidth, higher capacity of networks and better signal-to-interference ratio.

Ad b) Objective of the dissertation

The objective of the dissertation was achieved.
Comment:

The targeted objectives of the dissertation have been reached: a design of a basic THz antenna at 350 GHz, with a comparison of simulated results vs. some measurements (some other planned measurements were not executed for the lack of the required measurement equipment), a design of antenna arrays (a couple of examples) using the initially designed antenna element, and a conversion of the design to lower frequencies with a view to space applications.

Ad c) Problem-solving procedure and the results of the dissertation and the concrete contribution of the doctoral student

The problem-solving procedure and the results of the dissertation are average.
Comment:
The author has adequately introduced the topic in Chapter 1 and, in Chapter 2, made an overview of the current state of the art on this topic. In Chapter 3, dissertation objectives were specified. Chapter 4 discusses the challenges about modeling of metal at THz frequencies. Chapter 5 is the central part of the dissertation, dealing with the design of the basic antenna element. Chapter 6 describes the technologies needed to manufacture the antenna at THz frequency. In Chapter 7, the initial design was scaled to lower frequencies, for the use with space applications, demonstrating the applicability and scalability of the initial design to other (lower) frequencies.
The doctoral student has contributed the field by providing sufficient insights and discussions about the design of low-profile antenna at terahertz frequencies, tackling the modeling and fabrication challenges. The Conclusions chapter offers directions for future research and prospective extensions of this work.

Ad d) Significance for practical application or progress in the field

The significance for practical application or progress in the field is average.
Comment:
The author presented a low-profile antenna design that has been prepared for the use within the terahertz frequency band, yet also being scalable to lower frequencies, as explained in Chapter 7. The manufactured antenna showed competitive characteristics to some earlier works that were referenced in the dissertation. The results presented in this dissertation could motivate some of the following research endeavors: design of larger arrays with higher gains, development of passive phase shifters at THz frequencies based on liquid crystal or carbon nanotubes, or beam steering within the feeding waveguide using liquid crystal. The progress will also depend upon the availability of sophisticated technologies that are required to successfully manufacture structures at THz frequencies, where accuracy and precision are critical.

Ad e) Formal and language qualities of the dissertation

Formal and language qualities of the dissertation are average.
Comment:
The language and grammar should be improved throughout the text. The reviewer has indicated most of such spots within the PDF version of the dissertation (sent enclosed with this review form). Specifically, Chapter 4 has quite a few unclear sentences, which should be improved.
In Section 5.1.3., the optimal distance of the slot should have rather been expressed in terms of some generalized parameters, e.g., in terms of the signal wavelength, rather than as the absolute distance, with which the specific operating frequency is not clearly declared. In addition, graphs of numerical analyses, which had lead to that optimal value, would be interesting to be presented.
Likewise, numerical analyses that lead to the optimal design of the patches (Section 5.1.3) could have been presented in a way to make the reader more involved and the text less dry and more cogent.
From the typical drawing of the antenna in Section 5.3.2, with the zenith above the z-axis, it is quite relative what is referred to as the azimuthal plane and what is the elevation plane. It would be unambiguously presented if it were referred to as the zx-plane and yz-plane.

Ad f) The dissertation fulfils the conditions of Section 47 (4) of the Act

The dissertation fulfils the conditions of Section 47 (4)*) Act No. 111/1998 Sb. Higher Education Act: YES

((4) Studies are duly finished with a doctoral state exam and dissertation defence, which prove the ability and readiness to work independently in the field of research or development, or in theoretical and creative arts. The dissertation must comprise original and published results or results accepted for publication.*

Ad g) Creative abilities of the student in the given research field. Compliance with the standard requirements placed on the dissertations in the given field.

The doctoral student did prove his/her creative abilities in the given research field and the work does comply with the standard requirements placed on the dissertations in the given field.
Comment:
The author followed a systematic approach in tackling the research problem, starting from the introduction with a broader context, followed by comparison with the prior art, identifying the challenges, developing the solution, testing its characteristics and comparing with other comparable works.

Miss Warmowska paid attention to modeling challenges of the materials and structures at such high frequencies and made a discussion on it (e.g. metal at THz frequencies). She also made an informative discussion on the possible choices of manufacturing technologies (e.g. laser cutting vs. reactive ion etching) and analyzed the quality of the results that were achieved with the selected manufacturing technology as well as discussed possible improvements in future attempts.
The author also critically examined the lack of expected results for the antenna design at lower frequencies (for space applications) – use of nickel spray for metallization at 9 GHz and CNC machining for the array at 35 GHz. Even though the deficiencies were not quite corrected, the author has made an effort to examine the problem and come up with an explanation for the defects.

Overall evaluation:
Strengths
1. The author provided a good discussion on difficulties and challenges to design antennas at THz frequencies due to small dimensions, technological challenges, and a lack of exact information on the materials at such high frequencies.
2. Miss Warmowska has achieved a successful design of the basic antenna element and then successfully extended the work to a few antenna array scenarios at the primary- and a scaled-down- frequencies.
3. A topic that is quite new and insufficiently researched up to date in the small-antenna design field for not being that needed in the past. The author has done most of the reasonable steps to cover the topic within the available possibilities.

Objective and Random Drawbacks
1. Measurements of the radiation pattern, gain and radiation efficiency at 350 GHz were not done due to the lack of another frequency extender that was instrumental to perform the measurements.
2. The laser cutting was not precise enough, while deep reactive ion etching (DREI) technology was not deployed to improve the manufacturing results instead of the laser cutting, for no apparent reason, which is regretful since access to such scarce and expensive premises capable of manufacturing THz-minded components is a rare opportunity.
3. The 8x8 35-GHz antenna array manufacturing failed using a CNC machining, while manufacturing by wire cutting, as the prospective alternative, did not take place due to "unpredicted financial issues," thus leaving us guessing whether the final results would be better.

Non-objective Downsides
1. No pertinent theoretical background (essential theory, design relations, relevant references etc.) was provided for the basic antenna design in Chapter 5. The reader is simply presented the design in Section 5.1 with no particular information on what theoretical foundations it stems from. Oddly, there are also no design equations that one can repeat this design based on them, which is a twofold drawback: an interested reader cannot learn how to design the geometry of each particular layer constituting this antenna; second: any article review is based on the principle of repeatability of the work presented therein. Here, it is hardly possible when lacking the design equations, while some illustrations of the antenna layers also do not reveal the horizontal and vertical placement and alignment of respective layers.

2. The 9 GHz antenna did not succeed for the reason of using a nickel spray to metalize the surface, which did not produce desired results. While it is positive that the author further investigated possible reasons for the bad results, it remains unexplained why the author did not then repeat the manufacturing using copper strips, which showed to be a viable alternative to nickel spray.
3. The initial antenna design is impressive as well as the results, yet the extensions of the design to the 2x2, 4x4, and 8x8 arrays do not bring much of the depth and breadth into the overall work (i.e. they were more of just a repetition of the design with small variations), but were supposed to demonstrate scalability of the design. It is, however, known from the general antenna theory that antenna designs are scalable because particular theories and designs are always based with regard to wavelength. Scalability to lower frequencies is even easier task due to the fact that design and manufacturing errors are less critical at lower frequencies. Perhaps, work with some sort of real phase shifters could have been done in Section 5.3.1. (eventually on smaller arrays).

With all said and done, the reviewer can here conclude that Miss Warmowska has achieved a successful design of the basic antenna element and then successfully extended the work to a few antenna array scenarios at the primary- and a scaled-down- frequencies, which were the major objectives of the dissertation, which qualifies it for the defense.

Opponent's questions:

1. **In the Introduction, the author claimed circular polarization requires no alignment between the transmitting and the receiving antenna. Can the author state what is the theoretical (and practical) parameter that describes polarization mismatch (i.e. what is that parameter called) and how it is defined?**
2. **Specify what should be modified in the design to create an elliptical polarization (e.g. with Ey = 2 Ex)?**
3. **In Section 5.3.2, the author achieved ±8◦ of beam steering using 80◦ of progressive phase shift. Does the author believe that ±8◦ is a sufficient beam shift in terms of the beam steering application and mobile communications? Did the author try to steer the beam to a larger degree range and what would it take in this design to accomplish it?**
4. **How can the gold layer thickness on the quartz be estimated knowing the frequency of quartz oscillation?**

I ☒ recommend ☐ do not recommend the dissertation for the defence.

Date: 16.08.2020

Signature: …… [redacted] ……..