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I. IDENTIFICATION DATA

Thesis title:	**Bluetooth Low Energy Positioning on FPGA**
Author's name:	**Jan Kreisinger**
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Microelectronics
Thesis reviewers:	Prof. Dr. Qiuting Huang, Mauro Salomon, Stefan Lippuner
Reviewer's department:	Integrated Systems Lab, D-ITET, ETH Zürich

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment   challenging
How demanding was the assigned project?

The student adapted a previously designed Bluetooth Low Energy (BLE) digital receiver block to ensure standard compatibility, integrated it into a RISC-V SoC, ported it to an FPGA testbed, and developed a driver and a positioning application. The project required the interaction with different tools and concepts like Matlab simulations for performance assessment, RTL simulations for hardware debugging, embedded software development, and RF testing with commercial equipment. The main challenge was to develop a working BLE positioning prototype in a real-life environment with all the issues related to debugging a complex system and dealing with the unstable RF environment of wireless communications.

Fulfilment of assignment   fulfilled
How well does the thesis fulfil the assigned task? Have the primary goals been achieved? Which assigned tasks have been incompletely covered, and which parts of the thesis are overextended? Justify your answer.

All assigned tasks were successfully accomplished. A working BLE receiver was implemented on an FPGA testbed and successfully tested over the air. Considering that the initial version of the digital receiver had never been tested with real BLE signals, as expected, a significant effort was needed to develop a working system first. Despite that, the student was able to have working positioning application ahead of schedule. This allowed him to investigate methods to improve the accuracy, achieving 2.75 m mean positioning accuracy, which is comparable to state of the art.

Activity and independence when creating final thesis   A - excellent.
Assess whether the student had a positive approach, whether the time limits were met, whether the conception was regularly consulted and whether the student was well prepared for the consultations. Assess the student's ability to work independently.

The student was able to learn new concepts very quickly. He worked very independently during the project and brought in many ideas of his own. He was able to complete the milestones ahead of the proposed schedule. Even though this was not asked or required, he regularly prepared a progress summary for the scheduled weekly project meetings.

Technical level   A - excellent.
Is the thesis technically sound? How well did the student employ expertise in his/her field of study? Does the student explain clearly what he/she has done?

The thesis is technically sound. He has successfully integrated the RTL block into the SoC and developed a working driver and positioning application. His C code is well written and documented. The student performed relevant experiments and critically analyzed the performance of the system that he developed. He proposed and tested multiple methods to improve the positioning performance of the system for a realistic application scenario. The student clearly states the state at the start of the project and his contributions.

Formal level and language level, scope of thesis   B - very good.
Are formalisms and notations used properly? Is the thesis organized in a logical way? Is the thesis sufficiently extensive? Is the thesis well-presented? Is the language clear and understandable? Is the English satisfactory?

QH

The thesis has a good structure and follows the conventions in the field. It has an appropriate length and presents the interesting topics well without spending too much time on irrelevant details. The language is understandable and varied, but the English grammar leaves room for improvement (but we consider this to be of minor importance).

Selection of sources, citation correctness   A - excellent.

Does the thesis make adequate reference to earlier work on the topic? Was the selection of sources adequate? Is the student's original work clearly distinguished from earlier work in the field? Do the bibliographic citations meet the standards?

The question of sources and citations primarily applies to the positioning algorithms. The most relevant papers use off-the-shelf devices (mostly smartphones), while original hardware was developed during this project. Nonetheless, a good selection of comparison papers is presented and evaluated against. The issue of comparability without a standardized environment is also discussed within the thesis. The contributions are clearly separated from other work in the field. The bibliography follows the IEEE standard.

Additional commentary and evaluation (optional)

Comment on the overall quality of the thesis, its novelty and its impact on the field, its strengths and weaknesses, the utility of the solution that is presented, the theoretical/formal level, the student's skillfulness, etc.

The student was quick in getting to know the complex system (including a state-of-the-art RF transceiver, multi-core RISC-V processor system, and a low power SoC on an Matlab, RTL, and C software level) and adding his contributions to enable Bluetooth LE. The developed hardware and software are of high quality and we intend to use them going forward.

III. OVERALL EVALUATION, QUESTIONS FOR THE PRESENTATION AND DEFENSE OF THE THESIS, SUGGESTED GRADE

The student chose a challenging project where he started with an RTL block developed in a previous student project, which was never tested with real-world Bluetooth signals. His task was to integrate the block into a RISC-V SoC and get it to receive real Bluetooth LE packets on an FPGA testbed. Based on the RSSI measurements he should then develop a positioning test application and evaluated its performance. Not only was he able to complete all these tasks, but he also proposed and evaluated several options to improve the resulting positioning performance. His proposed method was able to reduce the positioning error by up to 60%. Throughout the project he was very independent and solved arising problems with his own ideas. His results are of high quality and will be a boon for future projects based on them.

The grade that we award for the thesis is **A - excellent.**

Date: **25.8.2020**   Signature: *Qiuting Huang*

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Author's name:	**Jan Kreisinger**
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Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Microelectronics
Thesis reviewer:	Prof. Ing. Pavel Hazdra, CSc.
Reviewer's department:	Department of Microelectronics

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment — challenging

How demanding was the assigned project?

The project required deep understanding of the FPGA design and the principles of Bluetooth Low Energy (BLE) Positioning, the acquaintance with previously developed BLE receiver and its integration into SoC on the FPGA testbed, the development of a driver and a positioning application. The developed prototype was debugged and systematically tested in real-life environment. Solution required interaction with different tools and concepts.

Fulfilment of assignment — fulfilled

How well does the thesis fulfil the assigned task? Have the primary goals been achieved? Which assigned tasks have been incompletely covered, and which parts of the thesis are overextended? Justify your answer.

All required tasks were successfully completed. The Blootooth baseband accelerator was considerably improved and the adapted receiver was implemented in FPGA testbed and tested in real conditions. On the top of it, several methods to increase positioning accuracy have been investigated.

Activity and independence when creating final thesis — A - excellent.

Assess whether the student had a positive approach, whether the time limits were met, whether the conception was regularly consulted and whether the student was well prepared for the consultations. Assess the student's ability to work independently.

The student worked independently and proactively, he was in regular contact with his supervisor.

Technical level — A - excellent.

Is the thesis technically sound? How well did the student employ expertise in his/her field of study? Does the student explain clearly what he/she has done?

From a technical point of view, the work is at a very good level. The author showed an excellent understanding of the topic, used his expertise to improve and implement RTL design into SoC, he developed a working driver and positioning application. The improvement of the positioning performance is clearly described and documented.

Formal level and language level, scope of thesis — A - excellent.

Are formalisms and notations used properly? Is the thesis organized in a logical way? Is the thesis sufficiently extensive? Is the thesis well-presented? Is the language clear and understandable? Is the English satisfactory?

The thesis is well and logically organized. Its length is appropriate and English is good.

Selection of sources, citation correctness — A - excellent.

Does the thesis make adequate reference to earlier work on the topic? Was the selection of sources adequate? Is the student's original work clearly distinguished from earlier work in the field? Do the bibliographic citations meet the standards?

The thesis makes an adequate reference to earlier works made in the field of BLE positioning. The selection of sources is adequate and bibliographic citations meet IEEE standards. The author clearly distinguishes his original work from work of others.

Additional commentary and evaluation (optional)
Comment on the overall quality of the thesis, its novelty and its impact on the field, its strengths and weaknesses, the utility of the solution that is presented, the theoretical/formal level, the student's skillfulness, etc.
Please insert your comments here.

III. OVERALL EVALUATION, QUESTIONS FOR THE PRESENTATION AND DEFENSE OF THE THESIS, SUGGESTED GRADE

Summarize your opinion on the thesis and explain your final grading.

I fully agree with prof. Qiuiting Huang, the supervisor of Jan Kreisinger from ETH Zurich, that Jan successfully fulfilled a challenging project. He considerably improved Blootooth baseband accelerator and implemented the adapted receiver in FPGA testbed and tested it in real conditions. He significantly increased positioning accuracy of the developed prototype. His results are original, of a high quality and can be used in future projects.

The grade that I award for the thesis is **A - excellent.**

Date: **30.8.2020**   Signature:

Prof. Ing. Pavel Hazdra, CSc.