# IMIKO-Radar: Laboratory and Test-Ground Interference Measurements of Today's Automotive Radar Sensors

Alicja Ossowska[#1], Leen Sit[#2], Sarath Manchala[#3], Thomas Vogler[*4], Jana Vanova[**5], Jan Hejtmanek[**6], Kevin Krupinski[#7], Urs Luebbert[#8]

[#]Valeo Schalter und Sensoren GmbH, Bietigheim-Bissingen, Germany

[*]CTC advanced GmbH, Saarbrücken, Germany

[**]Valeo Autoklimatizace k.s., Prague, Czech Republic

{[1]alicja.ossowska, [2]leen.sit [3]sarath.manchala [5]jana.vanova [6]jan.hejtmanek [7]kevin.krupinski [8]urs.luebbert}@valeo.com, [4]thomas.vogler@ctcadvanced.com

***Abstract*— The topic of interference mitigation in radar is an important point in automotive system development. More and more cars equipped with radar sensors are driving on the roads. Also more cars are equipped with more then one radar sensor. This leads to higher probability of radar interference. In the publicly funded IMIKO-Radar project new cooperative mitigation methods shall be developed forfor interference between various automotive radars as well as between automotive radars and road infrastructure radars.. This paper summarizes procedures and results from the task of this project which investigated the interference situation for today‘s uncooperative radars.**

***Keywords*— radar, automotive, interference, interference measurement.**

## I. Introduction

Modern cars provide multiple comfort and safety functions to support a driver like Blind Spot Detection (BSD), Lane Change Assist (LCA) or Auto Cruse Control (ACC). Novel function are already available or will be available soon, which will support quasi-autonomous or autonomous driving. The comfort and safety functions are available now, not only for premium, but also for middle price cars. Many of the functions are developed using radar sensors. Some, like for example Automatic Parking with radar, require multiple radar sensors on a single car. This results in increase of the number of radar sensors on the road. The prediction is that this number will still significantly increase in future years with assist functions as series equipment. Higher density of radar sensors on the road will result in higher probability of mutual interference. The interference mitigation methods used in today's radars will have to be further improved. There are already studies available on this topic, for example from former project MOSARIM [1], [2]. In this paper we now present interference measurements from the new public founded project IMIKO-Radar, [3] [4].

## II. IMIKO-Radar Project

The IMIKO-Radar project (Interference Mitigation by Cooperation in Radar for Autonomous Electric Cars) is funded by the German Federal Ministry of Education and Research. The project started in November 2018 and is planned to continue for three years. The project consortium consists of fourteen members from industry and research, including 12 Industry members: Aptiv, Astyx, Bosch, CTC advanced, Continental, Daimler, Hella, Rhode&Schwarz, Smartmicro, Valeo, Veoneer and Volkswagen, and two universities: Ulm University and Karlsruhe Institute of Technology, Fig. 1. The main goal of the project is to evaluate cooperative methods for further reducing mutual interference potential between cars and between cars and road infrastructure radars. This includes formulation of requirements on radar based automotive systems, especially autonomous driving Level 4 and Level 5, with regard to reliability and robustness, investigation of cooperative methods, solutions for interference mitigation and development of measurement methods for verification, and evaluation of investigated solutions. Finally, recommendation and standardization proposals will be prepared.


Fig. 1. IMIKO-Radar project partners.

The IMIKO-Radar project consists of overall nine work packages. One work package investigates the mutual interference potential of modern uncooperative automotive and road infrastructure radars. In the IMIKO-Radar project laboratory as well as test ground measurements were conducted. To complement the investigation in another work package simulations for radar interference are developed. A simulation has the advantage that also complicated scenarios, that are difficult or even not feasible for measurements, or novel ideas for radar design can be analyzed.

## III. Interference Measurements

Two test campaigns were conducted to investigate mutual interference of modern uncooperative automotive and road infrastructure sensors. The first laboratory test campaign was conducted in test chamber of CTC advanced. The second test ground campaign took place in Boxberg Proving Ground.

### A. Radar Sensors

Sensors and cars equipped with radar sensors were provided by project industry partners. The sample covers a broad range of today's sensors working in the 24GHz, 77GHz and 79GHz bands. It is although to be noted that it is not claimed for the sample to be representative nor complete. Included were all automotive sensors: long, mid and short range sensors, front and corner mounted radars as well as road infrastructure radars. The test sensors were provided by consortium members: Astyx, Aptiv, Bosch, Continental, Hella, SMS, Valeo and Veoneer. Each of the partners provided sensor samples for interfering radar and victim test radar for the laboratory measurements. In interfering radar samples the active interference mitigation methods, where the transmitted signal changes if interference is detected, if implemented on sensor were switched off in order to get conservative estimate. Overall 23 various sensors were measured in test chamber, including: five sensors working in 24GHz band, eleven sensors working in 77GHz, five working in 79GHz and one interfering sensor working in combined 77/79GHz band. In the test campaign on the test ground radar sensors were mounted on cars. The cars were provided by the same project partners as test sensors. Overall eleven cars from eight partners, with eleven different front sensors and eleven different corner radars were measured. To note is that the number of front and corner sensors coincides only by chance with the number of cars. Some cars were equipped with more than one front or corner radar type, while others has only front or corner radars mounted on them. Additionally two 24GHz and one 77GHz band road infrastructure sensors took part in measurements. There was no requirement to switch of active interference mitigation sensors on the test ground.

### B. Design of laboratory experiment

The first test campaign was conducted in a test chamber of CTC advanced. The laboratory tests have the big advantage that the measurement environment can be precisely defined and adjusted. The repeatability of such tests is very high. The disadvantage is, that it is very hard to design experiments close to real world road scenarios. In IMIKO-Radar experiment pairs of radars: victim test sensor and interfering sensor were measured. The 24GHz radars were measured only against other 24GHz sensors, 77GHz and 79GHz sensors were measured also against each other. The test and interfering sensors were mounted on poles of the same height and positioned so that they did not look directly towards each other. This can be seen on the schematic of the measurement in Fig. 2. A target was positioned at the same height as both sensors and in a distance of 3.6m from the test sensor. This distance

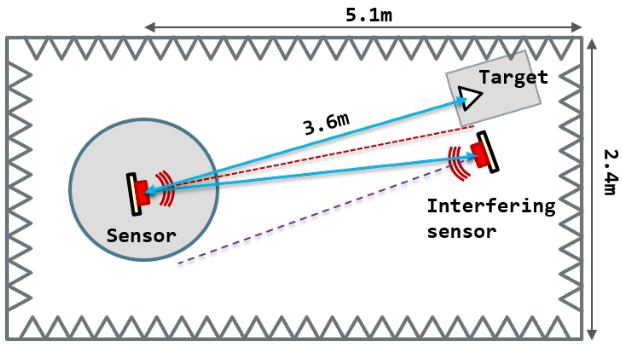


Fig. 2. Schematic of the laboratory scenario.

is comparably low to average distances in typical driving scenario, again tending to a conservative estimate for the measured interference. In the measurements we used two targets types: 0dBsm corner reflector and target generator AREG100A from Rhode&Schwarz, [6]. It was decided to consider only stationary targets. All targets generated by the AREG100A had the Doppler zero. Four targets with same RCS were generated at distances: 6.9m, 27.9m, 52.9m and 152.9m from the test sensor. This covered all possible radar maximal ranges from short range at 6.9m to long range radars with 152.9m. The RCS values were chosen to cover all common targets, with weak target at -8dBsm corresponding to a pedestrian, middle size target like bicycle at 0dBsm and finally strong target corresponding to a car at 15dBsm. All measured laboratory scenarios are summarized in Table 1. The target at 6.9m with RCS of 15dBsm was not included. We found that is was not possible to generate such a strong target at close distance without introducing additional unwanted targets due to harmonics.

Table 1. Laboratory measurements scenarios in test chamber

| No. | Target | RCS | Distance |
|---|---|---|---|
| 1 | corner reflector | 0dBsm | 3.6m |
| 2 | Person | -8dBsm | 6.9m |
| | | | 27.9m |
| | | | 52.9m |
| | | | 152.9m |
| 3 | Bicycle | 0dBsm | 6.9m |
| | | | 27.9m |
| | | | 52.9m |
| | | | 152.9m |
| 4 | Car | 15dBsm | 27.9m |
| | | | 52.9m |
| | | | 152.9m |

### C. Scenarios for test ground measurements

The second campaign conducted within IMIKO-Radar project was a test ground measurement. Test ground measurement are much closer to real world scenarios than laboratory test. At the same time the reproducibility of measurements is still moderate. The Boxberg Proving Ground was chosen for tests. Overall ten scenarios were measured on this test campaign. The scenarios can be divided to: parking scenarios, intersection scenarios, breaking scenarios, passing and overtaking scenarios. With the choice of scenarios we tried to cover most of the corner cases, [4], with high interference power density. In Fig. 3 presented are examples of measured test cases. Scenarios were repeated for all feasible

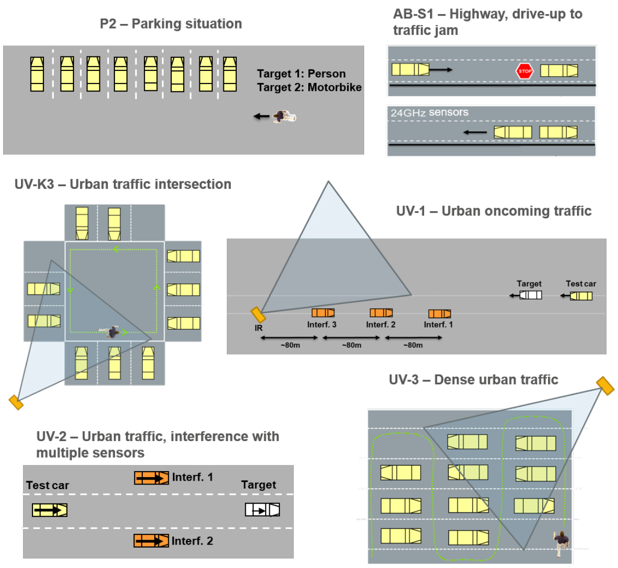


Fig. 3. Examples for test scenarios measured on Boxberg Proving Grounds.

configuration of test and interfering sensors. The focus of the campaign was to measure high interference density scenarios rather than check interference between two sensors.

### *D. Evaluation criteria*

Measured sensors included samples of short-, mid-range as well as long-range radars with various bandwidth, middle frequency, waveforms, cycle time and signal processing, with various applications from Park Assist, Lane Change Assist (LCA) or Auto Cruise Control (ACC) to traffic motoring. Evaluation criteria needed to be general enough to provide reliable results independent of sensor design. Three criteria have been selected: false negative (FN) rate, mean noise increase and maximum noise increase caused by interference. The mean and maximum increase of noise level due to interference and FN rate were estimated from at least 600 radar cycles. In test ground measurements only time when interference was present was considered. The false negative rate was calculated as a number of cycles with detection loss , with detection lost of the named target according to Table 1, to the number of all evaluated cycles in percent. In order to limit the influence of various radar signal processing on results, a detection was defined as spectrum peak with minimum possible number of processing steps. The detection should not be processed with any tracing or tracking algorithms. Since the proprietary tracing and tracking algorithms differ from sensor to sensor, the use oft the unfiltered raw false negative rate improves comparability of results. However in real world a vast amount of FN counted here would be filtered out by tracking, because they last only a short period in time.

## IV. RESULTS

Results from all partners were anonymously collected and neutral histograms were generated. One measurement, with a single test sensor and interfering sensors for laboratory test and one test sensor per scenario repetition, gave one data point. All results per scenario were collected and represented in form of histograms showing distribution of data points over evaluation criteria values. Example results from laboratory interference measurements are presented in Fig. 4, Fig. 5 and Fig. 6.

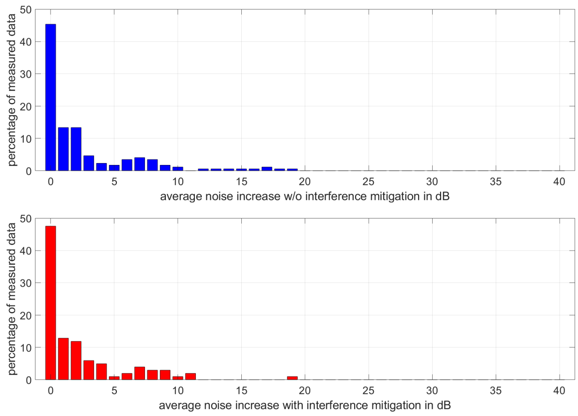


Fig. 4. Laboratory measurements: average increase of noise level due to interference, upper figure: without interference mitigation, lower figure: with uncooperative interference mitigation.

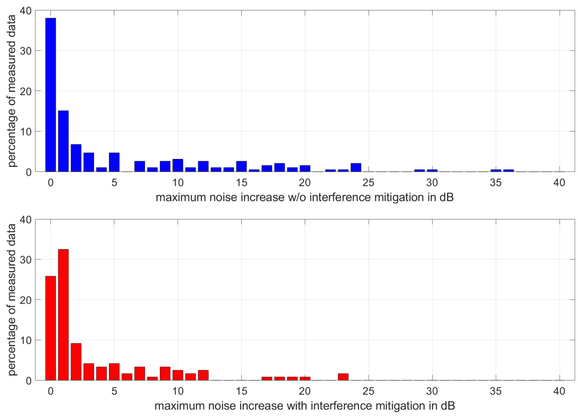


Fig. 5. Laboratory measurements: maximal increase of noise level due to interference, upper figure: without interference mitigation, lower figure: with uncooperative interference mitigation.

Each of the figures shows the results for scenario with 0dBsm target (bicycle) generated with AREG100A at 28m without interference mitigation (blue histograms) and for sensors with uncooperative interference mitigation (red histograms). Results from laboratory measurements were divided on sensors without and with interference mitigation active. Here available were methods that can be seen as state of the art, like detect and repair, timing or frequency change, already implemented on today's sensors. To note is that not all of the sensors could be

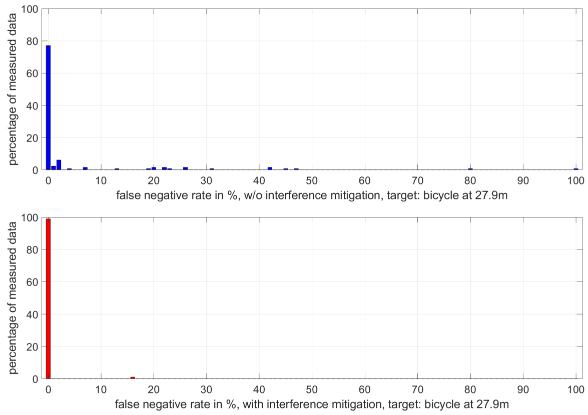


Fig. 6. Laboratory measurements: false negative for a bicycle target at 27.9m, upper figure: without interference mitigation, lower figure: with uncooperative interference mitigation.

measured without and with interference mitigation. To notice is that even without interference mitigation there are many radar cycles with no or only little interference effects. It can be also clearly seen that uncooperative interference mitigation, as expected, reduces the amount of interference according to all of the evaluation criteria. Novel cooperative interference mitigation methods are expected to even further improve the performance of radar sensors in the future.

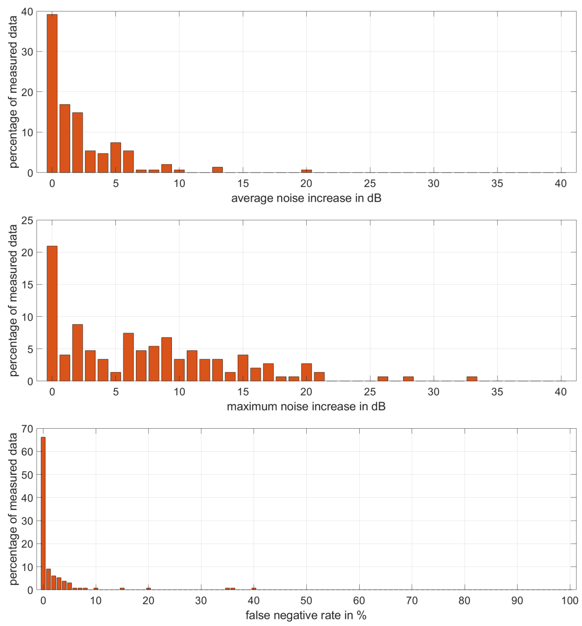


Fig. 7. Boxberg measurements: scenario UV-1, upper figure: average increase of noise level due to interference, middle figure: maximum increase of noise level due to interference, lower figure: false negative.

Boxberg measurement results for scenario UV-1 are presented in Fig. 7. Here the results for sensors without and with uncooperative interference mitigation implemented are not distinguished and all results are presented on single histogram. This is due to limited number of data points per scenario as each sensor was measured only once with a standard road configuration. Presented figures shows average and maximum noise increase and FN rate. In principle, noise increase and detection loss as visible in Fig. 7 leads to a reduced detection range. In the end this can result in a delayed vehicle reaction, especially if interference occurs in several consecutive radar cycles. The continued project will show how much cooperative mitigation methods can further improve that.

## V. Conclusion

The Project IMIKO-Radar is evaluating cooperative methods for further reducing mutual interference in automotive radar. As a part of this project mutual interference of modern radar sensors was measured and evaluated. In this paper described was the procedure, evaluation methods and results of this measurements. The results are intended to be used for validation of simulations and also for reference for future measurements campaigns. We hope that this work will benefit future radar and lead to development of even more powerful radar interference mitigation methods.

## Acknowledgment

The IMIKO-Radar Project (German: Interferenz-minimierung durch Kooperation bei Radarsensoren für Autonome Elektrofahrzeuge) is funded by the German Federal Ministry of Education and Research (project: IMIKO-Radar grant: 16EMO0336K). The authors would like to thank the Ministry for the financial support and also to all IMIKO-Radar partners for the successful and fruitful cooperation in the IMIKO-Radar project.

SPONSORED BY THE

Federal Ministry of Education and Research

## References

[1] M. Kunert, "The EU project MOSARIM: A general overview of project objectives and conducted work," EuRad 2012.

[2] M. Kunert, "D5.3 – Recommendations on sensor design, mounting and operational parameters to minimize radar interference," MOSARIM project report, Contract no.: 248231, 2012.

[3] IMIKO-Radar Project Web Page, Available at: https://www.elektronikforschung.de/projekte/imiko-radar, [Assessed: 14.01.2020].

[4] Werner Sörgel, Tim Poguntke, Thomas Binzer, "IMIKO-Radar: Towards Cooperative Radar-Interference Mitigation", Automotive Forum, European Microwave Week, 2019.

[5] F. Roos, J. Bechter, C. Knill, B. Schweizer and C. Waldschmidt, "Radar Sensors for Autonomous Driving: Modulation Schemes and Interference Mitigation," in IEEE Microwave Magazine, vol. 20, no. 9, pp. 58-72, Sept. 2019.

[6] "R&S®AREG100A Automotive Radar Echo Generator User Manual," Manual, Available at https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/pdm/cl_manuals/user_manual/1178_7417_01/AREG100A_User_Manual_en_05.pdf, [Assessed: 13.01.2020].