The EU project MOSARIM

A general overview of project objectives and conducted work

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Abstract—**The European funding project MOSARIM (MOre Safety for All by Radar Interference Mitigation) started in January 2010 with the main objectives to investigate possible automotive radar interference mechanisms by both simulation and real-world road-tests and assess possible countermeasure and mitigation techniques in general guidelines and recommendations.**

Keywords: Vehicular radar interference, interference mitigation techniques, countermeasures, radar interference models, road test campaigns, radar norm interferer, interference mitigation guidelines and recommendations

I. Introduction

The MOSARIM project was selected for funding by the European Commission in the Seventh Framework Program, Theme ICT-2009-4-6.1 – ICT for safety and energy Efficiency in Mobility under grant agreement No. 248231. The consortium is composed of two OEMs, 5 automotive radar suppliers, two research institutes and three small companies.

Figure 1. The MOSARIM consortium members

The total project budget of all partners is 4.820.693 € with a funding of 2.897.173 € (ca. 60% of total budget).

II. Background and Motivation

Since several years millimeter-wave radar systems are used for vehicular applications, predominantly in comfort functions and, up to now, only in a few safety applications. Different frequencies and modulation schemes, emission powers and radiation patterns are used and due to still rather small sensor quantities on the market possible interference is currently not seen as a problem. Within the next years the penetration rate of vehicular radar systems will significantly increase in the new emerging vehicular radar market and especially for safety-related applications. Trying to find efficient and pragmatic countermeasures to avoid possible interference risk at that point in time in the future, when interference problems may have already created malfunctions or "sensor blind" situations of safety radar devices, is far too late.

The only reasonable and valid approach is to counteract in advance before this situation possibly becomes manifested.

As almost nothing exists regarding radar interference mitigation for automotive radars, this research project aims to generate a first assessment on general basic features and interference mechanisms, a common understanding of the interference effects and dimension of the problem as well as a first set of guidelines or recommendations to avoid inefficient interference troubleshooting at a later stage in time.

A well-selected consortium of specialists from all necessary disciplines is working in this project and prepared to tackle the demanding challenges in all aspects. The project outcome and results are vitally important for a long-standing success of radar-based devices for automotive systems.

Finally, the results of this project will create the foundation for taking the next step in further reducing the number of fatalities or injured people in road accidents. This will be realized by increasing the availability and robustness of safety-related automotive radar applications to the limits stipulated by the respective ASIL requirements.

III. The Project Structure and Approach

The MOSARIM project is broken down in 6 work-packages and 36 subtasks to handle all the challenges and objectives. Starting from a general interference risk assessment several steps are taken to finally make up guidelines and recommendations that will lead to a minimum interference risk or even an interference-free operation of all automotive radar systems in the near future. The main intermediate steps are laboratory radar tests, radar interference simulation models, definition and investigation of radar interference mitigation and counter-measures both in simulation and in real world road measurements, test-track measurement campaigns and validation of the simulated interference mitigation effects by comparison with the recorded data collected during the different road test campaigns. A coarse timing with some important milestones of the MOSARIM project is shown in Figure 2.

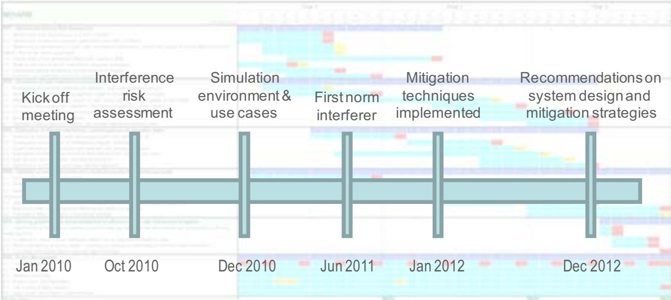

Figure 2. The MOSARIM timing

The final project focus and objectives are currently limited up to the stage where commonly agreed guidelines and recommendations are drafted. Further steps like the generation of a de-facto standard or the incorporation of elaborated recommendations into existing regulations or directives is beyond the timeline of MOSARIM and will be the subject of a possible successor project (see Figure 3).

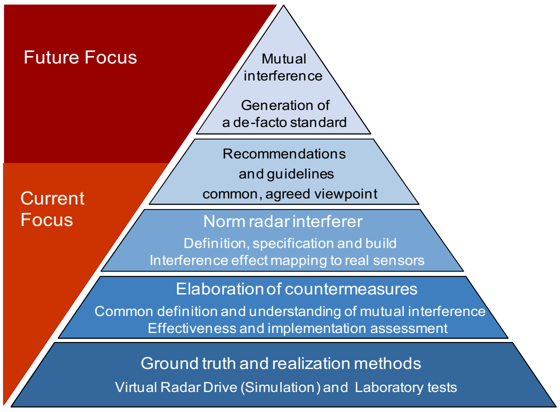

Figure 3. Current and future focus of MOSARIM

At an even later stage, but going beyond the capacity of the MOSARIM project, the generation of a world-wide harmonized de-facto standard on mutual radar interference could be envisaged.

The project working concept is based on a mixed simulation/real world measurement approach that is sketched in Figure 4.

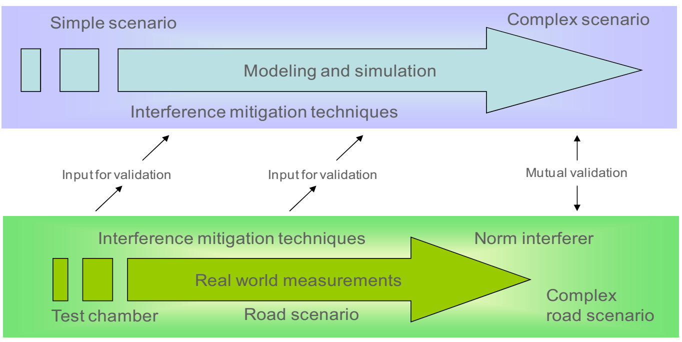

Figure 4. Mixed approach of simulation and real world tests

IV. GENERAL INTERFERENCE RISK ASSESSMENT

In a first step the basic mechanisms of radar interference were investigated. The determination of relevant use cases, key sensor and interference parameters and a study on existing radar interference mitigation techniques were the first subtasks to be coped with. Then a market study on future radar penetration rates and the assessment of interference risk due to incumbent frequency users was analyzed. First laboratory tests with off-the-shelf radar sensors at 24 GHz and 77 GHz were conducted in the anechoic chamber of project partner Telefication B.V. in the Netherlands (see Figure 5).

Figure 5. Laboratory measurement in an anechoic chamber

Radar sensors from all MOSARIM radar suppliers were tested against each other to get a first feeling on interference impact. The considered sensors are shown in Figure 6.

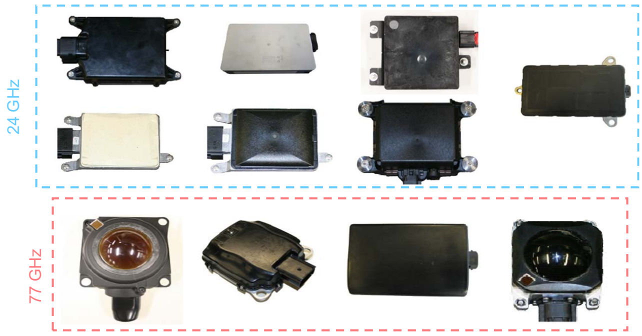

Figure 6. The radar sensor test candidates

For measurement campaigns on different test tracks vehicles were equipped with the different radar sensor test candidates, being installed in the respective locations according to the desired application or just on special test fixtures. The entire test fleet is shown in Figure 7.

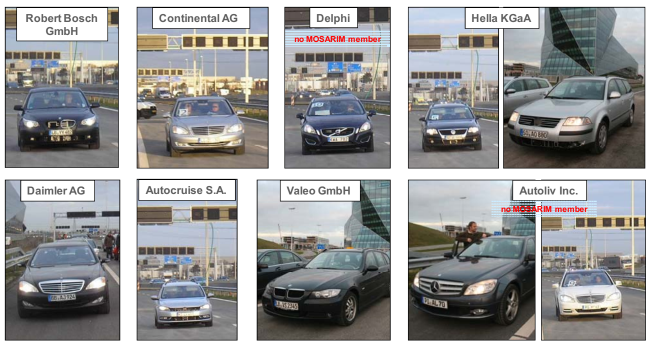

Figure 7. MOSARIM test fleet used in real world test campaigns

V. Simulation of Radar Interference Mechanisms

As described in Figure 3 and 4, one intention and goal within the MOSARIM project is to develop a common understanding of radar interference effects, both on a theoretical and a practical level. Already in the beginning of the project it became evident that very complex interference scenarios are difficult, if not at all impossible to realize in real world test setups. So the mixed approach to use simple real world data for adaption, fine-tuning and validation of the simulation models was chosen. Meanwhile a complete tool-chain is available to simulate most of the relevant scenarios with good accuracy compared to the recorded data of the test campaigns, conducted on the different test tracks in the last two years.

Simulation tools are based on a flexible channel model with a ray-tracing preprocessing and Matlab™ as the post-processing and evaluation tool.

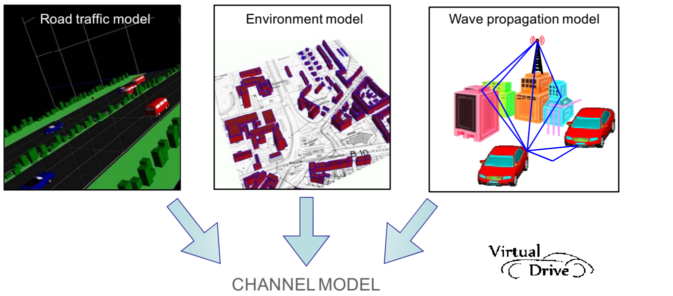

Figure 8. Simulation model approach with scenario editor and ray-tracer

As all the radar test candidates are using a frequency modulated operation principle, the interference effects are intensively analyzed for this class of radar systems. Radar interference in the receive path typically increases the receiver noise level in a very broadband manner. The appearance of ghost peaks in the frequency spectrum would require a complete synchronization of the frequency generation unit of both the interferer and victim receiver device in time, frequency and phase. Due to the existing phase noise and non-linearities of the VCOs (being individual and different for each device) such ghost peaks were never observed in any of the conducted tests for any of the radar device under test.

Wave propagation modeling is composed of the three prevailing spreading modes that are multiple reflections, multiple diffractions and diffuse scattering (see Figure 9).

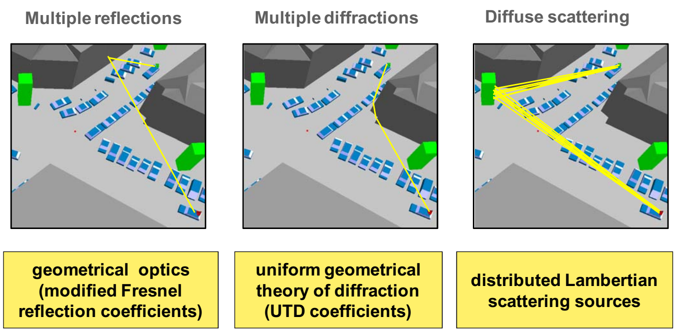

Figure 9. Wave propagation modelling by three spreading modes

Ray-tracing is foremost done omni-directional and antenna patterns of the respective radar sensors are applied on a post-processing level.

Currently the simulation tool-chain is capable to handle multiple interferer sources in very complex road scenarios by applying superposition principles to the individual channel models. Both static interferers (like roadside radar speed meters) and moving objects with either forward looking ACC (Adaptive Cruise Control) radar or backward mounted BSD (Blind Spot Detection) radar can be simulated and evaluated for different scenarios (see Figure 10).

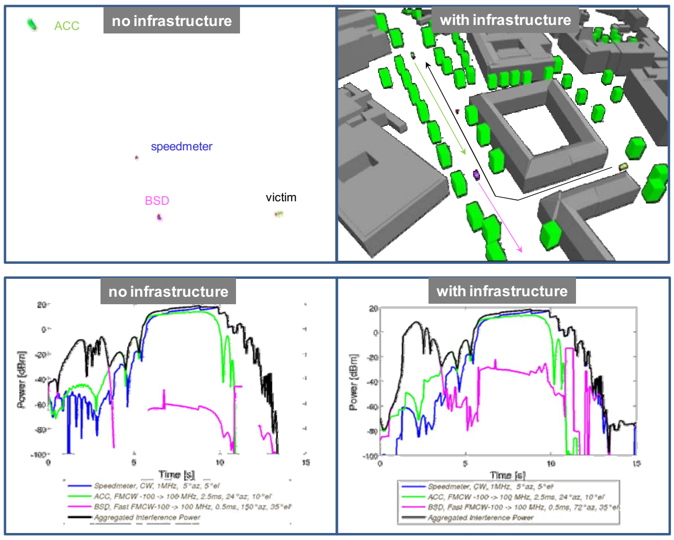

Figure 10. Multi-interferer simulation with and without infrastructure

Simulation studies with incumbent frequency users to determine the possible interference thread were also performed. Here the interference to noise ratio (I/N) is of special interest to judge the interference risk (see Figure 11 for a radar speed meter vs. blind spot radar case study).

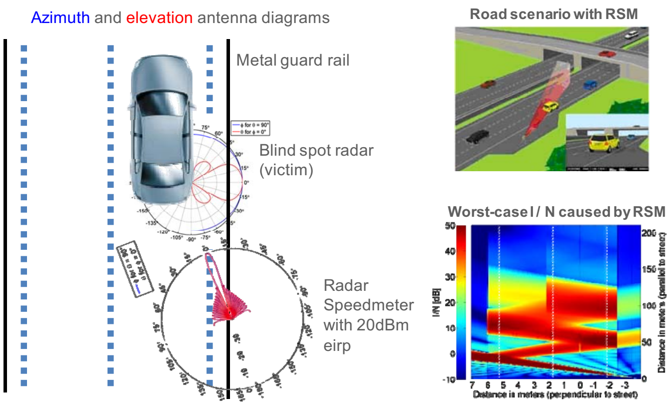

Figure 11. Blindspot victim radar with radar speed meter interferer

Final simulations are planned for very complex interference scenarios with many interferers in dense infrastructure environments.

VI. Elaboration of Efficient Radar Interference Countermeasures

Based on a survey of existing interference mitigation techniques a classification into six different domains was done. In total 23 different techniques were deeply analyzed and ranked regarding different performance criteria. Some of the most promising ones were implemented in the simulation tool and in the radar sensors of the participating radar suppliers.

In Table I a rough estimation of possible interference mitigation factors for the six domains is provided.

Mitigation domain	Mitigation effect in dB (only rough estimations)	Is interference free operation possible?
Polarization	~ 15 dB	No, only limited possibilities
Time domain	~ 20 dB	No, depends on duty cycle
Frequency domain	up to ∞	Yes, by frq. band separation
Space domain	~ 20 dB	No, by antenna pattern only
Coding techniques	10 dB to 50 dB	No, but rather effective
Strategic or adaptive	10 dB to ∞	Yes, can combine all above

TABLE I. Preliminary Interference mitigation effectiveness

In Figure 12 the mitigation effect that occurs when using different polarization planes is sketched.

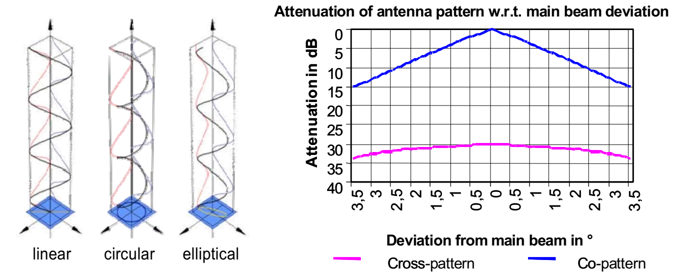

Figure 12. Mitigation effect of different polarizations

The interference countermeasure principle “Detect and Repair” from the domain “Strategic or adaptive” is explained in Figure 13.

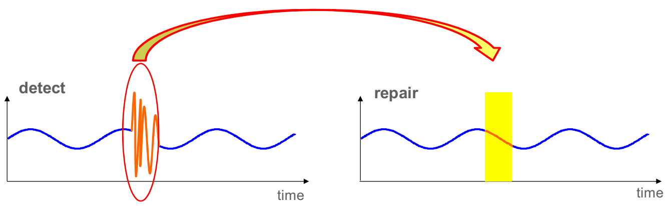

Figure 13. Time domain mitigation technique – Detect and repair

Another interference mitigation technique, “Detect and Avoid” is sketched in Figure 14.

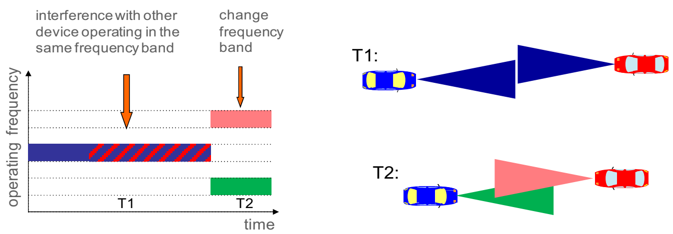

Figure 14. Frequency domain mitigation technique – Detect and avoid

The detailed description of further interference mitigation techniques can be found in the relevant deliverables of the MOSARIM project (see References).

VII. Assessment and Validation in Test Campaigns

One of the most interesting and exciting parts in the MOSARIM project were the various test campaigns that were conducted during the three year runtime of the project.

Starting with simple basic test scenarios (BTS) the complexity and number of simultaneous interfering devices and test cars was steadily increased.

In several test campaigns the scenarios defined beforehand in earlier tasks and deliverables were accomplished. The following Figures 15 to 17 show a short extract of what has been done so far:

Figure 15 shows some of the test scenarios done in May 2011 during the measurement campaign at the abandoned Malmsheim airport/ Germany.

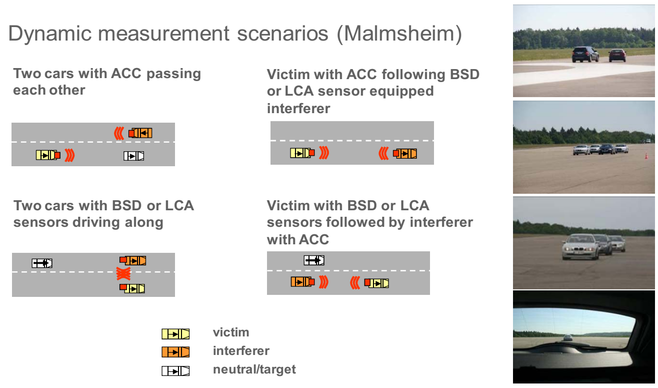

Figure 15. Malmsheim test campaign – May 2011

In Figure 16 some of the tests conducted during the two days event end of September 2011 at the discontinued August Euler airport in Griesheim/Germany are shown. Pedestrians, motorbikes and large trucks were use as neutral targets for the first time.

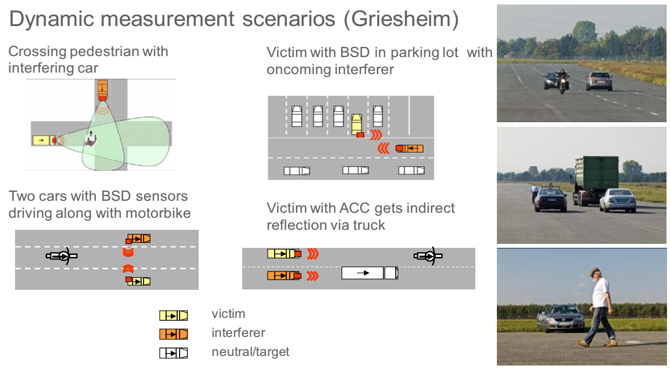

Figure 16. Griesheim test campaign – September 2011

In Figure 17 some impressions of tests realized in January 2012 inside the new Rijn-Tunnel in Utrecht/The Netherlands are presented. Tunnels, due to the all-side closure, were estimated to behave somehow like a waveguide. Propagation measurements revealed that free space loss is reduced from 20 dB to ca. 13 dB per each decade in distance.

Test car with 10 stationary 24/77 GHz interferers

10 test car in tunnel for multi-interferer scenario

Five cars and 3 stationary 77 GHz devices interfer an oncoming victim radar

Setup for signal attenuation measurement in tunnel

Figure 17. Tests in Rijn Tunnel/Utrecht, The Netherlands – January 2012

Further test campaigns are still planned in the course of the year 2012. Special interest will then be given to shielding effects by other cars or roadside obstacles as well as the validation tests to be conducted with new norm interferer devices that were also developed and assembled within the framework of the MOSARIM project.

VIII. Conclusions and Outlook

At the time of preparation of this document the last MOSARIM work package WP5, dealing with recommendation and guidelines, was not yet started. The main objective of this work package will be to gather and compile all the findings and results regarding possible ways and methods to mitigate or avoid interference in a comprehensive compendium. A second task will be to identify possible bodies and organizations that could be contacted for implementation of the interference mitigation and countermeasure results and validation methods in respective recommendations or any kind of other regulations.

Figure 18 shows possible points-of-contact.

Figure 18. Possible points-of-contact for implementation of MOSARIM results in regulations or standards

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References

All the material and information presented or used in this paper can be found in the documentation and records of the MOSARIM project. Many deliverables and information are publicly available on the project website www.mosarim.eu.