EMC VAlidation of Multiple Sensor systems - eVAMS

Public report

Project within FFI - Electronics, Software and Communication

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Date 2017-09-30

Content

1. Summary

EMC testing of autonomous vehicles is challenging because the involved systems are designed to identify unrealistic driving conditions, which is exactly what we have in a typical anechoic EMC chamber. When the system detects unrealistic conditions, autonomous driving functions are disabled or set to predefined states, which means that EMC testing of autonomous functions is not possible. To fully test autonomous driving systems, we therefore need to emulate a realistic environment in many aspects, i.e., we need to stimulate involved sensors in a realistic way.

In the project, it was demonstrated that it is possible to stimulate radars and cameras used for active safety systems, and to simulate the vehicle position by transmitting a synthetic GNSS (Global Navigation Satellite System) signal in the chamber, so that realistic EMC testing of a complete vehicle can be done for systems using these sensors.

The partners Volvo Car Corporation, Rise and Provinn, initiated this project partly financed by Vinnova within the FFI-program. The eVAMS project (diarienr. 2015-06892) was a FFI project within the Electronics, Software and Communications program. eVAMS was an 18 month project that started 2016-03-01 and ended 2017-09-30. The project had a total budget of 2 MSEK.

2. Sammanfattning på svenska

EMC provning av autonoma fordon är utmanande eftersom bilens system är designade för att identifiera orealistiska körförhållanden, vilket är vad vi har i en typisk ekofri EMC-kammare. När systemen detekterar orealistiska förhållanden, stängs funktioner av eller försätts i något fördefinierat tillstånd, vilket innebär att vidare EMC provning av funktionen inte är möjlig. För att fullt ut kunna prova de autonoma systemen, måste vi därför emulera en, ur många aspekter, realistisk miljö för de aktuella sensorerna.

I projektet har visats att det är möjligt att stimulera radar och kamerasensorer, som används för aktiva säkerhetssystem, så att en realistisk provning kan utföras på de system i fordonet som använde dessa sensorer. Det var även möjligt att simulera en position för fordonet genom att sända en syntetisk GNSS (Global Navigation Satellite System) signal in i kammaren.

Projektet eVAMS (diarie nr 2015-06892 initierades av Volvo Car Corporation, RISE (Research Institutes of Sweden) och Provinn för att adressera ovan nämnda problem. Projektet har delvis finansierats av Vinnova inom FFI programmet Electronik, mjukvara och kommunikation. eVAMS var ett 18 månaders projekt som startade 2016-03-01 och slutade 2017-09-30. Projektet hade en total budget på 2 MSEK.

3. Background

There are several factors driving the development towards increasing degree of automation in vehicles, with the ultimate goal being fully autonomous vehicles. The transport system of today is not sustainable; an increasing population with a wish for individual mobility in combination with strong urbanization worldwide drives energy consumption, creates congestion and increased pollution. The strategy of the European Commission[1] for smart, sustainable and inclusive growth should be reflected in the development of the transportation system and road safety is pinpointed to be one of the major societal issues with more than 35 000 people killed and 1.5 million people injured on the European roads in 2009. The cost for society is huge for these accidents, approximately 130 billion Euro in 2009 [1]. Together with the fact that accidents are in 70-90 % connected to the human behavior[2], has led to a belief that the automation of vehicles could serve as a major contributor to the solution for the future sustainable transport system.

For the path towards autonomous vehicles, automatic cruise control can serve as an illustrative example of the evolution of the vehicular functions towards autonomy. In the early 1990´s the ordinary cruise control function, enabling driving at constant speed, was complemented by a lidar-based distance detection system. At first the system would only give drivers distance warning however it evolved and in the mid 1990´s the system would use throttle and downshifting, but not brakes, to control speed. In the end of the 1990´s a radar assisted automatic cruise control was introduced. Intense development followed in the early 2000 and by 2005 collision avoidance functions was being integrated into the automatic cruise control. These functions are all based on data from on-board sensors, radar, lidars and cameras. The next step for some brands is the GPS-aided ACC, where the GPS navigation system supports the vehicle in understanding the traffic ahead, whereas other brands are moving directly towards the cooperative automatic cruise control, where data from the other surrounding vehicles are also incorporated in decision making. However the later functions depend not only on the sensor systems onboard but also on secure communication and the sensor systems onboard other vehicles. Therefore these future functions will rely on all the surrounding vehicles involved including the robustness of all the multi sensor systems and communication systems of these vehicles. Moreover, these functions will not just support the drivers anymore but soon take over the responsibility of the vehicles from the drivers. To test these advanced systems immunity against electromagnetic fields, it is important to be able to put the vehicle in a representative (i.e. autonomous) state within the test chamber.

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[1] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Towards a European road safety area: policy orientations on road safety 2011-2020 {SEC(2010) 903}

[2] Hans von Holst, ed., Transportation, traffic safety and health: The new mobility, Springer Publishing, 1997. McKinsley report "Disruptive technologies: Advances that will transform life, business, and the global economy", may 2013.

Furthermore, in order to increase reliability of sensor data, sensor fusion is being used and will be used to an even greater extent the more complex the functions grow. However, when testing on complete vehicle level it is often difficult to fully activate a multi-sensor function in a laboratory environment. This is because many functions are intelligent in the sense that the algorithms are designed to identify unrealistic sensor input and if detected the function is disabled or set to a predefined state. It is therefore necessary to emulate an environment that makes all different sensors (camera, radar, LIDAR, V2X etc.) believe that the vehicle actually is driving on a road when doing EMC testing. If a realistic enough emulated environment is created it would not only mean that some specific function could be tested but that also unknown future functions, reliant on similar technology, could be tested with the same setup.

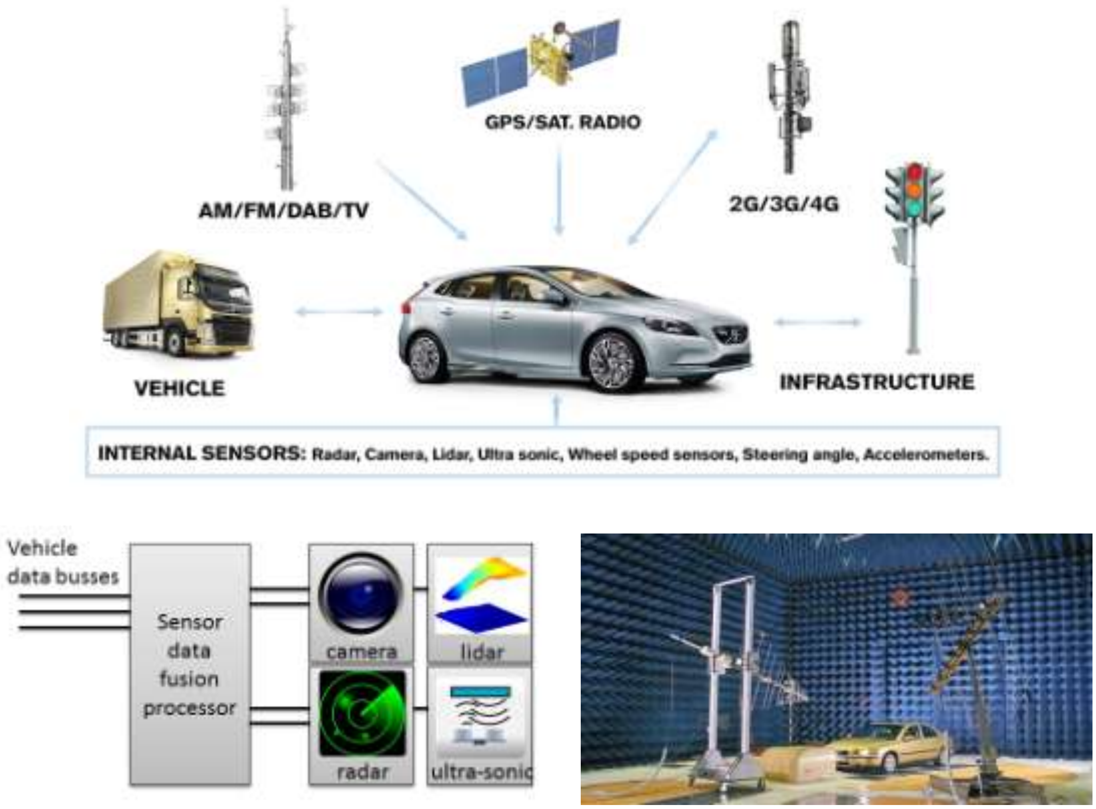

Figure 1. Future vehicle functions will depend also on the robustness of all the multi sensor systems and communication systems of surrounding vehicles and infrastructure (above), illustration of block diagram of sensor data fusion system for vehicle control or warning (below left) and EMC testing facility Faraday at RISE (below right).

In this project we created, for some initial vehicular sensors, methods for external stimuli that are compatible with use in an EMC test facility. These would then enable the creation of an emulated environment possible to use for demonstration of testing methods for three functions; automatic cruise control (ACC), lane keeping aid (LKA) and pilot assist (PA2). Together these functions form an important basis for automation from level 2, defined by the National Highway Traffic Safety Administration (NHTSA) levels of autonomy:

- **Level 0:** The driver completely controls the vehicle at all times.
- **Level 1:** Individual vehicle controls are automated, such as electronic stability control or automatic braking.
- **Level 2:** At least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping.
- **Level 3:** The driver can fully cede control of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control.
- **Level 4:** The vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time.

Project partners have, before the start of this project, visited German vehicle OEMs, the University of Ilmenau and French test institutes in order to learn about the current international research. There is a strong focus on EMC test environment and procedures for communication and active safety.

4. Purpose, research questions and method

Modern automotive active safety function are difficult to activate during complete vehicle EMC testing in anechoic chambers. The functions are based on data from many different sensors and the sensor fusion algorithms are designed to identify unrealistic driving scenarios as part of the system safety solution. If an unrealistic driving situation is detected the function is disabled or set to a predefined state.
When more complex safety critical functions are developed, where the availability of the functions needs to be maximized, the need to be able to verify and validate the complete functions on complete vehicle level increases.
Therefore RISE, Volvo Cars and Provinn decided to start a project to investigate if it was possible to emulate an environment inside an anechoic chamber to be able to run some basic, today existing, active safety functions during complete vehicle EMC immunity testing.

Early development of EMC validation methods will ensure Swedish world leading position in vehicle safety. It will benefit and contribute to future certification of active safety systems, cooperative applications and autonomous vehicles. Furthermore it will contribute to AWITAR and the test and development capacity of the Swedish vehicle industry by complementing the test facility of AstaZero. AWITAR and AstaZero will constitute a strong cluster of competences and test facilities, supporting and strengthening the Swedish vehicle industry.

The project was constituted of five work packages:
WP 1 was project management and dissemination. WP 2 provided vital information on system sensor interaction to both WP 3 and WP 5. WP 3 used the information from WP 2 to develop test procedures for WP 4 and contribute to WP 5 with an outlook for the road map on test procedures for other AD systems. WP 4 was an experimental work package

with an iterative process in order to realize the equipment and set up needed to emulate an environment suitable for EMC testing of active safety functions reliant on radar and/or camera only. WP 4 also included piloting the EMC testing of ACC, LKA and PA2. WP 5 provided a road map for development of EMC testing of autonomous vehicles and demonstrated the functionality of the emulated environment and equipment developed both live and by video documentation.

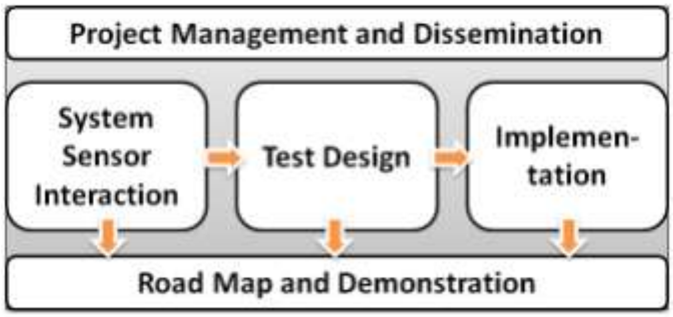

Figure 2. Interdependency of work packages; arrows indicating knowledge and information

5. Objective

The development of new EMC validation procedures is absolutely necessary to ensure robustness of present and coming active safety and autonomous driving functions. The OEMs have a responsibility to make sure that the systems don't fail. If a function is disturbed by an electromagnetic field, a graceful degradation of the functions must be performed. But, what is more important for the project is the participating OEM's inherent endeavor for world leading safety, and this project will be the first addressing EMC validation of complete active safety and autonomous driving functions. The objective of the project is to find strategies towards enabling reliable EMC validation of active safety and autonomous driving functions, through:

- Development of accurate and repeatable EMC validation procedures for multi sensor systems.
- A first system level EMC validation of the active safety functions ACC and LKA.
- Demonstration of developed EMC validation environment.
- Supporting international standardization (ISO) with standard methods and results enabling future EMC validation of complete functions reliant on multiple sensor systems.

During the project time the project has concluded that the important objective is to describe methods to emulate the environment for the sensors involved, radar and camera. If the environment can be emulated in the chamber, any function based on the sensors data can be verified. The methods can then also be used to verify ECU HW I/O signals when the function application software is not available at the time of testing. This is very

important when hardware and software design process shall be decoupled from each other. The conclusion within the project is that this infers a more long term strategy for a wider diversity of sensor systems. As a testament to this can be seen that the project has expanded from only testing the functions ACC and LKA to also include Pilot Assist 2 (PA2), which in some senses was a better candidate for evaluation as it directly relied on more than one sensor system.
As navigation systems are expected to play a large part in the functionality of autonomous vehicles the objectives of the project was also expanded to include simulation of GPS (GNSS) as part of the emulated environment.

The project results will:

- Contribute in reaching the goal of VisionZero, i.e., zero deadly traffic accidents.
- Strengthen the Swedish automotive industry's competitiveness in a global perspective.
- Be part in developing RISEs AWITAR laboratory to a world class test site for EMC validations of complete active safety and autonomous driving functions.

The project will contribute to several of the overarching FFI objectives:

- We will develop test methods for ensuring the robustness of active safety systems. These methods will be used in the further development of advanced systems ensuring the Swedish position within the safety area.
- The project will be a part of the competence cluster that will be built around the new projected Awitar test facility at RISE, and is also connected to the research environment around AstaZero
- In a previous project EMCCOM we had a fruitful co-operation with FOI combining competences from the vehicle and military industries. We foresee that the work in eVAMS will have a continuation were we again will team up with FOI and other partners from the military industry to utilize their experience in autonomous vehicles and intentional EMI.
- The project has participants from both industry and research institute.

The project will also contribute directly to the road map in the Electronics, Software and Communication sub-program. The project will particularly contribute to “Verification and Validation”, but the results will have a direct impact also on the development within “Green, Safe & Connected functions.

6. Results and deliverables

The automated functions used to evaluate the emulation of an environment were Adaptive Cruise Control (ACC), Lane Keeping Aid (LKA) and Pilot Assist (PA), as implemented by Volvo Car Corporation in the 2016 XC90. These three functions, together with the positioning system, play an important role for automation and therefore form a firm foundation to build future test procedures on. These functions use primarily three remote sensors: radar, forward looking camera, and GNSS.

6.1 Radar and camera input emulation

The camera was stimulated by using a roof-mounted projector which projected a video on a screen placed over the car's hood. The setup is shown in Figure 3-6. A corner reflector was used to simulate a vehicle moving in and out of the lane in front of the car. The car, screen and projector were placed on the rollers in Faraday at RISE in Borås. The battery-powered projector was mounted in a shielding box with a conductive glass opening. By positioning the projection accurately with respect to the car, the projection could be aligned with the camera's expected forward direction.
The driving wheel was strapped down with rubber bands, to allow movement while still providing enough turning resistance to avoid the "steer the car" warning that is issued by the car if the steering wheel is left unhindered.

The functions ACC, LKA, and PA2 were provoked simultaneously. First, the cruise control was set to 70 km/h. When the speed was stabilized, the corner reflector shifted position every 10 seconds, including 2-3 seconds of travel. A video of a road view was played on the projector. When the radar target appeared in front of the car, the "car ahead"-symbol lit up in the driver information module, as shown in Figure . The car's velocity then oscillated between approx. 35 km/h and 60 km/h as the radar target moved back and forth with a 20 s period. PA2 made the steering wheel turn repeatedly to follow the projected lane. The LKA symbol indicated that the Both LKA, ACC, and PA2 made engagements in a repeatable pattern.

The car was successfully irradiated with the interferers listed in Table 1, with the antenna in the position shown in Figure . For the irradiation test, the car's cruise control was set to 50 km/h, below the threshold for activation of LKA.

It was found that some kind of radar reflector was always needed to suppress unintended reflections (clutter) from the chamber and equipment. If the corner reflector was not in the lane in front of the car, it was enough to keep it in the neighboring lane.

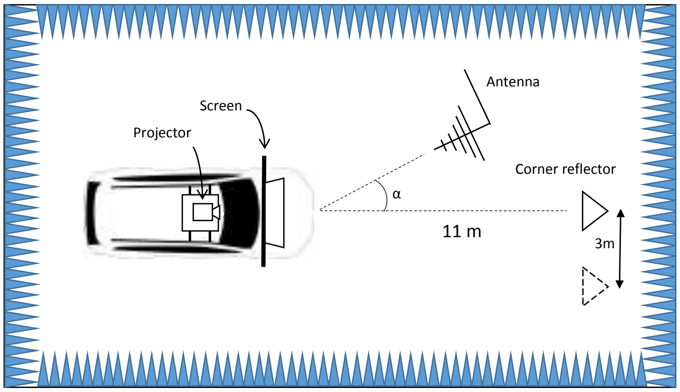

Figure 3: Top view of EMC chamber during ACC, LKA and PA2 tests, with a passive radar target simulator.

Figure 4: Experimental setup with an XC 90 and EPS-supported white paper and roof mounted projector.


Figure 5: View of the projector screen, and the passive radar target rig during test 1. During test 2, the antenna was angled towards the car and placed much closer.

Figure 6: Driver information display, before and after the radar target has appeared in front of the car.

Table 1: Interferer settings for the two EMI tests.

	Sweep A	**Sweep B**
Frequency	200-20 MHz	800-230 MHz
Front:	-15 deg	-15 deg
Modulation:	CW+ISO AM 2s+2s 1000 Hz 80%	CW+ISO AM 2s+2s 1000 Hz 80%

A second method to generate a plausible radar input was to use an active radar target simulator from Rohde & Schwarz, with the setup depicted in *Figure* 7. The target simulator records the transmitted radar signal, adds a delay and attenuation, and retransmits the signal back to the radar. As illustrated in *Figure* 8, several scenarios with 1-2 echoes (vehicles) were emulated by the simulator. One echo was made to approach or move away from the radar independently from the other echo. With a car equipped with extra read-out tools, it could be observed that the radar echoes were identified as intended.

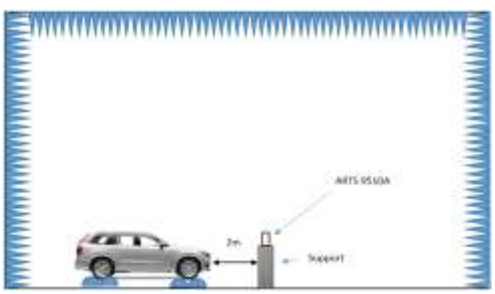

Figure 7: Side view of setup with an active radar target simulator.

Figure 8: Example of test scenario with the active radar target simulator.

6.2 GNSS input emulation

Two different GNSS tests were done, one using a GNSS recorder and the other using a GNSS simulator. Pictures of the two instruments are shown in *Figure* . The reason for using two different instruments was that the recorder can be used for re-playing a previously recorded real route as received from the satellites, while when using the simulator any satellite system (GPS, Gallileo, Glonass, Beidou) can be simulated, one by one or in combination. It is also possible to on top of the satellite RF-signals add effects of multipath and other types of disturbances.

In the test with the GNSS recorder, satellite RF-signals were collected by mounting a GNSS-antenna on a vehicle, connected to the recorder. The measurements were done by driving from central Gothenburg to Volvo Cars in Torslanda, a 15 minutes route. In the second step the recorded signal was re-played in the EMC chamber by connecting a passive antenna to the recorder, see *Figure* . Since the navigation system in the vehicle stores previous location and satellite information (almanac data) a ‘cold start' of the system needs to be done before the test.

With the GNSS simulator, the route was defined using Spirent software in combination with Google maps. A similar antenna setup was used in the test with GNSS playback.

For both tests the simulated routes could be seen on the vehicle navigation system, see *Figure 1*. Since the navigation system in the vehicle uses more than the GNSS signals as input (wheel speed sensors, steering angle sensor, IMU) the test environment was not complete, in the sense that the inputs were not synchronized. We found that the simulated route was followed well when the speed of the wheels was zero, and not that well when the wheels were rotating. It should be noted that in the latter case the speed of the wheels were not the same as the speed of the simulated route.

Figure 9: Spirent GSS6300 simulator and Spirent GSS6450 recorder.

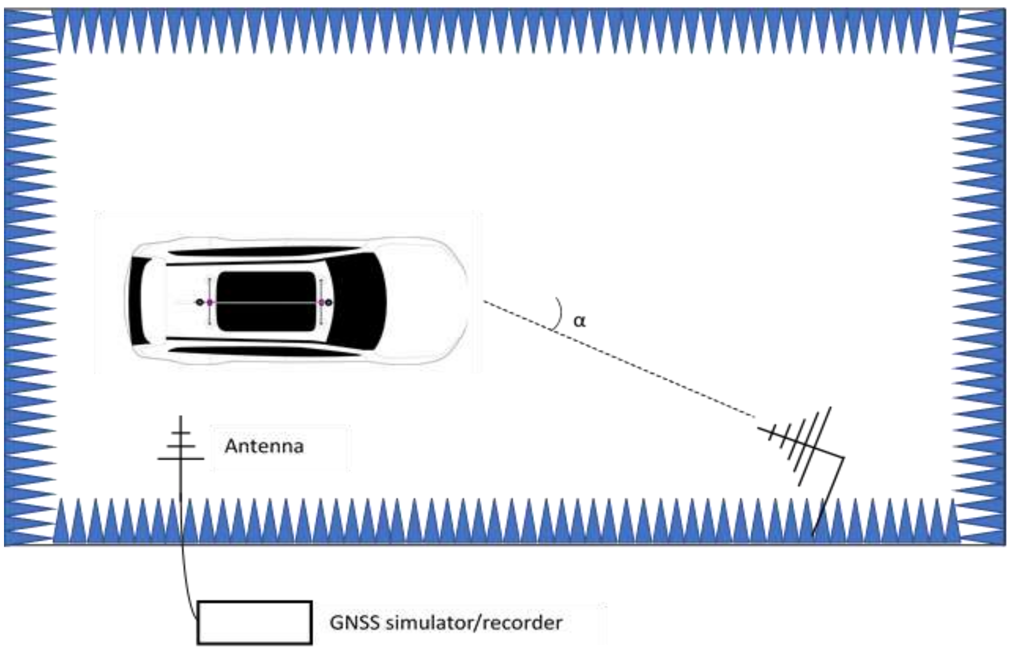

Figure 10: GNSS test setup.

Figure 1: The car's navigation system showing the car passing over the Älvsborg bridge in Gothenburg.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	x	The knowledge and results collected within the project has been shared with the community through a project seminar with participants from related Swedish industry and by organizing, and presenting at a workshop related to the project at EMC Europe 2017. Finally, an article was published in Electronic Environment.
Be passed on to other advanced technological development projects	x	The knowledge collected within this project will be passed on to be used in the new EMC research and test facility AWITAR currently being built at RISE. Input from this project will be, and has already been, passed on to other research projects. So far it has mainly concerned dealing with radar properties of difficult environments
Be passed on to product development projects	x	VCC will use the methods developed within this project for further development
Introduced on the market	x	VCC as well as other OEMs have already used parts of the methods developed within this project for evaluation of similar ADAS functions
Used in investigations / regulatory /	x	Through representative Krister Kilbrandt from RISE

licensing / political decisions		we have passed on input to ISO. Specifically about how we believe ISO 11451-2 should be updated

Towards the end of the project two major dissemination events have taken place. In Borås, a seminar including a demonstration of methods developed within the project was held. The seminar had about 40 participants from related industry, most of which were not working in the project. To interact with other projects and activities in the field a workshop on "Virtual Environments for System Level Automotive EMC Testing" was organized by the project and held at EMC Europe, Angers, France 2017. At this workshop several presentations directly related to the project were held (see publications). For the same reason the project was also presented at the IEEE EMC Swedish Chapter meeting in Göteborg, 2016.

Furthermore information about the project and its intentions has been spread through articles in NyTeknik 2016-04-06 and Swedac Magasin 2016-06-23.

7.2 Publications

J. Carlsson, "EMC Test Methodology for Autonomous Vehicles - The Research Project eVAMS", IEEE EMC Swedish Chapter meeting, Gothenburg, Sweden, Nov. 11, 2016

H. Toss, B. Bergqvist, T. Persson, J. Carlsson, A. Westlund, Seminarium i FFI-projektet eVAMS - EMC Validation of Multiple Sensor systems, Borås, Sweden, 16 Jun, 2017

H. Toss, B. Bergqvist, T. Persson, J. Carlsson, A. Westlund , "Virtual Environments for System Level Automotive EMC Testing" Workshop Organizer at EMC Europe 2017, Angers, France, 4-8 Sep, 2017

B. Berqvist et al, "Challenges of Simultaneous Testing of ACC and LKA in Semi-Anechoic Chamber", Workshop presentation at EMC Europe 2017, Angers, France, 4-8 Sep, 2017

J. Carlsson, T. Persson, A. Caignault, "Simulated GNSS/GPS for Autonomous Drive Testing", Workshop presentation at EMC Europe 2017, Angers, France, 4-8 Sep, 2017

H. Toss et al, "AWITAR – Semi-anechoic chamber testing/ road map for the future", Workshop presentation at EMC Europe 2017, Angers, France, 4-8 Sep, 2017

B. Bergqvist, J. Carlsson, H. Toss, T. Persson, A. Westlund , "How to Perform EMC Testing of Autonomous Vehicles", Electronic Environment 3-2017

8. Conclusions and future research

In the eVAMS project it was demonstrated that it is possible to emulate a realistic environment for radars, cameras and GNSS sensors, so that realistic EMC testing of a complete vehicle can be done in an anechoic chamber. The successful emulation of sensor environment was confirmed by observing normal behaviour of the functions adaptive cruise control (ACC), lane keeping aid (LKA) and pilot assist (PA). Remaining tasks for the future include to find methods for synchronizing stimuli for the various sensors and to find methods also for other sensors, such as lidar, ultrasonic etc. Table 1 shows a sketch of which sensors are involved in different automated functions, and thereby also the need for synchronization of sensor stimuli. The next step for the future is to develop methods for other sensors as illustrated in Table 1, and the process of demonstrating the performance and safety of autonomous vehicles.

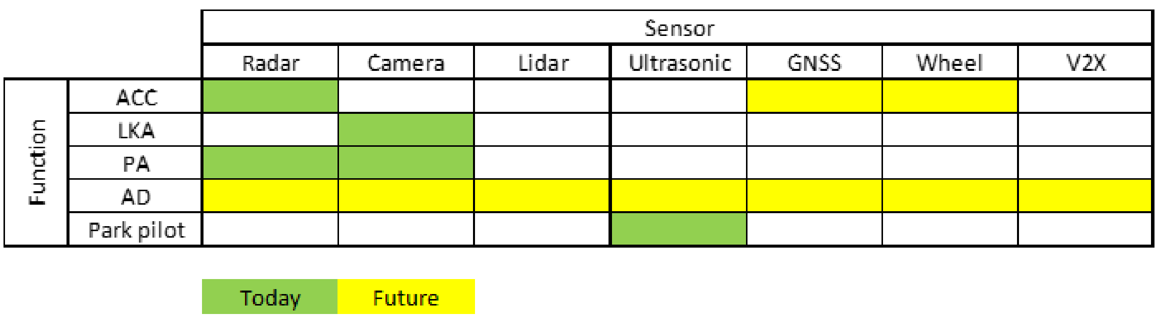

Table 1. Sensors involved in different functions, today and in the future.

9. Participating parties and contact persons

Partners in the projects have been:

RISE Research Institutes of Sweden	(556464-6874)
Volvo Car Corporation	(566074-3089)
Provinn AB	(556842-1423)

Contact persons at the partner companies are:

Company	Contact person	Email address
RISE	Henrik Toss	henrik.toss@ri.se
VCC	Björn Bergqvist	bjorn.bergqvist@volvocars.com
Provinn AB	Torbjörn Persson	torbjorn.persson@provinn.se

The project leader has been Henrik Toss, RISE. The steering committee consisted of Mats Lundin, Malcolm Resare and Göran Humleby (VCC), P-O Bergström (Provinn AB) and Christer Karlsson (RISE).

The work has been conducted in closely cooperating working groups with cores consisting of the named authors of this report and test engineers Johnny Larsson (VCC), Markel Bertilsson and Niklas Arabäck (RISE). Other persons in the companies have been supporting to less degree.