FFI

EMC for wireless Communication systems in Vehicles - EMCCOM

Project within the FFI program Vehicle Development (diarienr. 2012-00923)

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, half of which is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

FFI

1. Executive summary

The EMCCOM project (diarienr. 2012-00923) is a FFI project within the Vehicle Development program. EMCCOM is a three year project that started 2012-09-14 and ended 2015-06-30. The project had a total budget of 7,3 MSEK.
Partners in the project have been VCC, Volvo AB, Provinn AB, FOI Swedish Defence Research Agency and SP Technical Research Institute of Sweden.

EMCCOM have developed new EMC test methods for vehicle electronic units and simulation models. Both to be used to protect the performance (both reliability and capacity) of wireless digital communication services and by that ensure high availability of implemented safety and transport efficiency functions. Better precision in test methods and models will further reduce the costs in current test procedures and in a longer perspective greatly reduce the need for complete vehicle testing, which is very time consuming, costly and only possible late in the product development.

Questions that have been addressed in the project include:

- Which detector has the best correlation between a Radio Frequency (RF) electromagnetic interference measurement and the resulting degradation of wireless system performance?
- What level of electromagnetic interference is acceptable for a wireless communication system in a vehicle?
- What level of electromagnetic emission is acceptable for an electronic control unit to be used in a vehicle?
- What measurement method (detector, resolution bandwidth, …) is best suited to characterize the RF electromagnetic emissions from an electronic control unit to make it possible to predict the resulting performance degradation of an exposed wireless communication system?
- Is it possible to develop very simple models to be used to predict the performance degradation of an exposed wireless communication system?

Systems that have been studied are 3G, 4G, GNSS (GPS), WLAN (802.11g), C-ITS (802.11p).

The results have shown that:

- Best overall correlation have the RMS detector for the studied technologies and frequency bands with an average Pearson correlation coefficient of 0,88. The Average detector is however not far behind, 0,86.
- Acceptable level of electromagnetic interference is a concept containing many underlying standpoints. What data rate is needed and by that, what modulation? How much error correction is acceptable to use for this single type of interference? In the result from the

EMCCOM measurements the standpoint have been highest modulation and lowest code rate as a basis.

- Based on the measurements simple binary logistic regression models have been developed that can be used to predict the resulting probability of error (BLER or PER) from an interfering signal. These simple models have been developed in parallel to more complex models to understand the underlying mechanism for a technology to be disturbed.

The result of the project will be used in the work to update existing international standards aiming at the protection of radio receivers on board vehicles. In fact, the project has given input to the standardisation working group CISPR/D/WG2 in the form of a white paper.

2. Background

In the beginning of 2012, when the application for this project was written, VCC and Volvo AB for a longer time had experienced the need of deeper knowledge about how electromagnetic emissions from modern vehicle electronics degrade the different wireless communication systems used in vehicles. Modern vehicles contain several different broadcasting and communication radio systems that are used both for entertainment and vehicle functions. In Figure an example of different systems used in a Volvo car now or in the near future is shown.

Figure 1. *Example of radio and communication systems used in a modern vehicle now or in a near future*.

The development goes towards more complex safety functions and autonomous vehicles. Examples of such functions are the Use Cases described at the Car-2-Car communication consortium home page (https://www.car-2-car.org):

- Location warning
- GLOSA (Green Light Optimal Speed Advisory)
- Motorcycle warning
- Warning lights on
- Warning of roadworks
- Avoidance of traffic jams

Functions like these require information from “off board sensors”, sensors not located in the vehicle itself. These sensors can be positioned on other vehicles or in the infrastructure close to or far away from the vehicle. In order to maintain high availability of functions, communication link performance metrics such as range and signal delay have to be addressed to a higher degree than in traditional entertainment broadcasting radio systems.
In order to increase the knowledge, develop new requirements and test methods as well as low complexity simulation models to be able to predict how the link performance is affected by electromagnetic emissions from the vehicle electronics, the EMCCOM project was started.

3. Objective

The project objectives are:

- Increase knowledge among the partners of how electromagnetic interference degrade the performance of digital radio communication
- Develop methods for characterisation of interference
- Develop methods for determining interference impact on digital radio receivers
- Develop simple simulation models
- Gain input to contribute to standardisation

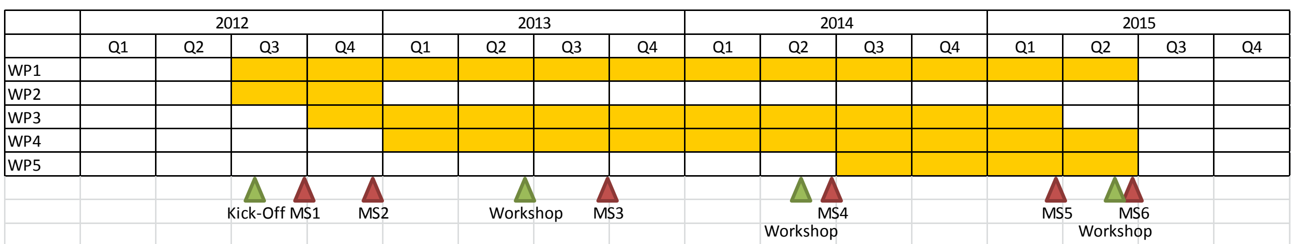
Systems to analyse are 3G, 4G, GNSS (GPS), WLAN (802.11g), C-ITS (802.11p).

4. Project realization

The EMCCOM project has been a 3-year project consisting of five Work Packages:

	Description	WP Leader	Budget [kSEK]
WP1	Project Management	VCC	462
WP2	Literature study and evaluation of previous work	VCC	398
WP3	Measurements	Volvo AB	2985
WP4	Modelling	SP	3060
WP5	Test method development	SP	441
			Total=7346

Table 1.



Partners in the projects have been:
SP Technical Research Institute of Sweden (Sveriges Tekniska Forskningsinstitut AB)
FOI Swedish Defence Research Agency (Totalförsvarets Forskningsinstitut)
Volvo Car Corporation
Volvo AB
Provinn AB

The project leader has been Björn Bergqvist, VCC. The steering committee consisted of Mats Lundin, Göran Humleby and Malcolm Resare (VCC), Alejandro Cortes and Ulf Herbertsson (Volvo AB), P-O Bergström (Provinn AB), Hans Frennberg (FOI) and Christer Karlsson (SP).
The work has been conducted in closely cooperating working groups consisting of the following core persons. Other persons in the companies have been supporting to less degree.

Name	Company	WP Leader in	Participated in WP
Björn Bergqvist	VCC	1, 2	1, 2, 3, 4, 5
Johnny Larsson	VCC		2, 3
Leif Kindberg	VCC		3
Stefan Lindqvist	VCC		3
Tomas Gustafsson	Volvo AB	3	3
Stefan Larsson	Volvo AB		2, 3, 5
Ulf Herbertsson	Volvo AB		2, 3, 5
Torbjörn Persson	Provinn AB		1, 2, 3, 5
Kia Wiklundh	FOI		2, 3, 4
Peter Stenumgaard	FOI		2, 3, 4
Karina Fors	FOI		4
Sara Örn Tengstrand	FOI		4
Jan Carlsson	SP		2, 3, 4, 5
Peter Ankarson	SP	4	3, 4, 5
Ulf Carlberg	SP		2, 3
Markel Bertilsson	SP		3, 5
Krister Kilbrandt	SP	5	5

Table 2.

5. Results and deliverables

5.1 Delivery to FFI-goals

The project was financed via the Vehicle Development program.

EMCCOM has increased the knowledge needed to increase efficiency in the development process. Interference discovered in late stages usually calls for expensive redesign and retesting. The result from EMCCOM will:

- Increase the reliability of measurements at ECU level. By using reliable test methods on ECU level, the chance of detecting design flaws in early stage is greatly increased.
- By using modelling the results from the ECU measurements requirement specifications at ECU level can be written more exact.
- The previous two points will increase the reliability of vital radio services and improve safety
- Increased knowledge behind the requirement levels leads to cheaper components since extra margins can be avoided. Balancing against other attribute requirements can be performed with increased confidens.
- Cost reductions by means of a more effective verification procedure.

In a longer perspective that goes beyond the EMCCOM project, the vision is to be able to greatly reduce the need for complete vehicle testing, which is very time consuming, costly and only possible late in the product development. The long-term goal is a transition from testing to make way for an increased part of simulations. It consists of:

1. Proper characterization of emission sources (unintentional transmitters as well as intentional transmitters) by measurements. (source specific)
2. Simulation of coupling paths from source to antenna port (body specific)
3. Calculation of the resulting received quality. (receiver system specific)

EMCCOM contains activities to increase the knowledge within steps 1 and 3. In a first phase, step 2 can be performed by using coupling measurements and simple modelling.

The vision is that products reaching market 2020 can be based on the above activities and characterization of emission sources are based on a new international standard better suited for simulation of digital radio receivers.

5.2 Measurements and results from EMCCOM

In the EMCCOM project, we have conducted measurements on several digital radio systems with the aim to find acceptable interference levels at the radio receiver input. Several different types of interference signals have been used as test signals. We have measured on the following systems and frequencies:

- 3G (WCDMA), 2112.6 MHz, 16 QAM, Code rate 0.97, 14 Mbit/s
- 4G (LTE), 2140 MHz, 64 QAM, Code rate 0.94, 75 Mbit/s
- WiFi (IEEE 802.11g), 2450 MHz, 64 QAM, Code rate 0.75, 54 Mbit/s
- ITS (IEEE 802.11p), 5900 MHz , QPSK, Code rate 0.5, 6.0 Mbit/s

We have used the highest modulation and lowest code rate as a basis for our measurements. The philosophy behind this is that the vehicle shall not degrade the potential of the communication technology. If the performance is degraded, it shall be due to other factors than emissions from on-board vehicle electronics.

The acceptable interference level was determined in the following way;

- The signal (S) was adjusted to a level 10 dB above the threshold level, i.e., where the throughput goes from 100% to 0% (very sharp knee). This corresponds approximately to the “edge of service” for each system with the above given modulation, code rate etc.

- Probability of Block Error (BLER) or an equivalent measure (system dependent) was measured as a function of signal to interference amplitudes (S/I) for each type of interference signal.
- A binary logistic regression model, taking all interference types into account, was made. An example of regression model for WCDMA is shown in Fig. 2.
- From the regression model, the signal to interference level at 10% BLER was derived. This level defines the acceptable signal to interference level at the radio receiver input.
- The acceptable interference level in dBm is then computed as the threshold level + 10 dB - S/I from the above step.
- This level is finally converted to the acceptable voltage at the receiver input, assuming 50 ohm by adding 107 dB.

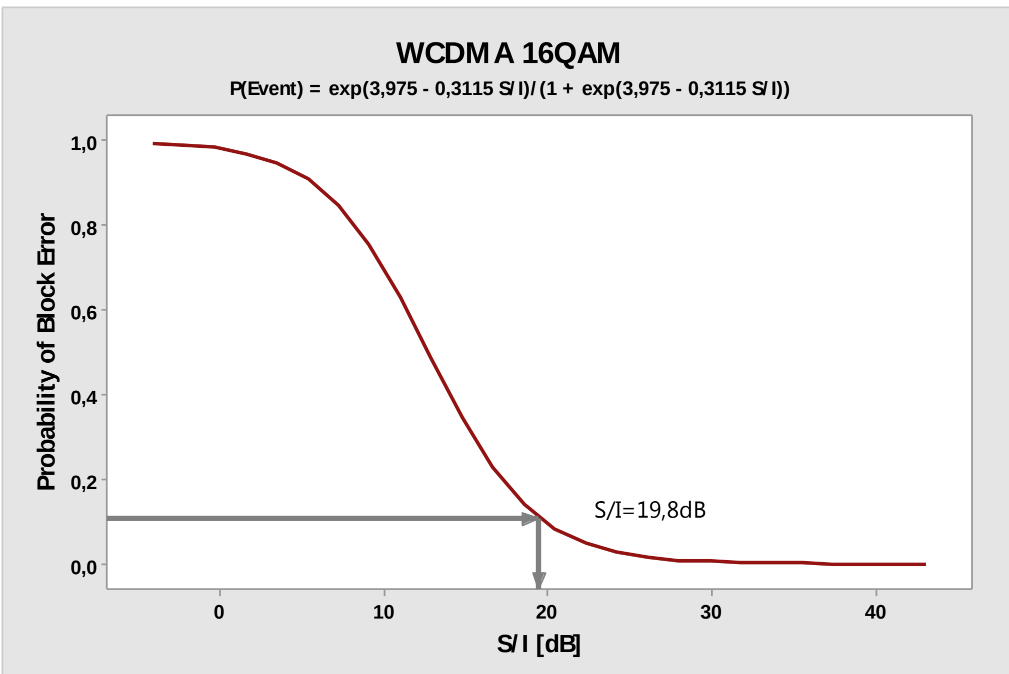


Fig. 2. Example of binary logistic regression model for WCDMA based on measurements on Sony Xperia Z1.

MEASUREMENT SETUP

In order to have a well-defined measurement setup we have used a conducted measurement setup, as shown in Fig. 3. In principal, the same setup has been used for all tested radio systems. For GPS and C-ITS the Communication Tester was changed to a GPS simulator and a Transmitting IEEE 802.11p node respectively. The measurements are static in the sense that fading is not included.

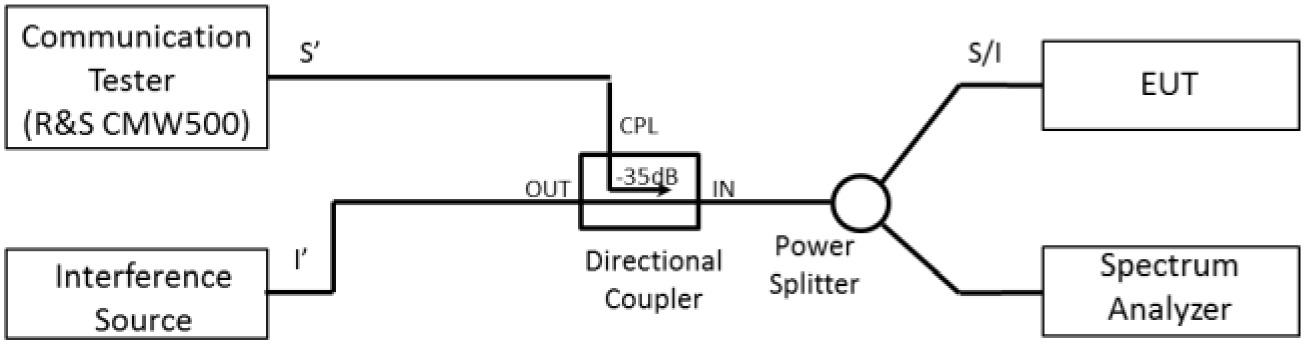


Fig. 3. Measurement setup.

TESTED INTERFERENCE SIGNALS

The tested interference signals are defined in Table 3.

Interference type	**Modulation frequency (kHz)**
CW	NA
AM, 80% sinusoidal	1, 7.5, 15, 30
FM, deviation 30 kHz	7.5, 15, 30, 100, 250
FM, deviation 100 kHz	7.5, 15, 30, 100, 250
Pulse Modulation Pulse width 66.7 µs	1, 2, 5, 10

Table 3. Interference signals.

ASSUMPTIONS USED FOR DERIVING LIMIT LINES

The measured quantity was the acceptable level, in dBµV, at the input of the radio receiver, as defined above. In order to compute the component requirements as in IEC CISPR 25, in dBµV/m, we have used the antenna factor for a quarter wavelength monopole. We have used this antenna factor for all frequencies. The rational for this choice is that this is the “best possible” antenna for vehicle applications and is normally the design goal when designing an automotive antenna. The antenna factor we have used is thus given by equation (1);

$$AF_{monopole} = \frac{9.73}{\lambda\sqrt{G_{monopole}}} = \frac{9.73 \cdot f_{MHz}}{300 \cdot \sqrt{G_{monopole}}} \approx 0.018 \cdot f_{MHz} \text{ or in dB as } AF_{monopole,\,\mathrm{dB}} = 20 \cdot \log\left(f_{MHz}\right) - 34.9 \quad (1)$$

The acceptable voltage at the receiver input calculated as above then becomes:

		VCC		CISPR 25/ Volvo AB		EMCCOM	
System	**Frequency [MHz]**	**BW**	**Level [dBµV]**	**BW**	**Level [dBµV]**	**BW**	**Level [dBµV]**
WCDMA	2112,6	120kHz	6	120kHz	6	20MHz	6
LTE	2140	120kHz	6	120kHz	6	20MHz	12
IEEE 802.11g	2450	120kHz	6	120kHz	6	20MHz	6
IEEE 802.11p	5900	120kHz	6	120kHz	N/A	20MHz	30

Table 4. Vehicle limits resulting from above mentioned measurements and assumptions.

Based on vehicle limits above and using the antenna factor in (1), the corresponding component limits become:

		VCC		CISPR 25/AB Volvo		EMCCOM	
System	**Frequency [MHz]**	**BW**	**Level [dBµV/m]**	**BW**	**Level [dBµV/m]**	BW	**Level [dBµV/m]**
WCDMA	2112,6	120kHz	18	120kHz	24	20MHz	38
LTE	2140	120kHz	18	120kHz	24	20MHz	44
IEEE 802.11g	2450	120kHz	18	120kHz	24	20MHz	39
IEEE 802.11p	5900	120kHz	25	120kHz	N/A	20MHz	70

Table 5. Component limits resulting from above mentioned measurements and assumptions.

It should be noted that the IEEE 802.11p radio we used in our measurements was a prototype based on a modified IEEE 802.11a transceiver.

MEASUREMENTDETECTOR AND BANDWIDTH
Correlation between measured amplitude of the interference signal, I, and the probability of error (BLER or PER) was calculated for Peak-, RMS- and Average-detector.

System	Modulation	Corr Error-Ampl Peak	Corr Error-Ampl RMS	Corr Error-Ampl Avg
WCDMA	16QAM	0,939	0,918	0,873
LTE	64QAM	0,941	0,959	0,944
IEEE802.11g	64QAM	0,936	0,942	0,939
IEEE802.11g	QPSK	0,824	0,815	0,808
IEEE802.11p	QPSK	0,671	0,747	0,757
Average Correlation		0,8622	0,8762	0,8642

Table 6. Correlation between Probability of Error (BLER or PER) and measured interference amplitude using 3 different spectrum analyzer detectors: Peak, RMS and Average.

A measurement bandwidth of 20 MHz has been used during the measurements.
Recommendation is to use:

1. Use the bandwidth of the radio system. Problem: measurement noise can be too high. Not all spectrum analyzers have the needed RBW.
2. 1 MHz is a compromise that is acceptable for the noise sources present in the cars today.
3. In case the measurement noise is to high, decrease the bandwidth down to 120kHz or 10kHz to get required margin between measurement noise level and requirement level.

6. Dissemination and publications

6.1 Knowledge and results dissemination

During the project, two open seminars have been organized to spread the result. The first seminar was held in June 2013 where the result of the literature study was presented and comments from the participants were gathered as an input to the coming project work. The second seminar was held in June 2015. Results and conclusions from the project were presented and compared to existing specifications and standards. At both seminars around 40 participants were attending. Many of them not working in the project.
The project results have also been presented at a number of conferences, Electronic Environment 2013, EMC Europe 2014 and EMC Europe 2015. See list of publications in section 6.2.

To interact with other projects and activities within the field, EMCCOM results have been presented at IEEE EMC Sweden's meeting in September 2014, FFI projekt WCAE workshop at Lindholmen Oct. 2014 and FFI projekt RelCommH workshop at ASTA ZERO Oct 2014. A White paper have been sent to the standardisation working group CISPR/D/WG2 with input to the work to update the standard IEC CISPR 25.

6.2 Publications

S. Örn Tengstrand, K. Fors, P. Stenumgaard, K. Wiklundh, "Jamming and interference vulnerability of IEEE 802.11p", EMC Europe 2014, Gothenburg, Sweden, 1-4 Sept., 2014.

P. Ankarson, U. Carlberg, J. Carlsson, S. Larsson, B. Bergqvist, "Impact of Different Interference Types on an IEEE 802.11p Communication Link Using Conducted Measurement", EMC Europe 2014, Gothenburg, Sweden, 1-4 Sept., 2014.

S. Örn Tengstrand, P. Stenumgaard, ”Performance Estimation of DSSS Wireless Systems in Impulsive Interference" , Accepted for presentation at IEEE/EMC Europe 2015, Dresden, Germany, 18-22 Aug., 2015.

P. Ankarson, J. Carlsson, B. Bergqvist, S. Larsson, M. Bertilsson, "Impact of Different Interference Types on an LTE Communication Link Using Conducted Measurements", Accepted for presentation at IEEE/EMC Europe 2015, Dresden, Germany, 18-22 Aug., 2015.

Dengzheng Huang, Ragad Majeed, "Development of IEEE 802.11p Transceiver in Simulink & Evaluation of the Electromagnetic Interference Effects"
Report number: EX047/2015, Master thesis at Department of Signals and Systems Chalmers University of Technology Göteborg, Sweden 2014

B. Bergqvist, T Persson "Vehicle development-an EMC challenge" Electronic Environment #3 2013

B.Bergqvist, K. Kilbrandt, P. Ankarson, J. Carlsson "CISPR/D/WG2 N315-Comments on CISPR/D/WG2 N296" 2015-05-13

7. Conclusions and future research

As can be seen in Table 4 and 5, there are differences in the measured acceptable interference level for vehicles and components compared to the current VCC, Volvo AB and IEC CISPR 25 levels. There are also discussions going on in the working group, CISPR/D/WG2 where new limits are proposed by other groups. Our levels are based on measurements on commercially available or prototype digital receivers. EMCCOM have also a fundamental difference in the approach used for transforming from vehicle to component levels compared to current CISPR 25 standard. We have used the antenna factor for a quarter wavelength monopole, which is linearly increasing with frequency, while in the current standard a constant antenna factor of 18 dB/m has been used. This result is considerable differences at higher frequencies. As an example, the difference in antenna factor is 23 dB at 5.9 GHz. We have described our rational for our choice above. The work will continue in the CISPR working group to achieve an updated harmonized standard for measuring electromagnetic interference on the digital communication bands.

It should be noted that the IEEE 802.11p radio we used in our measurements was a prototype based on a modified IEEE 802.11a transceiver.

8. Participating parties and contact person

Partners in the projects have been:

SP Sveriges Tekniska Forskningsinstitut AB	(556464-6874)
Totalförsvarets Forskningsinstitut (FOI)	(202100-5182)
Volvo Car Corporation	(566074-3089)
AB Volvo	(556542-4321)
Provinn AB	(556842-1423)

Contact persons at the partner companies are:

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Volvo AB	Tomas Gustafsson	tomas.gustafsson.3@volvo.com
Provinn AB	Torbjörn Persson	torbjorn.persson@provinn.se

Table 7.