Trends in development of SiGe based 76-81 GHz Automotive Radar

Hans-Ludwig Bloecher[1], Alfons Sailer[2], Markus Andres[2], Markus Goppelt[2], Juergen Dickmann[1]

[1] Daimler AG, Group Research & Advanced Engineering, D-89081 Ulm, Germany
[2] University of Ulm, Institute of Microwave Techniques, D-89081 Ulm, Germany

hans-ludwig.bloecher@daimler.com, alfons.sailer@uni-ulm.de, markus.andres@uni-ulm.de, markus.goppelt@uni-ulm.de, juergen.dickmann@daimler.com

***Abstract*-- Automotive UWB (Ultra-Wideband) short range radar (SSR) is on the market as a key technology for novel comfort and safety systems. SiGe based 79 GHz UWB SRR will be a definite candidate for the long term substitution of the 24 GHz UWB SRR. This paper will give an overview of the finished BMBF joint project KOKON and the recently started successing project RoCC, which concentrate on the development of this technology and sensor demonstrators. In both projects, the responsibilities of Daimler AG deal with application based sensor specification and test & evaluation of realized sensor demonstrators. Recent UWB SRR frequency regulation approaches and activitites will be reviewed shortly. Thereafter, the BMBF KOKON successing project RoCC will be introduced in detail. Project motivation, project goals and the underlying organization will be outlined.**

***Index terms*-- Automotive Radar, SRR, UWB, SiGe-Technology, 79 GHz, BMBF, KOKON, RoCC.**

I. Introduction

Automotive radar facilitates various functions which increase the driver's safety and convenience. Exact measurement of distance and relative speed of objects in front, beside, or behind the car allows the realization of systems which improve the driver's ability to perceive objects during bad optical visibility or objects hidden in the blind spot during parking or changing lanes.

Radar technology has proved its ability for automotive applications for several years. When compared to its optical counterpart video (with image processing) or lidar, the advantages of radar are obvious:

- direct distance and speed measurement
- robust against weather influences and pollution
- unaffected by light
- measurement of stationary and moving objects on and in the vicinity of the road
- invisible integration behind electromagnetically transparent materials (e.g. bumpers).

Meanwhile, many car manufacturers use 77 GHz radar for autonomous cruise control (ACC) or recently even for pre-crash or collision mitigation. It was first introduced to the market in the Mercedes-Benz S-class under the name "Distronic" in 1998. In addition, UWB short range radar operating at 24 GHz has been developed and introduced (Mercedes-Benz S-class, Distronic Plus, 2005) and is a key enabling technology for actual and novel driver assistance and safety systems. Fig. 1 gives an overview on possible (UWB) SRR based vehicle applications.

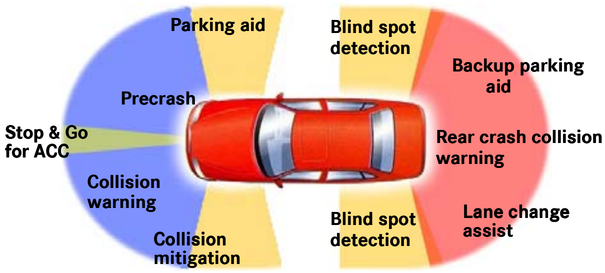

Fig. 1. SRR based assistance and safety applications.

The need for a UWB bandwith is given by the application. Especially safety applications like the prediction of a possible collision need capability of reliable object tracking and object discrimination. Thus, SRR has to have sufficiently high range resolution in the centimeter range to detect smaller objects and vulnerable road users such as motor cyclists and children.

II. UWB SRR Frequency Allocation in Europe

In 2004 and 2005, the EC and the ECC (Electronic Communications Committee of the CEPT) adopted decisions [1, 2] that regulate the temporary introduction of vehicular UWB SRR using 24 GHz spectrum in Europe until July 1, 2013 and the unlimited allocation at 79 GHz (see Fig. 2). This regulation was the basis for the worldwide first market introduction of UWB SRR in the Mercedes-Benz S-class in 2005.

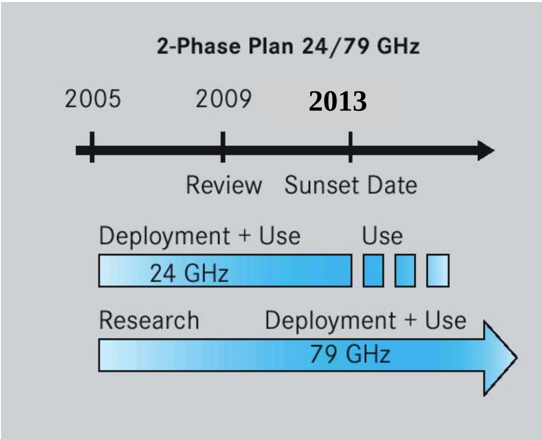

Fig. 2. European 2-phase-solution for 24 GHz UWB SRR frequency allocation.

The EC requested a fundamental review of its regulation, to be carried out by December 31, 2009, at the latest to verify the continuing relevance of the initial assumptions concerning the operation of vehicular SRR and development progress in the 79 GHz range technology. This process started in December 2008.

Automotive manufacturers product lines have long lead times and need assured access to technology. Meanwhile, there seem to be indications that 79 GHz UWB SRR products are probably not mature enough in time for a seamless transition from 24 GHz to 79 GHz in 2013. Thus, the EC recently mandated the CEPT to review the present 24 GHz UWB SRR regulation and to consider flexible regulatory approaches to avoid a technology gap until the availability of 79 GHz UWB SRR sensors.

III. BMBF Joint Project KOKON

In comparison to 24 GHz, the frequency range around 77-81 GHz offers different advantages, e.g.:

- one common technology platform for SRR and LRR available (frequency range 76-81 GHz)
- decreased dimensions and weight
- increased doppler sensitivity
- higher angular resolution with moderate antenna aperture dimensions possible.

Due to this, and as a consequence of the EU regulation, the BMBF joint project KOKON ([3, 4], 2004-2007) was launched to develop the basis technologies of 79 GHz UWB SRR and of 77 GHz advanced LRR. SiGe technology was chosen to achieve the required cost reduction and to establish the basis for highly integrated and compact radar front-ends.

KOKON was a very successful project. The feasibility of 79 GHz UWB SiGe based technology and components was clearly demonstrated. Continental realized UWB SRR demonstrators (Fig. 3) and Bosch decided to use the SiGe technology in the new LRR3 ACC-radar.

Fig. 3. 79 GHz UWB SRR demonstrator based on SiGe technology (source: Continental AG)

IV. KOKON Successing Project RoCC

A. Introduction

RoCC (“Radar-on-Chip for Cars”) is the follow-up project of KOKON. Like KOKON, it is a German national funding project sponsored by the BMBF (Federal Ministry of Education and Research). The RoCC consortium spans almost the complete automotive supply chain from component manufacturer (Infineon) over Tier1 suppliers (Bosch, Continental) to OEMs (BMW, Daimler).

These companies, with exemption of BMW, have already collaborated very successfully within KOKON, where they were able to demonstrate for the first time the feasibility of low-cost Silicon based radar technology in the 76 GHz to 81 GHz band. Commercialization of the results of the

KOKON project already began. Last year (2008) Infineon introduced its first SiGe radar chipset (RASIC TM) to the open market comprising a single-chip 4-channel radar transceiver for 76-77 GHz advanced ACC applications together with a 19 GHz reference oscillator. Robert Bosch GmbH utilizes these chips for its new LRR3 automotive radar system (3rd generation Long-Range-Radar). It is world-wide the first automotive radar sensor in that frequency range using only silicon semiconductors (Press Release Infineon 1/12/2008 [5]). A first 79 GHz UWB SRR prototype system based on the same SiGe building blocks has been successfully demonstrated by Continental.

RoCC is targeted to further advance Silicon based radar technology in the 76 to 81 GHz band now with special emphasis on SRR. Final goal is to bring down cost of 79 GHz automotive radar sensors significantly and make them cost-competitive to 24 GHz systems, thus enabling enhanced and affordable road safety for everyone [6].

B. Project Organization

RoCC is lead by Infineon as project coordinator. It started on September 1, 2009, and will run until August 31, 2011. Five work packages each of which is lead by one of the main partners comprise the project's organizational frame work (Fig. 4).

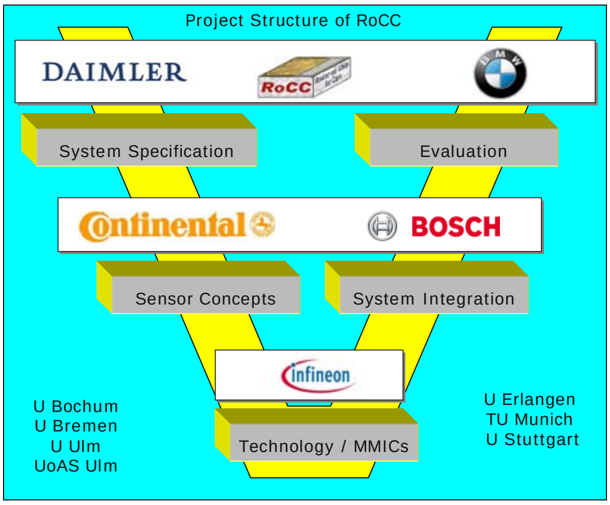

Fig. 4. Organizational structure of BMBF joint project RoCC, project partners and work packages.

- system specification: Daimler (with contributions from BMW, Bosch, Continental)
- sensor concept: Continental (with contributions from BMW, Bosch, Infineon)
- technology and MMICs: Infineon (with contributions from Bosch, Continental)
- sensor integration: Bosch (with contributions from Continental)
- system evaluation: BMW (with contributions from Daimler, Bosch, Continental)

The industrial partners are supported by sub-contracted universities which will contribute with their excellent competences in the fields of radar systems, antenna design or millimeter wave circuit design.

C. Project Goals

The main technical, scientific and socio-political goals of the RoCC project are:

- affordable vehicle and road safety for everyone
- strengthening of technological leadership in automotive high frequency products and processes
- application based sensor specification, test and evaluation of realized 79 GHz SiGe UWB SRR sensors
- investigation and optimization of conditions of covered sensor packaging and sensor operation in the vehicular environment
- further enhancement of sensor performance and reliability (e.g. noise reduction, angular resolution)
- development of a cost-competitive radar sensor technology in the 76 to 81 GHz range with special emphasis to 79 GHz SRR and evaluation beyond 100 GHz
- foundation of a sound technology base for migration from 24 GHz SRR to 79 GHz SRR
- development of highly integrated universally applicable radar MMIC demonstrators (RoCC: "Radar-on-Chip for Cars")
- improvement of energy efficiency of SiGe-MMICs
- demonstration of radar sensors with superior signal to noise ratio (S/N)
- adaptive (smart) sensors from short range to long range (multi-mode, multi-range)
- pave way to SMD-Package for SiGe-MMICs in the frequency range of 76 to 81 GHz
- benchmarking versus 24 GHz solutions
- demonstration of feasibility of 500 GHz SiGe technology for automotive radar applications
- extended self-test, diagnosis and –calibration features.

As an OEM, Daimler is active in the fields of sensor specification, test and evaluation. Further responsibilities include frequency regulation, standardization and the evaluation of frequencies above 100 GHz for future SRR/LRR applications.

D. Current Activities of Daimler AG in RoCC

Sensor Integration and Packaging Aspects

Within the car, SRR sensors are typically mounted invisibly behind painted bumpers or other layered components. Any cover of an antenna of a radar sensor has to be carefully designed in order to avoid performance degradation due to transmission loss, reflections, and edge effects. Even more than for lower operating frequencies, this is a crucial issue concerning sensor systems working in the frequency range from 76 GHz to 81 GHz. Bumpers and other kinds of components mounted on a vehicle's front- or rear-end have to be considered as radome structures (Fig. 5). For the desired frequency range, their thickness is commonly in the order of not more than a couple of wavelengths.

The OEMs among the project partners, Daimler and BMW, have to consider a wide range of sensor packaging aspects in RoCC. Special attention has to be turned on the impact of the necessary frequency bandwidth around 79 GHz:

- electromagnetic characteristics of bulk material and painting (permittivity and loss tangent)
- manufacturing tolerances
- multiple paintings, especially repair paintings
- covering of radomes with water, snow, ice, dust or salt, etc.

In [7], first results concerning sensor integration behind painted bumpers have been shown. One further aspect addressed in RoCC is the optimization of radome structures for LRR radar sensors. Fig. 5 shows a transmission measurement through a state-of-the-art ACC radome. The radome consists of two substrate layers with a very thin metallization in between. RF design rules were proposed and applied to a novel production engineering approach. The two graphs in Fig. 6 show the frequency response |t| of the transmission through such a radome before and after optimization and prove the significant gain in performance. The highlighted part of the graph depicts the relevant operating frequency band for LRR applications from 76 GHz to 77 GHz.

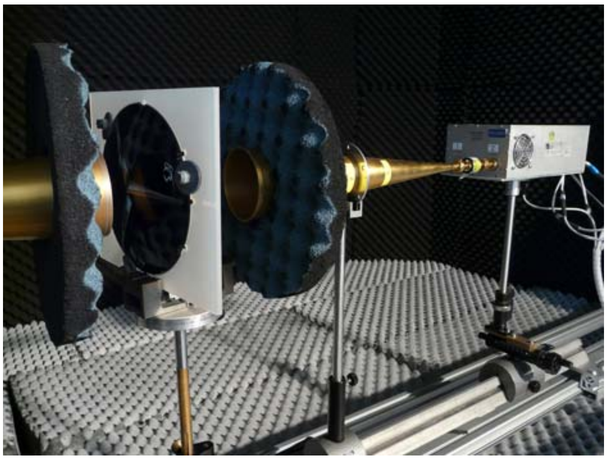

Fig. 5. Transmission measurement of LRR radome structure with vectorial, polarimetric, quasioptical setup.

.

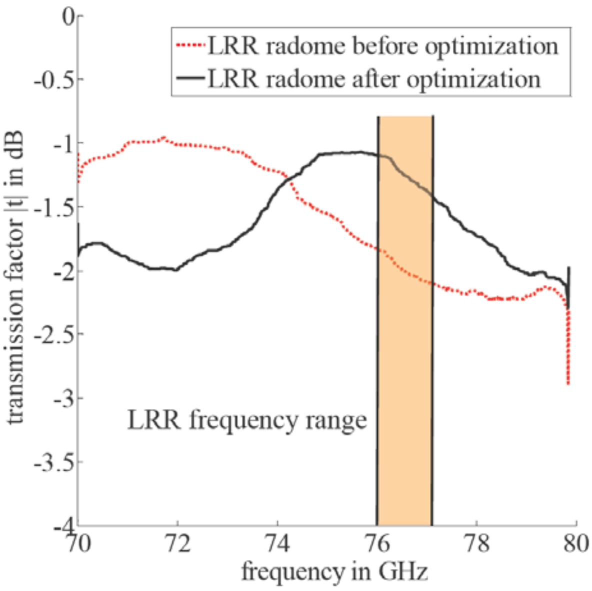

Fig. 6. Transmission factor |t| measured over frequency for LRR radomes of the kind shown in Fig. 5 (before and after RF optimization); the highlighted region is the LRR frequency range.

Mutual Interference of Automotive Radar Sensors

When more than one automotive radar sensor is being operated at the same time, radar sensors may also receive signals generated by other radar sensors. The reception of foreign signals (interference) can lead to problems, such as ghost targets or a reduced signal-to-noise ratio. In particular for safety functions (e.g. pre-crash) very low failure rates have to be achieved. The probability of interference-induced problems in the radar sensors therefore has to be ultra-low.

In the future, the percentage of vehicles equipped with radar sensors will increase, as will the traffic density in large cities. This will require efficient countermeasures against mutual interference to enable safety functions to have very low failure rates. Interference-related activities in RoCC are to:

- analyze interference mechanisms using analytic and simulator based approaches (e.g. explain how ghost targets are generated or how the signal-to-noise ratio is decreased)
- find efficient countermeasures (e.g. pseudo-random variations of the transmit signal to avoid ghost targets)
- test countermeasures in the lab and with vehicles.

The first task was to find publicly available information (publications, patents etc.) on automotive radar mutual interference and countermeasures. Interference mechanisms were covered by few sources (mainly universities). Many interference avoidance techniques were found (e.g. pseudo-noise and spread-spectrum techniques). The number of interference elimination techniques was smaller (mainly by manufacturers of radar sensors). No publications were found on the use of spatial countermeasures (e.g. adaptive beamforming). This will be one focus of Daimler within RoCC. The analysis of automotive radar interference was first conducted using simple analytic approaches. As an example, Fig. 7 depicts the interference between pulsed radars using the same pulse repetition period/frequency. It can be seen that along with the real target, a ghost target in a constant "distance" is formed.

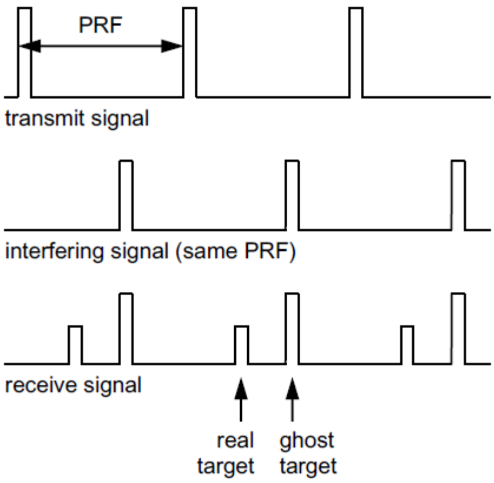

Fig. 7. Interference between pulsed radars using the same pulse repetition period/frequency.

Furthermore, first measurements using a generic radar frontend and waveguides are set up (Fig. 8).

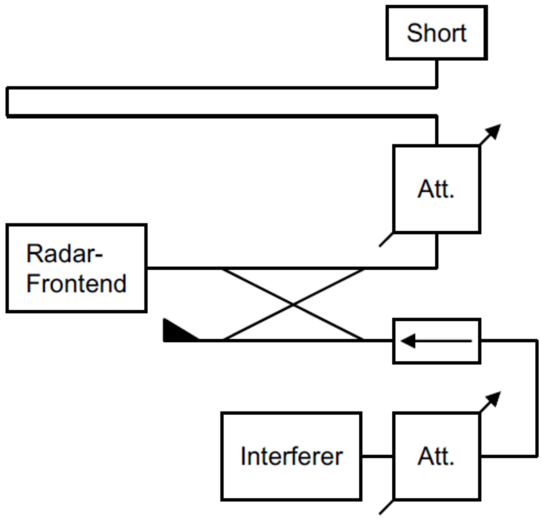

Fig. 8. Measurement setup using a generic radar frontend and rectangular waveguides.

Impact of Radar System Parameter Selection

In the automotive industry, time and costs are key criteria in the development of new products. Thus, car manufactorers seem to use the "bottom-up" strategy based on available sensors for function development. In the case of several available competing radar sensor technologies, a problem occurs for the automotive OEMs to identify the best suited sensor due to the lack of an application based "bottom-up" requirement specification. Thus, in RoCC, the impact of radar parameter selection on the design and performance of driver assistance systems and safety functions will be studied in detail.

One typical radar system parameter is the range resolution ΔR. It indicates the separation in range direction of two scattering targets with identical radar cross section (RCS). However, the range resolution depends on the received scattered power density of both targets. If both targets have a different RCS coefficient, the range resolution will be downgraded. A typical scenario is an unobservant pedestrian waiting in front of a car to cross the street (see Fig. 9). In this case, the radar sensor should be able to separate the two targets to classify the risk. Fig. 10 depicts this simulated situation from the point of view of the radar sensor with a range resolution of 60 cm. The woman is standing at the fixed position at 20 m and the car is standing behind her. Curve 1 of Fig. 10 shows the merging lobe of the pedestrian and the car. In this scenario, the radar sensor can't provide sufficient information to highlight a potentially dangerous situation. Even by increasing the spacing between the two targets to the order of the range resolution, illustrated in curve 2 of Fig. 10, these two targets can't be resolved properly. To distinguish the pedestrian from the car, the distance between the targets has to be increased furthermore. In this way, the two lobes can be identified clearly (see curve 3 of Fig. 10). In effect, to be able to separate two targets with different RCS, that are close to each other, the radar sensor has to have a better range resolution than originally specified in the sensor data sheet.

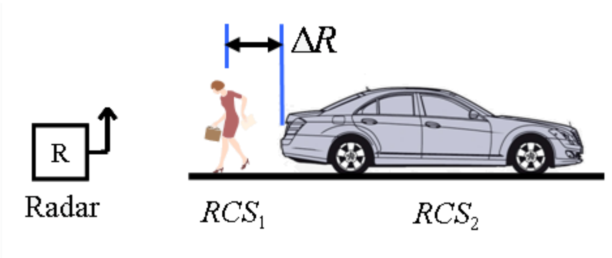

Fig. 9. Scenario of a passenger standing in front of a car.

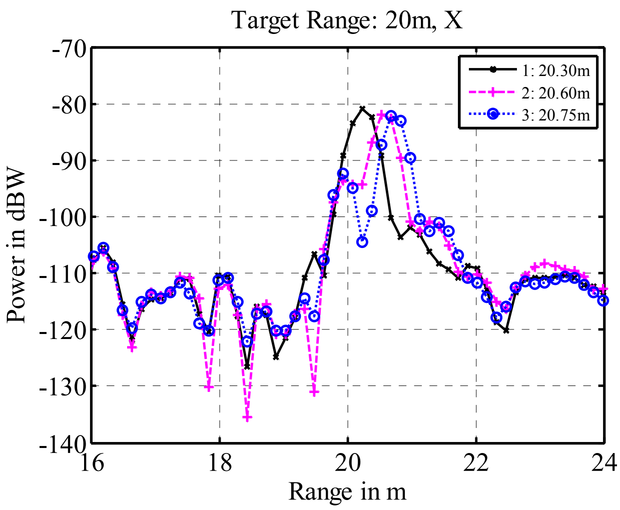

Fig. 10. RCS dependent range resolution. Pedestrian standing 20 m away from the radar sensor and 30 cm, 60 cm and 75 cm in front of a car.

V. CONCLUSION

Automotive short range radar is an important sensor technology for present and future automotive active safety and comfort functions. The UWB approach provides a real-time high range resolution, which is of particular importance for the time critical safety functions, e.g. pre-crash. The European frequency regulation for UWB automotive SRR requires the shift from 24 GHz to the 79 GHz band in 2013. Beneath this, the 79 GHz frequency range offers application of the same technology platform for LRR and UWB SRR. Furthermore, frequency dependent parameters as angular and velocity resolution, are improved significantly. SiGe technology has been chosen to realize low-cost sensors. Within the BMBF public funded joint project KOKON, the feasibility of SiGe based SRR/LRR has been shown successfully. The successing project RoCC has been started recently to commercialize the technology developed within KOKON and to support the availability of cost efficient and reliable 79 GHz UWB SRR products after 2013.

VI. ACKNOWLEDGEMENT

The authors wish to thank the German Federal Ministry of Education and Research (BMBF) for the funding of the KOKON and RoCC joint projects.

VII. REFERENCES

[1] The ECC Decisions ECC/DEC(04)10 (24 GHz SRR) and ECC/DEC(04)03 (79 GHz SRR) are available in the Internet: ERO-Homepage (http://www.ero.dk/deliverables/decisions)

[2] The EC Decisions 2005-50-EC (24 GHz SRR) and 2004-545-EC (79 GHz SRR) are available in the Internet: EC-Homepage: (http://www.europa.eu.int/eur-lex)

[3] Proceedings of the BMBF joint project KOKON final meeting (Workshop WSW5 of the EuMW 2007), Munich, October, 2007.

[4] Final reports of the KOKON project partners, German National Library of Science and Technology (online ressource); http://tiborder.gbv.de/psi/DB=2.63/LNG=DU/SID=1ea59db2-3b/CMD?ACT=SRCHA&IKT=1016&SRT=YOP&TRM=kokon

[5] http://www.infineon.com/cms/en/corporate/press/news/releases/2008/INFATV200812-015.html

[6] https://www.infineon.com/cms/en/corporate/press/news/releases/2009/INFATV200905-058.html

[7] H.-L. Bloecher, A. Sailer, G. Rollmann and J.. Dickmann, "79 GHz UWB automotive short range radar – Spectrum allocation and technology trends", Adv. Radio Sci., vol. 7, pp. 61-65, 2009