BMBF Joint Project RoCC: Next Generation of Radar Technologies for Automotive Applications

Hans-Ludwig Bloecher, Jürgen Dickmann
Group Research & Advanced Engineering, Daimler AG
89081 Ulm, Germany
hans-ludwig.bloecher@daimler.com,
juergen.dickmann@daimler.com

Markus Andres, Markus Goppelt, Alfons Sailer, Wolfgang Menzel
Institut of Micowave Technique, University of Ulm
89081 Ulm, Germany
markus.andres@uni-ulm.de, markus.goppelt@uni-ulm.de,
alfons.sailer@uni-ulm.de, wolfgang.menzel@uni-ulm.de

Abstract— **Automotive UWB (Ultra-Wideband) short range radar (SSR) is on the market as a backbone for present day 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 to enable novel automotive applications. This paper will give an overview of the BMBF joint project RoCC, which concentrates on the development of this technology and sensor demonstrators. In this project, 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, the underlying organization and the current activities of Daimler AG will be outlined.**

Keywords- 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.

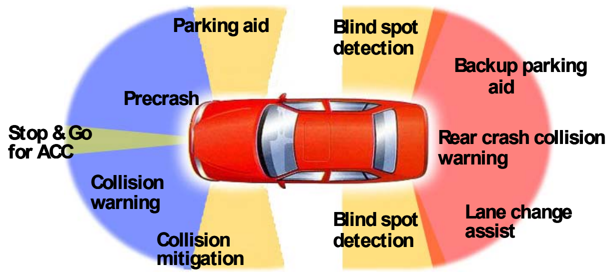

Figure 1. SRR based assistance and safety applications.

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 Europa

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.

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.

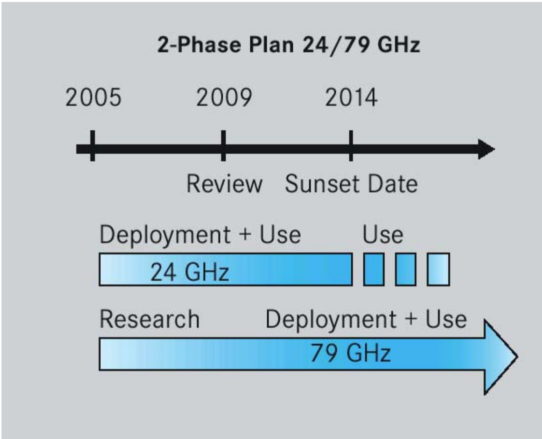

Figure 2. European 2-phase-solution for 24 GHz UWB SRR frequency allocation..

III. BMBF PROJECT ROCC

A. An Introduction

RoCC ("Radar-on-Chip for Cars") is the follow-up project of KOKON [3, 4]. RoCC started on September 1, 2009, and will run until August 31, 2011. 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 exception 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. Two years ago (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).

- 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.

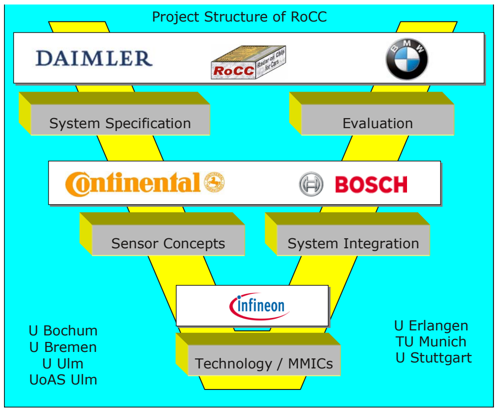

Figure 3. Organizational structure of BMBF joint project RoCC, project partners and work packages..

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.

IV. Current Activities of Daimler AG in RoCC

A. System Aspects: Scenario Dependent Range and Angular Resolution

Range and angular resolution of automotive radar sensors are not only depending on the radar system parameters but also on the traffic scenario. Future safety and comfort function innovation areas definitely have to cope with urban city situations. Hence, parameters which not yet been in the focus are now being in attached importance to range and angular resolution. The important question to be answered is what kind of radar system parameter set up is best suited to fulfill future demands with respect of safety and comfort functions.

For the investigation of these effects a 2D FMCW radar simulator model was developed, analyzing the received radar signals. The raised calculation time of high frequency radar signals in simulations can be reduced by processing the signals in the baseband [7]. The radar simulator model uses different radar system parameters like the influence of carrier frequency, bandwidth, period duration of the frequency sweep and antenna array size. The property of each point target in the scenario is specified by radar cross section, position and velocity.

To evaluate the influence of the scenario on the target detection, a 2-target-scenario is defined (see Fig. 4). The radar sensor, located in the origin of the coordinate system, is attached to the light-colored car and has an angular resolution of 2°. The car is driving at a vehicle speed v of 10 m/s (36 km/h) towards a potential obstacle. The dark-colored target car, modeled with an L-shape of point scatterers, is standing on the parking lane at the distance of 11 m. A pedestrian located with a spacing of 60 cm in front of the parking car will be analyzed using different range resolutions.

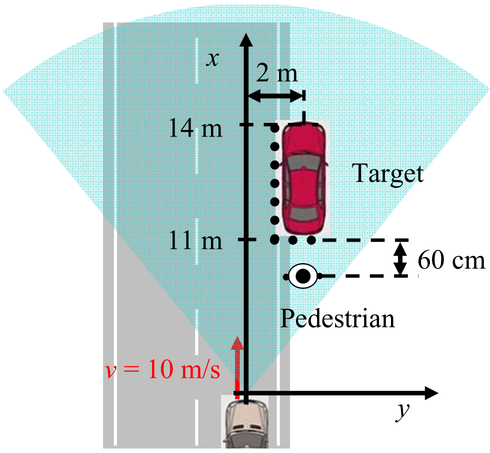

Figure 4. Scenario of a pedestrian standing in front of a car.

Fig. 5 illustrates the simulation result with a bandwidth of 600 MHz. Even if the spacing between the pedestrian and the target car is larger than the theoretical range resolution of 25 cm these two targets merge. The amplitude fluctuation of the area beside the car is resulting from the superposition of the reflected wave fronts of each modeled point scatterer. To separate both targets in range, the bandwidth has to be increased. With a bandwidth of 4 GHz, the pedestrian and the vehicle can be separated clearly as depicted in Fig. 6. Furthermore, the L-shape of the target car can be detected. It can be shown that for different radar cross sections of the targets the theoretically defined range resolution will be degraded and therefore more bandwidth is necessary.

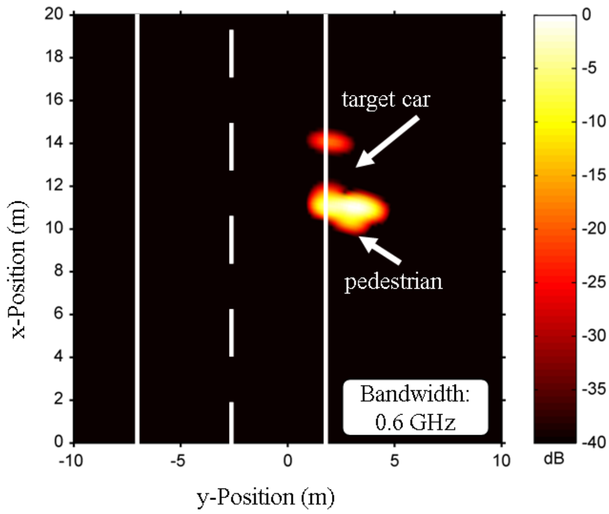

Figure 5. Simulation result of the 2-target-scenario at a bandwidth of 600 MHz. The target car and the pedestrian are merging.

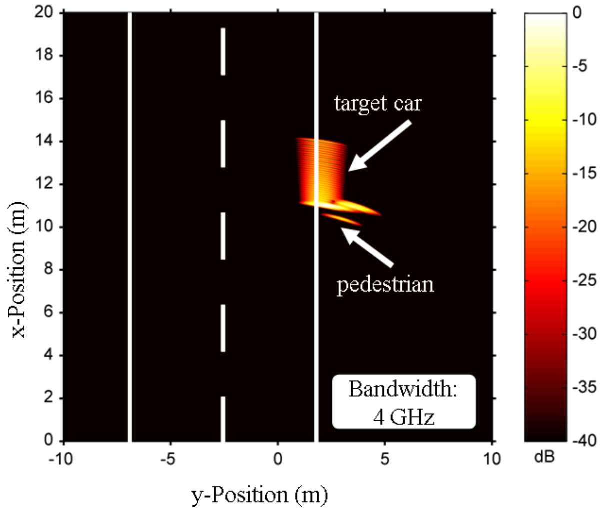

Figure 6. Simulation result of the 2-target-scenario at a bandwidth of 4 GHz. The target car and the pedestrian are separated clearly.

B. Sensor Intergration 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. 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 [8, 9], first results concerning sensor integration behind painted bumpers and particular LRR radomes are depicted. Some more investigations were carried out by Daimler within the project RoCC. Extensive studies of manufacturing tolerances and the composition of substrate materials as well as paint are in preparation. As a first result, Fig. 7 shows the transmission $|t|$ and the reflection $|r|$ through a bumper with metallic paint. The simulation was carried out with a multi-layer model implemented in Matlab. For the ideal case of properly chosen substrate thickness $d_{sub} = 3.44$ mm, the reflection $|r|$ can be found to be better than -20 dB for the whole SRR frequency band of 77 to 81 GHz. Introducing a variation of the equivalent permittivity of the paint would shift the desired minimum of $|r|$ to lower or higher frequencies. Nevertheless, the transmission $|t|$ stays approximately constant.

A radome that is robust against variation of the material parameters and thickness of substrate and paint has to provide an increased frequency bandwidth. In consequence, variations of dedicated scale would not seriously affect the radar performance. Thickness optimization as well as surface matching (introducing grooves as quarter wavelength transformer) both lead to radome designs that are too narrow-band for the integration of UWB radar sensors around 79 GHz. One radome design approach for improved frequency bandwidth is shown in [10]. Inductive structures on the back side of the bumper are used to compensate the effects of metallic paint. Although their behavior is already better than for the matching strategies mentioned before, the radome bandwidth is still not sufficient for future UWB SRR sensors. Therefore, Daimler works on broadband matching strategies during the second half of the project RoCC.

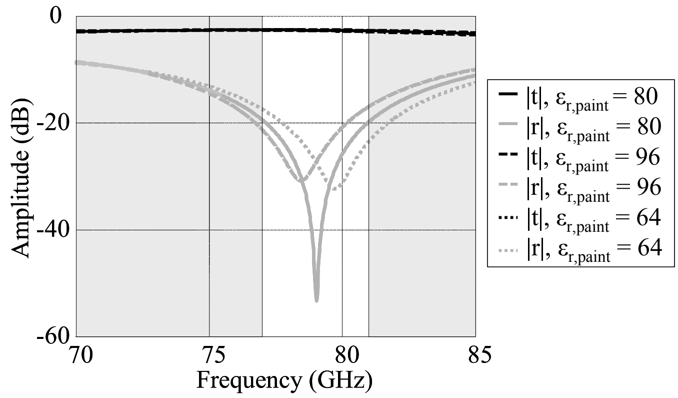

Figure 7. Simulation of transmission $|t|$ and reflection $|r|$ through a bumper with metallic paint. Variation of the permittivity of the paint $\varepsilon_{r,paint}$ shifts the reflection minimum.

C. Mutual Interference between 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 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 with 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 (e.g. 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 as well as measurements (e.g. explain how ghost targets are generated or how the signal-to-noise ratio is reduced)

- find efficient countermeasures (e.g. pseudo-random variations of the transmit signal to avoid the generation of ghost targets)
- test countermeasures in the lab and with vehicles.

First measurements were conducted to investigate the interference sensitivity of an FMCW radar. An experimental FMCW radar realized by the University of Ulm was used in conjunction with the waveguide-based measurement setup in Fig. 8.

Interference by a continuous-wave (CW) signal led to the appearance of a transient pulse in the radar's intermediate-frequency (IF) signal and thereby to an increase of the noise floor in the radar's range profile. The transient pulse can be seen in Fig. 9, Fig. 10 shows the increase of the radar's noise floor from below -60 dBm without interference to about -45 dBm.

Interference mechanisms will be further investigated to gain a precise understanding, in order to be able to design and to verify the effectiveness of countermeasures to minimize mutual interference.

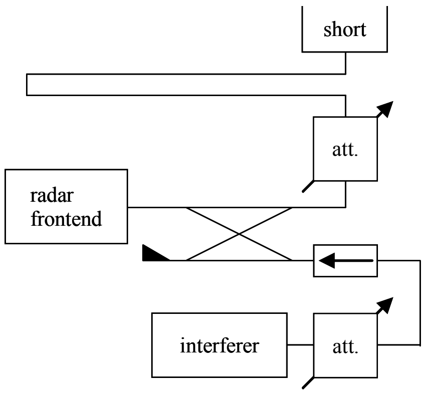

Figure 8. Block diagram of the waveguide-based measurement setup to demonstrate the effects of interference on an FMCW radar.

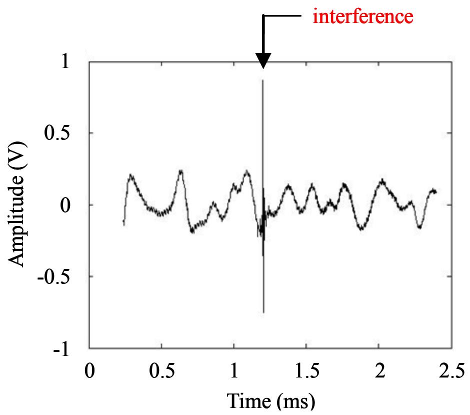

Figure 9. Measured FMCW radar IF signal with transient pulse due to CW interference.

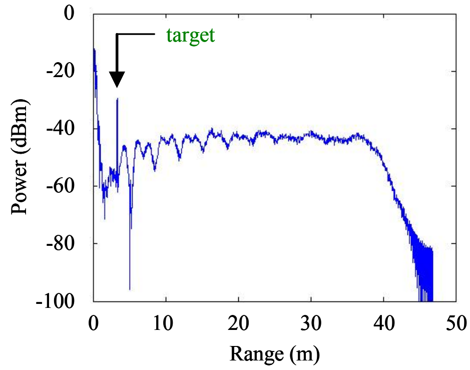

Figure 10. Measured FMCW radar range profile with an increased noise floor due to CW interference.

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 to commercialize the technology developed within KOKON and to support the availability of cost efficient and reliable 79 GHz UWB SRR products after 2013.

ACKNOWLEDGMENT

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