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79 GHz UWB automotive short range radar – Spectrum allocation and technology trends

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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, test and evaluation of realized sensor demonstrators. Recent UWB SRR frequency regulation approaches and activitites will be introduced. Furthermore, some first results of Daimler activities within RoCC will be presented, dealing with the packaging and operation of these sensors within the complex car environment.

1 Introduction

Automotive radar facilitates various functions which increase the drivers 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 drivers 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 precrash or collision mitigation. It was first introduced to the market in the Mercedes-Benz S-class under the name "Distronic". 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. Figure 1 gives an overview on possible (UWB) SRR based vehicle applications.

The need for a UWB bandwith is given by the application. E.g. the prediction of a possible collision needs a reliable object tracking capability. 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.

2 UWB SRR frequency allocation in europe

In 2004 and 2005, the EC and the ECC (Electronic Communications Committee of the CEPT) adopted decisions that regulate the temporary introduction of vehicular UWB SRR using 24 GHz spectrum in Europe until 1 July 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 added a fundamental review of its regulation, to be carried out by 31 December 2009, at the latest, to verify the continuing relevance of the initial assumptions concerning the operation of vehicular SRR and development progress

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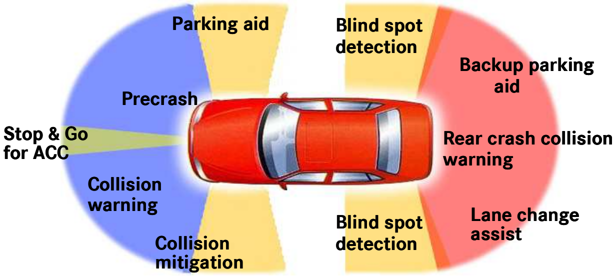

Fig. 1. SRR based assistance and safety applications.

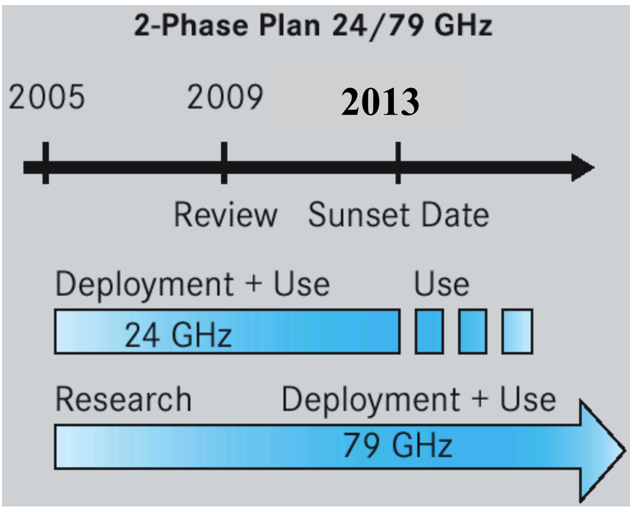

Fig. 2. European 2-phase-solution for 24 GHz UWB SRR frequency allocation.

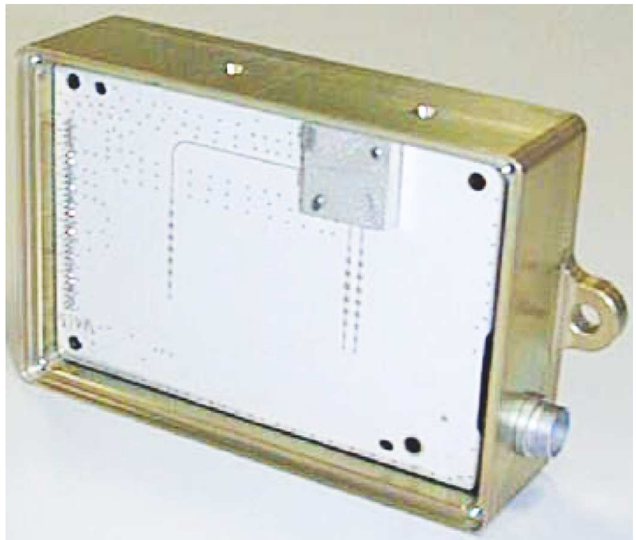

Fig. 3. 79 GHz UWB SRR demonstrator based on SiGe technology (source: Continental AG).

in the 79 GHz range technology. Automotive manufacturers base product lines on long lead times and assured access to technology. Meanwhile, there seem to be indications that 79 GHz UWB SRR products are probably not mature enough in time for car lines being launched in the years 2010/2011 and produced beyond 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 availability of 79 GHz UWB SRR sensors.

3 BMBF joint project KOKON

In comparison to 24 GHz, the frequency range around 77 GHz to 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 (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. 4).

4 KOKON successing project RoCC

Within the recently launched BMBF joint project RoCC (“Radar-on-Chip for Cars”, 2008–2011), the SiGe technology developed in KOKON shall be refined for production and application in sensor products. The RoCC consortium partners are BMW, Daimler, Bosch, Continental, and Infineon (Fig. 5). Main goals of RoCC are:

– affordable vehicle and road safety for everyone

– strengthening of technological leadership in automotive high frequency products and processes

– application based sensor specifications, 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

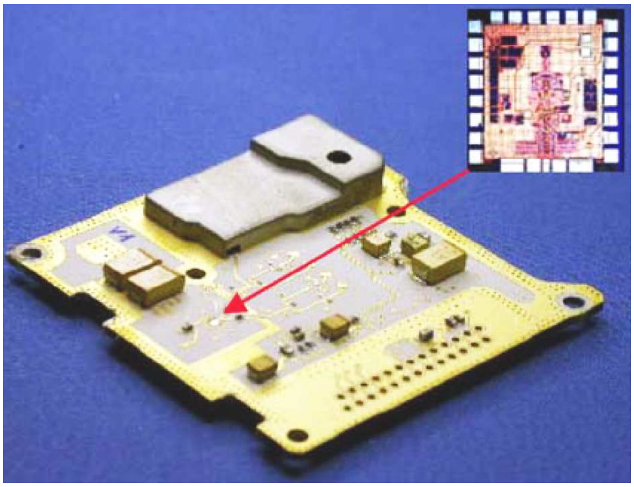

Fig. 4. Bosch 76.5 GHz ACC demonstrator realized in KOKON: RF board of the LRR2 sensor using SiGe-MMICs instead of split block components (source: Robert Bosch GmbH).

- 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.

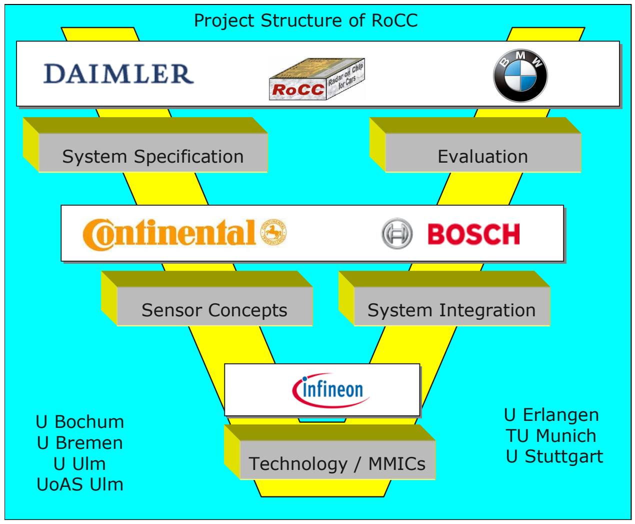

Fig. 5. Organizational structure of BMBF joint project RoCC, project partners and work packages.

Fig. 6. Front bumper of current Mercedes S-class.

5 Current activities of Daimler AG in RoCC

A. Sensor integration and packaging aspects

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 vehicles front- or rear-end have to be considered as radome structures (Figs. 6 and 7). 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)

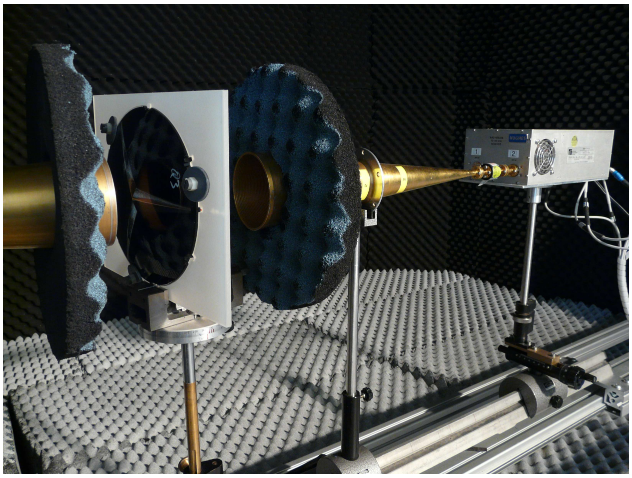

Fig. 7. Transmission measurement of LRR radome structure with vectorial, polarimetric, quasioptical setup.

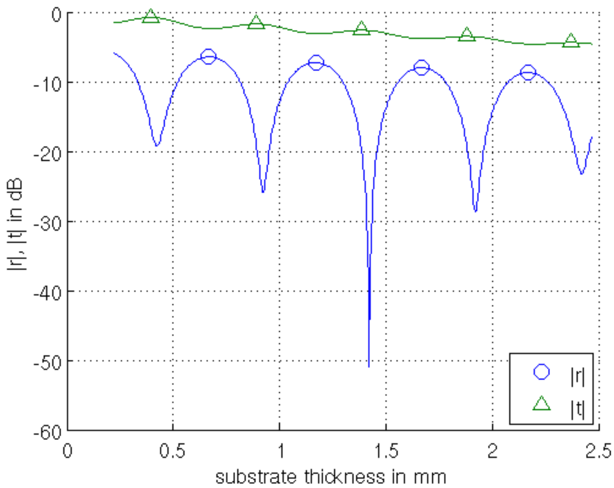

Fig. 8. Simulated transmission and reflection coeffixient for variation of substrate thickness in a multi-layer radome ($\varepsilon_{r,\text{substrate}}$=2.4, $\varepsilon_{r,\text{paint}}$=80 and f=79 GHz).

- manufacturing tolerances
- multiple paintings, especially repair paintings
- covering of radomes with water, snow, ice, dust or salt etc.

Within KOKON, it was shown that even metallic paintings with very large permittivity will not influence the radar operation inordinately, if certain design rules are applied. The main focus of the former investigations aimed towards optimizing metallic paint in terms of reduced loss and permittivity. Still, it is necessary to optimize the transmittive multi-layered radome structure for very low reflection. Varying the substrate thickness, it is possible to find a setup with

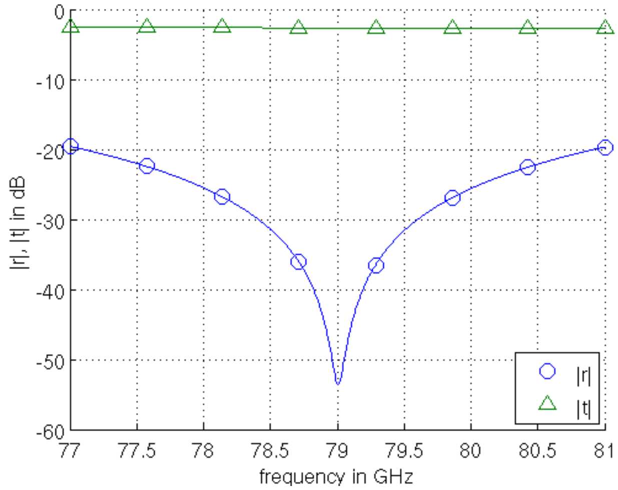

Fig. 9. Simulated transmission and reflection coefficient of the multi-layered radome shown in Fig. 8 with optimized substrate thickness d=3.44 mm.

a reflection coefficient of less than −20 dB in a very broad frequency band even for paint with permittivity as high as ε_r>80 (Figs. 8 and 9).

B. Investigation of interdependence of radar and object tracking in single- and multi-sensor systems

The request for driver assistance and active safety applications is increasing significantly. The functions shown in Fig. 1 require varying sensor output performance. Various suppliers and research groups offer and report sensors based on various principles and with very individual performance.

Either single sensors or sensor networks can accomplish environment perception around the car. One important parameter with severe influence on the functionality is the operating frequency bandwidth. The competing systems are narrow band and UWB radar sensors. Because of the bandwidth that is used, both systems will show different behavior concerning range resolution. Still, from the point of view of a safety application, this is not the only important factor. The sensor has always to be considered in its interaction with an object tracker. As a starting point, the focus lay on the application of SRR systems in pre-crash applications (Fig. 10). An ideal trajectory of a point target was corrupted with noise to simulate the inaccuracy of a real sensor (two upper curves in Fig. 11). Then, the surroundings of the sensor were discretized, and the detected obstacle was matched to a range cell (third curve in Fig. 11). This was done for two different antenna concepts. In the case of a beamforming antenna, one can consider angular and range cells, whereas in the case of a monopulse system, only range cells can be assigned. The cell that has been assigned is the input data of a tracker, a Kalman filter or extended Kalman filter, respectively. Varying parameters such as update rate, field of view, maximum

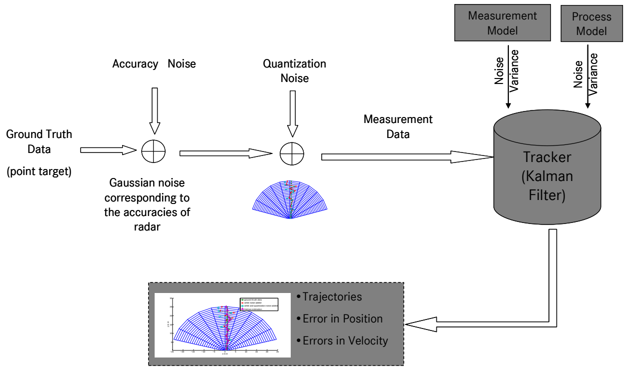

Fig. 10. Radar and tracking model for the investigation of sensor concepts in single- and multi-target scenarios (switched beam radar modeled using antenna coverage diagram and addition of Gaussian noise).

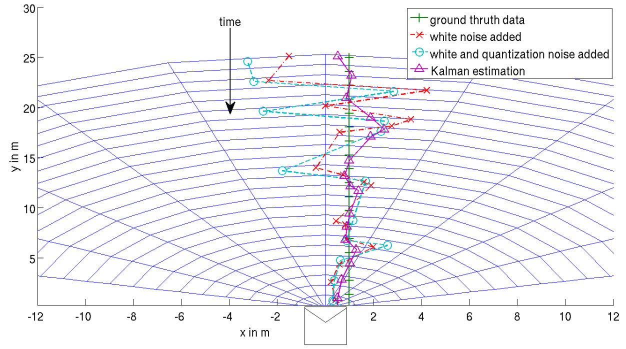

Fig. 11. Investigation of the influence of tracking on target detection in range and angle (edges of the vehicle at x=+/−80 cm). Point target position is corrupted (white noise), assigned to an angular and range cell (quantization noise) and estimated with a Kalman filter.

range, sensor resolution and accuracy allows to verify proposed sensor concepts and to create a knowledge base for the RoCC work packages sensor specification and sensor evaluation. Further work will be done by implementing typical multi-target scenarios for both beamforming and monopulse systems.

6 Conclusions

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, offers the application of the same 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.

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