New Automotive Applications for Smart Radar Systems

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Abstract
This paper gives an overview of the application of radars in the automotive field in general. A number of Advanced Driver Assistance System (ADAS) functions are described, and the special requirements of the automotive business are considered. Single- and multi-sensor setups are discussed. A new sensor category, a so-called Medium Range Radar (MRR: 40m) is introduced. The application-driven need for this kind of radar, filling the gap between short range radars (SRR: 15m) and long range radars (LRR: 150m) is explained. Concept, technical data and results of such a high performance MRR sensor are given.

I. Introduction

One first traffic application of radar technology was invented by Christian Huelsmeyer, described in a well known German patent certificate dated April 30, 1904. Since this time many different radar systems have been developed for vehicle, vessel and air traffic control in several civil, transportation or defense applications.

Beside some early experiments of radar pioneers in the automotive industry's research departments (see photograph), a true technology and business driven new market for smart radar sensors started to develop in the early nineties for trucks and passenger cars. The typical requirements for automotive sensors, components and subsystems are:

- high volume production (in the order of a few 100k units/year)
- low cost figures (in the order of less than up to a few 100EUR)
- simple manufacturing process, no end-of-line calibration
- no servicing over the full lifetime
- high robustness (temp./vibration/dirt)
- new product introduction every 2y. / product lifetime 4-8y.

Thus economical and manufacturing conditions in this market are completely different with respect radars for defense applications. One first application for automotive radar sensors was the Adaptive Cruise Control (ACC) function. It was introduced first in passenger cars in 1998 as a comfort feature. (The cruise control systems previously controlled speed only but did not control the distance to the vehicle ahead).

Every leading car manufacturers today does want to exclusively introduce new electronics and sensor technologies, and everyone wants to do this first. Hence the latest radar innovations are quite welcome in the "scene", and based on the positive technical experiences with the LRR based ACC function, in the last few years many additional ADAS applications have been under evaluation or development at the OEM's labs. The key requirement for most functions is: a high performance, flexible and inexpensive smart sensor.

II. Automotive Applications

In the list below a number of functions are given along with a brief description and some key questions from the radar expert's point of view. The list can not complete, and we have to consider that different OEMs have different names as well as a slightly different understanding for their desired functions. Each OEM has its own predicted sequence for the introduction of those functions. It depends on what the customer research & marketing studies have identified so far as functions a customer is willing to pay for.

Sensor and Display (Comfort)

Parking Aid. Invisibly mounted distributed sensors behind the bumpers replace ultrasonic technology. Key questions: Cost, Number of sensors, Minimum Range, Frequency Approval Problems.

Blind Spot Surveillance. The zones beside a vehicle are covered by radar sensors, a warning is displayed when the driver is about to change the lane but the (radar) field of view is occupied. Key questions: Cost, Mounting position.

Vehicle Control related (Comfort + Control)

ACC. Longitudinal vehicle control at constant speed with additional distance control loop. Key questions: Cost, only narrow field of view, vehicle-lane association, for use on Autobahns only, restricted velocity interval of operation, Stop function only, Function is already available in series production.

ACC plus. Improve the handling of cut-in situations with a wider field of view at medium range. Key questions: Cost, Sensor fusion, Usage on motorways, Stop function only.

ACC plus Stop & Go. Improve/allow the vehicle control function in an urban environment, complete coverage of the full vehicle width. Key questions: Cost, Number of sensors, Mounting positions, Sensor fusion, Liability issues related to automatic "Go".

Restraint Systems related (Safety)

Closing Velocity Sensing. The main technical challenge in this application is to decide whether a crash will happen and to measure the impact position and speed before it happens to adaptively adjust thresholds/performance of restraint systems (which are not fired by the radar system). Key questions: Cost, Low False Alarm Rate, Number of sensors, Mounting position.

Pre-Crash Firing for Reversible Restraints. See above. In this case reversible restraint systems (like electrical belt tensioners) or pedestrian protection systems (like bonnet lifters) are fired by the radar system. Key questions: Cost, Very Low False Alarm Rate, Number of sensors, Mounting positions.

Pre-Crash Firing for Non-Reversible Restraints. See above. Non-reversible restraint systems (like airbags) are directly fired by the sensor system. This can be done even before the crash happens, crash position and severity selective. This function is of most importance for side crashes to gain a few life-saving milliseconds to fire before the crash happens. Key questions: Cost, Ultra Low False Alarm Rate, Number of sensors, Mounting positions, Sensor fusion, Liability issues.

Collision related (Safety + Control)

Collision Mitigation. See restraint systems related functions. The sensor system detects unavoidable collisions and applies full brake power (by overruling the driver). Key questions: Cost, Ultra Low False Alarm Rate, 3rd dimension information (height above lane) required, Number of sensors, Mounting positions, Sensor fusion, Liability issues.

Collision Avoidance. Future function, the vehicle would automatically take maneuvers to avoid a collision and calculate an alternative path, overruling the driver's steering commands.

As cost is always an issue, the OEMs wish to use a sensor system that is able to accomplish at least two new applications at the same time, with a minimum number of (flexible platform) sensors applied [1]. Regarding the sequence of introduction, it should be mentioned that official organizations are already evaluating the feasibility of certain functions and a forced introduction is under discussion.

III. Automotive Radars – Categories and System Designs

The general requirement for automotive radars is to detect any targets in the field of view with high probability, high accuracy and low false alarm rate. Automotive sensors usually operate in the dedicated frequency band of 76.0 – 77.0GHz. Beside this technology, today SRR sensors are under development in the 24.0 –24.25GHz ISM band. They are supposed to be less expensive but still provide the advantages of microwave based sensing with respect to laser sensors and video cameras.

High performance automotive radars measure target range, azimuth and radial velocity simultaneously in a short time and have the ability to resolve reflectors in multiple target situations. The main technical challenge lies in the waveform, antenna and signal processing design.

Sensor Categories

Although many other ways to technically distinguish radars would be possible, one simple but suitable parameter is the maximum range. Therefore LRR with a maximum range of 150m, MRR with a maximum range of 40m and SRR with a maximum range of 15m shall be distinguished. Their application for the automotive functions listed above is given in the following table.

Function	Requirements Range/Velocity Field of view	Sensors, Category	Proposed Radar Principle	Proposed Carrier Freq.	Alternative Sensors	Remarks
Parking Aid	- 0.2...5m - 0...±30km/h - full vehicle width	2-4xSRR per bumper	UWB Pulsed	24GHz	Ultrasonic	- 100ms cycle time
Blind Spot Surveillance	- 0.5...10m/0.5...40m - reasonable velocity interval - two lanes beside vehicle	1-2xSRR or 1-2xMRR per side	FMCW/ FSK/ Pulsed	24GHz	Video/ Laser	- 50ms cycle time
ACC	- 1m...150m - reasonable velocity interval - three lanes in front of vehicle in 65m	1xLRR	FMCW/ FSK/ Pulsed	77GHz	Laser	- 50ms cycle time
ACC plus	- 1m...150m/0.5...40m - reasonable velocity interval - three lanes in front of vehicle in 20m	1xLRR/ 1xMRR	FMCW/ FSK/ Pulsed	77GHz/ 24GHz	Laser	- 50ms cycle time - Laser/Video sensor fusion reasonable
ACC plus Stop&Go	- 0.5m...150m/0.5...40m - reasonable velocity interval - three lanes in front of vehicle in 10m - full vehicle width in 0.5m	1xLRR/ 2xMRR	FMCW/ FSK/ Pulsed	77GHz/ 24GHz	Laser	- 50ms cycle time - Laser/Video sensor fusion reasonable
Closing Velocity Sensing	- 0.5m...10m/0.5...30m - any velocity - about 45°	1xSRR/ 1xMRR	FMCW/ FSK	24GHz	None	- 10ms cycle time
Pre-Crash Reversible Restraints	- 0.5m...10m/0.5...30m - any velocity - full vehicle width in 0.5m	2xSRR/ 2xMRR	FMCW/ FSK	24GHz	None	- 10ms cycle time - function is add-on to line above, - very low false alarm rate
Pre-Crash Non-Rev. Restraints	- 0.5m...10m/0.5...30m - any velocity - full vehicle width in 0.5m	2xSRR/ 2xMRR	FMCW/ FSK	24GHz	None	- 10ms cycle time - function is add-on to line above, - ultra low false alarm rate, - laser/video sensor fusion requ.
Collision Mitigation	- 0.5m...150m/0.5...40m - any velocity - three lanes in front of vehicle in 10m - full vehicle width in 0.5m	1xLRR/ 2xMRR	FMCW/ FSK	77GHz/ 24GHz	None	- 10ms cycle time - function is Add-on to ACC plus S&G, - ultra low false alarm rate, - laser/video sensor fusion requ.
Collision Avoidance	- 0.5m...150m/0.5...40m - any velocity - three lanes in front of vehicle in 10m - full vehicle width in 0.5m	1xLRR/ 2xMRR	FMCW/ FSK	77GHz/ 24GHz	None	- 10ms cycle time - function is Add-on to line above, - ultra low false alarm rate, - laser/video sensor fusion requ.

Table 1: LRR, MRR and SRR

A LRR is typically implemented at 77GHz and used for ACC applications with a limited coverage (typ. 12°) in azimuth. ACC radar sensors are developed in many cases as multi beam antenna systems with sequential lobing technique. LRRs thus measure range, angle and relative radial velocity of multiple targets within typical cycle times of 50ms, and are applied as single units. In some cases the maximum range can be increased to 200m, but the higher the range, the bigger the problem of target-lane association becomes.

SRR sensors have been developed at 24GHz mainly for parking aid functionality, and are in most cases designed as Ultra Wide Band Pulse radars, measuring down to very low ranges (typ. 0.2m). Velocity is estimated from the range rate, and angle information is usually derived by triangulation techniques in a SRR (each having up to 60° beamwidth) network consisting of 2-6 units and a central triangulation/tracking processor [2].

FMCW-based MRRs can fill the gap between SRR and LRR regarding maximum range. The minimum range is usually less than 1m. They can be implemented as a radar network of distributed MRR and a central processing unit. But single sensor operation is also possible and is preferred in many cases for cost reasons. Measuring range, angle and relative radial velocity in multi-target scenarios at a time, they are capable of handling highly dynamic situations. For direct angular measurement either sequential lobing or monopulse techniques may be applied.

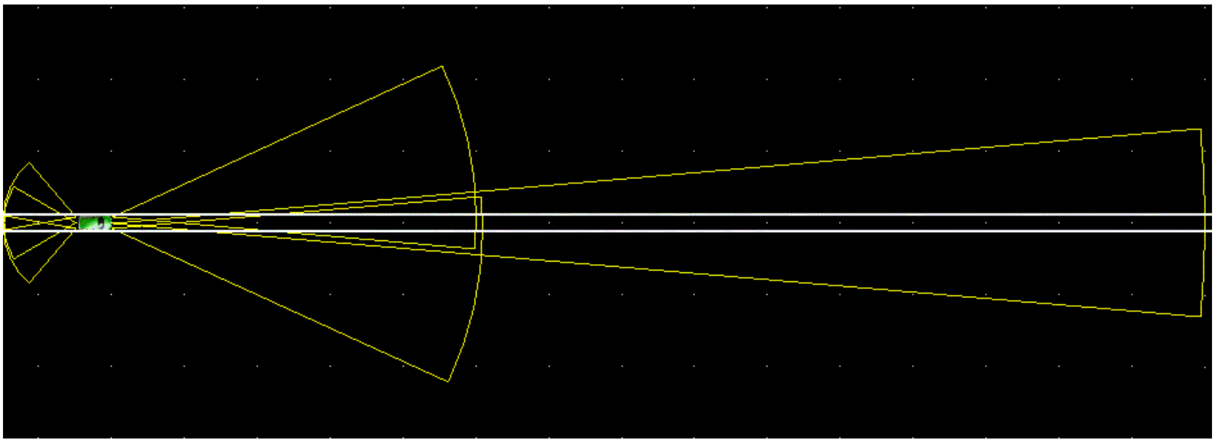

Figure 1: Example Radar Combination: 1xLRR(10°,150m), 2xMRR(30°,50m), 3xSRR(60°,10m)

The low total system cost is one of the key requirements for automotive applications. Therefore, in the first step single sensors that fulfil a certain function are of interest (like it was the case with ACC). The next functions to be introduced by the OEMs will certainly require a network of radars. A realistic example for an ACC plus Stop & Go function, in combination with a parking aid system in the rear bumper, is given in figure 1. Other than in standard radar setups where the field of view is represented by an angular sector, here in most cases it must be defined as a rectangle in Cartesian coordinates.

IV. An Example Medium Range Radar System

As specified above, the requirements for many new automotive applications are quite demanding. High speed, highly dynamic measurement situations, for example, require a direct measurement of relative target speed. For cost reasons, some functions have to be fulfilled by single sensor operation. Furthermore, for ACC plus and other functions an effective range of up to 40m is required.

Universal Medium Range Radar (UMRR)

Hence a new, flexible multifunction radar sensor concept has been developed. It is intended to keep the system cost low and still fulfil the requirements of several applications with a single radar sensor platform. The following design facts were considered:

- High performance system design being able to handle highly dynamic applications.
- Medium maximum range (typ. 40m).
- Direct measurement of range, angle and relative radial velocity.
- Conformity with RegTP/ETSI/FCC frequency regulations.
- Single sensor and sensor network operation.

A photograph of the sensor is shown in the following figure.

Figure 2: UMRR Radar Sensor

Concept

The bloc diagram of the UMRR is given in the figure below. A sensor consists of two components: RF frontend module and DSP module. The monopulse antenna was designed to allow for direct angle measurement.

The selectable FMCW/FSK waveforms have important influence on the overall system performance [3]. They do influence not only the technical performance parameters like range and velocity resolution and accuracy but has also a major impact to the resulting computation complexity. The multi-mode UMRR concept allows a flexible change between different waveforms which can be applied for different applications.

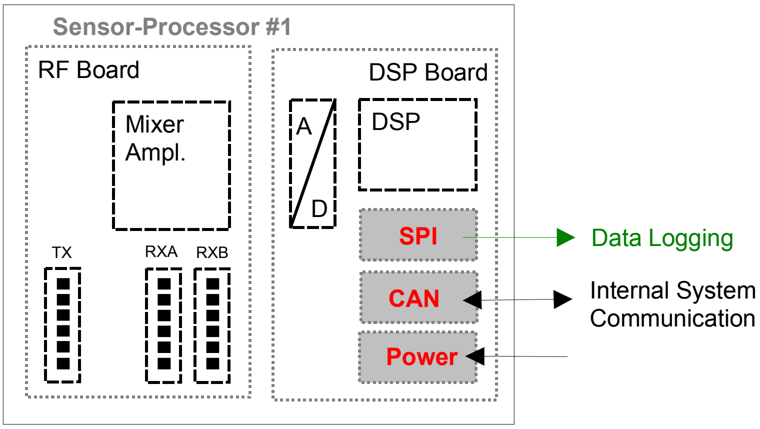

Figure 3: Bloc Diagram of the UMRR Radar Sensor

Technical Data

Some important technical data for the UMRR sensor are given in the following table.

Parameter	Value
Carrier Frequency	24.125GHz
Operation Principle	FMCW/FSK multi-mode
Maximum Range	40m
Velocity Interval	-25...+50m/s
Antenna Type	Patch Antenna
Field of View	30° (Azimut) x 16° (Elevation)
Size (including processor)	90x100x50mm (WxHxD)
Supply/Interface	12V/CAN

Table 2: UMRR Technical Data

Results
As an example, a radar network consisting of UMRR sensors has been implemented in an experimental car for testing the new technology in real street situations. A normal Autobahn situation is shown in the following figures (graphic: 40x30m). The measured results show the high potential of the UMRR sensor category for additional automotive applications.

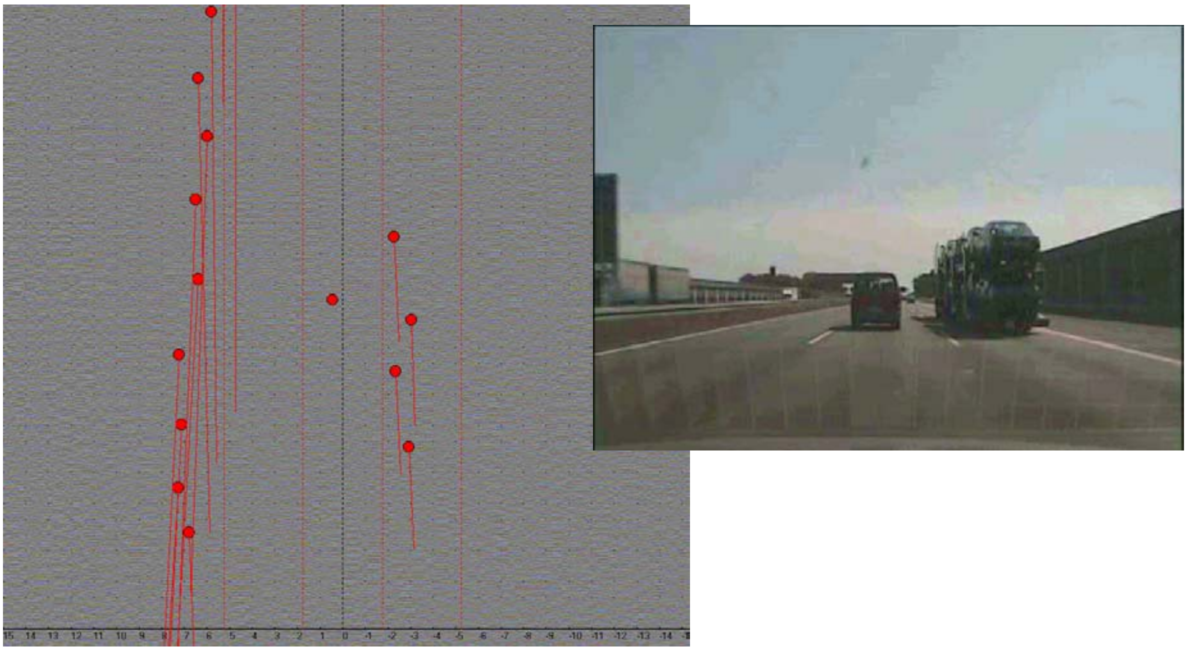

Figure 4: Autobahn scenario: detected radar targets and photograph of the situation.

V. Outlook

The development of radar systems for automotive applications is a challenging task for radar technology. But there there seems to be a big market for automotive radars. While in a number of years we may see all automotive sensors operating at 77GHz, in the near future it seems more realistic that 24GHz radar technology will be introduced in addition to the already existing 77GHz LRRs.

For cost reasons, multifunction sensors that are able to perform more that just one function will have a good chance on the market. Networks of radars will definitely be required to cover the specified fields of view. Those networks generate a need for sensor fusion strategies and algorithms [4]. Not only radar-radar, but also radar-laser and radar-video sensor fusion will be of importance. The combination of radar and video has excellent chances due to the complementary detection properties.

VI. References

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