Radar Target Simulator

Publik rapport

Författare: Lars Pettersson

Datum: 2018-11-05
Projekt inom Trafiksäkerhet och automatiserade fordon

FFI Fordonsstrategisk Forskning och Innovation

Innehållsförteckning

1 Sammanfattning 3

2 Executive summary in English 3

3 Bakgrund 3

4 Syfte, forskningsfrågor och metod 3

5 Mål 4

6 Resultat och måluppfyllelse 4

6.1 Architecture definition 4

6.2 Base-band domain 5

6.3 Front-end domain 5

6.4 AoA generation 5

6.5 Mapping of radar requirements for target simulator development 5

6.6 Measurement Campaign 6

6.7 Instruments and equipment 6

6.8 Measurement results 7

7 Spridning och publicering 7

7.1 Kunskaps- och resultatspridning 7

8 Slutsatser och fortsatt forskning 8

9 Deltagande parter och kontaktpersoner 8

1 Sammanfattning

Analys och teoretiska beräkningar av angle of arrival (AoA) problematiken har gjorts för att utröna om man kan på ett effektivt sätt lösa denna problematik. Den analys som gjorts inom projektet visar på att det är möjligt att hitta en framkomlig väg gällande detta genom att använda avancerade MIMO lösningar. Denna teknik kommer nu kombineras med ASGARD1 system för att teoretiskt sett simulera ett oändligt antal radarmål med deras radarmålegenskaper, detta överträffar dagens radarmålssimulatorer både vad gäller prestanda, flexibilitet och pris. Ett koncept för radarmålsimulatorarkitektur är analyserad och mätningar har utförts på kommersiella radarmoduler.

2 Executive summary in English

Analysis of angle of arrival (AoA) has been done in the project to solve the problem for constructing effective radar target simulators. The results show that it is possible to achieve this goal using advanced MIMO configurations. Thus, this will lead in the long run to high performance radar target simulators, which can simulate unlimited number of targets, target characteristics as well as their position and speed. Also, the price will decrease due to higher integration level and compactness of the radar target simulator. This report also presents a concept for radar target architecture. Measurements of commercial radar units has been done as well to understand more clearly what signals these radars generate.

3 Bakgrund

Automotive electronics is continuously becoming more complex, especially with regard to the rapid development towards autonomous vehicles and Automated Driving (AD). AD as well as Advanced Driver Assistance Systems (ADAS) depend on data and sensor fusion from several different sensors such as radar, camera, ultrasound etc. [1]. Both Narrow Band (NB) as well as Ultra-Wide Band (UWB) millimeter wave radar is among the most important vehicle components for sensing and evaluating the surroundings of the vehicle at both close as well as far range [2]. The radar ensures detection performance under harsh conditions, such as rain, darkness, bright sunshine, in which optical systems, such as camera and lidar, may not function in a reliable manner [3]. This makes the mm-wave radar a vehicle component crucial for safety and thus needs extreme function reliability. Testing of mm-wave radar is thus also very important, both for a sustainable production chain of the radar itself, but also for autonomous vehicles.

Sustainable production of mm-wave radar for autonomous vehicles or vehicles equipped with ADAS demands thorough production testing and evaluation of individual mm-wave radars. This would only be one part of the testing of the entire radar system of the vehicle. In addition, when the vehicle is fully assembled and the complete radar system, including multiple radars and sensor fusion, is ready to be used it should also be thoroughly tested. Each and every parameter and radar component need testing to ensure proper function.
Field testing of radar is costly and will not necessarily be relevant or practical for sustainable production of automotive radars or autonomous vehicles. It is thus necessary to create a radar test platform with a radar target simulator that can be set up and used in a controlled lab environment, or product test environment, and that can simulate a number of different kind of targets and scenarios, which often can be rapidly changing and complex. To simulate and test such complex test cases a RTS should be able to create and generate test signals that mimic the signals that would occur in the different real traffic test scenarios. This means simulating multiple targets at different speed and position both in distance and Angle of Arrival (AoA) in relation to the radar under test. Testing could also include relevant interfering signals or noise.

4 Syfte, forskningsfrågor och metod

The aim of this project was to conduct a pre-study which investigates feasibility of and prepares a concept for an RTS possible to use for both NB (76 GHz – 77 GHz) and UWB (77 GHz – 81 GHz) mm-wave radar. RTS based on this concept should have the potential to be both cheaper and more flexible as compared to the commercial RTS solutions available today. The project intended to address and answer the following questions:

- How can testing and production test results of individual radars and complete radar systems be ensured to meet the high demands and complex scenarios that the radar systems of autonomous vehicles will encounter?
- What performance and quality are needed for RTS for production testing of radars and radar systems for autonomous vehicles?
- Can the demands be met in a sustainable manner and to a relatively low cost?

The answers to these questions will be particularly important to the radar component and radar system suppliers for the automotive industry, production testing of radar systems for ADAS and autonomous systems for the automotive industry, as well as safety rating of radar systems for the automotive industry.

5 Mål

Projektet syftar till en undersökning för att förbereda inför ett efterföljande större projekt som föreslår att utveckla en lämplig prototyp mm-vågsradarmålssimulator som uppfyller behoven för fordonsradarmarknaden. Projektet ska utföra en analys av den senaste tekniken för mm-vågsradarmålsimulatorer, identifiera kraven för radarmålssimulatorn, och föreslå en arkitekturdefinition för radarmålssimulatorn som ska utvecklas i det senare projektet. Dessutom var målet för projektet att utföra några karaktäriserande mätningar på befintliga kommersiella mm-vågsradar.

Den viktiga slutsatsen från den teoretiska analysen och simuleringar som gjorts inom projektet visar på att MIMO liknade lösning visar på att beräkning av vinkel till objekt är möjlig. En teknik som är utvecklad för att kunna simulera avstånd, radar objekt storlek samt hastighet med ett obegränsat antal objekt kommer vara möjligt i många olika fiktiva komplexa situationer. Detta koncept kan möta en ökande efterfrågan inom bilindustrin att få till en mer billig, flexibel och kompakt lösning än vad som finns på marknaden idag.

Förstudien genomfördes i ett samarbete mellan RISE AB och Uniquesec. Arbetet har fördelats på partnernas kompetens och intresse. Genom regelbundna möten har flera frågeställningar och problemformuleringar kunnat lyftas upp och lösningar har kunnat ges. Genomförandet har skett systematiskt där varje partner tilldelats ett ansvarsområde som senare diskuterats och analyserats.

Genom detta förfarande har projektet i slutänden presenterat genomförbarheten av ett radarsystem som är relevant och grundat i den senaste forskningen inom området.

6 Resultat och måluppfyllelse

6.1 Architecture definition

The exact architecture of the RTS is not yet set, but the pre-study has led to several conclusions narrowing the scope of possible implementations:

- To generate AoA the RTS will have an array of antennas.
- Antenna elements can be realized with, e.g., wideband patch antennas or parallel horn antennas CNC milled from a single metal cuboid.
- Antenna separation is not necessarily the standard separation often used for antenna arrays. Simulation (see AoA generation section below) indicates that larger separations could be advantageous. E.g., it seems to lower power variations of the excitation signal in the RTS. Large separation between antennas basically means a distance bigger than 1λ.
- Number of antenna elements needs to be decided. It is possible to some limitation to steer AoA if number of antenna elements on the RTS is less than the number of elements at the radar. But optimal is if the RTS has equal amount or more antennas compared to the radar under test.
- Measurement distance radar to RTS is also something that has to be set. Around 200 mm gives good results in the simulations, but this needs more investigations. It is fully possible to vary the distance even after the RTS has been constructed.
- The amplitude and phase of the signal fed to each antenna needs to be possible to control individually by the RTS.
- Synchronization is needed for the signals fed to the antennas.

6.2 Base-band domain

The automotive radars are mostly (probably all) operating in the frequency domain. After sending a chirp with a certain bandwidth of B in the RF domain, they remove the chirp from the receive signal. This de-chirped signal contains the beat frequency corresponding to the distance delay and doppler frequency. The following expression explains the dependency of the beat frequency to the radar sweep parameters:

$$f_B = f_0 \frac{2}{c} v_r + \frac{B}{\tau} \frac{2}{c} R$$

Here, the sweep parameters include the bandwidth and sweep length. What is extracted on the radar side is thus essentially the beat frequency and the distance and speed calculated from it. To be able to create instantaneous speed and distance perception, we thus need to create corresponding instantaneous beat frequency.
When this instantaneous beat frequency is mixed with the radar signal at the RTS, this frequency is received in the IF section on the radar side and the radar will then receive exactly the right frequencies.

6.3 Front-end domain

The pre-study has concluded on a suitable front-end setup. It will consist of M parallel chains each having an I/Q modulator, antenna, and other supporting equipment. Number of parallel chains, M, will depend on a few design parameters, such as distance between radar and RTS in the test setup and the maximum AoA that shall be generated. Based on the studies in this project we foresee approximately three parallel channels for a first prototype to prove the concept. After verification and measurements of the three-channel version, an extension to a version containing up to eight parallel channels of the system can be implemented and tested.

6.4 AoA generation

The proposed RTS will, besides range, speed and RCS, also be able to generate targets at different angle of arrival (AoA) relative to the radar under test. To facilitate investigation of AoA generation a MATLAB model has been developed. This model takes into account number of antennas in the RTS, distance between RTS antenna elements, number of antennas in the radar under test, and the setup distance between radar and RTS.

So far, for simplicity, all antennas have been modelled as omni-directional, but this can be changed to something more realistic in the future. E.g., simulated radiation patterns, or EM simulations including both radar and RTS.

6.5 Mapping of radar requirements for target simulator development

Requirements and features for a future system has been mapped through a discussion with a reference group including representatives from both vehicle manufacturers as well as manufacturers of automotive radars. From this discussion we have been able to deduct a few specifications that are desired and could be used to set an ultimate objective for a future radar target simulator system. Below we list a brief summary of these specifications.
Today the most common radar type for the automotive industry is Frequency Modulated Continuous Wave (FMCW) and this is not expected to change. It is however still interesting to look at e.g. Pulse Modulated (PM). It is mainly 76-81 GHz that is of interest and a bandwidth of 4-5 GHz is likely needed.
Dynamic range of 60 dB desirable. Point cloud evaluation of radars put a higher demand on the requirement for number of generated targets. The possibility to simulate 20 targets could be considered a good starting point. For this reason, both angular and range resolution for the position of the simulated targets need to be quite good. A good aim is 0.1 degree for the angular resolution and 15 cm for the range resolution.
The radar target simulator also needs to be able to handle the full Field of View of the radar. For side looking radars this could be as much as ±60° while for front looking radars it might be enough with ±45°. Some automotive radars can function at distances as short as 0.5 m which would thus be good to simulate if possible. The maximum range possible to simulate should be at least 150 m.
Sensor fusion could possibly be an issue in future testing. It is not just the radar together with some other sensor, but also the fusion of data from several different radars. If using multiple radar target simulators, for multiple radars, they also need to be synchronized in some way to handle the fusion of the data from the different radars.
In addition to adding simulated targets it is desirable to test issues with e.g. coexistence or jamming of the radar which could perhaps be injected into the simulated scenarios.

Some of these features could be implemented independently from each other and perhaps the development of a future system could be done in parts where e.g. coexistence is tested without implementation of the simulated angle of arrival.
The results from the theoretical work and simulations performed within this project indicates that a MIMO-like solution for simulating AoA is possible. Compared to existing solutions for creating AoA in RTS, the MIMO

approach would be more versatile than mechanically changing the position of the RTS antenna and much more compact and less costly than the large antenna wall array. The combination with the technique used in e.g. the ASGARD1 system to generate target properties, such as distance, RCS and speed, for (theoretically) an unlimited number of targets it will be possible to simulate very complex scenarios.

When looking at trying to meet the expressed requirements for a future system the already existing technology that this project is built upon could fulfill all requirements but the generation of AoA. Although there are expressed requirements for the AoA possible to generate up to ±60°, the simulation results from this project only go as far as ±20°. There is little reason to think that this could not be expanded further. Many radars lose angular resolution towards the edges of their field of view and perhaps one could thus even accept a lower precision in the simulated AoA at higher angles.

The method does however come with drawbacks that need to be addressed. Specifically, how the channel matrix [A] is derived might need to be different depending on what kind of test is meant to be performed. If it is a complete radar system that is tested it could be enough to perform the feedback optimization, described in this report, which can be confirmed by measurements on simpler real targets. This would be useful for function testing rather than testing of the actual radar performance. For production testing a different approach might be needed so that it is known what is actually tested. One could e.g. imagine performing more intense testing with real targets on a "golden sample" produced by the manufacturer. The RTS would then train on this "golden sample" and the rest of the radars produced thus be tested on how they perform relative to that sample. For future work it would also be very interesting to perform more advanced EM simulations on a complete, set architecture and test object set-up. If such simulations agree well with real tests that could perhaps also be enough for production testing.

6.6 Measurement Campaign

There were two rounds of measurement campaigns performed at RISE (Borås) with the presence of participants from RISE (Borås and Norrköping) and Uniquesec. In total, there were 6 automotive radars from Continental, Veoneer (Autoliv) and Aptiv (Delphi). These radars were in both 24 GHz and 77 GHz bands. Following measurement instruments and equipment were used during these two measurement sessions.

6.7 Instruments and equipment

- Rohde and Schwarz FSW-43 signal analyzer with and without K60C transient analysis option
- Boonton 4500A RF peak power meter/analyzer
- R&S E-band harmonic mixer
- E-band horn antenna

- K-band horn antenna
- Power supply for radars
- Continental SRR2-A FCC-ID OAYSRR2A 24GHz
- Autoliv NB24 FCC-ID WU8NB24G175V1 24GHZ
- Continental ARS 404-21 FCC-ID OAYARS4B 77GHz
- Continental ARS 308 FCC-ID OAYARS3-A 77GHz
- Autoliv MMRv1 FCC ID WU877MMRV1 77GHz
- Delphi SRR2 FCC ID L2C0055TR 77GHz

A radar is mounted on a stand to the right in the image. To the left in the image is a horn antenna, receiving the radar signal, connected to a mixer. The mixer is in turn connected to the FSW-43 (located to the left just outside the picture) with which the radar signal is analyzed.

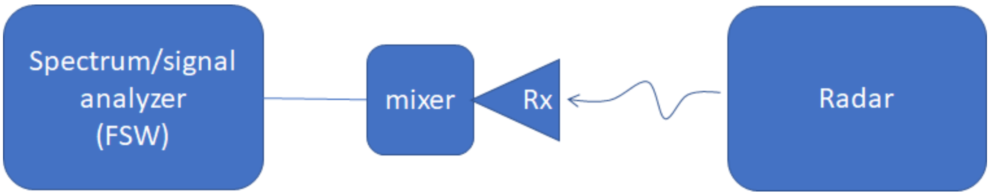

Figure 1. Radar measurement set up.

6.8 Measurement results

The strategy for base-band/IF signal creation proposed in this project requires the signal modulation parameters. For this reason, we were mostly interested in signal bandwidth and sweep length of the FMCW signals in these measurement campaigns. The signal analyzer had a limitation on the bandwidth of the signal and the sweep length measurement was thus limited within the FSW bandwidth. The slope could however still be correctly calculated.
In the following table a summary of the results is shown:

Radar	SRR2-A	NB24	ARS 404	ARS 308	MMRv1	SRR2
Bandwidth	188 MHz	194 MHz	461 MHz	223 MHz	974 MHz	303 MHz
Sweep length	8.36 us	516 ns	58 us	19 us	4.29 us	?
Frequency	24.24 GHz	24.125 GHz	76.5 GHz	76.5 GHz	76.5 GHz	76.5 GHz

7 Spridning och publicering

7.1 Kunskaps- och resultatspridning

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar

Öka kunskapen inom området	X	
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	
Föras vidare till produktutvecklingsprojekt	X	
Introduceras på marknaden	X	
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

8 Slutsatser och fortsatt forskning

- We need to study both in simulation and with real hardware the performance of the target simulation for different radars under test. Specifically, the AoA resolution deeply depends on the geometry of the deployment of RTS vs. radars and the position of radar/RTS antennas.
- Another, issue that we can study is the utilization of the calibration vector knowledge in improving AoA resolution.
- Most crucial step in the next phase should be prototyping the RF front end for 77GHz target system. This includes both design of the antennas, RF circuits and implementation of the entire system.
- The characterization of different specifications of this system in front of different radars would be also needed. Since, the complexity of the scenarios will be dependent on those specifications.
- More detailed and advanced EM simulations of complete set up with RTS and specific radar.

9 Deltagande parter och kontaktpersoner

Uniquesec,

Kasra Haghighi, kasra.haghighi@uniquesec.com

RISE Safety and Transport,

Henrik Toss, henrik.toss@ri.se

RISE Acreo

Duncan Platt, duncan.platt@ri.se