

# A dataset for radar scattering characteristics of vehicles under real-world driving conditions: Major findings for sensor simulation

Lukas Elster\*, Martin F. Holder\*, and Manuel Rapp

**Abstract**—In virtual validation of automated driving, trustworthy simulation models of perception sensors are required. Radar sensors are particularly hard to model, as their measurements are notoriously difficult to interpret. This is due to their complex measurement principle, involving multi-path propagation of mm-waves, varying backscattering characteristics of objects, and further factors such as limited measurement ranges and resolutions that introduce uncertainty to the measurements. This work presents a method for studying the backscatter characteristics of vehicles under real-world driving conditions. A slalom-like driving scenario, which is representative for road-driving where the vehicle is visible under different aspect angles, has been designed. It aims at a high level of reproducibility of the trajectories driven by the vehicles, hence reducing additional sources of uncertainty that were otherwise present in the measurements. In a large-scale measurement campaign, 13 vehicles have been studied. The vehicles-under-test are observed by multiple radars, mounted at different heights, and carry reference sensors for obtaining their positions. In this paper, we present the measurement campaign and show major findings from our measurement results. Our focus lies on drawing conclusions for trustworthy sensor simulation. Both sensor measurement data, and MATLAB code for data analysis are made publicly available alongside this paper.

**Index Terms**—sensor testing and evaluation, millimeter wave sensors, sensor model analysis



## I. INTRODUCTION

**V**IRTUAL test methods are required for the release of automated driving. Such methods use simulation models of the involved sensor modalities. Radar sensors are of the utmost importance for automated driving functions, due to their ability to measure relative velocity, robustness against adversarial weather conditions, and low costs in comparison to frequency-modulated continuous-wave (FMCW) lidar systems.

Still, the development of simulation models of radar sensors, which are ready for deployment in simulation-based testing tool chains, is subject of current research. A research problem, that is closely linked to radar sensor simulation, is the ability to model mm-wave scattering behaviour realistically in virtual

environments. Radar measurement are known to have a noisy characteristic, which originates from the measurement principle. Physically interpretable quantities, such as range, velocity due to the Doppler effect, and angular positions are deduced from spectral analysis of modulated mm-wave signals.

The backscattered energy is dictating the existence and achievable accuracy of a radar detection. In radar theory, the physics for obtaining backscatter is conceptually absorbed in the radar cross-section (RCS) denoted as  $\sigma$ . It is a measure for the strength of the signal reflected by an object. Influencing factors include object size, geometry, material, wavelength, and aspect angle under which the object is visible to the sensor [1]. When inserted into the radar equation [2], as given in eq. 1, the received power  $P_{Rx}$  can be obtained.

$$P_{Rx} = P_{Tx} \frac{G^2 V_{\text{sep}}^2 \sigma \lambda^2}{(4\pi)^2 r^4} \quad (1)$$

Here,  $P_{Tx}$  denotes the transmitted power,  $G$ ,  $\lambda$  and  $r$  denote antenna gain, wavelength, and radial distance, respectively. This equation disregards the atmospheric attenuation and introduces  $V_{\text{sep}}$  as the so called shaking factor ( $0 \leq V_{\text{sep}} \leq 2$ ) to account for influences by multipath propagation.

The RCS is well known, or analytically available, for simple geometries such as flat plates, spheres, or corner cube reflectors (CCRs). Analytical models are, however, not available for large objects with complex surfaces, such as vehicles.

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# Suburbreal Drive A Scattering

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