U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA

DOT HS 813 648 January 2025

Passenger Vehicle Surrogate Test Target Radar Return Repeatability

This page intentionally left blank.

DISCLAIMER

Suggested APA format citation:

Zeits, R., Nagy, I., Peterson, B., Davis, I., Forkenbrock, G. J., & Neer, A. (2025, January). *Passenger vehicle surrogate test target radar return repeatability* (Report No. DOT HS 813 648). National Highway Traffic Safety Administration.

This page intentionally left blank.

Technical Report Documentation Page

1. Report No. DOT HS 813 648	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Passenger Vehicle Surrogate Test Target Radar Return Repeatability		**5. Report Date** January 2025 **6. Performing Organization Code** NSR-120
7. Author(s) Roger Zeits, Ian Nagy, Blair Peterson, Transportation Research Center, Inc. Ian Davis, Garrick J. Forkenbrock, Arden Neer, National Highway Traffic Safety Administration		**8. Performing Organization Report No.**
9. Performing Organization Name and Address NHTSA Vehicle Research and Test Center P.O. Box 37 East Liberty, OH 43319		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590		**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**
15. Supplementary Notes		

16. Abstract

This report identified the variance in the radar cross section (RCS) of one vehicle test device (VTD), a test surrogate designed to emulate a small passenger car. Additional RCS measurements were performed on various types of vehicles for comparison with the VTD. Descriptions of the test equipment, measurement process, evaluation method, and results are provided. The RCS consistency of the objects used to calibrate the radars used (two trihedrals) was successfully demonstrated. These results validate that the RCS variations observed for the VTDs can be attributed to the VTDs themselves, not to equipment or evaluation method limitations. Apart from one subset of the fixed angle scans, the RCS returns of the VTD repeatability study were found to be within their minimum percent of the applicable upper and lower boundaries defined by ISO 19206-3:2021 (ISO, 2021). Fixed angle reflection categorization tended to return a higher percentage of total return per region when a category value was not within the specified bounds. Vehicle measurements confirm the RCS boundaries and reflection categories defined ISO 19206-3:2021 (ISO, 2021) can be used to represent a VTD as well as a small passenger vehicle. It can be surmised that the variations in wheelbase and body shape cause all other vehicles, measured in this study, to be out of specified bounds to certain degrees.

17. Key Words vehicle test device, VTD, global vehicle target, GVT, radar cross section, RCS, advanced driver assistance system, ADAS, test track evaluations		**18. Distribution Statement** Document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, https://rosap.ntl.bts.gov.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	21. No. of Pages 65	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This page intentionally left blank.

Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

AEB	automatic emergency braking
CIB	crash imminent braking
FCW	forward collision warning
GPS	global positioning system
GST	guided soft target
GVT	global vehicle target
IMU	inertial measurement unit
ISO	International Organization for Standardization[1]
LPRV	low-profile robotic vehicle
POV	principal other vehicle
RCS	radar cross section
VTD	vehicle test device
VUT	vehicle under test

1 The ISO itself explains, "Because 'International Organization for Standardization' would have different acronyms in different languages (IOS in English, OIN in French), our founders decided to give it the short form ISO. ISO is derived from the Greek word isos (ίσος, meaning "equal"). Whatever the country, whatever the language, the short form of our name is always ISO." https://www.iso.org/about.

This page intentionally left blank.

Executive Summary

This report used ISO 19206-3:2021[2] procedures to identify the repeatability of measuring the radar cross section of one vehicle test device, a surrogate vehicle designed to emulate a small passenger car. RCS boundary lines from ISO 19206-3:2021 (ISO, 2021) that define the expected radar return of a real vehicle were included to compare results. Additional work was done on vehicles under tests of different vehicle types to compare VTD results against and to determine if the ISO boundaries define an accurate range for the VTD and similarly sized vehicles.

Details about the equipment used cover two calibrated objects, two radar sensors, the robotic device guiding the radar sensors, the VTD under observation, and nine vehicles under test are included. Further, a visual satellite overlay shows about where and how measurements were performed.

ISO 19206-3:2021 methods were used to calibrate radar sensors, scan vehicles, and compile data. Scanning techniques included fixed angle, varying range measurements and fixed range, varying angle measurements. Results from the fixed range, varying angle measurements were used for an additional evaluation technique called RCS angle penetration. The results section below includes both types of measurements and the RCS angle penetrations. Results include calibration objects (fixed range only), the VTD, and nine VUTs.

The RCS consistency of the objects used to calibrate the radars used (two trihedrals) was successfully demonstrated. These results show the RCS variations observed for the VTDs can be attributed to the VTDs themselves, not to equipment or evaluation method limitations.

Apart from one fixed angle scan subset, the RCS returns of the VTD repeatability study were within their minimum percentages of applicable upper and lower boundaries defined by ISO 19206-3:2021. Fixed angle reflection categorization tended to return a higher percentage of total return per region when a category value was not within specified bounds.

Vehicle measurements confirm the RCS boundaries and reflection categories defined ISO 19206-3:2021can be used to represent a VTD as well as a small passenger vehicle. We surmise the variations in wheelbase and body shape cause all other vehicles, measured in this study, to be out of specified bounds to certain degrees.

[2] Full title: Road vehicles — Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions – Part 3: Requirements for passenger vehicle 3D targets.

This page intentionally left blank.

Introduction

Performance testing of advanced driver assistance systems such as automatic emergency braking often requires the use of a test surrogate to safely elicit a response from the VUT. Unlike the object it is intended to emulate, the test surrogate is designed to withstand impacts from the VUT, should a VUT-to-surrogate collision occur. This feature helps to ensure the safety of those performing the tests and minimizes the potential for damage to the test equipment and/or VUT during test conduct. However, realism is also a critical consideration as the surrogate's appearance, from a sensor perception and/or object classification perspective, must not affect the response of the VUT in an unrepresentative manner.

The goal of the work was to use ISO 19206-3:2021 (ISO, 2021) procedures to identify the repeatability of measuring the radar cross section of one VTD, a surrogate vehicle designed to emulate a small passenger car. Additional work was done on different VUT classes and styles to compare against VTD results. RCS boundary lines from ISO 19206-3:2021 that define the expected radar return of a real vehicle were included to compare results.

This page intentionally left blank.

Test Equipment

This section covers equipment used to perform the measurements described in this research. All measurement sensors were mounted to a robotic cart with an attached inertial measurement unit for local positioning and tracking. This equipment also includes calibration objects used to correct the radar sensors' perceived RCS returns.

Radar Measurement Equipment

A robotic cart from Dynamic Research, Inc., called the ScanR, was used to perform, process, and display the radar measurements. The ScanR was primarily comprised of two automotive-grade radar sensors mounted to a height-adjustable bracket, an inertial measurement unit, and a self-propelled robotic cart that could be programmed to accurately approach the object being measured. Also included was a tablet with software used to calculate RCS values from the raw radar measurements, calculate and apply radar calibration factors, and to compare VTD RCS magnitudes against a library of reference values.

Table 1 provides an overview of the radar sensors[3] installed on the ScanR. Both radar sensors operate in the 76 to 77 GHz range.

Table 1. Technical Details of the Bosch and Continental Radar Sensors

Manufacturer	Description	Model	Frequency (GHz)	Distance Range (m)	Horizontal Field of View (degrees)	Typical Measurement Rate (ms)
Bosch	General Purpose Radar v1.0	F 037 S07 149	76-77	Up to 160	Near: ±42.6 Far: ±21.0	≈100 ms
Continental	Long-Range Radar Sensor	ARS 408-21	76-77	0.20 to 250	Near: ±60 Far: ±9	≈72 ms

To facilitate an accurate approach toward the object being measured, the ScanR uses an OxTS RT3000[4] inertial navigation system including an inertial measurement unit and real-time kinematic GPS. Figure 1 (left) shows the ScanR measurement cart and its equipment. Figure 1 (right) highlights the two radar sensors installed on the ScanR, where the Continental and Bosch sensors are shown on the left and right sides of the mounting arm.

[3] Bosch Engineering GmbH, Baden-Württemberg, Germany, and Continental Engineering Services, Continental Engineering Services, a division of Continental AG, Hanover, Germany.

[4] Oxford Technical Solutions Ltd., Middleton Stoney, United Kingdom.

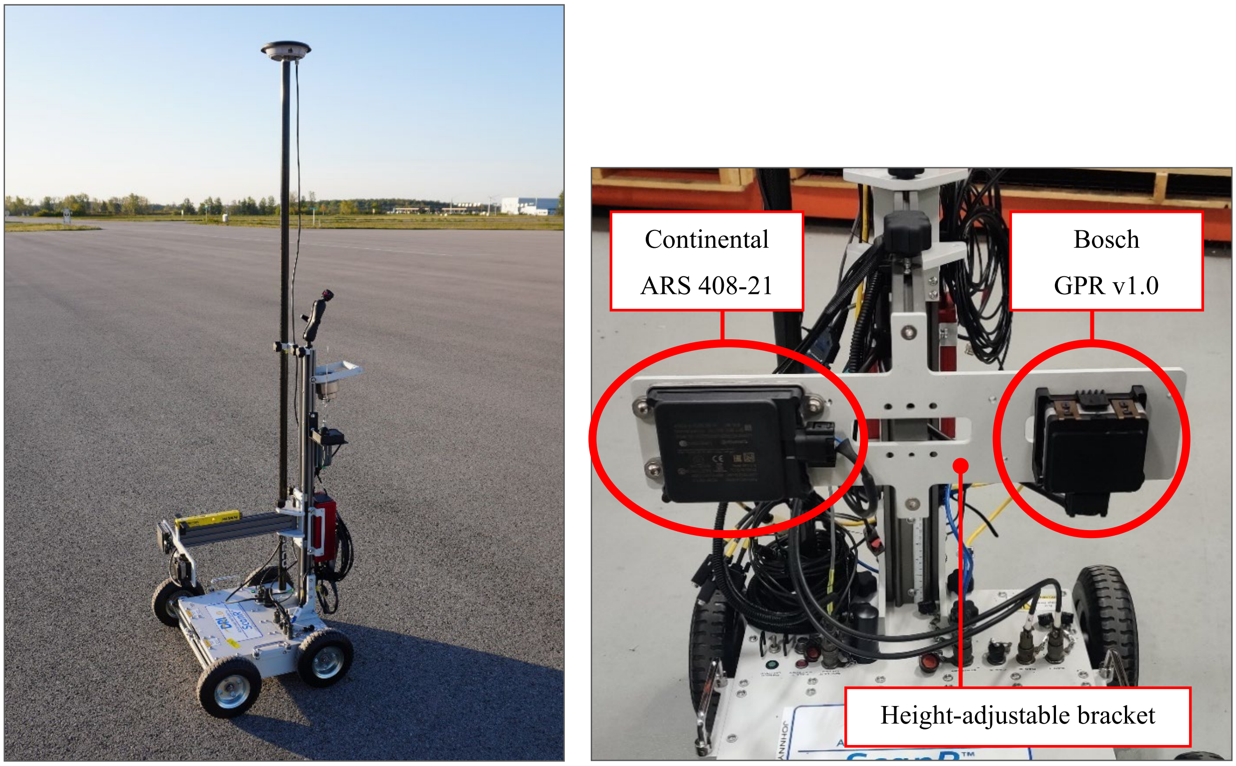


Figure 1. ScanR Measurement Cart (left) and Radar Sensor Closeup (right)

Trihedral Specifications (Calibration Targets)

Per ISO 19206-3:2021recommendations, each radar sensor was calibrated by performing reference measurements using two trihedrals of different sizes with known RCS characteristics. Each trihedral RCS was within one of the following two ranges specified in ISO 19206-3:2021: -20 dB-m^2 to 0 dB-m^2 for the smaller trihedral and 5 dB-m^2 to 20 dB-m^2 for the larger trihedral. Table 2 lists details of the trihedrals used.

Table 2. Trihedral Information

Manufacturer	Model	RCS at 77 GHz (dB-m^2)	Allowable Range* (dB-m^2)
Eravant[5]	SAJ-043-S1	10	5 to 20
Eravant	SAJ-020-S1-1.97	-3.6	-20 to 0

*As defined in ISO 19206-3:2021

[5] Eravant (formerly SAGE Millimeter, Inc.), Torrance, CA.

Each trihedral was mounted to a tripod and positioned with the face vertically level and its center located 480 mm above the ground. The tripod was occluded using radar absorbent material (MAST MF11[6] reticulated foam with a nominal thickness of 12.7 mm) attached to posterboard and positioned as shown in Figure 2.

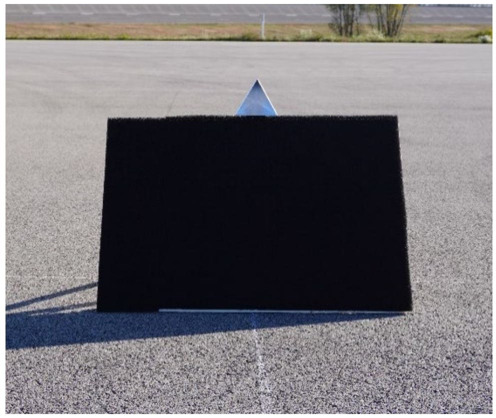


Figure 2. Example of a Trihedral Fixed to a Tripod Masked With Reticulate Foam

Vehicle Test Device

The VTD used was a DRI Soft Car 360. Euro NCAP has approved[7] this VTD for use in its AEB car-to-car test protocol as "[g]lobal [v]ehicle [t]argets (GVT)," stating that it "…meets the requirements as detailed in ISO 19206-3:2021" (European New Car Assessment Programme, 2024). The DRI Soft Car 360 used for this research was a model SC-FF-7 Revision G. This VTD was secured to the top of an AB Dynamics[8] GST 120 low-profile robotic vehicle (see Figure 3).

Figure 3. DRI Soft Car 360 Rear (left) and Front Passenger Corner (right) Profiles

---

[6] MAST Technologies, San Diego, CA.

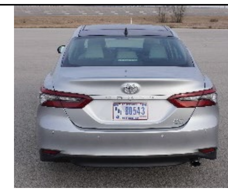
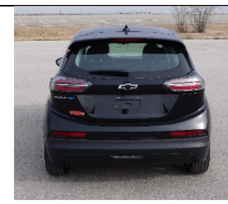
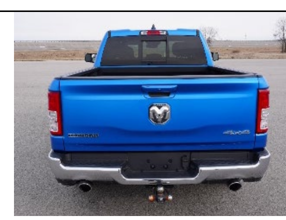
[7] When secured to an appropriate robotic platform. The VTD and robotic platform combinations used are Euro NCAP-approved configurations (Euro NCAP, 2024).

[8] AB Dynamics, also called Anthony Best Dynamics Limited, Bradford on Avon, UK.

Vehicles Under Test

Measurements were collected from a variety of vehicles for comparison with the VUT. Results were also used to determine if the ISO boundaries define an accurate range for the VTD and similarly sized vehicles. The vehicle used and vehicle class/style are listed and shown in Table 3. These were selected from the pool of available vehicles previously used for testing at NHTSA's Vehicle Research and Test Center. Additional profile images can be seen in Appendix A.

Table 3. Real Vehicle Details and Rear Profile Image

Class/Style	Year/Make/Model	Rear Profile Image
Sedan	2022 Toyota Camry	
Hatchback	2020 Chevrolet Bolt	
Minivan	2022 Honda Odyssey[2]	
SUV/Crossover	2022 Nissan Rogue	
Light-Duty Truck	2022 Ram 1500	
Tractor	2021 Freightliner Cascadia PT126SLP	

Class/Style	Year/Make/Model	Rear Profile Image
Tractor With Trailer	2021 Freightliner Cascadia PT126SLP and 53 ft trailer with no aero panels	
Straight Truck	2021 Ram 5500 Tradesman w/Kaffenbarger Truck Eq. Box Van Body	
School Bus	2023 IC Bus CE 78-Passenger School Bus (PB105)	

This page intentionally left blank.

Test Facility and Environmental Conditions

The following section covers where the measurements took place and the environmental conditions under which measurements were conducted.

Facility Location

ISO 19206-3:2021 specifies a 20 m wide and 110 m long facility for fixed angle, variable range measurements (enough for a 100 m approach plus an additional 10 m behind the object being measured) and a 40 m radius clearing centered about the test object for the fixed range, variable angle measurements. To accommodate these requirements, all measurements were performed at the Transportation Research Center Inc. SMARTCenter Urban East Roundabout. The ScanR measurement paths, relative to the center of the test object are depicted on the paved SMARTCenter Roundabout, are shown in Figure 4.

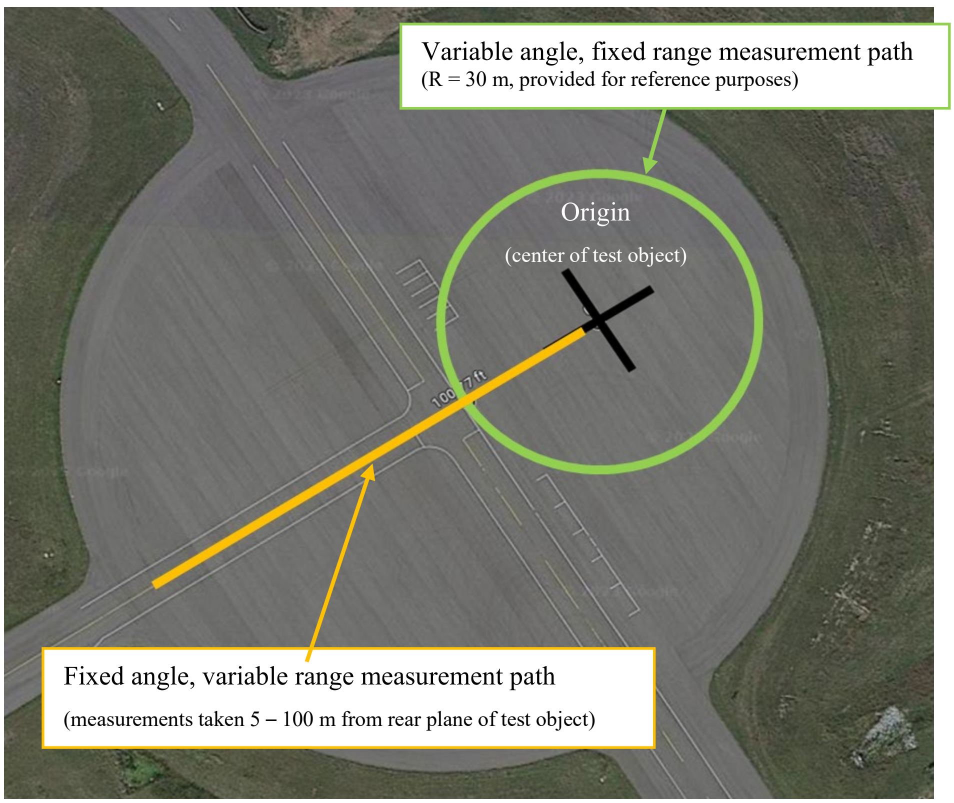


Figure 4. ScanR Paths and Origin Used at the SMARTCenter Urban Roundabout

Environmental Conditions

Radar measurements can be affected by environmental conditions; therefore ISO 19206-3:2021 states one environmental condition for test conduct, an ambient temperature between -5 ˚C to 40 ˚C. Rain can also cause radar signal degradation so all tests were performed when there was no active rain. The environmental conditions during the testing timeline are shown in Table 4.

Table 4. Weather Conditions Observed During Testing

Cloud Cover	Any
Sun Angle	Any during working hours (6:00 a.m. – 5:00 p.m.)
Precipitation	None
Surface Wetness	Dry to Damp (no standing water on test surface)
Ambient Temperature	0 ˚C to 38 ˚C
Wind	Up to 40 mph gusts

Test Methodology for Performing and Analyzing Measurements

The following sub-sections cover both test conduct and analysis of measurements. Sub-sections include specifications from ISO 19206-3:2021 of how testing should be conducted, and various aspects related to operating the equipment. The Analysis of Measurements section briefly covers the theory and background about how calibration data is used for determining RCS calibration values and how GVT measurements are evaluated.

Measurement Approaches

The left image of Figure 5 illustrates the fixed angle, variable range scans, where measurements are taken from 100 to 5 meters. A measurement approach of 180° is referencing an approach to the rear of the vehicle. Figure 5 right shows an approach for the fixed range, variable angle measurements, where a constant radius of 30 meters is followed for 360°. The 100-to-5-meter range and 30-meter radius are defined in ISO 19206-3:2021.

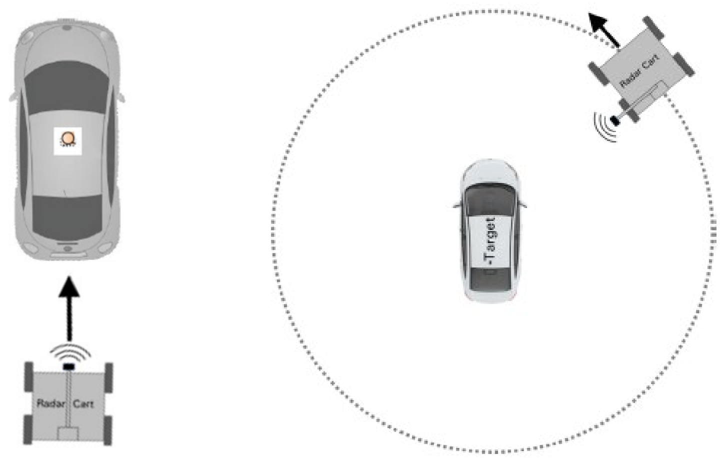


Figure 5. Fixed Angle (left) and Fixed Range (right) Measurement Positions defined in ISO 19206-3:2021 ("1" indicates the center of the vehicle)

Radar Sensor Heights

Using the ScanR's height-adjustable mounting bracket, the centers of the respective radar sensors were positioned at three heights relative to the test surface (230, 430, and 900 mm per recommendation by ISO 19206-3:2021. At each height, the ScanR was driven towards the face of a trihedral for calibration measurements, or to the 180° aspect of a VTD for fixed angle measurements over a distance ranging from 100 m to 5 m, or at a constant range of 30 meters for 360° around the object for fixed range measurements. Radar measurements were taken continuously during each approach. The practice of the three measurement heights compensates for radar signal fading, specifically multipath propagation. Wireless system signal fading is a known characteristic of wireless signals. Figure 6 illustrates the effect of signal fading on a fixed angle approach to the 10 dBm^2 trihedral. The composite line in Figure 6 represents the average of the measurements taken at the three heights, yielding an approximate true RCS return from 100 to 5 meters. Further detail on how the composite line is calculated is covered in Section 4.6. Signal fading will not be further discussed in this report.

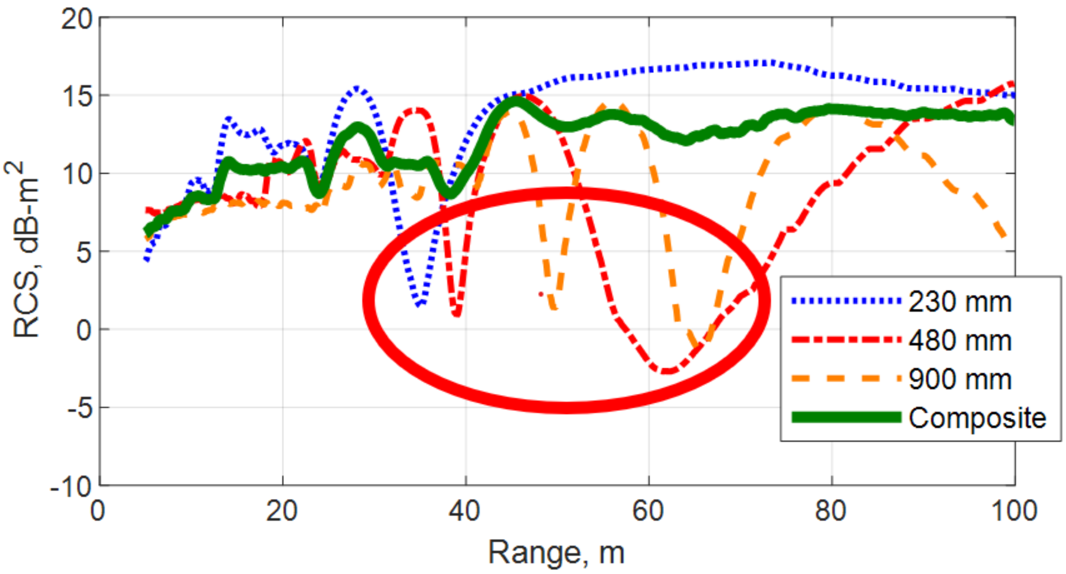


Figure 6. Example of Signal Fading Effect with a 10 dBm^2 Trihedral (Fading circled in red)

Radar Measurement Approach Velocity

ISO 19206-3:2021 states that the radar scans shall be performed in a manner that produces at least five measurement samples per meter for fixed angle, variable range measurements or five measurement samples per angular degree for fixed range, variable angle measurements. To calculate the ScanR velocity needed to satisfy this criterion, ISO 19206-3:2021 provides one equation for each measurement type. To avoid having to configure the ScanR to operate at different speeds for each measurement scenario, the outputs of both equations were considered, and the most conservative speed (i.e., the slowest) was retained for further use.

Equation 1: Maximum Velocity for Fixed Angle Measurments

$$v_{max,fixed\_angle} \leq \frac{1}{n\tau}$$

Equation 2: Maximum Velocity for Fixed Range Measurements

$$v_{max,fixed\_range} \leq \frac{2\pi R}{360 n\tau}$$

Where

R = the measurement range radius

n = the numbers of samples per unit of measure (meters in Eq. 1, degrees in Eq. 2)

τ = the time between sensor measurements (seconds)

Since each of the two radar sensors described in Table 1 were observed to have different output rates (based on a review of the reference times associated with the respective raw data points), the slower of the two values was identified and a conservative rate of 10Hz was used in Equation 1 and Equation 2 (which translates to τ = 0.1 s). Taking n = 5 samples per meter and setting R =

30 m (the radius specified in ISO 19206-3:2021 for fixed range measurements, which involve the measurement equipment being operated in a circle around the object being scanned), Equation 1 yields 2.0 m/s (7.2 km/h) and Equation 2 yields 1.0 m/s (3.6 km/h). Therefore, the ScanR was configured to operate at 1.0 m/s during collection of all measurements described in this report.

Radar Calibration Factor Determination

The radar sensors were calibrated using the procedure defined in ISO 19206-3:2021 Section C.3.4 prior to collecting general object measurements. The frequency of calibration varied depending on whether the VDT or the VUTs were being scanned. For VTD measurements, calibration occurred with every set of object fixed angle and fixed range scans (as seen in Table 5). For VUTs, calibration occurred once daily.

Table 5. General Measurement Set

Sensor Height (cm) (± 1cm)	**10 dBm^2 Trihedral Fixed Angle (180°)**	**-3.6 dBm^2 Trihedral Fixed Angle (180°)**	**Object Fixed Angle (180°)**	**Object Fixed Range (30m)**
23	✓	✓	✓	✓
48	✓	✓	✓	✓
90	✓	✓	✓	✓

The calibration process uses the fixed angle measurements taken from a range of 100 m to 5 m by each radar sensor, for each radar sensor height. The complete process was performed for each trihedral using software provided with the ScanR, and the calibration factors calculated for each trihedral were averaged to create a final (overall) calibration factor in units of dB-m^2 for each radar sensor. These calibration factors were then applied as an offset calibration (magnitude shift) to the respective RCS composites.

General Object RCS Determination

After collecting the calibration measurements, either the VTD or a VUT was centered about the origin and respective fixed range and fixed angel measurements were collected.

VTD Repeatability Schedule

Under the VTD repeatability study, one general measurement set was collected all within the same ScanR power cycle. Once the set was completed, the ScanR was powered down. The ScanR was powered back up after 15 to 30 minutes to ensure all equipment was completely powered down, and another general measurement set was collected. This process was repeated for a total of three times a day for 5 days. For this work, the three general measurement sets had to have all occurred within the same day. It was preferred for days to be consecutive but was not possible due to weather and available working days. This test matrix in Table 6 has the general measurement set broken out into the respective power cycles and days.

Table 6. Test Matrix for VTD Repeatability

VTD Repeatability					
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Power Cycle 1	✓	✓	✓	✓	✓
Power Cycle 2	✓	✓	✓	✓	✓
Power Cycle 3	✓	✓	✓	✓	✓

The purpose of this practice was to verify that signal fading and power cycling yielded minimal variability to measurements within the same day as well as across days.

VUT Schedule

After confirming that signal fading and power cycling effects to the radar sensors were minimal (from VTD Repeatability results discussed below), calibration measurements were reduced to once a day. This allowed for reduced overall measurement collection time and testing ease. Periodically, the ScanR experienced issues where the radar sensors would disconnect, or the steering would become erratic. Power cycling the ScanR was often required to resolve these issues. After an extended amount of scans the ScanR would also require being powered off to change the battery for continued testing. With the one set of calibration measurements per day expectation, if more than one real vehicle were scanned in a day, or multiple power cycles occurred, additional rows would be added to Table 7 for fixed angle and fixed range measurements. Additional columns were added for as many days required to scan all the listed real vehicles. It was required to perform both types of measurements of a single vehicle in the same day.

Table 7. Test Matrix for Real Vehicles

Real Vehicles				
	Day 1		**Day #**	
Power Cycle #	**GMS**		**GMS**	
	FA V#	FR V#	FA V#	FR V#

GMS General Measurement Set
FA Fixed Angle
FR Fixed Range
V Vehicle Scan Sub-Set
\# Additional as Needed

Analysis of Measurements

Analysis software was supplied by DRI with ScanR configured to evaluate the collected radar measurements. This software includes calculation of sensor calibration values for each radar sensor, RCS values, ISO RCS bounding, in-bound percentage for fixed angle and fixed range measurements, and spatial RCS regions for angle-penetration.

Calibration Value Calculations

Per ISO 19206-3:2021 specifications, the DRI ScanR software uses the following described method to calculate the calibration value. Data of each individual scan per trihedral is binned via 1-meter increments from 5-100. The data within the bins is averaged in units of meters squared to create a single value at each integer value. Next, all the binned RCS data is grouped for all three scan heights and the median RCS is determined. This median value, P_{cal}, is then factored against the known RCS of the trihedral, P_{meas}, via Equation 3. This results in the calibration factor, $K_{n,D}$, in units of dBm^2 where P_{cal} and P_{meas} are in units of meters squared. The calibration value for each trihedral of the general measurement set are averaged to obtain an averaged calibration value. This average calibration value is then applied to object RCS composite returns as a magnitude shift, raising or lowering the RCS return.

Equation 3

$$K_{n,D} = 10Log_{10}\left(\frac{P_{cal}}{P_{meas}}\right)$$

VTD RCS Return and Boundaries

Filtering of object RCS returns vary to that of the calibration process. Instead of binning the data, ISO 19206-3:2021 specifies that the largest returns should be filtered using a moving average window of 5.0 m for each scan height. To obtain the composite line, the filtered data should be averaged across the three scan heights.

Fixed Angle RCS Boundaries

ISO 19206-3:2021 defines that at least 92 percent of the filtered data points of the composite line must fall within the upper and lower boundaries to be considered valid. The upper and lower boundaries, B_U and B_L, are defined by Equation 4 and Equation 5 respectively as a function of range (*D*). Figure 7 illustrates these bounds plotted from a range of 5 to 100 meters for a view angle of 180°. Table 8 provides values of the terms used for the 180° view angle.

Equation 4: Upper Boundary Line

$$B_U = P_{FAR} - K_{DEC} * \min(D - D_{FAR}, 0)^2 + \Delta_P$$

Equation 5: Lower Boundary Line

$$B_L = P_{FAR} - K_{DEC} * \min(D - D_{FAR}, 0)^2 - \Delta_P$$

Table 8. RCS Boundary Parameters defined in ISO 19206-3:2021

Angle (°)	K_{DEC}**(dBm²/m²)**	D_{FAR}**(m)**	P_{FAR} **(dBm²)**	Δ_P **(dBm²)**
180	0.013	40	20	10

Where

B_U = *upper boundary (dBm2)*

B_L = *lower boundary (dBm2)*

D = range (m)

P_{FAR} = *average RCS at far distances (dBm2)*

D_{FAR} = *range beyond which the average RCS is PFAR (m)*

K_{DEC} = *factor of decreasing RCS as a function of distance (dBm2/ m2)*

Δ_P = *half width of the RCS boundary (dBm2)*

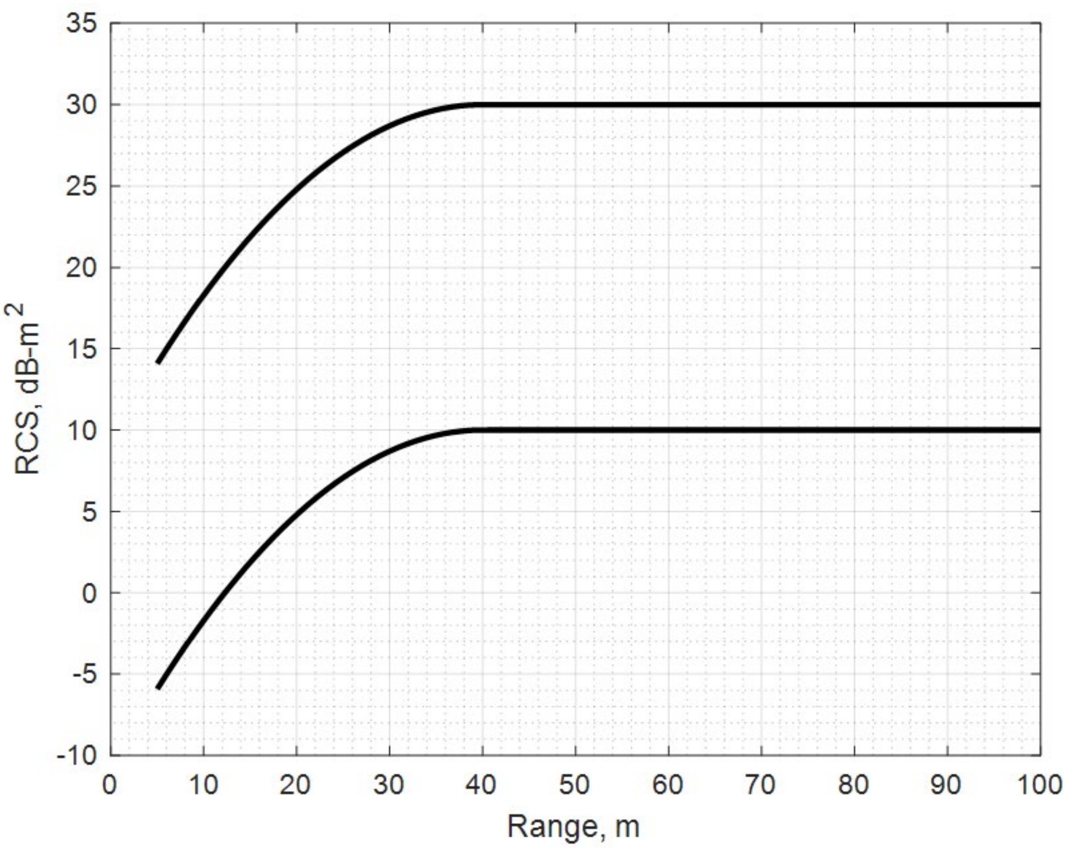


Figure 7. Illustration of 180° Fixed Angle RCS Bounds

Fixed Range RCS Boundaries

Like the fixed angle RCS boundaries, ISO 19206-3:2021 defines for fixed range approaches that at least 95 percent of the filtered data points of a composite line must fall within the upper and lower boundaries. The upper and lower boundaries are defined by a cubic spline function of the data in Table 9 and visually represented in Figure 8. For the boundaries to form correctly about 0° and 180°, Table 9 must be extended by 90° to -90° and 270°.

Table 9. Fixed Range RCS Boundary Breakpoints defined in ISO 19206-3:2021

Angle (°)	Lower boundary (dBm^2)	Upper boundary (dBm^2)
0	1	19
10	-4	14
30	-6	8
60	-5	12
80	-2	20
90	13	30
100	-2	20
120	-5	12
150	-5	12
170	-2	18
180	2	25

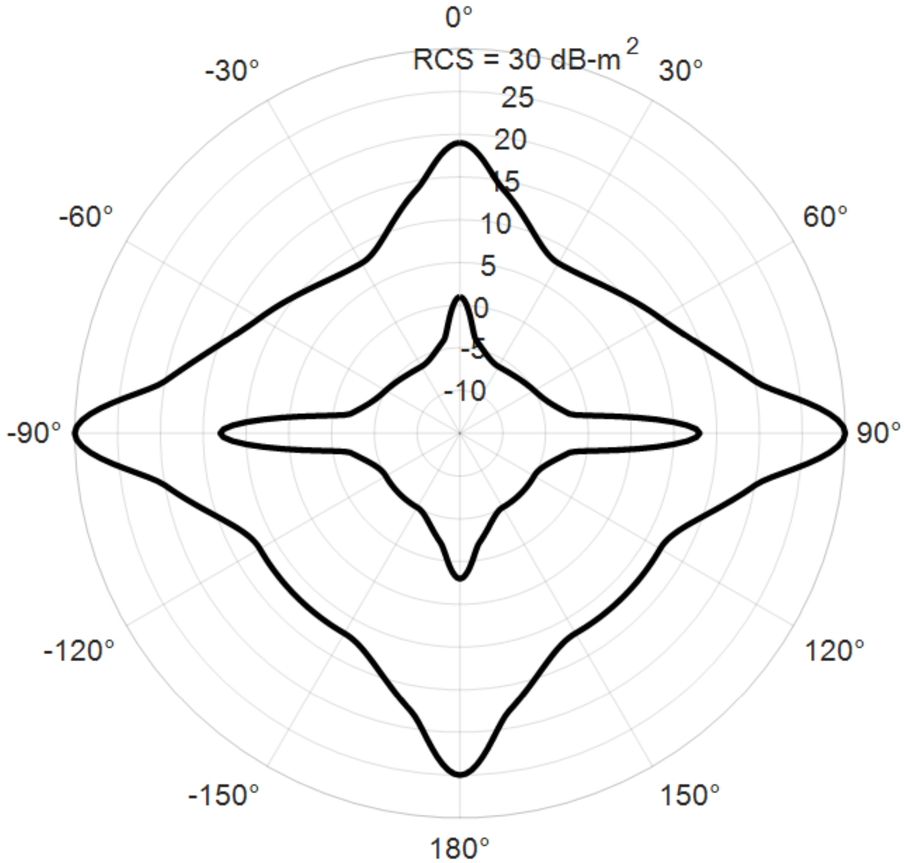
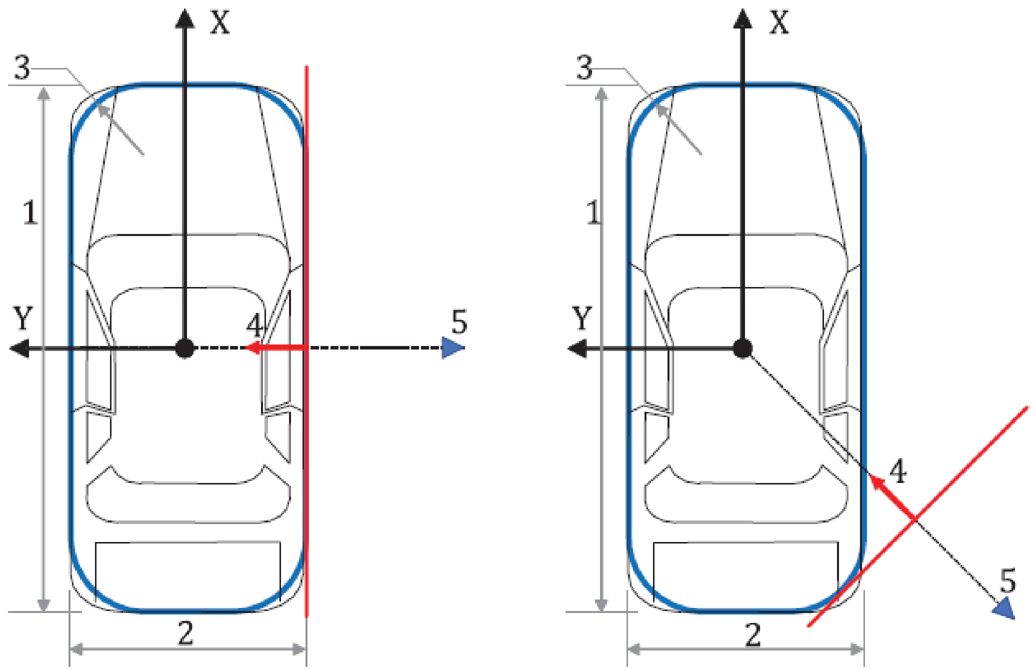


Figure 8. Illustration of Fixed Range RCS Boundaries

RCS Angle-Penetration

An additional aspect of analysis for fixed range measurements is evaluating the depth of measurements in respect to specific viewing angles. Figure 9 illustrates two example viewing angles and direction of penetrations. This method results in every RCS return to be rated with a specific penetration distance.



Key

1 vehicle length, L_V

2 vehicle width, W_V

3 vehicle corner radius, R_V (= $W_V/3$)

4 penetration distance, D_P

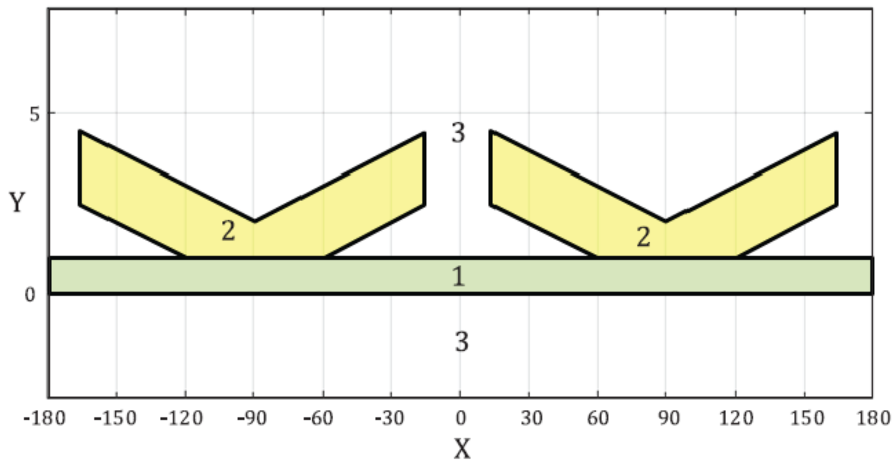
5 radar sensor

Figure 9. Penetration Distance Example for Viewing Angle of -90° (left) and -135° (right) Defined in ISO 19206-3:2021

Each RCS return is plotted against its associated penetration distance and categorized into one of three regions. The power in each region is summed in units of meters squared to determine the percentage of total power within each region. The percentage in each region must be within a specified range defined by ISO 19206-3:2021. The regions and associated power ranges can be observed in Table 10 and Figure 10. The dimensions for regions 1 and 2 are not explicitly defined in ISO 19206-3:2021 and can only be inferred from Figure 10 within the ISO document. However, the analysis software provided with the ScanR has these boundaries defined (as seen in Table 10) and can perform the calculation to determine the percentages within each region.

Table 10. VTD Radar Power Reflection from each Vehicle Region

<table>
<tr><th>Region</th><th>Description</th><th>Angle (degrees)</th><th>Penetration Distance (m)</th><th>Reflection Power Percentage (%)</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">Primary Reflections</td><td>-180</td><td>-0.1</td><td rowspan="4">86 – 95</td></tr>
<tr><td>180</td><td>-0.1</td></tr>
<tr><td>180</td><td>1.0</td></tr>
<tr><td>-180</td><td>1.0</td></tr>
<tr><td rowspan="14">2</td><td rowspan="14">Internal Reflections</td><td>-120</td><td>1.0</td><td rowspan="14">2 – 14</td></tr>
<tr><td>-165</td><td>2.5</td></tr>
<tr><td>-165</td><td>4.5</td></tr>
<tr><td>-90</td><td>2.0</td></tr>
<tr><td>-15</td><td>4.5</td></tr>
<tr><td>-15</td><td>2.5</td></tr>
<tr><td>-60</td><td>1.0</td></tr>
<tr><td>60</td><td>1.0</td></tr>
<tr><td>15</td><td>2.5</td></tr>
<tr><td>15</td><td>4.5</td></tr>
<tr><td>90</td><td>2.0</td></tr>
<tr><td>165</td><td>4.5</td></tr>
<tr><td>165</td><td>2.5</td></tr>
<tr><td>120</td><td>1.0</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Extraneous Reflections</td><td>-180</td><td>-3.0</td><td rowspan="4">0 – 4</td></tr>
<tr><td>180</td><td>3.0</td></tr>
<tr><td>180</td><td>7.0</td></tr>
<tr><td>-180</td><td>7.0</td></tr>
</table>



Key
X View Angle
Y Penetration Distance

Figure 10. VTD Spatial RCS Regions for Angle-Penetration Method Defined in ISO 19206-3:2021

This page intentionally left blank.

Results

In this section, results from the calibration trihedrals, VTD, and VUTs are presented visually. Specifically, composite RCS magnitudes defined in ISO 19206-3:2021 are shown.

Calibration Trihedral Results

The trihedral measurements used for radar calibration were recorded from September 5 to February 20, 2024. All 18 measurements were taken with the trihedrals located at the same origin on the test track and with identical approach paths. Figure 11 presents the 18 respective composite RCS data traces shown for each trihedral and radar sensor combination. Figure 12 provides the average calibration factors (i.e., including results from both trihedrals) derived from the composite RCS measurement. These were then used to correct the RCS measurements recorded on the respective measurement day, for each radar sensor.

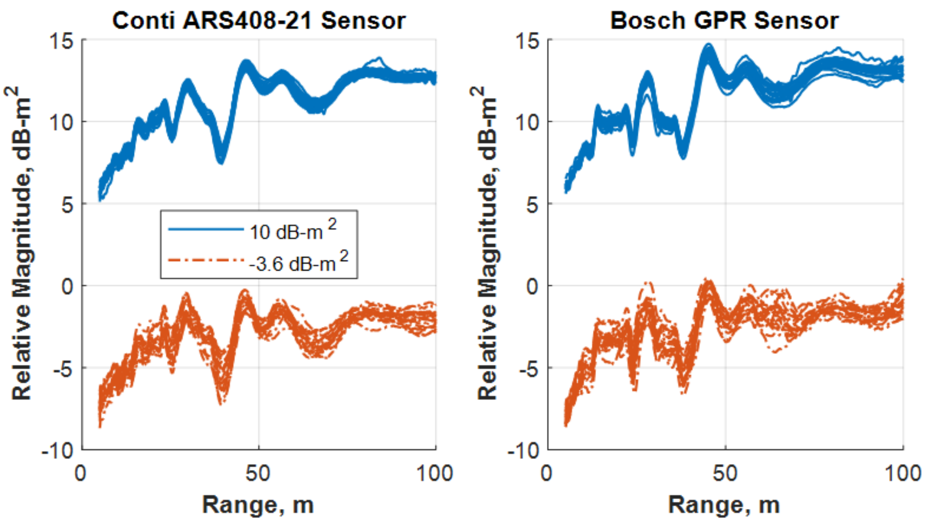


Figure 11. Calibration Trihedral Composite RCS Magnitudes

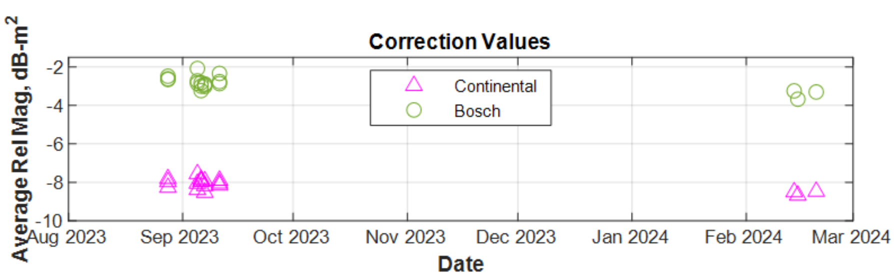


Figure 12. Average RCS Calibration Values Over Time

VTD RCS Results Relative to ISO 19206-3:2021 Boundaries

Results of VTD RCS measurements are presented in the following sections. As previously stated, above, all sets of scans covered in this subsection were performed in their own respective power cycles.

VTD Fixed Angle Approach

Table 11 quantifies the percentage of the points within the upper and lower RCS bounds for the fixed angle approach measurements. The only occurrence of the VTD not meeting the specified in bound criteria of 92 percent was with the Bosch sensor within Day 2, Set 3. This can be seen in further detail in Figure 12 where the respective RCS return line falls out of the lower bounds from 80 to 90 meters.

Table 11. VTD Fixed Angle Approach Tabulated Results

		Percentage Inbounds (%)	
		Continental	**Bosch**
Day 1	**Set 1**	100	94.2
	Set 2	100	100
	Set 3	100	99.9
Day 2	**Set 1**	100	96.5
	Set 2	100	100
	Set 3	100	85.0
Day 3	**Set 1**	100	100
	Set 2	100	100
	Set 3	100	100
Day 4	**Set 1**	100	100
	Set 2	100	100
	Set 3	100	100
Day 5	**Set 1**	100	94.5
	Set 2	92.1	95.9
	Set 3	100	100

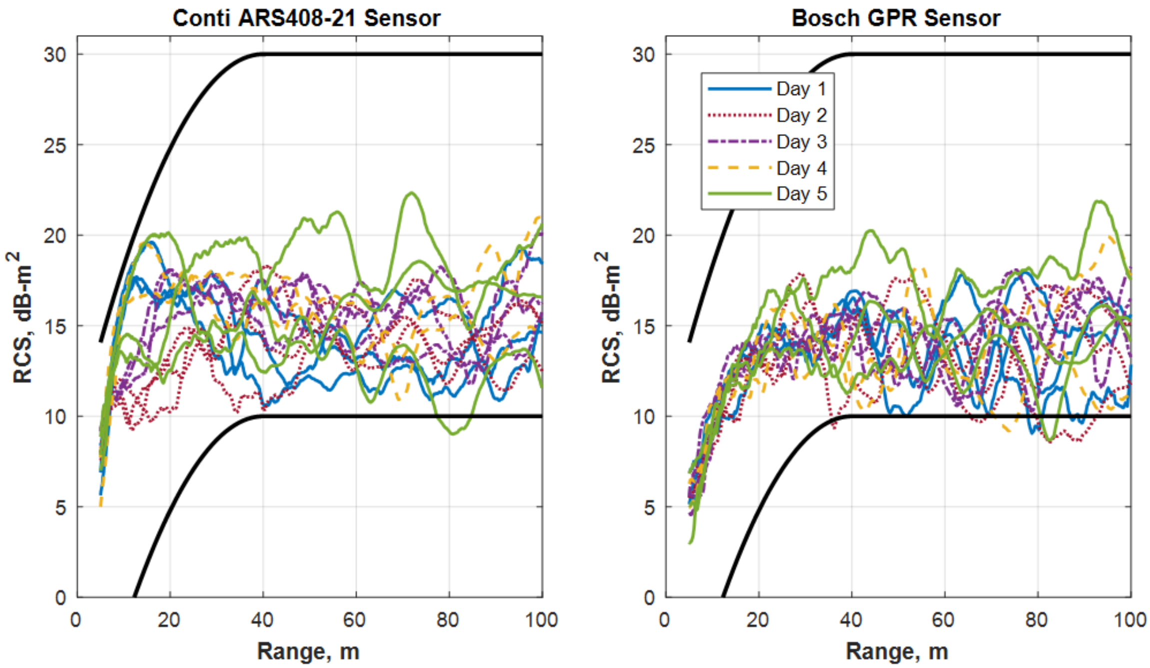


Figure 13. VTD RCS Repeatability Results (Continental, Bosch right)

VTD Fixed Range Approach

As it is not possible to effectively overlay all angle-penetration figures, these results are represented in tabular form in Table 12 along with the fixed range RCS in bound percentage. As seen in Table 12, there is some variation with the VTD. Notably, the VTD does meet the 360° ISO Spec classification type with all measurements taken. The primary out of bounds classification type is predominantly within the Primary Reflections for the Continental sensor. Additional out of bounds reflections were observed with the Extraneous Reflections from both radar sensors.

Figure 13 shows the RCS returns and boundaries for the fixed range measurements. The angles of 0° and -45° appear to be common for higher returns, thus causing the 360° ISO spec classification type in bound percentages to be below 100 percent, but above 92 percent.

Table 12. VTD Fixed Range Approach Tabulated Results

		Percentage Inbounds (%)							
		360° ISO Spec		Primary Reflections (R1)		Internal Reflections (R2)		Extraneous Reflections (R3)	
		>95%		95.0%-86.0%		14.0%-2.0%		4.0%-0.0%	
		Continental	**Bosch**	**Continental**	**Bosch**	**Continental**	**Bosch**	**Continental**	**Bosch**
Day 1	Set 1	95.6	97.2	95	94	3.1	3.2	1.8	2.7
	Set 2	96.2	97.7	91.7	89	2.9	3.3	5.5	7.7
	Set 3	97.3	98.6	95	93.3	3.4	3.7	1.6	3
Day 2	Set 1	97.7	100	95.2	93.4	2.9	3.5	1.9	3.1
	Set 2	98.8	100	94.9	92.9	3.1	3.8	2	3.4
	Set 3	97.5	100	95.3	93.8	3	3.3	1.6	2.9
Day 3	Set 1	98.3	100	94.5	92.9	3.5	3.8	2	3.3
	Set 2	97.5	99.7	94.9	92.8	3.2	3.7	2	3.4
	Set 3	97.1	99.6	93.3	92.4	2.9	3.4	3.8	4.2
Day 4	Set 1	97.4	99.6	95.5	94.3	2.8	2.8	1.8	2.9
	Set 2	98	99.5	95	94	2.9	2.6	2.1	3.5
	Set 3	98.4	99.6	95.1	93.5	3.2	3.4	1.7	3.1
Day 5	Set 1	98	99.6	95.1	93.8	3	2.9	1.8	3.2
	Set 2	97.5	99.8	95.6	94.4	2.7	2.9	1.7	2.7
	Set 3	96.6	98.6	95.6	93.7	3	3.4	1.4	2.9

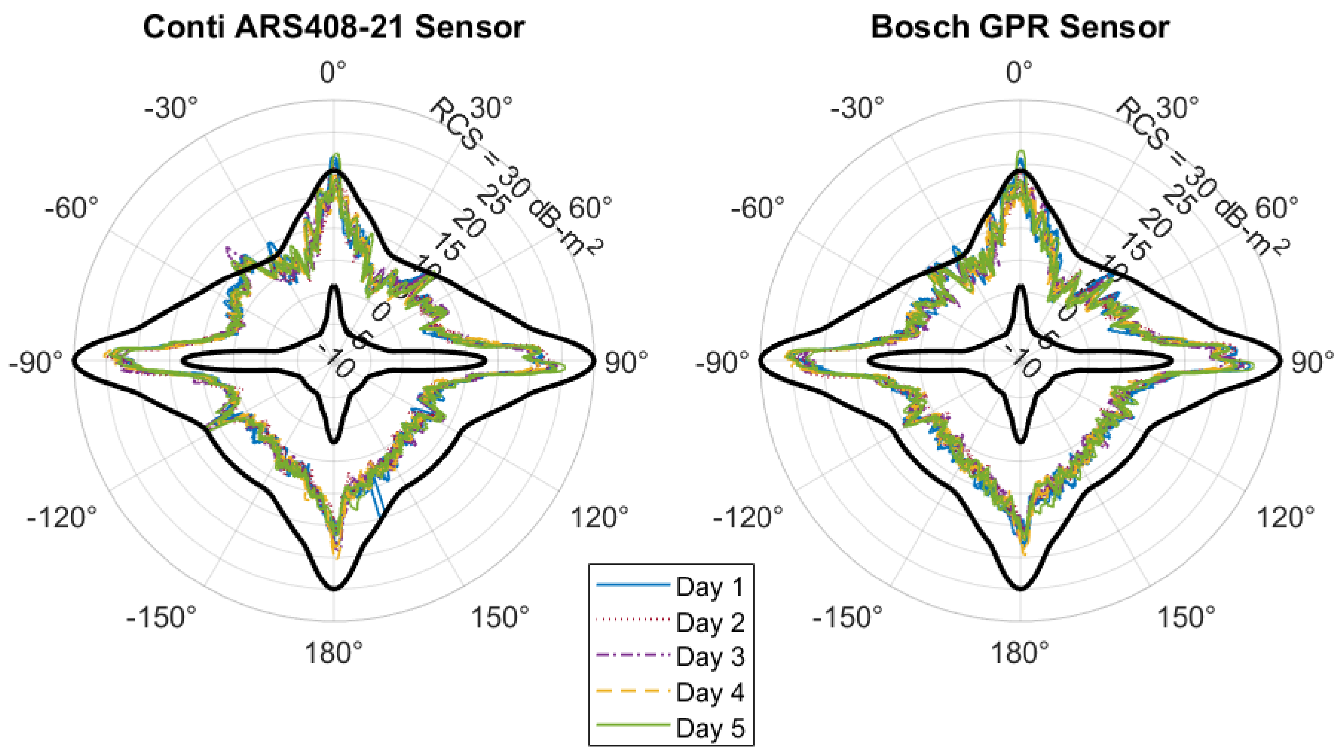


Figure 14. VTD Variability Fixed Range (30m) RCS Returns (Continental left, Bosch right)

VUT RCS Results Relative to ISO 19206-3:2021 Boundaries

Results of VUT RCS measurements are presented in the following sections. As previously stated, all sets of scans covered in this subsection were performed with one power cycle for the day. The following results of the real vehicles uses the same RCS bounds as the VTD. This is to compare the set of scanned vehicles to the RCS boundaries themselves.

VUT Fixed Angle Approach

For the 180° fixed angle approach, all passenger vehicles achieved the inbounds criteria, and included the bobtail tractor. The passenger vehicle achievement supports the 180° fixed angle boundary values. It could be surmised that the flat backing of the tractor trailer, straight truck, and school bus contributed to results with fewer returns inbounds. Figure 14 shows the higher returns along with all the 180° fixed angle values vehicle returns.

Table 13. VUT Fixed Angle Approach Tabulated Summary

VUT	Percentage Inbounds (%)	
	Continental	Bosch
Sedan	100	100
Hatchback	100	100
Minivan	100	95.9
Crossover	100	100
Light Duty Truck	100	100
Bobtail Tractor	100	100
Tractor and Trailer	81	73.5
Straight Truck	90.4	87.8
School Bus	38.9	51.2

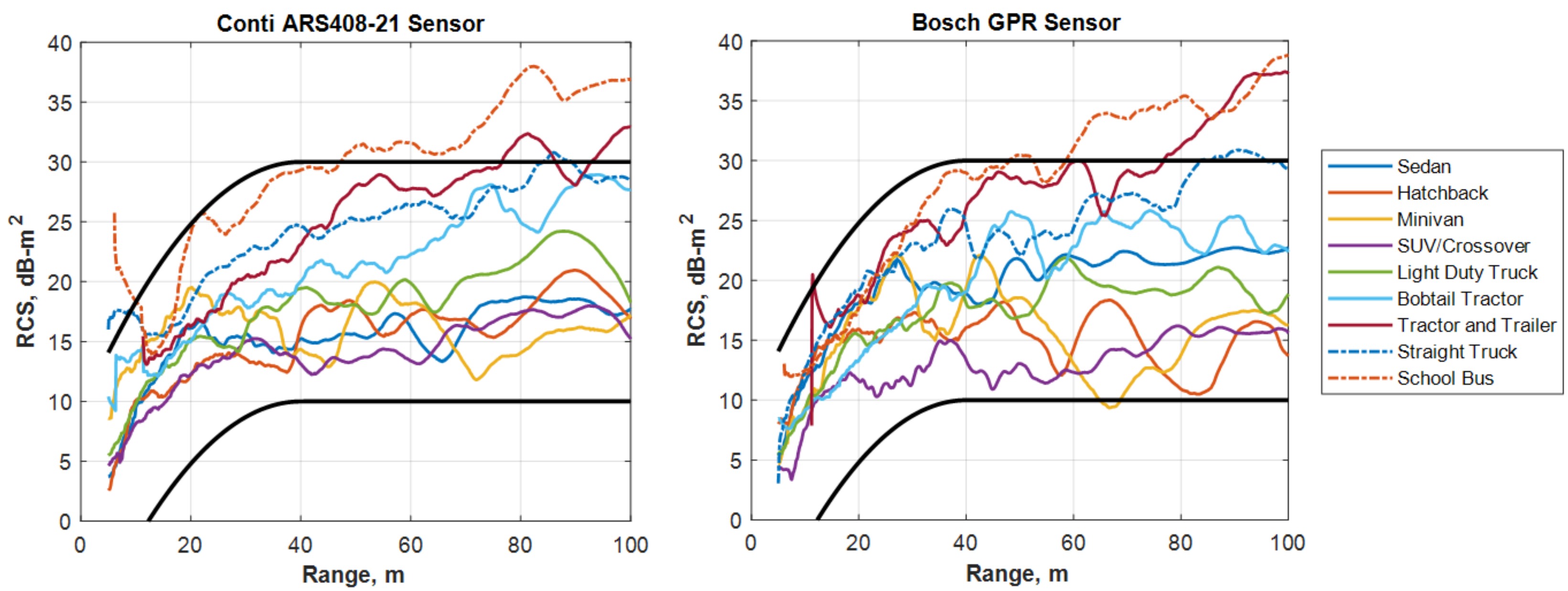


Figure 15. Real Vehicles Fixed Angle RCS Returns (Continental left, Bosch right)

VUT Fixed Range Approach

The hatchback, objectively the most similarly shaped VUT to the VTD, is within all specified fixed range criteria, as seen in Table 14. We surmise that the variations in wheelbase and body shape cause all other vehicles to be out of specified bounds to certain degrees.

Figure 15, shows the RCS returns of the vehicles. Notably the bobtail tractor, tractor trailer, straight truck, and school bus significantly deviate from the rest of the vehicles. Again, this can be surmised from their abnormal shape compared to that of what the ISO bounds have been created from.

Table 14. VUT Fixed Range Approach Tabulated Results

VUT	**Percentage Inbounds (%)**							
	360° ISO Spec		**Primary Reflections (R1)**		**Internal Reflections (R2)**		**Extraneous Reflections (R3)**	
	>95%		**95.0%-86.0%**		**14.0%-2.0%**		**4.0%-0.0%**	
	Continental	**Bosch**	**Continental**	**Bosch**	**Continental**	**Bosch**	**Continental**	**Bosch**
Sedan	100	100	70.5	65	5.6	7.4	23.9	27.5
Hatchback	100	97.7	91.9	89	5	7.3	3.2	3.6
Minivan	99.1	98.8	54.9	52.9	5.4	5.5	39.7	41.6
Crossover	100	99.8	89.7	85.9	4.4	6.6	5.9	7.5
Light Duty Truck	100	96.8	60.8	51.7	4.8	7.6	34.4	40.7
Bobtail Tractor	82.9	72.2	30.9	25.4	10.1	12.5	59	62.1
Tractor and Trailer	23.1	25.2	4.6	5.2	28.6	31.9	66.8	62.9
Straight Truck	27	25.1	23.2	19.5	29.4	30.8	47.4	49.7
School Bus	46.1	40.5	9.7	10.2	5.7	14.3	84.5	75.5

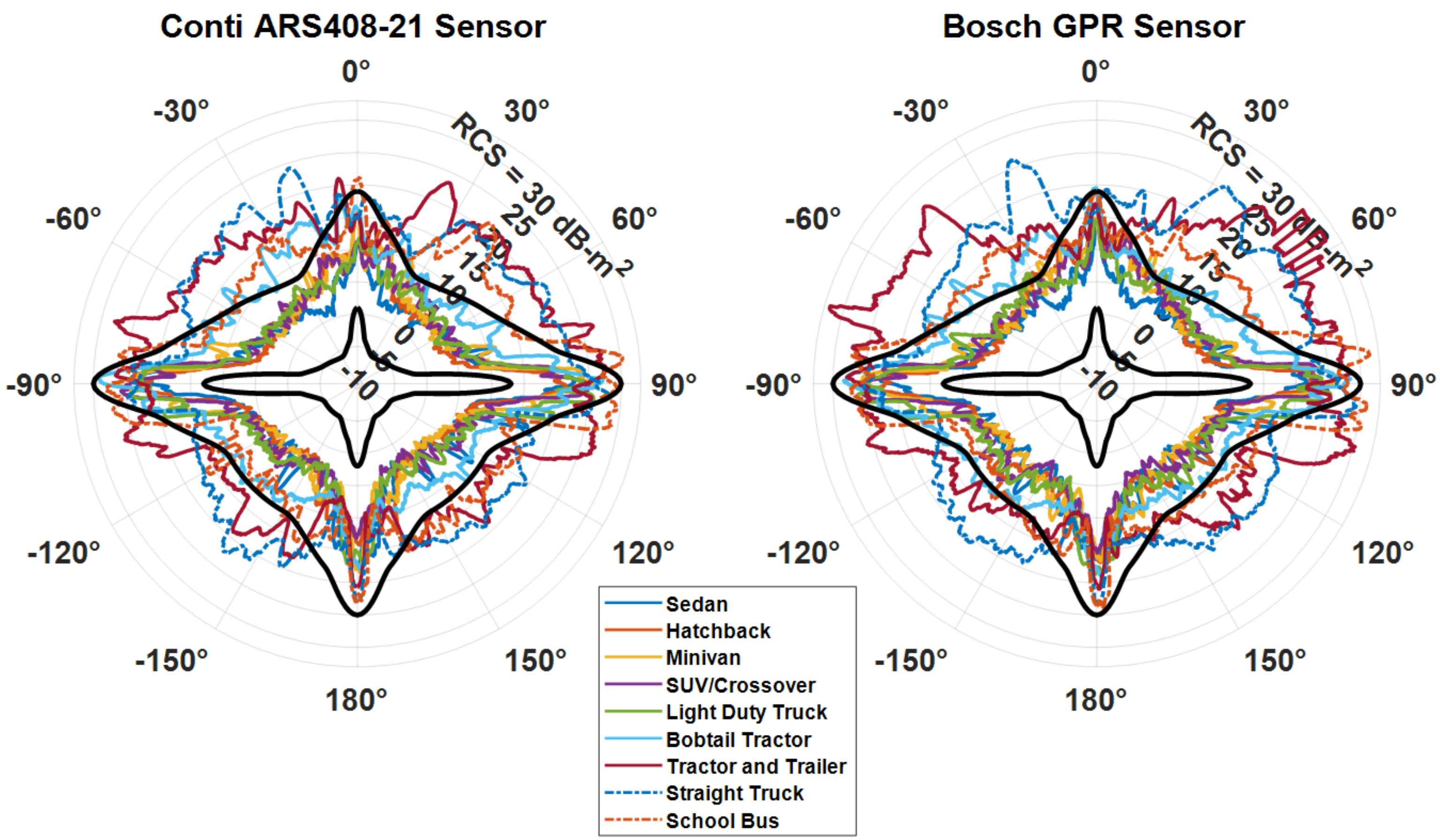


Figure 16. VUT Fixed Range (30m) RCS Returns (Continental left, Bosch right)

VTD and VUT Fixed Angle Overlay

Figure 17 contains the real vehicles overlayed with all the GVT composite returns for the 180° fixed angle approaches. For this illustration, all GVT lines are the same color, effectively blanketing the range of RCS values observed through the repeatability testing.

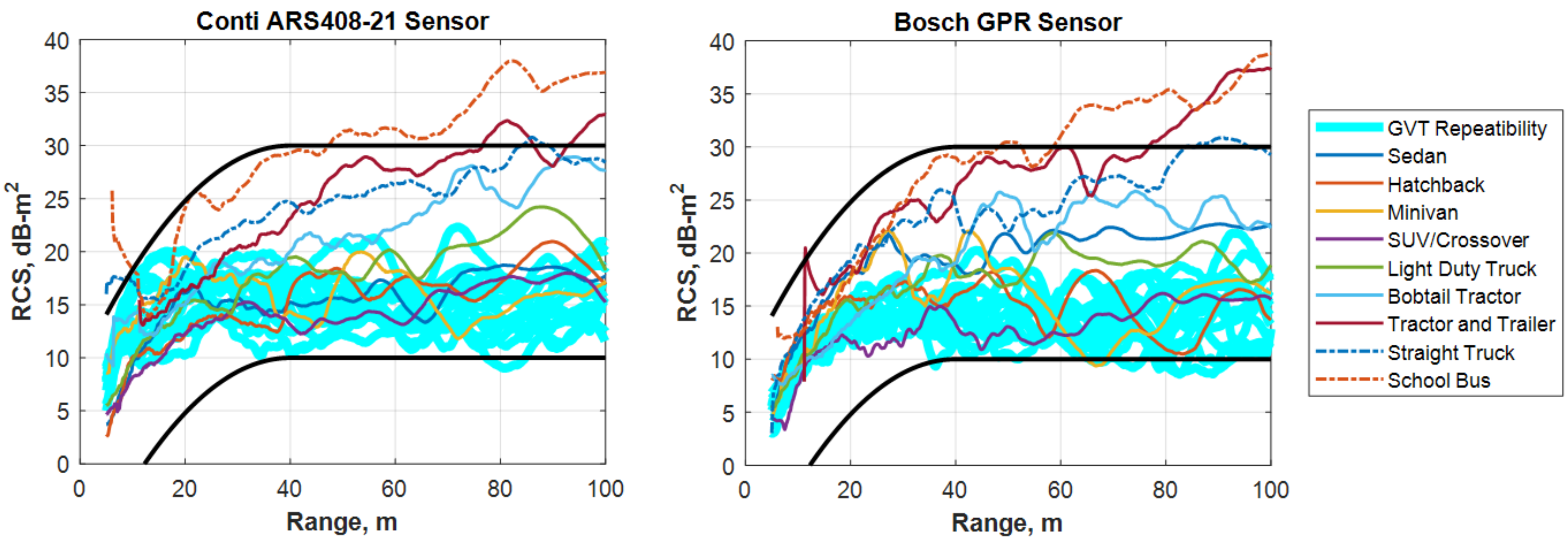


Figure 17. Real Vehicles Overlayed Onto GVT Fixed Angle RCS Returns With First Repeatability Scan (Continental left, Bosch right)

Assessment of Test Anomalies

When all GVT repeatability and real vehicle scans were assumed to be completed, it was discovered that an adjustable parameter called the "Position Filter Distance" was set at a value of ±2m. This value affects what data is written and saved during scanning. The value works to define a longitudinal distance in front of and behind the object center point, in respect to the ScanR. As readings come from the radar sensors, each reading is checked to see if it falls longitudinally within the window. If the reading is outside of the window, then that reading is not saved. By using the Position Filter Distance set to ±2m, this created a window of length equal to 4 meters centered about the origin. Investigation into the validity of all VTD repeatability data was done as the VTD was measured at 3.95m in length. This did require all real vehicles to be rescanned as they were all greater than 4m in length. To investigate and verify the VTD repeatability measurement, two sets of scans were performed, one with Position Filter Distance set to ±2m as a baseline and the second with Position Filter Distance set to ±6m, seen in Figure 18.

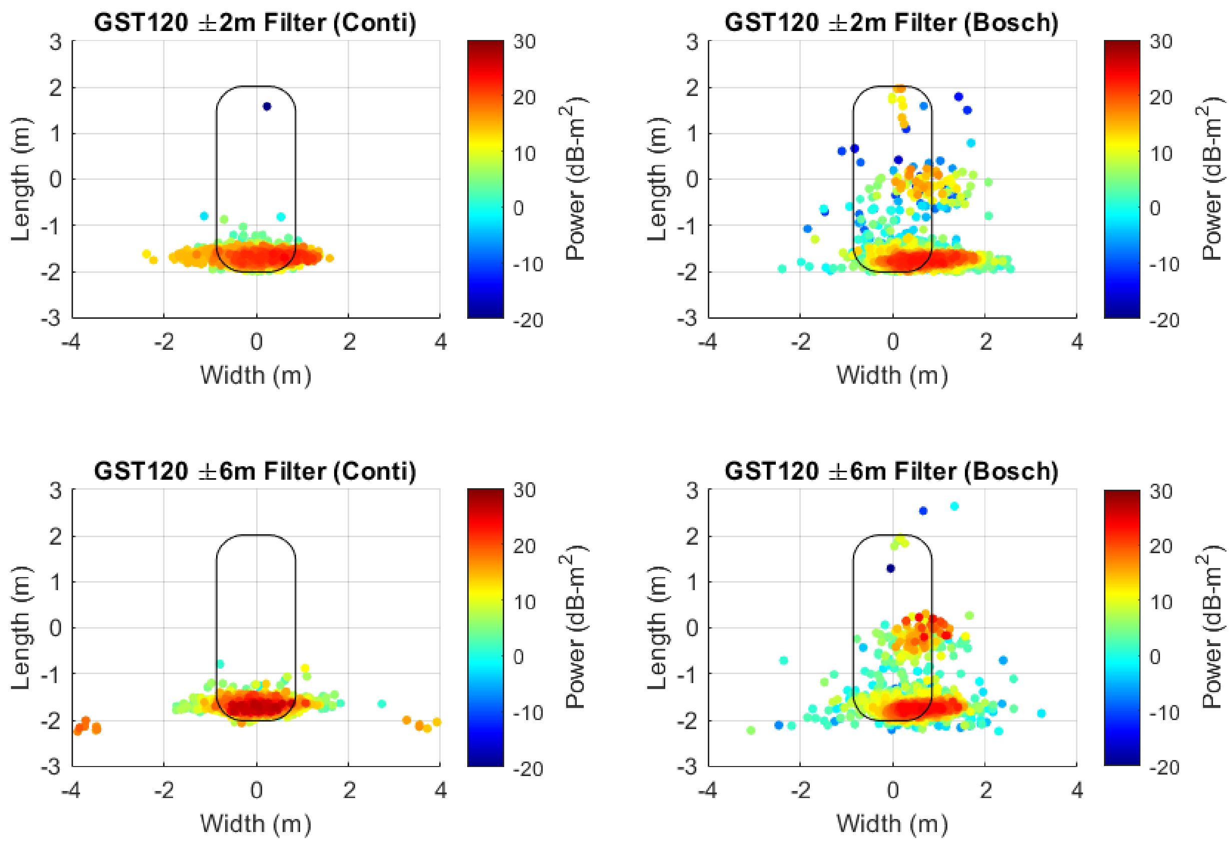


Figure 18. Position Filter Distance Comparison of ±2m and ±6m

Further analysis of the ±6m scanned data set yields confidence that a significant amount of the data was already within the ±2m distance window. As values are in terms of power (logarithmic scaling) larger RCS returns contribute more than that of lower power returns. This is shown in Figure 19 with the percentage of data within the ±2m distance window and the overall weighting of bins of RCS values. This was done to show returns in value less than or equal to -10 dBm^2 have little to no contribution to the complete data sets.

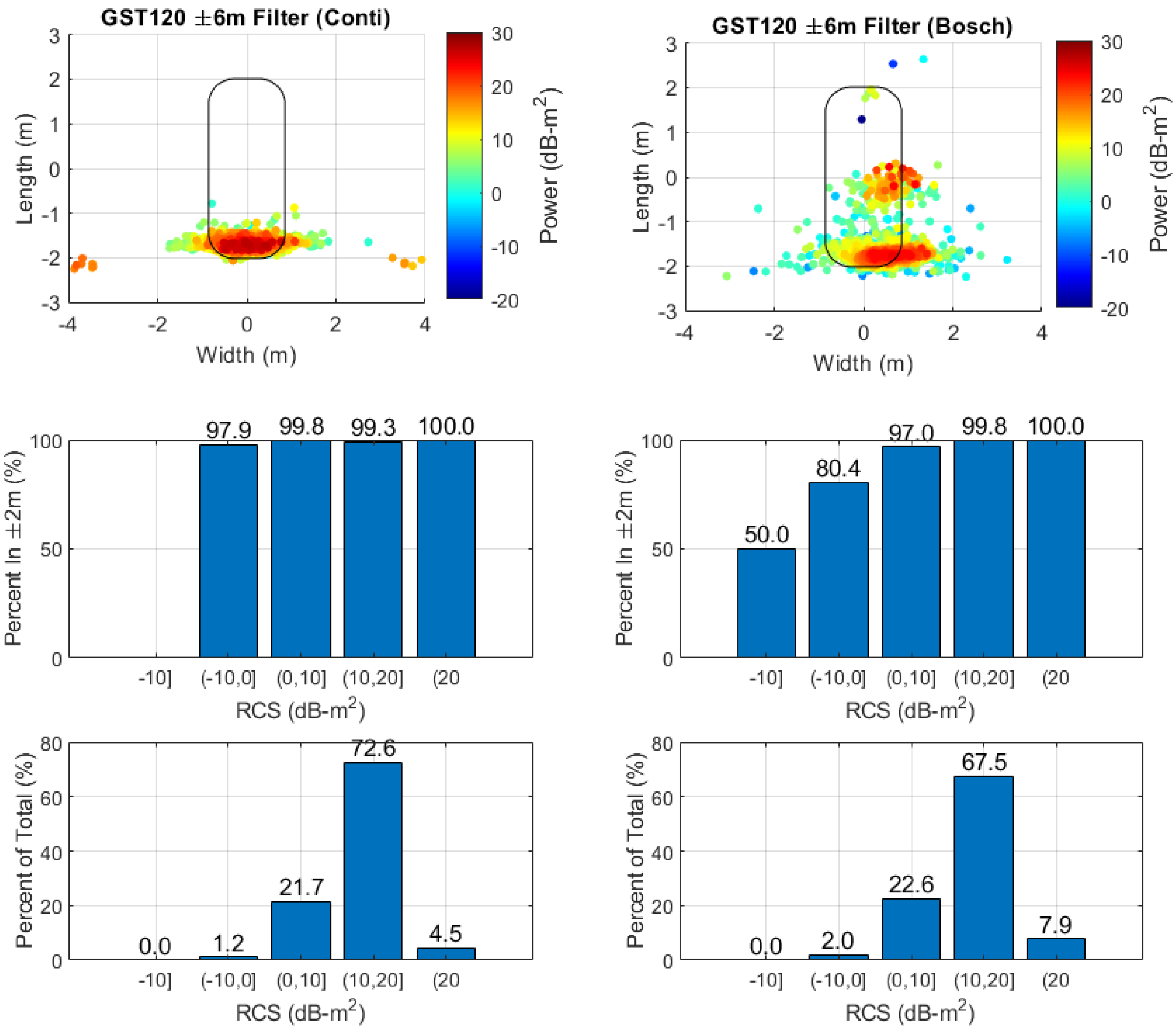


Figure 19. Percent Value of Data Location of ±6m Position Filter Distance (Continental left and Bosch Right)

Summary of Results

The goal of the work discussed in this report was to use ISO 19206-3:2021 procedures to identify the repeatability of measuring the RCS of one VTD, a surrogate vehicle designed to emulate a small passenger car. Additional work was done on VUTs of different classes and styles to compare VTD results against. RCS boundary lines from ISO 19206-3:2021 that define the expected radar return of a real vehicle were included to compare results.

In summary, the following were observed.

- RCS qualitative consistency of the calibration trihedrals was successfully demonstrated, especially for the larger 10 dB-m^2 version. This result indicates the measurement variations observed for the VTDs can be attributed to the VTDs themselves; not to equipment and/or evaluation method limitations.
- Variation in RCS return was observed with the VTD repeatability study using methods defined by defined by ISO 19206-3:2021.
    - For the fixed angle scans, the RCS returns from the Continental sensor were within their minimum percentage of the applicable upper and lower boundaries defined by ISO 19206-3:2021. Scans using the Bosch radar sensor produced one result outside of the defined boundary, where a value of 85 percent was observed. All other measurements performed with the Bosch radar were greater than 94 percent and within the upper and lower RCS boundaries.
    - For the fixed range scans, primary reflections from the Bosch radar fell within the specified bounds. Results from the extraneous reflections yielded two cases where reflection percentage inbounds did not fall within the specified bounds. Primary and extraneous reflections from the Continental radar produced several returns outside of the specified bounds.
- VUT vehicle measurements confirm the RCS boundaries and categories defined in ISO 19206-3:2021 are reasonably appropriate.
    - VUT vehicle measurements yield varying but expected results. Generally, light passengers' vehicles are within the RCS return boundaries defined by ISO 19206-3:2021 for both fixed angle and fixed range measurement types. The scanned heavy vehicles tend not to satisfy the boundary criteria. For the VUT reflection categorizations, the hatchback, most representative in shape to the VTD, achieves all category requirements.

This page intentionally left blank.

References

European New Car Assessment Programme. (2024, February). *Technical bulletin TB 029, Euro NCAP supplier list appendices I & II.* www.euroncap.com/media/80157/tb-029-appendices-i-ii-29-02-2024.xlsx

European New Car Assessment Programme. (2024, February). *Test protocol – AEB car-to-car systems.* Implementation 2023, Version 4.3.1. www.euroncap.com/media/80155/euro-ncap-aeb-c2c-test-protocol-v431.pdf

International Organization for Standardization. (2021). *ISO 19206-3:2021, Road vehicles — Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions – Part 3: Requirements for passenger vehicle 3D targets*. www.iso.org/standard/70133.html

This page intentionally left blank.

Appendix A. Additional pictures

DRI ScanR Measurement Cart

Trihedral and Tripod Mount

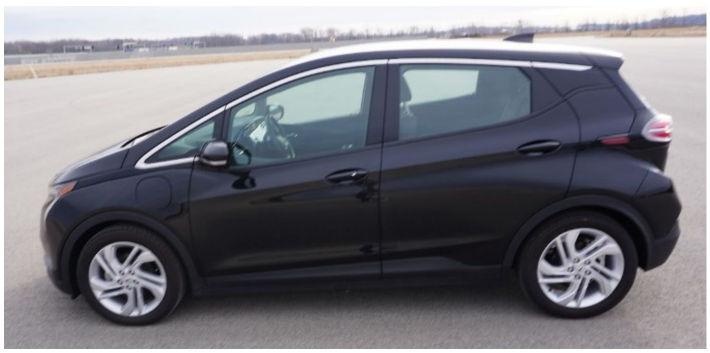
DRI GVT Profile Pictures

Real Vehicles

- Sedan – 2022 Toyota Camry




Hatchback – 2020 Chevrolet Bolt



Light-Duty Truck – 2022 Ram 1500

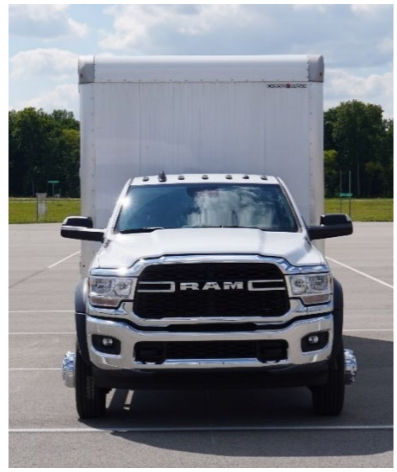
Minivan – 2022 Honda Odyssey

SUV – 2022 Nissan Rogue

Bobtail Tractor – 2021 Freightliner Cascadia PT126SLP

Tractor and Trailer – 2021 Freightliner Cascadia PT126SLP and 53 ft Trailer With No Aero Panels

Straight Truck – 2021 RAM 5500 Tradesman With Kaffenbarger[9] Truck Equivalent Box Van Body



[9] Kaffenbarger Truck Equipment Company, Columbus, Ohio, was recently acquired by Knapheide Manufacturing Company, also of Columbus, Ohio.

School Bus – 2023 IC Bus CE 78-Passenger School Bus (PB105)


DOT HS 813 648
January 2025

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

NHTSA

16377-010625-v4