CATS/4a

CATS D3.4 Bicyclist Target Specifications

CATS/4a – Bicyclist Target Specification

Version 1.1

Document history

Version	Modified by	Date	Description / Modification
1.0	Martin Fritz (4a) Thomas Wimmer (4a) Sjef van Montfort (TNO)	02.09.2016	CATS Bicyclist and Bike Target Specifications
1.1	Martin Fritz (4a) Thomas Wimmer (4a) Sjef van Montfort (TNO)	23.12.2016	CATS Bicyclist and Bike Target Specifications including RCS and micro-Doppler information

Contents

1 Introduction

1.1 General Information

The overall number of fatalities in road traffic accidents in Europe is decreasing, however unfortunately the number of fatalities among cyclists does not follow this trend with the same rate. AEB systems, dedicated to avoid or mitigate car-to-cyclist collisions, are being introduced. To develop protocols and appropriate equipment to test such systems, TNO has initiated the CATS “Cyclist-AEB Testing System” consortium, in which around 20 industry partners, including several OEM’s and TIER1s, have joined forces. Accidentology was used to determine the three most common car-to-cyclist accident scenarios in the EU. Accident data and data from observation studies were used to determine the parameter ranges in the proposed test matrix for the selected test scenarios. A bicyclist target has been specified to represent a real bicyclist on a bike, taking into account all different types of sensors used in AEB systems. 4activeSystem GmbH has developed and manufactured a bicyclist target and propulsion system that meet the requirements set to represent the defined scenarios. Together with car manufacturers and suppliers, a test matrix has been proposed and verified.

1.2 Definitions

BT .... bicyclist and bike target
VUT.. vehicle under test
VRU .... vulnerable road user

2 Bicyclist and Bike Target

Figure 1: bicyclist and bike target

The bicyclist and bike target (BT) described in this paper, represent an average human adult bicyclist on an average standard adult utility bike (Figure 1) in relation to the vulnerable road users (VRU) detection sensors used in vehicles. The requirements relate, unless not specified otherwise, to the BT including a platform. The BT is designed to work with the following types of automotive sensors technologies: RADAR, Video, Laser, and Near-IR-based system similar to the definition by ACEA[1]. The BT must be a full 3D-dimensional representation of a real bicyclist and bike, must have rotating wheels (synchronized to speed), pedalling legs are not mandatory.

2.1 Bicyclist and Bike Target Dimensions and Posture

The dimensions of the bike target are based on an average Dutch utility bike for average male according to data from TU Delft with additional dimensions taken from a standard Dutch utility bike (Gazelle Paris Pure male size 57) to complete the dimension specifications. Also alternative European bikes have been taken into account. The bike target is based on a standard utility bike and has a double triangle frame shape. Typical dimensions include dimensions indicated in Figure 2. The centre of the bottom bracket (crank shaft) of the bike target (red circle in Figure 2) will be used as reference 0-point in X-direction and the floor level as reference 0-point in Z-direction.

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[1] ACEA: Articulated Pedestrian Target Specifications Version 1.0

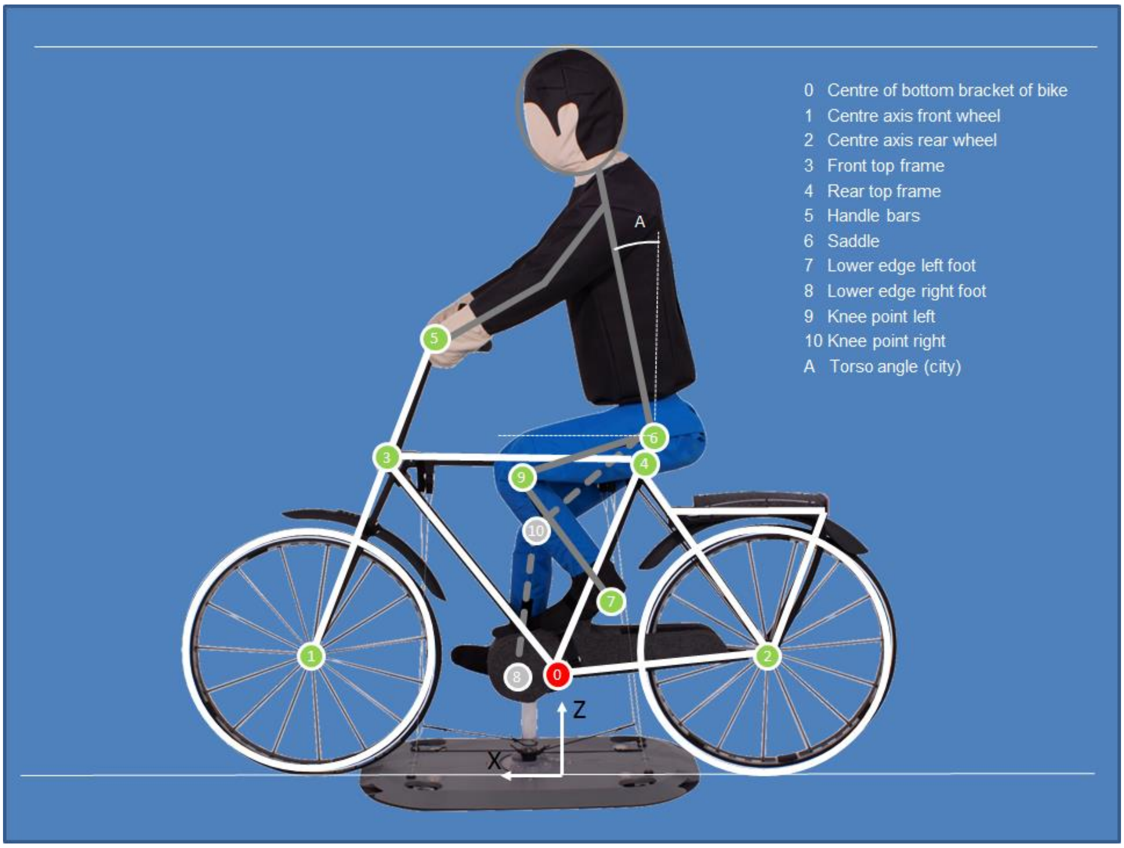


Figure 2: bike target dimensions and dummy posture

Table 1: bike target dimensions

Segment	X	Z	Unit	Tolerance	Unit
0 Centre of bottom bracket of bike	0	280	mm	± 10	mm
1 Centre axis front wheel	670	340	mm	± 10	mm
2 Centre axis rear wheel	-540	340	mm	± 10	mm
3 Front top frame	430	855	mm	± 10	mm
4 Rear top frame	-215	860	mm	± 10	mm
5 Handle bars	310	1180	mm	± 10	mm
6 Saddle	-235	935	mm	± 10	mm
7 Lower edge left foot[2]	105	495	mm	± 20	mm
8 Lower edge right foot	80	200	mm	± 20	mm
9 Knee point, left [3]	150	860	mm	± 20	mm
10 Knee point, right	85	700	mm	± 20	mm
Total height	1865		mm	± 20	mm
Total length	1890		mm	± 20	mm
A Torso angle	10 (optional 30)		°	± 2	°

[2] Lowest point of shoe – centre line tibia

[3] Knee point: rotation point of knee

In order to ensure a realistic scenario, special requirements concerning radar reflection must be fulfilled. Thus, the diameter of the frame, seat stay and chain stay must be as followed:

Frame:.. 25mm – 35mm
Seat stay: .... 15mm – 25mm
Chain stay: .... 15mm – 25mm

The material of the frame, stays, spokes, steering and rim consists of a black coloured metallic outer surface to ensure that their reflection represent the one of a real bicycle.

Dimensions of the bicyclist target are based on an adult pedestrian target, described by ACEA[4], representing average (50th %-ile) male. The shape of the bicyclist target has to comply in its contours with the 50% RAMSIS Bodybuilder based on the RAMSIS version 3.8.30 to a permitted tolerance of ± 2cm. The stature body height of the adult BT is, according to EN ISO 7250-1: 2016-05 is 1800mm.

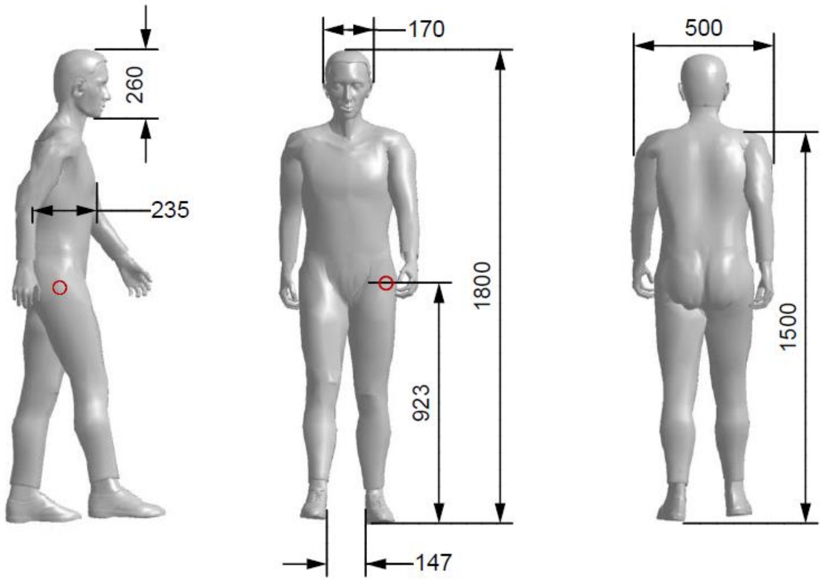


Figure 3: bicyclist target dimensions in standing posture

Table 2: bicyclist target dimensions in standing posture

Segment	Dimension / Angle	Unit	Tolerance	Unit
Body height (incl. shoes)	1800	Mm	± 20	mm
H-Point height	920	Mm	± 20	mm
Shoulder width	500	Mm	± 20	mm
Shoulder height	1500	Mm	± 20	mm
Head width	170	Mm	± 10	mm
Head height	260	Mm	± 10	mm
Torso depth	240	Mm	± 10	mm

[4] ACEA: Articulated Pedestrian Target Specifications Version 1.0

The posture of the bicyclist target represents a natural driving position, facing forward, both hands on the steering wheel, with right foot down and left foot up (see Figure 4). The same dummy posture is used for all driving directions. The posture definition includes: lower edge of left and right foot, knee point left and right (see Figure 4 and Table 2).

Figure 4: posture of bicyclist target

There must be a possibility to check and correct the body posture and angle of legs and arms in an easy and practical way corresponding to the defined tolerances, e.g. with the help of a tool with a reference shape.

2.2 Visible and Infrared Properties

Similar to the adult pedestrian target specified by ACEA[5], the BT shall be look like clothed with a long-sleeved t-shirt and trousers in different colours: t-shirt in black, jeans in blue and shoes in black. The clothing has to be made from tear-proofed and water-resistant material. Skin surface parts have to be finished with a non-reflective flesh-coloured texture.

The IR reflectivity from 850 to 910 nm wavelength of clothes and the skin must be within the following range of 40% to 60%. The IR reflectivity from 850 to 910 nm wavelength of the head hairs must be within the following range of 20% to 60%. At the selection of the clothes it has to be ensured, that the IR reflectivity measured with the 45° probe must not differ for more than 20% from the reflectivity measured with the 90° probe.

The visual and infrared properties based on measurement method described in appendix A1 are defined in Figure 5, Table 3 and Table 4.

Figure 5: infrared properties of BT

[5] ACEA: Articulated Pedestrian Target Specifications Version 1.0

Table 3: infrared properties of BT

Segment	Reflectivity 90°, 45°
1 Black Top, Shoes	40% - 60%
2 Hair	20% - 60%
3 Skin, Face, Hands	40% - 60%
4 Trousers	40% - 60%
5 Rubber Tire (outside)	3% - 9%
6 Frame	2% - 20%

Table 4: colour properties of BT, sRGB (0-255, Observer = 2°, Illuminant = D65)

Segment		Colour	Red	Green	Blue
1 Black Top, Shoes	min		35	36	37
	mean		45	46	47
	max		55	56	57
2 Hair	min		35	36	37
	mean		45	46	47
	max		55	56	57
3 Skin, Face, Hands	min		102	95	72
	mean		182	165	142
	max		72	33	0
4 Trousers	min		0	90	133
	mean		0	110	153
	max		20	130	173
5 Rubber Tire (outside)	min		35	36	37
	mean		45	46	47
	max		55	56	57
6 Frame	min		35	36	37
	mean		45	46	47
	max		55	56	57

The colour of stiffening ropes must be light grey and low optical reflective.

The front, rear and all four pedal reflectors (left – right and front - rear) should be marked BS6102/2 (or equivalent) and coloured respectively white (front), red (rear) and amber (pedals). The front and rear reflector should be located on the bike target between 350mm and 900mm from the ground level, with the white front reflector positioned between most forward point of bike target and point 3 in Figure 1 facing forward. The red rear reflector is positioned between most rearward point of the bike target and point 4 in Figure 1 facing rearward. The amber coloured pedal reflectors should be on the front and rear side of both left and right pedal. The wheel reflectors will be white reflective strips on both sides of the rims or tyres.

To provide robust behaviour of the outer cover, the textile should have the following characteristics:

- area weight..< 300 g/m²
- water resistance (AATCC 127) ....> 600 mm
- strength (ASTM D5034)... > 350 lbs
- light fastness (AATCC 169) ....> 6000 h
- wear resistance ASTM (D3884)..> 500 cycles

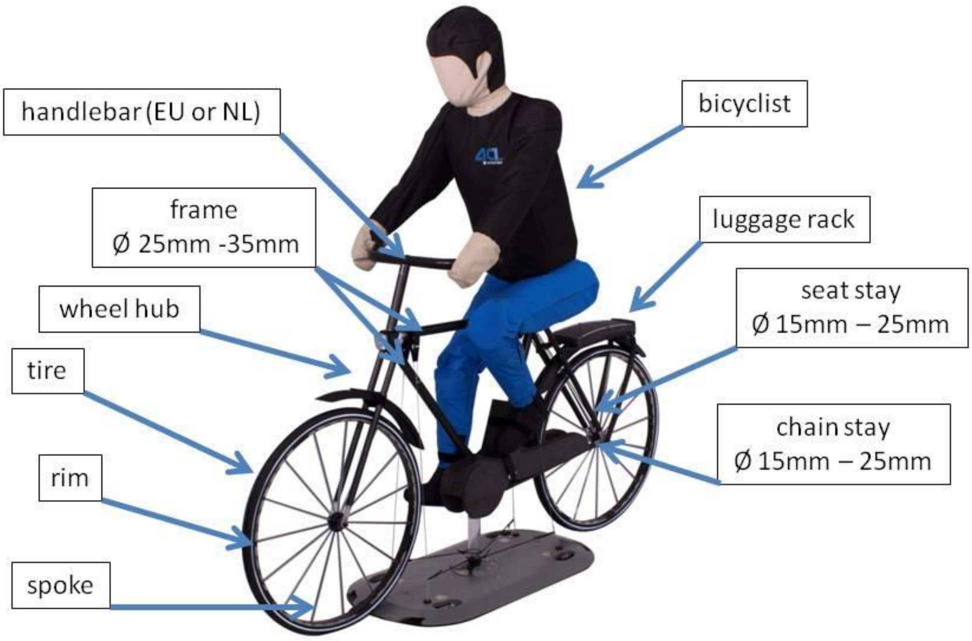


Figure 6: components of BT

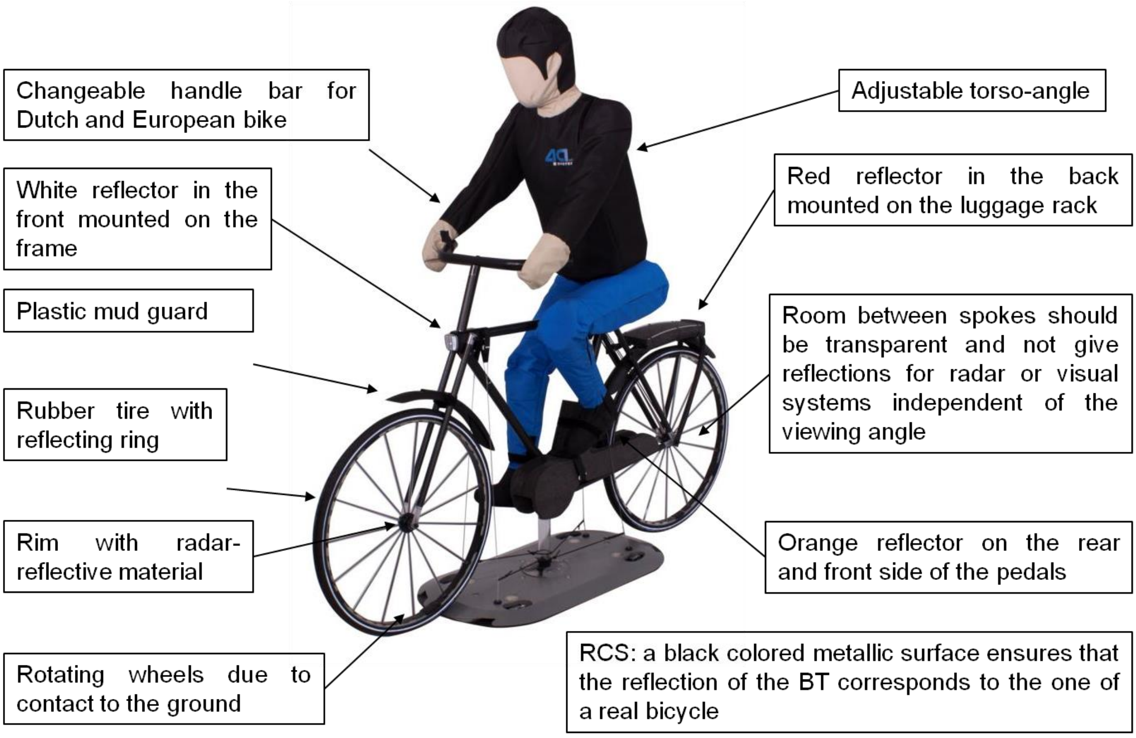


Figure 7: description of the different components of the BT

2.3 Radar Properties

The radar reflectivity characteristics of the bicyclist and bike target should be equivalent to a human being cycling of the same size.

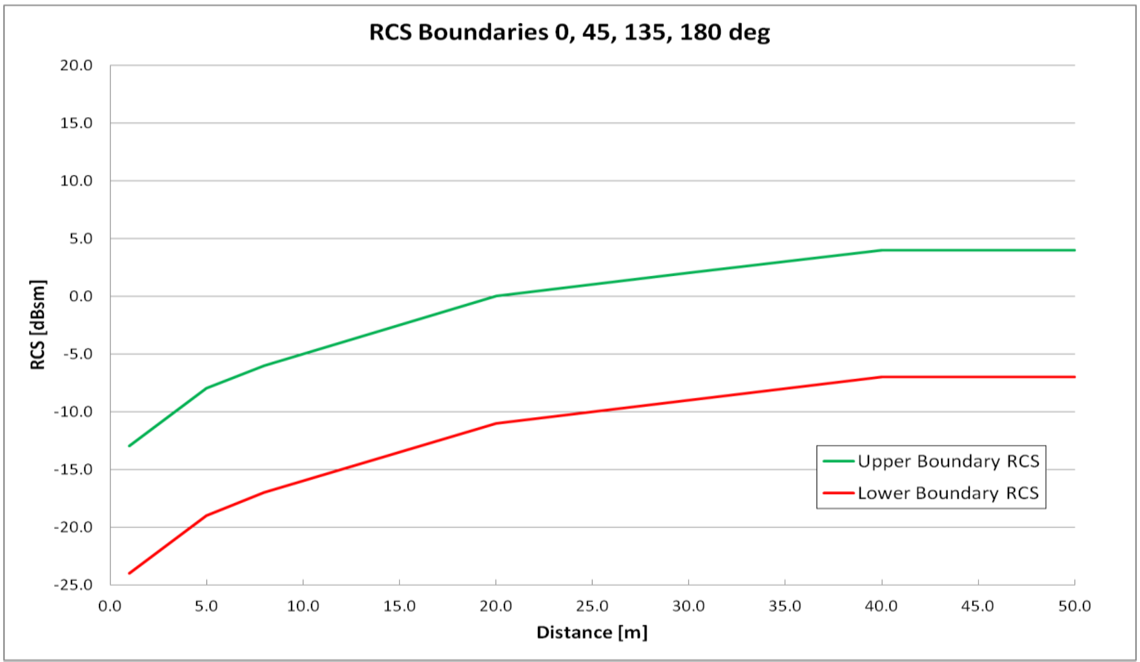
2.3.1 Radar Cross Section (RCS)

The radar cross section of a bicyclist depends on the observation angle and typically varies significantly. Theoretically there is no RCS variation with the distance. However due to the field of view of the radar sensor and the implemented free space loss compensation the measured RCS significantly varies over distance and in near distances the bicyclist is not scanned over its complete height. Therefore, in this document RCS is referred to as the measured RCS by radar sensor with its specific parameter set and it does not correspond to the physical RCS. The RCS is also influenced by geometrical effects (i.e. multi path with constructive and destructive interferences).

Therefore, it must be taken into account that the RCS will be reviewed not only constantly, but by a description of the RCS by closing on the BT. (see example of the RCS distribution at 76GHz of real bicyclist in appendix A3). It must be ensured that the RCS value is homogeneously distributed over the whole body of the BT. This allows achieving the effect of decreasing RCS at a shorter distance by only partial coverage. A more precise definition including mounting position and orientation must be made individually for each frequency and sensor variant.

Additionally, a homogenous and realistic distribution of the RCS over the whole dummy area shall be ensured. At a viewing angle of 90° the RCS per wheel shall be about 1 to 10 dBsm, for the frame about 1 to 16 dBsm and for the bicyclist target about -5 to 5 dBsm (measurement setup see appendix A2, far field condition).

The radar cross section of the bicyclist target, achieved with a 77GHz Sensor Bosch MRR-SGU (see appendix A3), should stay within a defined range, depicted in Figure 8.



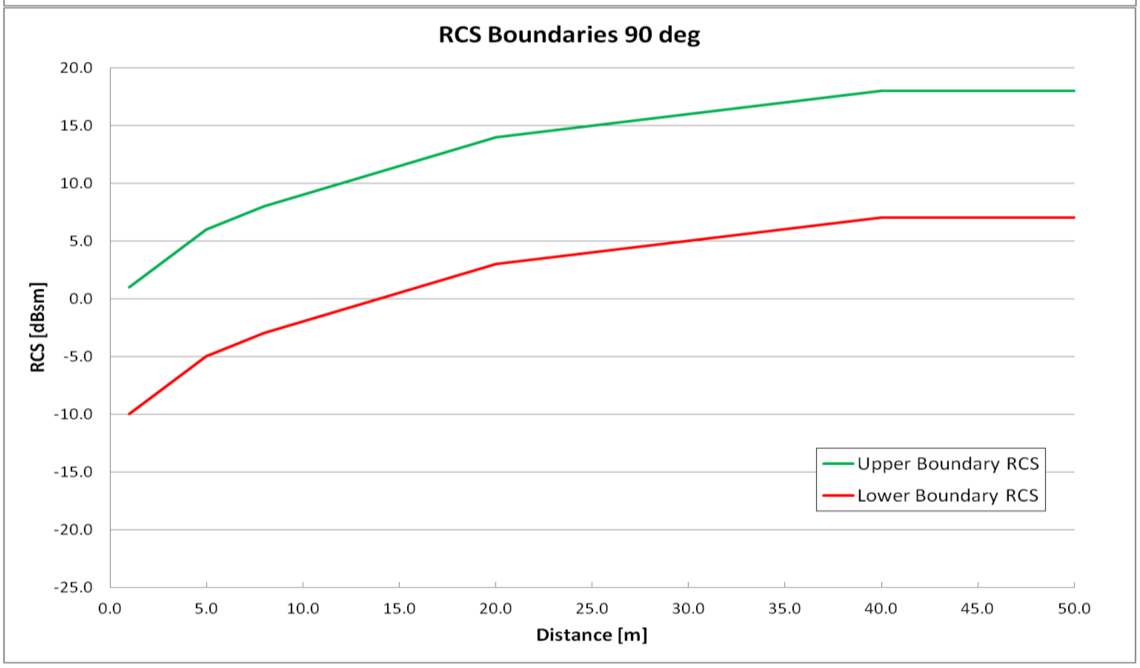


Figure 8: bicyclist and bike target RCS-boundaries (77GHz Sensor Bosch MRR-SGU)

If other sensors are used or the mounting position of the sensor is different, slightly other RCS values may be obtained. In that case an additional verification/adaption of the boundaries may be necessary for validation of the BT.

2.3.2 Doppler Effect of Articulation

Radar sensor technology may be able to measure and detect the relative velocities of rotating wheels on the bike. This characteristic of moving wheels will be referenced as micro-Doppler in the specifications (an example of the distribution of relative velocities of a transversal moving bicyclist, measured by radar (77 GHz Sensor, 1 GHz bandwidth), is provided in appendix A4).
Since the circumferential speed of a rolling wheel without slip is the same as the wheel centre speed, the maximum positive velocities have to be two times the bicyclist speed, the minimum velocities have to be zero. Main reflection points contributing to the micro-Doppler must be located on the wheel's outer rims. The RCS per wheel shall be about 1 to 10 dBsm at 90° viewing angle (measurement setup see appendix A2, far field condition).

Both wheels shall rotate to achieve the typical H-shape with one rotation centre at the back and one at the front wheel. The micro-Doppler spread shall be homogenously distributed referencing to the two rotation centres within zero speed and the double bicycle speed.

2.4 Articulation

Only wheels articulation is requested by the dummy, since rotating wheels are always available at crossing bicyclist. Pedalling legs are not a necessarily characteristic of human while biking.
The wheels should be in constant contact with the ground and rotate at the corresponding speed forward.

2.5 Mounting and Guidance System

- All visible parts of the BT mounting and guidance system must be coloured in grey. In case of a uniform background the colour shade of the background can be used.
- It must be ensured that the BT mounting is not influencing radar return.
- Any supporting ropes or tubes for fixing the dummies position must not interfere with the VRU emergency braking system.

2.6 Bicyclist and bike Target Weight and Collision Stability

After a collision the correctness of the BT posture and dimension has to be checked before start of a new test. The most relevant BT parameters are defined in Table 2 and are requested during the testing phase (wind, acceleration). Additionally to the values mentioned in the table, a lateral (relative to moving direction of BT) oscillation has to be prevented: sideward tolerances +/- 5°.

- The BT must not have any hard impact points to prevent damage of the VUT.
- Max. relative collision velocity of 60 km/h (crossing) / 45 km/h (longitudinal).
- Max BT weight: 11kg
- The Bicyclist shall be coated with a closed textile outer cover.
- After a series of test repetitions and previous collisions the target must not show relevant changes in its shape and the functionality of the articulations.

Appendix

A1 Measurement of the IR reflectivity

The measurement of the IR reflectivity must be carried out using a measuring device according to the following specification.

- <u>IR Reflectivity measurement device:</u>

e.g.: *Jaz – mobile miniature spectrometer, Fa. Ocean Optics,* wavelength range *350 – 1000 nm, in combination with Reflexionssonde QR600-7-VIS125BX (see* Figure 9*)*

Figure 9: Jaz spectrometer

- <u>Calibration:</u>

Before the start of the measurement, the device must be calibrated with a reflection standard, material spectralon, reflectance 99%. The calibration has to be verified by reflectance standards with reflectivity of 50%, 20%.

Example of reflection standards: *Labsphere Reflexionsstandards SRS-99-020, SRS-50-020, SRS-20-020 (see* Figure 10*)*

Figure 10: reflexion standards; 99% - 75% - 50% - 20% - 2%

- <u>Measurement setup:</u>

The measurement of the target must be conducted with a special attachment, which ensures a defined distance between probe and target as defined in Figure 11.

Figure 11: measurement probe 90°, measurement probe 45°

- Entire test setup with Jaz-Spectrometer, reflectance probe, 90° measuring attachment and reflection standards:

Figure 12: complete measurement setup

The measurement shall be performed at three different points of the measuring object and shall be recorded.

The resulting IR reflectivity value corresponds to the average of the three reflectivity measurements.

A2 Measurement of Radar Reflectivity

The measurement of the radar reflectivity must be carried out by using a measurement setup according to the following specification.

Measurement Setup

A reference measurement with a corner reflector (calibrated → 10 dBsm) before and after measurements is recommended.

Sensor:

- vertical distance to ground as sensor application height 50cm +/- 15cm
- horizontal alignment +/-1° to centre line
- vertical alignment +/-1° to centre line
- 77 GHz sensor:
  Bosch MRR-SGU
  Continental ARS300/ARS301/ARS400 series (optional)

Car (or sensor carrier):

- angular driving deviation < 2° (driving direction)
- positioning accuracy longitudinal/lateral < 5cm

Bicyclist and bike Target:

- positioning accuracy longitudinal/lateral < 1cm
- angular orientation deviation < 3° (moving direction)

Test Environment

- no additional objects/buildings in the observation area
- proving ground surface completely covered with tarmac or concrete
- ground conditions: flat, dry street
- no metallic or other strong radar-reflecting parts in-ground or surrounding area
- reference measurement with 10dBsm @40m distance, corner reflector mounting height: 1m

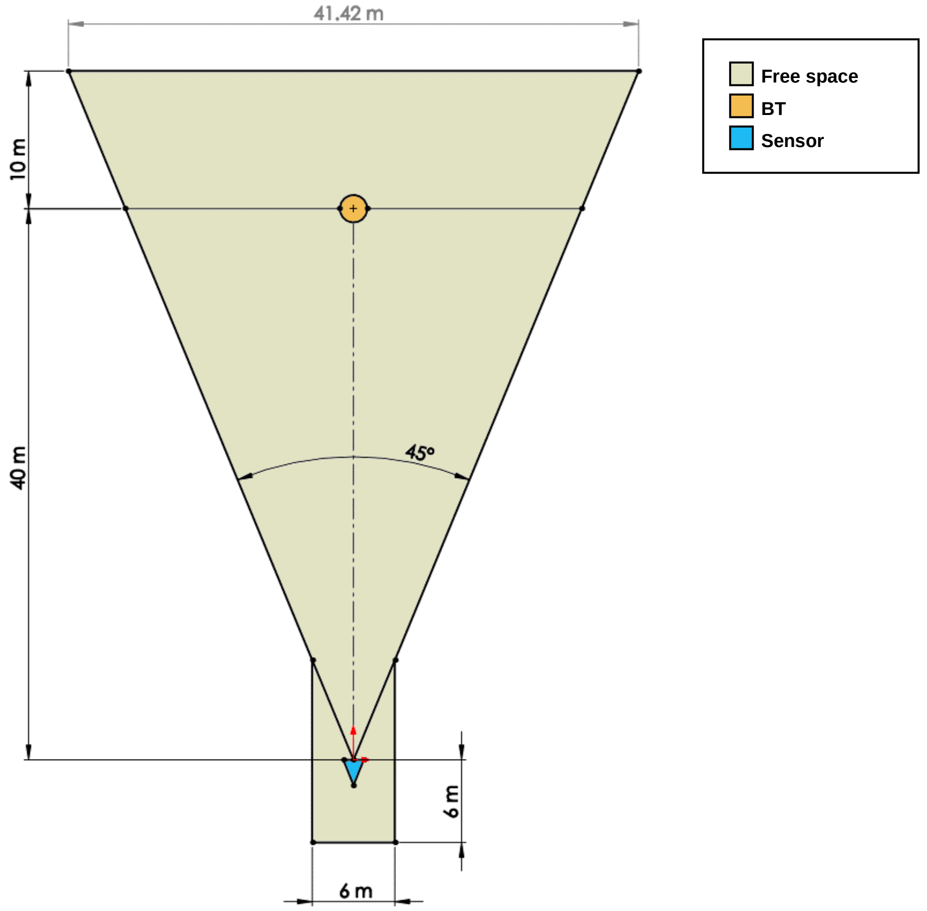


Figure 13: test environment

Measurement Scenario

Scenario 1

- static BT with moving vehicle
- initial distance 40m to 4m
- max. approaching speed 10km/h, no abrupt deceleration
- measurement angles 90°,180°, 270° (static BT facing direction relative to vehicle)
- averaging 5 approaches
- low pass filtering using a sliding average window (+/-2.5m)

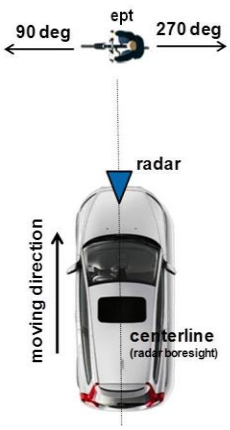


Figure 14: radar test scenario 1

Scenario 2

- moving BT with stationary vehicle
- BT velocity: 10km/h
- measurement VUT-BT distance 20m
- measurement angles 90°, 180° and 270° (BT facing direction relative to vehicle)
- BT moving direction 90°, 180° and 270°
- low pass filtering using a sliding average window (+/-2.5m range of radar)
- averaging 5 measurements per distance and orientations

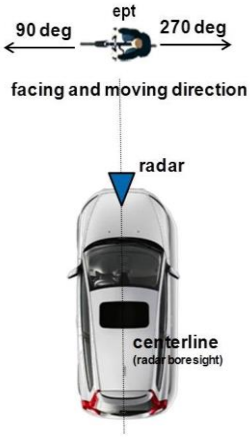


Figure 15: radar test scenario 2

A3 Measurements of RCS

Figure 16, Figure 17, Figure 18, Figure 19 and Figure 20 provide examples, comparing real bicyclist versus 4a bicyclist dummy using the evaluation methodology of appendix A2 for different viewing angles.

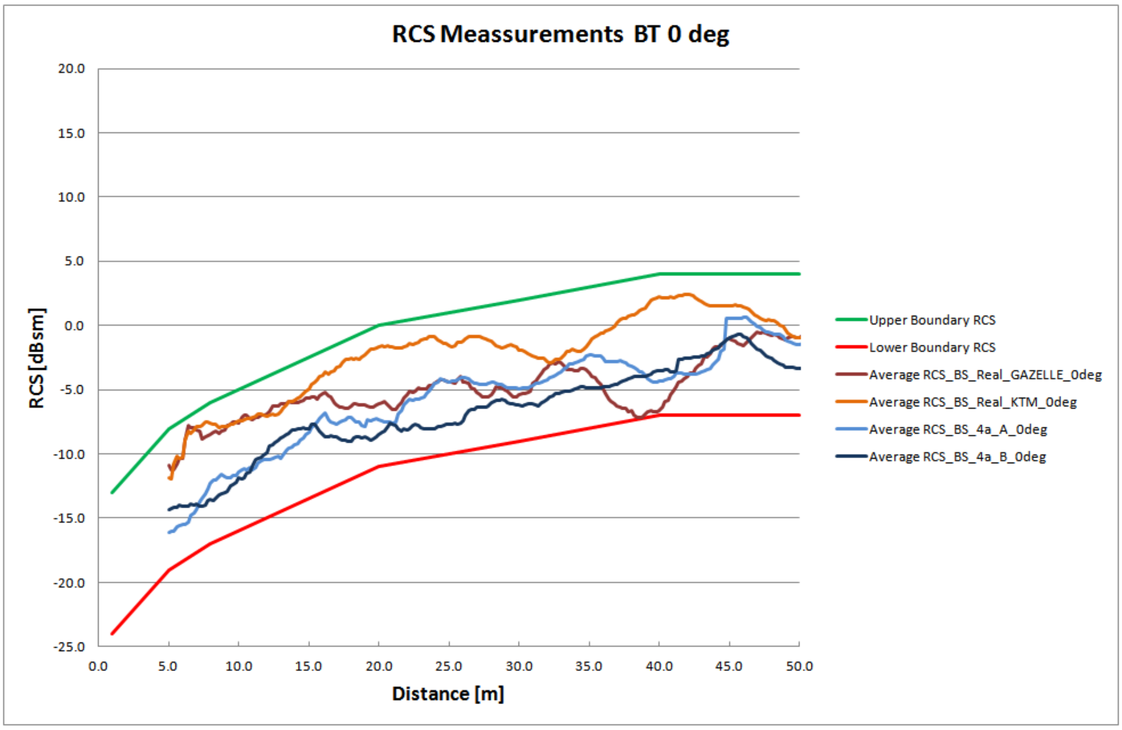


Figure 16: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 0°

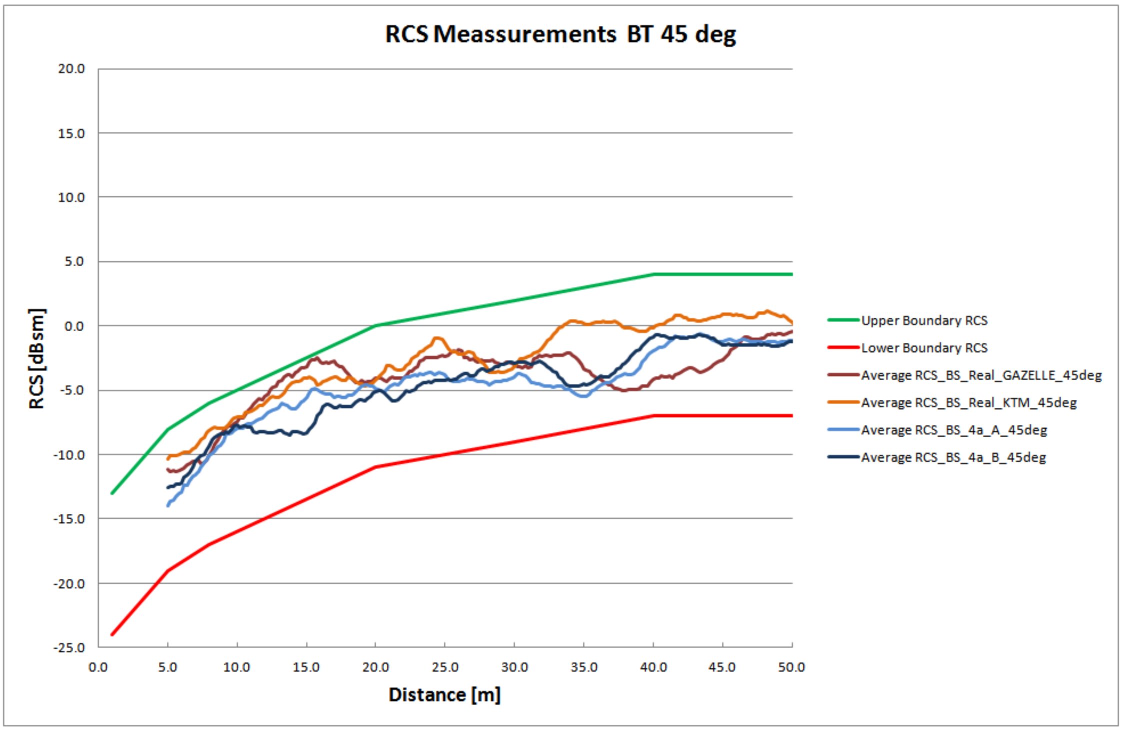


Figure 17: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 45°

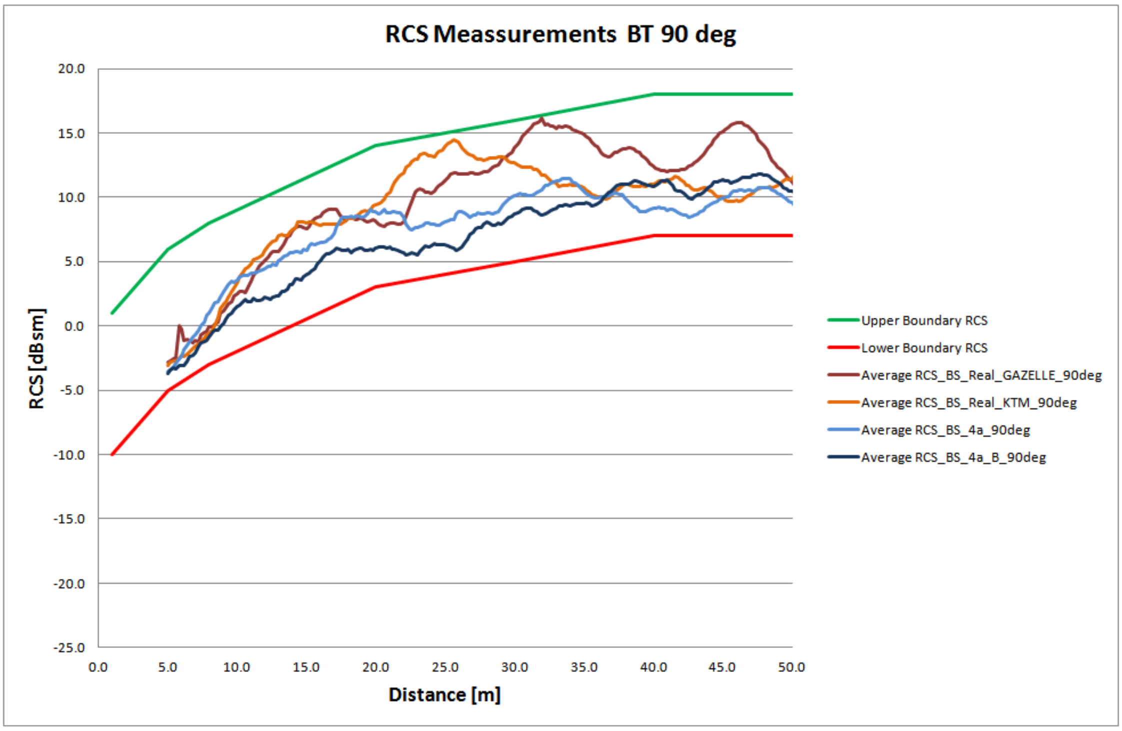


Figure 18: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 90°

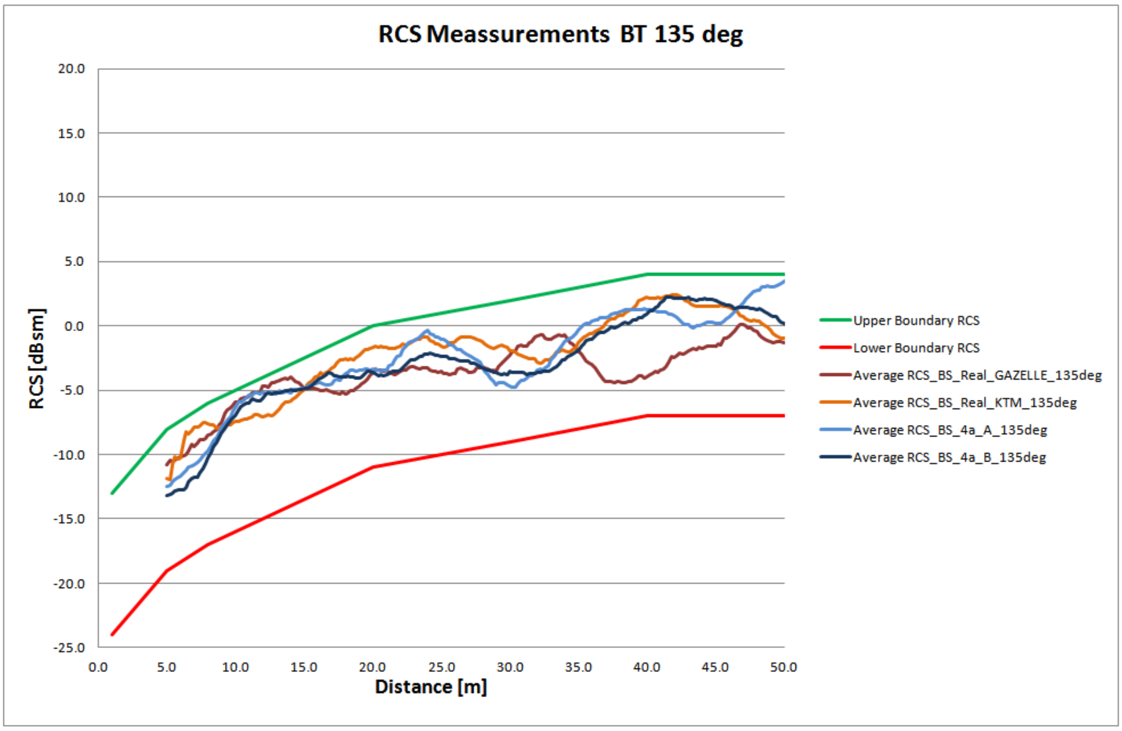


Figure 19: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 135°

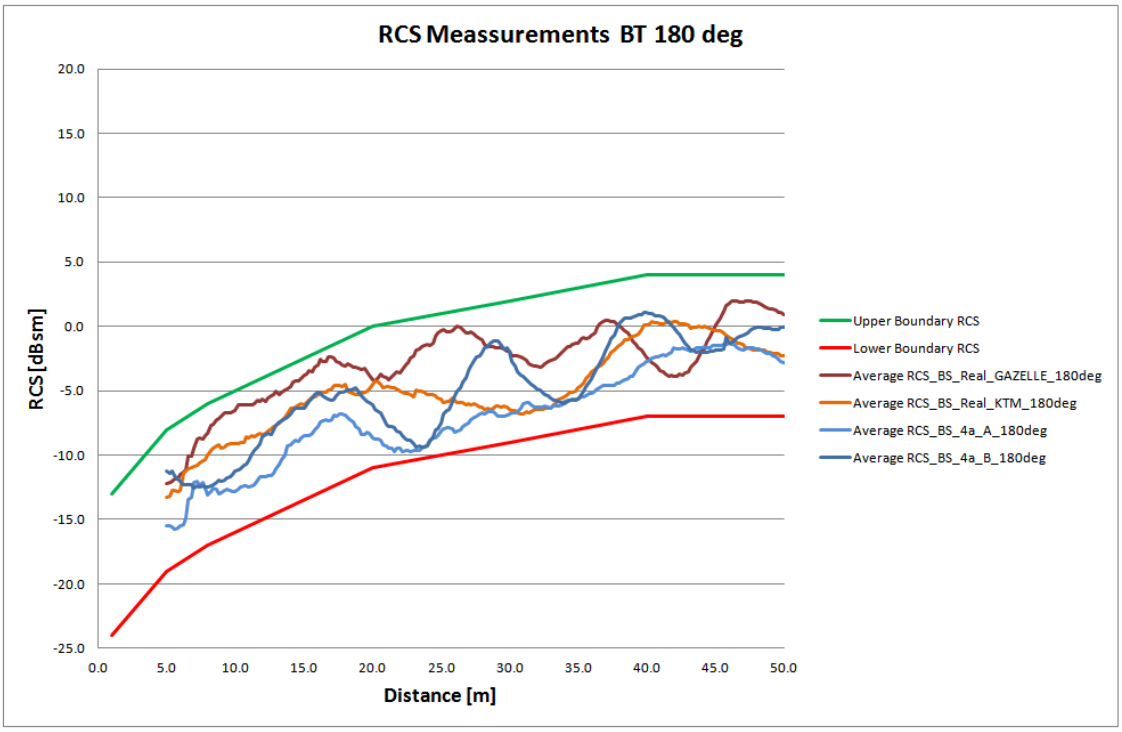


Figure 20: Example RCS of 4a bicyclist dummy target versus real Bicyclist (77 GHz Sensor Bosch MRR-SGU) 180°

A4 Measurements of micro-Doppler

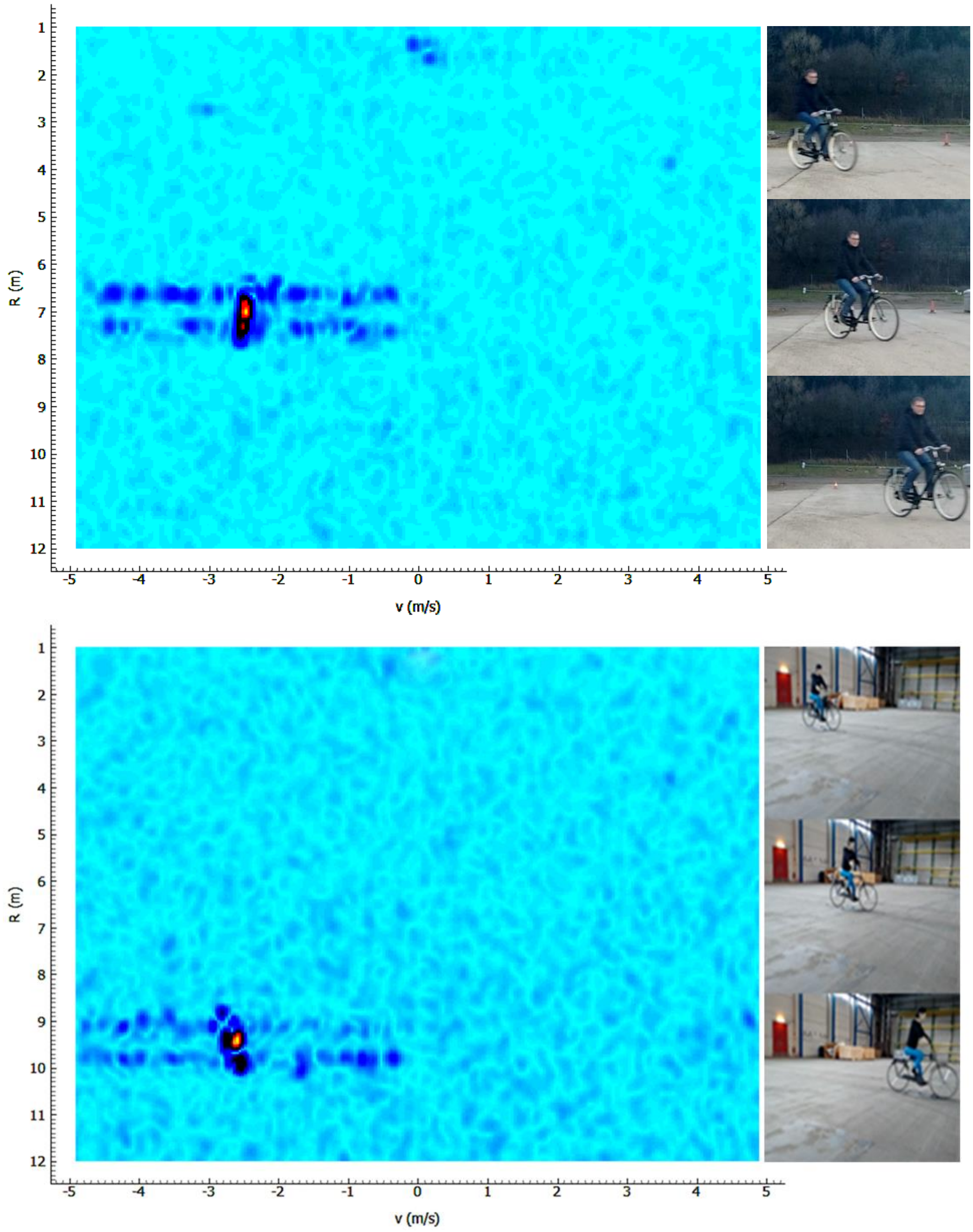


Figure 21: Micro-Doppler effect example, distance vs. distribution of relative velocities for a non-pedalling transversal moving bicyclist (top), and for a non-pedalling BT (bottom) (77 GHz sensor, 1 GHz bandwidth).