Valeo SCALA® 3D Laser Scanner (Gen 2)

User Manual

Version 2.0

February 2022

VALEO **MOBILITY KIT**

TABLE OF CONTENTS

SYMBOLS, UNITS & ABBREVIATIONS

A	Ampere
APD	Avalanche Photodiode
BrR	BroadR-Reach 100Base-T1
CAD	Computer aided design
c	Speed of light in air, $c \approx 2.997 \times 10^{8} m/s.$
cm	Centimeter
DC	Direct current
deg = [ ]°	1 degree = π / 180
EPW	Echo pulse width
Eth	Ethernet 1000Base-Tx
fps	Frames per second
GND	Ground (zero reference level electrical potential)
HI	Point cloud resulting from a high TDC threshold
IP	Internet protocol (address)
IR	Infrared
kB	Kilobyte
kg	Kilogram
LED	Light emitting diode
LO	Point cloud resulting from a low TDC threshold
m	Meter
MB	Megabyte
Mbps	Megabit per second

mm	Millimeter
ms	Millisecond
ns	Nanosecond
ROS	Robot Operating System
rpm	Rounds per minute
Rx	Ingress (receiver) side
s	Second
SCALA	Scanner Laser (Valeo laser scanner)
SCALA 2	2^{nd} generation SCALA
SDK	Software Development Kit
SUTP	SCALA Unified Transport Protocol
TDC	Time-to-Digital converter
UDP	User Datagram Protocol
USB	Universal serial bus
V	Volt
W	Watt
φ	Azimuthal (horizontal) scan angle
$\delta\varphi$	Azimuthal (horizontal) resolution (= separation between scan column centers)
ϑ	Polar (vertical) scan angle
$\delta\vartheta$	Polar (vertical) resolution (= separation between scan layer centers)

1. INTRODUCTION

Welcome to the user manual for the SCALA 3D Laser Scanner (Gen 2) Mobility Kit, and thank you for choosing this Valeo product. The present document will provide a description of the kit including all of its parts, the operation principle, specifications of the sensor, instructions for interfacing the sensor, and a troubleshooting guide. Please read the entire manual before operating the sensor or any part of the kit.

For further information on Valeo Mobility Kits,
please visit our website

https://www.valeo.com/en/valeo-mobility-kit/

or write to

cda.valeo-mobilitykits.mailbox@valeo.com

VALEO **MOBILITY KIT**

2. SAFETY PRECAUTIONS

2.1 General Safety Notes

The Valeo SCALA 3D Laser Scanner (Gen 2) (SCALA 2 for short) can cause danger to humans, animals or property if handled or used improperly. The operator must ensure that every person working with SCALA 2 has read and understood this user manual.

National and / or international legal requirements may apply to installation and usage of SCALA 2, as well as for commissioning and regular technical inspection. The operator of a vehicle or any other machinery equipped with SCALA 2 is responsible for consulting the responsible authorities about applicable safety rules and regulations, and to adhere to them.

Adhere in particular to the following safety notes in order to prevent danger to people and/or property:

⚠ **Note**: The SCALA 2 sensor and the entire SCALA 2 Mobility Kit represent prototype hardware for test & development purposes only.

⚠ **Note**: Point cloud output via the 1000Base-Tx Ethernet (Eth) and/or 100Base-T1 BroadR-Reach (BrR) interface has not been qualified for automotive use and is for test and development purposes only.

⚠ **Note**: Local safety and accident prevention regulations must be observed while operating SCALA 2.

⚠ **Note**: A malfunction of (vehicle / robot / machinery) control functions that depend on SCALA 2, or a malfunction of SCALA 2 itself can cause danger to human life or property damage.

⚠ **Note**: SCALA 2 and the remaining parts of the mobility kit must only be operated in a clean, breathable atmosphere. Do not submerge any part of the kit into fluids, and do not operate the kit in the presence of flammable gases or substances, chemicals, or in other hazardous environments.

⚠ **Note**: The operator must ensure by suitable instructions and inspections that the SCALA 2 is always clean.

2.2 Laser Class

Valeo SCALA 2 fulfills the requirements of a laser class 1 product according to the European laser standard EN 60825-1: 2007-10.

Note: SCALA 2 is a Class 1 Laser Product

Note: SCALA 2 must be immediately switched off by removing the power supply in any case of any technical malfunction or damage.

2.3 Infrared emission

SCALA 2 emits near-infrared laser pulses (around *905 nm*) that may interfere with, or hamper the operation of other infrared-based technologies such as, but not limited to, infrared remote control and receiver units.

Note: SCALA 2 may interfere with the operation of infrared sensitive technology.

2.4 Sensor inspection and cleaning

We recommend verifying that SCALA 2 is not damaged or obstructed by dirt (such as mud, snow, excessive dust) prior operation. In addition to causing safety issues, damages and obstructions may deteriorate the performance of the sensor.

Note: Avoid using chemical-based or abrasive cleaners on SCALA 2.

Note: Do not use a high-pressure power washer directly on SCALA 2.

Note: Do not paint or otherwise obstruct the sensor's optical front cover (*i.e.* the darkish polycarbonate part that covers the sensor front).

3. TECHNOLOGY OVERVIEW

3.1 Time of Flight principle

SCALA 2 is a compact laser scanner device based on the time-of-flight measurement of emitted, reflected and detected infrared (IR) laser pulses of approx. *905 nm* wavelength and few (~4) *ns* duration. The measured round-trip time of a light pulse is directly proportional to the distance between the scanner and a reflective object. Reflected light is picked up by a receiver unit consisting of several avalanche photodiodes (APDs), converting the optical signal into a time-resolved analogue electrical signal which is then fed through a time-to-digital converter (TDC) and a postprocessing chain to result in scan points. Figure 1 includes a schematic of the outgoing laser beam (left panel of Fig. 1) and the backscattered, detected beam (right panel of Fig. 1), which are both deflected by the rotating mirror. Note that the sender unit is located on the top part of the sensor, while the receiver side is located in the lower part. A kink in the optical front cover (not visible in Fig. 1) separates the receiver and the sender areas.

Figure 1: Schematic deflection of the emitted laser beam (left panel) and of the reflected light pulse (right panel) by one side of the rotating mirror.

3.2 Scanning principle and pattern

3.2.1 Rotating mirror: Azimuthal scan pattern

The laser scanner covers a wide horizontal angular range of *133°* so that a single sensor is typically sufficient to scan the area in front of a car. Figure 2 features the horizontal projection of the scan pattern or, equivalently, the field of view (FOV) that consists of $2600 = 4 \times 650$ emitted laser pulses. Note that the laser is emitting in a larger horizontal range of *145°*, but that scan points in the peripheral horizontal angle intervals [*-72.5°, -66.5°*) and (*66.5°, 72.5°*] are omitted or marked invalid in the point cloud.

Both the sending laser diode and the receiving APD array and their respective optical assemblies are mounted in fixed positions within the device. As shown in Fig. 1, a rotating mirror assembly, spinning at *750 rpm,* deflects the emitted laser pulses and reflects the backscattered light into the receiver unit. The rotor is equipped with two mirrors at *180°* azimuthal displacement, resulting in two scans per full rotation. The data acquisition time for a single point cloud is *60 seconds / minute / 750 rpm * 133° / 360° / 2 = 14.8 ms*. In this acquisition time formula, the final divisor *2* on the left hand side accounts for the effective scan angle doubling at the rotating mirror: In order to cover a *133°* horizontal scan, the mirror needs to rotate by *133° / 2 = 66.5°* only.

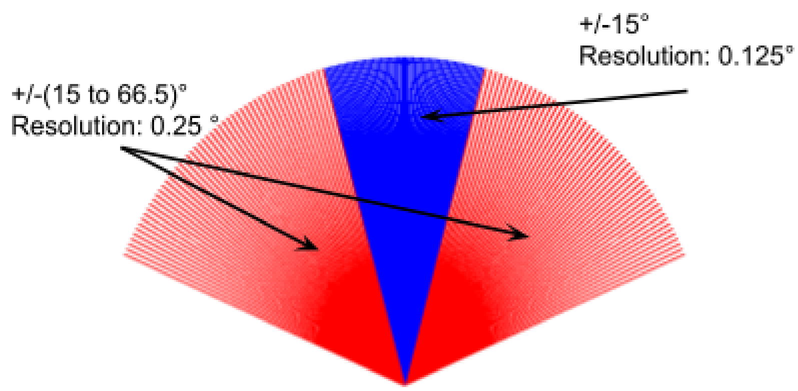


Figure 2: The *133°* azimuthal field of view / scan pattern in which valid scan points are contained.

While the angular spacing between two laser pulses is *0.25°* in the outer lobes (red regions in Fig. 2), the resolution is doubled in the central FOV that extends ± *15°* around the forward direction (blue region in Fig. 2). In this central FOV, the azimuthal spacing between laser pulses is *0.125°*. The sender and receiver units feature separate vertical characteristics.

3.2.2 Sender / receiver unit and tilted mirror: Polar scan pattern

The laser emitter unit consists of four vertically stacked emission elements, while the APDs are arranged in four groups of four APDs each, all of which are vertically stacked. As a result, the polar scan pattern consists of *16* layers in every single scan. A vertical dissection of a single scan, consisting of *16* scan points, will be denoted as a 'column' here.

An effective doubling in the number of layers, from *16 per scan* to an effective *32 per scan pair*, results from adjusted vertical tilt angles of ± *0.05°* for the two mirrors that are mounted on either side of the rotor: The tilted mirrors deflect and project the sender and receiver optical paths downwards and upwards in every second scan, resulting in an interlaced scan pattern that is depicted in *Fig. 3* and quantified in *Eq. 1*. Note that the spacing between layer centers varies as a function of the azimuthal angle, as the amount of mirror-tilt induced deflection depends on the position of the rotor. When the rotor is nearly perpendicular to the impinging laser beam from the emitter, the deflection is strongest and results in the largest amount of layer splitting (see the right hand side in the left panel of *Fig. 3*, where azimuthal angles approach *-66.5°*). On the opposite side of the scan pattern, the amount of vertical deflection due to the mirror tilt is smallest, resulting in almost coinciding layers for both mirror sides (see the left hand side in the left panel of *Fig. 3*, where azimuthal angles approach *+66.5°*, and where the black and red layers are almost merging).

Note that *Fig. 3* represents an overlay of two consecutive, interlaced scans (*i.e.* two subsequent point clouds), projected into the polar-azimuthal plane. The sensor sends individual scans via its Eth and/or BrR interface at a frame rate of *25 frames per second (fps)*. Thus, an entirely new two-scan overlay such as the one displayed in *Fig. 3* can be constructed on the decoder side at *12.5 fps* or, equivalently, every *80 milliseconds (ms)*.

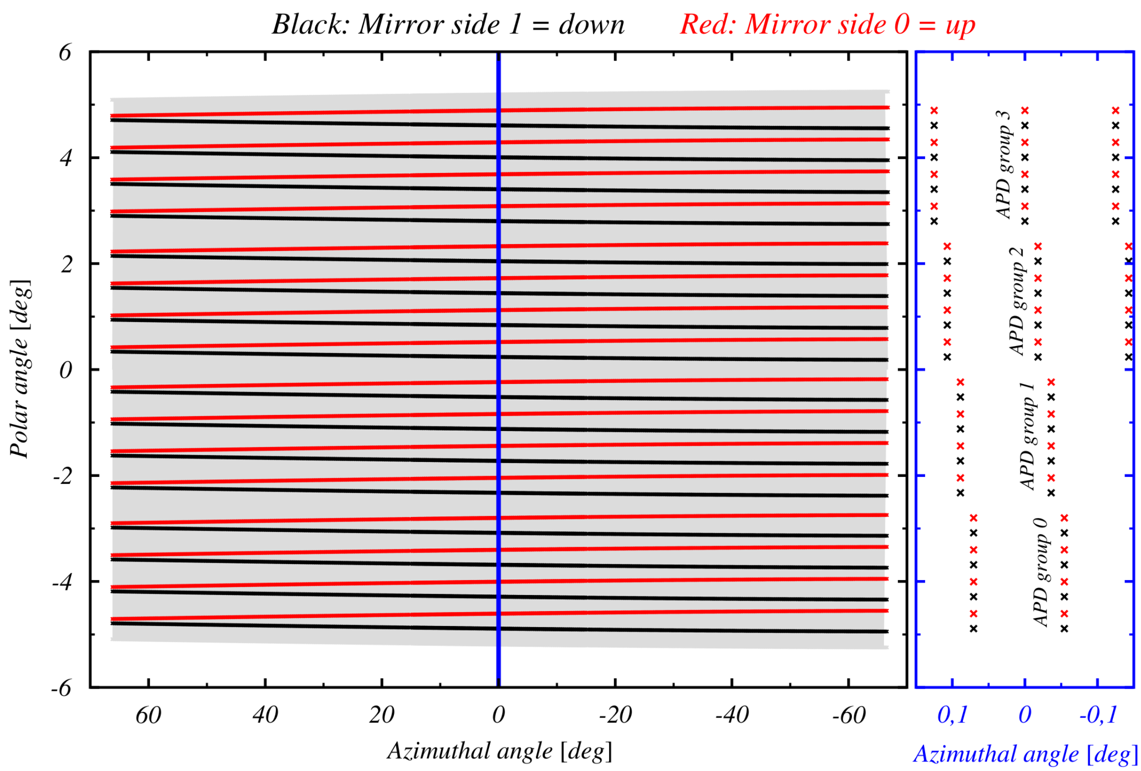


Figure 3: Left panel, gray area: SCALA 2 field of view, spanning the azimuthal range φ = *66.5° … -66.5°*, and a polar range that increases from ϑ = *-5.1° … 5.1°* at the left border (φ = *66.5°*) to ϑ = *-5.25° … 5.25°* at the right border (φ = *-66.5°*). The black and red camber-line curves in the left panel represent the polar centers of the 16 + 16 near-horizontal layers. The polar (vertical) width or sensitivity- / pickup-range of each layer is *0.6°*, defining the polar resolution of the device. Layers that correspond to the mirror pointing down are displayed in black, while red layers correspond to the mirror pointing up. The clustering of layers and scan points into four APD groups is clearly visible in the right panel, representing a zoom into the central field of view that contains *2.5* columns in the figure panel. Each APD group contains four APDs, resulting in eight (black and red) scan points per group due to the mirror-tilt induced splitting. Points corresponding to subsequent APD groups are slightly offset by *0.0181°* in the azimuthal direction, causing a slight, stepwise slant of each column. The azimuthal spacing between columns is *0.125°* in the azimuthal angle range [*-15°, 15°*] and *0.25°* in the outer lobes, where the absolute value of the azimuthal angle is in (*15°, 66.5°*]. Note that this figure represents an overlay of two subsequent point clouds (two mirror sides).

The polar angles in the scan pattern in *Fig. 3* follow *Eq. 1*, which represents a high-fidelity polynomial approximation of the actual physical scan pattern:

$$\vartheta = (-1)^{MS} \times \left(1.512 \times 10^{-8} \times \varphi^{3} - 5.152 \times 10^{-6} \times \varphi^{2} - 1.233 \times 10^{-3} \times \varphi + 0.1412\right)$$
$$+ 0.6025 \times Layer + 2.564 \times APDgroup - 4.749$$

(Equation 1)

Here, ϑ and φ are the polar and azimuthal angles in units of degrees, $MS \in \{0, 1\}$is the mirror side, where value *0* encodes the upwards-deflecting mirror side (red curves in *Fig. 3*) and value 1 encodes the downwards-deflecting mirror side (black curves in *Fig. 3*). $Layer \in \{0, 1, 2, 3\}$ refers to the layer number within one APD group, counting from bottom to top, and $APDgroup \in \{0, 1, 2, 3\}$ refers to the APD group, as indicated in *Fig. 3*, counting from bottom to top.

As described in *Sec. 7*., the mirror side '*MS'* is included in the SCALA 2 User Datagram Protocol (UDP) traffic, in a point cloud header (*Tab. 11*), and the azimuthal angle φ is contained for every 'Shot', representing a group of *24* scan points (*Tab. 12*).

3.3 Echo pulse width

SCALA 2 output for every scan point consists of three-dimensional position information (azimuthal and polar angle, and the distance from the sensor at which a reflective object was detected), along with an echo pulse width (EPW) information that is extracted from the received, reflected laser pulse. The EPW measurement principle is illustrated in *Fig. 4*: An APD detects the returned light pulse and converts it into an amplified electrical output, represented by the red curve in *Fig. 4*. The horizontal axis in *Fig. 4* is a time axis, along which the electrical APD output signal exhibits a non-zero duration (peak width). A threshold is applied to the APD electrical return by the TDC, defining the value of the peak width which is *7 ns* = *308 ns* - *301 ns* in *Fig. 4*. The EPW of *2.1 m* results from multiplying the peak width by the speed of light in air, $c \approx 2.997 \times 10^{8} m/s$.Note that the temporal duration of the received, reflected pulse may exceed the duration of the emitted laser pulse (approx. *4 ns*). The duration of the reflected pulse depends on atmospheric dispersion and, more importantly, on the geometric orientation and the material properties of the reflecting object. Some consequences of these variations on the measured EPW will be addressed at the end of the current section.

The noise floor, represented in *Fig. 4* by the erratic, low-amplitude APD electrical output before and after the peak is caused by various influences that include ambient light and electronic random noise. Note that the peak in *Fig. 4* starts to rise significantly above the noise floor at approx. *300 ns*, corresponding to an object distance of $89.9\,m = c \times 300\,ns$. The temporal lag between this initial significant rise into the peak and the first TDC threshold overshoot (occurring at *301 ns* in *Fig. 4*), and the correction of that lag time will be addressed in the following *Sec. 3.4*.

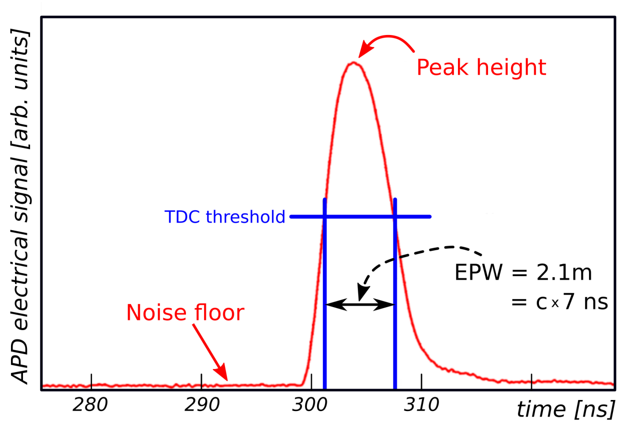


Figure 4: Illustration of an APD electrical output signal (red curve) and its conversion via the TDC, where the TDC threshold (horizontal blue line) defines the width of the peak (black double-headed arrow). The resulting EPW, in units of meters, is the product of the speed of light, *c*, and the sample temporal 'width' (duration) of the peak.

Echo pulse width is related to, but not to be confused with, the returned laser light intensity and energy. Simple and strict one-to-one relationships between EPW and intensity or between EPW and energy do not exist: While the maximal intensity relates to the peak height of the red curve in *Fig. 4*, and the returned energy relates to the integral under that peak, the EPW measures the width of the peak. All three quantities (height, width and integral) are correlated, but the details of these correlations depend on the surface properties of the target, ambient light conditions, and other influences. Note, however, that for most practical purposes and use cases, EPW correlates positively with intensity and, consequently, with object reflectivity. An illustration of this positive EPW-to-reflectivity correlation is provided in *Fig. 5*, where highly reflective objects in a typical use-case environment appear as high-EPW scan points, whereas weakly reflective objects appear as low-EPW scan points.

Figure 5: An example scene that demonstrates EPW contrast on surfaces with different reflectivities. Top panel: camera image, Bottom panel: SCALA 2 point cloud (one mirror side only). The positions and orientations of camera and SCALA are slightly offset, resulting in the visibly different points of view for the top and bottom panel. Scan points in the bottom panel are displayed with a linear EPW color coding, ranging from red for small values of the EPW through orange, yellow, green and up to blue for increasing values of the EPW. Note the stark difference in EPW between strongly and weakly reflective surfaces, as seen on and around the vehicle’s license plate, the traffic cone, and the delineator pole on the right. The two optical reference targets next to the vehicle’s passenger side have reflectivities of *50%* and *5%*. Note that the *50%* target results in a significantly higher EPW (yellowish scan points) as compared to the *5%* reflectivity target (reddish/orange scan points). As a general observation, EPW correlates positively with intensity of the reflected laser pulse and with the reflectivity of the object, in most practical use cases.

The underlying reason for the positive EPW-to-intensity and EPW-to-reflectivity correlations observed in *Fig. 5* is a shape similarity in the APD electrical output signal peak (one of which is shown in *Fig. 4*), for a variety of targets or objects: More reflective targets tend to increase not only the height of the APD electrical signal peak, but also its width.

Note, however, that the EPW-to-intensity correlation weakens under certain circumstances, some of which may be encompassed in typical sensor use cases. The perhaps most prominent example where a high EPW does *not* necessarily imply a high reflected peak intensity, nor a highly reflective surface is the grazing incidence of the laser beam on a surface. Consider, for instance, the road paving 'far' away from a vehicle on which SCALA is mounted, as illustrated in *Fig. 6:* Every APD picks up light from a finite range (*0.6°*) of polar angles which, under grazing incidence conditions, corresponds to a large range of distances on the reflecting object. This range is labelled 'layer projection' in *Fig. 6*. Due to the different times of flight for light returning from all parts of the layer projection, the APD receives reflected light with a large temporal spread, which will be translated into a widespread APD electrical output signal. As a consequence, the EPW may be high even if the height of the peak and the object reflectivity are relatively low.

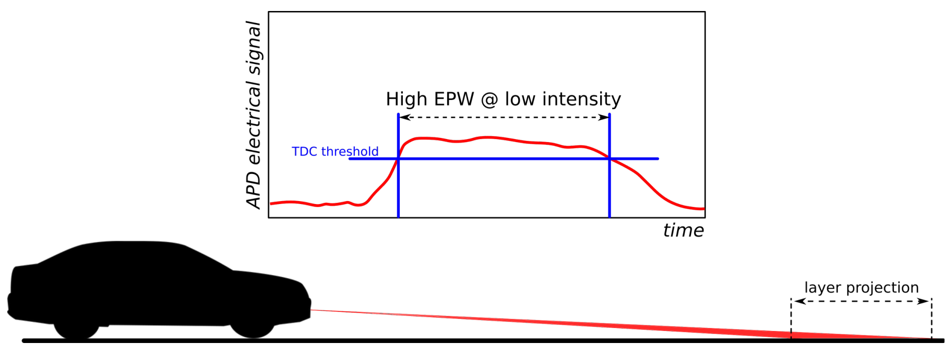


Figure 6: A schematic of grazing incidence on a road pavement, where the laser emission and APD pickup polar angle intervals for a single layer in the scan pattern are projected and spread out over a large distance range on the ground. The backscattered light, originating from a large range of object (road pavement) distances, results in a temporally extended optical input signal at the APD, which will be translated into a temporally extended APD electrical output, and result in a large EPW after TDC conversion. In this case, a high value of the EPW does not necessarily imply a high value in the peak intensity.

3.4 Walk error compensation

Sampling the APD electrical signal through a TDC threshold, as described in *Sec. 3.3*, results in a lag time between first arrival of light from a reflective object and peak detection. As illustrated in *Fig. 7*, this lag time can cause an overestimation of object distance, referred to as 'walk error'.

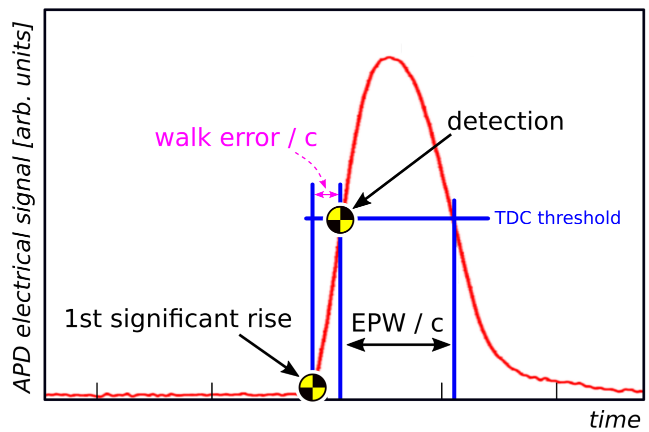


Figure 7: Illustration of walk error: The first significant rise of the APD peak (red curve) above the noise floor corresponds to the first arrival of light from a reflective object and thus to the true object distance. Sampling the APD peak at the TDC threshold induces a lag time between the first significant rise and the time of detection. The product of this lag time and the speed of light, c, is referred to as 'walk error', and is corrected within certain limitations by the SCALA firmware.

SCALA 2 corrects every scan point through a walk error compensation, which eliminates the walk error within certain limitations and accuracy levels. The major challenge for walk error compensation is caused by differences in object reflectivities: Highly reflective objects such as white paint, car finish, or retroreflectors tend to create an APD electrical signal peak with a steeply rising flank, while dull or diffuse objects such as black paint or tarmac typically result in a shallower, more gently increasing peak. As a consequence, walk error tends to be small for highly reflective objects, and vice versa. The walk error compensation algorithm in the SCALA Firmware is taking this into account and corrects for differences in object reflectivities.

3.5 Up to three echoes per point

Partially reflecting and transmitting objects, such as window panes or rain drops, in SCALA's optical line of sight may cause detection of more than one reflected laser pulse (also referred to as an 'echo') in the sensor, even for a single emitted laser pulse. Objects that protrude the optical line of sight partially may cause 'graze shot' reflections. *Figure 8* illustrates a situation in which two particularly situated opaque objects and one partially reflective glass surface may lead to three echoes for one single emitted laser pulse.

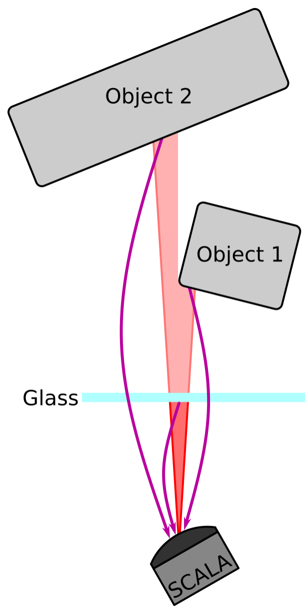


Figure 8: Schematic illustration of a situation where SCALA 2 may return up to three echoes for one single scan point, defined by one pair of polar and azimuthal angles and one emitted laser pulse. The first echo here is caused by partial reflection of the laser pulse on a glass surface. Object 1 protrudes the laser pulse and causes a 'graze shot' reflection. The remaining part of the laser pulse is reflected by object 2, causing a third echo.

Although there is no strict upper physical boundary for the number of echoes that might return to the sensor per scan point, more than three echoes occur very rarely in the laser scanner's typical use cases. The maximal number of sampled echoes is thus limited to three in the SCALA 2 firmware.

The point cloud format in the SCALA 2 UDP data stream (see *Sec. 7*) reserves three echoes for each scan point. For any one of the three echoes that was not physically recorded, the pertinent object distance is set to a predefined value of *65535 cm,* signalling the absence of that echo.

Figure 9 is a snapshot of a SCALA 2 point cloud that demonstrates the relevance of returning more than one echo per san point. The representation of the person behind a glass door in *Fig. 9* consists mostly of 2nd or 3rd echoes, preceded by 1st or 2nd echoes from the glass door.

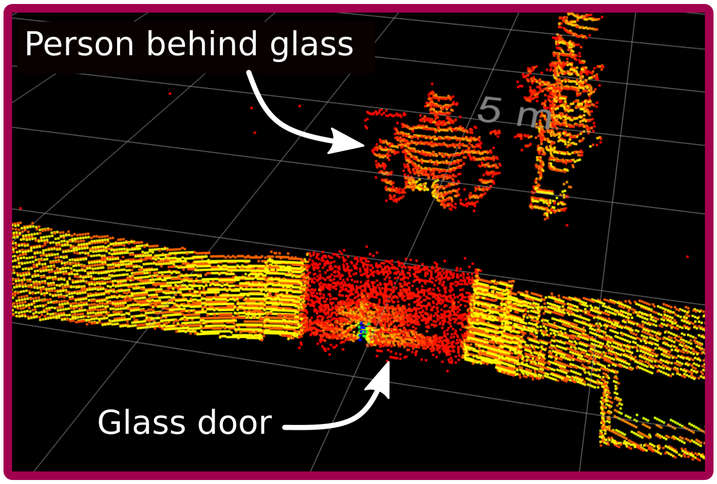


Figure 9: A SCALA 2 point cloud snapshot (one mirror side only), where the optical path in the forward direction contains a glass door and a person standing behind that door. The upper body part of the person including head, chest and angled arms is clearly visible in the scan. Point color-coding represents the EPW, where red encodes a low EPW and orange, yellow, green and blue encode increasingly higher EPWs. Note that the scan points from the glass door exhibit low EPWs, due to the weak optical reflectivity of glass. The scan points on the person exhibit rather low EPWs as well, since the corresponding light pulses have passed the partially absorbing and reflecting glass twice in their sensor→glass→person→glass→sensor round trips. The white painted walls to the left and right of the glass door show comparatively high EPW values.

3.6 Double point cloud

As explained in *Secs. 3.3 & 3.4*, every SCALA scan point results from an analogue-to-digital conversion, where the key parameter is the TDC threshold. Selecting a high value of the threshold tends to avoid sampling of the noise floor in the APD electrical output signal and results in a 'cleaner' point cloud with little noise and few 'ghost' points (false positive detections). At the same time, a high TDC threshold increases the likelihood of undersampling (false negative non-detections): If the threshold is selected too high, a peak in the APD electrical output might not be sampled, even if it corresponds to a true physical object.

The opposite statements apply to low values of the TDC threshold: If a low threshold is selected, the point cloud may include a relatively high amount of noise and ghost points, but also a higher rate of true positive detections. The point cloud sensitivity vs. robustness tradeoff is summarized in *Tab. 1*, where the TDC threshold acts as the control parameter.

Point cloud quality	**Low TDC threshold**	**High TDC threshold**
High sensitivity (true positive rate)	+	-
High robustness (true negative rate)	-	+

Table 1: Sensitivity vs. robustness tradeoff for low and high values of the TDC threshold.

In order to overcome the sensitivity vs. robustness tradeoff and to provide the end user with an optimal sensitivity *and* robustness, SCALA 2 operates in 'Double Point Cloud' mode, where every APD electrical output is sampled twice. The first sampling occurs at a high TDC threshold and the second sampling at a low TDC threshold. The resulting two point clouds 'HI' and 'LO' are both transmitted via the UDP protocol, through the Eth and / or BrR interface, as outlined in *Sec. 7*. *Figure 10* features an exemplary SCALA 2 recording, where the HI point cloud is displayed in the top panel and the LO point cloud is displayed in the bottom panel. Both point clouds in *Fig. 10* correspond to the same SCALA 2 frame, and differ only in the applied TDC threshold.

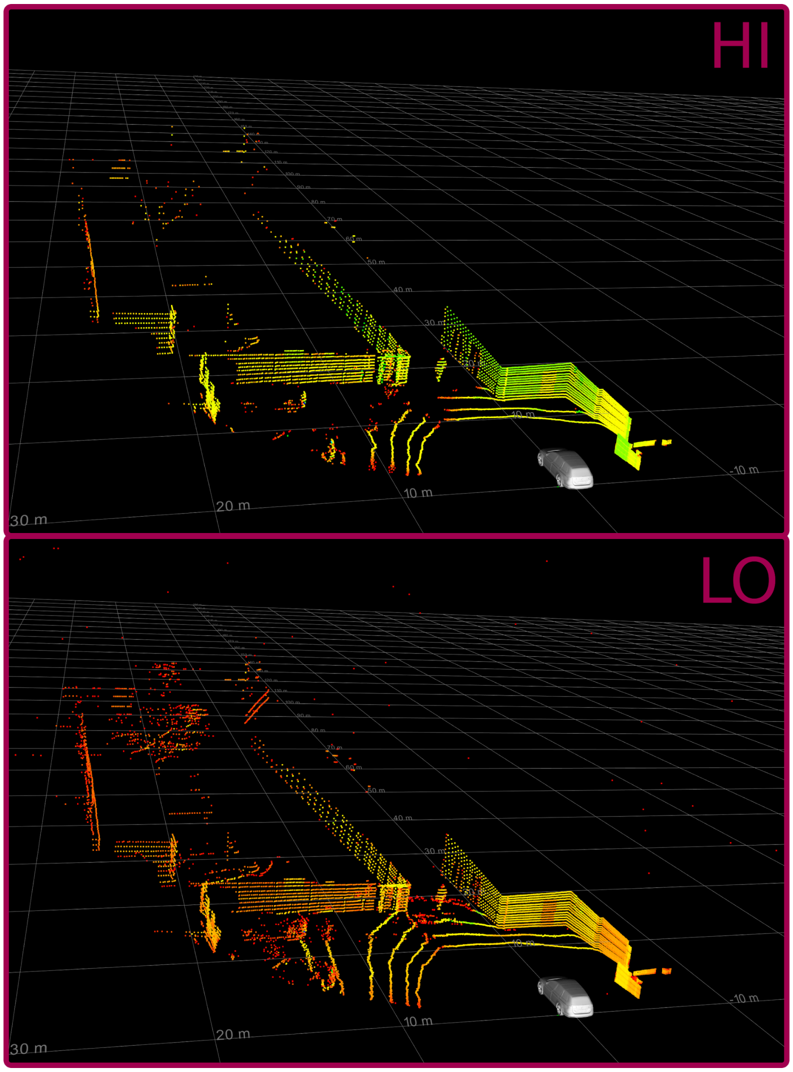


Figure 10: A test scene recording, featuring the HI (top panel) and LO (bottom panel) point clouds corresponding to one SCALA 2 frame (one mirror side only). Note that the HI point cloud is more well-defined and largely free of noise, while the LO point cloud exhibits a larger detection range and higher likelihood of object detection, especially at large distances. An EPW color coding, similar to the one in *Fig. 5*, is used in both panels. The color ranges are separately normalized for both panels (red/blue = lowest/highest EPW in the respective displayed point cloud).

Valeo recommends to sample both point clouds in your decoder software and processing toolchain, and to select between HI and LO on the basis of performance indicators such as the noise level (variance in scan point presence / absence, ability to cluster scan points, *etc.*). Such a selection between HI and LO will typically result in sector- or range-based switching. Typically, the HI point cloud may be preferred at small distances from the sensor, while the LO point cloud is the more sensible choice at larger distances. An optimal switching between HI and LO will allow you to operate along the green diagonal in *Tab. 1*. Many environmental conditions influence the optimal choice between HI and LO, which is the reason for leaving the decision to the end customer of the Generic Mobility Kit, instead of pre-selecting irreversibly in the sensor Firmware.

Note that *Sec. 5.2.3*, where the range performance of SCALA 2 is quantified, provides a rough estimate on which point cloud is usable at which ranges.

3.7 Sensor limitations

The Valeo Mobility Kit policy is to provide the end user with maximum flexibility and freedom of choice in raw data access. Sensor firmware is thus restricted to a minimal amount of irreversible point cloud preprocessing, and will pipe out data that is as close as possible to the recorded, raw physical signals. This easy access to low-level data comes at the price and requirement of user awareness, regarding possible data misinterpretation and the corner cases of sensor operation conditions.

Caused by the physical principles of operation and signal processing, the point cloud output from SCALA 2 can exhibit artifacts in different types of corner case operation or in cases where the sensor is operated outside the envelope of recommended conditions. The most prominent point cloud artifacts are listed in this section, along with recommendations on how to spot and avoid them.

3.7.1 Ultra-near field limitation

SCALA 2 is not designed as an ultra near-field sensor. Scan points at distances of less than *0.5 m* from the sensor must be interpreted with great caution, or better rejected / ignored in point cloud interpretation. The ultra near range shows a significant false positive detection rate, which is mostly due to internal reflections (see *Fig. 11*).

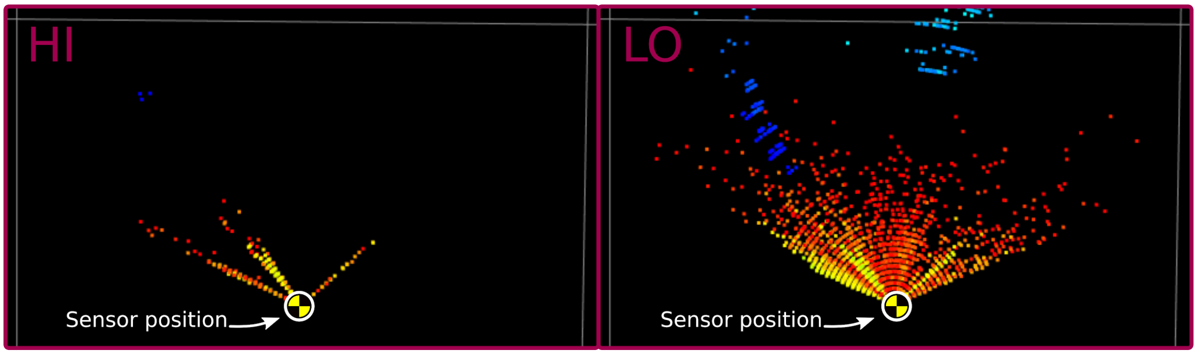


Figure 11: Birdseye perspective of ultra-near range (up to *0.5 m* distance) point clouds with EPW color coding. Left panel: HI threshold point cloud. Right panel: LO threshold point cloud. The red-to-yellow scan points correspond to internal reflections, i.e. false positive detections.

The internal reflections will typically intensify and increase the false positive rate in case of dirt or other optical obstructions on the front cover. True positive detections of physical objects in the ultra-near field may occur, but the distance and EPW values of such ultra-near field, true positive scan points will be prone to large errors.

Note: Refrain from over-interpreting the SCALA 2 point cloud at ultra-near range distances of less than *0.5 m* from the sensor. Sensor output is not reliable and in the ultra-near range. Keep the front cover as clean as possible to reduce internal reflections.

3.7.2 Near field ghosts

SCALA 2 is designed as an intermediate- to long-range sensor. Special care has to be taken in the interpretation of point clouds, when the sensor is operated in the presence of close-range objects, less than *1.5 m* away from the sensor. *Figure 12* illustrates near field 'ghost' points or echoes, which might emerge between a close-distance reflective object and the sensor.

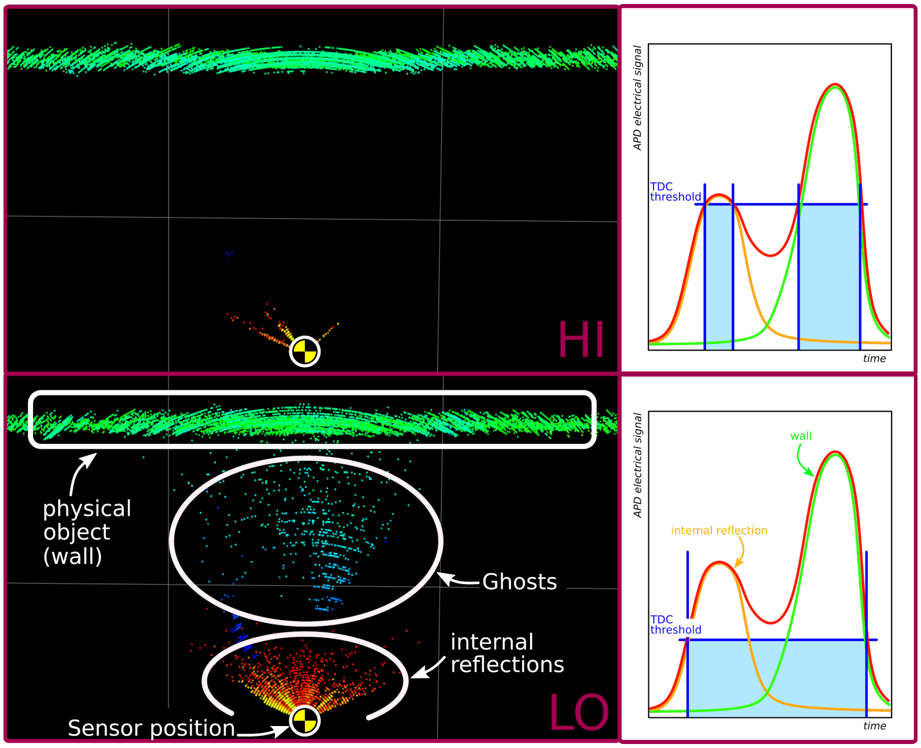


Figure 12: Left two panels: Birdseye-perspective point cloud snapshots with EPW color coding, where SCALA 2 is facing a wall at a close distance of approximately *1 m*. Top left panel: HI threshold point cloud. Bottom left panel: LO threshold pointcloud. Near-field ghost points are visible in the LO point cloud (blue points). The ghosts are caused by peak fusion at low TDC threshold, as illustrated in the two panels on the right, which also explains the high EPW of the ghost points.

Near-range ghosts are typically caused by fusion of an APD electrical signal peak that is related to a physical object (green curves in *Fig. 12*), and another peak caused by an internal reflection (orange curves in *Fig. 12*). The total APD electrical return (red curves in *Fig. 12*) is the sum of the internal reflection peak and the object-related peak. If the TDC threshold is lower than a critical value, the two peak contributions are not discriminated in the analogue-to-digital conversion, but fused into one single, high-EPW ghost detection. The HI point cloud is considerably less prone to ghost echoes, as seen in the top left panel of *Fig. 12*.

Note: Ghost echoes may appear if SCALA 2 is operated at very close object distances of less than *1.5 m*. Choosing the HI point cloud at close distances reduces the probability of encountering ghost points. Ghost echoes will typically exhibit a high EPW.

3.7.3 APD bleeding and saturation: blooming and ringing

Very reflective objects, such as the retroreflector target in *Fig. 13,* can cause artifacts in the point cloud that are referred to as blooming and ringing. The magnitudes of both blooming and ringing typically increase when the sensor-to-object distance is decreased, and the HI threshold point cloud is less prone to both artifacts than the LO threshold point cloud.

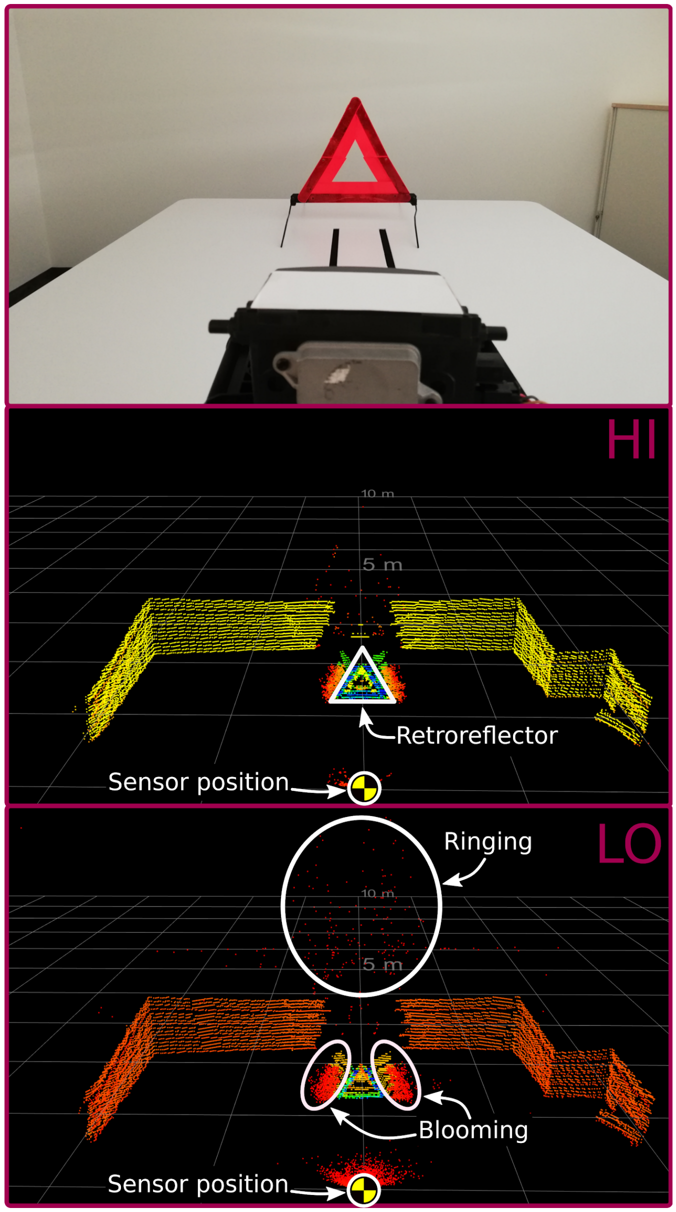


Figure 13: HI and LO point cloud recordings (one mirror side only) in a closed room with a retroreflector target at a near distance of approximately *1.5 m*. Scan point artifacts due to blooming are visible to the left and to the right of the retroreflector. Artifacts due to ringing are visible in the forward direction area behind the solid wall, at distances larger than approximately *2.5 m* from the sensor. The LO threshold point cloud is more prone to blooming and ringing than the HI threshold point cloud.

Blooming can occur in the lateral perimeter of highly reflective objects, such as retroreflectors at close range (*see Fig. 13*). The underlying reason for blooming is APD bleeding: The intense returning light from a very reflective object might be picked up and detected by an APD even outside of the APD's nominal angular perception range. Note that the emitted laser pulses from SCALA 2 show some angular divergence as they propagate forward. This laser pulse divergence results in an illumination pattern which is a little more widespread than the nominal pickup pattern of the APDs. A (highly reflective) object may thus be partially illuminated, even if SCALA 2 is nominally scanning an angular range that does not cover the target at that moment in time. The high sensitivity of SCALA's APDs may then result in bleeding and blooming.

Ringing may occur behind highly reflective objects, as seen in *Fig. 13*, where some scan points are visible behind the solid, optically opaque wall. The reason for ringing is APD electrical saturation, caused by intense optical input. During the transient decay that follows the saturated state, the APD electrical output may settle in a non-monotonic fashion that includes local maxima at different times. Sampling of these maxima through the TDC can result in false positive scan points behind the highly reflective target.

Note: Blooming and ringing may occur around and behind highly reflective objects, especially when the sensor-to-object distance is small. The HI threshold point cloud exhibits less blooming and ringing than the LO threshold point cloud.

3.7.4 Noise

SCALA 2 output is not free of noise in general, even if artifacts such as near-field ghosts, blooming and ringing are excluded. Typical sources of noise include internal causes, such as the APD electrical signal noise floor which is visible and marked out in *Fig. 4*. In limiting cases, this electrical noise floor may rise above the TDC threshold and mistakenly be sampled into a scan point. Note that SCALA adapts the amplification factor between optical APD input and electrical APD output dynamically, depending on ambient light conditions. A high amplification factor may, in rare cases, amplify the noise floor to an extent where it causes false positive detections. Bright ambient light tends to reduce the signal-to-noise ratio between the laser pulse echo and the APD noise floor, resulting in a relatively high likelihood for noise points.

In addition to internal causes for noise, there are various external, environmental conditions causing scan points where there is no solid, reflective object. Such external sources include direct incidence of sunlight (typically when the sun is low) or strong artificial light sources with sufficient spectral density at and around a wavelength of *905 nm*. Other external sources of 'noise' can be rain, fog or (exhaust) fumes which may result in backscattered laser pulses. In such cases, where the scattering is due to a transient, microscopic physical object (such as a raindrop) or a quasi-continuous medium (such as fog) there is a fluid transition between what should be classified as 'noise' or as a true positive scan point.

Note: Noise, i.e. false positive scan point detections, can and will occur at different levels of magnitude, depending on environment conditions such as ambient light, temperature, humidity, or weather. As a rule of thumb, noise will be stronger under bright ambient light conditions. The HI threshold point cloud exhibits less noise than the LO threshold point cloud.

4. SYSTEM OVERVIEW

4.1 Kit overall description

The Valeo SCALA 2 Mobility Kit is a plug-and-play system consisting of a SCALA 2 sensor, mechanical mounting bracket, a BrR–Eth converter, cables. Also included is a USB pen drive with decoder / visualizer software, a C++ software development kit, and computer aided design (CAD) files for easy sensor integration into your platform.

Raw point cloud output is provided by the sensor via its 100 Mbps (100Base-T1) BrR interface, and can be converted to 100Base-Tx ethernet with the added BrR–Eth adapter, featuring a standard RJ45 output jack.

4.2 Kit contents

The following *Tab. 2* features all hardware components that are contained in the SCALA 2 Generic Mobility kit.

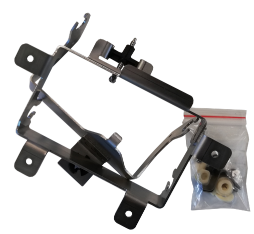
SCALA 2 Sensor	
Mounting bracket Including accessories	
BrR–Eth converter 100Base-T1 slave to 100Base Tx	
Cables Sensor power + wakeup (left) BroadR-Reach (middle) BrR–Eth converter power (right)	
USB pen drive with decoder software, manual, and CAD files	

Table 2: SCALA 2 Generic Mobility kit contents.

To operate the kit, you need to provide a 12V DC power supply (banana jack).

For decoding the sensor output into point clouds, you can run the provided decoder software on your host PC. The provided software is compatible with GNU/Linux Ubuntu 18.04 LTS and with Microsoft Windows 10. The included C++ Software Development Kit (SDK) features a simple interface to fetch point clouds into Standard Template Library containers. The SDK is the starting point for implementing your own point-cloud based perception or other algorithms. White coded, simple example applications that demonstrate SDK usage, are included.

4.3 Required additional hardware

Hardware that is required for operating, but not included in the SCALA 2 Generic Mobility kit, is listed in *Tab. 3*.

Item	Minimum requirement	Recommendation
Network cable	Cat 5 	Cat 5 or higher 
Power source	9 V -- 14 V DC voltage stabilized, 3 A, Banana jacks	12 V DC stabilized, 3 A, Banana jacks
Decoder PC	100 Mbps eth. interface, 1MB UDP receive buffer, MS Windows 10 or GNU/Linux Ubuntu 18.04	2+ GHz dual core, 100 MB RAM avail. for decoder Software

Table 3: Hardware that is required for operation, but not included in the SCALA 2 Generic Mobility kit. Valeo does not promote any potential supplier listed here. Part numbers are reference guidelines only.

5. PRODUCT SPECIFICATIONS

5.1 Sensor form factor and weight

Property	Range / Value
Sensor dimensions (H x W x D) Without mounting bracket	68 mm x 150 mm x 95 mm
Sensor dimensions (H x W x D) with mounting bracket attached	137 mm x 191 mm x 123 mm
Sensor mass	0.57 kg
Mounting bracket weight	0.40 kg

Table 4: Sensor form factor and weight

5.2 Point cloud characteristics

5.2.1 Field of view

Azimuthal (horizontal) range $\varphi = -66.5° \ldots +66.5°$, polar (vertical) angle range increasing from $\vartheta = -5.1° \ldots +5.1°$ at $\varphi = +66.5°$ to $\vartheta = -5.25° \ldots +5.25°$ at $\varphi = -66.5°$. The field of view consists of 16 + 16 interlaced, nearly horizontal layers, stacked in the vertical direction. For additional details and full specification of the scan pattern, see *Sec. 3.2.1* and *Sec. 3.2.2*.

5.2.2 Angular resolution

Azimuthal resolution $\delta\varphi = 0.25°$ in the outer-lobe angular ranges $\varphi = -66.5° \ldots -15°$ and $\varphi = +15° \ldots +66.5°$, and $\delta\varphi = 0.125°$ in the central field of view $\varphi = -15° \ldots +15°$. Polar (vertical) resolution $\delta\vartheta = 0.60°$ between adjacent horizontal layers of one APD group, and $\delta\vartheta = 0.64°$ between adjacent APD groups. Every APD group contains *4* layers. For additional details and full specification of the scan pattern, see *Sec. 3.2.1* and *Sec. 3.2.2*.

5.2.3 Range

5.2.3.1 Typical objects and use case

The exact range at which SCALA 2 can detect an object may be defined as the maximal sensor-to-object distance for which the sensor will produce object-related scan point output in the majority of its output frames. This sensor range depends on various object-related and environmental conditions. Object-related influences on the range include, but are not limited to, the size of the object, its geometric orientation, and its surface properties, in particular its optical reflectivity at *905 nm* wavelength. Environmental influences include atmospheric attenuation, ambient light from natural and artificial sources, temperature, *et cetera.* The following *Tab. 5* is a list of approximate ranges that can be expected for typical objects and operation conditions, in the typical sensor use case (mounted on a passenger car in urban or highway environment).

Object	Approximate SCALA 2 range
Truck, large (highway) road sign	200 m
Passenger car	150 m
Motorcycle, traffic pole, construction site cone, small road sign	100 m
Pedestrian, bicycle	50 m

Table 5: Approximate SCALA 2 sensor detection ranges for typical objects in the typical sensor use case, where the sensor is mounted on the front of a car at intermediate height, with neutral pitch angle, and the car is driving in regular weather conditions (excluding weather extremes such as heavy rain, fog or snowfall). The entries in this table refer to the LO threshold point cloud.

Note: SCALA 2 detection range depends on object properties and environmental (weather) conditions.

5.2.3.2 Optimal range performance with reference targets

The previous *Sec. 5.2.3.1* and the included *Tab. 5* are mere guidelines of what ranges can be expected in the typical sensor use case. Exact object detection ranges in your application and operation conditions may vary. A more precise and quantitative representation of SCALA 2 range is provided in *Tab. 6*, where the true positive detection rates or probabilities are reported for static optical reference targets of calibrated *10%* and *80%* reflectivity at *905 nm* wavelength. Both targets are diffuse, nearly perfect Lambertian reflectors. The *10%* reflectivity target shows a dull, darkish gray surface comparable to (smooth) tarmac. The *80%* reflectivity target exhibits a bright white, matte surface.

Target distance, reflectivity	LO True positive rate *p*	HI True positive rate *p*
150 m, 10%	10%	0%
100 m, 10%	50%	10%
150 m, 80%	100%	100%
200 m, 80%	55%	5%

Table 6: SCALA 2 detection rates (true positive probabilities) for the LO and HI threshold point cloud, for static reference targets of *10%* and *80%* reflectivity at *905 nm* wavelength. Measurements were taken under near-optimal conditions: absolutely dark environment, clean atmosphere at *12* centigrade and *80%* relative humidity.

True positive detection rate *p*, as reported in *Tab. 6*, is defined as $p = N_{hit} / N_{total}$, where N_{total} is the total number of recorded frames (point clouds) in a one minute data-acquisition interval, and N_{hit} is the number of frames that include one or more scan point(s) on the target. Note that the entries in *Tab. 6* correspond to near-optimal recording conditions, as the measurements were taken in an absolutely dark, quiescent and clean atmosphere environment. The entries in *Tab. 6* should therefore be interpreted as upper limiting values for the pertinent targets and distances. True positive rates for the same targets and distances in bright daylight or in adverse weather conditions will be smaller. On the other hand, the true positive rates for (large) retroreflectors such as (highway) road signs may considerably exceed the values reported in *Tab. 6*.

5.2.3.3 Angular dependence of range

SCALA 2 detection range is not independent of the scan angle. Optimal range performance is achieved in the forward direction $\varphi = \vartheta = 0°$. As the outer perimeter of the field of view is approached, the range decreases by an attenuation factor which is plotted in *Fig. 14*.

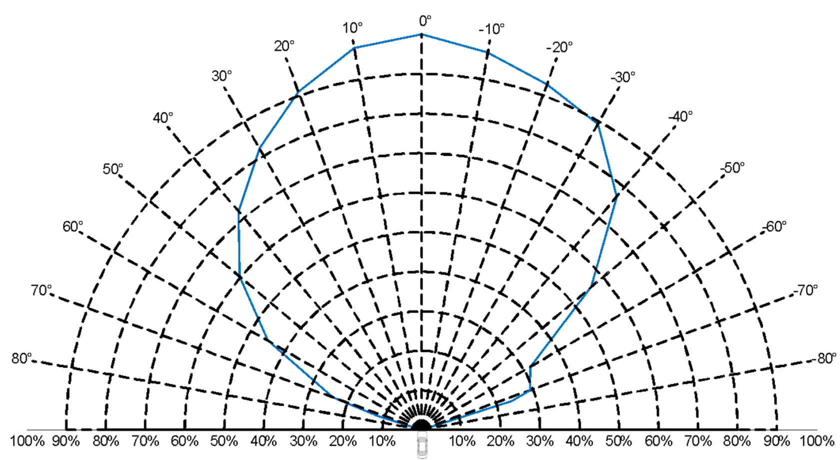


Figure 14: Azimuthal plot of the SCALA 2 range attenuation factor.

Since the variation of SCALA 2 range as a function of polar angle ϑ is rather weak, the plot in *Fig. 14* features the azimuthal angle (φ) dependence only.

Note: SCALA 2 range performance depends on the scan angle, predominantly in the azimuthal (horizontal) direction. The best range performance is achieved in the forward direction.

5.2.4 Precision

By the term 'precision', we shall refer here to the difference between an average measurement result reported by SCALA 2 (such as a polar or azimuthal angle, or a scan point distance), and the true reference value (free of any error) for that same measurement. The average in this 'average measurement' is with respect to time, environmental conditions, object properties, and all other influencing factors. The corresponding scatter, or standard deviation from the average, will be addressed in *Sec. 5.2.5* as the 'accuracy' of the measurement.

5.2.4.1 Angular precision

Both the azimuthal and polar angle precision is approximately *0.1°*.

5.2.4.2 Distance precision

The scan point distance precision contains an absolute contribution of less than *10 cm* (typically *5 cm*) and a relative contribution of *0.1%*. That is: A scan point from an object at true (reference) distance d_{ref} will be included in the SCALA 2 point cloud with a typical, average measured distance of $d = f \times d_{ref} \pm 5$ *cm*, where the factor f may vary between *0.999* and *1.001*. Values of f larger than *1* are more likely to occur than values of f smaller than *1*.

5.2.5 Accuracy

By the term 'accuracy', we refer here to the scatter (standard deviation) of measurement results reported by SCALA 2 (such as a polar or azimuthal angle, or a scan point distance). The reported standard deviation is with respect to time, environmental conditions, object properties, and all other influencing factors.

5.2.5.1 Angular accuracy

The accuracy of the azimuthal (horizontal) angle is approximately *0.1°*. The polar (vertical) accuracy is approx. *0.6°*, as caused by the APD optical pickup pattern and vertical opening angle.

5.2.5.2 Distance accuracy

Scan point distance accuracy is better than *10 cm*, and typically approx. *5 cm*.

5.3 Power source requirements

Characteristic	Requirement
Stabilized DC Output voltage	9 V -- 14 V
DC Output power	10 W permanent, 36 W transient (sensor startup, approx. 3 seconds)
Connector	Banana jack (female)

Table 7: Required specifications of the DC power source (not included in the kit)

5.4 Temperature range

The sensor may be operated in a temperature range of −40 centigrade to +85 centigrade.

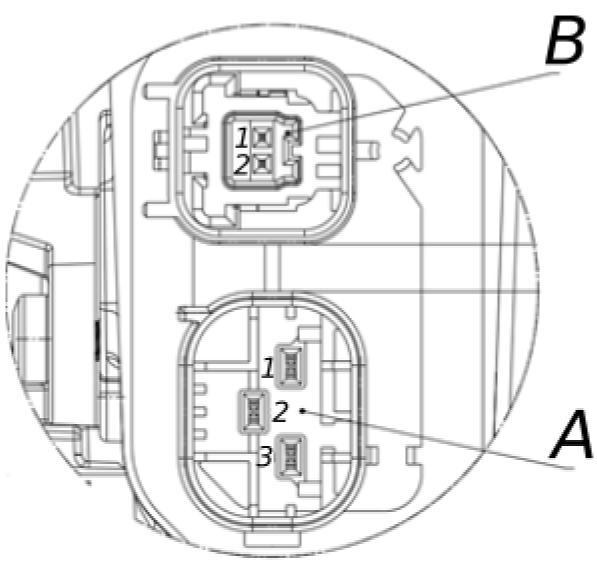
5.5 Ingress protection classification of the sensor

The sensor complies with ingress protection class **IP6K4K**, provided that both cables (power and BroadR-Reach) are firmly connected. The IP rating applies to the sensor and its connector plugs only. It does not apply to the BrR-Eth converter box, nor to any other part of the kit. With exception of the sensor itself, every part of the kit must be operated in a waterproof, dustproof environment.

6. HARNESS AND CONNECTORS

6.1 Pinning

The two connector plugs on the sensor side are for connection to a BroadR-Reach data BUS, which may be optionally used for time synchronization and for point cloud output), and for power supply and wake up, as shown in *Fig. 15*.



BroadR-Reach connector (top)

Pin B1: BroadR-Reach +

Pin B2: BroadR-Reach -

Power and wake up connector (bottom)

Pin A1: Power (+12 V)

Pin A2: Ground

Pin A3: Wakeup (+12 V)

Figure 15: Pin assignment on the BroadR-Reach and power connector plugs, on the side of the sensor housing

.

6.2 Connectors

The Mobility Kit includes both a power and wakeup cable and a BroadR-Reach cable for optional use. The Banana plug color coding on the power and wakeup cable is pin A1 ↔ red, pin A2 ↔ black and pin A3 ↔ green. Please refer to *Fig. 15* for the pin numbering. Operate the sensor only when both connectors (power and BrR) and plugged in tightly connected. Please also observe *Sec. 5.5*.

7. ETHERNET (UDP, SUTP) DATA PROTOCOL

This section contains a comprehensive specification of the SCALA 2 point cloud UDP traffic and enables you to write your own SCALA 2 decoder. Note, however, that Valeo does not recommend you to write your own decoder. Instead, you are encouraged to use the C++ SDK that is included with the Mobility Kit. The SDK has been thoroughly tested to provide lossless access to point clouds on both platforms GNU/Linux Ubuntu 18.04 and MS Windows 10.

7.1 Overview

An overview of the UDP Ethernet traffic from SCALA 2 is provided in *Fig. 16.* Note that UDP encapsulates the 'SCALA Unified Transport Protocol' (SUTP), defined by a SUTP header. The SUTP in turn encapsulates a content consisting of a 'Stream Type header' and payload parts *1 … N*. For the SCALA 2 (double) point cloud, *N = 219*.

The size of each UDP message is less than or equal to *1472 bytes*, including the SUTP header and all that follows, but excluding the UDP header. This size limit allows receiving the UDP datagrams on a host ethernet adapter with standard Memory Transmission Unit (MTU) of *1500 bytes* (jumbo frames need not be enabled). The exact size of *1472 bytes* applies to the datagrams *1 … N - 1*, whereas the terminal message number *N* is shorter than *1472 bytes*.

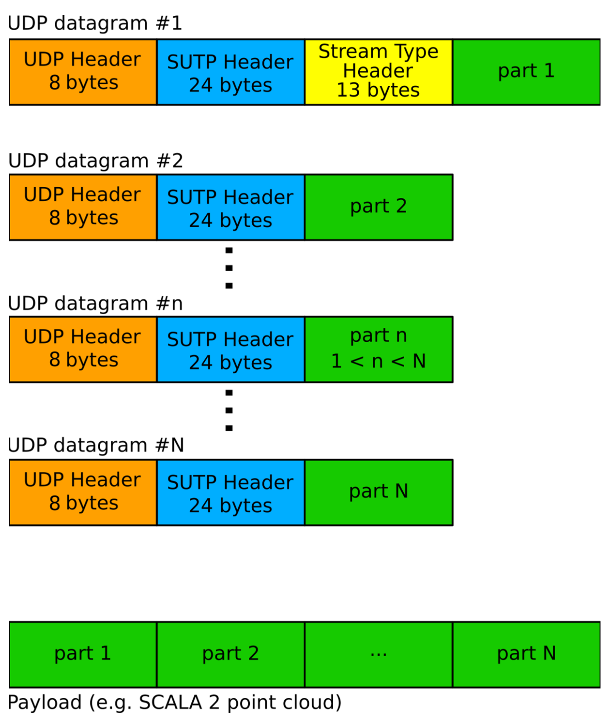


Figure 16: SCALA 2 UDP traffic overview. The payload (SCALA 2 point cloud in the relevant case here) is obtained by concatenating its parts *1, 2, … N.* Note that, in general and depending on the network connection, the UDP datagrams are not guaranteed to arrive in their natural order as they may 'overtake' each other while traveling from the sensor to the decoder PC. The number of the current point cloud and the fragment number *n* are included in the SUTP header, which allows sorting the fragments into the correct order.

7.2 UDP encapsulation

Scala transfers its data via the UDP-encapsulated SUTP protocol (SCALA Unified Transport Protocol), as shown in the following *Tab. 8.*

	Bytes	**0**		**1**		**2**		**3**	
Bytes offset	**Bits offset**	**0**	**7**	**8**	**15**	**16**	**23**	**24**	**31**
0	**0**	Source Port				Destination Port			
4	**32**	Length				Checksum			
..	**..**	UDP Payload: SCALA Unified Transport Protocol (SUTP)							
..	**..**								
..	**..**								

Table 8: UDP datagram encapsulation of a SUTP Frame. The *8*-byte, standard UDP header is highlighted in orange.

The complete UDP payload is little endian, except for the following SUTP header, which is big endian.

7.3 SUTP protocol

The SCALA Unified Transport Protocol is defined by the following SUTP header:

	Bytes	**0**		**1**		**2**		**3**	
Bytes offset	**Bits offset**	**0**	**7**	**8**	**15**	**16**	**23**	**24**	**31**
0	**0**	Reserved							
4	**32**								
8	**64**	Protocol version		Magic number		Sequence Number			
12	**96**	Reserved		Scanner ID		Data Type ID			
16	**128**	Firmware Version				Scan Number			
20	**160**	Fragments Total				Fragment Number			

Table 9: SUTP Header (*24* bytes, big endian)

- Reserved (*64* bits): All zeroes.
- Protocol version (*8* bits): 0x53
- Magic number (*8* bits): 0xCA
- Sequence Number (*16* bits): The sequence number is incremented by one for each data packet sent and is to be used by the receiver to detect packet loss or to correct the order of the incoming packets. The initial value of the sequence number may be random. The next value after *65535* is *1* This overflow can happen within one scan.
- Scanner ID (*8* bits): Identifies the sensor.
- Data Type ID (*16* bits): ID of Data Type which is encapsulated in the payload of the UDP packet. The data type ID for Point Cloud Stream is 0xEE02.
- Scan Number (*16* bits): Indicates the scan (point cloud) that the present UDP packet belongs to.
- Fragments Total (*16* bits): Total amount of fragments that current payload is fragmented into. In case the payload is not fragmented at all, this field has a value of *1*. For Point Cloud Stream data type this value is a constant 219 (0x00DB).
- Fragment Number (*16* bits): Sequential number of the payload fragment sent with the present datagram. The counting starts at 1.

7.4 Stream Type header

The Stream Type header is only included in the first datagram that belongs to a SUTP-encapsulated SCALA 2 payload, as shown in *Fig. 15*. The Stream Type header contents are defined in the following *Tab. 10*.

	Bytes	**0**		**1**		**2**		**3**	
Bytes offset	**Bits offset**	**0**	**7**	**8**	**15**	**16**	**23**	**24**	**31**
0	**0**	Stream Type							
4	**32**	Reserved							
8	**64**	Frame Size							
12	**96**	Reserved							

Table 10: SUTP SCALA 2 Stream Type Header (*13* bytes, little endian)

- Stream Type: Identifies the type of a stream
  0x02EEFFA5 (little endian) - Point Cloud Stream

- Frame Size: Sum of the size of 'Device ID' and the payload in bytes

7.5 Payload: SCALA 2 double point cloud

Any type of generic payload may be encapsulated in SUTP. Here, we limit the description to the relevant case for Valeo SCALA2 Mobility Kit users, which is the SCALA 2 double point cloud payload.

The double point cloud is encoded in the form of a 'SCAN_S' with Data Type ID 0xEE02, as shown in *Tab. 11:*

SCAN_S	Size (Bytes)	Data Type	Min Value	Max Value	Description
Interface Version	2	uint16	0	0	
MISC.	2				
Timestamp	4	uint32	0	$2^{32} - 1$	Nanoseconds part of time
	4	uint32	0	$2^{32} - 1$	32 least significant bits of the 48 bits of the seconds's part of time
	4	uint32	0	$2^{16}-1$	16 most significant bits of the 48 bits of the seconds's part of time
MISC.	20				
Scan Number	2	uint16	0	$2^{16}-1$	Number of the scan. It is increased by 1 for every new scan. Same value as in SUTP Header "Scan Number".
MISC.	4				
Mirror side	1	uint8	0	1	0 = up, 1 = down
MISC.	5				
mount_x	2	uint16	0	$2^{16}-1$	centimeter
mount_y	2	uint16	0	$2^{16}-1$	centimeter
mount_z	2	uint16	0	$2^{16}-1$	centimeter

mount_yaw	2	uint16	0	2^{16}-1	65536 = 360 deg
mount_roll	2	uint16	0	2^{16}-1	65536 = 360 deg
mount_pitch	2	uint16	0	2^{16}-1	65536 = 360 deg
MISC.	52				
Shot [num_shots]	314048	Shot_S			See *Tab. 12*, num_shots = 2804
MISC.	1808				

Table 11: SCALA 2 double point cloud payload (SCAN_s, Data Type ID 0xEE02, little endian)

Every SCAN_s contains *314048* 'Shot_S', as defined in the following *Tab. 12*:

Shot_S	Size (Bytes)	Data Type	Min Value	Max Value	Unit	Description
Azimuthal Angle	4	uint32	0	2^{32} - 1	360° / 2^{32}	Direction in which the laser pulse is emitted. A value of 0° corresponds to the forward direction.
MISC	12					
Scanpoints_LO [num_points]	48	Point_S				Array of scan points / echoes num_points = 12
Scanpoints_HI [num_points]	48	Point_S				Array of scan points / echoes num_points = 12

Table 12: Structure of a Shot_S (*112* bytes, little endian)

Every Shot_S contains *24* = *2 x 12* Point_S, which are defined in *Tab. 13*:

Point_S	Size (Bytes)	Data Type	Min Value	Max. valid Value	Unit	Description
Radial Distance	2	uint16	0	65533	cm	Distance of echo to the sensor origin. Default value: 65534 (Laser Shot not fired). Default value: 65535 (No echo received)
Echo Pulse Width	2	uint16	0	65534	cm	Width of the pulse of the echo. Default value: 65535 (No echo received)

Table 13: Structure of a scan point - Point_S (*4* bytes, little endian)

8. Time synchronization

SCALA 2 will synchronize its clock to that of a PTP802.1as master in the same network, provided that the PTP sync messages are received with **vlan tag 127**. This has been tested with the PTP master

```
ptp4l - PTP Boundary/Ordinary/Transparent Clock,
```

running on

```
5.4.0-96-generic #109~18.04.1-Ubuntu SMP Thu Jan 13 15:06:26 UTC 2022 x86_64
x86_64 x86_64 GNU/Linux
```

and connecting to the sensor through the network card physical interface

```
Ethernet controller: Intel Corporation Ethernet Connection (2) I219-LM
```

9. GETTING STARTED

9.1 Hardware setup

First, connect the 100 Mbps (100BASE-Tx) RJ45 Eth output on the BrR-Eth converter to your decoder PC. The entire ethernet connection from the BrR–Eth converter to the decoder PC must fulfill CAT 5 standard or higher. Connect the BrR cable to the SCALA 2 sensor and to the BrR–Eth converter, handling the connector on the BrR-Eth converter side with care. All connectors are mechanically encoded to match only their respective ports, and the BrR port is labeled 'BR' on the converter box. Use the BrR-Eth converter power cable to connect the converter to a *12* V DC power supply (black banana plug: GND, red banana plug: +*12* V DC).

Figure 17: The BrR-Eth converter with RJ45 connector

In the next step, connect the provided sensor power cable to a stabilized *12* V DC power supply: First connect the black (GND) banana plug, then the red (+*12* V DC) plug. After this, wait for approx. 1 second, before connecting the green (wakeup) plug to the +*12* V DC outlet, too. You should observe a quick stabilization of power consumption around a steady *7* W (such as *12* V, *0.6* A DC).

9.2 PC settings

Make sure that no firewall is blocking the UDP protocol communication between the sensor and your decoder PC. The sensor will Multicast its UDP payload to the default ingress (Rx) port *22001* and to the Internet protocol (IP) multicast group address *224.111.111.111*. You should make sure that multicast is enabled on your PC's ethernet adapter, which should be the default in most cases. Make sure that the UDP Rx buffer size is at least 1MB (see the Troubleshooting Section for instructions on this).

9.3 Point cloud viewer app

The USB pen drive included in the Valeo SCALA 2 Generic Mobility Kit includes a standalone application for point cloud decoding and visualization. Please refer to the included README files for installation instructions, covering Microsoft Windows 10 and GNU/Linux Ubuntu 18.04. Once the application is running, you should adjust the Host (decoder PC) IP and the HostRxPort in the Menu '*File → Open Stream*'. The default HostRxPort that SCALA 2 multicasts to is port number *22001*.

The two check boxes in the graphical user interface allow to toggle display of the LO threshold point cloud (left checkbox) and the HI threshold point cloud (right checkbox).

With focus on the application window, press buttons *1*, *2*, *3*, and *4* to toggle between Cartesian *x*, *y*, *z* and *EPW* point coloration. An example snapshot of the point cloud viewer app, displaying a SCALA 2 LO threshold point cloud with Cartesian x-coordinate point coloration, is shown in *Fig. 18*.

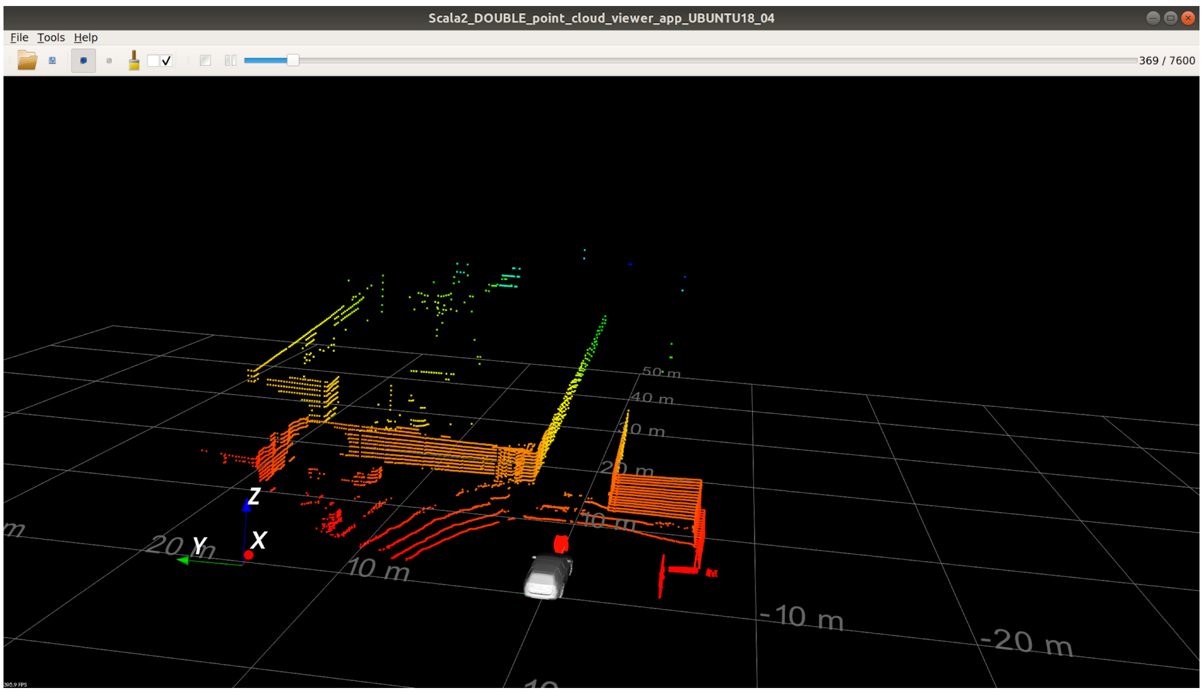


Figure 18: A snapshot of the point cloud visualizer displaying a HI threshold point cloud, with color coding based on the point's Cartesian x-Coordinates.

9.4 ROS node

The software provided on a USB pen drive with the SCALA 2 Generic Mobility Kit includes a Robot Operating System (ROS) node, along with detailed documentation. The node represents a ROS publisher, which publishes the ROS data type sensor_msgs::PointCloud2. To start the node, follow these three steps:

First, load the ROS environment:
Make sure that the source
/opt/ros/<ros-distro>/setup.bash
is automatically added to your bash session every time a new shell is launched.
(e.g., by editing ~/.bashrc)

Second, load the SCALA 2 transmitter node:
Move to the directory
`ros/<ros-distro>/scala_gen2_transmitter`
open a terminal here and issue the command
`source setup.bash`

Third, launch the transmitter:
Issue the command
`roslaunch share/scala_gen2_transmitter/launch/run.launch`

The ROS node should now start, together with the rviz visualization. An exemplary snapshot of rviz displaying a SCALA 2 point cloud received from the ROS node is provided in Fig 19. Note that, since the employed ROS data type does not reserve a field for EPW, the intensity field is used synonymous here. Please consult Sec. 3.3 for an explanation of the relation and differences between EPW and intensity.

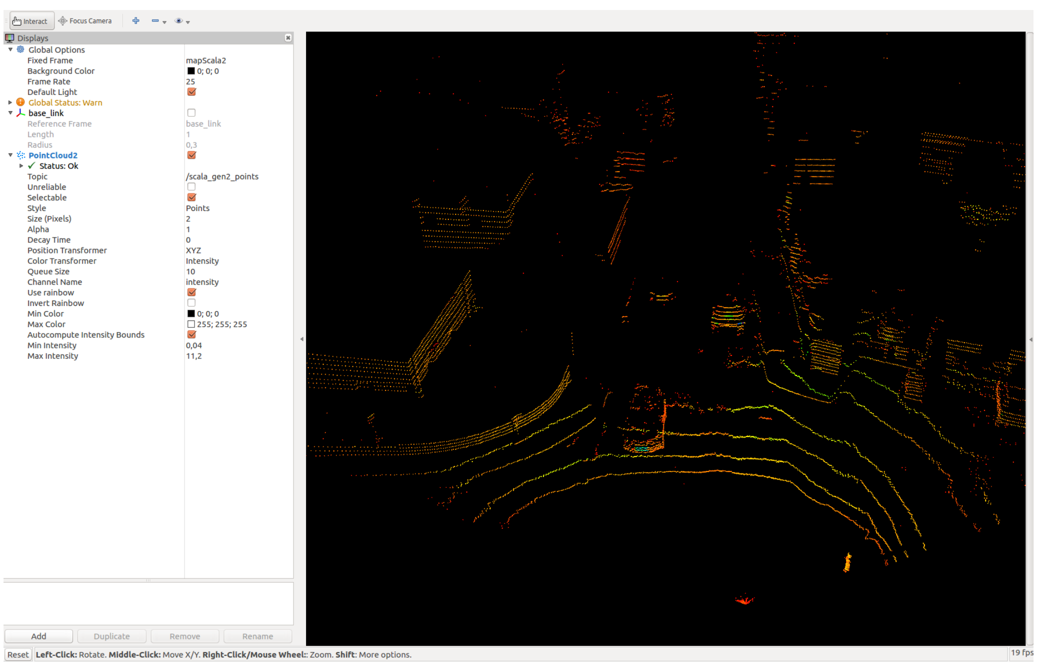


Fig 19: An exemplary snapshot of the ROS rviz visualizer displaying a HI threshold SCALA 2 point cloud with EPW color coding.

10. TROUBLESHOOTING

10.1 Powering

If no point cloud (UDP) output is received from the sensor, try disconnecting and reconnecting the wakeup line (green banana plug) to +*12* V DC. If this has no effect, disconnect all three banana plugs and reconnect them in the order black (ground), red (+*12* V) and green (wakeup, +*12* V), waiting at least *1* second between each connection. When the sensor operates normally, its power consumption should be close to a steady *7* W (such as *12* V, *0.6* A DC). Make sure that your DC power supply meets the specifications listed in *Tab. 7*. During an initial, short transient after providing power to the sensor, the source is required to provide up to approx. *36* W (*3* A at *12* V), and the power source control electronics must act sufficiently swiftly to stabilize the nominal voltage through this initial transient. If you are in doubt about the quality of your power source, you may want to try running the sensor with a *12* V car or motorcycle battery.

10.2 BrR–Eth connection

During nominal operation, both of the green indicator LEDs on the BrR-Eth converter should reside in the permanent ‘on’ state, and both of the yellow indicators should be quickly blinking, indicating traffic throughput. If this is not the case, first check that the BrR-Eth adapter is connected to a *12* V DC power source with correct polarity. The nominal, steady power intake to the BrR-Eth converter is approx. *0.67* W (such as *0.056* A at *12* V DC). Check also, that the host PC to which the BrR-Eth converter is connected via a CAT5+, RJ45 cable, features a multicast-enabled physical Eth (100Base-Tx or 1000Base-Tx) interface. It may be helpful to use a network diagnostic software such as Wireshark, to check SCALA traffic arriving to the host PC ethernet interface. Make sure that the BrR cable, connecting the sensor to the BrR-Eth converter box, is undamaged, in particular at and around the small two-pin plug towards the converter box.

10.3 Network issues / frame drops

The time-averaged ethernet bus load caused by SCALA 2 is around *84 Mbps*. If you experience frame losses on your decoder PC, you should check and increase the ingress UDP buffer size for your ethernet adapter. The recommended UDP Rx buffer size is *1* MB or higher, to ensure that the buffer can accommodate more than one entire point cloud. One point cloud consists of *219* UDP datagrams, the combined size of which is little less than *320 kB*.

On a decoder PC that runs GNU/Linux Ubuntu 18.04, you can set the UDP Rx buffer size to 2 MB by the following two commands:

```
sudo sysctl -w net.core.rmem_max=2097152
sudo sysctl -w net.core.rmem_default=2097152
```

On a decoder PC that runs Microsoft Windows 10, you can set the UDP Rx buffer size to 2 MB in the Windows registry as follows:

Open the registry editor app by pressing the `Windows key` and the `R key` at the same time to open the Run box.
Type `regedit` and hit `Enter` and you can access `registry editor` immediately.
Now move to `HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\AFD\Parameters`.
If the parameters `DefaultReceiveWindow` and `DefaultSendWindow` do not exists you need to add them to the registry.
Add a new entry by left-clicking `Edit->New->DWORD(32-bit) Value` and set the value with double click on the respective parameter.
A recommended value for `DefaultReceiveWindow` and `DefaultSendWindow` is 2097152 in decimal or 0x200000 in hexadecimal (2 MB) or a higher value.

If you are unsure about whether or not the sensor is sending point cloud output via ethernet at all, or about the capability of your decoder PC to receive this ethernet traffic, you may want to use a diagnostic software such as Wireshark to check for the arrival of UDP packages at *224.111.111.111:22001*.

10.4 Point cloud visualizer app

If you should fail to see a point cloud displayed in the point cloud viewer app, please make sure that the Host IP and the HostRXPort are set to the correct values, as shown in the example *Fig. 20*. After changing these settings, expect an approximate 2 second lag before the first point cloud is displayed.

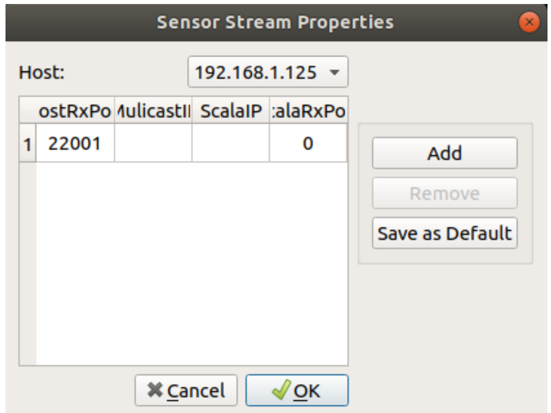


Figure 20: The ‘Open Stream’ dialogue with settings that correspond to a default SCALA 2, assuming here that the ethernet adapter on your decoder PC is configured to IP 192.168.1.125

10.5 ROS node

If you are trying to use the ROS nodes in the install directory

```
ros/<ros-distro>/scala_gen2_transmitter
```

and the command

```
source setup.bash
```

returns an access error, then you might need to add execution rights via the commands

```
chmod +x _setup_util.py
```

and

```
chmod +x lib/scala_gen2_transmitter/scala_gen2_transmitter_node
```

After this, try

```
source setup.bash
```

again.