

# Simulating Automatic Obscuration and Multipath for Realistic GNSS Receiver Testing

## Application Note

### Products:

| R&S®SMBV100A

The R&S®SMBV100A is both, a versatile general-purpose vector signal generator and a powerful GNSS signal simulator. It can simulate up to 24 satellites in realtime for testing GNSS receivers flexibly, reliably, and cost-efficiently.

The R&S®SMBV100A supports receiver testing under realistic conditions by offering features such as obscuration simulation and automatic multipath generation. Out of a multitude of possible test scenarios – with predefined or user-specific settings – this application note presents some examples to give an impression of the instrument's capabilities.

# Table of Contents

<b>1</b>	<b>Introductory Note .....</b>	<b>3</b>
<b>2</b>	<b>Overview .....</b>	<b>4</b>
<b>3</b>	<b>Predefined Scenarios &amp; Simulation Models .....</b>	<b>7</b>
<b>4</b>	<b>Basics .....</b>	<b>10</b>
4.1	Vehicle Type.....	10
4.2	Permittivity .....	11
4.3	Multipath.....	11
4.4	Vehicle Body Mask.....	12
<b>5</b>	<b>Ship with Sea Reflection and Obscuration .....</b>	<b>16</b>
<b>6</b>	<b>Aircraft with Ground Reflection .....</b>	<b>20</b>
<b>7</b>	<b>Car with Roadside Reflections and Obscuration .....</b>	<b>26</b>
<b>8</b>	<b>Car with Full Obscuration.....</b>	<b>31</b>
8.1	Bridges and Tunnels.....	31
8.2	Parking .....	34
<b>9</b>	<b>Car with Reflections and Obscuration from Stationary Obstacles .....</b>	<b>37</b>
9.1	Creating Trajectory Files for the “Vertical Obstacles” Simulation Model .....	42
<b>10</b>	<b>Summary.....</b>	<b>45</b>
<b>11</b>	<b>Abbreviations .....</b>	<b>46</b>
<b>12</b>	<b>References.....</b>	<b>46</b>
<b>13</b>	<b>Ordering Information .....</b>	<b>46</b>

# 1 Introductory Note

The abbreviation “SMBV” is used in this application note for the Rohde & Schwarz product R&S®SMBV100A.



The SMBV is a cost-efficient general-purpose vector signal generator with outstanding RF performance capable of generating signals for all main communications and radio standards. Equipped with one or more GNSS options, the SMBV is also a full-fledged satellite signal simulator for reliable and flexible GNSS receiver testing. Please see reference [2] for more product details and feature set.

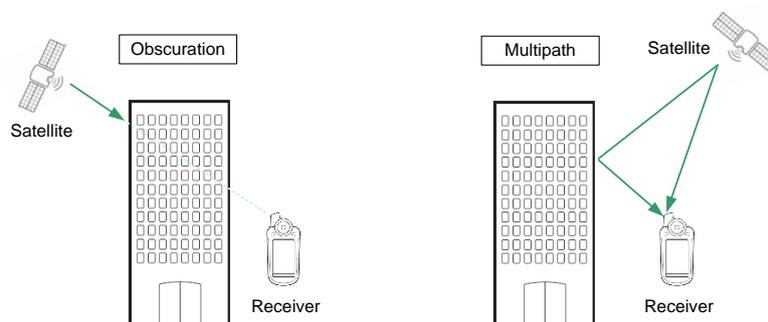
In this application note, the position of the receive antenna is assumed to be close to the position of the GNSS receiver such that the term “receiver” can be used as an equivalent to the term “antenna of the receiver”. Generally, the simulated satellite signals correspond always to the position of the antenna – the placement of the remaining receiver hardware is irrelevant. For better readability however only the term “receiver” is used in this document. Mainly in the context of vehicle body masks it is important to keep in mind that “receiver” actually stands for “receiver’s antenna”.

## 2 Overview

GNSS receivers can be tested easily, reliably and cost-efficiently by using the SMBV as satellite simulator. Signals for up to 24 satellites can be generated in realtime with a single standalone instrument. The SMBV supports receiver testing under realistic conditions by offering features such as vehicle attitude simulation, antenna pattern modeling, simulation of rotating vehicles, advanced obscuration simulation, and manual as well as automatic multipath generation. This application note focuses on obscuration and automatic multipath simulation with the SMBV.

The SMBV can emulate different kinds of obstacles. In general, an obstacle can cause

- obscuration of satellite signals.
- reflection of satellite signals which leads to multipath reception at the receiver.



Obscuration is caused for example by natural or urban objects such as cuttings and buildings. The consequence of obscuration is that the receiver loses satellite signals – permanently or for a period of time. For example, in urban environments many satellite signals are blocked by huge buildings and only satellites that are high in the sky are visible for the receiver. Constellations formed by those few high-elevation satellites however have poor dilution of precision (DOP) values. It is therefore important to test the receiver's performance by reproducing different obscuration scenarios with a GNSS simulator. These scenarios span the whole range, from short-term to permanent obscuration, from blockage of only few satellites to total blockage of all signals, from fix obscuration (e.g. by the vehicle's body surrounding the receiver) to time-varying obscuration changing its characteristics. The SMBV covers all these scenarios – with predefined or user-specific settings.

In addition to obscuration, the SMBV can simulate multipath propagation. Multipath propagation results from satellite signals that reflect on obstacles and reach the receiver as signal echo. The echoes of a satellite signal arrive at the receiver with different delays and attenuations. Depending on the signal processing implemented in the receiver, signal echoes can cause problems because they distort the correlation peak leading to errors in the determined pseudorange. In case the line of sight (LOS) signal is obscured, the receiver will misinterpret the first signal echo as the LOS signal, which can result in major difficulties in the receiver. It is therefore important to test the receiver's multipath mitigation performance. The SMBV can simulate both, static and automatic multipath propagation.

- Manual multipath: manual configuration of settings (user-mode) such as signal attenuation, delay/time shift, Doppler frequency shift and carrier phase for each satellite individually.
- Automatic multipath: predefined or user-specific configuration of obscuration scenario with automatic simulation of associated multipath propagation based on satellite constellation, receiver position, obstacle position and surface material.

The user can choose between simulating obscuration only and simulating obscuration with additional automatic multipath.

Various presets such as predefined scenarios, waypoint files, and body masks simplify handling and testing.

Please see reference [3] for details on the test setup, e.g. on how to connect the receiver under test to the SMBV.

The following table gives an overview of the GNSS options available for the SMBV. The obscuration and automatic multipath feature covered in this application note is highlighted.

Overview of GNSS options for the SMBV		
Option	Name	Remark
R&S®SMBV-K44	GPS (6 satellites)	
R&S®SMBV-K65	Assisted GPS	Requires K44
R&S®SMBV-K93	GPS P code	Requires K44
R&S®SMBV-K66	Galileo (6 satellites)	
R&S®SMBV-K67	Assisted Galileo	Requires K66
R&S®SMBV-K94	Glonass (6 satellites)	
R&S®SMBV-K96	Assisted Glonass	Requires K94
R&S®SMBV-K91	GNSS extension to 12 satellites	Requires K44, K66 or K94
R&S®SMBV-K92	GNSS enhanced (e.g. moving scenarios, manual multipath, HIL)	Requires K44, K66 or K94
R&S®SMBV-K96	GNSS extension to 24 satellites	Requires K44, K66 or K94 and K91
R&S®SMBV-K101	Obscuration and automatic multipath	Requires K44, K66 or K94 for obscuration only Requires K44, K66 or K94 and K92 for obscuration and multipath
R&S®SMBV-K102	Antenna pattern / body masks	Requires K44, K66 or K94
R&S®SMBV-K103	Spinning / attitude	Requires K44, K66 or K94 and K102

The following table lists the GNSS options that are recommended in the context of this application note.

Recommended GNSS options for obscuration and automatic multipath simulation		
Option	Name	Remark
At least one of the following: R&S®SMBV-K44 R&S®SMBV-K66 R&S®SMBV-K94	GPS Galileo Glonass	6 satellites
R&S®SMBV-K91	GNSS extension to 12 satellites	12 satellites Recommended because 6 satellites are too less to represent realistic conditions
(R&S®SMBV-K96)	(GNSS extension to 24 satellites)	(24 satellites, optional)
R&S®SMBV-K92	GNSS enhanced (e.g. moving scenarios, manual multipath, HIL, waypoint smoothening)	Required for moving receiver Prerequisite for automatic multipath
R&S®SMBV-K101	Obscuration and automatic multipath	Main focus of this application note
(R&S®SMBV-K102)	(Antenna pattern / body masks)	(Required if obscuration due to vehicle body mask shall be simulated)

This application note starts with presenting the predefined obscuration scenarios and the different simulation models in section 3. Section 4 introduces some fundamental points about the obscuration and automatic multipath feature of the SMBV. Sections 5 to 9 present each an application example. The different scenarios are listed below. The application note closes with a short summary.

#### Presented example scenarios:

The GNSS receiver is located in/on a ...

- Ship on a waterway (canal) experiencing sea reflection and obscuration due to natural environment (section 5).
- Aircraft experiencing ground reflection from dry desert ground and obscuration due to the aircraft's body mask (section 6).
- Car experiencing obscuration and multipath reflections from suburban obstacles along both sides of the road (section 7).
- Car experiencing complete obscuration of satellite signals due to bridges, tunnels and parking decks (section 8).
- Car experiencing obscuration and multipath reflections from all directions in an urban street canyon (with stationary obstacles) (section 9).

## 3 Predefined Scenarios & Simulation Models

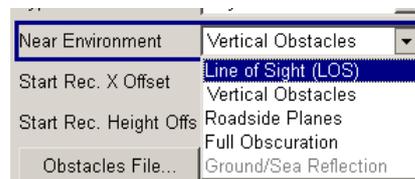
The SMBV supports various predefined scenarios for different kinds of obscuration – with and without additional multipath propagation:

Predefined scenarios overview			
Predefined scenario	Near environment simulation	Physical model	Remark
City block	Vertical obstacles	Obscuration + multipath	Urban area with an average building height of 20 m.
Urban canyon	Vertical obstacles	Obscuration + multipath	Dense urban area with an average building height of 30 m.
Suburban area	Roadside planes	Obscuration + multipath	Suburban building density at relatively large distance from receiver (40 m on each side).
Highway	Roadside planes	Obscuration only	Periodic short-term obscuration from passing vehicles on opposite lane and (noise) barriers on the other side.
Cutting	Roadside planes	Obscuration only	Natural or urban cutting.
Bridge <sup>1</sup>	Full obscuration	Obscuration only	Periodic obscuration from bridges.
Parking <sup>1</sup>	Full obscuration	Obscuration only	Obscuration with varying durations due to parking in parking decks.
Tunnel <sup>1</sup>	Full obscuration	Obscuration only	Obscuration due to tunnels.

These predefined scenarios are customizable and can be used as a basis for user-specific settings. Modified scenarios as well as completely user-defined scenarios can be saved in the SMBV for later recall.

Depending on the obscuration/multipath scenario different simulation models are used. The SMBV supports four different simulation models (termed “Near Environment” simulations). These are:

- Vertical obstacles
- Roadside planes
- Full obscuration
- Ground/sea reflection



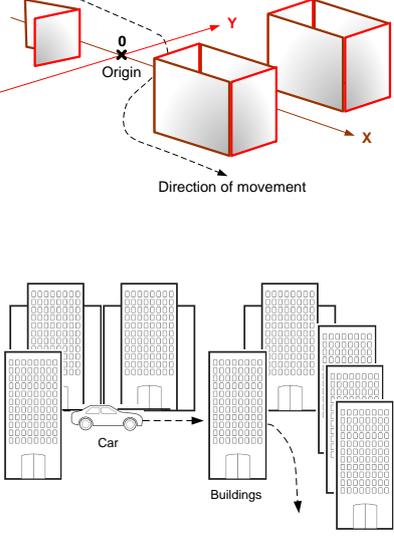
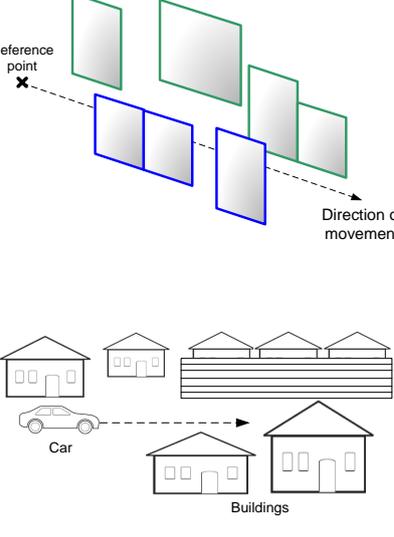
The entry “Line of Sight (LOS)” corresponds to no obscuration/multipath simulation.

The four simulation modes are presented in great detail in sections 5 to 9: Ground/sea reflection in sections 5 and 6, roadside planes in section 7, full obscuration in section 8, and vertical obstacles in section 9.

<sup>1</sup> Multiple predefined scenarios are available.

**Simulation models overview**

**Main characteristics and distinctions**

Near environment simulation	Short description	Illustration
Line of sight (LOS)	No obscuration/multipath	
Vertical obstacles	<p>Vertical planes arranged on a coordinate plane (map) – parallel and perpendicular to the coordinate axes.</p> <p>All obstacles are considered in the simulation resulting in obscuration and reflections from all directions.</p> <p>The orientation of the obstacles on the map is fix. The trajectory of a moving receiver must match to the stationary arrangement of the obstacles. Suitable waypoint files are required.</p> <p>Simulation of obscuration only or obscuration and multipath.</p> <p>No ground reflections.</p> <p>Real-world example: car driving through a city.</p>	
Roadside planes	<p>Vertical planes parallel to the direction of movement on the right and/or left side.</p> <p>Only the pair of planes that is currently to the left and right side of the receiver is considered in the simulation.</p> <p>Selectable whether the two planes are assumed to have the specified length or alternatively infinite length.</p> <p>The orientation of the obstacles is not fix, but “follows” the trajectory of the moving receiver. Suitable for all waypoint files.</p> <p>Simulation of obscuration only or obscuration and multipath.</p> <p>No ground reflections.</p> <p>Real-world example: car driving through a suburb.</p>	

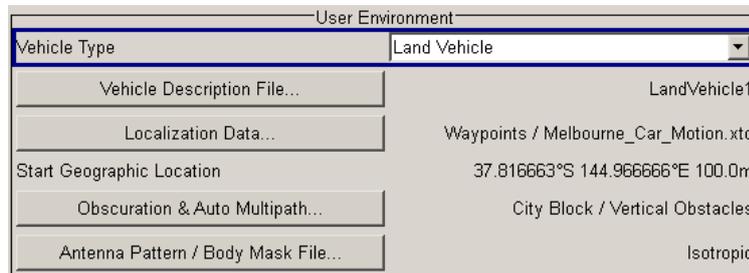
Simulation models overview		
Main characteristics and distinctions		
Near environment simulation	Short description	Illustration
Full obscuration	<p>Obscuration areas specified in terms of size (distance) or time period.</p> <p>Outside these areas the satellite signals are fully receivable. Inside these areas they are completely obscured.</p> <p>The obscuration areas (specified in terms of distance) "follow" the trajectory of the moving receiver. Suitable for all waypoint files.</p> <p>Simulation of full obscuration only.</p> <p>No reflections of any kind.</p> <p>Real-world example: car driving through a tunnel.</p>	
Ground/sea reflections	<p>Two vertical planes parallel to the direction of movement on the right and left side.</p> <p>The two planes are assumed to have infinite length at each waypoint.</p> <p>The orientation of the obstacles "follows" the trajectory of the moving receiver. Suitable for all waypoint files.</p> <p>Simulation of obscuration and multipath only.</p> <p>No reflections off the obstacles – only ground reflections</p> <p>Real-world example: ship driving through a canyon.</p>	

## 4 Basics

This section introduces some fundamental points about obscuration and multipath simulation with the SMBV.

### 4.1 Vehicle Type

The “Vehicle Type” parameter is a main parameter that influences the “User Environment” settings such as the “Obscuration & Auto Multipath” settings.



This parameter acts like a selection filter. For example, the available items of the “Near Environment” parameter depend on the selected vehicle type.

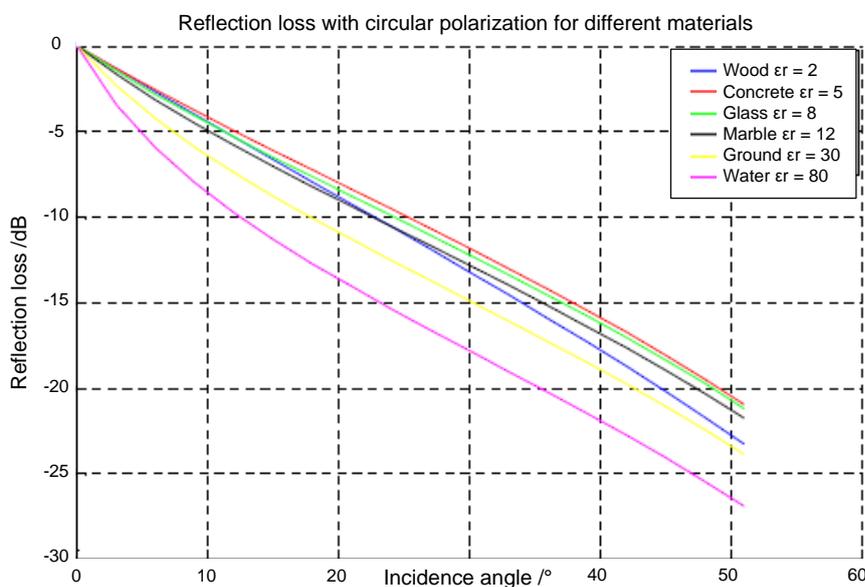
Vehicle type overview		
Vehicle type	Receiver	Near environment simulation
Pedestrian	Moving + static	Vertical obstacles Roadside planes (for moving receiver only) Full obscuration (for moving receiver only)
Land vehicle	Moving + static	Vertical obstacles Roadside planes (for moving receiver only) Full obscuration (for moving receiver only)
Ship	Moving + static	Ground/sea reflection <sup>2</sup> Full obscuration (for moving receiver only)
Aircraft	Moving only	Ground/sea reflection
Spacecraft	Moving only	Ground/sea reflection

<sup>2</sup> The simulation model “Ground/sea reflection” includes also vertical planes for obscuration simulation.

## 4.2 Permittivity

The relative permittivity  $\epsilon_r$  is a physical material property that determines the reflectivity of a surface.

When a GNSS satellite signal impacts on a surface, it generally gets partly reflected and partly transmitted (into the medium). Physical quantities such as wave polarization, angle of incidence, and permittivity of the medium determine how much signal is reflected off the surface. Since part of the incident wave is transmitted into the medium, the reflected signal is not as strong in power as the incident signal. The resulting loss strongly depends on the incidence angle and also on the permittivity as shown in the following figure for circular polarized waves.



On the SMBV, the user can specify the permittivities of the reflecting surfaces. In this case, the SMBV determines the reflection loss for the specific permittivity and the current angle of incidence. The latter is deduced automatically from the satellite position relative to the reflecting obstacle.

Alternatively, the user can specify the reflection loss of the surfaces directly. In this case, the influence of the incidence angle is not considered, but the fixed loss is applied – independent of the angle.

## 4.3 Multipath

In general, the SMBV simulates one reflection at maximum per signal echo. In other words, multiple reflections of a single echo are not simulated. The reason for this is simple. GNSS signals are by nature very low in power. Each reflection causes signal loss, often 6 dB and much higher. After a second reflection, the attenuation on the signal is so high that it is likely not detected by the receiver. It is therefore a valid approximation to neglect multiple reflections.

The SMBV simulates therefore one echo per satellite and obstacle.

Some theoretic examples for a better understanding:

- One satellite and one obstacle result in maximally one echo.
- One satellite and two obstacles result in maximally two echoes.
- Two satellites and one obstacle result in maximally two echoes.
- Two satellites and two obstacles result in maximally four echoes.

For each echo, the SMBV simulates automatically the additional signal attenuation, delay/time shift, Doppler frequency shift and carrier phase as compared to the virtual LOS signal.

Each satellite LOS signal and each satellite echo requires one simulation channel. The available channel budget depends on the installed options and is given in the table below. In scenarios where there are more LOS and echo signals than available channels, some of the echo signals cannot be simulated. In this case, the echoes are filtered out according to the following factors: elevation, signal power and additional delay (with respect to the theoretical LOS). The SMBV shows a warning message when this happens.

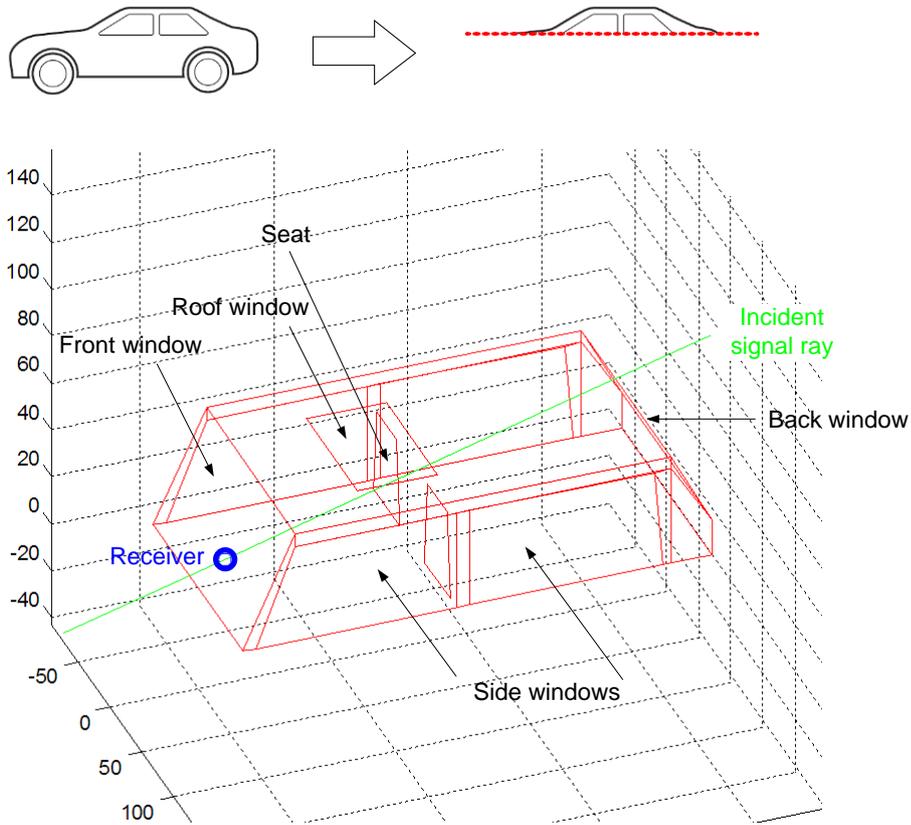
Channel budget of SMBV	
Number of channels	Condition
16	GNSS extension to 24 satellites (K96 option) not installed GPS P-code not activated
24	With installed GNSS extension to 24 satellites (K96 option) Only GPS and/or Glonass satellites activated GPS P-code not activated
19	With installed GNSS extension to 24 satellites (K96 option) Only Galileo satellites activated (see reference [4] for details) GPS P-code not activated
12	With activated GPS P-code

## 4.4 Vehicle Body Mask

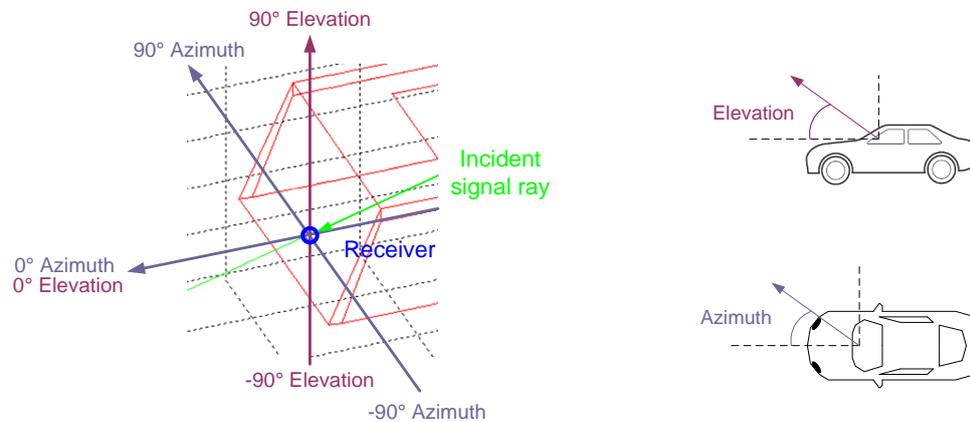
This application note focuses mainly on obscurations caused by urban environment and natural terrain. For example, a GNSS receiver in a mobile navigation system mounted on the front window of a car will face time-varying obstacles such as buildings and mountains while moving through the landscape. The obstacles change their characteristics such as distance, high, occurrence, etc.

In addition, the receiver will experience signal attenuation and obscuration due to the vehicle body surrounding the receiver. This obstacle, i.e. the vehicle body is generally fixed with respect to the receiver and does not change its characteristics. This “stationary” obstacle can be modeled using a vehicle body mask.

The SMBV provides various predefined body masks for different vehicle types. The following figure shows the simplified 3D model for a medium sized car. The upper half of the car is considered in more detail, the lower half is assumed to cause uniform obscuration. The position of the receiver is indicated in the figure (more precisely the position of the receiver's antenna – please see the note in section 1).

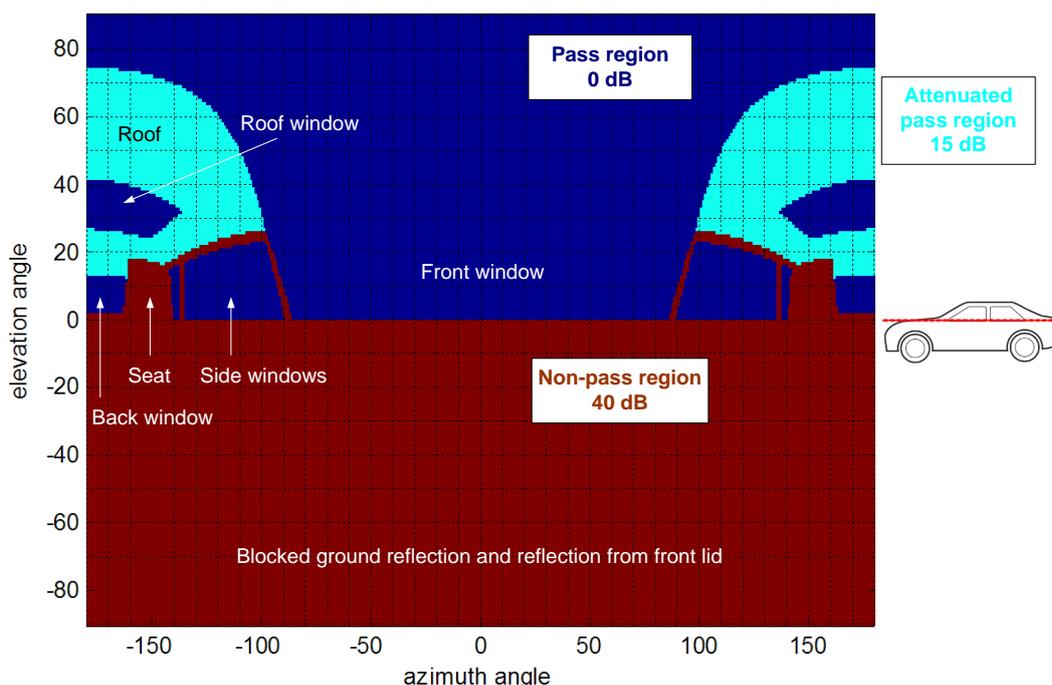


From this simplified vehicle model a body mask is deduced. A body mask is basically a table with rows of elevation angles from  $+90^\circ$  to  $-90^\circ$  and columns of azimuth from  $-180^\circ$  to  $+180^\circ$ . Each table element gives the respective signal power attenuation in dB of the incident signal. The orientation of the azimuth-elevation spherical coordinate system relative to the modeled car is shown in the following figure.



The predefined body masks have up to three regions: pass, attenuated pass and non-pass. In the pass region, the incident signal is not attenuated – the corresponding table elements are 0 dB. Pass regions correspond to areas with unobstructed view such as windows or roof openings. In the attenuated pass region, the incident signal is attenuated but not fully blocked – the corresponding table elements are defined to be 15 dB. Attenuated pass regions correspond to e.g. the roof top of the car. These areas consist of materials that are thin enough for signal rays to penetrate. In the non-pass region, the incident signal is heavily blocked – the corresponding table elements are defined to be 40 dB. Non-pass regions correspond to areas such as doors and trunk.

The body mask is deduced from the simplified vehicle model shown above in the following way: if the incident signal ray (having particular azimuth and elevation angles) passes through a window and reaches the receiver, the respective azimuth-elevation element is set to 0 dB in the body mask table. The receiver is placed behind the front window as shown in above figures. If the incident ray hits the roof, it is attenuated and the respective azimuth-elevation element is set to 15 dB. If the ray hits any other vehicle surface (e.g. metal body), it is blocked and the respective azimuth-elevation element is set to 40 dB. The following body mask is obtained:



General remark: Changing the receiver position relative to the 3D car model would result in a different body mask. Similar, changing the 3D car model would also result in a body mask that is different from the predefined one.

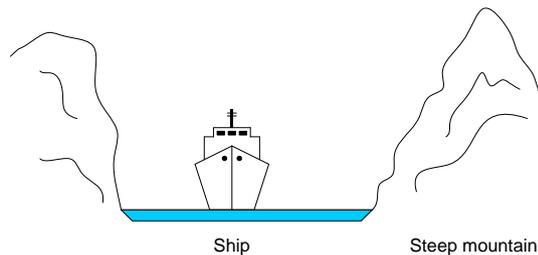


## 5 Ship with Sea Reflection and Obscuration

### Real-world scenario:

A ship is driving through a canal with obstacles on either or both sides of the waterway that obscure satellite signals. In addition, the water surface inside the cutting/canyon causes reflections of the satellite signals.

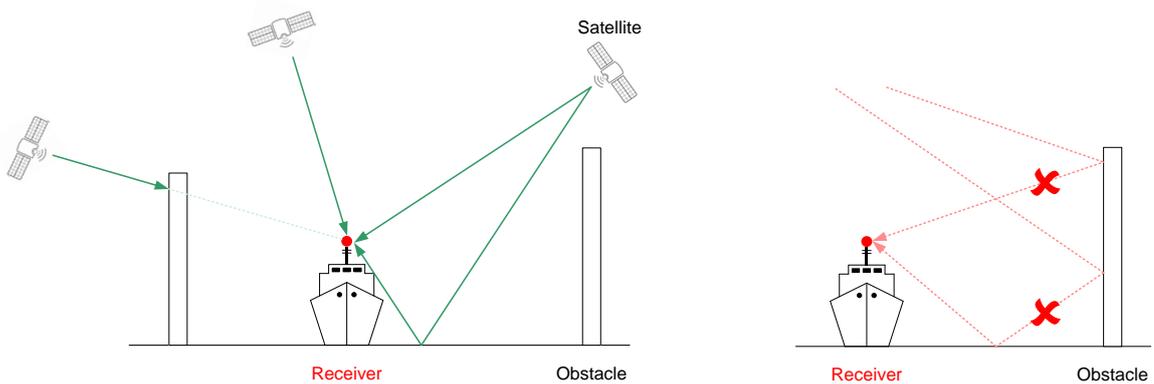
An example would be a supply ship driving through a Norwegian fjord with steep mountains on both sides of the waterway.



### Simulation scenario:

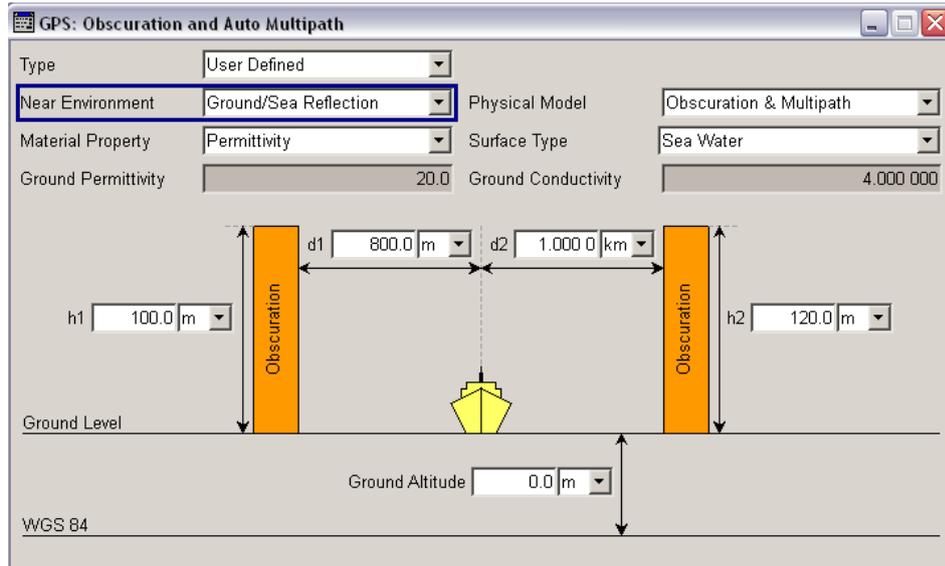


The obstacles are modeled by vertical planes. Their height and distance can be specified individually for each side of the waterway to resemble the natural environment. The SMBV simulates obscuration of satellite signals due to the obstacles and multipath propagation due to sea reflections from the flat water surface. Reflections off the obstacles and multiple reflections are not simulated as shown in the following figure.



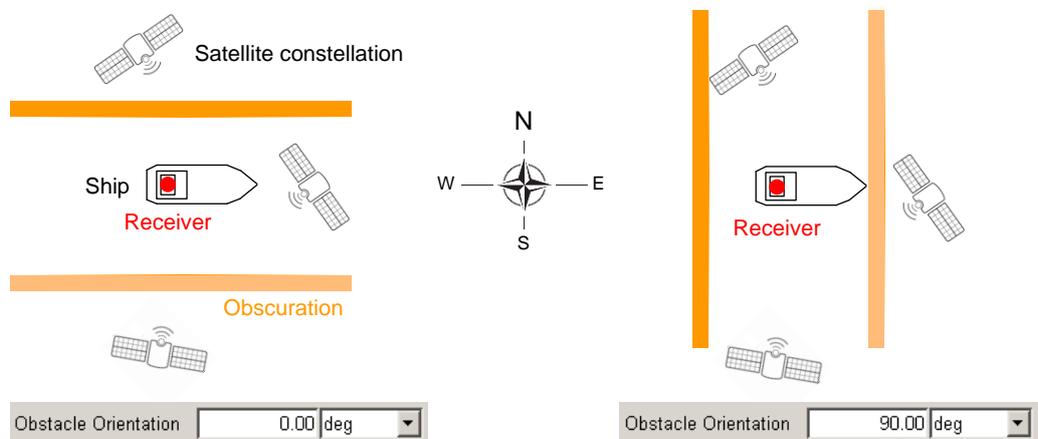
The user can specify the permittivity (or alternatively the power loss) of the reflecting surface. For ease of use, predefined surface types such as seawater are supported. The associated permittivity and conductivity are indicated.

Predefined surface types	
Ground/sea reflection	
Surface type	Relative permittivity
Fresh water	80
Seawater	20



**Static receiver:**

The position of a static receiver is specified by fixed latitude, longitude, and altitude values. The horizontal distance between obstacles and receiver can be specified as well as the orientation of the obstacles relative to the geographic direction. The obstacle orientation influences which satellites of the sky's constellation are obscured. The obstacles are assumed to have infinite length.

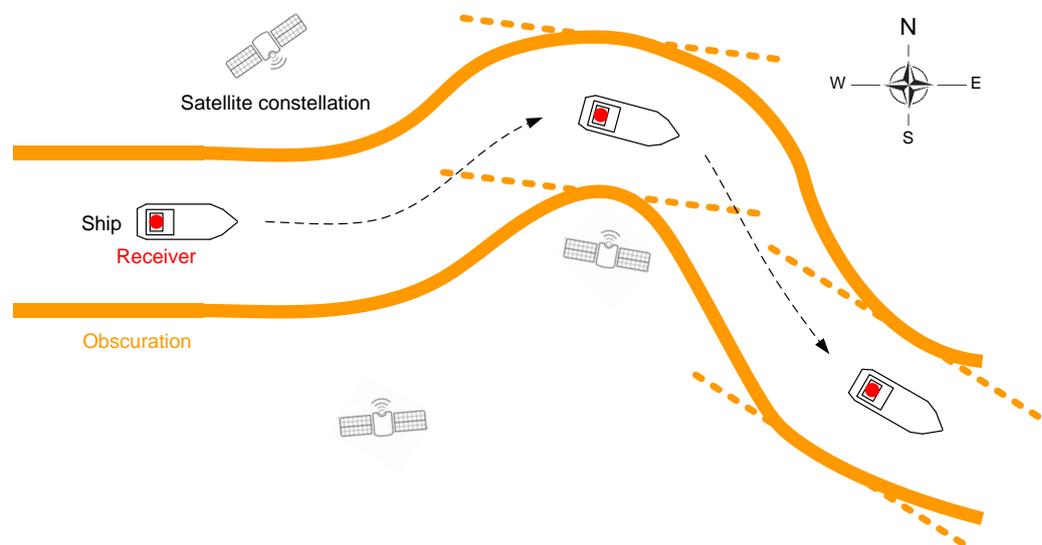


The vertical distance between the receiver and the sea level is specified by the altitude value (set in the “Localization Data” menu) according to the following relation:  
 $\text{altitude} = \text{ground altitude} + \text{height above sea level}.$

Special case: static receiver without obscuration but with sea/ground reflection  
 This scenario can be achieved by setting the obstacle height to zero on both sides.

#### Moving receiver:

The position of a moving receiver is specified by a waypoint file (please refer to references [1] and [3] for information about the supported file formats). While the ship is moving along a specified trajectory, the obstacles stay always parallel to the direction of movement. The obstacles maintain the specified height and horizontal distance to the receiver. At each waypoint, the obstacles are assumed to have infinite length in that moment.

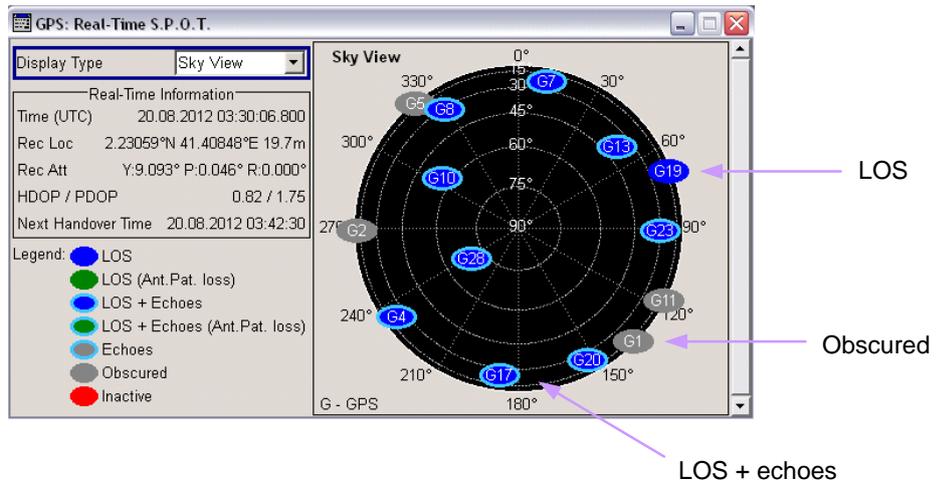


The vertical distance between the receiver and the sea level is specified by the altitude value in the waypoint file according to the following relation:  $\text{altitude} = \text{ground altitude} + \text{height above sea level}.$

Special case: moving receiver without obscuration but with sea/ground reflection  
 This scenario is described in section 6. It can be achieved by setting the obstacle height to zero on both sides.

#### Sky view:

The SMBV's “Sky View” display shows the effect of multipath propagation and obscuration of the simulated satellite signals in real-time. Some satellites, particularly those with low elevations, are hidden behind the obstacles and their LOS signals do not reach the receiver. They are indicated as obscured satellites, e.g. G5, G2, etc. in this snapshot example. The signals of other satellites get reflected on the sea surface and reach the receiver in addition to the direct LOS signal, e.g. G8, G10, G4, etc. Some satellites are visible but do not cause multipath echoes, e.g. G19.

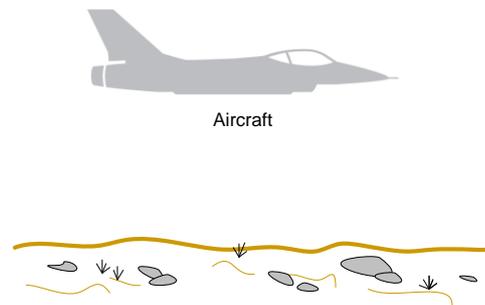


## 6 Aircraft with Ground Reflection

### Real-world scenario:

An aircraft is flying over land, sea or through cuttings/canyons with walls that obscure the satellite signals. The ground and sea surfaces cause reflections of the satellite signals.

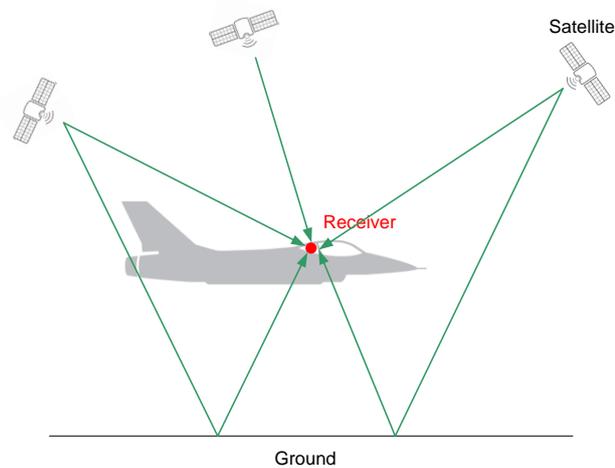
An example would be a jet flying over flat, desert-like land at high speed.



### Simulation scenario:

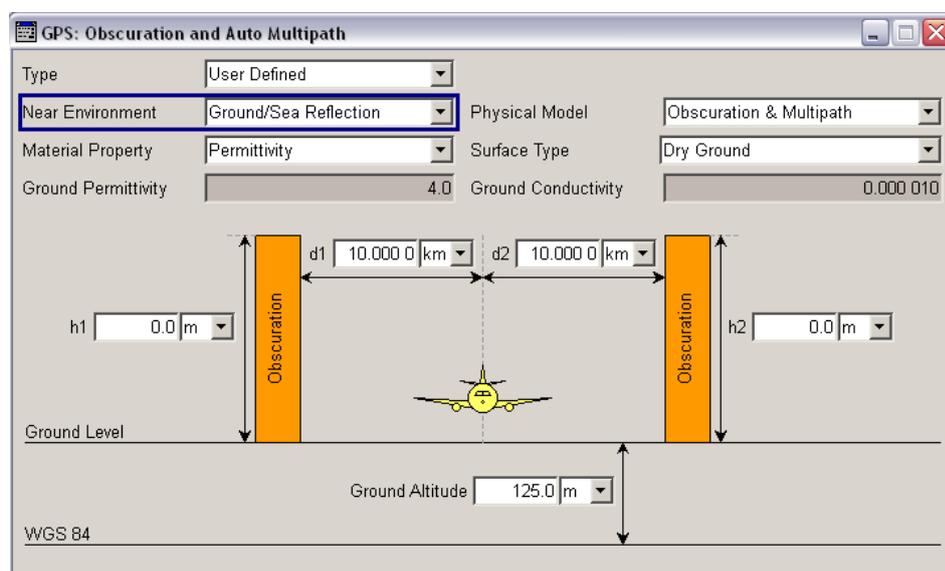


The SMBV simulates multipath propagation due to ground reflections. The ground surface is assumed to be flat.



The user can specify the permittivity (or alternatively the power loss) of the reflecting ground. For ease of use, predefined surface types such as dry ground are supported. The associated permittivity and conductivity are indicated.

Predefined surface types	
Ground/sea reflection	
Surface type	Relative permittivity
Dry ground	4
Medium dry ground	7
Wet ground	30
Fresh water	80
Seawater	20



### Moving receiver:

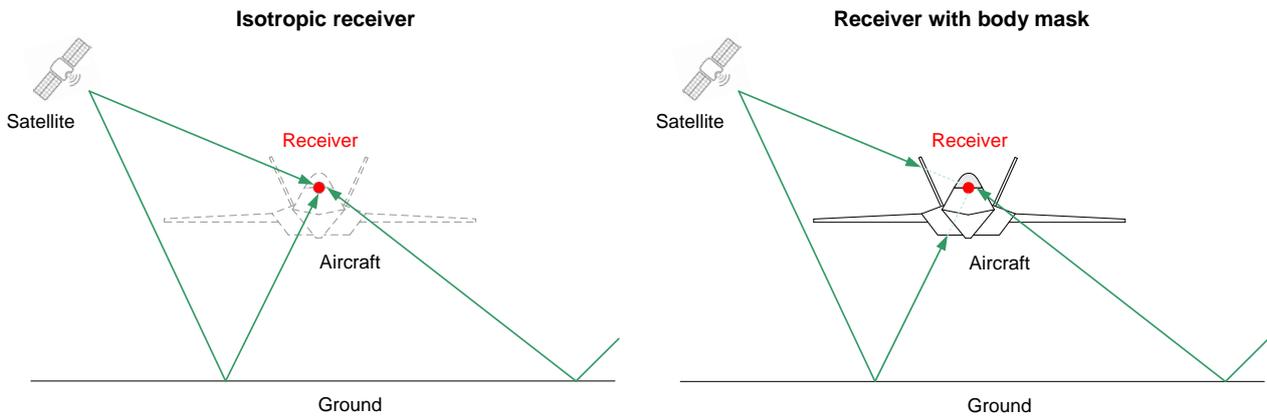
The position of the moving receiver is specified by a waypoint file.

The vertical distance between the receiver and the ground is specified by the altitude value in the waypoint file according to the following relation: altitude = ground altitude + height above ground.

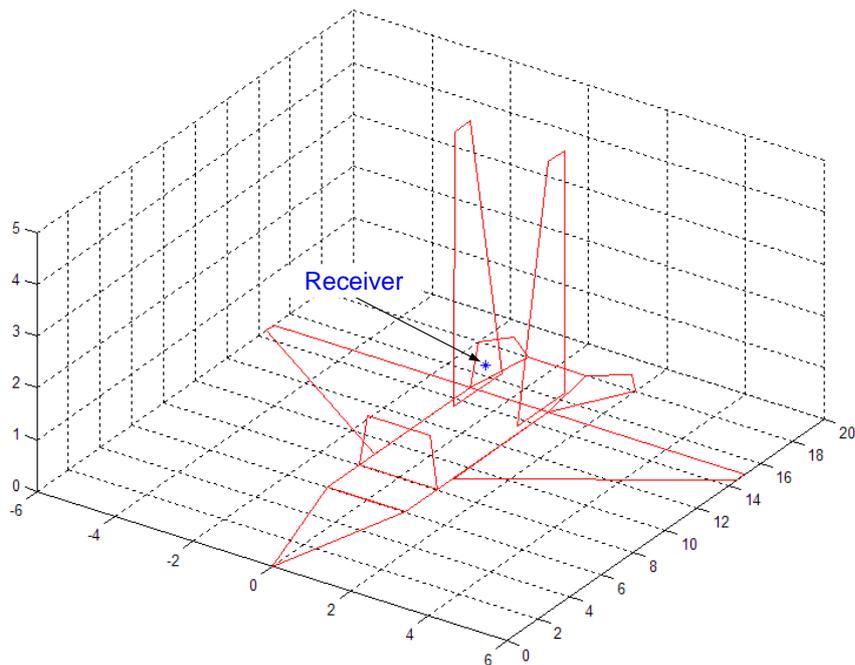
The flight speed of the aircraft results from the waypoint file. For classical waypoint files, the physical distance between two consecutive waypoints and the specified time resolution (between two waypoints) determine the current speed. The SMBV supports speeds as high as 10000 m/s (36000 km/h) with option SMBV-B10F.

### Body mask:

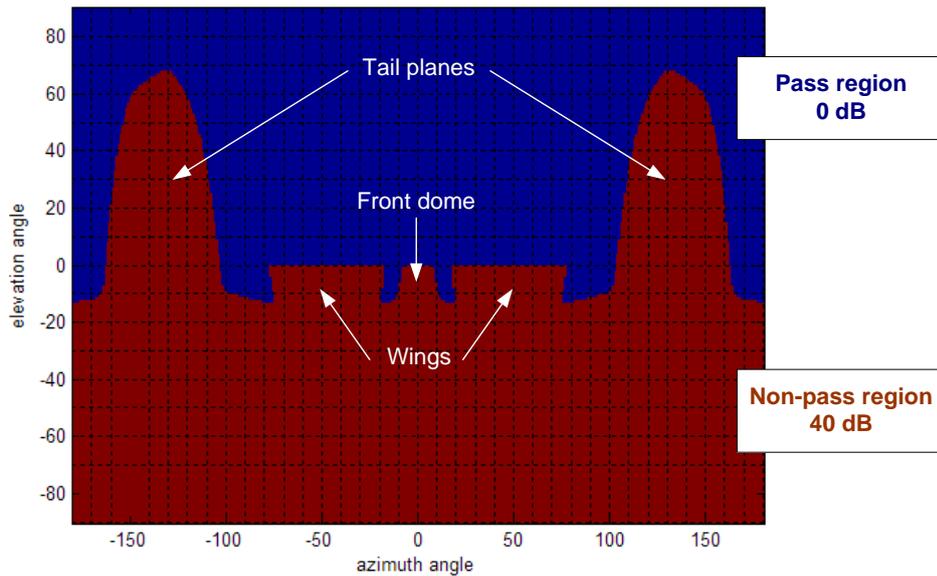
Per default, an isotropic receiver is assumed, i.e. the receiver receives satellite signals and ground reflections from all directions. In reality, some of these signals are blocked by the vehicle and do not reach the receiver. For example, if the receiver is placed on top of the aircraft, certain ground reflections are blocked by the aircraft's body.



In the SMBV, the user can define a vehicle body mask to simulate obscuration caused by the vehicle's body. Various predefined body masks are available. For example, the predefined "Jet" body mask uses the following simplified 3D model. The front dome is modeled as a vertical obstruction plane. The position of the receiver is indicated. It is placed right in front of the tail planes.



From this simplified jet model the following body mask is deduced (see section 4.4 for more details).



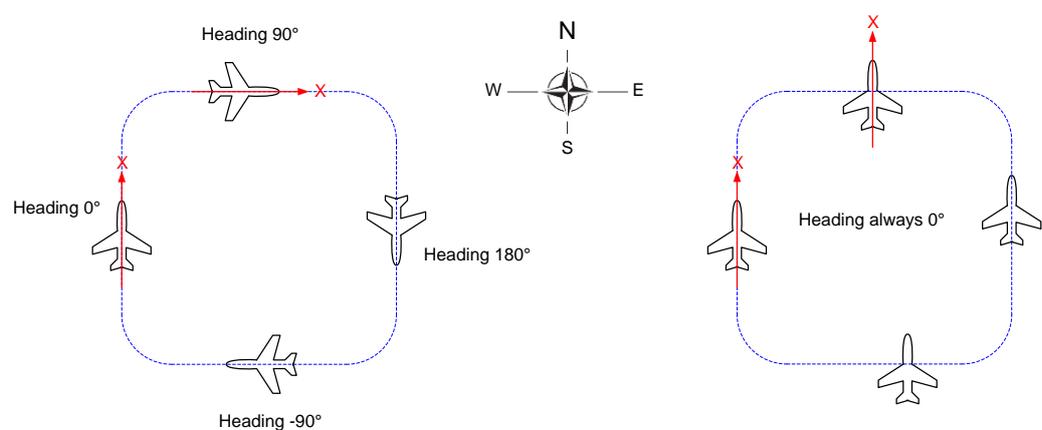
If this body mask is applied, some ground reflections and also certain LOS satellite signals are blocked by the aircraft's body and wings. Reflections of signals caused by the aircraft's body are not considered.

#### Moving receiver (with body mask):

The exact position of the moving receiver is specified by a waypoint file and by a body mask file. The position coordinates (longitude, latitude, altitude) specified in the waypoint file relate to the vehicle's COG. The receiver position is offset from the waypoint coordinates according to the x-, y-, and z-offset values specified in the body mask file.

The following question may arise: Can a body mask be used in a realistic way when no attitude data such as heading information can be provided by the user?

As described in section 4.4, the spherical azimuth-elevation coordinate system of the receiver antenna is fixed relative to the XYZ vehicle body coordinate system. In the real world, the body system will turn relative to the geographical north direction while moving (see below figure) and so will the spherical receiver antenna system.



The illustration on the right in the above figure shows the effect on the vehicle body system if no suitable heading information is available. (The heading is the angle between the north direction and the x-axis of the body system.) As long as no body mask is used, this is not critical. However when a body mask is applied, this becomes more important. For example, imagine a body mask with a single pass region corresponding to a large front window. Without suitable heading information the pass region would always point to the north in the above example. To achieve a more realistic simulation the vehicle body system should be rotated according to the movement direction. This rotation is defined via the heading parameter. The heading (or yaw) of the vehicle can either be specified in the waypoint file (\*.xtf file – see reference [1] for details) or in case such attitude information cannot be provided by the user it can be deduced automatically from the motion.



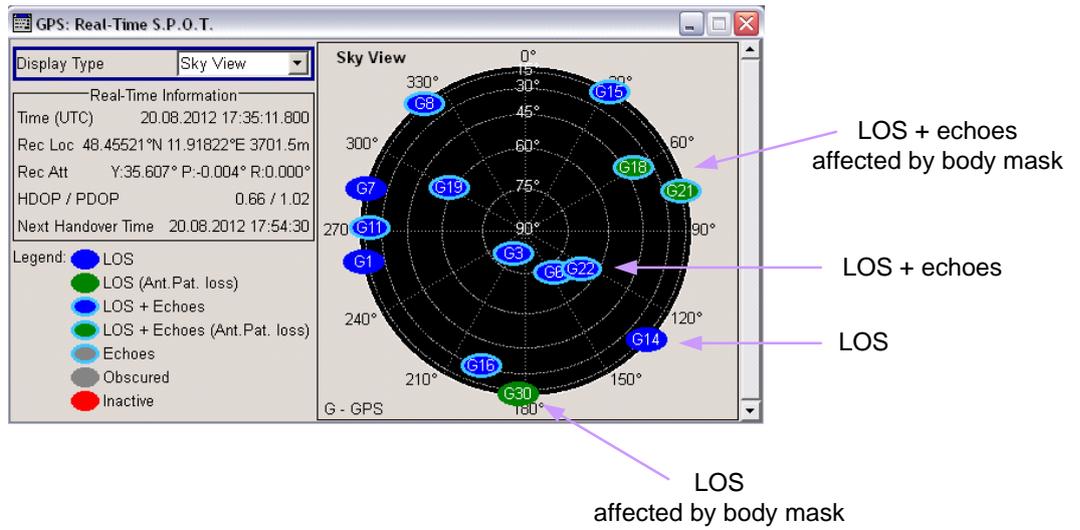
Yaw / Heading  From Motion  deg

If this check box is enabled, the SMBV automatically determines the heading of the vehicle from its motion along the specified trajectory. That means, the x-axis of the body system will be rotated with the movement direction and so will the body mask. To keep the explanation simple, only heading was mentioned up to this point. However, the same principle holds also for the other attitude parameters pitch/elevation and roll/bank. (Roll/bank cannot be deduced automatically from the motion).

Please note that although the SMBV provides means to deduce some attitude data automatically, fully realistic simulation e.g. of landing and special fight maneuvers can only be achieved with attitude data provided by the user via the waypoint file.

#### **Sky view (with body mask):**

The SMBV's "Sky View" display shows the effect of multipath propagation and obscuration (e.g. due to the body mask) of the simulated satellite signals in real-time. The signals of most of the satellites get reflected on the ground and reach the receiver in addition to the direct LOS signal, e.g. G8, G19, G3, etc. in this snapshot example. Some satellites are visible but do not cause multipath echoes, e.g. G7, G1, and G14. Other satellites are obscured by the vehicle's body mask and their LOS signals do not reach the receiver. They are indicated in green, e.g. G18, G21, G30. The body mask also blocks ground reflections of course. However obscured echoes are not extra indicated in the display to keep the color-coding less complex. The colors blue (visible) green (obstructed/attenuated by body mask), and gray (obstructed by obstacle) refer to the LOS signal only. It is likely that ground reflections especially from high-elevation satellites impact on the bottom side of the "virtual" aircraft and get blocked (not extra indicated). Even if the direct LOS signal is obscured by the body mask, the signal of a satellite can still reach the receiver via a ground reflection path, possibly G18 and G21.

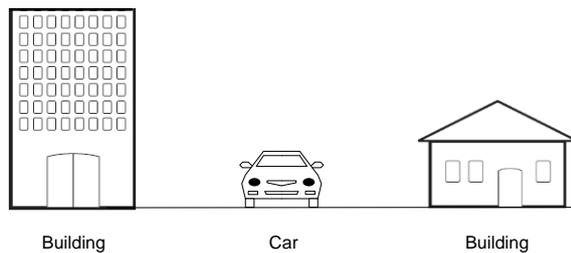


## 7 Car with Roadside Reflections and Obscuration

### Real-world scenario:

A car is driving along a road in a suburban area. On either or both sides of the road there are obstacles such as buildings that obscure and reflect the satellite signals.

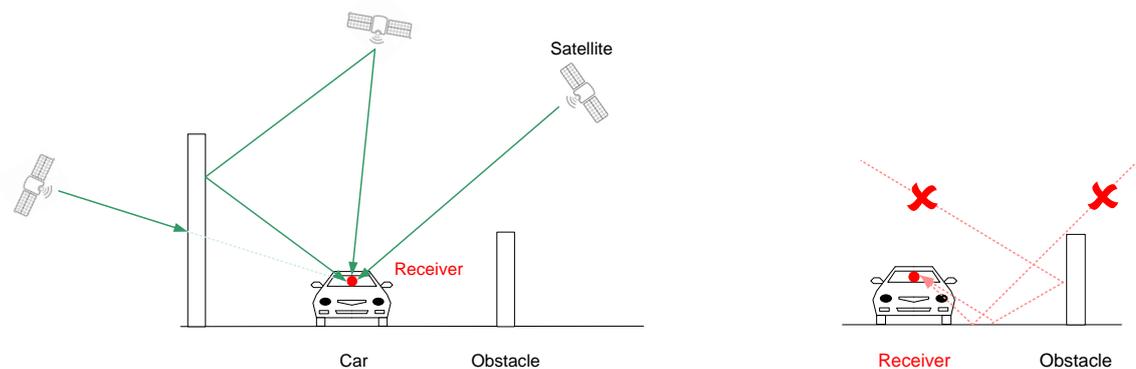
An example would be a car driving through a suburb with a densely built up district on the one side of the road and a less populated area on the other side.



### Simulation scenario:

Near Environment

The obstacles are modeled by vertical planes along the direction of movement. Their height and their transversal distance to the receiver can be specified individually for each side of the road to resemble the environment. The SMBV simulates obstruction of satellite signals and multipath propagation due to reflections off the obstacles. Ground reflections and multiple reflections are not simulated as shown in the following figure.



The user can specify the permittivity (or alternatively the power loss) of the reflecting surface for each plane separately. For ease of use, predefined surface types such as concrete are supported. The associated permittivity is indicated.

Predefined surface types	
Roadside plane	
Surface type	Relative permittivity
Glass	7.0
Concrete	5.0
Wood	1.5
Gypsum	3.0
Formica	4.0
Marble	12.0
Dry wall	6.0
Brick	4.0



GPS: Obscuration and Auto Multipath

Type: User Defined

Near Environment: Roadside Planes Physical Model: Obscuration & Multipath

Receiver Height Offset: 1.5 m Repetition Window: 0.550 km

Set Length to Infinite:  On

Planes File... Suburban\_1 View Type: Height vs. Position

Height / m

Receiver Position / km

Left Planes Right Planes

Viewport: from 0.000 km to 0.500 km Zoom Out

	Alignment	Ref. Receiver Position /km	Distance /m	Height /m	Material	Permittivity
1 >	Left	0.000	40.0	0.0	Brick	4.2
2	Right	0.000	40.0	0.0	Concrete	5.0
3	Right	0.030	40.0	20.0	Concrete	5.0
4	Left	0.040	40.0	10.0	Brick	4.2
5	Right	0.070	40.0	0.0	Concrete	5.0
6	Left	0.080	40.0	0.0	Brick	4.2
7	Right	0.100	40.0	20.0	Concrete	5.0
8	Left	0.110	38.0	10.0	Brick	4.2
9	Right	0.140	40.0	0.0	Concrete	5.0

Hide Editor <<<

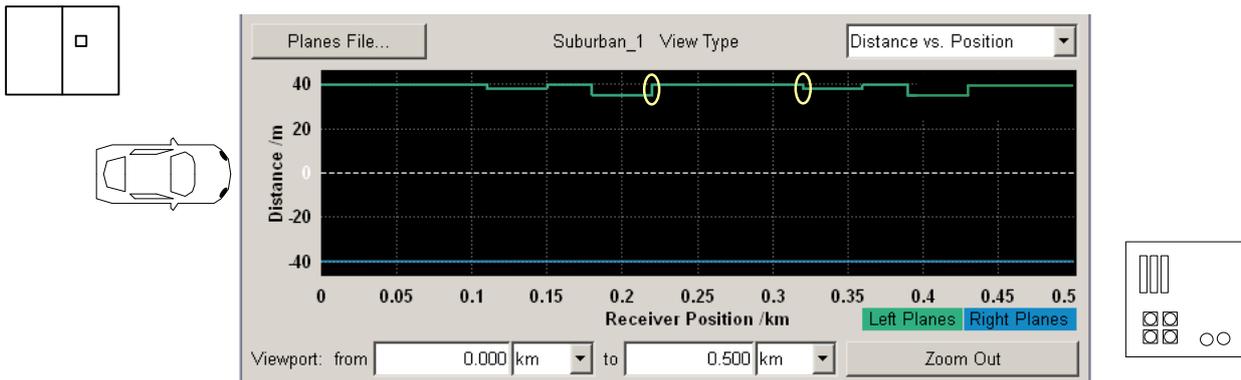
Filt. Filter: All

Mat. Prop.: Permittivity

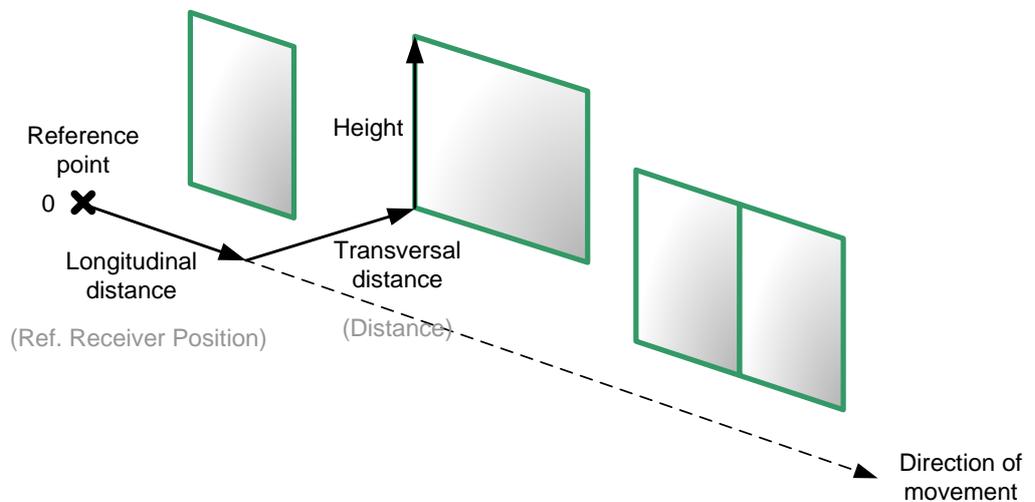
Insert Left Insert Right

Delete Undo All

Save

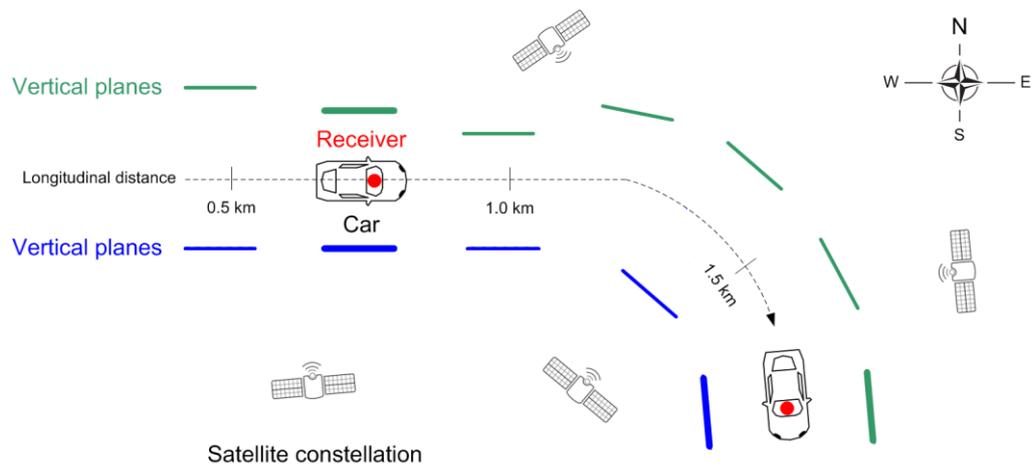


The vertical planes are all parallel to the direction of movement. There are no vertical planes that are perpendicular to the direction of movement. (The perpendicular green lines in above screenshot (two are highlighted by a yellow circle) are only displayed for clarity.) The planes are defined by their height, transversal distance, and longitudinal distance to a reference point. The longitudinal distance is the distance in the direction of movement, the transversal distance is the distance perpendicular to the direction of movement. In the SMBV GUI, the longitudinal distance is termed “Ref. Receiver Position” and the transversal distance is termed “Distance”. The length of a plane is specified indirectly: a plane always extends up to the next plane. Gaps can be implemented by planes with zero height. The planes can be specified on both sides (left and right) relative to the direction of movement.

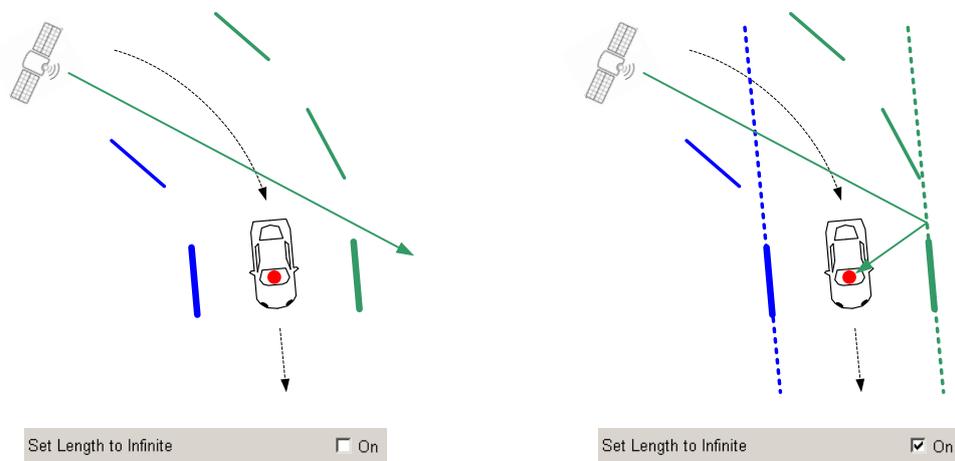


**Moving receiver:**

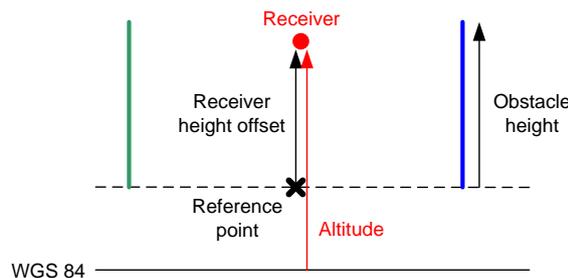
The position of the receiver is specified by a waypoint file. The first waypoint in the file is interpreted as the reference point. While the receiver is moving along the specified trajectory, the SMBV automatically calculates and tracks the virtually travelled distance (longitudinal distance), because the current longitudinal distance determines which obstacles (left/right pair) are simulated. Only the pair of vertical planes that is currently to the left and right side of the receiver is considered in the simulation. The other specified planes are not considered at the current waypoint. While the receiver is moving, the vertical planes are exchanged depending on mileage according to the settings made in the “Obstacles Configuration” table. The simulated obstacles therefore change characteristics such as height and (transversal) distance. The obstacles’ orientation is not fix relative to the north direction, but „follows“ the trajectory of the moving receiver.



At each waypoint, only the two planes that are currently to the left and right side of the receiver are considered in the simulation. There are however two options: Either the two planes are assumed to have the specified length or alternatively they are assumed to have infinite length in that moment. The global parameter “Set Length to Infinite” determines which of the two options is used in the simulation.

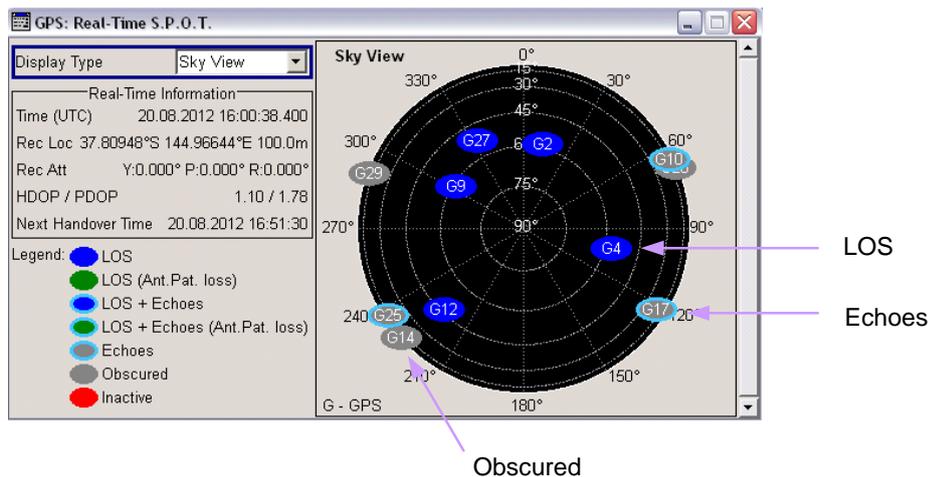


The position coordinates (longitude, latitude, altitude) of the moving receiver are specified by a waypoint file. The first waypoint in the file influences the coordinates of the reference point: If the “Receiver Height Offset” parameter is zero, the reference point has the same coordinates as the first waypoint in the file. If the user sets the “Receiver Height Offset” parameter to a non-zero value, the following relation holds: reference point position = receiver altitude (first waypoint) – receiver height offset. Note that the altitude coordinate specified in the waypoint file always relates to the receiver position. The “Receiver Height Offset” parameter therefore does not influence the position of the receiver – it influences the absolute position of the reference point.



**Sky view:**

The SMBV’s “Sky View” display shows the effect of multipath propagation and obscuration of the simulated satellite signals in real-time. Some satellites, particularly those with low elevations, are hidden behind the vertical planes and their LOS signals do not reach the receiver. They are indicated as obscured satellites, e.g. G29, G14, G25, etc. in this snapshot example. Even if the direct LOS signal is obscured, the signal of a satellite can still reach the receiver via a reflection path. These multipath echoes are indicated as echoes without a corresponding LOS signal, e.g. G25, G10, and G17.

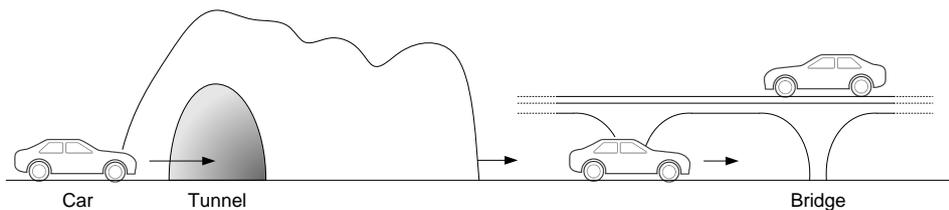


## 8 Car with Full Obscuration

### 8.1 Bridges and Tunnels

#### Real-world scenario:

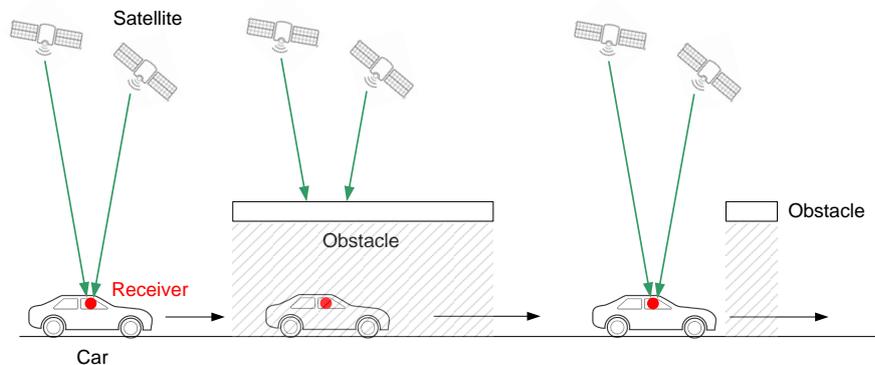
A car drives through tunnels and/or passes under bridges that obscure the satellite signals completely for a certain distance or period of time.



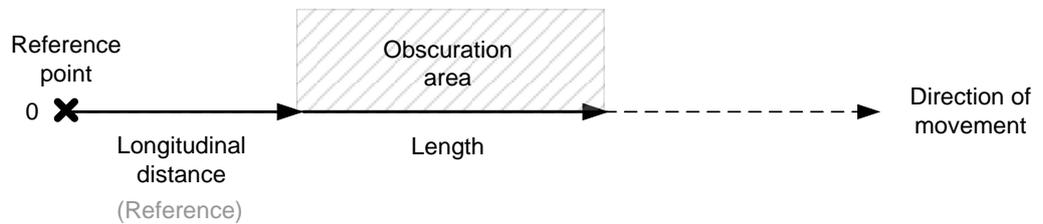
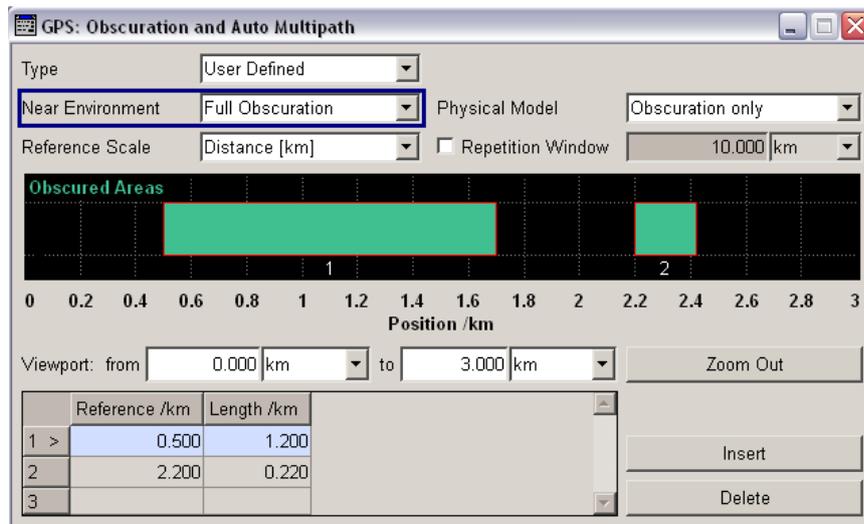
#### Simulation scenario:



Obstacles such as tunnels and bridges are modeled by areas with full obscuration. Outside these areas the satellite signals are fully receivable. Inside these areas they are blocked completely, i.e. the SMBV simulates full obstruction of the satellite signals. The receiver receives then no signals. Reflections of any kind are not simulated. This simulation scenario can be used to test the receiver's reacquisition performance.

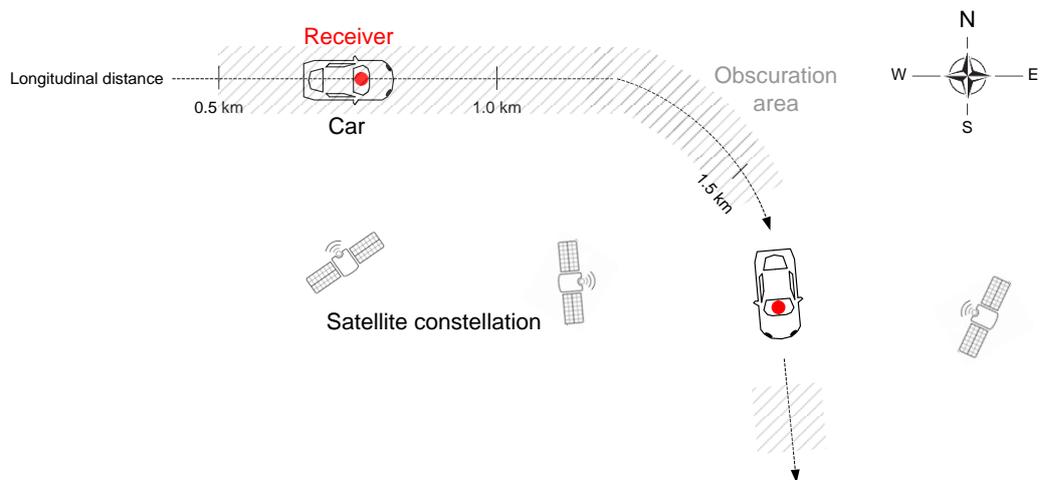


The user can define the obscuration areas in units of distance (km) or time (s). For tunnels and bridges, distance is most suitable. The areas are specified by their length and longitudinal distances to a reference point. The longitudinal distance is the distance in the direction of movement. In the SMBV GUI, the longitudinal distance is termed "Reference".

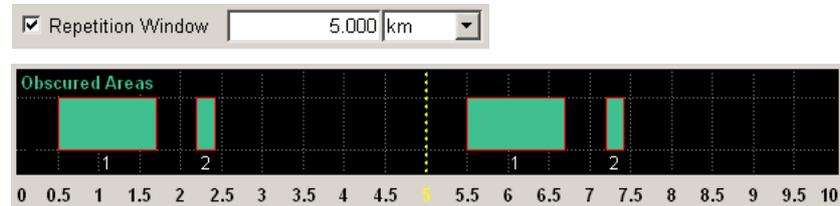


**Moving receiver:**

The position of the receiver is specified by a waypoint file. The first waypoint in the file is interpreted as the reference point. While the receiver is moving along the specified trajectory, the SMBV automatically calculates and tracks the virtually travelled distance (longitudinal distance). Depending on the current longitudinal distance either full view or full obscuration is simulated according to the settings made in the “Full Obscuration Configuration” table. The obscuration areas do not have a fix orientation, they “follow” the trajectory of the moving receiver.

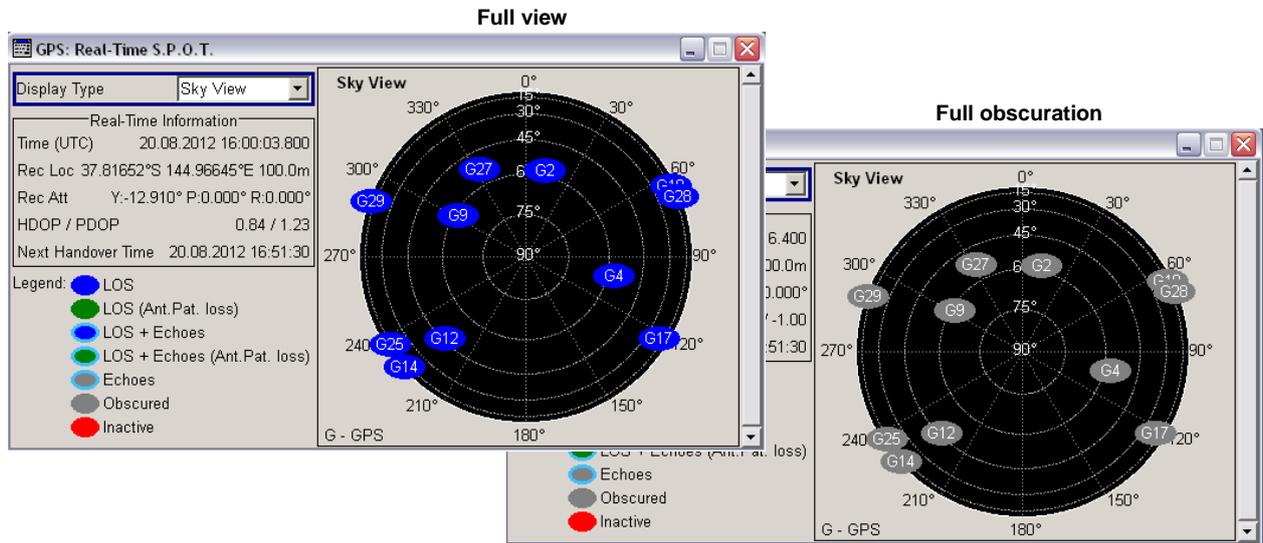


The specified sequence of obscuration areas (two areas in the above example) can be repeated continuously. This way, a few entries in the “Full Obscuration Configuration” table are sufficient to simulate a continuous series of obscuration areas. The repetition window can be specified.



**Sky view:**

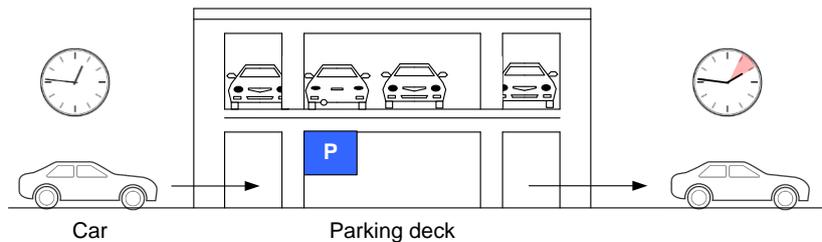
The SMBV’s “Sky View” display shows the effect of full obscuration on the simulated satellite signals in real-time. In areas with no obscuration, all satellites are visible. In areas with full obscuration, all satellites are obscured and not visible for the receiver.



## 8.2 Parking

### Real-world scenario:

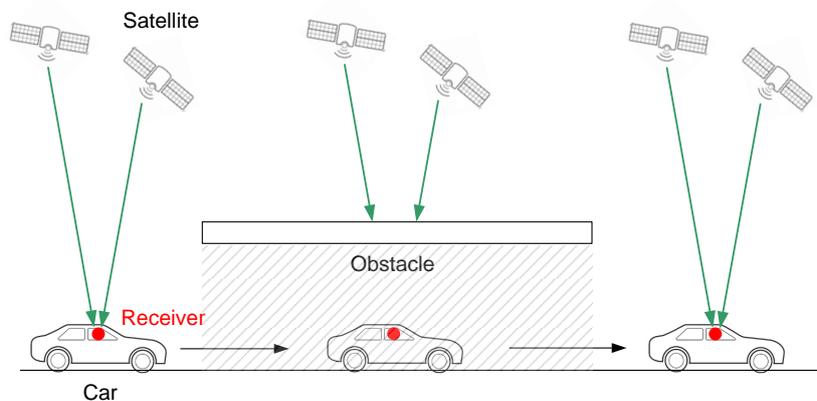
A car drives into a parking deck and parks there for a certain period of time, e.g. for one hour. During parking, the satellite signals are completely obscured.



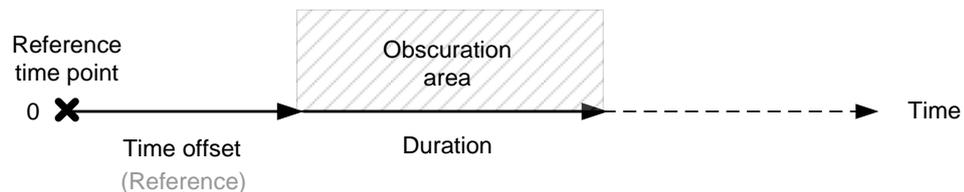
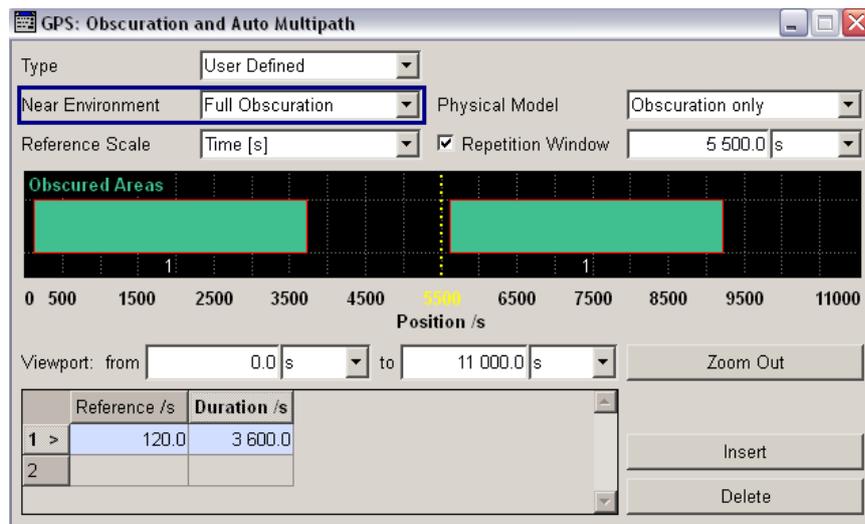
### Simulation scenario:



Like tunnels and bridges, parking decks are modeled by areas with full obscuration. Outside these areas the satellite signals are fully visible to the receiver. Inside these areas they are blocked completely, i.e. the SMBV simulates full obstruction of the satellite signals. The receiver receives then no signals. Reflections of any kind are not simulated. This simulation scenario can be used to test the receiver's reacquisition performance.



The user can define the obscuration areas in units of distance (km) or time (s). For parking, time is most suitable. The areas (i.e. periods of full obscuration) are specified by their duration and time offset to a reference time point. In the SMBV GUI, the time offset is termed "Reference".



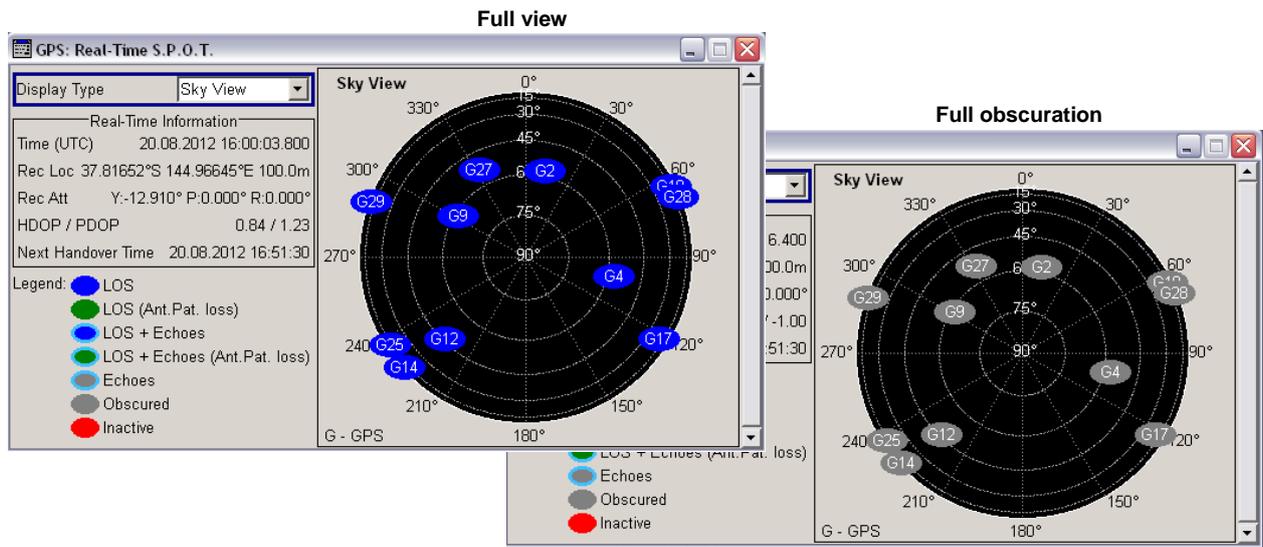
The specified sequence of obscuration periods (just one in the above example) can be repeated continuously. In principle, a single entry in the “Full Obscuration Configuration” table is sufficient to simulate a continuous series of obscuration periods. The repetition window can be specified (5500 s in the above example).

#### Moving receiver:

The position of the receiver is specified by a waypoint file. The starting time of the simulation is interpreted as the reference time point. While the receiver is moving along the specified trajectory, the SMBV automatically tracks the elapsed time (time offset from starting time). Depending on the current elapsed time either full view or full obscuration is simulated according to the settings made in the “Full Obscuration Configuration” table. Parking, i.e. staying at a fixed location, can be implemented in the waypoint file by repeating the same waypoint coordinates line by line as long as needed. The SMBV provides suitable waypoint files for the predefined parking scenarios called e.g. “Scen\_Parking\_1min”.

#### Sky view:

The SMBV’s “Sky View” display shows the effect of full obscuration on the simulated satellite signals in real-time. In areas/periods with no obscuration, all satellites are visible. In areas/periods with full obscuration, all satellites are obscured and not visible for the receiver.

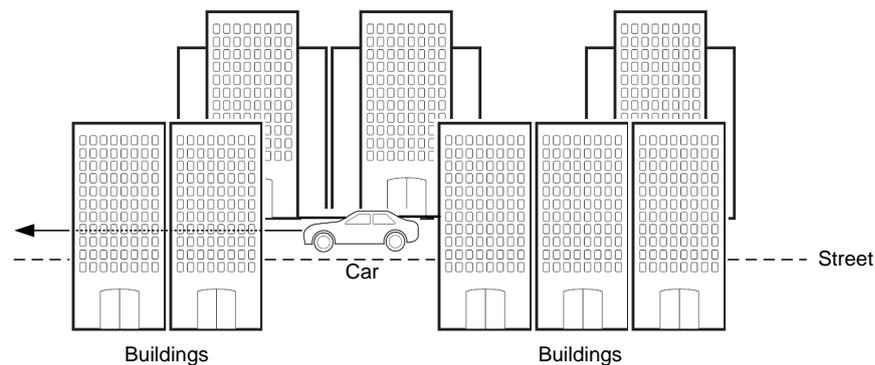


## 9 Car with Reflections and Obscuration from Stationary Obstacles

### Real-world scenario:

A car is driving along a street in a suburban or urban area. Along the street there are obstacles such as buildings that obscure and reflect the satellite signals.

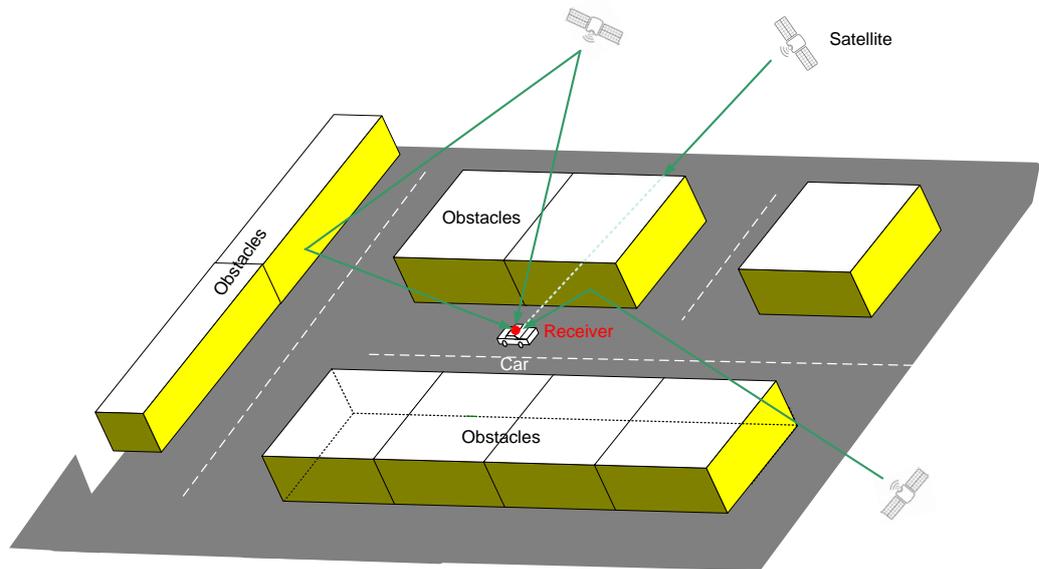
An example would be a car driving through a street canyon of a dense city with large buildings.



### Simulation scenario:

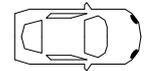
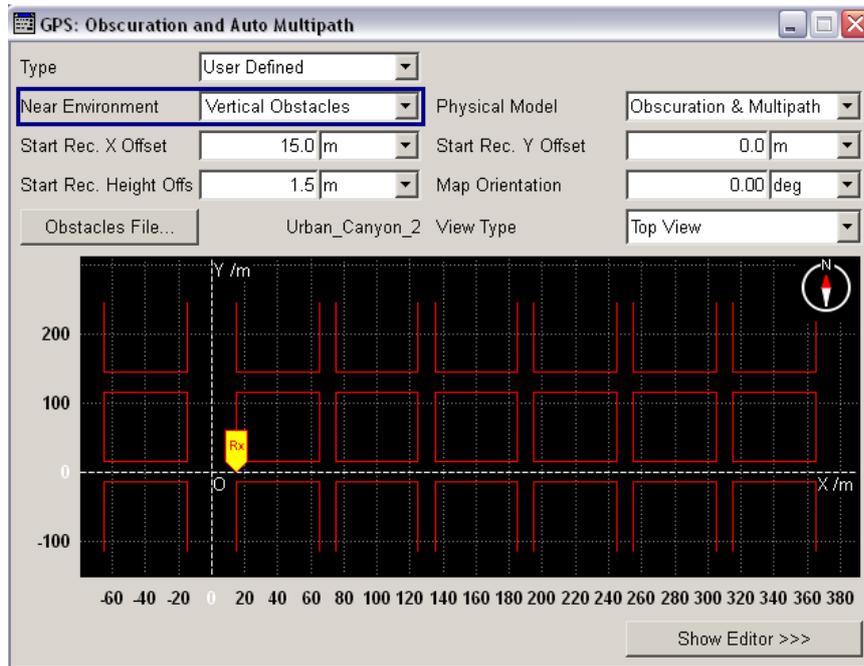


The obstacles are modeled by vertical planes which are placed on a map in a fixed geometry. The planes can be arranged as to represent buildings. Note that, these buildings are fixed on the map, i.e. they are stationary. A static receiver should be placed relative to the obstacles on a meaningful position, e.g. on the street between two buildings (not inside the building). A moving receiver should move along a trajectory that matches to the specified obstacle geometry, i.e. it should drive along the streets and not across the building blocks. It is generally the user's task to take care of this. The SMBV provides however suitable waypoint files for the predefined scenarios "City Block" and "Urban Canyon". The benefit of the stationary obstacle geometry is that the SMBV can simulate obstruction and multipath propagation from all directions – not just from the left and right sides but also from the front and back sides. Ground reflections and multiple reflections are not simulated.



The user can specify the permittivity (or alternatively the power loss) of the reflecting surface for each plane separately. For ease of use, predefined surface types such as glass and concrete are supported. The associated permittivity is indicated.

Predefined surface types	
Vertical Obstacles	
Surface type	Relative permittivity
Glass	7.0
Concrete	5.0
Wood	1.5
Gypsum	3.0
Formica	4.0
Marble	12.0
Dry wall	6.0
Brick	4.0



Each vertical plane is defined by its direction (either parallel to x-axis or to y-axis), its x-y-coordinates, length, and height. The (start) position of the receiver relative to the vertical planes is defined by offsets: x-y-coordinates and height. It is termed “Rx position” in this application note.

	Direction	1st Edge X-Coord /m	1st Edge Y-Coord /m	Length /m	Height /m	Material	Permittivity
1 >	OX	-65.0	15.0	50.0	30.0	Glass	7.0
2	OX	-65.0	145.0	50.0	30.0	Glass	7.0
3	OX	-65.0	115.0	50.0	30.0	Glass	7.0
4	OX	-65.0	-15.0	50.0	30.0	Glass	7.0
5	OY	-65.0	145.0	100.0	30.0	Glass	7.0
6	OY	-65.0	15.0	100.0	30.0	Glass	7.0
7	OY	-65.0	-115.0	100.0	30.0	Glass	7.0
8	OY	-15.0	15.0	100.0	30.0	Glass	7.0

Hide Editor <<<

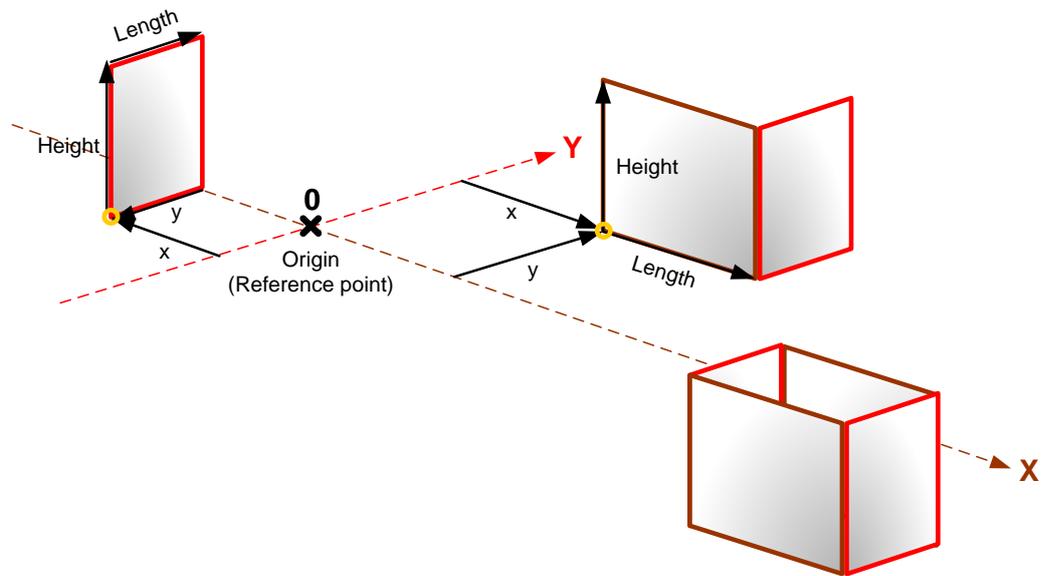
Dir. Filter: All

Mat. Prop.: Permittivity

Insert

Delete Undo All

Save



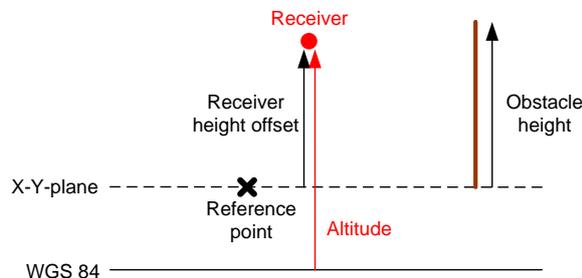
Per default, the x-axis aligns with the East. The user can change the orientation of the defined obstacles relative to the geographic direction by setting the “Map Orientation” parameter. The map orientation influences which satellites of the sky’s constellation are obscured by the vertical obstacles. A value of 90° turns the map such that the x-axis aligns with the North.

**Static receiver:**

The position coordinates of a static receiver are specified by fixed latitude, longitude, and altitude values. This position is interpreted as the “Rx position”.

Latitude	<input type="text" value="40.714 167"/>	deg
Longitude	<input type="text" value="-74.006 389"/>	deg
Altitude	<input type="text" value="1.0"/>	m

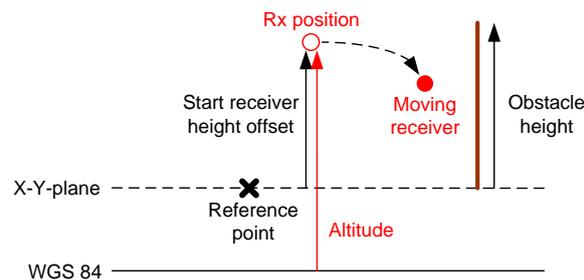
The user can offset the receiver from the X-Y-plane by using the “Receiver Height Offset” parameter. Note that the specified altitude coordinate still relates to the receiver position. The “Receiver Height Offset” parameter does not influence the position of the receiver – it influences the position of the X-Y-plane relative to the receiver.



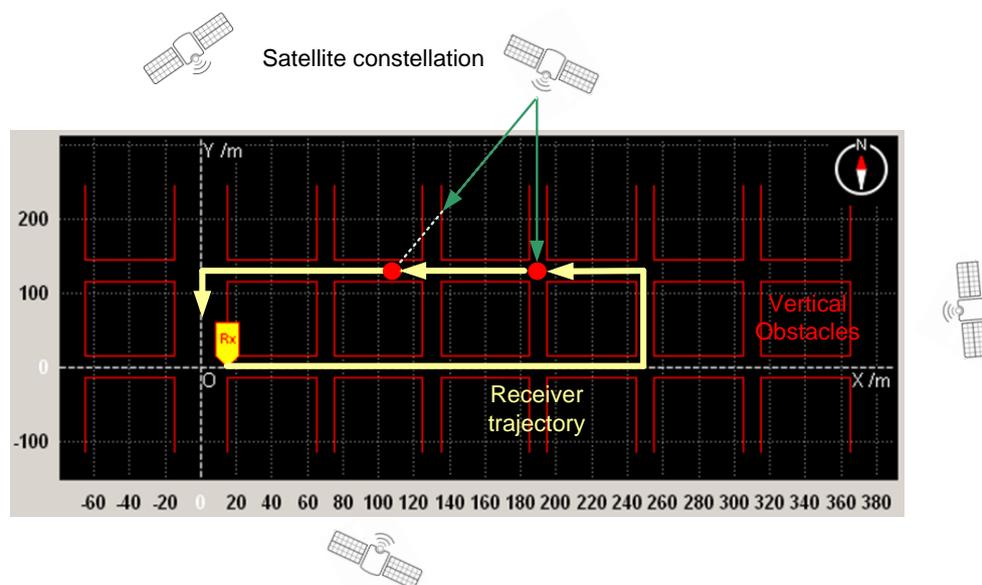
All specified obstacles are considered in the simulation – regardless of their orientation relative to the receiver. The receiver therefore experiences obscuration and receives reflection signals from all sides.

#### Moving receiver:

The position coordinates (longitude, latitude, altitude) of the moving receiver are specified by a waypoint file. The first waypoint in the file is interpreted as the “Rx position”. The user can offset the “Rx position” from the X-Y-plane by using the “Start Rec. Height Offs” parameter. Note that the altitude coordinate specified in the waypoint file always relates to the receiver position. The “Start Rec. Height Offs” parameter therefore does not influence the position of the receiver – it influences the position of the X-Y-plane relative to the “Rx position”.

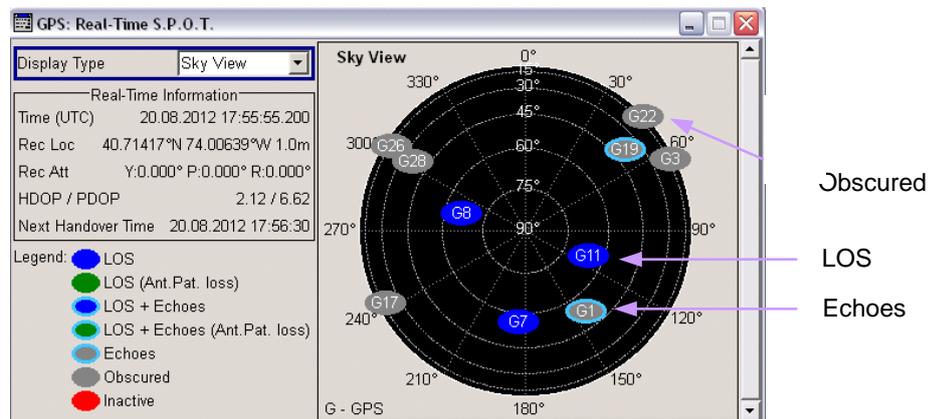


While the receiver is moving along the specified trajectory, all specified obstacles are considered in the simulation – regardless of their orientation. The receiver experiences obscuration and receives reflection signals from all sides. Obscuration and multipath reception will vary with time while the receiver moves through the stationary obstacles. The obstacles’ orientation is fix relative to the geographic direction. It is therefore required that the trajectory of the receiver matches to the specified obstacle arrangement in order to drive along the streets and not across the building blocks. The SMBV provides suitable waypoint files for the predefined scenarios “City Block” and “Urban Canyon”: “Scen\_City\_Block” and “Scen\_Urban\_Canyon\_1”, respectively. A way to create such waypoint files is described in section 9.1.



**Sky view:**

The SMBV's "Sky View" display shows the effect of multipath propagation and obscuration of the simulated satellite signals in real-time. Some satellites, particularly those with low elevations, are obscured by the vertical obstacles and their LOS signals do not reach the receiver. They are indicated as obscured satellites, e.g. G26, G28, G17, etc. in this snapshot example. Even if the direct LOS signal is obscured, the signal of a satellite can still reach the receiver via a reflection path. These multipath echoes are indicated as echoes without a corresponding LOS signal, e.g. G19 and G1. Particularly the satellites with high elevations are not obscured and their LOS signals can reach the receiver, e.g. G8 and G11.



## 9.1 Creating Trajectory Files for the “Vertical Obstacles” Simulation Model

Since the obstacles are stationary and have a fix orientation relative to the geographic direction, the trajectory of a moving receiver must match to the obstacle arrangement in order to drive along the streets and not across the building blocks. This section explains one of different ways to create suitable trajectory files for scenarios that use the “vertical obstacles” simulation model.

In general, a trajectory file can have the following format:

- (classical) waypoint file
- script file
- NMEA data file
- KML data file
- trajectory description file (may include velocity and attitude data)

Please see reference [1] for details on the different file formats.

In the following, this section focuses on the script file format because this format is well suited to generate geometric trajectories such as rectangles and polygons in an easy way. Such rectangular trajectories match well to the intersections/junctions on the obstacle map.

**Script file:**

A script file is a text file (.txt) that contains a set of commands:

- REFERENCE: longitude [°], latitude [°], altitude [m] (relative to WGS84 ellipsoid)
- START: east [m], north [m], up [m], velocity [m/s]
- ARC: center east [m], center north [m], angle [°]
- LINE: distance east [m], distance north [m], acceleration [m/s<sup>2</sup>]
- STAY: time [ms]

The REFERENCE command sets a reference location. The START command sets the start location with respect to the reference location using east, north, up (ENU) coordinates. It also sets the start velocity. The ARC command generates a movement with constant velocity along a 2D circular arc. The arc center coordinates need to be specified relative to the reference location. The sign of the specified angle determines the rotation direction; positive angles correspond to a counterclockwise rotation and negative angles to a clockwise rotation. The LINE command generates a movement along a 2D line. The movement can exhibit a constant acceleration/deceleration. The STAY command causes the movement to stop for the specified time period. Please see reference [1] for a full description of the commands and their syntax.

**File example:**

```
***** MOVEMENT FILE *****
%% This is a comment. The line above is MANDATORY as first line
in the file. If this line is missing, the SMBV will interpret
this script file as a classical waypoint file, which will lead
to an error.
%%
%% Set reference location
REFERENCE: 144.96667,-7.816633,100
%% Set start location (here identical to reference location) and
start velocity
START: 0, 0, 0, 6.9444
%% Stay at start location for 1000 ms
STAY: 1000
%% Move north for 400 m with constant velocity
LINE: 0, 400, 0
%% Turn 90 degrees right in a sharp curve
ARC: 0, 380, -90
%% Move east for 1000 m with constant acceleration
LINE: 1000, 0, 0.55
%% Move further east for 100 m with constant deceleration
LINE: 100, 0, -0.25
...
...
```

The command lines in the file are processed sequentially. From command to command, the end position of the previous command is used as start position for the next command so that a continuous trajectory is created. The same applies for the velocity; the velocity at the end position is used as the starting velocity for the next command.

Please note: It is recommended to use the ARC command for turning left or right. Sequencing of LINE commands only (leaving out the ARC commands in between) will result in a polygon with sharp edges. The resulting abrupt direction change cannot be handled by most receivers. In case the created trajectory has such sharp edges, the SMBV offers the possibility to smooth the receiver's movement to overcome this problem. Please see reference [1] for details.

Smooth Movement  On

## 10 Summary

The SMBV is a versatile general-purpose vector signal generator with outstanding RF performance. It can generate signals for all main communications and radio standards as well as GNSS signals for GPS, Galileo and Glonass. The SMBV simulates up to 24 satellites in realtime for testing GNSS receivers easily, flexibly, reliably, and cost-efficiently.

The SMBV supports receiver testing under realistic conditions by offering features such as vehicle attitude simulation, antenna pattern modeling, simulation of rotating vehicles, advanced obscuration simulation, and manual as well as automatic multipath generation. This application note was focused on obscuration and automatic multipath simulation.

The SMBV covers a multitude of scenarios – with predefined or user-specific settings. For example, receivers experiencing ground/sea reflection and obscuration due to natural environment, receivers experiencing obscuration due to the vehicle's body mask, receivers experiencing complete obscuration of satellite signals due to bridges, tunnels and parking decks, receivers experiencing obscuration and multipath reflections from obstacles alongside the track or from surrounding urban obstacles (e.g. houses, sky scrapers), to name just a few. For every scenario the SMBV automatically simulates the resulting obscuration and multipath propagation based on satellite constellation, receiver position, and obstacle position. Even different surface materials are taken into account for calculating the signal power of the echoes.

For ease of use various presets such as predefined scenarios, waypoint files, and body masks are provided. GNSS receiver testing is therefore quick and easy with the SMBV.

This application note introduced some fundamentals about the obscuration and automatic multipath feature of the SMBV. Different test scenarios were presented to give an impression of the instrument's capabilities and to explain the different characteristics of each scenario.

## 11 Abbreviations

3D	Three-dimensional
COG	Center of gravity
DOP	Dilution of precision
ENU	East, north, up system
Galileo	Galileo (global navigation satellite system of the European Union)
Glonass	Globalnaja Nawigazionnaja Sputnikowaja Sistema (global navigation satellite system of the Russian Federation)
GNSS	Global navigation satellite system (stands for all satellite-based navigation systems)
GPS	Global positioning system (of the United States of America)
GUI	Graphical user interface
HIL	Hardware in the loop
KML	Keyhole Markup Language
LOS	Line of sight
NMEA	National Marine Electronics Association
RF	Radio frequency
WGS 84	World Geodetic System 1984

## 12 References

- [1] Rohde & Schwarz, "Satellite Navigation Digital Standards for R&S®SMBV100A and R&S®WinIQSIM2" Operating Manual
- [2] Rohde & Schwarz, "GNSS Simulator in the R&S®SMBV100A Vector Signal Generator" Product Brochure
- [3] Rohde & Schwarz Application Note, "GPS, Glonass, Galileo Receiver Testing Using a GNSS Signal Simulator" (1GP86)
- [4] Rohde & Schwarz, "GNSS Simulator in the R&S®SMBV100A Vector Signal Generator" Specifications

## 13 Ordering Information

Please visit the R&S®SMBV100A product website for comprehensive ordering information ("Options") at [www.rohde-schwarz.com](http://www.rohde-schwarz.com).

### **About Rohde & Schwarz**

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

### **Environmental commitment**

- Energy-efficient products
- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system



### **Regional contact**

Europe, Africa, Middle East

+49 89 4129 12345

[customersupport@rohde-schwarz.com](mailto:customersupport@rohde-schwarz.com)

North America

1-888-TEST-RSA (1-888-837-8772)

[customer.support@rsa.rohde-schwarz.com](mailto:customer.support@rsa.rohde-schwarz.com)

Latin America

+1-410-910-7988

[customersupport.la@rohde-schwarz.com](mailto:customersupport.la@rohde-schwarz.com)

Asia/Pacific

+65 65 13 04 88

[customersupport.asia@rohde-schwarz.com](mailto:customersupport.asia@rohde-schwarz.com)

China

+86-800-810-8228 /+86-400-650-5896

[customersupport.china@rohde-schwarz.com](mailto:customersupport.china@rohde-schwarz.com)

This application note and the supplied programs may only be used subject to the conditions of use set forth in the download area of the Rohde & Schwarz website.

R&S® is a registered trademark of Rohde & Schwarz GmbH & Co. KG; Trade names are trademarks of the owners.

**Rohde & Schwarz GmbH & Co. KG**

Mühlhofstraße 15 | D - 81671 München

Phone + 49 89 4129 - 0 | Fax + 49 89 4129 - 13777

[www.rohde-schwarz.com](http://www.rohde-schwarz.com)