Hardware in the Loop (HIL) Testing with a GNSS Simulator
Application Note

Products:

| R&S®SMBV100A

The vector signal generator and GNSS simulator R&S®SMBV100A is remote-controllable in realtime and can therefore be implemented into a dynamic HIL environment. The HIL simulator can dictate position coordinates, kinetic parameters, and vehicle attitude information based upon which the R&S®SMBV100A updates the simulated receiver movement in realtime.

This application note presents background information and details about operating the R&S®SMBV100A in HIL applications.

ROHDE&SCHWARZ

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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.

2 Overview

2.1 Hardware in the Loop (HIL)

Hardware in the loop is a test method where a device under test (DUT) is embedded into a simulator system that emulates the real environment of the DUT, mostly in realtime.

The DUT, usually an electronic control unit (ECU) is connected to the simulator system (termed the "HIL simulator") via its in- and outputs. The HIL simulator is application-specific but generally consists of

- a processor computing the virtual environment in realtime using mathematical models
- digital, analog and/or bus in- and outputs for interfacing with the DUT
- dummy loads / models for simulating actuators connected to the DUT's outputs
- operator station (user interface) providing command and monitoring functionality
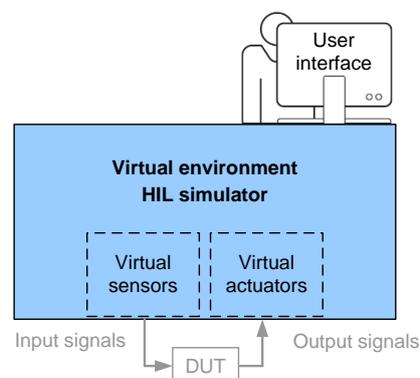
During HIL testing, the embedded ECU under test receives inputs from simulated sensors or other simulated system components and outputs control signals to simulated actuators without experiencing significant difference between this virtual reality and the real world. Testing the ECU (prototype) in a virtual environment before testing it together with the complete system in the real-world is beneficial because the ECU's functionality, performance, and failure handling can be tested systematically under controlled, reproducible, and safe conditions. HIL testing is well established in the automotive, avionics and aerospace sectors.

2.2   Realtime Control of the SMBV

One part in the virtual world of HIL testing is the simulation of GNSS satellite signals. For this purpose a GNSS simulator such as the SMBV is used.
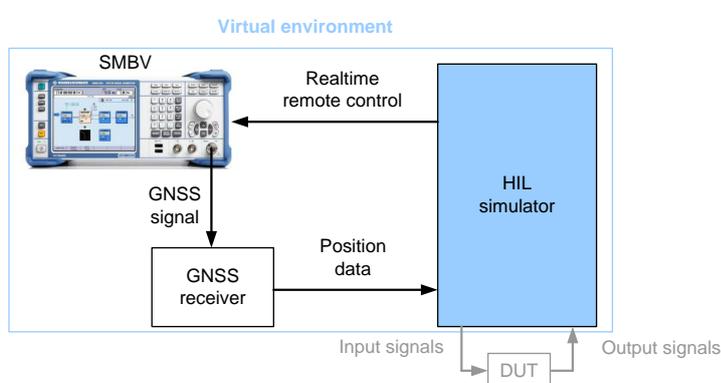
Most GNSS simulators support moving receiver simulation but only with predefined trajectories, i.e. the movement of the receiver is entirely predetermined. For HIL applications however the movement of the receiver must be controllable in real-time. This means the GNSS simulator must support realtime update of the simulated trajectory.

The SMBV can be remote controlled in realtime and can therefore be implemented into a dynamic HIL environment. The HIL simulator can dictate position coordinates and kinetic parameters such as velocity, acceleration, and jerk while the GNSS simulation is running and the SMBV adjusts the simulated movement accordingly – in realtime and without signal interruptions. Vehicle attitude information such as pitch, roll, and yaw values provided by the HIL simulator is also processed by the SMBV. In HIL applications, the SMBV stands out due to its high signal/position accuracy, its stable and reliable timing, its low processing latency, and its high position update rate of 100 Hz.

This application note addresses questions important for the user such as "Which latency time is to be expected from the SMBV?" and "How to transfer the position coordinates to the SMBV?". But first, this application note describes the test setup in section 3. How to prepare and control the SMBV is explained in section 4. Section 5 details synchronization and timing issues. Section 6 explains the trajectory prediction feature of the SMBV. Finally, this document closes with a summary.

2.3 SMBV Options for HIL Operation

The following table gives an overview of the GNSS options available for the SMBV. The HIL feature covered in this application note is highlighted. It is part of the R&S®SMBV-K92 option.

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-K107	Beidou (6 satellites)	
R&S®SMBV-K91	GNSS extension to 12 satellites	Requires K44, K66, K94 or K107
R&S®SMBV-K92	GNSS enhanced (e.g. moving scenarios, static multipath, HIL)	Requires K44, K66, K94 or K107
R&S®SMBV-K96	GNSS extension to 24 satellites	Requires K44, K66, K94 or K107 and K91
R&S®SMBV-K101	Obscuration and automatic multipath	Requires K44, K66, K94 or K107 for obscuration only Requires K44, K66, K94 or K107 and K92 for obscuration and multipath
R&S®SMBV-K102	Antenna pattern / body masks	Requires K44, K66, K94 or K107
R&S®SMBV-K103	Spinning / attitude	Requires K44, K66, K94 or K107 and K102
R&S®SMBV-K111	Ground based augmentation system (GBAS)	

The following table lists the GNSS options that are recommended for HIL operation.

| Recommended GNSS options for HIL operation		
Option	Name	Remark
At least one of the following: R&S®SMBV-K44 R&S®SMBV-K66 R&S®SMBV-K94 R&S®SMBV-K107	 GPS Galileo Glonass Beidou	6 satellites
(R&S®SMBV-K91)	(GNSS extension to 12 satellites)	(12 satellites)
(R&S®SMBV-K96)	(GNSS extension to 24 satellites)	(24 satellites)
R&S®SMBV-K92	GNSS enhanced (e.g. moving scenarios, static multipath, HIL)	Required for HIL with movement simulation only
(R&S®SMBV-K102)	(Antenna pattern / body masks)	(Prerequisite for attitude simulation)
(R&S®SMBV-K103)	(Spinning / attitude)	Required for HIL with movement and attitude simulation

3 Test Setup

A typical test setup, e.g. for testing an ECU, is shown in the following figure. (Please see reference [3] for details on connecting a GNSS receiver to the SMBV.)
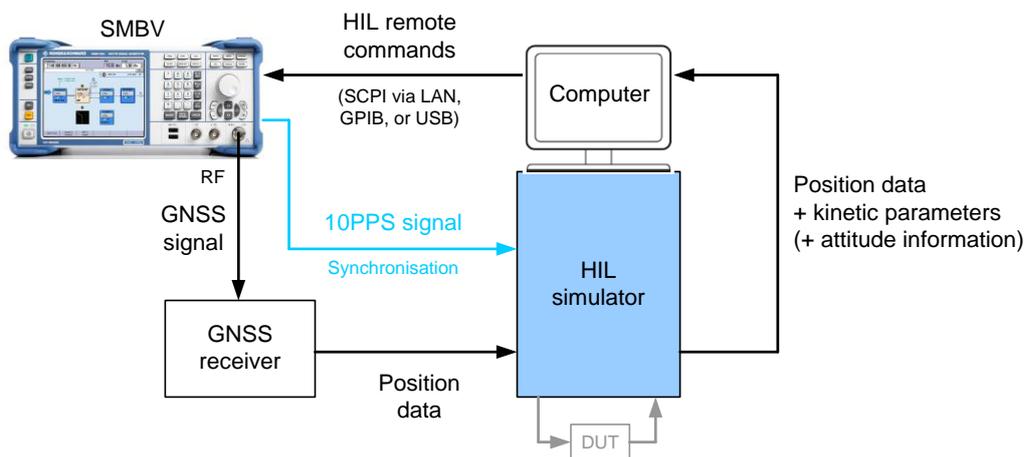
A user-specific HIL simulator emulates a real-world situation for an embedded device under test (DUT). The HIL simulator generates position data and also kinetic parameters such as velocity, acceleration and jerk plus optionally attitude information in the form of yaw, pitch and roll angles. This data is sent to the SMBV in form of specific SCPI remote control commands. The SMBV processes these HIL commands and generates a GNSS signal accordingly. The simulated GNSS signal is fed to a GNSS receiver. The receiver calculates a position fix and sends the position data to the HIL simulator. Now, the loop continues. The HIL simulator sends new position data, kinetic parameters, and attitude information to the SMBV and the SMBV adjusts the simulated GNSS signal accordingly in real-time. The updated GNSS signal is fed back to the GNSS receiver and so on.

For synchronization, the SMBV provides a 1PPS (one pulse per second) and a 10PPS signal at its MARKER output. This signal can be fed to the HIL simulator to synchronize timing. Please see section 5.3 for details.

Another HIL setup is shown in the following figure. In this application, the SMBV is implemented in a flight simulator.
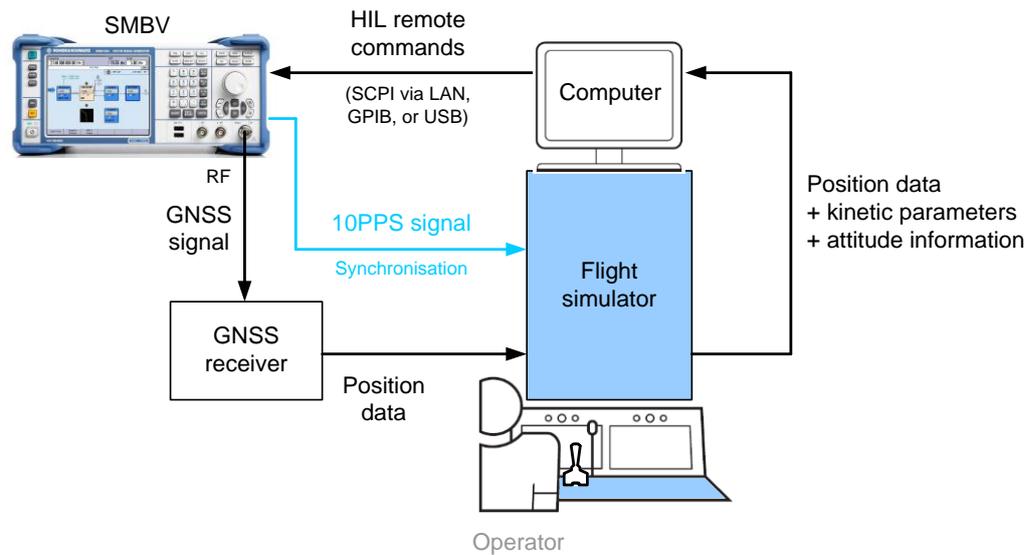
The SMBV simulates a GNSS signal that is fed to the GNSS receiver of the flight simulator. The flight simulator emulates a realistic flight situation for the operator (pilot). The operator dictates the flight trajectory. Depending on the operator's action, the flight simulator generates new position data, kinetic parameters, and attitude information. This data is sent to the SMBV in form of specific SCPI remote control commands. The SMBV adjusts the simulated GNSS signal accordingly in real-time. The updated GNSS signal is fed back to the GNSS receiver of the flight simulator and the loop continues.

The SMBV's 1PPS or 10PPS signal is fed to the flight simulator for synchronization. Please see section 5.3 for details.

4 Instrument Configuration & Control

4.1 Initialize HIL Operation

The following settings configure the SMBV for use in a HIL test setup. These settings have to be done once before starting the HIL test.

The simulation mode "Auto Localization" and "User Localization" can be used.


```
SOUR:BB:GPS:SMOD AUTO
```

The vehicle type is set to "HIL".


```
SOUR:BB:GPS:VEH:TYPE HIL
```

It is recommended to define a start position that is not too far away from the first HIL waypoint (specified by the first sent HIL command).


```
SOUR:BB:GPS:LOC:COOR:DEC 50.765544, 46.609857, 432.0
```

Per default, both marker outputs of the SMBV provide a 1PPS signal. A 10PPS signal is also supported. The width of the pulses is configurable.


```
SOUR:BB:GPS:TRIG:OUTP1:MODE PPS10
```

4.2 HIL Remote Control Commands

The following remote commands control the SMBV in a HIL test setup. These commands are sent in real-time to the SMBV during the test.

There are two HIL commands – mode A and mode B – with different notations. Mode A relates to the Earth Fixed Earth Centered (ECEF) coordinate system, mode B to the World Geodetic (WGS 84) system.

Command syntax mode A:

```
SOUR:BB:GPS:RT:HILP:MODE:A <ElapsedTime>, <X>, <Y>, <Z>, <XDot>,
<YDot>, <ZDot>, <XDotDot>, <YDotDot>, <ZDotDot>, <XDotDotDot>,
<YDotDotDot>, <ZDotDotDot>,[ <Yaw>, <Pitch>, <Roll>, <YawDot>,
<PitchDot>, <RollDot>, <YawDotDot>, <PitchDotDot>, <RollDotDot>,
<YawDotDotDot>, <PitchDotDotDot>, <RollDotDotDot>]
```
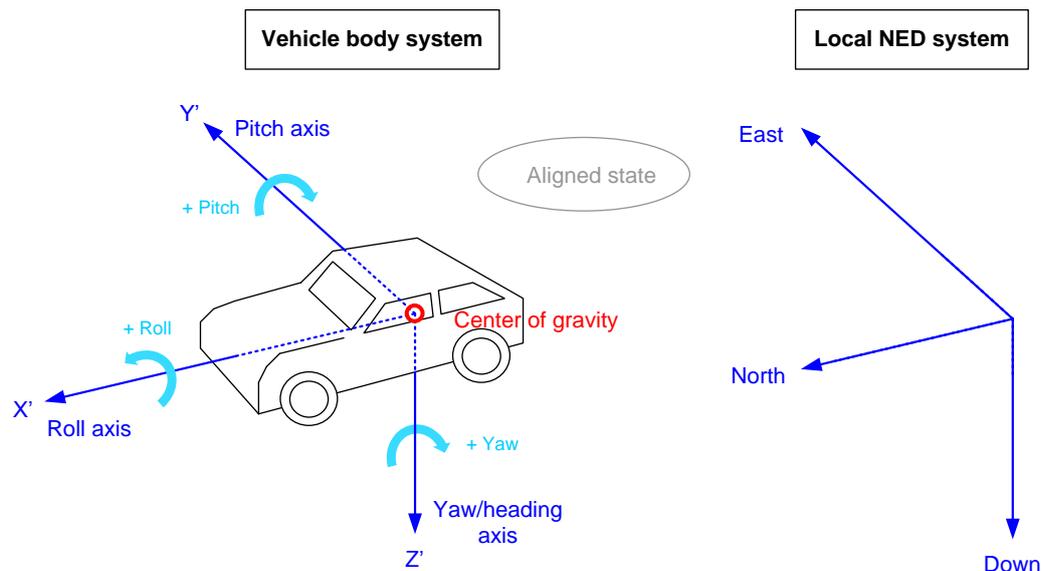
HIL remote control command syntax		
Mode A		
Parameter	**Description**	**Unit**
Elapsed time	Time elapsed since the start of the simulation	s
X, Y, Z	Position coordinates in the earth centered, earth fixed (ECEF) system	m
XDot, YDot, ZDot	(i.e. v_X, v_Y, v_Z) Velocity vector in the ECEF system	m/s
XDotDot, YDotDot, ZDotDot	(i.e. a_X, a_Y, a_Z) Acceleration vector in the ECEF system	m/s^2
XDotDotDot, YDotDotDot, ZDotDotDot	(i.e. j_X, j_Y, j_Z) Jerk vector in the ECEF system	m/s^3
Yaw, Pitch, Roll	(i.e. Heading, Elevation, Bank) Attitude angels (Not limited to 2·π to signal more than one cycle rotation between two updates)	rad
YawDot, PitchDot, RollDot	Attitude angular velocity (i.e. rate of change of attitude angle)	rad/s
YawDotDot, PitchDotDot, RollDotDot	Attitude angular acceleration (i.e. rate of change of angular velocity)	rad/s^2
YawDotDotDot, PitchDotDotDot, RollDotDotDot	Attitude angular jerk (i.e. rate of change of angular acceleration)	rad/s^3

The "Elapsed time" is the time that has elapsed since the start of the simulation. It can be queried using the command: `SOUR:BB:GPS:RT:HWT?`

The kinetic parameters (velocity, acceleration, jerk) are mandatory. They are used for trajectory prediction as explained in detail in sections 5.1 and 6. Usually, HIL simulators calculate these parameters per default.

The attitude parameters are optional. The total number of required parameters is either 13 (if no attitude information is given) or 25 (if attitude information is given).

The attitude angles (and their time derivatives) are obtained by rotating the vehicle body system (X' Y' Z') starting from an aligned state with the local NED system by a sequence of three consecutive Euler rotations around the Z' axis, the Y' axis and finally the X' axis.

Command syntax mode B:

```
SOUR:BB:GPS:RT:HILP:MODE:B <ElapsedTime>, <Latitude>,
<Longitude>, <Altitude>, <NDot>, <EDot>, <DDot>, <NDotDot>,
<EDotDot>, <DDotDot>, <NDotDotDot>, <EDotDotDot>, <DDotDotDot>,
[<Yaw>, <Pitch>, <Roll>, <YawDot>, <PitchDot>, <RollDot>,
<YawDotDot>, <PitchDotDot>, <RollDotDot>, <YawDotDotDot>,
<PitchDotDotDot>, <RollDotDotDot>]
```

HIL remote control command syntax		
Mode B		
Parameter	**Description**	**Unit**
Elapsed time	Time elapsed since the start of the simulation	s
Latitude, Longitude, Altitude	Position coordinates in the WGS 84 system	° and m
NDot, EDot, DDot	(i.e. v_N, v_E, v_D) Velocity vector in the north east down (NED) coordinate system	m/s
NDotDot, EDotDot, DDotDot	(i.e. a_N, a_E, a_D) Acceleration vector in the NED system	m/s^2
NDotDotDot, EDotDotDot, DDotDotDot	(i.e. j_N, j_E, j_D) Jerk vector in the NED system	m/s^3
Yaw, Pitch, Roll	(i.e. Heading, Elevation, Bank) Attitude angels (Not limited to 2·π to signal more than one cycle rotation between two updates)	rad
YawDot, PitchDot, RollDot	Attitude angular velocity (i.e. rate of change of attitude angle)	rad/s
YawDotDot, PitchDotDot, RollDotDot	Attitude angular acceleration (i.e. rate of change of angular velocity)	rad/s^2
YawDotDotDot, PitchDotDotDot, RollDotDotDot	Attitude angular jerk (i.e. rate of change of angular acceleration)	rad/s^3

The attitude parameters are optional. The total number of required parameters is either 13 (if no attitude information is given) or 25 (if attitude information is given).

4.3 Real-Time S.P.O.T. Display and Real-Time Commands

Please note that the SMBV's S.P.O.T. display (see [1] for details) is not updated during HIL operation. The map view for example does not show the simulated receiver trajectory and the associated SCPI command `SOUR:BB:GPS:RT:RLOC:COOR:DEC?` `<parameters>` does not report it. This fact should not confuse the user – the SMBV simulates nevertheless the trajectory as commanded by the HIL simulator.

Generally, all SCPI commands starting with `SOUR:BB:GPS:RT:` – the so-called "realtime" (RT) SCPI commands – should not be used during HIL operation to not overstress the internal signal processor.

Similarly, realtime changes of the satellites' power, state (active or not) and pseudorange bias are not supported during HIL operation.

5 Synchronization & Timing

The first parameter in the HIL remote control command is the elapsed time. This parameter determines the time point at which the specified position coordinates are in effect. In other words, the specified position coordinates are output at this time point.

The elapsed time T is a relative value and refers to the starting time of the simulation. It can be queried using the command: `SOUR:BB:GPS:RT:HWT?`
(The command `SOUR:BB:GPS:NAV:SIM:TIME?` returns the starting time of the simulation.)

Ideally, the elapsed time in the HIL command (T_{SCPI}) should be synchronized to the current elapsed time in the SMBV (T_{SMBV}). However, the SMBV can also handle T_{SCPI} values that are less or greater than T_{SMBV} by applying a dedicated prediction algorithm in both cases.

> T_{SCPI} is the elapsed time in the sent HIL command.
> T_{SMBV} is the current elapsed time at the SMBV.

5.1 Command Processing

At first, it is helpful to understand how the SMBV processes the received HIL commands. Internally the SMBV uses a 100PPS signal (100 pulses per second = 100 Hz) that gives a time resolution of 10 ms. Every hundredth pulse is synchronous with a GPS second. This signal is not externally available. However synchronous 10PPS and 1PPS signals are available at the marker outputs of the SMBV.

5.1.1 Ideal case: T_{SCPI} synchronized to T_{SMBV}

How to synchronize T_{SCPI} and T_{SMBV} is explained later on in section 5.3.
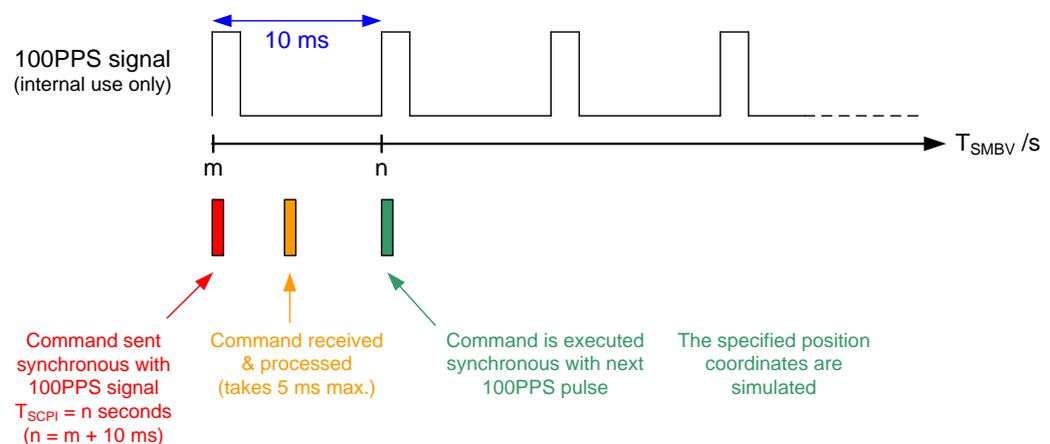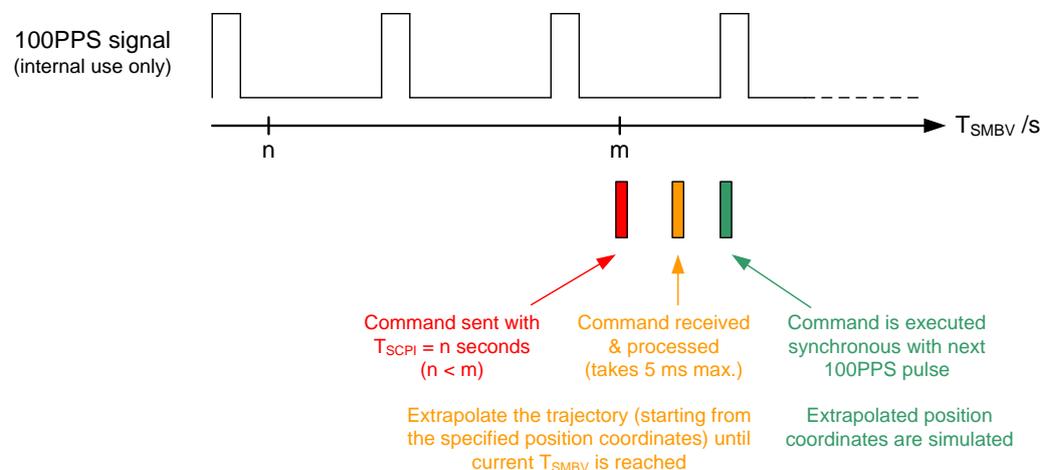
Assuming a HIL command is sent out synchronous to the SMBV's internal 100PPS signal at a time point that corresponds to T_{SMBV} = m seconds. This command includes a T_{SCPI} of n seconds where n is m + 10 ms. The HIL command is received and evaluated by the SMBV. This takes maximally 5 ms. The execution of a HIL command is always synchronous with the internal 100PPS signal. This means, the specified position coordinates are simulated at the next upcoming 100PPS pulse.

It is not necessary to send the HIL command perfectly synchronous to the SMBV's internal 100PPS signal. A small synchronization uncertainty α is allowable. Assuming the HIL command is sent out at a time point that corresponds to T_{SMBV} = m + α seconds. This command includes a T_{SCPI} of n seconds where n is m + 10 ms. Receiving and evaluating the command takes some time – maximally 5 ms. Therefore, α must not be more than 10 ms – 5 ms = 5 ms.
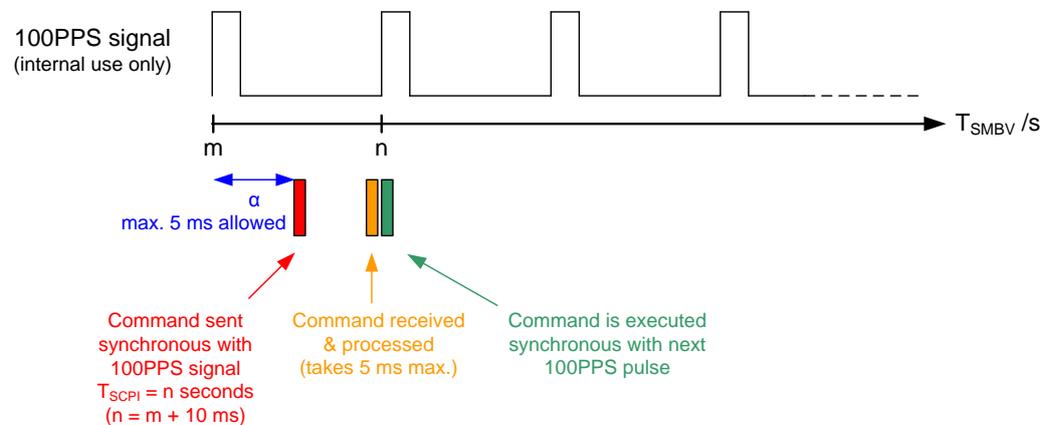

5.1.2 T_{SCPI} less than T_{SMBV}

In this case, T_{SCPI} is already in the past with respect to T_{SMBV}. The specified position coordinates are already outdated.

Assuming a HIL command is sent out at a time point that corresponds to T_{SMBV} = m seconds. This command includes a T_{SCPI} of n seconds where n is less than m. The HIL command is received and evaluated by the SMBV. This takes maximally 5 ms. Since the specified elapsed time T_{SCPI} is already in the past, the SMBV extrapolates the trajectory – starting from the specified position coordinates – using a dedicated prediction algorithm (see section 6 for details). The command is executed synchronous with the next upcoming pulse of the internal 100PPS signal. At this pulse, the extrapolated position coordinates are simulated. (The position will be extrapolated further at each subsequent 100PPS pulse until a new HIL command is received.)

### 5.1.3 T_{SCPI} greater than T_{SMBV}

In this case, T_{SCPI} is still in the future with respect to T_{SMBV}. The specified position coordinates are still to come and not yet valid.
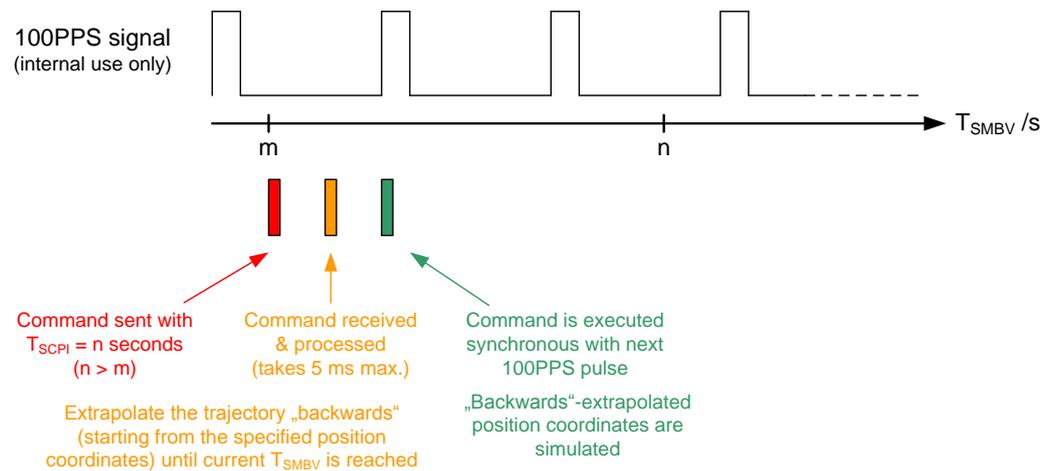
Assuming a HIL command is sent out at a time point that corresponds to T_{SMBV} = m seconds. This command includes a T_{SCPI} of n seconds where n is greater than m. The HIL command is received and evaluated by the SMBV. This takes maximally 5 ms. Since the specified elapsed time T_{SCPI} is still in the future, the SMBV extrapolates the trajectory "backwards" – starting from the specified position coordinates – using a dedicated prediction algorithm (see section 6 for details). The command is executed synchronous with the next upcoming pulse of the internal 100PPS signal. At this pulse, the "backwards"-extrapolated position coordinates are simulated. (The position will be "backwards"-extrapolated further at each subsequent 100PPS pulse until a new HIL command is received.)

5.2 Latency

The term "latency" describes how fast the SMBV can react to an incoming HIL command – from receiving to executing.
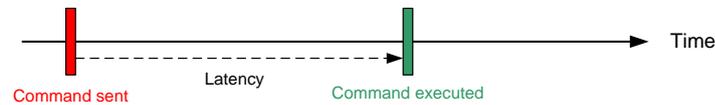
First, when talking about latency it makes sense to distinguish between
- Processing latency
- Update latency

The processing latency describes how fast the SMBV can process an incoming HIL command – from receiving to being prepared for execution. The SMBV's processing latency is less than 5 ms, approximately. (This value already includes the time needed to transmit the HIL command via LAN/GPIB/USB, which is generally less than 1 ms [4].)
The update latency describes how fast the SMBV can update the simulated position coordinates according to the input from the HIL simulator. The SMBV's update latency is 10 ms at minimum. To achieve this minimum value timing synchronization is necessary (see section 5.3).

In general, long latency is not an issue with the SMBV. After approximately 15 ms at the latest (worst unsynchronized case) the SMBV simulates proper position coordinates thanks to its prediction algorithm.

5.3 Synchronization Mechanism

Many HIL simulators require an update latency as short as possible. The internal 100PPS signal determines the minimal update latency of the SMBV: 10 ms. This means position coordinates (waypoints) can be commanded by the HIL simulator at a rate of 100 Hz maximum, i.e. one waypoint per 10 ms cycle. This value can be achieved if the HIL simulator is synchronized to the SMBV. For this purpose the SMBV provides a 10PPS or 1PPS signal at its marker output. The HIL simulator can synchronize to this signal such that both units step the seconds synchronously.
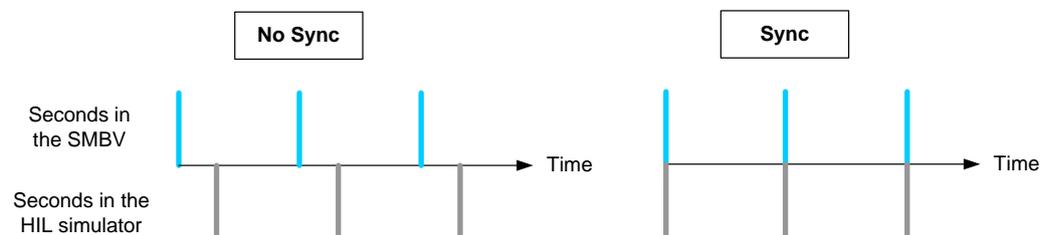
To achieve an update rate of 10 ms, the HIL simulator sends the commands synchronous with the 10PPS signal – each 10 ms a new HIL command. The SMBV needs some time to process the received HIL command – less than 5 ms. Sending the command synchronous to the internal 100PPS signal (with an allowable delay of maximally 5 ms) gives the SMBV enough time to receive and process the command. Execution takes place at the subsequent 100PPS pulse. At this pulse, the HIL simulator also issues the next command.
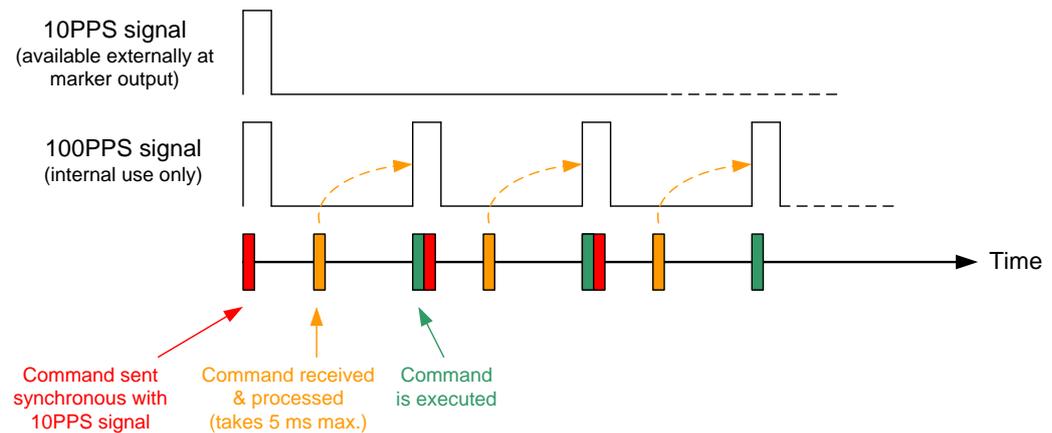
Ideally, T_{SCPI} and T_{SMBV} should be synchronized if possible, i.e. the HIL command sent at time point $T_{SMBV} = m + \alpha$ seconds should contain $T_{SCPI} = m + 10$ ms. For example, if $m = 12.450$ s and $\alpha = 1$ ms such that $T_{SMBV} = 12.451$ s, then the simultaneous HIL command should contain $T_{SCPI} = 12.460$ s. In this case, no trajectory prediction takes place and the specified position coordinates are simulated at the next 100PPS pulse. Please note that absolute synchronization may not be reached. A small delay (α) is acceptable. However, α should be less than 5 ms.
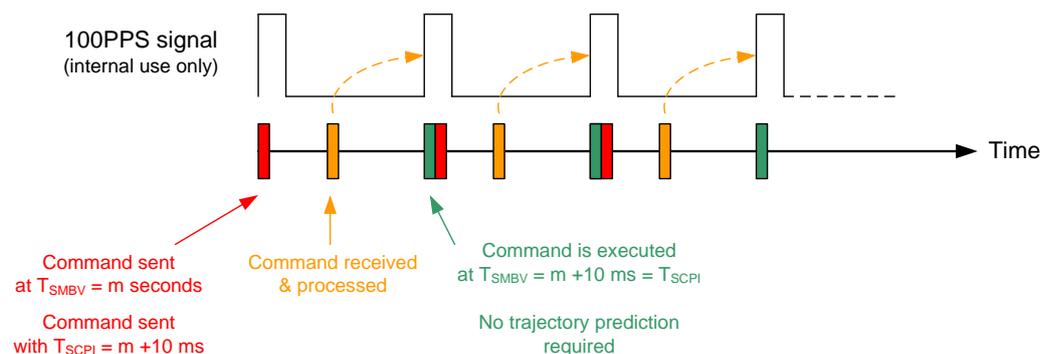
Please note also that it is not mandatory to perfectly synchronize T_{SCPI} and T_{SMBV}. If they are not synchronized, the SMBV performs a trajectory prediction as explained in section 5.1 and extrapolated position coordinates are simulated. This works generally excellent. However, if the difference between T_{SCPI} and T_{SMBV} is very large this can lead to problems in the prediction. For this reason, T_{SCPI} and T_{SMBV} should at least be aligned closely to keep their time difference small.

How to synchronize TSCPI and TSMBV?

The user can query the SMBV for its current T_{SMBV} using the command
`SOUR:BB:GPS:RT:HWT?`
The SMBV will report its T_{SMBV} in seconds with a resolution of 10 ms. Please note that the communication itself (i.e. sending the query and receiving the answer) via the LAN/GPIB/USB connection takes some time as well – generally less than one millisecond [4]. To synchronize T_{SCPI} and T_{SMBV} one single query at the beginning is enough. In fact, it is not recommended to query T_{SMBV} before each HIL command. For example, if the commands are sent at a rate of 100 Hz, T_{SCPI} can be simply increased by 10 ms each time.

In addition, the user can query the SMBV for the current time difference (ΔT) between T_{SCPI} and T_{SMBV} using the command `SOUR:BB:GPS:RT:HILP:LAT?`
This command[1] returns $\Delta T = T_{SMBV} - T_{SCPI}$ in seconds with a resolution of 1 ms. (T_{SMBV} is the current elapsed time at the SMBV at the time point of query and T_{SCPI} is the elapsed time sent in the last received HIL command.) Again, a single query is generally enough. The command can be used to cross-check the synchronization between T_{SCPI} and T_{SMBV}. If needed, T_{SCPI} can be adjusted in the HIL commands. For example, if the SMBV's response is +22 ms, T_{SCPI} can be increased by 22 ms such that the time offset is removed. Ideally, ΔT should be in the range of -10 ms to 0 ms.

Both commands should be used for initial synchronization at the beginning of the test. During the test, the second command may be used to cross-check the synchronization but it is recommended to send it not more than twice per second.

5.4 Do's and Don'ts

Don'ts

- Don't query the SMBV for T_{SMBV} before each HIL command. One query at the beginning is sufficient to synchronize T_{SCPI} and T_{SMBV}.

- Don't send multiple HIL commands within a single 10 ms cycle. The SMBV can only handle and execute one command per 10 ms.

- Don't send multiple HIL commands with different T_{SCPI} values all greater than the current T_{SMBV} ahead (trying to "build up a stack"). The SMBV has no buffer storage for HIL commands. It will consider only the command received last.

Do's

- Send the HIL commands synchronous to the 100PPS signal pulses. (Use the 10PPS marker signal for synchronization.)

- Keep the time difference between T_{SCPI} and T_{SMBV} small, if possible, to minimize the time span and distance/trajectory to predict. In other words, send a HIL command (containing a certain T_{SCPI}) always shortly before or after the equivalent T_{SMBV}. Ideally, the command is sent 10 ms before.

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[1] This command is supported by firmware versions 3.01.130.21 and later.

This gets important when the movement has high perturbations, e.g. high acceleration and jerk as this will lead to inaccurate trajectory prediction.

5.5 Triggering the Simulation Start

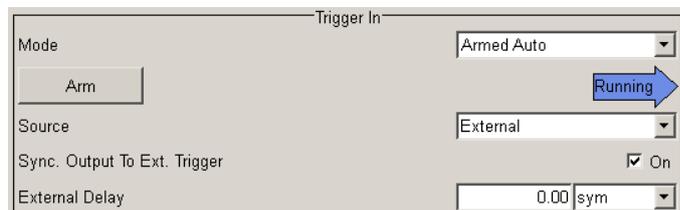Per default, the trigger mode in the SMBV is "Auto".


```
SOUR:BB:GPS:TRIG:SEQ AUTO
```

In this case, the satellite simulation is started as soon as the GNSS standard is turned on.


```
SOUR:BB:GPS:STAT ON
```

In principle, it is not necessary to change the trigger mode, however it is possible. Instead of "Auto", the trigger modes "Armed Auto" or "Armed Retrigger" can be used for example in combination with an external trigger signal. The trigger signal, e.g. coming from the HIL simulator, is fed in via the TRIG connector of the SMBV.


```
SOUR:BB:GPS:TRIG:SEQ AAUTO
SOUR:BB:GPS:TRIG:SOUR EXT
```

In this case, the satellite simulation is not started immediately as soon as the GNSS standard is turned on, but the SMBV waits for the external trigger. The first trigger event will start the simulation.

6 Trajectory Prediction

This section describes some background information about trajectory prediction for the interested user. Since knowledge of the presented details is not strictly relevant for operating the SMBV in a HIL setup, this section may be skipped by the reader.

The SMBV applies trajectory prediction in the following cases:

- If T_{SCPI} is less than T_{SMBV}: The specified position coordinates are already outdated; the current position coordinates need to be determined by prediction.
- If T_{SCPI} is greater than T_{SMBV}: The specified position coordinates are still to come and not yet valid; the current position coordinates need to be determined by "backwards"-prediction.
- If the SMBV does not receive a new HIL remote command every 10 ms: After having received a HIL command, the SMBV executes this command at the next 100PPS pulse. At the subsequent 100PPS pulse, the position coordinates are automatically updated again using prediction/"backwards"-prediction. The SMBV always uses the position coordinates specified in the last received HIL command for trajectory prediction.

To determine the current position coordinates the SMBV uses the following prediction algorithm. The kinetic parameters which correspond to the specified waypoint, i.e. velocity (v), acceleration (a), and jerk (j) vectors are used to predict the next waypoints of the trajectory according to the following formula:

$$x = x_0 + v\,\Delta t + \frac{a}{2}\Delta t^2 + \frac{j}{6}\Delta t^3 \qquad (1)$$

where x is the predicted waypoint, x_0 is the specified waypoint, and Δt is the difference between T_{SMBV} and T_{SCPI}.
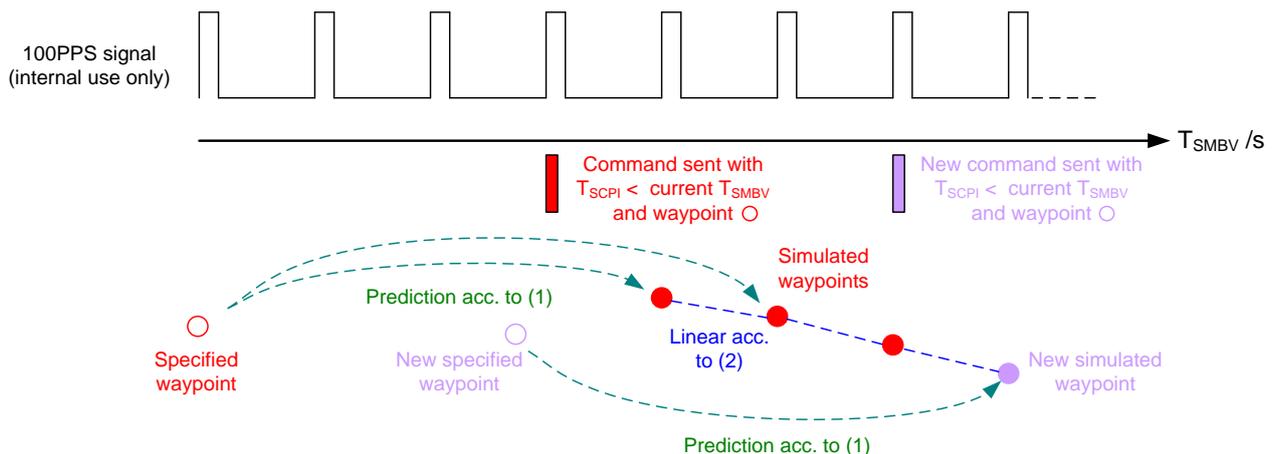
Every 10 ms, the SMBV extrapolates the position coordinates according to the same third order polynomial (i.e. formula (1)) until it receives a new HIL command with new position coordinates.

The predicted waypoints have a rate of 100 Hz. However, the SMBV updates the simulated GNSS signal at a much higher rate. In between the predicted waypoints, the simulated position coordinates are extrapolated linearly according to the following formula:

$$x = x_0 + v\,\Delta t \qquad\qquad (2)$$

where x is the next waypoint, x_0 is the current waypoint, v is the velocity at the current waypoint, and Δt is a small time interval in the nanoseconds scale.

The same prediction concept is also applied for predicting the attitude angles (yaw, pitch, and roll) using their time derivatives. The difference is that the linear extrapolation is at a rate of 800 Hz.

Summary:

Position:
The SMBV performs a third order extrapolation at 100 Hz and a linear (first order) extrapolation in between at 60 x 1.023 MHz.

Attitude:
The SMBV performs a third order extrapolation at 100 Hz and a linear (first order) extrapolation in between at 800 Hz.

7 Summary

The SMBV is a versatile general-purpose vector signal generator with outstanding RF performance. In addition, it is a powerful GNSS simulator capable of generating up to 24 satellites for testing GPS, Galileo, Glonass and Beidou receivers easily, flexibly, reliably, and cost-efficiently.

The SMBV is remote-controllable in realtime and can therefore be used for HIL testing. The HIL simulator can dictate position coordinates, kinetic parameters, and vehicle attitude information based upon the SMBV updates the simulated receiver movement in realtime. The input data is provided in form of SCPI commands. An update rate of up to 100 Hz is supported.

Update rate overview	
Streaming rate of HIL commands	Variable up to 100 Hz
Update rate of Doppler shift, propagation delay, and carrier phase	100 Hz
Update rate of position (waypoints)	100 Hz with linear update in between at 60 x 1.023 MHz
Update rate of signal power	800 Hz relevant for attitude simulation

The SMBV is ideal for HIL applications due to its low latency and its high command streaming rate. Its built-in trajectory prediction feature minimizes or even avoids latency issues in the HIL system.

This application note explained in detail how to synchronize the SMBV and the HIL simulator and it provided background information on how the instrument processes the HIL commands.

8 Abbreviations

1PPS	One pulse per second
10PPS	Ten pulses per second
100PPS	Hundred pulses per second
DUT	Device under test
ECEF	Earth centered, earth fixed
ECU	Electronic control unit
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)
GPIB	General purpose interface bus
HIL	Hardware in the loop
LAN	Local area network
NED	North east down
RF	Radio frequency
USB	Universal serial bus
SCPI	Standard commands for programmable instruments
T	Elapsed time since simulation start
WGS	World geodetic system

9 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 Application Note, "Fast Remote Instrument Control with HiSLIP" (1MA208)

10 Ordering Information

Please visit the R&S®SMBV100A product website for comprehensive ordering information ("Options") at 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.

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