



**Qosmotec**  
**Software Solutions GmbH**

**Technical Overview**

**QPER C2X -**  
**Car-to-X Signal Strength Emulator and HiL Test Bench**



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## **0 Document Control**

### **0.1 Imprint**

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### **0.2 Document Description**

This document gives an overview about the Qosmotec Propagation Effects Replicator QPER for Car-to-X testing. It is intended to give potential customers a first technical insight into the architecture and the product's capabilities.

## Car-to-X Signal Strength Emulator and HiL Test Bench

# 1 System Description

## 1.1 General Concept

Car-to-X communication is based on the IEEE 802.11p WLAN standard, where radio devices inside vehicles and traffic infrastructure components communicate with each other on the frequency range between 5.850 and 5.925 MHz. On these dedicated short range communication (DSRC) channels, which have a coverage of up to 1.000 meter, signal propagation effects that occur on every radio communication link, have an extremely heavy impact on connectivity and radio link quality. This explains, why the communication between vehicles shall not be verified only on the roads, but must be replicated in a reproducible way in the test lab.



Figure 1: Car-to-X communication environment

*Simulation* of a radio environment means to model the radio transmission and representing its main signal propagation characteristics under dynamic and permanently varying conditions for transmitter and receiver. While a radio channel simulation might end with theoretical investigations or computed results, *emulation* of a radio environment means to imitate the communication channels on a technical system that is able to reproduce the characteristics in a controllable environment.

The Qosmotec Propagation Effects Replicator QPER emulates the signal strength conditions between vehicles in the lab by keeping the transmitting ITS stations in a shielded environment and leading the transmitted radio signals through coaxial cables and a fully meshed setup of attenuators that is controlled according to a modeled traffic scenario and its calculated impact on the radio channel between the vehicles – especially on the path loss on the radio link.

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The emulation with QPER is used to verify the reliability of the Car-to-X communication entity in cars or in traffic infrastructure components and its interoperability with other vendors and installations under controlled RF conditions on a test bench. To achieve this, realistic traffic conditions form the basis for the

- Emulation of path loss on a high number of radio links
- Emulation of the all signal propagation and fading conditions on selected radio channels
- Monitoring and analysis of OBUs' and RSUs' behavior in a controlled and reproducible environment

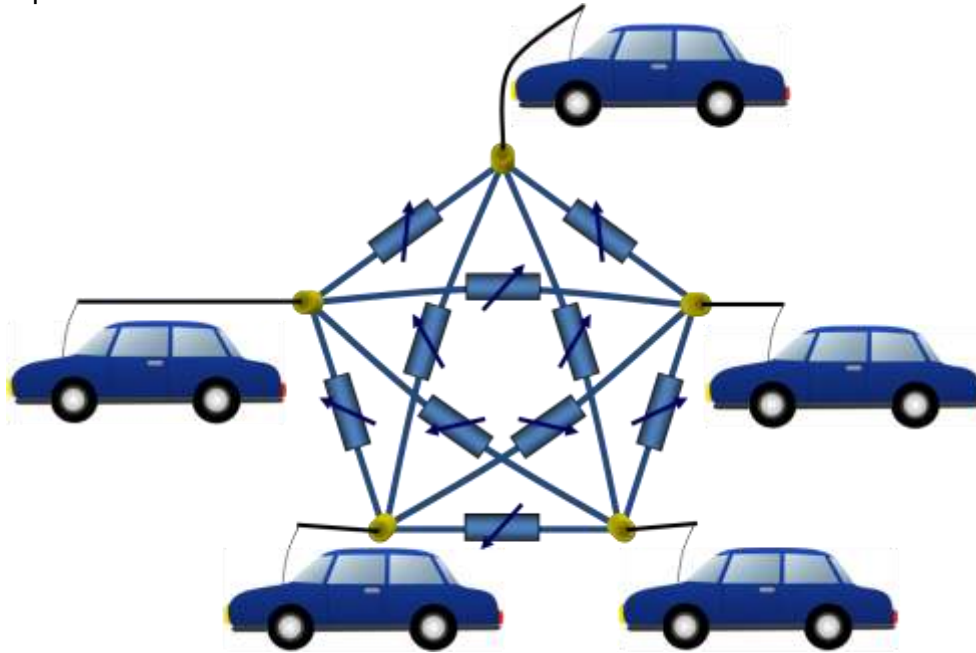


Figure 2: Fully meshed attenuator setup of the QPER signal strength emulator

### 1.2 Application Cases

The emulation of signal strength between radio devices is used for the following purposes:

- Reproducing complex RF scenarios between various communication devices accurately on a test bench
- Benchmarking of IEEE 802.11p capable ITS stations and communication modules between various vendors
- Interoperability tests between different vendor ITS stations and communication modules
- Regression tests after software updates on ITS stations
- Testing the dynamic behavior of a system (e.g. achieving higher coverage by message re-broadcasting)

In most of these cases it is not sufficient to examine a single radio link. The emulation system must be capable to involve a higher number of interconnected communication units, and their radio links must be controlled automatically based on modeling the end-to-end applications in order to remain manageable for the tester.

The Car-to-Car Consortium has specified several Day-1 applications that are expected to provide assistance to the driver in critical road situations. These kind of situations can easily

### Car-to-X Signal Strength Emulator and HiL Test Bench

be created with the QPER software as very simple tests or in complicated traffic situations involving many vehicles, allowing the tester to verify the interoperability between ITS stations under varying circumstances.

Furthermore, the compatibility of the IEEE 802.11p standard with other WLAN standards – especially those operating in the 5 GHz range - can easily be tested, since the system allows to connect interferers from other standards. This is especially important to test the impact of potential overlaps with other WLAN standards with the one currently reserved for Car-to-X communication (e.g. the planned extension of 802.11n up to 5.9 GHz).

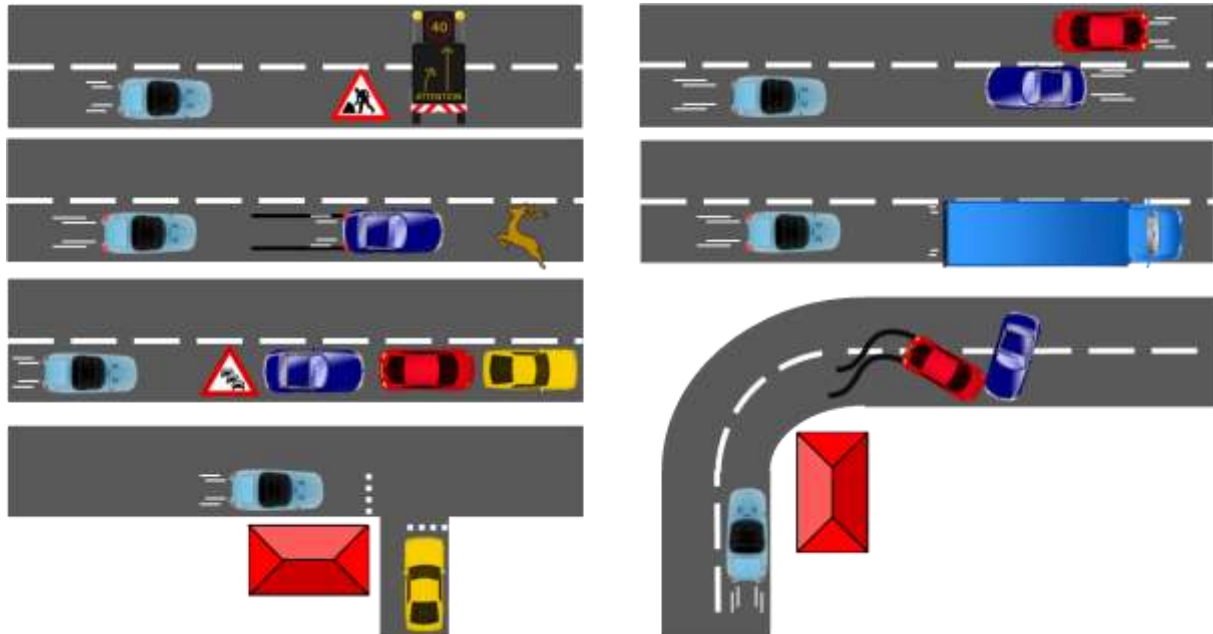


Figure 3: Day-1 applications for the Car-to-X communication technology

- |                                   |                                   |
|-----------------------------------|-----------------------------------|
| a) Road work warning              | e) Vehicle approaching            |
| b) Emergency brake warning        | f) Slow vehicle warning           |
| c) Traffic jam warning            | g) Road hazard / obstacle warning |
| d) Intersection collision warning |                                   |

### 1.3 Hardware

The QPER signal strength emulation hardware is available in 5 system sizes with 5, 7, 9, 13 and 17 input ports (N(f) type connector). Internally, it interconnects all ports with each other by digitally controllable step attenuators with a dynamic range from 0 to 95.5 dB a step width of 0.5 dB. This allows to adjust the signal strength conditions between every pair of connected radio devices individually on a bidirectional radio link. In total,  $n*(n-1)/2$  bidirectional radio links are emulated inside the system, where  $n$  denotes the number of hardware ports (for example 10 links in a system with 5 ports). With a frequency and system-size dependant insertion loss between 20 and 35 dB, the system guarantees the best measurable signal reception level at 0 dB as well as a fully interrupted signal link at 95.5 dB attenuator setting with precisely adjustable signal strength settings within the in the communication and sensitivity ranges of the radio devices.

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Figure 4: The QPER hardware with five ports and 10 attenuator controlled radio links

One of the main characteristics is the fast and fully parallel attenuator control with more than 4000 switching cycles per second. A real time operating system guarantees switching all attenuators exactly at the same time with equidistant switching cycles. This allows to simulate the effects of fast fading on signal strength for speeds of up to 300 km/h.

The hardware supports a broadband frequency range from 500 MHz to 6 GHz so that besides to IEEE 802.11p communication also 2.4 and 5 MHz WLAN as well as handsets and UEs from all kind of public wireless telecommunication technology can be connected.

The radio modules are individually kept in shielding boxes, which are connected via coaxial cables to the input ports of the signal strength emulator. This setup ensures that communication between radio devices is only directed via the attenuator controlled links and no communication link is setup over the air. The shielding boxes protect the radio modules from outside RF reception and interferences with more than 60 dB and provide interfaces for 1 Gbit/s Ethernet, USB 2.0 and AC/DC Power from 5 to 230 Volt. 4 internal connectors of type SMA (f) are available to provide RF signals so that several antennas of a radio module inside (e.g. 5.9 MHz, 2.4 MHz, GPS) can be supplied with RF signals individually.



Figure 5: Shielding Box with a interior size of 30 x 30 x 17,5 cm

## Car-to-X Signal Strength Emulator and HiL Test Bench

### 2 Software Control

There are currently three ways to control the signal strength emulator QPER via software.

1. The virtual drive test approach – a way to create traffic situations on an easy to use graphical user interface.
2. The control via a programming interface – this allows integrating QPER into any custom test automation environment or in other traffic simulation environments (e.g. into the traffic simulation suite SUMo)
3. The integration of QPER into the test automation software CANoe from Vector Informatik. This combination provides for a full Hardware-in-the-Loop test setup for Car-to-X testing.

A fourth approach to control the QPER system based on a ray tracing approach that emulates signal strength based on a multipath prediction for a specific urban area is currently under development.

#### 2.1 QPER virtual drive test software

The QPER virtual drive test approach is a graphical and intuitive way to enable the user to simply create traffic situations, to specify conditions affecting the radio transmission, and run the scenario from a high level perspective. During the traffic model execution, the QPER software permanently calculates the resulting radio propagation conditions for each individual radio link and sets the attenuators accordingly.

Radio devices are represented as cars, lorries or infrastructure devices (traffic lights, road signs, construction areas, etc.). They can be positioned per drag & drop in a geo-referenced map and moved along freely configurable routes with variable speeds. Depending on their position, the path loss between pairs of devices is calculated automatically by the QPER software and set on the corresponding attenuator on the signal strength emulation hardware.

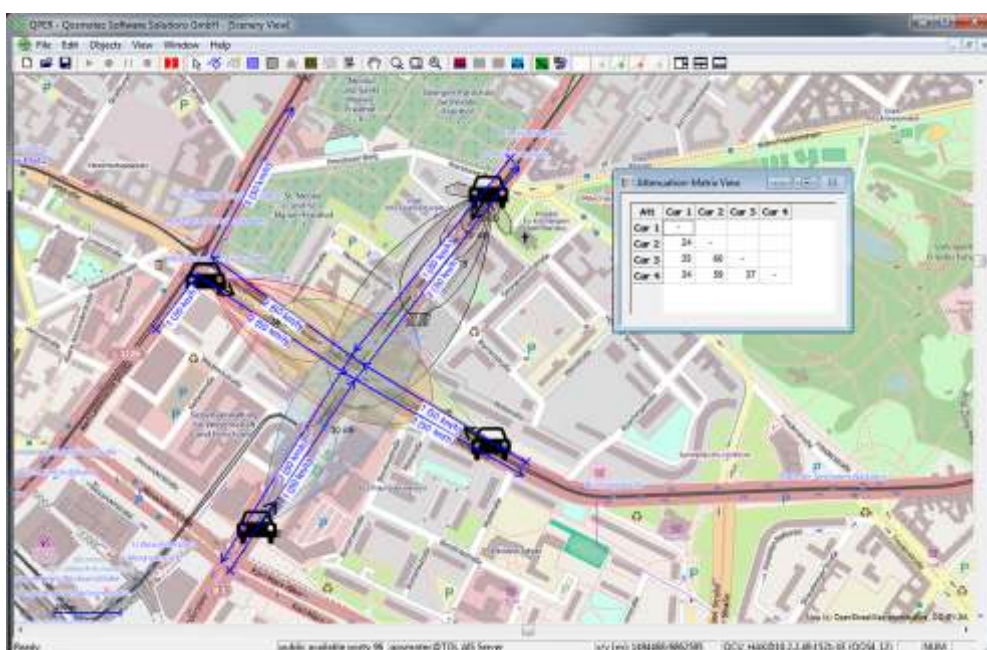


Figure 6: The QPER virtual drive test software



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The path loss calculation is based on

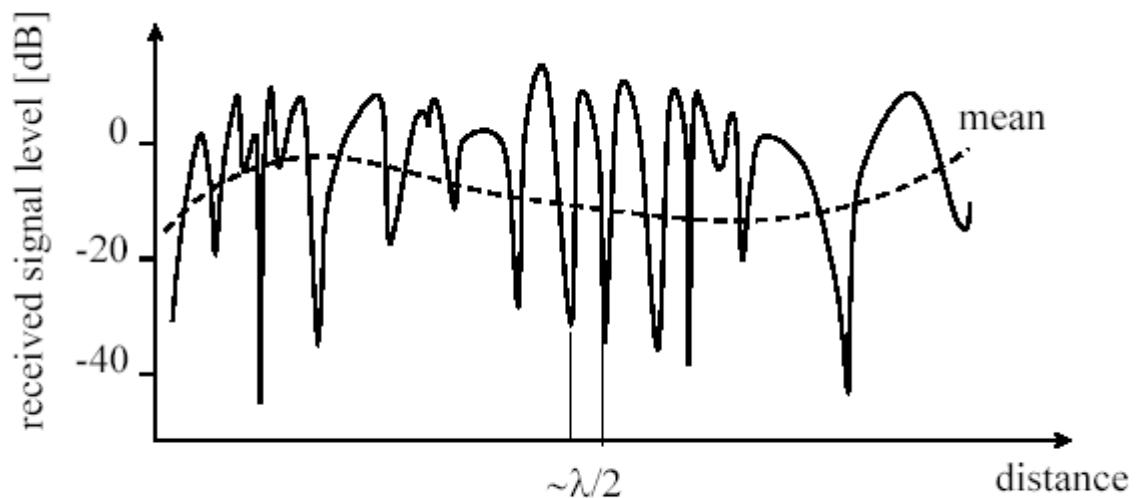
- The selected path loss model
- A selected fading model
- The influence of shadowing
- The antenna radiation pattern and its parametrization (elevation, azimuth, tilt)

All internal attenuation settings can be automatically transformed and displayed to the user in terms of received signal strength (RxLevel in dBm), taking into account the radio devices' output power, the system insertion loss and external cable loss.

Fast fading effects are simulated by adding a fading process to the results of the distance dependant path loss calculations. For each radio link, the fast fading profile is specified, i.e.

- Rayleigh fading for simulation of NLOS conditions between two devices
- Rician fading for simulation of LOS conditions. The K-factor parameter specifies the strength of the LOS path compared to the reflected paths

Figure 5 shows the heavy fluctuations on the received signal strength due to multipath reception.



Measured signal level as a function of the travelled distance

Figure 7: Fast fading process added to the path loss

Shadowing effects are realized by analyzing the obstacles between two radio devices. Each obstacle (a building or another moving vehicle like a lorry) is assigned a shadowing value, that is added to the calculated distance dependant path loss under line-of sight assumptions.

## Car-to-X Signal Strength Emulator and HiL Test Bench

### 2.2 API control

QPER offers the following possibilities for external control and integration into other programs and automation systems:

1. The execution of virtual drive test scenarios via an API
2. The execution of own traffic scenarios or path loss models via a UDP interface.

The programming interface is provided as a C++ library for Windows or Linux operating systems. It provides functions for

- Reading scenarios that have previously be created with the QPER virtual drive test GUI from the database
- starting, stopping and interrupting the mobility simulation in these scenarios
- retrieving execution updates (positions, attenuation settings)

Apart from the usage of the library, the user can take over control of the mobility as well as the path loss emulation by sending positions or attenuation settings via UDP to the QPER system. This user intervention is possible in combination with the GUI as well as with the library API. The UDP interface gives the user the possibility to take control over all parameters that would be normally calculated by the QPER software. Thus, this UDP interface allows to combine QPER with traffic modeling environments like SUMO (Simulation of Urban Mobility) or with ray tracing algorithms optimized for a certain application case, but also to replay data, that have been recorded during drive test measurements with real vehicles on the street.

### 2.3 HiL Test Automation

The setup for complete automation of Car-to-X tests on a hardware-in-the loop test bench combines the QPER field strength control system with the test automation software CANoe and its Car2X module. While QPER takes over the control of the radio channel between ITS stations, CANoe controls the ITS stations themselves via Ethernet, USB or CAN interface. This control of ITS stations comprises:

- Feeding them with the simulated positions from the scenery. These positions are necessary, because they are part of the CAM and DENM messages that are broadcasted to other ITS stations within the coverage area.
- Monitoring, which messages are broadcasted and received by each ITS stations at which time and on which position.

Thus, the combination of the two applications QPER and CANoe allows a full end-to-end test under realistic radio conditions in the test lab.

In the HiL setup, CANoe software takes over the control of mobility scenarios that have been previously designed with QPER. It provides direct access to the database, from where scenarios can be loaded. For the mobility control, Qosmotec has designed an dedicated mode within CANoe, which does not belong to the standard feature set of the software. From there, the signal strength scenarios are executed and the involved ITS stations are permanently updated with their simulated positions via the USB interface. This ensures that the CAM and DENM messages broadcasted by the ITS stations contain the same position information as in the simulation.

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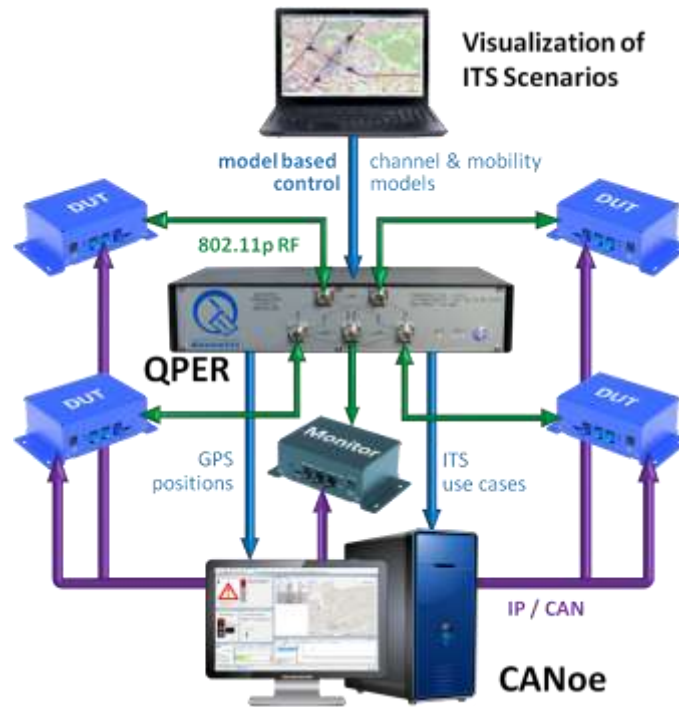


Figure 8: Schematic overview of a HiL setup consisting of Vector CANoe and QPER

Furthermore, the IP or USB interface to the ITS stations in the test setup is used to sent ITS specific messages, and to verify which messages have been received under the emulated radio conditions. This is particularly useful, if the devices under test are the radio modules, but not the complete OBU or RSU and their specific implementation of the ITS station for the installation in the car or the road site. For this purpose, Qosmotec has implemented typical application cases like

- Emergency Brake Warnings
- Slow Vehicle Warnings
- Obstacle Warnings
- Emergency Vehicle Warnings
- Road Work Warnings
- Traffic Light Information



Figure 3: A traffic situation causing an emergency brake emulated with CANoe and QPER



## **Car-to-X Signal Strength Emulator and HiL Test Bench**

Transmission and reception of application specific messages are displayed graphically in maps and application views. The CANoe Trace View additionally provides a detailed view with full expansion capabilities for each message.

If the test object is the whole ITS station including its OEM specific implementation, CANoe can be used to generate CAN messages, which are intended to provoke a specified message generated by the ITS station.

Even without an interface to the devices under test, the HiL test setup can be used to analyze the message flow in an mobile ad-hoc network. All broadcasted ITS messages can be monitored with a dedicated reference ITS station that is connected to a reserved port of the signal strength emulator. This monitoring station has minimum attenuation to all other radio devices. It is therefore guaranteed that the monitor receives all messages broadcasted in the emulation environment. All messages are displayed in the CANoe Trace Monitor.

## Car-to-X Signal Strength Emulator and HiL Test Bench

### 3 Technical Data

Frequency range:	300 – 6000 MHz
Impedance:	50 $\Omega$
Dynamic attenuation range:	0 – 95.5 dB
Attenuation steps:	0.5 dB
Attenuation accuracy:	$\pm 0.8$ dB or 2.5 % ref. to insertion loss
Number of switches:	> 4000 / sec, real time, up to 128 parallel settings (i.e. up to 512.000 HW settings per second)
Max. input power:	+ 23 dBm
System variants:	5, 7, 9, 13 and 17 ports fully meshed
Insertion loss (5 port system):	30 db @ 1 GHz, 38 dB @ 6 GHz
Port-to-Port Isolation @ 0dB:	> 75 dB @ 1 GHz, > 90 dB @ 6 GHz
RF-connectors:	N(f)
Operating system:	Windows XP, Vista or 7 for client application Windows XP, Vista, 7 or Linux System for API
Data storage:	Locally in file system for non-shared usage Centrally in database for multi-user application
Number of users:	unlimited parallel user access to the system
Software control options:	Graphical user interface API for C++ UDP messaging