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## **MOre Safety for All by Radar Interference Mitigation**

### **D2.7 - Validation check of simulation models with selected real world laboratory tests**

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## Revision chart and history log

Version	Date	Reason
0.1	2012-07-01	Initial version
0.x	multiples	Intermediate versions
0.9	2012-12-04	Version for peer review
0.95	2012-12-05	Update after peer review
1.0	2012-12-06	Final version for submission





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## 1. Executive summary and introduction

In this deliverable it is shown that the radar simulation tools, developed in work package WP2 and WP3 under the lead of the Karlsruhe Institute of technology (KIT), are suited to model automotive radar operation in the presence of interference by other radars.

In addition to the first verifications as presented in Deliverable 2.4 [D24], this Deliverable 2.7 also includes special wave propagation aspects (e.g. propagation effects in tunnel and parking garage and shielding of cars, see chapter 2) and measurements outside the anechoic chamber. The simulation tools are validated with well-known radar targets wherefore RCS models are available (chapter 3). After proofing that simulated signals are comparable to real world signals, the “interference is present” case is also conducted and checked against real world records.

Remark: The tunnel and parking garage results are considered as highly important w.r.t. the specific path loss measured in the respective test campaigns. Other organizations (i.e. ITU-R WP3a) already showed interest in these results.

## 2. Influence of environment and traffic participants on wave propagation behaviour

### 2.1. Wave propagation in a tunnel

During the measurement campaign in Utrecht in January 2012 there was an opportunity to measure wave propagation effects in a recently constructed tunnel, which was still closed for regular traffic. This test was done to check the validity of the wave propagation software. Details about the measurement and simulation setup can be found in [D25], the measurement was done for a single frequency at 24.125 GHz.

Fig.1 shows the results for:

- a) the measurement conducted with a spectrum analyzer in max. hold mode
- b) the free-space path loss compliant to a 10-log rule
- c) the free-space path loss compliant to a 20-log rule
- d) the mean pass loss from the wave propagation simulation

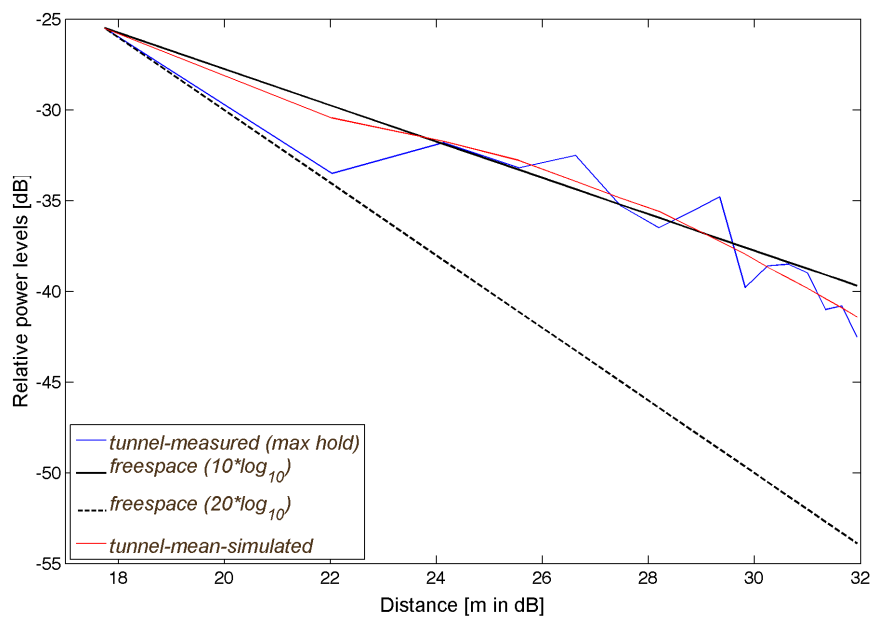


Fig. 2-1: Comparison of measured and simulated wave propagation in the tunnel

Tab.2-1 provides the original data in table-form as acquired and described in [D25].

Polarization / Distance [m]	VV [dBm]	VH [dBm]	HV [dBm]	HH [dBm]
59.4	-25.5	-46.2	-49.2	-25.2
159.4	-33.5	-45.8	-47	-32.7
259.4	-31.8	-42.2	-48.8	-30.5
359.4	-33.2	-48.2	-48.2	-35
459.4	-32.5	-51.5	-51.5	-33.7
559.4	-35.5	-55.5	-51.3	-35.3
659.4	-36.5	-55	-57.7	-36
759.4	-35.6	-56	-57.8	-37

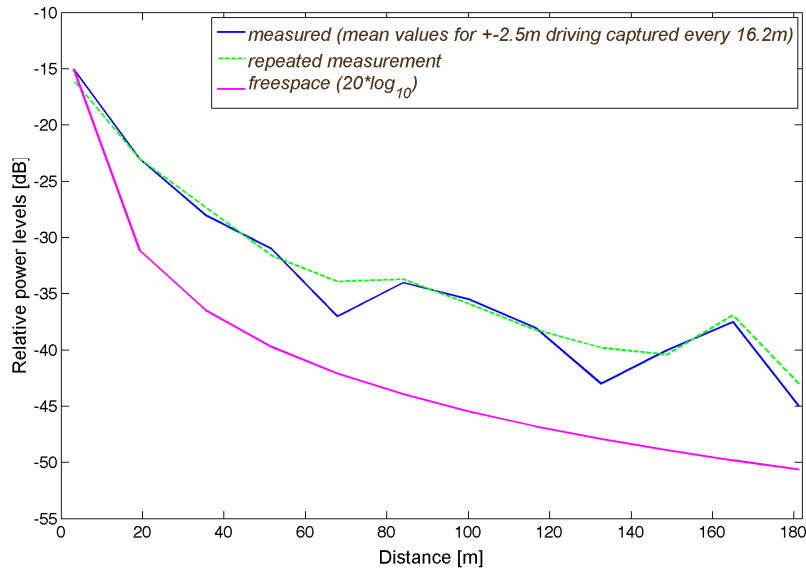
Polarization / Distance [m]	VV [dBm]	VH [dBm]	HV [dBm]	HH [dBm]
859.4	-34.8	-58	-54.3	-35
959.4	-39.8	-58.7	-56.5	-36.2
1059.4	-38.6	-59.3	-55.7	-38.8
1159.4	-38.5	-57.7	-60.7	-41.3
1259.4	-39	-61.5	-58.2	-44.3
1359.4	-41	-61	-59.8	-47.3
1459.4	-40.8	-63.5	-63.5	-44
1559.4	-42.5	-61.3	-62.2	-45.2

*Tab.2-1: Measured absolute power levels in dBm for 4 polarizations in a tunnel (antennas and amplification are included here, 24.125 GHz measurement frequency)*

## 2.2. Parking garage

A similar wave propagation attenuation was measured in a parking garage in Sindelfingen, Germany on October 13<sup>th</sup>, 2012. The received power levels in the parking garage are dropping slower compared to the free space case, but the focussing effect seems limited for distances up to 60m in the documented case. Tab.2-2 shows the original data which was acquired by capturing the maximum received power level with a spectrum analyzer  $\pm 2.5m$  around the given distances.

Here again absolute values in dBm are given. Interpretation of the results should be used consequently only relative to each other.



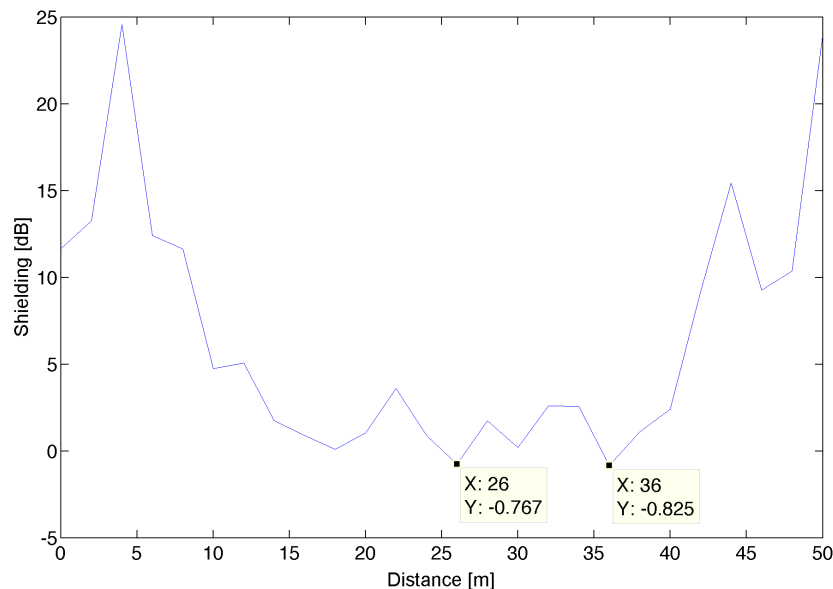
*Fig. 2-2: Measured wave propagation in the parking garage for VV-polarization*

Measurement number/ Distance [m]	Nr.1 [dBm]	Nr.2 [dBm]
3	-15	-16
19.2	-23	-23
35.4	-28	-28
51.6	-31	-31
67.8	-37	-37
84	-34	-34
100.2	-35.5	-35.5
116.4	-38	-38
132.6	-43	-43
148.8	-40	-40
165	-37.5	-37.5
181.2	-45	-45

*Tab.2-2: Measured absolute power levels in dBm for vertical polarization in a tunnel (antennas and amplification are included here, 24.125 GHz measurement frequency)*

### 2.3. Shielding of cars

In [D25] the effect of car shielding was demonstrated by ray-tracing simulations. In this document the former results and findings are checked and demonstrated again, i.e. that a *negative* shielding is possible when using the two-path propagation model (with constructive superposition!). See the measurements presented in Fig.2-3. Hereby a Volkswagen Sharan is driving from a transmitter to a receiver, over a distance of 50 m. A negative shielding can be achieved, probably caused by focusing effects under the car and the passenger cabin.



*Fig. 2-3: The shielding of cars has a minimum at the middle of the total distance*

### 3. Simulation of radar operation

In this section comparisons are presented of some measurement and simulation examples.

Because the simulation of useful signals is realized on the basis of scatterers with one interaction point allowed, the two-path propagation is not inherently included in the simulation. For simulation of interfering sources this limitation does not exist. The two-path propagation for the simulation of useful signals could be modelled separately or can be considered by updating the ray-tracing core software that is IP of the Karlsruhe Institute of Technology. During the MOSARIM project this major software update could not be realized.

More information about the radar, which was used for the presented measurements, can be found in [HARTER1],[HARTER2]. This radar has eight transmit and eight receive channels, where only the raw data from the single channels was used for comparison between measurement and simulation (no beamforming was applied).

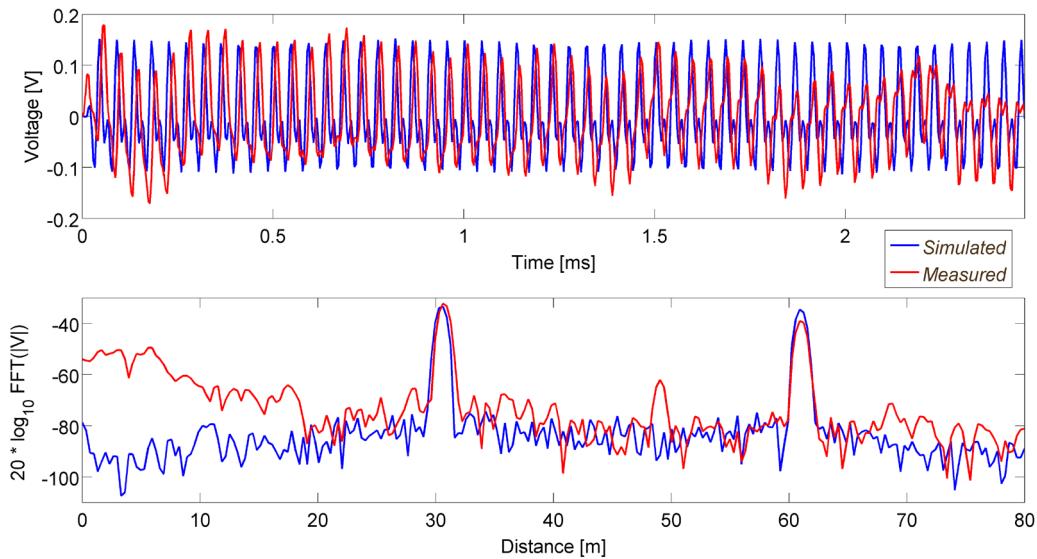
#### 3.1. Verification with perfectly known targets

A first setup consists of two corner reflectors (Figure 3-1). The distance between the radar and the first corner reflector with an RCS of 16.4 dBsm is about 30 m, the second corner reflector is placed at 60 m distance with an RCS of 32.1 dBsm. Figure 3-2 shows the simulation results in comparison to the measurements without consideration of antenna coupling or clutter effects in near vicinity. Figure 3-2 shows a simulation result, which considers the ground clutter from a few meters away by adding an empty room measurement of clutters.

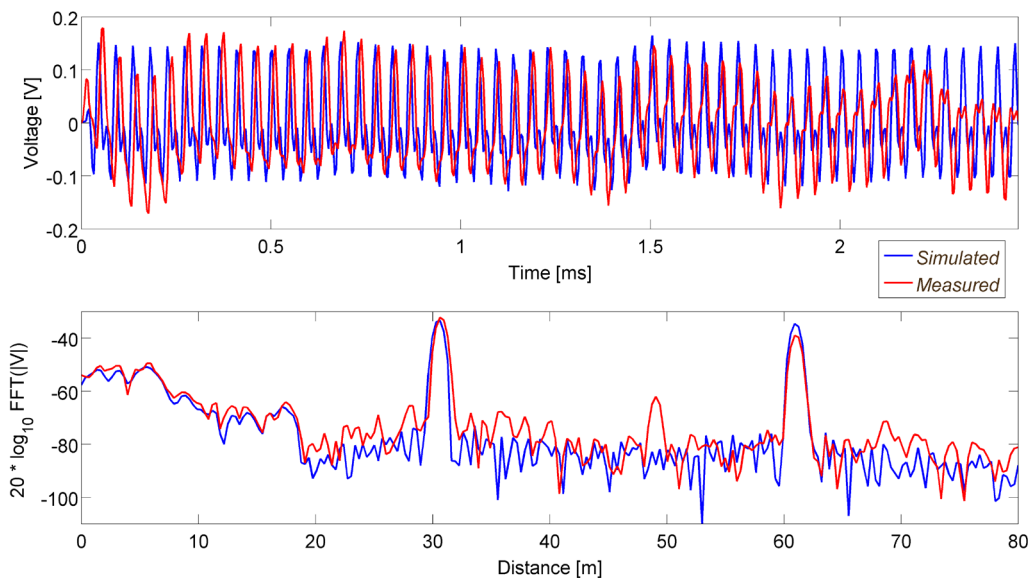


*Fig. 3-1: Two corner reflectors in a distance of 30 and 60m from the radar*





**Fig. 3-2:** In this upper picture the corner reflectors and the noise floor are well met. Because the useful signals are higher in amplitude, the clutter does not dominate the signal shape in time domain. Clutter is not modeled here.



**Fig. 3-3:** This figure is a hybrid of simulation and measurement. The clutter up to 20 m is taken out of the measurements by gating in frequency domain and added to the simulated time domain signal. The benefit is a more realistic “slow fading” behavior in time domain signals if clutter dominates the highest amplitude values. By measuring “empty rooms” of different road surfaces a clutter bibliotheque can be created.

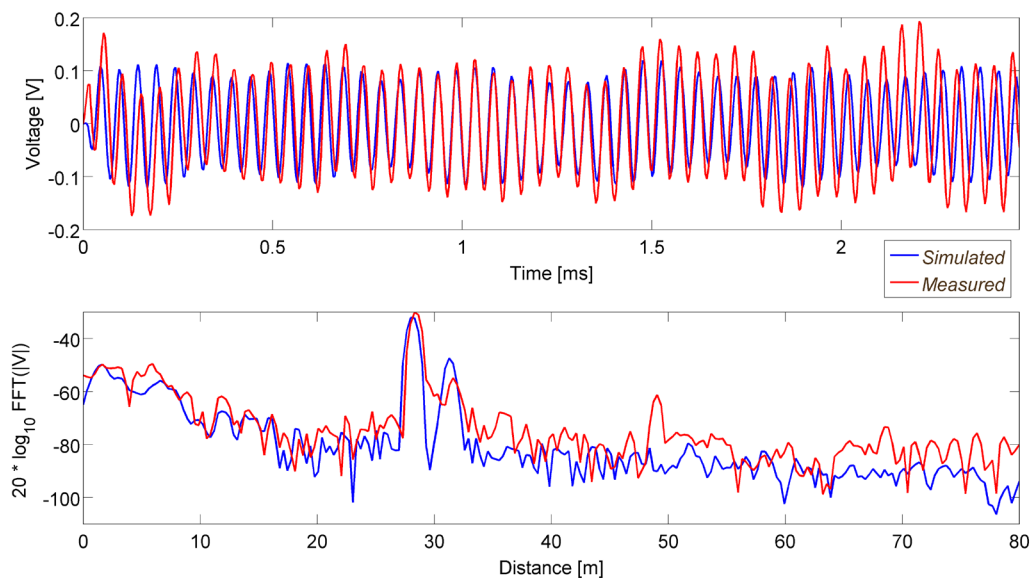
### 3.2. Target return from a van

The backscattering behavior of traffic participants can also be considered by simulation.

Fig. 3-4 shows the van about 30 m away from the radar. Fig. 3-5 shows the measurement and simulation results.



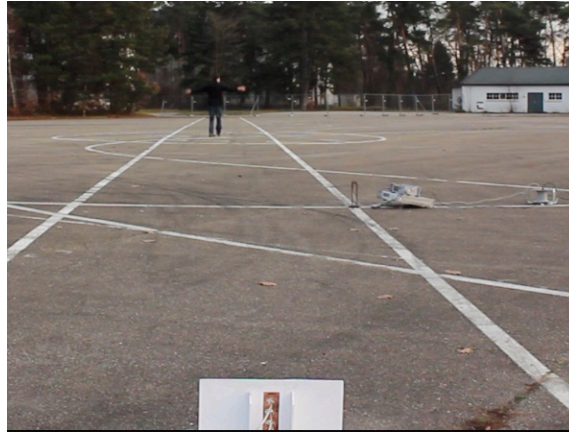
**Fig. 3-4:** A van is placed in the middle of the circle with a radii of 30 m.



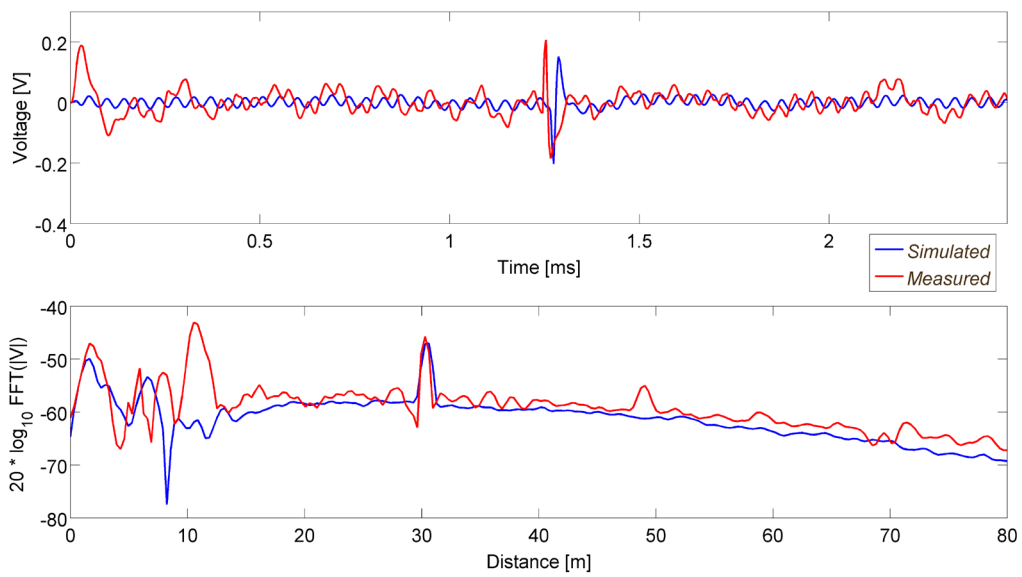
**Fig. 3-5:** Here an independent empty room clutter was added (for distances up to 20 m). The two strong reflections at 30 m arise from the back of the van and from the rearview mirrors. This measurement underlines that road participants can be considered as distributed targets.

### 3.3. Target return from a pedestrian in the presence of interference

Fig. 3-6 shows a measurement setup which includes a target, interference and again clutter. In Fig. 3-7 the measurement is compared with simulation. The target (human) is modelled by two scattering centers, with a total RCS of about 0 dBsm. For this setup, the target is still 10 dB above the increased noise level.



**Fig. 3-6:** The radar illuminates a person at 30 m distance, with interference caused by a CW interferer (with an output of 20 dBm EIRP) from 10 m distance.



**Fig. 3-7:** Comparison of simulation and measurement. The interference effect is recognizable as a noise increase of slightly more than 20 dB in comparison to Fig. 3-5. In addition to the target at 30 m, the interfering source can be clearly seen at 10 m distance.

## 4. Conclusions

The simulation results presented in this deliverable are demonstrating that it is possible to re-create adequate radar raw signals, which are including interference disturbances.

The simulator can cover several levels of detail. Practically it turned out that “hybrid“ variants are likely the most effective. These “hybrids“ use measurements based on statistical models, to overcome the otherwise very intensive processing parts of the simulation with highly randomised behavior (especially the consideration of clutter).

The wave propagation by ray-tracing is important to get deterministically defined useful received signals and interference power levels, as well as the angles of the incident waves and doppler shifts.

In general, all modelling should be done up to the level of detail, which is really needed.

With some modifications of the ray-tracing core software and an updated version of the editing toolkit and Matlab control software, the simulation tool chain used in MOSARIM is suitable for ample use in industry.

## 5. References

- [D24] The MOSARIM Consortium, "Simulation setup assessment: interferer – free space propagation – victim radar," Workpackage WP2: Simulation of radar interference mechanisms, [www.mosarim.eu](http://www.mosarim.eu), December 2011
- [D25] The MOSARIM Consortium, "Simulation of effects and impact of environment, traffic participants and infrastructure," Workpackage WP2: Simulation of radar interference mechanisms, [www.mosarim.eu](http://www.mosarim.eu), August 2012
- [HARTER1] M. Harter, T. Schipper, L. Zwirello, A. Zirotff and T. Zwick, "24GHz Digital beamforming radar with T-shaped antenna array for three-dimensional object detection," *International Journal of Microwave and Wireless Technologies*, pp. 327-334, vol. 4, 2012
- [HARTER2] M. Harter, A. Zirotff and T. Zwick, "Three-Dimensional Radar Imaging by Digital Beamforming," *Proceedings of the European Radar Conference EuRAD*, Manchester, UK, 2011

## Abbreviations

dB	decibel
dBm	decibel milliwatt
dBsm	decibel square meter
EIRP	Equivalent Radiated Isotropic Power
HH/hh/pp	horizontally polarized transmit-antenna, horizontally polarized receive antenna
HV/hv/pt	vertically polarized transmit-antenna, horizontally polarized receive antenna
IP	Intellectual Property
RCS	Radar Cross Section
VH/vh/tp	horizontally polarized transmit-antenna, vertically polarized receive antenna
VV/vv/tt	vertically polarized transmit-antenna, vertically polarized receive antenna
WP	work package