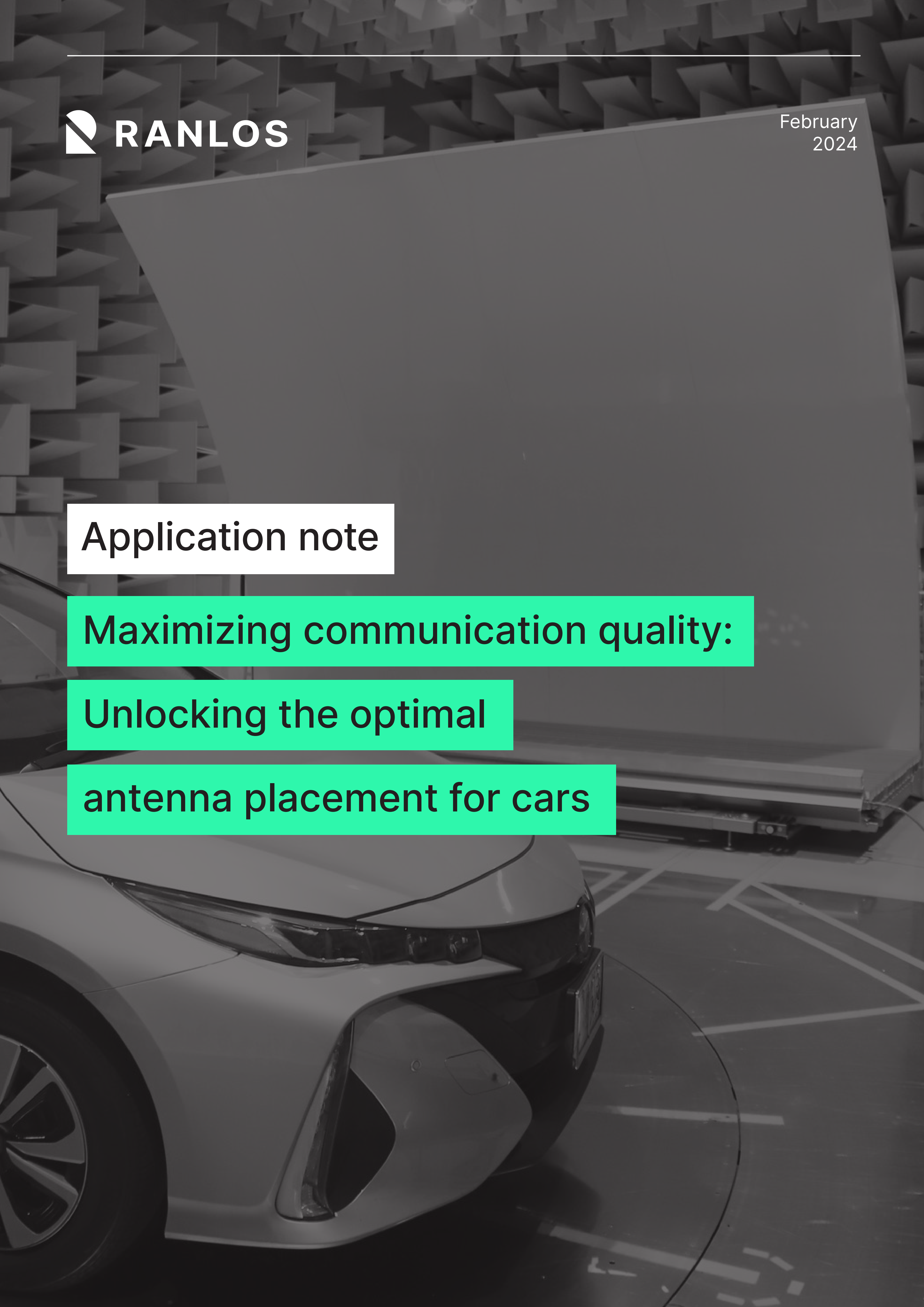
RANLOS

February
2024



Application note

# Maximizing communication quality: Unlocking the optimal antenna placement for cars

## Introduction

To optimize the connectivity of the car, the position of the antennas is of high importance. The car is normally made of metal parts which are acting as a ground plane, therefore the body of the car, i.e., the shape, is very much affecting the antenna performance and thereby the connectivity.

A relatively common vehicle antenna type is the shark-fin antenna that normally is placed on the roof of the car. It is important that the position of the antenna is optimized to get the best possible performance, both regarding the radiation pattern of the antenna and the connectivity.

The material of the roof has, of course, also a big impact on the overall performance of the system. The roof can be made of, for example, carbon fiber or glass (2). The roof can also be missing (3), and then an alternative placement of the antenna is needed. This will for sure have an impact on the communication system performance.

An antenna mounted on a glass roof can be an attractive design but is not optimal for the performance of the communication system. The same applies to a car without a roof because the antenna must be placed in an alternative location, for example at the back of the car. In this application note, we will give examples on how different placements of the antenna can result in a reduction of the maximum communication distance.

*In order to test the whole car, which is necessary to have a complete understanding of the connectivity quality, a test facility with accurate test equipment is needed.*

To be able to position the antenna with best possible communication quality as a result, there is a need of accurate test methods. Tests of a whole car are rather complex processes and expensive test facilities are needed. The needed test equipment is advanced and there is only a few of these test facilities available which make the verification cumbersome.

This is not a practical way forward; the engineers need to perform measurements throughout the whole development process. As described in this application note, a misplaced antenna will result in unnecessary bad communication system performance such as, for example, too short maximum communication distance and low communication capacity. RanLOS test system is designed to be an easy-to-use measurement tool for antenna and throughput measurements. The test equipment is designed to be used in existing chambers or in open areas with weather protection. A long series of verifications and tests have been carried out to verify the quality of RanLOS test technology and these have shown that the technology is very reliable.

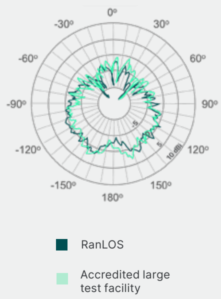
### Different antenna placements

*The position of the antenna will give different communication performance.*

*(1) Roof-mounted antenna with a position at the rear of the roof*

*(2) Modern car with glass or carbon fibre roof*

*(3) Cabriolet car without roof*



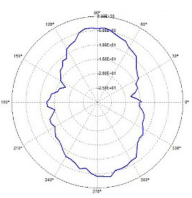

*RanLOS test system placed in a tent compared with an advanced test facility in Denmark. These measurements were done during SIVERT - a FFI-Vinnova project.*

# Measurements with RanLOS test equipment

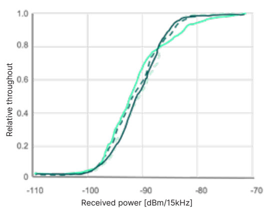
RanLOS test equipment is designed to be fitted into simple test sites or existing EMC chambers.

The car is positioned in front of the RanLOS test system, and two different types of measurements can be performed to characterize the antenna and the quality of the wireless connection to the car (4)(5).

The antenna radiation pattern (6) is a measure of how the antenna radiates or receives wireless signals in different directions. Typically, the radiation pattern is visualized in a polar plot where the antenna's radiation is shown as function of the azimuth angle from 0 to 360 degrees. The amplitude is in such a plot defined by the distance from the origo.

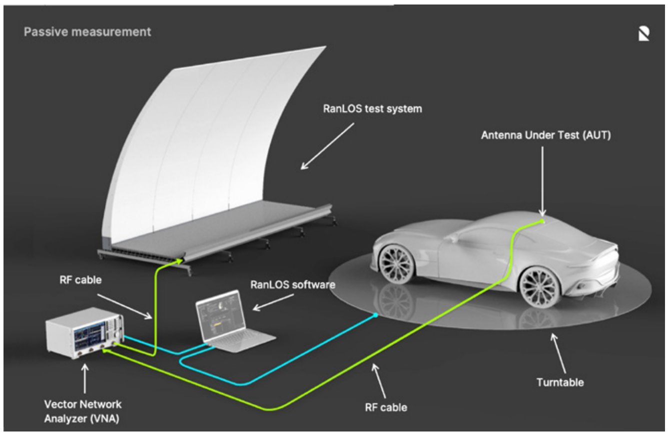


*Typical antenna radiation pattern polar graph (6)*

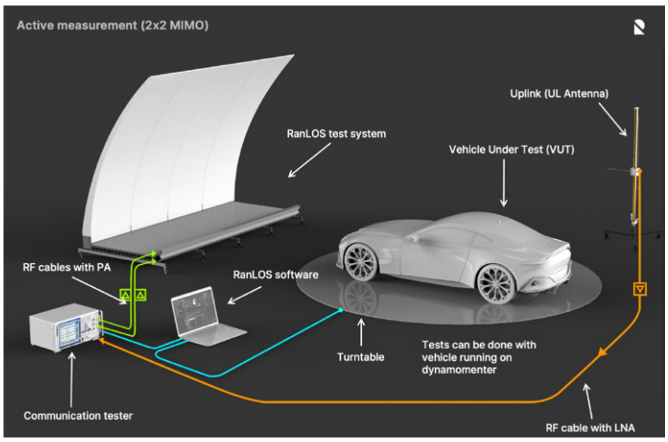



*Typical throughput and threshold graph (7)*

The quality of the wireless connection is measured with a Radio Communication Test Station which is simulating wireless communication with the car under test. The test result is presented in a throughput graph (7) as a function of received power. Often we plot the relative throughput where 100% indicates maximum throughput. From the throughput graph, the threshold is defined as the received power level when the relative throughput is 50% of the maximum throughput. Normally the transition from 100% to 0% is very steep, and therefore the threshold can be easily found.




*(4) Measurement of the antenna pattern*




*(5) Measurement of the quality of the wireless connection*

# Practical example with RanLOS test equipment

The RanLOS system is used to do Over-the-Air (OTA) measurements and can measure, for example, how antennas radiate in different directions (antenna radiation pattern) or the quality of a communication system. This is important information for the engineer in order to understand how, for example, vehicles receives and transmits data (connectivity/throughput).

In order to find the most optimal position of a roof-mounted antenna the engineer needs to move the antenna and perform measurements after each change of its position.

If, for example, the antenna is moved from the back of the roof to the front of the roof (8) the communication performance will change. The best way to detect this is to measure the antenna radiation pattern, and/or the throughput of the communication system.

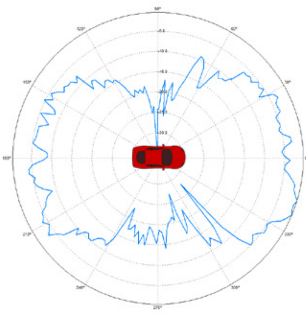
Antenna radiation pattern can be presented in polar graphs (9)(10). The graph makes it possible to detect weak directions where the antenna has inferior performance. In the graph (10) the red trace represents the radiation pattern with the antenna placed at the back of the roof, and in the blue graph (9) when the antenna is moved to the front of the roof. As can be seen in the graphs, it is not only the antenna design that is of importance it is also the position of the antenna. Therefore it is of importance for the design engineer to have a tool to understand the impact of both the antenna design and its position on the vehicle.

If the measurements are compared (12) it is easy to see that one position, blue trace, has different radiation pattern than the other, red trace, but what does that mean?

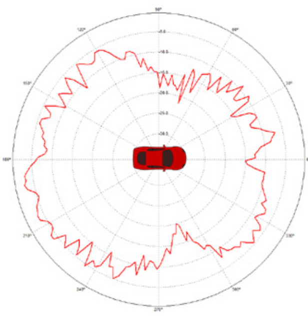
*(8) LTE-antenna at the front of the roof*

**Antenna radiation patterns**

*(9) front of the roof*



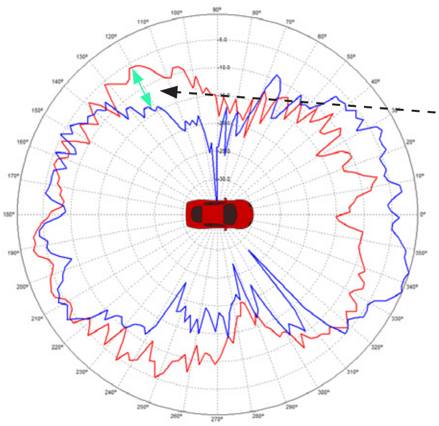
*(10) back of the roof*

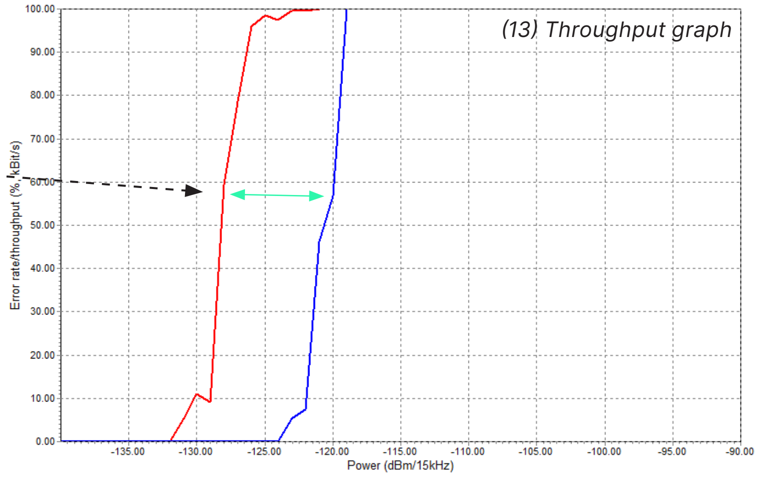


*(11) LTE-antenna at the back of the roof*

LTE-antenna at the front of the roof
LTE-antenna at the back of the roof

*(12) Antenna radiation pattern comparison*






*(13) Throughput graph*

The quality of the wireless connection can be measured with a Radio Communication Tester, simulating wireless communication with a vehicle under test. The test result is presented in a throughput graph (13). The graph presents the data throughput as a function of received power. In this graph, it's possible to identify the receiver threshold which is defined as the received power level when 50% of the communication signal is received without any errors. This is an important quality parameter of the communication system. As can shown in the throughput graph (13) the step from 100% to 0% throughput is very steep, and therefore the threshold is rather easy to be found and a practical parameter to be used in the engineering work.

Therefore, when studying the effect of moving the antenna on the roof, it is very useful to use both an antenna radiation pattern and a value of communication throughput to better understand and find optimal performance of the communication system.

As can be seen in the graphs the antenna radiation pattern, in a specific direction (120°) can be transformed to a throughput measurement to better understand the impact on the system performance. In this case, the threshold of the communication system is almost 10 dB worse when the antenna is placed on the front of the roof instead of on the back.

# Simple theory

To estimate the range of a communication system we first need to compute the power received by the receive antenna. This can be computed given the transmitted power, the gain of the transmit and receive antennas, and the distance between the transmitter and the receiver. The formula relating the transmit and receive powers below is known as Friis transmission formula and is valid in free space, i.e., when there are no objects neither in-between nor close to the two antennas.

Free space path loss: $\left(\frac{4\pi df}{c}\right)^2$

Where: d is the distance between antennas [m]
f is the frequency [Hz]
c is the speed of light [m/s]

*Received power:*

$P_{Receive} = P_{Transmitt} \, G_{Transmitter} \, G_{Receiver} \left(\frac{c}{4\pi df}\right)^2$

Where: $P_{Receive}$ = received power [W]
$P_{Transmitt}$ = transmitted power [W]
$G_{Transmitter}$ = transmitter antenna gain
$G_{Receiver}$ = receiver antenna gain

Often, Friis formula is expressed in decibels as:

$P_{Receive} = P_{Transmitt} + G_{Transmitter} + G_{Receiver} - 20\log_{10}(d) - 20\log_{10}(f) - 92.45$ [dB]

Where: $P_{Receive}$ = received power [dBm]
$P_{Transmitt}$ = transmitted power [dBm]
$G_{Transmitter}$ = transmitter antenna gain [dBi]
$G_{Receiver}$ = receiver antenna gain [dBi]
d = distance between antennas [km]
f = frequency [GHz]

For in-depth studies, see also Friis' transmission formula that can, for example, be found in the textbook; Foundations of Antenna Engineering: A Unified Approach for Line-of-Sight and Multipath by Professor Per-Simon Kildal.

The above equation gives us an idea of what a degradation in antenna performance means. The lowest power level for which the receiver can decode the message is given by the sensitivity level defined as the level when the throughput is lower than 1%. The sensitivity level typically corresponds to the previously mentioned threshold level and in modern communication systems is normally a part of a dB lower than the threshold value. Using Frii's transmission formula, the output power and the knowledge of the threshold, and thus the sensitivity level, we can calculate the maximum communication distance. We can also easily compare the difference in communication distance if the system performance is somehow degraded, e.g. worse antenna performance. For example, if the antenna has a 10 dB poorer antenna pattern, and therefore a 10 dB worse threshold, the communication distance is affected. If the communication distance is 10 km with the first antenna position the second antenna position will result in approximately 3.2 km communication distance, which is a significant deterioration of the performance.

# Summary

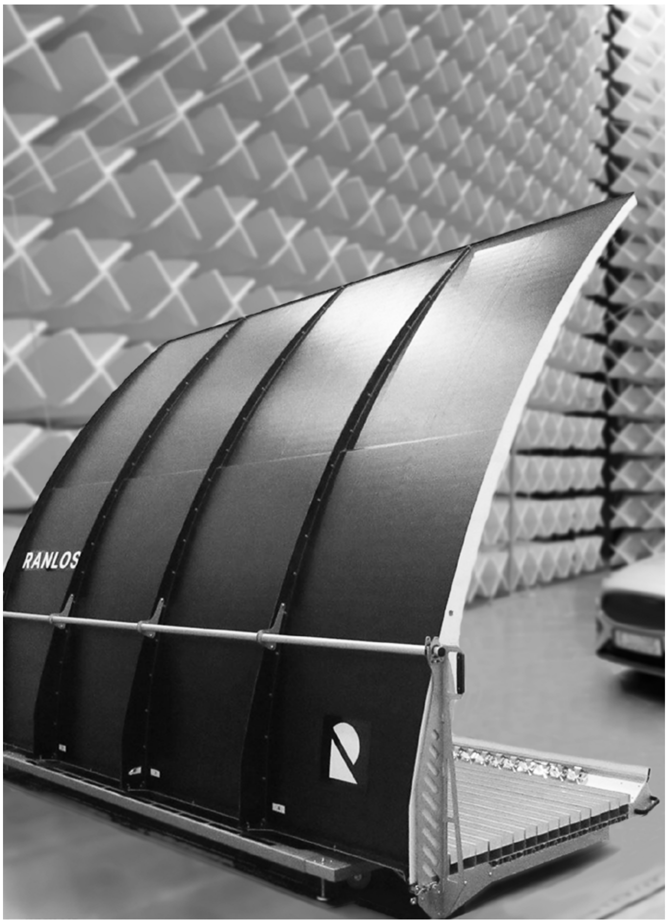
In real life, a non-optimized antenna position on the roof of the car can result in an unnecessary poorer communication performance which in turn will be a bad experience for the user of the car.

However, it is not only the free space path loss that limits the communication range. Attenuation is also caused by obstacles, weather conditions such as rain or snow, ground reflections, etc. So it is of high importance that the margins are as good as possible in order to optimize the communication to and from the car.

The conclusion is that there is a clear need to measure antenna and communication system performance early in the development process, as well as throughout the process.

*Measurement early in the development process*


*Measurement late in the development process*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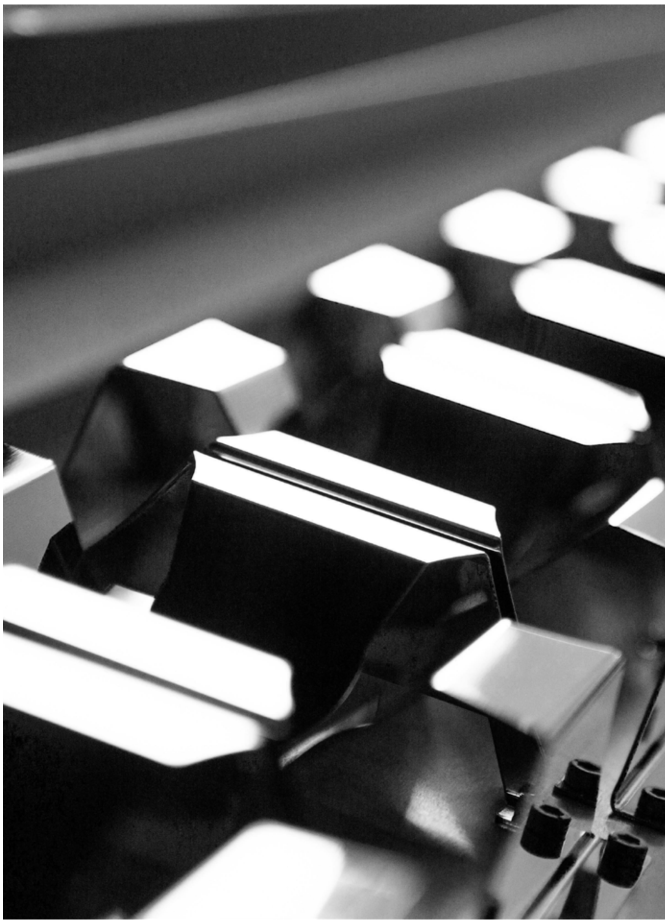

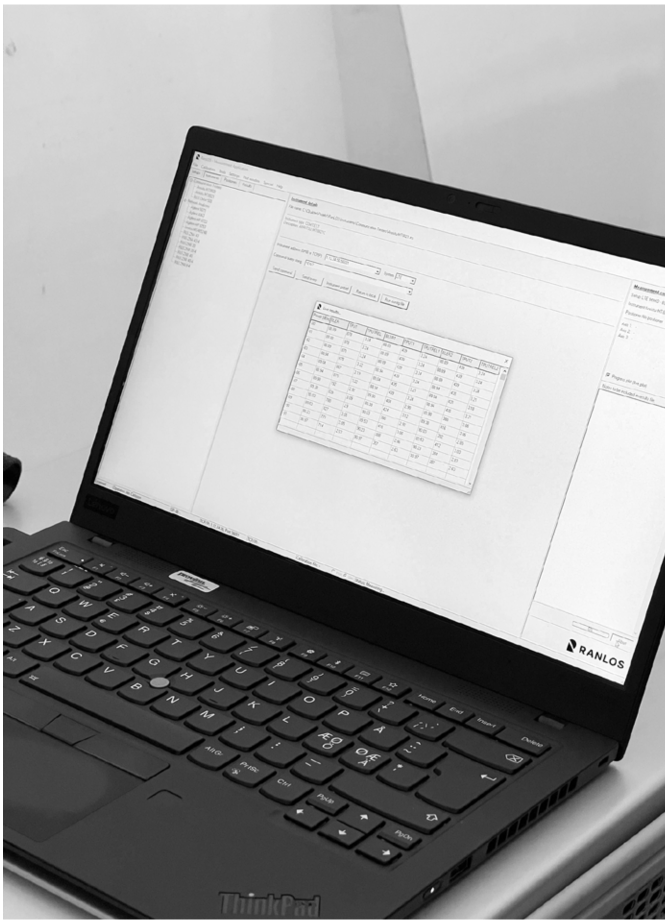
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