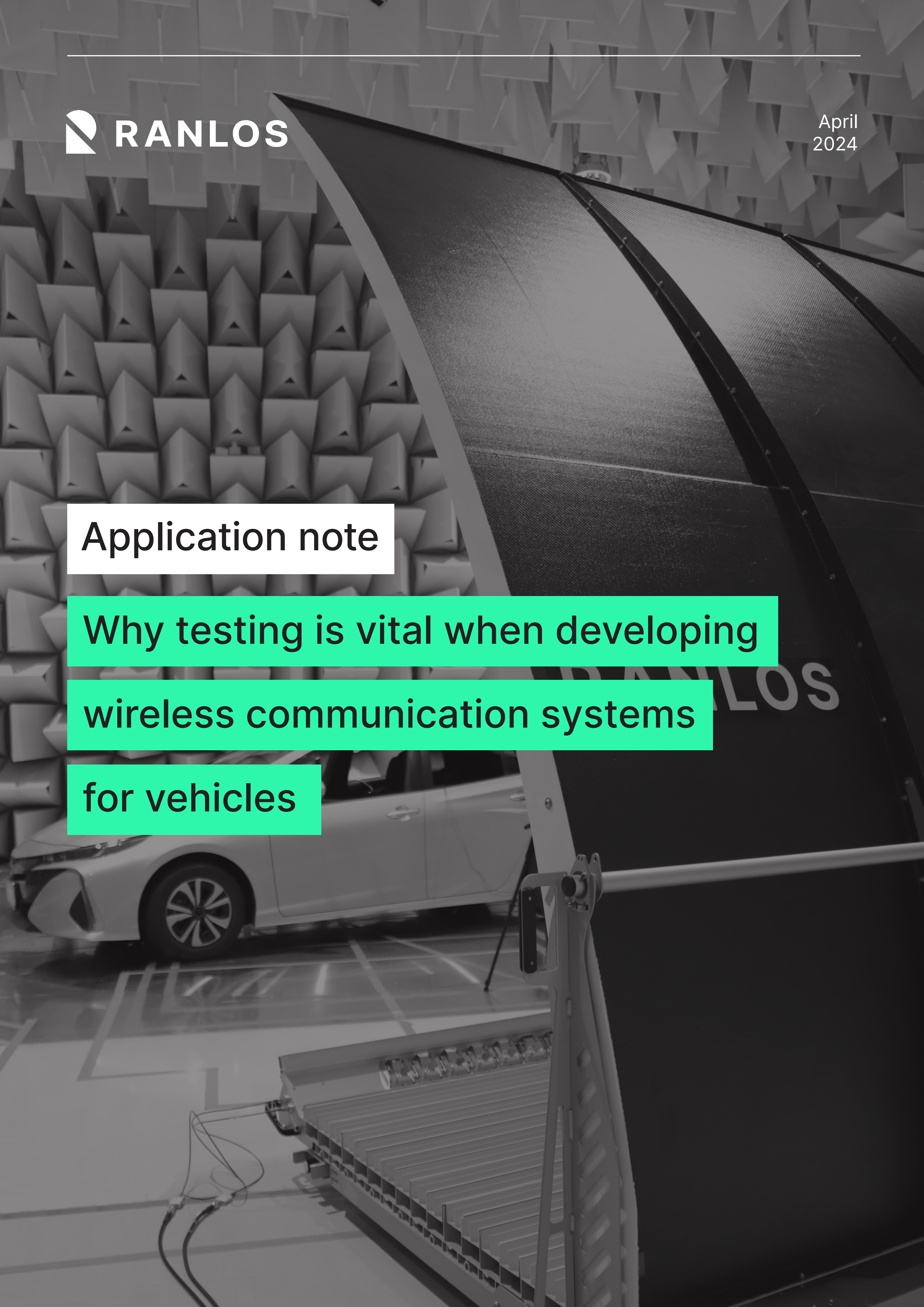


RANLOS

April
2024

Application note

Why testing is vital when developing wireless communication systems for vehicles

Executive summary

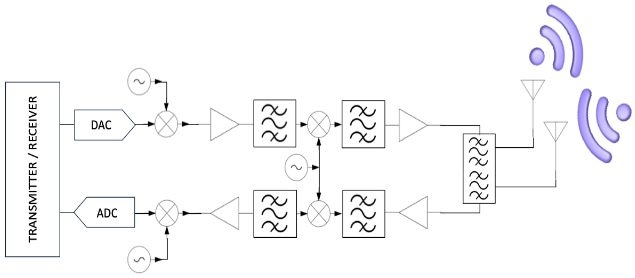
This application note emphasizes the critical importance of comprehensive testing in developing wireless communication systems for vehicles. These systems, characterized by complexity involving digital components, analog components, and software, demand thorough testing for both customer satisfaction and system reliability.

The theory of signal modulation underscores the significance of accurate signal detection at the receiver's end, particularly in systems with higher modulation schemes that store more information. Natural and in-car disturbances impact signal quality and need to be considered when the test system is chosen to be used for measurements and verification of the vehicle communication system.

In conclusion, this application note highlights why it is important to perform tests when developing wireless communication systems for vehicles. It also presents RanLOS test system as a cost-effective and reliable solution to ensure optimum measurement performance.

Short description of a typical communication system

When establishing a wireless connection, the capacity and therefore the throughput is important. The communication system consists of a number of components and subsystems, see the example below:



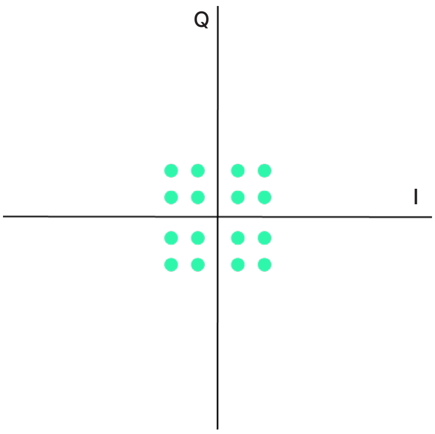
(1) Example of a typical wireless communication system.

It is a complex system with digital and analog subsystems and much software. Customer experience is of high importance and the quality of the communication system is very important. Testing the entire communication system in a car is therefore of high priority. In addition, a growing percentage of the vehicle's technical performance depends on how well the communication system works. All this shows that tests of the communication system are a vital part of the development process of new vehicles.

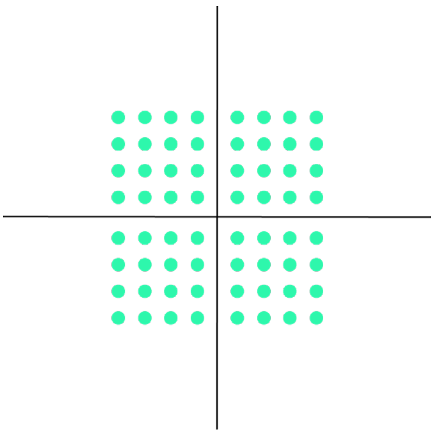
A wireless communication channel uses a space in the frequency spectrum. In order to use the frequency space as efficiently as possible the frequency spectrum is divided into areas that can be used for different purposes and functionalities. The frequency space is then used for transferring digital data at a certain speed (capacity/throughput). To be able to communicate with as high capacity/throughput as possible, different modulation technologies are being used. High order modulation scheme enables high data rates but will also require a high signal-to-noise ratio (SNR).

QAM constellation diagrams

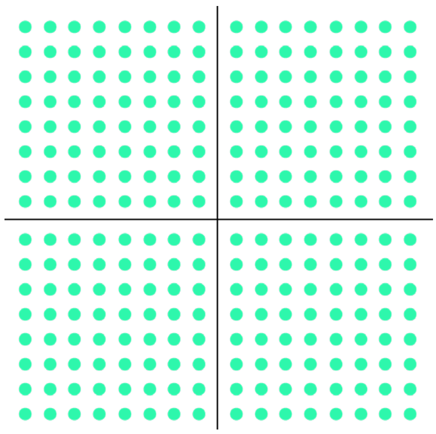
(2) Examples of Quadrature Amplitude Modulation (QAM) constellation diagrams, 16 QAM, 64 QAM, and 256 QAM.



16 QAM



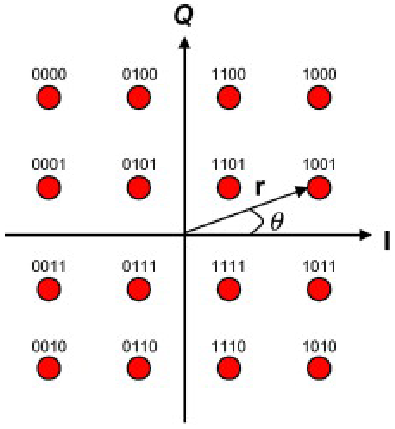
64 QAM



256 QAM

Brief theory

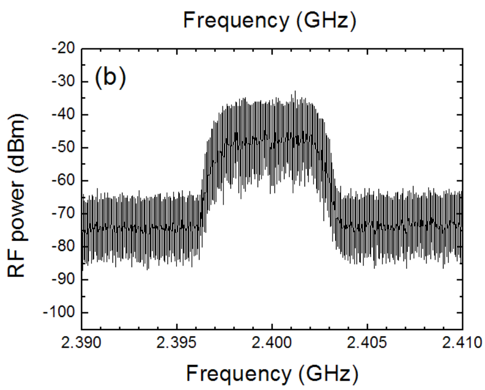
High modulation schemes are able to carry more information, i.e., more bits per symbol, and therefore also per second. The information is "stored" in a vector, so called decision vector, via the angle and the amplitude. Each position (dot) represents a unique position in the diagram, see below, and therefore also a unique angle and distance. In such a way, each dot represents a unique address that is represented by a binary number, see diagram below.



(3) The angle and the amplitude of the vector represent a unique position in the constellation diagram.

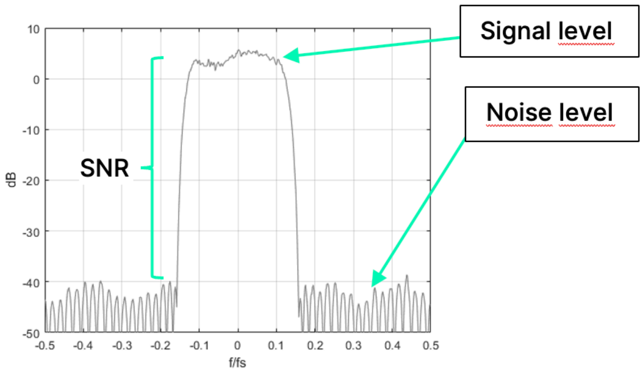
If 16 decision points are used the modulation is called 16 QAM and each position represents 4-bits (2^4=16). This means that each position will transfer one symbol that contains 4 bits. If the modulation is 256 QAM each position represents 8-bits (2^8=256) and one symbol contains 8 bits.

A typical frequency spectrum of a 16 QAM signal can be seen in the picture below:

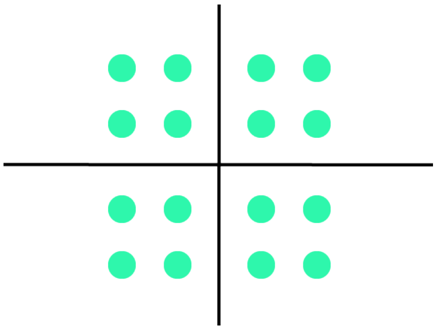


(4) Frequency spectrum of a 16 QAM signal

Important parameters in a modulated signal are, among others, the signal level, noise, spuriouses, system linearity, phase noise, etc. In order to detect the signal correctly, i.e., the amplitude and angle of the decision vector, at the receiver side it is important that the ratio between the signal level and the noise and spuriouses are above a specific level. A higher modulation scheme has a higher requirement for the signal-to-noise ratio (SNR) than a lower modulation. This can easily be understood if the constellation diagram is studied since the decision points are denser with a higher modulation scheme, see figure (2) on the previous side.



(5) Signal-to-noise ratio (SNR) in a communication channel



(6) Constellation diagram for the same signal

If the signal is attenuated or disturbed in any way, the communication quality and capacity will suffer and, in some cases, the communication channel will be broken. This is easy to understand when the constellation diagram is studied together with the frequency spectrum. If the SNR is too small the signal will be too close to the noise and therefore distorted. This will result in errors when the receiver is trying to detect the amplitude and the angle of the decision vector.

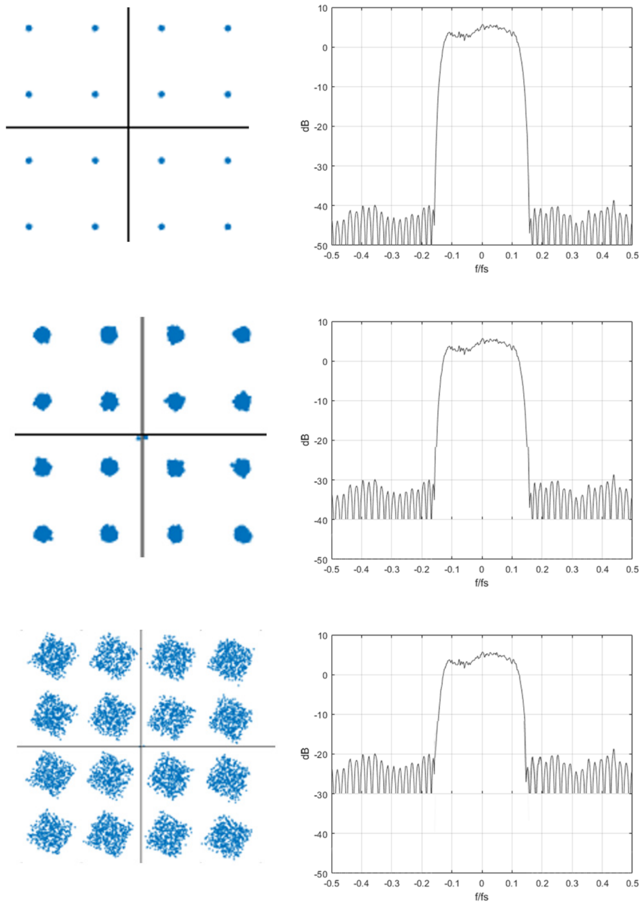
From the graphs above it is also easy to understand that a higher modulation order requires a higher signal-to-noise ratio. This is because a higher modulation order has more decision points than a lower modulation order. More decision points lead to a denser constellation diagram and therefore smaller decision area around the decision points. This is used by modern communication systems by simply changing the modulation order to a lower order when the SNR is under a critical value. This functionality is called adaptive modulation.

If the signal is attenuated, for example, because of path loss, rain attenuation, and obstacles the SNR will be affected. If the signal is attenuated so the SNR is low, the communication will be significantly affected, and eventually completely interrupted.

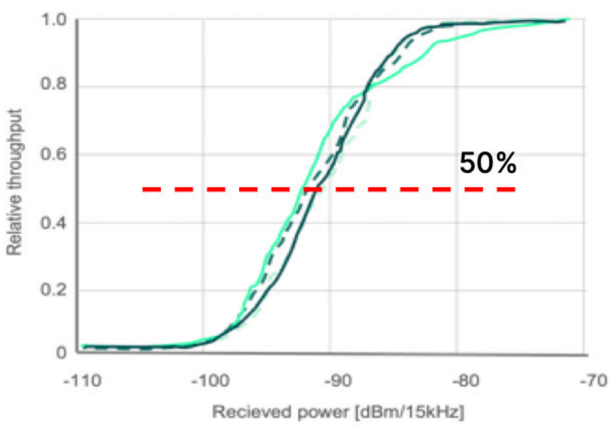
A useful parameter to understand the performance of the communication system is the receiver threshold. The receiver threshold is defined as the received power level when 50% of the communication signal is received without any errors.

The throughput graph can be used to define the quality of the communication channel. As can be seen in the figure the curve is falling from 100% to 0% relative throughput when the received power is decreasing. The receiver threshold is shown in the graph as a red line. In modern communication systems, the step from 100% to 0% relative throughput is very steep, and therefore the threshold is rather easy to find and a practical parameter to be used in the engineering work.

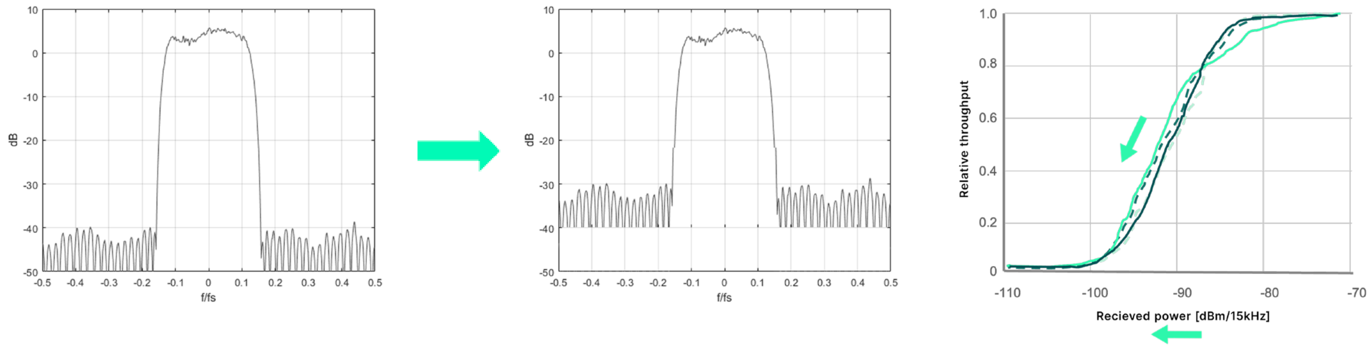
If, as described above, the SNR is small the signal will be close to the noise, and consequently also the receiver threshold, and the connection will be affected. As described in the figure (9) on next page, this can be shown by comparing measurements of a signal with a spectrum analyzer at different SNRs and the graph from measurements of the receiver threshold.



(7) Signal-to-noise ratio (SNR) from good to worse in a 16 QAM constellation diagram



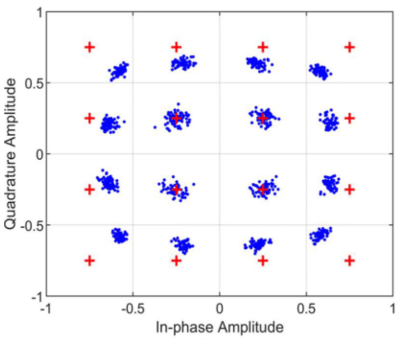
(8) Threshold, the received power level when 50% of the communication signal is received without errors.



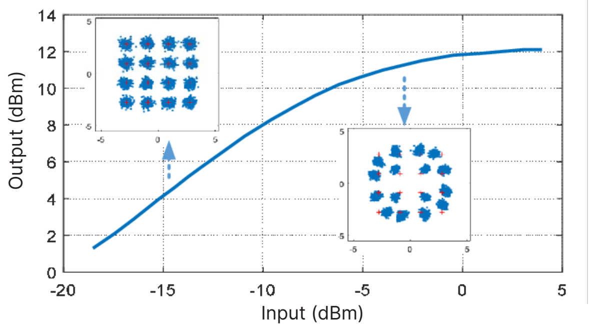
(9) Signal-to-noise ratio (SNR) from good to worse (left) results in a lower relative throughput that can be shown in the throughput diagram (right)

In modern communication systems, very advanced error correction methods are used to improve performance. Therefore, the threshold is lowered and the transition from full throughput to zero is very steep. This means that communication can be maintained to a lower receiver signal level, and then suddenly interrupted.

Other imperfections are for example when the linearity of the system is poor, for example when the amplifiers in the signal chain are driven too hard, resulting in a skewed constellation diagram, see figures (10)(11) below.



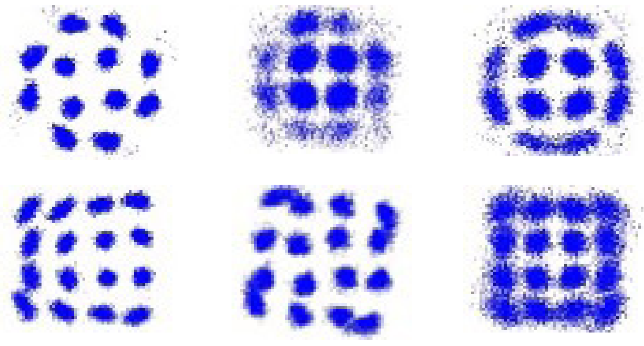
(10) Skewed 16 QAM constellation diagram



(11) Relationship between linearity and constellation diagram

Extensive phase noise results in another problem as can occur.

As mentioned, a number of imperfections in the communication channel will result in bad performance. With good measurement equipment, these problems can be detected during the development phase and corrected.



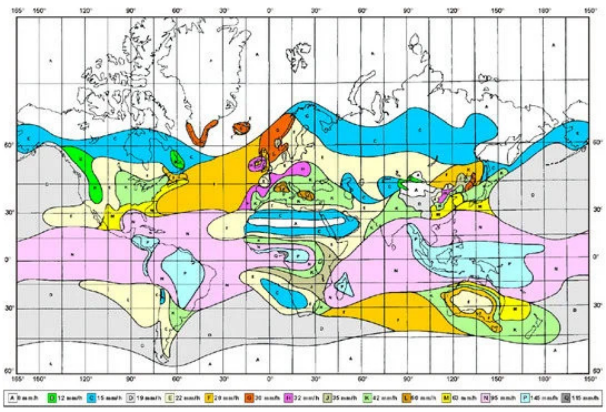
(12) Distorted 16 QAM constellation diagrams due to different problems in the communication channel.

It is important to find errors and problems early in the project, and it is also important to see the performance of the whole system, i.e., the vehicle together with the communication system. To do this, test chambers with adequate measurement equipment are needed.

Sources of disturbances and attenuation

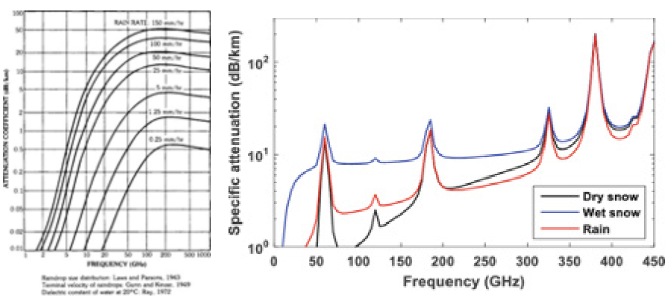
Natural sources

It is obvious that if there is an obstacle between the transmit and receive antennas, the attenuation will increase and therefore the received signal will be weaker. But also rain and snow have an impact on the attenuation. Since the vehicles are used all over the world it is important that the attenuation, because of the local weather, is considered. For example, the rain attenuation is not the same in Sweden and Norway. Looking into statistics, Sweden is in rain-zone E (22mm/hour) and Norway is in rain-zone G (32mm/hour) and some parts of the world have rain zones over 100 mm/hour.



(13) World map with rain zones

The attenuation because of rain is well studied and as can be seen in the figure below the attenuation at 3 GHz varies from 0,02 dB/km to 0,1 dB/km in rain-intensities from 25 mm/hour to 150 mm/hour. Also, snow has an impact, and will attenuate the signal. As can be seen in the graphs' below, wet snow has a greater impact than rain and therefore also needs to be taken into account when designing a communication system.



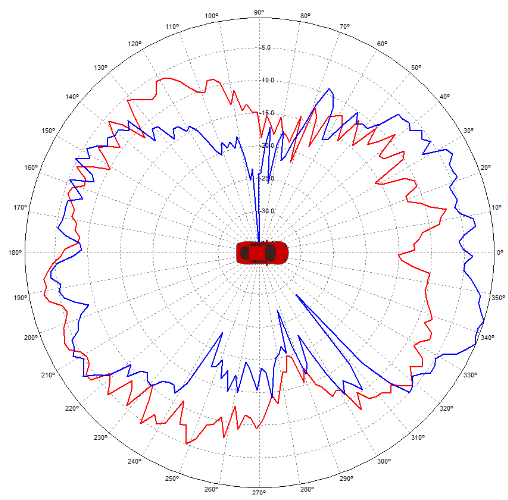
(14) Attenuation versus frequency for rain intensity and snow

In addition, there is attenuation from other sources as described earlier in this application note. Attenuation, caused by natural obstacles and phenomena, is called fading. To handle this the wireless systems are designed with a SNR margin, called a fading margin. The fade margin is the attenuation the signal can handle from natural sources and is dependent on the distance the communication system is designed to cover. If, for example, the mean distance between a mobile phone and a base station is 20 km, the fading margin because of natural attenuation has to be 5-10 dB.

Influences from the communication system

In our application note **"Maximizing communication quality: Unlocking the optimal antenna placement"** we described the importance of a correct placement of the antenna on the car. An incorrect placement can greatly degrade the performance of the communication system and can therefore destroy all the development work done on the antenna and other components of the system.

A bad placement of the antenna will result in bad antenna radiation which in turn will reduce the signal-to-noise ratio which will distort the QAM diagram and result in a lower threshold. The result is that customers will experience bad communication quality.



(15) Antenna radiation pattern comparison

Sources of disturbances and attenuation

In-car disturbances

The car itself has many systems that use electrical motors or other electrical systems. Examples are windows, wipers, outdoor rear mirrors, fans, etc. Cars that have electric motors for the car's propulsion also have a lot of complicated electrical functions and systems that can cause background noise or spuriouses. Therefore, it is very useful, and important, to test the communication system in the car when the car is in use, for example on a running test bench such as dynamometers.

Interferences from external sources

Several external interference sources exist in the daily environment in which vehicles operate. This can be other communication systems, radar, electronic control, and regulation systems, etc.

To test how vehicles handle external sources of interference measurements are performed in EMC chambers with standardized measurement methods. By supplementing the EMC chamber with RanLOS test equipment, it is also possible to measure how the vehicle's communication system is affected by these interference sources. This will become even more important now when the use of wireless systems is increasing rapidly.

All the above-mentioned sources of attenuation or disturbances will contribute to the performance of the system. It is very important that the engineers have access to test instruments and tools throughout the development process and that these are easily accessible and easy to use. If this is done correctly it will save cost and reduce time to market.

(16) The influence of external sources of interference can be checked by making throughput measurements with RanLOS test systems

RanLOS test system

RanLOS test technology is based on practical parameters and is designed to be easy to use, cost effective and to deliver excellent measurement quality. The test systems are designed to be used in anechoic chambers, semi-anechoic chambers, EMC chambers, open measurement sites, etc.
Car on dynamometers can be tested with RanLOS test systems.

Compared with other systems on the market today, see below, the RanLOS system is portable, less costly, and easier to operate.

The RanLOS test technology makes it possible to perform measurements in far-field conditions whilst the competitors mainly measure in near-field conditions and thereafter convert the result to far-field conditions with mathematical methods. This means that the RanLOS system is easy to use and that it is possible to supplement an already existing EMC chambers to do the measurement on the communication system in the vehicle.

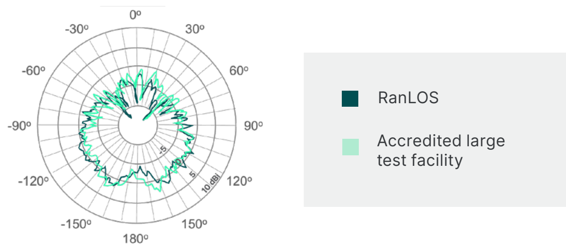
(17) RanLOS test system in an EMC chamber

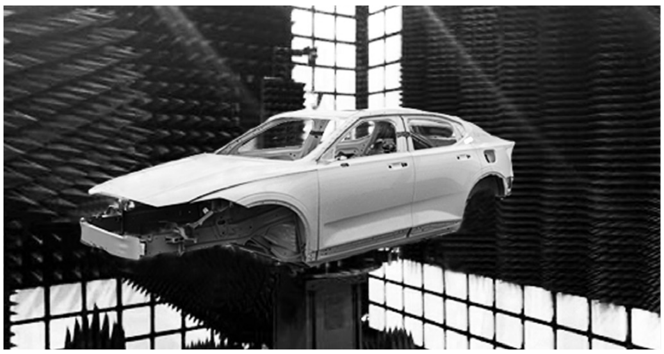
(18) RanLOS test system in a weather-protected open-area test site during SIVERT - a FFI-Vinnova project

Test set-up

The RanLOS test system can be used in two configurations, passive and active (see next page). The passive configuration is used to measure the antenna radiation pattern and the active configuration is used to measure the over-the-air throughput of the communication system.

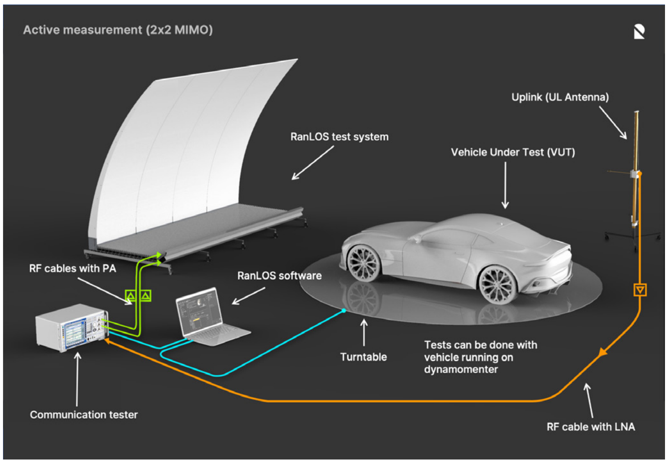
The RanLOS test technology delivers excellent measurement quality and has been validated for many years. The test results are comparable to advanced and more expensive test facilities, which underscores RanLOS reliability and effectiveness.

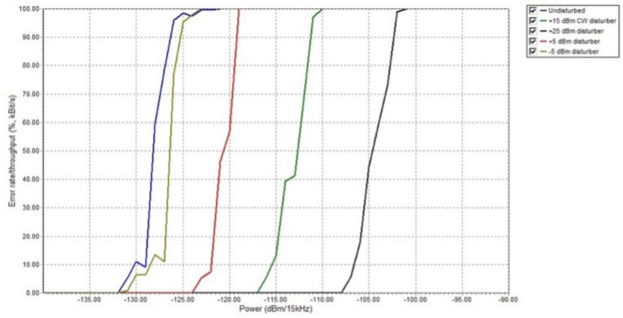




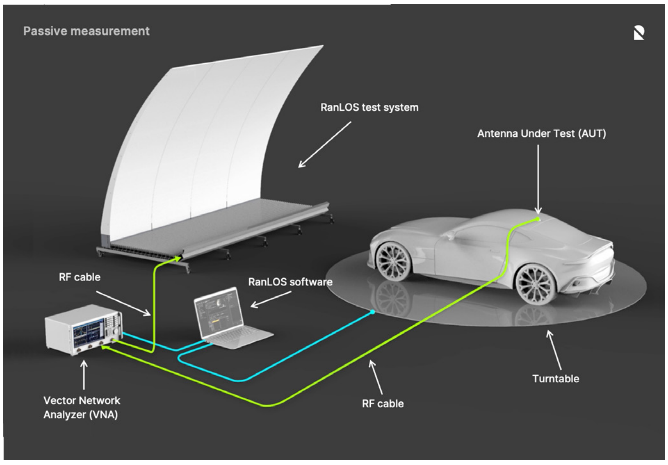
(19) RanLOS test setup placed in a test tent compared with an advanced test facility in Denmark. These measurements were done during SIVERT - a FFI-Vinnova project

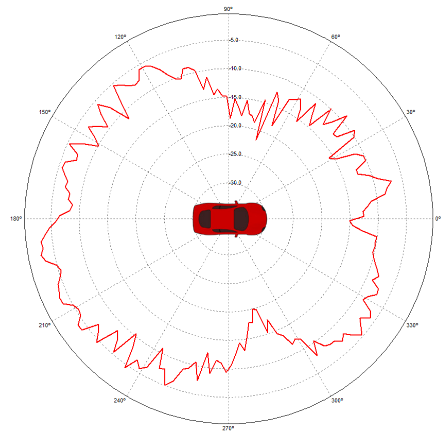
The RanLOS test system in two configurations – passive and active



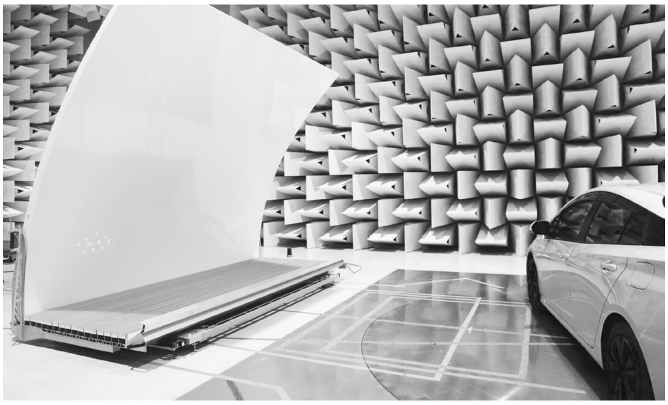


(20) RanLOS BeamForce 42 set-up in active configuration to measure throughput and receiver threshold in a 2×2 MIMO communication system. Note that the threshold is affected by the level of the disturbances





(21) RanLOS BeamForce 42 test set-up in passive configuration to measure antenna radiation pattern



Conclusion

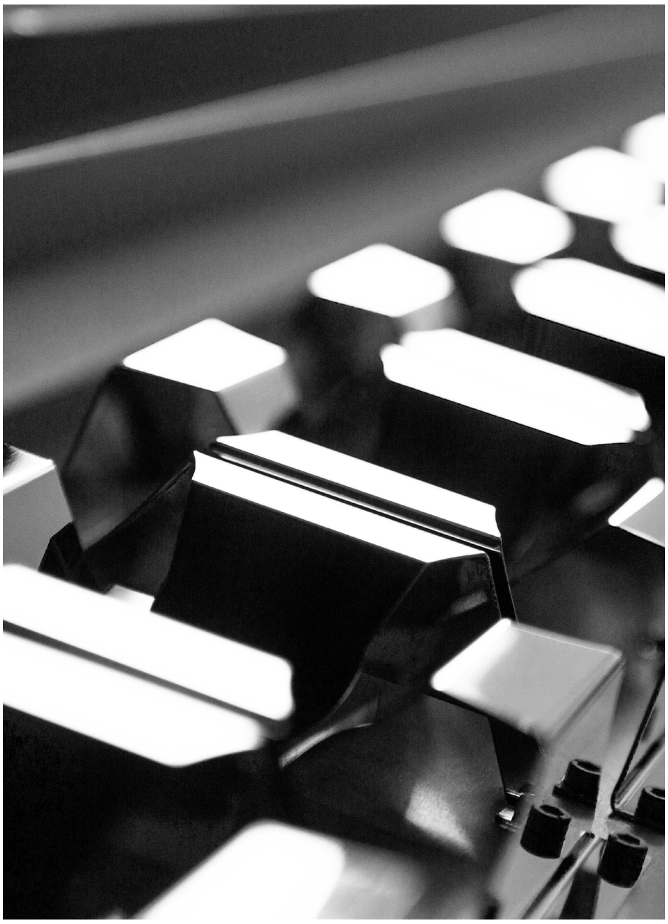
The importance of a robust test philosophy in the development of wireless communication systems, particularly those used in vehicles, is essential. The complexity of these systems, which involve digital and analog subsystems along with extensive software, requires thorough testing to ensure customer satisfaction and the overall quality of the communication system in cars.

The communication system utilizes frequency spectrum areas efficiently for different purposes and functionalities. High-order modulation schemes, such as Quadrature Amplitude Modulation (QAM), enable higher data rates by carrying more information. Higher modulation schemes demand a higher signal-to-noise ratio (SNR) for accurate signal detection at the receiver's end.

Various disturbances and attenuations, both natural and from the communication system itself, can affect signal quality and capacity. The impact of obstacles, weather conditions (rain and snow), and in-car disturbances from electrical systems on communication performance will influence communication quality. Fading, caused by natural obstacles and phenomena, is addressed by incorporating a signal-to-noise ratio margin, known as the fading margin, into wireless system designs.

The correct placement of antennas on vehicles is stressed as crucial for optimal communication system performance. Incorrect placement can lead to system degradation, reducing the signal-to-noise ratio and affecting the communication quality experienced by the customer.

In conclusion, this application note underscores the importance of a comprehensive testing approach for wireless communication systems in vehicles, considering various sources of attenuation and disturbances to ensure optimal performance and customer satisfaction. The RanLOS test system is a reliable, flexible and cost-effective solution for conducting these crucial tests.

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