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A Cost-Effective Method to Measure Vehicle Antenna Radiation Patterns and Data Throughput

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Vehicles are becoming more dependent on reliable radio communications, whether it be for safety or autonomous driving-related systems or data streaming for software updates or entertainment purposes. The capabilities and performance of these systems and services have become important differentiators in the competition for customers. Even so, only a handful of vehicle manufacturers around the world have invested in test systems to measure antenna performance and connectivity. The main reasons for this are that conventional measuring technologies are complex, often time-consuming to use and require special test facilities, along with large investments. In contrast, the RanLOS test system represents an affordable and easy-to-use alternative solution. The RanLOS system can be used on an ongoing basis during the development process to guarantee reliable and superior performance of the end product. This article explains the ideas and technology behind the RanLOS test system and how it enables vehicle manufacturers to measure both antenna radiation patterns and over-the-air (OTA) data throughput in a cost-efficient way.

BACKGROUND

One way to evaluate the performance of a radio communication system is to measure its performance in the actual environment of use. For vehicles, this is normally referred to as a drive test and this simply means that the vehicle is driven around on public roads. This is how many vehicle manufacturers test their systems today. However, this method poses questions; is the environment the same today as it was the last time the measurements were done and are the results comparable? Does the environment represent typical use? Are all the possible cases covered? The answer to all these questions is, strictly speaking, no, bringing into question the value of the tests. Another problem is that a drive test requires a vehicle that is almost finished, which in many cases cannot be driven around in public, at least not during the daytime, due to secrecy. Due to all the practical problems and the limited value of drive tests, other approaches have been proposed. One such approach is to mimic the environment in a laboratory setup. This can be achieved by placing several antennas in a circle, a hemisphere or a similar configuration around the vehicle. These antennas are then fed with suitable signals to mimic a real environment. With such a setup, it is possible to generate waves coming from different directions that simulate reflections, diffraction and scattering from objects in a real environment. The questions then become what environment gets simulated and is this environment the worst case? Another question is how many different types of environments should the test bed emulate to build the confidence level that the test needs have been covered sufficiently.

To begin addressing these questions, the RanLOS founder, Per-Simon Kildal, a professor at Chalmers University of Technology founded Bluetest in 2000. Bluetest made manufacturing reverberation chambers to test mobile devices in rich isotropic multipath (RIMP) environments. The RIMP environment contains many isotropic multipath

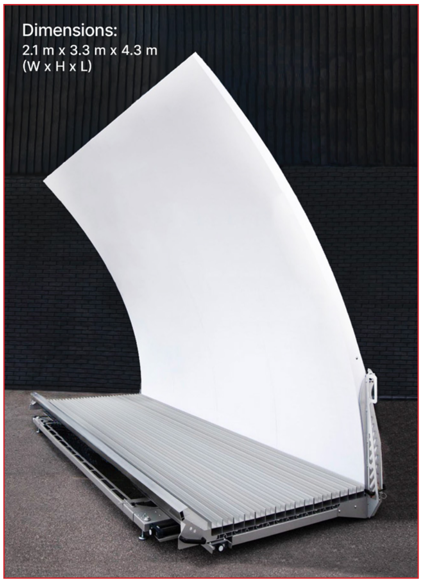

Fig. 1 The RanLOS test system for vehicular applications.

Fig. 2 The RanLOS test system.

waves with signals coming from all possible directions, amplitudes, phases and polarizations.[1] Professor Kildal began to formulate the idea that to accurately test a communication system, the line-of-sight (LOS) environment must be replicated as well. The LOS environment contains only a single wave incident on the vehicle under test. That environment replicates traditional point-to-point communication links. As he explored these boundary conditions in 2013, Professor Kildal came up with the idea that it would be necessary to test a communication system in both the RIMP and LOS edge environments.[2]

In 2016, Professor Kildal founded RanLOS to manufacture test systems that accommodated this LOS edge environment. The RIMP environment presents an extreme multipath environment that we rarely see in real life, but which can be emulated in a reverberation chamber. In the LOS edge environment, there is only a single wave incident on the vehicle under test. This is another type of environment that rarely occurs in real life, but Professor Kildal hypothesized that all real environments could be described as something in between these two edge environments. He concluded that if a device is performing well in both edge environments, it will also perform well in a real environment. Also, if a device is not performing well in either of the two edge environments, it will probably not perform well in a real environment, or at least not as well as a device that does better in both edge environments. Since Professor Kildal's passing in 2016, the theoretical and development work has been carried out by an expert team including his daughter Madeleine.[3] Based on these theories, RanLOS has developed OTA measurement systems for vehicular applications as well as for smaller mmWave devices. ***Figure 1*** shows the latest production version of an OTA test system for vehicles.

RANLOS TEST SYSTEM AND APPLICATIONS

The RanLOS test system consists of a cylindrical reflector fed by a linear array of dual polarized antennas, along with software for controlling measurement instruments and other peripheral devices. Supported measurement instruments include vector network analyzers (VNAs) and communication test instruments. One example of a peripheral device is a turntable that could also be a 3D positioner. The software controls the measurement steps and collects measured data, as well as performing post-processing and visualizing results in different ways. The feed array is easily exchangeable and it covers an octave bandwidth. To cover the 0.75 to 6 GHz frequency band, the most useful frequencies for vehicular communication systems used today, three feed arrays are needed. RanLOS has developed feed arrays that operate up to 6 GHz. Feed arrays for higher frequencies are on the roadmap, so existing customers can easily upgrade with no need to alter the reflector.

The RanLOS hardware can be viewed as a passive two-port, dual polarized antenna that generates a plane wave at a short distance. In function, it is very similar to the feed horn and spherical reflector used in a traditional compact antenna test range. One advantage of the cylindrically shaped reflector is that it is easier and cheaper to manufacture as compared to a double-curved reflector. It is also scalable in width and can be made in sections.

Figure 2 shows a weather-protected outdoor measurement range with the RanLOS test system in front of a vehicle under test. The vehicle is placed on a turntable so that it can be rotated in front of the reflector. The reflector shown in Figure 2 consists of four identical sections and even though the reflector antenna is physically large, it is equipped with wheels to make handling easier. This makes it possible to conveniently roll the reflector in and out of EMC chambers that many automotive manufacturers already have. The RanLOS setup makes it possible to measure antenna performance and connectivity in an existing chamber.

ANTENNA RADIATION PATTERN MEASUREMENTS

As can be seen in Figure 2, the vehicle under test is placed on a turntable in front of the reflector. By rotating the turntable, the vehicle will experience an incident wave from different directions, emulating the LOS edge environment. Since the generated field is a plane wave, this results in far-field conditions and far-field parameters such as the antenna gain pattern of a vehicle-mounted antenna can be measured by the test personnel. The gain pattern is measured by connecting one port of a VNA to the antenna on the vehicle and the other port to the RanLOS system to measure the signal transmission. The test setup, with all connections, is shown schematically in ***Figure 3***. To enable rotation, it is preferable that the turntable be equipped with a rotary joint for the RF cable.

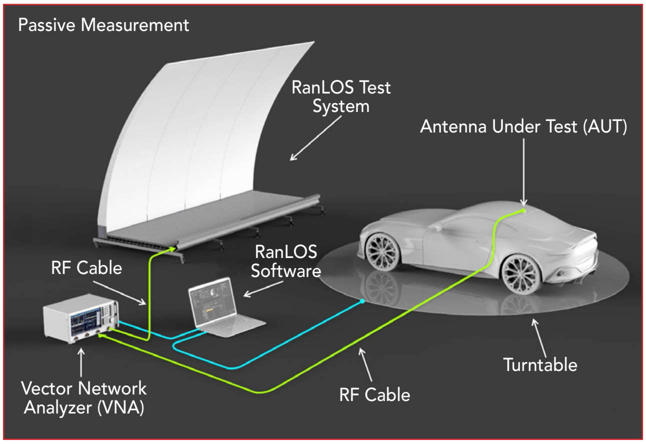

Fig. 3 **Measurement setup for an antenna radiation pattern measurement.**

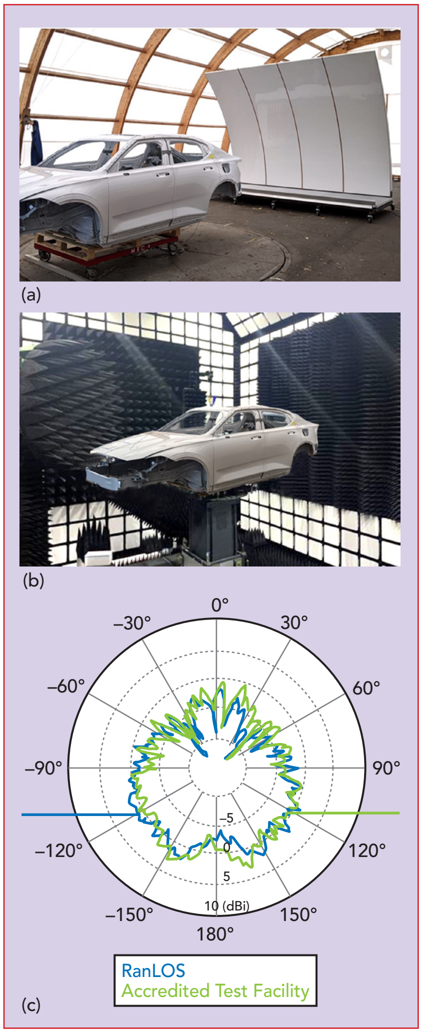

Fig. 4 **(a) RanLOS system measuring a monopole on the roof of a Polestar body. (b) Monopole on the roof of a Polestar body in an accredited NF-FF antenna test range. (c) Measured antenna gain patterns for the Polestar monopole.**

The feed array has two ports, one for each polarization. With a 4-port VNA, it is possible to measure both polarizations simultaneously, for up to two vehicle-mounted antennas. If absolute gain values are desired, a calibration must be done first, using a reference antenna with known gain.

As a performance comparison with other measurement methods, ***Figure 4a*** shows a Polestar body with a monopole antenna placed on the roof in the RanLOS measurement setup.[4] ***Figure 4b*** shows the same Polestar body and antenna combination measured in an advanced accredited near-field to far-field (NF-FF) range in Denmark. Finally, ***Figure 4c*** shows the gain pattern for the two test setups measured at 2.6 GHz. The agreement between the two test methods is very good. In the NF-FF measurement of Figure 4b, the field is probed in points on a hemisphere around the vehicle and later post-processed to obtain the far-field gain. The time for a measurement using the RanLOS system depends on the instrumentation and the time to rotate the turntable one revolution. The rotation can be done in discrete steps or continuously, in which case, the measurements are taken on the fly. The measurement in the RanLOS chamber in Figure 4a took less than 10 minutes, implying that the RanLOS system can be used as an engineering tool for investigating how the performance is affected by factors such as antenna position, type or manufacturer.

CONNECTIVITY MEASUREMENTS

In modern vehicles, the antenna is often tightly integrated with the radio module with the consequence that we do not have access to the antenna ports needed for measuring the antenna gain pattern. In such cases, a communication test instrument is connected to the RanLOS system instead of a VNA and OTA measurements of characteristics like the throughput can be performed. A typical measurement setup, in this case for an LTE 2 × 2 MIMO OTA measurement, is shown in ***Figure 5***.

In the measurement setup in Figure 5, the communication test instrument, together with the RanLOS system, act as a base station sending a data stream to the antennas and radio modem in the vehicle. This is the downlink. The uplink, which normally is configured to have a lower data speed and modulation scheme, is connected to the instrument via a separate antenna. In ***Figure 6***, several measured downlink throughput curves for the 2 × 2 MIMO LTE system as a function of power for different rotation angles of the vehicle under test are shown.

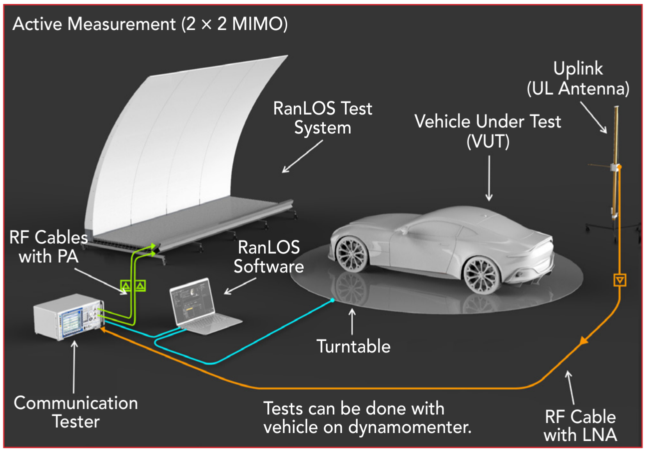

Fig. 5 **Typical measurement setup when the antenna cannot be accessed.**

Each curve corresponds to one angle of rotation of the turntable, representing different incident signal paths as seen by the receiving antennas on the vehicle. As expected, the throughput is at a maximum value for high power levels. When the power is decreased and we approach the sensitivity level of the radio module, the throughput falls to

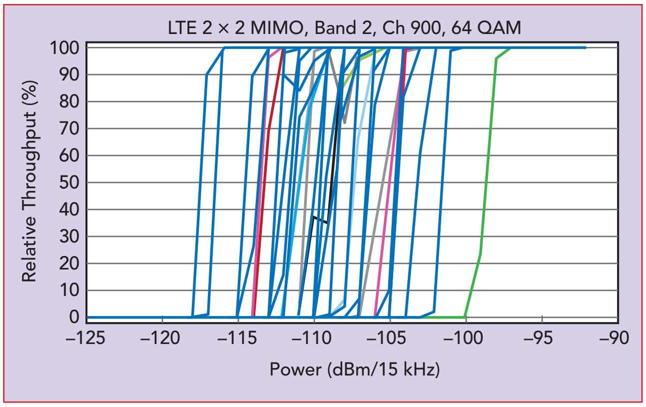

Fig. 6 **Measured downlink throughput as a function of power and vehicle rotation angle.**

zero very quickly and we lose the connection. From Figure 6, it can also be seen that there is almost a 20 dB difference between the best, leftmost curve and the worst, rightmost curve, cases. In practice, this means that the maximum distance to the base station to maintain connectivity will be different for different orientations of the vehicle to the base station. This delta between best and worst cases translates to a sizable difference in distance. As an example, if the maximum communication distance is 10 km in the best case, it will only be about 1 km in the worst case. This assumes pure LOS communication in free space.

If we have electromagnetic disturbances at the downlink frequency coming from sources in the surroundings or from internal sources in the vehicle, we expect all the curves to be shifted to the right in Figure 6. The consequence of disturbances is that the maximum communication distance will be shorter. The reduction in communication distance will be the same in all directions if the disturbances are coming from the vehicle, but this is not necessarily the case if the disturbances are coming from the surroundings. Due to the large number of electronic control units in modern vehicles, there are many possible sources of disturbances. It is therefore important for vehicle manufacturers to be able to investigate the possible influence of disturbances on the radio communication quality, especially for critical safety systems. Such investigations can be done conveniently in an EMC chamber equipped with a dynamometer so that the vehicle can be run in realistic operation modes. In these cases, the RanLOS test system is a useful tool.

CONCLUSION

RanLOS has developed a unique, patented OTA test system including both hardware and software for measuring antenna performance metrics as well as connectivity quality. The system is mobile, so it can easily be rolled in and out of an existing semi-anechoic chamber, like EMC chambers that many vehicle manufacturers already have. The system should not be seen as a competitor to advanced specially-tailored antenna test ranges, but rather as an engineering tool that can be used regularly to improve antenna performance and connectivity quality, especially for vehicular applications. The system is future-proof in the sense that the frequency range can be extended simply by exchanging the feed array with testing to 3G, 4G or 5G radio requirements determined by auxiliary instruments. ■

References

1. K. Rosengren and P.-S. Kildal, "Theoretical Study of Angular Distribution of Plane Waves in a Small Reverberation Chamber for Simulating Multipath Environment and Testing Mobile Phones," *IEEE Antennas and Propagation Society International Symposium, 2001 Digest*, Vol. 3, 2001, pp. 358–361, doi: 10.1109/APS.2001.960107.
2. P.-S. Kildal and J. Carlsson, "New Approach to OTA Testing: RIMP and Pure-LOS Reference Environments & a Hypothesis," *Antennas and Propagation (EuCAP)*, 7th European Conference, 2013, pp. 315–318.
3. M. Schilliger Kildal, *The Random Line-of-sight Over-the-air Measurement System*, Ph.D. Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2020.
4. "Simulation and Verification of Wireless Technologies (SIVERT)," *Vinnova FFI report 2017–05502*, Dec. 2021.

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