Perfect Vision for Autonomous Vehicles

Straightforward Analysis and Characterization of Plastic Materials for Radar Systems

Autonomous and semi-autonomous vehicles rely on a complex hardware and software architecture that uses data from many different types of sensors. In order to generate reliable data, the sensors require an undisturbed view of the surroundings. For example, plastic parts used in radar systems must not disturb the functioning of the sensors. Comprehensive tests are required to investigate the suitability of such parts for radar applications. Specialized measuring systems and test setups can greatly simplify the testing process.

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Radar technology is based on transmission and reception of electromagnetic waves in the radio frequency (RF) range. Radar has been used for many years as a positioning technique in applications such as navigation. Due to the growing importance of sensors in many automotive applications all the way through autonomous driving, the automotive industry finds itself increasingly reliant on radar technology. Radar sensors have a significant engineering design advantage since they can be covered with materials that are optically opaque. This is because radar waves have a significantly different wavelength compared to visible light. However, the materials used in the protective cover (commonly known as a radome) and the sensor's mounting position can influence the results of radar measurements. Comprehensive tests are thus required in order to ensure proper functioning of the sensors. Complex measuring systems are needed for investigation of the attachment parts and emblems in the appropriate frequency band. Rohde & Schwarz has presented a system of this type for use especially during development of complex design emblems [1]. The system allows analysis of single-layered plastic parts and can help to tap into potential savings during characterization of parts in terms of radar transparency.

The behavior of radar radiation on a radome can be illustrated with an analogy to how light behaves on a window pane: the radiation can pass through the material and illuminate the space behind it. If the radiation is reflected at a boundary surface, however, disruptive effects are produced. Since unsuitable radomes can likewise produce disruptive multiple reflections that influence the image of the surroundings, spatially resolved measurement of the reflections can help to improve the quality of data in the radar system. **Figure 1** illustrates the effects that typically occur on a radome. Besides general frequency considerations, it is important to pay attention to the homogeneity of the radome. Inhomogeneous components can distort the previously planar wavefronts (**Fig. 2**) and corrupt the sensor's view of the surroundings.

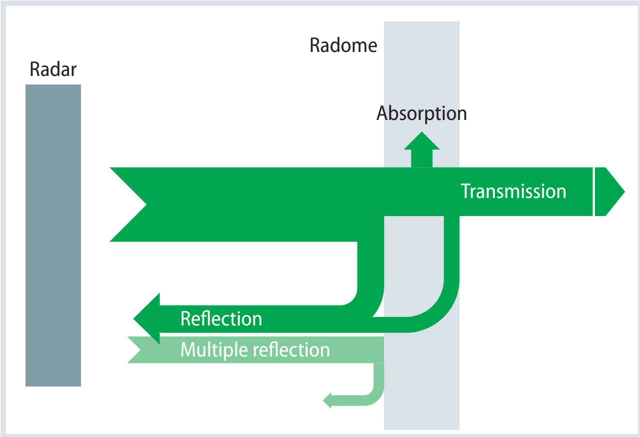

Fig. 1. Reflection, absorption and transmission on a radome: since the target reflects the signal, a maximum allowable two-way loss is always defined for radomes Source: Rohde & Schwarz; graphic: © Hanser

Characterizing Materials with a Vector Network Analyzer

Vector network analyzers (VNAs) are very useful for general characterization of materials in the radar frequency band. These instruments are available for various frequency ranges and come in a variety of price and quality levels. One major challenge in material characterization involves positioning of the item under test (IUT) in the beam path of the instrument. In general, there are two different approaches [2]. In the first approach, the sample is trimmed to a compact format and directly inserted into the waveguide. While this procedure has the highest precision, it is also the most costly in terms of preparation. Moreover, the sample is destroyed. As an alternative, a quasi-optical setup can be used. The setup must first be fully characterized and calibrated. However, this approach gives the user more flexibility in terms of the geometrical dimensions of the sample. It is still critical to ensure that the sample is precisely positioned.

Both approaches require trained personnel due to the high level of expertise in RF engineering needed to calibrate the measuring instrument and the overall test setup. However, a measuring system that is less complex and can be operated by less experienced personnel can also be used to verify the properties and material parameters. A system of this kind can be used, for example, as part of the measurement equipment deployed during production of emblems, or for characterization of plastic materials during the development phase.

Measuring System with Reduced Complexity

For development of complex radomes and radar attachment parts, the R&S QAR quality automotive radome tester from Rohde & Schwarz is a very powerful instrument. It can determine at the push of a button whether the sensor has a clear view of the surroundings. The general radar suitability, e.g. the thickness and homogeneity of the component, can be analyzed with the aid of the R&S QAR-K10 software from Rohde & Schwarz. **Figure 3** shows an example of the measurement results that are produced.

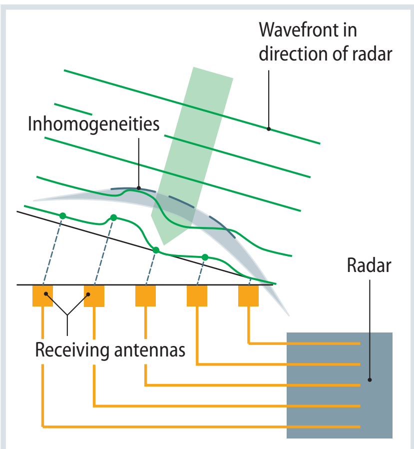

Fig. 2. The wavefront is distorted by inhomogeneities in the radome and provides a distorted image of the surroundings to the radar sensor Source: Rohde & Schwarz; graphic: © Hanser

The light areas reflect the incoming radiation and interfere with the signal. The dark areas exhibit low reflections and are generally suitable for placement of radar sensors. Phase discontinuities can occur in the material at the boundaries between areas of low and high reflectivity. They can potentially cause errors in the radar during angle detection of targets and thus corrupt the radar sensor's image of the surroundings. If the data is corrupted, even intelligent software is unable to draw appropriate conclusions.

Differences between Tests in Production and Development

Due to the safety-critical nature of radar attachment parts, 100% testing is required in production. However, the requirements for measurements in production differ to some extent from the requirements in development. Furthermore, the measuring system must support automated evaluation of IUTs. Based on the measured parameters, the radomes can be defined as suitable or unsuitable and labeled accordingly.

Even if 100% testing is mandatory in production, this does not automatically mean that the same level of accuracy is required for the measurements like in development. By suitably reducing the number of parameters to be measured, the complexity of the test setup can be decreased – along with the acquisition costs and the measurement time during production. In this way, delay times in production can also be reduced.

Figure 4 shows an example for the same radome as in **Figure 3** but with reduced resolution. This example illustrates the phase response of the beams through »

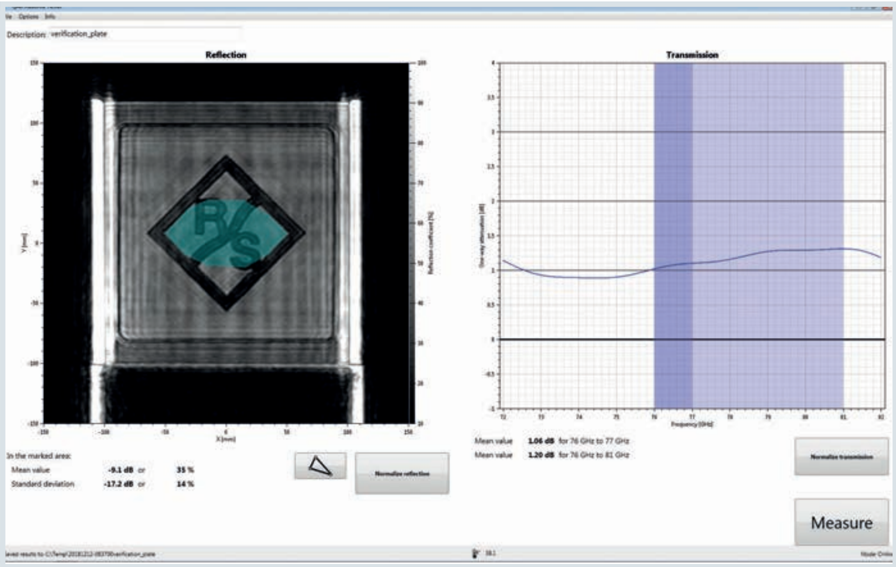

Fig. 3. Spatially resolved reflection image for a design emblem (left) with transmission curve vs. frequency (right): through analysis, it is possible to determine whether the radar sensor provides a meaningful picture of the surroundings © Rohde & Schwarz

the radome (as opposed to the reflectivity). The physical correlation of the data justifies the direct comparison of homogeneity in the reflection as well as the phase response of the test specimen [3]. Since the homogeneity of the emblems was optimized during development and the status thereof was certified with the aid of a radar from the radar manufacturer, it can be assumed that the homogeneity is basically suitable for the application and only needs to be monitored. For production, it is sufficient to ensure that the quality of the manufactured materials is uniform. A lower-resolution reflection image (allowing faster analysis) is therefore acceptable during production testing.

Identical Quality despite Lower Resolution

Furthermore, it makes sense to monitor the thickness during production. This step can be implemented on the basis of a transmission or reflection measurement vs. frequency (**Fig. 5**). The optima in the transmission loss as well as the reflection are also physically correlated for loss-free radomes. As a result, direct conclusions are allowable. The amplitude of the fluctuation is much more significant in the reflection measurement in case of matching compared to the transmission measurement. It can be possible to determine any production tolerances more clearly in this manner.

Through analysis of the homogeneity and monitoring of the frequency response of the transmission loss and reflectivity of the component, it is possible to ensure uniformly high quality in production despite using lower resolution for the test parameters. Due to the lower complexity, this helps to reduce both the test time and the cycle time and also to achieve direct investment savings for the measurement equipment.

By standardizing the test parameters, radomes can also be tested on a non-radar-dependent basis. This eliminates the need to purchase specialized test stations for different radar manufacturers. Testing with the aid of a reference radar sensor is no longer required in production. Due to direct compatibility between the measurements performed in development and production, uniformly high radome quality can be ensured without having to define and take into account different test methods and parameters for production. This leads to test parameters in development and production that are transparent, correlated, adaptable and easy to monitor – an important step towards ensuring proper functioning of radar systems.

Material Characterization with an Over-the-Air Setup

Another potential application of the measurement instrument involves uncomplicated over-the-air (OTA) characterization of plastic materials along with easy analysis of radar suitability. Until now, this application required complex

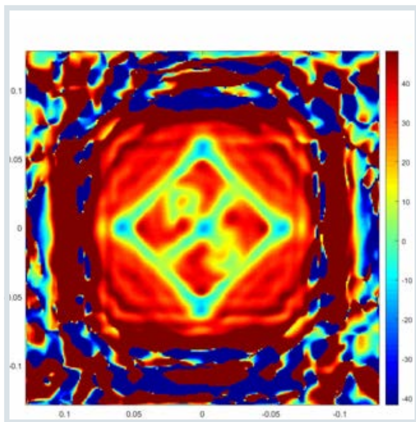

Fig. 4. Visualization of the phase response for the same radome from Figure 1 analyzed with an R&S QAR system: phase angle distortions are clearly visible © Rohde & Schwarz

The Authors

Andreas von Lösecke has worked in Product Management for Imaging Products at Rohde & Schwarz since 2018. He is responsible for automotive applications.
Yannic Kessler has been responsible for the strategic area of radar transparency as Business Development Manager for Future Mobility and Battery Concepts at LyondellBasell since 2019.

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References & Digital Version

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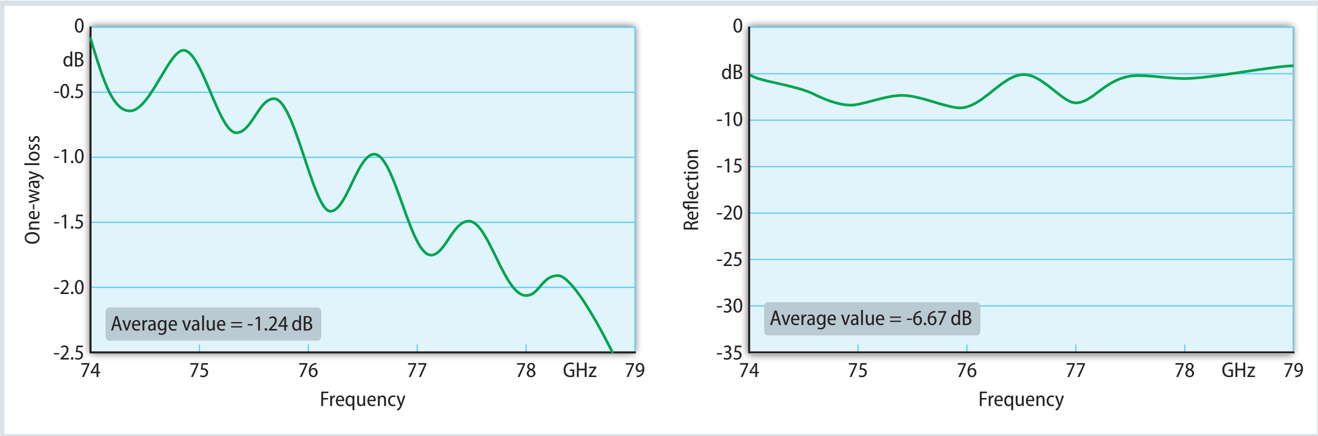

Fig. 5. Measurement of transmission loss vs. frequency (left) with reflection values (right), in each case for both sides of the radome: the differences in the reflection curve can be explained on the basis of the different measurement procedures, the inhomogeneity of the IUT and the different measurement surfaces that were selected Source: Rohde & Schwarz; graphic: © Hanser

systems using vector network analyzers that had to be operated by a trained expert. Using the approach presented here, it is possible to perform material characterization with the aid of a minimal setup that is easy to operate.

As an example, the accuracy of measurement is illustrated for a plastic sheet from the company LyondellBasell. The engineering plastics and polypropylene (PP) compounds manufactured by LyondellBasell are used in many different applications in the automotive sector. These materials can be optimized in terms of radar transparency. The sample considered here is an injection-molded sheet with a thickness of 2.5 mm. The material is Schulablend M/MK6501 LE (a blend of acrylonitrile butadiene styrene and polyamide; ABS+PA). The parameters can be assessed in quality control or material development.

In simplified terms, the relative permittivity is responsible for the deformation of waves in the material. Ideal wall thicknesses are obtained at a multiple of half the wavelength in the material. This is due to cancellation of the reflection through destructive interference which is triggered at the material transitions between air and plastic as well as between plastic and air [3].

The material characteristics can be calculated using information about the material thickness based on determination of the resonance frequency as follows:

$$\varepsilon_r = (\frac{c_0}{f_R \cdot d})^2$$

Due to the different angles of incidence produced during the imaging process, a correction term is required in the setup presented here. The relative permittivity is thus determined as follows:

$$\varepsilon_r = (\frac{c_0}{f_R \cdot d})^2 + \sin \partial_i^{\,2}$$

c_0 represents the speed of light, f_R the determined resonance frequency in the material, and d the material thickness. The average angle of incidence of the setup ϑ_i also enters into the correction term. **Figure 6** shows the frequency curve for the measured reflection. Based on the location of the minimum (resonance frequency f_R) a value of 2.83 was obtained for the permittivity ε_r of the sheet. For the same material thickness, a value of 2.80 was obtained for ε_r using a quasi-optical setup in a complex material characterization process. The value of ε_r as well as the sharpness of the minimum can be influenced by material manufacturers, thus allowing optimization of materials for radome applications. Optimization of this kind requires determination of the permeability during development as well as determination of the minima of the reflection and transmission curves. This standardized procedure can also be used to directly compare the influence of a multilayer system (e.g. in combination with paint) and thus detect negative interactions early in the development process.

The described approach helps to accelerate and simplify the steps involved in carrying out material characterizations and optimizations. In this manner, a standardized method for determination of radar permeability can thus be integrated into quality control. The quality of the starting materials can be analyzed beforehand to avoid high follow-up costs in later production steps. ■

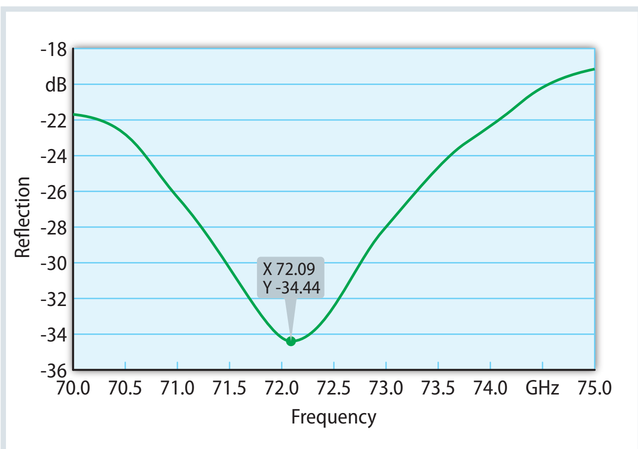

Fig. 6. Frequency response for the reflection measurement on a sheet of Schulablend M/MK 6501 LE: the determined permittivity value is practically equivalent to the result obtained through costly materials testing Source: Rohde & Schwarz; graphic: © Hanser