FUNDAMENTALS OF RADOME AND BUMPER MEASUREMENTS USING THE R&S®QAR

White paper | Version 01.00

ROHDE&SCHWARZ

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CONTENTS

This white paper deals with fundamentals of radomes and testing. It is intended to educate the reader on the complex process of radome production and evaluation. It describes the physical incident of rays transmitting through the radome and why thickness does not necessarily mean more attenuation. This paper also deals with the measurement principle and highlights some important instrument features that the operator needs to take into consideration when measuring.

1 NECESSITY OF RADOME TESTING

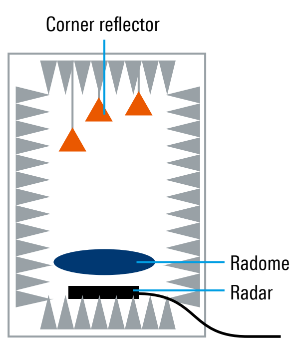
A wide range of sensors have made their way into autonomous vehicles: cameras to recognize lanes and traffic signs and assist with parking, ultrasonic sensors for near-range object detection and radars to determine the velocity and distance of moving objects. All this data is merged together to provide the vehicle with an impression of its surroundings.

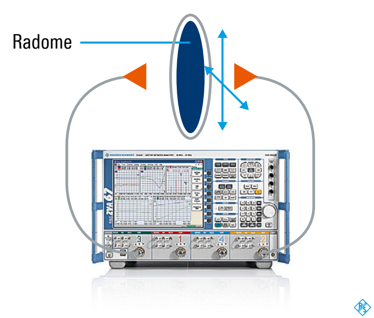
One advantage of radar sensors is that they have a different frequency than the spectrum of visible light. This means they are not distorted by e.g. fog and rain and not blinded by bright light. They can also be hidden behind nontransparent surfaces. This makes it very attractive for designers to hide these sensors behind parts such as design emblems and bumpers.

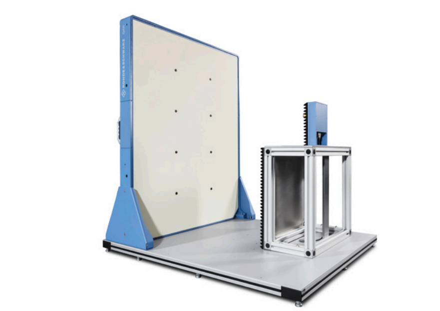
However, these parts must be checked for radar compatibility. In the past, there were mainly two different methods available. The aim of this section is to compare those methods with what can be achieved with R&S®QAR measurements (see Fig. 1).

Method	Corner reflectors	Network analyzer	R&S®QAR

Description

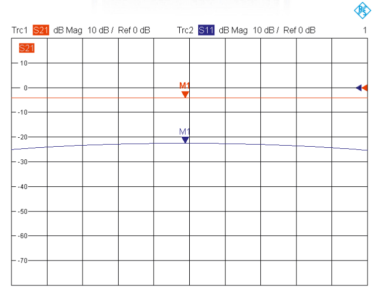






Result

Measurement point	Two-way attenuator	Azimuth error
#1	1.2 dB	0.2°
#2	1.4 dB	0.1°
#3	1.6 dB	0.3°



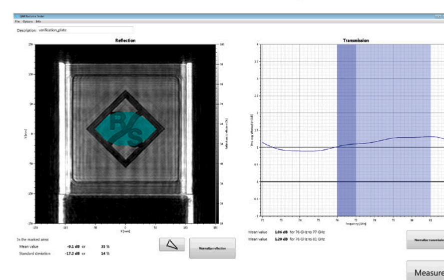


Fig. 1: Comparison of different methods for analyzing radomes in R&D and production

A method widely used in production is to use corner reflectors mounted at a certain distance and angle to the radar. The first measurement is taken as a reference without a radome. The second measurement is taken with the radome mounted. The results from these two measurements are subtracted to determine the influence of the radome on the radar performance.

This method is quick and easy to set up and intuitive to interpret, which is the main reason why it has been used in production testing for level 1 and level 2 autonomous cars. It has the disadvantage that it is not possible to draw conclusions about the homogeneity and reflection of the radome since the transmission loss is only evaluated at 2 to 4 points (depending on the number of reflectors). Another issue is that the results are sensor specific. A radome that has good results with a sensor from manufacturer A may not necessarily return good results when tested with radars from manufacturer B. Section 2.3 describes this phenomena in detail. This testing method is not sufficient for more automated level 2+ and level 3 cars.

Another widely spread testing method is to use network analyzers. The result of this measurement is a full set of S-parameters (in other words reflection and transmission loss measured from both sides of the DUT). In order to obtain the electrical parameters of a raw material, the network analyzer is the instrument of choice. It operates over a wide frequency range and offers precise measurement results. Unfortunately, getting a spatially resolved picture of the radome takes a huge amount of time. Usually, the measurement of one radome takes about four to six hours depending on the required resolution. And highly skilled experts are needed to operate the instrument. That is why this method is not used in production plants.

The R&S®QAR provides a unique combination of the advantages of measuring with a network analyzer and corner reflectors. The results are quickly available since full evaluation only takes about 7 s, and the homogeneity of the radome is measured. The intuitive results provide the operator with a quick and easy way to interpret the measurement results of the radome under test.

2 FUNDAMENTALS OF RADOMES

The most basic kind of radome is a sheet of a dielectric material with thickness d and permittivity ε_r. More complex radomes consist of multiple layers with different physical dimensions and material parameters. Fig. 2 shows a schematic representation of a multilayer radome. The following section gives a short insight into the reflection and transmission behavior of single layer radomes.

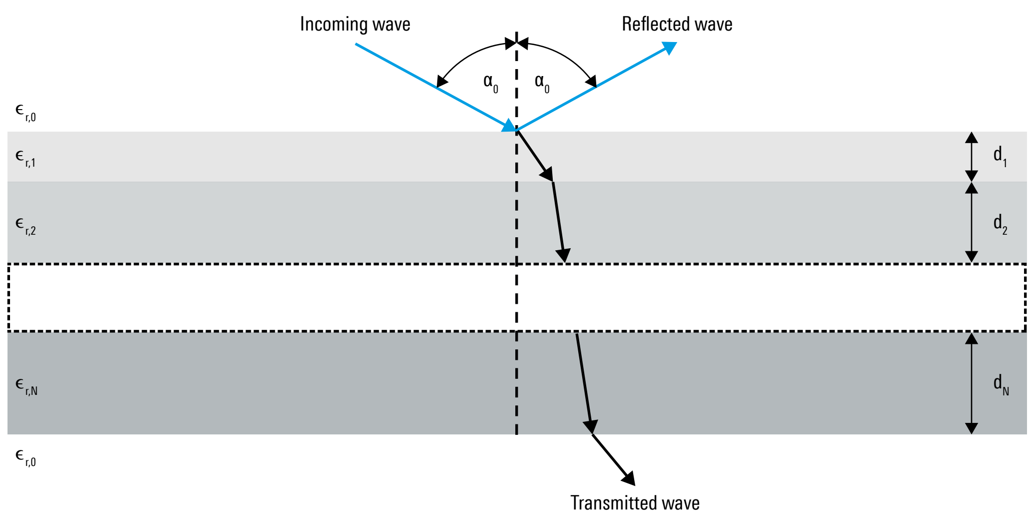


Fig. 2: Radome with multiple layers

2.1 Single layer radome

Let us assume a single layer radome for easier understanding.

An incoming wave will be reflected at the transition between the air and the dielectric material (see Fig. 3).

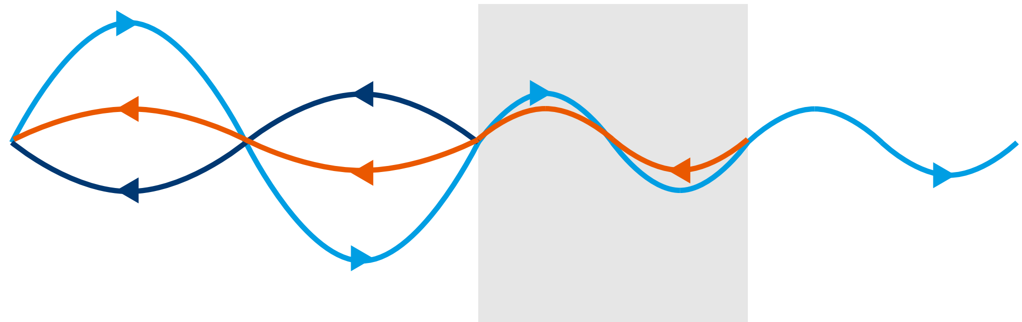


Fig. 3: Schematic waves interfering with a single layer radome

The incident wave moving from left to right is shown in light blue. The reflected wave of the first reflection is dark blue. Part of the light blue incident wave enters the material sheet and is reflected at the boundary between the material and the surrounding air. Since the reflection coefficient of the right transition is the negative reflection coefficient of the left transition, a 180° phase shift is introduced in the reflected wave. The overall phase shift between the dark blue and red reflected waves depends on the electrical length of the material sheet. If the electrical length of the sheet is equivalent to half the wavelength (or a multiple thereof) inside the material, the two reflected waves have a phase difference of 180° and therefore interfere destructively.

$$\Delta\phi = 2 \cdot \frac{d}{\lambda} \cdot 360° + 180°$$

One can see from the calculations that for a thickness $n \cdot \frac{\lambda}{4}$, where n is an uneven number, the phase difference $\Delta\phi$ is 0° or 360° or a multiple thereof; the waves interfere positively and the reflection of the material is high.

The reflection not only depends on the thickness of the material but also on the permittivity of the material.

The reflection coefficient for an exemplary radome with only one layer is simulated in Fig. 4. The relative permittivity of the sheet is chosen to be ε_r = 2.75, *tanδ* = 0.01. This is similar to the permittivity of a polycarbonate sheet.

As explained before, the reflection coefficient of the radome varies periodically with the thickness of the sheet (see Fig. 4). The blue line is the reflection coefficient of a sheet with an angle of incident of 0°. The red line is the reflection coefficient of the same sheet but at an angle of incident of 20°.

The electrical length of the material becomes smaller as the angle of incident increases. Therefore, the physical thickness of the sheet has to increase to achieve the minimum reflection.

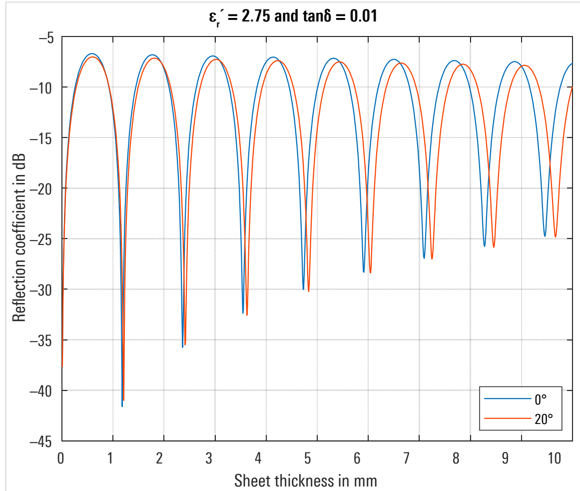


Fig. 4: Reflection coefficient of a material sheet at two angles of incident

The one-way attenuation or transmission attenuation of the radome is shown in Fig. 5. The attenuation is minimal when the reflection is minimal. For low thicknesses, the reflectivity of the sheet dominates the one-way attenuation. For thick radomes with layers greater than two times the wavelength, the attenuation of the material becomes more and more important.

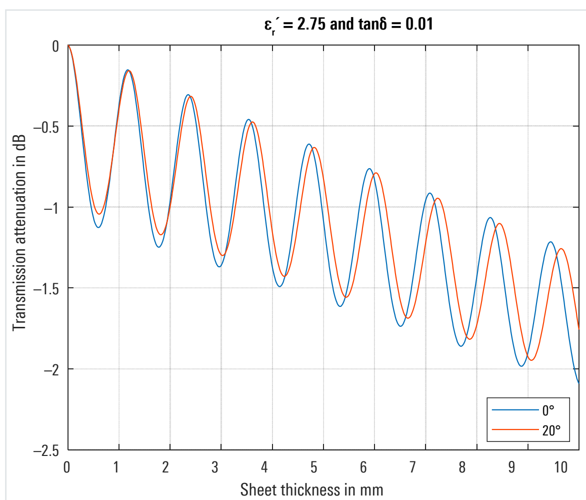


Fig. 5: Transmission attenuation of a material sheet at two angles of incident

2.2 Experimental verification

The dependence of the reflectivity on the thickness of the material can easily be seen in a sheet with different thicknesses.

A polycarbonate sheet milled in steps of varying thicknesses is tested. The steps have a width of 1 cm and differ 200 µm in thickness between each step. A schematic representation of the measurement setup is shown in Fig. 6. The used material has an ε_r between 2.7 and 2.8. The dissipation factor tan(δ) is around 0.01. The wavelength inside the material can be calculated with the formula:

$$\lambda_{PC} = \frac{c_0}{f}\frac{1}{\sqrt{\varepsilon_r}}$$

At 76.5 GHz (center frequency of the R&S®QAR), this results in a half wavelength of around 1.19 mm. The reflection coefficient should therefore be minimal every 1.19 mm of sheet thickness. The reflection is color coded in the R&S®QAR measurement result. Bright colors represent large reflection values, dark colors represent areas with low reflection.

A picture of the sheet as seen by the R&S®QAR is shown in Fig. 6. As expected, the reflection is minimal every sixth step (corresponding to 1.2 mm).

The R&S®QAR depicts the reflectivity as different shades of gray. Dark areas have less reflectivity than bright areas. The four bright dots in Fig. 7 are the metal screws holding the polycarbonate sheet in place. These screws have a reflectivity of 100 % or 0 dB. The dark horizontal stripes are the milled steps with the least reflection. Their thickness is multiples of $\frac{\lambda_{PC}}{2}$.

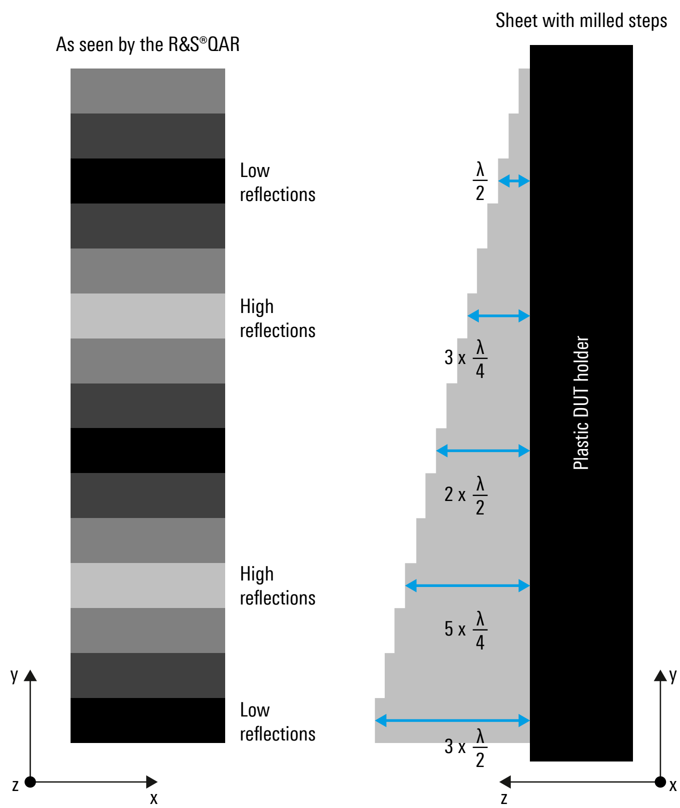


Fig. 6: Image of the milled test plate with different thickness

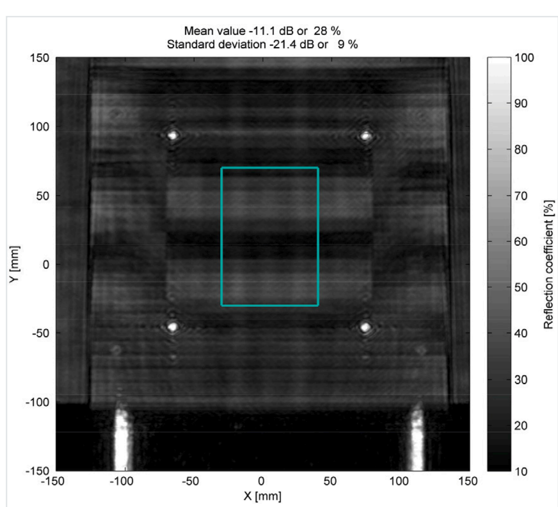


Fig. 7: Picture taken by the R&S®QAR.
The reflection measurement results are color coded and repeat about every 1.2 mm of thickness difference due to the interference effects described.

Another interesting effect can be seen in the area where the milled polycarbonate (PC) sheet overlaps the black plastic of the DUT holder. The zones of minimum reflection are shifted to steps of different thickness. This is a result of the different reflection coefficients between the front air/PC reflection and the back PC/holder reflection.

In addition, the DUT holder has a limited thickness and will therefore have frequency-dependent reflectivity resonances.

2.3 Challenges in radome design

Autonomous vehicles have increased requirements on the radome quality. In order to ensure compliance with the specification, a new measurement method is needed. When using corner reflectors during end-of-line testing, the homogeneity of radomes cannot be extensively evaluated. And the measurement results are only applicable for a certain radar/radome combination, making it unattractive for industry.

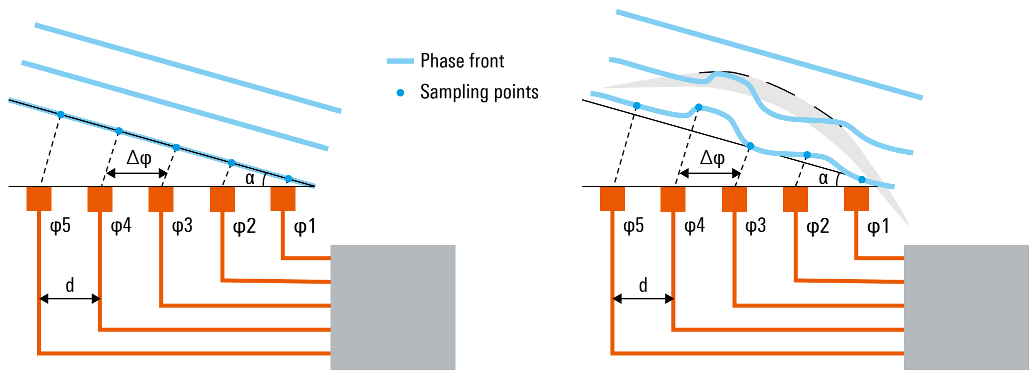


Fig. 8: Angle of arrival (AoA) estimation using the electrical phase of the reflected signal
Left: without radome, right: with improper radome and phase deviations

Fig. 8 shows the bending effect by using line representations symbolizing the respective phase fronts. The shades of gray symbolize the different radome materials. Each of these materials has a different permittivity, causing the rays to bend and influencing the speed of the signal. Therefore, when it leaves the radome again, the wavefront is no longer a straight line.

The structures that can possibly influence the radar waves might be very tiny. If the radome is not high quality, there might be additional air gaps, glue, etc. within the radome and its layers. All these effects cannot be seen by the human eye or by measuring the radome with a network analyzer. Only the R&S®QAR can highlight these structures. By knowing these structures, it is possible to draw conclusions about the radome quality and determine good positions for the radar.

In order to calculate or measure these effects, it would be necessary to precisely measure the permittivity and thickness of each layer. This is challenging with today's technology. The R&S®QAR provides the ability to analyze the homogeneity and find good radomes and positions for the radar. The final accuracy is dependent on the spacing of the radar antennas.

The imaging applied by the R&S®QAR makes it possible to evaluate these structures and helps avoid the use of improper radomes in autonomous vehicles.

2.4 Radome design with the R&S®QAR

Modern radomes consist of multiple layers. It can be difficult to calculate or simulate the reflections, especially when different kinds of paint and coatings in various patterns are involved.

The R&S®QAR can help with the design of these radomes. The image of the measured radome shows areas with high reflectivity in a bright color. Additional matching structures can be implemented to specifically reduce the reflectivity in these areas and increase the homogeneity of the radome.

The R&S®QAR also helps in the fabrication of radomes. Injection points or air bubbles in the radome can distort the radar image. These distortions can be seen and localized in the R&S®QAR image. With this knowledge, fabrication processes can be optimized. These errors would otherwise be very hard to locate.

More information on the interpretation of the captured measurement data is summarized in section 3.2. The Microwave Journal article referenced in the literature section provides detailed insights into radome development and testing.

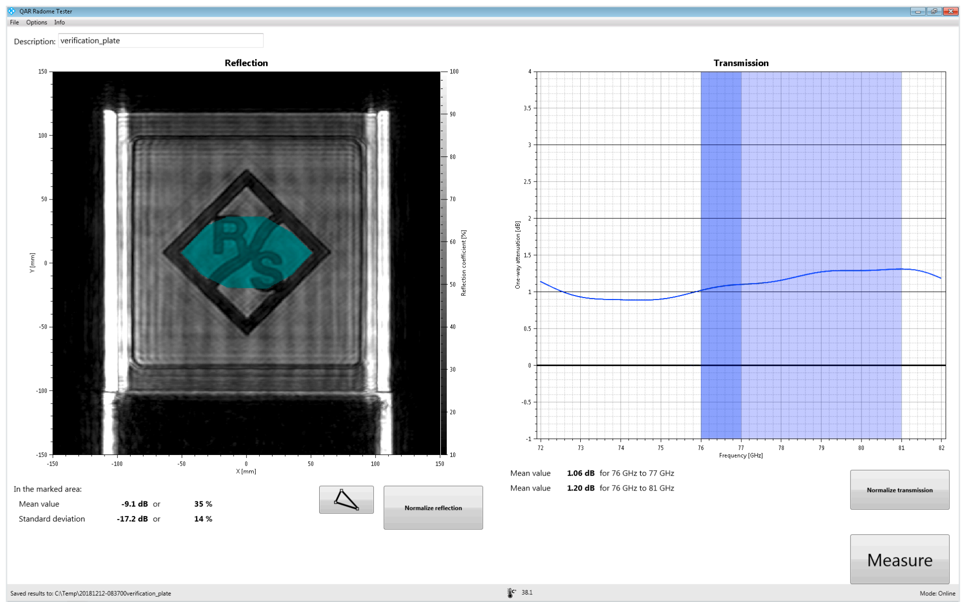


Fig. 9: User interface of the R&S®QAR showing the result of a radome measurement in transmission loss and reflection

Fig. 9 shows the user interface of the R&S®QAR. The result of the reflection measurement is shown on the left. Inhomogeneities in the radome can be evaluated using the measurement result. The result of the transmission loss measurement (Fig. 9 on the right) helps developers adapt the radome thickness to the radar frequency. More on the interpretation of measurement results can be found in section 4.

3 MEASUREMENT PRINCIPLE OF THE R&S®QAR

The following section discusses the measurement principle of the R&S®QAR. Two measurements are made and recorded: the transmission loss and the reflection data. The transmission loss is frequency resolved, while the reflection data is spatially resolved. This allows for various interpretations of the data and enables simple error analysis.

The R&S®QAR consists of a large panel with around 1200 transmit and receive antennas. It works similar to a MIMO radar, where a massive number of virtual antennas is created by correlating the transmit and receive antennas. A more detailed description of the imaging process is given in the respective sections.

3.1 Transmission loss

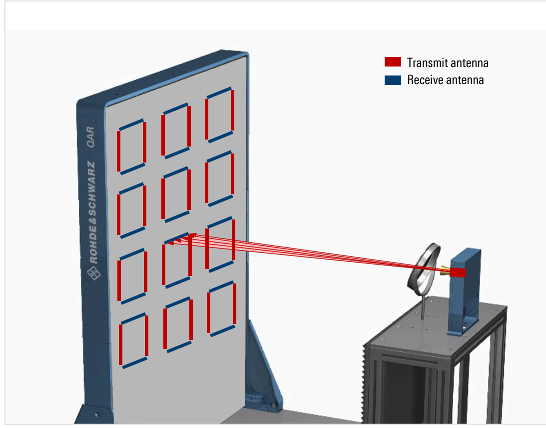


Fig. 10: Measurement of transmission loss using the R&S®QAR

For transmission loss measurements, the R&S®QAR-Z10 external transmit antenna is required. The external transmit antenna (shown in Fig. 10 on the right) acts as a source for transmission loss measurements. Transmission loss measurements are performed from 72 GHz to 82 GHz, perfectly covering the automotive radar frequency range from 76 GHz to 77 GHz.

The adjacent bandwidths allow the user to judge the frequency-wise adaptation of the thickness of the radome material. For single layer radomes, it can be said that if the lowest attenuation is reached with a lower frequency, the chosen material is too thick. If a lower attenuation is reached with higher frequencies, the material is too thin.

3.1.1 Transmission loss measurement

The measurement itself is performed with one single line of receive antennas activated. The signal transmitted from the external antenna (right) is then received by the line of antennas on the panel (left) at exactly the same height. The antenna patterns of the patch antennas on the panels do not play a role at the measurement distance. The spot size of the measurement is depicted by the antenna pattern of the transmit antenna. The diagram on the left in Fig. 11 shows the antenna pattern of the transmit antenna.

In order to reach a certain spot size, the user needs to choose the measurement distance accordingly.

The diagram shown in Fig. 11 on the right is intended to help the user choose the right distance between the transmit antenna and the material under test. It shows the approximate radius of the 3 dB and 6 dB antenna patterns. The spot size itself needs to be cooperatively defined by the radar supplier and the vehicle manufacturer.

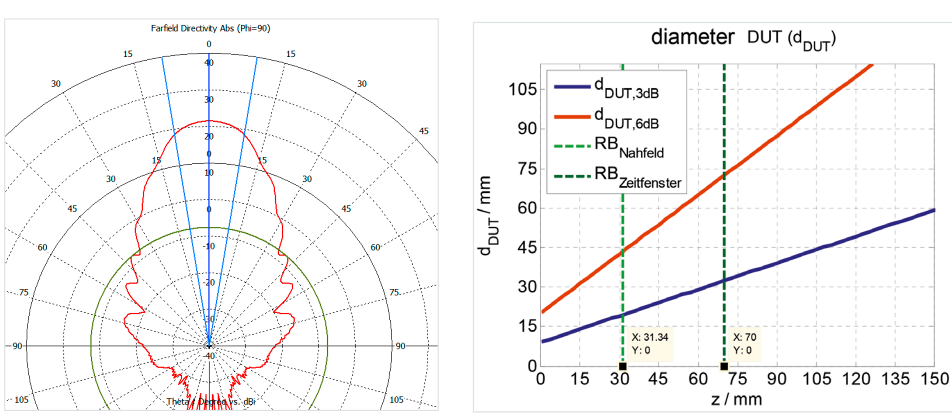


Fig. 11: Antenna pattern of the R&S®QAR-Z10 external transmit antenna option

The time gating functionality used in the verification mode delivers valid results with a distance of at least 70 mm between the material under test and the external transmit antenna. A minimum distance of 30 mm ensures that the near-field characteristics of the antenna are excluded.

In order to define the correct distance for transmission loss measurements, it is best practice to subtract around 10 mm from both sides in order to avoid border effects and sidelobes. Looking at the respective diameter on the Y-axis of the right-hand graph in Fig. 11, the necessary distance can be read on the X-axis.

3.1.2 Transmission loss normalization

In order to achieve maximum measurement accuracy, the transmission loss measurement needs to be normalized in regular intervals. The proposed length of these normalization intervals is stated in the user manual and data sheet.

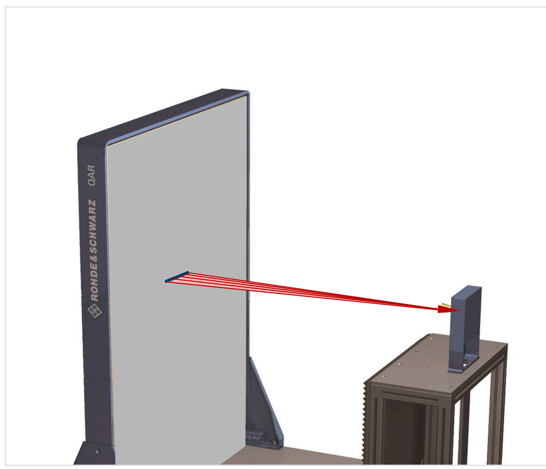


Fig. 12: Normalization of the transmission loss measurement

To perform the normalization, there should not be any objects or obstructions between the transmit antenna and the panel as shown in Fig. 12. The normalization can be started using the button on the GUI. To ensure proper normalization, verification can be performed using the verification samples supplied with the R&S®QAR-Z40 radome verification objects. More details about normalization are covered in the service manual and during service trainings. The trainings can be booked with the corresponding SLA levels.

3.2.3 Transmission loss verification

In order to verify the transmission loss measurement, the samples from the R&S®QAR-Z40 radome verification objects are used. All samples have plates with the transmission loss values printed on them. The operator needs to perform a measurement of these plates in the verification holder with the verification mode active. You can activate the verification mode in the GUI by selecting “options ▷ verification”.

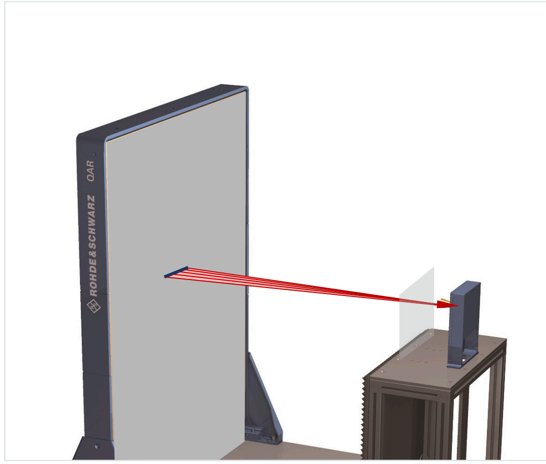


Fig. 13: Verification of the transmission loss measurement using the samples supplied with the R&S®QAR-Z40 radome verification objects

After performing the measurements, compare the transmission loss results with the transmission loss values printed on the plates. The verification kit includes three plates that cover a range of standard transmission losses for bumpers.

The transmission loss of the verification samples has been verified during the production process and is printed on the plates. The values shown in Fig. 14 need to be in line with the values imprinted on the plates. The measurement accuracy of the instrument has to be considered. a_{77} represents the mean transmission loss from 76 GHz to 77 GHz, while a_{81} represents the mean transmission loss from 76 GHz to 81 GHz.

Note: Remember to activate the verification mode in the GUI since otherwise large standing waves can occur and falsify the measurement results.

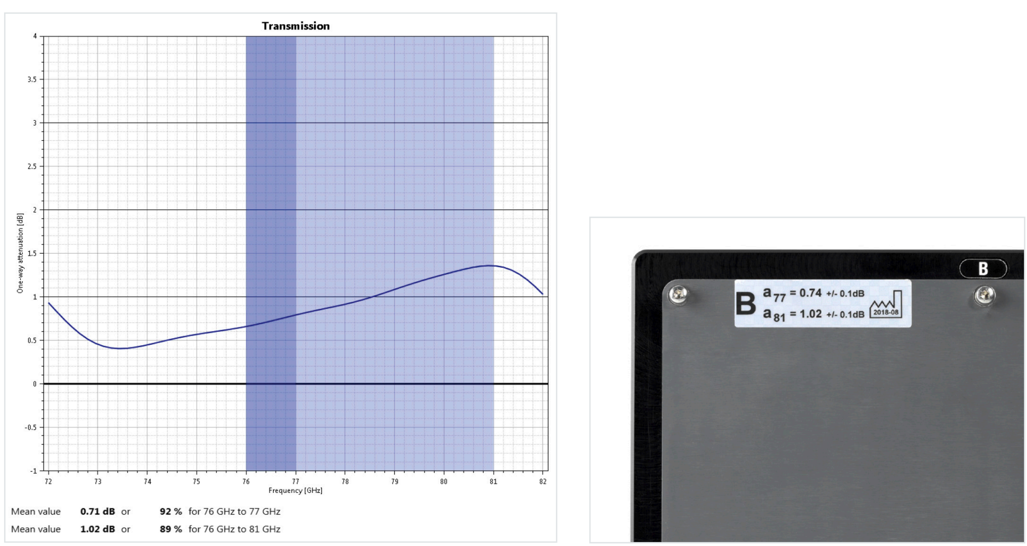


Figure 14: Comparing the results of the verification measurements with the values printed on the plate

3.2 Reflection

In order to measure the reflectivity of the radome, the R&S®QAR panel is used. The panel contains 12 clusters with 96 transmit and receive antennas each. The antennas are distributed in a way that only a few antennas are needed. This saves costs, resources and measurement time.

The data is postprocessed in the R&S®QAR system as described in the following sections.

3.2.1 Reflection measurement

For the reflectivity measurement, all of the R&S®QAR transmit antennas are switched on one after the other. The signal of each transmit antenna is sampled by every receive antenna on the panel. Most materials have spectral reflecting surfaces for millimeterwaves, meaning that the incident and emergent angles are the same.

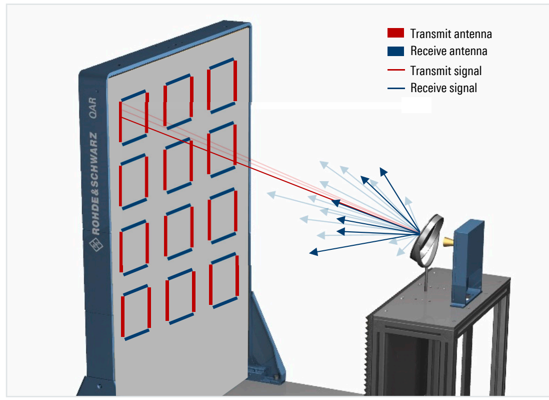


Fig. 15: Reflection measurement as performed by the R&S®QAR

Depending on the type of reflection, certain antennas will receive a significantly higher amount of reflectivity than others. The R&S®QAR works like a standard radar system, but due to its antenna design and huge aperture, the resolution of the image is much higher than is possible with an automotive radar.

The reconstruction area of the R&S®QAR imaging is a cube with the dimensions of approximately 51 cm × 35 cm × 55 cm. The maximum image projection (MIP) area is chosen as a subset of the reconstruction area. It is the area that is used for further evaluation using the max. hold function as described below and shown in Fig. 18. The exact dimensions and location of the MIP area is shown in Fig. 16.

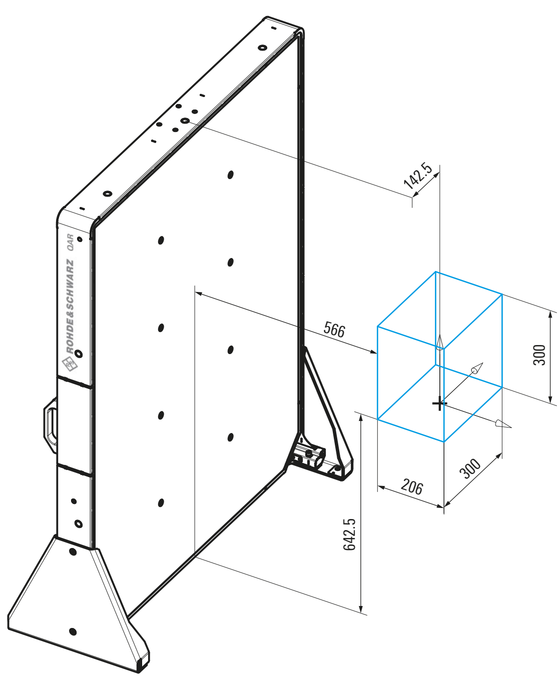


Fig. 16: Dimensions and position of the MIP area of the R&S®QAR

The user can store the volume data captured by the R&S®QAR if necessary. It can be selected in the GUI with "options ▷ recording". The volume data is very large in size (about 500 Mbyte) and contains the three dimensional data with amplitude and phase information for every voxel. The R&S®QAR performs various steps to decrease the data size. These are described below.

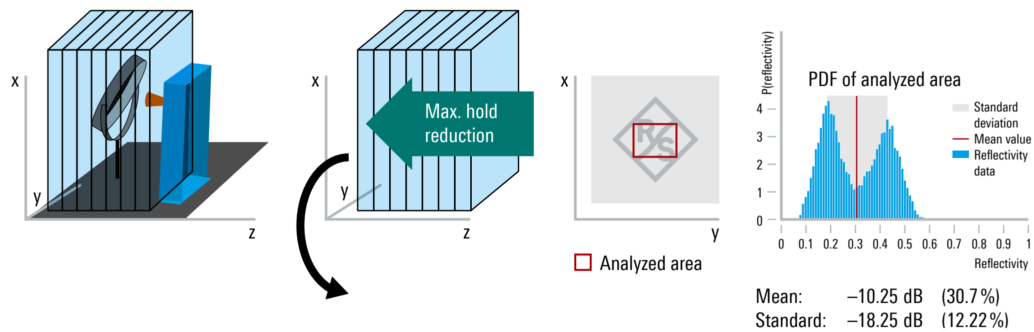


Fig. 17: Different steps of the reconstruction and data minimization

The volume for reflection measurements recorded by the R&S®QAR has a resolution of 0.5 mm in the x and y domains and approximately 6 mm in the z domain. This resolution is reached by using the huge aperture of the panel and a large bandwidth of 5 GHz (74 GHz to 79 GHz as described in the data sheet). In order to reduce the required storage, a max. hold reduction is performed in the z domain. Since the layers of the radome are usually thinner than 6 mm, a detailed analysis of the individual layers of a radome is not possible with the R&S®QAR. The image displayed by the R&S®QAR contains the maximum reflectivity values for each measurement point in the x and y domains. The user can select an area of interest that is further evaluated. In order to obtain a threshold for fast production testing, the mean value of all reflectivity values inside the previously defined area of interest together with its standard deviation is evaluated and displayed in the GUI.

The third picture from the left in Fig. 17 shows an example distribution of the reflectivity of a radome. The red rectangle is the area of further evaluation that is more deeply analyzed by the software. The reflection in this figure is color coded. Bright values represent areas with high reflection, dark values represent areas with low reflection. Inside the measurement area, two distinctive areas are visible: an area with low reflectivity (dark color) and an area with higher reflectivity (bright color). This leads to the standard deviation in this example being rather high.

The image reconstruction causes a certain amount of ripple in the reflection measurements. To reduce the ripple, use an area of at least 25 cm² to evaluate the reflectivity.

3.2.2 Reflection normalization

In order to normalize the reflection measurement, the R&S®QAR-Z40 radome verification objects option comes with a metal plate. This plate needs to be put into the provided holder. The user then presses the normalize reflection button on the GUI.

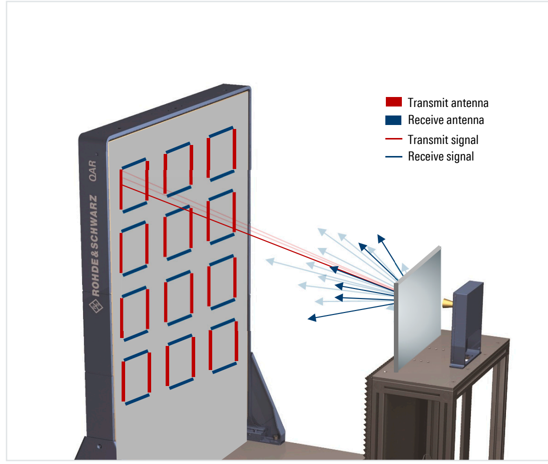


Fig. 18: Normalization of the reflection measurement using a metal plate

The metal plate reflects 100% of the energy and is therefore used as a reference for all further measurements. The measurements do need to be performed in the same plane as the verification in order to receive correct results.

4 PERFORMING MEASUREMENTS WITH THE R&S®QAR

The R&S®QAR was designed to enable quick and easy analysis of the radome's quality. This simplicity comes with a couple of risks that can be minimized by a knowledgeable user. This section provides an overview of the risks related to radome measurements with the R&S®QAR and information that will prevent users from performing incorrect and imprecise measurements.

Measurements are performed after an adequate warm-up time of 90 min and normalization (in transmission loss and reflection) of the instrument. This section will help users interpret the results and avoid wrong conclusions.

4.1 Interpretation of the transmission loss measurement

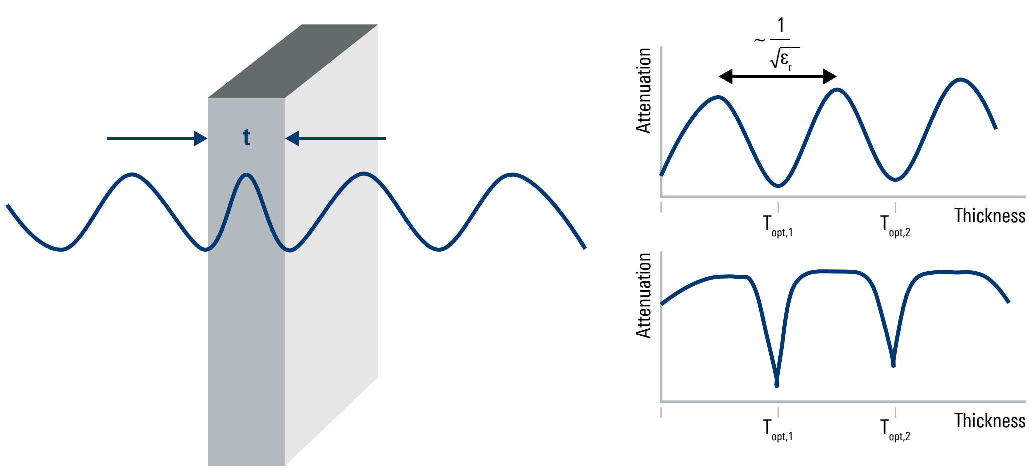


Fig. 19: Influence of wall thickness on reflection and transmission loss for single layer radomes

For single layer radomes as shown in Fig. 19, the optimal wall thickness can easily be calculated if the relative permittivity (ε_r) of the material is known. Both the attenuation and reflection have a repeating pattern influenced by the wavelength and ε_r. Reflection and transmission loss reach their minimum at $d = n \cdot \lambda/2$ where n is an integer and their maximum at $d = n \cdot \lambda/4$ where n is an odd number.

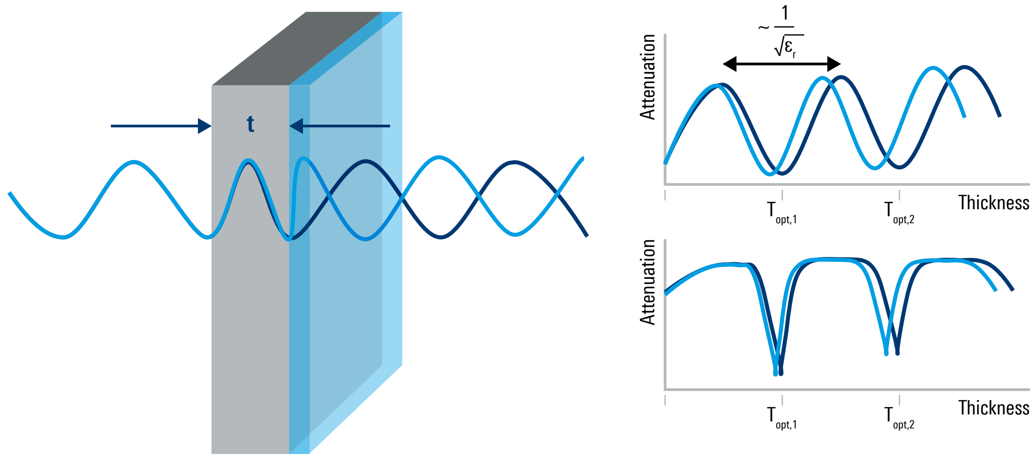


Fig. 20: Influence of paint and coatings on the optimal wall thickness of a bumper

For more complex radomes or bumpers with several coatings and paint layers, the same principle applies. But the layers sum up and the optimal thickness of a bumper after painting will not be the same as before. As illustrated in Fig. 20, the painting and coating process can drastically change the optimal wall thickness. Therefore, it is recommended to measure ready-made products only. Coatings and paints usually have a comparably large ε_r and therefore a huge impact on the optimal wall thickness even though their actual thickness is pretty small. The R&S®QAR can be used to optimize the wall thickness of radomes.

4.2 Interpretation of the reflection measurement

The R&S®QAR is the first instrument on the market that masters the challenge of measuring the inhomogeneity of automotive radomes. This inhomogeneity was the root cause of angular deviation that can cause misdetection in the automotive radar. Fig. 21 shows an example of a distorted phase front caused by a radome with large inhomogeneity.

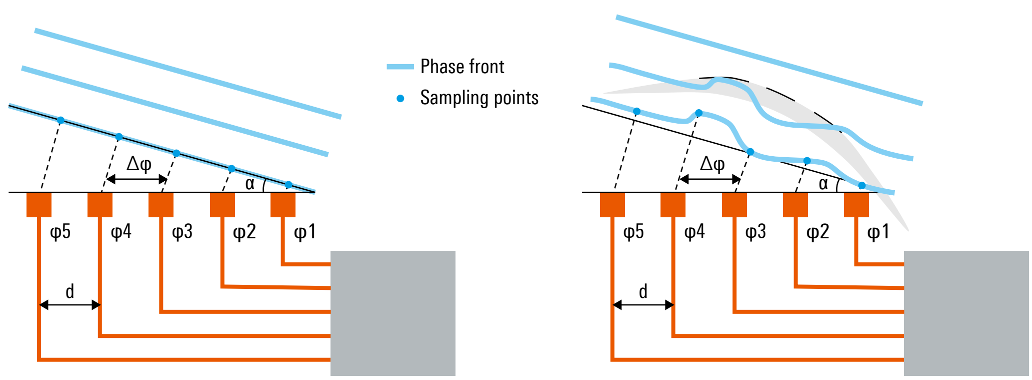


Fig. 21: Phase deviations caused by inhomogeneity of the radome and their effect in the R&S®QAR measurement

On the left side of Fig. 21, an undistorted phase is arriving at the receive antennas of the radar and the radar correctly calculates the angle of arrival (AoA). In the second case, a radome has been put on top of the radar. The radome has a certain influence on the phase front as shown on the right side of Fig. 21. The phase estimation of the radar is now influenced by the radome and might potentially be off by a fraction of 1°. With the long distances that automotive radars are dealing with, 1° is enough to be responsible for a lane mismatch and wrong interpretation of the environment. The influence on the angle of arrival cannot be determined when measuring the radome only since it is always dependent on the combination of radome and radar. If the antennas are at a different position, the angle estimation might also differ. If a radome works for a certain radar, it does not necessarily mean that it will also work well for another radar.

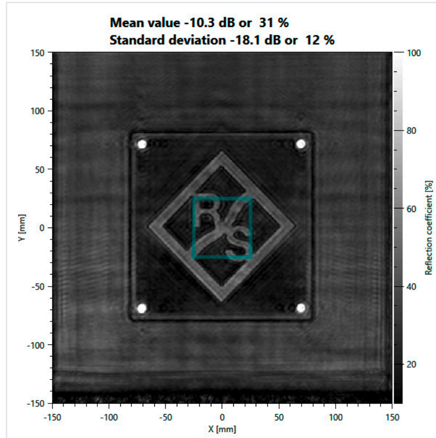
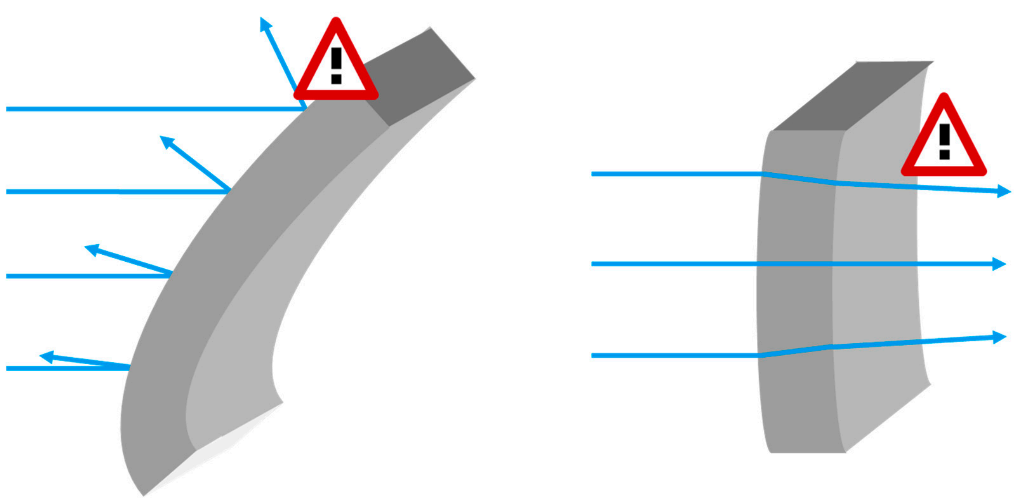


Fig. 22: Measurement result of the Rohde & Schwarz emblem with a thickness difference of 600 µm causing areas with low reflection (dark) and high reflection (bright colors).

To avoid having to deal with several test rigs at the end of a radome production line, the R&S®QAR was introduced. It provides the user with a measurement value of the homogeneity of a radome. As can be seen in Fig. 22 on the right, there are mainly two colors visible. This color coding of the reflection means that there are certain areas with high reflection and other areas with rather low reflection. The mean reflection of the radome would not be too big an issue, but the inhomogeneity might. By applying layers with adapted thickness, the homogeneity of the radome can be increased. This ensures compatibility with a larger variety of radars even though not all combinations have been tested.

4.3 Challenges when measuring radomes

As shown in section 4.1, the thickness of radomes, coatings and paints has a massive influence on the reflectivity. This is also true for the surface structure and shape. If the material forms an optical lens or the material is shaped in a way that the reflected energy does not find its way back to the panel, the displayed reflection value might be imprecise and misleading. If these samples are set up on an optical bench, the same misleading results can be generated. Fig. 23 shows two example settings where the displayed value is wrong. These effects have to be considered prior to measuring the parts.



The marked energy part is reflected outside the R&S®QAR measurement area, resulting in wrong values for reflection measurement.

The energy is focused, leading to wrong measurement values.

Fig. 23: Challenges when measuring curved surfaces

The effect on the left shows a decrease in reflection on a part that actually should be homogenous. E.g. a bumper with homogenous thickness and paint layers would show a decrease in reflection on the outer parts. In order to overcome this issue, the R&S®QAR-K60 software option for bumper measurements can be used. Instead of measuring the spatial resolved reflection of the bumper, about 100 points in transmission loss are measured using a reference reflector. When using the R&S®QAR-K60 option, the shape of the bumper does not influence the measurement result.

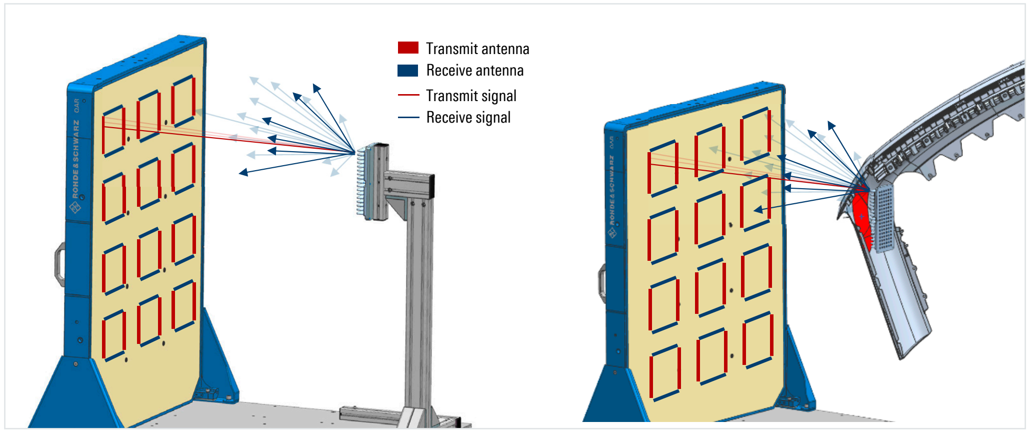


Fig. 24: Measuring transmission loss of a bumper using the R&S®QAR-K60 option

Fig. 24 shows the R&S®QAR as a setup for measuring such surfaces. An image of the needle bed reflector is taken as a reference. The bumper is positioned in front of the reflector. For details, see the "Testing bumper material for installation of automotive radar sensors" application card (PD 3609.2081.92).

The effect of the multi static of the panel also has to be taken into consideration. Using the huge aperture of about 1 m² enables high resolution imaging, but comes with the downside that not all antennas are facing exactly rectangular to the material under test. The distribution of incident angles is shown in Fig. 25.

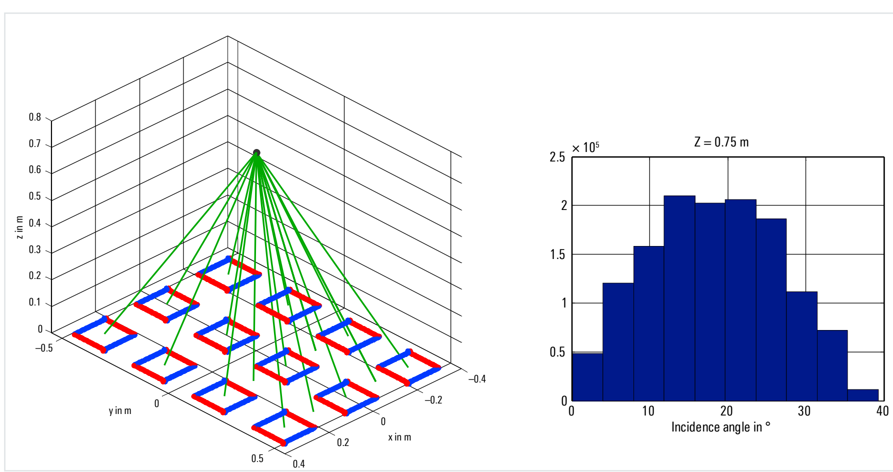


Fig. 25: Simulating the geometry of the R&S®QAR (left) and distribution of incident angles (right)

This causes a certain offset when measuring reflection values using the R&S®QAR. The instrument is the perfect tool for measuring the homogeneity of surfaces and getting an estimation of the reflection value. The following example gives the user an idea of the misalignment caused by the multi static of the R&S®QAR.

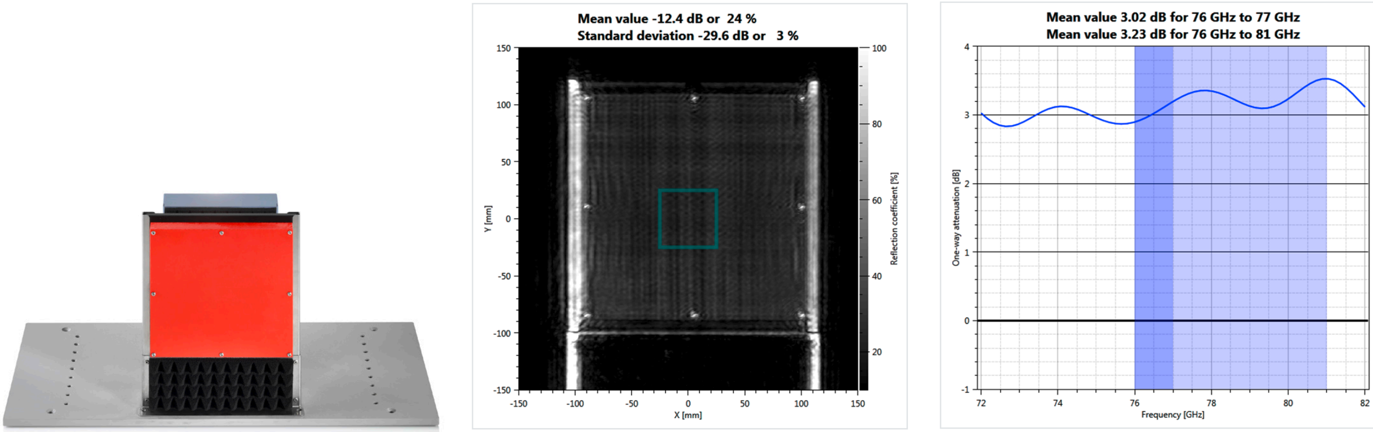


Fig. 26: Evaluation of a plastic plate using the R&S®QAR

Reflection results show a mean reflection of –12.4 dB in the range from 74 GHz to 79 GHz and a transmission loss of around 3 dB between 76 GHz and 77 GHz.

In this example, a 25 mm plastic plate is evaluated. The plate is shown on the left in Fig. 26. The R&S®QAR shows a reflection of –12.4 dB in the range from 74 GHz to 79 GHz. As a reference, an optical setup is used to compare the measurement results with the results captured by a vector network analyzer (VNA). Fig. 27 shows the setup on the right and the VNA result on the left. The VNA setup consists of an R&S®ZVA67 with E-band extenders mounted on an optical bench. Millimeterwave reflectors are used to focus the signal on the material under test. The setup has been extensively calibrated before the measurement.

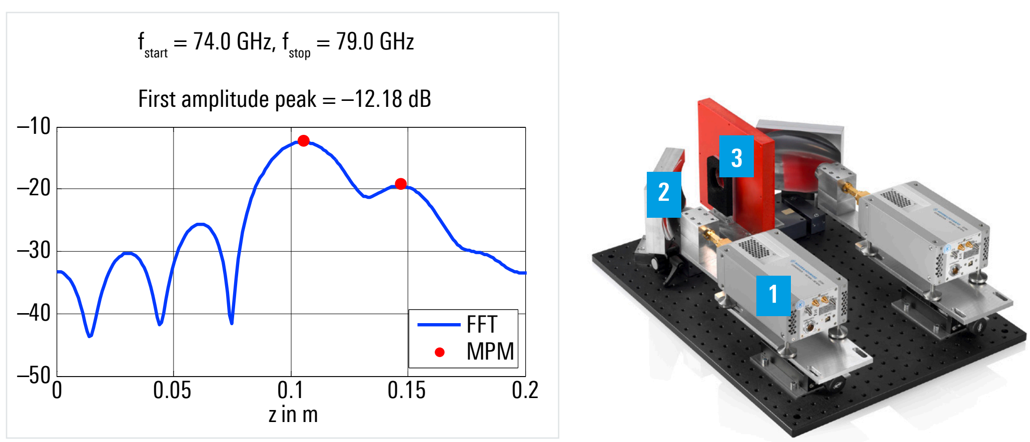


Fig. 27: Optical setup using a VNA

The measurement result for a 5 GHz pulse is shown. The VNA result displays a value of about –12.2 dB for the energy being reflected at the first air-to-material transition, giving an idea of the inaccuracy caused by the multi static of the R&S®QAR.

1: Frequency converters, 2: Optical bench, 3: Plastic plate

Due to the comparable settings on both the R&S®QAR and the R&S®ZVA and the use of the same material under test, the results can be directly compared. There is no linear relationship between the two measurement methods so the results depicted here do not allow any conclusions on other samples. They can just give an idea of the differences and variations to be expected.

There are two distinct peaks in the VNA result shown on the left in Fig. 27. The peak in the center is the reflection from the first air-to-plastic transition. The second peak represents the second transition where the signal is travelling from plastic back to air. The R&S®QAR result would contain both values in the volume data. However in this case, the data compressed as described in section 2.1 is used and therefore only the first peak is characterized by the R&S®QAR.

For this very specific plate, the R&S®QAR displays a reflection of –12.4 dB, while the VNA setup shows a value of –12.18 dB. The difference of 0.2 dB is explainable by the multi static effects. Therefore, care needs to be taken when interpreting reflectivity measurement results. Due to the rather large thickness of the plate (25 mm), both reflections (front and rear side) of the sample are separated and there is no interference. This explains why the measurement result of the R&S®QAR is very close to the result of the VNA.

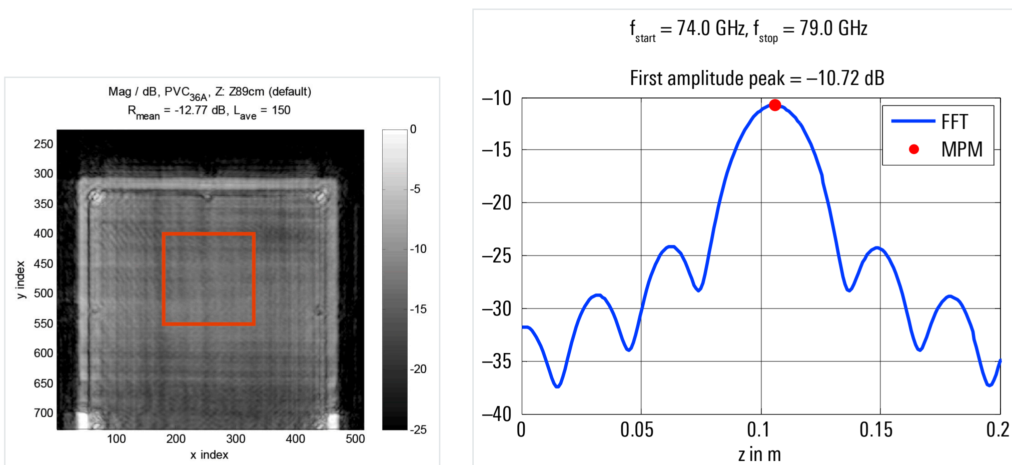


Fig. 28: Reflectivity of the 3.6 mm PVC plate; a discrepancy in the measurement result is noticeable

The second example shows the measurement of a thinner plate, where the multi static has a stronger influence. In this example, a 3.6 mm PVC plate is used. The same measurements as with the 25 mm plate are performed. Fig. 28 shows the reflectivity of the 3.6 mm PVC plate as measured with the R&S®QAR (left) and VNA (right). A discrepancy in the measurement result is noticeable. The R&S®QAR measured a reflection value of –12.77 dB while the quasi-optical setup comes up with a reflection value of –10.72 dB. Due to the multi static effects described before, the R&S®QAR measures a reflectivity that is about 2 dB higher than the reflectivity measured by a VNA setup. Therefore, R&S®QAR specific thresholds need to be applied when defining specifications for matched radomes.

There are two effects that potentially sum up in the R&S®QAR: the effect of the multi static and the summation of the two peaks (compare Fig. 27 on the left and Fig. 28 on the right) since the range resolution of the instrument is not sufficient to distinguish between the reflections coming from the two transitions (air to material to air).

Investigations are currently underway on how to correctly measure the absolute reflection values using the R&S®QAR. Please stay tuned for future software updates for the R&S®QAR regarding this issue.

5 SUMMARY

Autonomous vehicles place increased requirements on the quality of radomes. In order to ensure high quality radomes, a new measurement principle was required. Instead of using radar sensors for evaluation, a measurement device was needed. The R&S®QAR measures the homogeneity, mean reflection and transmission loss of radomes.

There are certain challenges associated with radome measurements that can currently not be solved by one single instrument. This means trade-offs have to be made. It might be necessary to adapt specifications to be compatible with the R&S®QAR. Care must be taken when setting up automation processes and in handling.

Rohde & Schwarz can help you master your measurement and integration challenges. If you have any questions regarding R&S®QAR and related applications, please contact your local Rohde & Schwarz representative.

6 REFERENCES

[1] Evaluating 77 to 79 GHz Automotive Radar Radome Emblems. Heuel, Steffen, Köppel, Tobias and Ahmed, Sherif. Microwave Journal, No. 01/2018.

[2] Determining the mounting position of automotive radar sensors. Munich: Rohde & Schwarz GmbH & Co. KG, 2019.

[3] Quality automotive radome tester analyzes your radar integration. Munich: Rohde & Schwarz GmbH & Co. KG, 2018.

[4] Testing bumper material for installation of automotive radar sensors. Munich: Rohde & Schwarz GmbH & Co. KG, 2019.

7 ORDERING INFORMATION

Designation	Type	Order No.
Panel	R&S®QAR	1336.6008.02
External transmit antenna (linear polarization)	R&S®QAR-Z10	1336.5401.02
External transmit antenna (horizontal polarization)	R&S®QAR-Z10	1336.5401.03
Floor plate	R&S®QAR-Z20	1336.5418.02
Calibration set	R&S®QAR-Z30	1336.5430.02
Radome verification objects	R&S®QAR-Z40	1336.5447.02
Bumper verification objects	R&S®QAR-Z41	1336.5499.02
Positioning verification objects	R&S®QAR-Z42	1336.5530.02
Mounting table	R&S®QAR-Z50	1336.5424.02
Reference reflector	R&S®QAR-Z60	1336.5453.02
Stand for reference reflector	R&S®QAR-Z61	1336.5476.02
Absorber wall	R&S®QAR-Z70	1336.5460.02
Software for radome measurement (with GUI)	R&S®QAR-K10	1336.5501.02
OPC interface for radome measurements	R&S®QAR-K11	1340.5219.02
Software for bumper measurements (with GUI)	R&S®QAR-K60	1336.5482.02
OPC interface for bumper measurements	R&S®QAR-K61	1340.5225.02
Software for radar positioning	R&S®QAR-K100	1336.5518.02

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PD 3608.0833.52 | Version 01.00 | March 2020 (sk)
White paper | Fundamentals of radome and bumper measurements using the R&S®QAR
Data without tolerance limits is not binding | Subject to change

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