Absorber Characterisation for Over-the-Air Radar Target Stimulation on Automotive Test Rigs

Michael Vorderderfler[1], Michael E. Gadringer[2], Wolfgang Bösch[3], Erich Leitgeb[4]

Institute of Microwave and Photonic Engineering, Graz University of Technology, Graz, Austria

{[1]michael.vorderderfler, [2]michael.gadringer, [3]wbosch, [4]erich.leitgeb}@tugraz.at

***Abstract* — Testing of automotive radar systems is mandatory to provide high safety standards in automated and autonomous driving systems. Full vehicle tests with a ready to drive car are often carried out on automotive dyno test rigs. To test the radar sensor within the whole system a radar target stimulator can be used to save space and ensure reproducibility of the tests. However, over the air stimulation is sensitive to the industrial environment on such automotive test rig. Reflections and scattering on metal surfaces cause clutter and undesired ghost targets. To guarantee reliable tests on these test rigs, a suitable absorber concept has to be developed to suppress these reflections. To achieve this, the environment at an automotive test rig was analysed and the demands on absorbers were identified. Based on this information, a measurement for comprehensive absorber characterisation was designed, allowing to find an absorber that fulfils the demands of this application.**

***Keywords* — radar applications, reflectivity, millimeter wave measurements, over-the-air.**

I. Introduction

Radar sensors become more and more important in the automotive industry. These sensors are integrated in modern vehicles to gain an improvement in safety and support upcoming automated and autonomous driving capabilities with important information on the environment. To provide the reliability needed for this functionality on a system level, major tests of the ready-to-drive car have to be performed. These tests have either to be conducted with real targets for the radar module, requiring very large test halls, or can alternatively be accomplished using a radar target stimulator (RTS). An RTS is able to generate artificial targets which are detected as valid objects by the radar sensor. This method is very space-saving and also gives the opportunity to test different scenarios with guaranteed reproducibility. These advantages trigger the development of multiple different concepts for radar target stimulators [1-2].

One such concept is over-the-air (OTA) stimulation, where the RTS receives the radar signal, modifies it and sends it back to the radar. The modifications include a delay to provide distance information, a Doppler shift for velocity and signal attenuation to configure the size of the object. An RTS based on the OTA principle is of course sensitive to the environment. This is not a big issue for end-of-line testing because these tests can take place in laboratory conditions using an anechoic chamber. In contrast the environment sensitivity of such RTS becomes challenging in the full vehicle test on an automotive test rig – a rough industrial environment.

Such industrial environment can cause scattering and undesired reflections to microwaves. To prevent this, a suitable absorber setup has to be developed to provide reasonable testing conditions [3].

II. Demands on Absorbers in RTS on a Test Rig

To make the challenge more clear, a possible RTS setup on an automotive test rig is depicted in Fig. 1a. In this figure, the car is placed on rollers of the dyno testbed. There it performs a typical driving scenario with acceleration as well as deceleration and braking phases. Though the car is fixed to the ground by belts to keep it in place, it moves back and forth in a range of 5 cm to 10 cm. This movement, as well as the movement of the fixture belts, makes it difficult to install stimulation equipment directly in front of the radar sensor. Additionally, the car's engine needs a constant flow of cool air to prevent overheating. On the one hand, this airflow should not be blocked by any obstacles. On the other hand, equipment not fixed well is blown away by the air flow.

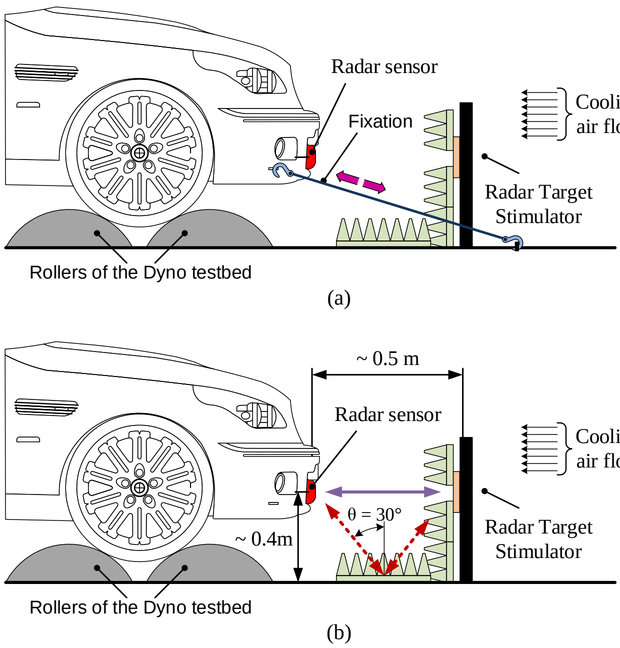

Fig. 1. (a) Radar Target Stimulator (RTS) setup at an automotive test rig. (b) RTS test rig setup showing paths of reflections

Disregarding these mechanical issues, the environment of an automotive test rig is crowded with metal. These surfaces cause reflections, multipath propagation as well as scattering. These effects may introduce unwanted clutter detected by the radar sensor. On a real road, objects moving with the same velocity as the radar sensor have zero Doppler shift. All other objects are affected by it. This fact is used to eliminate parts of the clutter by the radar´s signal processing. On a test rig however, the car is physically not moving and neither is the environment. So the radar is not able to distinguish between an object moving with the same speed and the environment. Hence, the radar sensor is not able to eliminate this clutter anymore.

Another problem caused by the reflections are ghost targets. This is illustrated by Fig. 1b. The dotted line indicates a possible reflection caused by the floor leading to multi path propagation compared to the direct path (solid line). This can create a ghost target near the wanted target generated by the RTS. Also the frontend of the RTS itself can be the reason for the radar sensor to see an unwanted close range target.

Last but not least, strong direct reflections with a high power level compared to other targets could block the radar sensor and lead to unwanted behaviour.

To get rid of these problems, suitable absorbers and their proper placement in respect to the mechanical restrictions are mandatory for such test setup. This means, unwanted reflections have to be attenuated to a level at which the radar does not detect them as a real targets anymore. The power level of a radar target at the radar sensor is dependent of the distance and the size of the target or radar cross section (RCS). For our RTS this range of target generation covers 2.5 m to 250 m. The power ratio provided by the RTS between minimum and maximum range targets equals 40 dB (one way path loss) for the given factor 100 in distance. The dynamic range for the target size is given by the minimum and maximum size of targets generated. For a pedestrian as a minimum size target the radar cross section equals about 1 m^2 and for a lorry as maximum target size the RCS is about 50-100 m^2. This gives us a target dynamic range of 20 dB. The total dynamic range sums up to 60 dB for our target. Hence, if absorbers can attenuate reflections by 60dB, we get rid of unwanted ghost targets. This is the main demand on absorbers.

As many absorber manufacturers provide little to no information on the performance of the absorbers at the mm-wave frequency range, we decided to characterise their performance at different angles of arrival (Fig. 1b).

III. Measurement Design

To characterise microwave absorbers for this application, we designed a suitable measurement system for our anechoic chamber (5 x 5 x 4.5m). This system had to be able to determine the absorption or reflectivity of the device under test (DUT) at different angles of arrival. The basic concept was to send a continuous sine wave from a transmitter to a receiver using the DUT as a reflector (Fig. 2, Fig. 4). The transmitter antenna targets the DUT and the power reflected by it is then received and determined by a spectrum analyser. The received provides the needed information to calculate the level of absorption of the absorber.

As transmitter, a signal generator in combination with a frequency multiplier was used. The output of the multiplier was connected to a WR12 waveguide horn antenna. The DUT was positioned on a turntable in the centre of the anechoic chamber. The used receiver consists of two horn antennas connected to two harmonic mixers and spectrum analysers. The benefit of using two different receive channels is the simultaneous recording of horizontal and vertical polarization of the incoming wave.

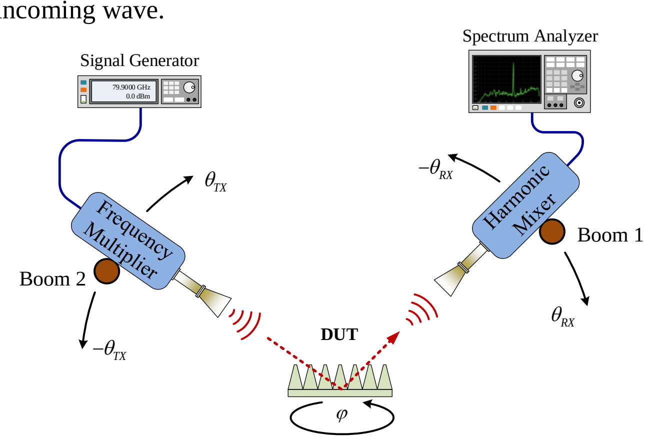

Fig. 2. Measurement setup 1, transmitted measurement

Our anechoic chamber is equipped with two independent moveable booms. These booms are circularly moveable in a distance of 1.5 m around the centre of the anechoic chamber. We mounted each, the transmitter and the receiver, on one of these booms. This allowed us to independently adjust the position of receiver and transmitter around the DUT. By this configuration (transmissive-setup) the measurement setup fulfilled our requirements of measuring the reflection of the DUT at different incident and emergent angles except one special case: the measurement of direct reflections back to the transmitter.

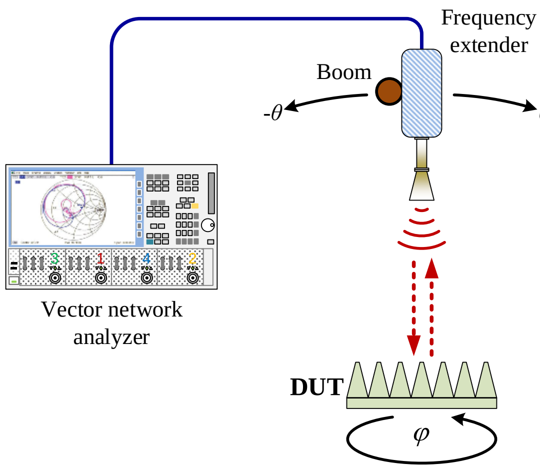

Fig. 3. Measurement setup 2, direct reflection measurement

The mechanical restrictions of the booms do not allow us to move them to the same position at one time. This aspect in addition to the increased coupling of transmit and receive antennas when positioned too close, restricts us from detecting the direct reflections of the absorber back to the transmitter. Therefore we implemented a second measurement setup. This setup consists of a vector network analyser (VNA) in combination with a frequency extender which was mounted on one of the booms in our anechoic chamber (Fig. 3). The antenna was again a waveguide horn antenna. In this configuration we performed a one port measurement (S11) with the VNA to determine the direct reflectivity of the DUT. This direct-reflectivity measurement setup completes our measurement methods.

Before any absorber was characterised, empty chamber measurements were performed to serve as a reference. This gives us the needed information to recalculate the absorber performance from the measured power level.

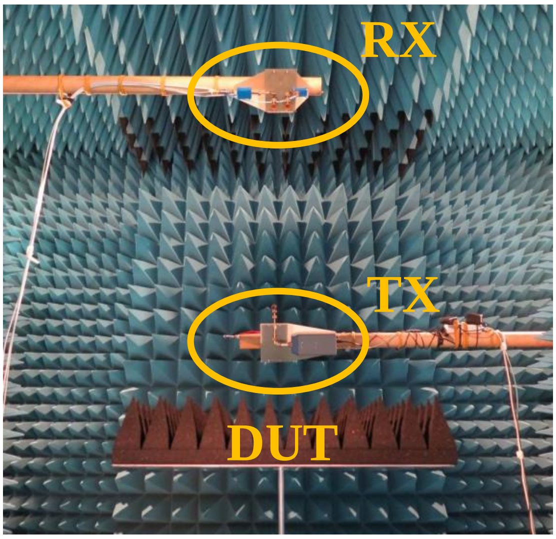

Fig. 4. Transmission measurement setup in anechoic chamber

IV. Measurement Results

During the measurement campaign multiple different types of absorbers were investigated. In this work we have chosen a pyramidal foam absorber shown in Fig. 5 as an example.

The associated results for both, transmissive and reflective measurements, are discussed in this section. The plot shown in Fig. 6 represents the transmissive measurement at 77 GHz. The transmitter for this measurement is positioned at an angle of 30 degrees from zenith, comparable to the position of the automotive radar sensor in Fig. 1b. The results in Fig. 6 show that the overall performance of this absorber is not suitable for our application as the maximum absorption is around 40 dB instead of the desired 60 dB. The performance decreases continuously as the angular distance of the RX boom to the zenith increases. Additionally, the plot gives evidence, that rotating the DUT on the turntable (x-axis) has no significant influence on the performance.

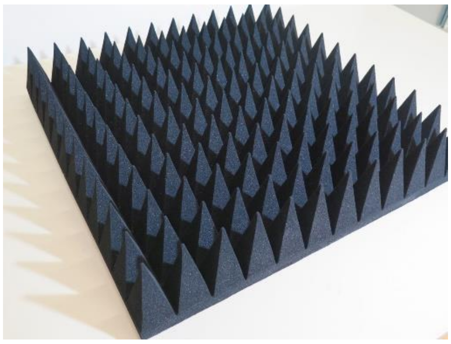

Fig. 5. Pyramidal foam absorber

The plot in Fig. 7 shows the standard deviation of the absorber performance over the frequency for the transmissive measurement. The measurement for these measurements was performed from 70 GHz to 85 GHz. This representation makes clear that the performance of microwave absorbers is not stable over a greater frequency range. The aberrations gain a maximum at elevation positions for the receiver between $\theta = 15°$ to $\theta = 35°$.

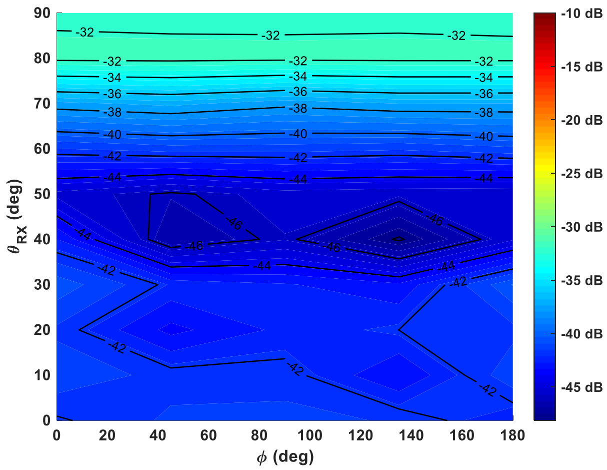

Fig. 6. Transmissive measurement of absorber performance

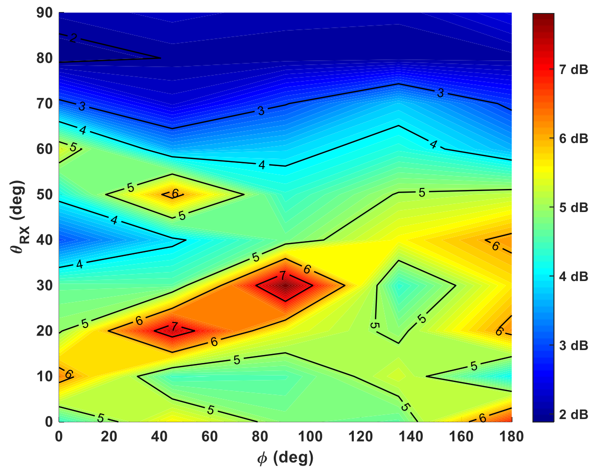

Fig. 7. Standard deviation of the absorption over frequency

The next step was the measurement of the reflective performance of the DUT. The plot in Fig. 8 shows a time domain reflectometry (TDR) measurement of an absorber and a metal plate which was placed on the top of the absorber. In this way, we were able to get a reference distance and reference magnitude for the reflectivity of a metallic surface. The TDR was calculated utilizing inverse Fourier transform of the measured S11. The VNA was configured to measure S11 from 70 GHz to 95 GHz. For the frequency range from DC to 70 GHz zeros were inserted. The dotted red line shows the measured result of the absorber only. The solid blue line visualises the TDR with a metal plate on top of the absorber. Comparing the two measurements a distance of 8 cm between the major reflections can be noticed. This distance is equal to the height of the absorber. The magnitude difference between the reflection produced by the backside of the absorber and the metal plate on top of the absorber is 65 dB. The absorber itself was mounted on a metal plate. This means the attenuation of the absorber is roughly 65 dB at $\theta = 0°$ which would fulfil our demand.

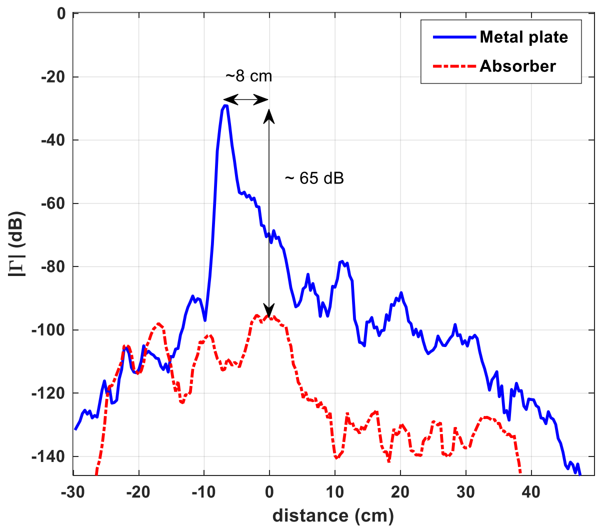

Fig. 8. TDR of reflective measurement

As in a real system 60dB attenuation over multiple angles is needed, a sweep over different angles was done. The result is provided in Fig. 9. Here we can recognise the elevation angle dependent performance of the absorber. Clutter in the TDR was identified to be caused by the absorbers of the anechoic chamber that are not designed for this frequency range. The absorber shows the best performance at an elevation angle of $\theta = 0°$. Looking at $\theta = 20°$, the performance of the absorber is significantly lower. Doing similar subtraction as before the resulting absorption is about 45 to 50 dB, which would not be acceptable.

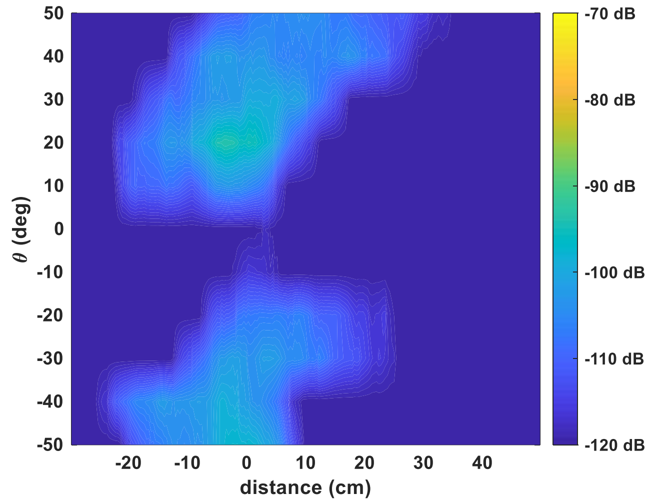

Fig. 9. Absolute values of |Γ| obtained by reflective measurement over multiple angles

V. Conclusion

Industrial environment of an automotive test rig requires a proper absorber setup for OTA RTS. Finding such absorber setup is however not straight forward. Our measurements illustrated that absorbers have to be investigated in detail to find a proper setup.

In particular, our experiment has illustrated that the chosen absorber may seem suitable from one perspective, but prove to be completely useless from the other. As shown in our measurement example, the performance of the absorber from the reflectivity point of view would make it a good choice for our application. But the transmission measurement revealed that we have to take a closer look especially at the angle dependency of absorbers. Future investigations will focus on these results and how they can be utilised to develop an appropriate absorber setup.

References

[1] M. E. Gadringer *et al.*, “Virtual reality for automotive radars,” *Elektrotech. Inftech.*, vol. 135, 4-5, pp. 335–343, 2018

[2] W. Scheiblhofer, R. Feger, A. Haderer, and A. Stelzer, “A low-cost multi-target simulator for FMCW radar system calibration and testing,” in *2017 47th European Microwave Conference: 10-12 October 2017, Nuremburg, Germany*, Nuremberg, 2017, pp. 1191–1194.

[3] M. E. Asghar, S. B. J. Gowdu, J. Nagel, F. Baumgartner, R. Stephan, and M. A. Hein, “Evaluation of absorber configuration for a low clutter environment for over-the-air automotive radar testing,” in *2019 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM)*, Detroit, MI, USA, Apr. 2019 - Apr. 2019, pp. 1–4.