Application Note

Anritsu envision : ensure

E-Band Based Car Radar Emblem Measurements

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Contents

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Automotive radar systems must operate in complex and dynamic environments where interactions with the host vehicle and its surroundings can have a significant impact on their performance. In particular, the material properties of the vehicle bumpers and location of the radar behind or within the bumper can impact performance. This application note will provide insight into the theory of frequency-modulated continuous wave (FMCW) car radars, their application, and their placement in a car chassis. It will also discuss how various types of dielectric material in front of the radar antennas (e.g., antenna dome or color-coated bumper) influences the radar's performance. This document will describe a way to characterize the 2D insertion loss of flat material slabs and logo emblems that are used today to cover the car radar sensors, and will present 2D measurements of the dielectric properties of such materials.

1.0 Introduction

With continued customer demand for advanced automotive safety systems like automatic emergency braking, blind-spot detection, lane-change assist, and adaptive cruise control (to name just a few), manufacturers continue to utilize automotive radar systems to enable these functionalities. Radar systems have proven to have inherent advantages that make them an ideal solution (all-weather, better measurements, detection of more objects, easily incorporated in to the design of the car, and more). These radar systems typically fall into three categories: short-range radar (SRR), ultra-wideband SRR (UWB SRR), and long-range radar (LRR) (Figure 1).

For example, with a range of 10 to 250 meters, LRR systems are often used for adaptive cruise control (ACC) systems. These impact driver safety and convenience, as well as increasing capacity of roads by maintaining optimal separation between vehicles and reducing driver errors. Utilizing LRR-provided data (transverse, longitudinal, and relative velocity), ACC is then able to make necessary adjustments based on the pre-selected car speed by moderately influencing breaking and acceleration. Typically, the LRR used is designed for an angular range of up to ±10° and a distance range of 10 to 150 m, which enables the adjustment of the automobile's velocity between 30 to 180 km/h.

SRR and UWB SRR systems, with a shorter range of .5 to 30 meters, are more typically used in automobile safety systems and commonly referred to as advanced driver-assistance systems (ADAS). These include functions such as blind spot detection (BSD), collision mitigation (CM), and lane change assist (LCA) radar systems. The focus of these systems is to enable applications like 360° degrees vehicle surveillance, object identification and distinction, rear-end crash avoidance, and car-to-car infrastructure communication (CAR2X). In the past, these radar systems were implemented in the 21.65 to 26.65 GHz frequency range. However, due to interference with radio astronomy and earth exploration applications, the European Union (EU) decided to migrate these radar applications to the 77 to 81 GHz band beginning July, 1, 2018 (use of this band in the US will not be available after 2021[1]). This has caused new issues with where and how the SRR and UWB SRR sensors are mounted on the car chassis as this can affect performance. Materials and coatings of radomes[1], emblems, and bumper skins can also interfere with the radar systems and pose a danger to drivers, passengers, and pedestrians.

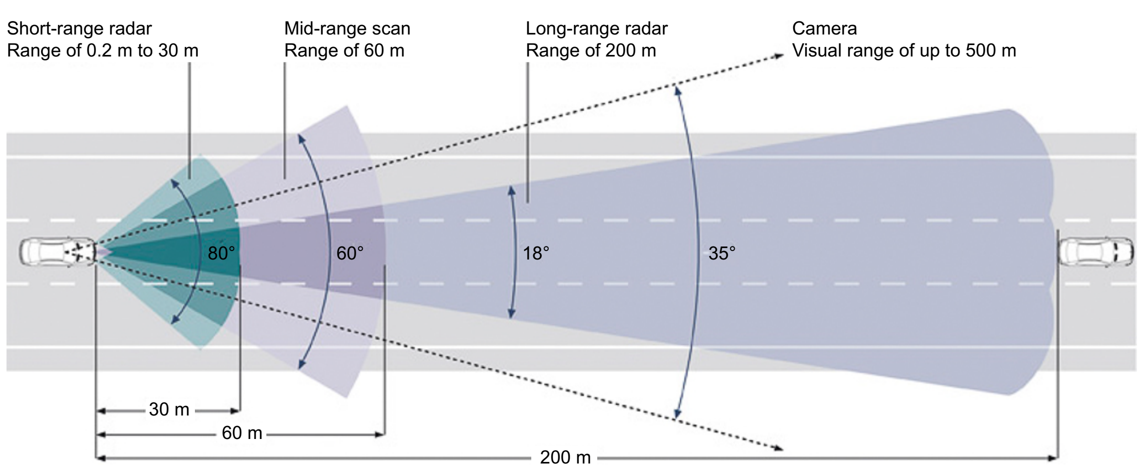

Figure 1. Typical Car Radar Field of View (FOV) and Range Distance

Even the demand for novel colors and effects for automobile chassis can potentially have a negative effect on the system signal quality. Manufacturers and after-market providers must understand and account for the attenuating and reflective effects that a car emblem, bumper material, or paint (e.g., metallic paint) might have.

[1] Radome = Antenna Dome, https://en.wikipedia.org/wiki/Radome

With the increase in cars manufactured with radar systems on roads and highways, along with the increased dependency on these systems, it is becoming critical that these manufacturers and after-market service providers have a complete understanding of how various materials used to build their products affect these various radar systems at microwave frequencies.

2.0 Car Radar Deployment and Positioning

When you look at the various cars available today, there are generally two different design styles used to incorporate the automotive radar system in to the overall aesthetic of the car. One is a more modern design that prominently features the radar systems to highlight their use of current technology, while the other (and more popular) places these systems in a more unobtrusive location (e.g., behind the car bumper or in-between or behind the brand emblem built-in to the radiator cowling [Figure 2]). In this implementation, often times the emblem or bumper is used as a type kind of radome to protect and hide the car radar antennas. However, this radome must be neutral and transparent in order for the electromagnetic radar waves to transmit properly. As we will see later on, this requirement might be hard to achieve, especially in safety relevant applications.

Figure 2. Examples for Open LRR Sensor Installed

Considered the marque position for a manufacturer's logo – the car emblem. Found on the front grill, these are typically used as a cover in front of the actual radome that protects the radar transmit and receive antennas. Some of these are made using a chrome-plated application. While the chrome-plating of the emblem may look slightly raised, it is often embedded and part of the "flat surface" of such cover. These radome covers are often made of a radio frequency transparent plastic cover plate that is placed on the back of the emblem or mounted to the radiator struts through recesses. In order to imitate the chrome look, a molecular metal layer (e.g., Indium) is applied and finally back-injected with opaque plastic. The metal layer must be very thin compared to the penetration depth of the radar frequency in order for it to be largely transparent to millimeter-waves (mmWaves).

Other automobile companies attach their radar systems behind the car bumpers, essentially making it the radome [2]. The bumpers are made of composite plastics covered with lacquer and paint. LRR sensors are operated in the frequency range between 76 and 77 GHz. In this frequency range, some paint colors (e.g., silver metallic), which have a high concentration of metal particles, will impact the radar beam and might restrict a placement behind painted plastic surfaces with high reflections and transmission losses.

3.0 Car Radar Technology

In almost all ACC systems, a 77 GHz LRR system is used and typically mounted behind the car emblem. Transmit and receive patch antennas of the radar are focused by a dielectric lens and operate at a 4 mm wavelength range. The radar beam looks through the car emblem and the reflected signal from the target is thus exposed twice to the influence of the radome [3]. While the measurement principle seems intuitively simple, the requirements for automation and safety are enormous. The advantage of using a frequency-modulated continuous wave radar (FMCW radar[2]) is that not only can it measure the distance of other vehicles, but more importantly, it can directly measure the speed at which they are travelling.

[2] Wolff, Christian Frequency-Modulated Continuous-Wave Radar (FMCW Radar), Radar Basics. Retrieved from: http://www.radartutorial.eu/02.basics/Frequency%20Modulated%20Continuous%20Wave%20Radar.en.html

Based on design principles, the range of a car radar can cover up to a maximum distance of 200 m.

Application	Detection range [m]	Operating frequency [GHz]
Adaptive Cruise Control	200	77
Pre-Crash	30	24, 76, 77, 81
Blind Spot Detection	20	24
Stop and Go	30	24, 76, 77,81

Table 1. Car Radar Detection Ranges

3.1 The Principle of FMCW Radar

When using an FMCW radar for distance measurements, the output signal frequency continuously changes over the transmission time, usually around 76-77 GHz, and it is linearly modulated to reach a maximum of 81 GHz over a given time period. This waveform is called a chirp. A frame consists of N number of chirps, each lasting for a given chirp time (T_{Chirp}). The bandwidth and slope of each chirp also crucial to the performance of the FMCW radar. These parameters have a direct influence on the maximum range, maximum velocity, and their corresponding resolutions.

In the example used here, the transmission frequency changes in a sawtooth manner (Figure 3) by 300 MHz per 100 ms and is then reset to the original starting frequency. In Figure 4, for example, a 76.15 GHz radar wave starts at 0 ms and 30 ms later a reflection is received that is influenced by the distance to the target and its speed (the frequency shifts are depicted by the red arrows for Δf_1 and Δf_2). The comparison between the transmitted signal generated by the radar to the reflected signal by the object gives an indication of the distance. The transmitted and received signals are mixed into an intermediate frequency signal whereby a Fourier transform (range FFT) on this intermediate frequency signal (also called a beat frequency) yields information on the distance of the object with a good degree of accuracy. The frequency difference is thus a direct measure of the distance (e.g., 2 kHz per meter). But that alone is not enough because vehicles are moving. Therefore, a second effect has to be included in the calculation – the relative speed of the object. The radar speed measurement takes into account the Doppler effect, which states that there will be an increase or decrease in the frequency of waves as the vehicle moves toward or away from an object. In Figure 4, the emitted frequency that is received is reduced, indicating that the object is moving away from the radar.

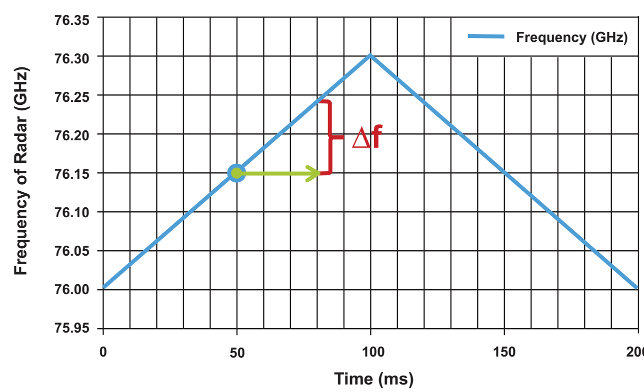

Figure 3. FMCW Radar Chirp

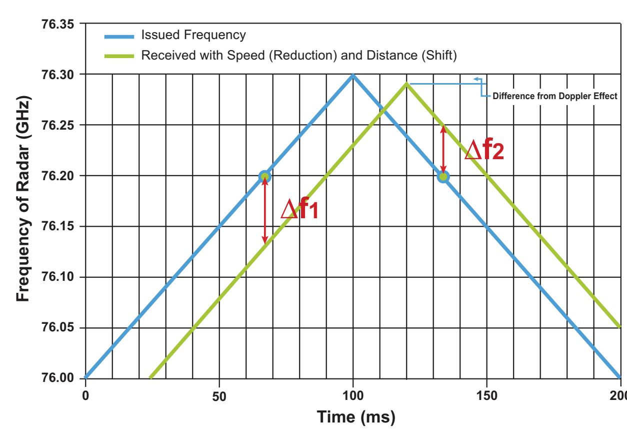

Figure 4. FMCW Transmit and Shifted Receive Frequency Chirp

[1] Radome = Antenna Dome, https://en.wikipedia.org/wiki/Radome

By selecting a triangle edge (i.e., increasing and decreasing frequencies), it is now possible to determine the distance and the velocity of an object after one cycle (in this case 200 ms). Because the Doppler effect changes both the rising and the falling edge of the received frequency by the same amount, in this example, that would equate to a 512 Hz per m s^{-1} differential speed. By adding or subtracting the two different frequencies, the distance (d_{target}) and relative speed (v_{rel}) (relatively) of a preceding object can be determined.

Equation 1: $$d_{target} = \frac{c_0 \cdot T_{chirp}}{4BW_{chirp}}(\Delta f_1 + \Delta f_2)\ [m] \qquad v_{rel} = \frac{\lambda_0}{4}(\Delta f_1 - \Delta f_2)\ [ms^{-1}]$$

LRR sensors continuously perform the above two measurements very quickly. The phase offset of the patch antennas can even measure the approximate direction to an object. While all this information is processed using complicated algorithms, it must be remembered that the real environment returns a multitude of echoes. The vehicle in front of us must be distinguishable from cyclists, signs, pedestrians, vehicles, trucks, curbs and peripheral buildings. In order to exclude these “ghost objects”, different frequency ramps with different gradients are sent one behind the other (Figure 5). The intersections in the "velocity distance diagram" then yields the unique objects as shown in Figure 6.

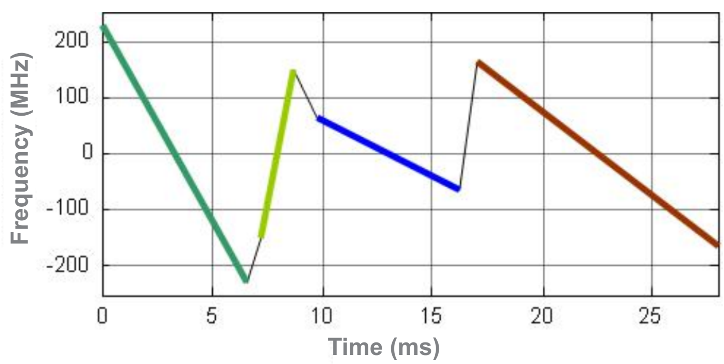

Figure 5. FMCW Radar Frequency Ramps Showing Different Slopes

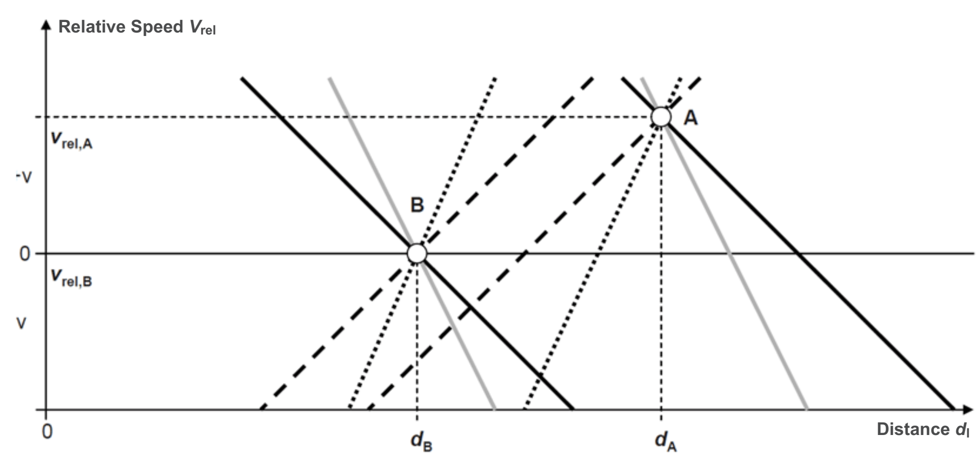

Figure 6: Locating of Two Different Targets by Using the Intercept Points of Different Frequency Ramps (Target A Has a Positive Relative Speed and Target B Has No Relative Speed) [4]

Furthermore, the LRR ACC control unit, based on the current vehicle status parameters, performs a course prediction to estimate the likely driving curve and lane. The measurements of the radar sensor ultimately result in an object list specifying all possible vehicles and obstacles in the "field of view" with their movement attributes (moving, stationary, sustained, etc.). The LRR ACC functionality has the task of following a preceding vehicle within a constantly safe distance and, should it disappear from its own lane, to accelerate to the desired cruise control speed until an obstacle again appears in the lane.

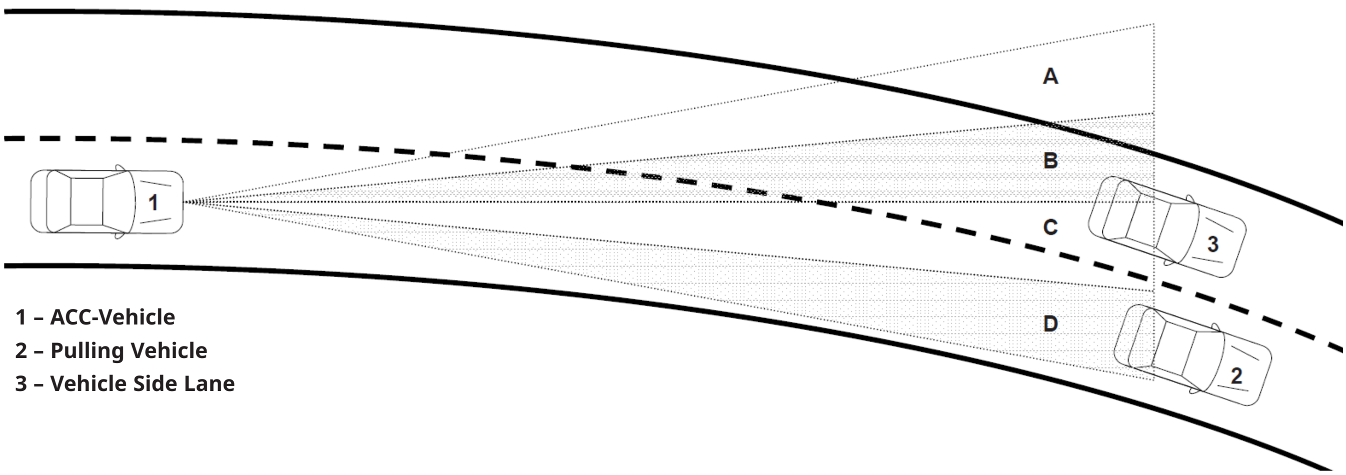

Figure 7. Selection of a Target Object When Cornering (A – D are the Radar Cones) [4]

Table 2 shows a comparison between different automotive radar sensor classifications. LRR sensors in the 76–77 GHz band operate over a distance range up to 200 m but require only a moderate distance resolution.

Specification	LRR	MRR	SRR
RF-Band	77 GHz	79 GHz	79 GHz
Max. output EIRP	+55 dBm	–9 dBm/MHz	–9 dBm/MHz
Bandwidth	6000 MHz	600 MHz	4 GHz
Distance Range	10 - 250 m	1 - 100 m	0.15 - 30 m
Distance Resolution	0.5 m	0.5 m	0.1 m
Speed Resolution	0.1 m/s	0.1 m/s	0.1 m/s
Angular Accuracy	0.1°	0.5°	1°
Azimuth 3 dB HPBW	± 15°	± 40°	± 80°
Elevation 3 dB HPBW	± 5°	± 5°	± 10°

Table 2. Comparison of Different Automotive Radar Sensor Classifications [6]

Therefore, a bandwidth of only 200 — 600 MHz is sufficient, but a high angular resolution is necessary due to the narrow field of view. However, the opposite is true of SRR sensors, which possess a wide beam width in the azimuth to cover a large viewing area.

In FMCW radars, the chirp configurations control all the basic requirements like maximum range, range resolution, maximum velocity, and velocity resolution. As the range resolution is dependent just on the chirp bandwidth (F_{Chirp} [8]), it becomes clear that range accuracy requirements below 10 cm necessitate a bandwidth of 4 GHz (or even larger). This large bandwidth is extremely beneficial as it increases range and velocity resolution, thereby enabling the distinction of objects that are closely spaced. This makes it ideal for features such as automated parking. Whereas the maximum range is mainly dependent on the maximum "designed" IF frequency, the range resolution is determined by chirp time and the chirp bandwidth. Equation 2 shows the fundamental math behind it (more details can be found in [8]).

F_{Chirp}	Range Resolution
4 GHz	3,75 cm
2 GHz	7,50 cm
1 GHz	155 cm
600 MHz	25 cm

Equation 2: $$d_{max} = IF_{max} \frac{T_{Chirp} \cdot c_0}{2 \cdot BW_{Chirp}} \qquad d_{min} = \frac{c_0}{2 \cdot BW_{Chirp}}$$

where:

d_{max}	Maximum radar detection range [m]
d_{min}	Minimum detectable distance (aka, range resolution)
IF_{max}	Maximum supported intermediate frequency, which is directly related to the sampling rate of the chirp, slope (S) of the chirp, T_{Chirp}, and c_0
S	Slope of the chirp defines the rate at which the chirp ramps up [MHz/s]
C_0	Speed of light
T_{Chirp}	Chirp time [s]
BW_{Chirp}	Chirp frequency bandwidth [Hz]

4.0 Influence of the Emblem and Bumper on Radar Transparency

It is also important to understand how multi-layered material, like a bumper or emblem, might influence the so-called radar transparency. The normal incidence of reflected and transmitted signals from a radar in an automobile are functions of the:

- Dielectric constants of each material
- Thicknesses of the materials and the attenuation thereof and
- Frequency of the electromagnetic radiation

Within the scope of this paper, the focus will only be on transmission measurements in order to characterize 2D radar radome properties.

4.1 Effective Radome Attenuation

Radomes are placed over an antenna for protection from its physical environment. Ideally, it does not degrade the antenna performance and is expected to be radio frequency transparent. However, a radome is typically made from dielectric materials, which, in fact, can cause some effects in an antenna's performance. This chapter explains how the character of an additional cover in front of a radome might influence the LRR detection range.

When a wave propagates through dielectric material, it will lose some energy. Power losses in radomes are caused by their ability to store electrical energy and emitting it as heat. Ideally, radomes used for communications are made using low-loss dielectric materials because they deal with low power signals. Any signal loss can be critical for communication systems. A measure of power loss in dielectric material to total power transmitted through the dielectric is called the loss tangent, which quantifies a dielectric material's inherent dissipation of electromagnetic energy (e.g., heat). The transmission loss of a radome reduces the power received by the radar system and also the first detection range.

Radar transmission power directly affects the distance at which a target can be detected. Generally, detection distance (D0) is determined by the well-known free space radar basic equation [5].

Equation 3: $D_0 = \sqrt[4]{\frac{P_{TX} \cdot G_{Ant_{TX}} \cdot G_{Ant_{RX}} \cdot \sigma_{Target} \cdot \lambda^2}{64 \cdot \pi^3 \cdot P_{RX_{min}}}}$ [m] $\quad D'_{max} = \sqrt[4]{\frac{P_{TX} \cdot G_{Ant_{TX}} \cdot G_{Ant_{RX}} \cdot \sigma_{Target} \cdot \lambda^2}{64 \cdot \pi^3 \cdot P_{RX_{min}} \cdot 10^{0.1 L_{tot}}}}$ [m]

where:

P_{TX} +10 dBm	Transmitter power	[W]
G_{AntTX} 23 dBi	Antenna gain in transmit mode	[dBi]
G_{AntRX} 16 dBi	Antenna gain in receive mode	[dBi]
σ_{Target}	Effective Radar Cross Section (RCS) equal to 1 m^2 If the target is a car, σTarget can be assumed equal to 1 m^2	[m²]
λ 77 GHz	Radar wave-length, equal to 3.859×10^{-3}	[m]
P_{RXmin} –120 dBm	Minimum receiver sensitivity	[W]
L_{tot} Variable parameter	Total 2-way attenuation of radome and propagation path	[dB]
D_0 ~157 m	Target detection distance inc. ideal lossless radome	[dB]
D'_{max} Range Reduction $=1-(D_0 - D'_{Max})$ [%]	Reduced target detection distance due to losses	[dB]

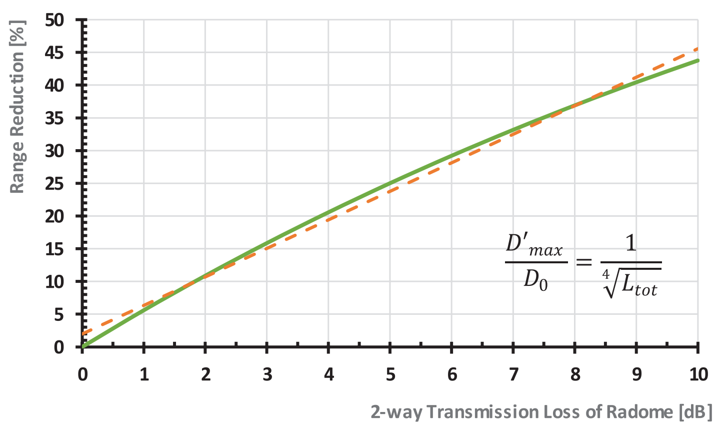

Figure 8. Radar Detection Range Reduction Versus 2-Way Radome Insertion Loss

With the above exemplified parameters, we can calculate with Equation 3 a target distance of approximately 157 m. This is the maximum detection distance assuming radar receiver sensitivity of –120 dBm, a perfect reflection signal of the car ahead, and no radome cover attenuation or other environmental losses.

Now, it is interesting to calculate how the initial radar detection range changes if a real radome cover with a loss is employed. Figure 8 shows how the initial radar detection range is influenced by the two-way attenuation of a radome cover. Up to a 10 dB loss occurs, of which the results can be approximated by a straight line. As a figure of merit, we can say that each 1 dB two-way loss is reducing the initial detection range by 5%. In this example, with D_0 equal to 157 m, a 3 dB two-way radome loss would decrease the range by 15.9% to 132 m. With the given maximum range of 157 m, a vehicle ahead would be detected 25 m later than the driving object. Assuming a differential speed of 60 km/h, this results in a 1.5 seconds delay in detection.

So far, the influence of backwards energy reflections on the radar receiver has not been addressed. A strongly unadapted radome causes high reflections in the immediate vicinity of the radar system. If the radome is or nearly perpendicular to the propagation direction, then part of the power reflected is picked up by the receiving antennas and leads to a loading of the input stage. Due to load-pulsing effects, such as the operating point shift of the input diodes, it can lead to further impairment of the sensor performance.

5.0 Measurement Setup

5.1 Mechanical Setup for Probing

For the characterization of a radome's cover transmission behaviour, this example will use a measurement setup that is capable of performing a 2D scan of the samples used along with a set routine (see Figure 9). The system is comprised of two linear platforms used to move a tray that holds the samples. The movement of the platforms used typically occurs in two driving routines: (1) the sample will be moved in the x-direction for a given distance at a constant speed, and (2) it is moved in the y-direction by a pre-determined increment while the reverse movement along the x-axis is performed. Another degree of movement is the possibility to tilt the radiation direction of the illuminating VNA head from an orthogonal to any other direction. This accounts for the fact that some radome covers are not mounted in a vertical direction at the car chassis and are typically tilted up to 20 degrees.

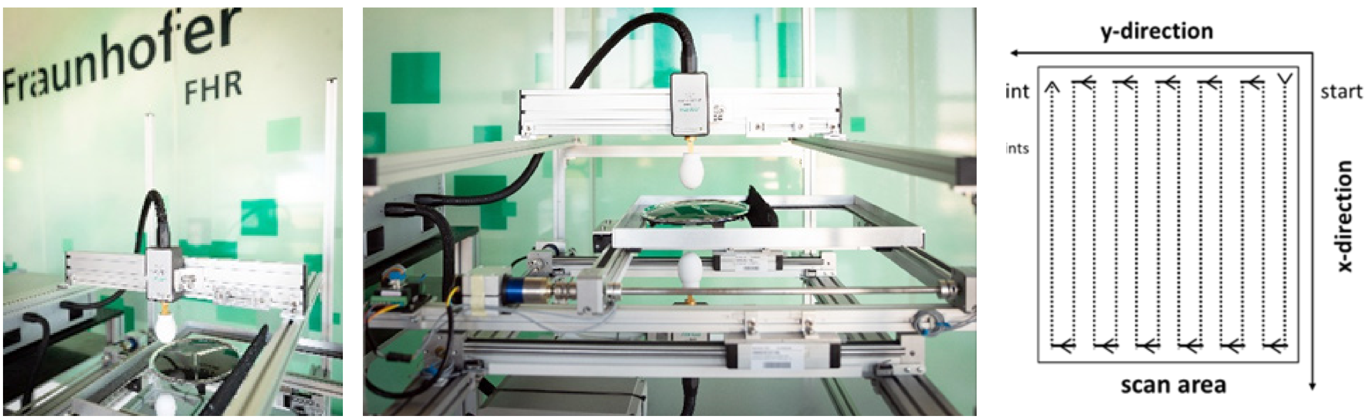

Figure 9. Measurement Setup and Scanner Movement Routines

Besides the movement of the platforms, the antennas used (which are elliptically shaped and made of Teflon [PTFE]) are in a fixed position both above and beneath the tray. The particular shape of these antennas leads to a planar wave front almost at the tip of the antenna. This is beneficial in terms of measurement errors due to a reduction of near field effects when placing the antennas right underneath and above the sample. The 3 dB beam width of the antennas' aperture is around 5°. This leads, for example, to a spot size of around 7 mm on the sample if the antenna is 80 mm above it. Table 4 illustrates the spot size at various distances. The generation of the measurement signal is performed by the ShockLine™ vector network analyser from Anritsu, which is described in the next section. For the linear movement in the x-direction, the ShockLine VNA is used in CW-mode at a constant frequency. For the stepwise movement, it is used in single frequency CW mode (SFCW-mode).

Antenna to sample [mm]	10	20	40	80	100
Spot size [mm]	0.88	1.74	3.49	6.99	8.73

Table 4. Spot Size vs. Antenna to Sample Space

To distinguish the influence of a sample to the measurement signal, its attenuation and phase shift can be characterized by a transmission measurement (S12) measured with the ShockLine VNA. The phase shift of the electromagnetic wave refers to a time delay, which is caused by longer transit time through the dielectric material. The attenuation of the wave is caused by loss of energy inside the material. The attenuation has an influence on the detection range of the radar, as mentioned above. The phase shift due to the emblem also has an impact on the measurement. The direction of the detected target is calculated by use of the phase difference between the transmitted and received signals at the radar. The phase shift through the emblem should be more or less constant so that the radar measurement is not distorted.

5.2 ShockLine MS46522B-082 Banded mmWave VNA

VNAs for mmWave applications have been historically large, heavy, complicated, and very expensive. A new approach that shows significant advantages for these car radar radome and bumper measurements can be seen with the Anritsu ShockLine MS46522B VNA (Figure 10) with option 82 or 83, a dedicated E-band VNA for 55-92 GHz applications.

Figure 10. ShockLine MS46522B-082 E-Band 2-Port VNA

For antenna characterization and material measurement, this kind of VNA is best suited for industrial applications where ease of use along with ruggedized handling and interfacing are major requirements. The ShockLine MS46522B E-band VNAs with options 82 or 83 configuration consists of small tethered source/receiver reflectometer modules and a base chassis. The modules are attached to the chassis with the option of either one or five meter cables that are permanently attached to the unit, making this a compact, ready-to-use E-band VNA. The remote, small form factor reflectometer modules (6 x 10 x 4 cm) have native WR12 waveguide interfaces for convenient connection to typical waveguide devices. In addition to their miniature size, these reflectometers provide highly attractive features such as: short/long term thermal stability due to the vanishing thermal gradient across the modules; high amplitude and phase stability; and, raw directivity (to mention a few). Most importantly, placing the sampling directional bridge closest to the AUT/DUT provides long-term amplitude and phase stability. The ShockLine MS46522 has a 3U high chassis and uses the same GUI, software, command syntax, drivers, and programming environments as the rest of the Anritsu ShockLine VNA family. Compatibility to the Interchangeable Virtual Instruments (IVI) Foundation allows users to get the maximum possible measurement speed for their own SCPI-based programs. This enables a reduction in test time, which is an important parameter for antenna or material characterization.

6.0 Transmission Measurement Results

A measurement of a car emblem was done using the setup described above. Figure 11a shows the attenuation at 77 GHz. The middle of the emblem is marked by a vertical and a horizontal line. The attenuation of both lines at 77 GHz is displayed in Figure 11b. The x-axis shows the length of both lines in the left image. In the region of interest, the attenuation is fairly flat (between 0 dB and –1 dB) and increases at the edges of the emblem due to the shape and characteristics of the material. In respect to a spot size of 8.73 mm at a 100 mm distance (Table 4), the edges of the emblem have a negligible effect on the radar when it is placed in the middle. An even more focused antenna (gain, HPBw) would allow an even higher resolution with the given setup.

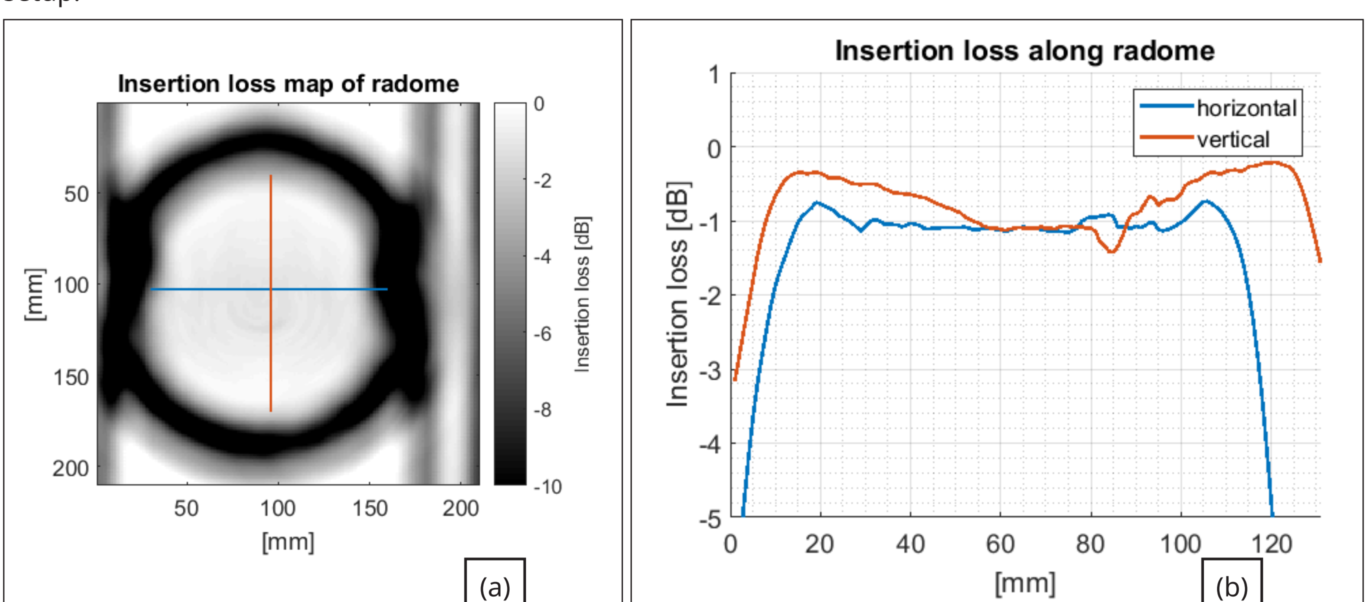

Figure 11. 1-Way Insertion Loss of the Radome

To give an overview of the attenuation of the whole frequency range, Figure 12a has five marked positions. The corresponding lines are shown in the same color in Figure 12b. The electromagnetic wave hits the central position orthogonally, and therefore, the signal has a higher attenuation than the other positions. The attenuation is between 0 dB and –1 dB in each position over the whole bandwidth. Therefore, the signal loss caused by the shape and material characteristics are minimal and do not affect the radar significantly. Using the information from section 4.1, the observed attenuation that is a maximum of –1 dB would translate to a theoretical radar range reduction of 10 meters.

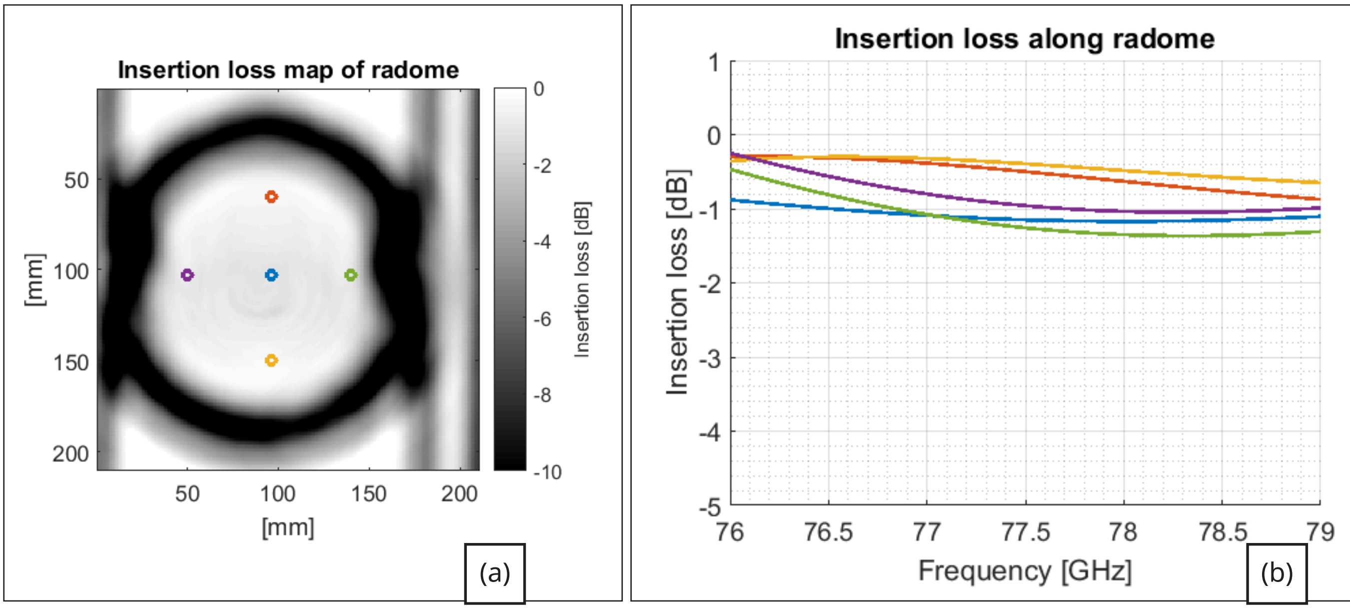

Figure 12. 1-Way Insertion Loss of Radome Versus Frequency

Besides attenuation, phase shift is another effect that provides additional information. Figure 13a shows a phase map of the emblem at 77 GHz. In Figure 13b, you can see that the vertical red line changes over the distance. It starts at 0° and ends around –80°. This might be due to an unevenly positioned emblem. The horizontal blue line has an average of –40° except on the edges of the emblem (for the same reasons as mentioned before). The constant phase over the horizontal length indicates a uniform emblem shape and characteristic over the observed distance, so the phase is not heavily affected.

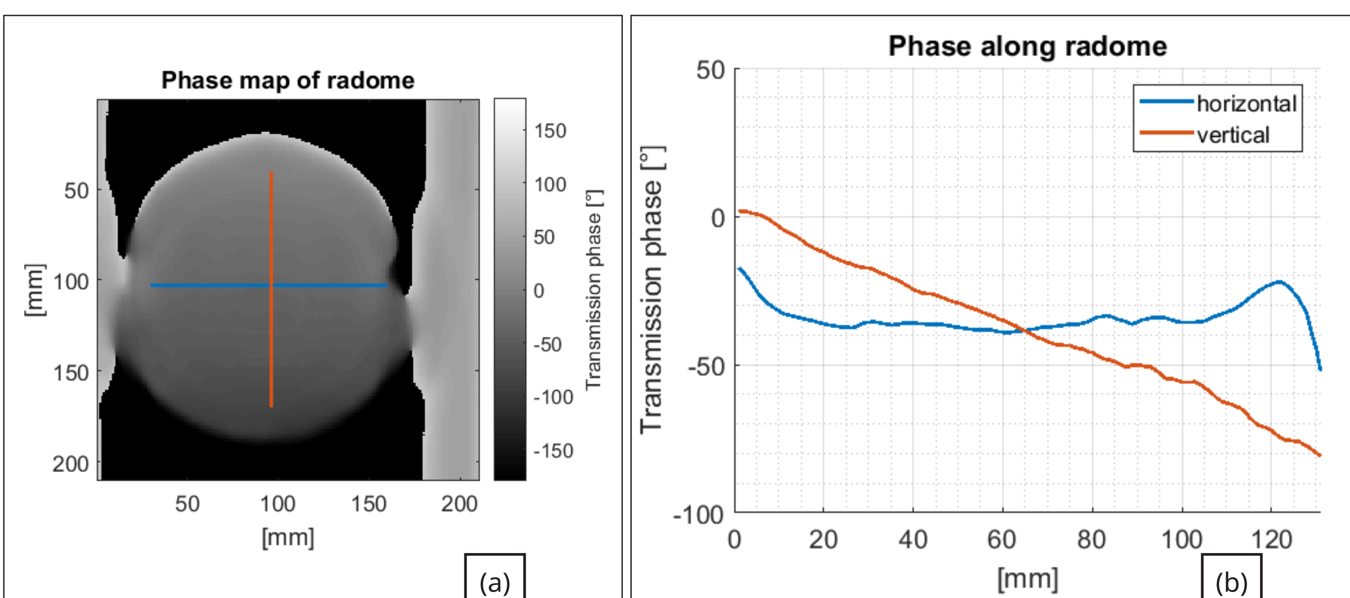

Figure 13. Phase Along Radome at 77 GHz

Figures 14a and 14b display an unwrapped phase in order to see continuous progress. Figure 14b displays the various frequency sweeps, where each line corresponds to the same coloured dot shown in Figure 14a. Due to the dispersion, the phase changes with increasing frequency so the shape of the emblem does not affect the phase of the transmitted signal. The red and yellow line have a different starting point because the emblem used for this measurement was uneven, otherwise both lines would start at a similar point as the others and would have a similar progress. The fact that there are no abnormalities visible reinforces the permeability of the emblem for this frequency range.

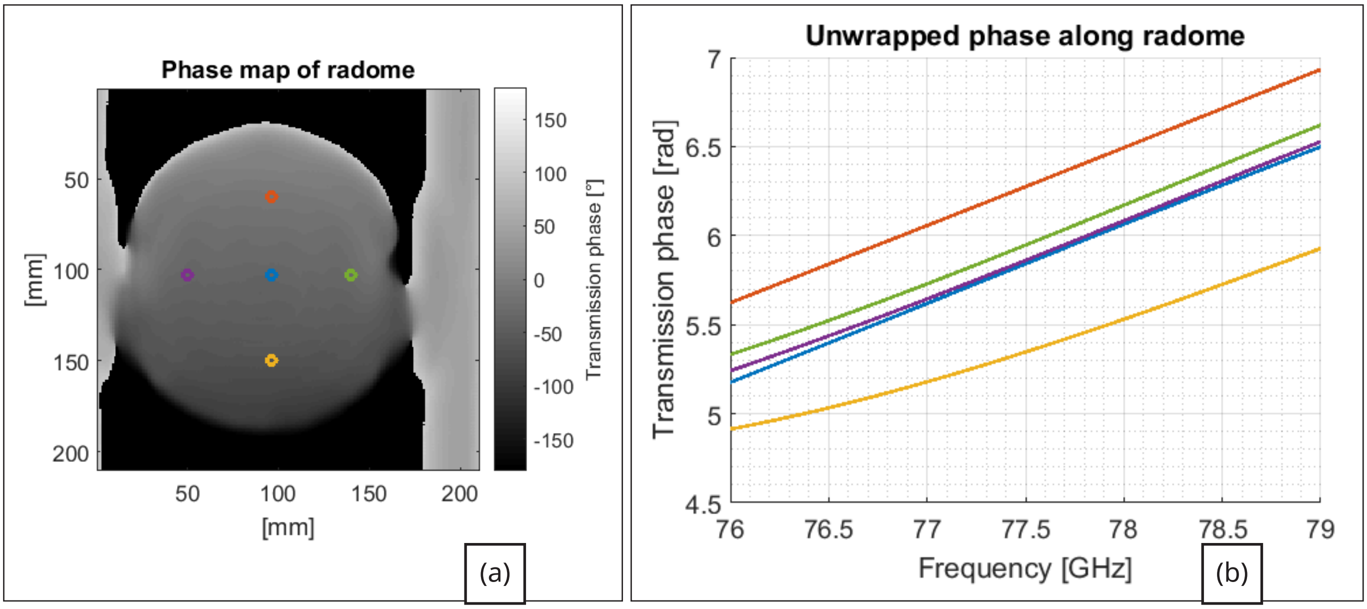

Figure 14. Unwrapped Phase Versus Frequency

6.1 Transmission Measurement Results

In order to show the influence of various materials on shielding effectiveness, pieces of rubber and copper tape were placed on the car emblem (Figure 15a and 15b). Figure 15a shows the prepared back-side of the emblem logo, while Figure 15b shows an overlay of the optical with the radio frequency domain. The visible displacement and distortion is based on the measurement parameters used and could be mitigated by using a more optimized parameter set.

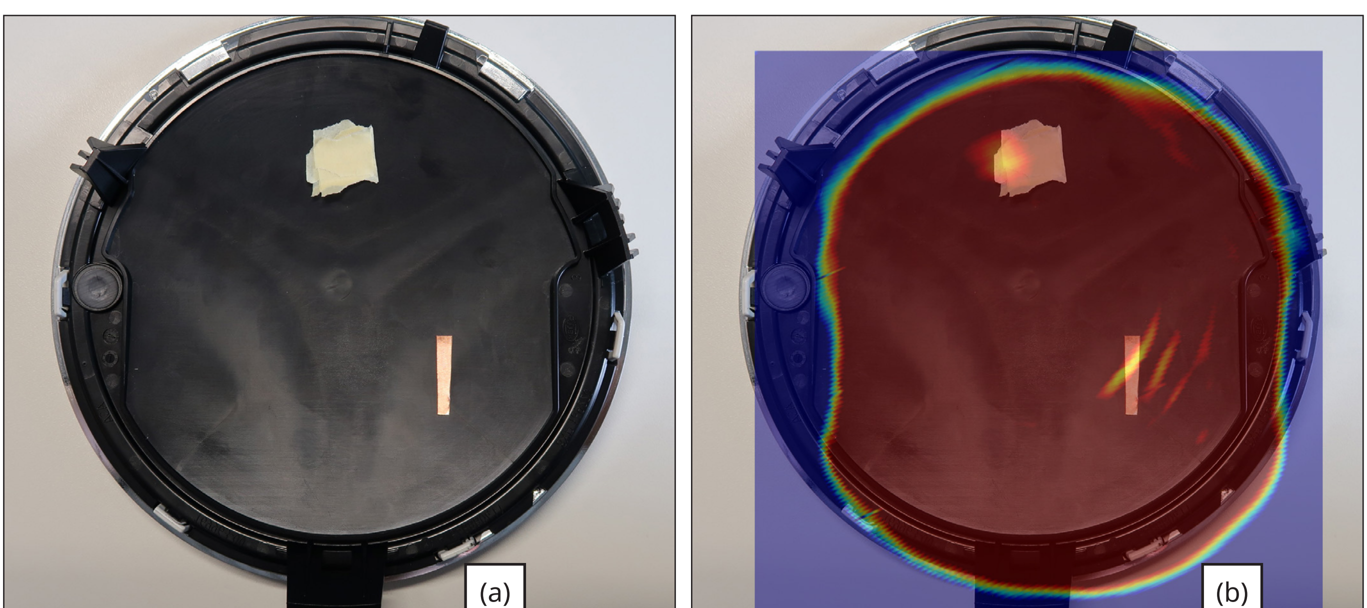

Figure 15. Car Emblem Specially Prepared With Some Shielding Material

Finally, another antenna with a different half power beam width (HPBW) was used. The previously used antennas had a HPBW of 5°, where in Figure 16 one with 30° was used. Due to the larger HPBW, the antennas can see larger areas and show the general shape of the emblem.

One can assume that other lossy logo material, metallic paint of car chassis elements, or just simply snow or mud can cause a two-way insertion loss that may reduce the detection range of a car radar.

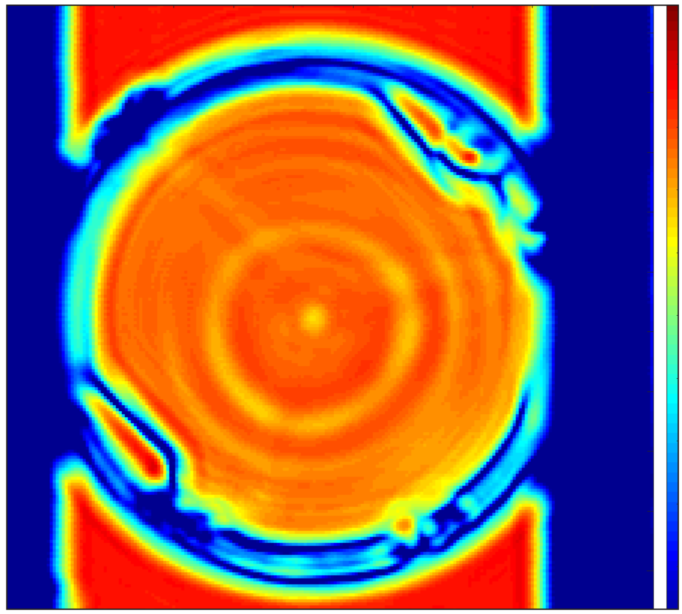

Figure 16. Car Emblem Measured With a Wider Antenna Beam Revealing Its Shape

7.0 Conclusions

Within the scope of this application note, the fundamental principle of frequency-modulated continuous wave car radar and typical car radar deployment and positioning possibilities have been discussed. It has shown that the insertion loss or phase change of the material in front of a car radar can have some significant influence upon the radar's detection range. It is possible to visualize the impact of materials in front of the radar by conducting VNA-based transmission and phase measurements. As a result, it is possible to judge if such material might have an influence upon the radar detection range. In the car emblem used in the examples, the measurement results show a nearly ideal behaviour proving that the car radar's detection range is most likely not negatively impacted by a two-way insertion loss.

8.0 Appendix

In this appendix we are presenting some comparative measurements of different car emblems:

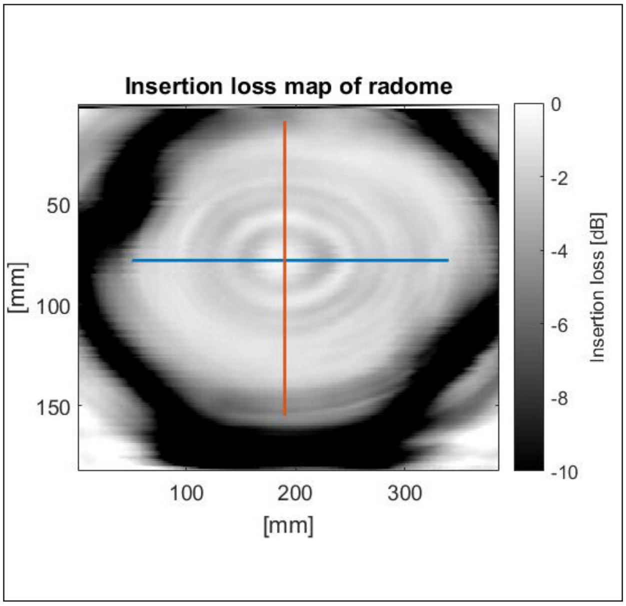

Figure 17. Insertion Loss Vendor A

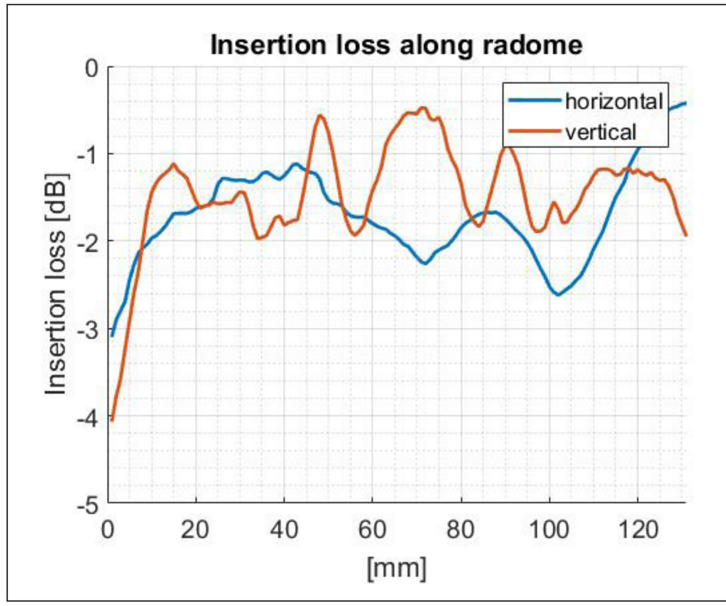

Figure 18. Insertion Loss Vendor A

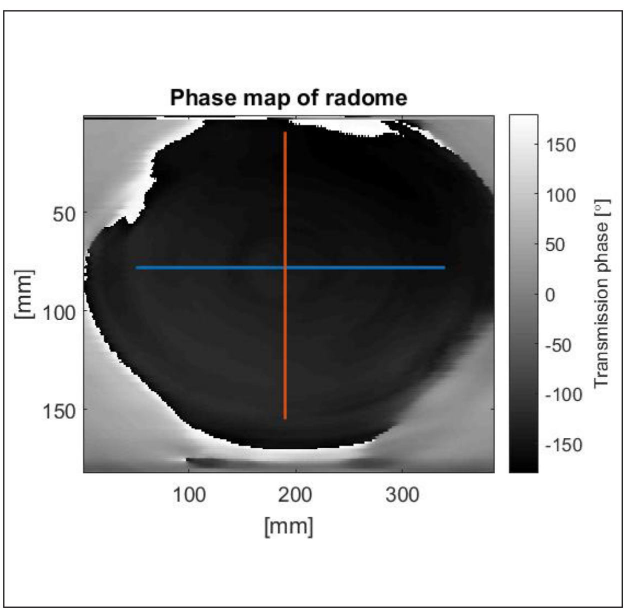

Figure 19. Phase Change Vendor A

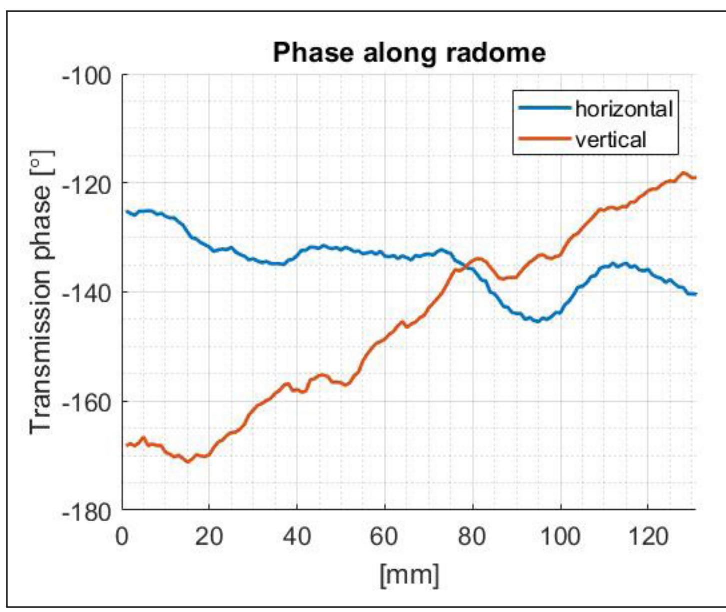

Figure 20. Hor. / Vert. Phase Distr. Vendor A

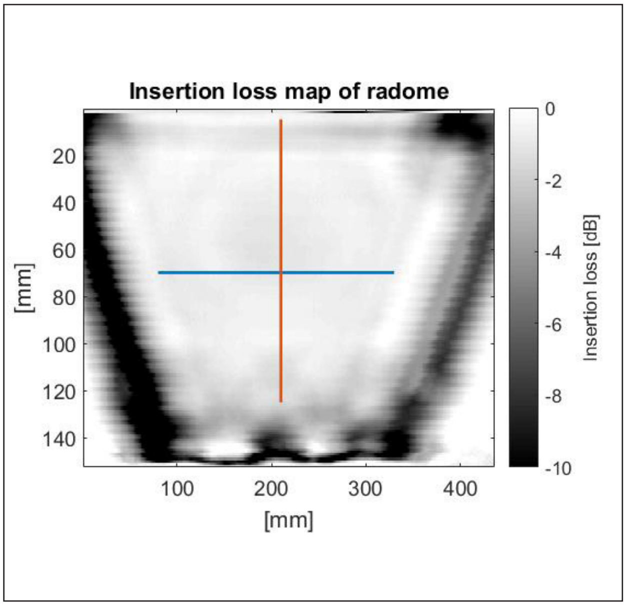

Figure 21. Insertion Loss Vendor A

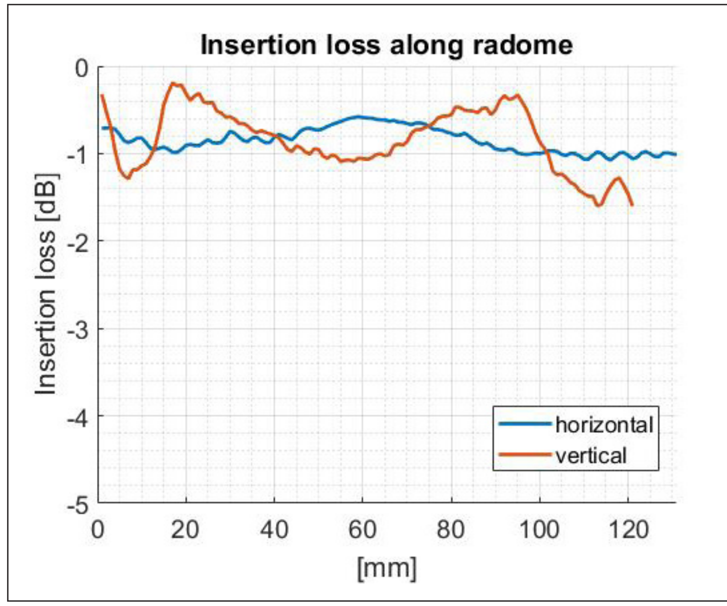

Figure 22. Hor. / Vert. Insertion Loss Distr. Vendor A

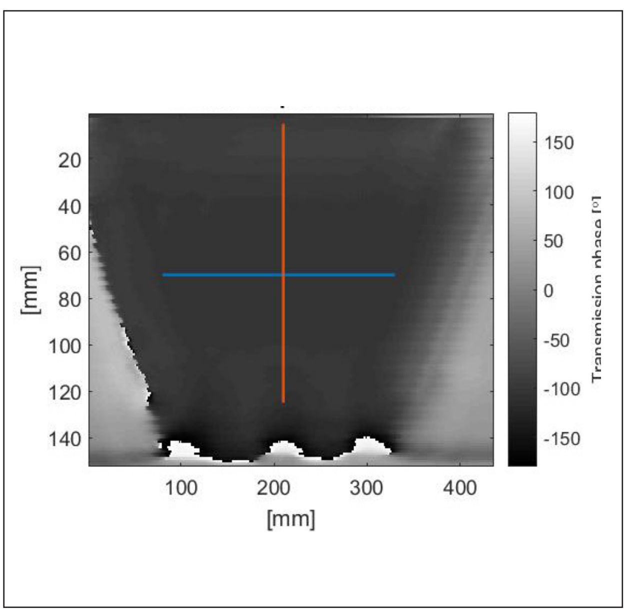

Figure 23. Phase Change Vendor A

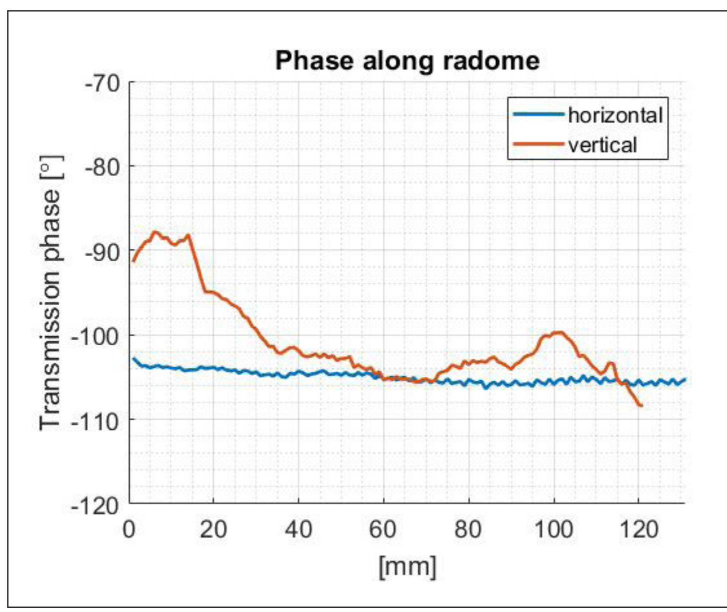

Figure 24. Hor. / Vert. Phase Distr. Vendor A

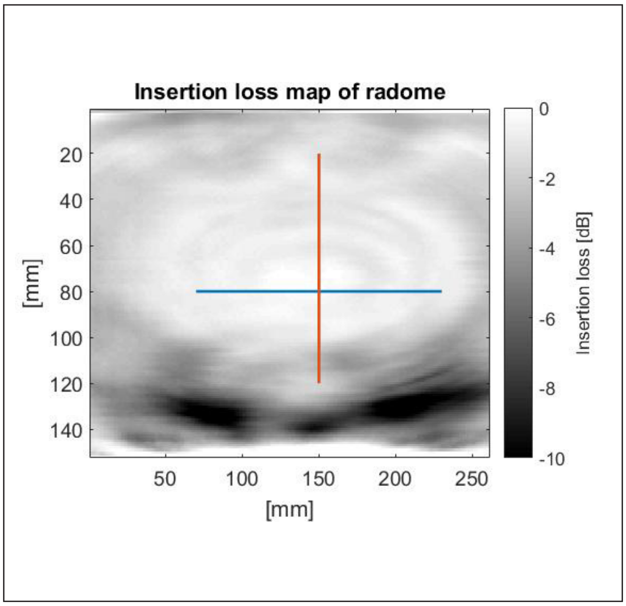

Figure 25. Insertion Loss Vendor A

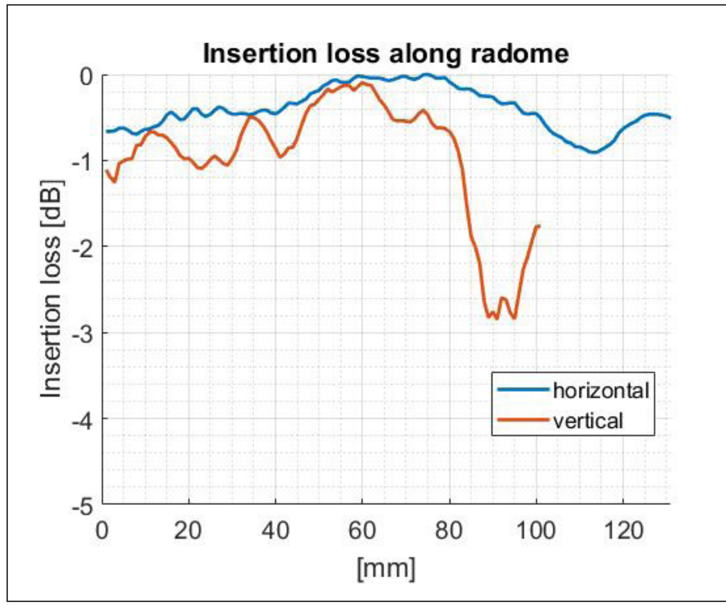

Figure 26. Hor. / Vert. Insertion Loss Distr. Vendor A

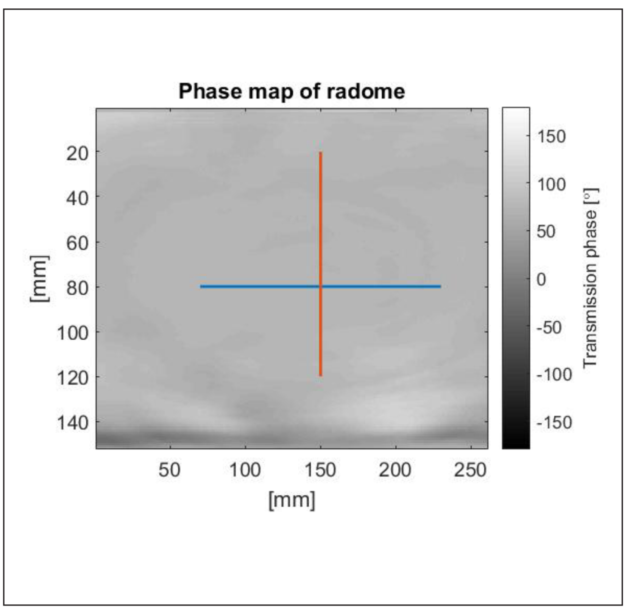

Figure 27. Phase Change Vendor A

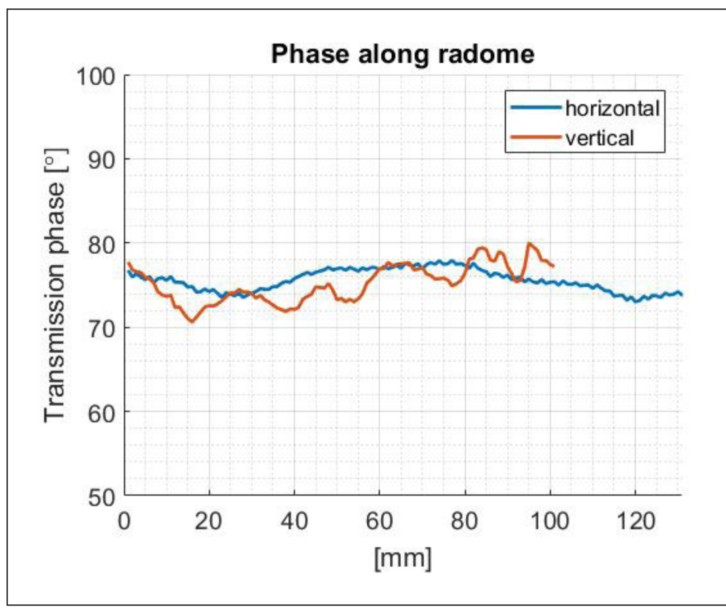

Figure 28. Hor. / Vert. Phase Distr. Vendor A

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