# Transmissivity Through Automotive Bumpers at mm-wave and Low-THz Frequencies

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# Transmissivity Through Automotive Bumpers at mm-wave and Low-THz Frequencies

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***Abstract:*** *This paper investigates signal attenuation through automotive bumpers at the conventional automotive radar frequency (77 GHz) and at a Low-THz frequency (300 GHz). A Frequency-Modulated Continues-Wave (FMCW) radar operating at 77 GHz and a Stepped Frequency Radar (SFR) operating at 300 GHz are used in this experiment. The measured transmissivity through three bumper samples are compared at both frequencies to analyze the performance difference between the current automotive radar and prospective Low-THz radars. Transmissivity through the bumper samples show difference of around 1- 2 dB between the two frequencies under study.*

## 1. Introduction

Automotive sensors have been widely applied in the new generation of cars over the last decade. They are a key technology to make driving safer, more convenient and more comfortable. Driving assistance systems require information such as distance and velocity of the targets on the road to achieve basic functions, such as parking aid, adaptive cruise control and automatic emergency braking [1]. Unlike commonly used automotive sensors like Light Detection and Ranging (LIDAR) and optical cameras, radar can provide all-weather and all-light operation.

At present, automotive radars are mostly operate at the frequency band of 76 - 77 GHz, with future plans to expand the bandwidth to a maximum of 4 GHz [2]. Low-TeraHertz (Low-THz) radars have potential as the next generation of automotive radar as they can offer advantages such as: higher image resolution due to the wider operational bandwidth, and the reduced size because of the smaller antenna size. The rapid development of solid state semiconductor THz technology [3, 4] make increasing automotive frequencies possible. However, higher frequency means potentially higher attenuation and dispersion, which is a challenge for applying Low-THz frequencies in an outdoor environment. The signal attenuation caused by the accumulation of contaminates on the radome, such as sand [5] and ice [6], and also propagation through adverse weather conditions, such as rain [7] and snow [8], needs to be investigated carefully before applying these radars in automotive applications. In addition, the integration of Low-THz sensors in a modern vehicle is another important aspect that needs to be studied to determine the feasibility of Low-THz radars for automotive applications since both of electromagnetic (EM) and car body design constraints have to be met [9]. Therefore, in the case of integration of the radar behind the bumper, knowledge of the transmissivity properties of automotive bumpers currently used in the market is essential. In our research, the radar is assumed to be installed behind the painted plastic fascia part of the bumper and operated in scanning mode. Therefore, transmissivity through automotive bumper samples is measured and is presented as function of incident angle.

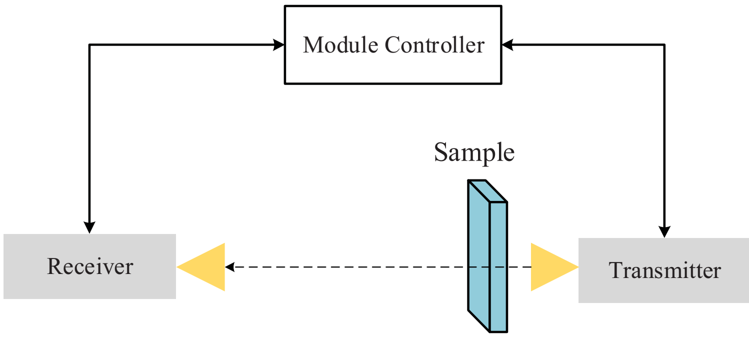
## 2. Experimental methodology

In this section, the experimental methodology of the transmissivity measurements and the structure of the measured automotive bumpers are discussed. Our measurements are based on two radar systems: a 77 GHz FMCW radar built by ELVA-1 [10], and a 300 GHz SFR system built by VivaTech [11]. Both systems were designed in collaboration with the University of Birmingham.

### 2.1 Experimental setup

The experimental setup and schematic are shown in Fig. 1, which is a forward propagation setup commonly used for measuring transmissivity [12]. A foam material which has low reflectivity at Low-THz is chosen as a sample holder. The reflectivity of the sample holder is measured to be -33 dB relative to the reflectivity from the metal sphere with similar size at 300 GHz. The bumper sample is fixed on the sample holder and placed on a rotating platform which can vary the angle between signal beam and the sample in steps of $1^{\circ}$. The distance between the transmitter and receiver is 1.4 m which is in the far field of the antennas. To guarantee that most of the signal beam passes through the material, the sample is positioned closer to the transmitter, at a distance of 0.4 m. The area of illumination on the sample is calculated by taking into account the distance between sample and transmitter antenna and 3 dB main lobe of the radiation. The signal foot print area are smaller than the area of the sample. Extra attention is paid to align the transmitter, receiver and the samples accurately, as well as to make sure the samples are perpendicular to the signal radiation. Low-THz absorber is used to avoid the reflection from the wall which is closest to the setup [13].
The 300 GHz SFR radar is a system based on a KEYSIGHT Programmable Network Analyzer (PNA) and a pair of up and down- converters. The up and down-converters and the PNA are phase locked to a common 10 MHz rubidium reference oscillator. To guarantee that incident angle is the only variable, a continuous wave (CW) signal is used. The PNA transmits a signal at 7 GHz which is up-converted to 289 GHz prior to propagation through the medium. After propagation, the received signal is down–converted back to 7 GHz and the scattering parameter $S_{21}$ is measured by PNA.
The transmitter and receiver of the 77 GHz FMCW radar are controlled by the module controller. The transmitted signal is in the frequency range of 77.0 GHz-77.1 GHz, since 100 MHz is the minimum chirp bandwidth available using this system. All the parameters of each system is summarized in Table 1.

(a)




(b)

Fig. 1 (a) The experimental setup for transmissivity experiment at 300 GHz and 77 GHz. (b) The experimental schematic for transmissivity experiment at both frequencies.

Table 1. Parameters of the 77 GHz FMCW and 300 GHz SFR radar systems

| Parameters of radar systems | 300 GHz SFR | 77 GHz FMCW |
|---|---|---|
| Transmitted Frequency | 289 GHz | 77 GHz-77.1 GHz |
| Frequency of signal from PNA | 7 GHz | × |
| Output Power | -10 dBm | 15 dBm |
| Antenna Azimuth/Elevation Beamwidth | $10^{\circ}/10^{\circ}$ | $10^{\circ}/10^{\circ}$ |
| Antenna Gain | 20 dB | 20 dB |

Transmisivity of each sample is measured by calculating the ratio of the received signal strength transmitted through the automotive component samples and transmitted through free space. Therefore, the measured transmissivity can be represented as:

$$\mathrm{T} = S_{21}^{s} - S_{21}^{b} = 20\log\left(\frac{V_2^s}{V_1^s}\right) - 20\log\left(\frac{V_2^b}{V_1^b}\right), \quad (1)$$

where, $S_{21}^{s}$ and $S_{21}^{b}$ are the $S_{21}$ parameter of the signal through the sample and through free space, respectively. $V_1$ is the voltages of port 1 and $V_2$ is the voltage of port 2 of the PNA, and b and s represent background and sample, respectively.

## 2.2 Automotive bumper samples

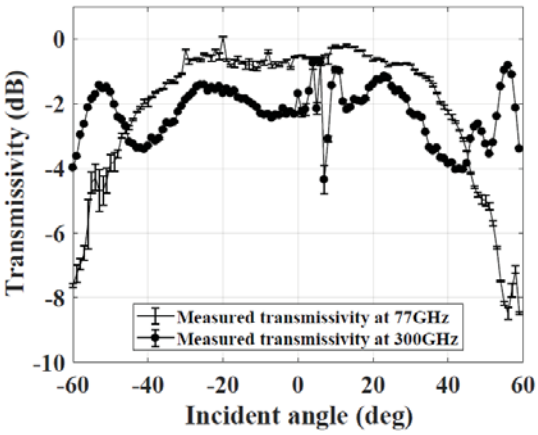
Automotive bumpers are mainly composed of three elements: fascia, energy absorber and bumper beam [14, 15]. In this experiment, only the fascia part which consists of a plastic substrate and multiple layers of paint is considered as the radome of automotive radar. The material of the substrate is usually made of a combination of thermoplastic polymer, carbon black and talc. The polymers which are typically used was reported as polypropylene (PP), polycarbonate (PC) and polyethylene terephthalate (PET) in [16] and [17]. The thickness of plastic substrate usually in the range of 2 mm-4 mm. Solid paint, metallic paint and pearlescent paint are commonly used in modern vehicles. Three layer of paints cover the bumper. The first layer of paint attached on substrate is primer, which is used to ensure better adhesion of paint on the substrate. The basecoat layer is then sprayed onto the primer for color application and finally a clear coat is applied on the top of basecoat to avoid scratches to the paintwork. Generally, metallic paints have higher permittivity compared with solid and pearlescent paints due to presence of metallic flakes [17].
The bumper samples used in this experiment cut from vehicle components which were provided by Jaguar Land Rover (JLR). Three automotive bumper samples with white solid paint (labelled as sample A), gold metallic paint (labelled as sample B) and red pearlescent paint were selected for this research. The material of the substrate is polypropylene (PP). The bumper samples are shown in Fig. 2.


(a) (b) (c)

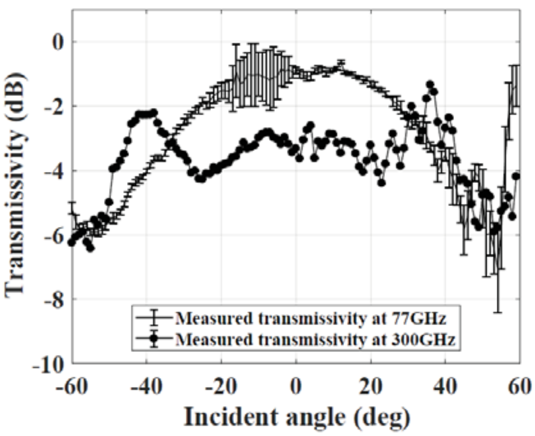
Fig. 2 Automotive bumpers with solid paint (A), metallic paint (B) and pearlescent paint (C) used for the experiments.

## 3. Experimental results

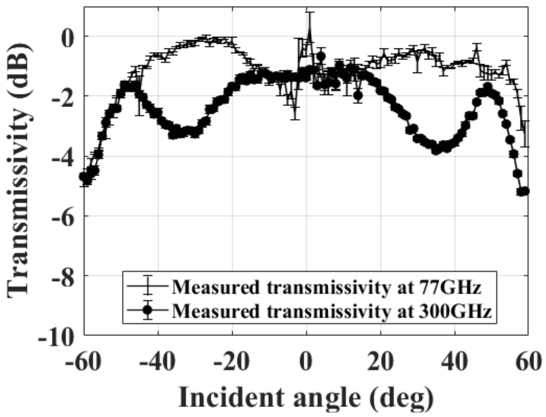
Fig 3. shows the measured transmissivity for each bumper sample at 77 GHz (solid line) and 300 GHz (dotted line). The results were measured as function of incident angle in the range of $\pm 60^{\circ}$. Error bars represent the standard deviation for three measurement runs. Comparison between the measured transmissivity through the bumpers at 300 GHz and 77 GHz is an important factor to consider when determining the feasibility of increasing operating frequency of automotive radars.




(A)




(B)




(C)

Fig. 3 Measured transmissivity of automotive bumpers with solid (A), metallic (B) and pearlescent (C) paints versus incident angles at 77 GHz and 300 GHz.

Table 2. Characteristics of automotive bumper samples and the measured transmissivity at $0^{\circ}$ incident angle

| Sample No. | Classification | Thickness | $T_0$ at 77 GHz | $T_0$ at 300 GHz |
|---|---|---|---|---|
| *A* | *Bumper with white solid paint* | *3.72 mm* | -0.7 dB | -2.1 dB |
| *B* | *Bumper with gold metallic paint* | *3.15 mm* | -1.0 dB | -3.1 dB |
| *C* | *Bumper with red pearlescent paint* | *3.33 mm* | -0.2 dB | -1.3 dB |

At 77 GHz, the measured transmissivity decreases when the incident angle deviates from the perpendicular position. When the incident angle changes from $0^{\circ}$ to $\pm 60^{\circ}$, the measured transmissivity of sample A decreases from -0.7 dB to -7.8 dB, which is a larger difference when compared with sample B (decreases from -1 dB to -6 dB) and sample C (decrease from -0.2 dB to -4.3 dB).

At 300 GHz, the measured transmissivity becomes periodic when incident angle is outside the range of $\pm 20^{\circ}$. This periodicity is due to the interference between reflections from each surface of the medium. Reflections from both boundaries of the medium will interfere destructively when the electrical thickness is a multiple of the half-wavelength. In this situation, reflectivity values will be reduced and this will result in corresponding maximal values in measured transmissivity. Therefore, the minima and maxima observed in the measured transmissivity is the result of the increased path length through the sample as the incident angle is increased. A greater number of maxima are observed at higher carrier frequencies due to the reduction in wavelength.

The minima and maxima of measured transmissivity for sample A, B and C are in the range of -1.5 dB to -4 dB, -2 dB to -6 dB and -1.3 dB and -5.2 dB, respectively. These differences are smaller than the results at 77 GHz. At incident angles in the range of $\pm 30^{\circ}$ the measured results show higher attenuation at 300 GHz compared to 77 GHz.

The characteristics of samples and the measured transmissivity at $0^{\circ}$ incident angle are shown in Table 2. The differences between the measured transmissivity through sample A, B and C at both frequencies at $0^{\circ}$ are about 1.4 dB, 2.1 dB and 1.1 dB, respectively. In addition, from the measured transmissivity values at $0^{\circ}$, we can observe that the transmissivity through metallic paint bumper (sample B) is lower compared with solid and pearlescent paints at both frequencies, even though the thickness of the metallic paint bumper is the smallest one as shown in Table 2. Metallic paints with high metal concentration have higher dielectric loss parameter, which will cause higher attenuation. Therefore, the higher attenuation of sample B is mainly caused by the metal concentration in the paint layers. Lower attenuation is observed at 300 GHz compared to the results at 77 GHz for other incident angle ranges.

## 4. Conclusion

In this paper, measurements of transmissivity through automotive bumpers with solid paint, metallic paint and pearlescent paint are shown as function of incident angle at 77 GHz and 300 GHz. Transmissivity through the bumper samples with PP substrate at 300 GHz is about 1-2 dB lower than at 77 GHz. The measured losses indicate that conventional bumper materials can offer sufficient performance, at both 77 GHz and 300 GHz, without the increased complexity of integrating additional radome components into the bumper design. Periodic minimal and maximal values are found in the measured transmissivity when changing the incident angle.

## 5. Acknowledgement

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