Influences of the radar properties of automotive plastic parts

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Abstract: Future mobility will be based more and more on self-driving or autonomous vehicles. They use sensors to perceive their environment and can move safely with little or no human intervention. The most common sensors are camera- or radar-based systems. Radar technology has been used for years by car manufacturers to assist with automated cruise control and blind spot detection, and the same technology, coupled with artificial intelligence, will soon be the backbone for autonomous driving.

This publication gives an overview about how to measure the radar relevant properties of PP – Compounds and provides insights into the most significant influences of the radar properties of automotive plastic parts. The stability of material properties in large-scale production is discussed and the associated influence on radar transparency.

Keywords: fillers, permittivity, polypropylene, compounds, glass fiber, talc, pigments, electrical properties, radar.

1. Introduction

1.1 Motivation and background

In recent years, radar technology has become an important part of modern vehicles. Radar can be used to support driver assistance systems to increase safety and comfort while driving., and the electrical properties of plastics, particularly their permittivity, play an important role. Therefore, it is of great importance to identify plastics that have low permittivity and do not affect the radar signal.

Polypropylene (PP) is a widely used plastic in the automotive industry and is used in various applications, including radar applications. PP is a thermoplastic that is typically modified with fillers to improve its mechanical and thermal properties. However, it is known that fillers can also affect the electrical properties of PP. Therefore, it is important to investigate the influence of fillers on the permittivity of PP.

1.2 Objectives and research questions

The objective of this publication is to investigate the influence of different fillers on the permittivity of PP and to discuss the differences in the permittivity of PP from different manufacturing sites. Specifically, we will focus on glass fibres, talc, and pigments as fillers. The following research questions will be addressed in this work:

How do glass fibres, talc, and pigments affect the permittivity of PP?
Are there significant differences in the permittivity of PP from different manufacturing sites?
What are the implications of the results for the application of PP in radar applications in automotive?
By answering these questions, we can provide recommendations for the selection of PP materials for radar applications in automotive.

2. Basics

2.1 Radar Technology

Radar (Radio Detection and Ranging) is a technology that uses electromagnetic waves to gather information about objects in the surrounding area.

In the automotive industry, radar is used to enhance safety and comfort while driving. There are various types of radar-reliant assistance systems in cars, such as Adaptive Cruise Control (ACC), Blind Spot Detection (BSD), and Pre-Collision Warning (PCW). These systems often additionally fuse data from radars with other sensor sources.

Radar can simultaneously measure target distance, target angle, and can directly measure target velocity relative to the sensor. Modern automotive radar operates at a frequency between 76 GHz to 81 GHz, which corresponds to a wavelength of slightly less than 4 millimetres.

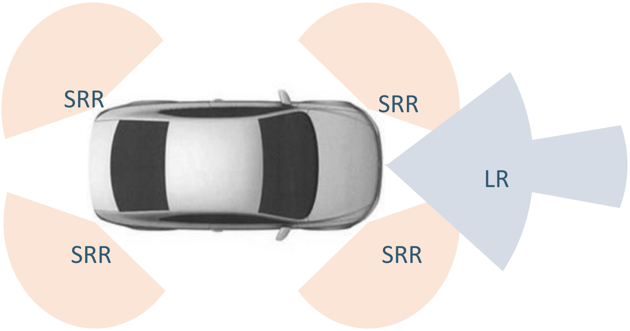


Figure 1: Examples for SRR and LRR.

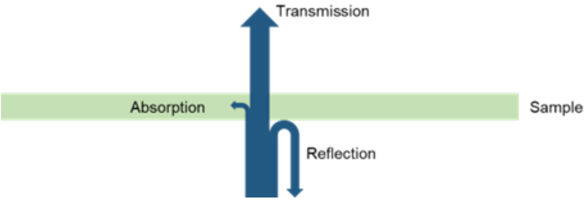
Short Range Radar (SRR) sensors are usually mounted behind bumpers in the corners of a car, whereas Long Range Radar (LRR) is mounted behind emblems or unpainted plastics. These covers are referred to as radomes.

Radar sensors utilize multiple transmit antennas, whose radiated waves transmit through the radomes, reflect off various targets surrounding the sensor and are then transmitted back through the radome and received there by multiple receiving antennas. Geometry and material properties of radomes have to be carefully designed and accounted for in order to limit negative influences, especially on maximum target range and angle accuracy. These influences arise, because plastics, and even more so paint, are not fully transparent to radar. The next section gives an overview over how this can be modelled.

2.2 Permittivity and Wave Propagation through Single Dielectric Layers

The electrical properties of plastics play a crucial role for automotive radar, as plastics are part of most radomes mounted in front of a radar sensor.

Relative Permittivity (also called dielectric constant) is a measure of how easily a material can store electrical charge compared to vacuum. Generally, plastics have a higher permittivity than air or vacuum. In full generality, relative permittivity is complex-valued and both frequency dependent and polarization dependent. For the case of plastics in the automotive radar frequency band, assuming isotropicity and constant permittivity is reasonable. The complex part of the permittivity is usually expressed as a loss tangent in terms of the real-valued permittivity and describes how much energy is dissipated.



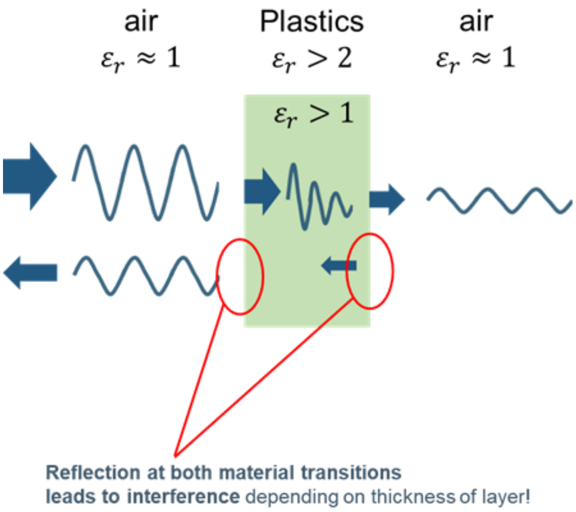


Figure 2: Reflection, Transmission and Absorption of radar waves.

When radar signals are transmitted through dielectric materials, the signal power is partially transmitted, reflected, and absorbed. Reflections happen at each material transition, so whenever the permittivity of the medium changes. For a single layer, the entry and exit point of the signal into and out of the layer provide two reflection boundaries. Absorption, on the other hand, scales linearly with the thickness of the medium.

The material thickness, the permittivity and the wavelength of the signal determine how constructively or destructively reflections from these reflection points superimpose.

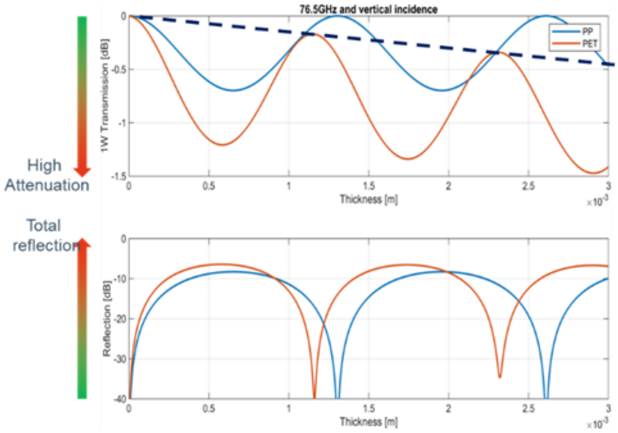


Figure 3: Reflection and Transmission as function of part thickness.

The resulting interference pattern takes a sinusoidal shape. Transmission, Absorption and Reflection energy together preserve the incident energy. For a given frequency, transmission loss is lowest when the optical thickness (given by thickness times square root of the permittivity) of the medium is equal to a multiple of half a wavelength. In this case, reflections at the material transitions superimpose in a constructive fashion.

Geometrical considerations – the polarity of the radiation and the incidence angle to the plastic part – have also a significant effect on wave propagation but are not treated here.

2.3. Material Characterization

The method for material characterization presented here is a free-space method, which is typically used in this frequency range. It requires three measurement steps. Firstly, a precise thickness measurement of a flat sample consisting of the material must be conducted. As there is an ambiguity between thickness and permittivity (via the optical thickness), the thickness measurement can in practice be the limiting factor for the accuracy of the material characterization. After that, two measurements are conducted with a setup, in which two opposing antennas face each other with a certain, fixed distance. First, a signal at a given frequency is sent by a transmitting antenna and received by a receiving antenna. After that, the sample is placed in the antenna path. As the transmission properties are dependent on the incidence angle, it is important to orient the sample precisely orthogonal to the axis between the antennas. Then, the measurement procedure is repeated. In both measurements, a complex-valued signal is measured. The amplitude and phase differences are then compared with each other. The phase difference can be related to the optical thickness of the sample, and via the thickness measurement hence to a permittivity. the measured amplitude can be used to estimate the absorption and hence also an estimate for the loss tangent – defining the complex part of the relative permittivity – can be obtained. For detailed formulas and analysis, we refer to [1].

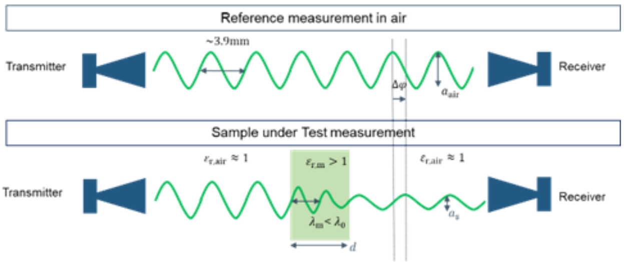


Figure 4: Test method to test materials for radar permitivity.

2.4 Influence of permittivity differences on radar transmission

To assess the influence of permittivity differences, one could compare the influence a typical permittivity change has on the attenuation of a signal. There are, however, several reasons, why this may be misleading. Firstly, the influence a permittivity change has on the transmission loss depends on how optimized the thickness of the medium is. The sensitivity of the transmission loss relative to permittivity changes is at its lowest when the medium is at its optimum thickness and is approximately described by the slope of the interference pattern in the previous illustration. Second, it is important to remember that a plastic layer can only ever be perfectly optimized for one frequency, as the interference patterns always depends on the wavelength. Furthermore, geometric considerations mean that for integration in cars, it is not sufficient to control the transmission attenuation at a single angle only.

Instead, via the optical thickness of the medium, we can approximately compare the effect of small permittivity differences to the effect of small thickness differences. From the formula for the optical thickness,

$$\boldsymbol{d_{optical}} = \boldsymbol{d}\sqrt{\boldsymbol{\epsilon_r}} \qquad [1]$$

we can see that a relative change of 2 percent in the thickness has a very similar effect to a change of 4 percent in the relative permittivity.

For example, increasing the thickness by 52 micrometer from an initial thickness of 2.6 millimetre (which is a typical optimized thickness for polypropylene), leads to almost the same effect as increasing the permittivity from 2.25 to 2.3409 (2.25 is a typical permittivity for polypropylene). Changes of ± 100 micrometer are typical thickness tolerances in bumper manufacturing.

This illustrates that the performance of a typical polypropylene radome will be limited by thickness variations, rather than permittivity differences, if the permittivity changes are significantly smaller than ±0.1.

This demonstrates that it is essential to understand the impact of fillers on the permittivity of plastics to ensure the radar system functions correctly.

2.5 Polypropylene

Polypropylene (PP) is a thermoplastic polymer commonly used in the automotive industry due to its excellent mechanical and thermal properties. PP is also popular due to its low density and recyclability. PP can be modified with various fillers to enhance its properties. However, fillers such as glass fiber, talc, and pigments can also influence the electrical properties of PP.

The following sections will examine the effects of fillers on the electrical properties of PP.

3. Effect of Fillers on the Electrical Properties of Polypropylene

Polypropylene (PP) is a thermoplastic polymer that is widely used in the automotive industry due to its excellent mechanical and thermal properties. PP can be modified with various fillers to improve its properties. However, the addition of fillers can also have an impact on the electrical properties of PP, which is an important consideration for the application of radar technology in automobiles.

3.1 Fillers and their effects on the electrical properties of PP.

There are several types of fillers that can be added to PP, such as glass fibbers, talc, and pigments. Each of these fillers has a different effect on the electrical properties of PP. All measurements in the following analysis were conducted with an RMS by perisens GmbH. This measurement equipment is working like the descript method in chapter 2.3.

3.2 Glass fiber

Glass fibres are commonly used as a filler in PP to improve its mechanical properties. However, the addition of glass fibbers can also increase the permittivity of PP. This is because glass fiber have a higher permittivity than PP. As a result, the addition of glass fiber can affect the performance of radar systems in automobiles.

3.3 Talc

Talc is often used as a filler in PP to improve its stiffness and impact resistance. The addition of talc can also affect the electrical properties of PP. Talc has a higher permittivity than PP, which means that the addition of talc can increase the permittivity of PP. This can have a negative impact on the performance of radar systems in automobiles.

Here is a graph showing the effect of different fillers on the permittivity of PP:

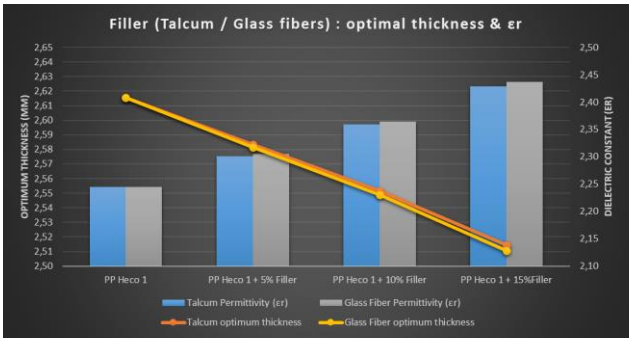


Figure 5: permitivity and optimal thickness depending on talcum and glasfiber content.

3.4 Pigments

Pigments are commonly used to colour PP. However, the addition of pigments can also have an impact on the electrical properties of PP. Pigments have a higher permittivity than PP, which means that the addition of pigments can increase the permittivity of PP. This can affect the performance of radar systems in automobiles. In our study, we examined the impact of different black pigments on the electrical properties of PP. We found that the content of black pigment used had a significant effect on the permittivity of the resulting composite. A graphical representation of the results of our study is presented in the following figure, which clearly shows the differences in permittivity between the various black pigment contents. These findings highlight the importance of carefully selecting the type of pigment and the content of the pigment used in PP to ensure that the desired electrical properties are achieved.

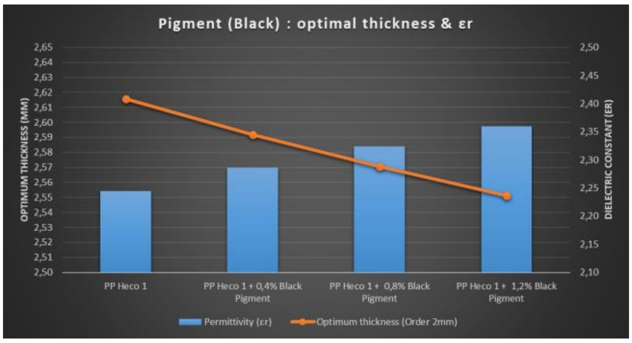


Figure 6: permitivity and optimal thickness depending on pigment content.

3.5 Conclusion of filler impact

Overall, the addition of fillers can have a significant impact on the permittivity of PP and can affect the performance of radar systems in automotive applications. Therefore, it is crucial to understand the effects of fillers on the electrical properties of PP to ensure the proper functioning of radar systems.

3.6 Influence of Different PP Types

In addition to fillers and pigments, the type of PP used can also affect its electrical properties. Two commonly used types of PP in the automotive industry are homopolymer PP (homo-PP) and copolymer PP (copo-PP).

Homo-PP is a PP type that is made of only propylene monomer units and has a high crystallinity, making it more rigid and stronger than copo-PP. Copo-PP, on the other hand, is made of a combination of propylene and ethylene monomer units, resulting in a lower crystallinity and a more flexible material.

In an in-house study, the electrical properties of homo-PP and copo-PP were compared, and it was found that there were no significant differences in their permittivity values. Both types of PP exhibited similar behaviour when filled with different types of fillers.

Rubber-modified PP (TPO) is another commonly used PP type in the automotive industry, which contains a blend of PP and elastomer. However, it was also found that the addition of rubber did not have a significant effect on the permittivity of PP.

Overall, the type of PP used in automotive applications does not appear to have a significant impact on the electrical properties of the material.

Figure 7: permitivity and optimal thickness depending material.

4. Impact of production plant and batches

4.1 Difference between batches

In chapter 4.1, we investigated whether there were any significant differences in permittivity between 12 batches of the same material produced in a single factory. Our results showed no significant differences between the batches, indicating that the manufacturing process is highly controlled and consistent. This finding is important for the automotive industry, as it suggests that variations in the electrical properties of PP are not caused by manufacturing variability. Overall, our study suggests that the permittivity of PP is mainly determined by the material composition and processing conditions, rather than manufacturing variability. The figure below displays the measured permittivity values for the 12 batches produced in the single factory.

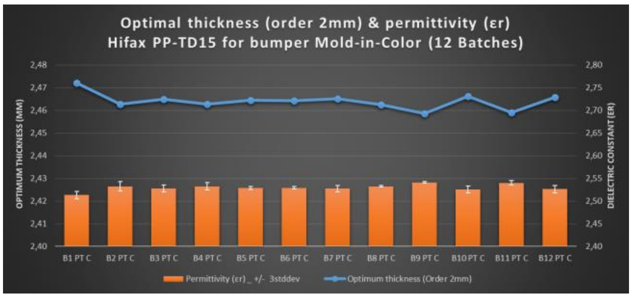


Figure 8: permitivity and optimal thickness depending material.

4.2 Difference between production plants

In Chapter 4.2, we did not observe significant differences in the permittivity among the 10 batches that were produced in two different LyondellBasell plants. We concluded that LyondellBasell's production quality is very high and that the differences in permittivity between the two plants are negligible. This is an important finding for the automotive industry, which relies on consistent electrical properties of materials across different batches and plants. The figure below shows the measured permittivity values for the 10 batches produced in the two plants.

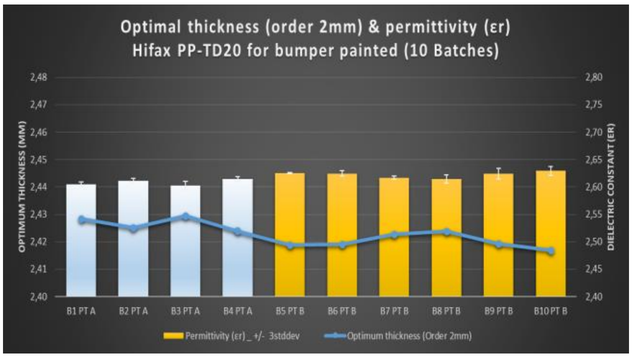


Figure 9: permitivity and optimal thickness depending material.

5. Impact of recycling feedstock

In chapter 5, we investigated the impact of using recycled polypropylene (rPP) on the permittivity of PP. We conducted this study to determine whether using recycled materials would have any impact on the electrical properties of PP and whether it would be a viable option for the automotive industry, which is increasingly focused on sustainable manufacturing practices.

We used a sample of PP with 15% rPP, which is a commonly used ratio in the industry. Our results showed that the addition of rPP had a slight but measurable effect on the permittivity of the PP. Specifically, we observed a slight increase in permittivity with the addition of rPP. While the increase was small, it is worth noting that any change in permittivity can impact the performance of electronic systems and therefore needs to be considered when using rPP in manufacturing.

Overall, our findings suggest that the addition of rPP to PP has a minimal impact on the permittivity of the material. However, it is important to note that we only tested one material with a specific percentage of rPP. Further studies are needed to investigate the impact of different ratios of rPP on the permittivity of PP.

The figure below shows the measured permittivity values for the sample of PP with 15% rPP.

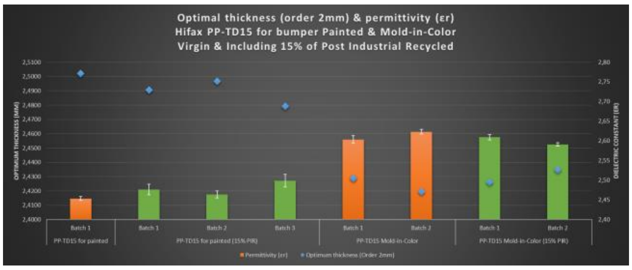


Figure 10: impact of recycling feedstock.

6. Conclusion

In conclusion, the results of this study show that material selection plays a crucial role in determining the final thickness of PP compound parts. The presence of talc and pigment in the PP compound has a significant influence on the final part optimum thickness. Furthermore, the stable batch-to-batch production of PP compounds with optimum thickness and permittivity properties supports the concept of radar positioning behind the final parts. However, it is important to note that the dimensional stability of the assembly and other factors, such as paint, must be considered when designing parts for radar performance. Further investigations are needed to analyse the impact of these factors on the radar performance of PP compound parts. Additionally, this study suggests that further research is needed to evaluate the performance of PP compound parts on a larger component range as well as on different recycling raw material sources and technologies. Overall, the findings of this study provide important insights into the selection of materials and the design of PP compound parts for optimal radar performance.

This analysis furthermore underlines the necessity to know plastic properties before radomes are optimized.

8. References

[1] Florian Pfeiffer: "*Analyse und Optimierung von Radomen f¨ur automobile Radarsensoren*", Cuvillier Verlag, 2010.

9. Glossary

ACC: Adaptive Cruise Control
BSD: Blind Spot Detection
LRR: Long Range Radar
PCW: Pre-Collission Warning
PP: Polypropylene
SRR: Short Range Radar
ϵ_r: Relative Permittivity