EUROPEAN COATINGS journal

www.european-coatings.com

04 – 2024

RECONCILING DESIGN CHALLENGES AND HIGH-TECH

By Dr Florian Pfeiffer, Perisens, Christoph Landmann and Clemens Günther, Merck.

Source: Andriy Medvediuk - stock.adobe.com

VINCENTZ

Source: zentilia - stock.adobe.com

RECONCILING DESIGN CHALLENGES AND HIGH-TECH

New pigment technologies for silver (and radar-transparent) automotive coatings. By Dr Florian Pfeiffer, Perisens, Christoph Landmann and Clemens Günther, Merck.

Automotive coating formulators have the tricky challenge of developing highly sought-after metallic paints that also allow integrated sensor technology to function. A new technology should enable greater creativity with pearlescent pigments and provide formulators with a radar-transparent coating that delivers on performance even after vehicle repairs.

Radar (radio detection and ranging) technology exploits the properties of electromagnetic (EM) waves to capture information about nearby objects. It does this by emitting EM waves at a given frequency, detecting the secondary signals these produce (through reflection and echoes) to determine the position and speed of objects relative to sensors.

In recent years, radar technology has developed into an important aspect of modern vehicles. Its key use lies in controlling advanced driver-assistance systems, not only to make it safer to drive around in vehicles, but also to improve passenger comfort.

Modern cars are equipped with various different types of radar-based assistance systems, from adaptive cruise control (ACC) technology to blind spot detection (BSD) and pre-collision warning (PCW). These systems merge data generated by radar devices with information supplied by sensors (such as ESPs).

Modern car radars operate at frequencies between 76 GHz and 81 GHz, corresponding to wavelengths of just under 4 mm. Compared to optical sensor technology (e. g. cameras and lidar), the advantage of radar is that it is much less sensitive to adverse weather such as fog, snow, or rain. Radar is also not confused by glare (low sunlight or other intense sources of illumination). Another benefit of radar systems – one that should not be underestimated – is that radar sensors are concealed; in many cases, they can be installed without spoiling the vehicle design.

Short-range radar (SRR) is usually mounted behind the corners of car bumpers, while the sensors used for long-range radar (LRR) are mounted behind logos, badges, or plastic trims. Such protective covers are known as radomes.

Radar sensors use a number of transmission antennas simultaneously. The waves these emit bounce back off nearby objects and are detected again by the sensor's receiving antennas. This means radio waves penetrate radomes twice. Attention must therefore be given to the design and material properties of radomes, as they have the potential to affect factors such as the maximum reach of radar waves and angular accuracy. These influences are caused by using materials that are not entirely transparent to radar.

SENSOR TECHNOLOGY: THE FUNDAMENTALS

As most radomes use plastics and coatings, their dielectric properties play a crucial role in automotive radar systems.

The relative permittivity (or the dielectric constant ε_r) of a material is the measure of its ability to store electrical charge, relative to a

RESULTS AT A GLANCE

- → Appealing silver shades could not be produced without metal effect pigments, which hinder radar-based driver assistance systems.
- → New pigment technology enables a silver pigment with radar transparency.
- → These radar-transparent pearlescent pigments can now also contribute to opacity in light metallic shades.
- → It is now possible to use light silver shades without restriction, even on components that conceal sensitive sensor systems.

Figure 1: The positioning of radar devices in modern cars.

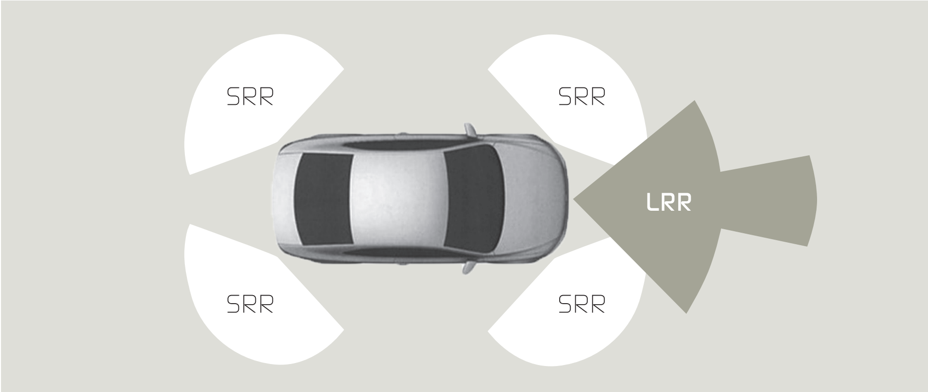
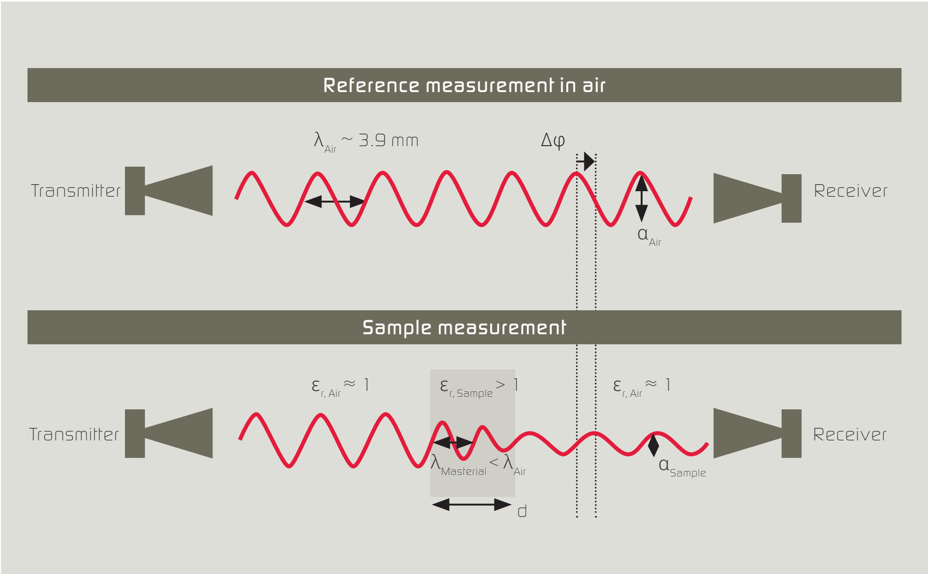


Figure 2: Illustration of the measuring principle behind the radome measurement system, which is used to determine material permittivity.

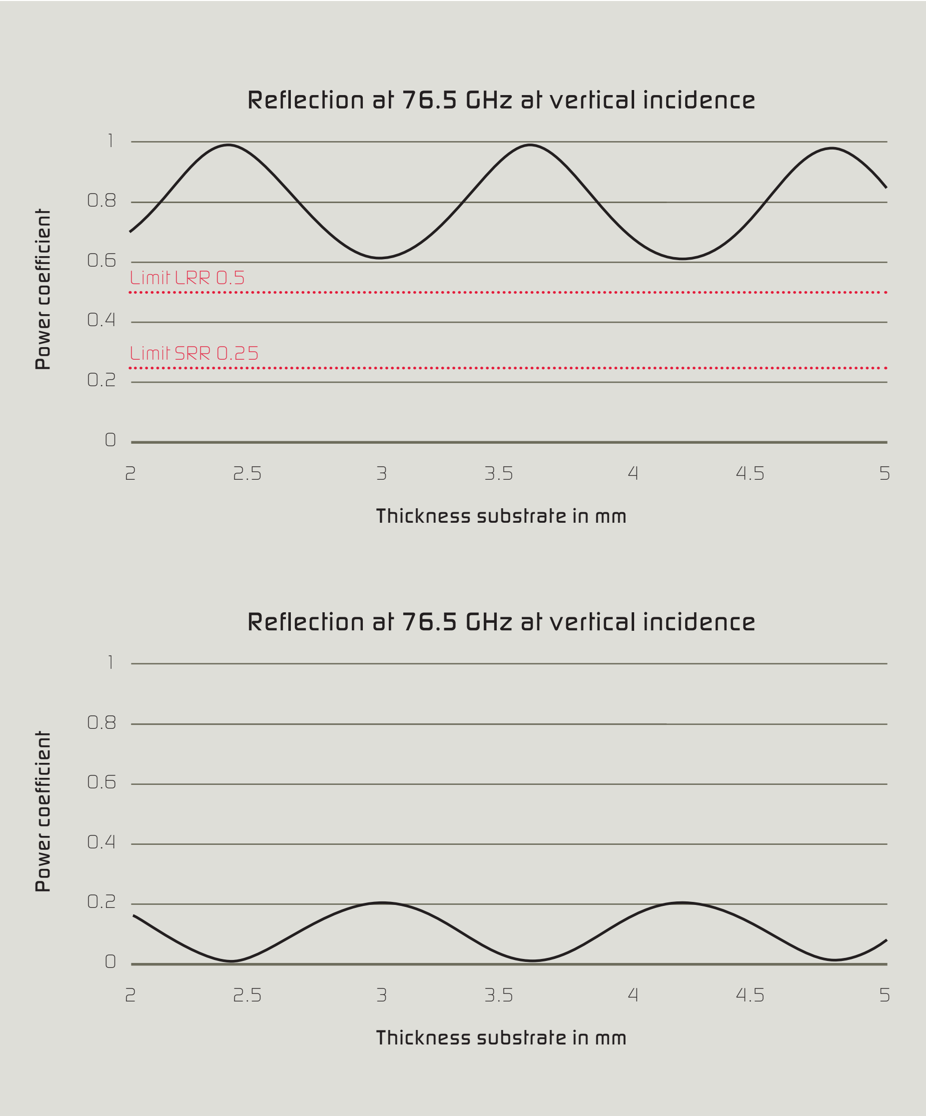


vacuum. Plastics and coatings typically have a higher permittivity than air or a vacuum.
When radar signals are transmitted through dielectric materials, signals are partially transmitted, reflected, and absorbed. It is therefore crucial to design radar covers to achieve sufficiently high levels of transmission, not only to meet sensor range requirements, but also to minimise reflection so that signals do not blind the receiving antennas.
If the thickness and permittivity of individual layers are known, the transmission and reflection properties of components can be calculated. To measure actual permittivity, special instruments are used. To do this, an EM wave within the frequency range of the radar sensors is beamed onto a flat sample plate. Inside the material in the sample, the EM wave propagates more slowly than in air, so the period of the wave is reduced. In addition, the amplitude of the wave is reduced due to the material's reflection and absorption properties. The former effect can be measured and expressed as phase difference Δφ. The latter is expressed by a transmission coefficient $\alpha_{Sample}/\alpha_{Air}$ (see *Figure 2*).
Based on measurements and the thickness entered into the software, the device uses regression analysis to determine actual permittivity and the loss tangent. The measurement principle can be applied to single-layer and multi-layer samples. It can also be used with coating layers down to a thickness of individual micrometres. In multi-layer samples, only one material can be unknown – i. e. the permittivity of all other materials must be determined beforehand.

VEHICLE BUMPER PERMITTIVITY AS PART OF COATING CALCULATIONS

Material permittivity depends on the base material itself in combination with additives and fillers, as well as production-related influences. Conductive pigments, in particular, can support very high permittivity levels thanks to interfacial polarisation in conductive primers and metallic basecoats. EM waves are reflected at every transition point between materials, i. e. whenever medium permittivity changes. The greater the difference between the actual permittivity of neighbouring materials, the greater the degree of reflection at the interfaces. This compares with absorption, which increases on a linear basis according to medium thickness.
In the simplest case, a radar cover consists of a homogeneous plastic material. The entry and exit points of signals entering and exiting the layer then form two reflection boundaries (air to plastic, plastic to air). The reflections that occur overlap and can increase or decrease the amplitude depending on the phase change, which correlates with material thickness. This interference effect is exploited in the design of radar covers, and component thickness is adjusted so that reflections at the two interfaces simply cancel each other out, thus minimising total reflection and maximising transmission.
Figure 3 shows the calculated transmission and reflection coefficients of bare PP/E TD30 as a function of material thickness. This clearly shows interference properties with periodic transmission maxima and minima, or reflection maxima and minima. If the right thickness is chosen, 98.5 % of the signal is transmitted; if a poor choice is made, this is only 61.9 %. Modern short-range radar sensors (SRRs) require two-way transmission levels of at least 25 % and long-range radar sensors ➜

Figure 3: Simulated two-way transmission and reflection of an EM wave on uncoated PP/E TD30 as a function of layer thickness at 76.5 GHz and vertical incidence.



(LLRs) at least 50 %, which in this case would be achieved regardless of the thickness.
This can also be calculated for coated bumpers, which are treated like a layered dielectric medium for modelling purposes. In general, the permittivities of individual materials will differ, so there will be reflections at each individual boundary layer. *Figure 4* shows the result of a calculation for a material consisting of three layers:

- conductive primer (10 µm),
- basecoat (20 µm),
- and clearcoat (30 µm).

For the model, four different basecoats (all other things being equal) with calculated permittivities of 3, 7, 20, and 50.
The simulation shows that basecoats with a permittivity of $\varepsilon_r = 20$ have a non-negligible influence on the radar properties. With an even higher permittivity value of $\varepsilon_r = 50$, the current limit values for SRR can only be achieved by adjusting the thickness of the bumper accordingly.

OEM COATING CONSIDERATIONS

From a design perspective, sensor systems would be integrated into cars but not seen. In the best-case scenario, this will entail positioning technology behind coated plastic parts. However, to do this requires entire components – including the paintwork – to be transparent to radar.
Due to their individual composition, there are significant variations in the permittivity of different coating materials. Metallic paints, in particular, interfere with signals. This is because they use metallic effect pigments, which have strong reflectivity and produce a pronounced light/dark flop and strong opacity, especially in light silver shades. Unfortunately, aluminium flakes also reflect the electromagnetic waves of sensors, which can result in permittivities of $\varepsilon_r = 50$ or more if they are used to coat components. In such setups, it is not possible to guarantee that sensor systems will function.
There are ways to work around aluminium. Instead, pearlescent pigments can be used to deliver metallic sheen and flop. They are almost entirely transparent to radar signals. However, they are also semi-transparent to visible light and pose challenges in achieving optimal brightness, flop, and hiding power. It would be possible to preserve opacity and brightness by adding titanium dioxide, but this reduces the required effect. Conversely, adding carbon black delivers flop and opacity, but it also makes formulations dark.
There are still ways to achieve acceptable radar transparency with grey or chromatic effect coatings, but with lighter silver tones,

Figure 4: Simulated two-way transmission and reflection of an EM wave on coated PP/E TD30 as a function of substrate layer thickness at 76.5 GHz and vertical incidence.

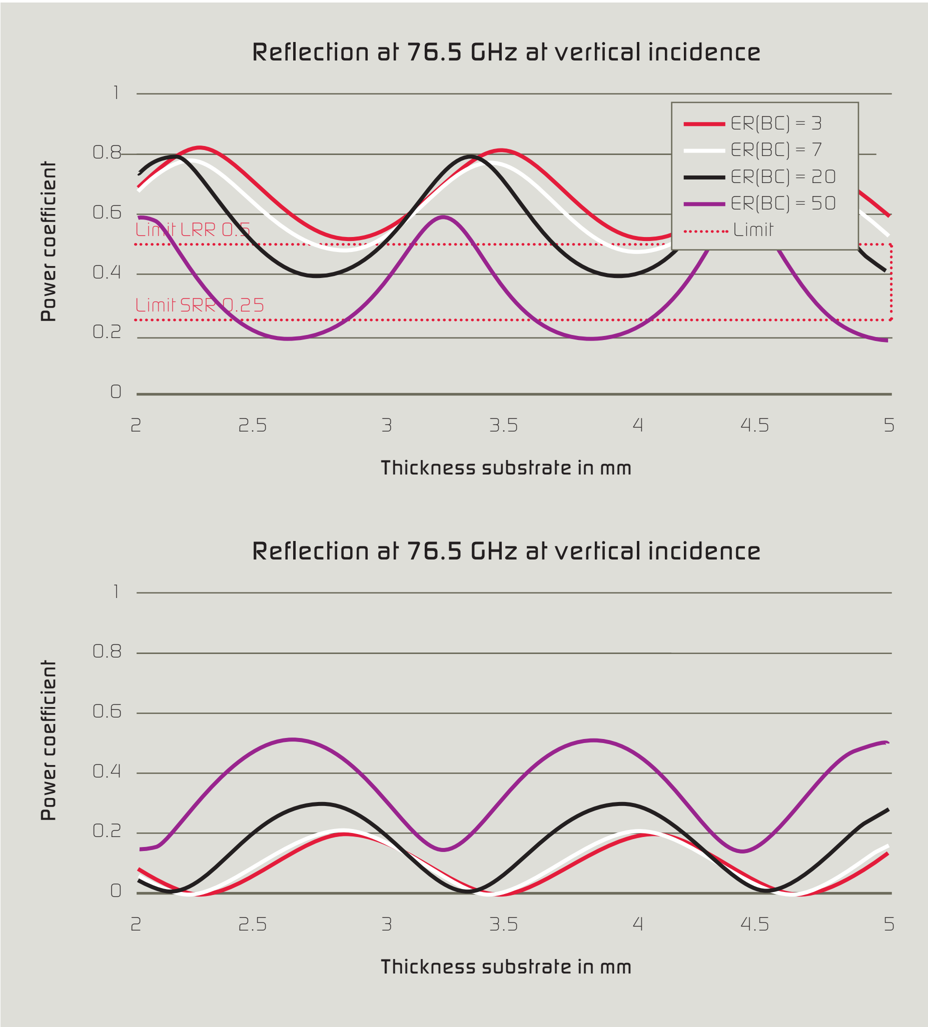
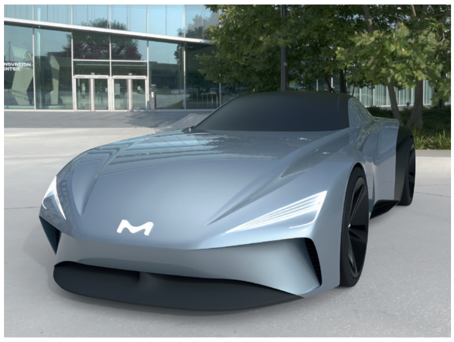


Figure 5: Practical application of the novel pigment in an automotive formulation.



however, it appears the problem has not yet been solved. As a result, these colours are increasingly disappearing from the configurators of car makers – an unwelcome loss given that they recently had a market share of just under 10%.
Repair requirements are also considered when formulating new OEM paints. It is therefore important that components remain radar-transparent even with much thicker coatings. It is not sufficient to simply reduce the proportion of aluminium pigments in formulations to OEM-compatible levels. New technologies are needed to find a fundamental solution to this problem.

SUITABLE PIGMENT TECHNOLOGIES FOR RADAR PENETRATION

To nonetheless formulate light, radar-compatible silver tones, the obvious option would be to resort to electrically non-conducting pearlescent pigments. Whether these are based on corundum, mica, or synthetic silicates is less important. Further development in doping is more important to ensure pigments achieve improved opacity and a more metallic appearance than they have to date.
It will only be possible to bring about the required improvements by finding new production methods. An xperimental pigment using new methods has been developed, and a patent application submitted before market launch later this year. The novel 'silver radar' pigment makes it possible to produce bright, metallic shades of silver that allow radar signals to pass through without any problems. Its fine particle size makes it particularly suitable for creating sought-after silky effects and adding further effect pigments makes it possible to fine-tune brightness and texture.

AN EXPERIMENTAL COATING FOR OEM APPLICATIONS

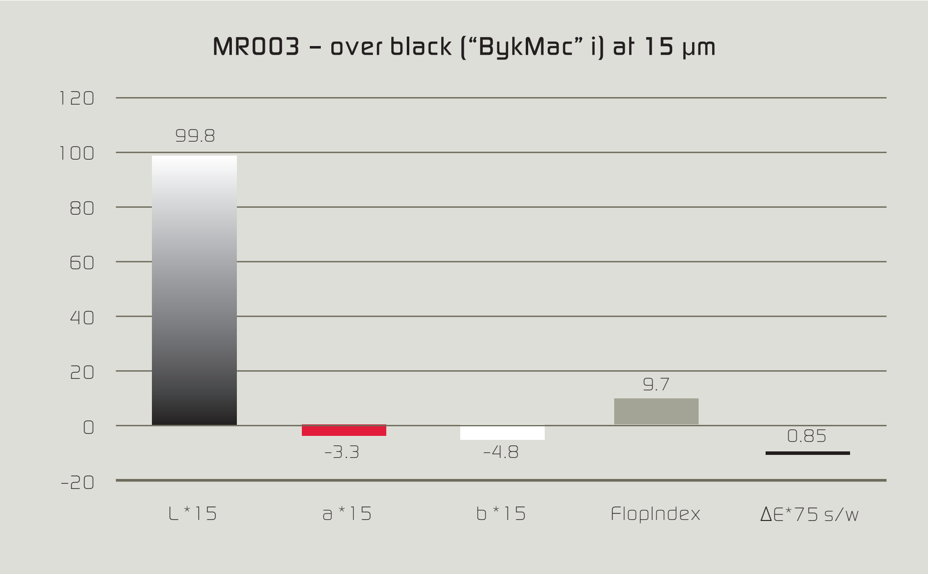
Figure 5 shows the realistic finishing of a car based on the novel pigment as a sample formulation. We created a combination of different effect pigment technologies and the colour effects are delivered by using:

- 16.80% novel silver radar pigment,
- 8.00% white mica-based pigment,
- 3.00% alumina effect pigment and
- 0.20% carbon black.

Our novel formulation provides an example of the potential appearance of silver without aluminium pigments. The strong metallic impression is confirmed by colorimetric measurements (see *Figure 6*).
Effect silver shades are usually set to a brightnesses of L≥100 at an angle of 15°. To create appealing silver metallic effects requires a strong light-dark flop. In terms of measurement, there is a correlation with texture: Highly glittery paints have a higher flop index. The 9.7 measurement in the sample formulation is of a magnitude that would also be achieved with comparably fine aluminium flakes. The third requirement that needs consideration in colour terms is opacity. At an angle of 75°, the colour difference over black and white must be DE<1. At 0.85, the difference in the novel formulation falls well within this requirement.
The new production technology positions pearlescent pigments to meet the challenging trio of requirements in this colour range.
Measurements would demonstrate the suitability of the sample formulation for coating components used to cover radar sensors. To take these measurements, we used a pneumatic spray to apply a 15 µm layer of the coating to a homogeneous PET substrate measuring 350 µm in thickness. We determined its dielectric properties in advance to make it possible to adjust measurements accordingly and gauge the precise characteristics of the coating layer. This can be used as a basis for conducting reliable simulations of radar performance and making calculations for other material combinations and layer thickness constellations.
The determined permittivity of the sample coating, $\varepsilon_r = 6.9$, roughly corresponds to the

green line in *Figure 4*. Signal transmission is strong enough for LRR, even behind plastic parts under a 20 µm film of our experimental coating. Its compatibility with SRR signals is beyond question, such that it is even worth considering two-way transmission in the event of repairs.

Figure 6: Colour characterisation.



RETAINED PERFORMANCE AFTER REPAIRS

Car bumpers are easily scratched. This is a common occurrence and the cost of repairs is eye-watering if a damaged component has to be completely replaced because it cannot be repainted.

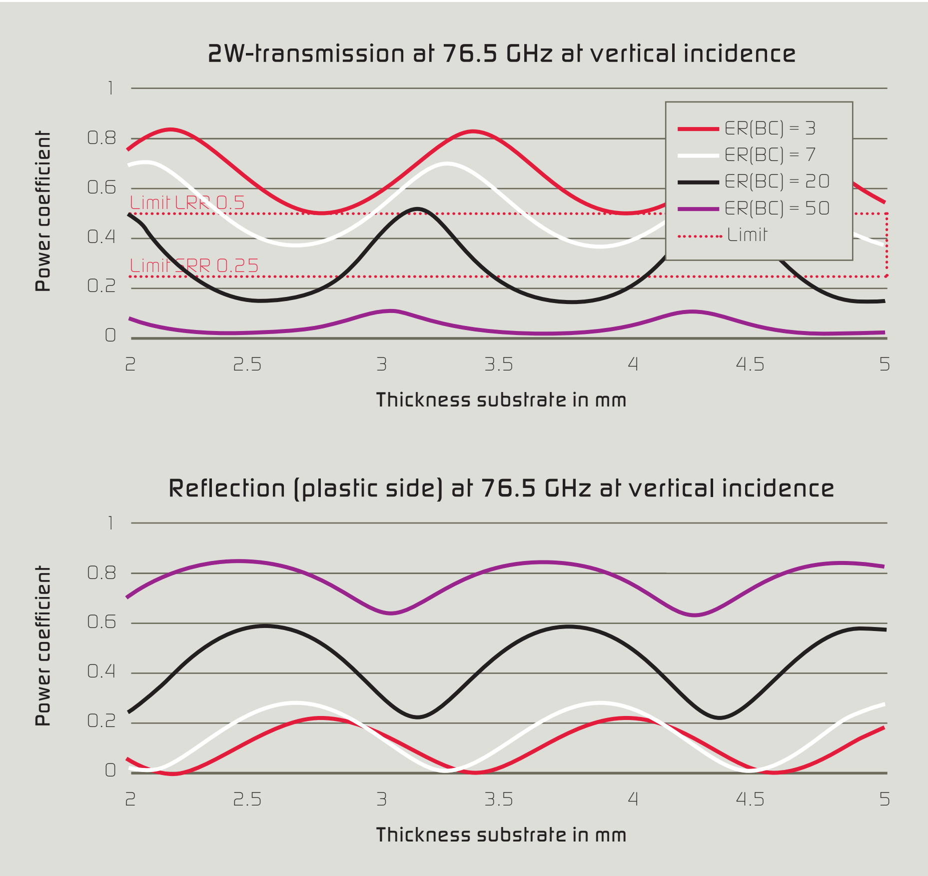
It is assumed that the part would be repaired by recoating a homogeneous layer on a standard paint finish. Accordingly, a 50 µm thick layer of basecoat and a layer of clearcoat (30 µm) are added to the original layer structure.

For the novel formulation, with a permittivity of $\varepsilon_r = 6.9$ (roughly corresponding to the green line in *Figure 8*), two-way transmission is reduced by around 10 %. This is such a small reduction that even if a component is repainted twice, it would still be sufficiently transparent for the required SRR signals – without having to consider the thickness of the plastic substrate.

DESIGN FREEDOM WITH ADVANCED TECHNOLOGY

New approaches to producing pearlescent pigments can play a crucial part in striking an important balance in the automotive industry – between offering designers the freedom to explore their creativity and integrating advanced technology. To make good use of the latest comfort features and safety systems, a number of major impediments have now been eradicated when it comes to colour selection. The new technology helps eliminate annoying constraints affecting the design of front-end modules and dispel some of the fear regarding repairs.

Figure 8: Simulated two-way transmission and reflection of an EM wave on post-coated PP/E TD30 as a function of substrate layer thickness at 76.5 GHz; vertical incidence.



Clemens Günther
Merck
coating-EMEA@merckgroup.com

Figure 7: A coated film on a radome measurement system.