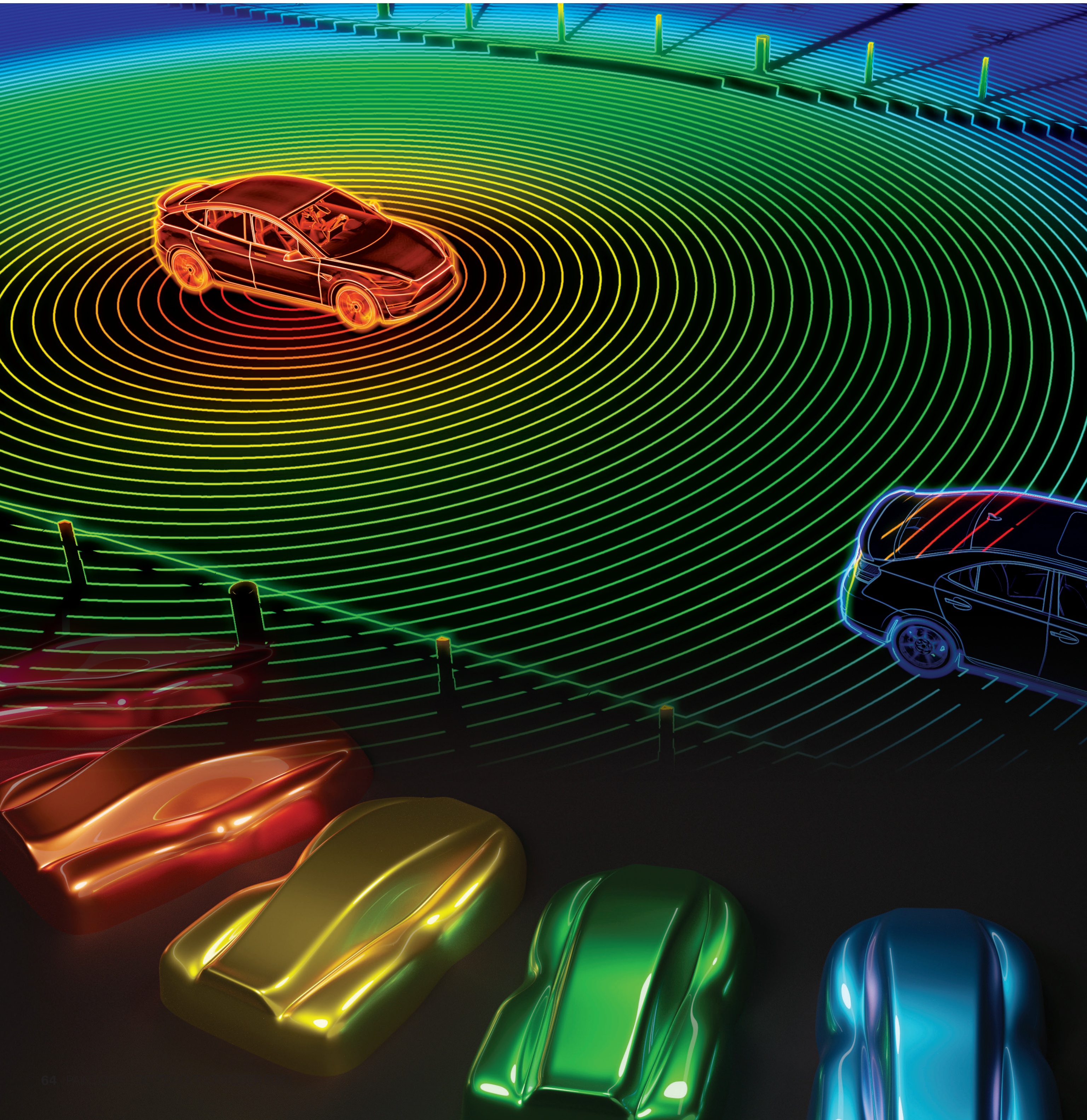
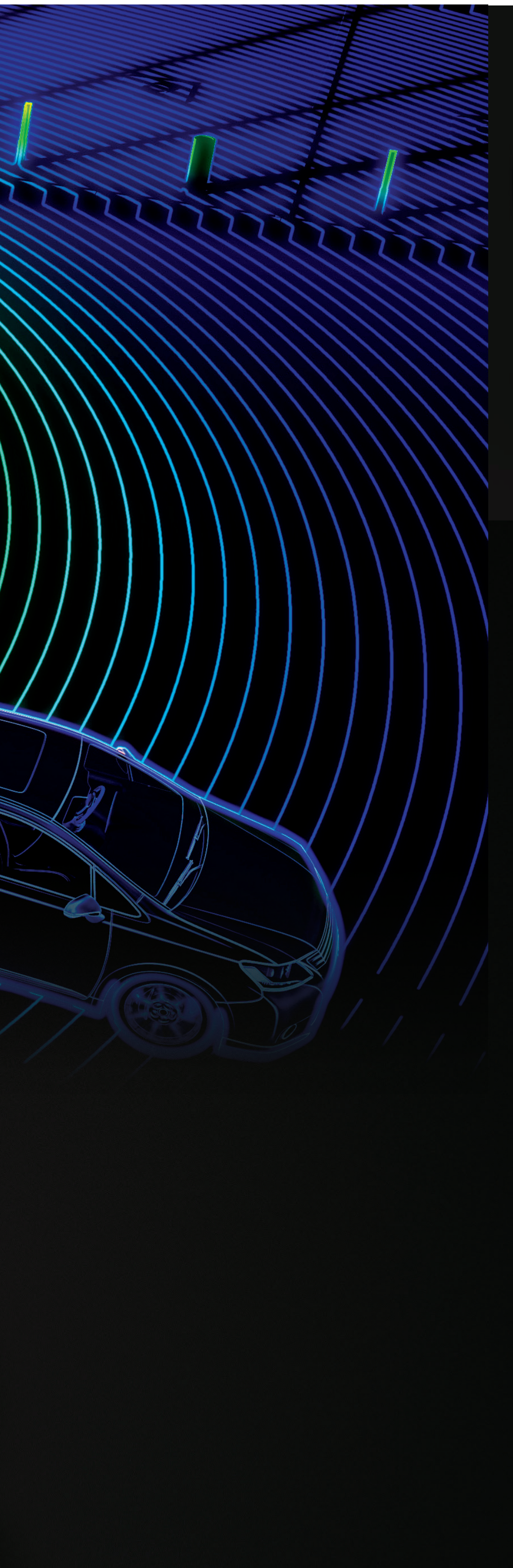
Radar and LIDAR

FROM THE VIEW OF A



Suitable Car Paints,

PIGMENT MANUFACTURER



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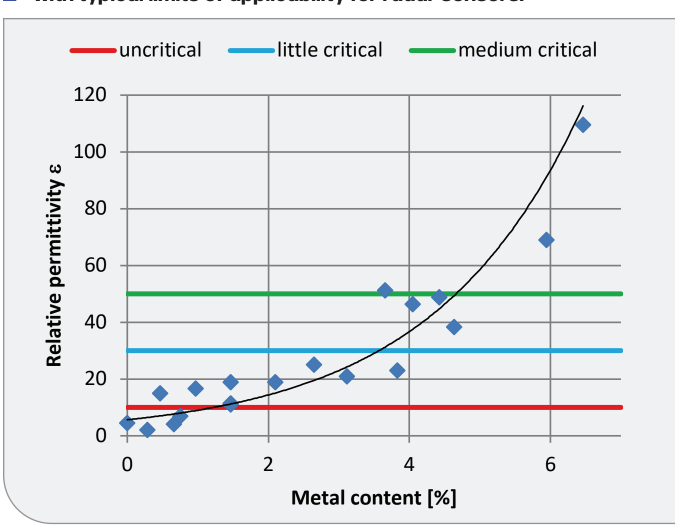
Introduction

Aluminum-based effect pigments are widely used in automotive coatings, but it has been found that such coatings frequently disturb the transmission of radar signals, if the radar source is hidden behind the coating. To measure this reduction in transmission, the permittivity dielectric constant (ε) and the loss tangent, *tan (δ)* (dissipation factor) of radio waves in the desired frequency band are used. Many published results show that the ε increases with rising pigment mass concentration,[2] while δ changes are negligible. **Figure 1** shows frequently cited data where the relative permittivity of automotive effect coating (including metal-based effect pigments) is analyzed with respect to the metal mass content.[1,3] According to Pfeiffer, the exemplary limits of radar transmission in terms of relative permittivity of automotive coatings are assumed to be < 10 as uncritical, < 30 as little critical, < 50 as medium critical, and > 50 as highly critical.[3]

FIGURE 1
Permittivity vs. metal content of automotive coatings together with typical limits of applicability for radar sensors.[3]



With a lack of information on the various properties of effect pigments used in the experiments (e.g., particle size distributions, thickness distributions, densities), no other conclusions were drawn other than to avoid or minimize the metal-containing effect pigments.[4-7] The requirements would imply a lot of effort to reformulate coatings components, and many of the appearance targets such as hiding, flop, lightness, and chromaticity, as well as suitable LIDAR visibility,[8] would not be fully reached.[1] Therefore, the present article deals with the radar transmission behavior of well-defined, metal-based effect pigments in combination with the expected coloristic requirements. There is a special focus on Metal Interference Pigments (MIP), introduced to the market under product names as Paliocrom, Meoxal, and Zenexo.

Experimental

Base coatings containing well-characterized, metal-based effect pigments were prepared with different pigment mass concentrations (PMCs) by a pneumatic spray application, at a layer thickness (T) of 14 µm on an optical transparent, 2-mm thick sheet of polycarbonate. No filler and no clear coat were used. The transmission of those samples is measured with a Radome Measurement System[2] at a frequency of 76.5 GHz for a perpendicular incidence. The substrate (the polycarbonate sheet), without the base coat, exhibits an ε of 2.736 and tan (δ) of 0.007.

The LIDAR reflection measurement was performed at a wavelength of 905 nm, utilizing an Ulbricht Sphere with a measurement geometry that excluded the specular component. This configuration ensured that only the integrated, diffusely scattered IR-radiation was detected. It was hypothesized that a high level of diffuse LIDAR reflection could serve as a relative measure for ensuring good LIDAR visibility.

Applying the same coating, as used for the radar measurement, on black and white steel substrates and adding a 40 µm clear coat on top, the coloristic data were evaluated using a goniophotospectrometer BYK-mac i. Thus, the color values for geometries of aspecular angles of -15°, 15°, 25°, 45°, 75°, and 110° for a light incidence of 45° were measured.

The effect pigments are characterized by measuring the densities using an Ultrapyc 1200e instrument, the equivalent diameter distributions by a Sympatec Helios/Quixel instrument, and the thickness distribution by Scanning Electron Microscopy.

According to these measurements, the pigments used in the experiments could be classified as shown in **Table 1**.

Pigments marked with the label UTP (Ultra-Thin Pigment[9,10]) distinguish themselves by having an extremely thin layer of aluminum substrate (less than 25 nm), while the coatings have comparable thicknesses to that of other pigments.

To find out the dominant parameters ruling the radar transparency, the following relations are used:

1. *PMC*, m_i is the mass of the effect pigment i; m_b is the mass of the binder component in the dry coating.

$$\mathrm{PMC_i} = \frac{m_i}{\sum_1^k m_i + m_b}$$

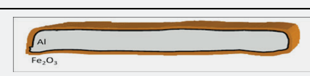
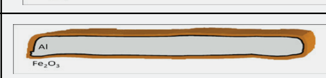
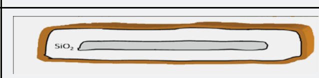
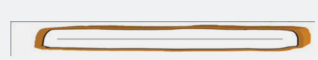
2. *PVC*, ρ_p is the density of the pigment; ρ_b is the density of the dry binder. For simplicity, ρ_b is assumed to be equal to 1.

$$PVC_i = \frac{PMC_i}{\frac{\rho_p}{\rho_b}(1 - PMC_i) + PMC_i}$$

3. *Coverage* is the area fraction covered by effect pigments; T is the thickness of the base coat; t_{50} is the median thickness of the pigment.

$$\text{Coverage} = 1 - e^{-PVC*\frac{T}{t_{50}}}$$

TABLE 1
Selection of Pigments and Pigments Data Used in This Paper, UTP = Ultra-Thin Pigment

Pigment	Density ρ (g/cm³)	Diameter d_{50} (µm)	Thickness span t_{span}	Thickness t_{50} (µm)	Type / Materials	Color
Competition Typ1	2.87	21.4	1.45	0.39		MIP: orange
Competition Typ1	2.95	18.7	1.95	0.23		MIP: gold
Competition Typ2	3.00	18.0	1.08	0.99		MIP: orange
Competition Typ2	2.81	17.9	1.08	0.63		MIP: gold
Zenexo Typ UTP	3.45	20.8	0.13	0.33		MIP: orange
Zenexo Typ UTP	3.05	19.0	0.13	0.33		MIP: gold
Zenexo Typ UTP	2.95	20.1	0.14	0.22		MIP: silver

4. N_p is the number of particles per unit area, for cylindrical particles with mean equivalent diameter d_{50} and median thickness t_{50}.

$$N_p = \frac{4\,PVC * T}{\pi\, d_{50}^2\, t_{50}}$$

5. M_{Al} is the mass aluminum per unit area; ρ_{Al} is the density of aluminum (Al; assumed to be 2.7 g/cm³); $t_{50(Al)}$ is the median thickness of the Al substrate.

$$M_{Al} = N_p\, t_{50(Al)} \pi \frac{d_{50}^2}{4} \rho_{Al}$$

Results of the Radar Experiments and Discussion

1. ε = ε *(PMC)*
   As expected, the permittivity rises with rising PMC but in a unique manner for different effect pigments, as seen in **Figure 2** in the range between the grey dots (Zenexo Typ UTP (silver)) and the red squares (Competition Typ2 (orange)). Furthermore, these dependencies are not linear.

   To check whether these strong differences between the effect pigments are induced by the different pigment densities, the same permittivity data are depicted as a function of PVC.

2. ε = ε *(PVC)*
   Result: Gives no improvement in unifying the data points; the dependencies stay non-linear.

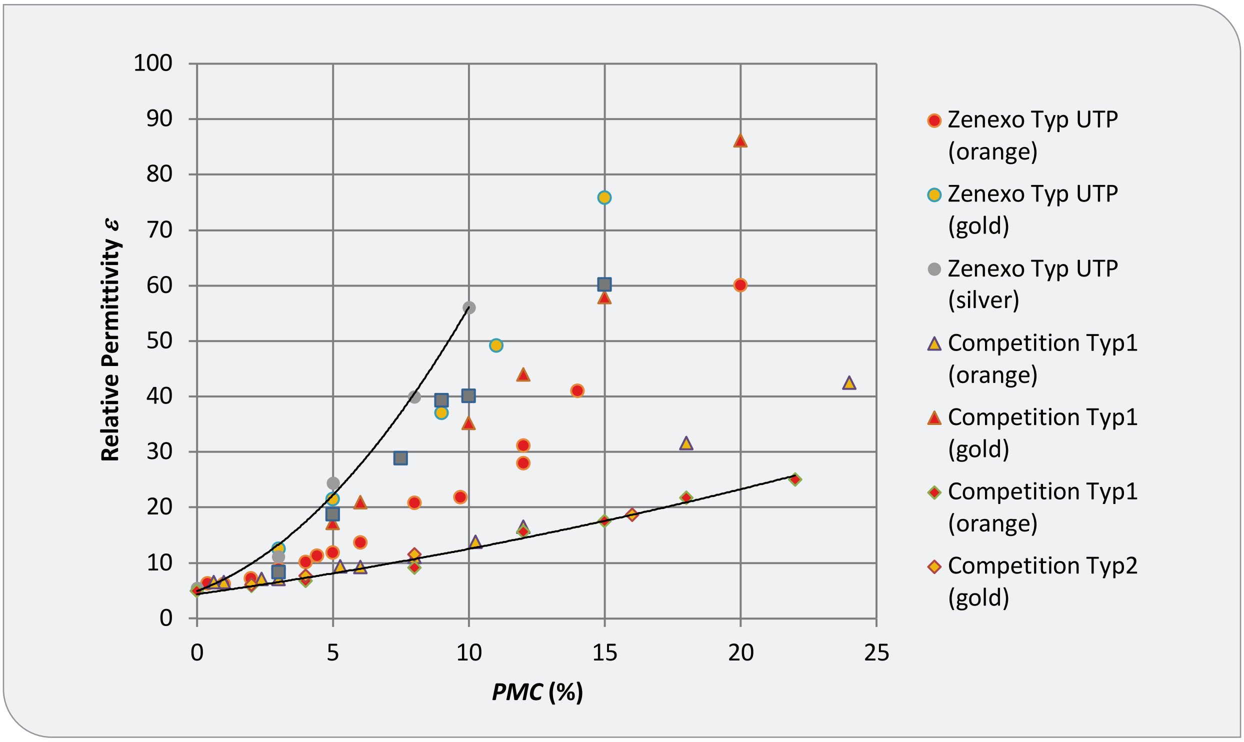
3. ε = ε (M_{Al}) and ε = ε *(Coverage)*
   Result: Gives no improvement in unifying the data points; the dependencies stay non-linear.

4. ε = ε *(Np)*
   Result: As expected, the permittivity rises with a rising number of pigments per unit area, but these dependencies can be regarded as linear (with a confidence of $R^2 = 0.98$), with different slopes for different pigments.

Analyzing the slopes in the ε = ε (N_p), no direct correlation with the pigments size, pigment thickness, or aluminum fraction of the pigment particles was found.

Results for pure aluminum pigments confirm the general dependence of permittivity on *PMC*, *PVC*, and *Np* but the reported influences of particle size and particle orientation[11] could not be verified, at least at no significant dependency for the given range of tested pigments.

FIGURE 2
Dependence of the permittivity on the PMC for mass tone coatings of different metal-containing effect pigments from Table 1.



Results of the Coloristic Experiments and Discussion

Figure 3 follows that, for each effect pigment, the target is to reach hiding with a minimum of particles per unit area and a maximum of reflectivity in the visual range and the LIDAR wavelength. It was found that all the UTP pigments exhibit better hiding. This is combined with a higher Lightness *L** (as15°), a higher Chroma *Cab*, a higher Flop Index *FI*, as well as a higher LIDAR Reflectivity (*R*), as depicted in **Figures 4a, b, and c**, shown by the three examples in the orange color area, respectively. This behavior is valid for all comparisons of UTP pigments and the corresponding competition products.

In sum, we predict that the formulation window for UTP pigments is broader than that for other MIP pigments. Although, for suitable radar transparency, the particle concentration must be reduced, and the use of absorption pigments is required. The superior lightness and flop index of the UTP pigments offer additional options to formulate bright, highly chromatic coatings with a metallic appearance.

FIGURE 3
Dependence of the permittivity on the number of particles per unit area N_p for mass tone coatings of different metal containing effect pigments of Table 1.

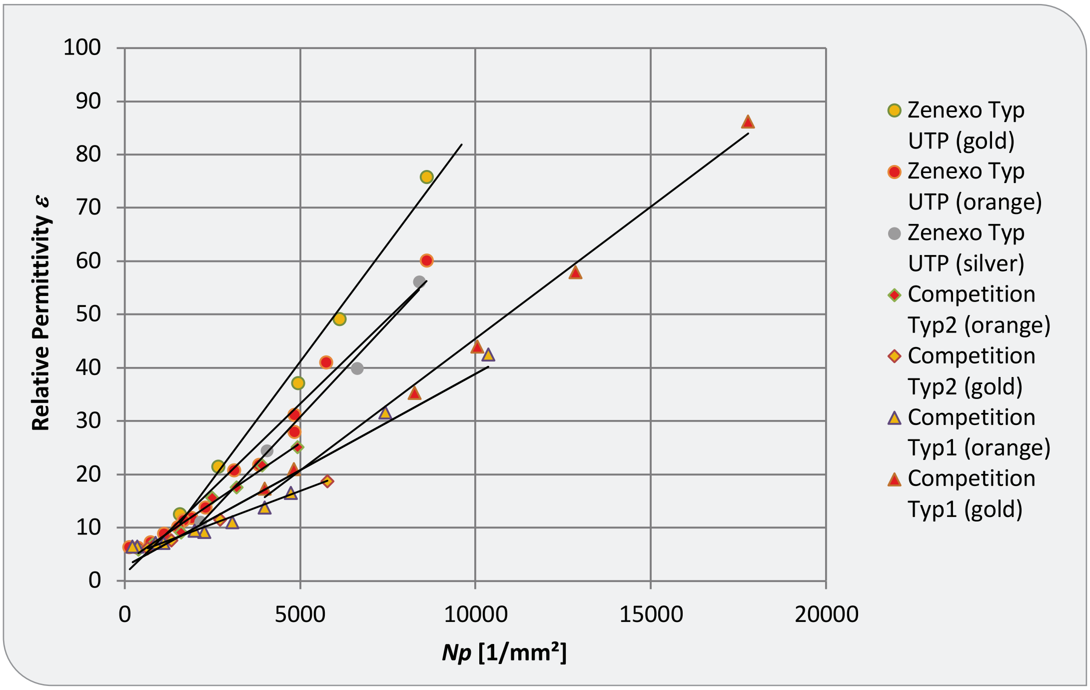
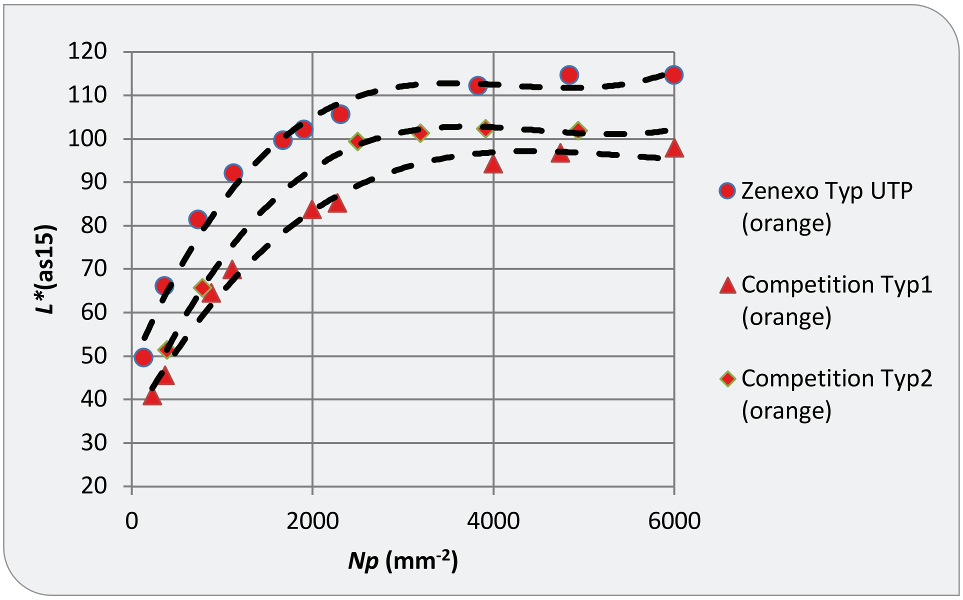


FIGURE 4A
Dependence of the Lightness *L(as15°) on *Np*.**



The superior lightness and flop index of the UTP pigments offer additional options to formulate bright, highly chromatic coatings with a metallic appearance.

FIGURE 4B
The correlation between the Lightness L*(as15°) and the LIDAR Reflectivity.

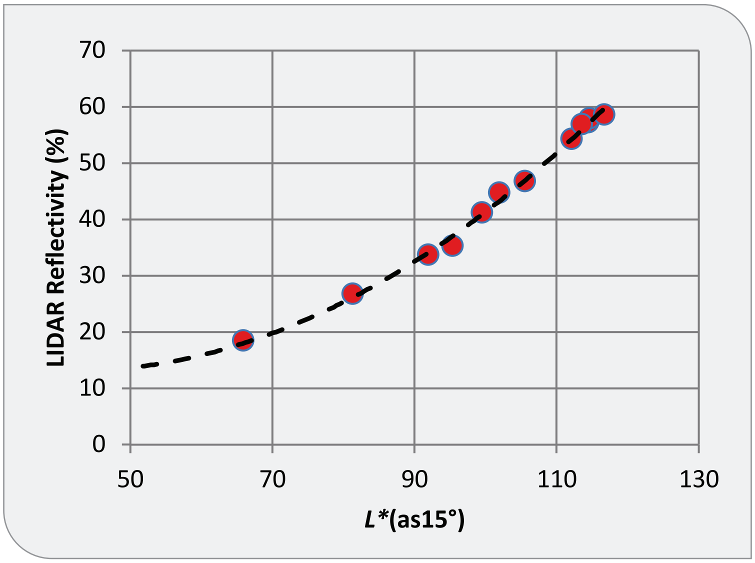
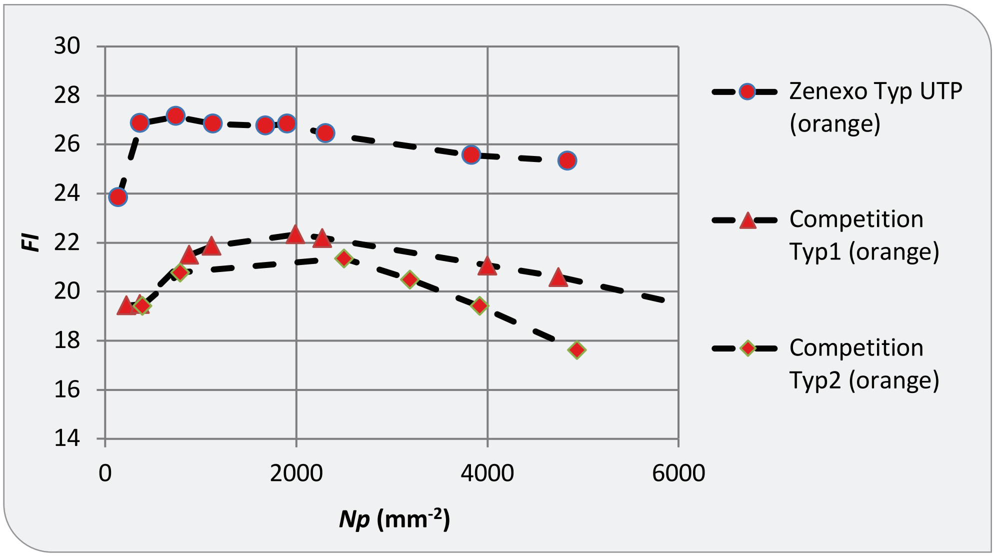


FIGURE 4C
The correlation between *Np* and the Flop Index *(FI)*.



Conclusion

The radar transmission depends on the type of metal interference pigments, and linearly, on the number of pigments per unit area. The higher this number the lower the radar transmission. On the other hand, the Lightness value L^*(as15°) and the flop also depend on the number of pigments, albeit in a nonlinear way. Only with MIPs, which already produce a high level of brightness and a good flop with a small number of particles per unit area, can the coating maintain a suitable radar transmission and at the same time a bright metallic appearance. The LIDAR reflection at 905 nm correlates with the L^*(as15°) value. The higher the L^*(as15°) value and therefore the higher the brightness, the better the LIDAR reflection. Among the pigments tested, those based on UTP technologies exhibited the highest brightness in the paint formulation, even at low particle concentrations. Therefore, with a fixed radar transmission, they offer the highest brightness and the best flop and LIDAR reflection. ❊

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