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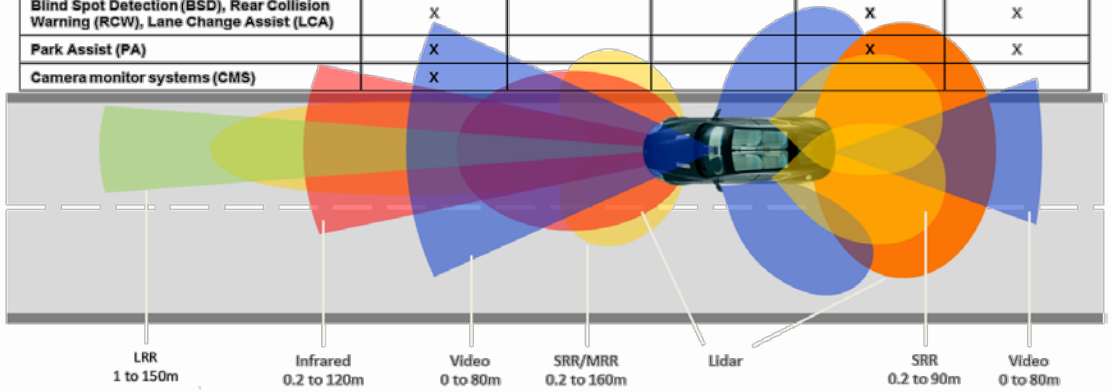
High-Tech Coatings to enable Autonomous Vehicles

Eldon Decker

PPG

Multi-component systems to accomplish a variety of functions

Application \ Sensor Type	Vision	Infrared / Thermal	Long Range Radar 76-81 GHz	Short / Mid Range Radar 24-26 / 76-81 GHz	Lidar
Adaptive Front Lighting (AFL), Traffic Sign Recognition (TSR)	X				
Night vision (NV)	X	X			
Adaptive Cruise Control (ACC)	X		X	X	X
Lane Departure Warning (LDW)	X				
Low-Speed ACC, Emergency Brake Assist (EBA), Lane Keep Support (LKS)	X			X	X
Pedestrian detection	X	X		X	
Blind Spot Detection (BSD), Rear Collision Warning (RCW), Lane Change Assist (LCA)	X			X	X
Park Assist (PA)	X			X	X
Camera monitor systems (CMS)	X				



Coatings in the Future of Mobility

- Sensor performance
- Sensor reliability
- Redundancy

Peter Labaziewicz, “Cars are becoming rolling sensor platforms”, *TI E2E Community*, Sept. 25, 2014, Texas Instruments Inc.

Coatings can improve sensor performance & reliability

PPG is a Global Leader in Paints and Coatings

PPG provides a broad array of leading products to various global industries and consumers

Business Units
- Aerospace
- Architectural
- Automotive OEM
- Automotive Refinish
- Industrial
- Packaging
- Protective & Marine
- Specialty Coatings & Materials
  - Optical Materials, Silicas, Teslin

Transportation

Building & Construction

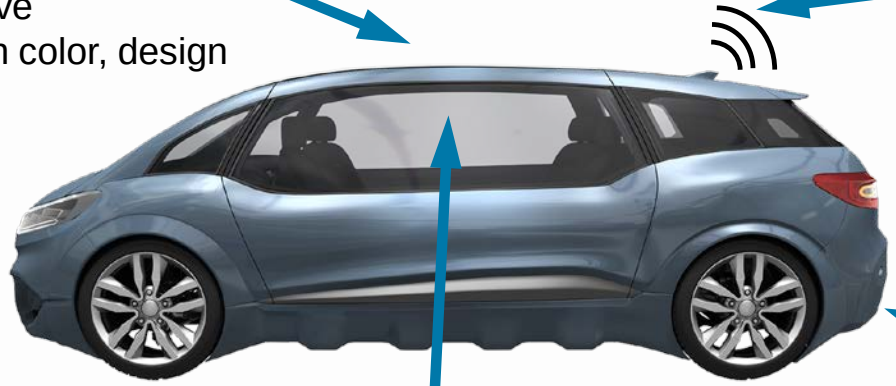
Industrial & Consumer Products

PPG has a broad high-tech coatings capabilities

PPG Coatings to Enable Autonomous Mobility

- Color palette for sensor performance
  - Radar compatible
  - LIDAR reflective
- Branding through color, design

- Printed antennas for communication
- EMI shielding solutions for advanced electronics



- Easy-to-clean for optical components
- Hardcoats for optical components

- Interior coatings
  - Anti-glare
  - Anti-fingerprint
  - Easy-to-clean display coatings
  - Soft touch coatings

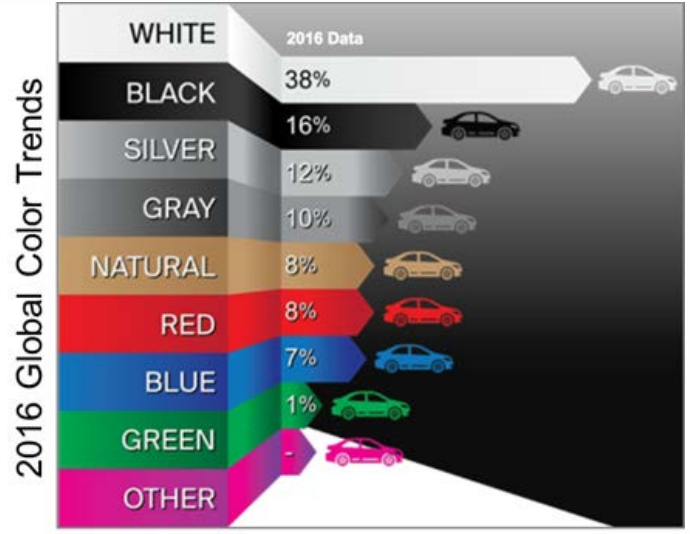
- Conductive adhesives

PPG coatings can be employed in numerous AV applications

LiDAR Challenges

Current State

- LiDAR uses near-infrared (NIR) laser to detect objects
- Dark colored objects, including vehicles and infrastructure, can be difficult to detect
  - Conventional dark coatings absorb at LiDAR wavelengths
  - 2016 global color trends show 16% of automotive builds were black



Environmental conditions

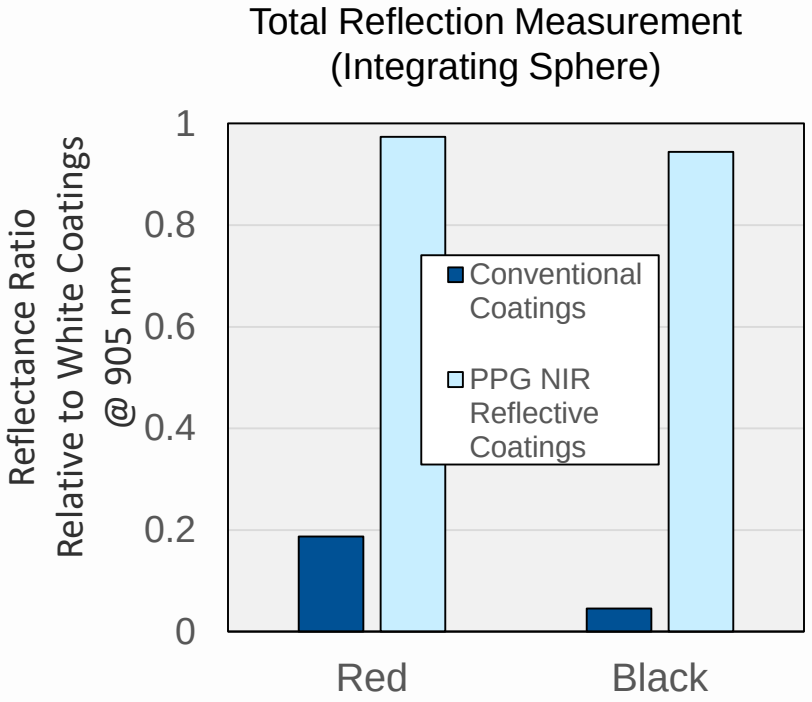
- Reduced signal detection due to light extinction
  - Dust, snow, fog, rain

Dark cars can be a problem for consistent detection

NIR Reflectance of Selected Automotive Colors

NIR Reflection Comparison

- Typical white coatings are about 20 times more reflective than typical black coatings at 905 nm
- PPG's NIR reflective coatings dramatically improve reflectance at 905 nm
- "Paint colors that reflect a greater amount of light at 905 nm are more easily detected by LiDAR" -- Dr. Christopher Seubert, Ford Motor Company*



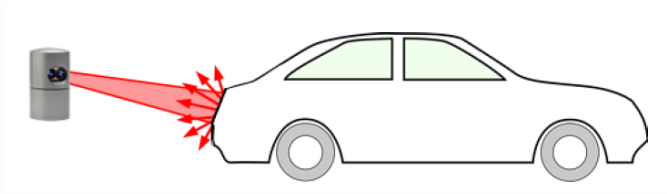
*"The Future of Coatings in a World of Autonomous Vehicles." American Coatings Association, 2017. https://www.paint.org/article/future-coatings-world-autonomous-vehicles/

PPG NIR reflective coatings can dramatically improve LiDAR detection

Improved LiDAR Sensing

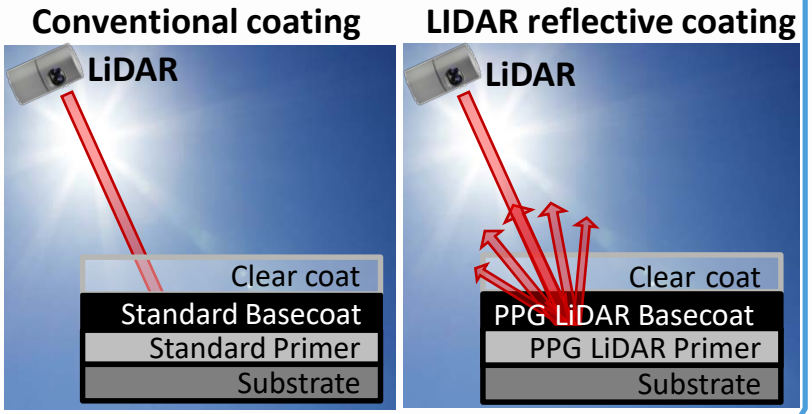
Ideal State

- Objects diffusely reflect LiDAR signals
- Coatings that do not absorb LiDAR signals



PPG NIR Reflective Coating Technology

- PPG LiDAR Primer
  - Dramatically improves reflectance at 905 nm
- PPG LiDAR Basecoat
  - Dramatically reduces absorbance at 905 nm
- Maintains:
  - Chromatic color palette
  - Jet black color



PPG's primer/basecoat stack provide the NIR reflection and maintain color palette

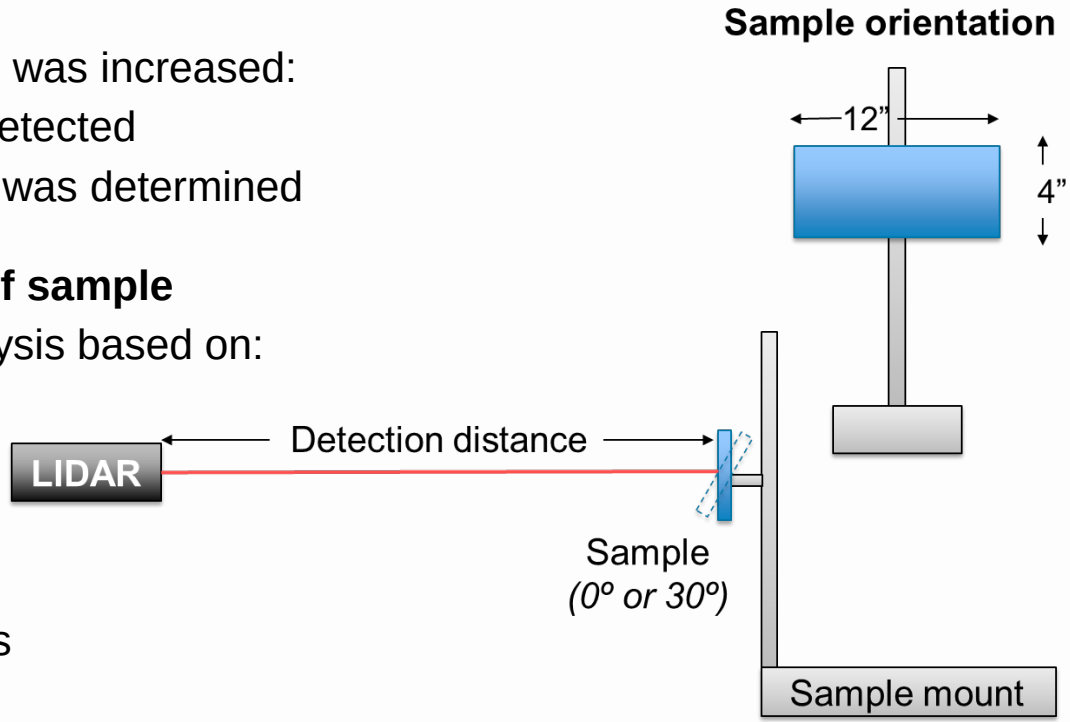
Experimental Testing at NREC*

Outdoor testing

- Distance from LiDAR to panel was increased:
  - Until panel was no longer detected
  - Maximum detection distant was determined

Maximum detection distance of sample

- Human operator's visual analysis based on:
  - Detection stability
  - Return intensity
- Compared:
  - Conventional coatings
  - PPG NIR reflective coatings

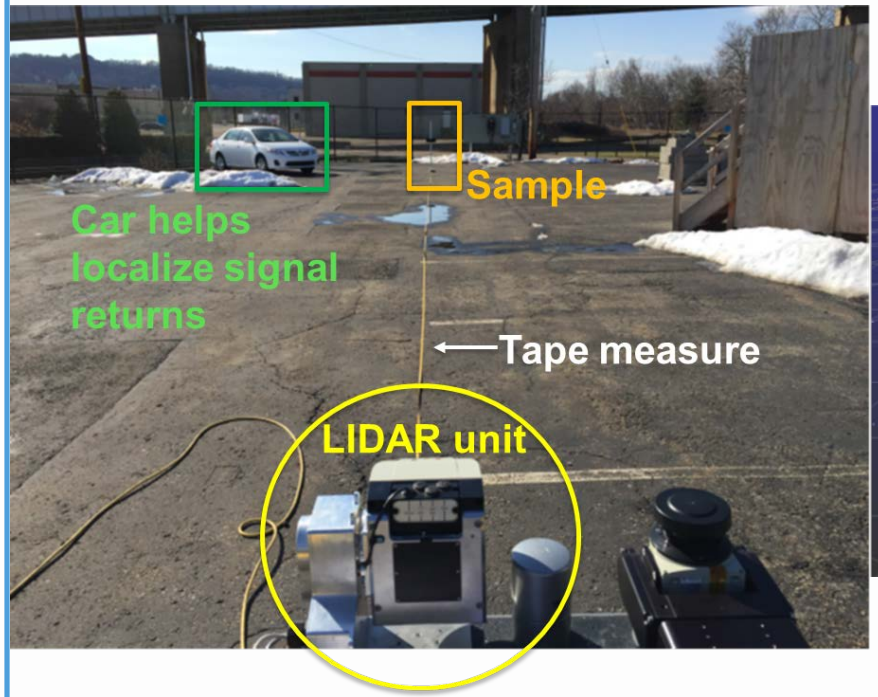


*National Robotics Engineering Center at Carnegie Mellon University

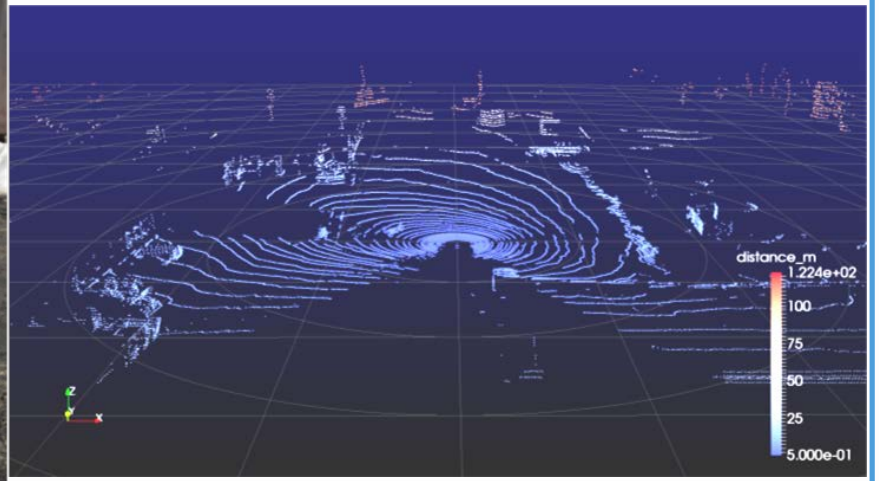
Initial testing to evaluate proof of concept

Experimental Testing at NREC*

Example Setup



Signal Map



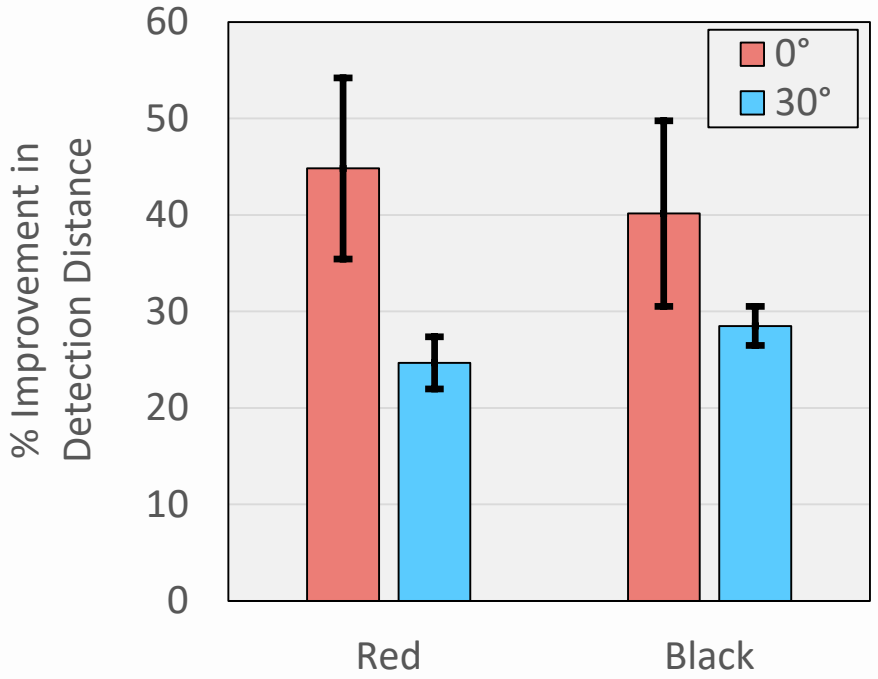
*National Robotics Engineering Center at Carnegie Mellon University

Initial testing to evaluate proof of concept

Improvement in Detection Distance

PPG NIR Reflective Coatings

- Improved detection distance
  - For each color
  - At two incidence angles
- Could improve LiDAR signal-to-noise in inclement weather conditions for various car colors

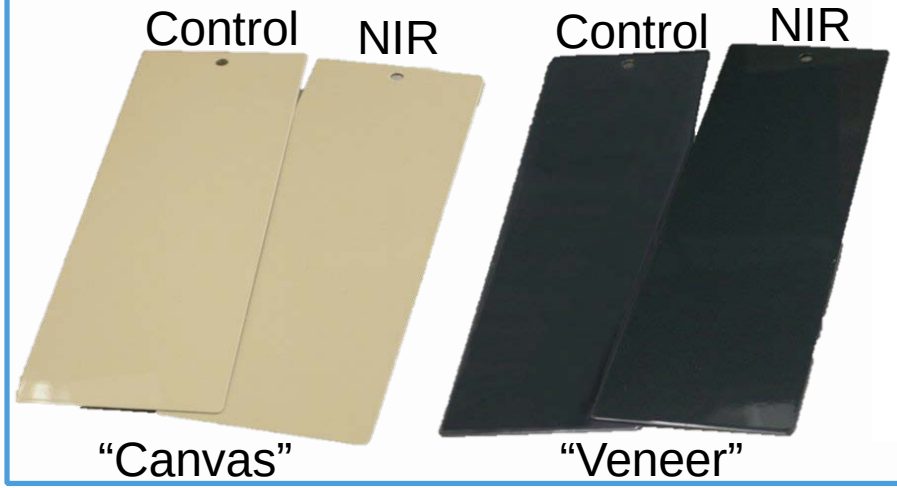


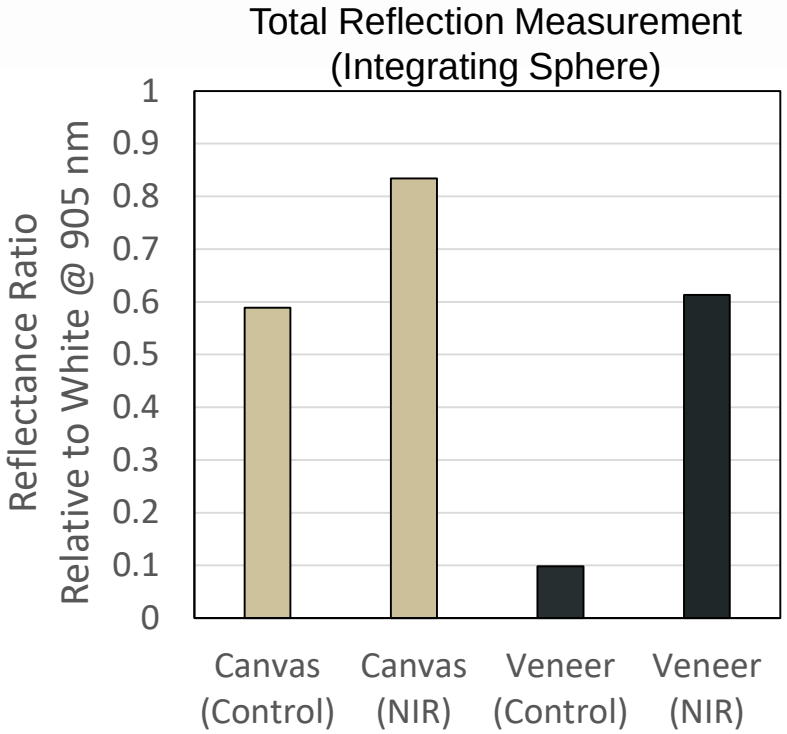
PPG's NIR coatings can extend detection distance

Maintaining Color Palette with Improved NIR Reflection

Not Just for Dark Colors

- Improved signal-to-noise
  - For most colors
  - In inclement weather
  - In dusty environments

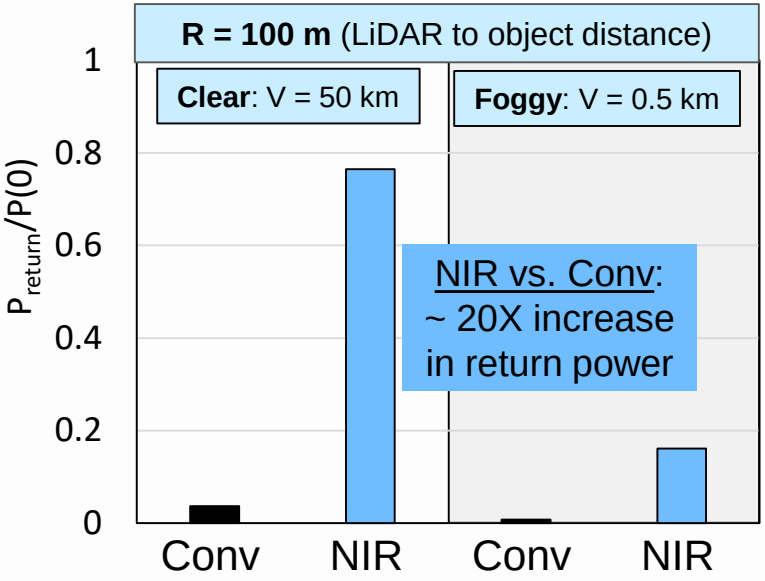




Many colors can be improved for NIR reflectance with PPG’s coatings

Improved Signal Power

Estimated signal improvement for a black car accounting for atmospheric attenuation*



$$\tau(R) = \frac{P(R)}{P(0)} = e^{-\sigma R} \qquad \sigma = \frac{3.91}{V}\left(\frac{\lambda}{550\ \text{nm}}\right)^{-q}$$

$$\frac{P_{\text{return}}}{P(0)} = e^{-2\sigma R}\left(\frac{\%R_{\text{coating}}}{100}\right)$$

$\tau(R)$ = transmittance at range R
$P(R)$ = laser power at R
$P(0)$ = laser power at the source
σ = attenuation or total extinction coefficient (per unit length)
V = visibility (in km)
λ = wavelength (in nm)
q = the size distribution of the scattering particles

$= 1.6$	for high visibility ($V > 50$ km)
$= 1.3$	for average visibility (6 km $< V <$ 50 km)
$= 0.16\,V + 0.34$	for haze visibility (1 km $< V <$ 6 km)
$= V - 0.5$	for mist visibility (0.5 km $< V <$ 1 km)
$= 0$	for fog visibility ($V <$ 0.5 km)

*Isaac I. Kim; Bruce McArthur; Eric J. Korevaar, Proceedings Volume 4214, *Optical Wireless Communications III* (2001).

PPG motifs can significantly increase range of detection even in bad weather

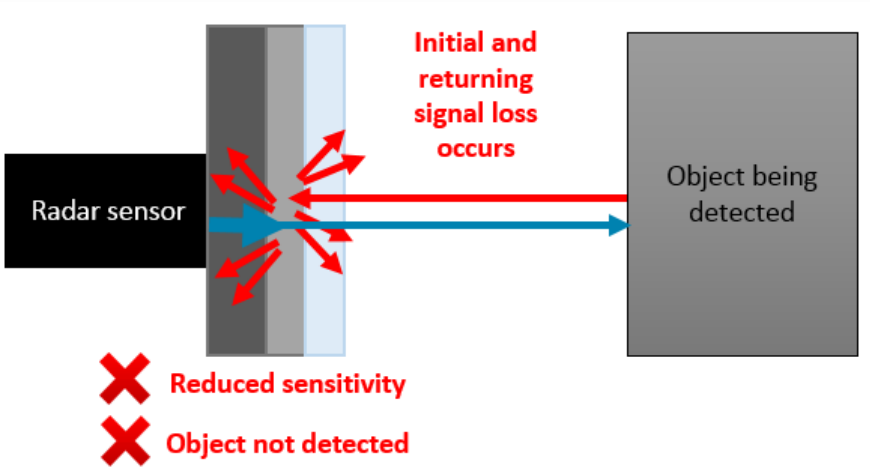
Radar Challenges

Coating Impact on Radar Sensing

- Initial back reflection in coating masks return signal from object
- Transmission loss in coating reduces initial intensity and return signal
- Need to design coatings to not impede radar transmission

"Twenty major automakers reached an agreement with the National Highway Traffic Safety Administration to put automatic braking into all their light-duty vehicles by 2022."

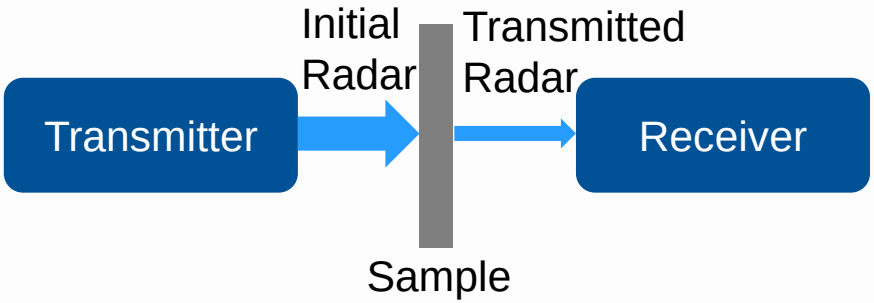
MONEYWATCH.COM / *January 1, 2018*

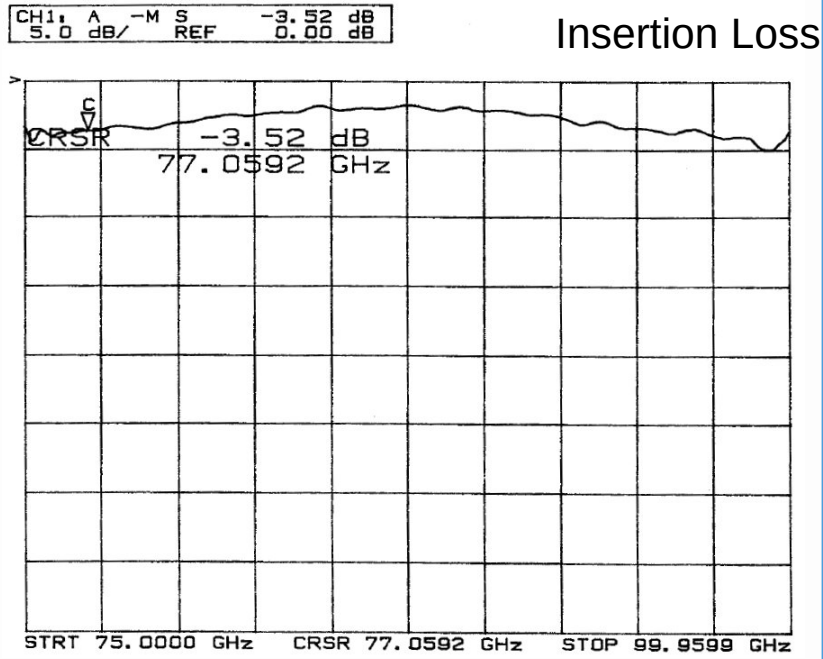


Important to design coatings to be compatible with radar systems

Insertion Loss (IL)

- Frequency sweep ~ 75 -100 GHz
- IL (dB) $= 10log_{10}\left(\frac{\text{Power received}}{\text{Power transmitted}}\right)$
- %Transmission $= 100\left[10^{\left(\frac{IL}{10}\right)}\right]$



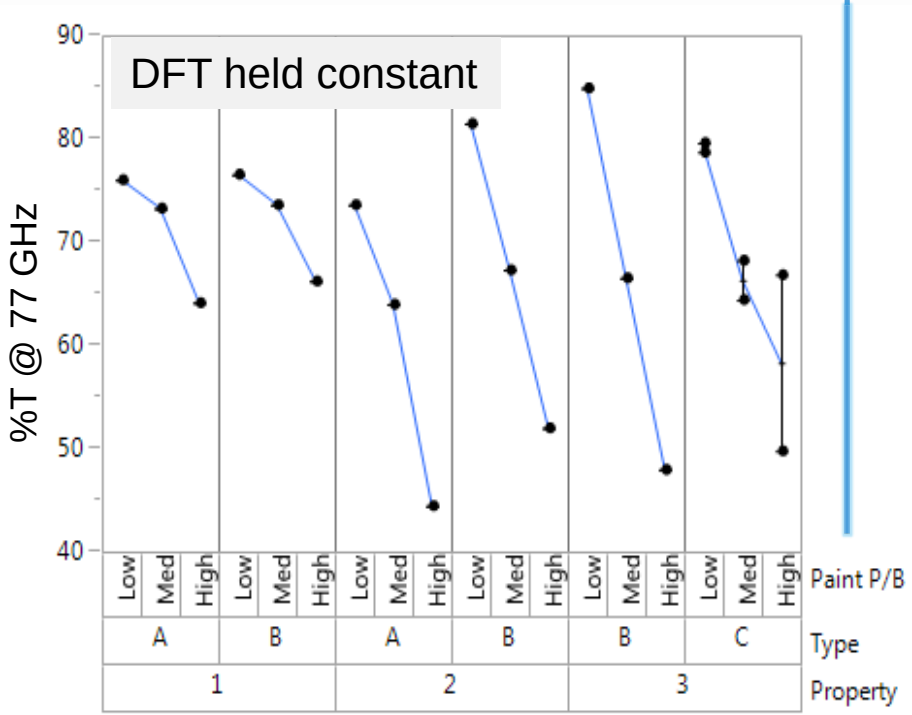


Insertion Loss

Radar results here are from measurement in transmission

Effect on radar signal from sensors mounted behind fascia

- Aluminum flake loading
  - Higher loading give less transmission
- Aluminum flake characteristics
  - Not much effect
- Further studies needed to better understand effect of flake size, type, composition,…



No dramatic variation between Al flake types – all affect radar transmission

Lens, Sensor Housing, & Display Screen Challenges

External: Dirt/snow build up hinder sensor capabilities

- Keeping lenses and sensor housings clean from dirt build up, snow/ice, bird droppings, rain, bug splatter, etc.
- Hydrophobic coating sheds water and prevents dirt build-up

Internal: Keeping displays clean

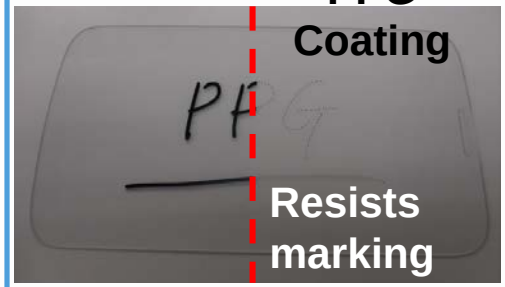
- Anti-smudge / anti-fingerprint

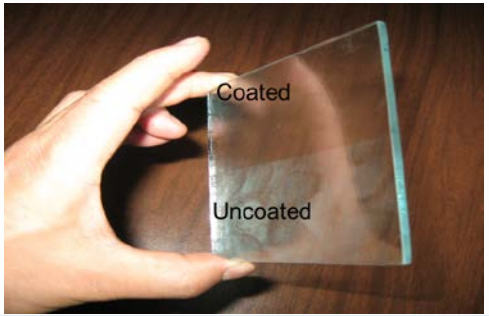
Lenses and lens housings will benefit from easy-to-clean coatings

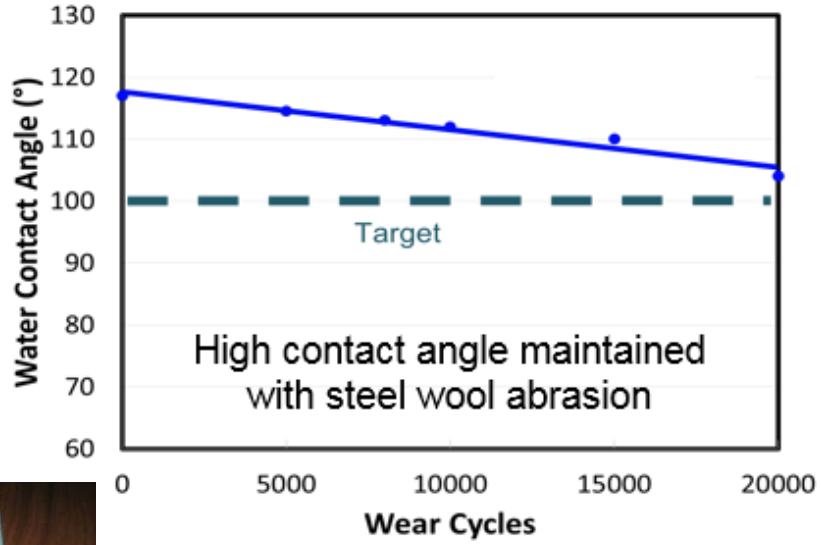
Easy-to-Clean for Interior Applications

Internal Displays

- Clear difference in performance properties
- Withstand tough abrasion conditions and weathering



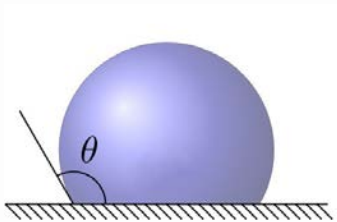


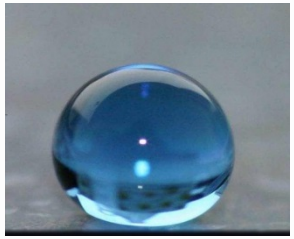


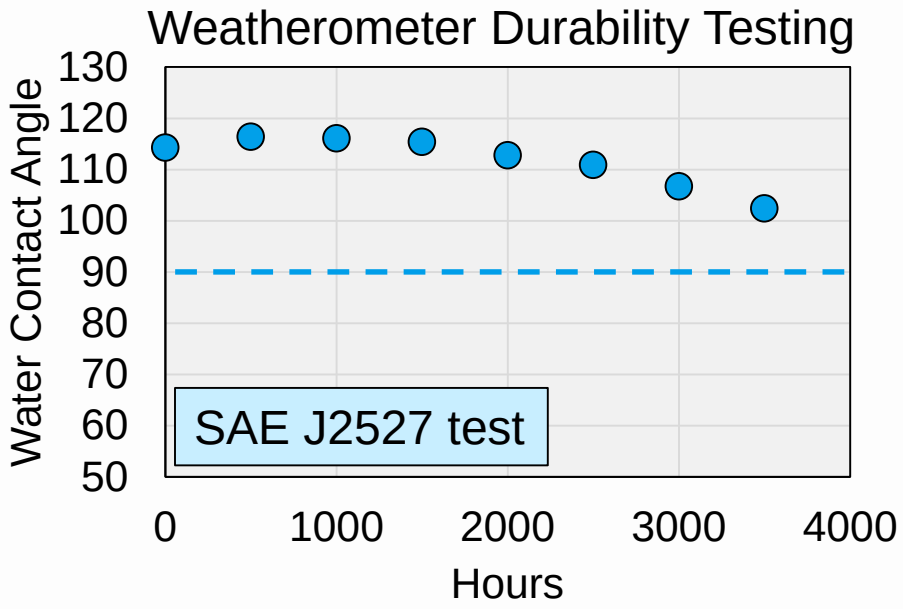
PPG's durable easy-to-clean coatings keep displays clean

External Lenses and Sensor Housings

- Super-hydrophobic coatings
- Maintains high contact angle
- Good durability







PPG has a durable exterior easy-to-clean coatings for lenses & housings

Other PPG Coatings for the Future of Mobility

Automotive interiors

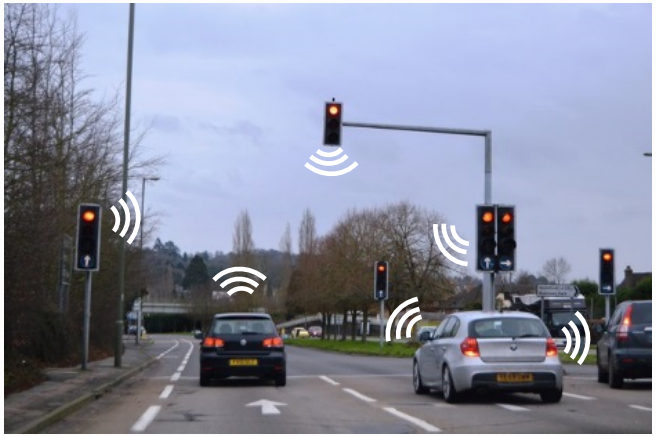
- Interiors will define personal experience when cars are autonomous
- Development of new technology based on multiple scenarios
  - Anti-glare
  - Anti-fingerprint
  - Easy-to-clean display coatings
  - Soft touch coatings

Infrastructure

- Smart road markings and signs detectable by multiple sensors
- Printable antennas for V2X communications and reduced complexity

Leaders announce a shared vision, launch the 2018 Smart Infrastructure Challenge at the Smart Regions Congress: Topics … included broadband and connectivity in urban, suburban, and rural cores; smart infrastructure and mobility including connected and autonomous transportation systems…

WASHINGTON, DC - 02/15/2018 (PRESS RELEASE JET)



PPG developing solutions for interiors and infrastructure

Summary

PPG has and is developing a wide range of coatings for automotive exterior and interior as well as for infrastructure that can:

- Enhance autonomous vehicle safety
- Help alleviate stringent sensor requirements
- Improve sensor function and decrease maintenance frequency
- Improve the passenger comfort and experience

Printed antennas for communication
EMI shielding solutions for advanced electronics

Color palette for sensor performance
- Radar compatible
- LIDAR reflective

Interior coatings
- Anti-glare
- Anti-fingerprint
- Easy-to-clean display coatings
- Soft touch coatings

Easy-to-clean coatings
Hardcoats for optical components

Thank you

Eldon Decker