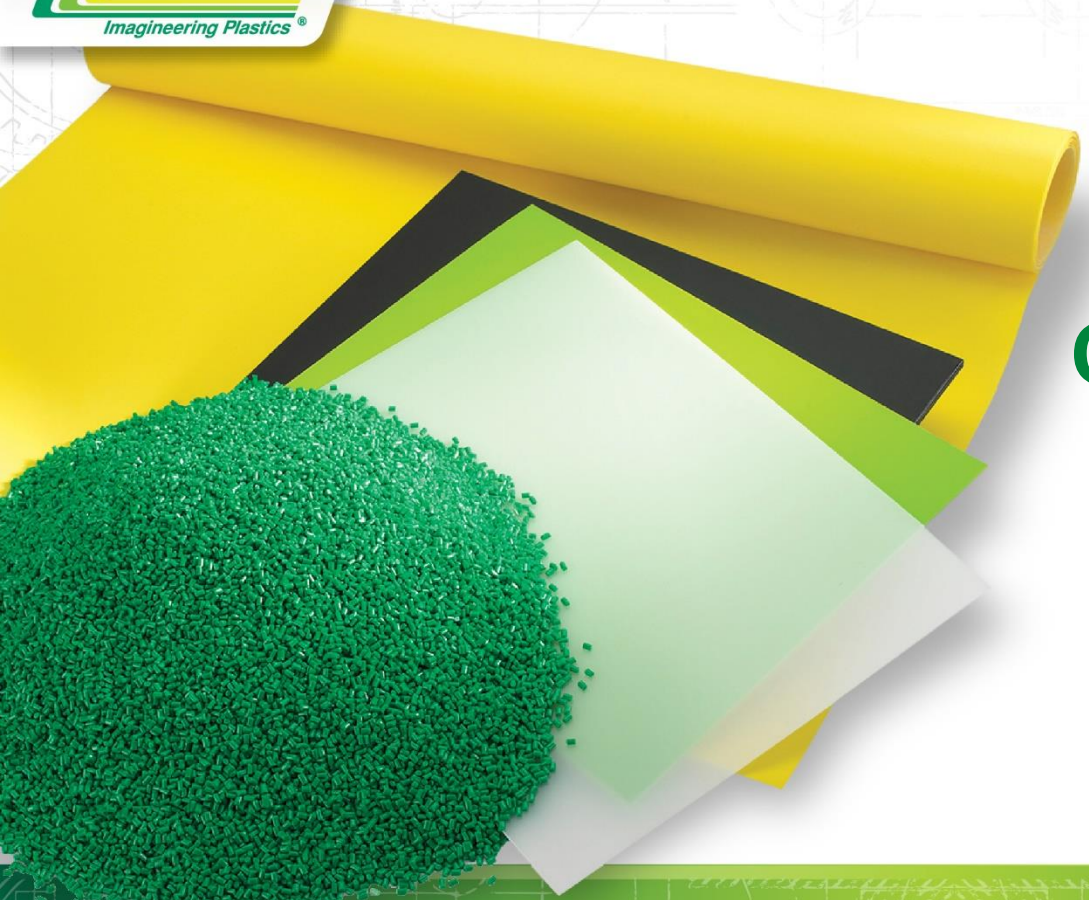
RTP Co. Imagineering Plastics®



Get Amped Up about Conductive Plastics

Ned Bryant

Senior Product Development Engineer - Conductive

OVERVIEW

Conductive Classification and Testing

Overview of Conductive Modifiers

- Migratory Anti-Stats
- Inherently Dissipative Polymers
- Carbon (Powder, Fiber, Nanotubes)

More Specialized Technology

- EMI Shielding
- Thermal Conductivity

Wrap Up and Questions

WHAT IS ELECTRICAL CONDUCTIVITY?

Measure of a material's ability to carry an electric current

Typically measured in S (siemens, inverse ohms, 1 Ω−1)

However, Ohmmeters measure RESISTIVITY

WHAT IS ELECTRICAL CONDUCTIVITY?

Measure of a material's ability to carry an electric current

Typically measured in S (siemens, inverse ohm, 1 Ω^{-1})

However, Ohmmeters measure *RESISTIVITY*

WHAT IS ELECTRICAL RESISTIVITY?

How strongly a material opposes the flow of electric current

Typically measured in Ω (ohms)

QUICK REFRESHER ON NOTATION

How many ways can you write “One Billion Ohms”?

- 1,000,000,000 Ω
- 1x10^9 Ω
- 1.0E+9 Ω
- 1x109 Ω
- 1E9 Ω
- 109 Ω
- 1 GΩ

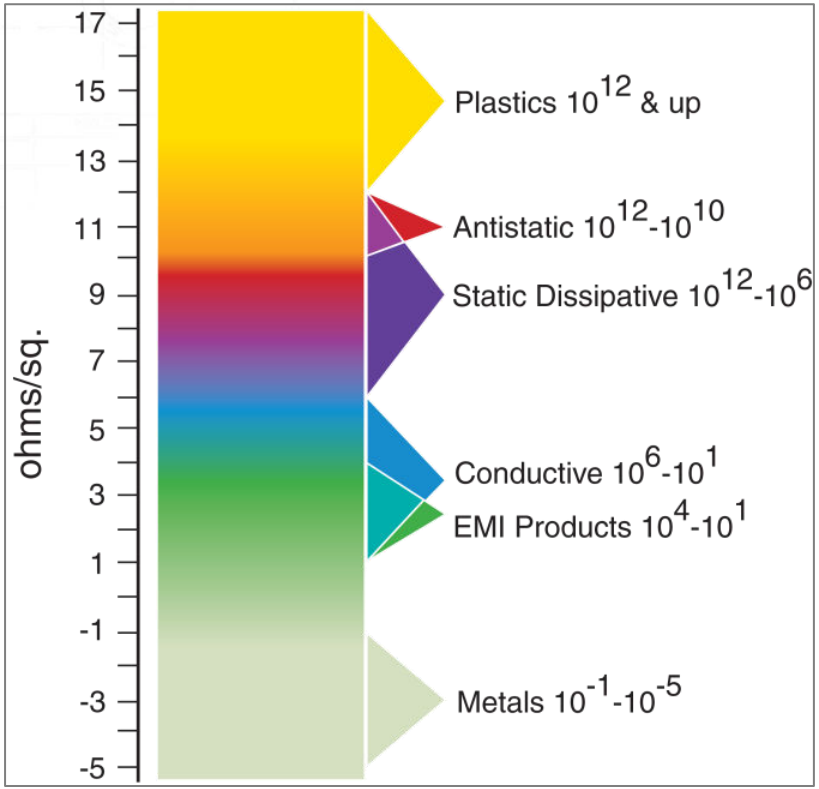
CONDUCTIVE CLASSIFICATION

Antistatic
- Cleanliness
- Prevent dirt and dust build up

Static Dissipative
- Protect delicate electronics
- Prevent explosions

Conductive (Current-Carry Devices)
- Electrical contacts
- Electrical circuits

EMI Shielding
- Provide protection against radiation



MORE NOTATION

Antistatic
- Cleanliness
- Prevent dirt and dust build up

Static Dissipative
- Protect delicate electronics
- Prevent explosions

Conductive
(Current-Carry Devices)
- Electrical contacts
- Electrical circuits

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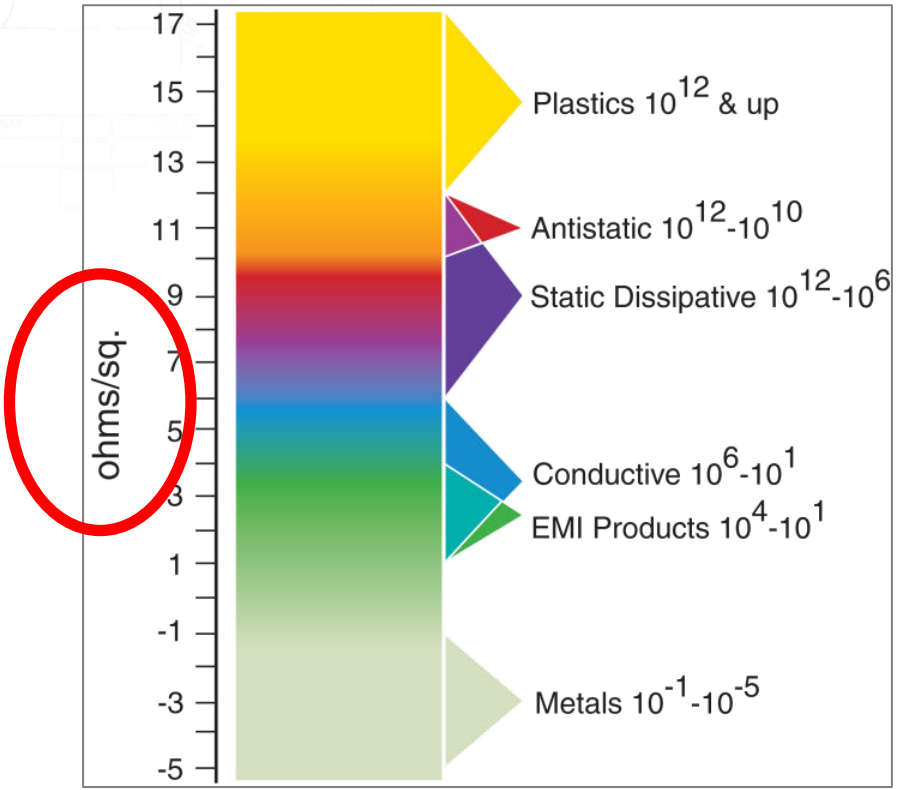
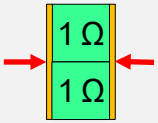
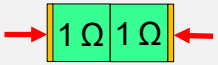
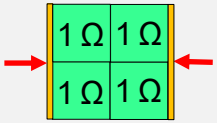
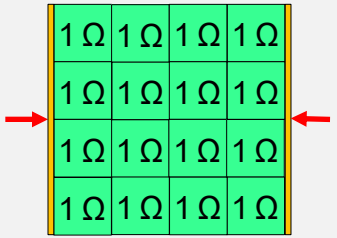
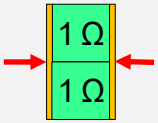
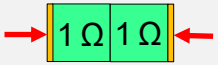
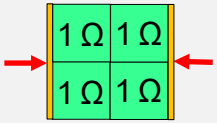
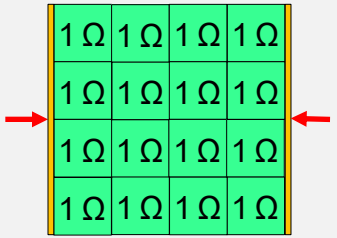


OHMS PER SQUARE WHAT?

Element under test					
Math	---	$\frac{1x1}{1+1}$	1+1	$\frac{1x1}{1+1} + \frac{1x1}{1+1}$	$\frac{1x1x1x1}{1+1+1+1} + \frac{1x1x1x1}{1+1+1+1} + \frac{1x1x1x1}{1+1+1+1} + \frac{1x1x1x1}{1+1+1+1}$
Total Resistance	1 Ω	½ Ω	2 Ω	½ + ½ = 1 Ω	¼ + ¼ + ¼ + ¼ = 1 Ω

OHMS PER SQUARE WHAT?

Element under test					
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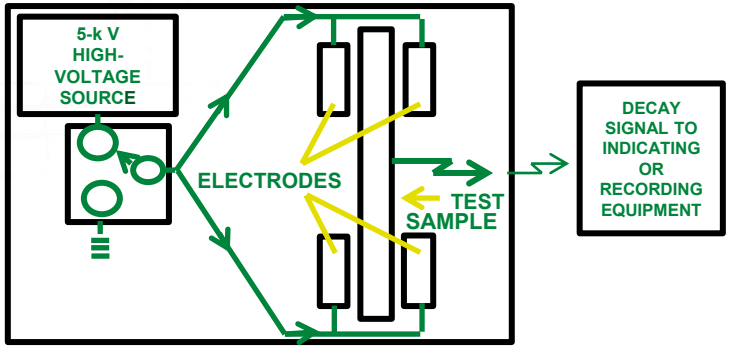
Total Resistance	**1 Ω**	½ Ω	2 Ω	½ + ½ = **1 Ω**	¼ + ¼ + ¼ + ¼ = **1 Ω**

...IT DOESN'T MATTER

STATIC DECAY TESTING

Static Decay Rate

- Measures seconds to decay
- 5000V to 50V (1%)
- 12% relative humidity
- Passing is t < 2 seconds



Standards/Specifications

- MIL PRF 81705 D
- NFPA 56A
- Numerous others

SURFACE TESTING

Surface Resistivity (Ohms/Sq) or Surface Resistance (Ohms)

- Standards and specifications:
  - ASTM D257
  - ESD STM 11.11
  - IEC 60093
  - Numerous others

SURFACE RESISTIVITY TEST

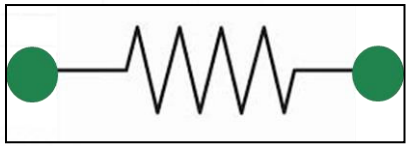
Guarded Ring Electrode

- Precise measurement
- Flat specimen required
- Units = Ohms/Sq.

SURFACE RESISTANCE TEST

Surface Resistance Meter

- Point to point
- Measuring small & critical areas on part
- Units = ohm



- There are many other test setups

VOLUME RESISTIVITY TEST

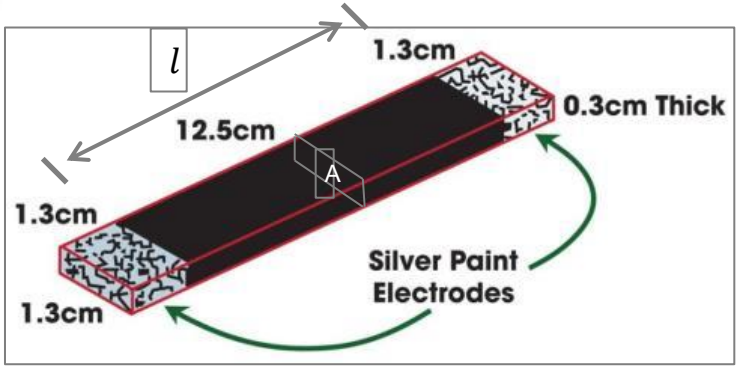
$$\rho = R\frac{A}{l}$$

ρ = Volume resistivity

R = Resistance

A = Cross-sectional area

l = Length



Units = ohm-cm ASTM D-257

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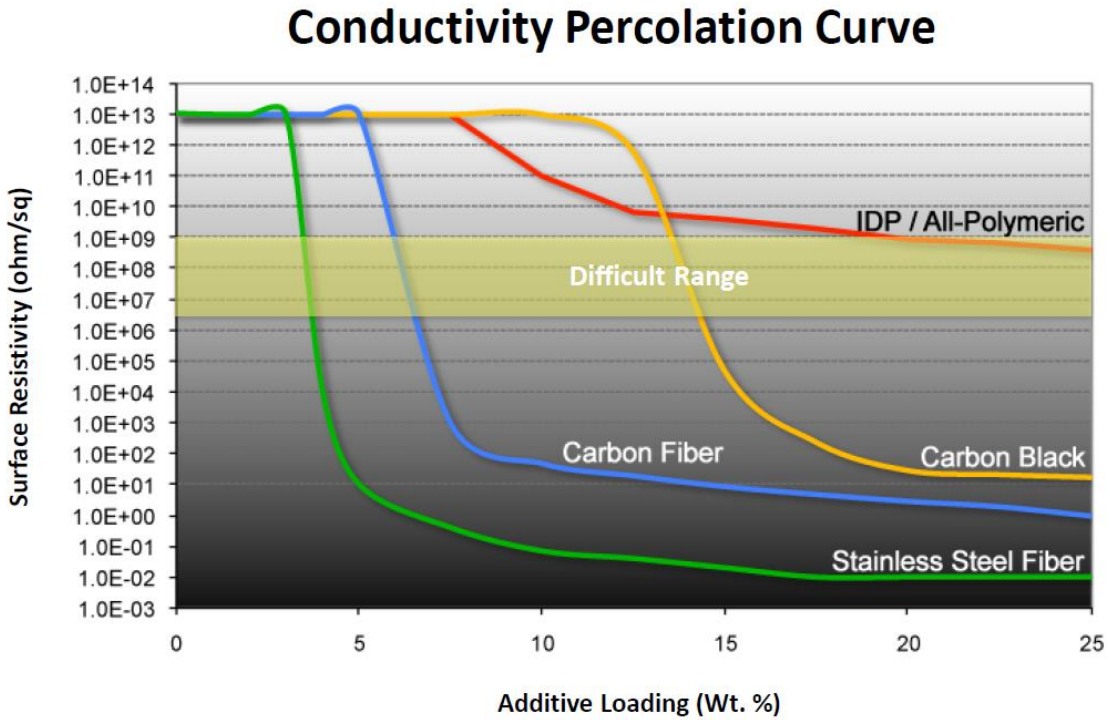
- Thermal Conductivity

Wrap Up and Questions

PERCOLATION CURVE



MIGRATORY ANTI-STATIC AGENTS

- Migrating surfactant based – not bonded to resin
- Temperature and humidity dependent
  - Best at room temperature and high humidity
- Colorable
- Liquids and semi-solids with low boiling points
- Compatible only with low temp. resins
  - Olefins, Styrenics, PVC
- Economical/commodity materials

INHERENTLY DISSIPATIVE POLYMERS (IDP)

All-polymeric, based on IDP

- Typically consist of PE oxide
- Other block dictates compatibility
- Forms a co-continuous morphology with the base resin

Over 20 different resin systems

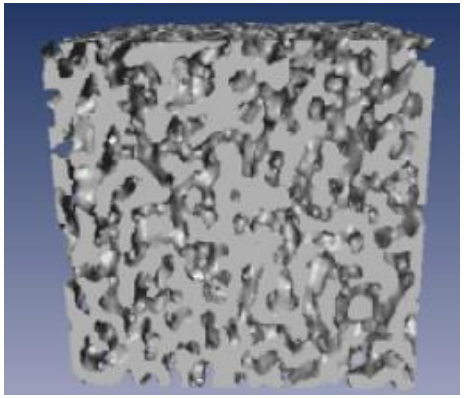
- Limited process temps (< 520 ºF)

Surface resistivity

- Standard: 10^{10} to 10^{11} ohm/sq
- PLUS: 10^{8} to 10^{9} ohm/sq

Static decay rate

- Standard < 2.0 s
- PLUS < 0.5 s



PermaStat®

PermaStat Plus®

PERMASTAT® TECHNOLOGY BENEFITS

- Permanent ESD protection – performance is independent of migration, humidity, or temperature
- Clean technology – FDA and Biocompatible grades available
- Fully colorable
- Transparent grades available
- Base resin properties retained
- Can meet ATEX requirements

TYPICAL APPLICATIONS

Reticle Boxes
ABS, PMMA

Inhalers
ABS, PP, PMMA

Gas Cap
POM

ATEX IBC
PE

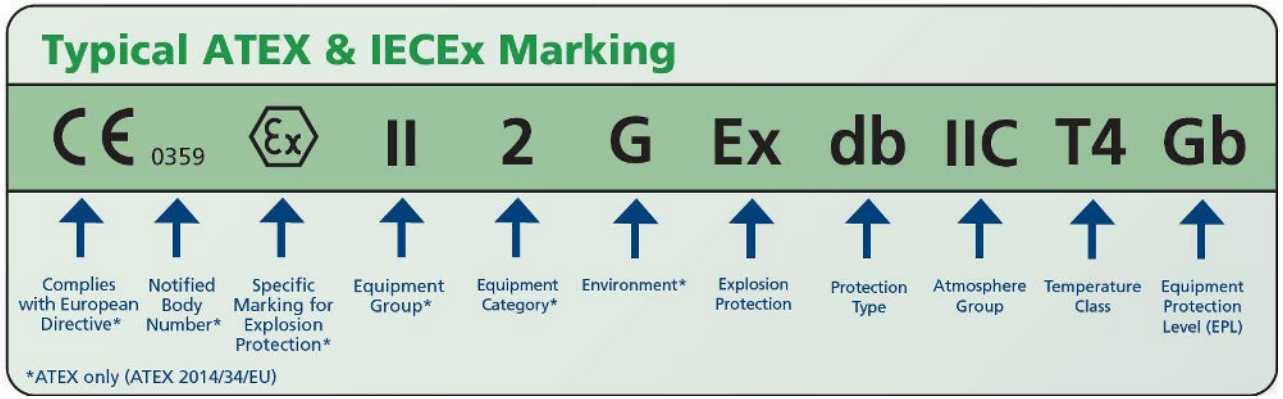
WHAT IS ATEX?

ATMOSPHERE EXPLOSIVE

- Potentially explosive environments

Began as a European Directive

- Standardize compliance procedure
- Now seen in US and other countries (IECEx)



ATEX TESTING

Actual requirements defined by customer

All tests are on actual parts

Tests could include:

- Surface resistance (almost always included)
- Relative Thermal Index (RTI)
- Chemical resistance
- Impact (low temperature)
- Ultraviolet (UV)
- High humidity aging testing
- Flame Retardant (FR)

Need to fully identify all requirements for proper material selection

ATEX SURFACE RESISTANCE

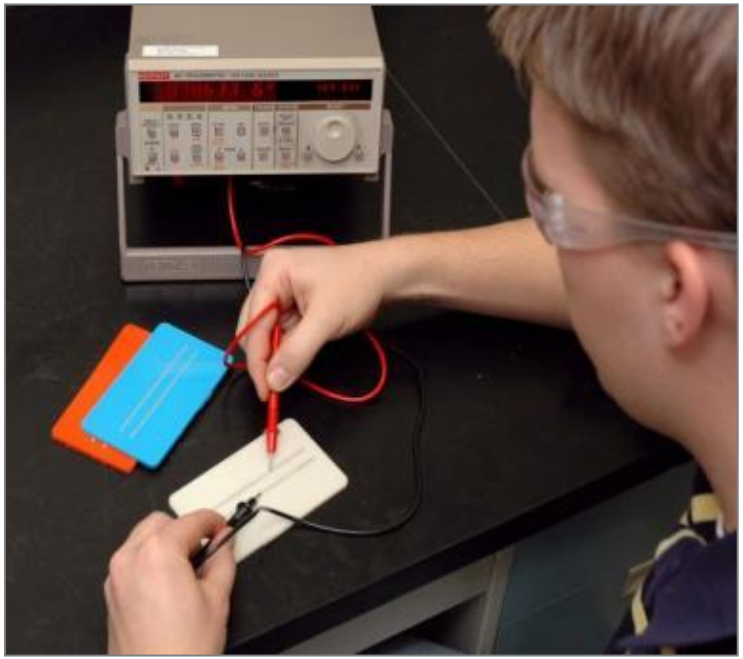
Specific test

- Isolation resistance
- $<10^{9}$ at 50% R.H.
- $<10^{11}$ at 30% R.H.
- Tested at 500 V

Different from:

IEC 60093 ASTM D 257 ESD STM11.11

No real correlation



ATEX MARKETS:

Safety, Safety, Safety!

- Mining
- Food
- Chemicals
- Paint
- Hand-held devices
- Industrial equipment

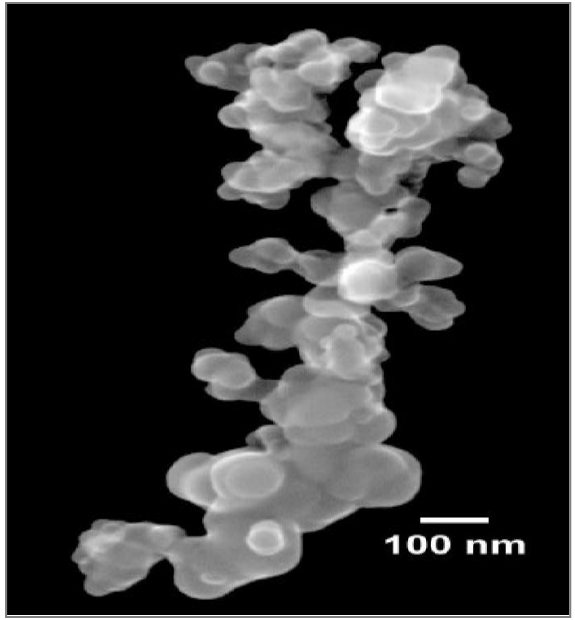
"Drager Oxyboks K 35A." Photograph. Drager. Dragerwerk AG & Co. KGaA, 2024. https://www.draeger.com/en_me/Products/Oxyboks-K35 , 10/14/2024.

"P50SY – 2" / 50mm Slurry Valve Yellow Series." Photograph. Pumps 2000. Pumps 2000 America, 2020. https://www.pumps2000.com/yellow-series/, 10/14/2024.

CONDUCTIVE CARBON BLACK

Characterized by:

- Structure
- Size of particles
- Porosity
- Surface chemistry



CONDUCTIVE CARBON BLACK

Permanent

Black color only

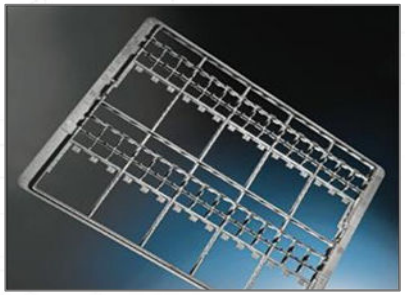
Sloughing / Marking / Crayoning

Economical

Dissipative or conductive

- SR 10^3 to 10^9 ohm/sq
- VR 10^0 to 10^6 ohm-cm

CARBON BLACK APPLICATIONS



Electronic device trays
PP, PS, PC

Pipette tips
PP

Storage bins & totes
PP

Fuel filler tubes
PE

CARBON / GRAPHITE FIBER

Non-sloughing

Colorable

Anisotropic shrinkage

Reinforcing

Dissipative or conductive

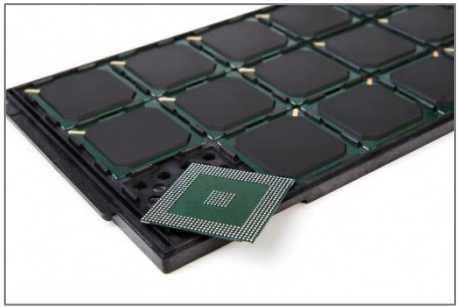
- SR 10^2 to 10^6 ohm/sq
- VR 10^{-1} to 10^4 ohm-cm

Chopped Fiber
¼" long "bundles"

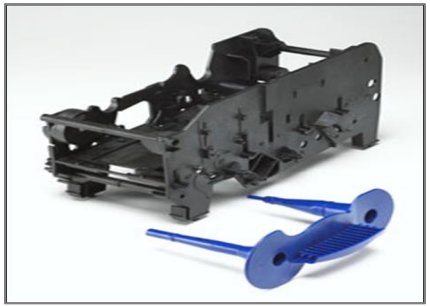
Milled Fiber
pulverized

CARBON FIBER APPLICATIONS

Fuel line components
PPA, Nylon, Acetal



Chip transport/Storage trays
PC, PSUL, PES



Card printer chassis
PC

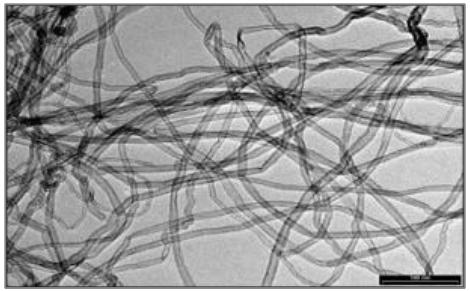
CARBON NANOTUBES (CNT)

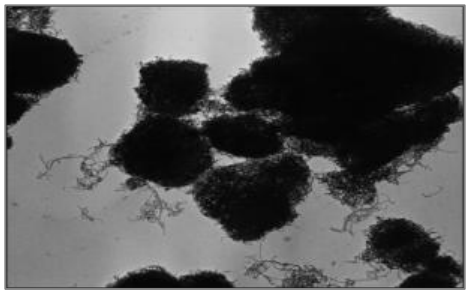
> 90% graphite

Hollow

10 nanometer diameter

High L/D ratio

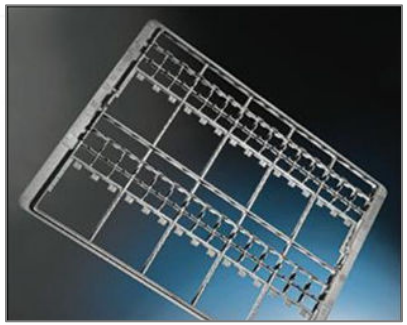




"A high resolution TEM image of the MWCNTs Nanocyl 7000 used in the present work." Photograph. ResearchGate. ResearchGate, January 2009. https://www.researchgate.net/publication/244592481, 10/14/24

ELECTRONICS INDUSTRY APPLICATIONS

- Very clean – especially when LCP is the issue
- Hard disc drive (HDD) handling components
- Silicon wafer handling components
- Semiconductor chip trays
- ESD shipping trays



Trays

Wafer Caddy

HDD

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- **EMI Shielding**
- Thermal Conductivity

Wrap Up and Questions

EMI SHIELDING

Electro**M**agnetic **I**nterference = EMI

Emitted from a source *or* Received by a device

Frequency range of 1 kHz to 10 GHz

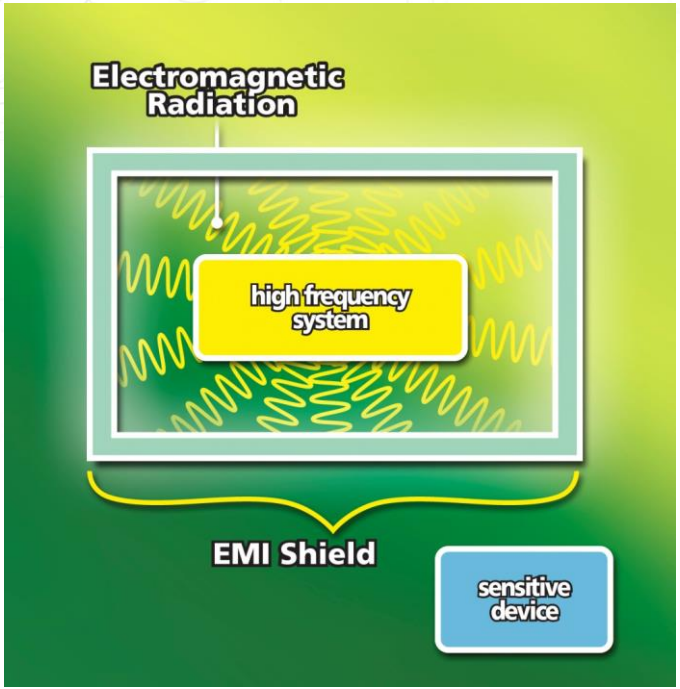
Faraday cage principle:

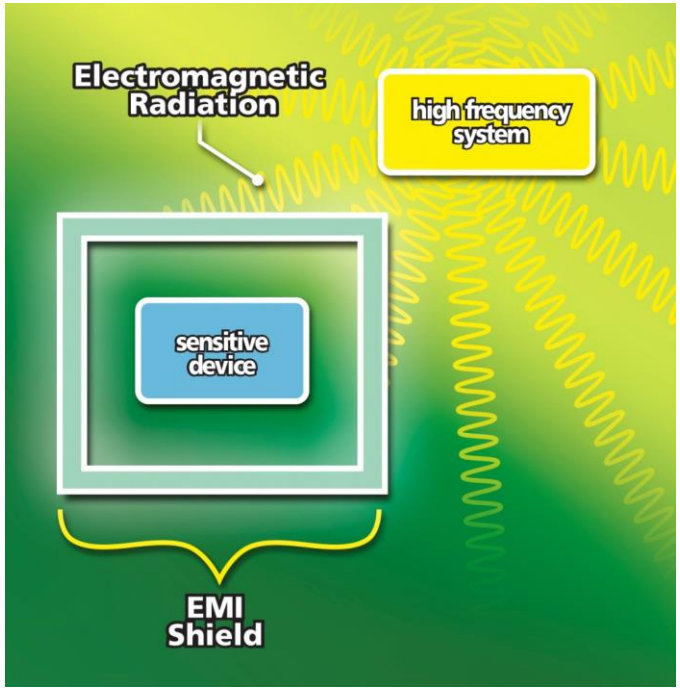
- Barrier that reflects or conducts signals to ground

Shielding provides “immunity”

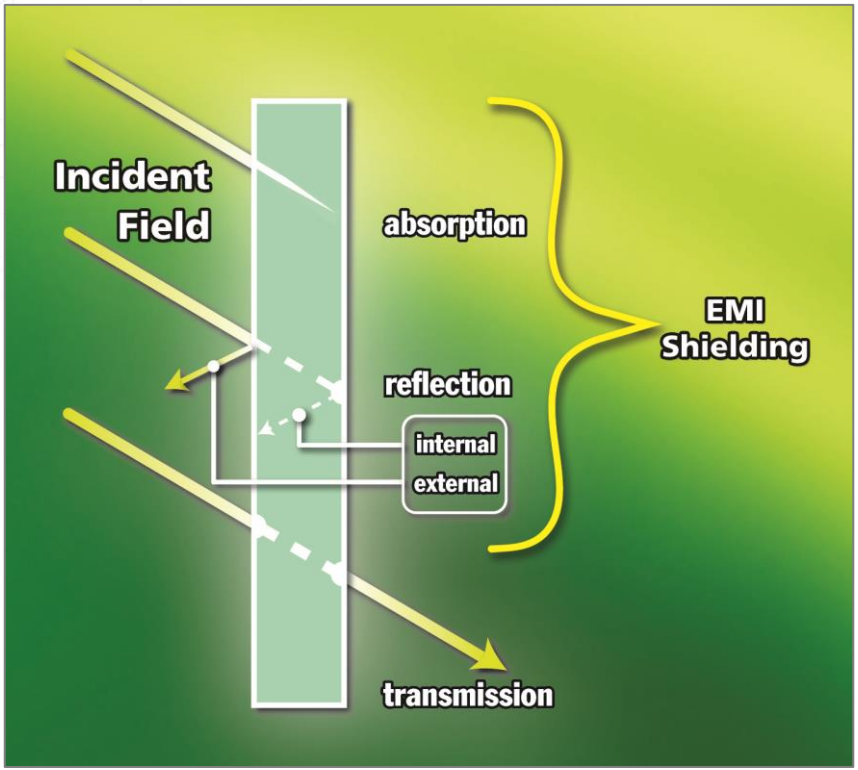
EMI IN ACTION

EMI shields protect sensitive devices





EMI IN ACTION



EMI SHIELDING FILLERS

Electrically conductive modifiers:

- Carbon powder
- Carbon fiber
- Graphite
- **Stainless steel fiber**
- **Nickel-coated carbon fiber**
- Other metallic additives

ADDITIVE COMPARISON

Stainless Steel Fiber (SSF)

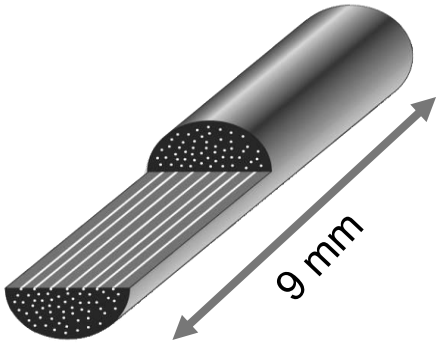
- Non-reinforcing
- **Equivalent shrinkage to neat resin**
- Moderate shielding performance
- **Colorable**

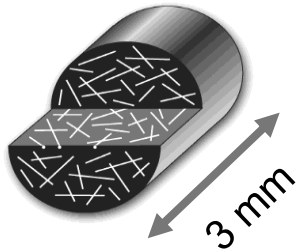
Nickel-Coated Carbon Fiber

- Reinforcing
- High shielding performance
- **Higher cost**
- Less colorable
- **Light weight**

CUBE BLENDS

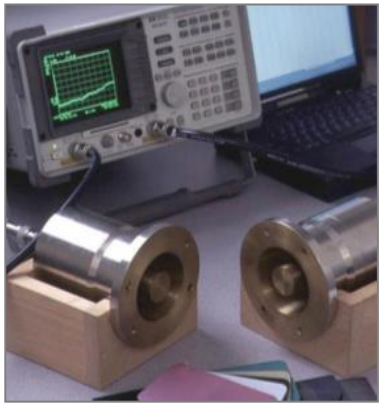
- Pre-blended mix of pellets “Salt & Pepper” blend
- Necessary to retain SSF aspect ratio
- SSF is dispersed during molding

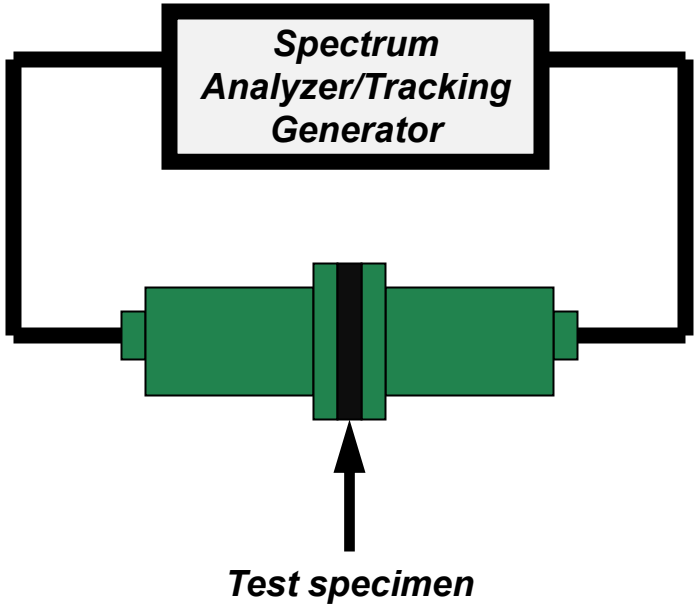




COAXIAL TRANSMISSION LINE TEST

- ASTM D 4935
- Direct measurement on flat specimens
- Fast and repeatable
- Relative ranking
- Frequency range of 30 MHz to 1.5 GHz
- Units = decibels of shielding effectiveness





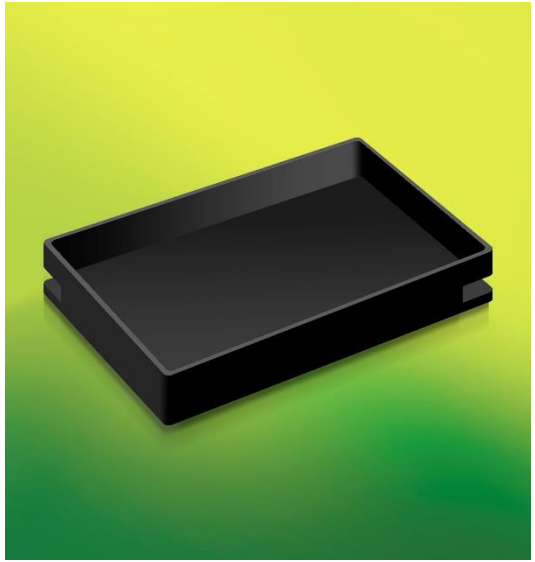
APPLICATION SUCCESS – RADAR BOX

RTP Conductive Resin:

Stainless Steel and Carbon Black Filled PBT
(Shielding through Reflection and Absorption)

Results:

- Better grounding
  - All surfaces are now conductive
- Eliminates process steps
- Eliminates added supplier
- Improves yield
- Reduces total cost



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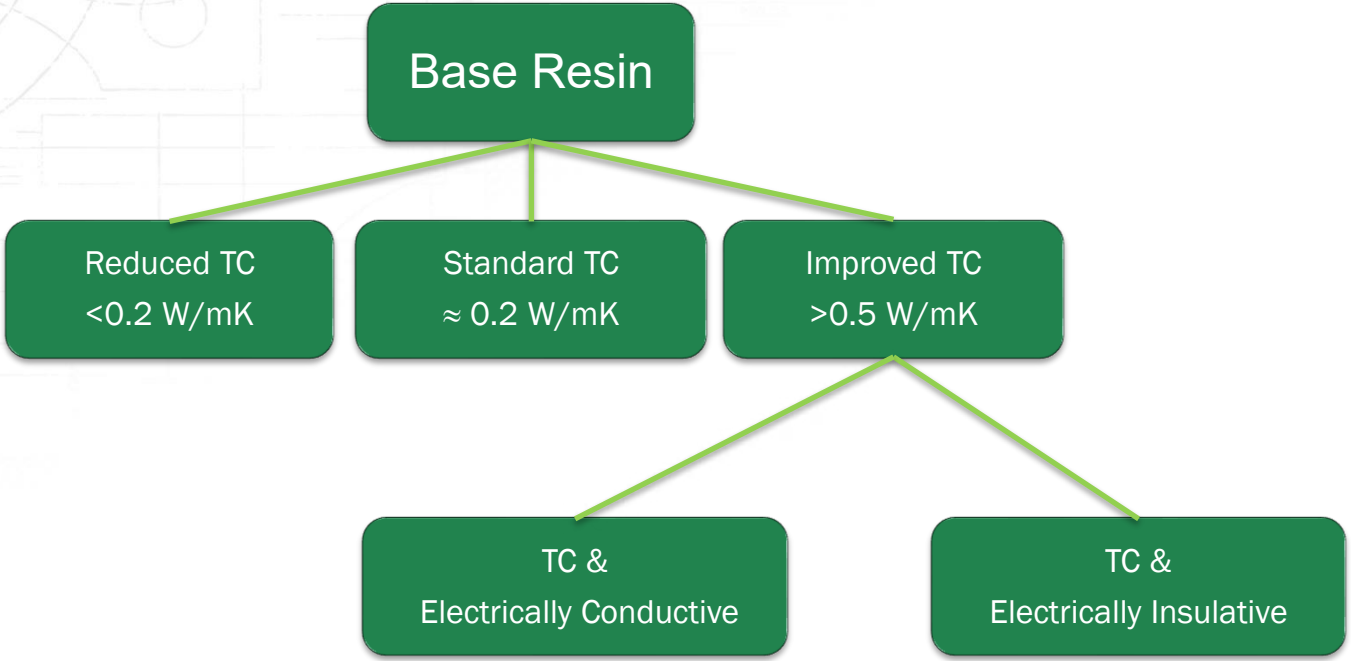
Wrap Up and Questions

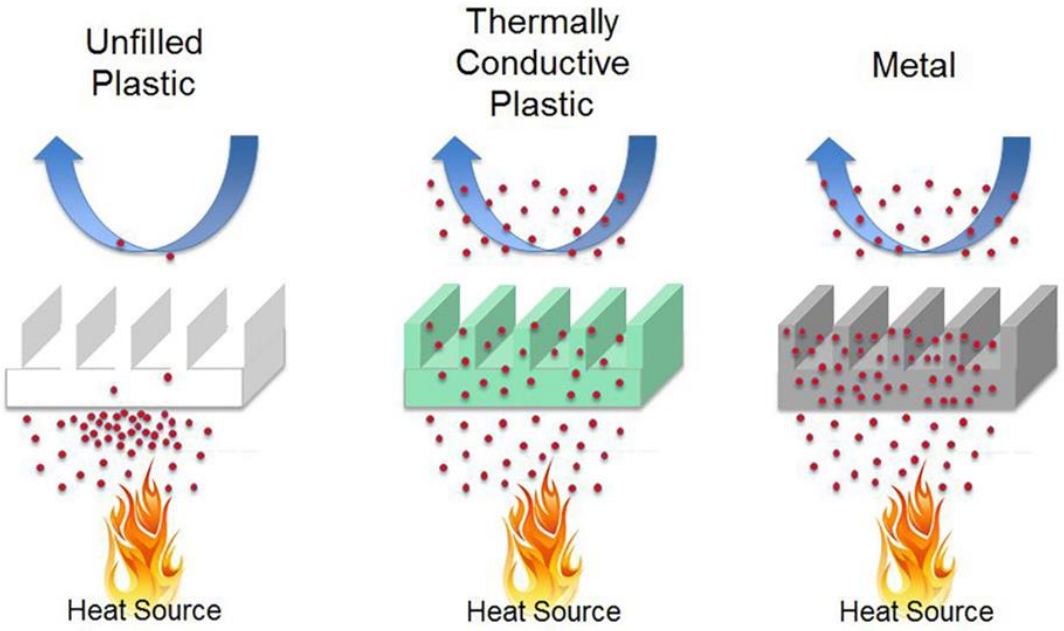
THERMAL CONDUCTIVITY (TC) IN PLASTICS



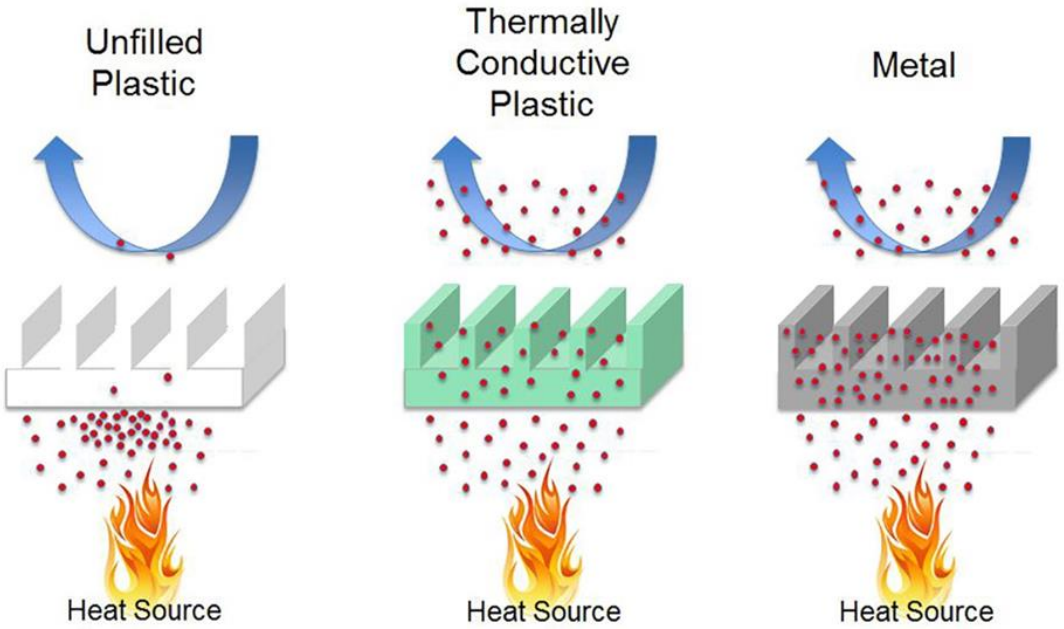
CONDUCTIVITY OF MATERIALS

Material	TC (W/mK)
Foamed Polystyrene	0.03
Standard Plastic	0.2 - 0.3
Glass	1
Thermally Conductive Plastic	1 - 35
Stainless Steel	18
Zinc	112
Aluminum	225
Copper	400

CONDUCTION VERSUS CONVECTION?

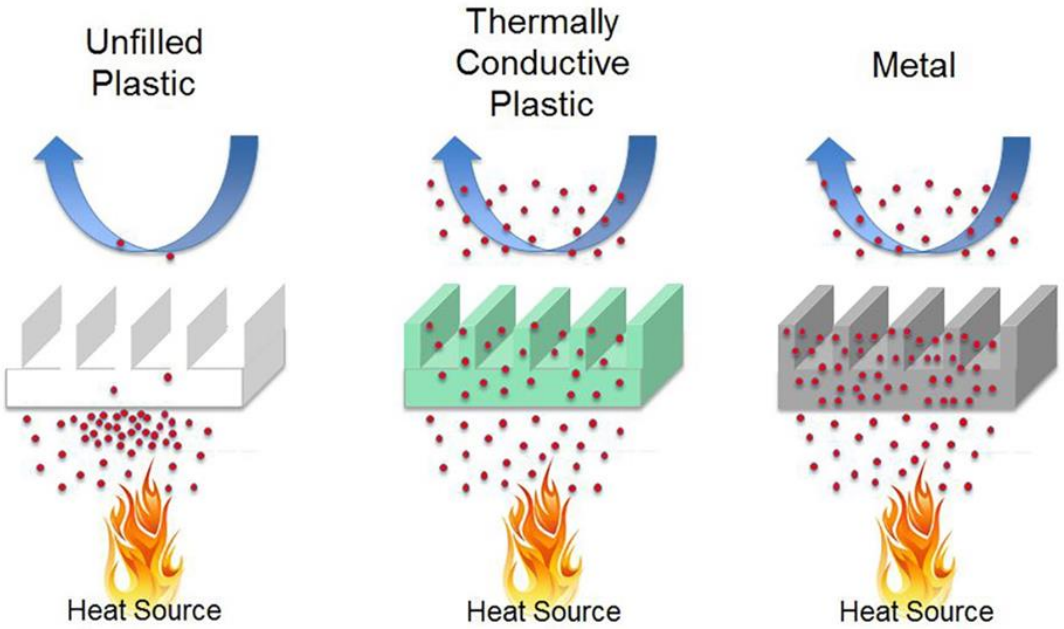


CONDUCTION VERSUS CONVECTION?



Conduction Limited
TC ≈ 0.3 W/mK

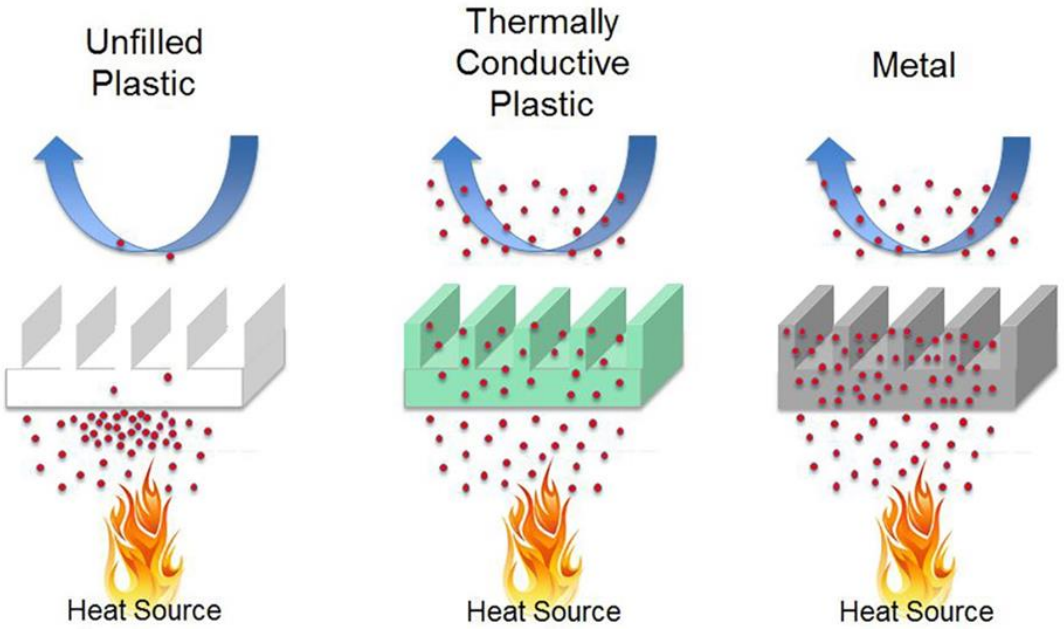
CONDUCTION VERSUS CONVECTION?



Conduction Limited
TC ≈ 0.3 W/mK

Convection Limited
TC ≈ 225 W/mK

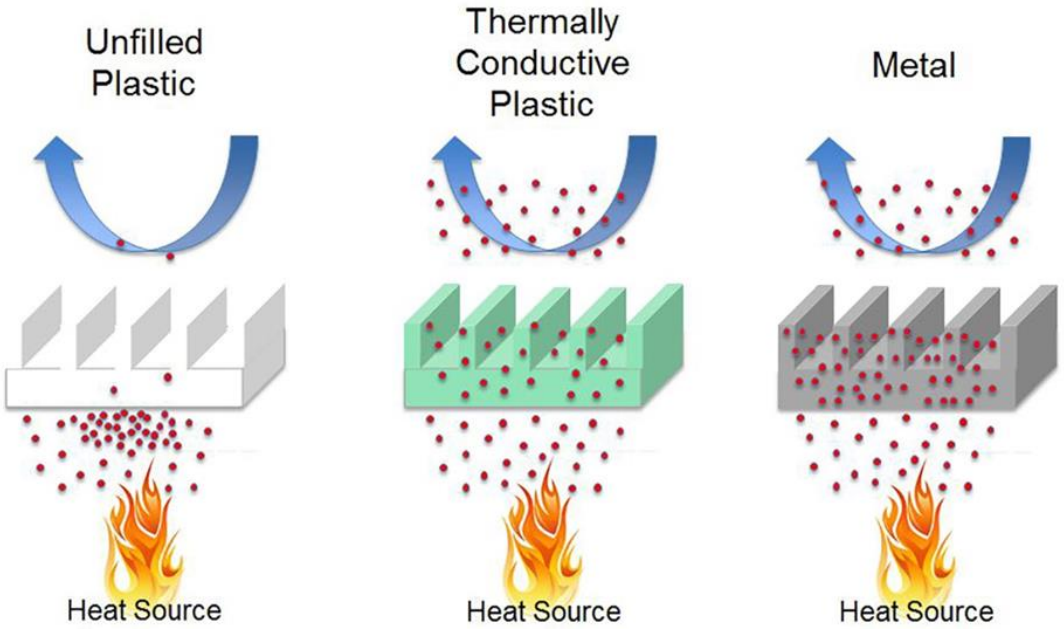
CONDUCTION VERSUS CONVECTION?



Conduction Limited	Balanced Heat Transfer	Convection Limited
TC ≈ 0.3 W/mK	TC ≈ ??? W/mK	TC ≈ 225 W/mK

CONDUCTION VERSUS CONVECTION?

What level of TC is required for Balanced Heat Transfer???

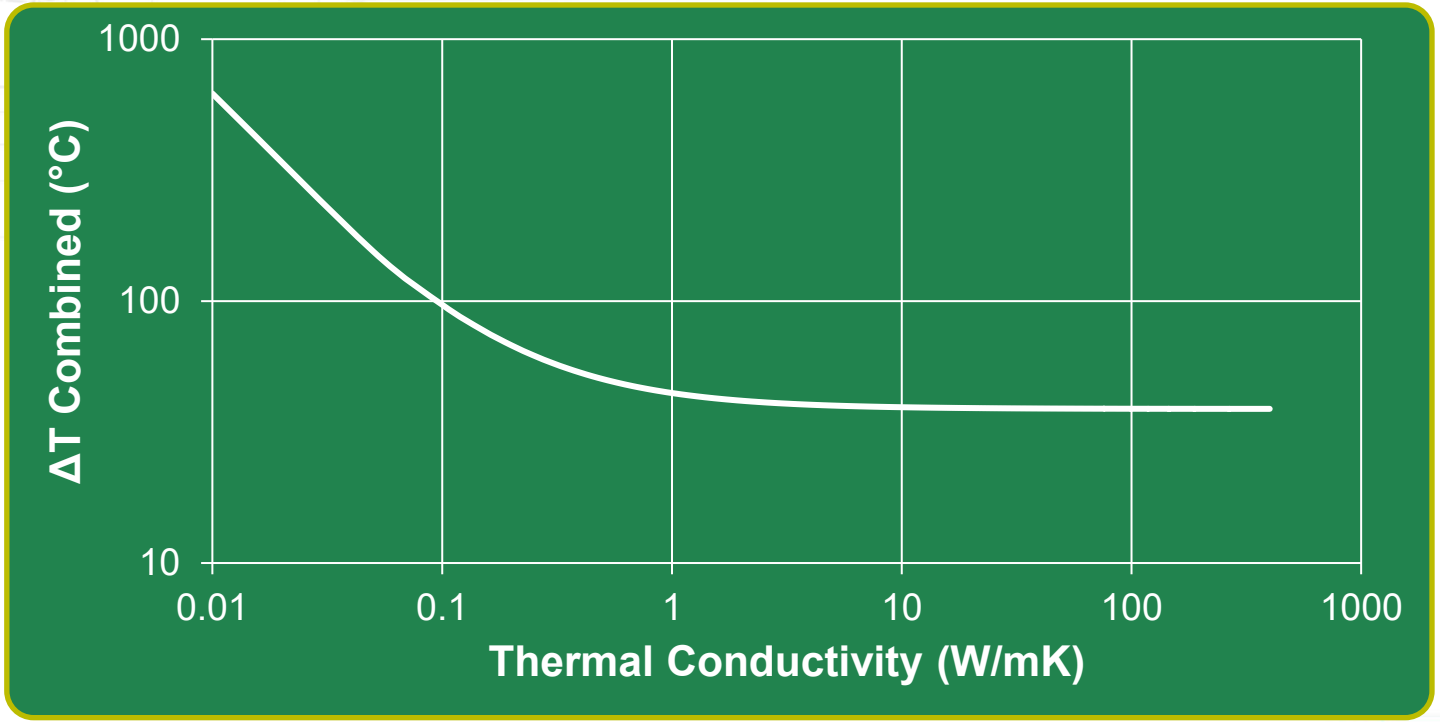


Conduction Limited	Balanced Heat Transfer	Convection Limited
TC ≈ 0.3 W/mK	TC ≈ ??? W/mK	TC ≈ 225 W/mK

CONDUCTION VS. CONVECTION

Conduction Limited > > > Convection Limited

Biot Number:

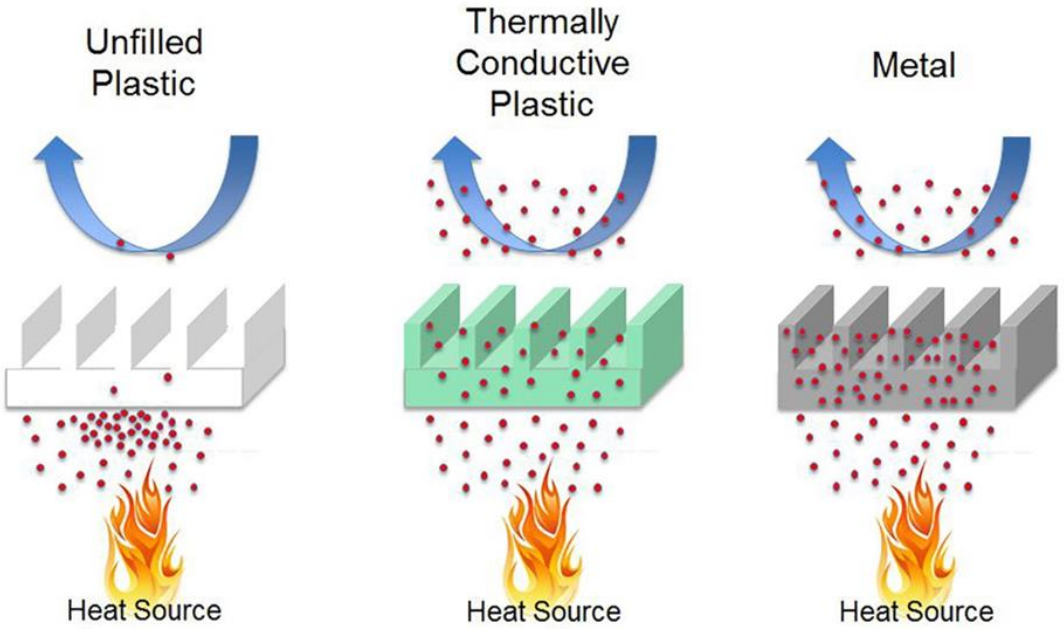


Jean-Baptiste Biot
(1774–1862)

CONDUCTION VERSUS CONVECTION?

What level of TC is required for Balanced Heat Transfer???

TC ≈ 1 – 3 W/mK



Conduction Limited
TC ≈ 0.3 W/mK

Balanced Heat Transfer
TC ≈ ??? W/mK

Convection Limited
TC ≈ 225 W/mK

RADIATIVE HEAT TRANSFER

- For black plastics:

  - Radiation is important

  - Due to high emissivity

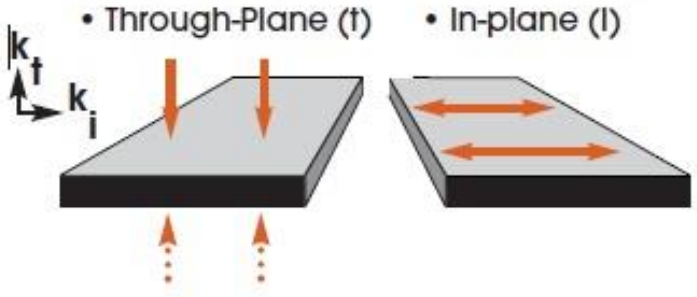
- Metals (especially aluminum) will require surface treatment to achieve a high emissivity value

Material	Emissivity (ε)
Aluminum	0.1
Stainless Steel, 301	0.5
Aluminum, anodized	0.7
Average Plastic	0.9

ANISOTROPY IN PLASTICS

- **Through Plane**
- Measured perpendicular to the flow of material
- “Worst case scenario” for TC

- **In Plane**
- Measured in same plane as flow of material
- Influenced by fillers with aspect ratio
- Important for spreading and directing thermal energy

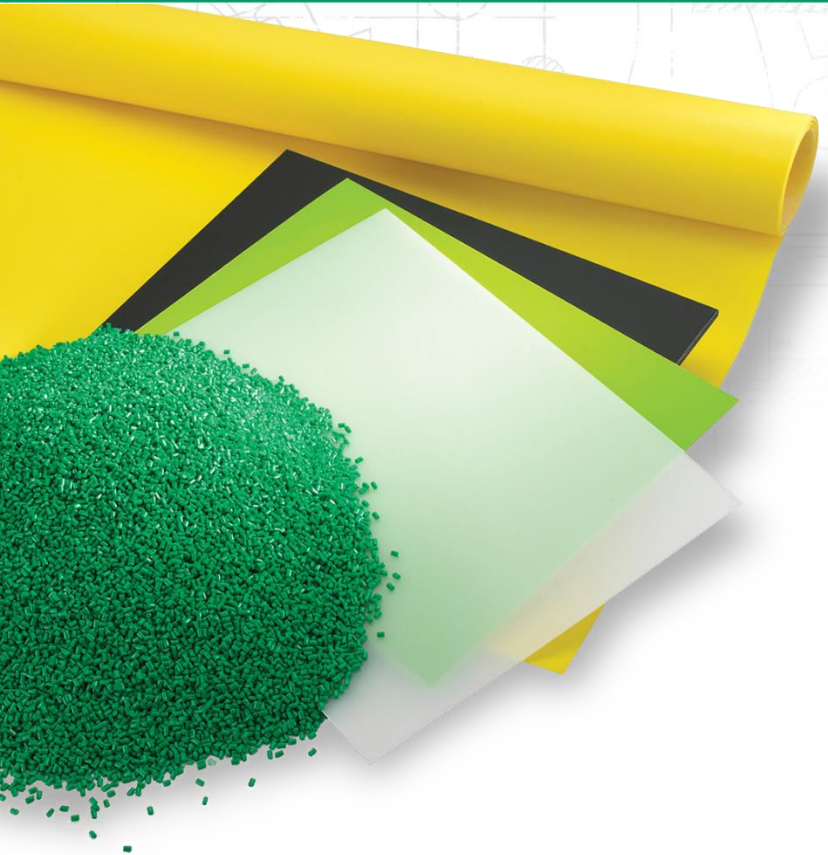


TC FILLER TECHNOLOGY

- **Electrically Isolative Fillers – Ceramic Based**
- Oxides
- Nitrides (Boron Nitride, aka White Graphite)
- Silicates

- **Conductive Fillers – Carbon Based**
- Graphite
- Carbon Fiber
- Carbon Black

- **Combined Systems – Controlled TC**
- PermaStat® and PermaStat Plus® additives for ATEX and Anti-Static
- Ceramic and Carbon blends for targeted ESD
- Metallic additives for EMI performance



THANK YOU!

Questions?

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