

**iNEMI Session @Imaps DPC April 2021**  
**Track Session Title: "5G Electronics Challenges: High Frequency  
Materials Characterization "**  
**Presented at Imaps Device Packaging Conference**

14 Apr 2021

# Industry Collaboration Brought Together by iNEMI

- Next-generation 5G communications solutions require ultra-low loss laminate materials and PCBs/substrates for efficient design and manufacturing.
- However, these materials pose challenges. For example, there is no consistent methodology for measuring transmission loss or Df/Dk, especially for higher frequencies (e.g., >30 GHz).
- Many different approaches are currently used, requiring different fixtures and test methods, sample preparation, and/or data analysis/extraction.
- In response, iNEMI members have organized the 5G/mmWave Materials Assessment and Characterization project to develop guidelines and best practices for a standardized measurement and test methodology that can be shared with industry and relevant standards organizations.

	Title	Author(s)
<b>Paper 1</b>	Challenges for High Dk/Df measurements	Urmi Ray, iNEMI <a href="mailto:Urmi.ray@inemi.org">Urmi.ray@inemi.org</a>
<b>Paper 2</b>	Benchmarking resonator based low dk/df material measurements	Richard Stephenson <a href="mailto:richard.stephenson@emdgroup.com">richard.stephenson@emdgroup.com</a>
<b>Paper 3</b>	Recent developments of resonator measurements for emerging materials and technologies	Marzena Olszewska-Placha <a href="mailto:molszewska@qwed.com.pl">molszewska@qwed.com.pl</a> Małgorzata Celuch, QWED <a href="mailto:mceluch@qwed.eu">mceluch@qwed.eu</a>
<b>Paper 4</b>	High Frequency measurements using wafer level techniques	Nathan Orloff, NIST <a href="mailto:nathan.orloff@nist.gov">nathan.orloff@nist.gov</a>
<b>Paper 5</b>	Optimizing Measurement accuracy and repeatability for high frequency measurements	Say Phommakesone, <a href="mailto:say_phommakesone@keysight.com">say_phommakesone@keysight.com</a>

# Challenges for High Frequency Measurement of Low Loss Dielectric Material

Presented at Imaps Device Packaging Conference

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# Who's iNEMI

The International Electronics Manufacturing Initiative (iNEMI) is

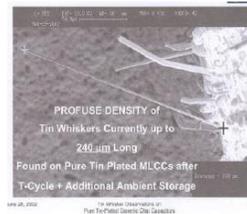
- a not-for-profit,
- industry-led,
- highly efficient

R&D consortium of approximately 80 leading electronics manufacturers, suppliers, associations, government agencies and universities.

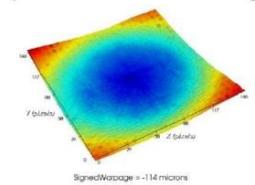


## Forecast and Accelerate improvements in the Electronics Manufacturing Industry for a Sustainable Future via Collaborative Innovation

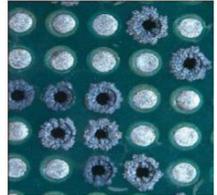
<b>Roadmap</b>	<ul style="list-style-type: none"> <li>• Anticipate technology requirements</li> <li>• Identify gaps</li> <li>• Focus R&amp;D priorities</li> </ul>
<b>Collaborative Projects</b>	<ul style="list-style-type: none"> <li>• Eliminate gaps</li> <li>• Deliver learning &amp; critical data</li> <li>• Leverage efforts &amp; participants' resources</li> </ul>
<b>Forums &amp; Workshops</b>	<ul style="list-style-type: none"> <li>• Share solutions &amp; best practices</li> <li>• Prioritize key challenges</li> <li>• Network with customers &amp; suppliers</li> </ul>



**Tin Whisker Susceptibility**



**Warpage Characterization of Organic Packages**



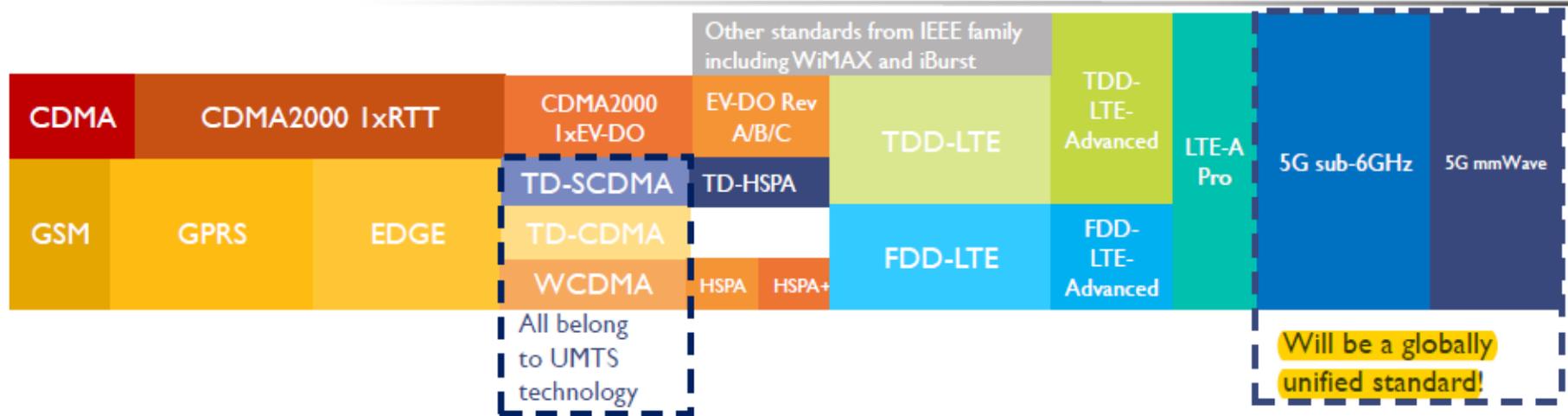
**Creep Corrosion**

# 5G: Telecommunications Technology: Evolution of Cellular Standards

Device Packaging Conference 2021 - April 12-15, 2021

## CELLULAR TECHNOLOGY DEVELOPMENT

From 2G to 5G: A journey of less than a 30 years



It takes around 10 years between two cellular generations, including a long transition phase with intermediate technologies.



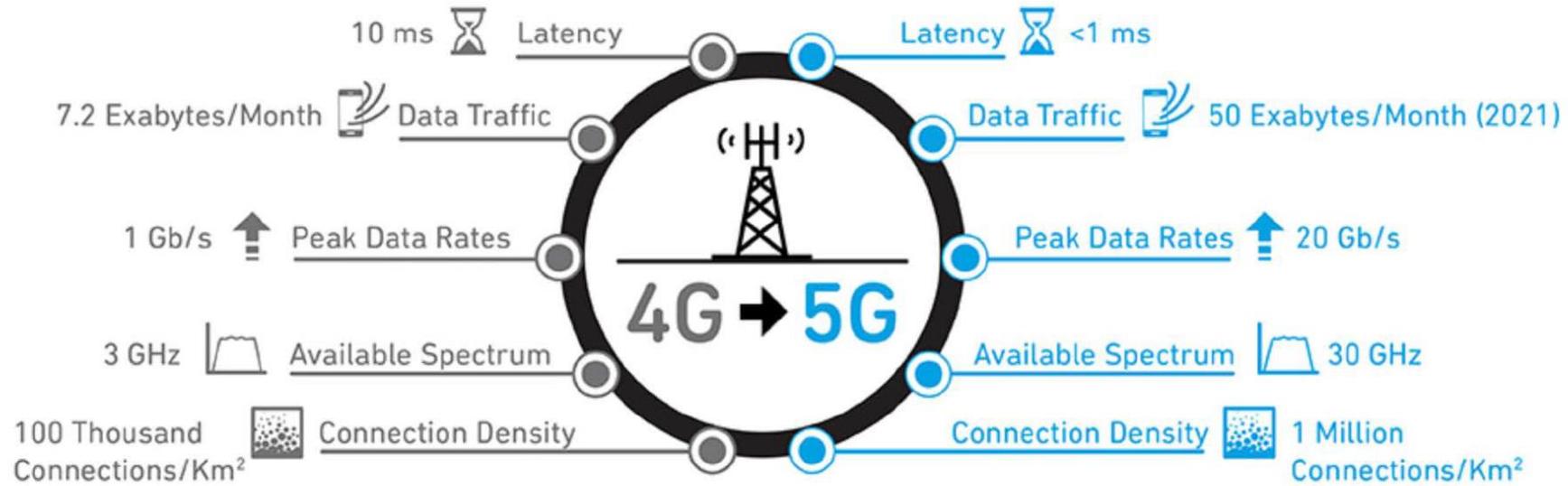
5G is revolutionary technology

Source: Yole

000202



# 5G: Comparison with 4G



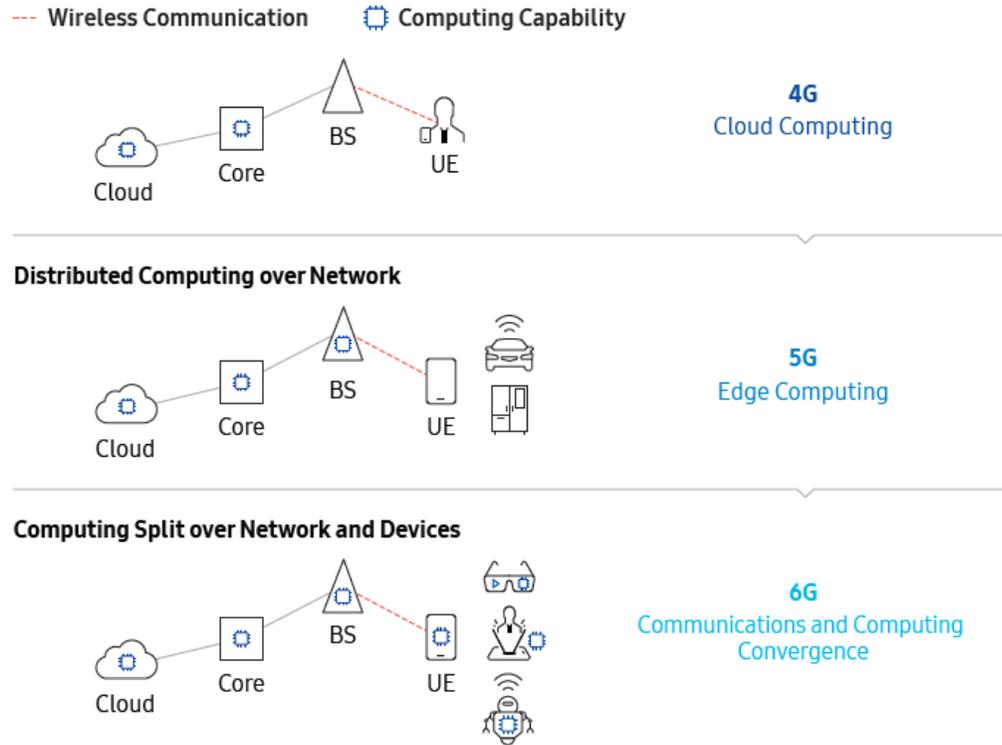
QORVO

©2017 Qorvo, Inc.

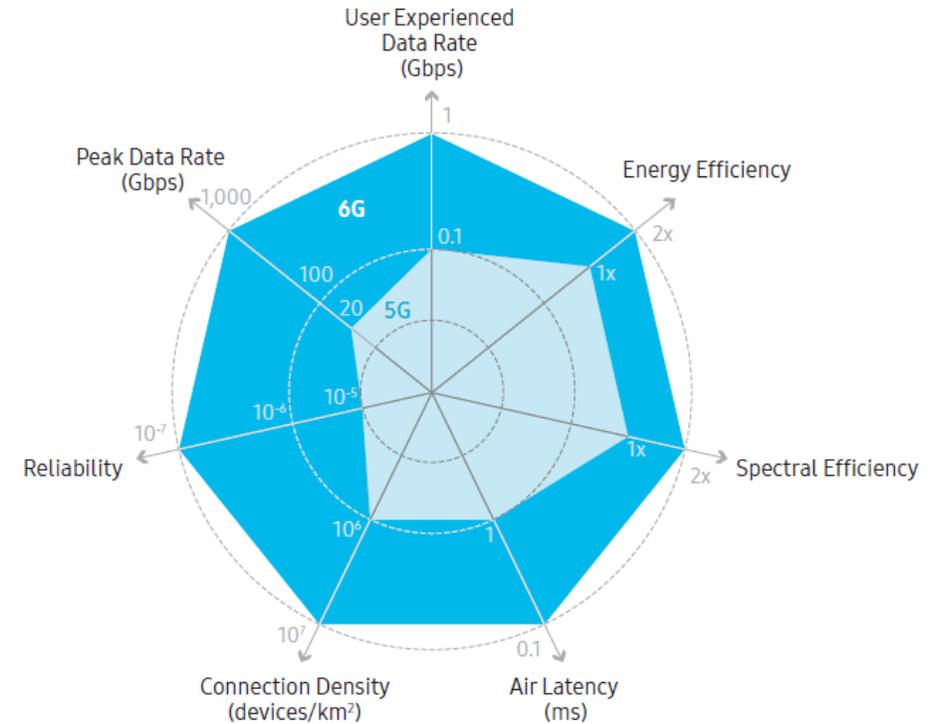
By 2022, 5G is expected to provide 20X the speed of 4G with 10X lower latency and 3X better spectral efficiency

# 5G → 6G: Telecommunications Technology: Evolution of Cellular Standards

Device Packaging Conference 2021 - April 12-15, 2021

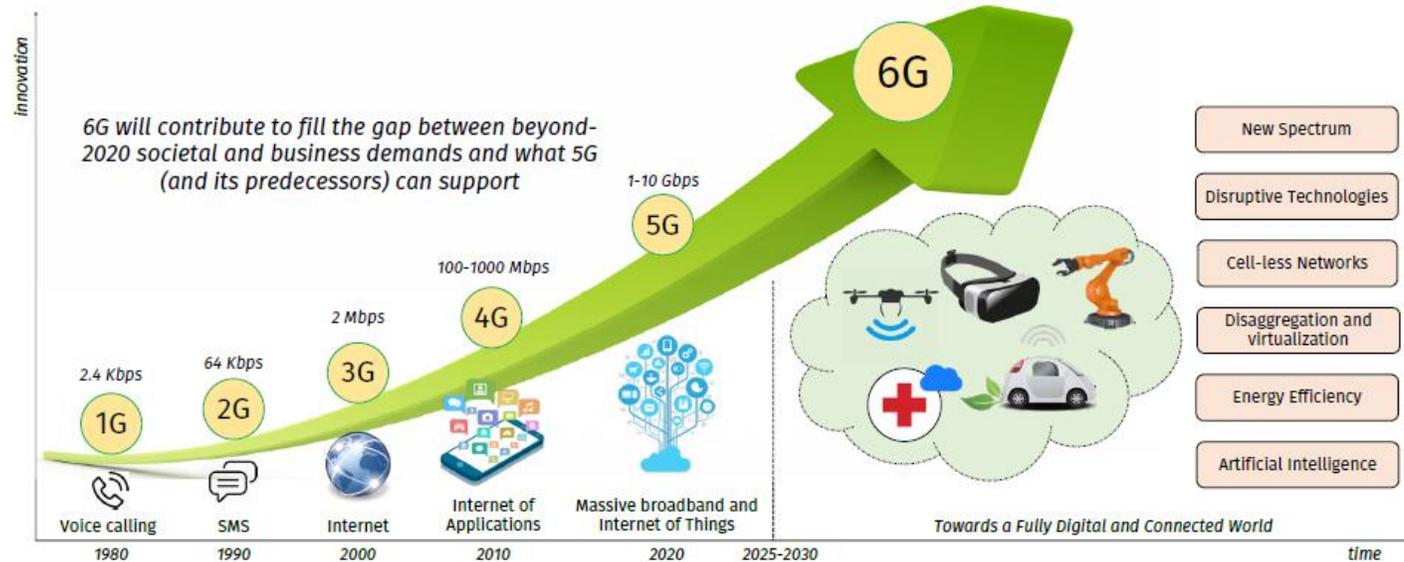


Architectural Requirements



Performance Comparison

# Wireless Communication



- ❑ Applications emerging in Augmented Reality, Virtual Reality, Teleportation, eHealth ....
- ❑ Pervasive Connectivity:  $10^6$  devices/km<sup>2</sup> (5G) to  $10^7$  devices/km<sup>2</sup> (6G)
- ❑ Capacity: 20Gbps (5G) to 1Tbps (6G)
- ❑ Unmanned mobility: Autonomous transportation with high reliability & low latency
- ❑ Intelligent Communications!

Marco Giordani, Michele Polese, Marco Mezzavilla, Sundeep Rangan, and Michele Zorzi, "Towards 6G Networks: Use Cases and Technologies", IEEE Communications Magazine 2020

# 5G: Disruptions Enabling next level of Communication

Device Packaging Conference 2021 - April 12-15, 2021



Source: CTIA Oct 2020

# 5G Challenges - List

- Novel Material –better electrical, microwave and thermal properties at a low cost
- Design - Co-Simulation of package, circuit and device –including circuit, EM and thermal analysis
- Multilayer substrate fabrication with fine geometry and accurate alignment – Low loss material, characterization
- Metallization with smooth and well-defined surface and near vertical edge
- Packaging -Tight integration of mm-wave active electronics, filters, and antenna in critical to 5G RF-Front-Ends
- Testing

Source: HIR 2019

# 5G/mmWave- Critical Industry Initiative Needed

## •5G Semiconductor Challenges Summary

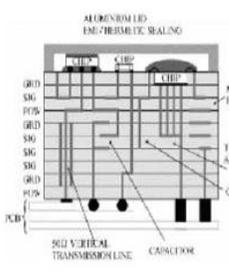
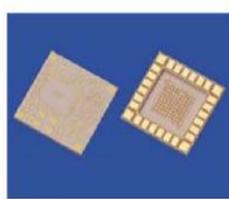
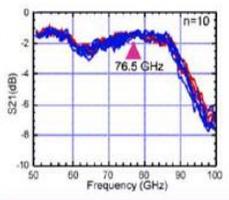
Challenge	Attractive Approaches
<b>Need for Antenna in Package (AiP)</b>	<ul style="list-style-type: none"> <li>• Laminate-based solutions</li> <li>• eWLB (FO-WLP) solutions</li> </ul>
<b>High speed/ Ultra Low Loss materials</b>	<ul style="list-style-type: none"> <li>• Cost-effective materials at mmWave frequencies</li> <li>• Materials characterization and test methods</li> </ul>
<b>Heterogeneous Integration (SiP)</b>	<ul style="list-style-type: none"> <li>• Increases in # of components → Miniaturization</li> <li>• Advanced molding technologies</li> <li>• Shielding</li> </ul>
<b>Test</b>	<ul style="list-style-type: none"> <li>• Contact vs OTA testing → still TBD</li> <li>• More sensitivities to process variations</li> </ul>

5G solutions require complex packaging approaches and requires close collaboration.

Source: Heterogeneous Integration Roadmap: 2019

# 5G Challenges – Substrate Comparison

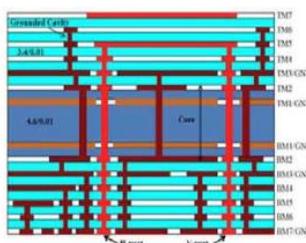
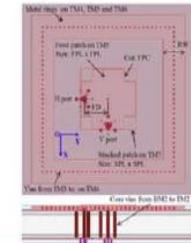
### Ceramic (LTCC)

**KYOCERA**

Insertion loss of full link  
~3dB at 60 GHz

### Low-loss Laminate

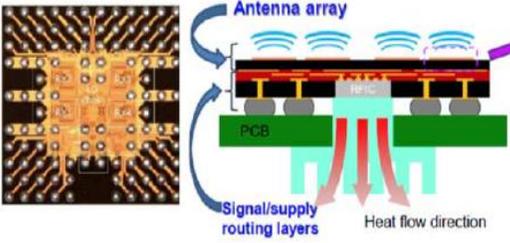
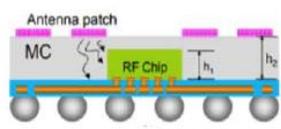



- 3 dBi/element
- Buildup: Dk=3.4, Df=0.01

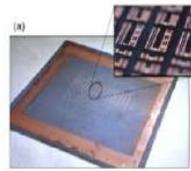
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### Fanout WLP

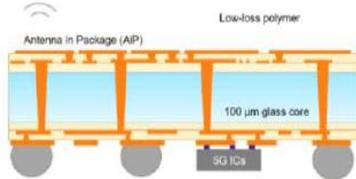
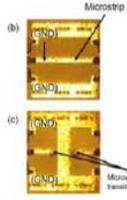


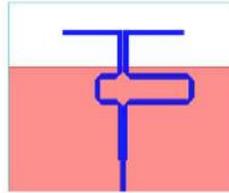
### Glass substrates



Low-loss transmission lines


Yagi-Uda antenna



Madhavan Swaminathan, IMS2019 Workshop: WMG-3: “Design and Fabrication of SIW at mm-Wave using Organic Substrates”

Source: HIR 2019

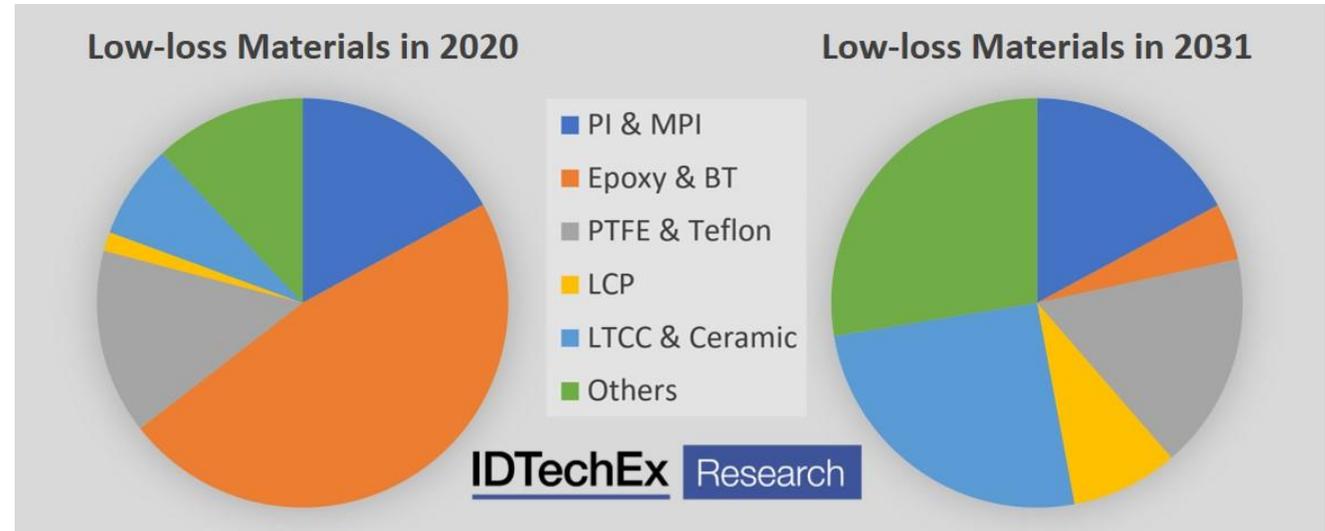
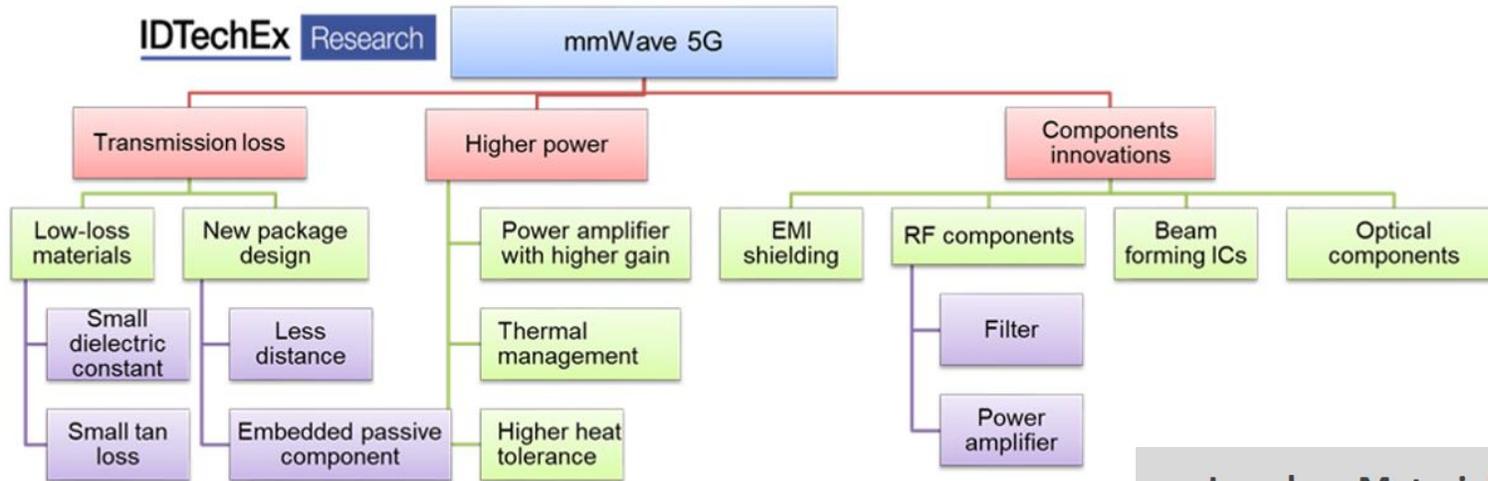
# 5G Challenges – Substrate Comparison

	Photo Definable Glass	Silicon	LTCC	FR4	LCP
<b>CTE [ppm]</b>	7.5-10	2.6	5.9-10	15	17 (CTE_z=150)
<b>Dielectric Constant</b>	5.7	11.7	5.9-8	4.7	2.2-3.2
<b>Tg [°C]</b>	450	N/A	N/A	110-200	280-250
<b>Young's modulus [Gpa]</b>	81		12-27	17	
<b>Manufacturing</b>	Semiconductor	Semiconductor	Screen-printing	Subtractive/Additive	Subtractive/Additive
<b>Drill Size [um]</b>	Very small	small	large	large	large
<b>Layer thickness [um]</b>	<100	<100	<100	40	25

Telesphor Kamgaing, IMS2019 Workshop: WSC-7: “Millimeter Wave Packaging and Antenna Integration for 5G Applications and Beyond

Source: HIR 2019

# 5G Challenges – Substrate Comparison



Source: IDTechEx 2021



material  
properties for  
5G

- Relative permittivity  $\epsilon_r$  or dielectric constant Dk
  - Miniaturization for higher  $\epsilon_r$  values
  - Trending toward lower Dk as frequency increases
  - Permittivity range of interest  $1 < \epsilon_r < 100$
- Dielectric loss ( $\tan\delta$  or  $1/Q$ )
  - Related to overall device loss and quality factor Q
  - Low loss is important for filters and transmission lines
  - Loss range  $10^{-5} < \tan\delta < 10^{-2}$  or  $10^5 > Q > 10^2$
- Temperature dependence
  - Permittivity and loss change with temperature
  - Affects the temperature dependence of frequency for filters
  - Coefficient of temperature  $|\tau_\epsilon| < 100 \text{ ppm}/^\circ\text{C}$

Source: Penn State

Important  
material  
properties for  
5G transmission  
lines

- **Dielectric loss ( $\tan\delta$ )**
  - Related to polarization losses in material
  - Loss range  $10^{-5} < \tan\delta < 10^{-2}$
- **Conductor resistivity ( $\rho$ )**
  - Related to resistive losses in material
  - Resistivity range  $1.6 \times 10^{-8} < \rho < 7.0 \times 10^{-8} \Omega\text{-m}$
- **Attenuation ( $\alpha$ )**
  - Related to conductor and dielectric losses

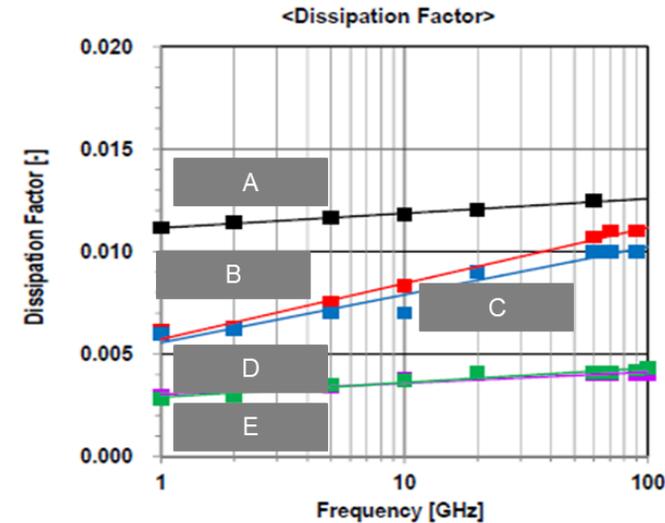
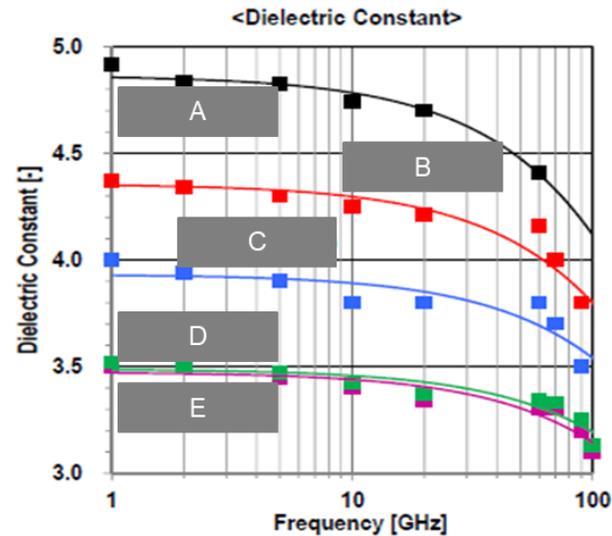
Source: Penn State

# 5G mmWave: materials Innovation: Low Loss Substrate Development for 5G

Device Packaging Conference 2021 - April 12-15, 2021

## Low loss material selection for 5G market using Laminate Packaging Accurate Measurement Needs at frequencies >10GHz

Vendor  
Data

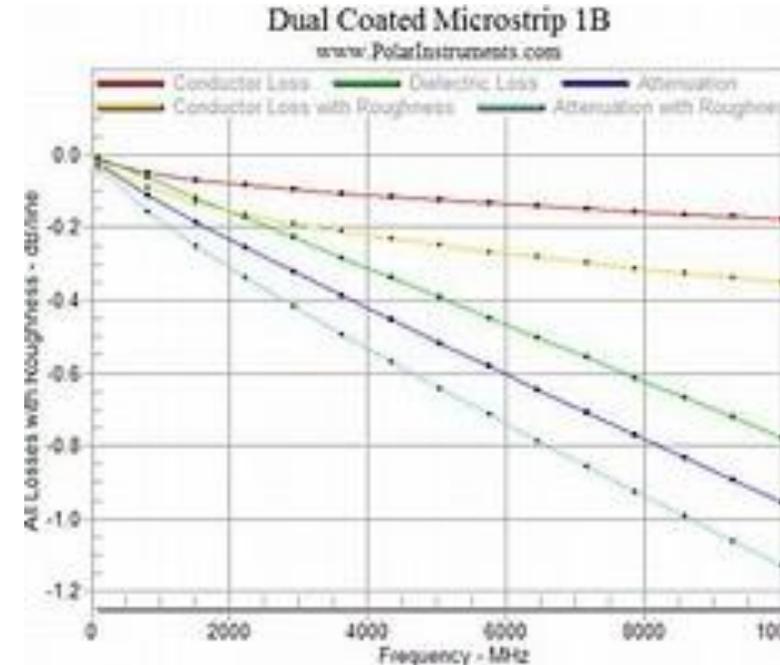


Build Up Material	A	B	C	D
Dk @ 10GHz	4.7	4.3	3.7	3.4
Df @ 10GHz	0.012	0.008	0.007	0.004

- Critical Parameters: Dk (dielectric constant) and Df (dissipation factor or loss tangent)

# Conductor Losses in PCB/Substrate

- Losses that need to be considered by the PCB designer/ fabricator can be summarized as *conductor and dielectric losses*.
- Conductor losses include DC, skin effect and surface roughness losses and the designer will need to balance the trade-off associated with foil roughness and conductor loss with the requirement for robust packaging.



Source: Polar Instruments

# Industry Collaboration Brought Together by iNEMI

## **Problem Statement:**

- Next-generation 5G communications solutions require ultra-low loss laminate materials and PCBs/substrates for efficient design and manufacturing.
- However, these materials pose challenges. For example, there is no consistent methodology for measuring transmission loss or Df/Dk, especially for higher frequencies (e.g., >30 GHz).
- Many different approaches are currently used, requiring different fixtures and test methods, sample preparation, and/or data analysis/extraction.

# Industry Collaboration Brought Together by iNEMI

## Approach for Solving Problem:

- Bring together Cross-functional team spanning industry Value Chain
- iNEMI Project team members cover wide range of industry, academia and equipment suppliers
- All have vested interest in mmWave materials characterization
- Develop pre-competitive collaboration to address low loss measurement issues by:
  - Developing a guideline/best practice for a standardized measurement and test methodology that can be shared with industry and relevant standards organizations
- Accomplishment to-date:
  - Two Comprehensive benchmarking reports on “Current” and “Emerging” measurement methods

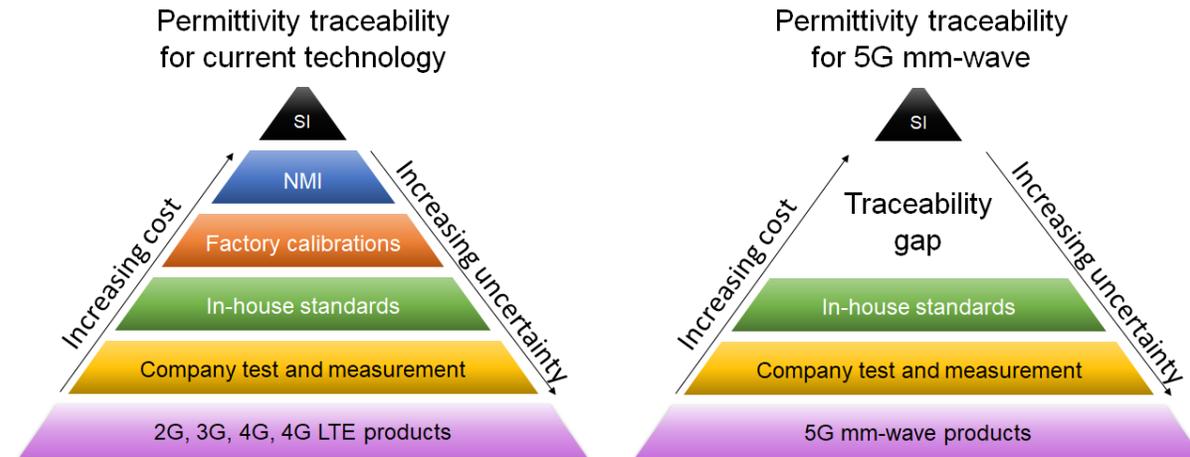
## Project Team

- |                              |                              |
|------------------------------|------------------------------|
| • AGC-Nelco                  | • Isola                      |
| • AT&S                       | • ITRI (Co-Chair)            |
| • Centro Ricerche FIAT-FCA   | • Keysight (Co-Chair)        |
| • Dell                       | • MacDermid-Alpha            |
| • Dupont                     | • Mosaic Microsystems        |
| • EMD Electronics (Co-Chair) | • NIST                       |
| • Flex                       | • Nokia                      |
| • Georgia Tech               | • QWED                       |
| • ShowaDenko Materials       | • Shengyi Technology Company |
| • IBIDEN Co Ltd              | • Sheldahl                   |
| • IBM                        | • Unimicron Technology Corp  |
| • Intel                      | • Zestron                    |

# Primary Materials Characterization Challenges

- Lack of traceable Standard Reference Material
- Inconsistency in test methods

- Focus is given on the importance of reference standard material and the need for national metrology institutes, such as NIST, to develop and supply new standards reference materials to the 5G sector.
- The traceability gap is shown in the Figure



# Project Goals

- Gather industry experts to understand needs and try to address these problems
- Encourage development of traceable material references by standards organizations
- Better linkage between equipment manufacturers and end users

## Task 1

### Benchmark

- Current techniques
- Typical material samples
- Potential reference materials
- Common practices & issues

Report complete 

## Task 2

### Benchmark

- Emerging techniques
- Possibilities beyond 100GHz

Report complete 

## Task 3

### Round Robin Tests

- Create reference samples
- Test metrology differences
- Study lab to lab variations

Round 1 Testing complete  
Data analysis in progress

Covered in next presentation

# Round Robin Overview – Task 3

## Sample Material Requirements

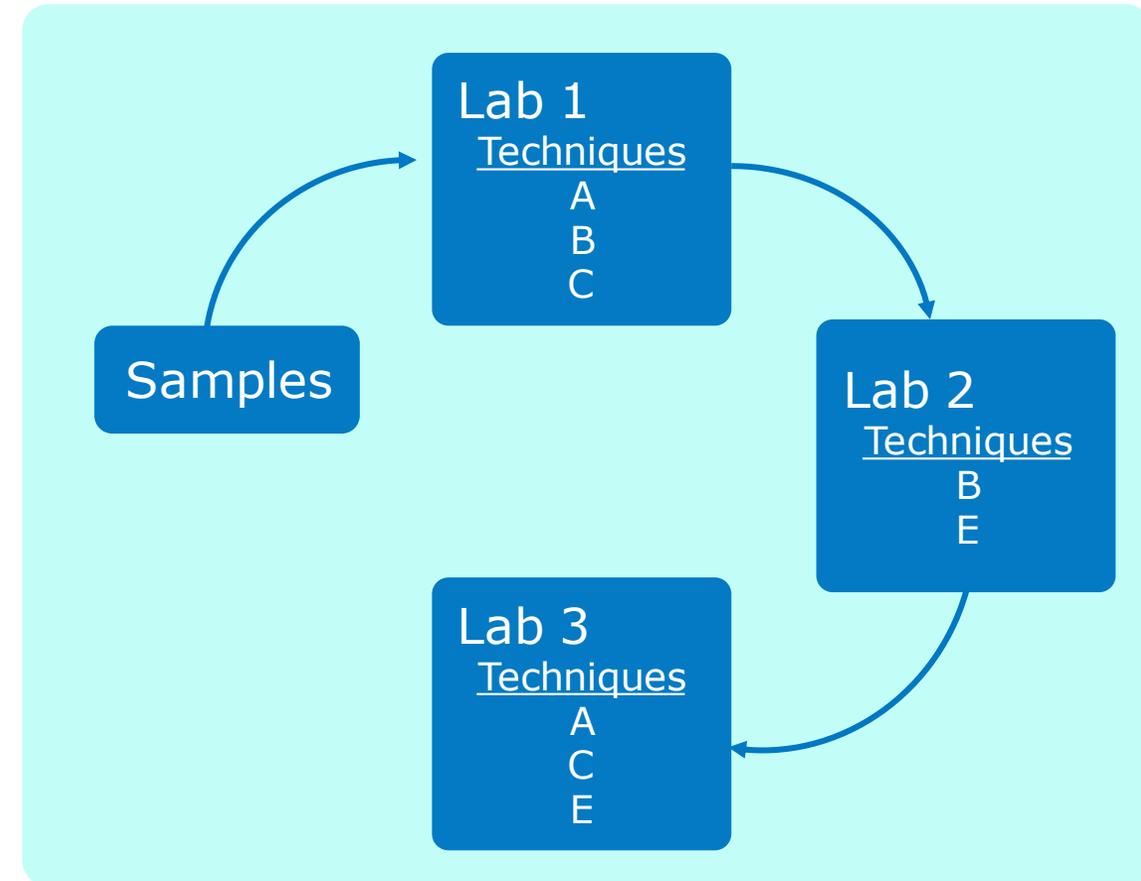
- Stable, Low loss
- Low moisture absorption / temperature dependency
- Isotropic
- Good mechanical & handling properties

## Current Selection

- Precision Teflon
- Cyclo Olefin Polymer

## Future additions

- Rexolite
- Fused Silica



9 Laboratory Effort

# Round Robin Overview – Task 3

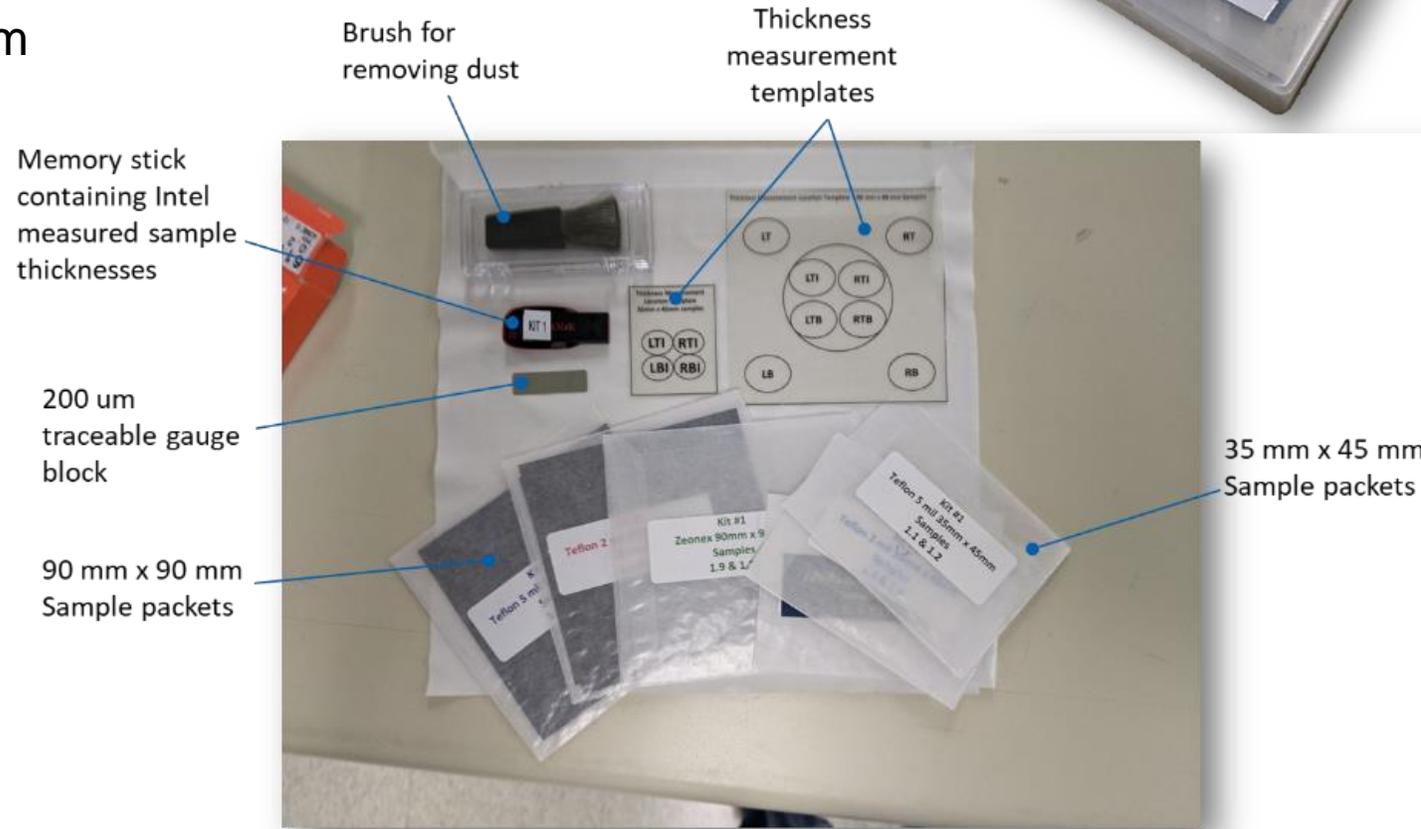
## 10 Kits Created

- Sample sizes 35 mm x 45 mm, 90 mm x 90 mm
- 9 International labs participating

## Techniques included

- Split Post Dielectric Resonator
- Split Cavity Resonator
- Fabry-Perot
- Balanced Circular Disk Resonator

Frequency Span : 10GHz – 100GHz



Brush for removing dust

Thickness measurement templates

Memory stick containing Intel measured sample thicknesses

200 um traceable gauge block

90 mm x 90 mm Sample packets

35 mm x 45 mm Sample packets

Expect results to come in over the next few quarters

# Summary and Next Steps

- iNEMI 5G Materials Characterization project was kicked off in 2Q2020
- Two reports benchmarking current and emerging characterization members were released to iNEMI members in Nov 2020
- Team is ramping up detailed Round robin testing across multiple resonator types and reference materials category to collect comprehensive data for repeatability, ease-of-use, applicability
  - Nine global test sites have volunteered for testing and data collection

Interested? Please contact [Urmi.ray@inemi.org](mailto:Urmi.ray@inemi.org)

# Questions??

THANK YOU FOR ATTENDING