Highlights from the iNEMI 5G Dielectric Material Measurements Project

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Motivation

Existing Stackup Dielectric

Working product

2 year old data
- Er=3
- TanD=0.0015

200 Million units shipped

New Stackup Material

MFG Datasheet

Er =3.05
TanD = 0.001

Process control data

Er =3.01
TanD = 0.0007

Service Lab Analysis

Er =3.1
TanD = 0.002

In House Analysis

Er =3.21
TanD = 0.0005

Environmental Test

Er =3.31
TanD = 0.0021

Service Lab#2 Analysis

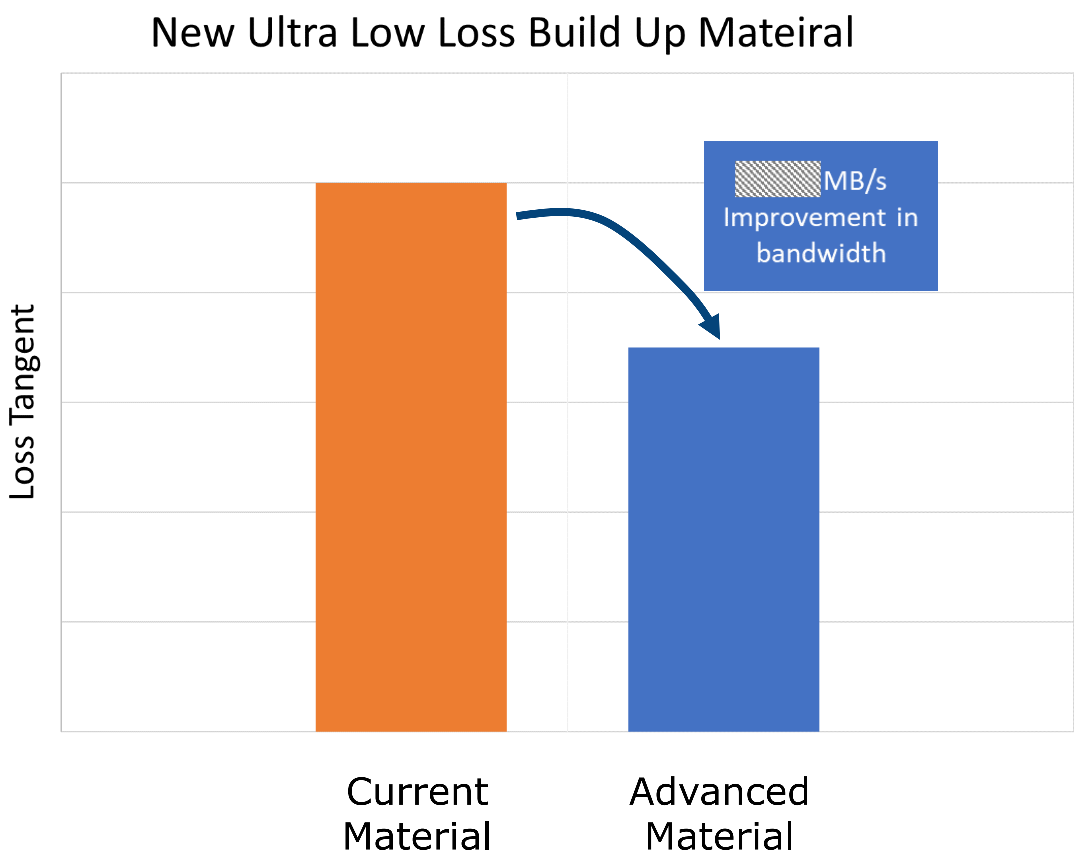
Er =2.9
TanD = 0.002

x 10's of candidate materials

You must have high confidence data to begin process of material changes

Material Characterizations Very Valuable

- Selection of package materials may involve measurements of 50 or more test materials
- Over temperature & humidity



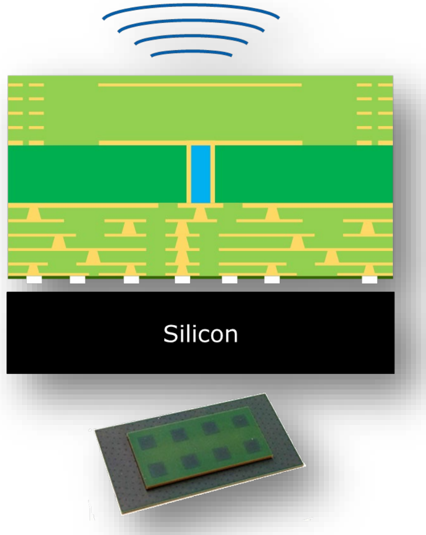
Cost to switch: ~$2 per CPU substrate

x 20M units = $40M

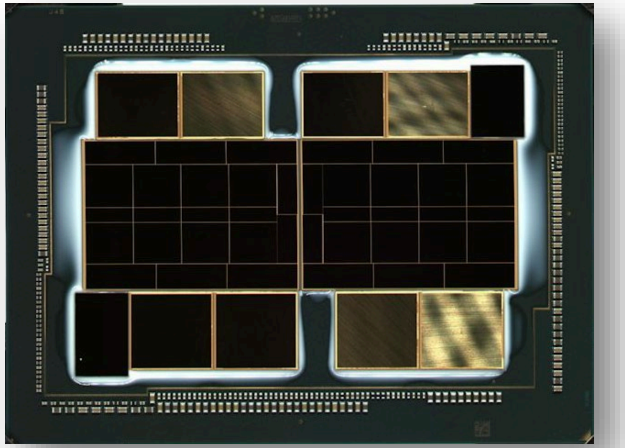
High volume industries, equipment suppliers, material manufacturers have significant exposure if characterizations are incorrect

First step in assessing material performance is a trusted, stable and accurate metrology

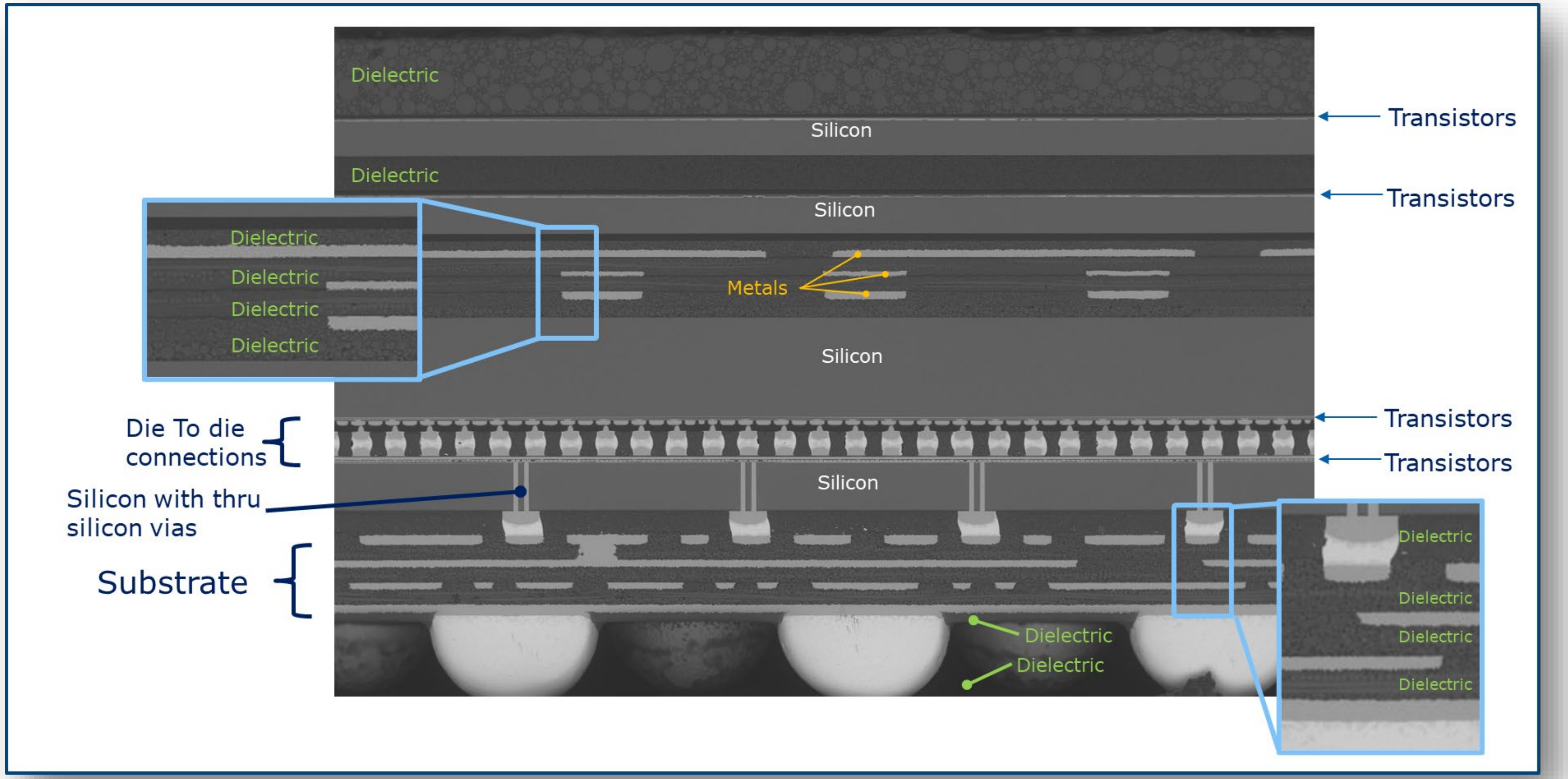
Permittivity & Loss Tangent Are Staple Measurements



mmWave Antennas



Complex multi-die packages



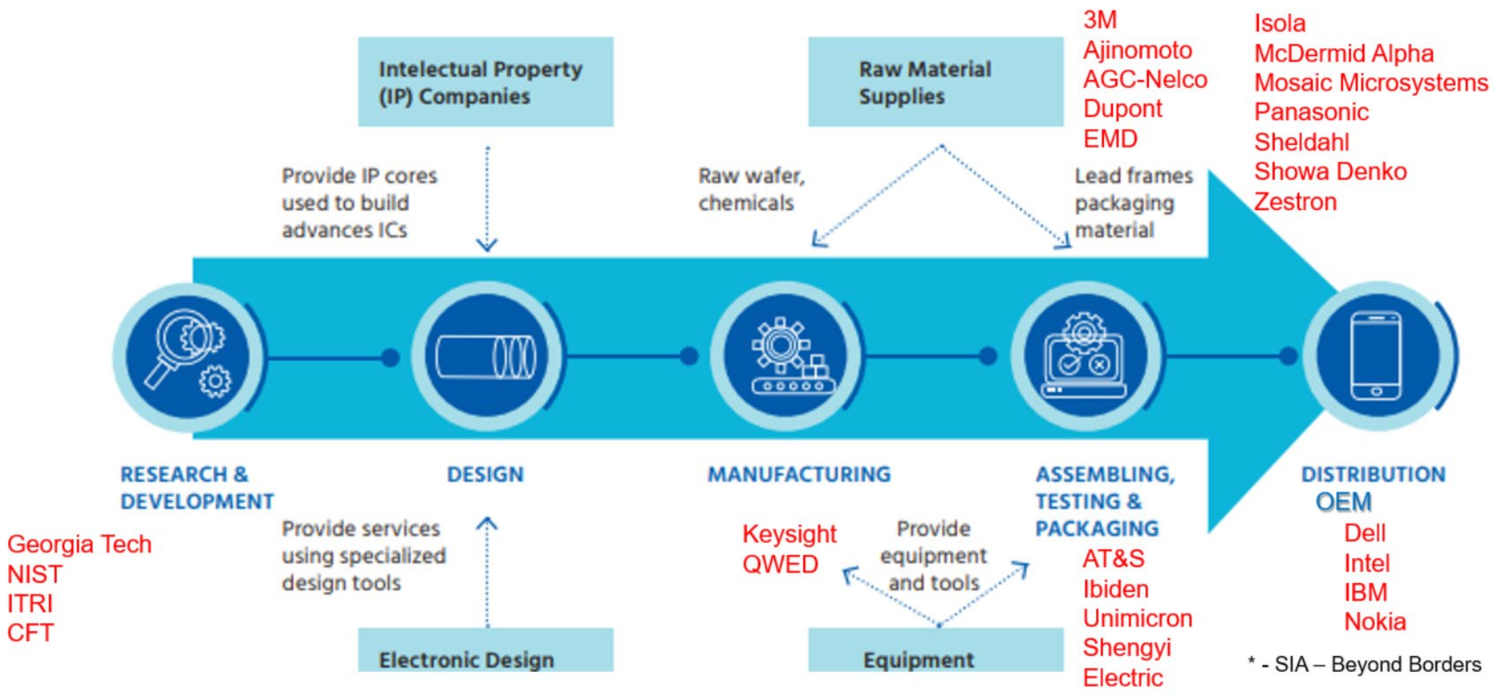
Today's advanced devices rely on many different low loss, high performance materials, operating well into mmWave frequencies

Agenda

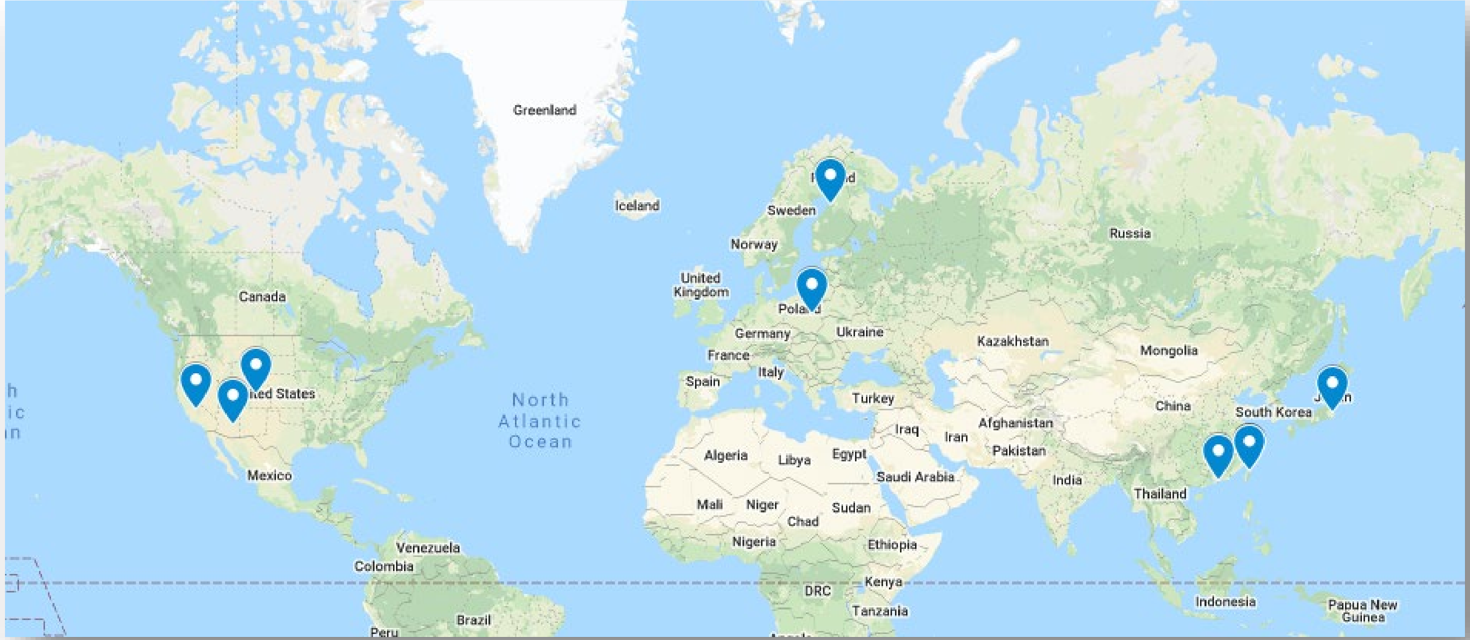
- Background – iNEMI 5 G Materials Characterization Project
- Example Results
- Drive for standards

iNEMI 5G Material Project - Project Tasks

- Task 1 – Benchmarking permittivity methods, potential reference materials
- Task 2 – Emerging technologies / 100GHz & beyond
- Task 3 – Multi Lab Round Robin Reference Experiment
- Task 4 – Extension to advanced substrate materials

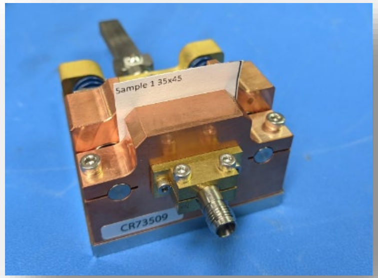


Phase 3: Round Robin Experiment

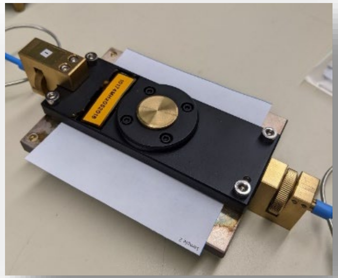


Round Robin Test Labs

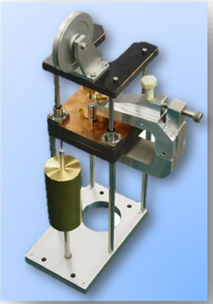
3M: USA	Keysight: USA
Dupont:USA	Nokia: Finland
Intel: USA	NIST: USA
ITEQ: Taiwan	Showa-Denko: Japan
ITRI: Taiwan	Shengyi Electric: China
QWED: Poland	



SCR
(Split Cavity Resonator)



SPDR
(Split Post Dielectric Resonator)



BCDR
(Balanced Circular Disk Resonator)

FPOR
(Fabry-Perot Open Resonator)

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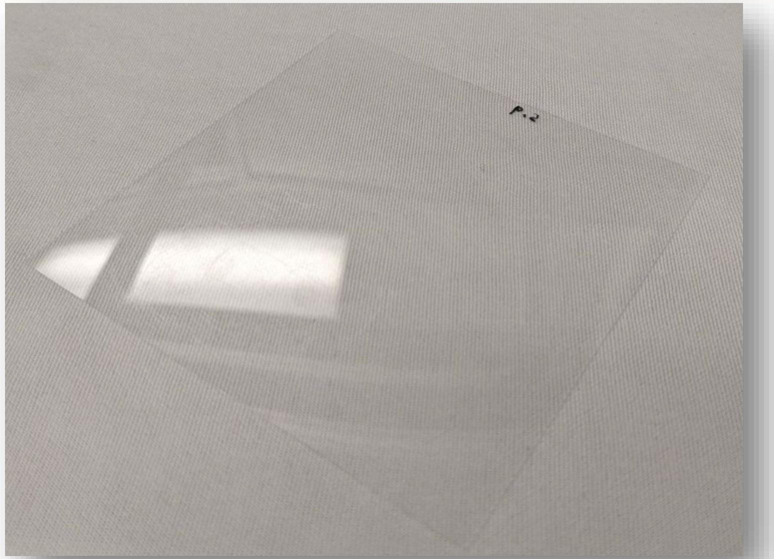
Material Samples



188 um Thick Cyclo Olefin Polymer

- Down selected to two materials
  - DuPont™ Teflon® FEP Type A
  - Zeonex® Cyclo Olefin Polymer ZF14-188
- Both known & demonstrated to:
  - Have little or no moisture absorption
  - Very low loss
  - Low frequency dependence
  - Available in optically clear, appropriate thickness sheets, good thickness uniformity
  - Isotropic & homogeneous
- Represent ‘best case’ substrate sample

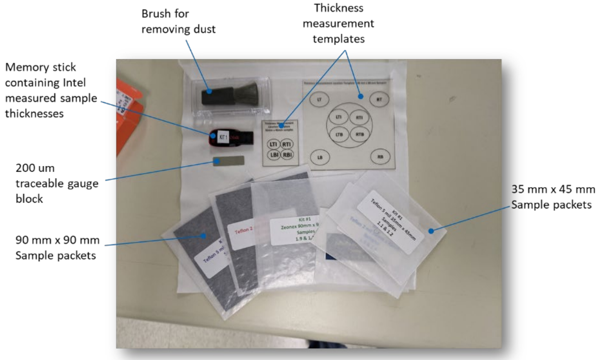
Results from the experiment represent the best we can do today using almost ideal samples

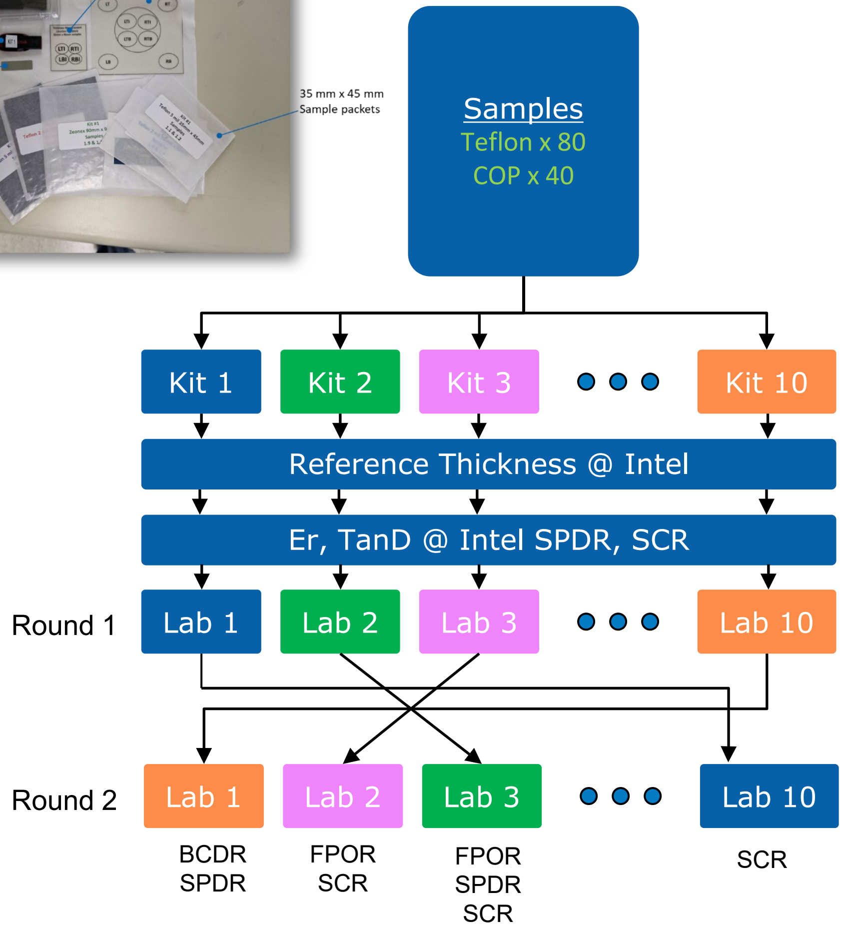
All real-world measurements will be worse.

Overview

- Round Robin Experiment
  - ~2200 Data points in data set
  - Spanning 10 labs, 4 methods, 10-110GHz
  - 2 Materials: COP, Teflon
  - Detailed, specific procedure

- Goals
  - High level – how much agreement is there in results
  - Thickness – how closely do labs assess thickness
  - Understand sample quality, handling and sizing / compatibility
  - Understand practicality of techniques
  - Look for obvious biases between equipment types
  - Look for frequency dependency at higher frequencies
  - Do we need traceable standards?





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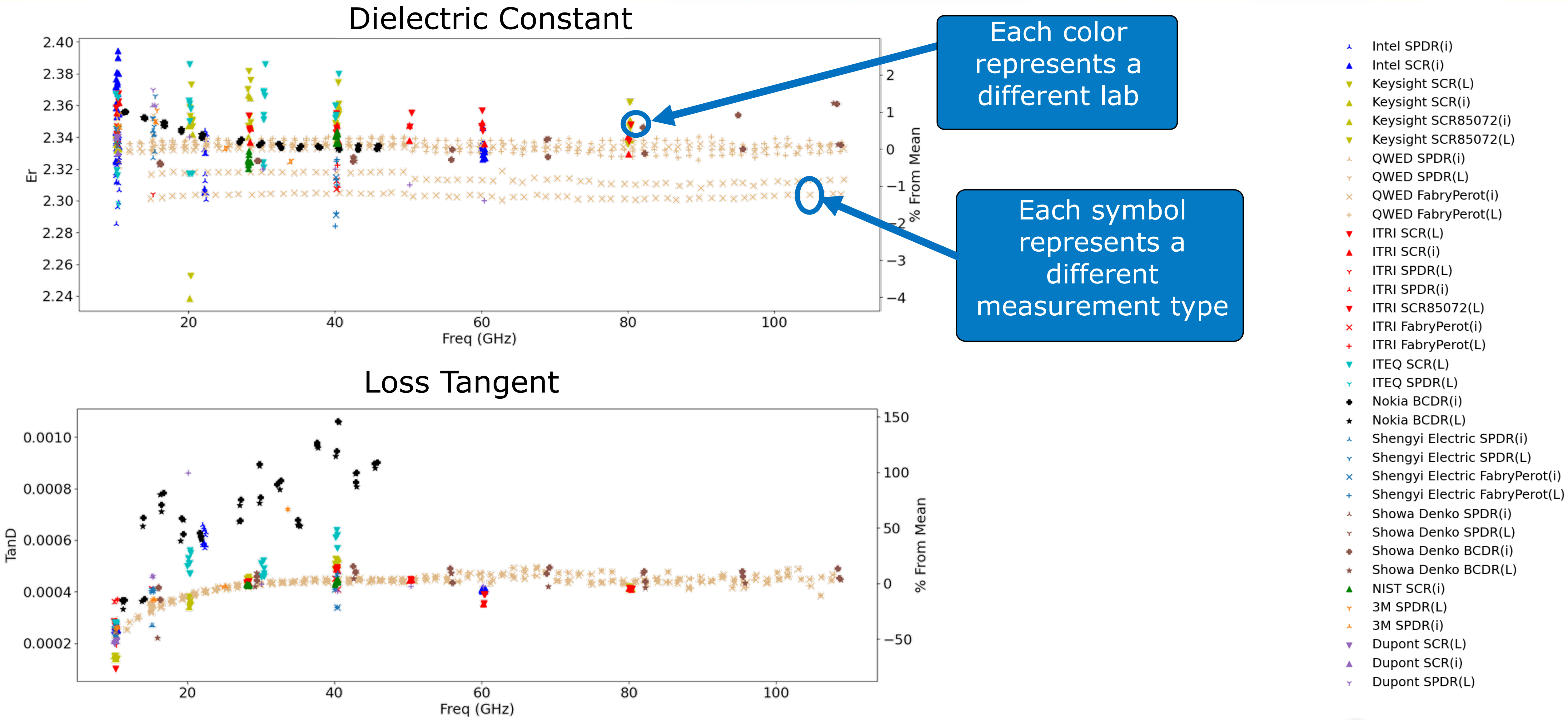
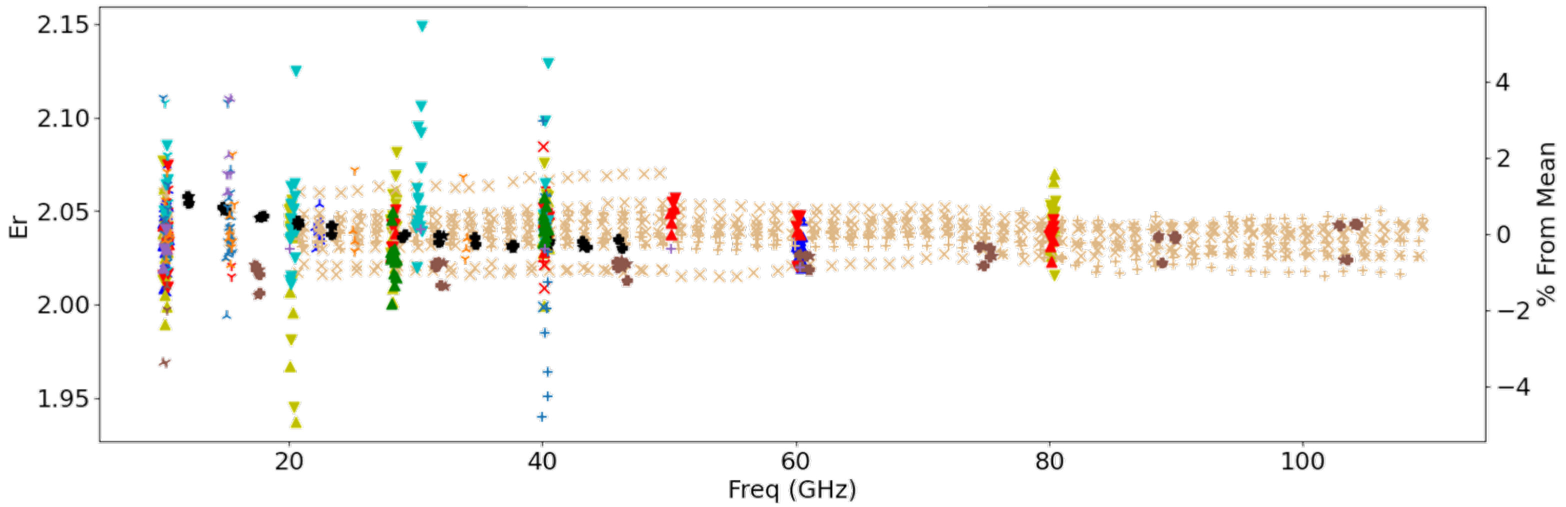
COP Results

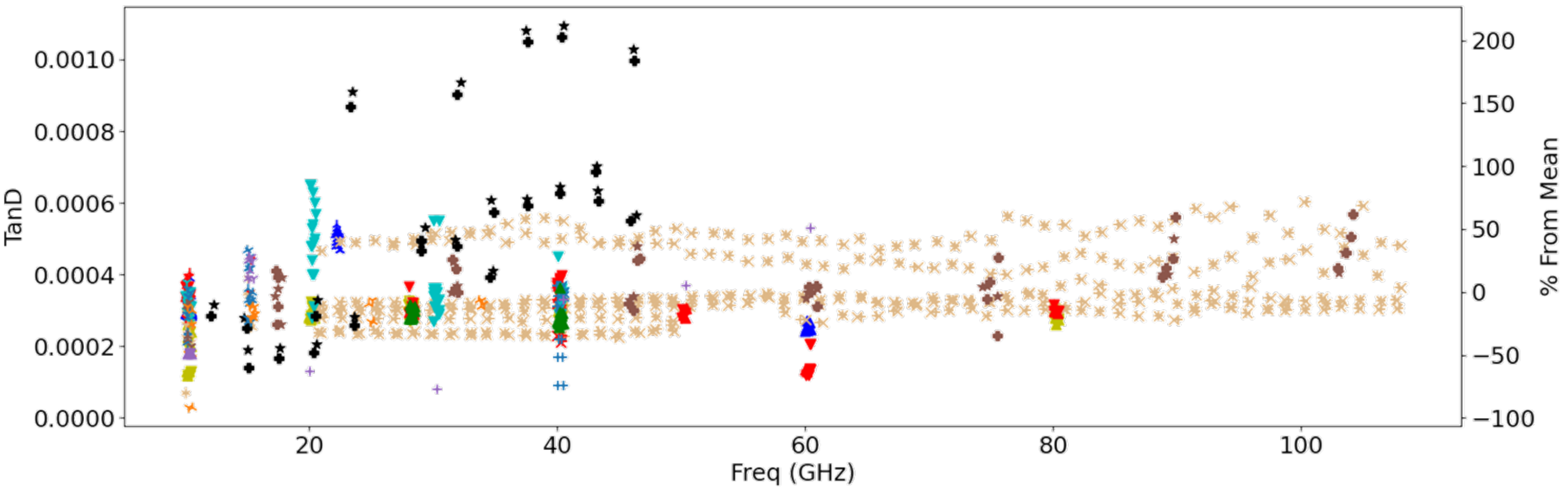

Dielectric Constant
Er
Freq (GHz)
% From Mean
Each color represents a different lab
Each symbol represents a different measurement type
Loss Tangent
TanD
Freq (GHz)
% From Mean
Intel SPDR(i)
Intel SCR(i)
Keysight SCR(L)
Keysight SCR(i)
Keysight SCR85072(i)
Keysight SCR85072(L)
QWED SPDR(i)
QWED SPDR(L)
QWED FabryPerot(i)
QWED FabryPerot(L)
ITRI SCR(L)
ITRI SCR(i)
ITRI SPDR(L)
ITRI SPDR(i)
ITRI SCR85072(L)
ITRI FabryPerot(i)
ITRI FabryPerot(L)
ITEQ SCR(L)
ITEQ SPDR(L)
Nokia BCDR(i)
Nokia BCDR(L)
Shengyi Electric SPDR(i)
Shengyi Electric SPDR(L)
Shengyi Electric FabryPerot(i)
Shengyi Electric FabryPerot(L)
Showa Denko SPDR(i)
Showa Denko SPDR(L)
Showa Denko BCDR(i)
Showa Denko BCDR(L)
NIST SCR(i)
3M SPDR(L)
3M SPDR(i)
Dupont SCR(L)
Dupont SCR(i)
Dupont SPDR(L)

Teflon Results

Dielectric Constant



Loss Tangent



Almost 'ideal' samples:

- ±2% Range for ε_r
- ±0.0002 to ±0.0004 for TanD
- Unknown accuracy

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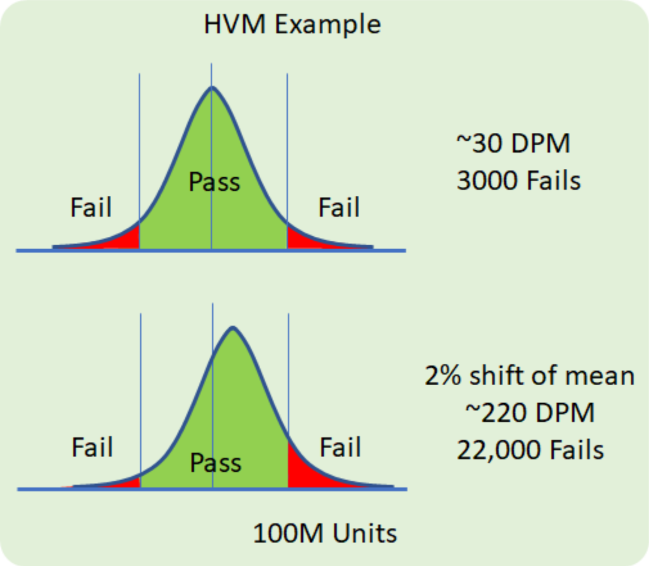
Is this good?

- Better than many expected
  - Lots of potential lab variations yet results are very good for 'perfect' samples
  - Even within a lab ±2% can be challenging for complicated metrologies

- But – for many applications this is not good enough
  - ±2% error could cause design cycle – customer & supplier could differ by 4%
  - Offset mean values can impact HVM distribution tails & DPMs
  - Intel example – this would cause miscorrelation with design
  - Real samples expected to be worse

- Reproducibility does not ensure accuracy
  - Certified standard references still needed
  - Accuracy is very important; we have no way to assess it today



A Year of effort to do this study. If SRM was available, labs would have been able to validate measurement tools independently

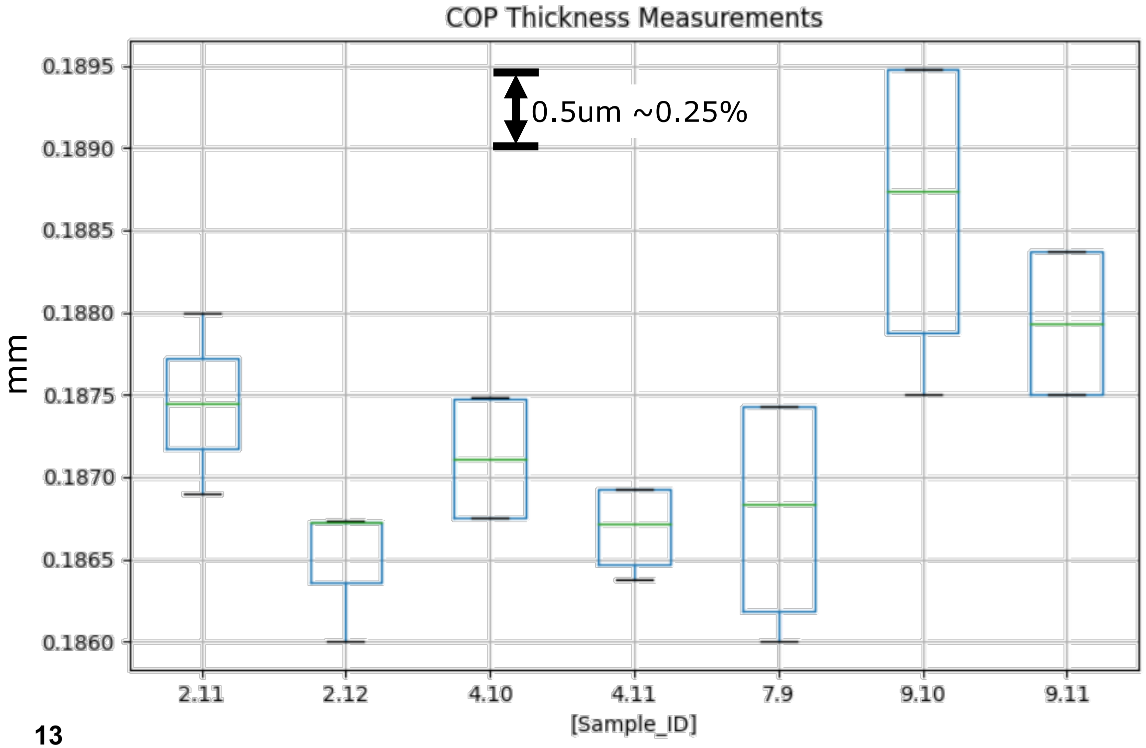
What about sample thickness?

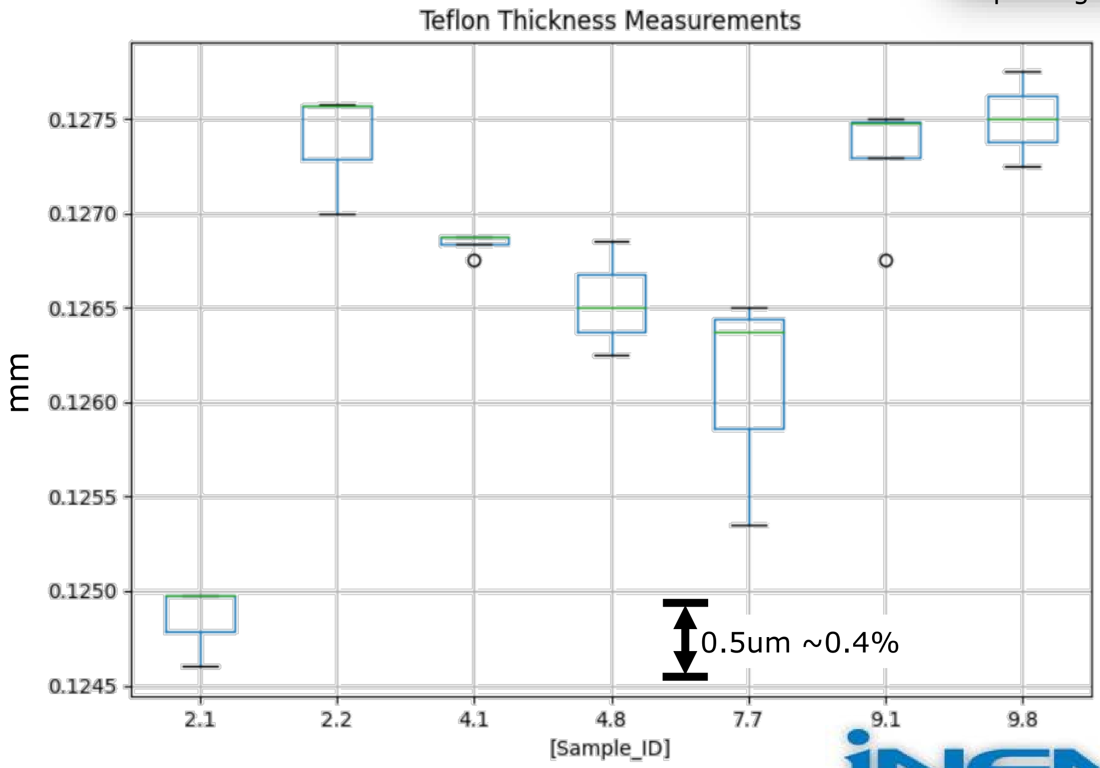
- Sample thickness is critical to results
  - Any errors in thickness assessment impact extracted ε_r ~1:1

- Labs generally have good agreement of an individual sample's thickness
  - ~±0.2 % – ±0.5 % of thickness value
  - But it is not known if this is the 'correct' thickness

Micrometer

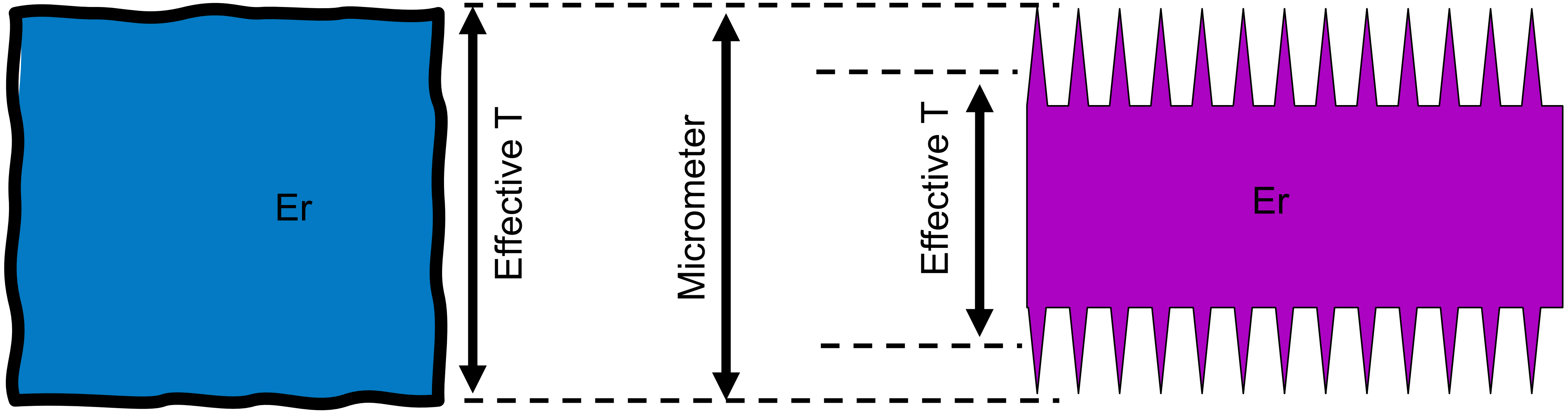
Drop Gauge





Sample Quality

- Samples have to be thin (typically<250um) – 1% variation only 2.5um
- Commonly available sample thickness variation is often unknown but this order
- Surface topology can be a factor
  - Difficult to assess
  - Easily on the order of thickness variation – potentially similar effects on results
- Best common micrometers have accuracy ~±0.5um with operator reproducibility of several um



Sample surface quality and thickness variation is important
Traceable, uniform & smooth SRM needed

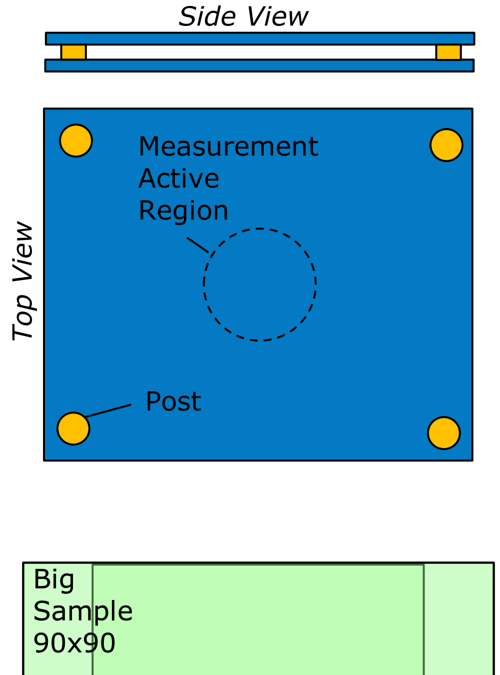
Sample sizing, compatibility & practical issues

- Common BCDR,SCR,FPOR,SPDR compatible with 2 different sample sizes 90x90 mm, 35x45 mm
  - Implications for traceable standard geometry

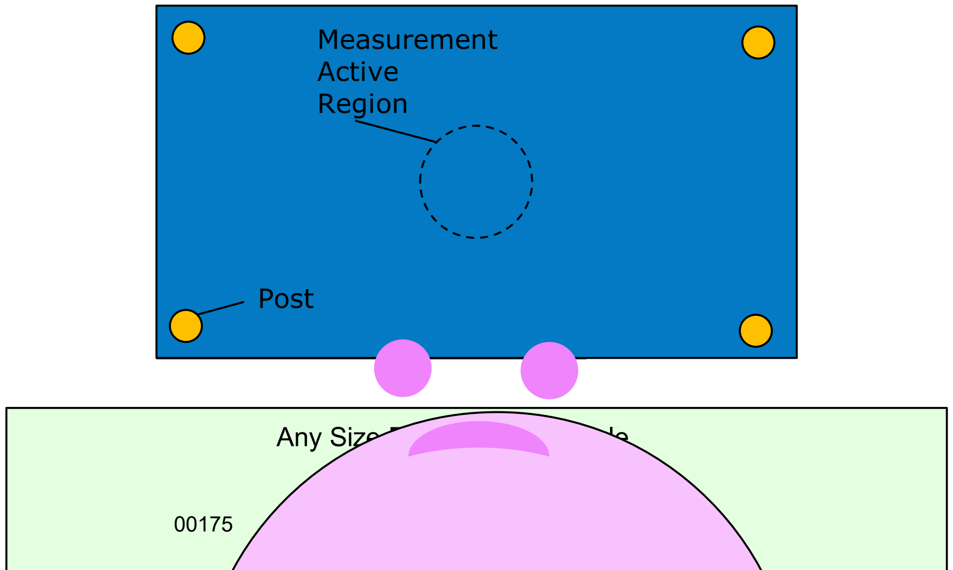
- Recommendations for equipment suppliers & customers
  - Make devices capable of arbitrarily large samples where possible
  - Even at the expense of fixture size
  - Customers: ask for this when purchasing, labs will regret not having this later

Importance of sample & device geometry compatibility can not be overstated

Sample size limited



Improved Sample Compatibility



Limitation – Lack of Standards

- No NIST traceable standards exist
- Previously available standard discontinued
- Why not redevelop previous SRM?

SRM 2870
Permittivity & Loss Tangent

Material Details

SRM 2870 - Relative Permittivity and Loss Tangent 1422 Cross-Linked Polystyrene

C - Certificate M - MSDS T - Table

Note: This material is not available for purchase.

- C Certificate
- M Material Safety Data Sheet (MSDS)
- T Related Materials: 208.2 - Electrical Properties of Dielectrics

Currently Available for Purchase!

SRM 2387
NIST Peanut Butter

SRM 3290
Dry Cat Food

Material Measurement Laboratory
Standard Reference Materials
SRM Online Request System
NIST
National Institute of Standards and Technology

*** Updated SRM Shipping Information 4/3/2020 ***

Login | My Account | View Cart | Checkout

Search for Materials
SRM/RM Number:
Search
Keywords:

Material Details

SRM 3290 - Dry Cat Food

C - Certificate M - MSDS T - Table

Customer
Not Logged In
Items in Cart: 0

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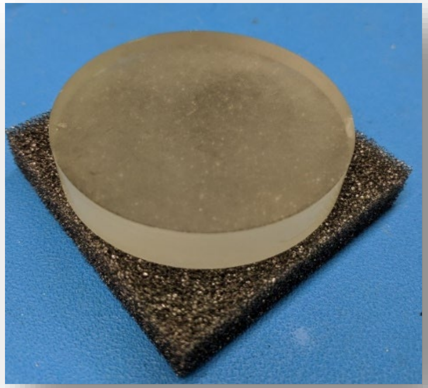
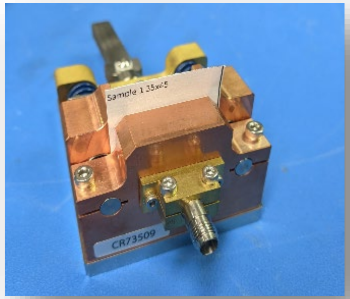
Previous Generation NIST SRM

- Mechanically incompatible with all common tools
- Required difficult to source machining to thin sample, ruining traceability
- X-Y dimensions of thinned sample still incompatible with most tools
- Certified only at 10 GHz – too low for mmWave / 5&6 G
- **Today, all permittivity tool vendors are operating without traceable standards for validating tool sets**



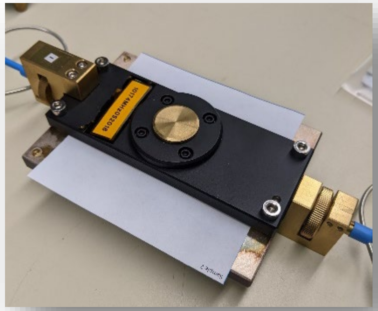
SRM 2870
Permittivity & Loss Tangent

SRM 2870 Too thick



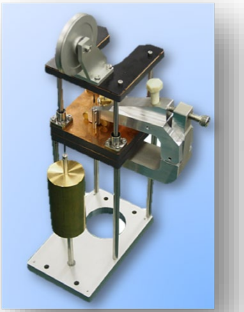
SCR

SRM 2870 Too thick



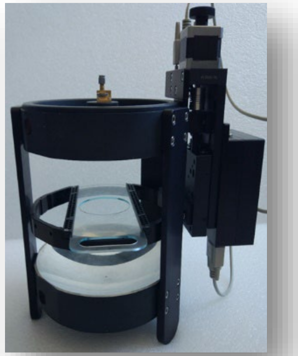
SPDR

SRM 2870 Too thick, too small



BCDR

SRM 2870 Too thick, too small



FPOR

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Summary

- Expect >±2% limitation in Er measurement reproducibility (accuracy unknown)
  - For the most part results seem independent of resonator type
- Several contributions to this – none dominant
  - Sample surface and thickness variation
  - Ability to measure thickness in reproducible way
  - Equipment & calibration variations
- 35mm x 45mm & 90mm x 90mm sample sizes fit most equipment sets
  - Thickness requirements vary by Er and specific device but 100-250um is commonly useful for many organic dielectrics
  - Recommend these sample sizes if specific measurement equipment is not known
- Individual labs - repeatability within a lab is much better than across labs
  - Remember this when evaluating the ‘correctness’ of your own results
- Need for traceable standards is clear from this study