5G Electronics: Bridging the Measurement Challenges

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iNEMI® Advancing manufacturing technology

iNEMI orchestrated an industrial round robin

10 labs measuring identical samples with 4 different methods

- Split-cylinder resonators
- Split-post dielectric resonators
- Fabry Perot open resonators
- Balanced-type circular disk resonators

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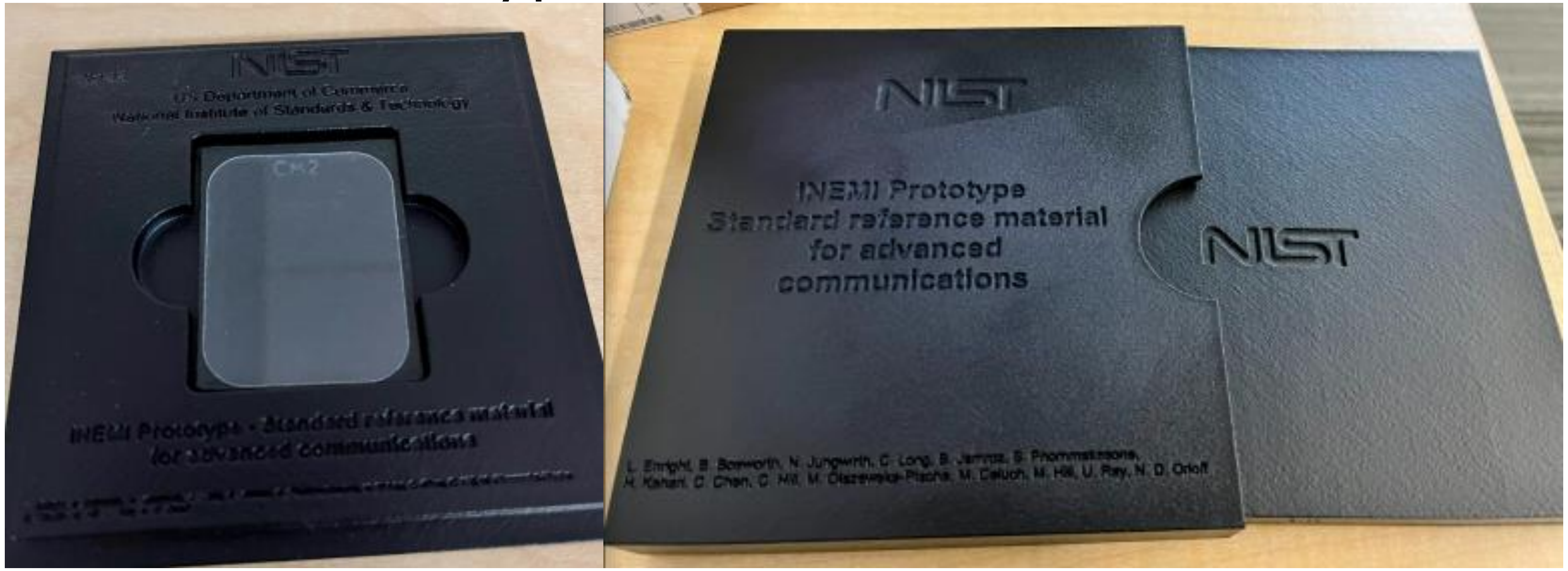
International Electronics Manufacturing Initiative

Panasonic
SHOWA DENKO
intel
KEYSIGHT TECHNOLOGIES
3M
ITRI Industrial Technology Research Institute
NOKIA



The results revealed a serious measurement problem

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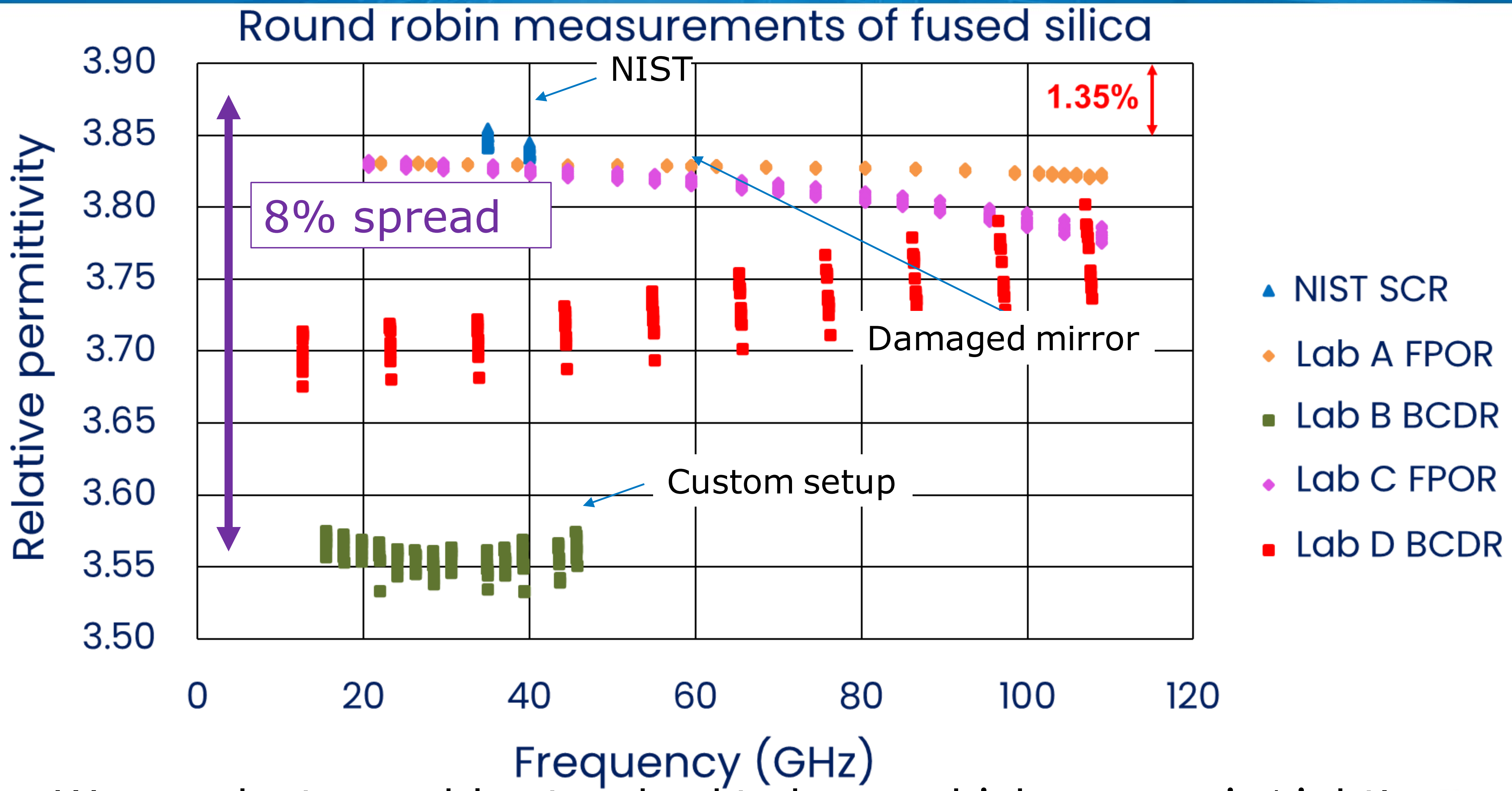
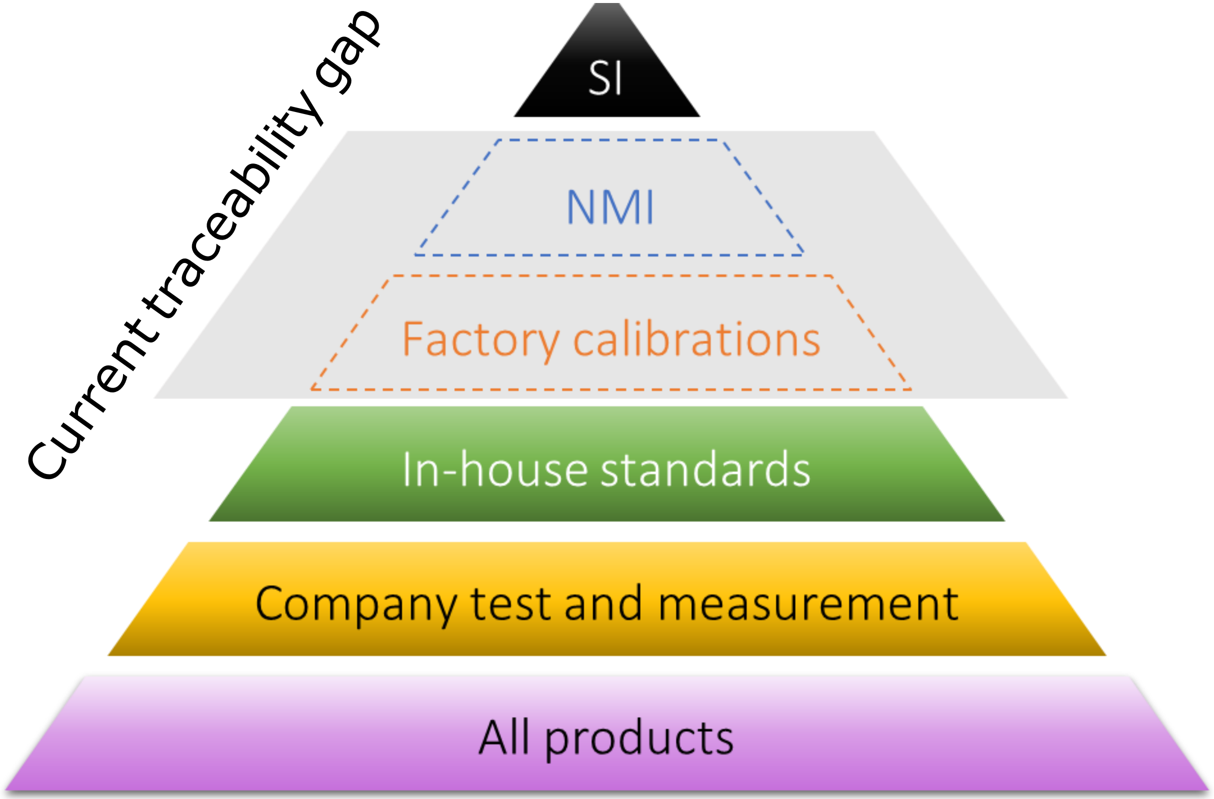
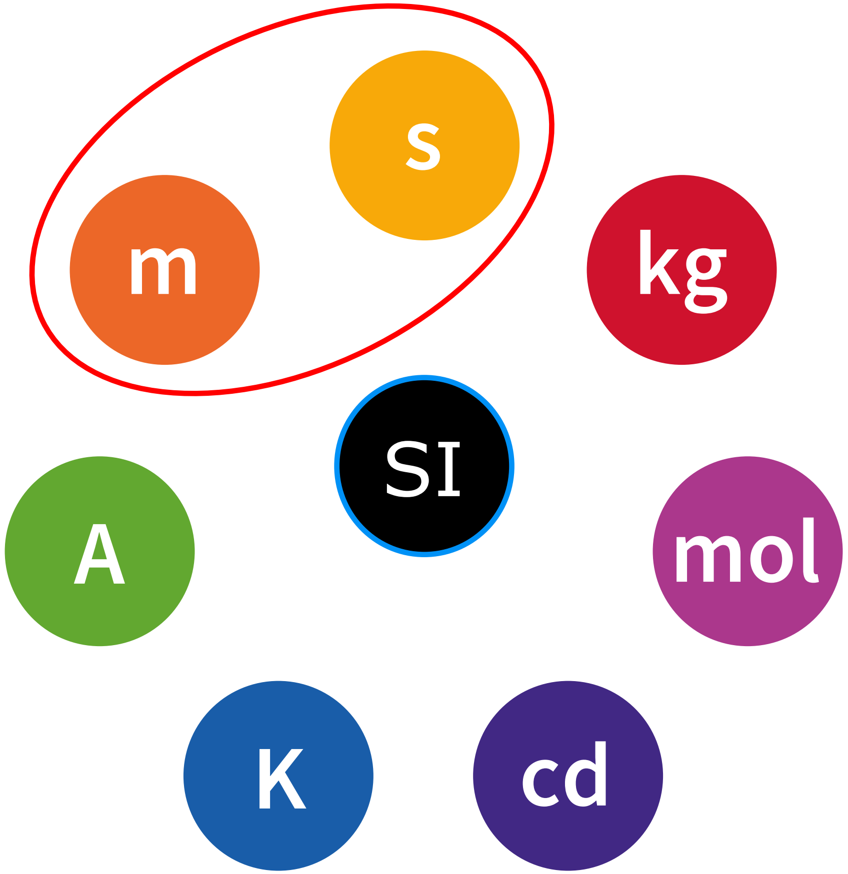
The semiconductor industry needs dielectric standards



We need a traceable standard to know which answer is 'right'

Currently, there is no traceable standard



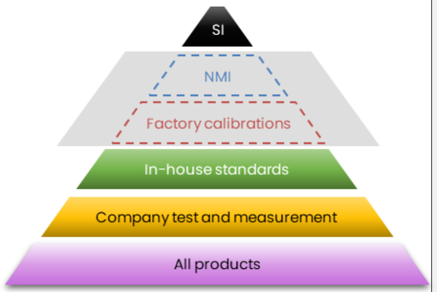


"Traceability" is an unbroken chain of measurements that end at the SI

We need to fill the traceability gap

YOU ARE HERE

Today



Already done

1 Choose material

2 Choose method

3 Use theory to map to permittivity

In progress

4 Measure Scattering parameters

5 Measure dimensions

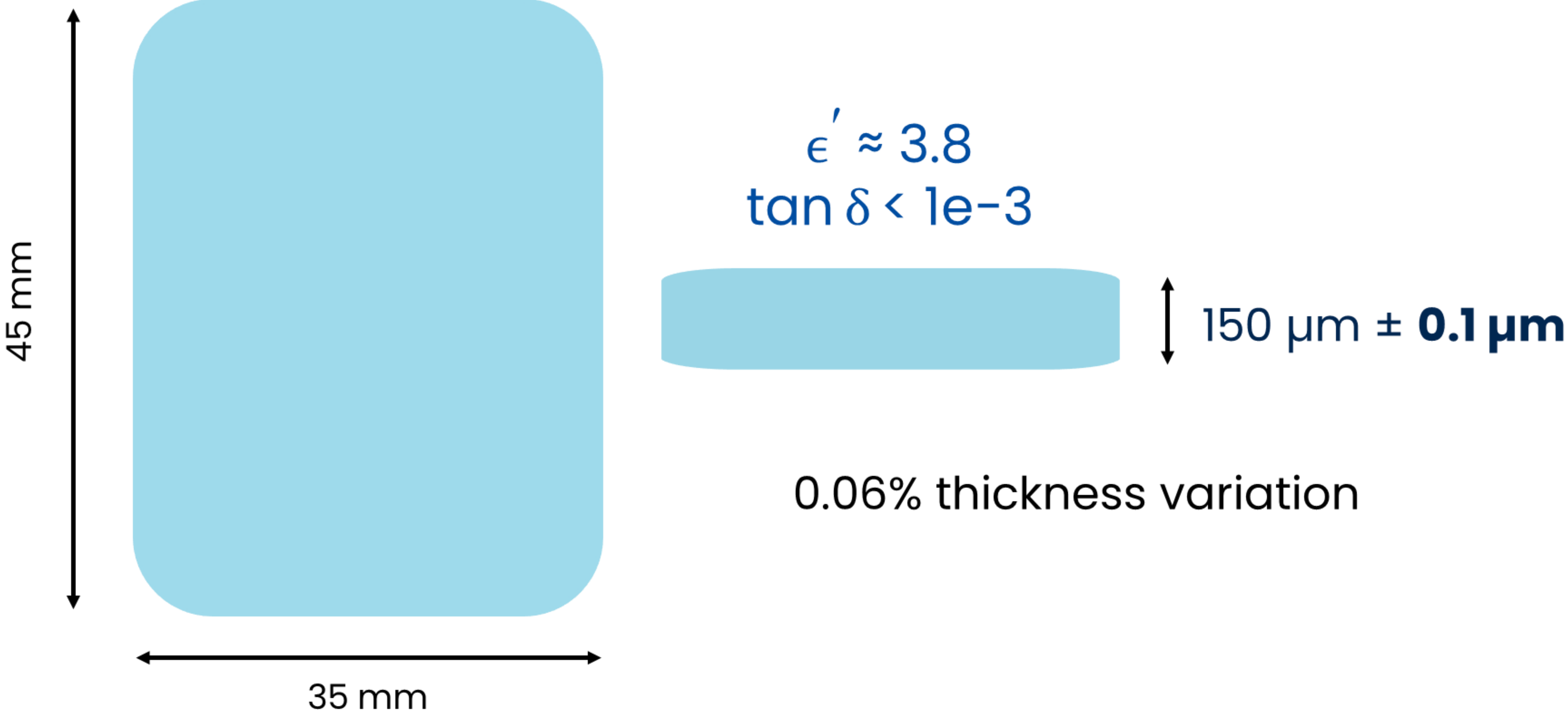
2024

Don’t worry we are going to break down all these steps

We built a fused silica prototype to meet industry needs

1

Choose material

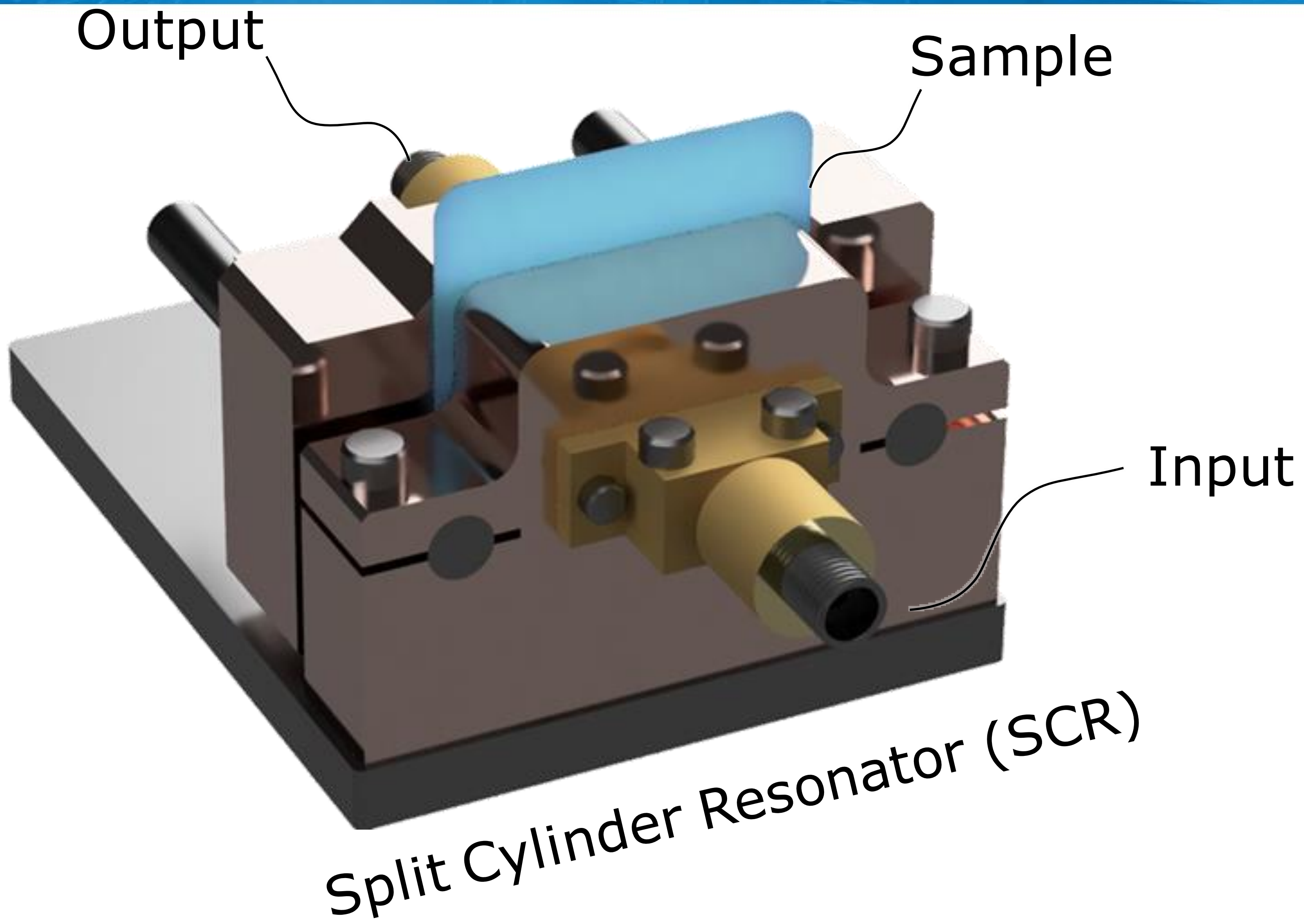


Thin + low ϵ' = compatible with commercially available resonators

We are using SCRs for this traceability path

2

Choose method

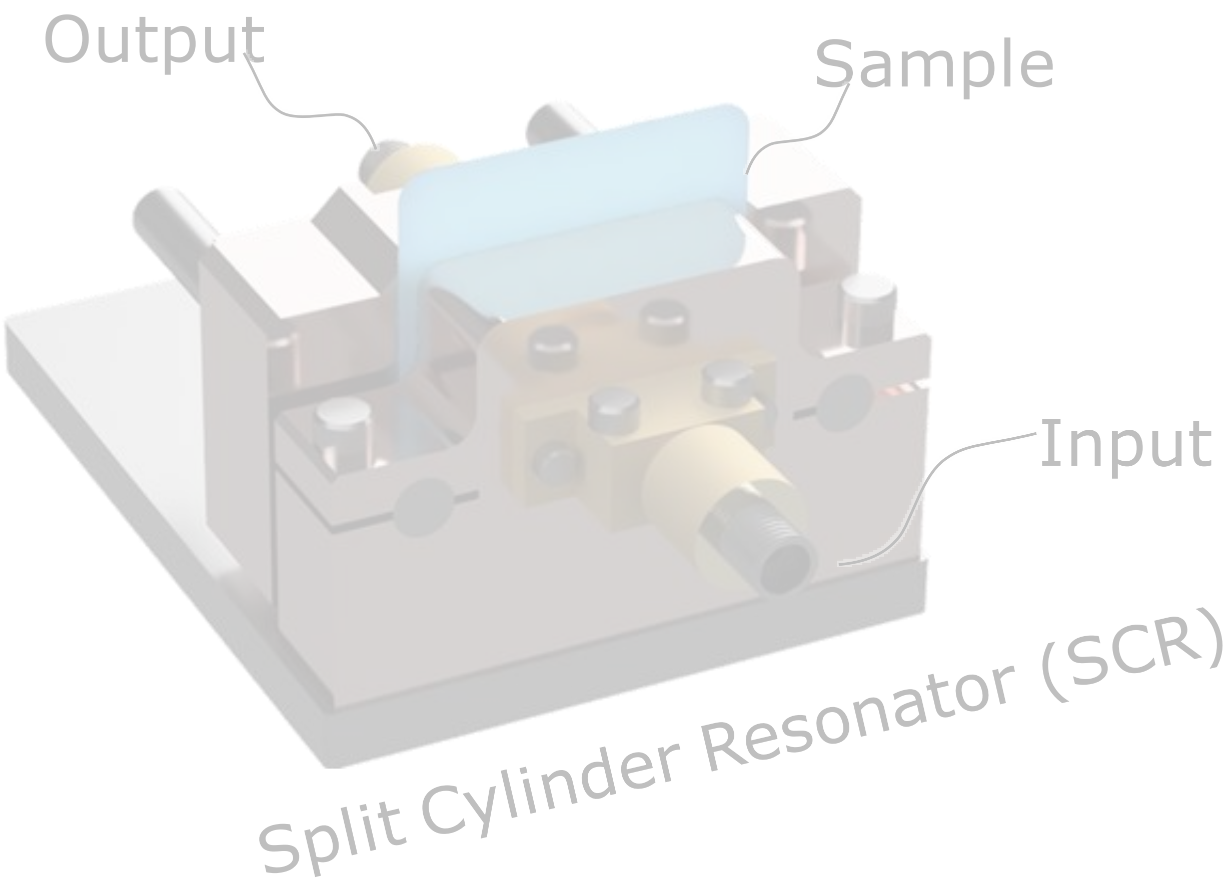


The dimensions of the cavity and sample are the critical features

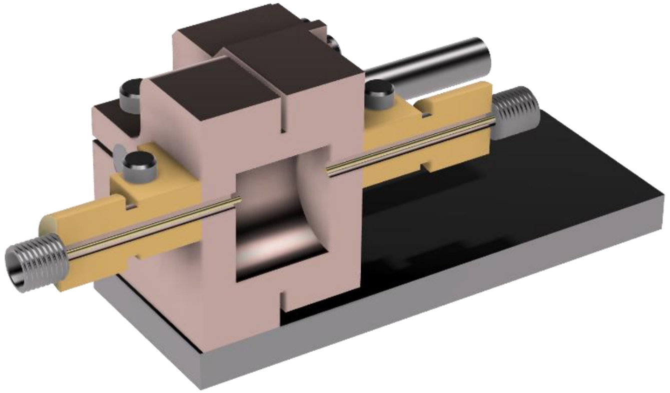
We are using SCRs for this traceability path

2

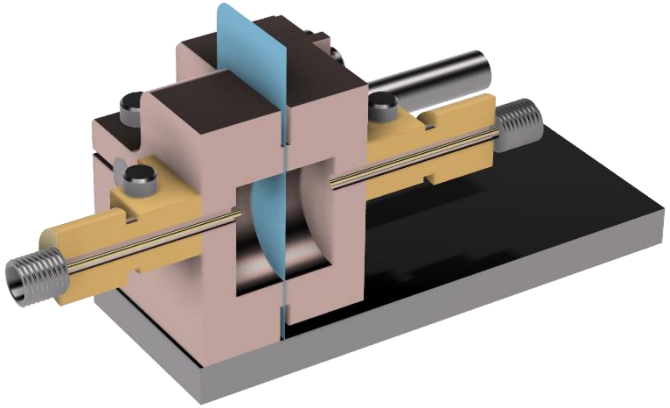
Choose method



no sample



sample

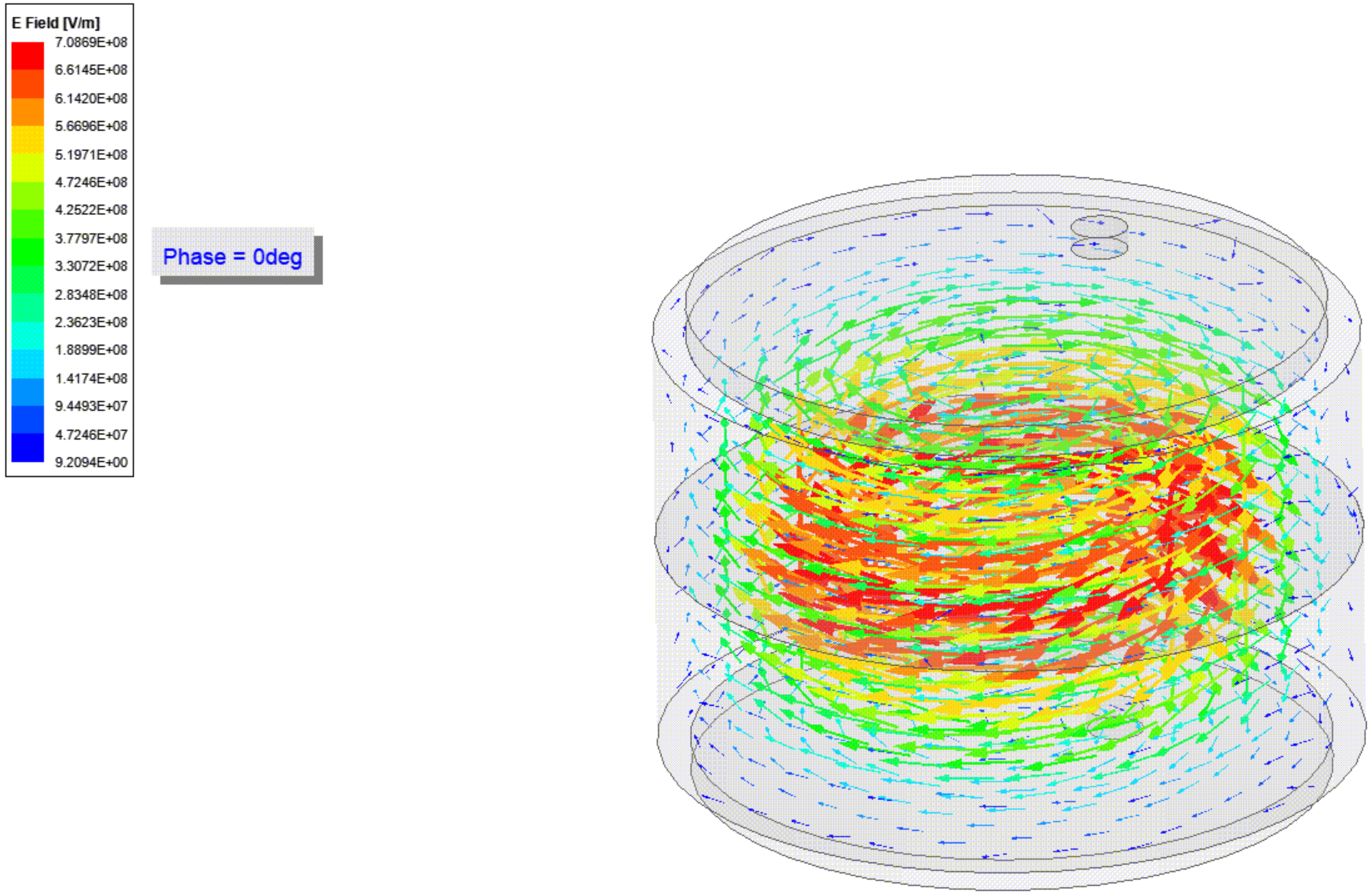


The dimensions of the cavity and sample are the critical features

We know what the TE_{011} mode looks like

2

Choose method

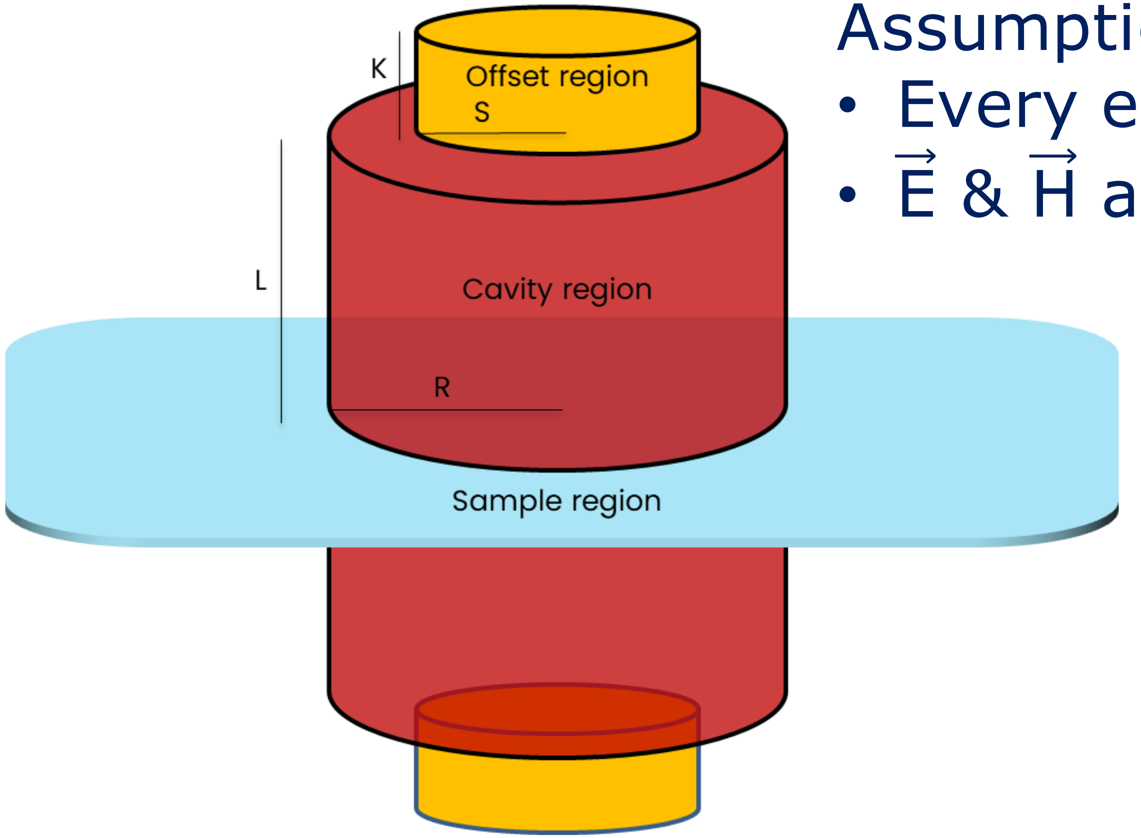


We use this mode's (perturbed) resonance frequency to extract sample permittivity

We use mode-matching to extract permittivity

3

Use theory to map to permittivity



Assumptions:

- Every edge is a perfect conductor
- $\vec{E}$ & $\vec{H}$ are continuous at each interface

Traceable dimensions + resonance frequency → (Analytical theory) → Traceable permittivity

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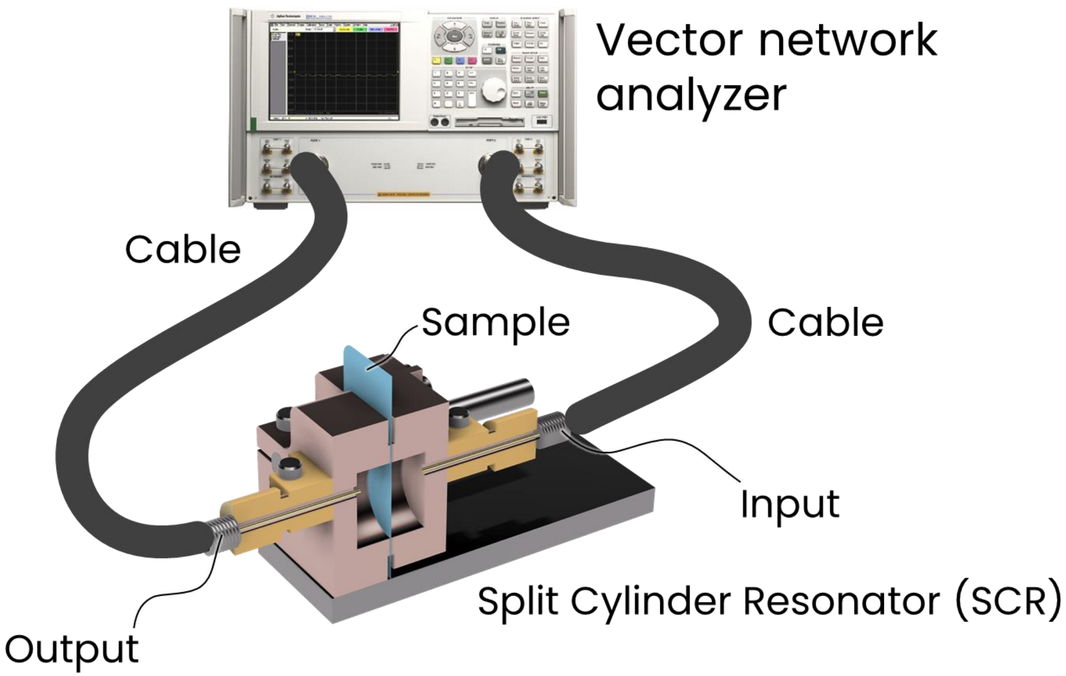
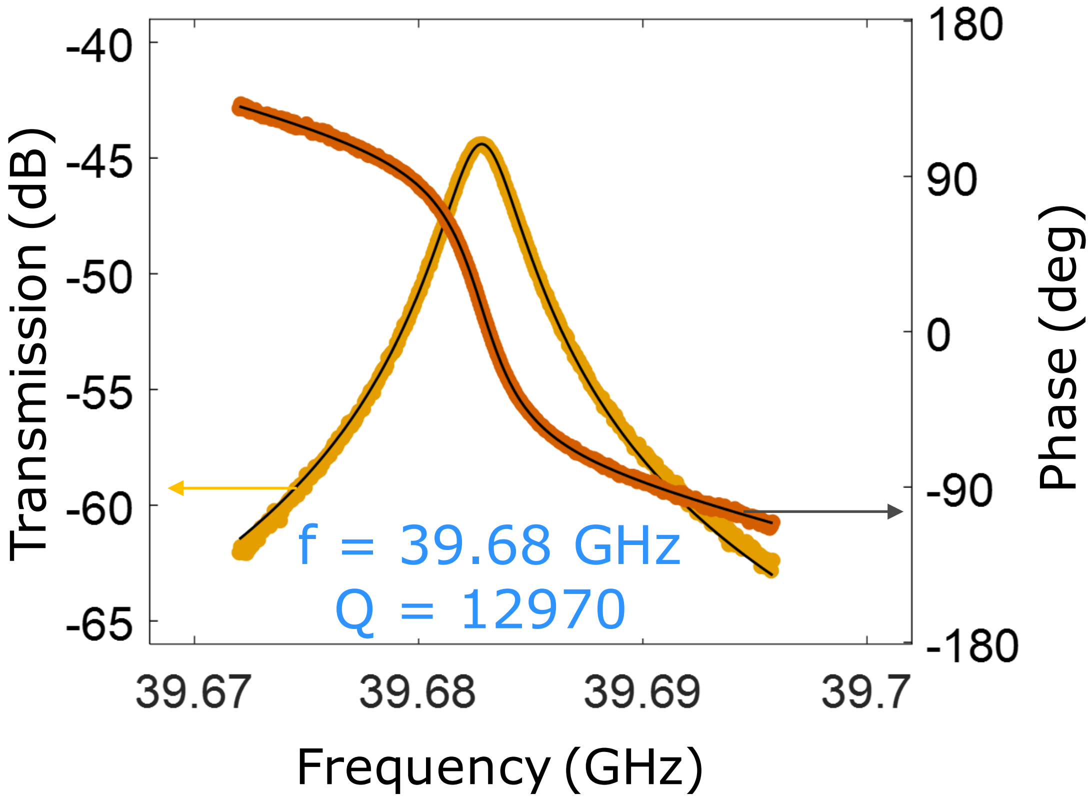
We use a vector network analyzer (VNA) to measure f_{res} & Q

4

Measure Scattering parameters

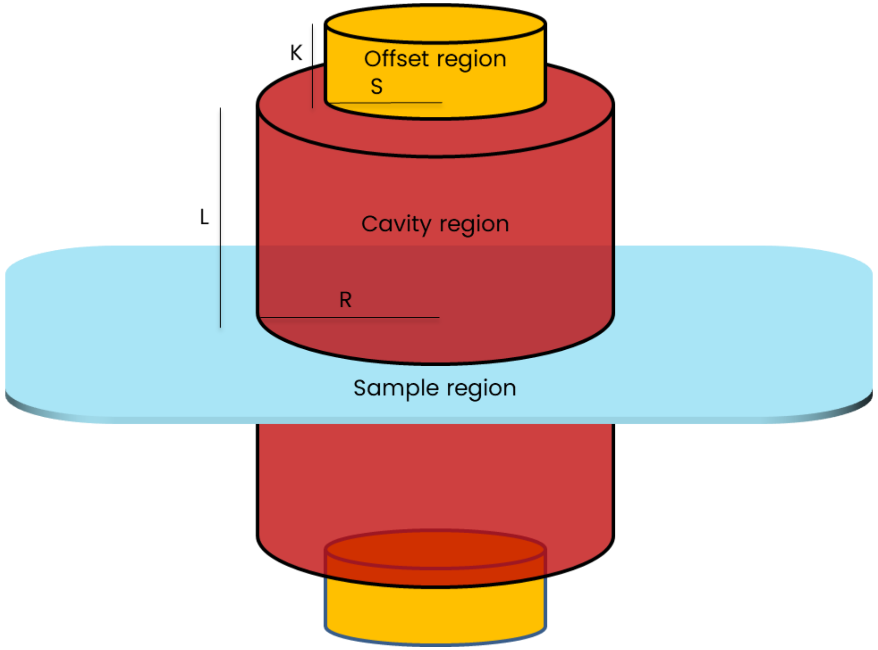




NIST collaborators are dimensioning the cavities

5

Measure dimensions



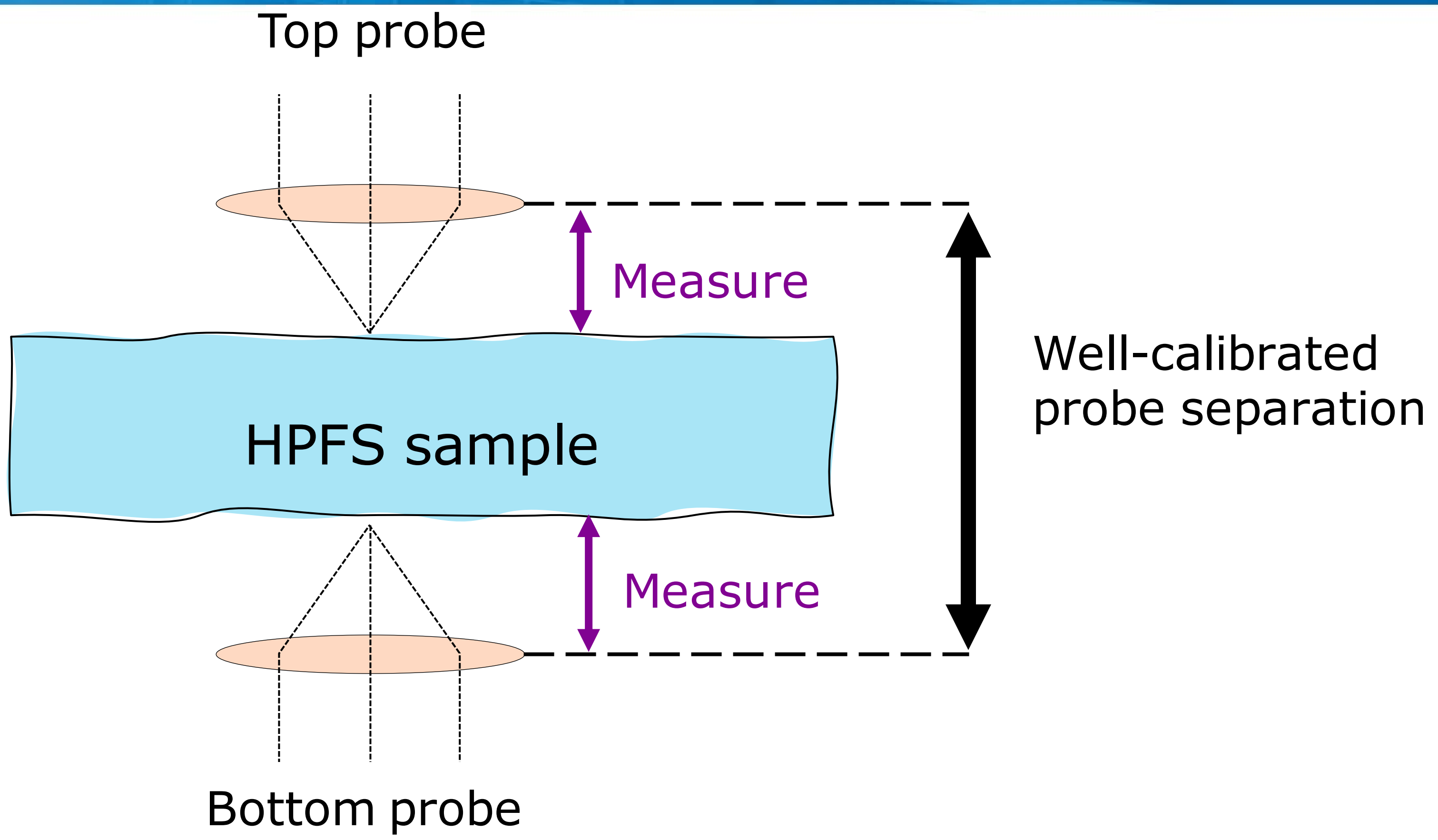
K	0.71100 ± 0.001 mm
S	6.89650 ± 0.001 mm
L	4.69874 ± 0.001 mm
R	7.60784 ± 0.0002 mm

Measurement uncertainties (≤ 1 micron) << our mean values

The sample dimensions are more difficult

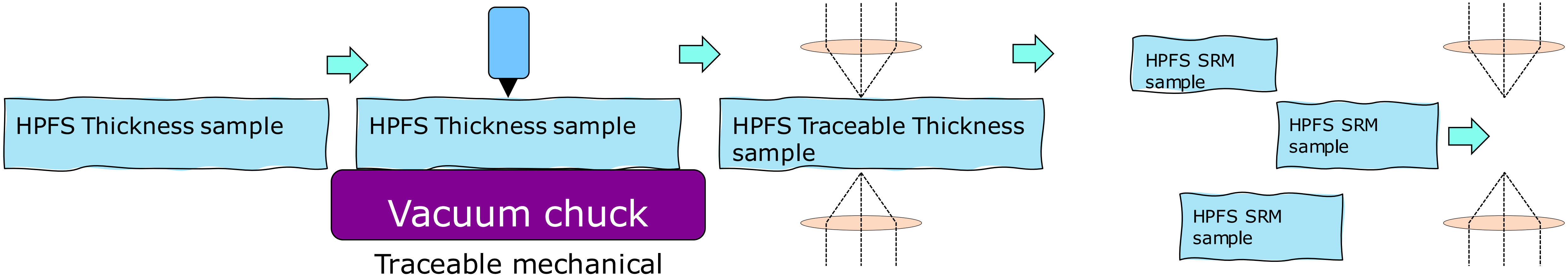
5

Measure dimensions



Confocal white light sensors let us find both sample surfaces without assuming refractive index

We use the mechanical measurements to validate



Traceable mechanical measurements @ NIST (Difficult, time consuming)

Confocal tool verification and transfer of traceability to the tool

Confocal tool makes traceable measurements on all future SRM samples

Our final uncertainties are on the order of 100 nm (0.067%)

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The project overall and the progress we have made

Objective: Develop a standard for relative permittivity and loss tangent

State-of-art: Resonant cavities for low-loss dielectric measurement

Key idea: High purity fused silica with ultra low TTV
Mode-matching theory including complete cavity geometry

Impact: Establishing a known 'right' answer for permittivity
Material acceptance testing and evaluating metrology

This standard is just the beginning

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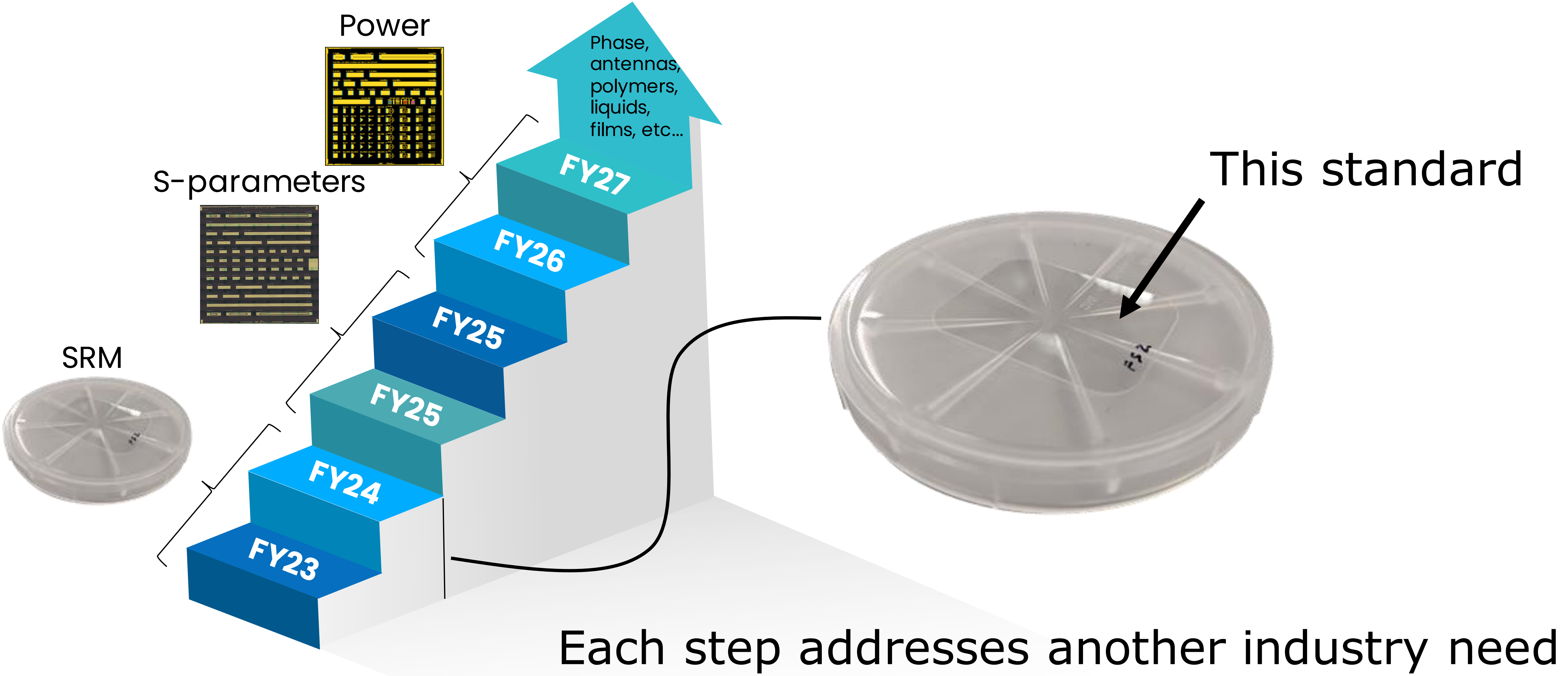
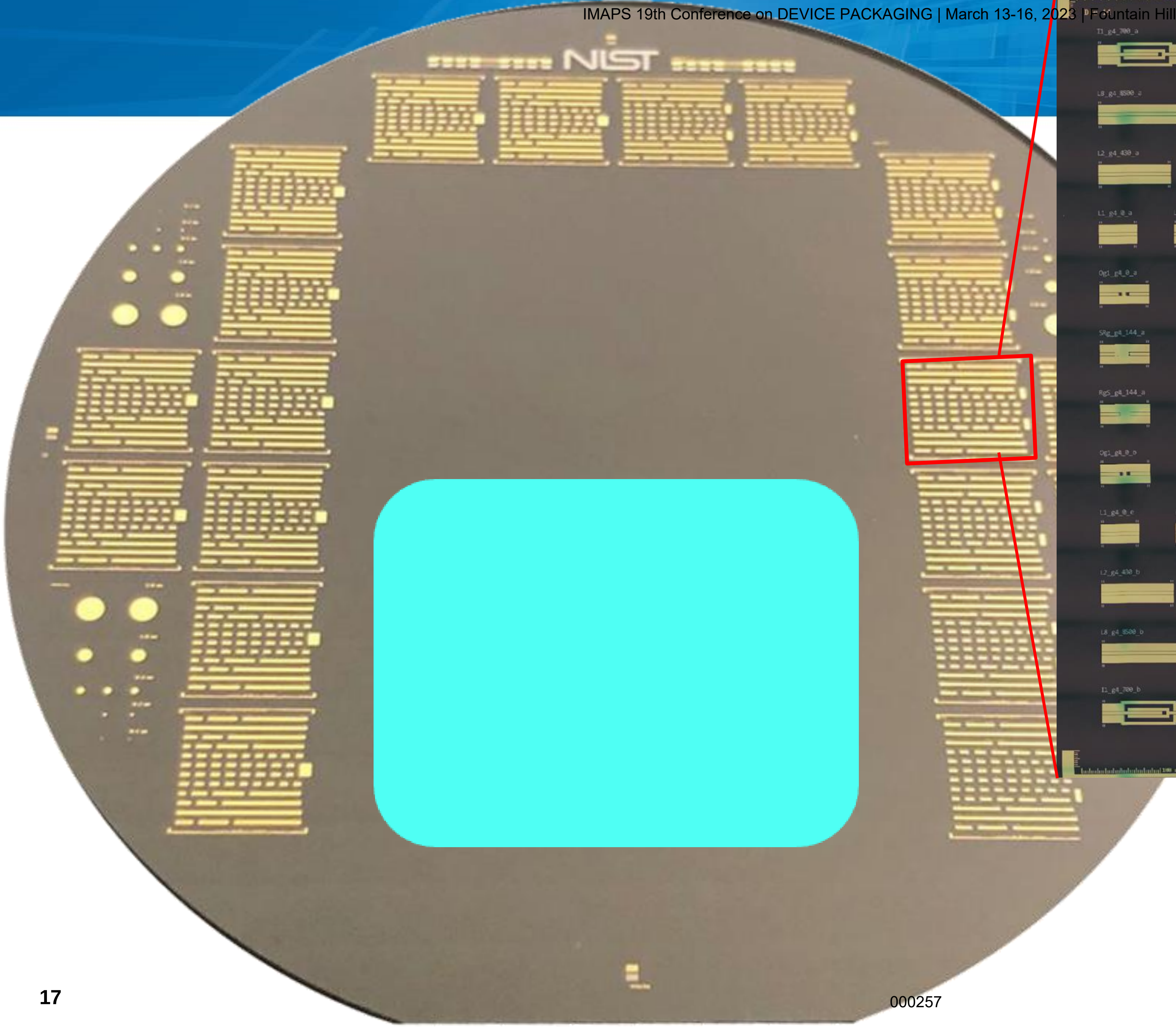
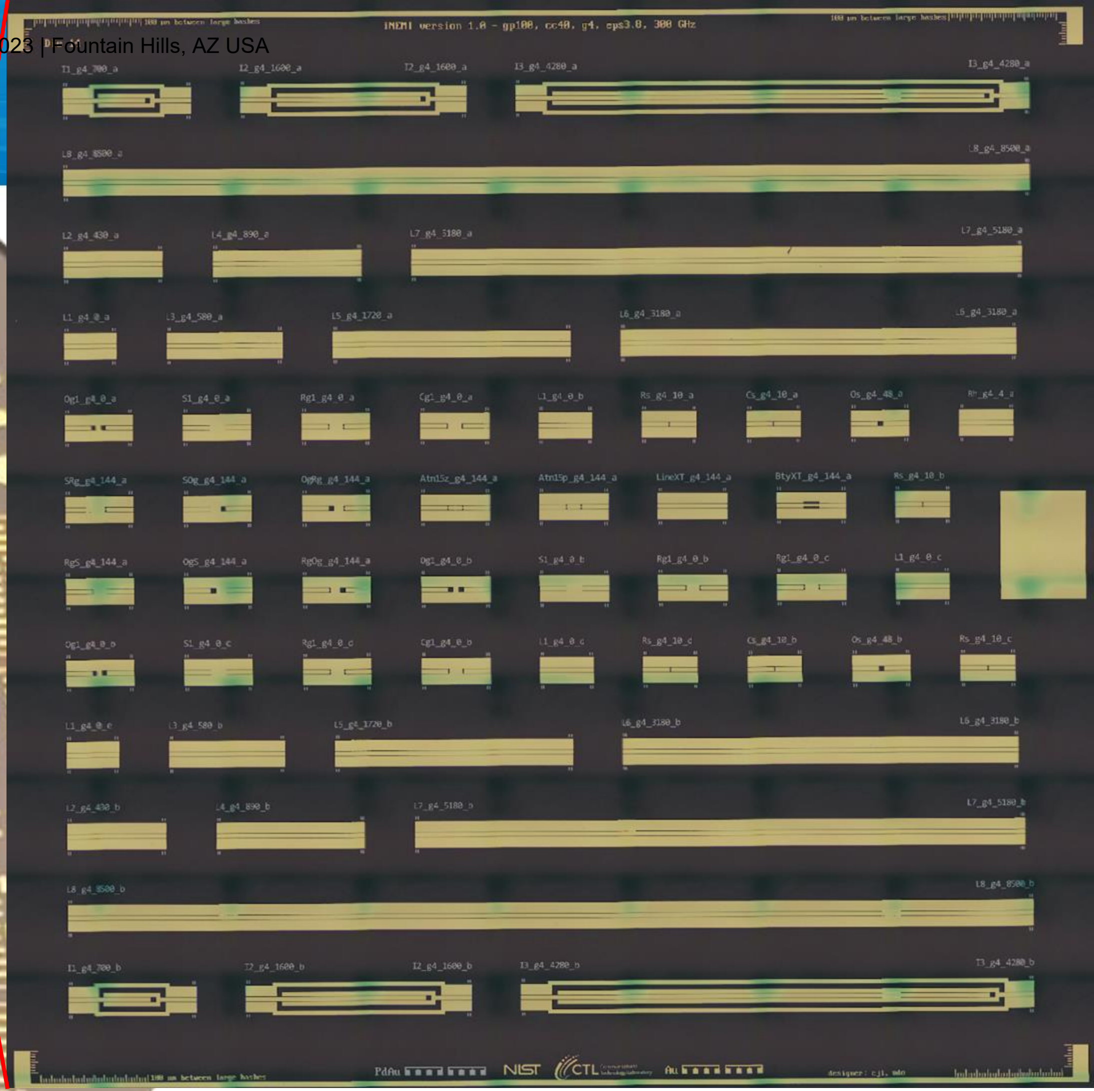
A staircase of future standards




NIST


iNEMI version 1.0 - gp100, cc40, g4, eps3.0, 300 GHz
NIST
CTL

Thank you!

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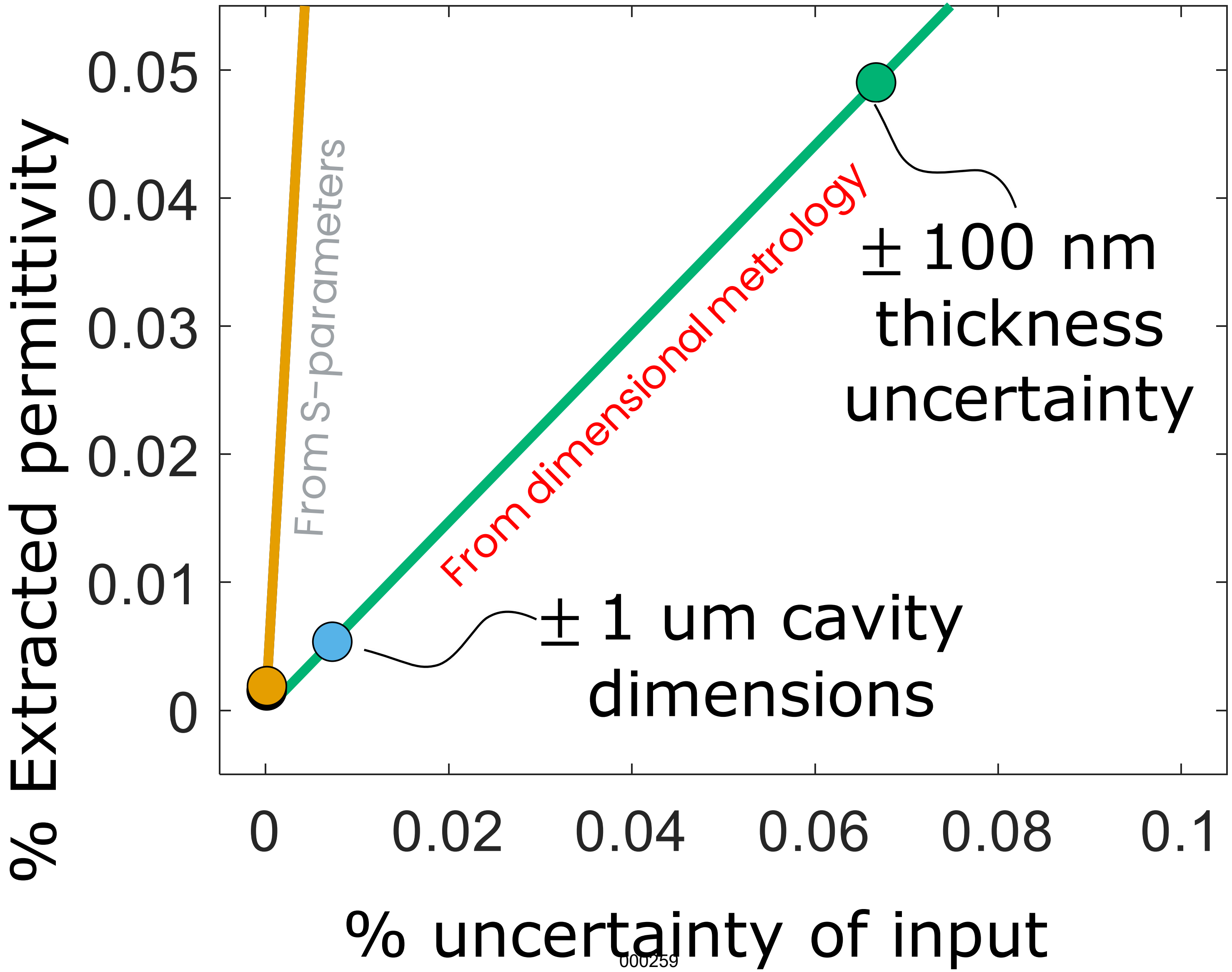
Advancing manufacturing technology

Our uncertainty is dominated by sample thickness



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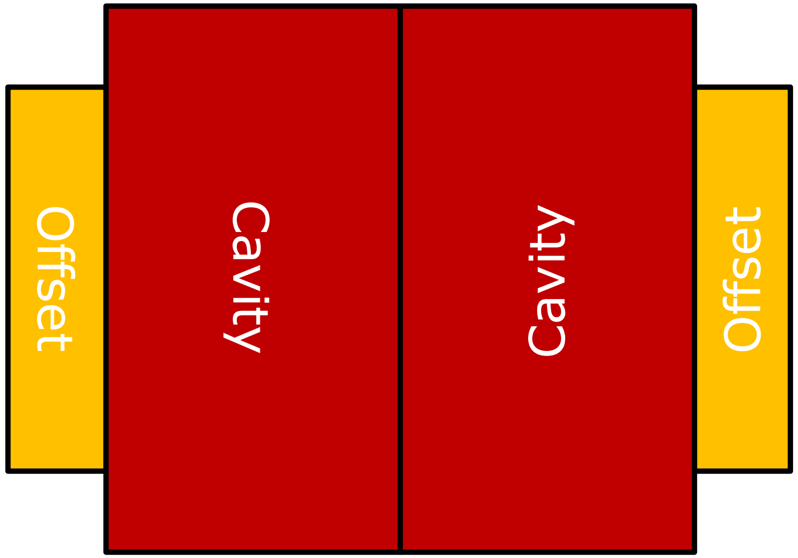
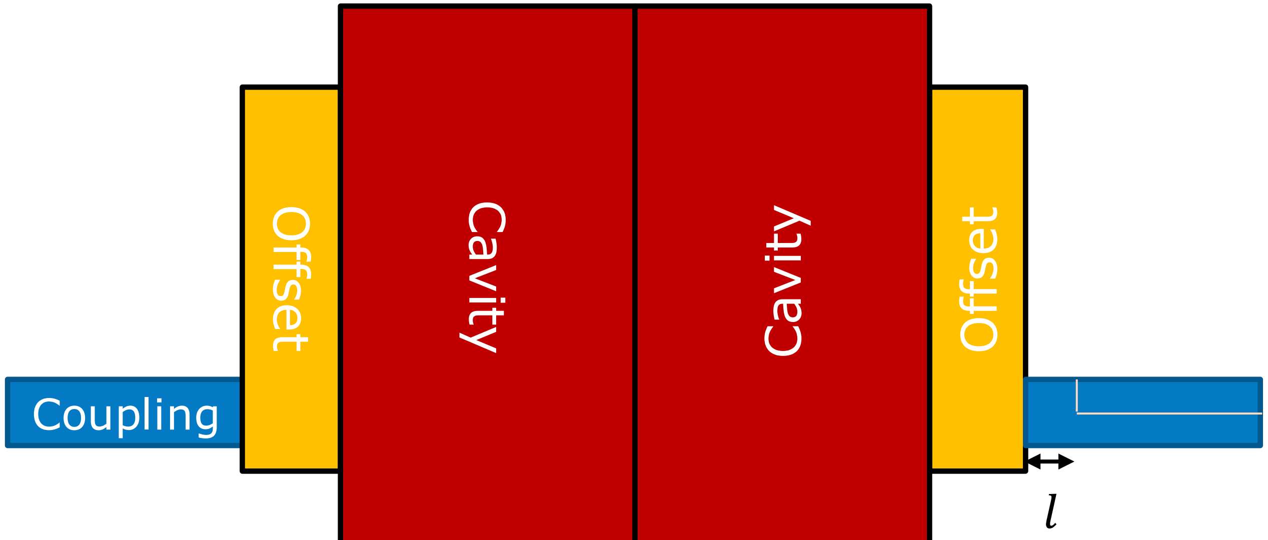
Mode-matching model:



Reality (i.e., with coupling):

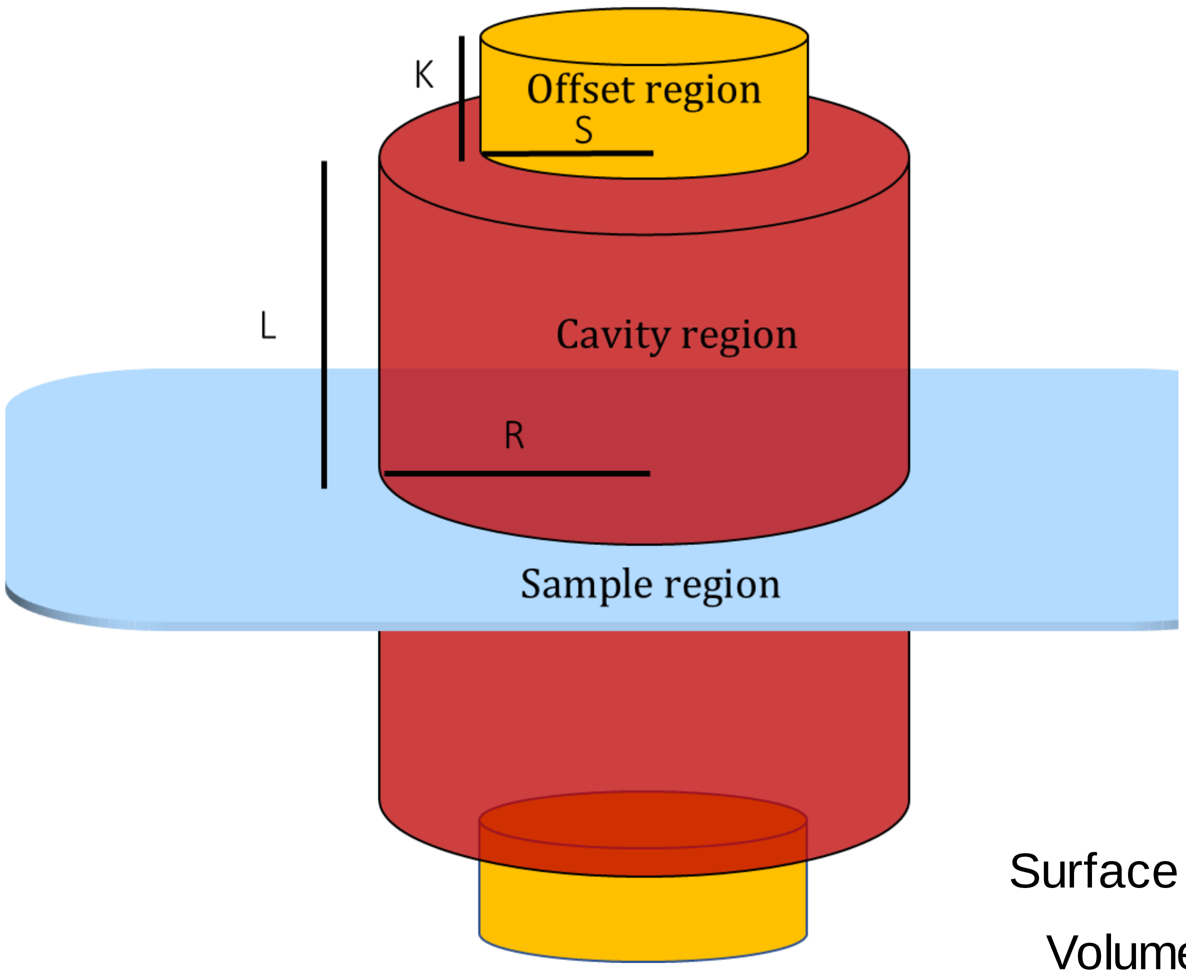


Going to use HFSS to vary l

Anticipating two competing effects:

1. Increasing l will increase coupling (freq ↑)
   Solution: fit to a network model with added inductors for coupling
2. Increasing l will increase the volume of the whole system (freq ↓)
   Solution: More complicated theory (Mode-matching assumes symmetry about axis ☹)

Some of the gory details



Fields in upper offset:

$$E_{\phi UO} = \Sigma A_n U_n J_1(h_{n_{UO}}\rho) \sin\left[p_{n_{UO}}\left(z - K_U - L_U - \frac{d}{2}\right)\right]$$

$$H_{zUO} = -\frac{1}{j\omega\mu_0} * \Sigma h_{n_{UO}} A_n U_n \sin\left[p_{n_{UO}}\left(z - K_U - L_U - \frac{d}{2}\right)\right] * J_0(h_{n_{UO}}\rho)$$

$$H_{\rho UO} = \frac{1}{j\omega\mu_0} * \left\{\Sigma p_{n_{UO}} A_n U_n J_1(h_{n_{UO}}\rho)\, cos \left[p_{n_{UO}}\left(z - K_U - L_U - \frac{d}{2}\right)\right]\right\}$$

Fields in upper cavity:

$$E_{\phi U} = \Sigma B_n V_n J_1(h_{n_U}\rho) \sin\left[p_{n_U}\left(z - \frac{L_U}{2} - \frac{d}{2}\right)\right] + C_n W_n J_1(h_{n_U}\rho) \cos\left[p_{n_u}\left(z - \frac{L_U}{2} - \frac{d}{2}\right)\right]$$

$$H_{zU} = -\frac{1}{j\omega\mu_0} * \Sigma h_{n_U} J_0(h_{n_U}\rho) * \left\{B_n V_n \sin\left[p_{n_U}\left(z - \frac{L_U}{2} - \frac{d}{2}\right)\right] + C_n W_n \cos\left[p_{n_u}\left(z - \frac{L_U}{2} - \frac{d}{2}\right)\right]\right\}$$

$$H_{\rho U} = \frac{1}{j\omega\mu_0} \Sigma p_{n_u} J_1(h_{n_U}\rho) \left\{B_n V_n \cos\left[p_{n_U}\left(z - \frac{L_U}{2} - \frac{d}{2}\right)\right] - C_n W_n \sin\left[p_{n_u}\left(z - \frac{L_U}{2} - \frac{d}{2}\right)\right]\right\}$$

Fields in sample:

$$E_{\phi S} = \Sigma D_n X_n J_1(h_{n_S}\rho) \sin[p_{n_S}(z)] + F_n Y_n J_1(h_{n_S}\rho) \cos[p_{n_S}(z)]$$

$$H_{zS} = -\frac{1}{j\omega\mu_0} * \Sigma h_{n_S} J_0(h_{n_S}\rho) * \{D_n X_n \sin[p_{n_s}(z)] + F_n Y_n \cos[p_{n_s}(z)]\}$$

$$H_{\rho S} = \frac{1}{j\omega\mu_0} \Sigma p_{n_S} J_1(h_{n_S}\rho)\{D_n X_n \cos[p_{n_S}(z)] - F_n Y_n * \sin[p_{n_S}(z)]\}$$

Surface currents → Power dissipated through each surface ($P_{surface}$)

Volume integrals → Average energy stored in each region (W_{region})