Welcome to

DESIGNCON® 2026

WHERE THE CHIP MEETS THE BOARD

Conference

February 24–26, 2026

Santa Clara Convention Center

Expo

February 25–26, 2026

An improved broadband material characterization method

Feng-Nan (Leon), Wu, (Samtec)
Xingling (Mick), Zhou, (Samtec)

Feng-Nan (Leon), Wu, (Samtec), Xingling (Mick), Zhou, (Samtec)
Tony, Chen, (Samtec)

SPEAKERS

Feng-Nan (Leon), Wu

Signal Integrity (SI) R&D Engineer , Samtec

Leon.wu@samtec.com | www.samtec.com | https://x.com/SamtecInc/

Leon Wu has 21 years of industry experience as an SI engineer having worked at FCI, Flextronics and Samtec. He received his Ph.D. from the National Taipei University of Technology in 2013. Leon works in the SI lab at Samtec Taipei and Dongguan facility which focus on connector measurements. He also performs full wave simulations which support research efforts. He has 6 patents related to connector/footprint design.

Objective

- Background/ Introduction
- Challenges of traditional NRW/NIST techniques
  - Method
  - Practical issues
- Propagation Constant
  - Dependencies
    - *Conductivity and plating*
    - *Geometric*
- Proposed correction method
  - Correct method(Remove dependencies)
- How does it work?
  - Time-Domain Gating
  - in NRW
  - in the Improved Method
- Accurate extraction of dielectric properties (Dk, Df)
  - Asymmetric airline, Time domain gating requirement
  - DOE design on dielectric
- Experimental validation
  - Sanity check in time and frequency domains
  - Correlation with the results from Swissto12 MCK

Background

- 112Gbps, 224Gbps,…, heavily relied on simulation and correlation.
- inaccurate Input may cause design fails. (data sheets, experience, products- correlations.)
- Correlate all parameters (size, manufacturing tolerance, process, material,…, etc.) in one design are mostly impossible.
- Simplify the correlation- method to separate the parameters.

Material Characterization

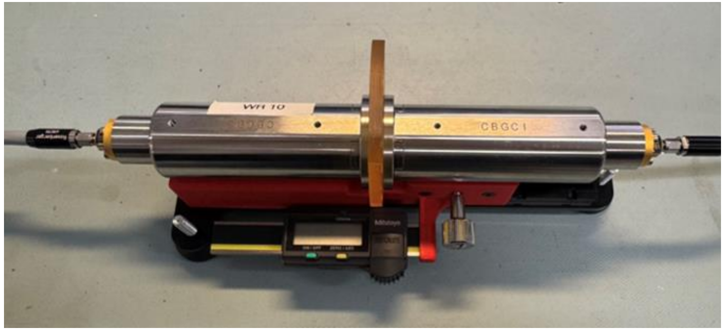
- Measurement techniques:

  T/ R line (coax and waveguide) [NRW/ NIST]

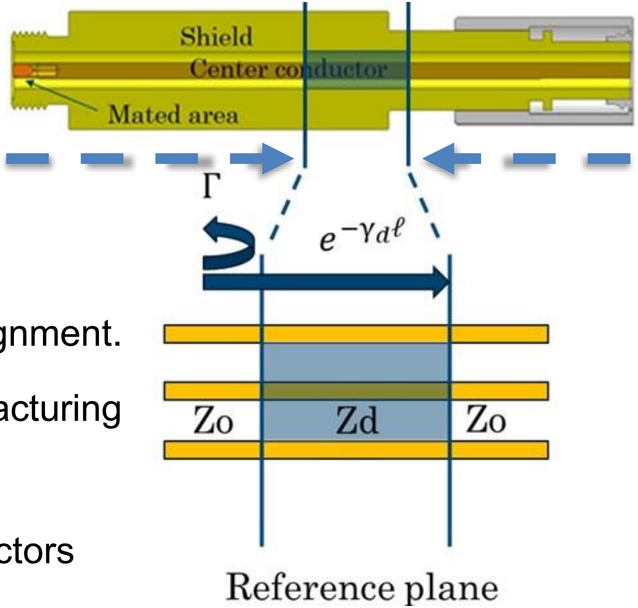
  Open-ended coaxial probe

  Free space

  Resonant Method



Challenges of Nicolson-Ross-Weir (NRW)Solutions



Rotating the ref. plane

Rotating the ref. plane

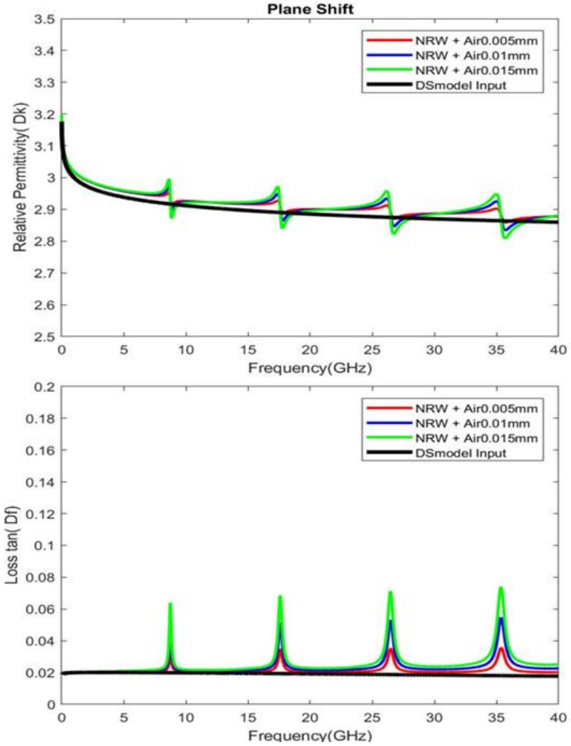
- Require precise reference-plane alignment.
- Sensitive to MUT length and manufacturing tolerances.
- Include metal loss and geometric factors
- Resonance issue at multiple one-half wavelengths(limited MUT length).

$$\mu_R = \frac{1+\Gamma}{(1-\Gamma)\Lambda\sqrt{\frac{1}{\lambda_o^2}-\frac{1}{\lambda_c^2}}}$$

$$\epsilon_R = \frac{\lambda_o^2}{\mu_R}\left[\frac{1}{\lambda_c^2}+\frac{1}{\Lambda^2}\right]$$

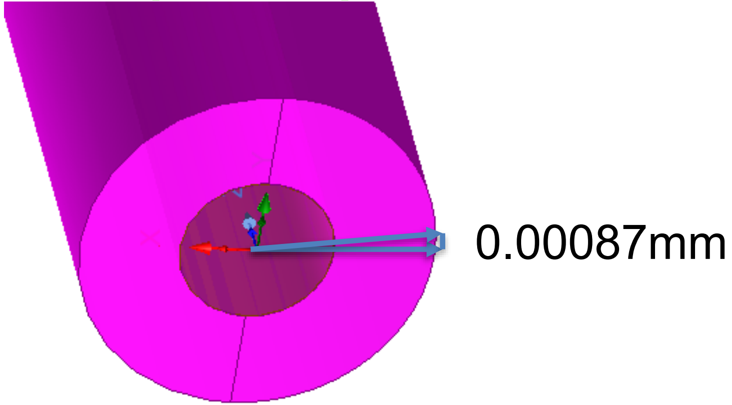
Challenges of Nicolson-Ross-Weir (NRW)Solutions

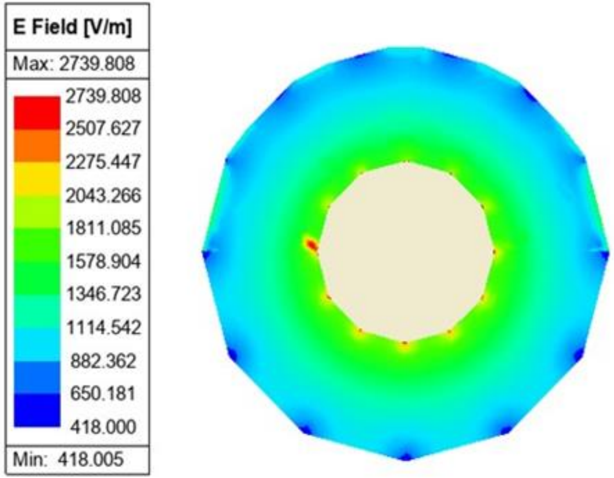
- Resonance issue at multiple one-half wavelength.
- Adding an air-section before the MUT. By: 0.005mm-0.015mm.
- The extracted Dk and Df are divergent from the input(good conductor assumption).
- Dependences are contained in transmission coefficient.
- The extracted Dk and Df dependent on the physical length.(Dk ∝ 1/L)
- D.S. model- DK=3, DF=0.02 @1GHz

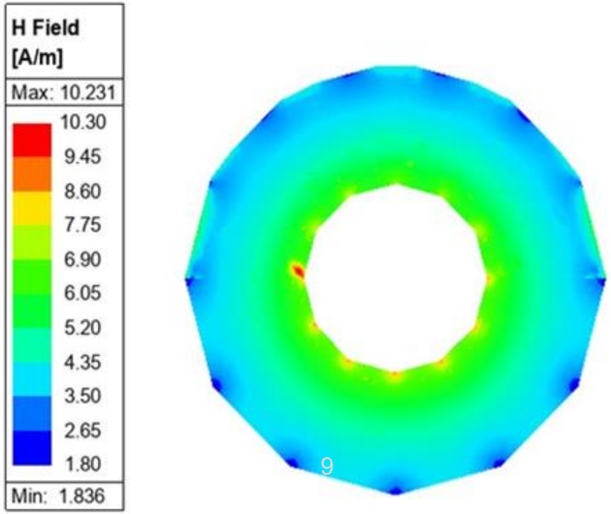


Challenges of Nicolson-Ross-Weir (NRW)Solutions

- The TEM assumption is no longer valid.
- The fields are distributed non-uniformly
- Rotating the face by 0.034º further increases the maximum length difference to 0.00087 mm.







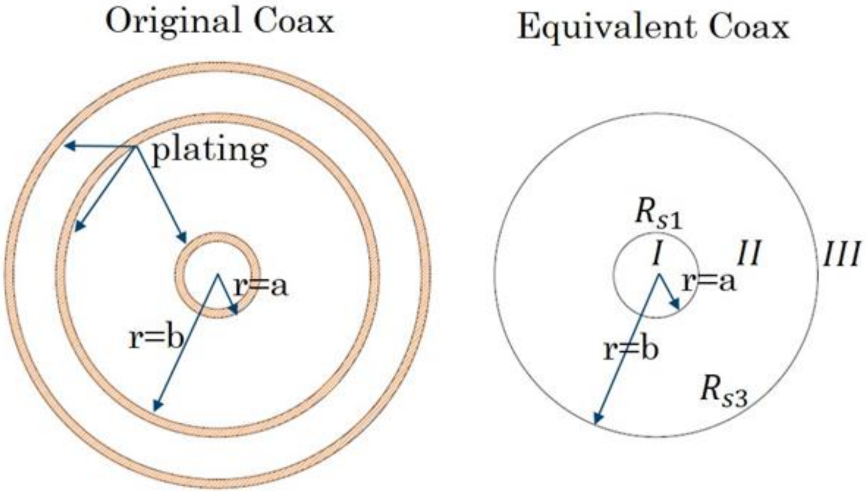
Microwave Approximation

- The propagation constant depends on the conductivity and permeability of the center conductor and shield, as well as the dimensions (a, b), regardless of whether the medium is air or dielectric.

$$\hat{\gamma}_X = \text{fx}(\mu_1, \sigma_1, \mu_{2X}, \epsilon_{2X}, \mu_3, \sigma_3, a, b)$$

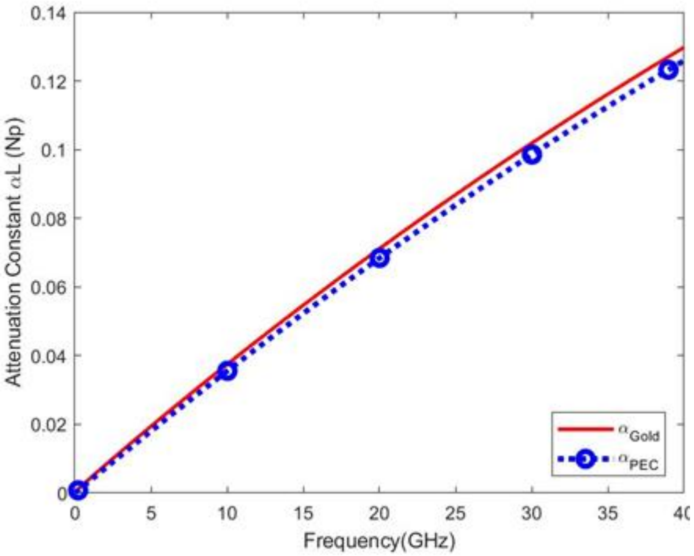
- If PEC is used, the propagation constant is independent of the dimensions, only depends on the medium.

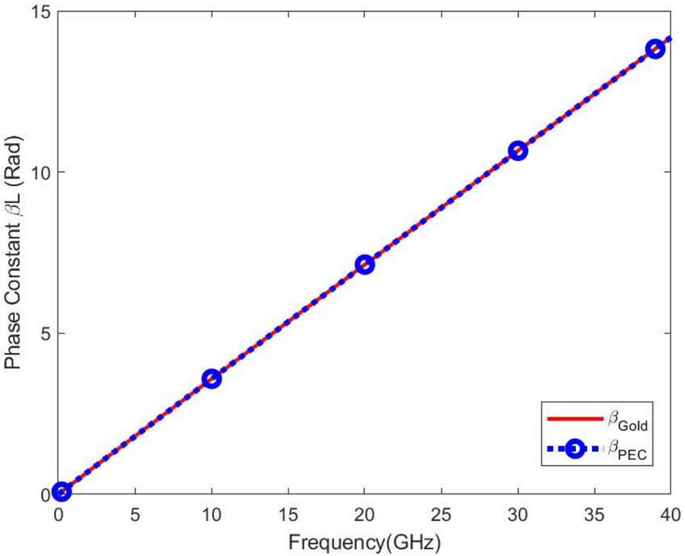
$$\hat{\gamma}_{XPEC} = \text{fx}(\mu_{2X}, \epsilon_{2X})$$



$$\hat{\gamma} = k_2 \frac{\left(\frac{1}{a}\sqrt{\frac{\mu_1}{\sigma_1}} + \frac{1}{b}\sqrt{\frac{\mu_3}{\sigma_3}}\right)}{2\sqrt{2\omega}\mu_2 \ln\left(\frac{b}{a}\right)} + jk_2\left[1 + \frac{\left(\frac{1}{a}\sqrt{\frac{\mu_1}{\sigma_1}} + \frac{1}{b}\sqrt{\frac{\mu_3}{\sigma_3}}\right)}{2\sqrt{2\omega}\mu_2 \ln\left(\frac{b}{a}\right)}\right] = \alpha + j\beta$$

Microwave Approximation

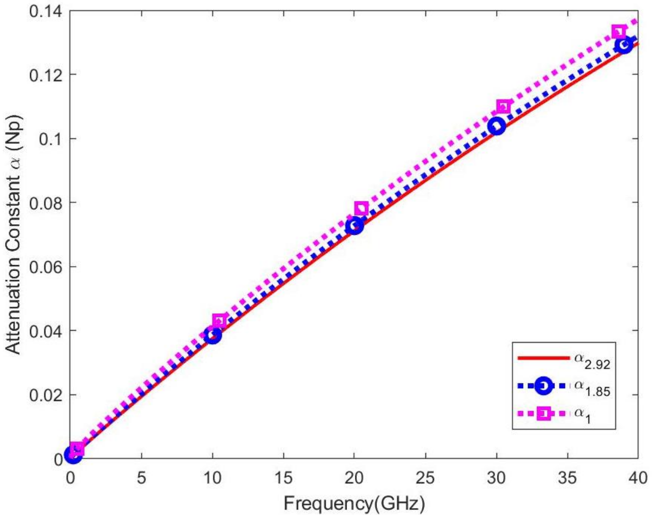


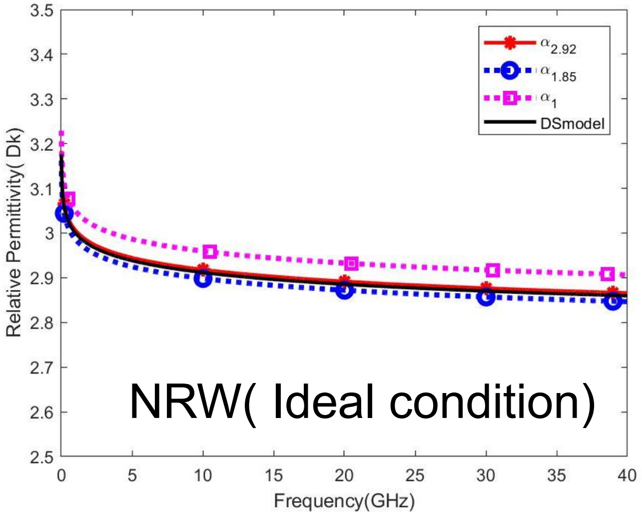


Attenuation constant has more impacts than phase constant(10mm).

$$\hat{\gamma}_d = \text{fx}(\mu_1, \sigma_1, \mu_{2d}, \epsilon_{2d}, \mu_3, \sigma_3, a, b)$$

Microwave Approximation





NRW(Ideal condition)

2b(mm)	a(mm)
2.92	0.635
1.85	0.4
1	0.22

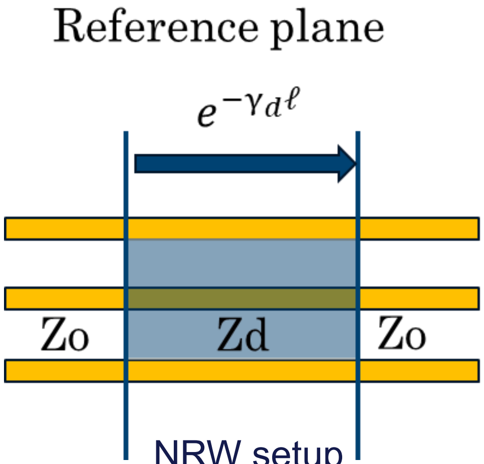
$\hat{\gamma}_d$ =fx$(\mu_1, \sigma_1, \mu_{2d}, \epsilon_{2d}, \mu_3, \sigma_3, a, b)$

Different form factors, $\frac{b}{a} = round(2.92/1.27)$

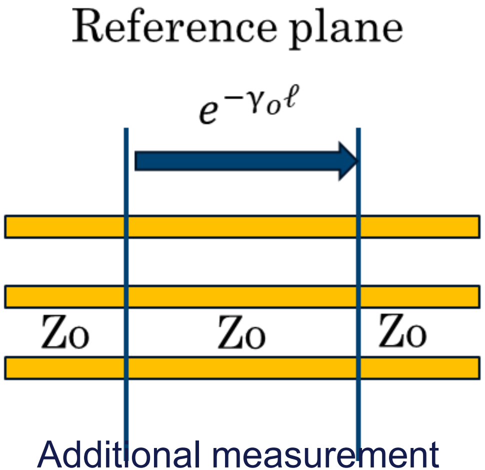
Corrected Propagation Constant

An additional measurement to obtain the dependences of α_o and β_o.

$$\hat{\gamma}_d\,\ell = \sqrt{\varepsilon_r}\left(\alpha_0\ell + \frac{1}{2}\,tan\delta\,\beta_0\ell\right) + \mathrm{j}\sqrt{\varepsilon_r}\left(\beta_0\ell - \frac{1}{2}\,tan\delta\,\alpha_0\ell\right)$$



NRW setup



Additional measurement

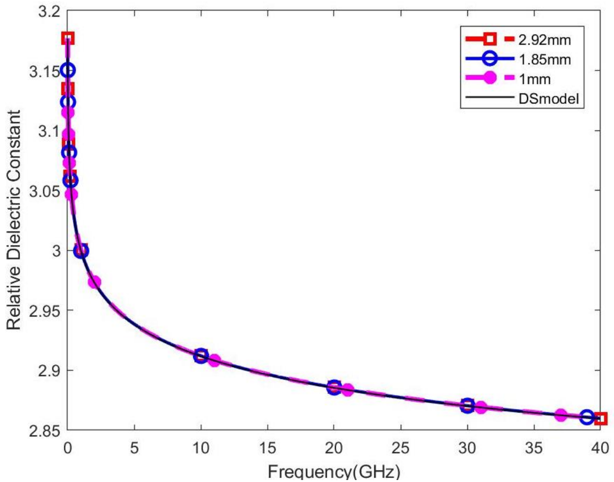
$$\mathcal{R} = \frac{\beta_d\ell}{\alpha_d\ell} = \frac{\beta_0\ell - \frac{1}{2}\alpha_0\ell(tan\delta)}{\alpha_0\ell + \frac{1}{2}\beta_0\ell(tan\delta)},$$

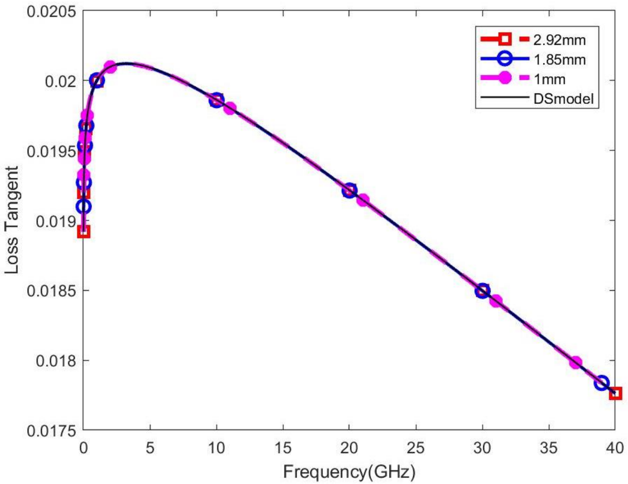
$$tan\delta = \frac{2(\beta_0\ell - \mathcal{R}\alpha_0\ell)}{\alpha_0\ell + \mathcal{R}\beta_0\ell}$$

$$\sqrt{\varepsilon_r} = \frac{\alpha_d\ell}{\alpha_0\ell + \frac{1}{2}\beta_0\ell(tan\delta)}$$

Since the length can be eliminated from each term, Dk and Df are **independent of the length.**

Corrected Propagation Constant





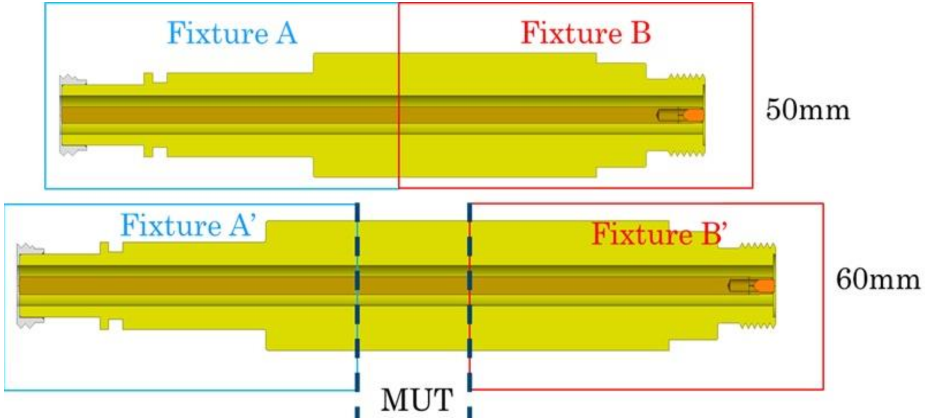
2b(mm)	a(mm)
2.92	0.635
1.85	0.4
1	0.22

From the proposed method, the extracted Dk and Df are **independent of different sizes a, b and the conductor property.**

$$\hat{\gamma}_d = \text{fx}(\mu_1, \sigma_1, \mu_{2d}, \epsilon_{2d}, \mu_3, \sigma_3, a, b)$$

$$Dk/Df = \text{fx}(\hat{\gamma}_d = \text{fx}(\cancel{\mu_1, \sigma_1}, \mu_{2d}, \epsilon_{2d}, \cancel{\mu_3, \sigma_3, a, b}))$$

Time-Domain Gating in NRW



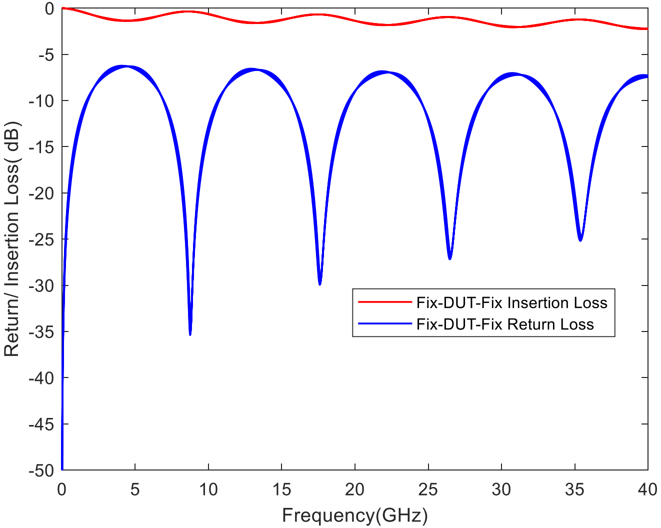
- The Time-Domain Gating method(IEEE P370) is used to de-embed the S-parameters and accurately move the reference plane to the faces of the MUT.
- De-embedding the air sections.
- Two different airline lengths(uses 50mm to de-embed 60mm)
- Ideal positioning case- the MUT in the center.
- a, b have manufacturing tolerances.

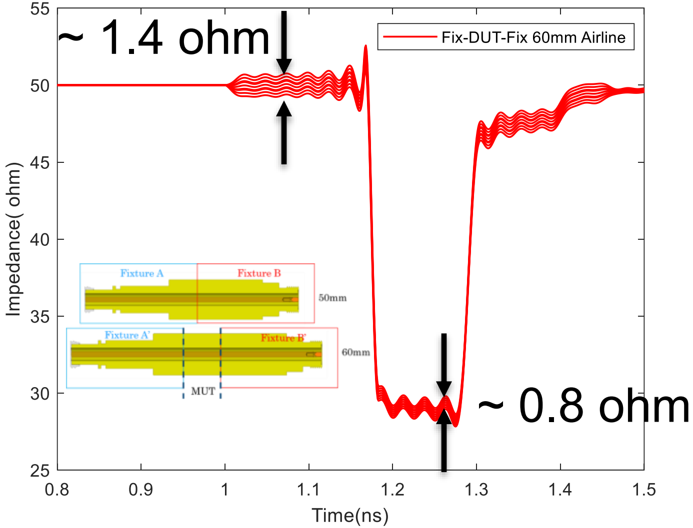
The impacts [Vary (a,b)]

- The 60 mm airline with a ~10 mm dielectric is positioned accurately at the center.

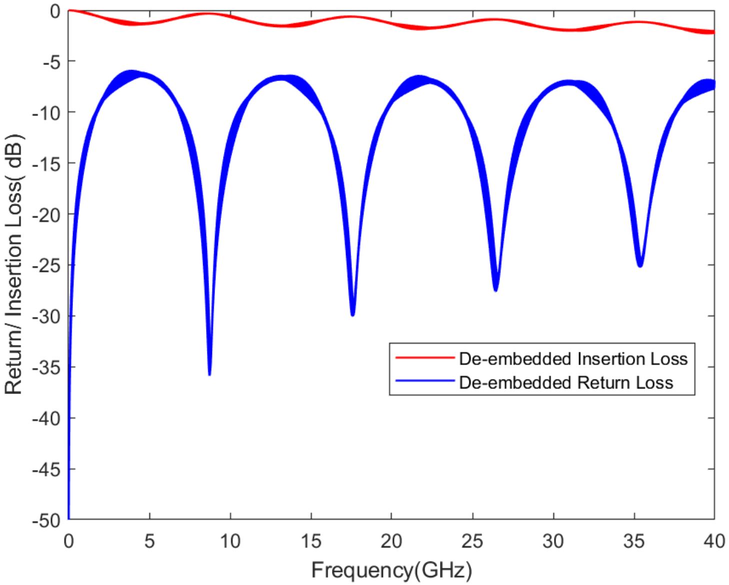
$$2X\ Thru(a \pm \Delta a, b \pm \Delta b)$$
$$\sim MUT(a \pm \Delta a, b \pm \Delta b)$$

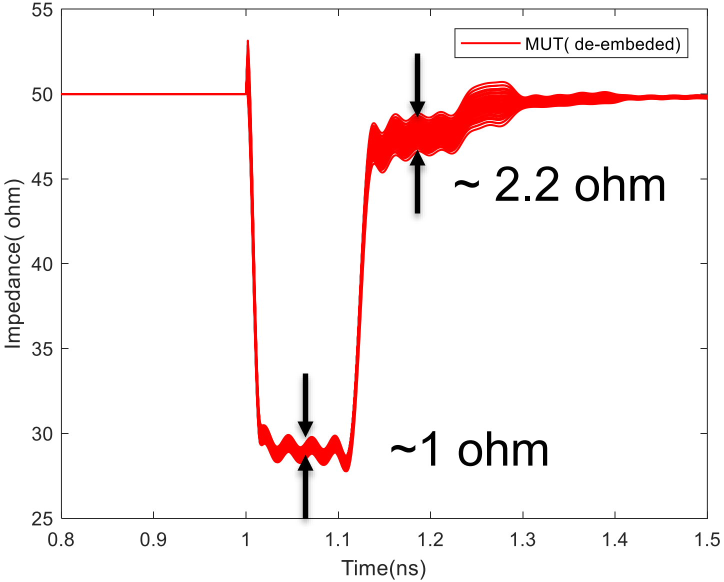
- The impact of manufacturing tolerances on dimensions a and b does not significantly affect the S-parameters of the 60 mm airline.





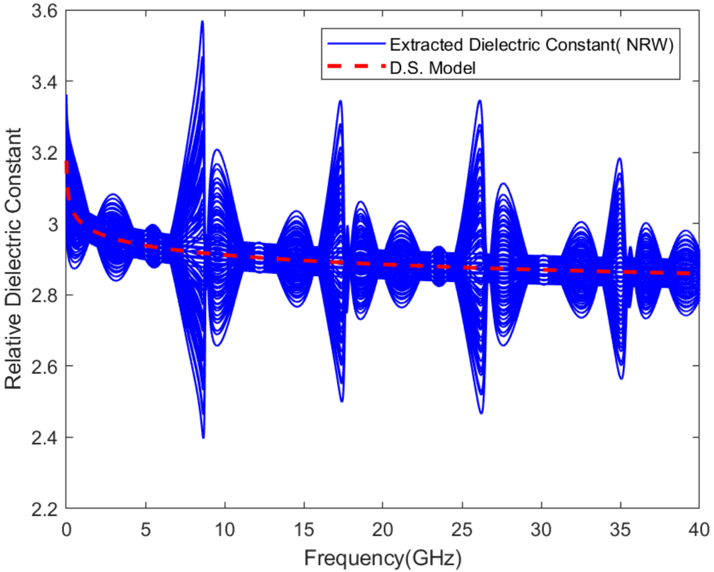
De-embedding(IEEE P370)

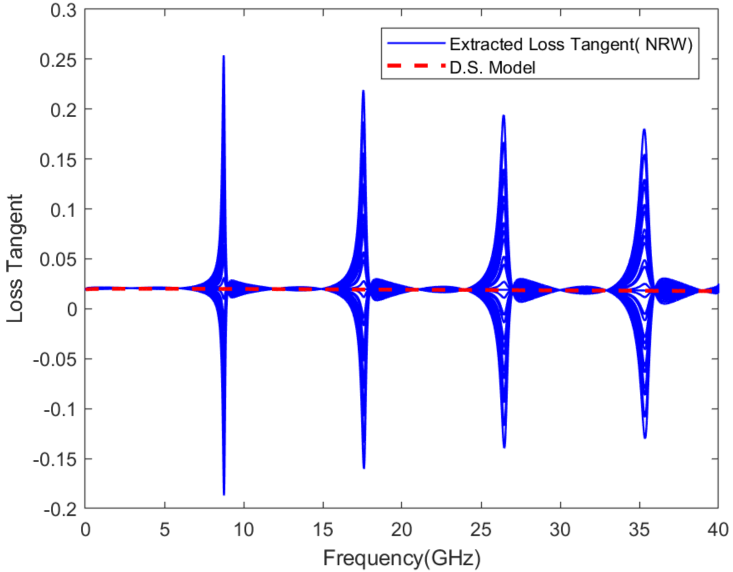




- The deviation after de-embedding is about 1 ohm in the MUT section and 2.2 ohm for the residue while they are 0.8 and 1.4 ohm before de-embedding.

De-embedding(IEEE P370)



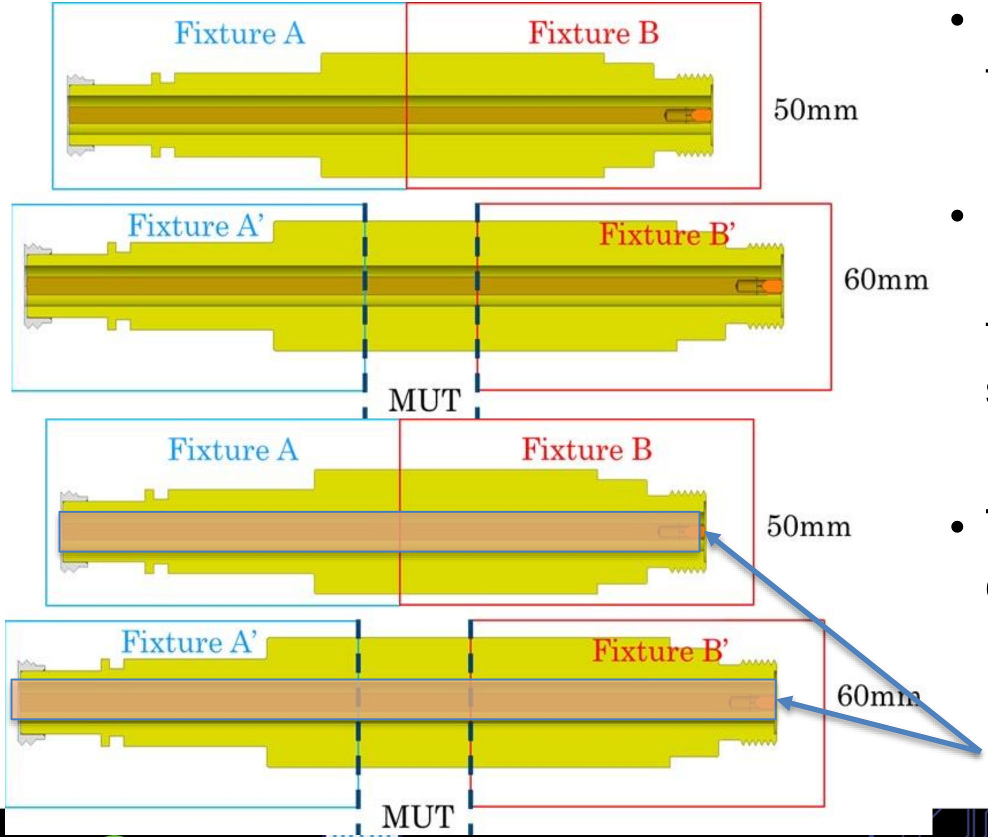


- The Dk and Df have significant errors due to the tolerances.
- Perfect positioning from NRW setting.
- The large deviations are at the multiple one-half wavelength(7.5GHz of 8GHz).

Summary of the NRW method

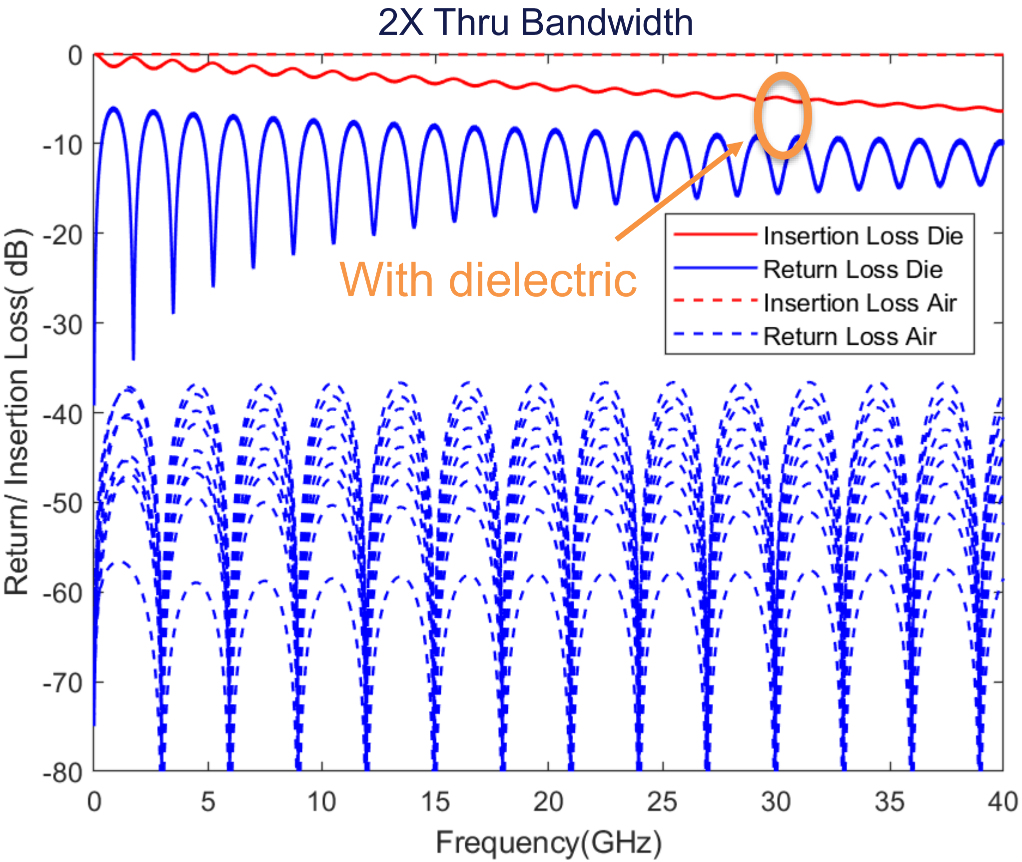
- Traditional NRW/ NIST techniques
  - Need rotating reference plane ideally or resonance(uncertainty occurred in multiple one-half wave length); limited on the MUT length.
  - The Dk and Df strongly dependent on metal, radii a and b of the test fixture.
  - Dependent on the MUT length.
  - Need to position MUT accurately
  - Time domain getting method may not be applicable or need high quality test fixture.
  - Sensitive to the tolerances.

The proposed method



- It is difficult to positioning the MUT at the center of 60mm airline.
- Fill out the airline with dielectric in both 50 and 60mm airline to eliminate the refection between MUT and air section.
- The MUT would be positioning at the center naturally.

Challenges

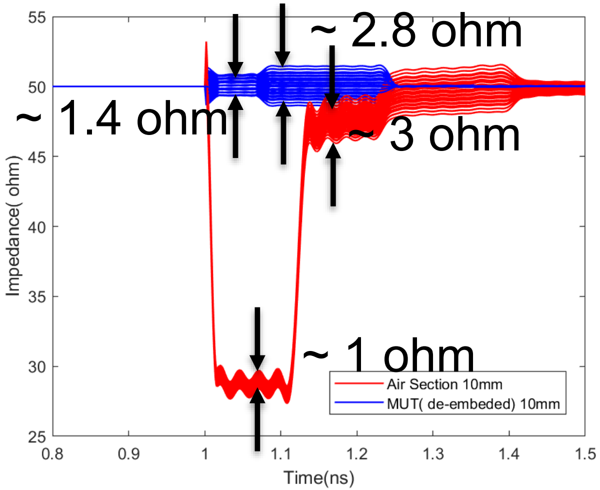


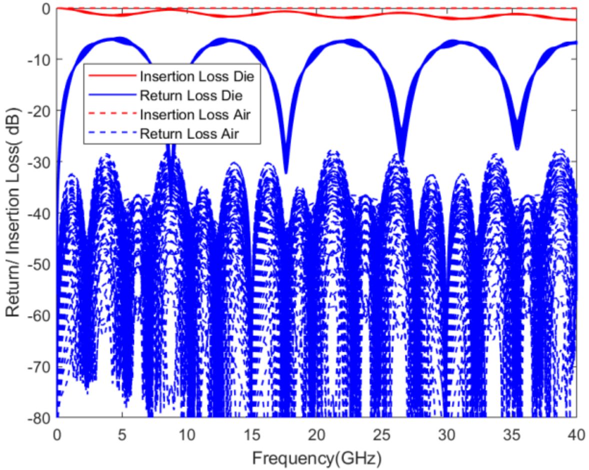
- De-embedding?

- The radius of a, b contained manufacturing tolerance, +/- 0.005. (9 combinations)

- Ideal conditions:
  - No discontinuities
  - There is no air gap between dielectric and metal.

Time-Domain Gating in the improved method

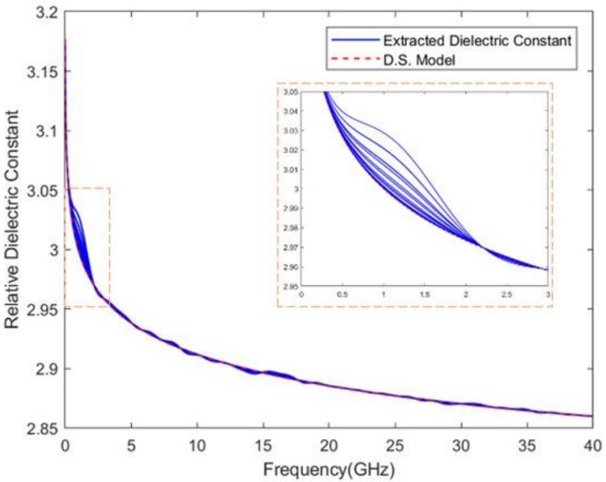


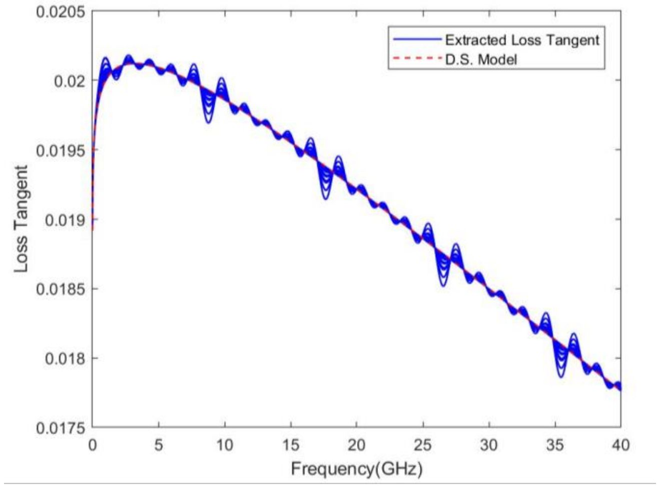


- From the de-embedded S-parameters (with and without dielectric), the error affects the return loss, causing the magnitude to vary rather than remain at the same level.

- Although the residue effects after de-embedding is larger than utilized airline sections. However, the tolerance and residual effects will be accounted for and subtracted using the proposed method.

Time-Domain Gating in the improved method



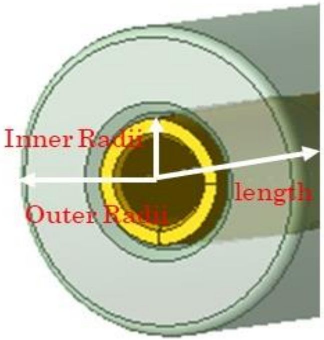


- The proposed method to extract Dk and Df as shown.
- The impacts of the manufacturing tolerance is much lower than NRW method.

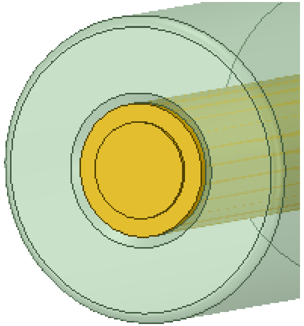
Summary of the improved method

- The improved method
  - The extracted Dk and Df dependencies of the test fixture are removed
  - Independent on the MUT length
  - Naturally positioning MUT at the center of an airline
  - Less sensitive to the fixture tolerance
  - Additional measurements

Practical Issue



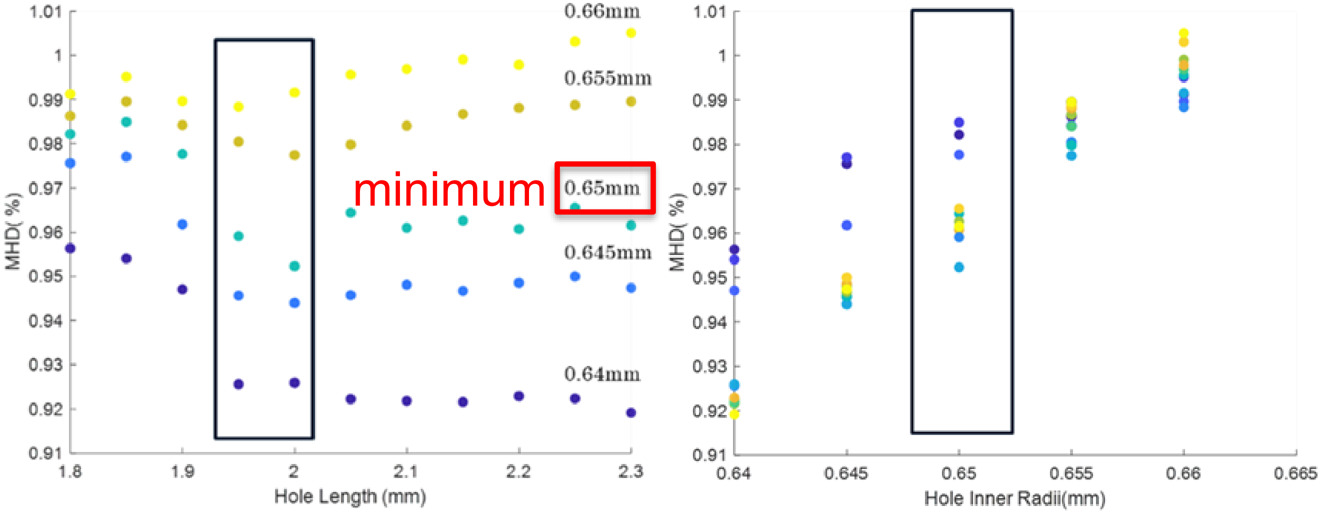
Female



Male

- Time domain gating method requires: S12A=S21B
- An airline with identical connector genders is currently unavailable.
- What if we have a proper design on the shape of dielectric.
- The length 50 and 60 mm of hollow shape with 2.92/ 1.27 mm radii are difficult to manufacture.

Optimization

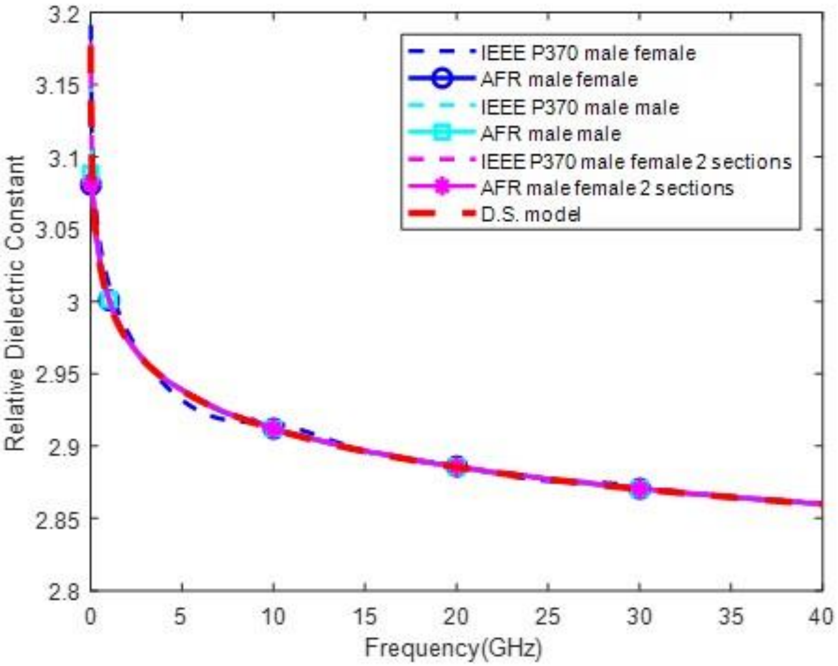


Minimum(physical limitation)

minimum

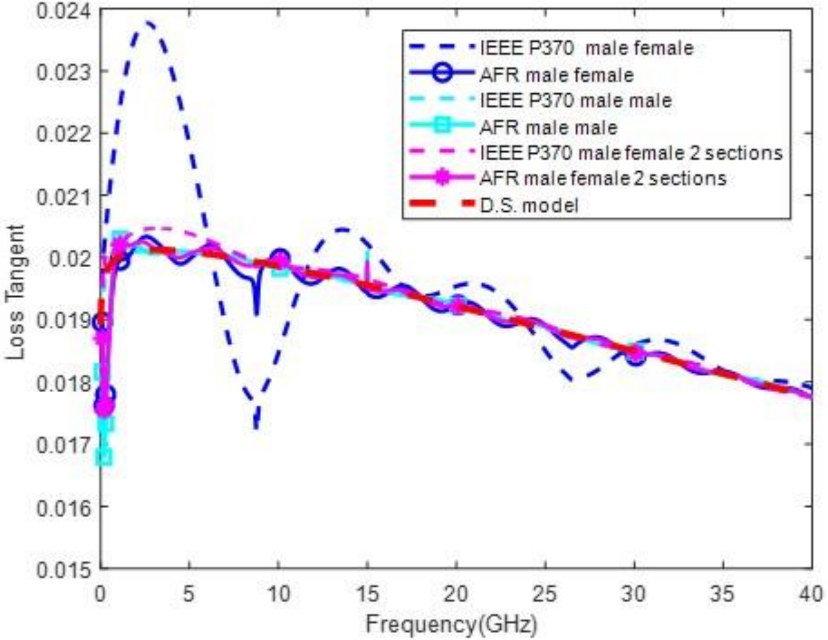
- Modified Hausdorff Distance (MHD) value is used to evaluate how close of two data sets.
- The male side as the reference.
- DOE analysis to find out the size of radius and length of the hole for female side.
- Also, the dielectric is separated into two sections (15+35 and 15+45 mm) and adding chamfers on the dielectric.

Simulation results



- The D.S. model(red dashed line) is used as input.
- To reduce the discontinuity and non-uniform effects, the impedance correction option is used in AFR.
- The male-male configuration is added as a reference.
- In the Dk, IEEE P370 in male-female config. is slightly deviate from the input.

Simulation results

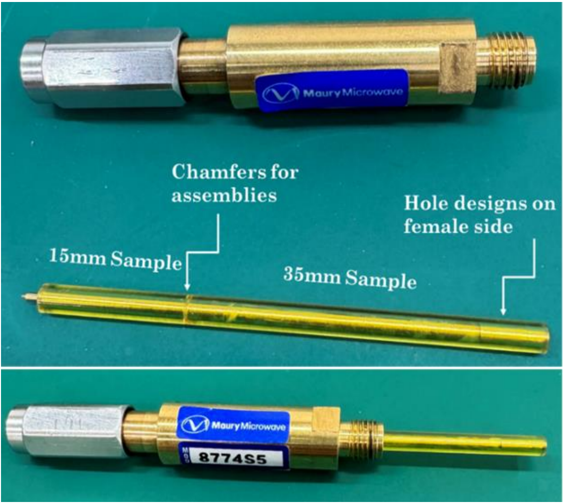


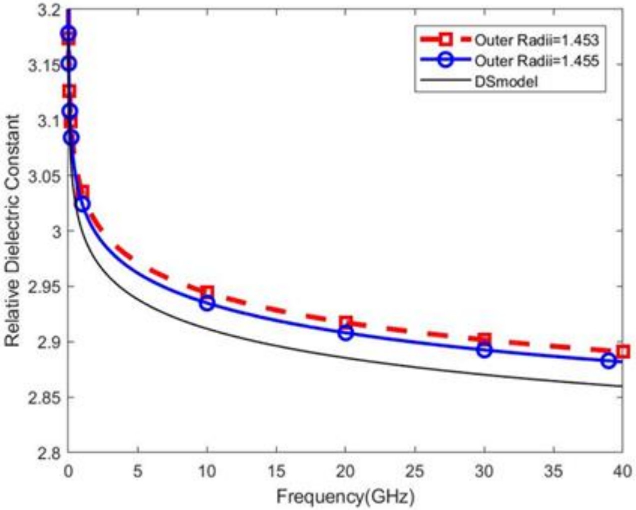
- In male-female configuration-
  - IEEEP370
    - deviation ~20%
    - 2 sections, deviation ~2%
  - AFR
    - deviation ~ 1.1%
    - 2 sections, deviation ~0.6%
  - largest DF deviation at ~100MHz

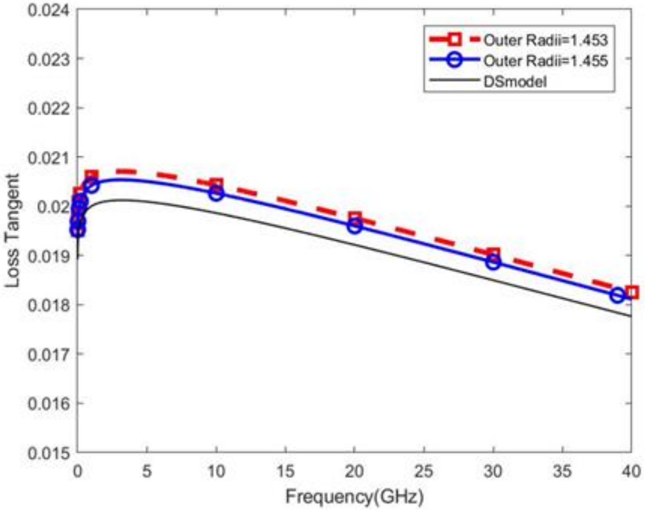
- By separating the dielectric and adding chamfer, it reduces the deviations significantly.

- In general, all configurations and both de-embedding methods matched the input.

Experiments and Data Correction

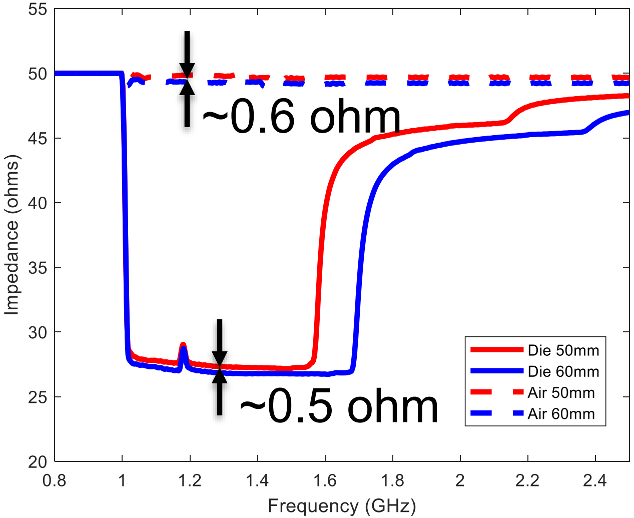


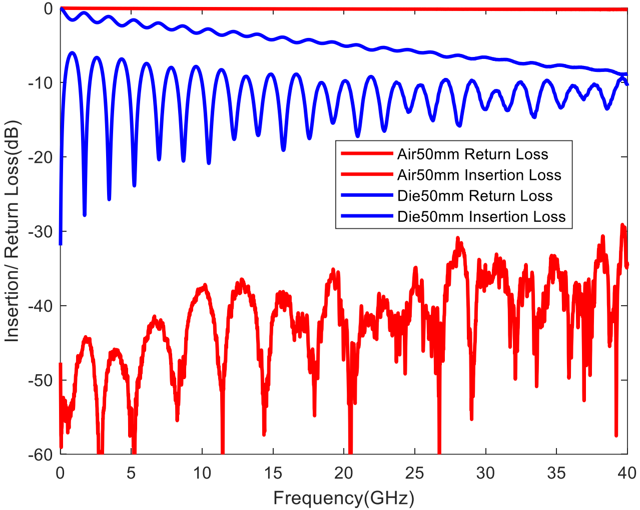


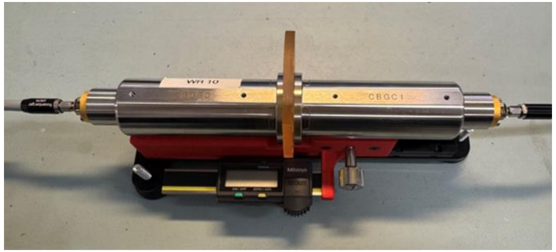


- The inner radius affects the results more than outer radius of a dielectric(error ∝ manufacturing tolerance/ radius).
- The correct method based on a capacitance model, if the input DS model as the measured data, both Dk and Df increased after compensation.
- The impacts are shown and can be ignored with tight control of the inner radius.

Correlations

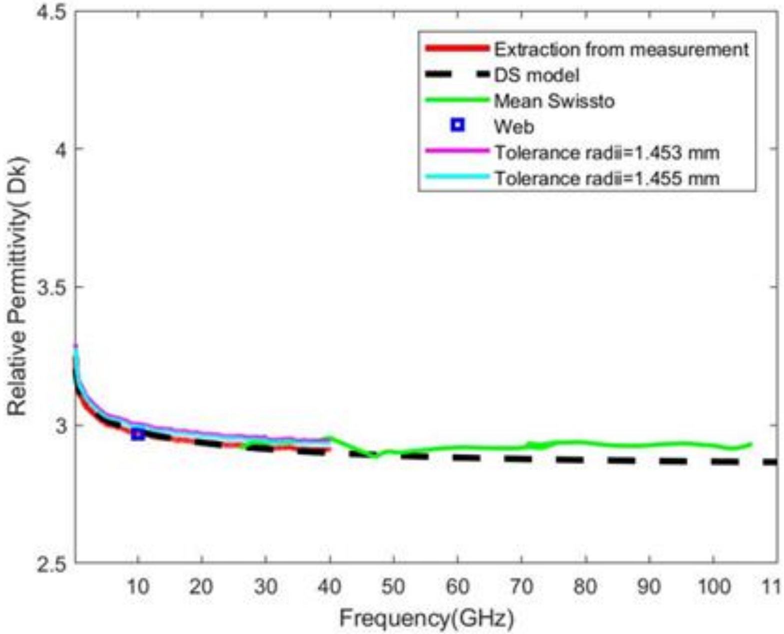


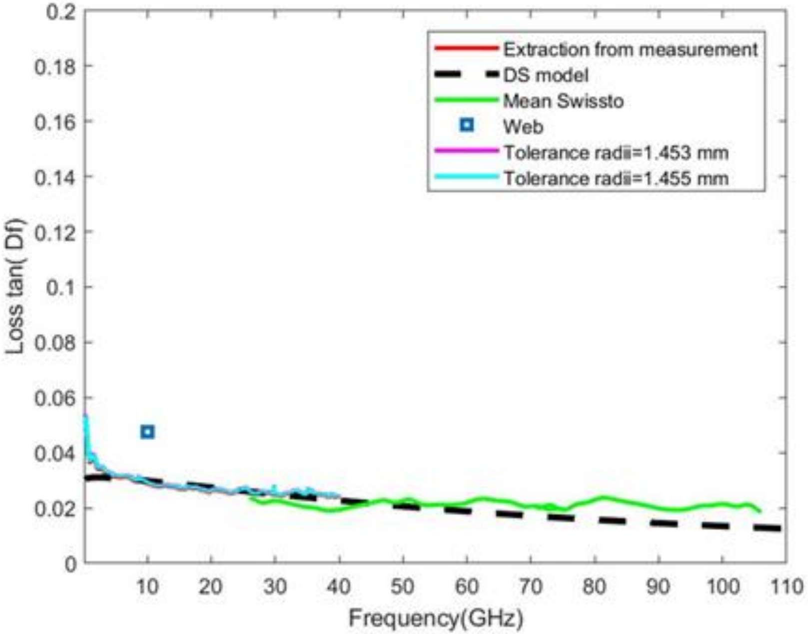




- From the impedance plot, the manufacturing tolerance is smaller than expected. Thus, the error are smaller than the assumptions as well.
- The min. separation between insertion and return loss of 2X thru kits are about 0.5dB which is smaller a bit than the assumption in simulations.
- In addition, the material is measured independently by Swissto12 waveguides to validate the results of the improved method.

Correlations





- The solid green line is extracted from Swissto12 MCK while the solid red line is extracted by the proposed method with airlines.
- The black dashed line represents the DS model, which is fitted by the solid red line (up to 40 GHz) and is extended up to 110 GHz.

Conclusions

- This study introduces an improved broadband material characterization method that overcomes key limitations(reference plane and dielectric length) of the traditional NRW/NIST techniques.

- The method leverages propagation constant relationships, making the extracted parameters largely independent of airline size, conductor conductivity, and MUT positioning after proper de-embedding and normalization.

- Experimental validation using 3D-printed HT200 samples and Swissto12 waveguide kit measurements confirm accuracy up to 40 GHz, with bandwidth extension beyond 100 GHz achievable through the Djordjevic-Sarkar model.

- Practical issues as fixture asymmetry and impedance mismatch addressed via:
  - Optimized dielectric design.
  - Impedance-corrected de-embedding (AFR vs IEEE P370, common tools).

Thank you!

QUESTIONS?

More Questions? Stop by Samtec Booth #939

Feng-Nan (Leon), Wu

Signal Integrity (SI) R&D Engineer , Samtec

Leon.wu@samtec.com | www.samtec.com