"다양한 물질의 유전율, 투자율 측정 솔루션"

TMgate
성보림 과장

TMG 티엠게이트

KEYSIGHT TECHNOLOGIES
Authorized Technology Partner

Agenda

Fundamentals

Considerations in choosing a Technique and Fixture

Measurement Techniques

- Parallel Plate
- Coaxial Probe
- Transmission Line
- Free-Space
- Resonant Cavity

Introducing the new measurement suite

- Options and Configuration Overview

Permittivity and Permeability Definitions

Permittivity (Dielectric Constant)

$$\kappa = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = \varepsilon_r^{'} - j\varepsilon_r^{''}$$

- interaction of a material in the presence of an external electric field.

Permeability

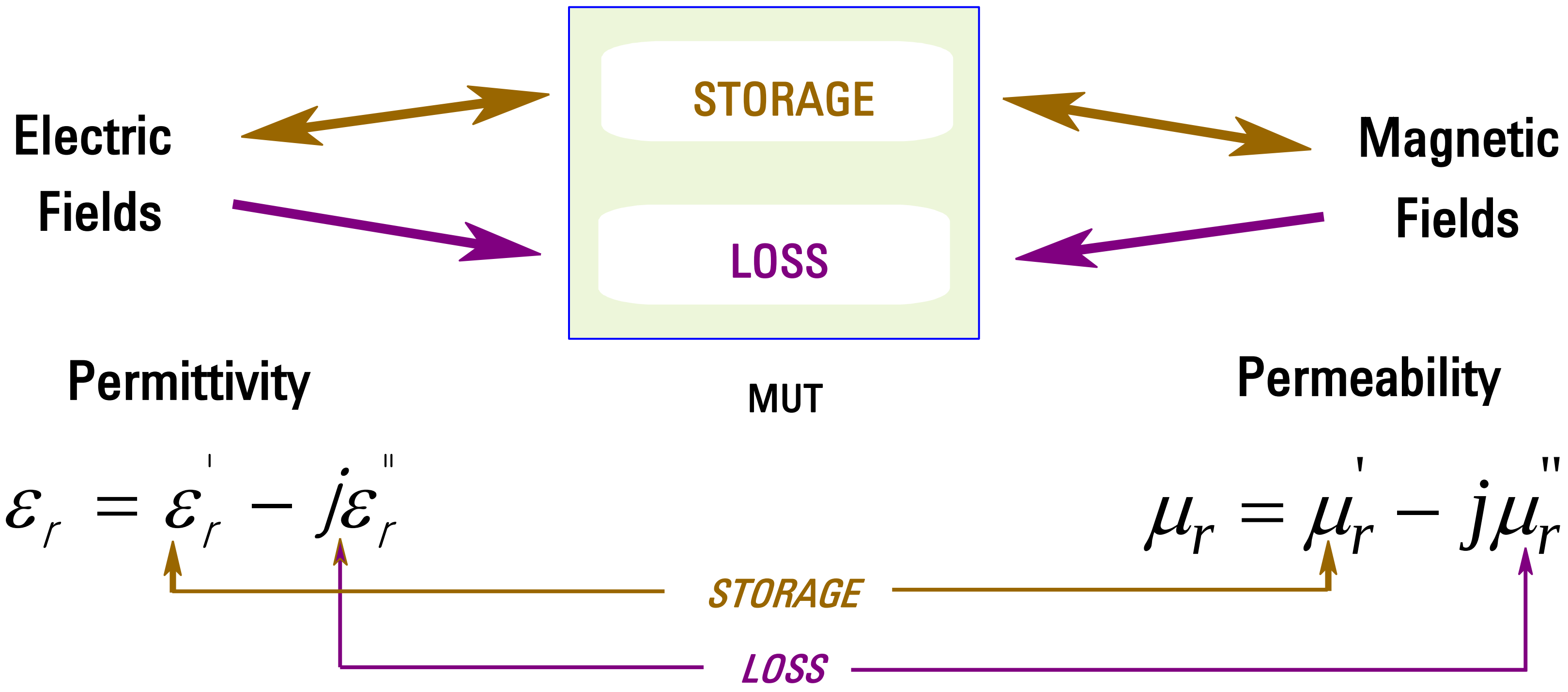
$$\mu = \frac{\mu}{\mu_0} = \mu_r^{'} - j\mu_r^{''}$$

interaction of a material in the presence of an external magnetic field.

Dk

Complex but not Constant!

Electromagnetic Field Interaction

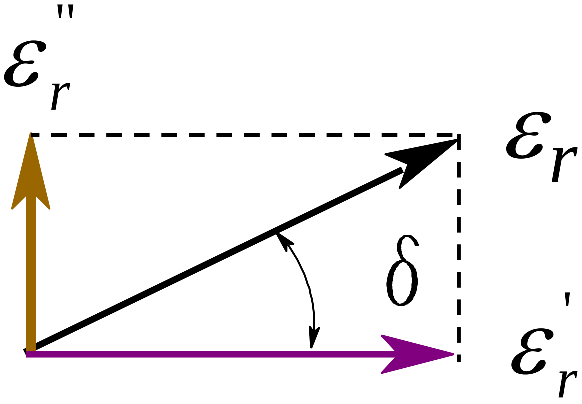


$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$$

$$\mu_r = \mu_r' - j\mu_r''$$

Loss Tangent

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}$$



$$\tan\delta = D = \frac{1}{Q} = \frac{Energy\ Lost\ per\ Cycle}{Energy\ Stored\ per\ Cycle}$$

Df → *D*

D Dissipation Factor *Q* Quality Factor

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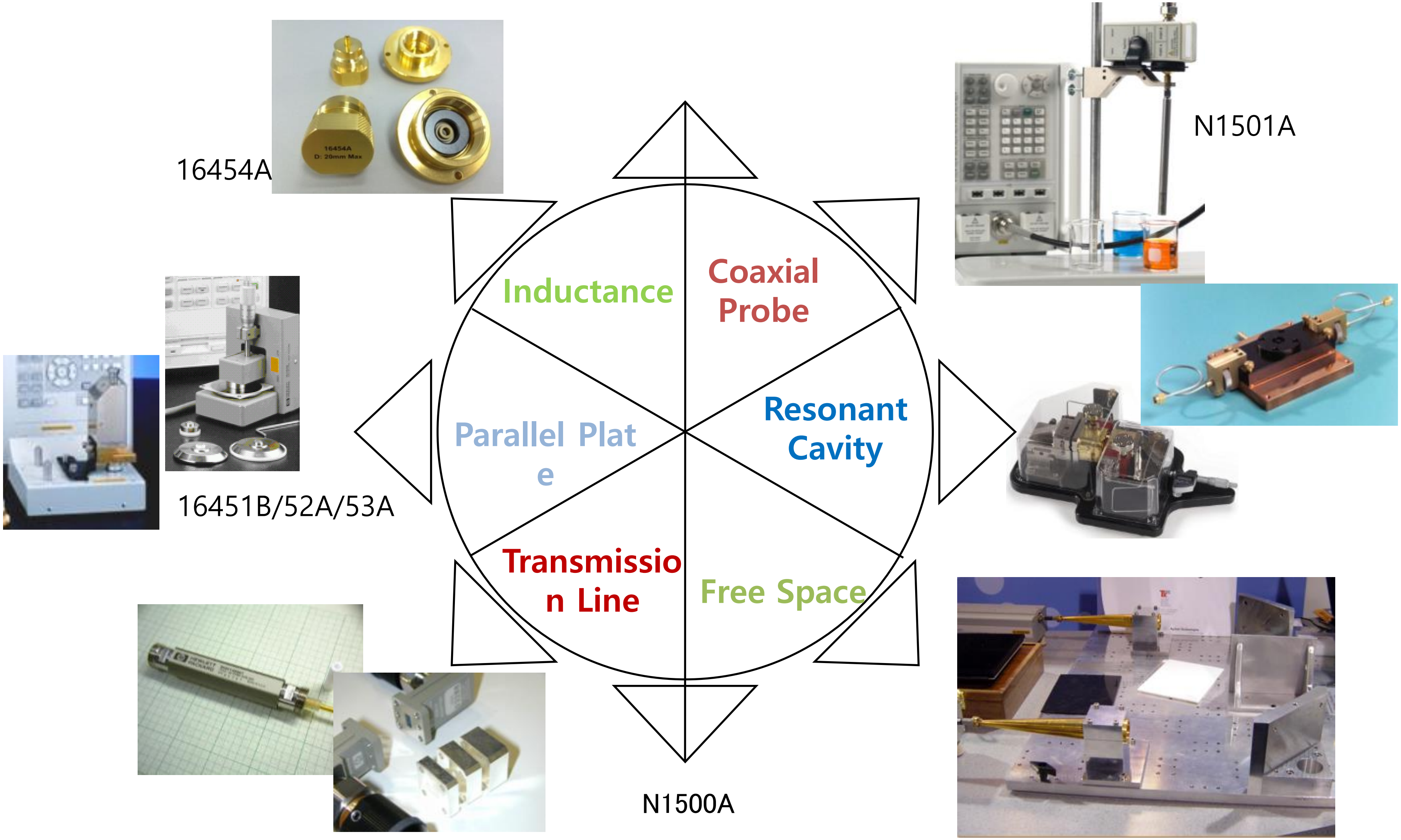
Keysight material measurement Solutions



16454A

N1501A

Inductance

Coaxial Probe

Parallel Plate

Resonant Cavity

Transmission Line

Free Space

16451B/52A/53A

N1500A

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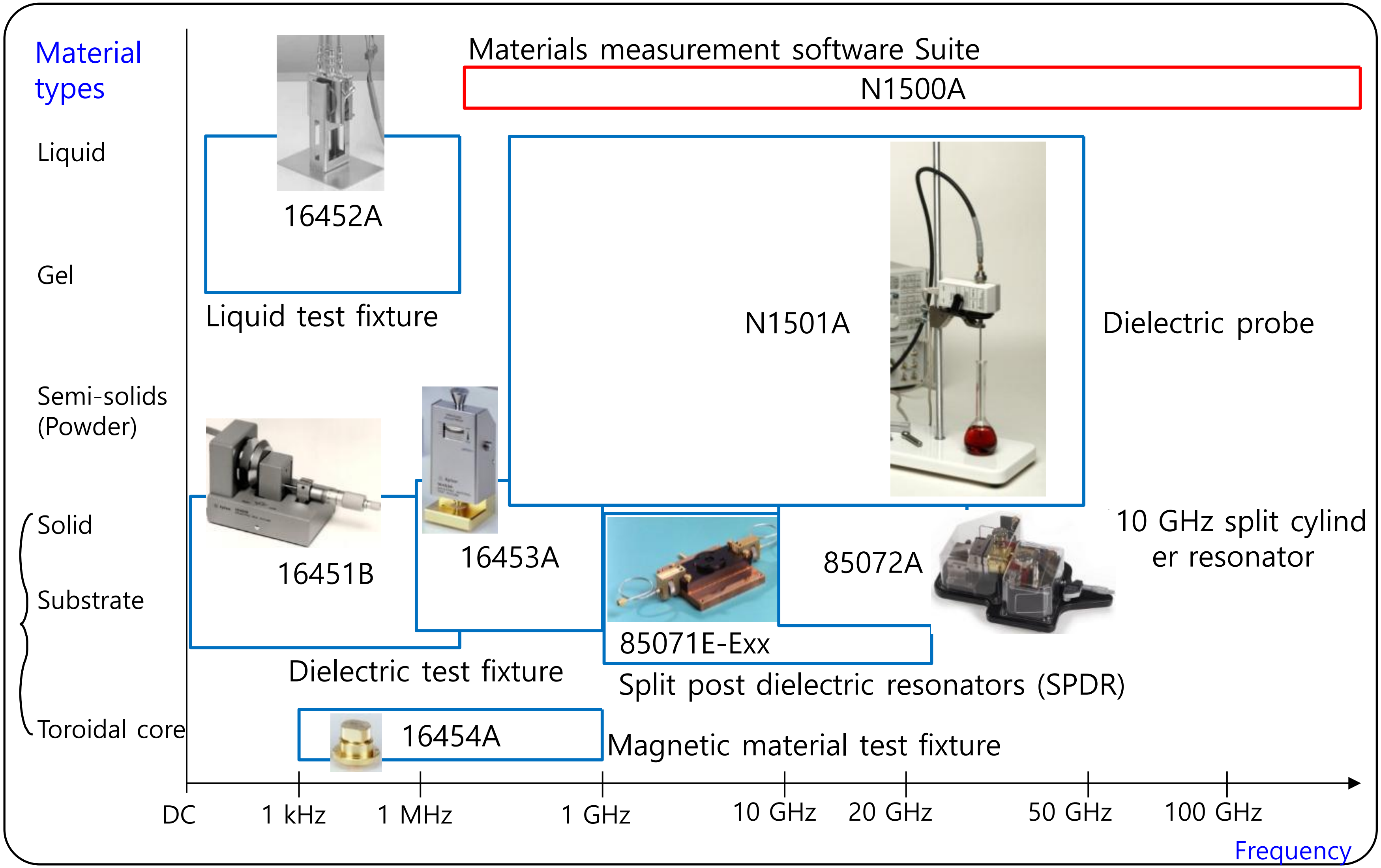
So many solutions. Which is the best?

It Depends… on:

- Frequency of interest
- Form of material (i.e., liquid, powder, solid, sheet)
- Expected value of ε_r and μ_r
- Required measurement accuracy
- Material properties (i.e., homogeneous, isotropic)
- Sample size restrictions
- Destructive or non-destructive
- Contacting or non-contacting
- Temperature

Solution Portfolio



Material types

Liquid

Gel

Semi-solids (Powder)

Solid

Substrate

Toroidal core

Materials measurement software Suite

N1500A

16452A

Liquid test fixture

N1501A

Dielectric probe

16451B

16453A

Dielectric test fixture

85071E-Exx

85072A

10 GHz split cylinder resonator

Split post dielectric resonators (SPDR)

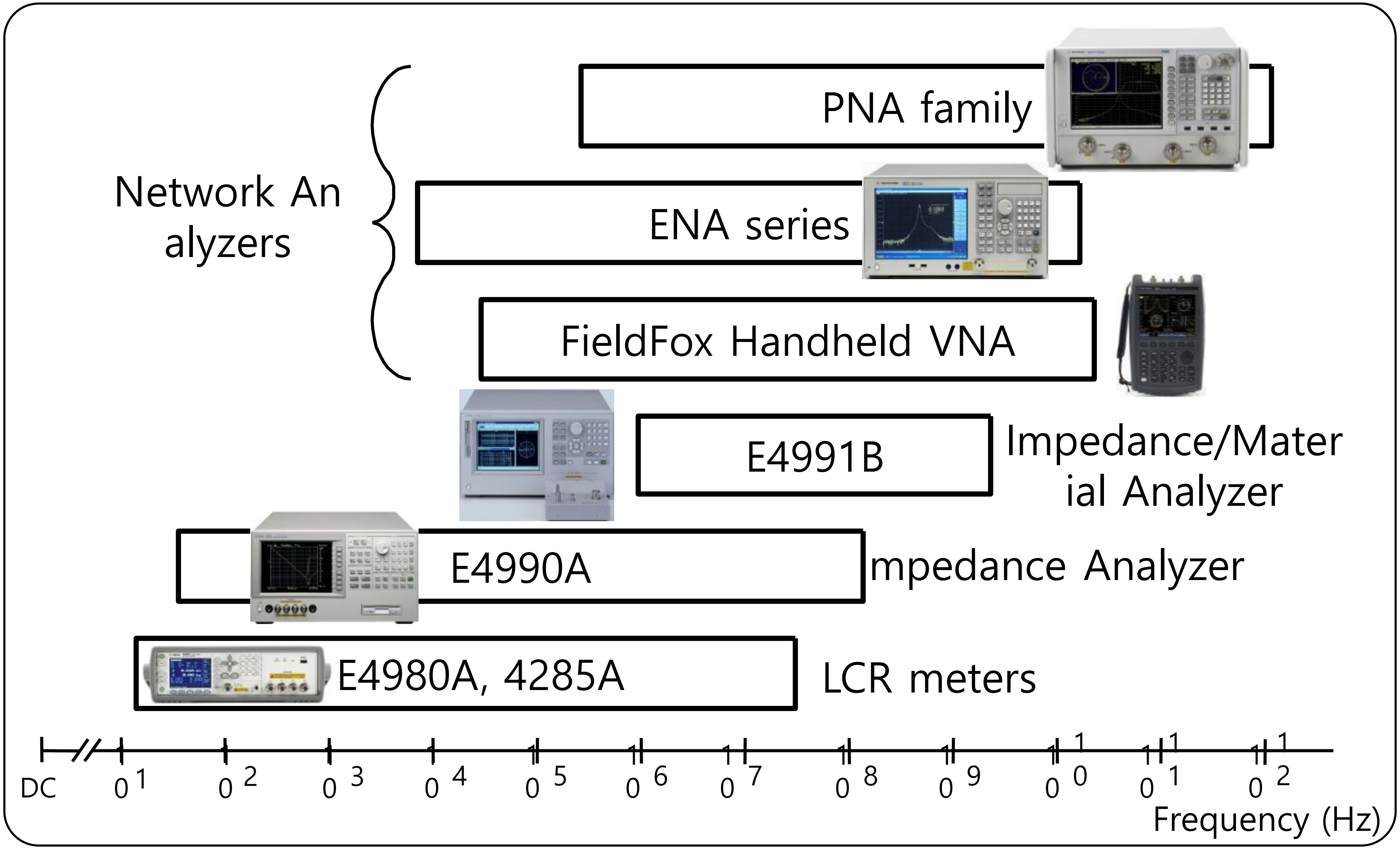
16454A

Magnetic material test fixture

DC
1 kHz
1 MHz
1 GHz
10 GHz
20 GHz
50 GHz
100 GHz

Frequency

Keysight Measurement Instruments



Network Analyzers

PNA family

ENA series

FieldFox Handheld VNA

E4991B

Impedance/Material Analyzer

E4990A

mpedance Analyzer

E4980A, 4285A

LCR meters

DC 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12}

Frequency (Hz)

Agenda

Fundamentals

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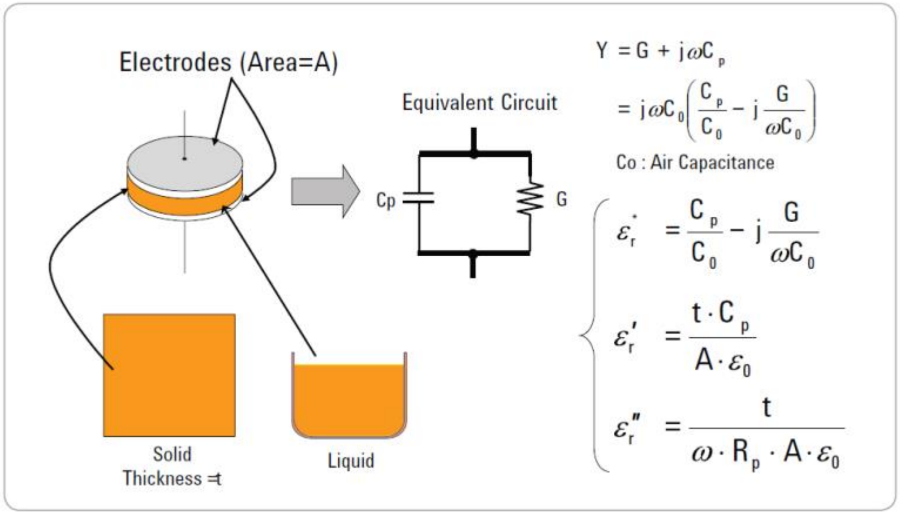
Introducing the new measurement suite
- Options and Configuration Overview

Parallel Plate Solutions

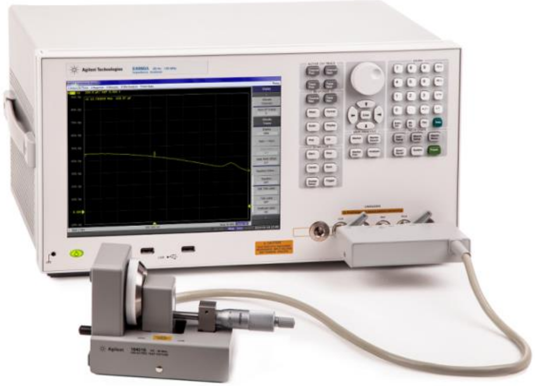
E4991B with 16453A



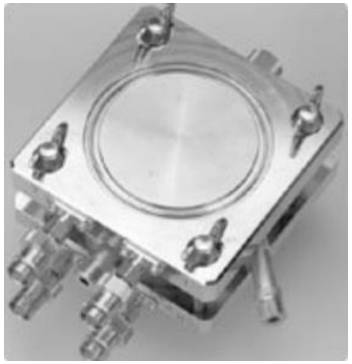
$$Y = G + j\omega C_p = j\omega C_0\left(\frac{C_p}{C_0} - j\frac{G}{\omega C_0}\right)$$

Co : Air Capacitance

$$\begin{cases} \varepsilon_r^* = \dfrac{C_p}{C_0} - j\dfrac{G}{\omega C_0} \\ \varepsilon_r' = \dfrac{t \cdot C_p}{A \cdot \varepsilon_0} \\ \varepsilon_r'' = \dfrac{t}{\omega \cdot R_p \cdot A \cdot \varepsilon_0} \end{cases}$$



E4990A w/16451B
20 Hz to 30 MHz
Solid sheet



16452A
Liquid Test Fixture

E4990A with 16451B

Parallel Plate Electrode Considerations

- When using the electrodes A and B, caution must be taken when measuring a material which is not smooth or changes thickness when pressure is applied. If such a material is to be tested, the non-contacting method can be used, but the material must be at least a few millimeters thick.

Electrode Type	MUT Diameter mm	MUT Thickness mm	Electrode Diameter mm	Max Frequency MHz
A	40 - 56	≤ 10	38	30
B	10 - 56	≤ 10	5	30

- When testing material which has thickness of less than a few hundred micrometers, it is recommended to apply a thin film electrode to the surface of the material and measure with electrodes C and D. If this method is employed, make sure that the resistance of the thin film electrode is small.

Electrode Type	MUT Diameter mm	MUT Thickness mm	Electrode Diameter mm	Max Frequency MHz
C	56	≤ 10	5 - 50	30
D	20 - 56	≤ 10	5 - 14	30

Parallel Plate Summary

- Relatively simple computation of ε_r from C and D
- Works well for thin sheets, PC boards, films, etc.
- Inexpensive
- Accurate: Best for low frequencies
- Accurate: typically
  $\pm$8% for $e_r' \leq 10$, and
  $\pm$ 0.003 for tan$d$ < 100 MHz
- Accurate: typically
  $\pm$1% for e_r', and
  5% $\pm$ 0.005 for tan$d$ < 1 GHz

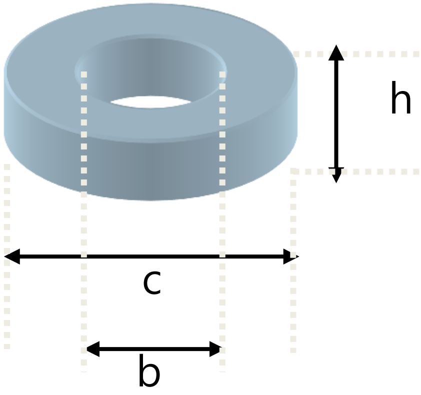
- Frequency limited to 1 GHz
- Sample should be flat, smooth sheet

Permeability Measurement Solutions

LF/HF Solution (1 kHz to 120 MHz)

RF Solution (1 MHz to 1 GHz)

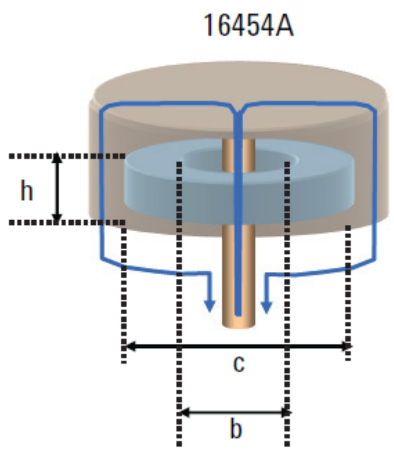
16454A



Small Size	Large Size
c ≤ 8mm	c ≤ 20mm
b ≥ 3.1mm	b ≥ 5mm
h ≤ 3mm	h ≤ 8.5mm

Magnetic materials

16454A



No magnetic flux leakage

$$\mu_r = \frac{L - L_S}{\mu_0} \frac{2\pi}{h \cdot \ln\left(\frac{c}{b}\right)}$$

where,

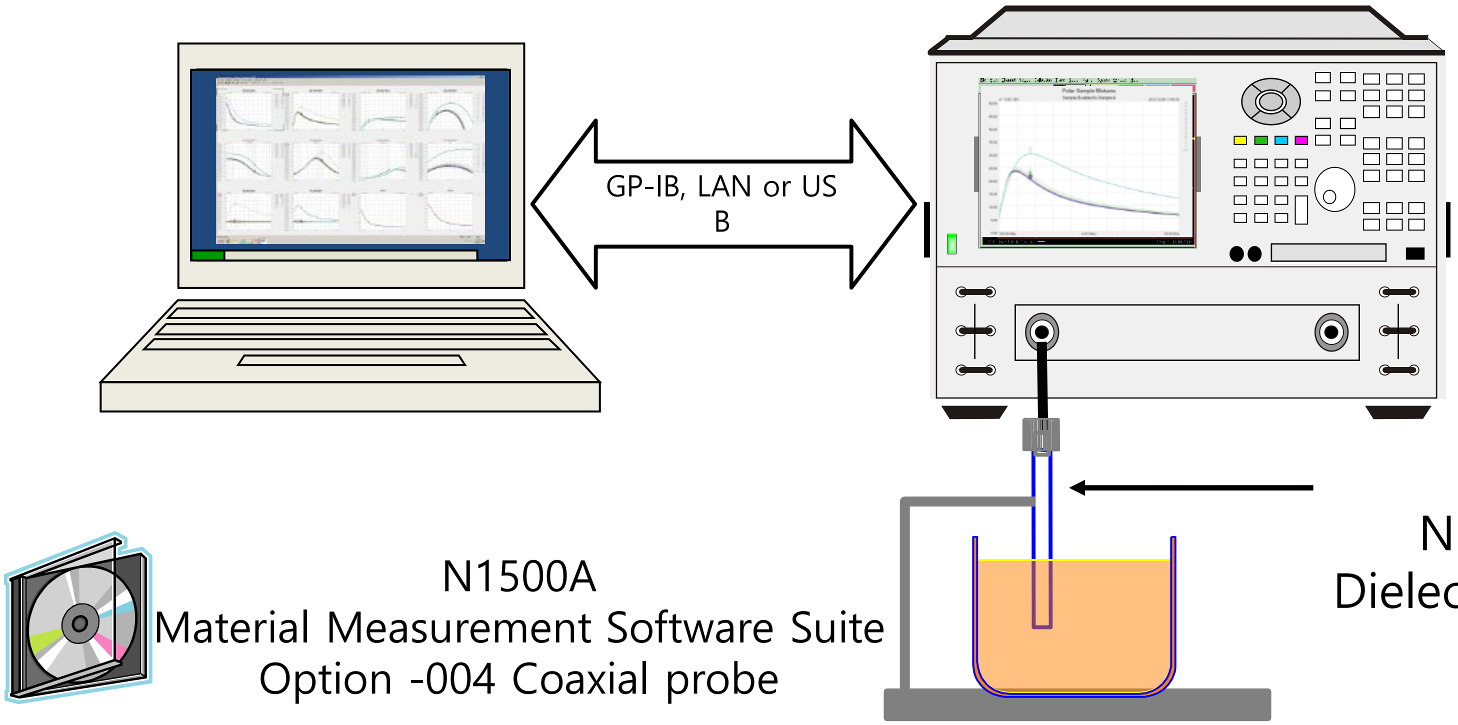
μ	relative permeability
L	measured inductance with MUT
Ls	measured inductance without MUT
μ_0	permeability of free space
h	height of MUT (Material Under Test)
c	outer diameter of MUT
b	inner diameter of MUT

Inductance Method Summary

- 👍 Broad frequency range in low frequencies
- 👍 Relatively accurate measurement
- 👍 Easy setup with low cost solution

- 👎 High frequency measurement limited by inter winding capacitance
- 👎 Can measure only materials with low permittivity

Coaxial Probe System



Computer
(Optional for PNA or ENA)

Network Analyzer
(or E4991B Impedance Analyzer)

GP-IB, LAN or USB

N1500A
Material Measurement Software Suite
Option -004 Coaxial probe

N1501A
Dielectric Probe

Calibration is required

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KEYSIGHT TECHNOLOGIES
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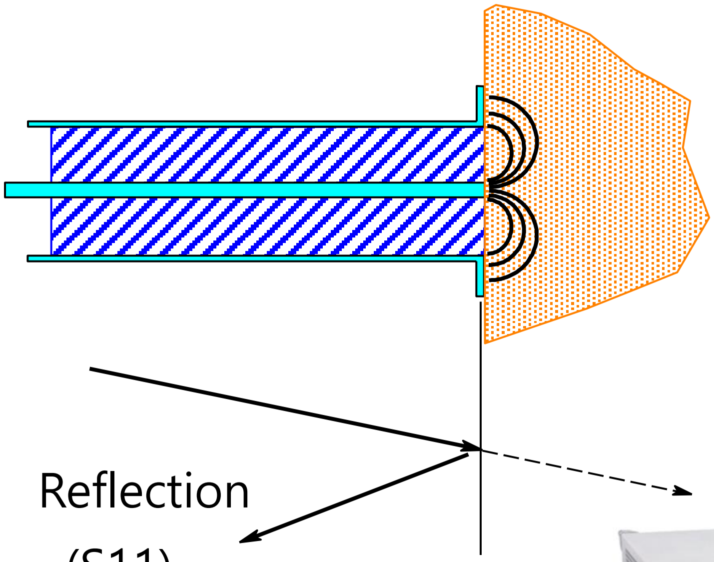
Coaxial Probe



Reflection

(S11)

e_r

Material assumptions:

- effectively infinite thickness
- non-magnetic
- isotropic
- homogeneous
- no air gaps or bubbles

Three Probe Design

		
High Temperature Probe • 0.200 – 20GHz (low end 0.01GHz with impedance analyzer) • Withstands -40 to 200 degrees C • Flanged design allows measuring flat surfaced solids	**Slim Form Probe** • 0.500 – 50GHz • Low cost consumable design • Fits in tight spaces, smaller sample sizes • For liquids and soft semi-solids only	**Performance Probe** • 0.500 – 50GHz • Withstands -40 to 200 degrees C • Hermetically sealed on both ends, OK for autoclave • Food grade stainless steel

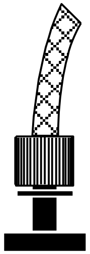
Coaxial Probe Calibration

Three term calibration (1-port)

corrects

- Directivity
- Tracking
- Source match

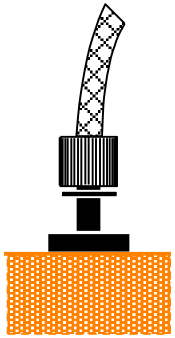
Measure three known standards



Open

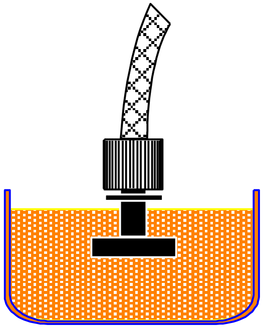
$\varepsilon_r = 1$

$\Gamma = 1$



Short

$\Gamma = -1$

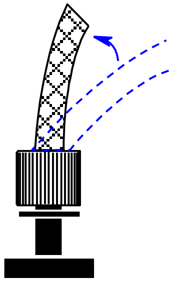


User-defined standard (usually water)

Difference in predicted and actual value is used to correct measurement

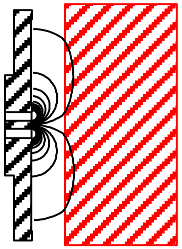
Coaxial Probe Errors

Cable stability



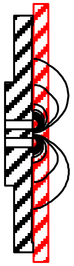
Allow time for cable to stabilize
Minimize cable flexing

Air gaps



Machine a flat sample face Probe flatness ~ 100 m inches (sample flatness should be similar)

Sample thickness



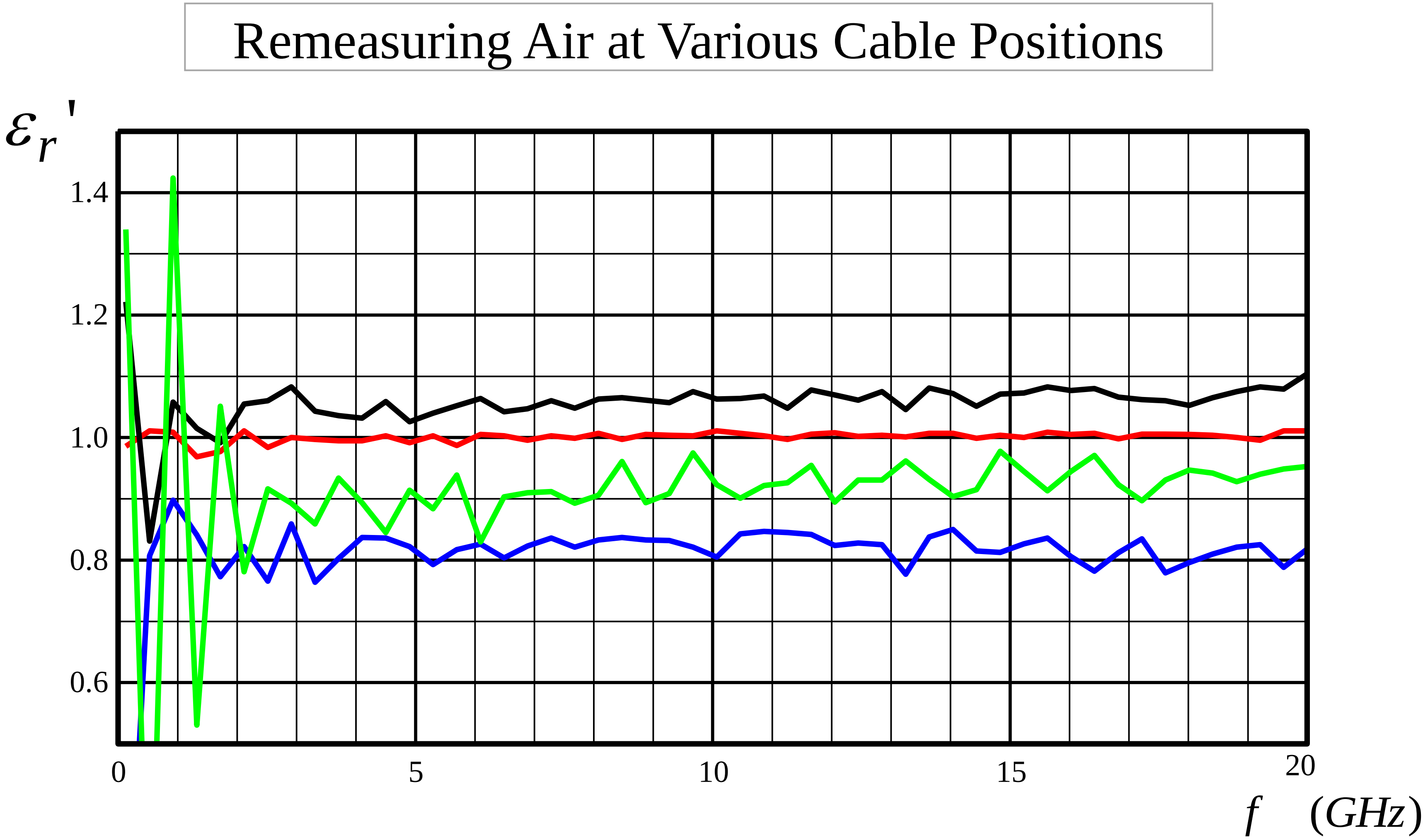
$$t_{\min} = \frac{20}{\sqrt{\varepsilon_r}} \quad (mm)$$

Recommended minimum thickness for high temperature probe

Powder measurements results depend on packing

Uniform packing and mixing theory

Cable Phase Stability

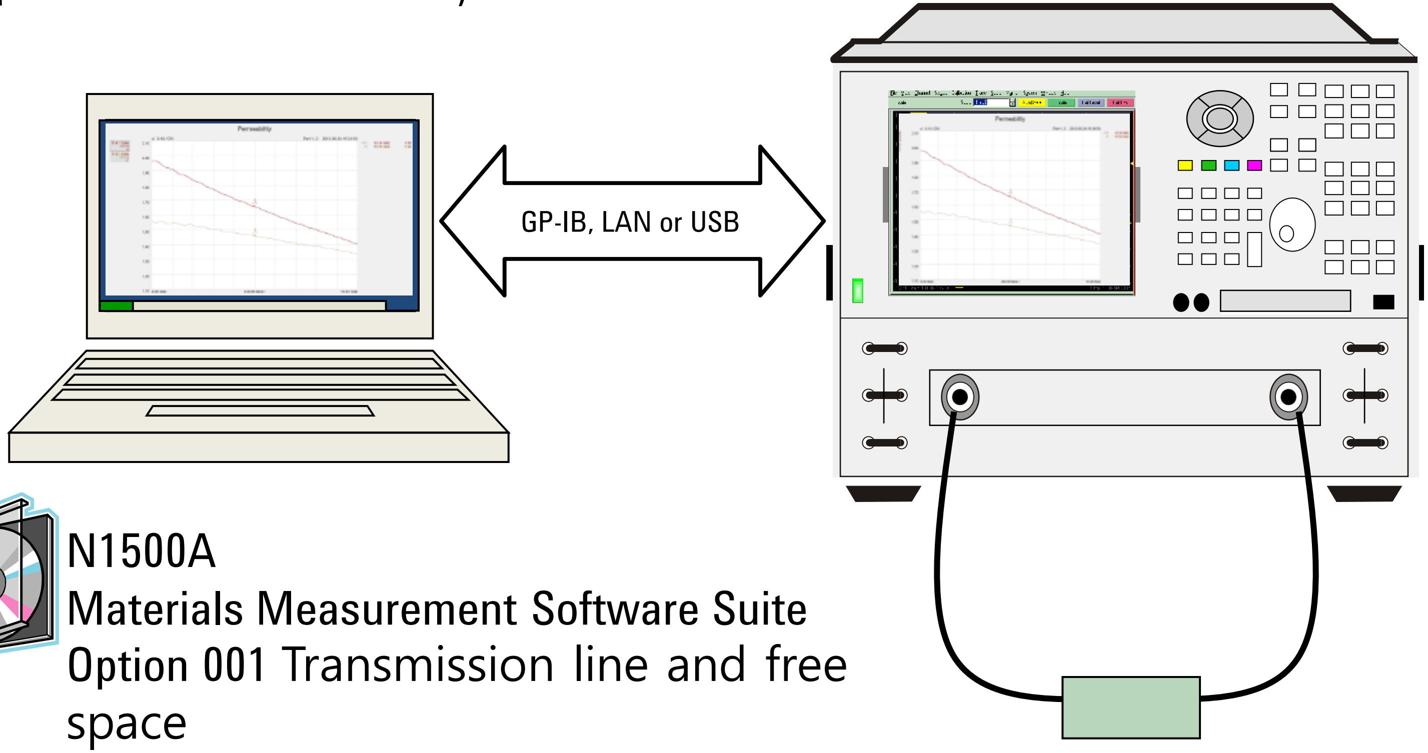


Coaxial Probe Summary

- Convenient, easy to use
- Little or no sample preparation
- Nondestructive for many materials
- Ideal for liquids or semisolids
- Broad frequency range (0.2-50 GHz depending on ϵ_r)

- Requires sample thickness of > 1 cm (typical)
- Solids must have a flat surface
- Limited accuracy in ϵ'_r ($\pm$ 5%) and low loss resolution ($\pm$ .05 in tanδ)
- Not suited to high ϵ'_r low ϵ''_r materials
- Does not provide μ_r
- Material has to be isotropic

Transmission Line System



Computer
(Optional for PNA or ENA)

GP-IB, LAN or USB

Network Analyzer

Sample holder
connected between coax cables

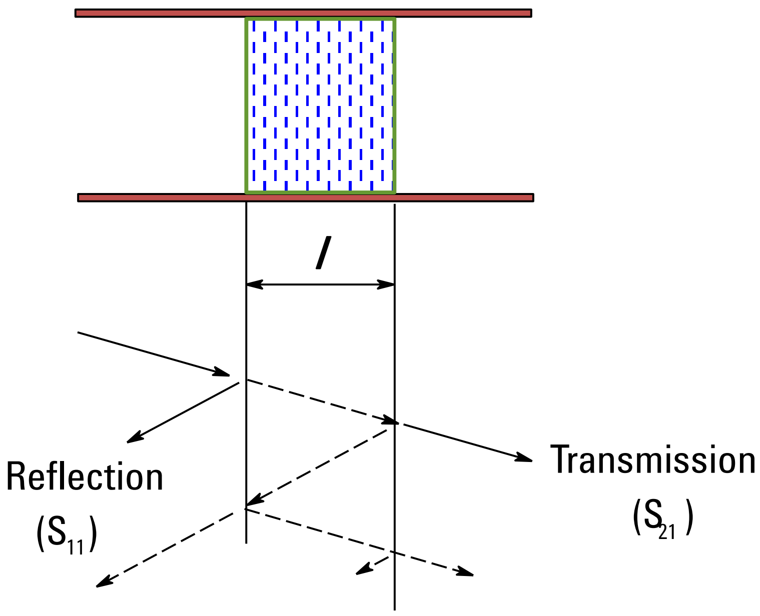
N1500A
Materials Measurement Software Suite
Option 001 Transmission line and free space

Calibration is required

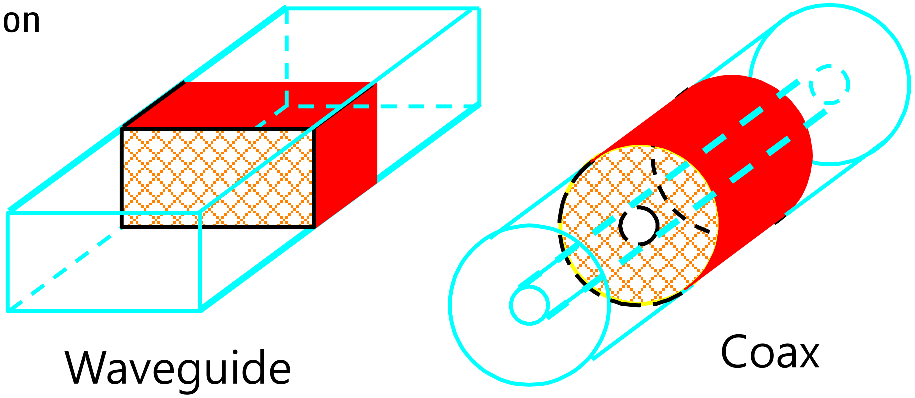
Transmission Line

Material assumptions:

- sample fills fixture cross section
- no air gaps at fixture walls
- flat faces, perpendicular to long axis
- Known thickness > 20/360 λ



e_r and m_r



Transmission Model in Material Measurement SW

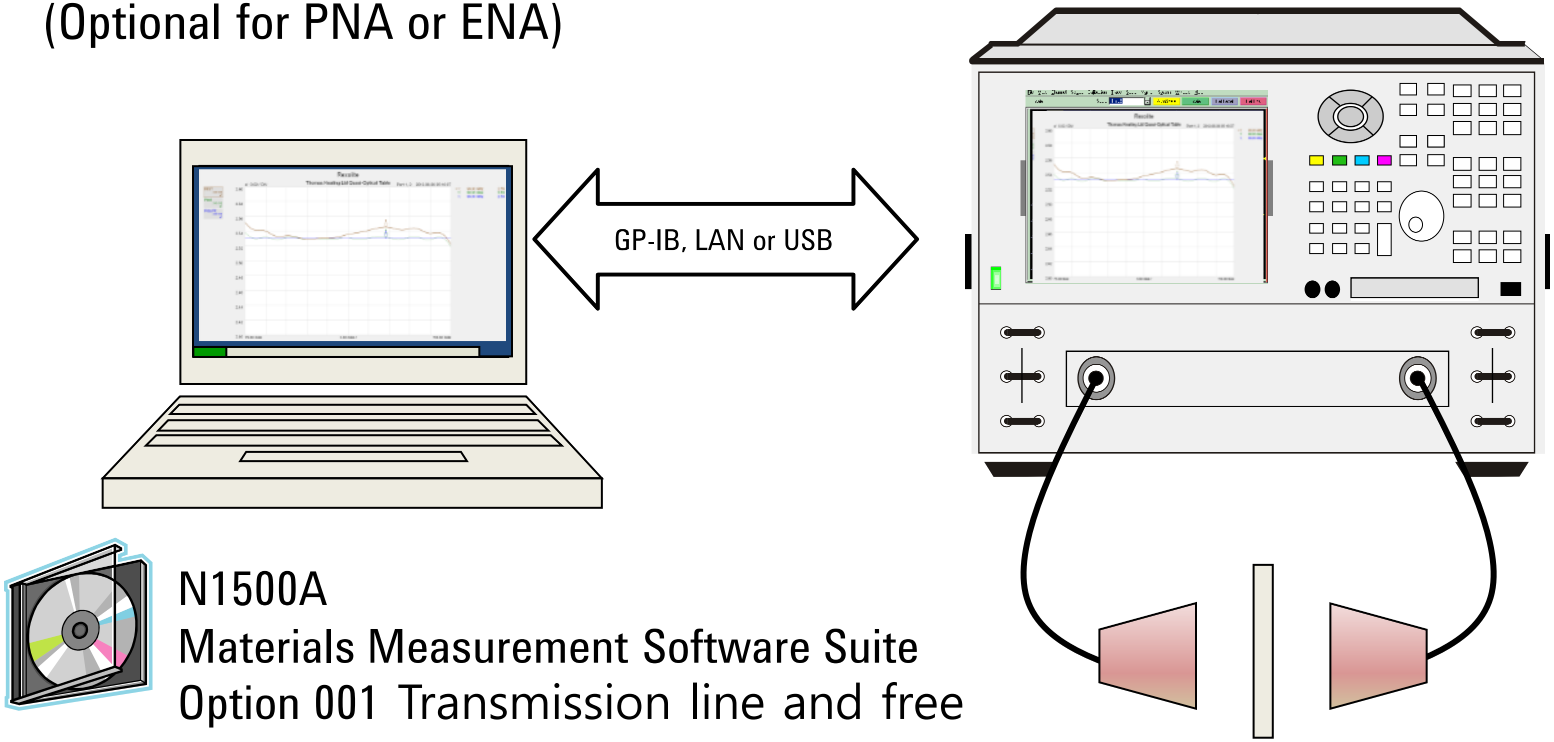
Algorithm	Measured S-parameters	Output
Nicolson-Ross	S11, S21, S12, S22	ε_r and μ_r
NIST Precision	S11, S21, S22	ε_r
Fast Transmission	S21, S12	ε_r
Poly Fit 1	S11, S21, S12, S22	ε_r and μ_r
Poly Fit 2	S12, S21	ε_r
Stack Two	S21, S12 (2 samples)	ε_r and μ_r
Short Backed	S11	ε_r
Arbitrary Backed	S11	ε_r
Single Double Thickness	S11 (2 samples)	ε_r and μ_r

Transmission Line Summary

- Provides both e_r and m_r
- Simple fixtures
- Broad frequency range (0.1-110 GHz)
- Adaptable to "free space"

- Frequency limited to >100 MHz (banded in waveguide)
- Precise sample shape required (usually destructive)
- Limited low loss resolution
- Liquids and gases must
  be contained

Free Space Technique



Computer
(Optional for PNA or ENA)

Network Analyzer

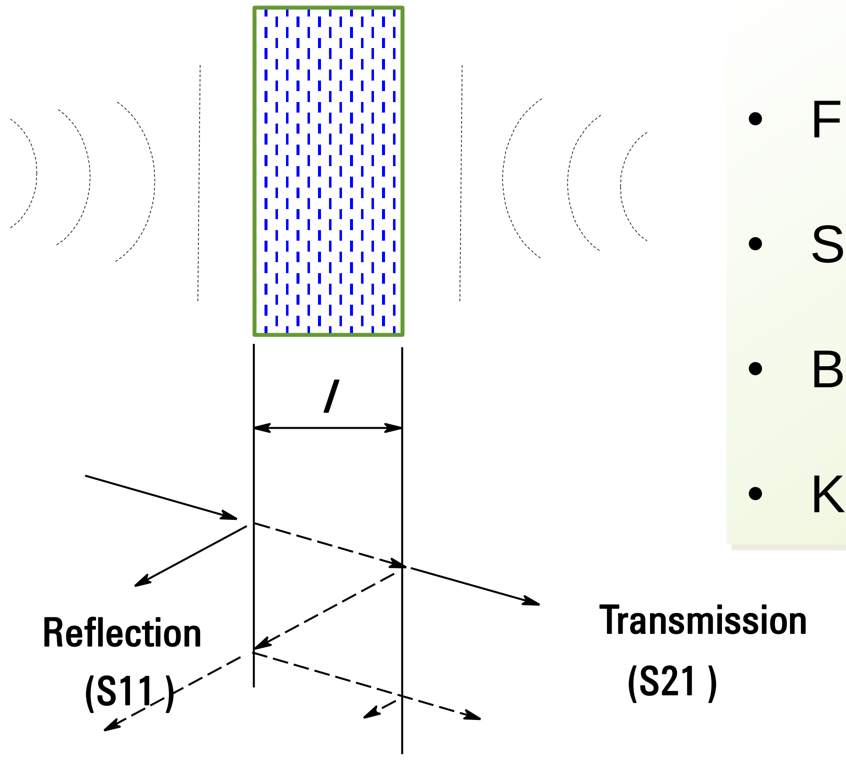
GP-IB, LAN or USB

N1500A
Materials Measurement Software Suite
Option 001 Transmission line and free space

Sample holder
fixtured between two antennae

Calibration is required

Transmission Free-Space



e_r and m_r

Material assumptions:

- Flat parallel faced samples
- Sample in non-reactive region
- Beam spot is contained in sample
- Known thickness > 20/360 λ

Free Space Summary

Noncontacting, often nondestructive

- Sample not contained
- Useful for high temperatures
- Remote sensing

Special calibration considerations

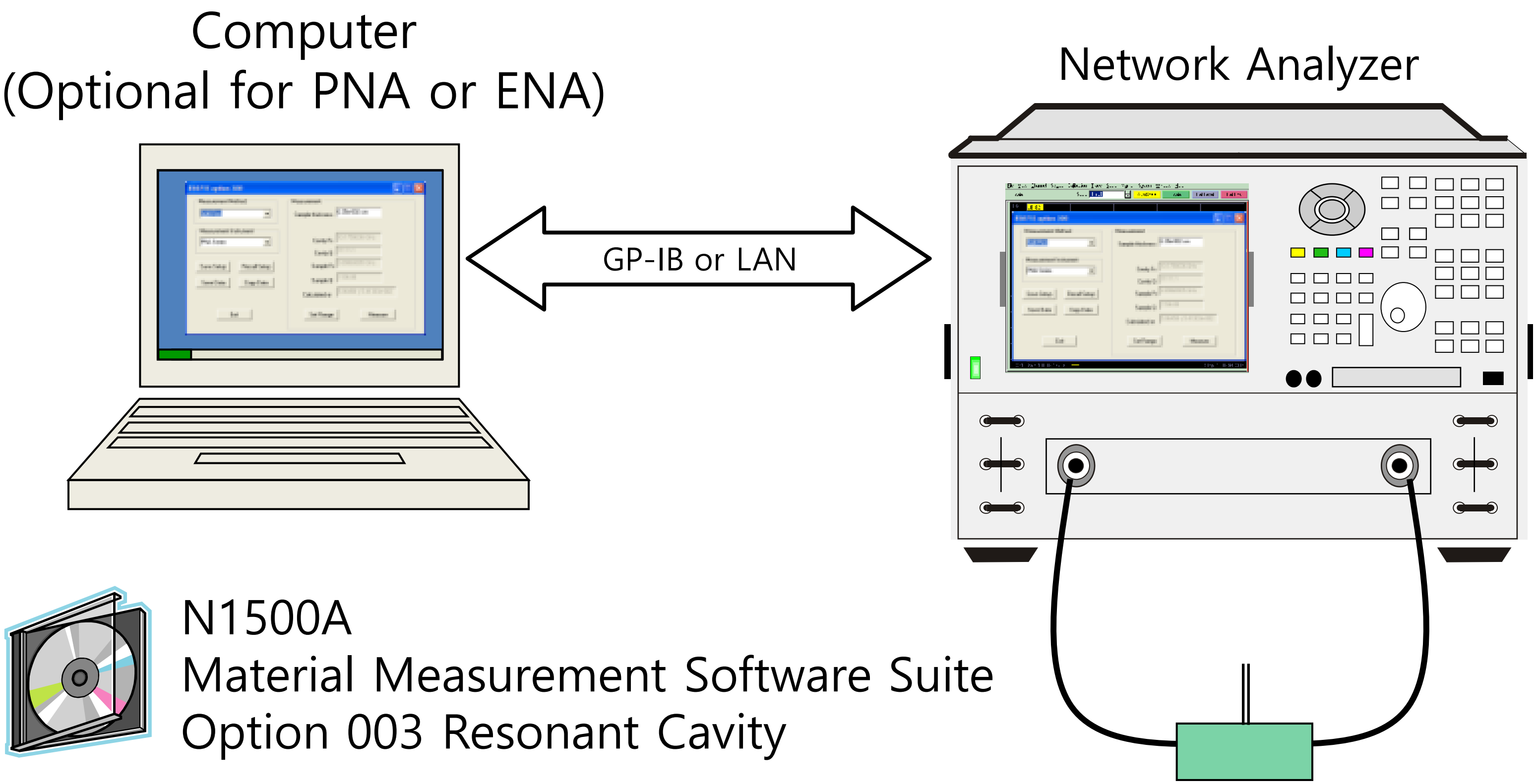
- Requires connectorless standards (TRL, LRM)
- Tightly controlled distance from antenna to sample (TRL)

GRL calibration

Time domain gating eliminates errors

Requires large, flat, thin, parallel faced sample

Resonant Cavity Technique



Computer
(Optional for PNA or ENA)

GP-IB or LAN

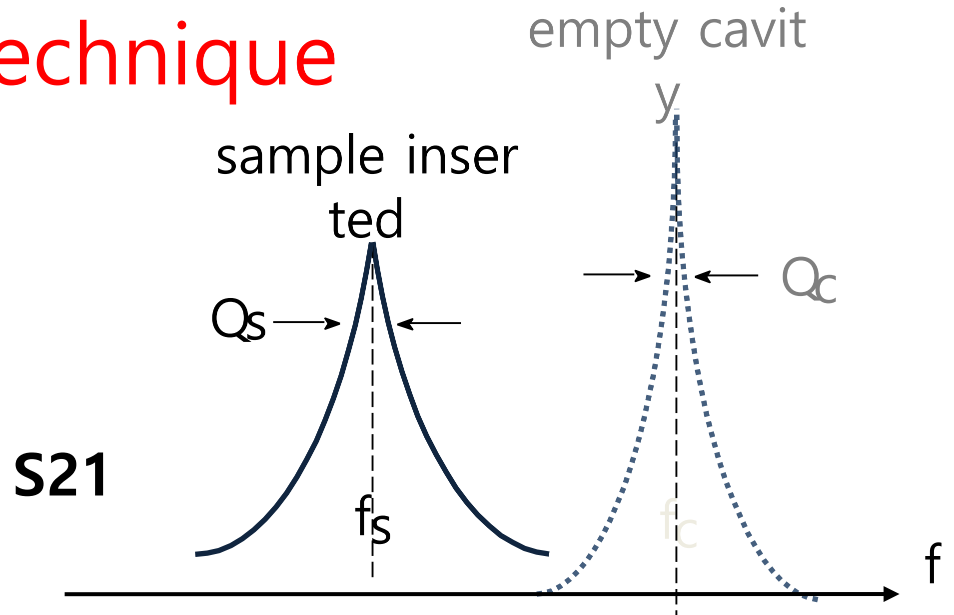
Network Analyzer

N1500A
Material Measurement Software Suite
Option 003 Resonant Cavity

No calibration required

Resonant Cavity with sample connected between ports.

Resonant Cavity Technique



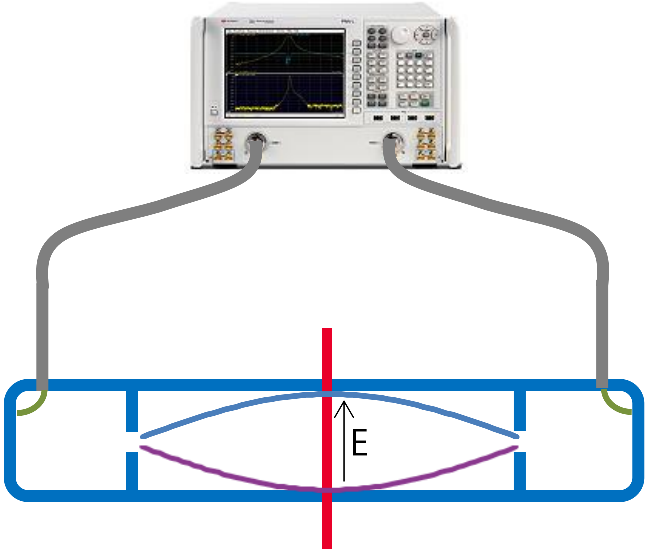
fc = Resonant Frequency of Empty Cavity
fs = Resonant Frequency of Filled Cavity
Qc = Q of Empty Cavity
Qs = Q of Filled Cavity
Vs = Volume of Empty Cavity
Vc = Volume of Sample

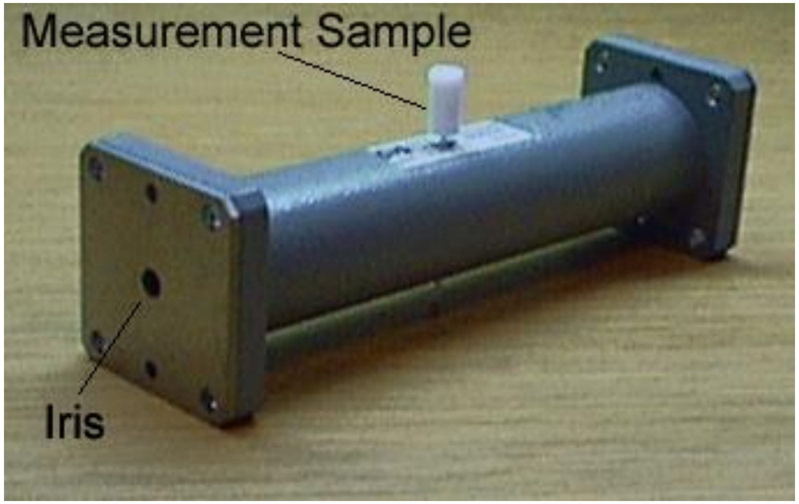
$$\varepsilon_r' = 1 + \frac{V_c\left(f_c - f_s\right)}{2V_s f_s} =$$

$$\varepsilon_r'' = \frac{V_c}{4V_s}\left(\frac{1}{Q_s} - \frac{1}{Q_c}\right)$$

ASTM 2520

Transmission Line Cavity (ASTM 2520)

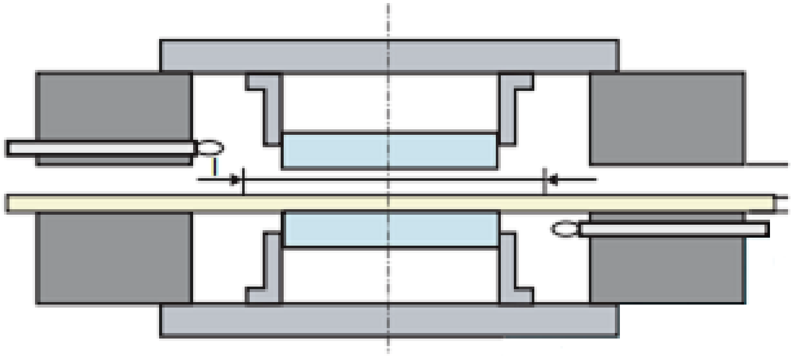


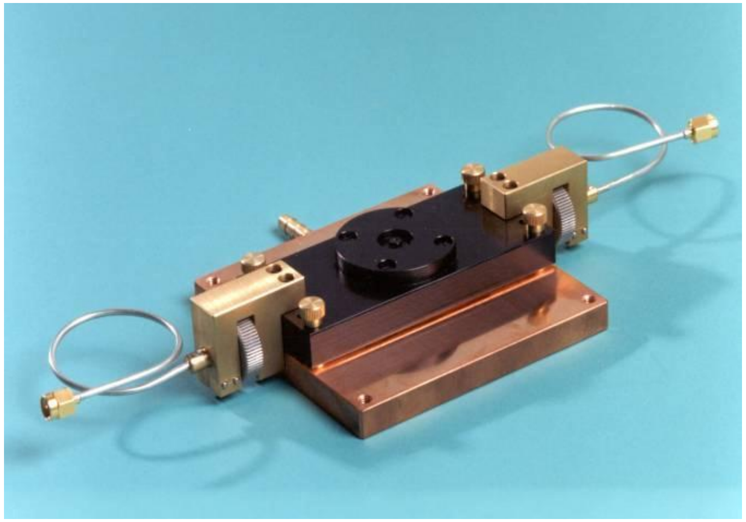


ASTM2520

- ◆ Rectangular waveguide cavity with TE_{10n} mode resonance
- ◆ Sample placed parallel to cavity E-field
- ◆ Fibers may be inserted through a fused silica rod

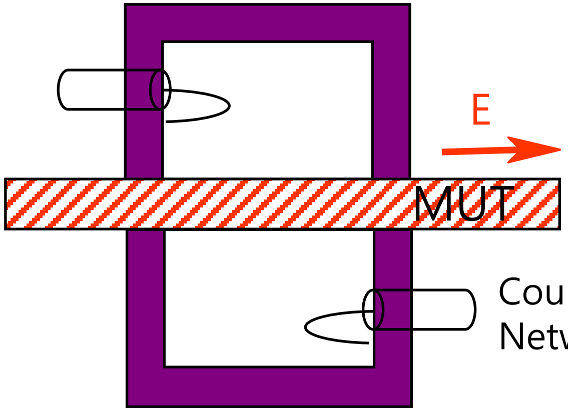
Split Post Dielectric Resonator (SPDR)





Next we will focus on the Split Post Dielectric Resonator (SPDR). It provides an accurate technique for measuring the complex permittivity of dielectric and ferrite substrates and thin films at a single frequency point in the frequency range 1–20 GHz. The resonator needs to be purchased. It is not easy to be manufactured like ASTM resonator.

Split Cylinder Resonator


Upper Cylindrical Cavity Region

Coupling loop to
Network Analyzer

Lower Cylindrical Cavity Region

Next we will focus on the Split Cylinder Resonator. It provides an accurate technique for measuring the complex permittivity of dielectric substrates and thin films at several frequency points. The resonator is not easy to be manufactured like ASTM resonator.

Split Cylinder Resonator

Advantages

- Accurate nondestructive measurement of dielectric substrates.
- No sample machining necessary.
- Broadband frequency coverage.
- Characterization of thin materials possible.

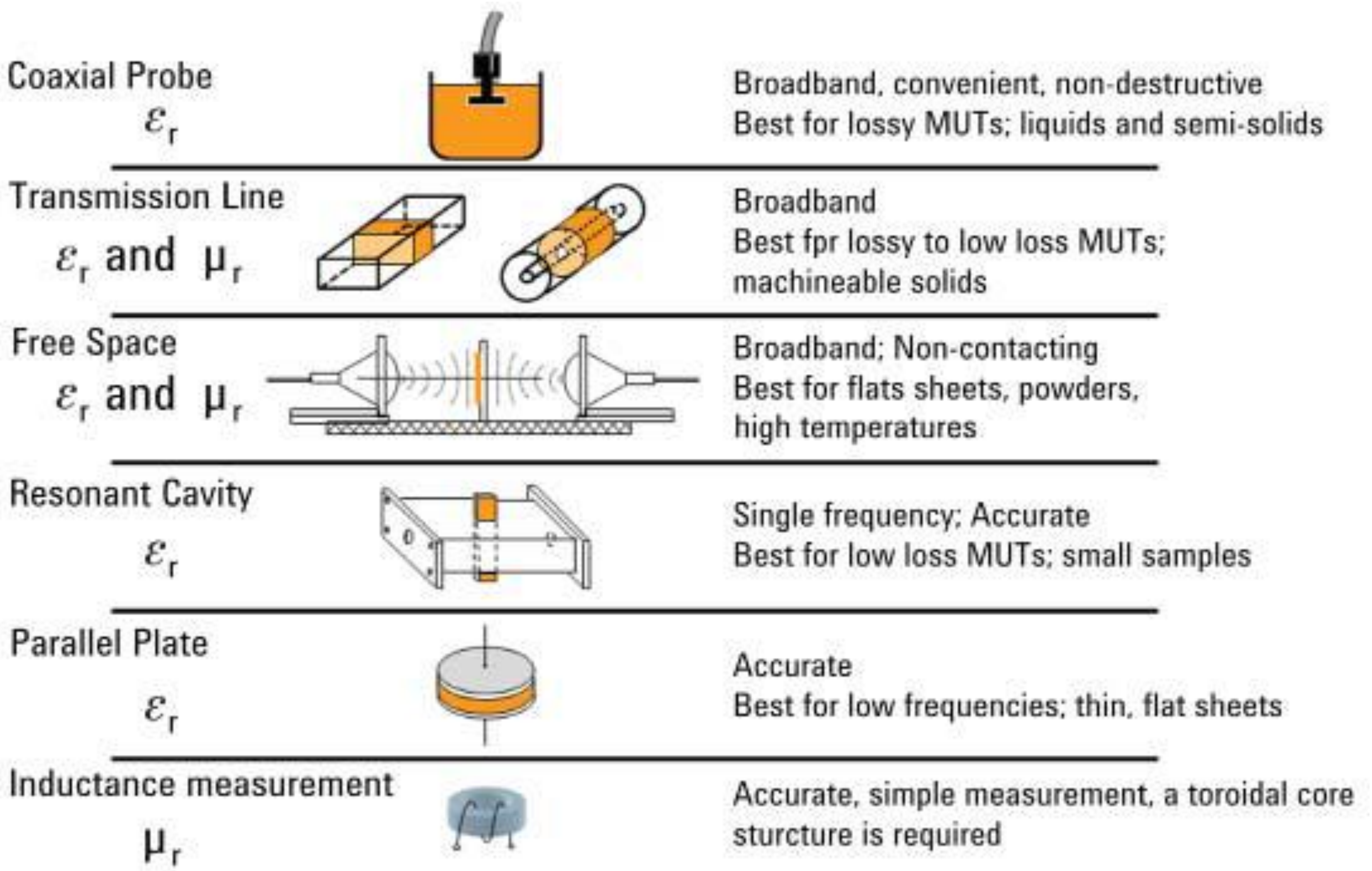
Disadvantages

- Electric field parallel to the dielectric substrate.
- Difficult to measure loss tangents below $5\text{x}10^{-5}$.
- Identification of TE_{0np} resonant modes sometimes difficult.

Cavity Summary

👍	Very accurate. Best for PCB materials.	👎	Does not provide broad band frequency data
👍	Very sensitive to low loss (to 10^{-6} for some cavities)	👎	Precise sample shape required for ASTM (usually destructive)
👍	SPDR and SCR methods are nondestructive	👎	Usually destructive

Summary of methods

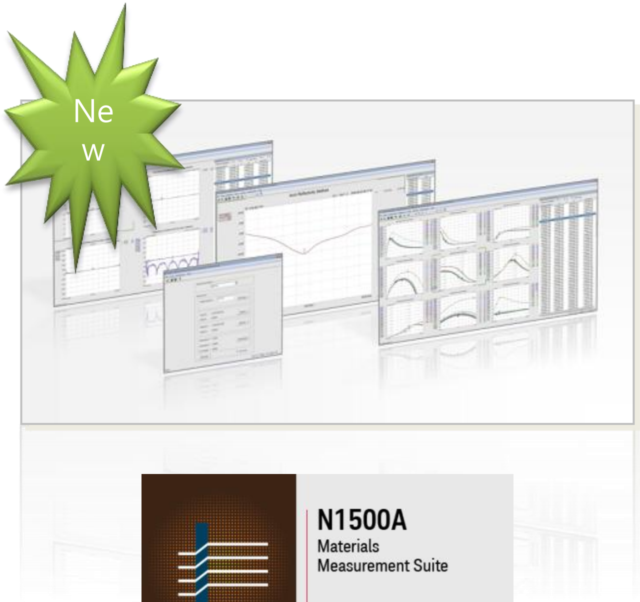


Method	Property	Description
Coaxial Probe	ε_r	Broadband, convenient, non-destructive Best for lossy MUTs; liquids and semi-solids
Transmission Line	ε_r and μ_r	Broadband Best fpr lossy to low loss MUTs; machineable solids
Free Space	ε_r and μ_r	Broadband; Non-contacting Best for flats sheets, powders, high temperatures
Resonant Cavity	ε_r	Single frequency; Accurate Best for low loss MUTs; small samples
Parallel Plate	ε_r	Accurate Best for low frequencies; thin, flat sheets
Inductance measurement	μ_r	Accurate, simple measurement, a toroidal core sturcture is required

N1500A Materials Measurement Software Suite

– What is in N1500A?

- Carries the software of the 85070E/71E products to the next generation software experience with greater simplicity, an improved user experience, more powerful data analysis features, and software updates.
- Software that automates complex permittivity and permeability measurements with Keysight network analyzers.
- Flexible option configuration allows you to choose the measurement methods needed
- Method loader interface to easily switch between measurement methods



N1500A Materials Measurement Software Suite

- New software features include multi-channel, trace data pane view, measurement reporting, *.snp file save / import
- One setup program for all network analyzer measurement methods, including dielectric probe
- Method loader interface switches between methods
- Probe hardware is orderable separately

Models	Description	Options	Comments
N1500A	Materials Measurement Software Suite	001: Transmission line and free space 002: Arch reflectivity 003: Resonant cavity 004: Coaxial probe	001 includes 85071E-100 GRL cal. All licenses tied to dongle key, ordered with N1500A-UL8
N1500AU	Subscription Update Service	Same as N1500A	

2014 reference pricing in Appendix
8507xE series software products will be available until December 2015.

Demo…

- 1. Parallel Plate

- 2. Permeability

감사합니다.