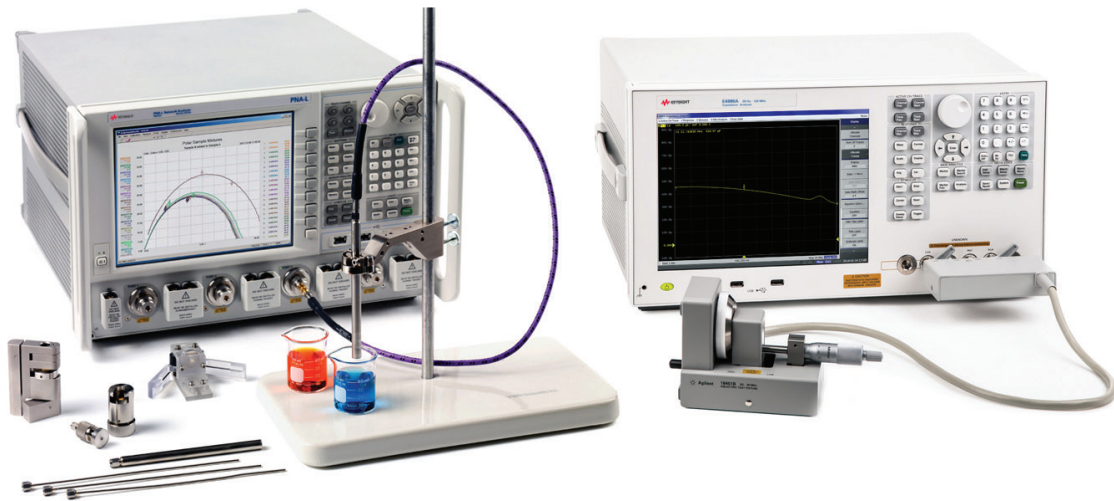
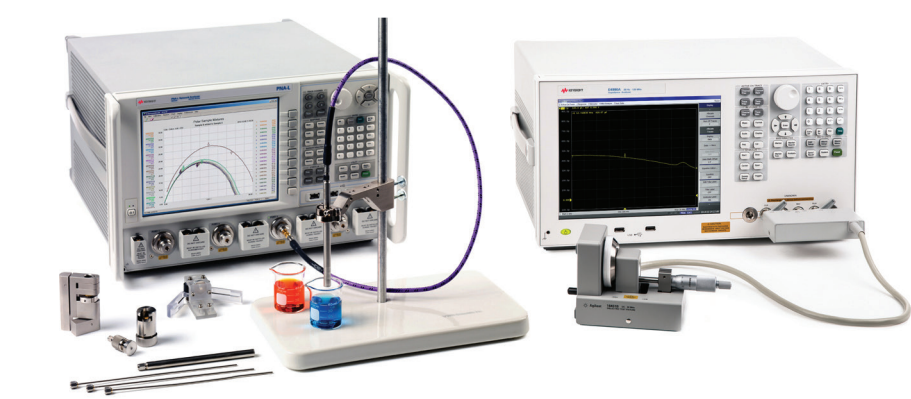


# Keysight Technologies

## Measuring Dielectric Properties Using Keysight's Materials Measurement Solutions





A wide variety of industries need a better understanding of the materials they are working with to shorten design cycles, process monitoring, and quality assurance. Every material has a unique set of electrical characteristics that are dependent on its dielectric properties. Accurate measurements of these properties can provide scientists and engineers with valuable information to properly incorporate the material into its intended application. A dielectric materials measurement can provide critical design parameter information for many electronics applications. For example, the loss of a cable insulator, the impedance of a substrate, or the frequency of a dielectric resonator can be related to its dielectric properties. More recent applications in the area of aerospace, automotive, food and medical industries have also been found to benefit from knowledge of dielectric properties.

The material evaluation systems that generate these measurements must combine precise measurement instruments, test fixtures that hold the material under test (MUT), and software that calculate and display material parameters. Keysight Technologies, Inc. offers you fast, accurate and often non-destructive solutions.

The measurement instruments, such as network analyzers, impedance analyzers and LCR meters provide accurate measurement results with wide frequency range up to 1.1 THz. Fixtures are available that are based on coaxial probe, parallel plate, coaxial/waveguide transmission lines, free space and resonant cavity methods. The easy-to-use materials measurement software streamlines the process of measuring complex permittivity and permeability. The table below shows product examples that can be measured by Keysight's material test solutions.

| Industry                 | Application/products                                                                                                                                                                                                                                                                 |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Electronics              | Capacitor, substrates, PCB, PCB antenna, ferrites, absorbers, SAR phantom materials                                                                                                                                                                                                  |
| Aerospace/defense        | Stealth, RAM (radiation absorbing materials), radomes                                                                                                                                                                                                                                |
| Industrial materials     | Ceramics & composites: A/D and automotive components, coatings<br>Polymers & plastics: fibers, films, insulation materials<br>Hydrogel: disposable diaper, soft contact lens<br>Liquid crystal: displays<br>Other products containing these materials: tires, paint, adhesives, etc. |
| Food & agriculture       | Food preservation (spoilage) research, food development for microwave, packaging, moisture measurements                                                                                                                                                                              |
| Forestry & mining        | Moisture measurements in wood or paper, oil content analysis                                                                                                                                                                                                                         |
| Pharmaceutical & medical | Drug research and manufacturing, bio-implants, human tissue characterization, biomass, fermentation                                                                                                                                                                                  |

- Fast, accurate and non-destructive solutions
- Wide frequency coverage, up to 1.1 THz
- A variety of measurement methods supported

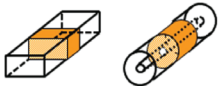
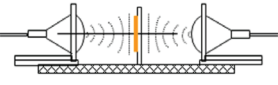
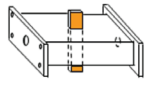
|                                               |                                                                                   |                                                                                        |
|-----------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Coaxial Probe<br>$\epsilon_r$                 |  | Broadband, convenient, non-destructive<br>Best for lossy MUTs; liquids and semi-solids |
| Transmission Line<br>$\epsilon_r$ and $\mu_r$ |  | Broadband<br>Best for lossy to low loss MUTs; machineable solids                       |
| Free Space<br>$\epsilon_r$ and $\mu_r$        |  | Broadband; Non-contacting<br>Best for flat sheets, powders, high temperatures          |
| Resonant Cavity<br>$\epsilon_r$               |  | Single frequency; Accurate<br>Best for low loss MUTs; small samples                    |
| Parallel Plate<br>$\epsilon_r$                |  | Accurate<br>Best for low frequencies; thin, flat sheets                                |
| Inductance measurement<br>$\mu_r$             |  | Accurate, simple measurement, a toroidal core structure is required                    |

Figure 1. Materials measurement techniques

## Measurement techniques

There are several measurement techniques that exist for measuring dielectric properties of materials. Users need to verify which technique is appropriate for their MUT. Keysight solutions cover all the measurement techniques.

### Coaxial probe method

The coaxial probe method is best for liquids and semi-solid (powder) materials. The method is simple, convenient, non-destructive and with one measurement. A typical measurement system consists of a network analyzer or impedance analyzer, a coaxial probe and software. Both the software and the probe are included in the Keysight N1501A dielectric probe kit. Depending on the analyzer and probe used, we can measure from 10 MHz to 50 GHz.

The high temperature probe (a) withstands a wide  $-40$  to  $+200^\circ\text{C}$  temperature range. The large flange allows measurements of flat surfaced solid materials, in addition to liquids and semi-solids. The slim probe (b) allows it to fit easily in fermentation tanks, chemical reaction chambers, or other equipment with small apertures. The performance probe (c) combines rugged, high temperature and frequency performance in a slim design. The probe can be autoclaved, so it is perfect for applications in the food, medical, and chemical industries where sterilization is a must.

### Transmission line method

The transmission line method is a broadband technique for machine-able solids. It puts the MUT inside a portion of an enclosed transmission line.

### Free space method

Free space methods use antennas to focus microwave energy at or through a slab of material. This method is non-contacting and can be applied under high temperatures. It is especially useful at mm-wave frequencies.

## Resonant cavity method

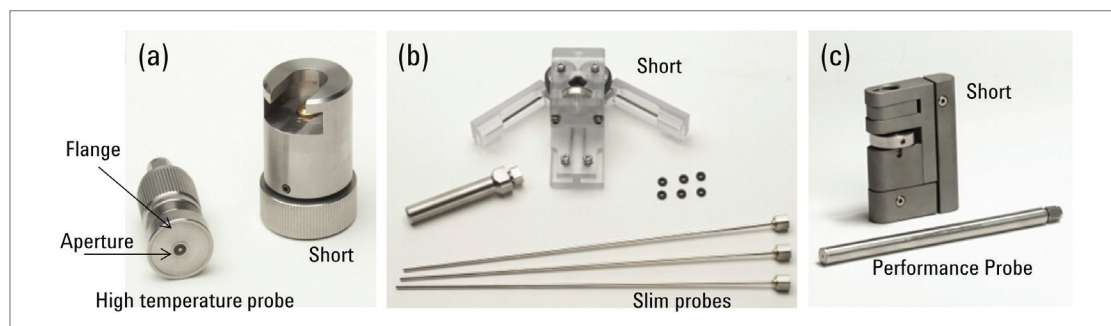
Resonant cavities are high Q structures that resonate at certain frequencies. A sample of the material affects the center frequency and Q factor of the cavity. The permittivity can be calculated from these parameters. Keysight offers 85072A 10 GHz split cylinder resonator, as well as Split post dielectric resonators (SPDR).

## Parallel plate capacitor method

The parallel plate capacitor method involves sandwiching a thin sheet of material between two electrodes to form a capacitor. The method works best for accurate, low frequency measurements of thin sheets or liquids. A typical measurement system using the parallel plate method consists of an LCR meter or impedance analyzer. Keysight offers several test fixtures such as 16451B, 16452A and 16543A depending on material types and applied frequency ranges that can cover up to 1 GHz.

## Inductance measurement method

This method derives the permeability by measuring the inductance of the material (toroidal core). The concept is to wind some wire around MUT and evaluate the inductance with respect to the ends of the wire. The Keysight 16454A magnetic material test fixture provides an ideal structure for single-turn inductor, with no flux leakage when a toroidal core is inserted in it.



Keysight N1501A dielectric probe kit

Measurement systems

Keysight offers a variety of fixtures and measurement instruments that covers many material types. The software is also provided depending on required measurement techniques or instruments. See related literature for more information.

Test fixtures and instruments

The lineup of Keysight test fixtures is summarized in Figure 2. See Table 1 for available measurement instruments.

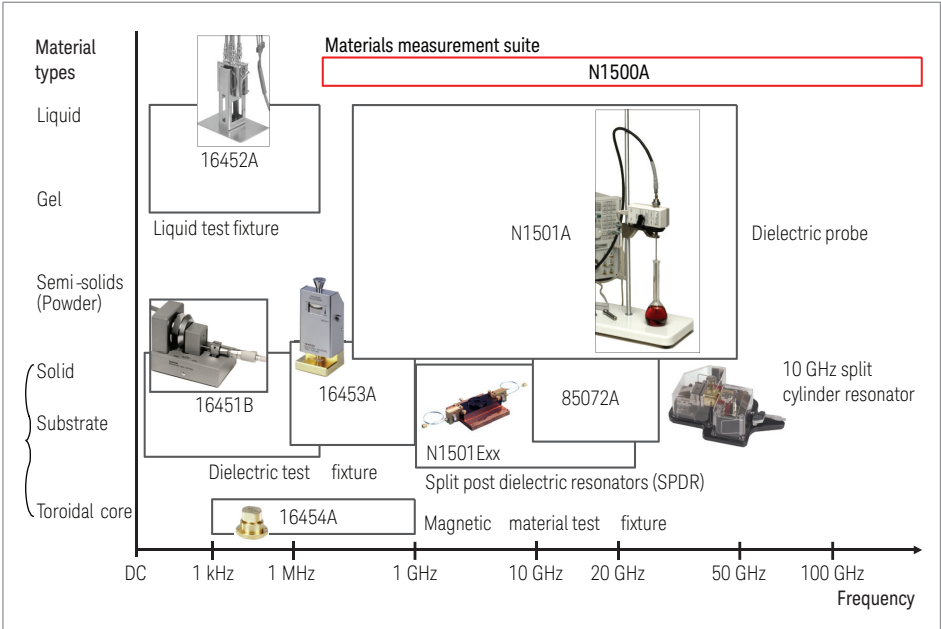


Figure 2. Keysight materials measurement fixtures

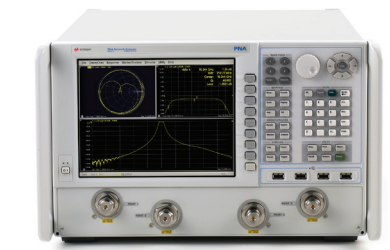
Table 1. Keysight test fixtures and instruments<sup>1</sup>

|                     |                                         | PNA | ENA | FieldFox | E4991B | E4990A | E4980A | 4285A | Method          |
|---------------------|-----------------------------------------|-----|-----|----------|--------|--------|--------|-------|-----------------|
| N1501A <sup>2</sup> | Dielectric probe kit                    | ●   | ●   | ●        | ●      |        |        |       | Coaxial probe   |
| N1501Exx            | Split post dielectric resonators (SPDR) | ●   | ●   | ●        |        |        |        |       | Resonant cavity |
| 85072A              | 10 GHz split cylinder resonator         | ●   | ●   |          |        |        |        |       | Resonant cavity |
| 16451B              | Dielectric material test fixture        |     |     |          |        | ●      | ●      | ●     | Parallel plate  |
| 16452A              | Liquid test fixture                     |     |     |          |        | ●      | ●      | ●     | Parallel plate  |
| 16453A              | Dielectric material test fixture        |     |     |          | ●      |        |        |       | Parallel plate  |
| 16454A              | Magnetic material test fixture          |     |     |          | ●      | ●      |        |       | Inductance      |

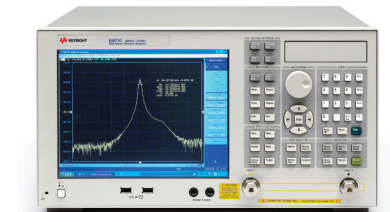
1. Refer to "Keysight LCR Meters, Impedance Analyzers and Test Fixtures, Selection guide" (5952-1430E) and "N150xA series supported analyzers" (<http://na.support.keysight.com/materials/docs/N1500A-VNAs.pdf>) for more detail.

2. N1501A with E4991B requires N1500A-004 software revision v2014-20150115 and above.

Keysight network analyzers, up to 1.1 THz



PNA family network analyzers

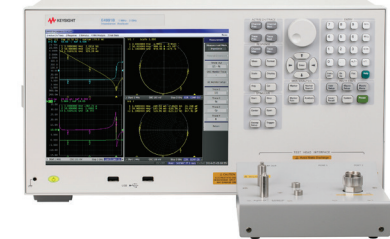


ENA series network analyzers

E4990A precision impedance analyzer, 20 Hz to 120 MHz



E4991B impedance/material analyzer, 1 MHz to 3 GHz



## Software

The Keysight N1500A materials measurement suite streamlines the process of measuring complex permittivity and permeability with a network analyzer. The easy-to-use software guides the user through setup and measurement, instantly converting S-parameter network analyzer data into the data format of your choice and displaying the results within seconds. Results can be charted in a variety of formats:  $\epsilon_r$ ,  $\epsilon_r''$ ,  $\tan \delta$ ,  $\mu_r$ ,  $\mu_r''$ ,  $\tan \delta_\mu$  and Cole-Cole.

A variety of measurement methods and mathematical models are provided to meet most application needs. The free space calibration option provides Keysight's exclusive gated reflect line (GRL) calibration for measuring materials in free space. Arch reflectivity option automates popular NRL arch method for measuring reflections off the surface of a sample. Resonant cavity option offers the highest loss tangent accuracy and resolution.

## Related Literature

*Basics of Measuring the Dielectric Properties of Materials, Application note,*  
Literature number 5989-2589EN

*Solutions for Measuring Permittivity and Permeability with LCR Meters and Impedance Analyzers, Application note,* Literature number 5980-2862EN

*Split Post Dielectric Resonators for Dielectric Measurements of Substrates, Application note,* Literature number 5989-5384EN

*Keysight N1501A Dielectric Probe Kit, Technical overview,*  
Literature number 5991-0264EN

*Keysight N1500A Materials Measurement Suite, Technical overview,*  
Literature number 5992-0263EN

*Keysight 85072A 10-GHz Split Cylinder Resonator, Technical overview,*  
Literature number 5989-6182EN

*Keysight LCR Meters, Impedance Analyzers and Test Fixtures, Selection guide,*  
Literature number 5952-1430E

## Web Resources

Visit our websites for additional product information.

Materials Test Equipment:  
[www.keysight.com/find/materials](http://www.keysight.com/find/materials)

Network Analyzers:  
[www.keysight.com/find/na](http://www.keysight.com/find/na)

Impedance Analyzers and LCR Meters:  
[www.keysight.com/find/impedance](http://www.keysight.com/find/impedance)

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