Agilent 85072A 10-GHz Split Cylinder Resonator

Technical Overview

Part of the complete turn-key solution for the IPC test method TM-650 2.5.5.13[1]

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Features

- Measures complex permittivity and loss tangent of thin film, un-clad substrates and low loss sheet materials
- Complies with IPC test method TM-650 2.5.5.13[1]
- Works with Agilent resonant cavity software
- Innovative design is robust and easy to use
- Depending on sample properties, higher frequency modes may also be measured

Agilent Technologies

The Agilent Technologies 85072A split cylinder resonator measures relative permittivity and loss tangent of thin film, un-clad substrates and low loss sheet materials. An Agilent vector network analyzer, cables and software, purchased separately, complete the test system.

The split cylinder resonator is a cylindrical resonant cavity separated into two halves. The sample is loaded in a gap between the two cylinder halves. One cylinder half is fixed, and the other adjusts allowing the gap to accommodate varying sample thicknesses. In order to measure the TE_{0np} modes in the resonator, a small coupling loop is introduced through a small hole in the side of each cylinder half.

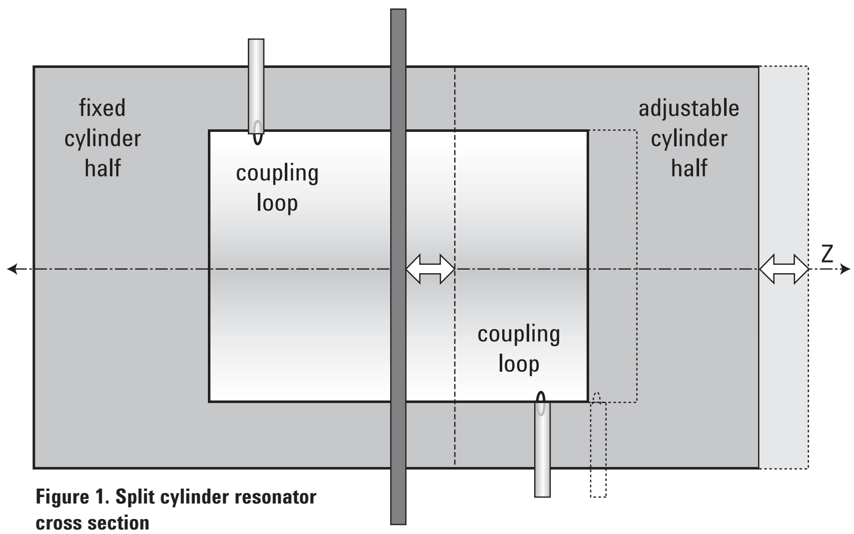


Figure 1. Split cylinder resonator cross section

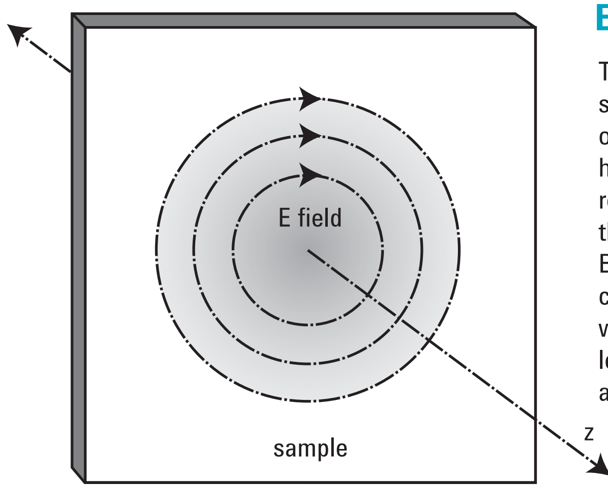


Figure 2. Electrical field orientation is parallel to the sample and perpendicular to the z axis of the cylinder

Electric Field Orientation

The electric field is parallel to the sample and perpendicular to the z axis of the cylinder halves. To achieve the highest sensitivity of the split cylinder resonator, the sample is placed where the electric field is at its maximum. Because of the symmetry of the cylinders, this occurs in TE_{0np} modes where p, the number of half wave-lengths along the cylinder z axis, is an odd integer.

The real part of permittivity, ϵ′, and loss tangent or tan delta, tanδ, are calculated from the sample thickness, cylinder length, and S-parameter measurements of the split cylinder resonator, both empty and loaded with the sample. Using a mode matching model developed at NIST in Boulder, Colorado, permittivity and loss tangent can be calculated at the TE_{011} mode as well as higher order TE_{0np} modes [2].

When the sample is loaded into the split cylinder resonator, the resonant frequency will shift downward so the measurement frequency is always lower than the frequency of the empty split cylinder resonator. The amount of frequency shift is dependent on the real part of permittivity and thickness of the sample. By varying the thickness of the sample, it may be possible to target a specific measurement frequency. It is also possible that the measurement frequency may shift down into a range where interference from other non-TE modes can cause distortion and decrease the accuracy of the measurement. Increasing or decreasing the thickness of the sample may shift the measurement frequency away from the interfering mode.

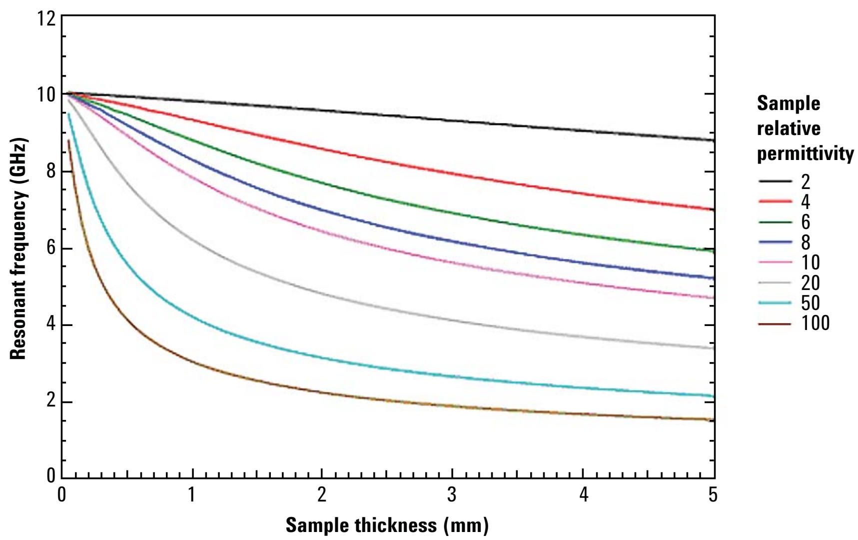


Figure 3. Resonant frequency the TE_{011} mode due to dielectric properties and thickness of sample

The quality factor, or Q factor, of the split cylinder resonator will also decrease when the sample is loaded into the split cylinder resonator. The amount of decrease is dependant on the loss tangent and the thickness of the sample. Thick or lossy materials can decrease the Q factor enough to cause the split cylinder resonator not to resonate properly making it difficult or impossible to measure these materials. Making samples thinner may help increase the Q factor, but for some lossy samples it may not be possible to make them thin enough to measure. Therefore the split cylinder resonator is only recommended for low loss materials.

Agilent's split cylinder resonator is designed for robustness and ease of use

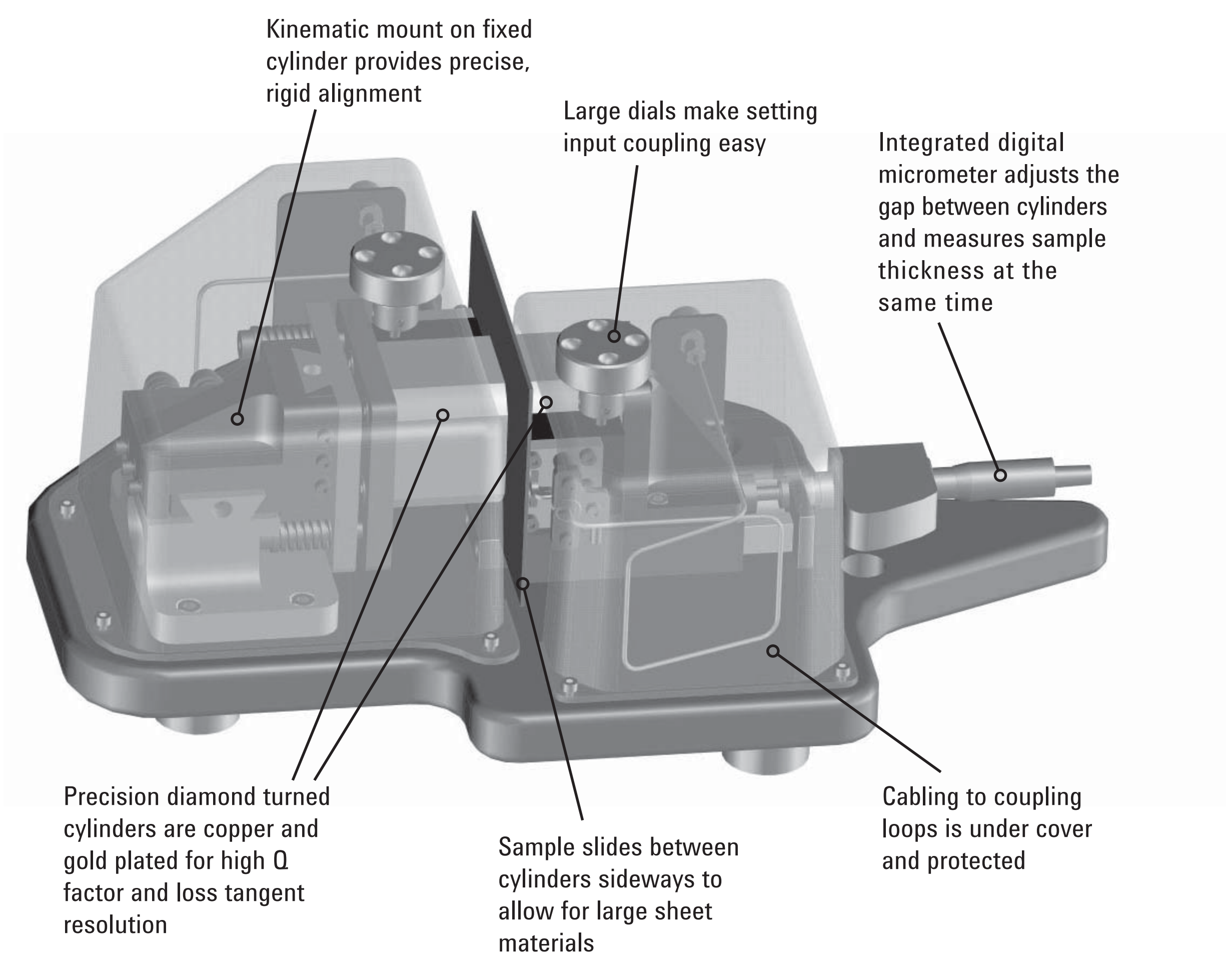


Figure 4. 85072A split cylinder resonator

The 85072A has lightweight aluminum cylinders are diamond turned for the best possible surface finish and then plated with copper and gold for better conductivity and durability. They have a kinematic mount for precise, rigid alignment of the cylinders. These features allow for a high Q cavity and the best loss tangent resolution. The side mounting of the cylinders allows for large samples to be measured. An integrated digital micrometer measures the sample thickness at the time of the measurement. Electrical coupling into the cavity is adjustable with large dials on the top of the fixture, while the coupling loops and cabling itself is protected under protective covers.

Agilent's resonant cavity software* guides you through the whole setup and measurement process

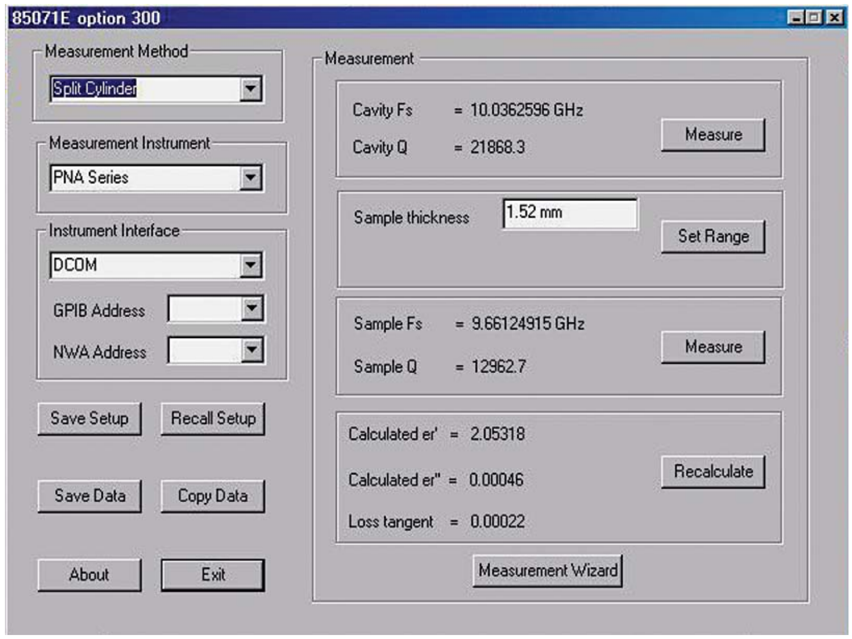


Figure 5. Agilent resonant cavity software guide you through the setup and measurement process

Agilent's resonant cavity software, purchased separately, calculates permittivity and loss tangent using algorithms developed at NIST's Electromagnetics Division in Boulder, Colorado[2]. It provides an intuitive user interface, controls the network analyzer, guides the user through the setup and measurement process and displays the results. Special features developed for the split cylinder resonator help the user select the correct TE_{0np} modes, determine if they useable, and set the optimum input coupling. It has an application programmable interface (API) which allows the user to develop customized software for their individual needs.

* **Purchased separately**

Example Measurements

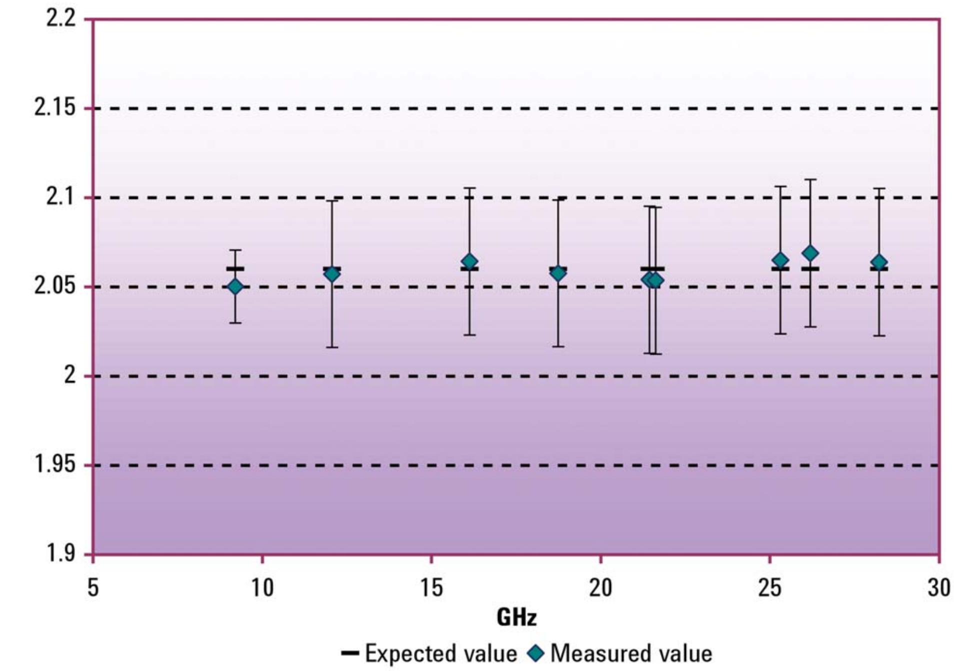


Figure 6. Real part of permittivity (Dk) Teflon ® PTFE

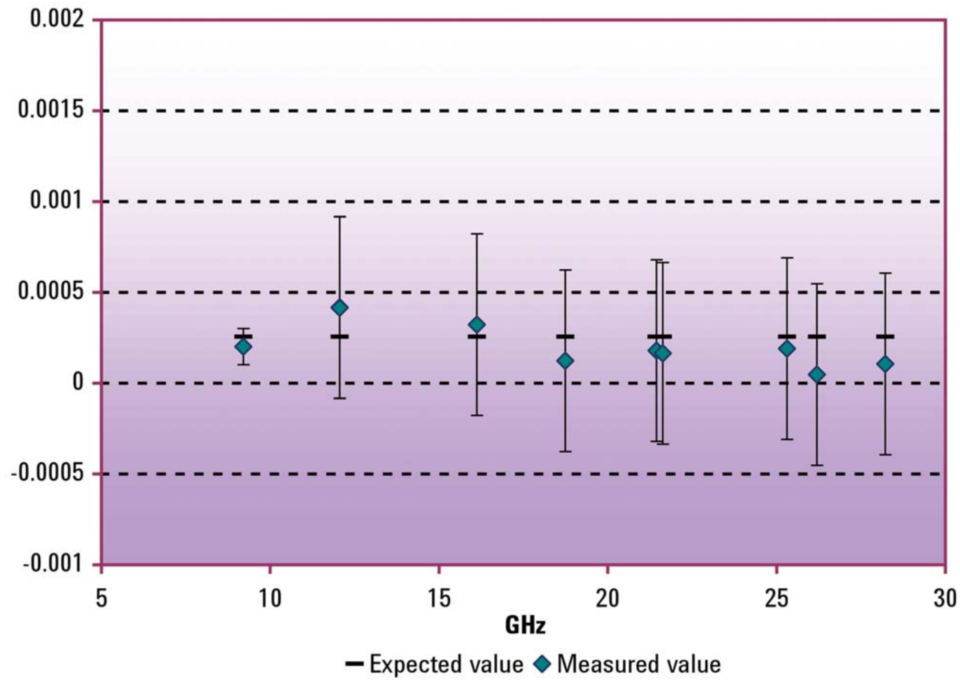


Figure 7. Loss Tangent (Df) Teflon® PTFE.

Agilent's resonant cavity software results displayed in Microsoft Excel® spreadsheets.

Electrical Characteristics

TE_{011} Resonant mode of closed empty cylinders at 23 °C
Frequency = 10.03 ± 0.03 GHz
Q ≥ 20,000 (input coupling at –55 dB)

Additional, possibly useable, higher order TE_{0np} modes exist in the empty cylinders at approximately

13.1 GHz	22.8 GHz	27.0 GHz
17.8 GHz	22.9 GHz	27.1 GHz
19.7 GHz	25.6 GHz	28.2 GHz

Usability of TE_{0np} modes depends on dielectric properties and thickness of the sample. For some samples, interference from other non-TE modes can make one or more higher order TE_{0np} modes unusable. Increasing or decreasing the thickness of the sample may shift the measurement frequency away from the interfering mode.

Typical Uncertainty

TE_{011} mode

Real part of permittivity:	±1%
Loss tangent:	±0.0001

Useable higher order TE_{0np} modes

Real part of permittivity:	±1 – 2%
Loss tangent:	± 0.0005

Sample Requirements

The sample is assumed to be non-magnetic (μr* = 1-j0), homogeneous and non-isotropic, with uniform thickness and flat parallel sides.

Actual values of permittivity and loss tangent that can be measured with the split cylinder resonator are dependent on thickness.
Suggested values for 1mm thick sample are:
Real part of permittivity < 100
Loss tangent < 0.01

Thickness: 0.1 to 3 mm, typically 1 mm. Thinner samples can be stacked.
Samples up to 5 mm can fit between cylinders but accuracy is degraded.
Minimum length or diameter 56 mm, ideally 60 mm or more for easier handling.

Mechanical Characteristics

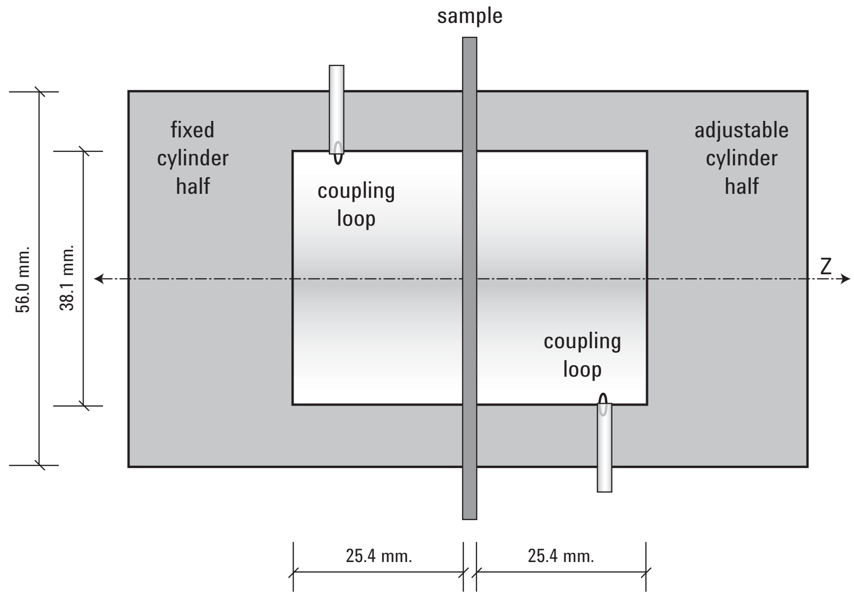
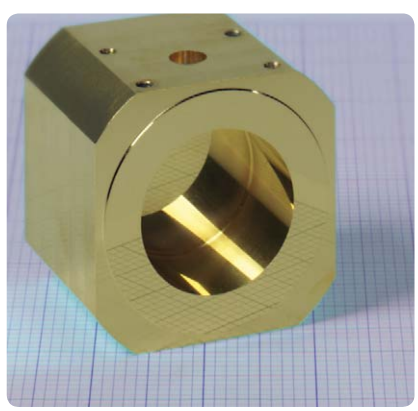


Figure 8. Split cylinder resonator cross section with dimensions

Cylinders are precision diamond turned Al 6061-T6 plated with 0.5 µm Cu, 0.25 µm PdNi, and 2.0 µm Au.

Length = 25.4 mm ± 0.010
Diameter = 38.1 mm ±0.005
Input connectors: 3.5 mm female
Micrometer resolution 0.001 mm
Micrometer typical accuracy 0.01 mm
Operating temperature: 0 to 60 °C (digital micrometer display: 5 to 40 °C)



Looking into one half of the split cylinder

The cylinders in Agilent's split cylinder resonator are precision diamond turned for a mirror surface finish, providing a highest Q factor for high accuracy and high resolution measurements.

Configuration Guide

Complete turn-key system

- 85072A split cylinder resonator
- 85071E materials measurement software with Option 300 resonant cavity software
- N4419AK20 3.5mm male to female cables, quantity 2
- N5230A PNA-L network analyzer, Option 220, 10 MHz to 20 GHz

Or

N5230A PNA-L network analyzer, Option 420,10 MHz to 40 GHz
(add 85130-60010 adapters, quantity 2)

Any other PNA, PNA-L, or PNA-X Series network analyzer can be substituted. For 40 GHz and higher PNA and PNA-L, add 85130-60010 adapters, quantity 2.

References

1. IPC TM-650 2.5.5.13 *Relative Permittivity and Loss Tangent Using a Split-Cylinder Resonator*

2. M.D. Janezic, ''*Nondestructive Relative Permittivity and Loss Tangent Measurements using a Split-Cylinder Resonator*,'' Ph.D. Thesis, University of Colorado at Boulder, 2003.

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