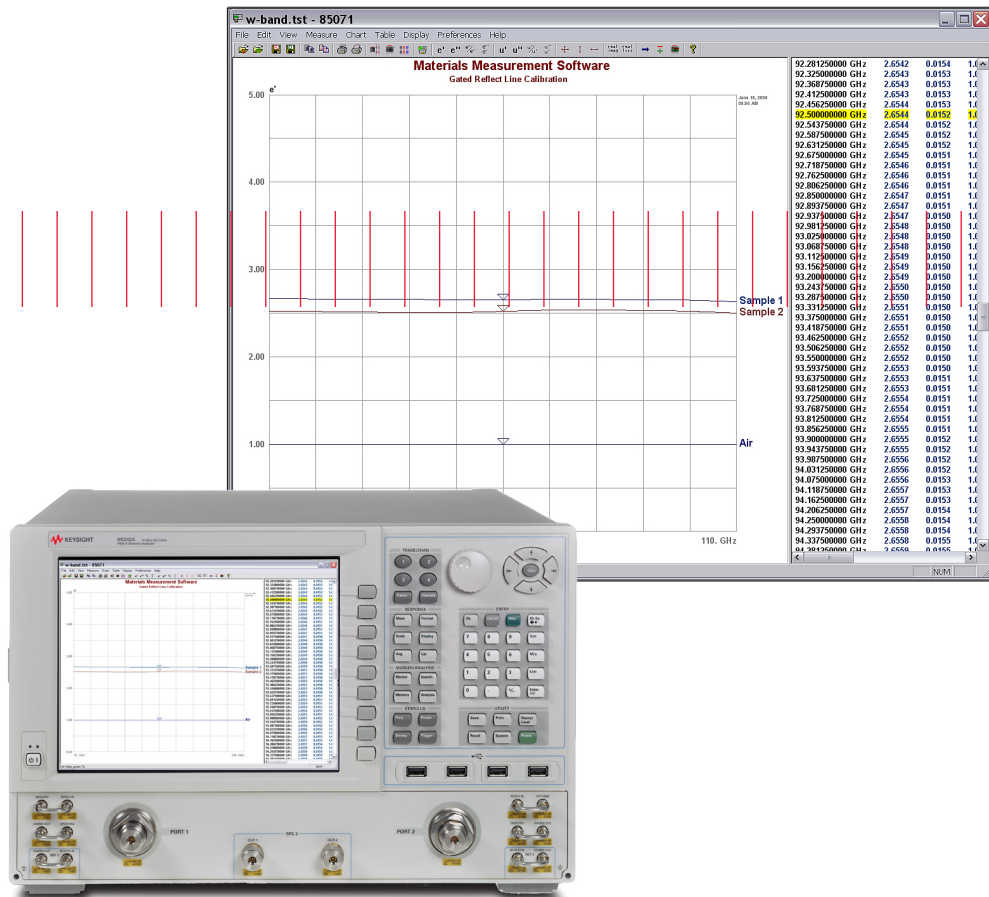


Keysight 85071E

Materials Measurement Software

Technical Overview



Introduction

Features of 85071E

- Software automates complex permittivity and permeability measurements.
- Results can be charted in a variety of formats (ϵ_r' , ϵ_r'' , $\tan \delta$, μ_r' , μ_r'' , $\tan \delta_m$ and Cole-Cole)
- Data is easily shared with other Windows-based programs or through the user programmable Component Object Model (COM) interface.
- A variety of measurement methods and mathematical models are provided to meet most application needs

New connection manager works with Keysight Technologies, Inc. Connection Expert to bring ease and flexibility to interface between software and analyzer. GPIB and LAN are both supported with most PNA and ENA network analyzers.

Download a free demo from our web site:
www.keysight.com/find/materials

Automate complex permittivity and permeability measurements with Keysight's 85701E materials measurement software

Measure ϵ_r^* and μ_r^* over a wide frequency range

The Keysight 85701E materials measurement software determines the intrinsic electromagnetic properties of many dielectric and magnetic materials. The complete system is based on a versatile Keysight network analyzer which measures the material's response to RF or microwave energy.

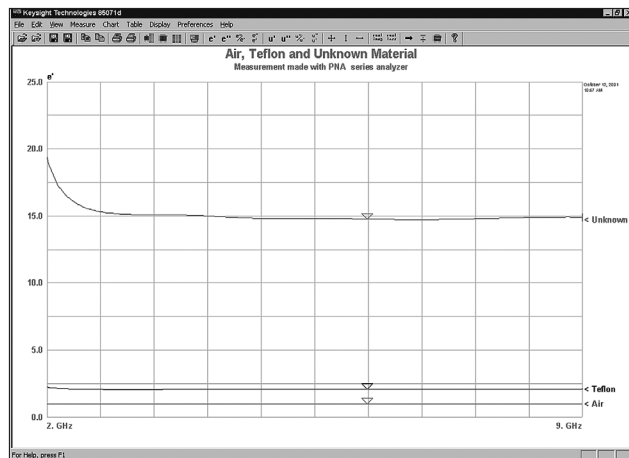


Figure 1. Examine the properties of materials across the RF and microwave frequency spectrum.

The 85701E software controls the network analyzer and calculates the complex permittivity ϵ_r^* (or dielectric constant) and permeability μ_r^* , including the loss factor or loss tangent. Results are displayed as a function of frequency, with 1 to 2% accuracy (typical). Depending on the Keysight network analyzer and fixture used, frequencies can extend into mm and sub mm wavelengths.

Display Data to Aid Analysis

The split screen window and markers aid in data analysis. Simply click on a point in the chart or table to activate and move the marker. Charts can be generated in a variety of formats: ϵ_r' , ϵ_r'' , $\tan \delta$, μ_r' , μ_r'' , $\tan \delta_m$, and Cole-Cole.

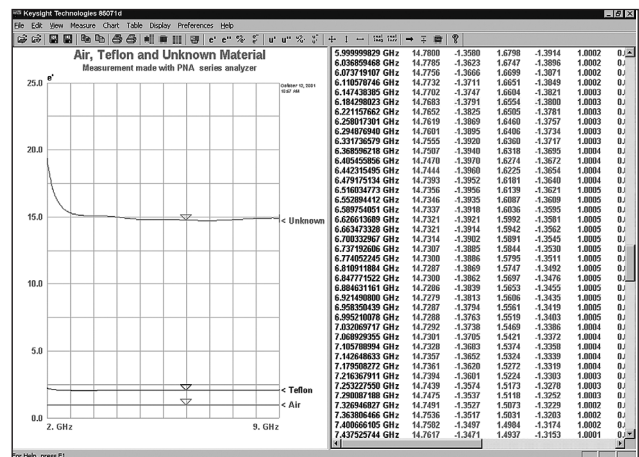


Figure 2. Display data in chart form, table form, or both!

Connect to other programs

Data charts and tables can easily be copied and pasted into any Windows-based application for further analysis or report generation.

The component object model (COM) interface allows the measurement to be setup, triggered and read from a user written program. This is particularly valuable for analyzing material changes over time. Example Visual Basic® and C++ projects are included to aid program development.

Measurement Methods

Transmission Line Method

Coaxial airlines or rectangular waveguide transmission lines are used as sample holders. The transmission line method works best for materials that can be precisely machined to fit inside the sample holder. The 85071E features an algorithm that corrects for the effects of air gap between the sample and holder, considerably reducing the largest source of error with the transmission line technique.

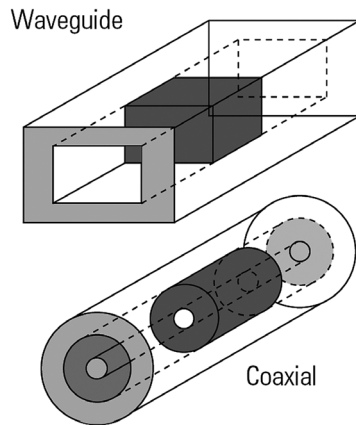


Figure 3. Simple coaxial or waveguide transmission lines hold the samples of material under test.

Free Space Method

In this method, materials are placed between antennas for a non-contacting measurement. The free space method works best for large flat solid materials, but granular and powdered materials can also be measured in a fixture. It is very useful for many applications such as non-destructive testing, measuring materials that must be heated to very high temperatures, or measuring a large area of material that is non-uniform such as honeycomb or a composite. Calibration and gating techniques performed in the network analyzer can be used to reduce measurement errors.

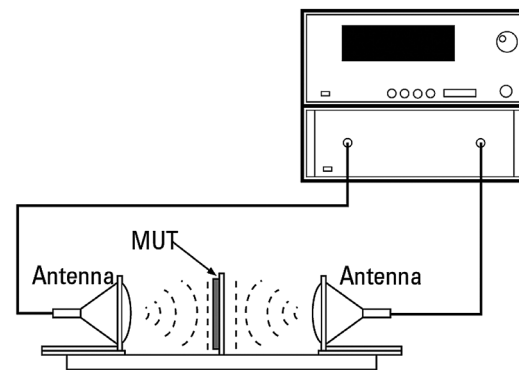


Figure 4. Antennas direct beams of microwave energy at or through a material, without enclosing it in a fixture.

Free Space Calibration (Option 100)

The Free Space Calibration Option increases ease of use and reduces the costs associated with TRM and TRL calibration methods. The Gated Reflect Line (GRL) calibration technique converts a coaxial/waveguide 2-port calibration into a full 2-port freespace calibration. Use of this option requires an 8510 or a PNA Series network analyzer with the time domain option, an appropriate freespace fixture and a metal calibration plate. This option also includes a gated isolation/ response calibration, which reduces errors from diffraction effects at the sample edges, and multiple residual reflections between the antennas.

Accurate free space measurements are now possible without expensive spot focusing antennas, micro positioning fixturing or direct receiver access. The software automatically sets up all the free space calibration definitions and network analyzer parameters, saving engineering time. In the PNA, additional ease and timesaving is provided with the use of ECal, electronic calibration, which features a guided calibration wizard that steps you through a fast and easy calibration process.

Table 1. Models in the 85701E Materials Measurement Software

85701E Name	Alternate Name(s)	S-parameters measured	Result	Description
Reflection/Transmission Mu and Epsilon	Nicholson-Ross -Weir, NRW	S11, S21, S12, S22	ϵ_r, μ_r	Originally developed by Nicholson and Ross, and later adapted to automatic network analyzers by Weir to calculate permittivity and permeability from transmission and reflection coefficients. Can have discontinuities for low loss samples with thickness of $> \frac{1}{2}$ wavelength.
Reflection/Transmission Epsilon Precision	NIST Precision	S11, S21, S12, S22	ϵ_r	Developed by NIST to calculate permittivity from transmission and reflection coefficients.
Transmission Epsilon Fast	Fast Transmission	S21, S12	ϵ_r	An iterative technique that estimates permittivity and then minimizes the difference between the S-parameter value calculated from that permittivity and the measured values until the error is less than the expected system performance. Uses only transmission parameters S21, S12, or the average of S21 and S12
Reflection/Transmission Mu and Epsilon Polynomial Fit	Poly Fit, Bartley-Begley, BB	S11, S21, S12, S22	ϵ_r, μ_r	Uses an iterative technique to fit material properties to a polynomial, incrementing the order of the polynomial until the difference between S-parameters calculated from the polynomial and the measured S-parameters is less than the expected system performance, or the maximum order specified by the user is reached. Best for magnetic samples. Not recommended for meta or left handed materials.
Transmission Epsilon Polynomial Fit	Poly Fit, Bartley-Begley, BB	S21, S12	ϵ_r	Similar to Reflection / Transmission Mu and Epsilon Polynomial Fit. Uses an iterative technique to fit material properties to a polynomial, incrementing the order of the polynomial until the difference between S-parameters calculated from the polynomial and the measured S-parameters is less than the expected system performance, or the maximum order specified by the user is reached. For non-magnetic materials. Not recommended for meta or left handed materials.
Stack Transmission Mu and Epsilon	Stack Two Transmission	S21, S12 (2 samples)	ϵ_r, μ_r	An iterative technique that uses two transmission measurements. One measurement is of the sample which optionally may be backed by a known dielectric. The second is of the sample, backing and another known dielectric. The model is useful for free space measurements. It requires a full 2-port or a two-port transmission resp/isol cal.
Reflection Only Epsilon Short-Backed	Short Backed	S11	ϵ_r	An iterative technique that minimizes the difference between the measured and calculated reflection coefficient of a material backed by a short. The idea of measuring a material backed by a short was published by Von Hippel. Although, Von Hippel uses tables to determine the value of permittivity instead of iteration.
Reflection Only Epsilon Arbitrary- Backed	Arbitrary Backed	S11	ϵ_r	An iterative technique that minimizes the difference between the measured and calculated reflection coefficient of a material backed by a separately measured backing. This model is an extension of method proposed by Von Hippel. It is useful when the material is electrically short such that the voltage across the material is effectively zero when backed by a short.
Reflection Only Mu and Epsilon Single/Double Thickness	Single/Double Thickness	S11 (2 samples)	ϵ_r, μ_r	Uses two reflection coefficient measurements to calculate S11 and S21 of the material. The measurements are a sample and a sample that is twice the length as the original. After doing so the Nicolson Ross model is used to determine the material properties.

Mathematical Models

The 85071E has eight different algorithms to choose from, each with specific benefits: The traditional method, as described by Nicolson and Ross, is best for magnetic materials such as ferrites and absorbers. It calculates both ϵ^* and μ^* (including loss) from a two-port measurement of a single sample, producing results quickly and easily.

The 85071E also includes two additional two-port algorithms for non-magnetic materials ($\mu^*=1$). These models do not suffer from discontinuities at frequencies where the sample length is a multiple of half-wavelengths and are best for long, low-loss materials.

While the two-port algorithms are best for most solid materials, one-port algorithms provide a simple calibration and measurement and can be better suited to measurements of liquids and powders. For example, a shorted waveguide can be turned on end and filled with a material for a one-port measurement. One-port fixtures are also better suited for high-temperature measurements where one end of the fixture can be heated, while cooling mechanisms at the other end protect the network analyzer.

Although one-port fixtures are usually terminated with a short circuit, the 85071E also accommodates an arbitrary termination which produces more reliable results for thin samples.

New Feature: De-embedding

De-embedding allows a sample to be backed with a dielectric backing. It mathematically removes the effects of the backing, so the electromagnetic properties of just the sample are reported. This is useful when a sample is not stiff or thick enough to stand up by itself, or it cannot be removed from a substrate. The backing must have a known permittivity and thickness. If the permittivity of the backing is not known, it can be measured separately first. The backing material cannot be magnetic and it must allow the microwave signal to transmit through it so that S21 and S12 can be measured.

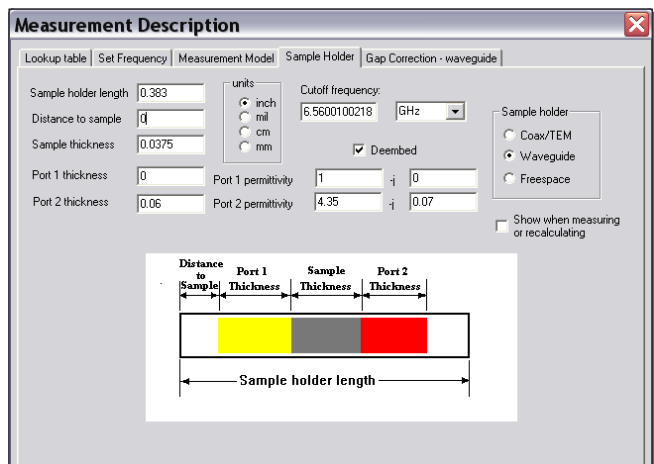


Figure 5. Example of the De-embed user interface for a sample backed on the port 2 side.

De-embedding feature works with the following transmission models:

- Reflection/Transmission Mu and Epsilon
- Transmission Epsilon Fast
- Polynomial Fit.

Performance Characteristics

Specifications describe the warranted performance over the temperature range 0 to 55 °C. Supplemental characteristics are intended to provide information useful in applying the instrument, by giving typical but non-warranted performance parameters. These are denoted as “typical,” “nominal,” or “approximate.”

Frequency range (typical)

100 MHz to 325 GHz depending on network analyzer, fixture and material.¹

Accuracy (typical)

1 to 2 percent

Transmission line fixtures

Coaxial fixtures (beadless airlines) are broadband but require a sample shaped into a flat-faced torus. Waveguide fixtures are band-limited but operate at higher frequencies and accept a simpler rectangular shape.

Samples must completely fill the cross section of the transmission line without gaps at the fixture walls. Faces at either end must be flat, smooth and perpendicular to the long axis.

Free space systems

Large, flat, thin, parallel-faced samples are placed between antennas and measured under free space conditions. Antennas should maintain a planar “far-field” wavefront to the sample.²

Material under test assumptions

Material is homogeneous (uniform composition) with no layers.³ Non-isotropic (uniform orientation) materials can be measured in waveguide.

1. Minimum frequency is set by the maximum practical sample length (L): f (in GHz) $> \frac{1}{\sqrt{\epsilon_r \mu_r}} \frac{30 \text{ cm}}{L(\text{in cm})} \frac{20}{360}$

2. Antenna should be placed $\approx 2d^2/\lambda$ from the sample, where d is the larger of the antenna or sample diameter.

3. If the material is not homogeneous through the length of the sample (i.e., layers), the reflection from the front (S_{11}) and back (S_{22}) face will be different and will lead to a potentially erroneous result. If the material is not homogeneous across the face of the sample, the result is an average value over the cross section that is exposed to the EM field (weighted by the intensity).

Software Menu Items

File

Save or recall measurement setups or previous measurement results. Print copies of the measurement results in a tabular or graphical format.

Edit

Copy the measurement results to the clipboard. Either graph or the tabular listing can be copied. This allows your measurements results to be pasted into other applications.

View

Select what you want to view. Selections include the toolbar, status bar, table of the measurement data and chart of the measurement data.

Measure

Trigger a measurement; recalculate without re-measuring the MUT; set measurement model; define sample holder; set measurement attributes and perform a GRL calibration.

Chart

Select the format to be displayed on the chart. Choices include ϵ_r' , ϵ_r'' , $\tan \delta$, μ_r' , μ_r'' , $\tan \delta_m$ and Cole-Cole. Set scale factors or “autoscale.” Select from linear, semi-log, or log-log representations.

Table

Choose between a tabular formatting of real and imaginary or real and $\tan \delta$.

Display

Display current measurement data; save/display up to 3 memory traces; compare data to reference trace with trace math. Turn the marker on or off.

Preferences

Select your preferences of fonts, colors, and annotations used to plot and list the measurement data.

Help

On line help including the product manual.

ToolBar

Provides single click access to the most important menu items.

Additional Measurement Methods

NRL Arch Free Space Method

First developed by the U.S. Naval Research Lab, the NRL arch measurement method is a useful technique to test angular dependent absorptive characteristics of a material. The typical setup involves a network analyzer connected to two horn antennas fixed to an arch armature above (or below) a flat piece of the material under test. One antenna operates as the transmitting antenna while the second one receives the reflected signal to complete a one-port measurement. Sample should be in “far field.”

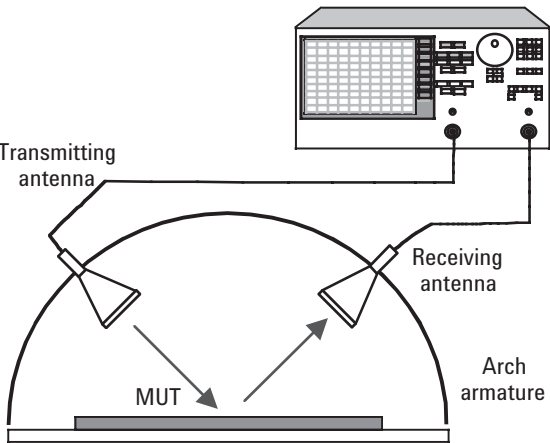


Figure 6. In the NRL arch method, one antenna transmits energy onto the MUT and the second antenna receives the reflected portion.

Arch Reflectivity Software (Option 200)

Now you can automate your NRL arch measurements with the new Arch Reflectivity Software addition.

Option 200 provides a separate software program that automates NRL arch measurements. The program guides you through the complete process of setup, calibration and measurement of material absorption. Measurements are displayed in both a graphical and tabular form — with up to four measurements displayed simultaneously for comparison. The software includes markers to aid in measurement analysis, and complete measurement results and setup can be saved and recalled. Also, data can be saved in a spreadsheet compatible file format or copied into other applications for further analysis.

Keysight’s Arch Reflectivity Software makes it possible to instantly update any NRL arch system to state-of-the-art hardware and measurement techniques.

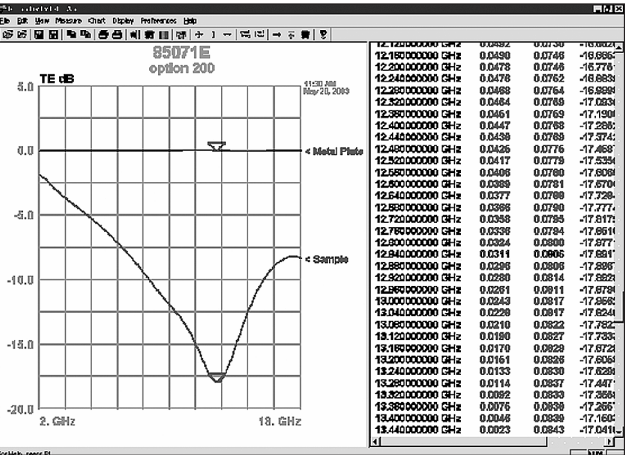


Figure 7. Example of arch reflectivity measurement results.

Additional Measurement Methods continued...

Resonant Cavity Method

Choose the Resonant Cavity method, for thin films, substrate materials, and other low loss materials. The resonant cavity method uses a network analyzer to measure resonant frequency and Q of a resonant cavity fixture, first empty and then loaded with the sample under test. Permittivity can then be calculated from these measurements, knowing the volume of the sample, and some other parameters about the resonant cavity. Because it is a resonant method, only one frequency point is reported. However, it is much more sensitive and has better resolution than the other techniques. Typical resolution for this method is 10^{-4} where the broadband methods is 10^{-2} .

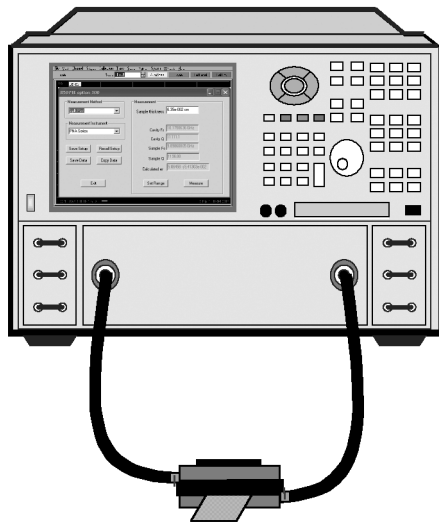


Figure 7. Resonant Cavity connected between ports.

New! Resonant Cavity Software (Option 300)

Keysight's new Resonant Cavity software controls an Keysight vector network analyzer to measure the resonant frequency of the loaded and unloaded resonant cavity. A least squares circle fitting technique is used to calculate Q, which uses both magnitude and phase information and is more repeatable than other Q calculation methods. The software then calculates ϵ_r' , ϵ_r'' and loss tangent and displays them in it's easy to use interface.

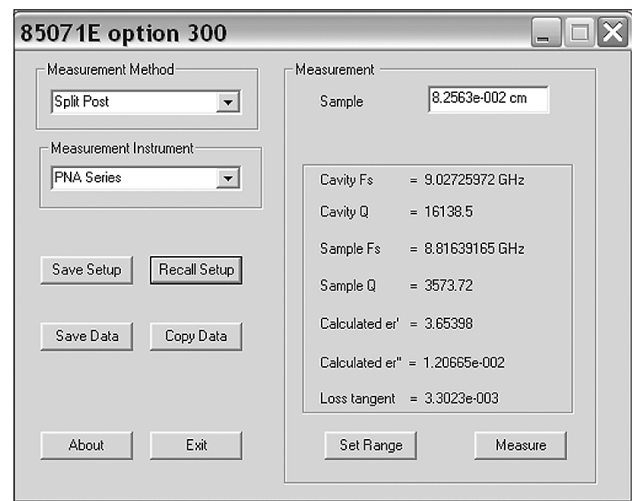


Figure 8. Resonant Cavity Software User Interface

Resonant Cavity Software has a COM applications interface, allowing users to automate measurements easily.

Resonant Cavity Software supports Split Post Dielectric Resonators from QWED. These resonators are high quality and are available in frequencies from 1 GHz to 20 GHz. For more information, please email info@qwed.com.pl or visit <http://www.qwed.com.pl/hardware.html>

Resonant Cavity Software also supports ASTM D2520 standard resonators and the Keysight 85072A Split Cylinder Resonator.

Ordering Information

85071E

Materials Measurement Software

Required, but not included:

- Network analyzer (see compatible network analyzers)
- PC (see PC requirements)
- Appropriate fixture for chosen measurement method

Required Security Key

- Option UL8 USB Software Security Key

Option 100¹

Free Space Calibration Option: Provides Gated Reflect Line calibration technique for free space measurement method.

Option 200¹

Arch Reflectivity Software: Provides a separate software program that automates the use of any NRL Arch measurements.

Option 300

Resonant Cavity Software: Provides a separate software program that automates the resonant cavity measurement technique.

Upgrades

85071EU-071

Upgrade from any older version of 85071 software

85071EU-100¹

Add Free Space calibration option to existing software

85071EU-200¹

Add Arch Reflectivity option to existing software

85071EU-300

Add Resonant Cavity option to existing software

Compatible Network Analyzers

A list of compatible network analyzers can be found on the 8507xE Series Support site at:

<http://na.tm.keysight.com/materials/SupportedVNAs.pdf>

PC Requirements

- Windows XP, Windows 7
- Keysight IO Libraries
- DVD Drive or internet connection to load software.

PC is optional for PNA and newer ENA series network analyzers where software can be installed directly on the analyzer. All other analyzers require a PC with a GPIB or LAN interface card. LAN is supported with PNA, newer ENA, and FieldFox models. GPIB is supported with newer PNA and ENA models. Please see: <http://na.tm.keysight.com/materials/SupportedVNAs.pdf> for model number and firmware requirements.

1. Requires time domain option installed on network analyzer

Ordering Information

continued...

Transmission Line Method Sample Holders

Waveguide

Keysight 11644A Series waveguide calibration kits contain a $\frac{1}{4}$ wavelength line and a straight section which can be used as sample holders. There are many third-party suppliers as well. Contact Keysight for information on choosing appropriate waveguide sample holders.

Coaxial

Keysight 8505x Series verification kits contain airlines that can be used as sample holders. There are many third party suppliers as well. Contact Keysight for information on choosing appropriate coax sample holders.

Antennas and Fixtures for Free Space and NRL Arch Methods

Contact Keysight for information on third-party suppliers of free space antennas and fixtures.

Cables and Adapters

Cables and adapters may also be needed to attach sample holders or antennas to the network analyzer. Keysight offers a wide variety of cables and adapters. For more information, visit: www.keysight.com/find/accessories

Calibration Kits

Electronic Calibration (ECal) modules are highly recommended, especially for the PNA Series network analyzer with the 85071E-100 Free Space Calibration Option. For more information about ECal, visit www.keysight.com/find/ecal. Keysight also offers a wide variety of mechanical coax and waveguide calibration kits. Contact Keysight for more information and assistance to choose an appropriate calibration technique.

Free Trial Demo

Evaluate a demo version of 85071E Materials Measurement Software for up to two weeks. Visit the Keysight Web site at www.keysight.com/find/materials to download this demo program.

For more information on materials measurement products such as our Dielectric Probe kit, visit us at www.keysight.com/find/materials

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For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

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