OPERATION MANUAL

FS-330 Free space test solution 18-330 GHz

EM LABS INC.

August 17, 2021

Table of Contents

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1. Product Overview

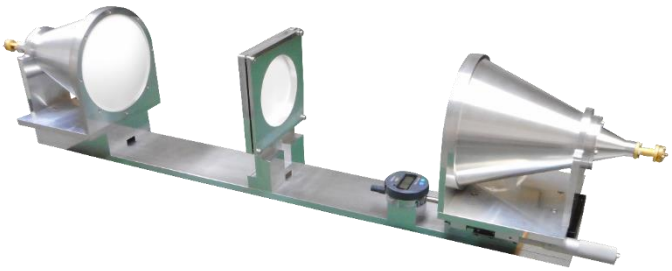
This section outlines the product.

The FS-330 free space test solution is designed to be used with a network analyzer to measure the transmission and reflection characteristics of various materials. It has a precise positioning mechanism of the antenna for accurate measurement using TRL calibration. Complex relative permittivity and permeability can be measured using Keysight Technology's Material Measurement Suite N1500A. The oblique incidence reflection measurement option, FS-330-OR, is available to evaluate the oblique reflection characteristics of various materials.

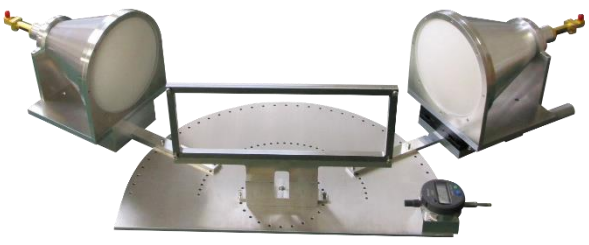
The FS-330 uses dielectric lens antennas to focus the measurement signal, so the sample size can be small. Also, since the side lobe of the antenna is extremely small, highly reproducible measurement is possible without using an anechoic chamber or electromagnetic absorbers.

Appearance and structure

FS-330 consists of a pair of dielectric lens antennas, sample holder and base. One of the antennas has a precise positioning mechanism for TRL calibration. Adapters are available to connect the antenna to the network analyzer depending on the measurement frequency band.



The special base is available for oblique incidence reflection measurement as shown below.



Product specifications

Frequency range: 18GHz – 330 GHz

Dielectric lens antennas:

- Focal length: 280 mm
- Beam size: 3 wavelengths (3 dB width)
- Side lobe: -30dB or less

FS-330-OR Oblique reflection measurement

- Antenna setting angle: 0 - 90 deg (resolution 5 deg)
- Measurable range of oblique incidence reflection characteristics: Antenna setting angle 30 - 60 deg
- Sample holder setting angle: 0 – 360 deg (resolution 15 deg)

Furnished Accessories

Sample holder standard type
- Two sub holders (Φ50 mm, Φ30 mm)
Sample holder for large samples
Sample holder for oblique incidence (FS-330-OR)
Oblique incidence positioning pins ϕ 4 x 6 (FS-330-OR)
Hex keys 2.5 mm, 3 mm, 4mm

Allen screws

For fixing lens antennas (M4 / L10 x 8)

For fixing adapter (M3 / L8 x 8)

For fixing micrometer (M3 / L8x 4)

For fixing sample holder base (M4 / L10 x 4)

For fixing sample holder (M5 / L10 x 2)

For fixing the sample hold base for oblique incidence (M5 / L8 x 1, FS-330-OR)

Optional Accessories

Adapters for connecting the antenna to the analyzer are available for various frequency bands. Depending on the configuration of the measurement system, you can choose between a coaxial connector (female) connection and a waveguide connection.

Coaxial type

Frequency band	Connector	Model Number
K (18-26.5 GHz)	2.4 mm (f)	FS-330-KCF
R (26.5-40 GHz)	2.4 mm (f)	FS-330-RCF
Q (33-50 GHz)	2.4 mm (f)	FS-330-QCF
U (40-60 GHz)	1.85 mm (f)	FS-330-UCF
V (50-75 GHz)	1 mm (f)	FS-330-VCF
E (60-90 GHz)	1 mm (f)	FS-330-ECF
W (75-110 GHz)	1 mm (f)	FS-330-WCF

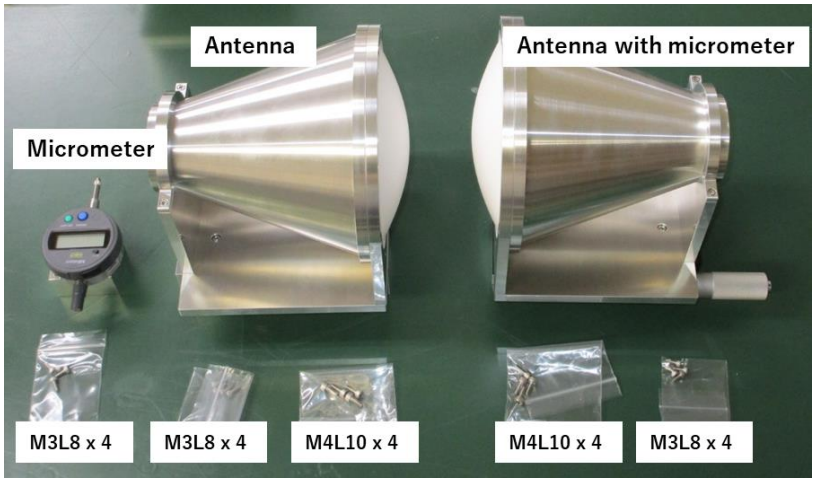
Waveguide type

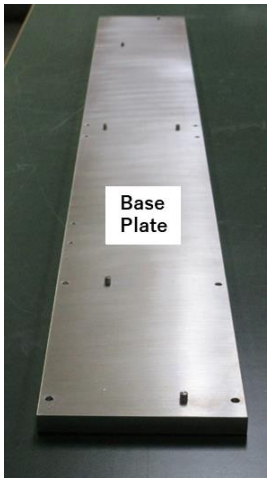
Frequency band	Connector	Model Number
K (18-26.5 GHz)	WR42	FS-330-KWG
R (26.5-40 GHz)	WR28	FS-330-RWG
Q (33-50 GHz)	WR22	FS-330-QWG
U (40-60 GHz)	WR19	FS-330-UWG
V (50-75 GHz)	WR15	FS-330-VWG
E (60-90 GHz)	WR12	FS-330-EWG
W (75-110 GHz)	WR10	FS-330-WWG
D (110 - 170 GHz)	WR6	FS-330-DWG
G (140 - 220 GHz)	WR5	FS-330-GWG
J (220 - 330 GHz)	WR3	FS-330-JWG

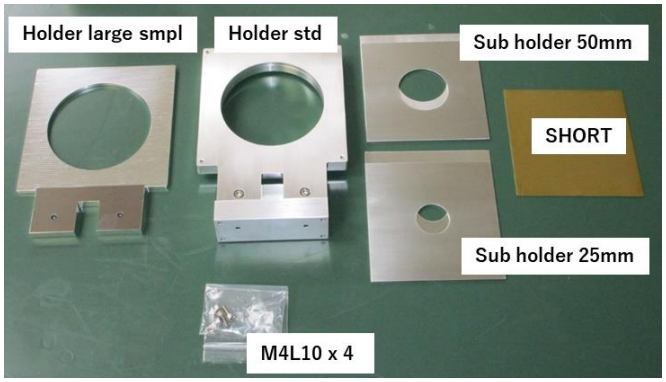
Contents list

The FS-330 contents are listed below, along with photos.

Standard contents

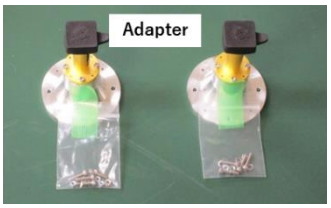




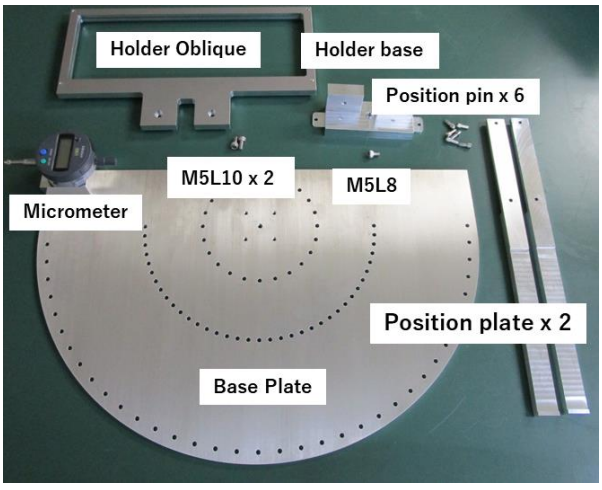


Options:

Adapter for connection (1 set)
(FS-330-xCF/xWG)



Oblique incidence reflection measurement
(FS-330-OR)



Installation

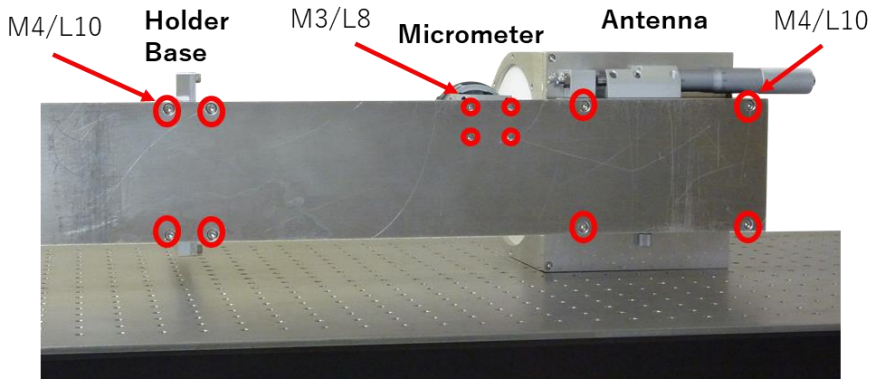
FS-330 must be installed on a flat plate. Ideally, use an optical surface plate. When installing on a normal workbench, it is necessary to pay attention to the top plate warping due to the load and the like. In particular, if the weight is applied to the tabletop after calibration, the antenna position may change and cause measurement errors. The installation procedures according to the measurement methods are described below.

Installation dedicated to transmission measurement

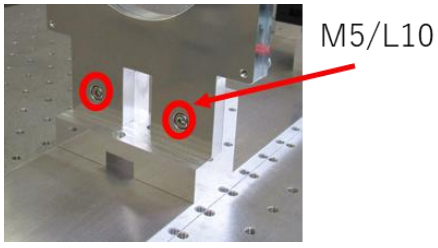
By fixing the antenna to the base dedicated to transmission measurement, the deviation of the antenna position can be minimized and the transmission S parameter can be measured most accurately. Particularly in permittivity and permeability measurements, even a slight change in S-parameters may not become very significant when converted to material parameters.

An example of an efficient installation procedure is shown below.

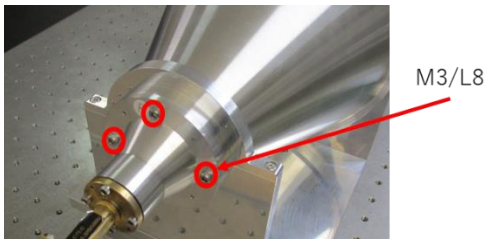
1. Fix the two antennas, micrometer and sample holder base to the base with allen screws. Note that the micrometer and the antenna with precise positioning mechanism are mounted on the same side. Install the antenna first, and then attach the micrometer so that its tip touches the antenna.



2. Fix the sample holder to the holder base using allen screws.



3. Fix the adapters for network analyzer connection to the antenna with allen screws. Make sure the orientation of the rectangular waveguide. An electric field is generated along the short side of the waveguide.



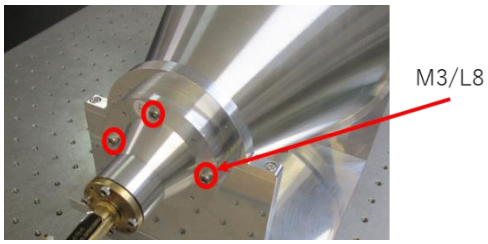
4. Finally, connect the network analyzer.

Installation for oblique incidence reflection measurement

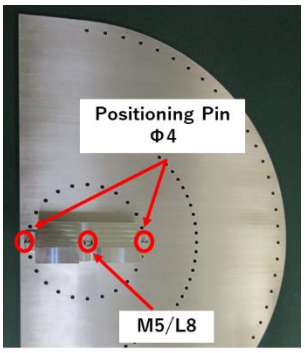
In oblique incidence reflection measurement, it is important to fix the antenna at an accurate angle towards the sample. By fixing the antenna positioning plate to the base with positioning pins, reproducible measurements are possible. Transmission S-parameters can also be measured by pointing the antenna directly, but if you want to minimize measurement errors, the configuration dedicated to transmission measurement is recommended.

An example of an efficient installation procedure is shown below.

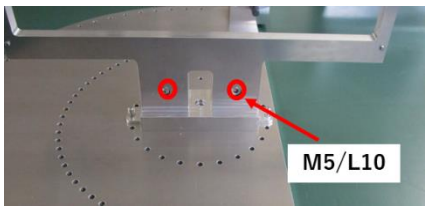
1. Fix the adapters for network analyzer connection to the antenna with allen screws. Make sure the orientation of the rectangular waveguide. An electric field is generated along the short side of the waveguide.



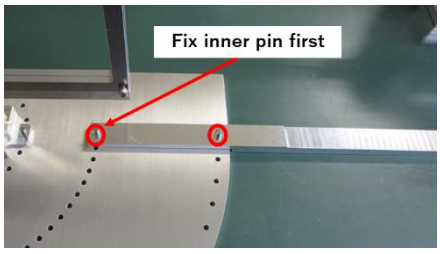
2. Fix the sample holder base to the oblique incidence base with allen screws, then fix the angle with the positioning pins. Loosely tighten the screw so that the holder can rotate.



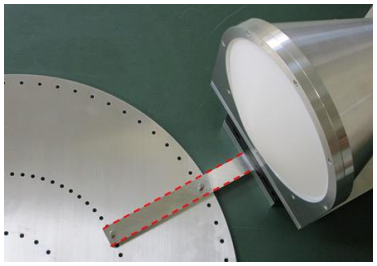
3. Fix the oblique incidence sample holder to the holder base using allen screws.



4. Fix the antenna positioning plates to the base using the positioning pin. First secure the inner pin, then secure the outer pin. Holes are open every 5 deg.



5. Place the antenna along the positioning plate.



6. Finally, connect the network analyzer.

2. Measurement

This section describes the basic procedures for various measurements using the FS-330 and a network analyzer. First, the preparation of the sample common to all measurement methods and how to fix the sample to the sample holder are described. Next, transmission S-parameter measurement will be explained, which is the basis for all measurements, followed by permittivity and permeability measurements. Finally, oblique incidence reflection characteristics will be covered.
For operation details of the material measurement software (Keysight N1500A) and the network analyzer, refer to the respective manuals.

Sample Preparation

In the free space method, a flat plate sample is used. Since the thickness of the sample is used for the calculation of permittivity and permeability, it is important to know the thickness accurately. Although the FS-330 sample holder can handle a variety of sample shapes, it is important to prepare a sufficiently large and flat sample for accurate measurement. It is also recommended to prepare a sample with an appropriate thickness according to the measurement conditions.

About sample size

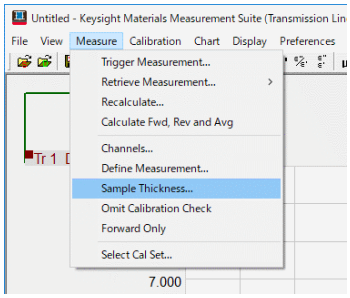
For accurate transmission characteristics measurement, a size of 6 wavelengths or larger at the measurement frequency is recommended. The table below shows the minimum sample size for each frequency band. The sample size that fits in the standard sample holder is up to 120 mm square. For thin film samples, the use of a standard sample holder is recommended. For details, see How to select and use the sample holders.

Band	Min (GHz)	Max (GHz)	Minimum sample size (diameter mm)
K	18	26.5	100
R	26.5	40	68
Q	33	50	55
U	40	60	45
V	50	75	36
E	60	90	30
W	75	110	24

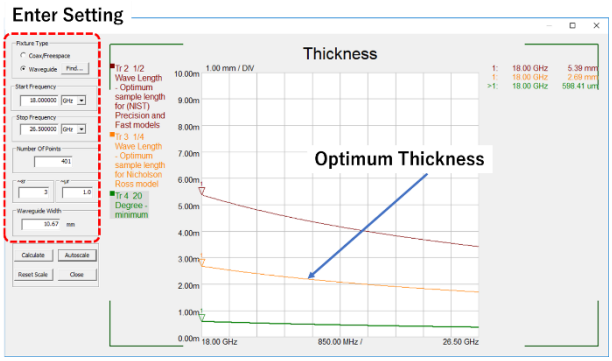
When measuring with oblique incidence, the measurement beam spreads out horizontally, so it is necessary to prepare a horizontally wide sample according to the angle of incidence. For example, if the incident angle is 30 degrees, a sample with twice the width is required. The oblique incidence sample holder is designed for wide samples.

The appropriate sample thickness depends on the measurement frequency and material properties. By using the [Sample Thickness Suggestion] function of the N1500A, you can find the appropriate value as follows.

1. Open the Sample Thickness Suggestion screen.



2. Enter the measurement frequency, permittivity and permeability values to calculate the optimal thickness.



About size measurement

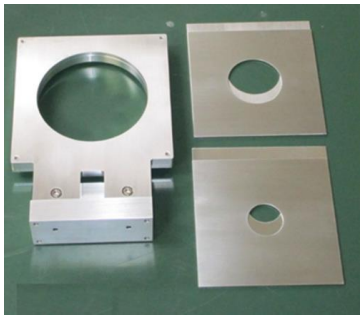
It is recommended to measure and record in advance the sample thickness to be input to N1500A when measuring permittivity and permeability. Accurate measurement is necessary because the error in the input value directly causes the error in permittivity and permeability measurements. Although it depends on the sample size and shape, it is generally recommended to measure about 3 places with a micrometer and use the average value.

How to select and use the sample holders

There are three types of sample holders: standard type, large sample type, and oblique incidence type. For transmission measurements, the standard sample holder is recommended if the sample size is within 120 mm square. The sample holder for large samples is available for the samples that do not fit in the standard type. For oblique incidence reflection measurements, the dedicated sample holder is recommended.

Standard sample holder

Place the sample in the sample holder body and fix it with the holding plate. For small samples or samples with easily distorted surfaces, such as thin films, sandwich them between the sub holders then fixing them to the holder body. At that time, ensure that the sample surface for 6 wavelengths (or larger) at the measurement frequency is available.



NOTE

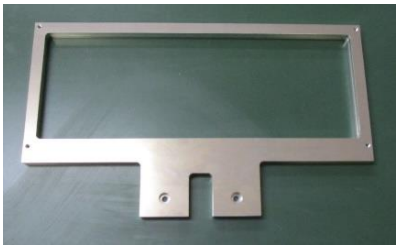
The position of the sample differs by the thickness of the sub holder depending on the sub holder is used or not, but the effect on the measured value can be ignored.

Sample holder for large samples

If the sample does not fit in the standard holder, press it against the sample holder and measure. Hold by hand or fix with large clips depending on the shape of the sample. Make sure that the sample does not move during the measurement and that the holding part does not obstruct the measuring beam.

Oblique incidence sample holder

The holder is designed to secure a horizontally long sample for oblique incidence reflection measurement. Put the sample in the holder body and fix it with the holding plate.



Transmission S-parameter measurement procedure

Transmission S-parameter measurement is the basis of all measurements, so please check the following section when performing other measurements. The overall flow is as follows.

1. Setting measurement conditions
2. TRL calibration
3. Setting the time domain gating function
4. Measurement

The following describes the individual steps, focusing on how to operate the hardware. For details on analyzer operation, refer to the analyzer manual.

Setting measurement conditions

Set the measurement conditions of the network analyzer according to the measurement requirement. Recommended settings for important parameters in the free space method are shown below.

- Power Level: initial value
- IF Bandwidth: 10 kHz
- Number of Points: 8000 points or more

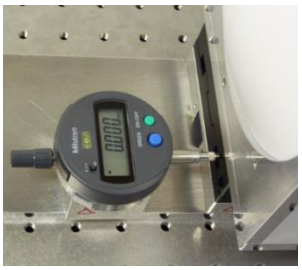
TRL calibration

Eliminate measurement system error factors with the TRL calibration of the network analyzer. In TRL calibration, the measurement system is evaluated in three states: Thru (direct connection), Reflect (full reflection), and Line (transmission line), and the characteristics are evaluated. Based on the results, the error factors are removed.

In the case of the free space method, it is efficient to set the antenna position to the initial state at first, and then perform Reflect, Line, and Thru in this order. The following describes how to set each step.

Initialization of positioning mechanism

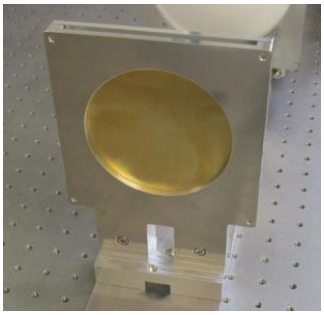
Operate the micrometer of the antenna positioner so that the upper and lower plates are visually aligned. Next, press and hold the [Origin] button on the micrometer to set the displayed value to 0. This state is the initial state of the antenna position.



Reflect setting

Fix the SHORT (metal plate) to the sample holder. Be sure to use the same sample holder as for sample measurement. When using the sub holders for sample measurement, sandwich the SHORT between the sub holders.

After fixing the SHORT, operate the positioner to move the antenna away by the thickness of the SHORT.



Line setting

Remove the short from the sample holder. When using the sub holder, remove only the short and leave the sub holders as they are.

Operate the positioner to move the antenna away by a quarter wavelength at the measurement frequency. There is no need to set it strictly. Use the following formula as a guide. (fmax and fmin are the measurement frequency limits.)

$$L = 3 \times 10^8 \div \sqrt{fmax \times fmin} \times \frac{1}{4} \text{ [m]}$$

Thru setting

When setting after Line, leave the sample holder and operate the fine movement mechanism to return to the initial state (digital micrometer display value 0).

Setting the time domain gating function

Eliminates the effects of unnecessary multiple reflections in the measurement system using the time domain gating function. The recommended settings are as follows:

- Gate Center: 0 s
- Gate Span: 1 ns

Measurement

Fix the sample on the sample holder and measure S-parameters. As long as you use the same sample holder, you can measure multiple samples continuously without re-calibration.

Permittivity and permeability measurement procedure: Use N1500A

Permittivity and permeability are obtained from the measured values of transmission S-parameters using N1500A. The overall flow is as follows.

1. Setting measurement conditions
2. TRL calibration
3. Setting the time domain gating function
4. Sample measurement: S-parameters measurement and conversion to permittivity / permeability

The following describes each step focusing on the basic operation of the N1500A. Refer to the N1500A manual for details.

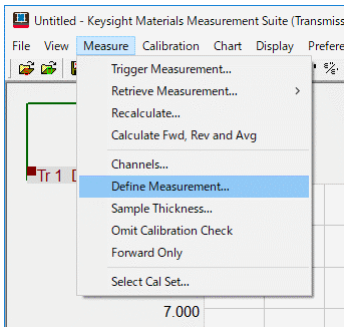
Setting measurement conditions

Measurement conditions must be set from the N1500A user interface, not from the network analyzer front panel. Recommended settings for important parameters in the free space method are shown below. (The same as transmission S-parameter measurement.)

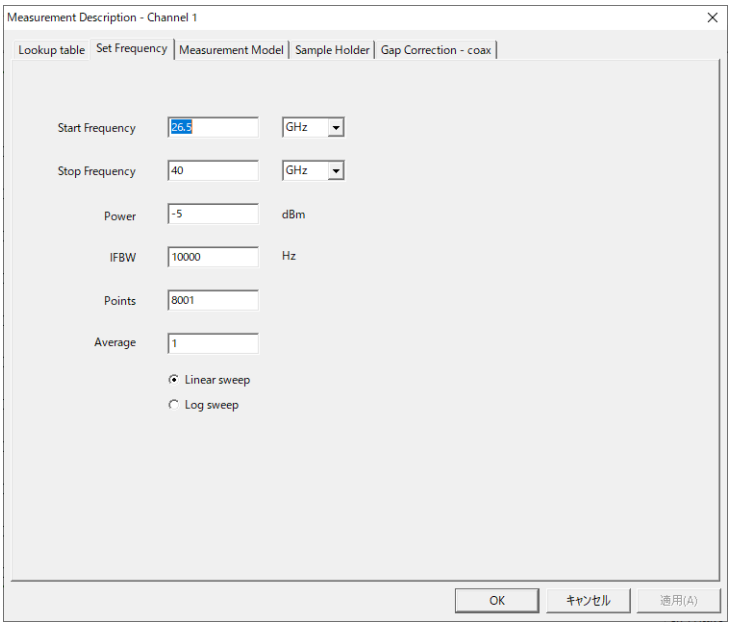
- Power Level: Initial value
- IF Bandwidth: 10 kHz
- Number of Points: 8000 points or more

The following describes the basic setting procedure using the N1500A. Use the [Define Measurement] function to set the measurement conditions in the following procedure. On the setting screen, set sequentially from the left tab.

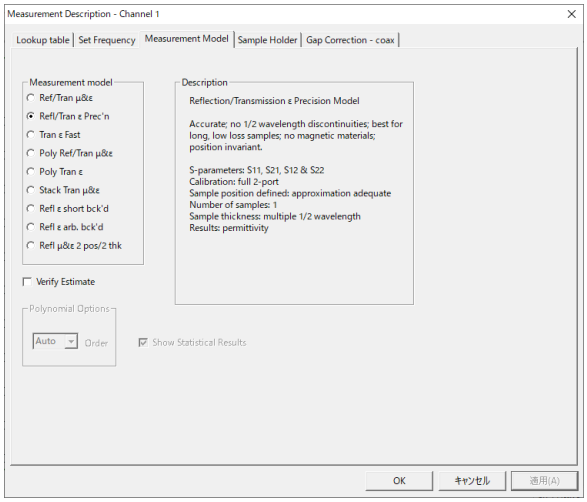
1. Open the [Define Measurement] screen.



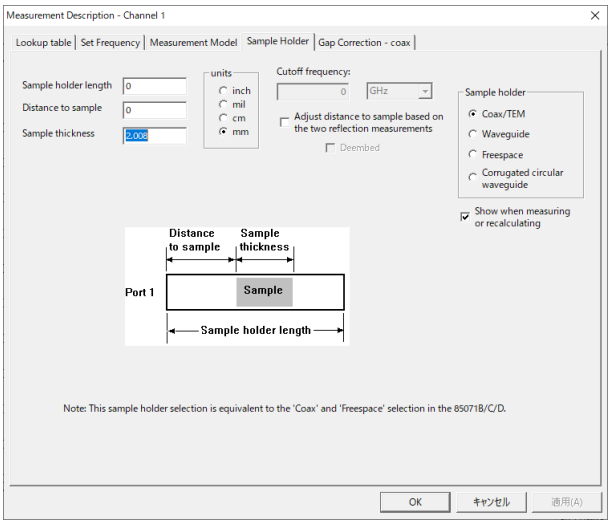
2. On the [Set Frequency] tab, set the measurement conditions. (Frequency, output power, IF bandwidth, number of measurement points)



3. Select the calculation model on the [Measurement Model] tab.



4. Enter the sample thickness in the [Sample Holder] tab. This completes the basic measurement condition settings.



TRL calibration

Same as normal transmission S parameter. See TRL calibration.

NOTE

When performing calibration, do not change the frequency, output power, IF bandwidth, or number of measurement points by operating the analyzer front panel. If changed, calibration will be invalid because of differences between the settings at the time of calibration and the settings at the time of measurement with the N1500A.

Setting the time domain gating function

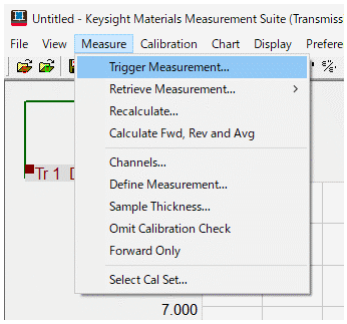
Eliminates the effects of unnecessary multiple reflections in the measurement system using the time domain gating function. This operation is performed on the analyzer itself, not on the N1500A. The recommended settings are as follows:

- Gate Center: 0 s
- Gate Span: 1 ns

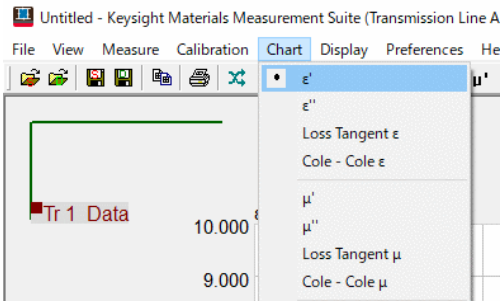
Measurement: S-parameter and conversion to material parameters

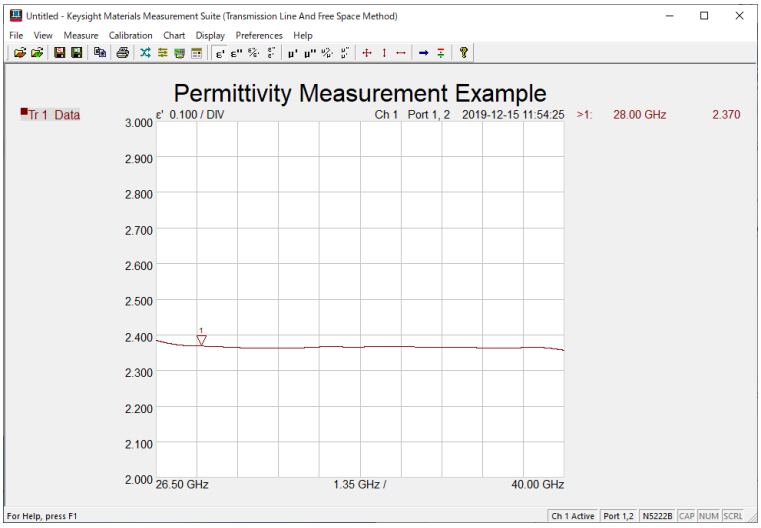
Fix the sample on the sample holder and measure S-parameters.

When the sample is ready, trigger the N1500A (click [Trigger Measurement]) to perform S-parameter measurement.

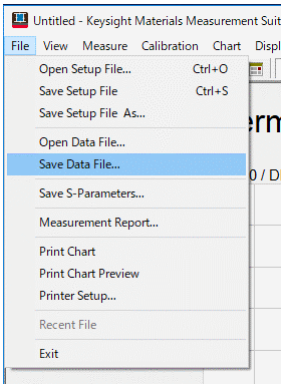


When measurement is completed, click [Chart] and then click the required parameter to display. The figure shows an example of displaying the permittivity ε '.





The measurement result can be saved using the [Save] function.



Oblique incidence reflection measurement procedure

The oblique incidence reflection measurement is performed by setting the antenna directions properly by fixing the antenna to the base plate. In the oblique incidence, the measurement beam becomes wider horizontally on the sample surface, so the special sample holder is required. The measurement procedure is basically the same as the transmission S-parameter measurement's, except that the antennas are set at various angles during measurement. The overall flow is as follows.

1. Setting of measurement conditions
2. TRL calibration
3. Setting the time domain gating function
4. Measurement

The following describes the individual steps, focusing on how to operate the hardware.

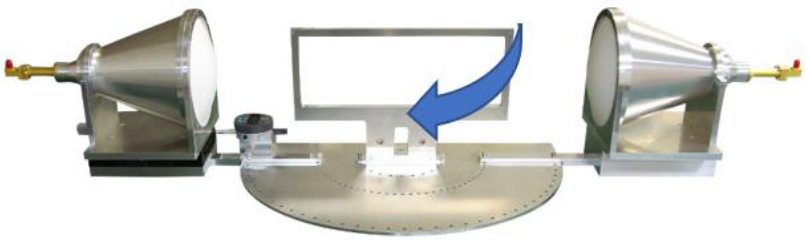
Setting measurement conditions

Set the measurement conditions of the network analyzer according to the measurement requirement. Recommended settings for important parameters in the free space method are shown below.

- Power Level: Initial value or maximum value
- IF Bandwidth: 10 kHz
- Number of Points: 8000 points or more

TRL calibration

Same as normal transmission S parameter measurement. See TRL calibration. Note that the two antennas face directly each other during TRL calibration, and the sample holder is set perpendicular to the measurement beam. Also, set the SHORT plate at the center of the holder for “Reflect” calibration.



Setting the time domain gating function

Eliminates the effects of unnecessary multiple reflections in the measurement system using the time domain gating function. The recommended settings are as follows:

- Gate Center: 0 s
- Gate Span: 1 ns

Measurement

Fix the sample on the sample holder and measure S-parameters. The amount of reflection at the sample surface is measured, but the measurement parameter on the network analyzer is transmission (S21 and S12).

For information on how to change the antenna angle, see Installation for oblique incidence reflection measurement. Measurements can be made continuously at different angle settings without re-calibration. However, when changing the direction of the electric field, it is necessary to change the direction of the connection adapter, which requires TRL re-calibration.

After the antenna angle change, fix the SHORT plate on the sample holder and perform normalize on the network analyzer. With that the oblique reflection reference to the full reflection can be measured accurately.

3. Maintenance and repairs

This section explains daily maintenance and simple troubleshooting.

Daily cleaning

FS-330 is basically maintenance-free. If there is noticeable dirt, clean using a nonwoven fabric with a small amount of alcohol.

Repairs

If repair is necessary, contact us directly from our website.

https://www.emlabs.jp