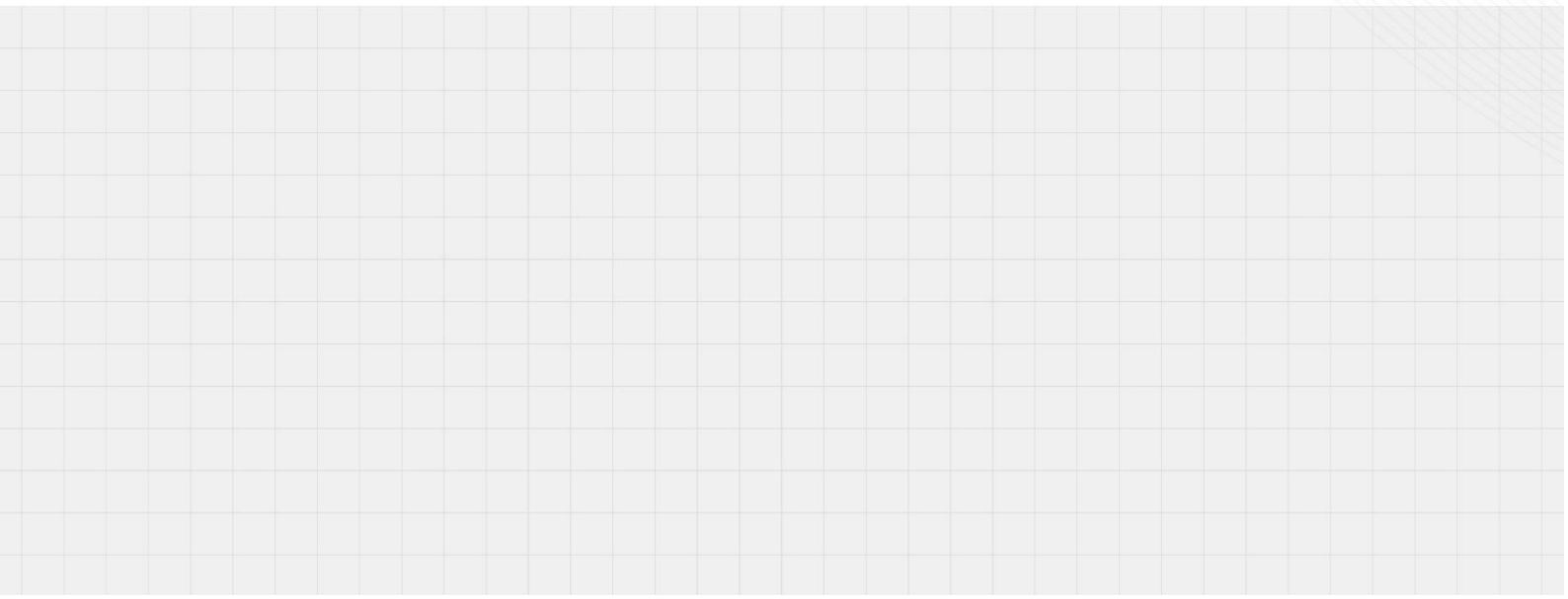


Measurement of Dielectric Material Properties



1 Introduction

Material measurement is integral when developing solutions in the millimeter-wave (mmWave) frequency range, it can provide the electrical or magnetic characteristics of the materials, which proved useful in many research and development fields. PCB, antenna, material science, microwave circuit design, biological research, and automotive engineers along with metrology and research institutes must characterize various materials to better understand their effects on electromagnetic wave propagation to achieve more expected designs, or to test manufacturing processes to control product quality, etc. Similar questions from different applications create a continual demand to accurately measure dielectric and magnetic properties of materials.

As of today, the industry mostly uses vector network analyzer, impedance analyzer and LCR meter and other instruments and algorithm software, combined with various professional fixtures, to achieve accurate measurement of material electrical permittivity and magnetic permeability through various methods. Each method has its application field, which depends on several factors: frequency range, expected values of ϵ_r and μ_r , required measurement accuracy, material properties (i.e. homogeneous, isotropic), material form (i.e. liquid, powder, solid, sheet), sample size restrictions, destructive or nondestructive, contacting or non-contacting, temperature and cost.

The application note describes the transmission line method to measure material dielectric properties using a vector network analyzer, methods for converting the S parameters to dielectric properties, and through the real case study shows the wide applicability of VNA as a characterization tool of high-frequency materials and the SIGLENT material test solution. Note that the conversion methods discussed is only suitable for solid material measurement.

2 Dielectric properties of materials

In general, various materials can be categorized as conductors, semiconductors or insulators (or dielectrics). A material is classified as a dielectric if it can store energy when an external electric field is applied. The electromagnetic energy stored and dissipated by materials is measured by dielectric constant and permeability, which indicates the insulation characteristics of materials. Dielectric constant is a physical parameter that describes the interaction between dielectric and applied electric field. We usually refer to relative permittivity or the ratio of absolute permittivity to free space permittivity.

$$K = \epsilon_r = \frac{\epsilon}{\epsilon_0} = \epsilon_r' - j\epsilon_r''$$

Where, K is dielectric constant, ϵ is absolute permittivity, ϵ_r is relative permittivity, the free space permittivity $\epsilon_0 = 8.85 \times 10^{-12} \text{F/m}$

The dielectric constant k is a complex number. Real part ϵ_r' is the measure of the amount of energy stored in the medium when an external electric field is applied. Complex part ϵ_r'' is the measure of amount of energy lost in the material when the material is under the influence of an external electrical field. When describing the dielectric constant with vector diagram, the ratio of the imaginary part and the real part of the complex permittivity is called the loss tangent, and is also called the dissipation factor. It gives the ratio of the lost portion of energy to the stored portion of energy and it's inverse is called the quality factor $Q=1/D$.

$$\tan \delta = \frac{\epsilon_r''}{\epsilon_r'} = D = \frac{1}{Q} = \frac{\text{Energy lost per cycle}}{\text{Energy stored per cycle}}$$

Where, $\tan \delta$ is loss tangent, D is dissipation factor, Q is quality factor.

Just like the permittivity of a material, there is also a magnetic response parameter for all dielectric materials called permeability. Permeability describes the interaction of a material with a magnetic field. We usually refer to relative permeability, or the ratio of absolute permeability to free space permeability.

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

Where, μ is absolute permeability, μ_r is relative permeability, the free space permeability $\mu_0 = 4\pi \times 10^{-7} \text{H/m}$

Permeability is a complex number. Real part μ_r' represents the energy storage term and complex part μ_r'' represents the energy loss term. Relative permittivity μ_r is the permittivity relative to free space. Likewise, the definition of loss tangent of magnetic materials is the ratio of imaginary part and real part of complex permeability.

3 Transmission line method

MUT is placed inside a transmission line, which can either be a piece of waveguide or coaxial cable. Permittivity and permeability are characterized from the measured transmission and reflection S parameters. The method has higher accuracy and more sensitivity than the open-ended coaxial probe technique and assumes that only the fundamental waveguide mode (i.e. TE mode in waveguides and TEM mode in coaxial lines) propagates. The sample requires precision machining according to the standard waveguide size and needs to fill the fixture cross-section with no air gaps at the walls. Thus, a key point of the method is the ability to fabricate MUT samples having flat faces, perpendicular to the long axis, and with known thickness $>20-360\lambda$. Coaxial transmission line can cover a wide frequency range below 18GHz, but it is relatively difficult to make ring samples. Waveguide transmission line can extend the frequency to millimeter wave band, and rectangular samples are relatively easy to process. However, because the frequency coverage of waveguide transmission line is segmented, the frequency coverage of testing materials using waveguide transmission line is also segmented. General error rates of the transmission line method are $<5\%$ for the permittivity and permeability, and $< 10\%$ for the loss tangent. Another aspect to take into account is attenuation due to conduction or radiation loss occurring at the transmission line fixture. Common values for the resolution of the loss tangent are ± 0.01 . Accordingly, materials having $\tan\delta < 0.01$ are not characterizable.

Advantages of transmission line method

- It can measure anisotropic materials with wide frequency band.
- It commonly used to measure samples with medium to high loss.
- It can be used to determine both the permittivity and permeability of MUT.

Disadvantages of transmission line method

- Measurement accuracy is limited by the air-gap effects.
- The waveguide transmission line can only cover a frequency range.
- It is not suitable for the measurement of low loss materials, liquid materials and thin film materials.
- It is limited to low accuracy when the sample length is the multiple of one-half wavelength in the material.
- Low frequency is limited by the actual sample length and the start frequency is generally higher than 100-500MHz.
- There is a high requirement for the manufacture of samples, which requires that the materials can be machined into the required size and the machining accuracy of the material size directly affects the test results, especially for ring samples (generally destructive).

4 Conversion methods

There are various approaches for obtaining the permittivity and permeability from S parameters. Each of the conversion method has different advantages and limitations. The user needs to know the appropriate measurement and conversion methods for a material in order to accurately measure its dielectric properties. It is necessary to use the right methods for the material to be measured because specific method is applicable to specific material. If the wrong methods are used, the measurement results will not be satisfactory.

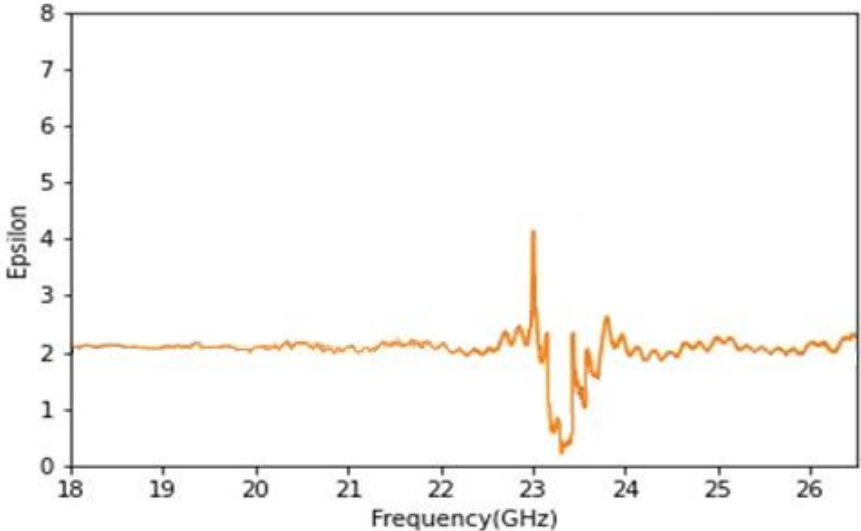
Table below presents a general guide of measurement and conversion methods for the different materials. The NRW method is fast and non-iterative, but its accuracy drops significantly when the MUT size is integer multiples of the incident beam's half-wavelength. This especially when broadband measurements need to be performed, often cannot be avoided. The NIST algorithm, although more complex than the NRW, helps overcome the issues concerning the sample dimensions, and is suitable for long samples and for characterizing lowloss materials. New non-iterative method is suitable for permittivity calculation for the case permeability $\mu_r = 1$. The method has the advantage of being stable over a whole range of frequencies for an arbitrary sample length. The accuracies are comparable to the iterative method.

| Materials | Length | Magnetic Properties | Measurement Methods | Conversion Methods | S-Parameters | Dielectric Properties | Speed | Accuracy |
|-----------------|--------|---------------------|---------------------|--------------------|--|----------------------------|-------|----------|
| Lossy solids | Short | non-magnetics | TR | NRW | S_{11} , S_{21} , S_{12} , S_{22} or S_{11} , S_{21} | ϵ_r , μ_r | Fast | Medium |
| Lossy solids | Short | magnetics | TR | NRW | S_{11} , S_{21} , S_{12} , S_{22} or S_{11} , S_{21} | ϵ_r , μ_r | Fast | Medium |
| Low loss solids | Long | non-magnetics | TR | NIST Iterative | S_{11} , S_{21} , S_{12} , S_{22} or S_{11} , S_{21} | ϵ_r , $\mu_r = 1$ | Slow | Good |
| Low loss solids | Long | non-magnetics | TR | New Non-Iterative | S_{11} , S_{21} , S_{12} , S_{22} or S_{11} , S_{21} | ϵ_r , $\mu_r = 1$ | Fast | Good |

4.1 Nicholson-Ross-Weir (NRW)

4.1.1 Introduction

Nicholson-Ross-Weir method provides a direct calculation of both the permittivity and permeability from S-parameters. When the measured sample is a low-loss material, and its frequency corresponds to an integer multiple of half the wavelength in the sample, the algorithm may lead to the deviation of the calculation results due to phase ambiguity. Hence, it is restricted to optimum sample thickness of $\lambda g/4$ and used preferably for short samples. The following is a graph of dielectric constant of polytetrafluoroethylene (PTFE) measured by NRW method in SNA5000A material measurement mode.



NRW method is divergent at integral multiples one-half wavelength in the sample. This is because at the point corresponding to the half wavelength, S_{11} gets very small, and VNA has great uncertainty when measuring the small S_{11} phase that eventually caused the divergence at these frequencies. These conditions can be improved by reducing the sample length, but it is difficult to determine the appropriate sample length when ϵ_r and μ_r are unknown.

Advantages of NRW method

- Fast, non-iterative
- Applicable to waveguides and coaxial line

Disadvantages of NRW method

- Divergence at frequencies corresponding to multiples of one-half wavelength
- Short sample should be used
- Not suitable for low loss materials

4.1.2 Calculation

According to the measured S_{11} and S_{21} of MUT, the steps for calculating permittivity and permeability are as follows: first calculate the intermediate variables x and Γ , then calculate the intermediate variables T and Λ , and finally calculate permittivity ϵ_r and permeability μ_r .

S_{11} and S_{21} parameters can be obtained directly from the network analyzer. The reflection coefficient Γ and transmission coefficient T are deduced from the following equations:

$$S_{11} = \frac{\Gamma(1 - T^2)}{1 - \Gamma^2 T^2} \quad (1.1)$$

$$S_{21} = \frac{T(1 - \Gamma^2)}{1 - \Gamma^2 T^2} \quad (1.2)$$

Combine the above equations to calculate the intermediate variables x and solve for the reflection coefficient Γ and transmission coefficient T .

$$x = \frac{S_{11}^2 - S_{21}^2 + 1}{2S_{11}} \quad (1.3)$$

$$\Gamma = x \pm \sqrt{x^2 - 1} \quad (1.4)$$

$$T = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21})\Gamma} \quad (1.5)$$

The permeability μ_r and permittivity ϵ_r are given as:

$$\frac{1}{\Lambda^2} = \left(\frac{\epsilon_r * \mu_r}{\lambda_0^2} - \frac{1}{\lambda_c^2} \right) = - \left(\frac{1}{2\pi L} \ln \left(\frac{1}{T} \right) \right)^2 \quad (1.6)$$

$$\mu_r = \frac{1 + \Gamma}{\Lambda(1 - \Gamma) \sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}}} \quad (1.7)$$

$$\epsilon_r = \frac{\lambda_0^2}{\mu_r} \left(\frac{1}{\lambda_c^2} + \frac{1}{\Lambda^2} \right) \quad (1.8)$$

In the process of calculating Λ , the problem of phase ambiguity is involved. When the material length increases by a multiple of the wavelength, the phase of the transmission coefficient T does not change.

$$\ln \left(\frac{1}{T} \right) = -\ln(|T|) - j\varphi + j2\pi n \quad (1.9)$$

After calculating T , the value of n ($n=0, \pm 1, \pm 2, \dots$) in the above equation cannot be determined. The n can be determined by two methods.

First method is by analysis of group delay. Delay through the material is a function of the material total length. The phase ambiguity can be resolved by finding a solution for ϵ_r and μ_r from which a comparison is made between the measured group delay and the calculated group delay to find a correct value of n.

The calculated group delay can be determined from

$$\tau_{cal} = L \frac{d}{df} \sqrt{\frac{\epsilon_r \mu_r f^2}{c^2} - \frac{1}{\lambda_c^2}} = \frac{L}{c^2} \frac{f \epsilon_r \mu_r + f^2 \frac{1}{2} \frac{d(\epsilon_r \mu_r)}{df}}{\sqrt{\frac{\epsilon_r \mu_r f^2}{c^2} - \frac{1}{\lambda_c^2}}} \quad (1.10)$$

The measure group delay is

$$\tau_{meas} = -\frac{1}{2\pi} \frac{d\phi}{df} \quad (1.11)$$

τ_{meas} can be determined directly from the network analyzer. τ_{meas} changes as n changes.

When $\tau_{cal-k} - \tau_{meas} \approx 0$, n=k is the correct root.

Second method is to use the initial guess values ϵ_r^* and μ_r^* in the sample to estimate the value of n through λ_g .

$$\frac{1}{\Lambda} = j \left(\frac{\gamma}{2\pi} \right) \quad \gamma = j \frac{2\pi}{\lambda_0} \sqrt{\epsilon_r^* \mu_r^* - \left(\frac{\lambda_0}{\lambda_c} \right)^2} \quad (1.12)$$

$$\text{Re} \left(\frac{1}{\Lambda} \right) = \frac{1}{\lambda_g} \quad (1.13)$$

Solve λ_g through the above equation to determine the n value.

4.1.3 Simplified calculation

The NRW algorithm can be simplified when it is known that the MUT is a non-magnetic material, $\mu_r = 1$. The permeability ϵ_r can be directly obtained through equations (1.6) and (1.7) and this method is not affected by phase ambiguity.

Substitute $\mu_r = 1$ into equation (1.7),

$$\frac{1}{\Lambda} = \frac{1 - \Gamma}{1 + \Gamma} \sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}} \quad (1.14)$$

Combined equations (1.6) and (1.14),

$$\frac{1}{\Lambda^2} = \left(\frac{1 - \Gamma}{1 + \Gamma} \right)^2 \left(\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2} \right) = \left(\frac{\epsilon_r}{\lambda_0^2} - \frac{1}{\lambda_c^2} \right) \quad (1.15)$$

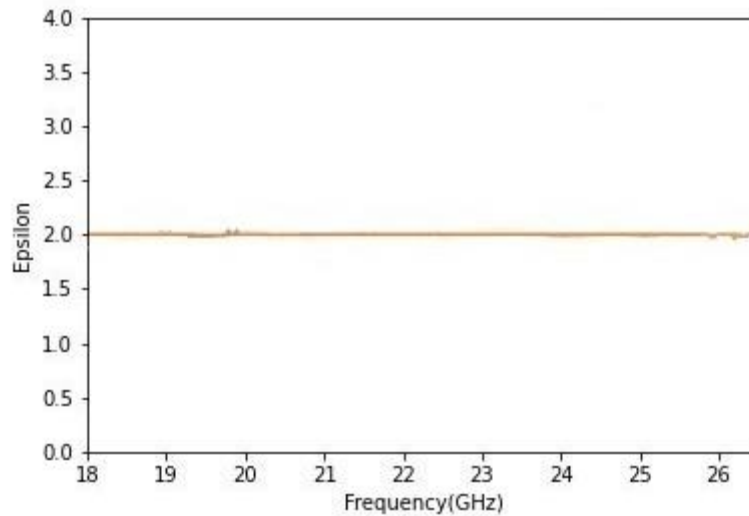
$$\epsilon_r = \left(\frac{1 - \Gamma}{1 + \Gamma} \right)^2 \left(1 - \frac{\lambda_0^2}{\lambda_c^2} \right) + \frac{\lambda_0^2}{\lambda_c^2} \quad (1.16)$$

4.2 NIST Iterative

4.2.1 Introduction

NIST Iterative method performs the calculation using a Newton-Raphson's root finding method and is suitable for permittivity calculation only. It works well if the initial estimate of dielectric constant is set properly. The method bypasses the inaccuracy peaks that exist in NRW method when the sample thickness is an integer multiple of one half wavelength ($n\lambda_g/2$) and is suitable for long samples and characterizing low loss materials. The calculation step of NIST iterative method is to set the initial values of MUT permittivity at selected frequency, and then obtain the final values of MUT permittivity

through step-by-step iterative algorithm according to the measured S parameters. The following is a graph of dielectric constant of polytetrafluoroethylene (PTFE) measured by NIST iteration method in SNA5000A material measurement mode.



NIST iterative method can obtain stable permittivity over the frequency spectrum through S parameter and can measure samples of any length. The instability in NRW method is minimized by setting $\mu_r = 1$, but only nonmagnetic materials can be measured under this method.

Advantages of NIST Iterative method

- Smooth permittivity results, no divergence
- Accurate
- Arbitrary length of samples can be used
- Robust for low loss and high loss materials

Disadvantages of NIST Iterative method

- Applicable for permittivity measurement only
- Need initial guess of permittivity value

4.2.2 Calculation

Before measurement, it is necessary to select the initial values of permittivity and permeability. Since there are multiple solutions to the operation equation involved, it is necessary to consider the rationality of the root value of the operation equation and obtain a suitable root value of the operation equation. The basic considerations are as follows: when the solution of the operation equation leads to an unstable result of the root value, this equation solution should not be selected; when the selected root value causes the operation result to fluctuate violently or suddenly change to another root value during repeated iterative operations, it can be considered that the selected root value is wrong and the initial value should be reselected for iterative calculation.

The reflection coefficient can be obtained as

$$\Gamma = \frac{\frac{\gamma_0}{\mu_0} - \frac{\gamma}{\mu}}{\frac{\gamma_0}{\mu_0} + \frac{\gamma}{\mu}} \quad (2.1)$$

The propagation constant in air γ_0 and propagation constant γ can be determined as

$$\gamma_0 = j \sqrt{\left(\frac{\omega}{c}\right)^2 - \left(\frac{2\pi}{\lambda_c}\right)^2} \quad (2.2)$$

$$\gamma = j \sqrt{\frac{\omega^2 \mu_r \epsilon_r}{c^2} - \left(\frac{2\pi}{\lambda_c}\right)^2} \quad (2.3)$$

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \quad (2.4)$$

By replacing equation (2.4) into (2.3) will yield the following equation with $\mu_r = 1$

$$\gamma = j \sqrt{\epsilon_r \epsilon_0 \mu_0 \omega^2 - \left(\frac{2\pi}{\lambda_c}\right)^2} \quad (2.5)$$

The reflection coefficient Γ and transmission coefficient T can be determined with $\mu_r = 1$

$$\Gamma = \frac{\frac{\gamma_0}{\mu_0} - \frac{\gamma}{\mu}}{\frac{\gamma_0}{\mu_0} + \frac{\gamma}{\mu}} = \frac{\gamma_0 - \gamma}{\gamma_0 + \gamma} \quad (2.6)$$

$$T = e^{-\gamma L} = e^{-jL \left(\sqrt{\epsilon_r \epsilon_0 \mu_0 \omega^2 - \left(\frac{2\pi}{\lambda_c}\right)^2} \right)} \quad (2.7)$$

By solving either one of the two equations will allow the determination of the permittivity

$$F(\epsilon_r) = S_{11}S_{22} - S_{21}S_{12} - [e^{-2\gamma_0(L_{air}-L)}] \frac{T^2 - \Gamma^2}{1 - \Gamma^2 T^2} \quad (2.8)$$

$$F(\epsilon_r) = \frac{S_{21} + S_{12}}{2(1 - \Gamma^2 T^2)} - T(1 - \Gamma^2) e^{-j\gamma_0(L_{air}-L)} \quad (2.9)$$

Calculate the real and imaginary parts of $F(\epsilon_r)$ according to the set initial value of the permittivity and calculate the Jacobian matrix J .

$$F(\epsilon_{r1}) = f_1(\epsilon', \epsilon'')$$

$$F(\epsilon_{r2}) = f_2(\epsilon', \epsilon'')$$

$$J = \begin{pmatrix} \frac{f_1(\epsilon' + h, \epsilon'') - f_1(\epsilon' - h, \epsilon'')}{2h} & \frac{f_1(\epsilon', \epsilon'' + h) - f_1(\epsilon', \epsilon'' - h)}{2h} \\ \frac{f_2(\epsilon' + h, \epsilon'') - f_2(\epsilon' - h, \epsilon'')}{2h} & \frac{f_2(\epsilon', \epsilon'' + h) - f_2(\epsilon', \epsilon'' - h)}{2h} \end{pmatrix} \quad (2.10)$$

ϵ' and ϵ'' represent the real and imaginary parts of permittivity, and h represents an infinitesimal value.

$$\epsilon_{n+1} = \epsilon_n + J^{-1} \epsilon_n \quad (2.11)$$

Determine whether ϵ_{n+1} satisfies the convergence condition. If so, stop the iteration; otherwise, continue the operation.

$$\max[|(\epsilon'_r)_{n+1} - (\epsilon'_r)_n|, |(\epsilon''_r)_{n+1} - (\epsilon''_r)_n|] < a \quad (2.12)$$

4.3 New Non-Iterative

4.3.1 Introduction

New non-iterative method is quite similar to NRW method and is suitable for permittivity calculation for the case permeability $\mu_r = 1$. The method has the advantage of being stable over a whole range of frequencies for an arbitrary sample length and no divergence is observed at frequencies corresponding to multiples of one-half wavelength in the sample. It does not need an initial estimation of permittivity and can perform the calculation very fast. The accuracies are comparable to the iterative method. The following is a graph of dielectric constant of polytetrafluoroethylene (PTFE) measured by a new non-iterative method in SNA5000A material measurement mode.

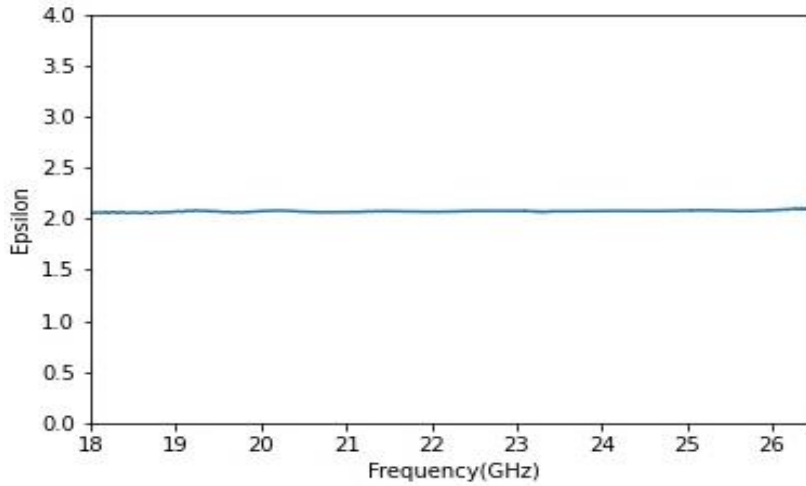


Figure 3 Permittivity of a PTFE sample using new non iterative method

Compared with NRW and NIST iterative methods, there are no divergences observed at frequencies corresponding to integer multiples of one-half wavelength in the sample and the accuracy of the obtained permittivity is similar to the iterative method.

Advantages of New Non-Iterative method

- Smooth permittivity results, no divergence
- Accurate
- Arbitrary length of samples can be used
- Fast, non-iterative
- No initial guess needed

Disadvantages of New Non-Iterative method

- Applicable for permittivity measurement only

4.3.2 Calculation

NIST iterative method is quite similar to NRW method with the exception that it introduces the effective electromagnetic parameters. The S parameters can be obtained directly from the network analyzer. The reflection coefficient Γ and transmission coefficient T can be deduced as

$$x = \frac{S_{11}^2 - S_{21}^2 + 1}{2S_{11}} \quad (3.1)$$

$$\Gamma = x \pm \sqrt{x^2 - 1} \quad (3.2)$$

$$T = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21})\Gamma} \quad (3.3)$$

Calculate the intermediate quantity $\frac{1}{\Lambda^2}$

$$\frac{1}{\Lambda^2} = \left(\frac{\epsilon_r * \mu_r}{\lambda_0^2} - \frac{1}{\lambda_c^2} \right) = - \left(\frac{1}{2\pi L} \ln \left(\frac{1}{T} \right) \right)^2 \quad (3.4)$$

Where λ_0 is free space wavelength and λ_c is the cutoff wavelength

$$\lambda_{og} = \frac{1}{\sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}}} \quad (3.5)$$

The effective electromagnetic parameters are defined as

$$\mu_{eff} = \frac{\lambda_{og}}{\Lambda} \left(\frac{1 + \Gamma}{1 - \Gamma} \right) \quad (3.6)$$

$$\varepsilon_{eff} = \frac{\lambda_{og}}{\Lambda} \left(\frac{1 - \Gamma}{1 + \Gamma} \right) \quad (3.7)$$

Finally calculate permittivity and permeability,

$$\mu_r = \mu_{eff} \quad (3.8)$$

$$\varepsilon_r = \left(1 - \frac{\lambda_0^2}{\lambda_c^2} \right) \varepsilon_{eff} + \frac{\lambda_0^2}{\lambda_c^2} \frac{1}{\mu_{eff}} \quad (3.9)$$

New non-iterative algorithm is only applicable to the case of $\mu_r = 1$. Substituting into the equation,

$$\varepsilon_r = \left(1 - \frac{\lambda_0^2}{\lambda_c^2} \right) \varepsilon_{eff} + \frac{\lambda_0^2}{\lambda_c^2} \quad (3.10)$$

4.4 Air gap correction

When the sample under test is placed in a waveguide transmission line, a capacitor series circuit model can be established when there is an air gap between the sample surface and the waveguide surface. This model can be used to correct the dielectric constant and permeability. The premise for applying this correction is that the air gap between the sample surface and the waveguide surface is very small, and the value of the sample dielectric constant is between small and medium values.

The corrected real part of the permittivity can be determined as

$$\varepsilon'_{rc} = \varepsilon'_r \frac{d(1 + \tan^2 \delta)[b - (b - d)\varepsilon'_r(1 + \tan^2 \delta)]}{[b - (b - d)\varepsilon'_r(1 + \tan^2 \delta)]^2 + b^2 \tan^2 \delta} \quad (4.1)$$

d = small width of sample, unit: meter (m)

b = small width of waveguide, unit: meter (m)

The imaginary part of the permittivity is

$$\varepsilon''_{rc} = \varepsilon''_r \frac{b \tan \delta}{b - (b - d)\varepsilon'_r(1 + \tan^2 \delta)} \quad (4.2)$$

As for the corrected real part of the permeability, it is described as

$$\mu'_{rc} = \mu'_r \frac{b}{d} - \frac{b - d}{d} \quad (4.3)$$

The imaginary part of the permeability is

$$\mu''_{rc} = \mu''_r \frac{b}{d} \quad (4.4)$$

5 Practical example

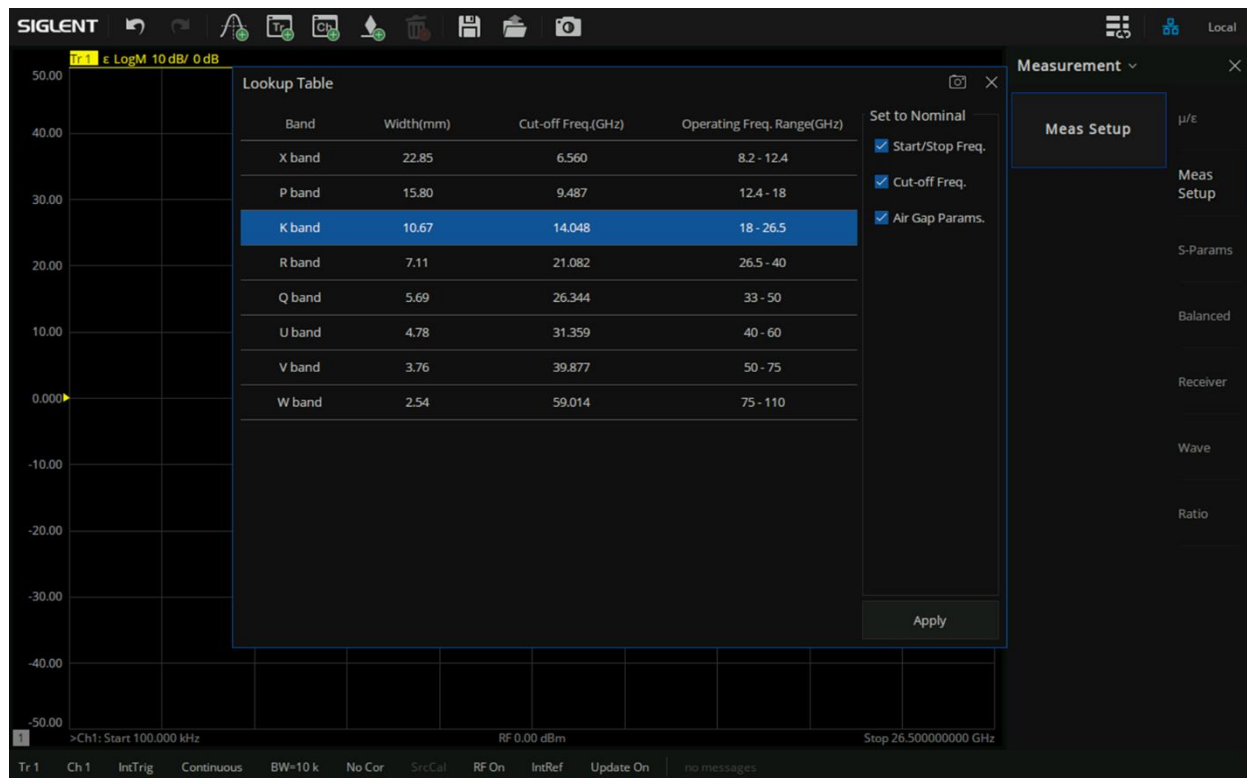
The typical measurement system of transmission line method consists of a vector network analyzer, coaxial or waveguide transmission line and material measurement option for calculating permittivity and permeability. The calibration type is TRL and it uses the non-iterative, NIST iterative and NRW algorithms for calculation. The MUT is placed in a waveguide measuring device. Both ends of the waveguide device are connected to the calibrated network analyzer through a waveguide coaxial

converter. Measure S11, S22, S21 and S12 parameters respectively. Select the appropriate data processing method to substitute S parameters value and calculate the permittivity and permeability to complete the material measurement. In order to obtain accurate results, the network analyzer must be fully preheated before material measurement.

- Measuring Instrument: SNA5032A Vector Network Analyzer
- Material Under Test: PTFE
- Fixture: Coaxial cables and waveguide fixture
- Purpose: To measure the dielectric constant of PTFE through the rectangular waveguide

5.1 Configure fixture parameter setup

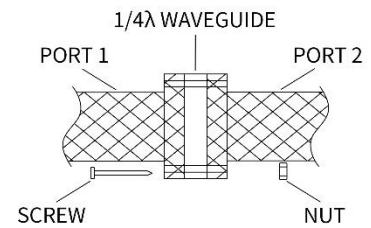
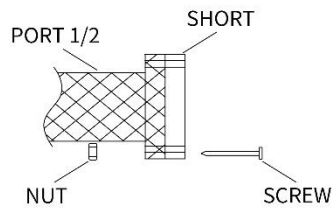
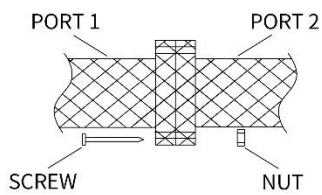
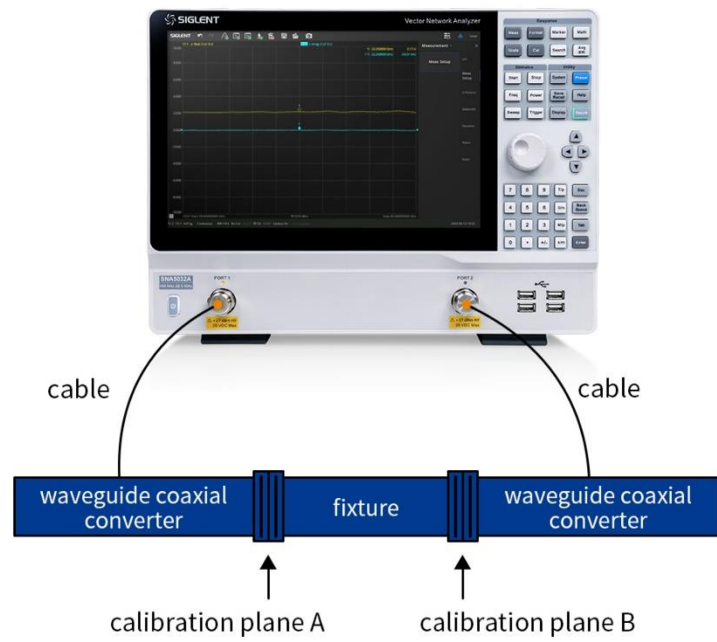
A series of settings (measurement mode, scanning frequency range, points, etc.) should be made in combination with the measurement conditions before measurement. Click **Meas** > **Mode** > **MATERIAL** to enter the material measurement mode and display the configuration dialog box. You can quickly set relevant parameters according to waveguide fixture information through **Quick Setting**. Click **Lookup...** to select and set relevant parameters of waveguide fixture. According to the current test conditions, select K-band waveguide, click **Apply** to apply waveguide configuration, automatically set the current frequency range of network analyzer, and return to the main configuration interface to complete the pre-configuration.



5.2 Waveguide TRL calibration

The network analyzer is calibrated after connecting the waveguide coaxial converters, and the calibration plane is extended to both ends of the converters. SIGLENT provides a waveguide calibration solution with the frequency range of 18GHz-26.5GHz, which can perform through-reflection-line (TRL) calibration, and all the error terms in the error model of the measuring device can be found through three simple connection methods, as shown in the figure. Connect short calibration element calibration plane A and other short calibration element on calibration plane B to complete reflection calibration. Connect 1/4-line calibration element between calibration plane A and calibration plane B to complete line calibration. Directly connect calibration plane A and calibration plane B to

complete through calibration. Finally complete all TRL calibration.



Thru



Reflect

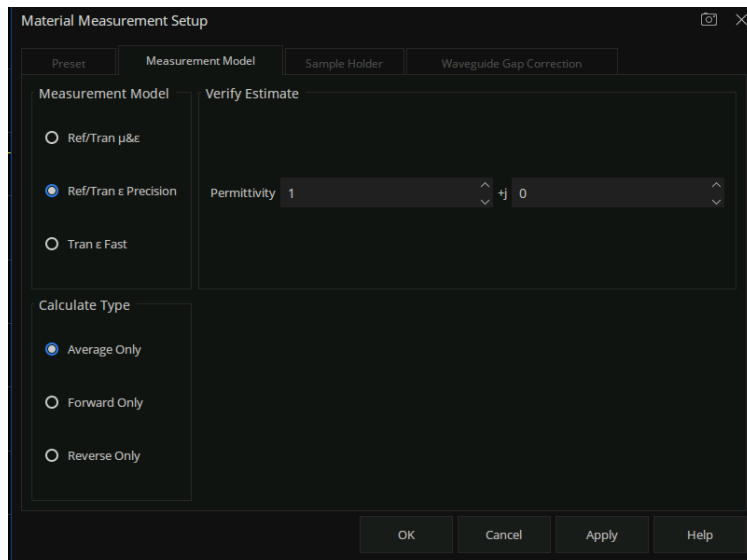


Line

5.3 Configure material measurement setup

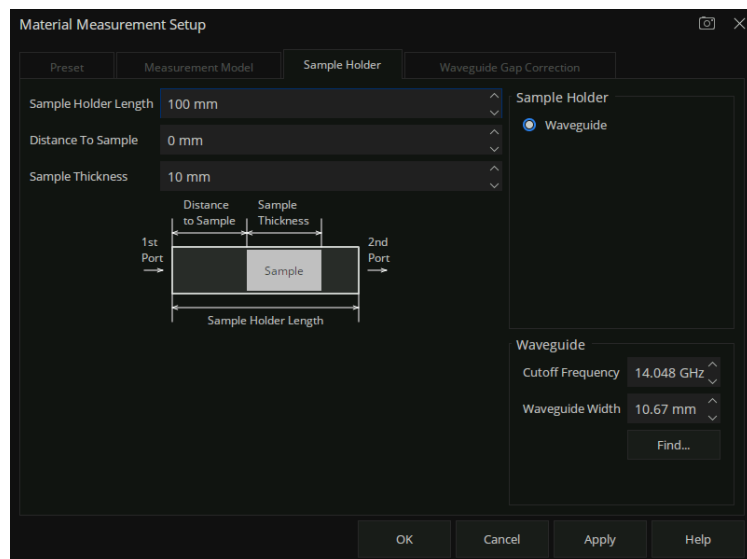
1. Configure the measurement model

Select the appropriate measurement model according to MUT and measurement target. In the example, select the Ref/Tran ϵ Precision measurement model based on NIST iteration method, and preset the appropriate initial value of dielectric constant for model iteration according to the current material characteristics.



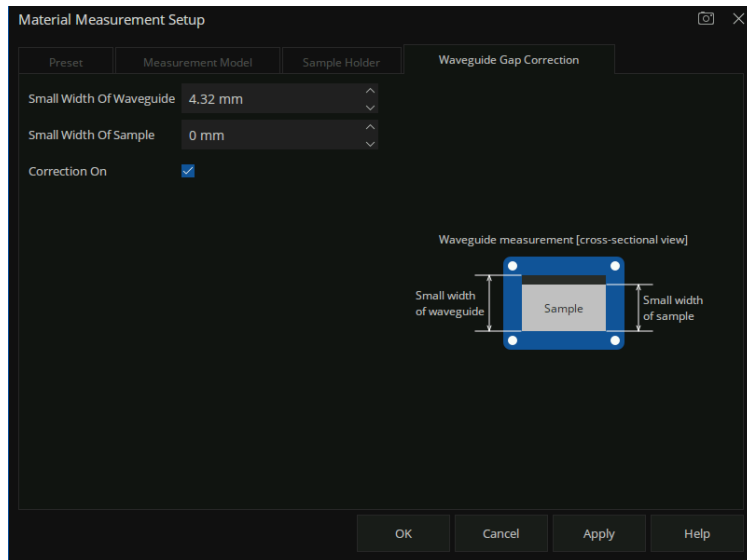
2. Configure the sample fixture parameters

Configure the fixture length, the distance between sample and the reference plane of the forward port and the sample length.

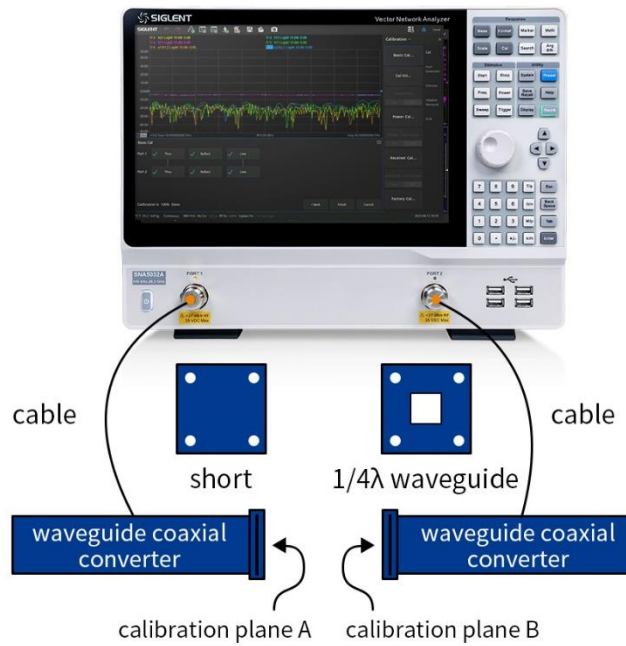


3. Configure gap compensation

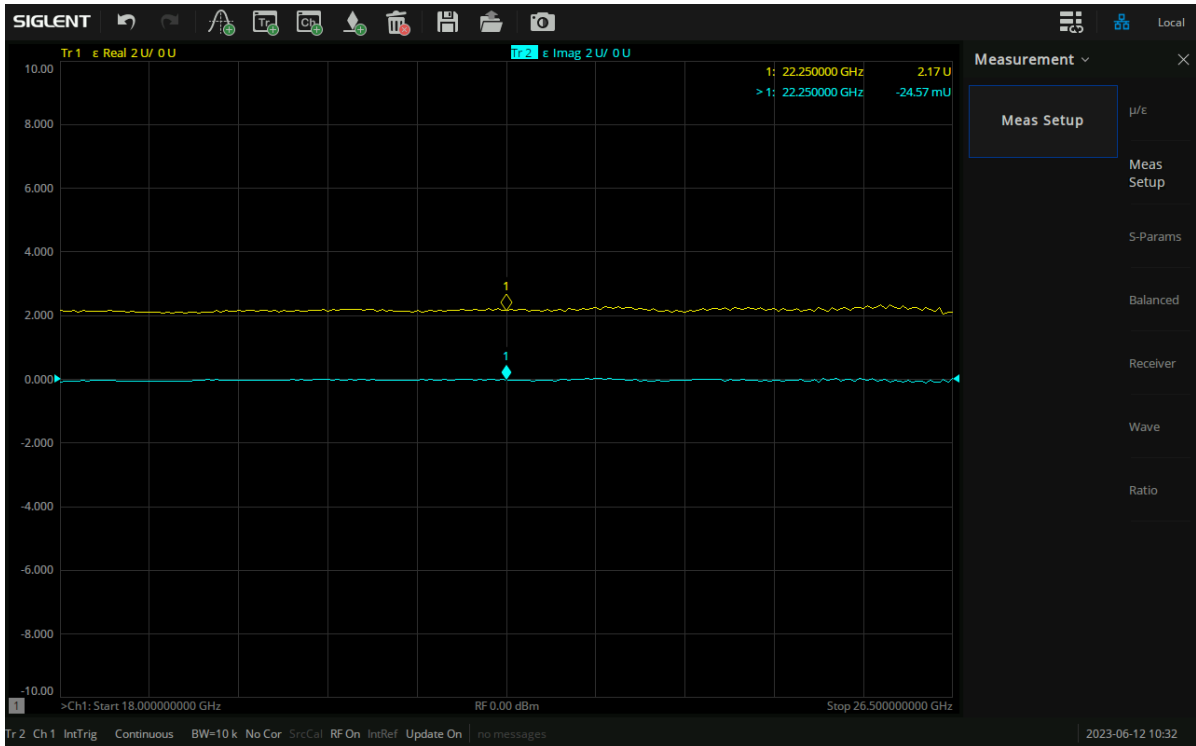
It is necessary to configure gap compensation if there is gap between sample and the waveguide. Configure the sample height and waveguide section height, check **Correction On** to correct the calculation results based on the waveguide and sample height information.



5.4 Sample measurement



Load the sample into the waveguide from the waveguide port. Be careful when loading the sample to avoid sample damage. After loading, the plane of one side of the sample should be flush with the waveguide reference plane. When measuring the permittivity, set the measurement mode to ϵ and the data format to the Real. When measuring the permeability, set the measurement model to Ref/Tran $\mu\epsilon$ and set the measurement mode to μ , and the data format should be set to Real.



6 Summary

SIGLENT deliver a comprehensive material measurement solution ideal for lab, manufacture and university environments, including SNA series precision instruments, MT materials measurement software, KWR42A waveguide calibration kit. The SNA series network analyzer can automatically perform transmission/reflection line methods to measure the permittivity and permeability of solid materials in the frequency range of 9kHz to 26.5GHz, with excellent measurement integrity and economic applicability. The measurement wizard guides the user through the measurement process and the results can be plotted in a variety of formats: ϵ_r , μ_r , $\tan \delta$, ϵ_r'' , ϵ_r' , μ_r' , μ_r'' , $\tan \delta_\mu$.