Keysight 16451B Dielectric Test Fixture

This is the Operation and Service Manual for 16451B Dielectric Test Fixture.

KEYSIGHT

Operation and Service Manual

Notices

Trademark Acknowledgments

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CAUTION

A **CAUTION** notice denotes a hazard. It calls attention to an operating procedure, practice, or the like that, if not correctly performed or adhered to, could result in damage to the product or loss of important data. Do not proceed beyond a CAUTION notice until the indicated conditions are fully understood and met.

WARNING

A **WARNING** notice denotes a hazard. It calls attention to an operating procedure, practice, or the like that, if not correctly performed or adhered to, could result in personal injury or death. Do not proceed beyond a WARNING notice until the indicated conditions are fully understood and met.

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1 Installation

Introduction

This chapter provides the information necessary for receiving and performing an incoming inspection, and preparing the 16451B for use.The WARNINGs, CAUTIONs, and NOTEs given throughout this document must be carefully followed to ensure the operator's safety and to not damage the 16451B.

Product Description

The 16451B is a Dielectric Test Fixture used with LCR meters and impedance analyzers for accurate measurement of insulating and dielectric materials.

Applicable Instrument

The 16451B has been designed to operate specifically with LCR Meters, Capacitance Meters and Impedance Analyzers which use the 4-terminal pair measurement configuration.

Initial Inspection

This fixture has been carefully inspected electrically and mechanically before being shipped from the factory. It should be in perfect condition, no scratches, dents or the like, and it should be in perfect electrical condition. Verify this by carefully performing an incoming inspection to check the fixture for signs of physical damage and missing contents. If any discrepancy is found, notify the carrier and Keysight Technologies. Your Keysight Technologies sales office will arrange for repair and replacement without waiting for the claim to be settled.

1. Inspect the shipping container for damage, and keep the shipping materials until the inspection is completed.
2. Verify that the shipping container contains everything shown in Figure 1-1 and listed in Table 1-1 of this Operation and Service Manual.
3. Inspect the exterior of the 16451B for any signs of damage.

The Electrode-A (38 mm electrode) and the Unguarded electrode are installed on the test fixture when the 16451B is shipped from the factory.

Figure 1-1 Product Overview

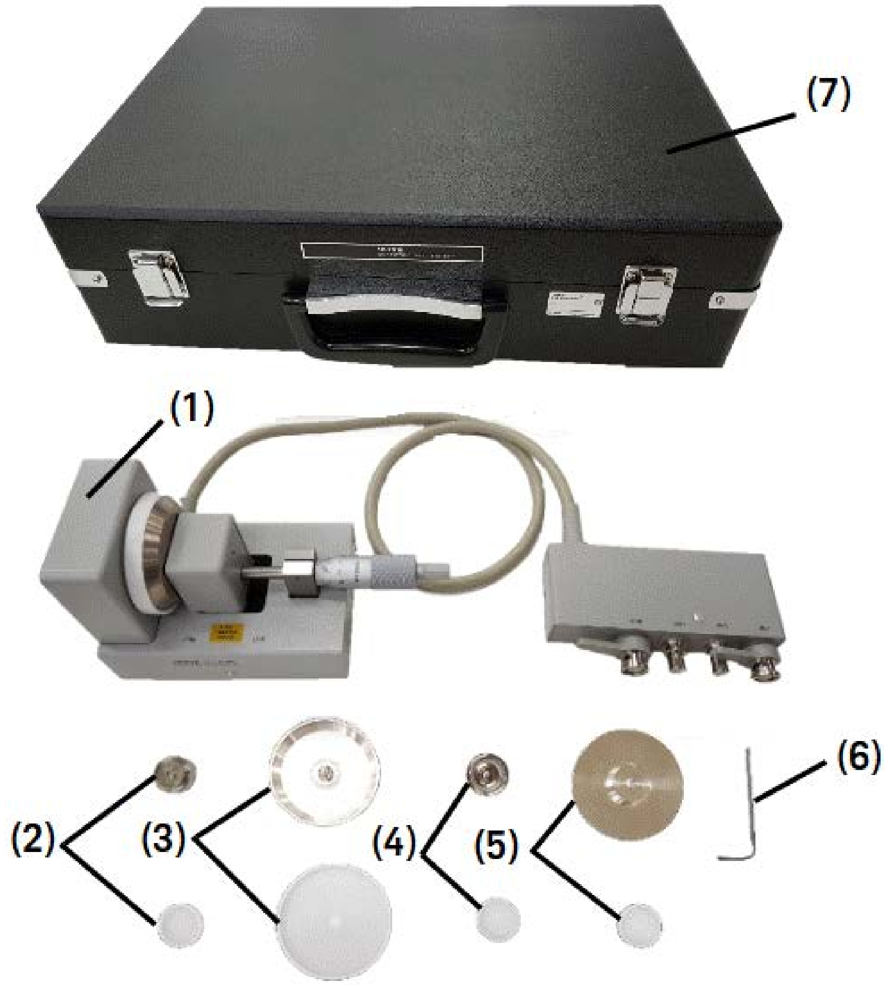


Table 1-1 Contents

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	16451-61001 (16451-61071)	Test Fixture (with Electrode A, Unguarded electrode and covers)	1	16451-61071	Test Fixture (with Electrode A, Unguarded electrode and covers)	1
2	16451-60013	Electrode B and cover	1	16451-60013	Electrode B and cover	1
3	16451-60012	Electrode C and cover	1	16451-60012	Electrode C and cover	1

Table 1-1 Contents

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
4	16451-60014	Electrode D and cover	1	16451-60014	Electrode D and cover	1
5	16451-60021	Attachment for error compensation and cover	1	16451-60021	Attachment for error compensation and cover	1
6	8710-1181	Hex key (for replacing electrodes)	1	5188-4452	Hex key (for replacing electrodes)	1
7	16451-60001	Carrying Case	1	16451-60001	Carrying Case	1

The Electrode-A and the Unguarded electrode are installed on the test fixture when the 16451B is shipped from the factory.

2 General Information

Introduction

This chapter describes safety consideration, serial number, specifications, supplemental performance characteristics, and information on storing and repacking the 16451B.

NOTE

In this manual, the term dielectric constant means “relative dielectric constant”. In common usage the word “relative” is frequently dropped. The term “dielectric constant” is often called “permittivity” in other documents. This manual will unify it to “dielectric constant”.

Safety Considerations

The 16451B conforms to the safety requirements of an IEC (International Electrotechnical Commission) Publication-348 (1971) Safety Class 1 instrument and is shipped from the factory in a safe condition.

Serial Number

The Serial Number plate is located on both the carrying case and 16451B. The serial number used by Keysight Technologies consists of ten characters. The characters are separated into two sections. The first two letters and three digits are the serial number prefix and the last five digits are the suffix. The prefix is the same for all identical 16451B which only changes when any changes made to 16451B. The letters placed in front of the digits identify the country where the 16451B was manufactured. The suffix is assigned sequentially and is different for each 16451B.

The contents of this manual applies to 16451B's with a serial number prefix(es) listed under the serial numbers on the title page. An 16451B manufactured after the printing of this manual may have a serial number prefix that is not listed on the title page. This unlisted serial number prefix indicates the 16451B is different from those described in this manual. The manual for this new 16451B may be accompanied by a yellow Manual Change supplement or have a different manual part number. The Manual Change Sheet contains “change information” that explains how to adapt manual to a newer 16451B.

In addition to change information, the supplement may contain information for correcting errors (Errata) in the manual. To keep this manual as current and accurate as possible, Keysight Technologies recommends that you periodically request the latest Manual Changes supplement. The supplement for this manual is identified by this manual's printing date and its part number, both of which appear on the manual's title page. Complimentary copies of the supplement are available from Keysight Technologies. If the serial prefix or number of a 16451B is lower than that on the title page of this manual, see Appendix A, Manual Changes.

For information concerning a serial number prefix not listed on the title page or in the Manual Change supplement, contact the nearest Keysight Technologies office.

Specifications

This section lists the complete 16451B specifications. These specifications are the performance standards and limits against which the 16451B is tested. When shipped from the factory, the 16451B meets the specifications listed in this section.

Function	Test fixture for measuring dielectric constant and dissipation factor. Permits connecting solid materials to the unknown terminals (4-terminal pair configuration) of the LCR meters, Capacitance meters and Impedance Analyzers.
Frequency Range	≤ 30MHz
Applicable Voltage Range	±42V peak max (AC + DC)
Cable Length (setting)	1m
Operating Temperature	0°C to 55°C
Operating Humidity	≤ 95% RH (40°C)
Weight	3.7kg (including accessories)
Furnished Accessories and Quantity	

Description	Quantity
Attachment for error compensation	1
Different size guarded/guard electrodes	3
Hex key for replacing electrodes	1
Carrying case	1
Operation Manual (Option ABA[1])	1

1. The manual is furnished only option ABA is ordered

Supplemental Performance Characteristics

This section gives supplemental performance characteristics. Supplemental performance characteristics are not specifications, but are typical characteristics included as additional information for the operator. Supplemental performance characteristics are not guaranteed.

Measurement Accuracy when using contact electrode method

ε'_r Accuracy$\left(\frac{\Delta\varepsilon'_{rm}}{\varepsilon'_{rm}}\right)$

tanδ <0.1:

$$A_z + 0.04f^2\varepsilon'_{rm}\,\varepsilon_o\frac{\pi\left(\frac{d}{2}\right)^2}{t} + \frac{100(\varepsilon'_{rm} - 1)}{\left(\varepsilon'_{rm} + \frac{t}{0.01}\right)} \quad \text{[\%] (typical)}$$

Dissipation Factor Accuracy (Δ tan δ)

tanδ <0.1: $A_d + E_a + E_b$

$$E_a = 0.005 + 0.0004f^2\varepsilon'_{rm}\,\varepsilon_o\frac{\pi\left(\frac{d}{2}\right)^2}{t} \quad \text{(typical)}$$

$$E_b = \frac{\tan\delta}{100}\frac{\Delta\varepsilon'_{rm}}{\varepsilon'_{rm}} \quad \text{(typical)}$$

f:	measured frequency [Hz]
f ≤ 30MHz	
ε'_{rm}:	measured permittivity
tanδ:	measured dissipation factor
ε_0:	permittivity of air 8.854×10^{-12} [F/m]
d:	diameter of electrode {A,B} [m]
t:	thickness of material [mm]
A_z:	Impedance measurement error of instrument

A_d: D measurement error of instrument

The surfaces of material are assumed to be ideally parallel, flat and smooth.

The above equation is only compatible for electrodes A and B.

Permittivity Measurement Accuracy including 4294A and E4990A (Supplemental Characteristics)

Figure 2-1 Electrode A, MUT Thickness: 1mm

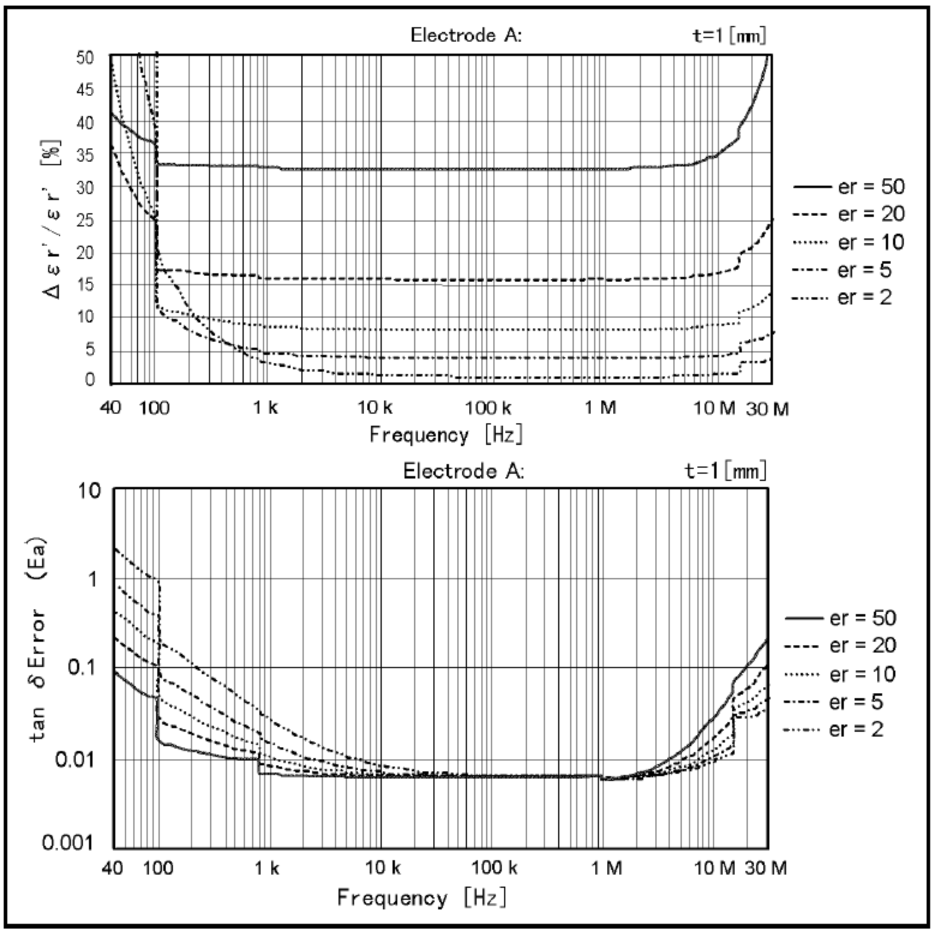
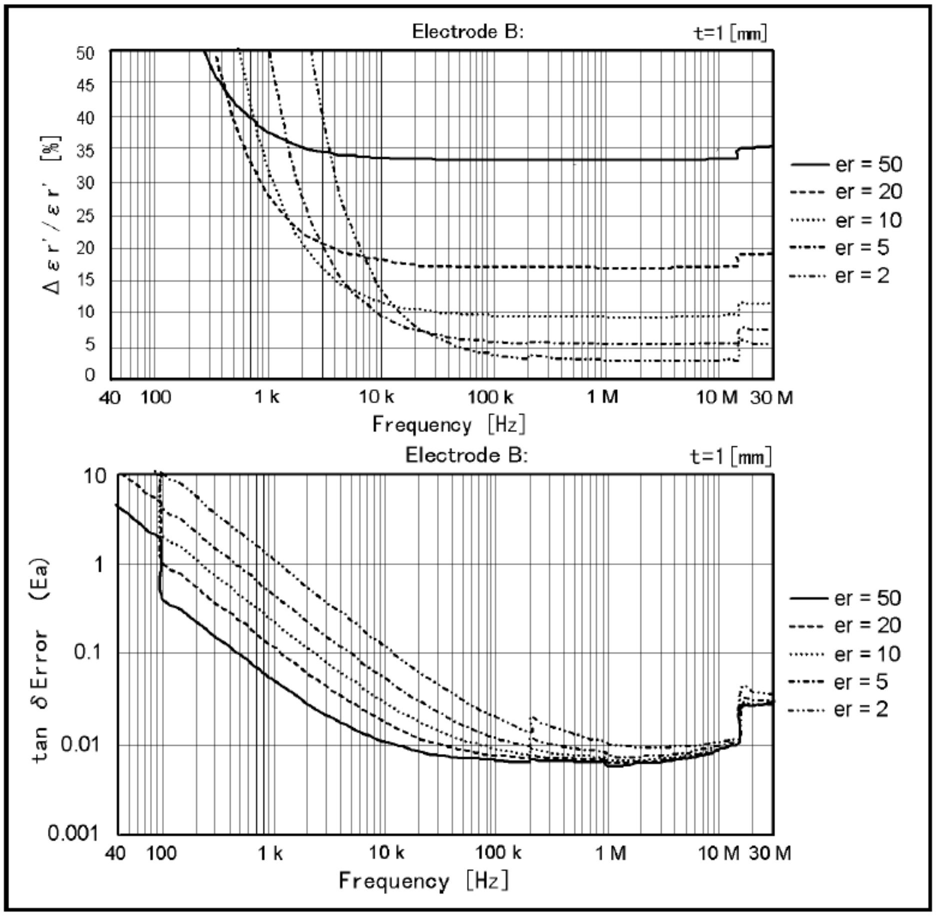


Figure 2-2 Electrode B, MUT Thickness: 1mm



1. OSC LEVEL: 500mV
2. BW: 5
3. ADAPTER TYPE: 4TP_1M
4. COMPENSATION: OPEN, SHORT & LOAD

Electrode Dimensions

Guarded/Guard Electrode (4 types, changeable)

1. For materials without applied thin film electrodes.

Figure 2-3 Dimensions of Electrode-A

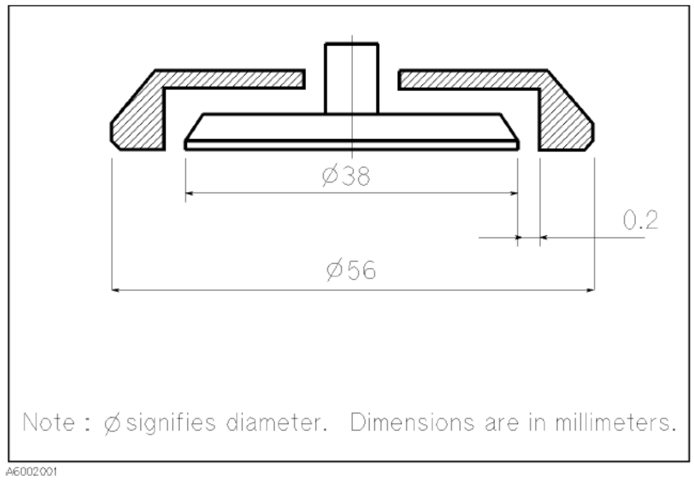
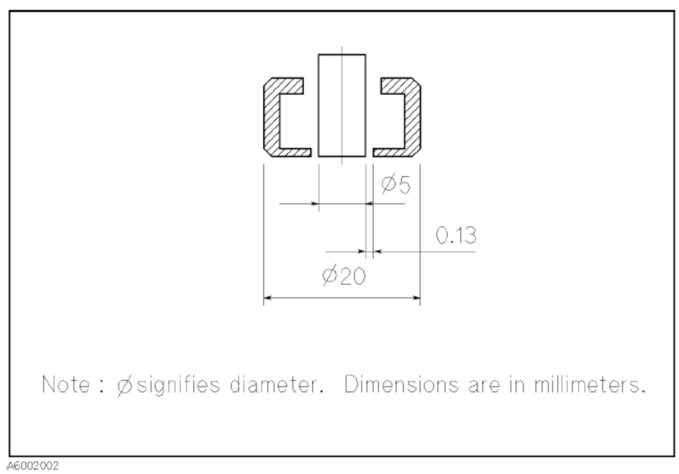


Figure 2-4 Dimensions of Electrode-B



2. For materials with applied thin film electrodes.

Figure 2-5 Dimensions of Electrode-C

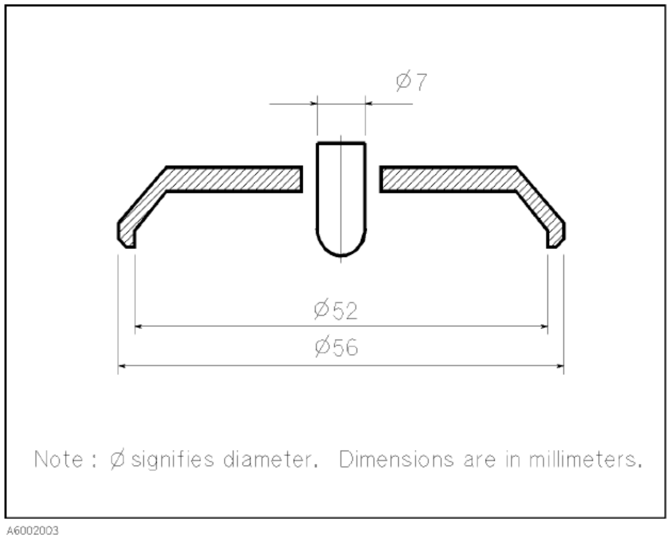
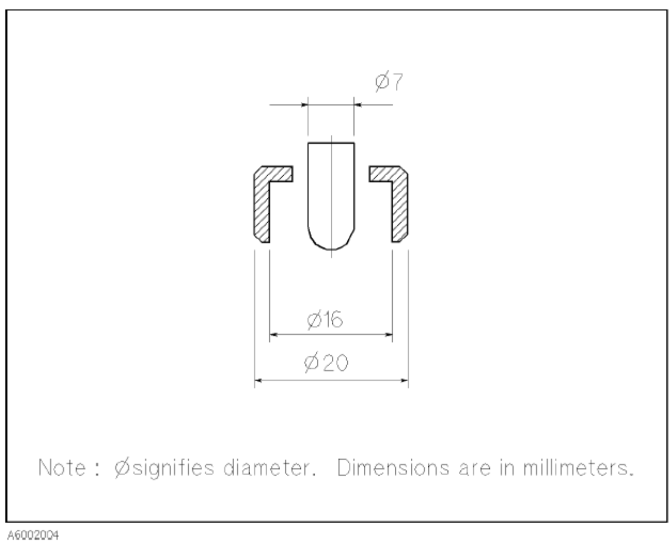
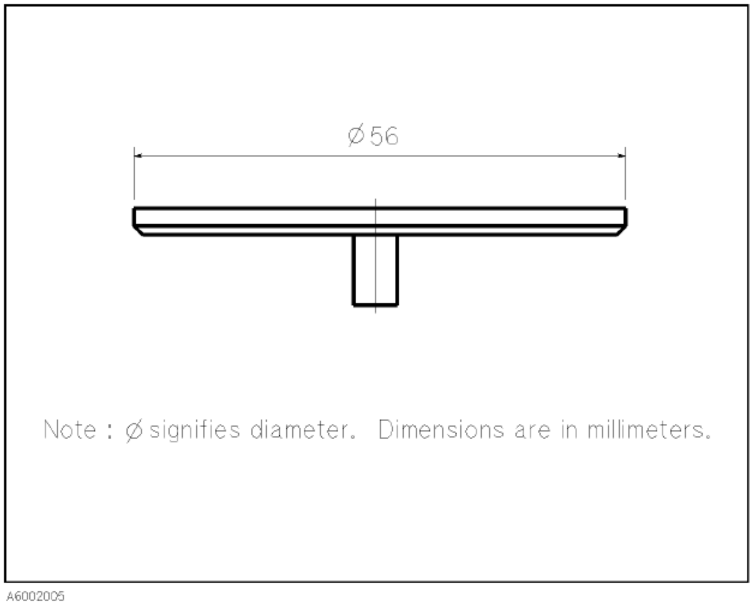


Figure 2-6 Dimensions of Electrode-D



Unguarded Electrode

Figure 2-7 Dimensions of Unguarded Electrode



Available Test Material Dimensions

Table 2-1 Available Test Material Dimensions

Electrode Used	Diameter	Thickness	Guarded Electrode Diameter
Electrode-A	40 to 56 mm	≤ 10 mm	38 mm
Electrode-B	10 to 56 mm	≤ 10 mm	5 mm
Electrode-C	56 mm	≤ 10 mm[1]	5 to 50 mm[2]
Electrode-D	20 to 56 mm	≤ 10 mm[1]	5 to 14 mm[2]

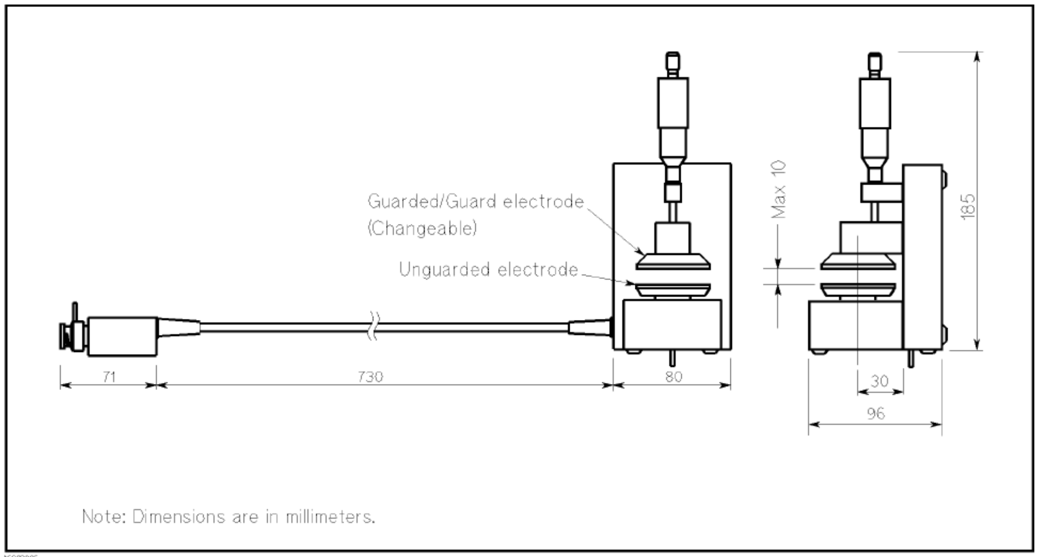
1. Including thickness of thin film electrodes
2. As a diameter of the thin film electrode

Micrometer Resolution

The micrometer resolution is 10µm.

Dimensions of Fixture Assembly

Figure 2-8 Dimensions of Test Fixture Assembly



Storage and Repacking

This section describes the environment for storing or shipping the 16451B, and how to repackage the 16451B for shipment when necessary.

Environmental Requirements

The 16451B should be stored in a clean, dry environment. The following environmental limitations apply for both storage and shipment.

Temperature:	-40°C to 70°C
Humidity:	≤95% RH (at 40°C)

To prevent condensation from taking place on the inside of the 16451B, protect the fixture against temperature extremes.

Original Packaging

Containers and packing materials identical to those used in factory packaging are available through your closest Keysight Technologies sales office. If the instrument is being returned to Keysight Technologies for servicing, attach a tag indicating the service required, the return address, the model number, and the full serial number. Mark the container FRAGILE to help ensure careful handling. In any correspondence, refer to the fixture by model number and its full serial number.

Other Packaging

The following general instructions should be used when repacking with commercially available materials:

1. Wrap the 16451B in heavy paper or plastic. When shipping to a Keysight Technologies sales office or service center, attach a tag indicating the service required, return address, model number, and the full serial number.
2. Use a strong shipping container. A double-walled carton made of at least 350 pound test material is the minimum adequate.
3. Use enough shock absorbing material (3 to 4 inch layer) around all sides of the 16451B to provide a firm cushion and to prevent movement inside the container. Use cardboard to protect the front panel.
4. Securely seal the shipping container.
5. Mark the shipping container FRAGILE to help ensure careful handling.
6. In any correspondence, refer to the 16451B by model number and its full serial number.

3 Operation

Introduction

This chapter describes the product overview, basic theory of measuring dielectric constant using the 16451B, methods for measuring dielectric constant step by step, details of measurement procedure basic measurement procedure summarized and typical measurement procedures. The last part of this chapter describes measurement error factors.

WARNING DO NOT apply more than ±42Vpeak total test signal level and DC bias voltage to the unknown terminals. An electrical shock hazard will exist during operation when the DC bias voltage is greater than 42 V DC.

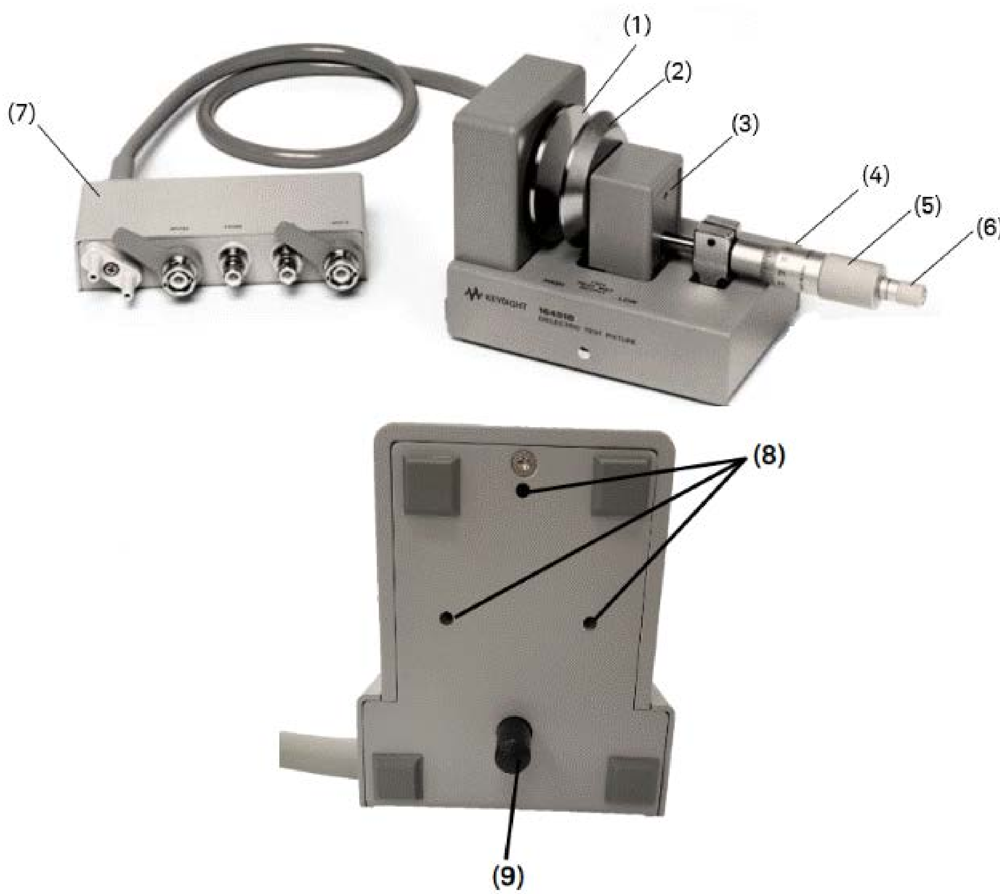
16451B Overview

The 16451B is a test fixture for measuring disc and film dielectric materials when connected to Keysight's LCR meters, Capacitance meters or impedance analyzers, and is usable up to 30MHz. The 16451B provides the fixture assembly, four interchangeable Guarded/Guard electrodes and accessories. Figure 3-1 shows the 16451B fixture assembly and Figure 3-2 shows the accessories furnished with the 16451B.

Fixture Assembly

The 16451B fixture assembly is equipped with a 4-terminal pair cable assembly, Guarded/Guard electrodes, and a micrometer to set the distance between the electrodes. The cable assembly can be connected directly to the 4-terminal pair measurement terminals of the instrument, and the configuration is changed to a 3-terminal at the Guarded/Guard electrodes. Figure 3-1 and Table 3-1 show the configuration name of each part of the fixture assembly.

Figure 3-1 Fixture Assembly



The name and description of the fixture assembly shown in Figure 3-1 are listed in the following table (Table 3-1).

Table 3-1 Name of Fixture Assembly

No	Name of Part	Description
1	Unguarded electrode	This electrode is connected to the Hc (High current) and Hp (High potential) terminal of the instrument.
2	Guarded/Guard electrode	This electrode is combined by a Guarded electrode and a Guard electrode. The guarded electrode is connected to the Lc (Low current) and Lp (Low potential) terminals of the instrument. The guard electrode is connected to the guard terminal. This electrode is interchangeable and is movable using the knobs on the micrometer.
3	Guarded/Guard electrode attachment screw	This screw secures the Guarded/Guard electrode.
4	Micrometer	The micrometer is used to adjust the distance between electrodes. Do not use this to measure thickness of the test material.
5	Adjustment knob (large knob)	This knob should be used for coarse adjustment of electrode distance. Do not use the large knob to bring the Guarded/Guard electrode into contact with the Unguarded electrode or test material.
6	Ratchet knob (small knob)	This knob is used to bring the Guarded/Guard electrode into contact with the Unguarded electrode or material.
7	Cable assembly	This cable assembly connects the 16451B to 4-terminal pair UNKNOWN terminals on the instrument's front panel.
8	Unguarded electrode adjustment screws	These screws are used to make the Unguarded electrode parallel with the Guarded/Guard electrode.
9	Guarded/Guard electrode pressure adjuster	When the 16451B is placed so that the surface of electrodes is horizontal, this adjuster pushes the Guarded/Guard electrode to adjust its pressure on the Unguarded electrode to be the same as when the 16451B is placed so that the surface of electrodes is perpendicular.

CAUTION

DO NOT use the large knob to bring the Guarded/Guard electrode into contact with the Unguarded electrode or test material, doing so will damage the micrometer or the surface of the electrodes. You must use the small knob when you bring the electrode into contact with another electrode or test material. It has a built in clutch which will slip at a specified torque.

Furnished Accessories

The 16451B provides some accessories, such as 4 types of changeable electrodes and their covers, an attachment for error correction, Hex key, and Carrying case. Figure 3-2 and Table 3-2 show the furnished accessories.

Figure 3-2 Furnished Accessories

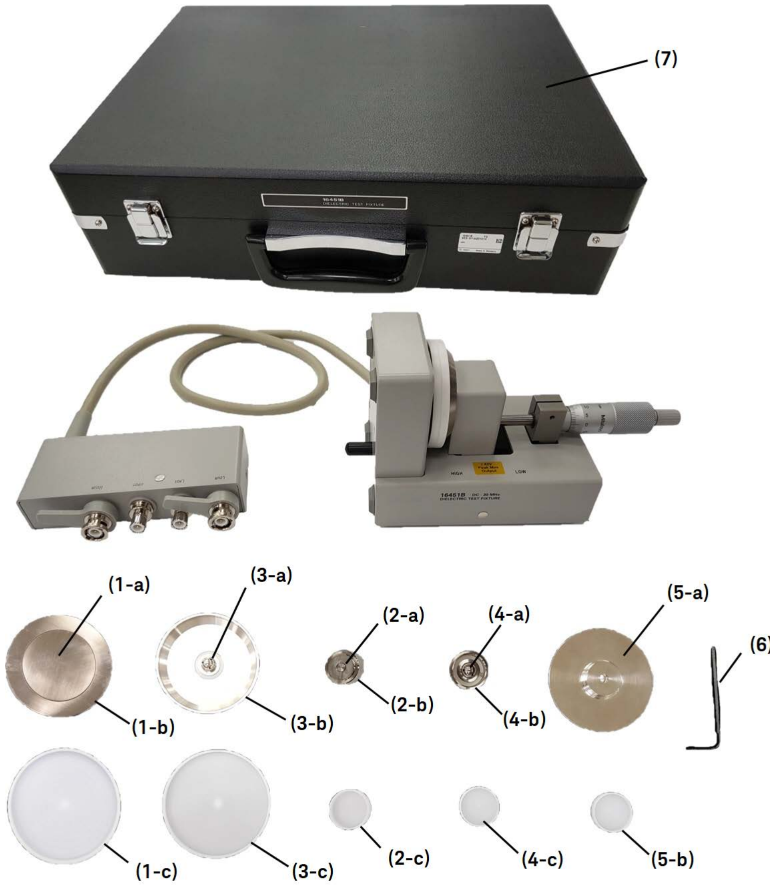


Table 3-2 Name of Furnished Accessories

No.	Name of accessory	Description
1	Electrode-A (38 mm Guarded/Guard electrode)	This electrode is used to measure a material without thin film electrode and consists of a Guarded electrode (1 -a) and a Guard electrode (1 -b). The diameter of guarded electrode is 38 mm. The electrode is provided with a cover (1 -c) to protect its surface.
2	Electrode-B (5 mm Guarded/Guard electrode)	This electrode is used to measure a material without thin film electrodes and consists of a Guarded electrode (2 -a) and a Guard electrode (2 -b). The diameter of guarded electrode is 5 mm. The electrode is provided with a cover (2 -c) to protect its surface.

Table 3-2 Name of Furnished Accessories

No.	Name of accessory	Description
3	Electrode-C (Electrode for large thin film electrodes)	This electrode is used to measure test materials which already have thin film electrodes applied and consists of a Guarded electrode (3 -a) and a Guard electrode (3 -b). The electrode is provided with a cover (3 -c) to protect its surface.
4	Electrode-D (Electrode for small thin film electrodes)	This electrode is used to measure test materials which already have thin film electrodes applied and consists of a Guarded electrode (4 -a) and a Guard electrode (4 -b). The electrode is provided with a cover (4 -c) to protect its surface.
5	Attachment for error correction	This is an attachment used for OPEN and SHORT corrections. (5 -a) shows the attachment and (5 -b) shows its cover.
6	Hex Key	This is a hex key used to interchanging and adjust the electrodes.
7	Carrying case	This is a carrying case used to store and carry the fixture assembly and its accessories.

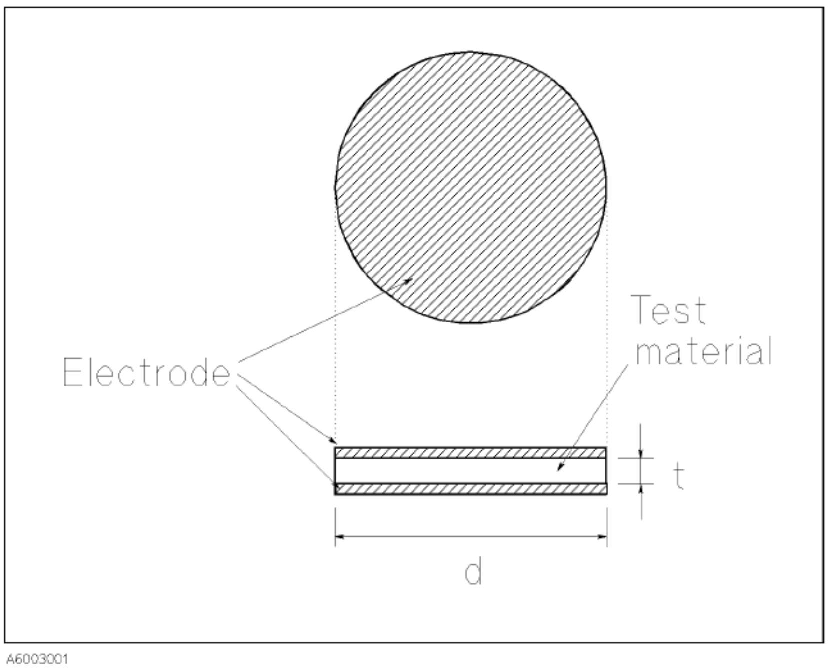
Dielectric Measurement Basic

This section contains information of the basic theory of dielectric measurements and its measurement methods.

Basic Theory

This section describes the basic theory of dielectric constant measurement. The dielectric constant, a fundamental parameter of insulating or dielectric materials, is calculated from the capacitance value when the material is used as the dielectric. A practical measurement procedure is described in “Typical Measurement Procedure by the Measurement Methods”. For the dielectric constant calculation, consider a solid material which is shaped into a disc as shown in Figure 3-3.

Figure 3-3 Basic Model for Dielectric Measurement



The dielectric constant can be obtained using the following equation.

$$\varepsilon = \varepsilon_0 \varepsilon_r$$
$$= \frac{t}{A} C_p$$

Where,

ε	Dielectric constant (permittivity) [F/m]
ε_0	Space permittivity = 8.85410^{-12} [F/m]
ε_r	Relative dielectric constant (Relative permittivity) of test material

C_p	Equivalent parallel capacitance value [F]
t	Thickness of test material [m]
A	Area of electrode [m^2]

Thus, the relative dielectric constant (generally called the dielectric constant) of the test material, ε_r, can be obtained by measuring the capacitance value and calculating using the following equation.

$$\varepsilon_r = \frac{t \times C_p}{A \times \varepsilon_0}$$

$$= \frac{t \times C_p}{\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_0}$$

Where,

d	Diameter of electrode [m]

The dielectric dissipation factor (= tan δ; loss tangent) of test material, Dr can be obtained directly by measuring the dissipation factor.

If the diameter of electrode is 38 mm, the denominator of the above mentioned equation becomes simple:

$$\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_0 \approx 1 \times 10^{-14}$$

Then, the equation to obtain the dielectric constant is:

$$\varepsilon_r = t \times C_p \times 1 \times 10^{14}$$

Guard Electrode

The dielectric constant of the disk material shown in Figure 3-3 is calculated from the measured capacitance value, as above-mentioned. When the capacitance of the disk material is measured, there is measurement error caused by stray capacitance at the edge of the test material, as shown in the left of figure of Figure 3-4. When the guard electrode as used by the 16451B surrounds the guarded electrode as used by the 16451B, it is possible to measure the capacitance of the test material accurately, because the guard electrode can avoid the stray capacitance at the edge of the electrode as shown in Figure 3-5.

Figure 3-4 Capacitance Measurement using Unguarded Electrode System

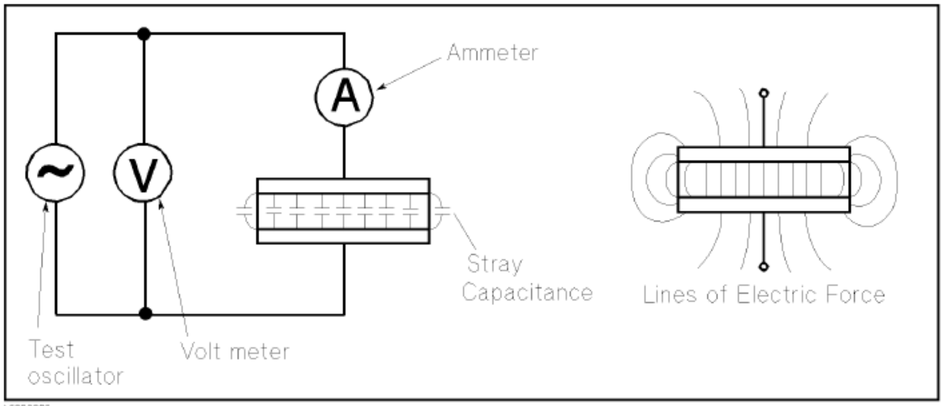
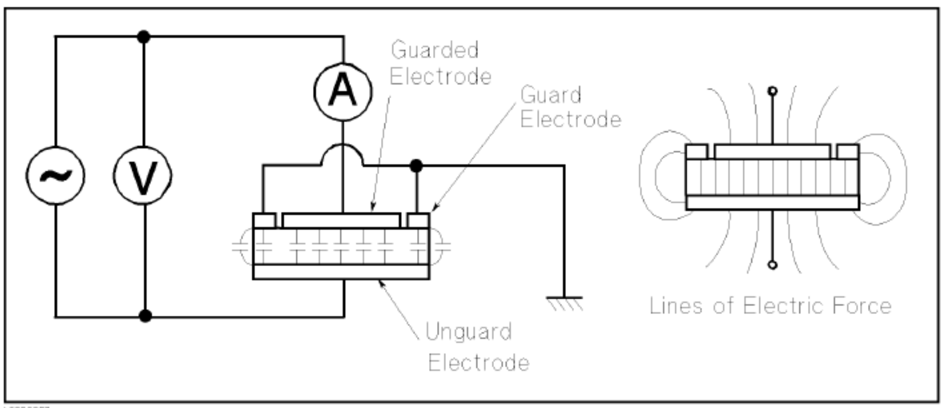


Figure 3-5 Capacitance Measurement using Guarded Electrode System



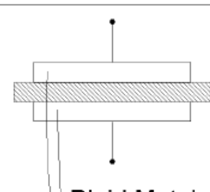
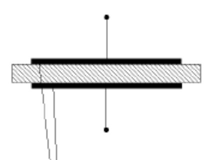
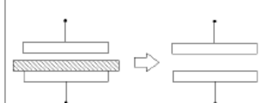
Measurement Method

This section describes three applicable measurement methods for the 16451B.

As the previous section “Dielectric Measurement Basic” explains, capacitance measurement of the test material is required when the dielectric constant of a solid test material is to be obtained. There are many kinds of methods to measure the capacitance of a solid material. Three measurement methods are applicable to the 16451B, they are the Contacting Electrode method (Rigid Metal electrode), the Contacting Electrode method (Thin Film electrode) and the Non-Contacting Electrode method (Air Gap method). You should select the suitable measurement method and the suitable electrode for your test material in order to measure it accurately.

Figure 3-6 shows a summary of three applicable measurement methods and the sections that follow describe them in more detail.

Figure 3-6 Summary of Measurement Methods

Measurement Method	Contacting Electrode Method (used with Rigid Metal Electorde)	Contacting Electrode Method (used with Thin FIlm Electorde)	Non-contacting Electrode Method (Air Gap Method)
Electrode* Structure	 Rigid Metal Electrodes	 Thin Film Electrode	
Operation	Simple →		Complex
Applicable Test Material	○ Thick material ○ Smooth material	Materials on which thin film electrode can be applied without changing its characteristics	○ Including contacting Method's applicable test Materials ○ Highly compressible material ○ Soft material
Electrodes of 16451B	Electrode-A Electrode-B	Electrode-C Electrode-D	Electrode-A Electrode-B

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* Guard electrodes are omitted

Contacting Electrode Method (used with Rigid Metal Electrode)

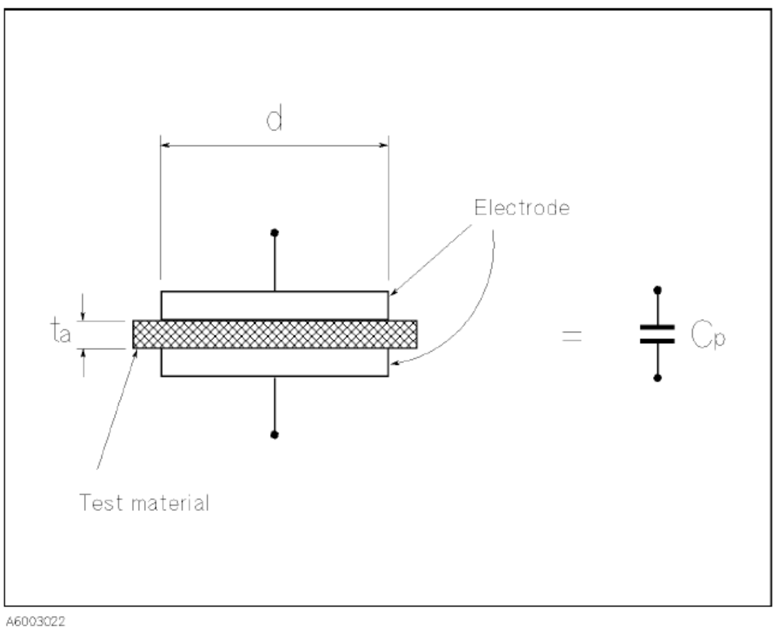
This method uses Rigid electrodes which make contact directly the surface of the test material. This method is applicable for thick, smooth or slightly compressible materials. The merits and demerits of this method are as follows:

- Merits
  - Procedure to measure capacitance is simple
  - It is not necessary to apply thin film electrodes
  - Equations to obtain dielectric constant are simple
- Demerits
  - Air film (error caused by air gap between electrodes and surface of the test material) causes error.

Principle

Figure 3-7 shows the schematic electrode structure for this method.

Figure 3-7 **Contacting Electrode Method (Rigid Metal Electrode)**



Dielectric constant and dissipation factor of a test material can be obtained using the following equations.

Parameters Needed:

C_p	Equivalent parallel capacitance [F]
D	Dissipation factor

t_a	Average thickness of test material [m]
A	Area of Guarded electrode [m^2]
d	Diameter of Guarded electrode [m]
	(38×10^{-3} [m] or 5×10^{-3} [m])
ε_0	$=8.854 \times 10^{-12}$ [F/m]

Equations:

$$\varepsilon_r = \frac{t_a \times C_p}{A \times \varepsilon_o}$$

$$= \frac{t_a \times C_p}{\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_o}$$

$D_t = D$

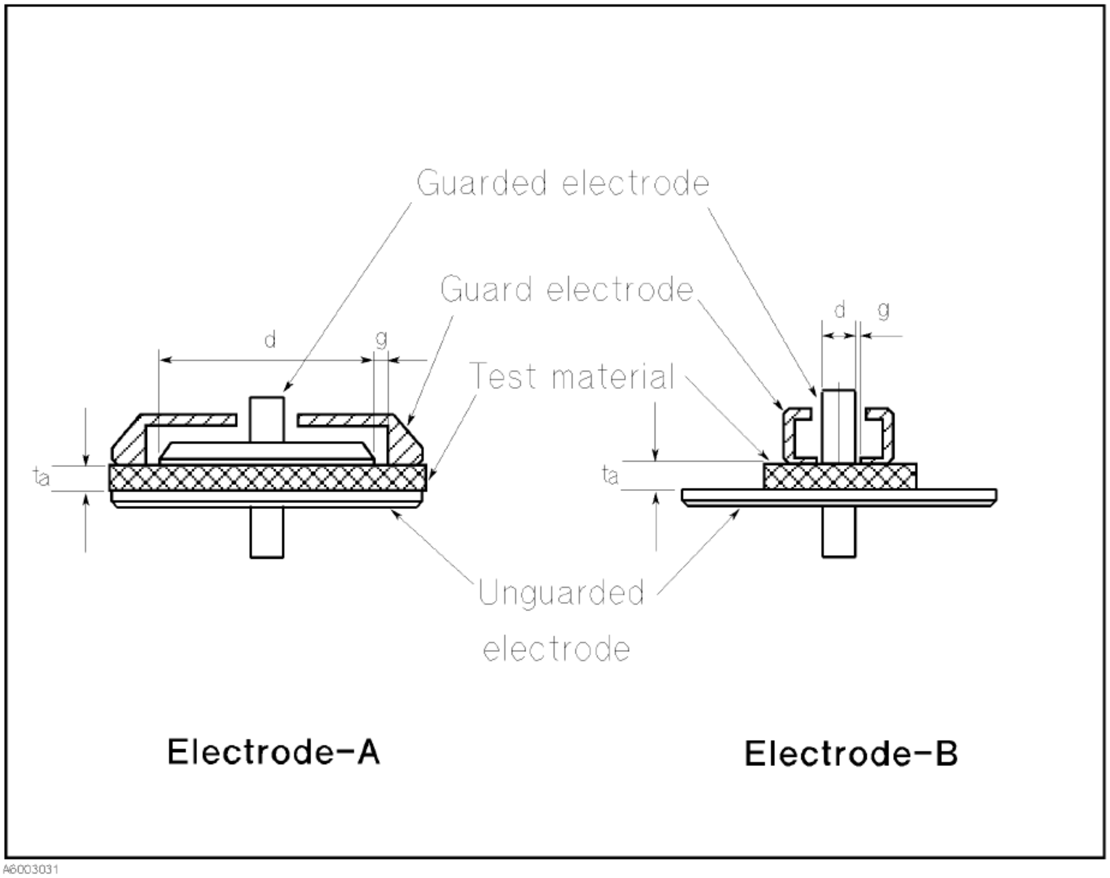
Where,

ε_r	Dielectric constant of test material
D_t	Dissipation factor of test material

Electrode of the 16451B

The 16451B provides two applicable electrodes, Electrode-A (38 mm electrode) and Electrode-B (5 mm electrode), for the Contacting Electrode method (Rigid Electrode method) to match the size of test material as shown in Figure 3-8. When these electrodes are used, the diameter of test materials should be much greater than the inner diameter of the Guard electrode and smaller than or equal to 56 mm. Figure 3-9 and Figure 3-10 show the applicable size of test material for these electrodes.

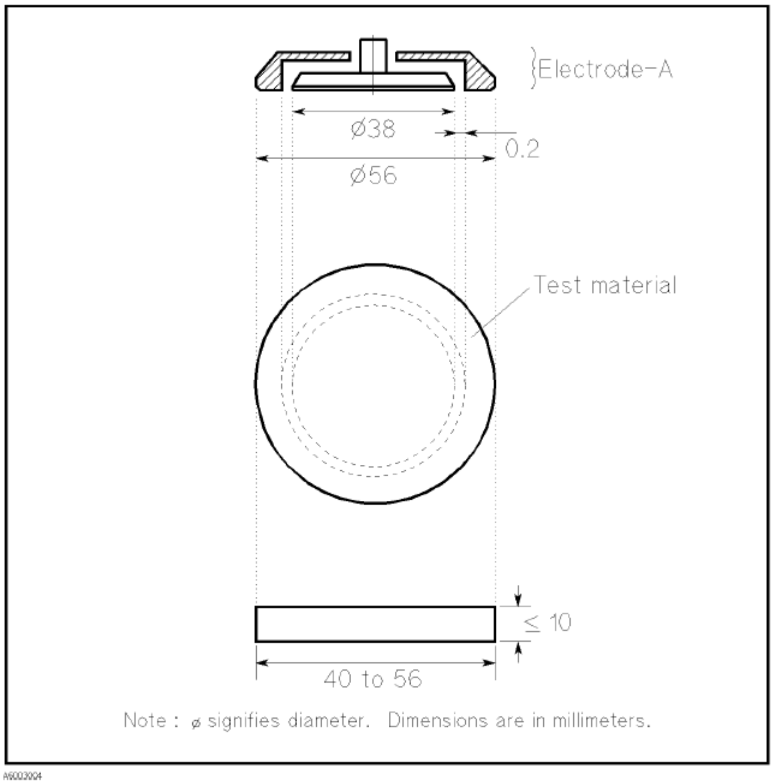
Figure 3-8 Electrode of the 16451B for Contacting Electrode Method (Rigid Metal Electrode)



Applicable Size of Test Material for Electrode-A
(38 mm Guarded/Guard Electrode)

Diameter of material	greater than or equal to 40 mm and smaller than or equal to 56 mm
Thickness of material	less than or equal to 10 mm

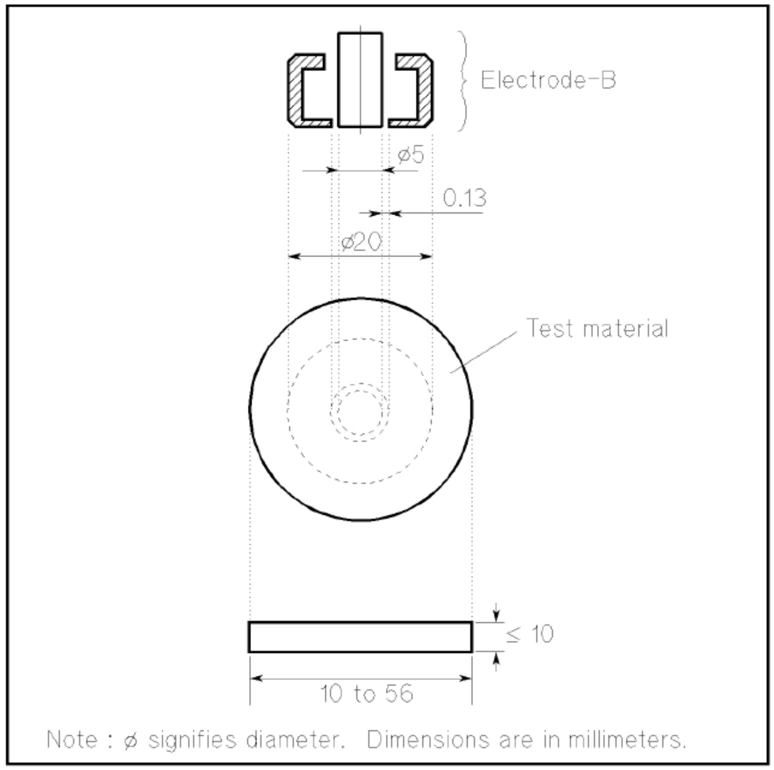
Figure 3-9 Applicable Size of Test Material for Electrode-A



Applicable Size of Test Material for Electrode-B (5 mm Guarded/Guard Electrode)

Diameter of material	greater than or equal to 10 mm and smaller than or equal to 56 mm
Thickness of material	less than or equal to 10 mm

Figure 3-10 **Applicable Size of Test Material for Electrode-B**



Contacting Electrode Method (used with Thin Film Electrode)

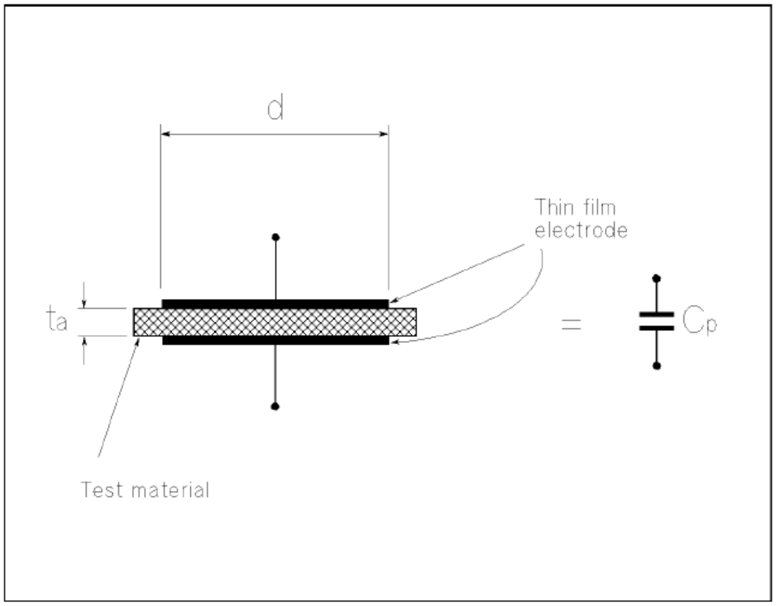
This method uses thin film electrodes applied on the test material. The thin film electrodes contact with the 16451B's electrodes. This method is applicable for materials on which the thin film electrodes can be applied without changing its characteristics. It should be noted that it is difficult to remove the thin film electrodes after the measurement. The merits and demerits of this method are as follows:

- Merits
  - Air film (error caused by air gap between the electrode and surface of the test material) causes minimum error
  - Procedure to measure capacitance is simple
  - Equations to obtain dielectric constant are simple
- Demerits
  - It is necessary to apply the thin film electrodes (Not applicable to materials which change their characteristics because of applying the thin film electrodes)

Principle

Figure 3-11 shows the schematic electrode structure for this method.

Figure 3-11 Contacting Electrode Method (Thin Film Electrode)



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Dielectric constant and dissipation factor of a test material can be obtained using the following equations.

Parameters Needed:

C_p	Equivalent parallel capacitance [F]
D	Dissipation factor
t_a	Average thickness of test material [m]
A	Area of Guarded electrode [m^2]
d	Diameter of Guarded thin film electrode [m]
ε_0	$=8.854 \times 10^{-12}$ [F/m]

Equations:

$$\varepsilon_r = \frac{t_a \times C_p}{A \times \varepsilon_o}$$

$$= \frac{t_a \times C_p}{\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_o}$$

$D_t = D$

Where,

ε_0	Dielectric constant of test material
D_t	Dissipation factor of test material

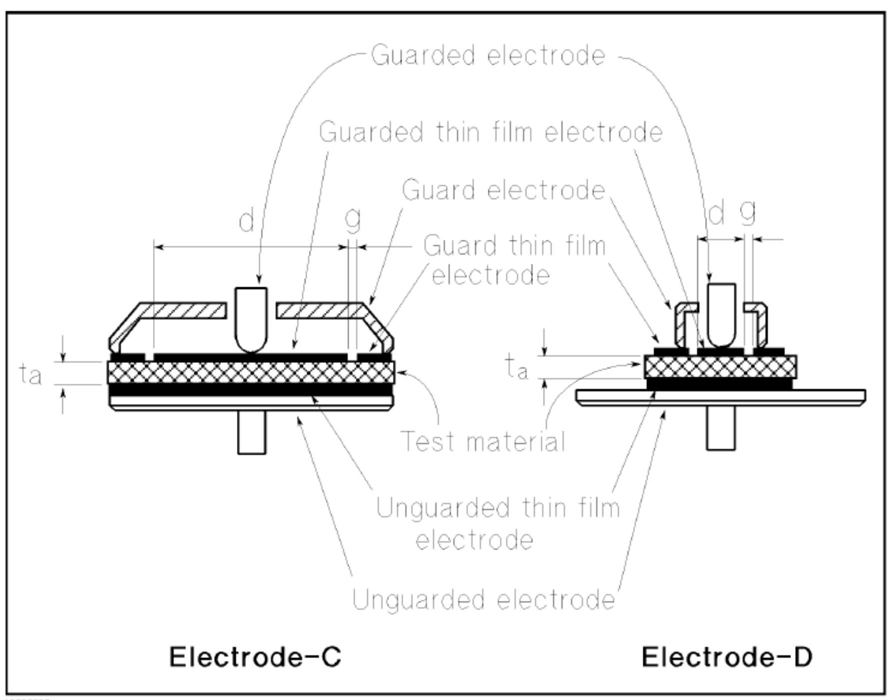
Thin Film Electrode

When this method is used, a metallic thin film is applied on surface of the test material. For more details, refer to “Thin Film Electrode” in “Preparation of Test Material”.

Electrodes of the 16451B

The 16451B provides two applicable electrodes, Electrode-C (electrode for large thin film electrodes) and Electrode-D (electrode for small thin film electrodes), for the Contacting Electrode method (Thin Film electrode) to match the size of the test material as shown in Figure 3-12. When these electrodes are used, the diameter of the thin film guarded electrode must be smaller than the inner diameter of the guarded electrode of the 16451B and the diameter of the thin film guard electrode must be greater than the inner diameter of the guarded electrode of the 16451B. Figure 3-13 and Figure 3-14 show the applicable size of test material for these electrode.

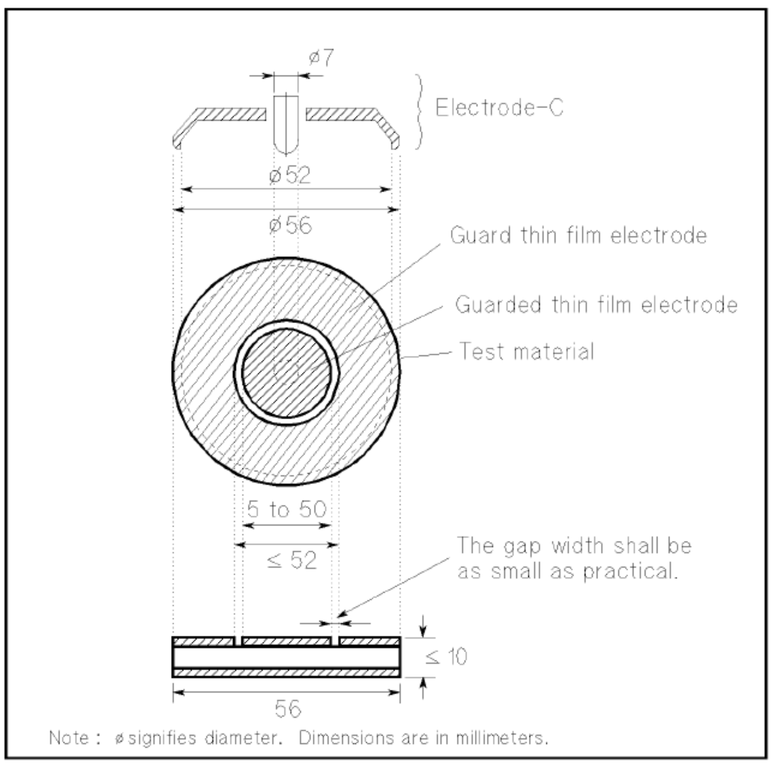
Figure 3-12 Electrode of the 16451B for Contacting Electrode Method (Thin Film Electrode)



Applicable Size of Test Material for Electrode-C (Guarded/Guard Electrode for Large Thin Film Electrode)

Diameter of test material	56 mm
Diameter of guarded thin film electrode	greater than or equal to 5 mm and less than or equal to 50 mm
Inner diameter of guard thin film electrode	less than or equal to 52 mm and greater than a diameter of guarded thin film electrode.
Gap distance between guarded thin film electrode and guard thin film electrode	as small as practical (0.5 mm is possible)
Thickness of material	less than or equal to 10 mm

Figure 3-13 Applicable Size of Test Material for Electrode-C

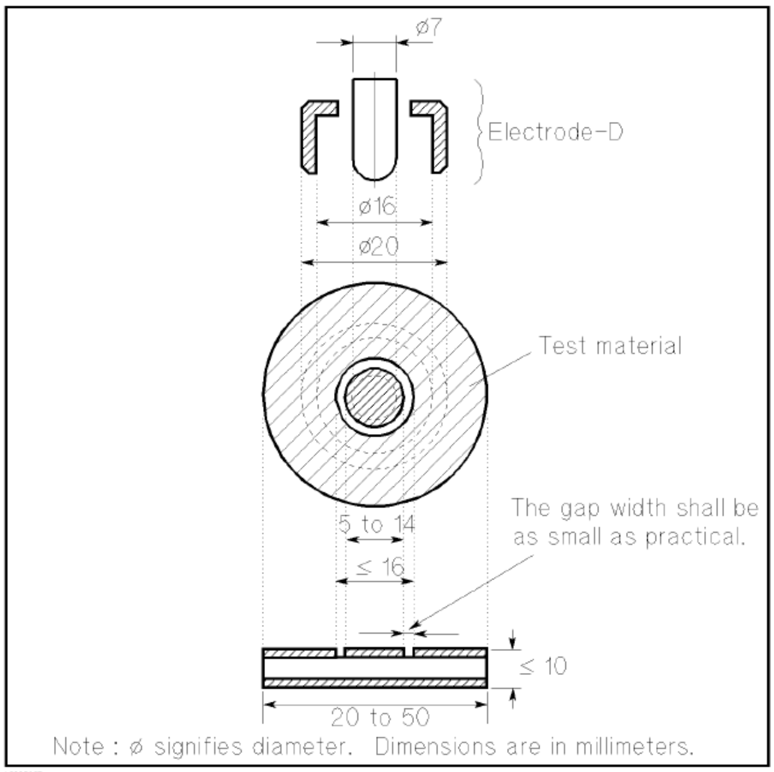


Applicable Size of Test Material for Electrode-D (Guarded/Guard Electrode for Small Thin Film Electrodes)

Diameter of test material	greater than or equal to 20 mm and less than equal to 56 mm

Diameter of guarded thin film electrode	greater than or equal to 5 mm and less than or equal to 14 mm
Inner diameter of guard thin film electrode	less than or equal to 16 mm and greater than a diameter of guarded thin film electrode.
Gap distance between guarded thin film electrode and guard thin film electrode	as small as practical (0.5 mm is possible)
Thickness of material	less than or equal to 10 mm

Figure 3-14 **Applicable Size of Test Material for Electrode-D**



Non-contacting Electrode Method (Air Gap Method)

This method accurately derives the dielectric constant from the capacitance difference between two measurements, without the test material, the other with the test material. These two measurements are made with the distance between the electrodes held constant. This method is especially applicable for film materials, highly compressible materials (such as foam rubber), or soft materials. The merits and demerits of this method are as follows:

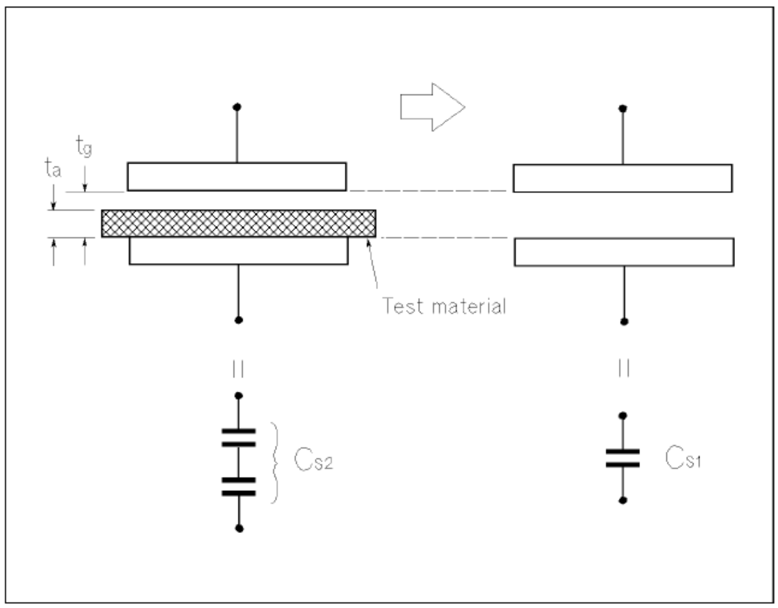
- Merits
  - Air film (error caused by air gap between the electrode and the surface of test material) does not cause error

  - It is not necessary to apply thin film electrodes
- Demerits
  - It is necessary to measure capacitance twice
  - Equation to derive the dielectric constant is complex

Principle

Figure 3-15 shows the schematic electrode structure for this method.

Figure 3-15 Non-contacting method (Air Gap method)



Dielectric constant and dissipation factor of a test material can be obtained with the following equations.

Parameters Needed:

C_{s1}	Series capacitance when the test material is not inserted [F]
D_1	Dissipation factor when the test material is not inserted
t_g	Gap between Guarded/Guard electrode and Unguarded electrode [m]
C_{s2}	Series capacitance when the test material is inserted [F]
D_2	Dissipation factor when the test material is inserted
t_a	Average thickness of test material [m]

Equations:

$$\varepsilon_r = \frac{1}{1-\left(1-\frac{C_{s1}}{C_{s2}}\right)\times\frac{t_g}{t_a}}$$

$$D_t = D_2 + \varepsilon_r \times (D_2 - D_1) \times \left(\frac{t_g}{t_a} - 1\right)$$

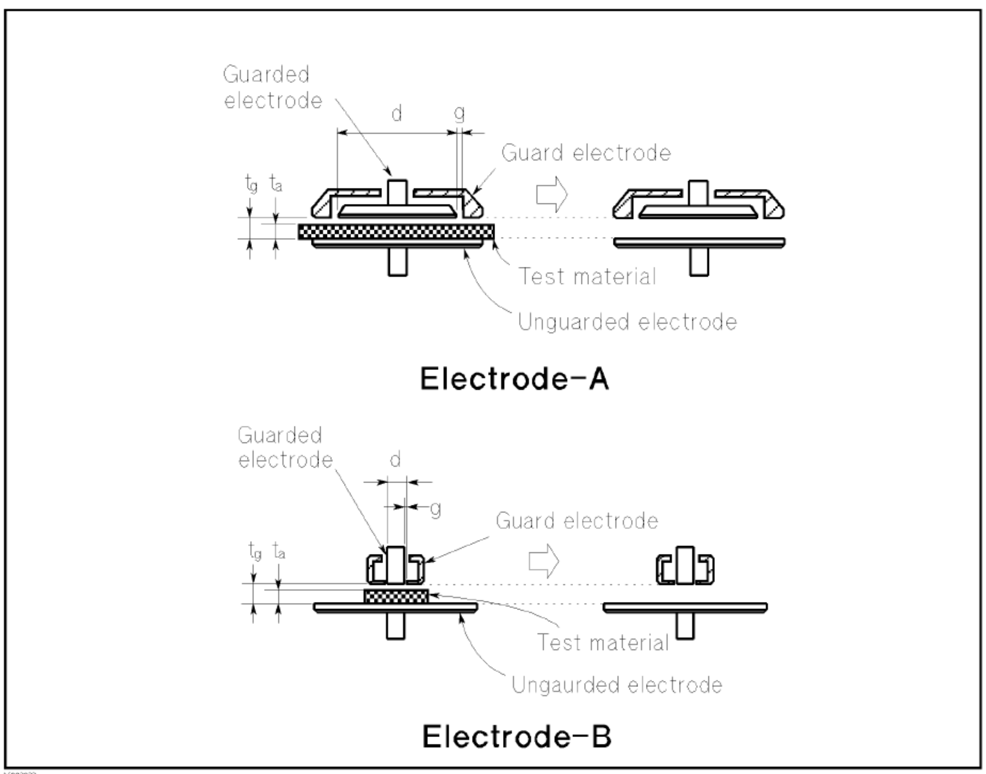
Where,

ε_r	Dielectric constant of test material
D_t	Dissipation factor of test material

Electrode of the 16451B

The 16451B provides two applicable electrodes, Electrode-A (38 mm electrode) and Electrode-B (5 mm electrode), for Non-contacting Electrode method (Air Gap method) to match the size of test material as shown Figure 3-16. When these electrodes are used, the diameter of test materials must be much greater than the inner diameter of the Guard electrode. Figure 3-17 and Figure 3-18 show the applicable size of test materials for these electrodes.

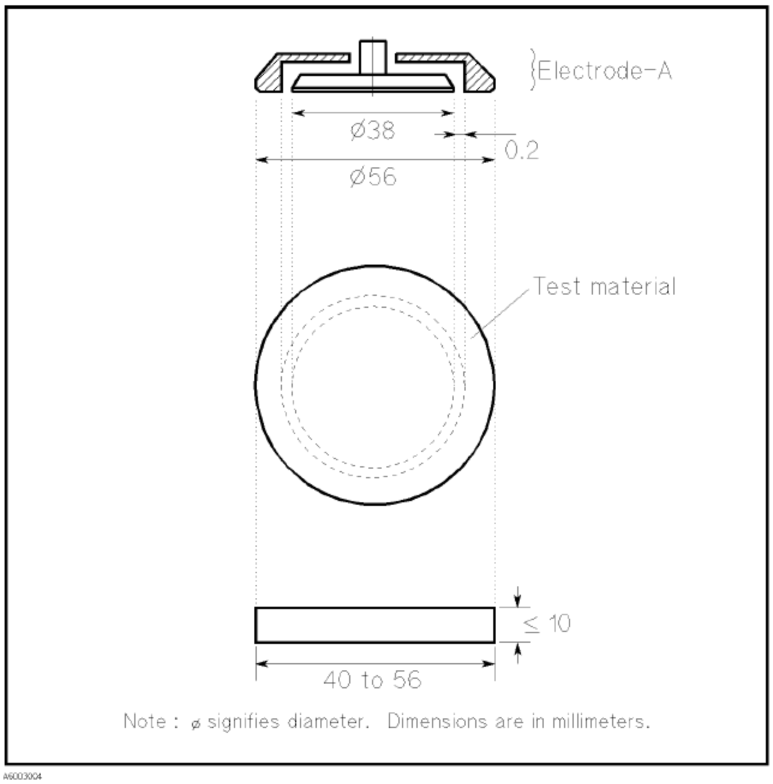
Figure 3-16 Electrode of the 16451B for Non-Contacting Electrode Method (Air Gap Method)



Applicable Size of Test Material for Electrode-A (38 mm Guarded/Guard Electrode)

Diameter of test material	greater than or equal to 40 mm and smaller than or equal to 56 mm
Thickness of material	less than or equal to 10 mm

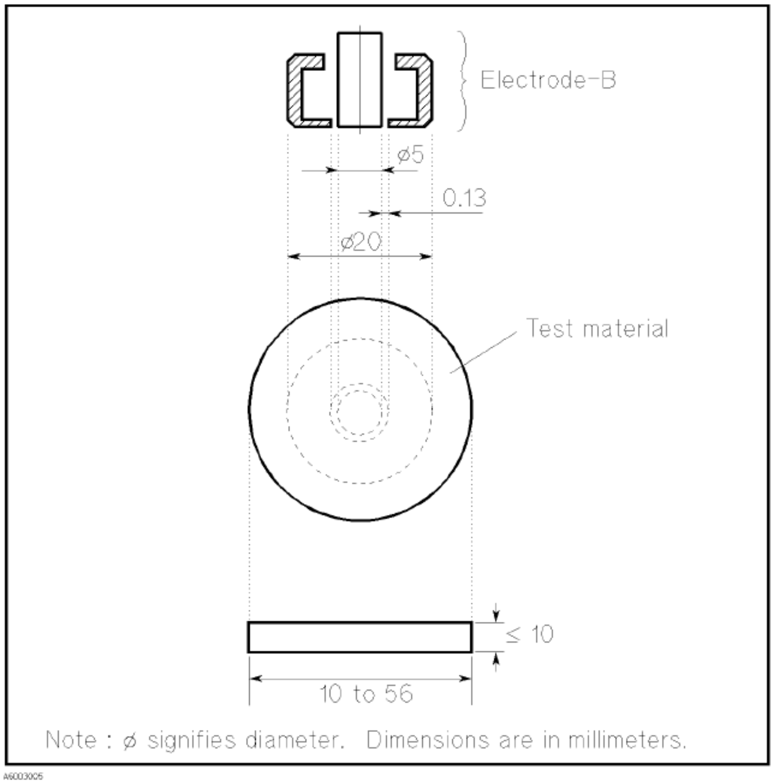
Figure 3-17 Applicable Size of Test Material for Electrode-A



Applicable Size of Test Material for Electrode-B (5 mm Guarded/Guard Electrode)

Diameter of test material	greater than or equal to 10 mm and smaller than or equal to 56 mm
Thickness of material	less than or equal to 10 mm

Figure 3-18 Applicable Size of Test Material for Electrode-B



Preparation of Test Material

Dielectric constant measurement error is caused by not only capacitance measurement error, but also by the error in the test material dimensions. Therefore the test material should be accurately cut or molded so that its dimensional error will not affect the dielectric constant value. Before proceeding to the actual measurement, read the following to prepare the test material.

Shape and Size of Test Material

The applicable shape of the test material for the 16451B should be a plate or a film. The applicable size (diameter) of the test material should be greater than the inner diameter of the Guard electrode used. The 16451B can also measure test materials whose shape is not a disk, when the size of the test material is greater than the inner diameter of the Guard electrode.

CAUTION **Do not measure a material whose size (diameter) is much greater than Unguarded electrode, doing so will overload electrodes and damage them.**

To obtain an accurate dielectric constant value, it is usually better to use larger diameter and thinner thickness of the test material so that its measured capacitance is greater. Therefore, when a low dielectric constant material is measured, it is better to use larger electrode (Electrode-A for using rigid metal electrodes and Electrode-C for using thin film electrodes). If Electrode-B or Electrode-D is used when low dielectric constant material is measured, you should change the thickness of test material so that the capacitance value is large (more than 0.1pF). (For more detail, refer to next section “Thickness of Test Material”.)

Thickness of Test Material

A thickness of a test material is limited to the 10 mm by the range for moving the electrode of the 16451B. Because thickness is needed to obtain the dielectric constant, you must know accurately thickness of your test material. To reduce the reading error, you must average the thickness values measured at the several points in the measurement area and then use this averaged value to obtain the dielectric constant.

NOTE **Do not use the micrometer attached the 16451B to measure thickness of test material, because it is for setting electrode distance and is not good enough for an absolute measurement.**

To obtain an accurate dielectric constant value, it is usually better to use larger diameter and thinner thickness of the test material so that its measured capacitance value is greater.

For example, when a test material whose dielectric constant is less than 10 is measured using the 16451B with an LCR meter, the value measured is only a few pF. When small capacitance is measured, measurement error increases. To reduce the error and to obtain accurate capacitance value, the capacitance value of your test material must be in the range shown in Appendix B. So you should change the thickness and diameter of your test material so that the capacitance value of your test material is in that range.

When either Electrode-B or Electrode-D are used, the measured capacitance value becomes too small because the diameter of the electrode is small. Especially, when the dielectric constant of the test material is less than 6, the capacitance value measured will be less than 0.1 pF if the thickness of test material is too thick. Such a small capacitance value is difficult to measure accurately. Therefore, when a test material whose dielectric constant is less than 6 is measured using Electrode-B or Electrode-D, you must cut or mold your test material so that the thickness (t) of the test material satisfies the following conditions (capacitance value measured becomes greater than 0.1pF).

$$\varepsilon_o \times \varepsilon_r \times \frac{\pi \times \left(\frac{d}{2}\right)^2}{t} \geq 0.1 \times 10^{-12}$$

Where,

t	Thickness of test material [m]
d	Diameter of Guarded electrode [m]
ε_r	Dielectric constant of test material
ε_0	$=8.854 \times 10^{-12}$ [F/m]

Flatness of Test Material's Surface

The surface of the test material must be flat at all points. When the Rigid Metal electrode (Electrode-A and Electrode-B) is used, flatness of the test material is especially important. If the surface of the test material is not flat, an air film (gap between an electrode and a test material) increases and this causes measurement error. Measurement error caused by non-flatness will increase when the test material is thin. For example, if the flatness error is 10μm, the dielectric constant measurement error will be 0.3% for a material of 1 mm thickness, but the error of capacitance measurement will be about 10% for a material of 40μm thickness.

Thin Film Electrode

Thin film electrodes can reduce the air gap between an electrode and a test material. Therefore the air film error (error caused by air gap between an electrode and a test material) using thin film electrodes is less than one using rigid metal electrodes. There are several types of thin films, such as Metal Foil, Conductive Paint, Fired on Silver, Sprayed Metal, Evaporated Metal, and Metal Spattering. Select the suitable thin film electrode. (For more detail, refer to ASTM Standards:D150-81, “Standard Test Method for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials”.) When attaching the thin film electrode, the gap width between the guarded thin film electrode and the guard thin film electrode should be as small as practical (0.5 mm if possible).

Connecting to the Instrument

The 16451B can be connected directly to the measurement terminals of a 4-terminal pair configuration. Set the Cable Length switch or softkey of the instrument to 1 m to compensate for the error caused by the test leads of the 16451B. The procedure for setting the cable length is different by instrument, refer to the operation manual.

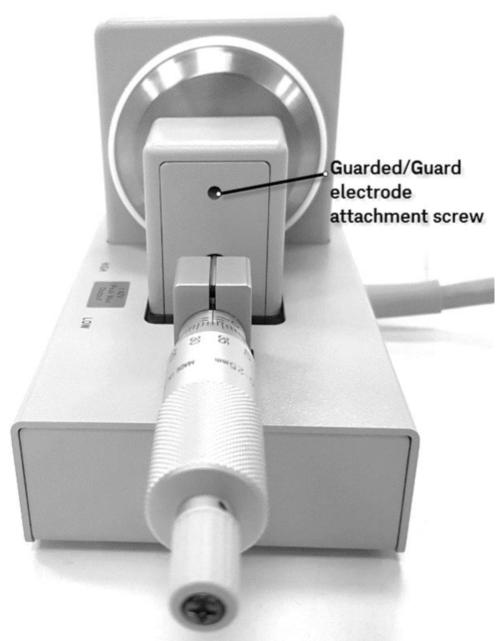
Changing the Guarded/Guard Electrode

This section describes the procedure to change the electrodes of the16451B.

When you change an electrode, be careful not to contaminate or not to make scratch on the surface of the electrode. Use lint free gloves to prevent putting fingerprints on it. Also, put the covers on both of the electrodes before removing one. The removed electrode should be stored in the carrying case. The electrode replacement procedure is as follows.

1. Turn the small knob of the micrometer ccw (counterclockwise) to move the Guarded/Guard electrode away from the Unguarded electrode.
2. Put the covers on both electrodes to protect their surface.
3. Remove the Guarded/Guard electrode by loosening the screw shown in Figure 3-19 using the furnished hex key. Put it into the carrying case and take out the electrode, which you will use, from the carrying case.

Figure 3-19 Screw Position to Attach Guarded/Guard Electrode



1. Clean the surface of the electrodes to be used. Use a lint free cloth with alcohol. After cleaning, return the covers to protect the surface.
2. Connect the Guarded/Guard electrode and tighten the screw using a hex key.
3. Turn the small knob until it slips when the covered electrodes touch each other.

NOTE

After the electrode is changed, you should adjust it for parallelism. For the detailed adjustment procedure, refer to “Electrode Adjustment” on page 54.

NOTE

Be careful not to contaminate or not to make a scratch on the surface of the electrode. A scratch or contamination of the electrode’s surface sometimes prevents the measured capacitance from falling within the limits shown in “Electrode Adjustment” on page 54. If it happens, replace the scratched/contaminated electrode or contact your nearest Keysight Technologies Sales and Service Office. As long as the measured capacitance falls within the limits, the electrode doesn’t need to be replaced or repaired.

Error Correction

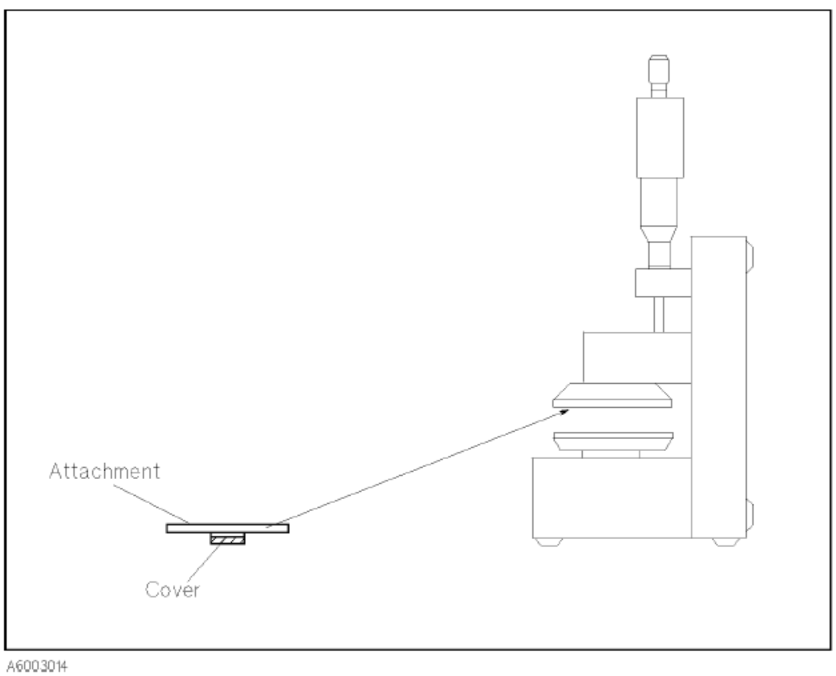
The recommended measurement instruments for the 16451B listed in Table 1-2 have error correction functions to reduce residual impedance and stray admittance in the 16451B. For precise dielectric constant measurements perform the error correction. An error correction attachment, furnished with the 16451B, is necessary.

Open Correction (ZERO OPEN Offset Adjustment)

The stray admittance contained in the 16451B can be reduced by performing the following procedure.

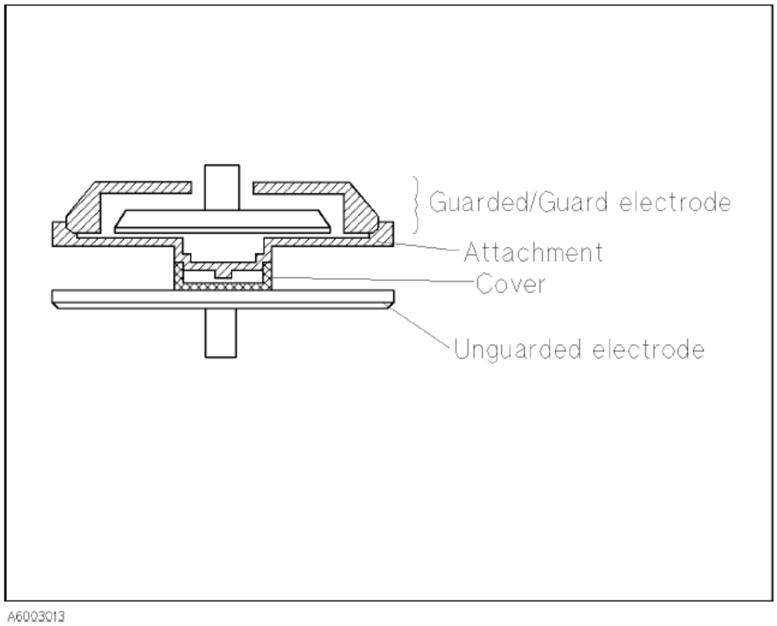
1. Turn the small knob of the 16451B ccw to move the Guarded/Guard electrode away from the Unguarded electrode.
2. After removing the covers of both electrodes, connect the attachment with the cover to the Guarded/Guard electrode as shown in Figure 3-20. As shown in Figure 3-21, the inner electrode of the Guarded/Guard electrode is completely surrounded by the guard.

Figure 3-20 Connecting the Attachment to the Guarded/Guard Electrode for OPEN correction



3. Turn the small knob of the 16451B cw (clockwise) to bring the Unguarded electrode into contact with the attachment (until the clutch slips). As shown in Figure 3-21, the inner electrode of the Guarded/Guard electrode is completely surrounded by the guard.

Figure 3-21 OPEN Correction



4. Perform the OPEN correction measurement. (The procedure to perform the OPEN correction depends on the measurement instrument, for the details of this procedure, refer to the operation manual of the measurement instrument.)
5. Turn the small knob ccw to move the electrodes away from each other, and remove the attachment.

Short Correction (ZERO SHORT Offset Adjustment)

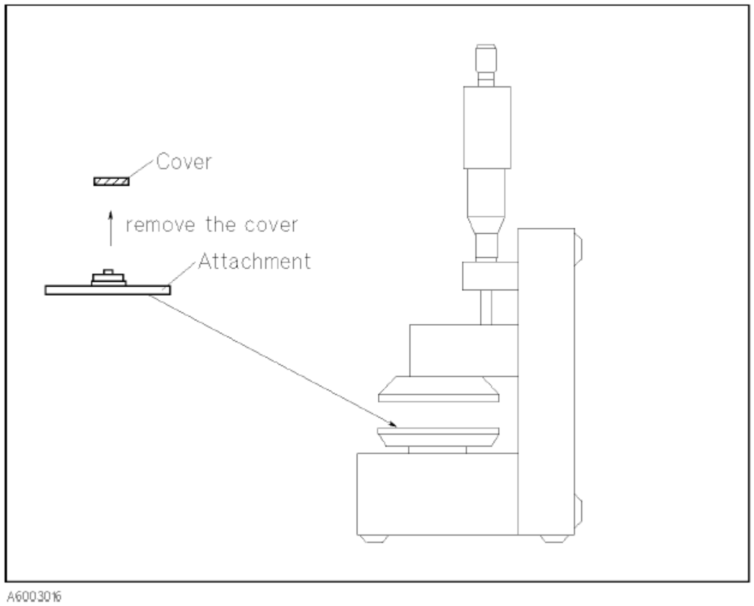
The procedure to perform SHORT correction depends on the type of the Guarded/Guard electrode used, so you should select the appropriate procedure according to the Guarded/Guard electrode you will use.

For Electrode-A and Electrode-B (Rigid Metal Electrode)

When you use Electrode-A (38 mm electrode) and Electrode-B (5 mm electrode), the residual impedance contained in the 16451B can be reduced by performing the following SHORT correction procedure.

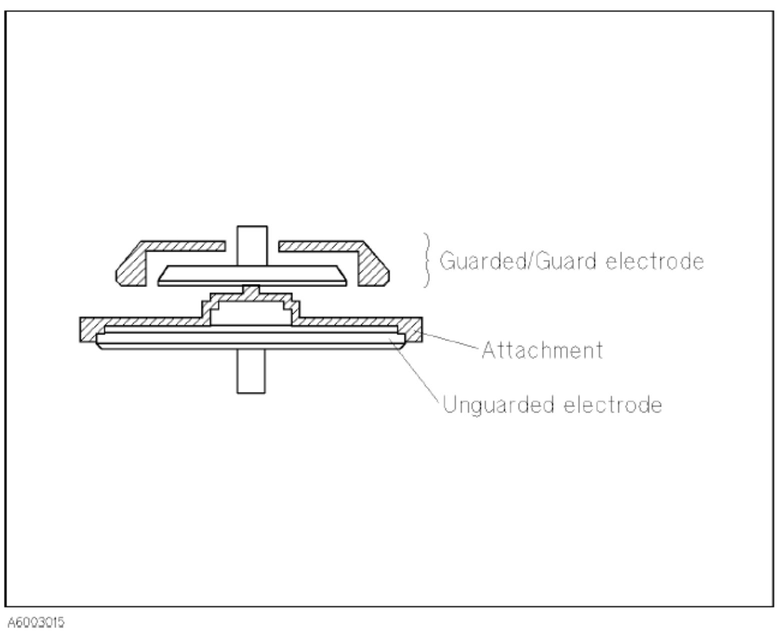
1. Turn the small knob ccw to move the Guarded/Guard electrode away from the Unguarded electrode.
2. After removing the cover from both electrodes, also remove the cover from the attachment. Then connect the attachment to the Unguarded electrode as shown in Figure 3-22.

Figure 3-22 Connecting the Attachment to the Unguarded Electrode for SHORT Correction



3. Turn the small knob cw to bring the Guarded/Guard electrode into contact with the attachment (until the clutch slips).

Figure 3-23 SHORT Correction for Rigid Metal Electrode



4. Perform the SHORT correction measurement. (The procedure to perform the SHORT correction depends on the measurement instrument, for the details of this procedure, refer to operation manual of the measurement instrument.)

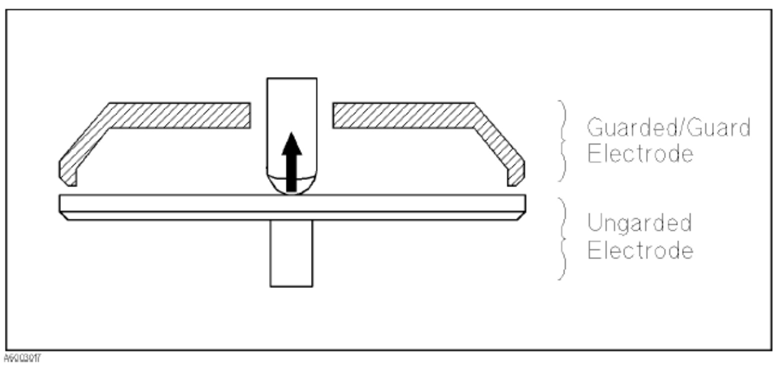
5. After the measurement, turn the small knob ccw to move the electrodes away from each other and remove the attachment.

For Electrode-C and Electrode-D (Electrode for Thin Film Electrodes)

When you use Electrode-C (electrode for large thin film electrodes) and Electrode-D (electrode for small thin film electrodes), the residual impedance contained in the 16451B can be reduced by performing the following SHORT correction procedure

1. Turn the small knob ccw to move the Guarded/Guard electrode away from the Unguarded electrode, then remove the cover from both electrodes.
2. Turn the small knob cw to contact the Guarded electrode to the Unguarded electrode as shown in Figure 3-24. The Guard electrode is spring-loaded and is designed to contact earlier than the Guard electrode. But do not turn the knob until the Guard electrode contacts with the Unguarded electrode.

Figure 3-24 SHORT Correction for Thin Film Electrodes



NOTE **When the Guard electrode contacts to the Unguarded electrode before the Guarded electrode contacts to the Unguarded electrode, the electrodes deviates from the parallel position. Perform a rough adjustment to make the electrodes parallel as described in the next section “Electrode Adjustment”.**

3. Perform the SHORT correction measurement. (The procedure to perform the SHORT correction depends on the measurement instrument, for the details of this procedure, refer to operation manual of the measurement instrument.)
4. After the measurement, turn the small knob ccw to move the electrodes away from each other

LOAD Correction (LOAD Compensation)

If the measurement frequency exceeds 5 MHz, you must perform LOAD compensation in addition to OPEN/SHORT compensation. Use an air capacitor (adjust the distance between the electrodes to obtain the value in the following table) as the standard when measuring the LOAD compensation data. As the standard value for LOAD compensation, use the equivalent parallel capacitance value (C_p) measured at a low frequency (100 kHz). (It is assumed that the air capacitor has no dependence on frequency.)

Electrodes	Value of Load (Air Capacitor)
A	50 pF ± 0.5 pF
B	5 pF ± 0.05 pF
C and D	1.5 pF ±0.05 pF

Actual measurement procedure for the LOAD standard is as follows:

Adjust the distance between the 16451B's electrodes, measure C_p at 100 kHz, and sets it as the LOAD compensation standard value (C_p: measured value and G: 0). Then, by maintaining the distance between the electrodes, measure data as the LOAD compensation data at the frequency points where you want to measure the material. For more information, refer to the instrument's manual.

Electrode Adjustment

You should adjust the Guarded/Guard electrode until it is parallel with the Unguarded electrode for accurate measurement. You must perform this adjustment in the following cases:

- Before measurement
- After changing electrodes
- When the result of the "Check Electrode Parallelism" fails (for more details, refer to "Check Electrode Parallelism")

NOTE When you use Electrode-A or Electrode-B, and after you measure the test material (or move the electrode) several times, it is recommended to check for electrode parallelism (refer to "Check Electrode Parallelism").

There are two adjustments, the one is a rough adjustment that visually adjust the electrode and the other is an accurate adjustment that electrically adjust the electrode using an LCR meter. (But the second one is not necessary for Electrode-C and D). Depending on the electrode you use, a different adjustment procedure should be used as follows.

- Contacting electrode method (Rigid Metal method): Using Electrode-A, Electrode-B
  1. Perform "Rough Adjustment to Make Electrodes Parallel"
  2. Perform "Accurate Adjustment in Vertical Position"
- Contacting electrode method (Thin Film electrode): Using Electrode-C, Electrode-D
  1. Perform "Rough Adjustment to Make Electrodes Parallel"
- Non-contacting electrode method (Air Gap method): Using Electrode-A, Electrode-B
  1. Perform "Rough Adjustment to Make Electrodes Parallel"
  2. Perform "Accurate Adjustment in Horizontal Position"

CAUTION DO NOT use the large knob to bring the Guarded/Guard electrode into contact with the Unguarded electrode or the test material, doing so may damage the micrometer or the surface of the electrodes. Use the small knob when you bring the electrode into contact with another electrode or test material. It has a built-in clutch which will slip at a specified torque.

CAUTION Do not turn the Unguarded electrode adjustment screws cw when the Guarded/Guard electrode contacts Unguarded electrode. If you do so, the micrometer will be overloaded and break.

NOTE

You should perform the adjustment in the same environmental conditions as you will measure the test material using the 16451B, because a change of temperature causes mechanical dimensions to change. When you change temperature condition, you should perform the accurate adjustment after temperature conditions have changed, because a change of temperature causes mechanical dimensions to change.

NOTE

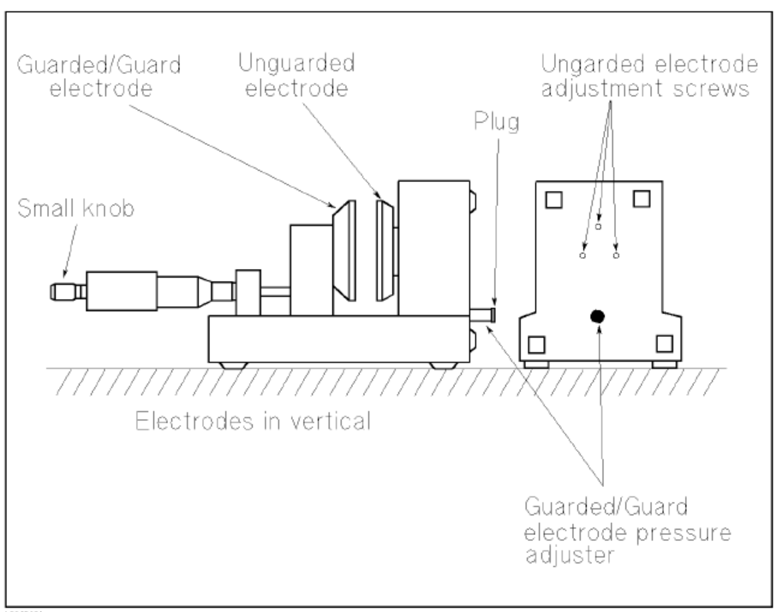
Be careful not to contaminate or not to make a scratch on the surface of the electrode. A scratch or contamination of the electrode's surface sometimes prevents the measured capacitance from falling within the limits shown in "Electrode Adjustment" on page 54. If it happens, replace the scratched/contaminated electrode or contact your nearest Keysight Technologies Sales and Service Office. As long as the measured capacitance falls within the limits, the electrode doesn't need to be replaced or repaired.

Rough Adjustment to Make Electrodes Parallel

This adjustment is made by checking parallelism of the electrodes visually. The adjustment requires the furnished hex key to adjust the physical position of the Unguarded electrode. Use the following procedure to perform this adjustment before the measurement and after changing the electrodes.

1. Place the 16451B so that the surface of electrodes are vertical as shown in Figure 3-25.

Figure 3-25 Vertical Position and Electrode Adjustment Screws



2. Remove the covers on both electrodes and turn the small knob of the micrometer cw to bring the Guarded/Guard electrode into contact with the Unguarded electrode until the clutch slips.

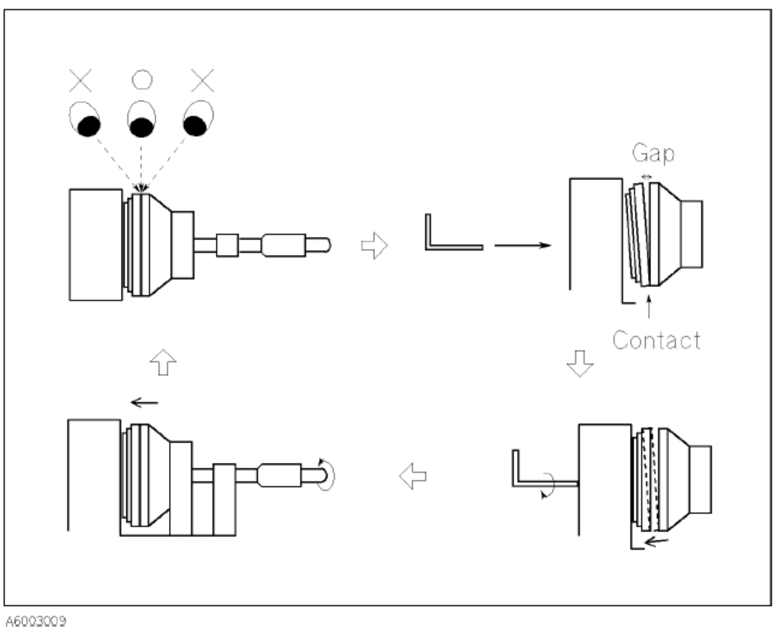
3. Check if the micrometer's scale indicates less than zero. If the clutch slips above zero, turn the small knob ccw to remove the electrodes, and then turn three Unguarded electrode adjustment screws (shown in Figure 3-25) ccw until the micrometer's scale indicates below zero when Guarded/Guard electrode contacts Unguarded electrode.

4. Check that there is no gap between the electrodes with the electrodes contacting as shown in Figure 3-26.

5. If there is a gap, turn the furthermost adjustment screw from the gap ccw to make the electrodes parallel and go to step 1. If you can not see a gap, the rough adjustment is finished.

Perform the next step "Accurate Adjustment to Make Electrodes Parallel", when using the Contacting electrode method (Rigid metal electrode) and Non-contacting Electrode method (Air Gap method).

Figure 3-26 Rough Adjustment Procedure



Accurate Adjustment to Make Electrodes Parallel

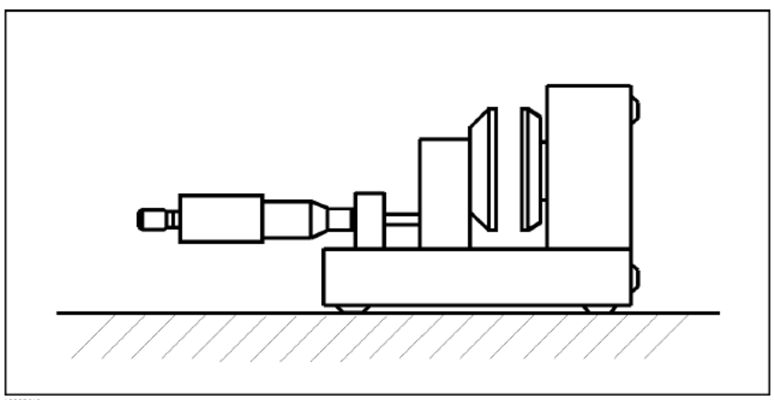
When Electrode-A and Electrode-B are used, perform the following procedure after performing the "Rough Adjustment to Make Electrodes Parallel". When you use Electrode-C and Electrode-D (Thin Film electrodes), you do not need to perform the rough adjustment.

Accurate Adjustment in Vertical Position

When the Contacting Electrode method (Rigid Metal electrode) is used with Electrode-A and Electrode-B, perform this adjustment after the above mentioned adjustment ("Rough Adjustment to Make Electrodes Parallel") is performed. The procedure of "Accurate Adjustment in Vertical Position" is as follows.

1. Clean the electrodes. This is necessary because the capacitance value is affected by dust. (Refer to "Changing the Guarded/Guard Electrode".)
2. Perform OPEN/SHORT correction.
3. Connect the 16451B to an LCR meter or an impedance analyzer and select the capacitance measurement function (C_p) for Circuit mode. (Refer to "Connecting to the Instrument".)
4. Place the 16451B so that the surfaces of electrodes are vertical as shown in Figure 3-27.

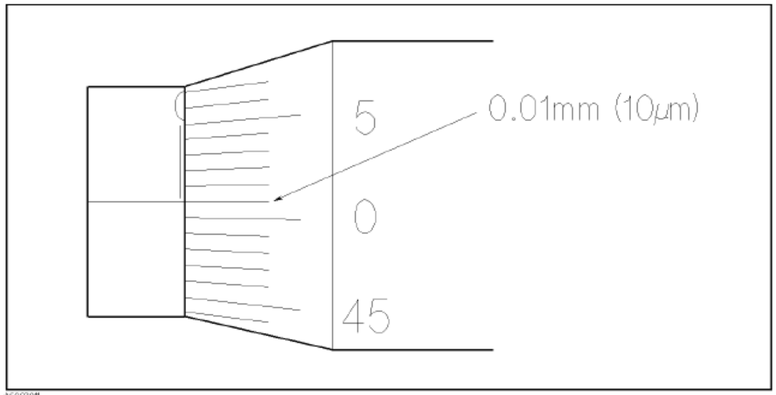
Figure 3-27 Vertical Position



5. Turn the large knob of the micrometer ccw to make enough room between the Guarded/Guard electrode and the Unguarded electrode to remove the covers of both electrodes.
6. Turn the small knob of the micrometer cw and adjust it until the micrometer scale indicates 0.01mm (10μm) as shown in Figure 3-28.

   If the electrodes make contact before 0.01mm, turn the three adjustment screws ccw to move Unguarded electrode the away from the Guarded/Guard electrode until the scale can be adjusted to 0.01mm.

Figure 3-28 The Micrometer Scale Adjusted to 0.01 mm



7. Measure the capacitance.
8. If the measured capacitance value is within the limits listed in Table 3-3, adjustment is not necessary. If the capacitance value is out of limits, go to the next step to make the electrodes parallel.

Table 3-3 Measured Capacitance Limits When the Micrometer is Set to 0.01 mm

Electrode	Capacitance Value
Electrode-A	700 pF to 1000 pF
Electrode-B	12 pF to 17 pF

9. Carefully turn the three adjustment screws cw or ccw until the measured capacitance value is within the limits listed in Table 3-3.

CAUTION

Stop turning the screw if the capacitance value becomes negative or extremely high, or the dissipation factor (D) increases suddenly (the electrodes are shorted). In this case, immediately turn the screws ccw to separate the electrodes. If the screw is turned further, it may damage the micrometer and the surface of electrodes.

NOTE

Be careful not to contaminate or not to make a scratch on the surface of the electrode. A scratch or contamination of the electrode's surface sometimes prevents the measured capacitance from falling within the limits shown in "Electrode Adjustment" on page 54. If it happens, replace the scratched/contaminated electrode or contact your nearest Keysight Technologies Sales and Service Office. As long as the measured capacitance falls within the limits, the electrode doesn't need to be replaced or repaired.

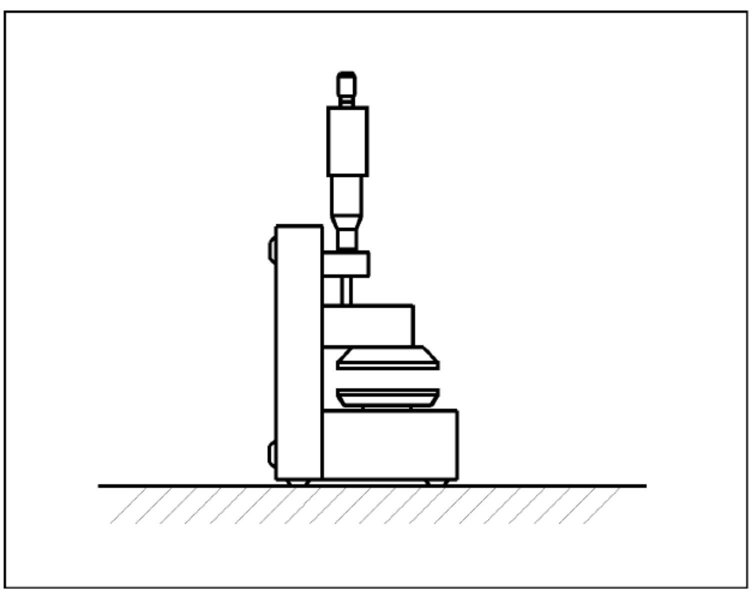
Accurate Adjustment in Horizontal Position

When the Non-contacting Electrode method (Air Gap method) is used, perform this adjustment after performing the "“Rough Adjustment to Make Electrodes Parallel”. The procedure is as follows:

1. Clean the electrodes. This is necessary because the capacitance value is affected by dust. (Refer to “Changing the Guarded/Guard Electrode”.)
2. Perform an OPEN/SHORT correction.
3. Connect the 16451B to an LCR meter or an impedance analyzer and select the capacitance measurement function (C_p) for Circuit mode. (Refer to “Connecting to the Instrument”.)
4. Place the 16451B so that the surface of electrodes is vertical as shown in Figure 3-27.
5. Turn the large knob of the micrometer ccw to make enough room between the Guarded/Guard electrode and the Unguarded electrode, and then remove the cover from both electrodes.
6. Turn the small knob of the micrometer cw and adjust it until the micrometer scale indicates 0.01mm (10µm) as shown in Figure 3-28.

   If the electrodes make contact before 0.01mm, turn the three adjustment screws ccw to move the Unguarded electrode away from the Guarded/Guard electrode Unguarded electrode till the scale can be adjusted to 0.01mm.

Figure 3-29 Horizontal Position



7. Starting with the top adjustment screw, turn the three adjustment screws cw in a clockwise sequence until the measured capacitance value is within the limit listed as follows:

Table 3-4 Capacitance Point for Starting to Press the Pressure Adjuster

Electrode	Capacitance Value
Electrode-A	Greater than 200 pF
Electrode-B	Greater than 5 pF

CAUTION **Stop turning the screw if the capacitance value becomes negative or extremely high, or the dissipation factor (D) increases suddenly. In this case, immediately turn the screw ccw to separate the electrodes. If the screw is turned further, it may damage the micrometer and the surface of electrodes.**

When the measured capacitance value increases widely during turning a screw, turn more slightly the screws.

8. Keep pressing the Guarded/Guard electrode pressure adjuster shown in Figure 3-25 and turn the three screws in a clockwise sequence until the measured capacitance value is within the limits listed in Table 3-5.

Table 3-5 Capacitance Limits at Vertical Position

Electrode	Capacitance Value
Electrode-A	700 pF to 1000 pF
Electrode-B	12 pF to 17 pF

Stop turning the screw if the capacitance value becomes negative or extremely high, or the dissipation factor (D) increases suddenly. In this case, immediately turn the screw ccw to separate the electrodes and redo adjustment.

9. Place the 16451B so that the surface of electrodes are horizontal and check that the measured capacitance value is within the limit listed in Table 3-6.

Table 3-6 Capacitance Limits at Horizontal Position

Electrode	Capacitance Value
Electrode-A	Greater than 700 pF
Electrode-B	Greater than 12 pF

When the measured capacitance value is less than the limit, place the 16451B so that the surface of electrodes are Vertical. Then keep pressing Guarded/Guard pressure adjustment and carefully turn the three screws in a clockwise sequence until the measured capacitance value is within the limits in Table 3-6.

If the capacitance value becomes negative or extremely high, or the dissipation factor (D) increases suddenly, place the 16451B so that the surface of electrodes are vertical. Then adjust the Guarded/Guard electrode pressure adjuster. Remove the plug as shown in Figure 3-25 and turn the screw in the pressure adjuster cw to strengthen the pressure. After that return the plug and redo the procedure from step 8.

NOTE

If the capacitance value measured is not within the limits shown in Table 3-5 even though you repeated steps 7 and 8, change the measured capacitance limits of Table 3-5 to the limits listed in the following table and repeat steps 7 and 8.

Electrode	Capacitance Value
Electrode-A	400pF to 700pF
Electrode-B	7pF to 12pF

NOTE

Be careful not to contaminate or not to make a scratch on the surface of the electrode. A scratch or contamination of the electrode's surface sometimes prevents the measured capacitance from falling within the limits shown in "Electrode Adjustment" on page 54. If it happens, replace the scratched/contaminated electrode or contact your nearest Keysight Technologies Sales and Service Office. As long as the measured capacitance falls within the limits, the electrode doesn't need to be replaced or repaired.

Typical Measurement Procedure by the Measurement Methods

The 16451B can be used for three measurement methods, Contacting Electrode method (Rigid Metal electrode), Contacting Electrode method (Thin Film electrode) and Non-Contacting Electrode method (Air Gap method), to obtain the dielectric constant and dissipation factor. This section provides typical measurement procedure for each measurement method. (For information about how to select the measurement method, refer to “Measurement Method”.)

CAUTION

DO NOT use the large knob to bring the Guarded/Guard electrode into contact with the Unguarded electrode or test material, doing so will damage the micrometer or the surface of the electrodes. You must use the small knob when you bring an electrode into contact with another electrode or test material. It has a built in clutch which will slip at a specified torque.

NOTE

You should perform the adjustment in the same environmental conditions as you will measure the test material using the 16451B, because a change of temperature causes mechanical dimensions to change. When you change temperature condition, you should perform the accurate adjustment after temperature conditions have changed, because a change of temperature causes mechanical dimensions to change.

Contacting Electrode Method

For the Contacting Electrode method, the 16451B provides two types of electrodes, Rigid Metal electrodes (Electrode-A and Electrode-B) and Electrode for Thin Film electrodes (Electrode-C and Electrode-D), and provides two diameters for each type, so you should select the electrodes. For more information on selecting electrode, refer to “Contacting Electrode Method (used with Rigid Metal Electrode)” and “Contacting Electrode Method (used with Thin Film Electrode)”. Figure 3-30 shows the model of Contacting Electrode (Rigid Metal electrode) and Figure 3-31 shows the model of Contacting electrode (Thin Film electrode).

Figure 3-30 Contacting Electrode Method (Rigid Metal Electrode)

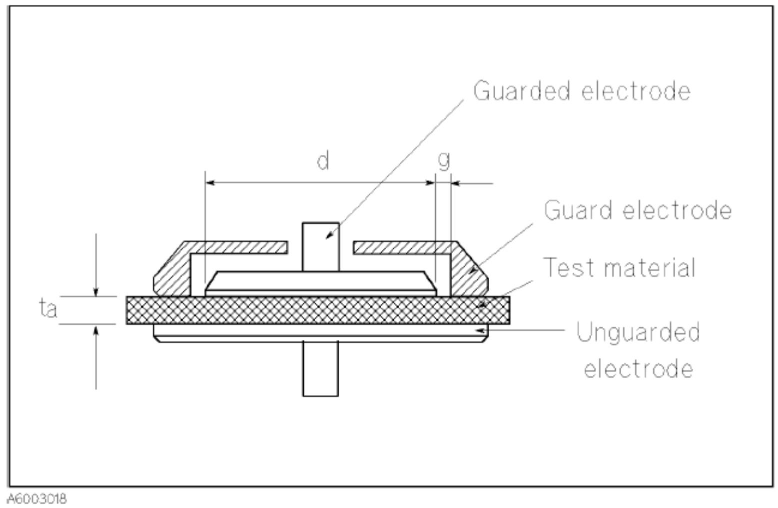
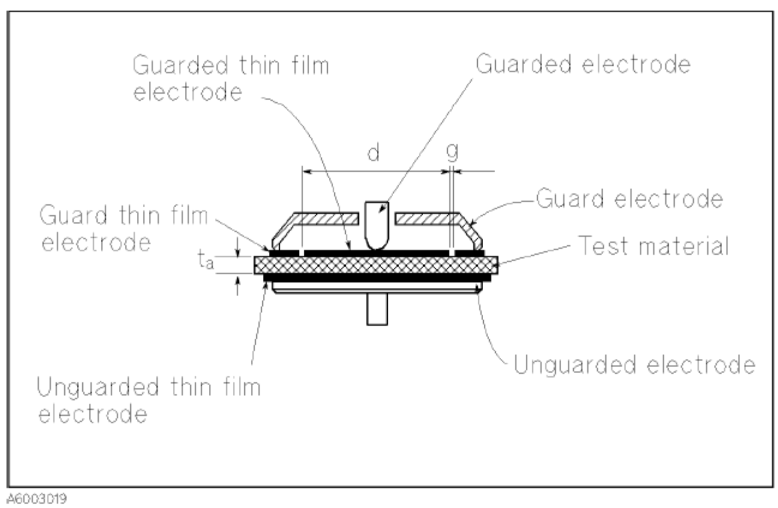


Figure 3-31 Contacting Electrode Method (Thin Film Electrode)



Procedure

1. Prepare test material so that the 16451B can measure it. (When you use Thin Film electrode, you should apply Thin Film electrodes on the surface of the material to be measured. For more information, refer to “Preparation of Test Material”.)
2. Connect the 16451B to the instrument. (For more information, refer to “Connecting to the Instrument”.)
3. Set up the instrument to measure capacitance (C_p-D).
4. Change to the electrode you will use and perform the rough adjustment. (Refer to “Changing the Guarded/Guard Electrode”.)
5. Perform an OPEN/SHORT correction (Refer to “Error Correction”.)

6. When you use the Electrode-A and Electrode-B, adjust the electrodes to be parallel using the accurate adjustment. When you use the Electrode-C and Electrode-D, you can skip this step. (Refer to “Electrode Adjustment”.)
7. Set the test material between the electrodes.
8. Measure the capacitance (C_p) and dissipation factor (D) and then calculate the dielectric constant (ε_r) and dissipation factor (D_t) of test material using the following equations.

Equations

$$\varepsilon_r = \frac{t_a \times C_p}{A \times \varepsilon_o} = \frac{t_a \times C_p}{\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_o}$$

$$D_t = D$$

Where,

Cp	Equivalent parallel capacitance [F]
D	Dissipation factor
t_a	Average thickness of test material [m]
A	Area of Guarded electrode [m^2]
d	Diameter of Guarded electrode [m]
ε_o	$=8.854 \times 10^{-12}$ [F/m]
ε_r	Dielectric constant of test material
D_t	Dissipation factor of test material

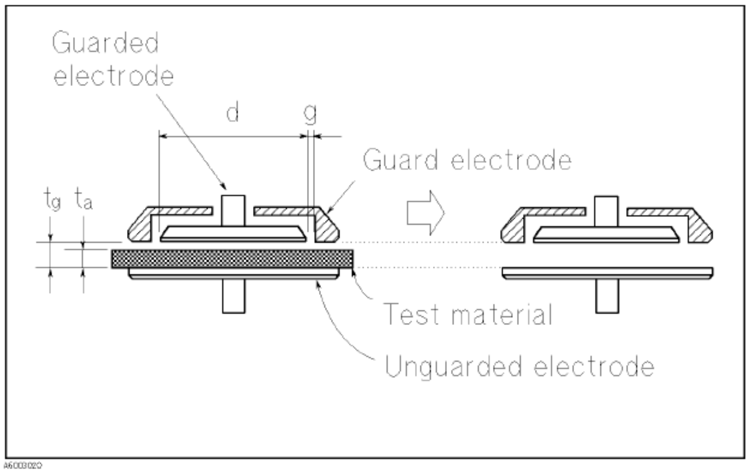
NOTE After you measure the test material (or move the electrode) several times, it is recommended that you check electrode for parallelism (refer to “Check Electrode Parallelism”) and clean the surface of electrodes.

NOTE For more information on measuring accurately, refer to “Measurement Error Analysis”.

Non-Contacting Electrode Method

For the Non-Contacting method, the 16451B can perform an Air Gap method. The 16451B provides two sizes of electrodes for the Air Gap method, so you should select the electrode for the material to be tested. For more information on selecting electrodes, refer to “Measurement Method”. Figure 3-32 shows a simple model of the Non-Contacting method.

Figure 3-32 Non-Contacting Electrode Method (Air Gap Method)



Procedure

1. Prepare the test material so that the 16451B can measure it. (For more information, refer to “Preparation of Test Material”.)
2. Connect the 16451B to the instrument.(For more information, refer to “Connecting to the Instrument”.)
3. Set up the instrument to measure capacitance (C_s-D).
4. Change to the electrode you will use and perform the Rough Adjustment. (Refer to “Changing the Guarded/Guard Electrode”.)
5. Perform an OPEN/SHORT correction.
6. Adjust the electrodes to be parallel using the Accurate Adjustment. (Refer to “Electrode Adjustment”.)
7. Set the test material between the electrodes.
8. Adjust the small knob of the micrometer to set the gap between Guarded/Guard electrode and Unguarded electrode to t_g so that the gap distance between the Guarded/Guard electrode and the test material is less than 10% of thickness of the test material.
9. Measure capacitance (C_{s2}) and dissipation factor (D_2).
10. Carefully remove the test material.

11. Measure capacitance (C_{s1}) and dissipation factor (D_1) and then calculate the dielectric constant ($\boldsymbol{\varepsilon}$) and dissipation factor (D_t) using the following equations.

Equations

$$\varepsilon_r = \frac{1}{1 - \left(1 - \frac{C_{s1}}{C_{s2}}\right) \times \frac{t_g}{t_a}}$$

$$D_t = D_2 + \varepsilon_r \times (D_2 - D_1) \times \left(\frac{t_g}{t_a} - 1\right)$$

Where,

C_{s1}	Capacitance without test material inserted [F]
D_1	Dissipation factor without test material inserted
t_g	Gap between Guarded/Guard electrode and Unguarded electrode [m]
Cs2	Capacitance with test material inserted [F]
D_2	Dissipation factor with test material inserted
t_a	Average thickness of test material [m]
$\boldsymbol{\varepsilon}_r$	Dielectric constant of test material
D_t	Dissipation factor of test material

NOTE After you measure the test material (or move the electrode) several times, it is recommended to check for electrode parallelism (refer to ""Check Electrode Parallelism") and clean the surface of electrodes.

NOTE For more information on accurate measurement, refer to "Measurement Error Analysis".

Check Electrode Parallelism

This section describes the procedure to check that the electrodes are parallel. When you measure test materials several times (or move the electrode) using Electrode-A or Electrode-B, perform the following procedure to check for electrode parallelism.

- Remove the covers of both electrodes.
- Turn the small knob of the micrometer cw and adjust it until the micrometer scale indicates 0.01 mm (10μ).
- Measure the capacitance.

If the measured capacitance value is within the limits listed in Table 3-7, the check is finished. If the capacitance value is out of limits, perform the Accurate Adjustment as shown in “Accurate Adjustment to Make Electrodes Parallel”.

Table 3-7 Measured Capacitance Limits for Check Electrode Parallelism

Electrode	Capacitance Value
Electrode-A	700pF to 1000pF
Electrode-B	12pF to 17pF

Measurement Error Analysis

This section describes error factors involved in dielectric constant measurement using the Contacting Electrode method and Non-contacting Electrode method, and how to perform measurements with minimum error.

NOTE

All data shown in this section, such as measurement accuracy, and tolerance of electrode diameter, are typical values and are not guaranteed.

Error Factor using Contacting Electrode Method

The dielectric constant of a test material is derived from measured capacitance value. When using the Contacting Electrode method, the dielectric constant ε_r of a test material is obtained using the following equation.

$$\varepsilon_r = \frac{t_a \times C_p}{\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_o}$$

Where,

Cp	Equivalent parallel capacitance [F]
t_a	Average thickness of test material [m]
d	Diameter of Guarded electrode [m]
ε_0	$=8.854 \times 10^{-12}$ [F/m]

The error factors included in the above parameters are as follow:

Capacitance measurement Error

This error is determined by the measurement accuracy of the LCR meter or impedance analyzer used. Measurement accuracy of LCR meters and impedance analyzers depends on the measurement frequency and the measured impedance value. Generally, an LCR meter and an impedance analyzer can accurately measure capacitance above 1pF. (For measurement frequency range of them, refer to Table 1-2.) For more information on measurement accuracy of LCR meters, Capacitance meters and impedance analyzers, refer to their Operation Manual or Technical Data Sheet.

Tolerance of Guarded Electrode Diameter

This error depends on the electrodes mechanical accuracy. The typical error for Electrode-A (ϕ38mm electrode) and Electrode-B (ϕ5 mm electrode) are given in Table 3-8.

Table 3-8 Tolerance of Electrode Diameter

Electrode	Tolerance (typical)
Electrode-A (ϕ38mm Electrode)	approximately ± 0.13%
Electrode-B (ϕ5mm Electrode)	approximately ± 1.0%

Gap Error

This error consists of two factors as following:

- Measurement Error of Test Material’s Thickness (Error caused by Micrometer): Thickness measurement of the test material depends on accuracy of the micrometer used. To reduce this error, measure the thickness at several points of the measured area of the test material using an accurate micrometer. Do not use the micrometer equipped with the 16451B.
- Parallelism and Flatness of Electrodes and Test Material: When contacting the MUT directly with the electrodes, an airgap is formed between the MUT and the electrodes. No matter how flat and parallel both sides of the MUT is fabricated, an airgap will still form. This airgap is the cause for measurement error because the measured capacitance will be the sum of the capacitance of the dielectric material and the airgap. The relationship between the airgap's thickness and measurement error is determined by the equation shown in Figure 3-33. Measurement error is a function of the relative permittivity (er') of the MUT, thickness of the MUT (d), and the airgap's thickness (t). Sample results of measurement error have been calculated in Table 3-9. Notice that the effect is greater with thin materials and materials with high permittivity.

  This airgap effect can be eliminated, by applying a thin film electrode to the surfaces of the dielectric material. An extra step is required for material preparation (fabricating a thin film electrode), but the most accurate measurements can be performed.

Figure 3-33 Airgap Effects

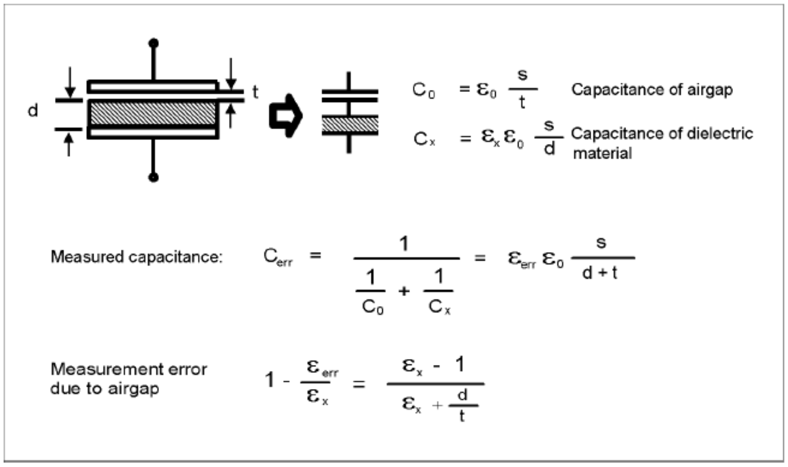


Table 3-9 Measurement Error Caused by Airgap

t/d	er'=2	er'=5	er'=10	er'=20	er'=50	er'=100
0.001	0.1%	0.4%	1%	2%	5%	9%
0.005	0.5%	2%	4%	9%	20%	33%
0.01	1%	4%	8%	16%	33%	50%
0.05	5%	16%	30%	48%	70%	83%
0.1	8%	27%	45%	63%	82%	90%

Effective Area of Electrode

The guard electrode reduces the error caused by stray capacitance at the edge of the electrodes as shown in "Guard Electrode". But the guard electrode cannot perfectly eliminate the error. This error makes the apparent area of the guarded electrode larger. To reduce the error, divide the dielectric constant value by the effective area constant. The effective area constant represents the increase of electrode area caused by stray capacitance, and is as follows:

when $\varepsilon = \varepsilon_a$

$$\alpha_a = \left(1 + \frac{g}{d} \times B_a\right)^2$$

when $\varepsilon > \varepsilon_a$

$$\alpha_b = \left(1 + \frac{g}{d} \times B_b\right)^2$$

Where,

$$B_a = 1 - \frac{2}{\pi} \times \arctan\left(\frac{g}{2t}\right) + \frac{2}{\pi} \times \frac{t}{g} \times \ln\left(1 + \left(\frac{g}{2t}\right)^2\right)$$

$$B_b = 1 - \frac{4}{\pi} \times \frac{t}{g} \times \ln\left[\cosh\left(\frac{\pi g}{4t}\right)\right]$$

g	Gap between Guard electrode and Guarded electrode [m] (refer to Figure 3-8, Figure 3-12 and Figure 3-16)
d	Diameter of Guarded electrode
t	For Contacting Electrode method, thickness of the test material ($=t_a$) [m]. For Non-contacting Electrode method, gap between Guarded/Guard electrode and Unguarded electrode ($=t_g$) [m]

Table 3-10 lists the effective area constants α_a, α_b calculated for Electrode-A (ϕ38mm electrode) and Electrode-B (5mm Electrode). To reduce the error caused by stray capacitance at the edge, divide α_a or α_b into equation to obtain dielectric constant as shown in following equation

$$\varepsilon_r = \frac{t_a \times C_p}{\pi \times \left(\frac{d}{2}\right)^2 \times \varepsilon_0 \times \alpha}$$

Table 3-10 Effective Area Constant

Electrode distance [mm]	α_a ($\varepsilon=\varepsilon_a$) ϕ38mm	α_a ($\varepsilon=\varepsilon_a$) ϕ5mm	α_b; ($\varepsilon>\varepsilon_a$) ϕ38mm	α_b; ($\varepsilon>\varepsilon_a$) ϕ5mm
10	1.0105	1.0526	1.0105	1.0524
9	1.0105	1.0526	1.0105	1.0524
8	1.0105	1.0525	1.0105	1.0523
7	1.0105	1.0525	1.0104	1.0523
6	1.0105	1.0525	1.0104	1.0522
5	1.0105	1.0525	1.0104	1.0521
4	1.0105	1.0524	1.0103	1.0520
3	1.0104	1.0523	1.0103	1.0518

Table 3-10 Effective Area Constant

	α_a ($\varepsilon=\varepsilon_a$)		α_b; ($\varepsilon>\varepsilon_a$)	
Electrode distance [mm]	ϕ38mm	ϕ5mm	ϕ38mm	ϕ5mm
2	1.0104	1.0521	1.0101	1.0513
1	1.0102	1.0516	1.0097	1.0500
0.9	1.0102	1.0515	1.0096	1.0497
0.8	1.0101	1.0513	1.0095	1.0493
0.7	1.0101	1.0511	1.0094	1.0488
0.6	1.0100	1.0508	1.0092	1.0482
0.5	1.0099	1.0505	1.0089	1.0473
0.4	1.0097	1.0499	1.0085	1.0460
0.3	1.0095	1.0490	1.0079	1.0438
0.2	1.0089	1.0473	1.0068	1.0397
0.1	1.0076	1.0423	1.0044	1.0293
0.09	1.0073	1.0413	1.0040	1.0274
0.08	1.0071	1.0401	1.0036	1.0253
0.07	1.0067	1.0387	1.0032	1.0230
0.06	1.0063	1.0387	1.0028	1.0203
0.05	1.0058	1.0346	1.0023	1.0173
0.04	1.0052	1.0317	1.0019	1.0140
0.03	1.0045	1.0278	1.0014	1.0106
0.02	1.0035	1.0225	1.0009	1.0071
0.01	1.0022	1.0147	1.0005	1.0035

(ϕ means diameter)

Error Factor Using Non-contacting Electrode Method

The dielectric constant of a test material is derived from two capacitance values, capacitance without a test material inserted and capacitance with a test material inserted, when using the Non-contacting Electrode method. The dielectric constant ε_r of a test material is obtained using the following equation.

$$\varepsilon_r = \frac{1}{1 - \left(1 - \frac{C_{s1}}{C_{s2}}\right) \times \frac{t_g}{t_a}}$$

Where,

C_{s1}	Capacitance without test material inserted [F]
Cs2	Capacitance with test material inserted [F]
t_g	Gap between Guarded/Guard electrode and Unguarded electrode [m]
t_a	Thickness of test material [m]

The error factors included in the above parameters used are as follows:

Capacitance measurement Error

This error is determined by the measurement accuracy of LCR meters, capacitance meters and impedance analyzers used. For more details, refer to “Capacitance measurement Error” in “Error Factor using Contacting Electrode Method”.

Gap Error

This error consists of three factors as follows:

- Measurement Error of Test Material's Thickness (Error caused by Micrometer): This error is included in thickness (t_a) of the test material. Thickness measurement of the test material depends on accuracy of the micrometer used. To reduce this error, measure the thickness at several points of the measured area of the test material using an accurate micrometer. Do not use the micrometer equipped with the 16451B.
- Parallelism and Flatness of Electrodes and Test Materials: This error is included in the thickness (t_a) of a test material and gap (t_g) between Guarded/Guard electrode and Unguarded electrode. When parallelism and flatness of electrodes of the test material are bad, air film (gaps between surfaces of electrode and a test material) causes error. To reduce this error, prepare the test material to make surfaces of the material parallel and flat and adjust to make electrode parallel as accurately as possible.

- Error in Gap between Electrodes: This error is included in the gap (tg) between Guarded/Guard electrode and Unguarded electrode. It is caused by difference of scale of the micrometer from actual distance between electrodes and depends on accuracy of micrometer which set the gap between electrodes.

To reduce this error, perform error correction as follows. This correction obtains an equivalent distance error of electrode gap distance by comparing the measured capacitance value of air gaps between electrodes and their theoretical value. Use the following procedure:

1. Measure the capacitance at three different electrode distances, such as 40µm, 50µm and 60µm.
2. Calculate the theoretical capacitance value of each distance. The theoretical capacitance value C_t can be obtained as follows.

$$C_t = \varepsilon_a \times \varepsilon_o \times \frac{\pi \times (d/2)^2}{t_{set}} \times \alpha_a$$

Where,

C_t	Theoretical capacitance value [F]
ε_a	Dielectric constant of air (=1.00059)
ε_0	$= 8.854\ 10^{-12}$ [F/m]
α_a	Effective area coefficient of electrode when the electrode distance is t_{set} (Refer to **"Effective Area of Electrode"** in **"Error Factor using Contacting Electrode Method"**.)
t_{set}	Reading value of the electrode distance on the micrometer [m]

3. Calculate the equivalent distance error at each electrode distance. The equivalent distance error of each electrode distance Δt_e can be obtained as follows:

$$\Delta t_e = \left(\frac{C_t}{C_m} - 1\right) \times t_{set} \qquad [m]$$

Where,

C_m	Measured capacitance value [F]

4. Average equivalent distance error. The average of equivalent electrode distance error Δt_a is derived as follows.

$$\Delta t_a = \frac{\Delta t_{40} + \Delta t_{50} + \Delta t_{60}}{3} \quad [\mu m]$$

Where,

Δt_{40}	Equivalent distance error Δt_e at 40µm
Δt_{50}	Equivalent distance error Δt_e at 50µm
Δt_{60}	Equivalent distance error Δt_e at 60µm

The equivalent electrode distance t_{eq} can be derived from a set value of micrometer t_{set} and equivalent distance error Δt_a shown as follows:

$$t_{eq} = t_{set} + \Delta t_a$$

The compensated dielectric constant is obtained as follows:

$$\varepsilon_r = \frac{1}{1 - \left(1 - \frac{C_{s1}}{C_{s2}} \times \frac{\alpha_b}{\alpha_a}\right) \times \frac{t_{eq}}{t_a}}$$

Where, α_a and α_b are Effective area constants. For more information, refer to “Effective Area of Electrode”.

Compensation Result Example

If the measured capacitance values are 227.6pF, 185.2pF and 156.58pF, when the set values of the micrometer are 40µm, 50µm, and 60µm. Each theoretical capacitance values and equivalent electrode distance errors are listed in Table 3-11.

Table 3-11 **Compensation Result Example**

t_{set} [µm]	C_m [pF]	C_t [pF]	Δt_e [µm]
40	227.60	252.48	4.4
50	185.20	202.11	4.6

Table 3-11 Compensation Result Example

t_{set} [μm]	C_m [pF]	C_t [pF]	Δt_e [μm]
60	156.58	168.51	4.6

So, the average of equivalent electrode distance error is obtained as follows:

$$\Delta t_a = \frac{4.6 + 4.6 + 4.4}{3} \approx 4.5 \quad [\mu m]$$

In this case, the equivalent electrode distance is as follows:

$$t_{eq} = t_{set} + 4.5\mu \quad [m]$$

Use the equivalent electrode distance (t_{eq}) to accurately calculate accurately the dielectric constant ε_r.

Effective Area of Electrode

This error is included in capacitance values measured C_{s1} and C_{s2}. It is caused by the stray capacitance at electrode's edge even though a guard electrode is used. To reduce the error, divide capacitance value C_{s1} and C_{s2} by effective area constants α_a and α_b as shown in following equation.

$$\varepsilon_r = \frac{1}{1 - \left(1 - \frac{C_{s1}}{C_{s2}} \times \frac{\alpha_b}{\alpha_a}\right) \times \frac{t_{eq}}{t_a}}$$

Where, t_{eq} is the equivalent electrode distance. For more information, refer to “Effective Area of Electrode” in “Error Factor using Contacting Electrode Method” and “Gap Error”.

4 Service

Introduction

This chapter gives the service information for the 16451B. Service information covers Assembly Replacement and Troubleshooting.

Serial Number for Non-RoHS 16451B:
“MY44100001 - MY44199999”or “SG44100001 - SG44199999”

Serial Number for RoHS 16451B:
“MY44200001 and above” or “SG44200001 and above”

Assembly Replacement

This section gives 16451B assembly and disassembly hints, and lists the replaceable parts.

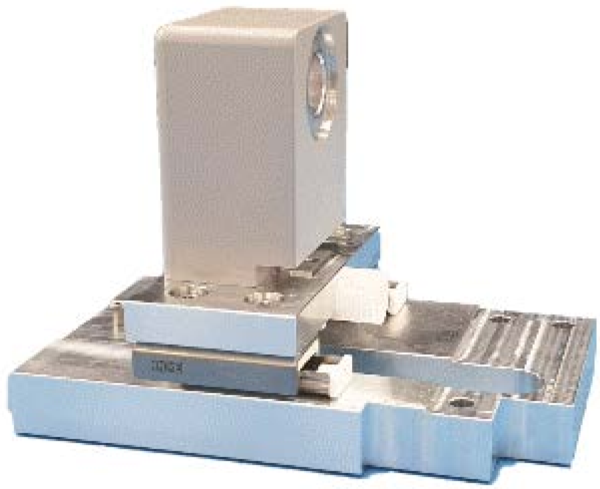
Assembly and Disassembly Hints

The assemblies in the 16451B are secured using metric threaded fasteners. All fasteners used in the 16451B, can be removed using medium and small pozidrive screwdrivers and a 2.5 mm hex key. A 2.5 mm hex key (Keysight PN 5188-4452) is included with the 16451B.

Slide Stand Assembly

Do not remove any part of the Slide Stand Assembly (Keysight PN 16451-60604) shown in Figure 4-1. Once the Slide Stand Assembly is disassembled, it cannot be reassembled, because special tools are required for reassembly.

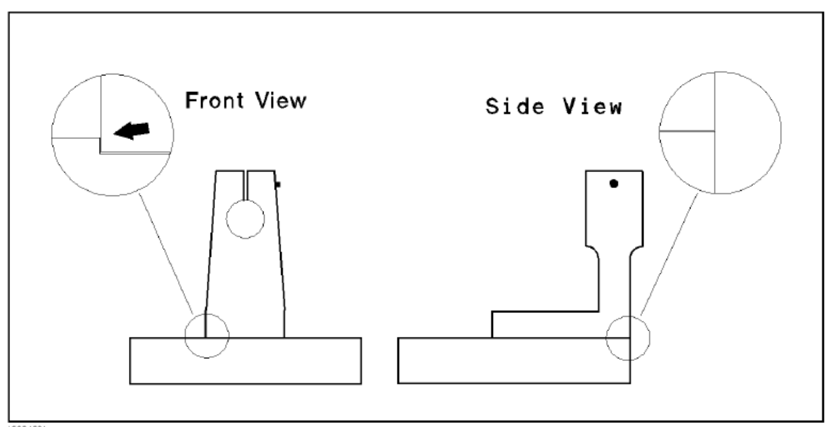
Figure 4-1 Slide Stand Assembly



Micrometer Stand Replacement

When replacing the micrometer stand, press it against the slide stand assembly's guide and align the back edge of the micrometer stand and the slide stand assembly, as shown in Figure 4-2.

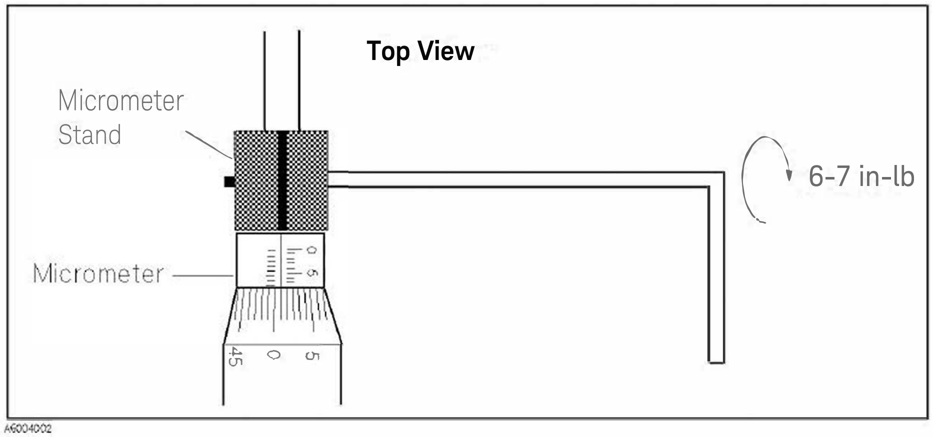
Figure 4-2 Micrometer Stand Replacement



Micrometer Replacement

When replacing the micrometer, put the micrometer completely into the micrometer stand and turn the fine scale adjustment line until it is facing vertical, as shown in Figure 4-3. Then tighten the micrometer stand's set screw to firmly attach the micrometer to the stand. The proper tightening torque is 6-7 in-lb. (About 6-7 in-lb may be applied to the screw when the furnished hex key is used.) If the screw is tighten too much, the micrometer will not function smoothly.

Figure 4-3 Micrometer Replacement



Replaceable Part List

Table 4-1 to Table 4-5 list the supported parts and their respective RoHS compliant replacement support part. Parts listed in these tables can be ordered from your nearest Keysight Technologies Service office. Ordering information should include the Keysight part number and the quantity required. Once the original support part is depleted, please proceed to obtain the RoHS compliant support part.

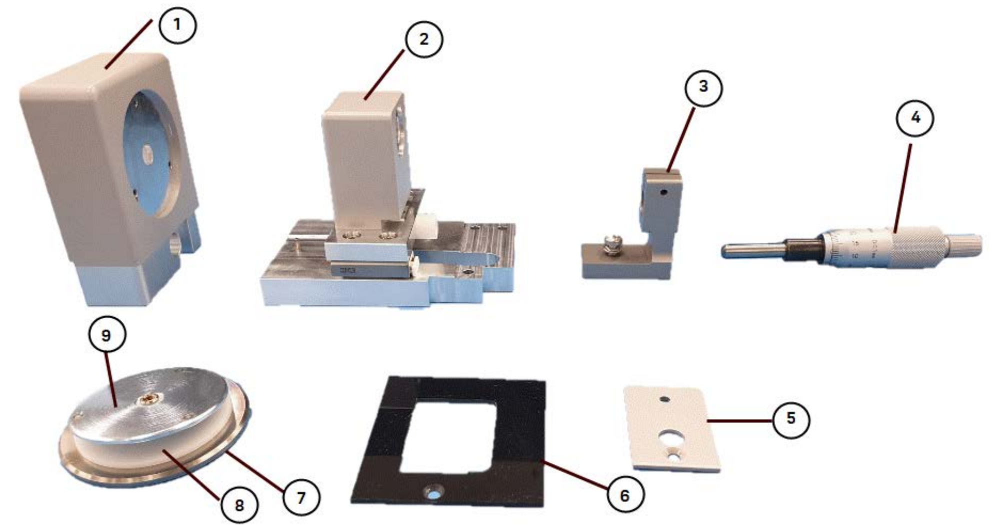


Table 4-1 Replaceable Parts List (1 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	Refer to Table 4-3		1	Refer to Table 4-3		1
2	Refer to Table 4-4		1	Refer to Table 4-4		1
3	8710-1889 (16451-20015)	Angle	1	16451-20015	Holder	1
	2190-0586	Washer	2			
	0515-0909	Screw	2	0515-0382	Screw with Washer	2
4	8750-0373	Micrometer	1	8750-0373	Micrometer	1
5	16451-04001	Cover	1	16451-04601	Cover	1
	0515-0914	Screw	1	0515-1946	Screw	1
6	16451-00602	Plate	1	16451-00602	Plate	1
	0515-0914	Screw	1	0515-1946	Screw	1
7	16451-24001 (16451-24021)	Unguarded Electrode	1	16451-24021	Unguarded Electrode	1

Table 4-1 Replaceable Parts List (1 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
8	16451-25001 (16451-25025)	Insulator	1	16451-25025	Insulator	1
9	16451-24008 (16451-24018)	Plate	1	16451-24018	Plate	1

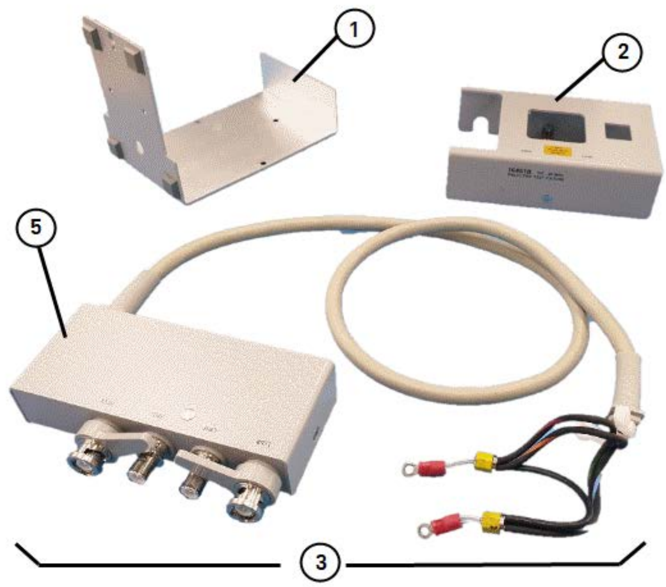


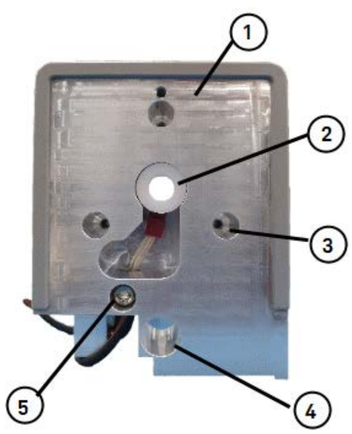
Table 4-2 Replaceable Parts List (2 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	16451-04003 (16451-04013)	Cover Bottom	1	16451-04613	Cover Bottom	1
	0403-0427	Bumper Foot	8	0403-0427	Bumper Foot	8
	0515-0914	Screw	4	0515-1946	Screw	4
2	16451-04002	Cover Top	1	16451-04602	Cover Top	1
3	16451-61002	Cable Assembly	1	16451-61072	Cable Assembly	1

Table 4-2 Replaceable Parts List (2 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
4[1]	16047-40000 (not shown in the picture)	Stopper	1	-	(RoHS unit doesn’t have STOPPER)	-
	2190-0206 (not shown in the picture)	Washer	1	-	(RoHS unit doesn’t have STOPPER)	-
	0515-1550 (not shown in the picture)	Screw	1	-	(RoHS unit doesn’t have STOPPER)	-
5[1]	16451-04004	Cover Top	1	16451-04604	Cable Top	1
6[1]	0515-0914	Screw	2	0515-1946	Screw	2

1. These parts are included in the Cable Assembly 16451-61072.



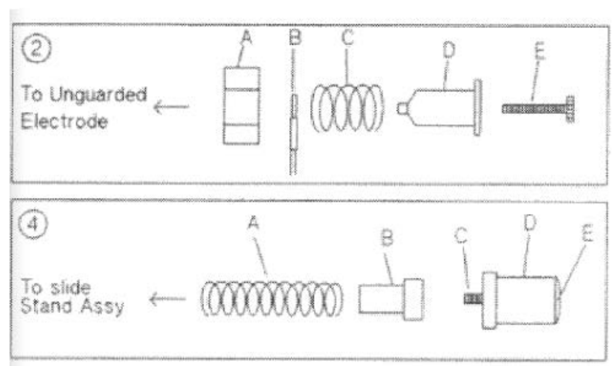


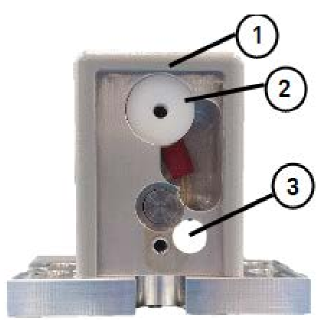
Table 4-3 Replaceable Parts List (3 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	16451-20002 (16451-20022)	Base	1	16451-20622	Base	1
2-A	16451-25007	Spacer	1	16451-25007	Spacer	1
2-B	16451-61002	Cable Assembly	1	16451-61072	Cable Assembly	1

Table 4-3 Replaceable Parts List (3 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
2-C	1460-2237	Spring	1	1460-2237	Spring	1
2-D	16451-25004	Bushing	1	16451-25004	Bushing	1
2-E	0515-1321	Screw	1	0515-1321	Screw	1
3	0515-1321	Screw[1]	3	0515-1321	Screw[1]	3
	16451-25008	Spacer	3	16451-25008	Spacer	3
4-A	1460-2238	Spring	1	1460-2238	Spring	1
4-B	16451-25009	Rod	1	16451-25009	Rod	1
4-C	0515-1321	Screw	1	0515-1321	Screw	1
4-D	16451-25011	Rod	1	16451-25011	Rod	1
4-E	6960-0147	Plug Hole	1	6960-0076	Plug Hole	1
5	0515-1550	Screw	1	0515-0372	Screw	1

1. Apply a drop of Lock Tile (Keysight PN: 0470-0013) to the screws, when replacing them.



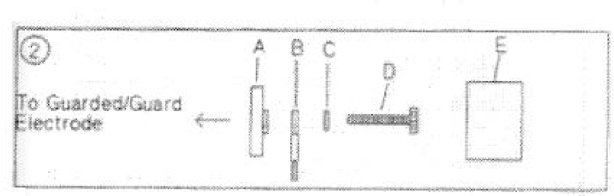


Table 4-4 Replaceable Parts List (4 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	16451-60002 (16451-60004)	Slide Stand Assembly	1	16451-60604	Slide Stand Assembly	1
2-A	16451-25002 (16451-25005)	Spacer	1	16451-25005	Spacer	1

Table 4-4 Replaceable Parts List (4 of 5)

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
2-B	16451-61002	Cable Assembly	1	16451-61072	Cable Assembly	1
2-C	2190-0584	Washer	1	2190-0584	Washer	1
2-D	0515-1321	Screw	1	0515-1321	Screw	1
2-E	16451-25006	Spacer	1	16451-25006	Spacer	1
3	0515-1550	Screw	1	0515-0372	Screw	1

Table 4-5 Replaceable Parts List (5 of 5)

Ref /D	Non-RoHS Part Number	Description	RoHS-Compliant Replacement Part	Description
	16451-60011 (16451-60031)	Electrode-A	16451-60031	Electrode A
	16451-60013	Electrode-B	16451-60013	Electrode-B
	16451-60012	Electrode-C	16451-60012	Electrode-C
	16451-60014	Electrode-D	16451-60014	Electrode-D
	16451-24011	Error Compen. Attachment	16451-24011	Error Compen. Attachment
	16451-25021	Cover 56mm	16451-25021	Cover 56mm
	16451-25022	Cover 20mm	16451-25022	Cover 20mm
	8710-1181 (5188-4452)	Hex Key	5188-4452	Hex Key
	16451-60001	Carrying Case	16451-60001	Carrying Case

Electrodes A and C include a 56mm Cover. Electrodes B and D include a 20mm Cover.

- Electrode-A: 38mm Guarded/Guard electrode
- Electrode-B: 5mm Guarded/Guard electrode
- Electrode-C: Guarded/Guard electrode for large thin film electrode
- Electrode-D: Guarded/Guard electrode for small thin film electrode

Troubleshooting

Mechanical Trouble

When the 16451B is mechanically defective, replace the defective parts, refer to “Assembly Replacement”, and confirm that the electrode distance can be changed smoothly from 0 to 10mm. If the electrode does not move smooth it may be because the cables are obstructing the operation.

Electrical Trouble

When the 16451B is electrically defective, check its cable connections, refer to Figure 4-4. The connection check points are as follows:

- The Lcur and Lpot Center conductors are connected to the Guarded Electrode.
- The Hcur and Hpot Center conductors are connected to the Unguarded Electrode.
- The Lcur, Lpot, Hcur and Hpot outder conductors are connected to the body. (The cables’ shields are connected to the body with screws.)
- The Guard Electrode is connected to the body.
- Insulation resistance between the Lpot center conductor and the Hpot center conductor us greater than 1MΩ.
- Insulation resistance between the center conductors and the outer conductors is greater than 1MΩ.

If the cable connections are correct, the electrodes may be defective.

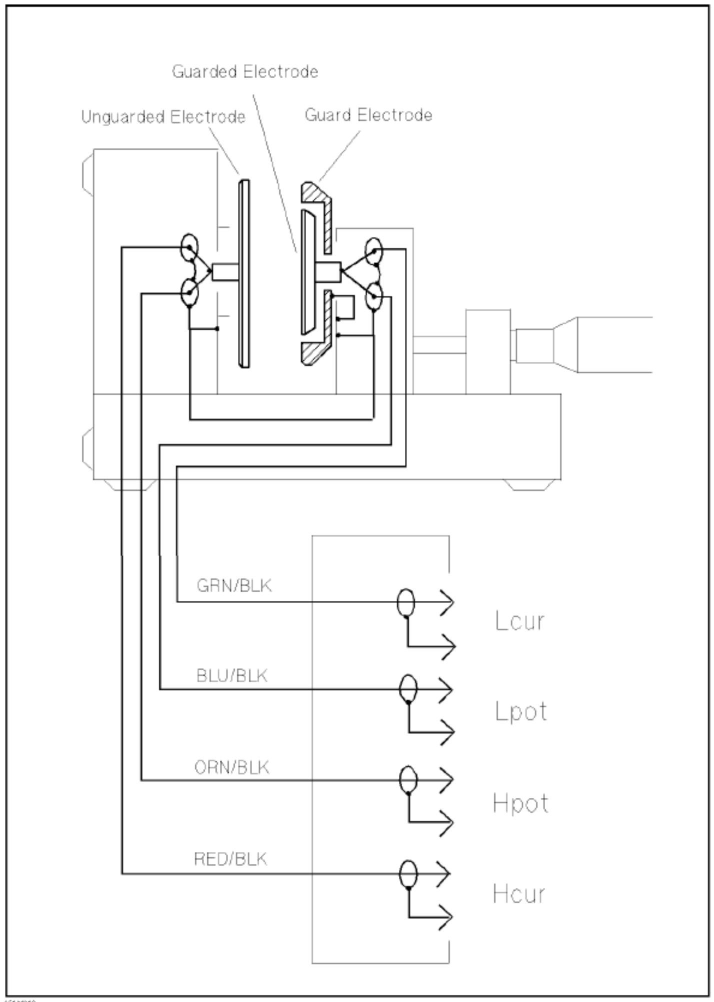
Operation Check

The Electrode Parallel Accurate Adjustment, described in “Electrode Adjustment” on page 54, can be used for the before and after repair operation check. The adjustment cannot be completed when the 16451B is electrically defective.

NOTE

Be careful not to contaminate or not to make a scratch on the surface of the electrode. A scratch or contamination of the electrode’s surface sometimes prevents the measured capacitance from falling within the limits shown in “Electrode Adjustment” on page 54. If it happens, replace the scratched/contaminated electrode or contact your nearest Keysight Technologies Sales and Service Office. As long as the measured capacitance falls within the limits, the electrode doesn’t need to be replaced or repaired.

Figure 4-4 Cable Connection Diagram



A Manual Changes

This appendix contains the information required to adapt this manual to earlier versions or configurations of the 16451B than the current printing date of this manual. The information is this manual applies directly to 16451B Dielectric Test Fixture whose serial number prefix is listed on the title page of this manual.

Manual Changes

To adapt this manual to your 16451B, refer to Table A-1, and make all of the manual changes listed opposite your fixture's serial number.

Fixtures manufactured after the printing of this manual may be different than those documented in this manual. Later fixture versions will be documented in a manual changes supplement that will accompany the manual shipped with that fixture. If your fixture serial number is not listed on the title page of this manual or in Table A-1, it may be documented in a yellow MANUAL CHANGES supplement.

For additional information on serial number coverage, refer to Chapter 2, "Serial Number.".

Table A-1 Manual Changes by Serial Number

Serial Prefix or Number	Make Manual Changes
2916J	Changes 1
JP1KH	Changes 2

Changes 1

Correct the Part Number as follows in Table 4-1, "Replaceable Parts List (1 of 5)," on page 80.

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
8	16451-25010	Insulator	1	-	-	-

Changes 2

1. Change the Part Number as follows in Table 4-1, “Replaceable Parts List (1 of 5),” on page 80.

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
8	16451-25025	Insulator	1	-	-	-
9	16451-24018	Plate	1	-	-	-

2. Change the Part Number as follows in Table 4-2, “Replaceable Parts List (2 of 5),” on page 81.

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	16451-04013	Cover Bottom	1	-	-	-

3. Change the Part Number as follows in Table 4-3, “Replaceable Parts List (3 of 5),” on page 82.

Ref /D	Non-RoHS Part Number	Description	Qty	RoHS Compliant Replacement Part	Description	Qty
1	16451-20022	Base	1	-	-	-

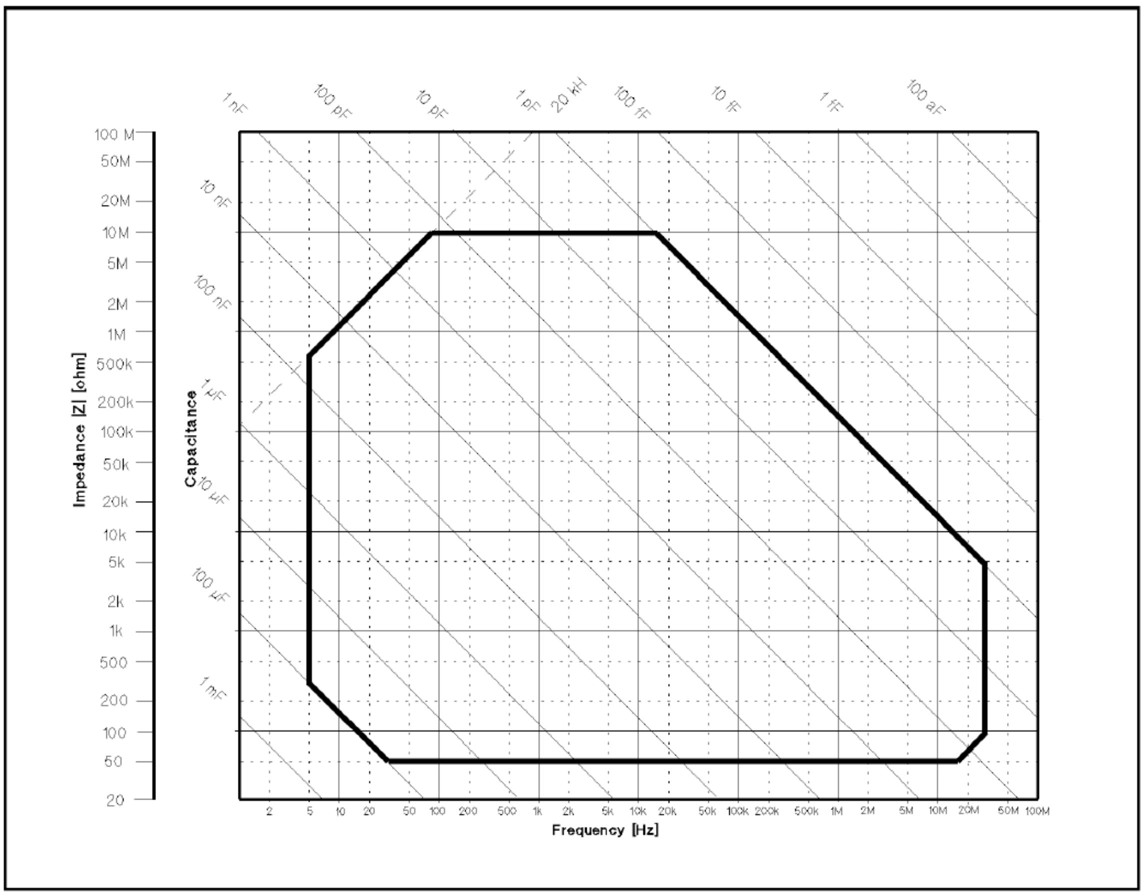
B Manual Changes

This section shows the recommended capacitance range of test materials for using the 16451B with Electrode-A (ϕ38 mm electrode) or Electrode-B (ϕ5 mm electrode).

Using Electrode-A (ϕ38mm electrode)

The area surrounded by bold lines in Figure B-1 shows the recommended capacitance range when using Electrode-A.

Figure B-1 Recommended Capacitance Range Using Electrode-A

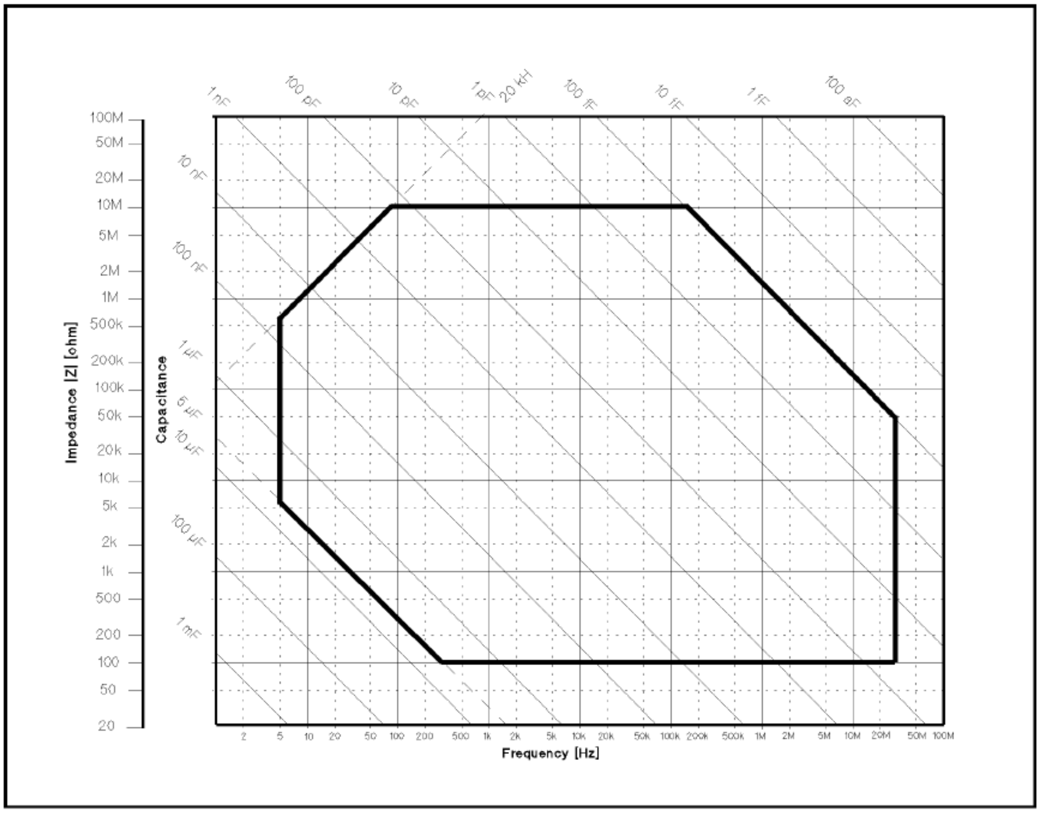


A60B001

Using Electrode-B (ϕ5mm electrode)

The area surrounded by bold lines in Figure B-2 shows the recommended capacitance range when using Electrode-B.

Figure B-2 Recommended Capacitance Range Using Electrode-B



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C Bibliography

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ASTM Standards:D150-81,\Standard Test Method for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials", Annual Book of ASTM Standards, Vol 10.02, July, 1987, pp.21-44.

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