

# IEEE Standard for Terminology and Test Methods for Circuit Probes

IEEE Instrumentation and Measurement Society

Sponsored by the

Waveform Generation, Measurement, and Analysis Technical Committee

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IEEE  
3 Park Avenue  
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USA

IEEE Std 1696™-2013



# IEEE Standard for Terminology and Test Methods for Circuit Probes

Sponsor

**Waveform Generation, Measurement, and Analysis Technical Committee**  
of the  
**IEEE Instrumentation and Measurement Society**

Approved 11 December 2013

**IEEE-SA Standards Board**

**Abstract:** Currently, no defined, industry-accepted method exists for characterizing the performance of electrical circuit probes. Each vendor has its own proprietary methods for characterization, leaving probe customers and users without a valid means of comparing probe performance and/or of understanding the circuit-loading effect of the probe. Methods for measuring parameters indicative of a probe's or probe system's performance and guidance on the design and use of a test fixture for measuring probe performance are provided by this standard. An industry-accepted, unbiased means for characterizing probe performance is given by these methods. High-impedance voltage probes that are used to measure the performance of electrical circuits are considered by this standard. The probe systems may include waveform acquisition hardware and software and signal/waveform analysis software. The probe will include the mechanism by which the circuit is contacted. This method and standard will be applicable to all individual probes having one signal conductor and one ground conductor or two signal conductors, and having an input impedance at least five times greater than the impedance of the circuit under test.

**Keywords:** common mode, frequency response, gain, IEEE 1696™, input resistance, linearity, offset error, offset range, probe, probe-only, probe system, scattering parameters, test fixture, text methods, time response, transfer function

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## Introduction

This introduction is not part of IEEE Std 1696-2013, IEEE Standard for Terminology and Test Methods for Circuit Probes.

This standard defines the terms, definitions, and test methods used to specify, characterize, and test circuit probes. It is intended for the following:

- Individuals and organizations who specify circuit probes to be purchased
- Individuals and organizations who purchase circuit probes to be used to make measurements
- Individuals and organizations whose responsibility is to characterize and write reports on circuit probes available for use in specific applications
- Suppliers interested in providing high-quality and high-performance circuit probes to acquirers

This standard is designed to help organizations and individuals do the following:

- Incorporate quality considerations during the definition, evaluation, selection, and acceptance of supplier circuit probes for operational measurements
- Determine how supplier circuit probes should be evaluated, tested, and accepted for delivery to end users

This standard is intended to satisfy the following objectives:

- Provide useful practices on evaluating and qualifying circuit probes
- Assist individuals and organizations judging the quality and suitability of circuit probes for referral to end users

IEEE Std 1696™-2013 is intended to focus specifically on terms and definitions, as well as on test methods for a wide range of probe applications.

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# IEEE Standard for Terminology and Test Methods for Circuit Probes

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## 1. Overview

Currently, no defined, industry-accepted method exists for characterizing the performance of electrical circuit probes. Each vendor has its own proprietary methods for characterization, leaving probe customers and users without a valid means of comparing probe performance and/or of understanding the circuit-loading effect of the probe. This method or these methods developed will provide an industry-accepted, unbiased means for characterizing probe performance.

### 1.1 Scope

This standard provides test method(s) and describes transfer (artifact) standards for characterizing electrical circuit probes and probes systems. The systems may include waveform acquisition hardware and software and signal/waveform analysis software. The probe includes the mechanism by which the circuit is contacted. This method and standard applies to all individual probes having one signal conductor and one ground conductor or two signal conductors, and having an input impedance greater than the impedance of the circuit under test.

### 1.2 Circuit probe background

A circuit probe is a device used to connect electronic test equipment (digital oscilloscope, sampling oscilloscope, network analyzer, etc.) to a device or circuit to be measured. There are many different types of circuit probes, ranging from simple low-frequency passive probes to complex high-frequency active probes.

### 1.3 Guidance to the user

Conditions described in this subclause are a general overview of the test environment. More detailed conditions about the environment will be included in relevant subclauses of the standard.

#### 1.3.1 Environmental test considerations

Temperature and humidity may affect instrument performance. Consequently, it is important to maintain a relatively constant temperature, to within  $\pm 2$  °C of a set temperature, usually in the range of 19 °C to 22 °C, and a relative humidity in the range between about 30% to about 50%. Temperature and relative humidity should be recorded during the measurement or, at the least, at the beginning and end of the measurement.

#### 1.3.2 Electromagnetic compatibility and electrostatic discharge

The background electrical environment can impact the quality of a test. The test setup should prevent external disturbances from affecting the test results. The test instruments selected for the measurement system should be electromagnetically compatible; that is, they should not generate electromagnetic interference that affects the performance of other instruments or components in the system. External disturbance or interference can come from computers, radio frequency (RF) devices, communication signals, and so on. The user of the standard should verify that the test system is not affected by external disturbances.

The user should also be aware of possible damage to sensitive electronics by electrostatic discharge. Consequently, the test instrumentation and device under test should be placed on antistatic surfaces that are connected to earth ground and have a surface resistance greater than  $10^6$   $\Omega$ . The operator of the instruments should be connected to earth ground using wrist straps or similar devices.

#### 1.3.3 Test equipment

The performance of the test equipment used for these tests should significantly exceed the desired performance of the circuit probe under test. How significantly more the performance of the test equipment must exceed that of the probe under test is dependent on user requirements for accuracy and uncertainty.

Testing labs should be compliant with ISO/IEC 17025 to ensure quality of measurement results. In particular, traceability of instrumental calibration to a known standard is important. The test equipment required to perform the tests given in this standard are described in Clause 4.

#### 1.3.4 Test selection

The test methods given in this standard are suggested methods for measuring the parameters that are indicative of probe performance. These test methods, although general, provide a logical process in which to acquire parameter information. To provide subsequent comparability with other measurements of the same parameter, deviation from the methods described in this standard should be noted by the user.

## 1.4 Manufacturer-supplied information

### 1.4.1 General information

To measure the performance of a probe satisfactorily, the manufacturer shall supply the following general information:

- a) Probe part number
- b) Physical characteristics: dimensions, packaging, and pinouts
- c) Power requirements (if applicable)
- d) Environmental conditions: safe operating, nonoperating, and specified performance temperature range; altitude limitations; humidity limits, operating and storage; vibration tolerance; and compliance with applicable electromagnetic interference specifications
- e) Any special or peculiar characteristics
- f) Compliance with other specifications
- g) Control signal characteristics (if applicable)

### 1.4.2 Important performance specifications

The manufacturer shall provide the following specifications (see Clause 3 for definitions):

- a) Analog bandwidth,  $-3$  dB
- b) Nominal attenuation
- c) Direct current (dc) input resistance (each side and/or differential)
- d) Alternating current (ac) input impedance
- e) Equivalent input noise (root-mean-square [rms] voltage or spectral density)
- f) Input signal full-scale range with nominal reference signal levels (minimum, maximum, and/or typical)

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 181<sup>TM</sup>-2011, IEEE Standard for Transitions, Pulses, and Related Waveforms.<sup>1, 2</sup>

IEEE Std 1057<sup>TM</sup>-2007, IEEE Standard for Digitizing Waveform Recorders.

ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories.<sup>3</sup>

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### 3. Definitions, abbreviations, and acronyms

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.<sup>4</sup>

#### 3.1 Definitions

**impedance:** The ratio of the phasor equivalent of a steady-state sine-wave voltage or voltage-like quantity (driving force) to the phasor equivalent of a steady-state sine-wave current or current-like quantity (response).

**scattering matrix:** An  $n \times n$  square matrix used to relate incident waves and reflected (and transmitted) waves for an  $n$ -port network.

**signal:** A measurable quantity (e.g., a voltage) that varies in time to transmit information.

#### 3.2 Abbreviations and acronyms

Abbreviations and acronyms are grouped in the following way: Greek symbols, then Roman alphabetic symbols, and then acronyms. The elements of each group are in alphabetical order.

|                 |                                                         |
|-----------------|---------------------------------------------------------|
| $CMRR$          | common mode rejection ratio                             |
| CPW             | coplanar waveguide                                      |
| $N_{inc}$       | number of voltage steps                                 |
| $R_{dut}$       | resistance of device under test                         |
| $R_{in}$        | input resistance of probe                               |
| $R_{in,pos}$    | input resistance of probe to positive polarity signals  |
| $R_{in,neg}$    | input resistance of probe to negative polarity signals  |
| $R_{inst}$      | input resistance of test instrument                     |
| $R_{out}$       | output resistance of probe                              |
| $R_{out,pos}$   | output resistance of probe to positive polarity signals |
| $R_{out,neg}$   | output resistance of probe to negative polarity signals |
| $V_{in}$        | probe input voltage                                     |
| $V_{inc}$       | voltage increment applied to probe                      |
| $V_{max}$       | most positive input voltage for the probe               |
| $V_{min}$       | most negative input voltage for the probe               |
| $V_{off,low}$   | lower voltage limit of probe offset range               |
| $V_{off,high}$  | upper voltage limit of probe offset range               |
| $V_{off,range}$ | probe offset voltage range                              |
| $V_{out}$       | probe output voltage                                    |
| $V_{prob,off}$  | probe offset voltage                                    |
| DMM             | digital multimeter                                      |
| GCPW            | grounded coplanar waveguide                             |
| RF or rf        | radio frequency                                         |
| VNA             | vector network analyzer                                 |

<sup>4</sup>*IEEE Standards Dictionary Online* subscription is available at: [http://www.ieee.org/portal/innovate/products/standard/standards\\_dictionary.html](http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html).

## 4. Special terms

**active probe:** A probe that requires an external power supply to function.

**analog bandwidth:** The difference between an upper frequency and a lower frequency, where both have a fixed amplitude relationship to a reference frequency. Typically, the ratio of the amplitude of the lower and upper frequencies to the amplitude of the reference frequency is  $-3$  dB.

**differential probe:** A probe that has two signal conductors and one ground conductor and is used to probe differential circuits.

**differential signal:** A signal configuration comprising two complementary signals that are transmitted concurrently, on separate signal conductors, and both having the same reference (ground).

**four-terminal (four-wire, Kelvin) resistance measurement:** A resistance measurement method in which current is passed through a device under test, and the voltage drop across that device under test is simultaneously measured. Typically, the voltage measuring function is provided by two probe contacts, and the applied current is provided by two different probe contacts. The two current contacts have a larger separation than the voltage contacts, and the voltage contacts lay between the current contacts.

**input impedance:** The impedance between the signal input conductor of an instrument or device and reference (ground).

**output impedance:** The impedance between the signal output conductor.

**probe:** An electrical device for making contact between a circuit or device under test and a measurement instrument, such as an oscilloscope or digital multimeter.

**probe system:** A probe designed to be used with a particular oscilloscope or measurement system. The probe of a probe system must be used with the oscilloscope designated by the manufacturer.

**single-ended probe:** A probe that has one signal conductor and one ground conductor and is used to probe single-ended circuits.

**stand-alone probe:** A probe designed to be used with any oscilloscope or measurement instrument.

**scattering parameters:** The elements of a scattering matrix and often abbreviated as s-parameters.

**single-ended signal:** Signal transmission comprising one signal that is transmitted on one signal conductor that has a fixed reference (ground).

**test fixture:** A device that provides electrical connection between the probe and a test signal. The test fixture is used for characterizing the performance of the probe.

## 5. Instrumentation

This clause provides general requirements for the test instruments required to perform the tests given in this standard. Details of instrument performance requirements will depend on the required performance of the probe. To increase measurement reproducibility, repeatability, and accuracy, it is recommended that all test equipment, where applicable, be digitally programmable through a standard communication or instrument control interface.

## 5.1 Digitizing oscilloscopes

The oscilloscope may be either a real-time or an equivalent-time sampling instrument that provides an amplitude-versus-time waveform of the signal being measured. Sampling oscilloscopes digitize both the amplitude and the temporal information of the waveform. Performance requirements that are important for measuring probe performance include, but are not limited to, input impedance, analog bandwidth, maximum record length, sampling interval, input voltage range, frequency response flatness, and step response flatness.

## 5.2 Voltage sources

The voltage source will be used to provide voltage inputs to probes for measurement of their static response characteristics. These sources should provide output levels that can exercise the operational range of the probes.

## 5.3 Vector network analyzers (VNAs)

The vector network analyzer supplies a stimulus signal (sine wave for a frequency domain VNA and step for a time domain VNA) to a device and then makes a complex measurement of the transmitted signal and the reflected signal. Performance requirements that are important for measuring probe performance include, but are not limited to, calibrated accuracy, frequency range, record length, and power levels.

## 5.4 Spectrum analyzers

The spectrum analyzer provides a measurement of the amplitude or power spectrum of an input signal. Performance requirements that are important for measuring probe performance include, but are not limited to, calibrated accuracy, frequency range, and frequency resolution (resolution bandwidth).

## 5.5 Digital multimeters (DMMs)

The DMM will be used to measure the input and output resistance values and the voltage offset and linearity of the probe. For more accurate measurements, the DMM should provide four-terminal resistance measurement capability.

## 5.6 Accessories

Accessories such as terminators, attenuators, delay lines, and other such devices are usually needed to match signal levels and to provide signal isolation to avoid corrupting the input stimuli. Transmission lines and connectors should have a characteristic impedance equivalent to the input or output impedance of the test instrumentation used and have an analog bandwidth that is greater than the probe under test.

## 5.7 Signal conditioning

Users may require signal conditioning devices such as filters and pulse shapers. The performance of these devices should be known. The input and output impedances of these devices should match the equipment to which they are connected.

## 6. Test fixture

A test fixture of appropriate design and quality is necessary to measure the performance of a voltage probe accurately and reproducibly. This clause provides guidance on the design of the test fixture and describes methods for assessing the quality of the test fixture.

### 6.1 Design

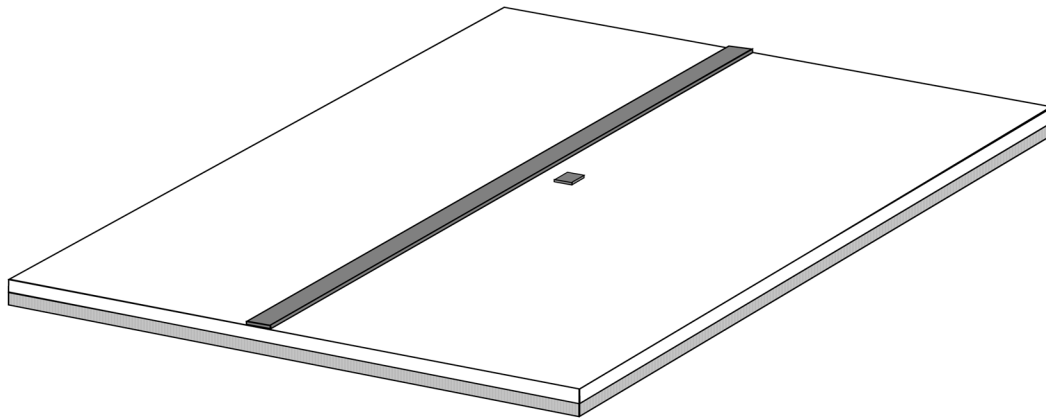
Three important topics to consider when designing a test fixture are transmission line structure, connectors, and ground inductance. Each of these will be discussed in 6.1.1 through 6.1.3.

#### 6.1.1 Transmission line structures

Several different planar transmission line structures are suitable for a test fixture. A critical design requirement of the transmission line is that the signal line and ground plane are on the same surface; this allows the probe to contact both the signal line and the ground plane of the test fixture simultaneously. If a transmission line structure does not normally have a ground contact on the same plane as the signal line, then vias or other connections can be used to address this deficiency. However, this solution may introduce parasitic responses that can affect the quality of the measurement. More detailed information on the signal propagation properties of transmission lines and how their modifications affect these properties can be found in textbooks on transmission line design or by using electromagnetic modeling and simulation tools.

##### 6.1.1.1 Single-ended microstrip transmission line with a ground pedestal (or via)

Figure 1 shows a microstrip transmission line designed for a single-ended probe. The ground contact has been brought to the same plane as the signal conductor by use of a via. This transmission line design is similar to those used in circuits that are likely to be probed.



NOTE—The white-colored region is the dielectric substrate, and the gray represents the conductors: The light gray is the ground plane, and the dark gray is the signal line and via to ground.<sup>5</sup>

**Figure 1—Single-ended microstrip transmission line**

The microstrip transmission line is ideal for characterizing single-ended probes because of its simple design and well-known propagating wave characteristics. A via between the ground plane and a topside ground contact is necessary with this type of structure because the ground plane is not otherwise accessible on the same surface as is the signal line. This topside contact defines the location where the probe contact to the test fixture is made. Having a known location for the probe contact point facilitates calculating the partial scattering parameters of the test fixture, which may be necessary in using de-embedding techniques to predict probe performance more accurately (as will be discussed in 6.2). The via does add inductance to the probe ground path, but this should be small if designed properly. The via and contact pad may also cause a discontinuity in the characteristic impedance of the transmission line if the via and contact pad are too close to the signal line or if they are too large. The ideal size and location of the via and contact pad can be determined using electromagnetic modeling tools.

The microstrip structure can also be used with differentially coupled probes that exhibit a high common mode rejection ratio (*CMRR*). In this case, the single-ended and common-mode input impedances are measured and the differential-mode impedance is computed from them. To measure the common mode impedance of a differential probe requires that the signal line of the test fixture be wide enough to accommodate the spacing between the differential signal contacts of the differential probe. Care must be exercised when making the signal line wide enough for this purpose as this widening affects the signal propagation characteristics of the transmission line.

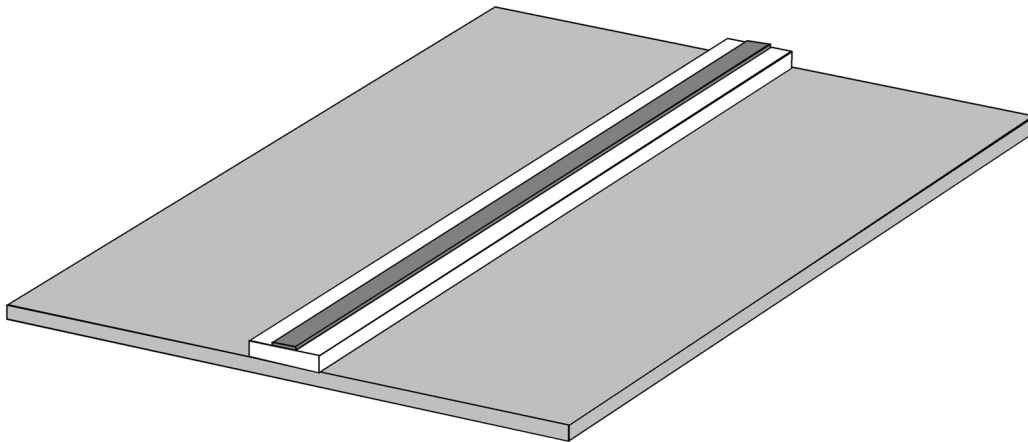
Microstrip lines exhibit the greatest amount of dispersion as compared to the other planar structures that will be described in this standard. If dispersion is an issue, then the substrate can be thinned and/or a substrate material selected with a lower permittivity. If this is done, then the signal line must also be narrowed. Narrowing the signal line will increase losses and the characteristic impedance of the transmission line.

<sup>5</sup> Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

#### 6.1.1.2 Single-ended microstrip transmission line with finite-width substrate

The microstrip transmission line with finite ground (see Figure 2) is physically similar to the microstrip transmission line except that the substrate is reduced to a narrow pedestal on which the signal line rests. Consequently, the probe ground can be connected directly to ground plane of the test fixture, thus, minimizing the effect of the probe via inductance that will occur in the test fixture described in 6.1.1.1. The width of the dielectric layer should be wide enough to encompass most of the electric fields of the propagating signal. If this is not the case, then the ground tip of the probe will create a discontinuity. The lack of a ground via allows a continuous range of probe locations on the test fixture, and this may cause problems if de-embedding of predefined sections of the test fixture is necessary. However, fiducials can be used to locate the probe on the fixture accurately.

This microstrip test fixture will suffer the same faults as the structure described in 6.1.1.1. The microstrip transmission line with finite-width substrate is not typical of the transmission lines that will be encountered in a circuit under test. The differences between the microstrip and microstrip with finite-width substrate are not expected to be significant and can be approximated with appropriate electromagnetic modeling tools.



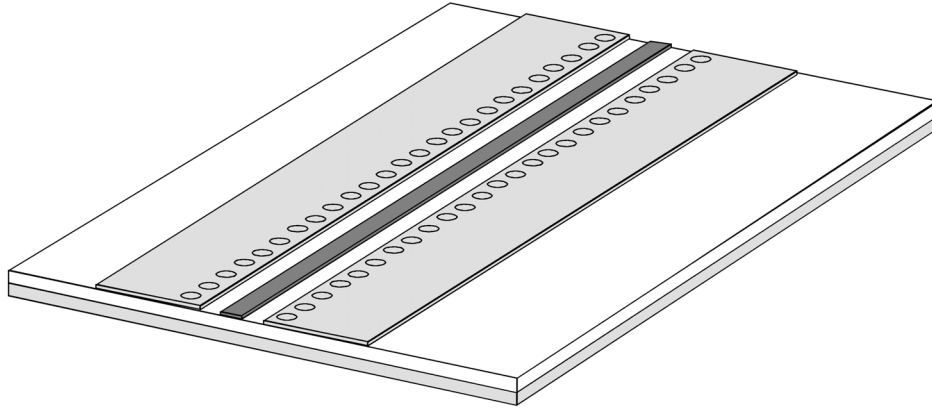
NOTE—The white region is the dielectric separating the signal line (dark gray) and ground plane (dark gray). In this figure, the ground plane acts as the substrate for the transmission line.

**Figure 2—Microstrip with finite-width substrate**

#### 6.1.1.3 Single-ended coplanar waveguide with ground plane

The coplanar waveguide (CPW) transmission line is commonly used in the design of high-frequency transmission line structures and consists of one signal line laying between two ground lines on the same surface. CPW lines typically have lower dispersion than microstrip transmission lines. The dispersion can be reduced further if the gap between the signal line and ground lines is reduced. However, to maintain the characteristic impedance of the CPW, a reduction in gap would require a reduction in the width of the signal line. CPW lines typically, however, exhibit greater losses than microstrip lines of comparable dimensions. The two grounds in the CPW must be electrically connected; otherwise non-quasi-transverse electromagnetic modes may propagate. To tie the grounds together, wire bonds or a secondary ground plane can be used. Because the test fixture must provide access for a probe, topside wire bonds are not a viable option. Shown in Figure 3 is a CPW with an additional ground plane, and this structure is called a grounded CPW (GCPW). The GCPW is a structure commonly used by probe manufacturers for testing their probes. The two ground planes on the top surface of the GCPW are electrically connected to the

bottom ground plane with vias. The via separation and their diameters have to be chosen to optimize signal propagation. If there is not a sufficient number of vias, then a resonance between the topside and bottom-side grounds may occur. Because some of the return current flows through the bottom ground plane, the inductance of the probe ground connection is increased.



NOTE—This transmission line structure has three ground conductors (light gray), two on the same plane as the signal line (dark gray) with one on either side of the signal line, and a third ground plane on the other side of the dielectric substrate (white). The circles in the topside ground planes represent vias to the bottom-side ground plane.

**Figure 3—Coplanar waveguide with ground plane**

#### 6.1.1.4 Differentially coupled microstrip transmission line

The differentially coupled microstrip transmission line structure (Figure 4) is ideally suited for measuring the performance of a differential probe. The concerns regarding dispersion are the same as that of the single-ended microstrip transmission line (6.1.1.1) and have the same solutions and cautions. In the differentially coupled microstrip transmission line, the two signal lines in the center of the test fixture run closer together and are narrower than the signal lines in the outer sections of the test fixture. The differential mode impedance in the central section is nominally 100  $\Omega$ .

For measuring differential mode parameters, the probe can be placed anywhere along the signal lines of the test fixture. To measure common mode parameters, the probe should be placed on the angled part of the transmission line on the side that is farthest from the source (input signal). Measuring common mode parameters of the probe with the probe at the center of the test fixture is not recommended because of the electric and magnetic field coupling.

The GCPW should be as symmetric as possible to avoid errors that affect the signal propagating modes. The launches (connectors) to the test fixture should also be similar to avoid mode problems.