The Forthcoming IEEE Standard 1696 on Test Methods for Characterizing Circuit Probes

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Abstract— **The Technical Committee 10 (TC-10) of the IEEE Instrumentation and Measurement Society initiated a new standards activity in 2006 for the development of test methods to characterize the performance of circuit probes. This standard contains a set of performance parameters that describe probe performance along with a test method for each of these parameters. All test methods consider both single-ended and differential probes. The probes may be either stand alone, that is, they are not necessarily constrained to operate with one model of waveform recorder (such as an oscilloscope), or a probe-scope system, where the probe is designed by the probe manufacturer to work with one or more models of oscilloscopes. The probes considered in this standard are all active high-input impedance devices. Both static and dynamic signal measuring performance parameters are considered in the P1696. The key to accurate measurements of the dynamic signal measurement properties of the probe is a quality test fixture, which is described in the standard.**

Keywords— ***circuit probe, differential, probe-scope system, single-ended, stand-alone probe, test fixture***

I. Background

The IEEE Technical Committee 10 (TC-10), the "Waveform Generation, Measurement and Analysis Committee," of the IEEE Instrumentation and Measurement Society was approached in 2005 with a request for a new standards activity. Specifically, stakeholders (users and manufacturers) had approached one of the TC-10 subcommittee chairs requesting assistance in clarifying the confusion regarding how different manufacturers were describing probe performance and specifying associated performance parameters. This request was brought to the attention of the TC-10 because of the potentially broad implications for uniformity and reproducibility of testing of devices (in this case probes) and in communicating device performance across an extensive international stakeholder community. After deliberations and subsequent vote by the TC-10 members, the TC-10 agreed that a probe-test-method standard was needed to address this articulated need for a broadly-accepted set of methods for measuring probe performance.

The TC-10 submitted a project authorization request (PAR) in April 2006 that was subsequently approved later in the same year by the IEEE Standards Association. The PAR was due to expire in December 2010. This new standard was given the identifier P1696 and title "Standard for Terminology and Test Methods for Circuit Probes." The TC-10 spawned a new subcommittee, the Subcommittee on Probe Standards, to develop the P1696.

The TC-10 recruited representatives from the major international manufacturers of circuit probes, the major US users of circuit probes, including manufacturing entities and Department of Energy national laboratories, and test and measurement laboratories.

Due to various delays in the development of the standard, a request for extension of the PAR was requested in August 2010 and granted later that year. The present PAR is due to expire on 31 December 2014.

II. The P1696

A. Overview

The P1696 contains terms and definitions that are either unique to a circuit probe or that have a unique meaning when describing the performance of the probe. The standard includes guidance on the instruments that could be used to perform the tests. However, because the performance of the probe itself and the requirements of the user can vary significantly for different users and measurement requirements, the standard only provides suggestions as to what instruments should be used based on the user's measurement requirements. Also contained in the standard is guidance on the design and characterization of a high-quality test fixture. Both single-ended and differential test fixtures are considered. A high-quality test fixture is essential for accurate measurements of the dynamic performance of the probe.

A single-ended system is one in which there is one conductor for the signal line and one conductor for ground. In a differential system, there are two signal conductors, propagating signals of opposite polarity, and one ground conductor.

The majority of the text of the standard is devoted to the 20 different parameters that describe the performance of the probe and the test methods associated with these parameters. The following is a list of these parameters:

1) Input resistance
2) Output resistance
3) Gain
4) Linearity
5) Output offset error
6) Input offset error
7) Equivalent input offset error
8) Offset range
9) Output return loss
10) Equivalent input noise spectral density
11) Equivalent integrated noise
12) Large signal response
13) Input impedance
14) Input return loss with 50 Ω termination
15) Transfer function, input referred
16) Transfer function, source referred
17) Common mode rejection
18) Common mode rejection ratio
19) Frequency magnitude response
20) Step (time) response

B. Examples of parameters and test methods

For all the parameters listed above, the standard indicates whether the parameter and test method are applicable to stand-along probes or probe-scope systems. For each parameter, a single-ended and a differential test method is described. Most of the differential test methods are identical to a single-ended test method with the exception of using signal generators, transmission structures, and receivers that support differential signals. The parameters listed in Sec. II A of this document from items 1 to 11, describe static signal measurement characteristics of the probe and do not require a test fixture for their measurement. The parameters for items 12 to 20 describe dynamic signal measurement characteristics of the probe and, therefore, require a test fixture for their measurement.

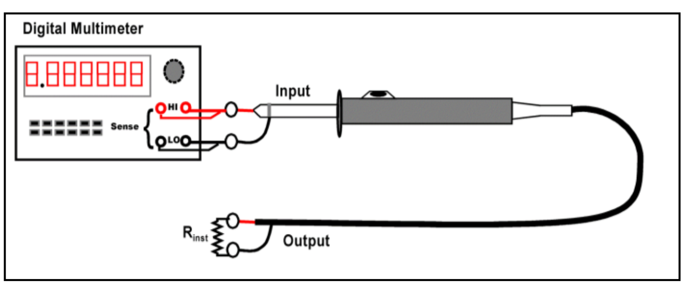

Figure 1. Setup for measuring the input resistance for a single-ended stand-alone probe. R_{inst} is equal to the input resistance of instrument to which the probe will be connected.

Many of the parameters contained in the standard are applicable to a probe-only measurement because they require access to the output of the probe that is not available with a probe-scope system. For example, the method described in the standard for the input resistance of the probe is measured with the output of the probe connected to a resistive load (see Fig. 1) and, therefore, input resistance is independent of waveform recorder to which the probe is attached.

There are some test methods for which optional implementations could be devised but these optional methods are not described in the standard because it would not be as accurate as the method described in the standard. For example, the method described in the standard for gain of the probe is measured with the output of the probe connected to a digital multimeter (see Fig. 2). An optional implementation would be to have the probe output connected to the waveform recorder and then record the static levels acquired by the waveform recorder. However, this optional implementation is not in the standard because the accuracy of the measurement results would not be as great as that when using a digital multimeter.

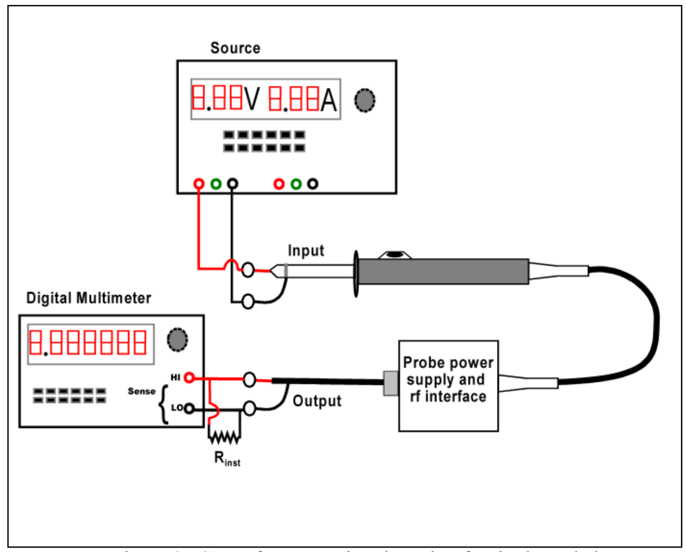

Figure 2. Setup for measuring the gain of a single-ended stand-alone probe.

C. Comparing single-ended and differential test methods

The gain measurement described in Sec. II, B will be used as an example of how, in the standard, the single-ended and differential test methods differ. The following is the list of steps for the single-ended test method given in the current draft of the standard:

a. "Ensure the probe is connected to its power supply and the probe is powered.
b. Connect the input signal conductor of the probe to the "high" output of the voltage source.
c. Connect the input ground (return) conductor of the probe to the "low" output of the voltage source.
d. Connect the output signal conductor of the probe to the "high" connection of the multimeter.
e. Connect the ground signal conductor of the probe to the "low" connection of the multimeter.
f. Define the voltage increment, V_{inc}, using the following:

$$V_{inc} = \frac{V_{max} - V_{min}}{N_{inc}}, \qquad (1)$$

where V_{max} is the most positive input voltage specified by the probe manufacturer, V_{min} is the most negative input voltage specified by the probe manufacturer, and N_{inc} is the user defined number of voltage steps for the probe gain curve.

g. Set the multimeter sensitivity scale (range) so that voltage value obtained contains the desired precision.
h. Set the measurement counter, i, to zero ($i = 0$).
i. Set the voltage output level of the voltage source to V_{min} and record this value as $V_{in,i}$.
j. Record the output voltage value as $V_{out,i}$.
k. Increase the measurement counter: $i = i + 1$.
l. Increment the applied voltage: $V_{in,i} = V_{in,i-1} + V_{inc}$, and record this value.
m. Record the output voltage value as $V_{out,i}$
n. Repeat steps l, m, and n until the $V_{in} = V_{max}$.
o. Determine the slope of the V_{out}-vs-V_{in} curve over the range of V_{in} from 0.5 V_{min}, or otherwise specified by the user, to 0.5 V_{max}, or as otherwise specified by the user, using the linear-least-squares curve fitting method.
p. Report the gain as the slope to the fitted V_{out}/V_{in} curve found in step n."

The following is the list of steps for the differential test method given in the current draft of the standard:

a. "Ensure the probe is connected to its power supply and the probe is powered.
b. Connect one of the two input signal conductors of the probe to the "high" output of the voltage source.
c. Connect the other input signal conductor of the probe to the "low" output of the voltage source.
d. Connect the input ground (return) conductor of the probe to ground connection of the voltage source.
e. Connect one of the output signal conductors of the probe to the "high" connection of the multimeter.
f. Connect the other output signal conductor of the probe to the "low" connection of the multimeter.
g. Define the voltage increment, V_{inc}, using the following:

$$V_{inc} = \frac{V_{max} - V_{min}}{N_{inc}}, \qquad (2)$$

where V_{max} is the most positive input voltage specified by the probe manufacturer, V_{min} is the most negative input voltage specified by the probe manufacturer, and N_{inc} is the user defined number of voltage steps for the probe gain curve.

h. Set the multimeter sensitivity scale (range) so that voltage value obtained contains the desired precision.
i. Set the measurement counter, i, to zero ($i = 0$).
j. Set the voltage output level of the voltage source to V_{min} and record this value as $V_{in,i}$.
k. Record the measured voltage value as $V_{out,i}$.
l. Increase the measurement counter: $i = i + 1$.
m. Increment the applied voltage: $V_{out,i} = V_{out,i-1} + V_{inc}$.
n. Record the output voltage value as $V_{out,i}$.
o. Repeat steps l,m, and n until the $V_{in} = V_{max}$.
p. Determine the slope of the V_{out}-vs-V_{in} curve over the range of V_{in} from 0.5 V_{min}, or otherwise specified by the user, to 0.5 V_{max}, or as otherwise specified by the user, using the linear-least-squares curve fitting method.
q. Report the gain as the slope to the fitted V_{out}/V_{in} curve."

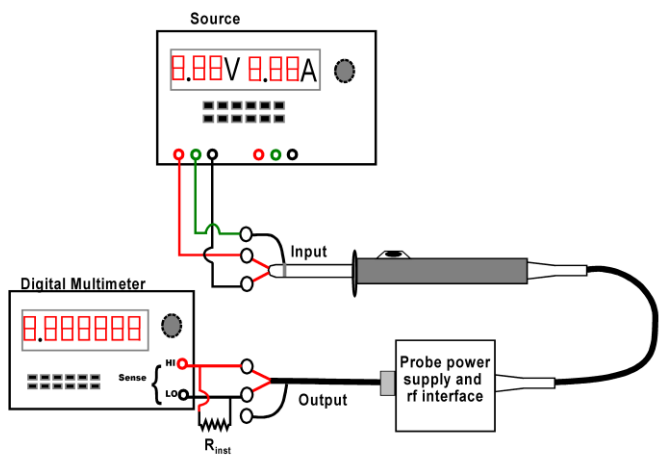

Figure 3. Setup for measuring the gain of a differential stand-alone probe.

From these two lists of steps, the first list for the single-ended probe and the second list for the differential probe, it can be seen that the difference between two methods is in how the instruments are connected to the input and output connections of the probe (see Fig. 3). The remainder of the steps, which describe acquisition of the data and its subsequent analysis to yield the gain curves, are the same.

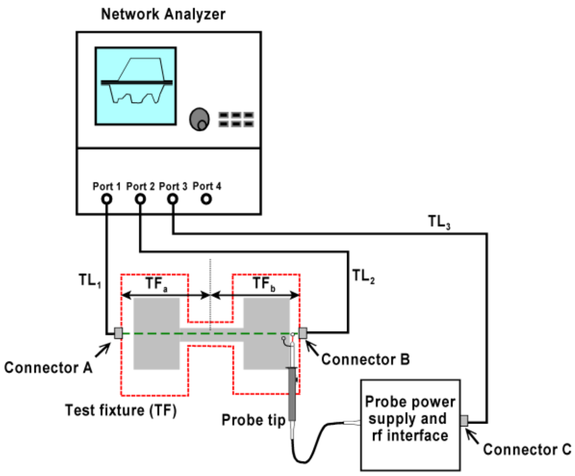

Figure 4. Setup for measuring the input impedance of a single-ended stand-alone probe.

The gain measurement setups just described are also used to perform measurements for linearity, input offset error, equivalent input offset error, and offset range. Similarly, there are other measurement setups common to more than one parameter. To minimize redundancy in the standard, the measurement setups for different parameters are cross-referenced as much as possible.

D. Input impedance: example of a dnyamic measurement method

The input impedance as a function of frequency is one of the parameters that describe the dynamic signal measurement characteristics of a probe. It's an important parameter because it influences the levels and bandwidths of signals that can be measured. The input impedance measurement setup, as described in the standard is given in Fig. 4 and the measurements steps, taken from the current draft of the standard are:

a. "Use a vector network analyzer (VNA) with the proper frequency range and appropriate test port cables to connect to the probe and to the test fixture. Use the appropriate calibration kit.

b. Setup the VNA to perform the measurement. It is important that the power level output from the VNA produces signals at the test fixture that are within the dynamic range of the probe.

c. Connect Port 1 of the VNA to one side of the test fixture. This is shown in Fig. 4 as connecting Port 1 to Connector A of the test fixture.

d. Perform a calibration of the test fixture using appropriate calibration loads connected to Connector B of the test fixture. This establishes Connector B as the reference plane. To verify this, connect Port 2 of the VNA to Connector B and measure s21. Without a probe contacting the test fixture, the s21 should be 0 dB and 0° phase.

e. Connect Port 2 of the VNA to Connector B of the test fixture.

f. Power the probe and connect the probe tip to the test fixture. The probe tip should be placed as close as possible to Connector B to minimize errors causes by losses in the test fixture.

g. Connect the probe output to a 50 Ω termination (which can also be an used port of the VNA).

h. Make an s21[*f*] measurement with the VNA. This measurement will give the insertion loss through the fixture with the probe loading the fixture. Record the s21[*f*] values measured as $v_{in}[f]$. Note $v_{in}[f]$ is not a voltage value but is a dimensionless ratio.

i. Compute the input impedance, $Z_{pr}[f]$, using:

$$Z_{pr}[f] = \frac{Z_{sys} v_{in}[f]}{1 - v_{in}[f]}, \qquad (4)$$

where Z_{sys} is the impedance of the measurement, which is typically 50 Ω, and is assumed to be constant over the bandwidth of the measurement."

III. STATUS

The draft of the P1696 is approximately 80 % completed as of mid-September 2012. It is expected that the draft will be completed by the end of November 2012. The major section requiring completion is that providing guidance on the design and characterization of the test fixture. As mentioned previously, the test fixture is the essential component for accurate measurements of the dynamic signal measurement characteristics of the probe.

Once the final draft has been approved by the Subcommittee on Probe Standards (SCOPS), it will be submitted to IEEE Standards Association for balloting.

The SCOPS welcomes and invites others to join the SCOPS and contribute to the development of this standard. If you are interested in contributing to the P1696, contact Tom Linnenbrink, TC-10 chair, at tom.linnenbrink@hittite.com.

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