P7313SMA
13 GHz Differential Probe

Technical Reference

www.tektronix.com
071-1968-01

Tektronix

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Preface

This is the technical reference manual for the P7313SMA differential probe. This manual provides operating theory, specifications, and performance verification procedures for the probe.

Operating Basics

This section discusses differential measurements using an SMA input probe for Serial Data compliance testing. It also provides information on the probe architecture and operational details to aid in its proper application. Refer to the *P7313SMA Quick Start User Manual* for a functional description of the P7313SMA probe. The probe is shown below. (See Figure 1.)

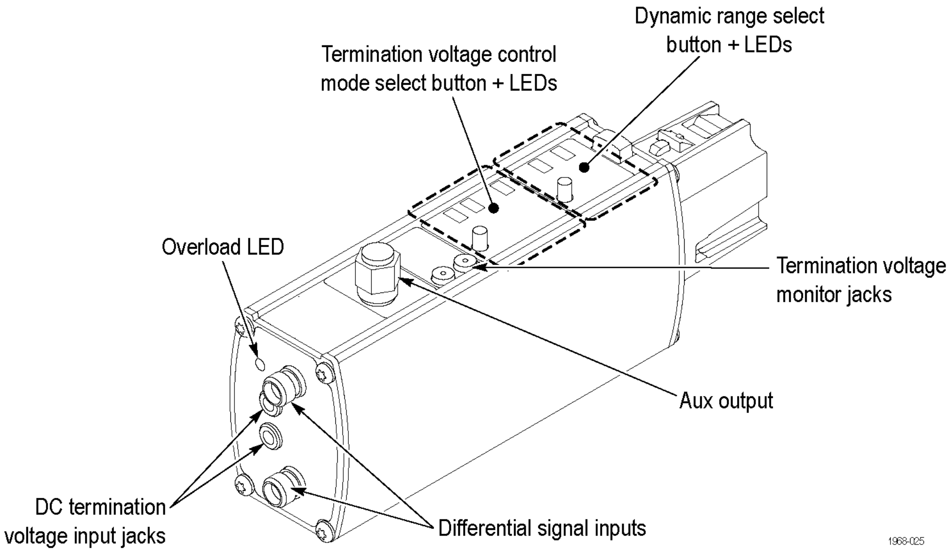


Figure 1: P7313SMA differential probe

Differential Measurements for Serial Data Compliance Testing

Differential Signaling

Gigabit serial data signals are commonly transmitted using differential signaling techniques because of improved signal fidelity and noise immunity. Although the physical layer specifications differ somewhat between the different gigabit serial data communication standards, they have some common elements. Most gigabit serial data signals are transmitted over 50 Ω transmission lines, which are terminated at both ends of a point-to-point differential interconnect. The signal transmitter provides a 50 Ω source impedance from each of its two differential outputs and the signal receiver provides an effective 50 Ω input impedance on each of its two differential inputs.

The two complementary single-ended signals that make up the differential signal are generally offset from ground at a common-mode voltage level, which allows the use of unipolar transmitters and receivers that are powered from a single power supply voltage. The transmitted signals are usually encoded using a DC-balanced encoding technique that allows the signals to be either AC or DC coupled in the transmission path. If DC coupled, the receiver termination must generally be terminated to the same DC common-mode voltage as the transmitter, to reduce DC loading on the transmitter output. An example of the single-ended signals transmitted by an InfiniBand standard driver and the resultant differential signal that would be measured by a differential measurement system is shown in *Infiniband*. (See Figure 15 on page 22.)

Although the differential response is generally the primary measurement of interest for a differential signal, full characterization of the signal also requires measurement of the single-ended response of the two complementary signals including the DC common-mode voltage.

Pseudo-Differential Measurements

A common differential measurement technique uses two single-ended probes or direct coaxial cable connection to two oscilloscope channels for the differential signal capture. By calculating the difference between the two input signals using waveform math, the effective differential signal seen by a differential receiver can be displayed for analysis.

This measurement technique, which is commonly refered to as pseudo-differential measurement, has a number of limitations when compared to the use of a differential probe like the P7313SMA. In addition to the obvious overhead of two oscilloscope channels for the measurement instead of the single channel needed by a differential probe, there are a number of additional problems.

Unlike the differential probe, which has been carefully designed with short, matched-input signal paths, a pseudo-differential measurement uses two oscilloscope channels, which are physically separated and generally not matched as well. Although it is possible to deskew the timing differences between two high performance oscilloscope channels to improve the accuracy of a pseudo-differential measurement, deskewing is a relatively involved procedure that may need to be repeated if any oscilloscope parameter, such as vertical gain, is changed.

The gain match between two different oscilloscope channels is also a potential problem, particularly at higher frequencies where channel gain mismatch can contribute to significantly reduced CMRR performance. DSP correction can be used to improve vertical channel matching, but is generally only available on high-performance oscilloscopes. The CMRR performance of a differential probe, on the other hand, is generally much better controlled, with fully characterized specifications over the full probe bandwidth.

The requirement of generating a math waveform for display of the differential signal in a pseudo-differential measurement can also introduce some subtle problems with waveform analysis, since some features such as COMM triggering or mask testing may not be fully supported with math waveforms. The use of a differential SMA-input probe like the P7313SMA also provides additional features like adjustable termination voltage that may be very useful in fully characterizing the performance of differential data transmitters. High performance oscilloscope channels are almost always limited to zero volt termination voltage, since the oscilloscope input termination resistor is connected directly to signal ground.

Differential Probe Measurements

A differential probe is designed to provide a differential input interface for a single-ended oscilloscope channel. It includes a carefully matched differential signal input path and a differential buffer amplifier.

A conventional differential probe input generally has a high DC input resistance and as small an input loading capacitance as possible. The light input loading of a conventional differential probe is designed to perturb the circuit being measured as little as possible when the probe is attached.

An SMA-input probe like the P7313SMA has a very different input structure. It has a dual, matched 50 Ω input that is designed to terminate the measured signal transmission path with minimum reflections. It is designed specifically for serial compliance testing. Its SMA input connectors provide a reliable, repeatable interconnect for making accurate eye pattern measurements that are used to characterize the quality of a serial data transmission channel.

The P7313SMA probe has also been carefully designed for flat amplitude response and very small pulse response aberrations. This helps to ensure accurate eye pattern measurements over a wide data rate range.

The differential amplifier is at the heart of any device or system designed to make differential measurements. (See Figure 2.) Ideally, the differential amplifier rejects any voltage that is common to the inputs and amplifies any difference between the inputs. Voltage that is common to both inputs is often referred to as the Common-Mode Voltage (V_{CM}) and difference voltage as the Differential-Mode Voltage (V_{DM}).

The simplified input signal voltage source model driving the differential amplifier shows a complementary differential signal without source or termination impedance. In a real-world measurement, the signal source and measurement termination impedance must be known and included in the measurement analysis.

The model also shows that the output from the differential amplifier has twice the peak-to-peak amplitude of each complementary input signal.

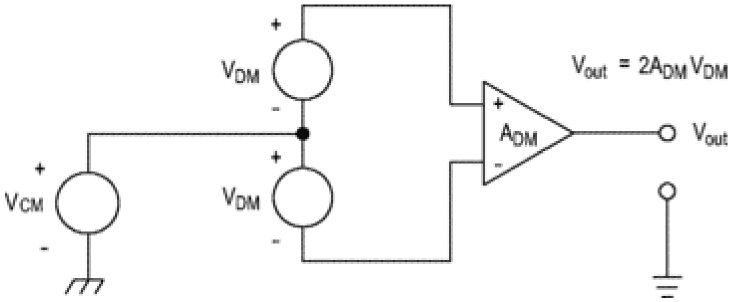


Figure 2: Simplified model of a differential amplifier

Common-Mode Rejection Ratio

Differential amplifiers cannot reject all of the common-mode signal. The ability of a differential amplifier to reject the common-mode signal is expressed as the Common-Mode Rejection Ratio (CMRR). The CMRR is the differential-mode gain (A_{DM}) divided by the common-mode gain (A_{CM}). It is expressed either as a ratio or in dB.

$CMRR = A_{DM} \div A_{CM}$

$CMRR(dB) = 20 \log (A_{DM} \div A_{CM})$

CMRR generally is highest (best) at DC and degrades with increasing frequency.

The typical CMRR response of the P7313SMA differential probe over frequency is shown in *Specifications*. (See Figure 16 on page 25.) High CMRR in a differential probe requires careful matching of the two input paths. Poorly matched signal source impedances can significantly degrade the CMRR of a measurement. Mismatches between the two differential signal input paths result in an effective conversion of V_{DM} to V_{CM}, which reduces the CMRR.

Probe Block Diagram (Simplified)

The SMA inputs and probe termination network provide a high frequency, 50 Ω signal path to the internal probe amplifier. The use of SMA-female connectors provides a reliable, repeatable attachment method for input signals. The symmetry of the input termination network is designed to reduce skew and maximize CMRR.

A simplified schematic of the P7313SMA input termination network is shown. (See Figure 3.)

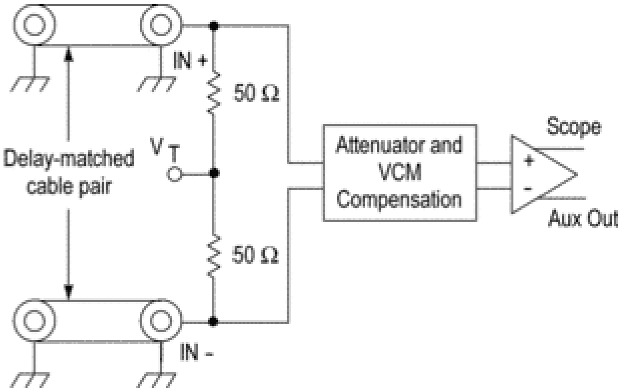


Figure 3: Input termination network

Matched-Delay Cables

The standard delay-matched cables for the P7313SMA differential probe have been carefully designed to provide guaranteed probe performance at the SMA connector interface on the end of the cable. The delay between the two matched cables in the standard cable assembly is adjusted to provide an initial skew of less than 1 ps. Cable skew this small can be degraded by cable flexure and through other environmental factors. Care should be taken to minimize physical mishandling of this quality cable assembly to preserve probe performance.

The cable used in the standard cable assembly has also been selected for its low-loss characteristics, and the cable length was selected to match the cable loss compensation designed into the probe differential amplifier. If an alternative cable assembly is used in measurements with the P7313SMA differential probe amplifier, this loss compensation characteristic must be considered. The following approximate equation for cable loss compensation can be used as a guideline in custom cable designs and is valid over a frequency range of about 1 GHz to 13 GHz:

$Loss = -[0.5\ dB + 0.15\ dB * (F/1.25)]$, *where F is frequency in GHz.*

Custom cable pairs must also be designed with very low skew or the skew must be minimized using a pair of adjustable phase trimmer adapters like those listed in the *Optional Accessories*. (See page 47, *Optional Accessories*.)

Input Termination Network

The input termination network in the P7313SMA differential probe includes a pair of attenuation resistor networks laser trimmed to 50 Ω terminations, connected together at a common-mode voltage node, labeled V_T. (See Figure 3.) The common-mode termination voltage node, V_T, is designed to provide a broadband, low impedance termination for input common-mode signals. The probe termination voltage can be adjusted using several different modes that will be described later.

The termination voltage range is +3.6 V/–2.5 V. For DC-coupled serial data signals, the termination voltage, V_T, should generally be set to equal the input signal common-mode voltage, V_{CM}; for AC-coupled serial data signals, the termination voltage, V_T, should generally be set to 0 V.

The adjustability of the termination voltage also provides measurement flexibility for characterizing or stressing serial data signal drivers. Because of the low impedance of the input termination and attenuator network, the signal termination currents can become quite large. The following table can be used to calculate the DC common-mode voltages and currents at the probe inputs and termination voltage driver under several common source impedance conditions. (See Table 1.)

Table 1: Common-mode voltage and current formulas

	. Source impedance [1]	
Common-mode term	**0 Ω**	**50 Ω**
. V_I	V_{CM}	$0.5 \times (V_T + V_{CM})$
. I_I(mA)	$40.00 \times V_T - 40.00 \times V_{CM}$	$20.00 \times V_T - 20.00 \times V_{CM}$
. I_T(mA)	$40.00 \times V_T - 23.33 \times V_{CM}$	$28.33 \times V_T - 11.67 \times V_{CM}$

[1] When inputs are AC coupled: $V_I = V_T$, $I_I = 0$, $I_T(mA) = 16.67 \times V_T$

V_I is the DC common mode voltage at the probe inputs with $V_{DM} = 0$.

I_I is the total DC source current from the input voltage source (V_{CM}).

I_T is the termination voltage driver current (±82.5 mA maximium).

Note: $I_T \neq I_I$ because of current flow through the V_{CM} compensation network shown. (See Figure 3 on page 4.).

The probe block diagram shows that the input termination network is followed by an attenuator and V_{CM} compensation circuit. The attenuator is used to increase the effective input dynamic range of the probe differential amplifier.

The P7313SMA probe has two attenuation settings, 2.5X and 12.5X, that allow dynamic range to be traded off against signal noise. The 12.5X attenuator setting has the largest dynamic range; the 2.5X attenuator setting has the lowest noise.

The V_{CM} compensation circuit automatically minimizes the DC common-mode voltage at the probe differential amplifier inputs even with varying termination voltage and input signal DC common-mode voltage. This maximizes the differential mode signal input dynamic range. The V_{CM} compensation circuit allows the DC common-mode input voltage range to be the same for both attenuator settings. (See Figure 5 on page 7.)

Internal Probe Amplifier

The P7313SMA differential probe is designed to measure high frequency, low-voltage circuits. Before connecting the probe to your circuit, take into account the limits for maximum input voltage, the common-mode signal range, and the differential-mode signal range. For specific limits of these parameters, see the *Specifications* section. (See page 23, *Specifications*.)

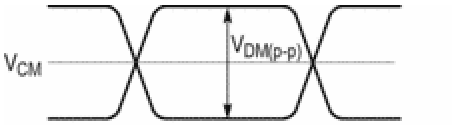
Maximum Input Voltage. The maximum input voltage is the maximum voltage to ground that the inputs can withstand without damaging the probe input circuitry.

⚠ ***CAUTION.*** *To avoid damaging the inputs of the P7313SMA differential probe, do not apply more than ±5 V (DC + peak AC) between each input and ground. In addition, to avoid probe damage, the maximum termination resistor power must not be exceeded.*

Maximum Termination Resistor Power. The internal termination resistors can safely dissipate 0.2 W of power continuously, which is the case for normal probe operation without termination driver current overload. However, the probe will be damaged if you apply more than 0.5 W of power through the termination resistors for more than 5 minutes.

If you suspect your measurement application will approach these limits, use the formulas that follow to calculate the power dissipated by the termination resistors.

The power calculation formulas are based on the simplified model, which represents the signal at the probe inputs. (See Figure 4 on page 6.) If a signal source with 50 Ω source impedances is used, the signal levels used should match the zero-ohm source impedance model shown in the figure.



$$\text{DC power} = \left[\frac{V_{CM} - V_T}{50}\right](V_{CM} - V_T) \text{ per side}$$

$$\text{AC power} = \left[\frac{V_{DM(p-p)}}{100}\right]\left[\frac{V_{DM(p-p)}}{2}\right] \text{ per side}$$

The signal source model defined for these equations is as follows:

$$V_+ \, and \, V_- = \text{Single} - \text{ended signals into a } 50\,\Omega \text{ load}$$

$$V_+ = V_{CM} + V_{DM} \quad V_- = V_{CM} - V_{DM}$$

This results in the terms to be used in the preceding power equations:

$$V_{CM} = (V_+ + V_-) \div 2 \qquad V_{DM} = (V_+ - V_-) \div 2$$

$$\mathrm{V_T} = \text{Termination input voltage}$$

***NOTE.** With a balanced DC signal, in the preceding equations, V_{DM} is half of the value of a conventional differential signal.*

$$V_{Diff} = V_+ - V_- = 2V_{DM}$$

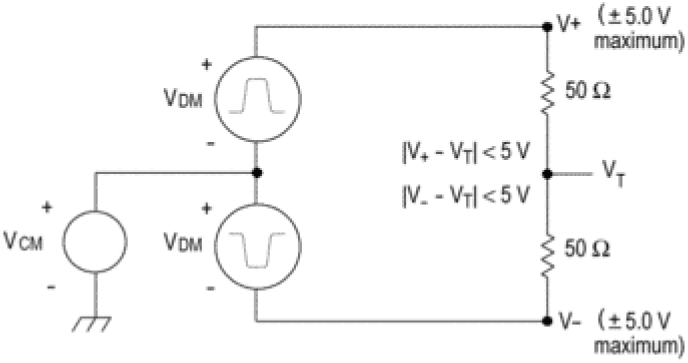


Figure 4: Probe maximum input limits

Common-Mode Signal Range. The common-mode signal range is the maximum voltage that you can apply to each input, with respect to earth ground, without saturating the input circuitry of the probe. A common-mode voltage that exceeds the common-mode signal range may produce an erroneous output waveform even when the differential-mode specification is met. The common-mode signal range shown in the figure assumes that an allowable termination voltage is used. (See Figure 5.)Refer also to *Overdrive Error*for more detail. (See page 9, *Overdrive Error*.)

Differential-Mode Signal Range. The differential-mode signal range is the maximum voltage difference between the plus and minus inputs that the probe can accept without distorting the signal. The distortion from a voltage that is too large can result in a clipped or otherwise distorted and inaccurate measurement. The differential mode signal range is dependent on the probe attenuator setting as shown. (See Figure 5.)The single-ended signal measurement range is shown later in this section. (See Table 2 on page 15.)

For a more detailed description of the differential mode dynamic range, see *Differential Measurement Topology*.

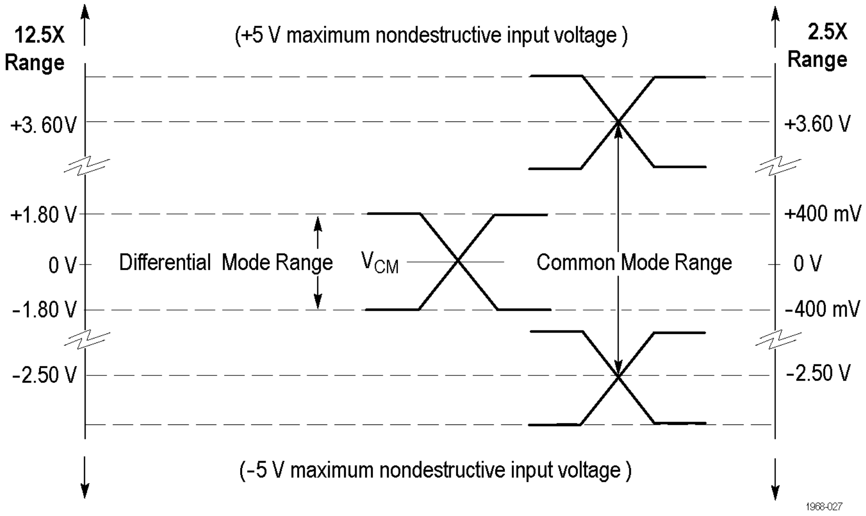


Figure 5: Differential and Common-Mode operating ranges for a complementary differential signal

Common-Mode Rejection. The common-mode rejection ratio (CMRR) is the ability of a probe to reject signals that are common to both inputs. More precisely, CMRR is the ratio of the differential-mode gain to the common-mode gain. The higher the ratio, the greater the ability to reject common-mode signals.

Probe Amplifier Outputs. The P7313SMA probe has a differential signal output. The positive polarity output is connected to the oscilloscope through the TekConnect probe interface. The inverted polarity output is connected to the Aux Output SMA connector on the top of the probe.

The positive polarity main output is automatically scaled by the intelligent TekConnect probe interface to compensate for probe attenuation and display the differential signal voltage at the probe inputs. The inverted Aux Output is an attenuated version of the differential signal input, which must be manually accounted for in signal measurements or processing.

Termination Voltage Control

The P7313SMA probe termination voltage can be controlled either internally or externally, as selected by three different modes. A block diagram of the probe termination network is shown. (See Figure 6.) A discussion of the circuitry follows.

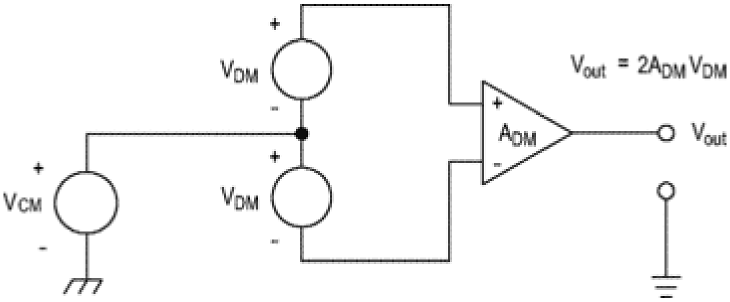


Figure 6: Termination voltage network drive

The P7313SMA probe is designed for compliance testing of high-speed, serial data standards such as PCI Express, InfiniBand, SerialATA, XAUI, Gigabit Ethernet, Fibre Channel, and others. All of these high-speed, differential data standards define a common-mode voltage less than the +3.6 V/–2.5 V termination range of the P7313SMA probe.

The probe termination voltage can be set to the desired input signal common-mode voltage using one of three control modes: Auto (the default mode at power-on), Internal, and External. The operation of these modes are described below.

Auto Mode

When the probe is first connected to the oscilloscope, a self test runs, and the default termination voltage control mode is set to Auto. When the probe is in Auto mode, the common-mode voltage of the input signal is monitored, and the DC termination voltage is set to match the common-mode input voltage. Auto mode provides the minimum DC loading on the input signal source.

With open inputs or a high DC source impedance, such as an AC-coupled input signal, the Auto mode select LED flashes, indicating that the termination voltage has been set to zero volts.

This mode can be useful when you do not know the common-mode voltage of the measured input signal. The termination voltage set by the Auto Mode generator can be checked by measuring the voltage at the termination voltage monitor jacks.

Internal (Int) Mode

The internal mode allows you to set the termination voltage with user controls that are available on some TekConnect-interface oscilloscopes. You can adjust the DC termination voltage within the +3.6 V/–2.5 V range. See your oscilloscope manual for details on using this mode.

External (Ext) Mode

When the probe is in external mode, it allows control of the DC termination voltage with an external power supply. You can adjust the DC termination voltage within the +3.6 V/–2.5 V termination voltage range of the probe.

The external DC termination voltage control input is buffered by an internal amplifier with 100 K Ω input impedance.

WARNING. *Do not exceed the ±15 V maximum external mode voltage for the probe. Excess voltage will damage the probe.*

In Ext mode, the external DC voltage is connected to the red (+) and black (-) terminals on the end of the probe head, which accept standard 80 mm plugs. A pair of 0.080 in-to-banana plug adapter cables are included with the probe for making connections from these connectors to external power sources. The black terminal is ground and is connected to the outer case of the shielded module that holds the SMA input terminals. When you are not using these terminals, they can be left open and unconnected. When the Ext mode input terminals are left open, the Ext mode termination voltage defaults to 0.0 V.

The termination voltage supplied to the input termination network by the Vterm driver can be monitored with a DMM on a pair of 0.040 inch pin jacks on the top of the probe. This allows you to verify the termination voltage setting, and when you are using Auto mode, allows you to measure the common-mode input voltage.

You can use a pair of 0.040 inch-to-0.080 inch pin jack adapters with the 0.080 inch-to-banana plug cables (both are standard accessories included with your probe), to make a more permanent connection to the monitoring DMM.

Overdrive Error

The P7313SMA differential probe can measure signals that have a common-mode voltage range of +3.6V/–2.5 V. Although the termination voltage range is specified to be +3.6 V/–2.5 V, limitations on the linear current range of the termination voltage driver restrict the voltage difference between V_{CM} and V_T.

Generally, you must keep the termination voltage within about 2 volts of the common-mode voltage (when using a supply with 0 Ω source impedance), or 3 volts of the common-mode voltage (with a 50 Ω source impedance), or the Overdrive Error LED will glow solid, indicating an over-current situation, which may lead to a measurement error.

The specific voltage difference between V_{CM} and V_T is dependent on both the source impedance and the V_{CM} and V_T values. You can use the input termination network table to determine allowable conditions, with the Overdrive Error current threshold for I_T set at about ±80 mA. (See Table 1 on page 5.)

The Overdrive Error LED will also flash red when the termination voltage exceeds the allowable +3.6 V/–2.5 volt range. This can occur in Auto mode when V_{CM} exceeds a threshold of about ±2.8 V, or in Ext mode when the V_T input voltage exceeds the same threshold. If this occurs, remove all signal sources from the probe to clear this LED.

The Overdrive Error LED provides an active status monitor of error conditions; it does not latch and store the occurrence of an error condition.

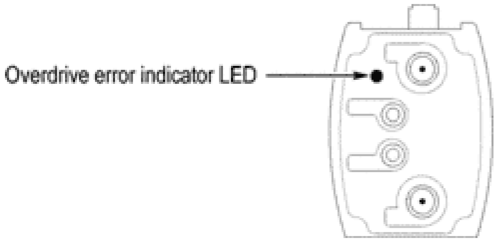


Figure 7: Overdrive Error indicator

Differential and Single-Ended Signal Measurement

Although designed for differential signal measurement, the P7313SMA probe can be used to make single-ended measurements when properly configured. The analysis that follows describes some differential and single-ended measurements of typical high-speed serial data signals.

Differential Measurement Topology

A typical differential measurement topology using the P7313SMA probe is shown. (See Figure 8.) The termination network for the probe in this figure includes a termination capacitor. This is intended to show that the termination network provides a broadband AC ground for common-mode signals.

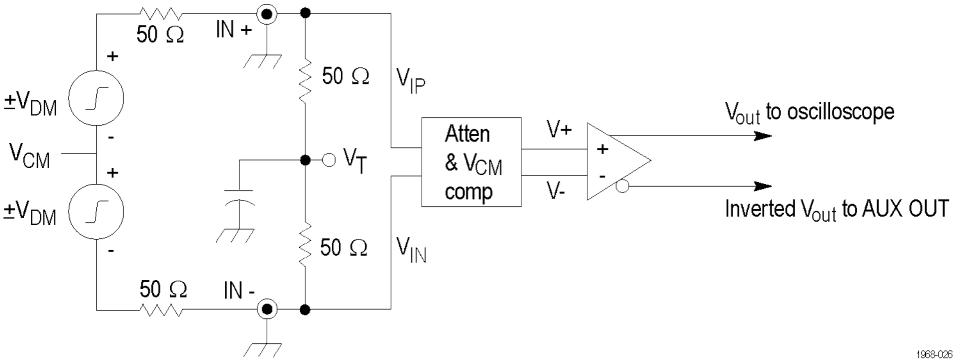


Figure 8: Differential measurement topology

Although an ideal differential signal is theoretically terminated at the V_T node due to symmetry, the low impedance V_T node terminates any non-ideal, AC common-mode signal components. The input signal source model includes a common-mode component, V_{CM}, and complementary differential mode components, $\pm V_{DM}$.

The differential mode signal source models have double the signal amplitude of the measured signal at each input because of the 50 Ω voltage divider between the source and termination resistance. The common-mode signal source model does not have double the signal source amplitude because most serial data transmitters are designed to drive a load resistance terminated with the DC common-mode voltage, not signal ground.

With V_T set equal to V_{CM} in this model topology, the DC common-mode voltage at each probe input should equal V_{CM}. The resulting differential signals at the probe inputs are:

$$V_{IP} = V_{CM} + V_{DM} \quad V_{IN} = V_{CM} - V_{DM}$$

The attenuator and V_{CM} compensation network that follows the termination network nulls out the V_{CM} signal and attenuates the V_{DM} signals. The resulting differential signals at the probe amplifier inputs for a 2.5X attenuation setting are:

$$V_+ = 0.4V_{DM} \quad V_- = -0.4V_{DM}$$

The resulting signals from the probe outputs are:

$$V_{Out} = 0.8V_{DM} \quad V_{AuxOut} = -0.8V_{DM}$$

The inverted polarity of the probe amplifier output can be verified by examining the probe Aux Output signal. The normal polarity, main probe output signal is routed through the TekConnect interface connector and is automatically scaled to show the correct differential amplitude at the probe input connectors.

Differential Dynamic Range

The V_{CM} compensation circuit in the probe attenuator is designed to maximize the dynamic range of the AC component of the input signal. For most high-speed serial data signals, the AC component of the signal is of most interest for compliance testing where an eye pattern display of the differential signal is checked for timing jitter and voltage amplitude and fidelity.

The DC common-mode component of the input signal is present primarily to bias the signal into the operating range of the receiver and may even be removed in the transmission path with AC coupling. The V_{CM} compensation circuit in the P7313SMA probe is designed to null out the DC common-mode component of the input signal, V_{CM}, so that only the differential mode component of the input signal is passed through to the probe amplifier inputs.

The V_{CM} compensation circuit allows the dynamic range of the probe to be specified as a differential peak-to-peak voltage with a separate DC common-mode range. The differential peak-to-peak voltage specification is different for the two probe attenuation settings, but the DC common-mode range is the same for both attenuation settings. Note that the allowable DC common-mode range may be restricted by the termination voltage setting as described in the *Overdrive Error* section. (See page 9, *Overdrive Error*.)

The DC common-mode range of the probe is actually describing the performance of the V_{CM} compensation circuit, rather than the dynamic range of the probe amplifier. The dynamic range of the probe has been specified as a differential peak-to-peak voltage because that best represents the way in which the signal is typically displayed and specified for compliance testing.

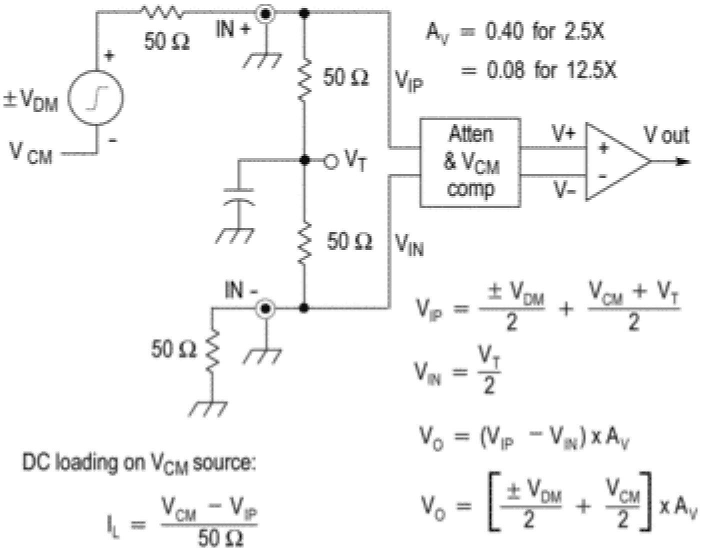
Single-Ended Measurement Topology

Although the P7313SMA differential probe can be used to make single-ended measurements, it is important to understand the impact of the termination network on the measured response, particularly on the DC common-mode component of the signal.

Because of the limited dynamic range of the probe amplifier, single-ended measurements, which also display the DC common-mode component of the signal, must be carefully checked for possible overdrive problems. The single-ended measurement topology can also affect the performance of Auto mode, which will only function properly with a matched source impedance configuration.

Three possible single-ended measurement topologies will be examined in this section. They differ in the termination used on the (-) input of the probe when the single-ended signal is connected to the (+) input.

50 Ohm Termination on (-) Input. A single-ended measurement topology with a 50 Ω termination on the probe (-) input is shown. (See Figure 9.) The general equations that describe the response of that topology are also shown, including DC loading on the signal source.



$$A_V = 0.40 \text{ for } 2.5X$$

$$= 0.08 \text{ for } 12.5X$$

$$V_{IP} = \frac{\pm V_{DM}}{2} + \frac{V_{CM} + V_T}{2}$$

$$V_{IN} = \frac{V_T}{2}$$

$$V_O = (V_{IP} - V_{IN}) \times A_V$$

$$V_O = \left[\frac{\pm V_{DM}}{2} + \frac{V_{CM}}{2}\right] \times A_V$$

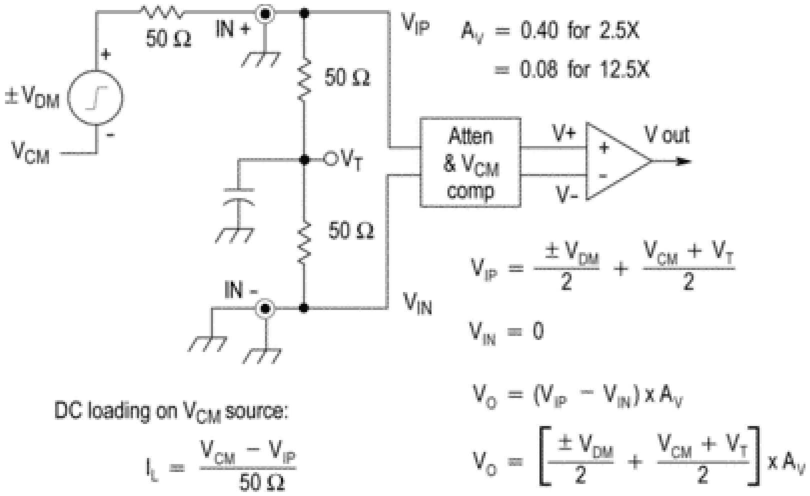
$$I_L = \frac{V_{CM} - V_{IP}}{50\ \Omega}$$

Figure 9: 50 ohm termination on (-) input

The equations for this topology show that varying the termination voltage, V_T, affects the DC loading on the signal source, but does not affect the measured DC voltage. The measured, single-ended DC voltage also represents only half the common-mode input voltage, V_{CM}, because of the voltage divider network formed by the four 50 Ω resistors and the differential amplifier response.

Although the 50 Ω termination resistors have been laser trimmed for guaranteed performance, it should be noted that the precision of the signal measurement in this topology is affected by the signal source impedance and the impedance of the 50 Ω termination resistor inside the probe positive input connector. This matched source impedance topology is the only single-ended topology that can be correctly used with Auto mode.

Shorting Termination on (-) Input. An alternative single-ended measurement topology with a shorting termination on the (-) input is shown. (See Figure 10.) The general equations describing the response and loading of this topology are also shown. The equations for this topology show identical loading of the signal source when compared to the 50 Ω termination topology. This is because the termination voltage, V_T, effectively isolates input signal loading from the termination on the probe negative input.



$$A_V = 0.40 \text{ for } 2.5X$$
$$= 0.08 \text{ for } 12.5X$$

$$V_{IP} = \frac{\pm V_{DM}}{2} + \frac{V_{CM} + V_T}{2}$$

$$V_{IN} = 0$$

$$V_O = (V_{IP} - V_{IN}) \times A_V$$

$$V_O = \left[\frac{\pm V_{DM}}{2} + \frac{V_{CM} + V_T}{2}\right] \times A_V$$

DC loading on V_{CM} source:

$$I_L = \frac{V_{CM} - V_{IP}}{50\ \Omega}$$

Figure 10: Shorting termination on (-) input

The measured single-ended signal response for this topology differs from the 50 Ω termination topology. The measured AC voltage, V_{DM}, is the same for both single-ended topologies, but the measured DC voltage is affected by both the common-mode input voltage, V_{CM}, and the termination voltage, V_T.

In the special case where the termination voltage is set equal to the common-mode input voltage, the input signal DC loading is minimized and the measured DC output voltage equals the full common-mode input voltage, scaled by the probe attenuation. The intelligent TekConnect probe interface automatically accounts for the probe attenuation setting and a TekConnect oscilloscope will display the full single-ended input signal when V_T equals $V_{CM.}$

Although this topology displays the correct DC common-mode voltage, it also has a greater risk of exceeding the probe dynamic range and overdriving the probe amplifier.

Open (-) Input. Another alternative single-ended measurement topology is shown. (See Figure 11.) In this case, the (-) input is left open, effectively keeping it at the V_T voltage level. The general equations describing the response and loading of this topology are also shown.

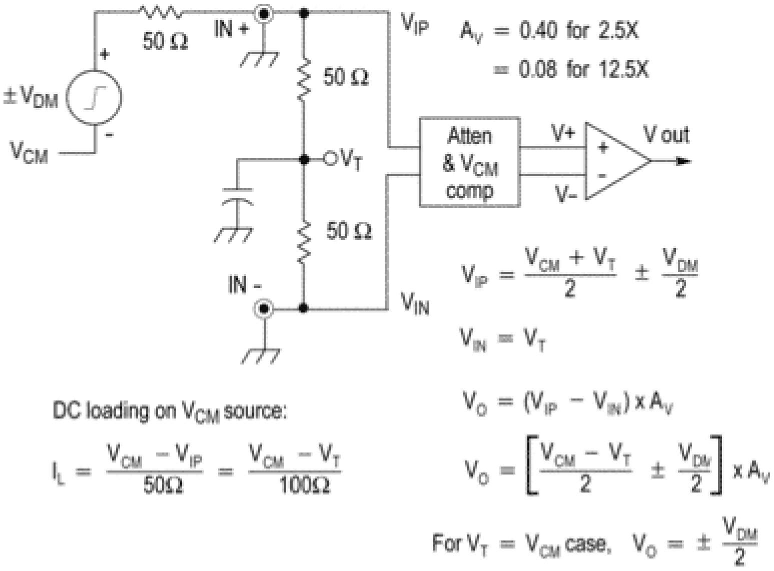


Figure 11: Open (-) input

The measured single-ended response for this topology has the same AC voltage, V_{DM}, as the other topologies, but has a common-mode voltage term that is proportional to the difference between V_{CM} and the termination voltage, V_T. In the special but common case, where $V_T = V_{CM}$, only the AC component is displayed, somewhat like an AC-coupled condition.

For the case where $V_T = V_{CM}$, this topology provides the best probe dynamic range, since the DC component of the signal is nulled out. This is probably the best single-ended measurement topology where DC common-mode voltage information is known or can be measured independently.

Single-Ended Dynamic Range

The dynamic range of the probe has been specified for differential measurements, as described in the differential measurement topology section. When single-ended measurements are made, the input common-mode voltage may no longer be nulled out, but becomes a differential mode DC signal that must be within the input dynamic range of the probe to be measured accurately. Since the P7313SMA probe does not have an offset voltage control, like most high impedance differential probes, any common-mode voltage present at the probe amplifier inputs limits the available dynamic range.

The specified dynamic range for differential signals, which is expressed as a differential peak-to-peak voltage, can be converted to a more conventional voltage range for single-ended signal measurements as shown. (See Table 2.)

Table 2: Differential to single-ended conversion table

Attenuation	Differential measurement dynamic range	Single-ended measurement dynamic range
2.5X	800 mVp-p	±0.400 V
12.5X	3.6 Vp-p	±1.8 V

Because the common-mode DC voltage of many serial data signals is larger than the signal differential mode voltage, the relatively small single-ended dynamic range in the 2.5X attenuation setting may not be adequate. As a result, single-ended measurements will generally be made using the 12.5X attenuation setting, unless the open (–) input topology is used and the termination voltage is set to null out the input signal DC common-mode voltage.

In the case where single-ended measurements are made on signals with a large common-mode DC voltage, it should be noted that the use of the 50 Ω termination topology effectively attenuates the DC common-mode voltage by half. If this is taken into account as an offset to the displayed signal, it allows single-ended signals with a relatively large DC common-mode voltage to be measured.

If only the AC component of the single-ended signal needs to be measured, then the open input topology provides the greatest dynamic range.

Although it is possible to attenuate an input signal with external attenuators to increase the effective dynamic range, care should be taken to account for the signal loading and the impact on the termination voltage of the probe.

If an external attenuator is used, its attenuation accuracy must be taken into account when factoring the impact on measurement accuracy. Both signal gain accuracy and CMRR can be degraded with poorly matched external attenuators. The increase in attenuation also brings an increase in noise.

Single-Ended Measurement Example

HDMI (High Definition Multimedia Interface) is an example of a serial data signal that can be measured with the single-ended range of the P7313SMA probe. The HDMI physical-layer standard specifies a complementary differential signal that is transmitted on a pair of 50 Ω transmission lines and is terminated at the receiver with 50 Ω resistors pulled up to 3.3 V. A P7313SMA probe can be used to terminate an HDMI signal by setting the probe termination voltage to 3.3 V.

When making single-ended measurements of an HDMI signal, the best measurement topology will generally be the open (-) input topology. (See Figure 11 on page 14.) With an open (-) input on the probe, the DC termination voltage will largely be nulled out by the probe CMRR. This maximizes the dynamic range available for measuring the HDMI digital signal. Depending on the HDMI signal amplitude and whether the measurement is made on a full size transmitted signal or attenuated by cable loss, the P7313SMA probe attenuation setting may need to be set to 12.5X, rather than the less noisy 2.5X setting.

An HDMI signal may also be measured using the single-ended measurement topology with a 50 Ω termination on the probe (-) input. (See Figure 9 on page 12.) Using this topology, the HDMI signal will be attenuated to half size, both the DC termination voltage and the HDMI switching signal. With this topology, the P7313SMA probe must be set to the 12.5X setting to provide sufficient single-ended measurement dynamic range. There is not enough dynamic range available with the P7313SMA probe to make single-ended HDMI measurements with the shorting termination on (-) input topology.

Extending the Input Connections

At times it may be necessary to extend the probe inputs with cables that are longer than the standard 38 inch cables. The 38 inch cables are precision-matched to minimize time-delay differences (skew).

If you substitute cables, you should use low-loss, flexible cables and keep the lengths matched and as short as possible to minimize skew and optimize common-mode rejection. Check the skew between the cables, and if necessary, use a pair of phase adjusters to minimize the skew.

Extending the input leads will also increase the skin loss and dielectric loss, which may result in distorted high-frequency pulse edges. You must take into account any effects caused by the extended leads when you take a measurement.

Checking Cable Skew

The time-delay difference (skew) between the ends of the matched-delay SMA cable pair supplied with the probe is typically less than 1 ps. If you use a pair of matched, high-quality, low-loss cables other than those supplied with the probe, you can bring the skew to within 1 ps by using a pair of phase adjusters. (See page 47, *Optional Accessories*.)

You can measure the skew of a pair of matched cables by connecting the cables to a Tektronix 80E08 or 80E10 Sampling Head, configured for a TDR output. (See Figure 12.)

1. Turn on the equipment and let it warm up for 20 minutes. Do not connect the cables to the sampling head yet.
2. Do a system compensation for the TDR module, and then verify the skew of the two outputs with the TDR outputs open, using a common-mode TDR drive.

Skew between the two outputs can be compensated with the TDR module deskew control. Refer to your sampling head or oscilloscope manual for instructions.

3. Connect the matched cable pair to the TDR outputs.

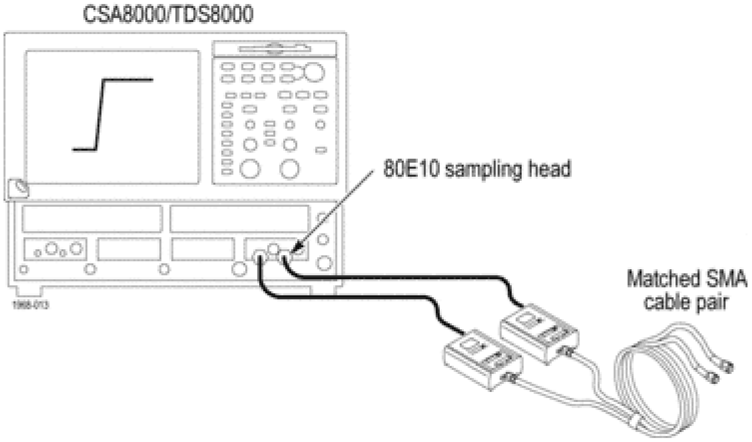


Figure 12: Checking skew between inputs

4. The measured skew of the matched cable pair that are supplied with the probe should be less than 1 ps. User-supplied cables may not be nearly as accurate, and may require some trial-and-error testing to select an optimally-matched pair. Adjust the horizontal scale to locate the pulse (to account for the cable delay; it is approximately 4.5 ns for the cable set supplied with the probe). If you use the system cursors, be aware that the displayed time is the round-trip time (step and reflection). You need to divide the displayed time difference by 2 to derive the actual skew.

If you need to minimize the skew of a pair of cables not supplied with the probe, continue with *Adjusting Cable Skew*. (See page 18, *Adjusting Cable Skew*.)

Adjusting Cable Skew

If you want to minimize the skew introduced by cable pairs other than those supplied with the probe, you can use a pair of phase adjusters to bring the skew to within 1 ps. (See page 47, *Optional Accessories*.) The phase adjusters have male and female SMA connectors to simplify connections to your measurement system.

You must add a phase adjuster on each cable to balance the delay and insertion loss introduced by the phase adjuster. You only adjust (add delay to) the phase adjuster on the cable with the shorter delay.

The adjustment range of the phase adjusters on the Optional Accessories list is 25 ps, so if you use cable pairs other than those supplied with the probe, the initial delay mismatch should be less than 25 ps.

1. Connect the phase adjusters to the cables.
2. On the cable with the longer delay, loosen the phase adjuster locking nuts, set the phase adjuster to minimum delay (shortest length), and secure the locking nuts. (See Figure 13.)

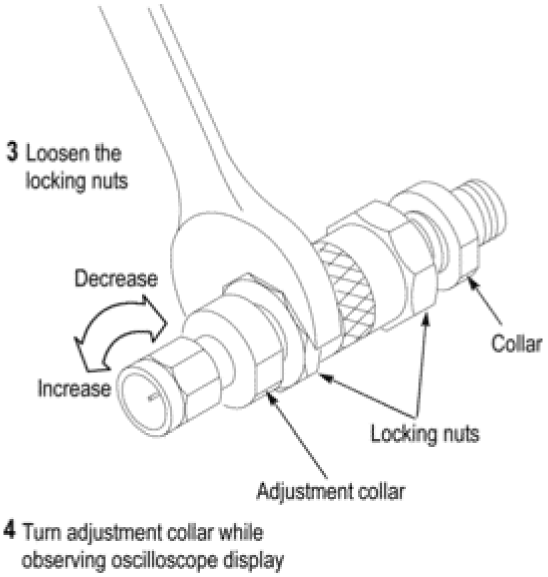


Figure 13: Using the phase adjuster

3. Loosen the locking nuts on the adjuster that is connected to the other cable (with the shorter delay).
4. While observing the oscilloscope display, turn the collar on the phase adjuster counterclockwise to increase the delay.
5. When the displayed skew on screen is less than 1 ps, tighten the locking nuts.
6. Confirm that the skew is acceptable after you tighten the locking nuts, as the adjustment may change slightly during tightening.
7. Disconnect the cables from the sampling head, and connect them to the P7313SMA probe head.

Deskewing Probes

You can measure the skew between two P7313SMA probes by using a Tektronix 80E10 Sampling Head configured for a TDR output. Because the skew of the P7313SMA probe inputs is less than 1 ps, two P7313SMA probes can be deskewed using single-ended drive signals from a dual-channel TDR source. The TDR output provides a pair of time-aligned pulses that you can use to compare probe response times, and if necessary, adjust them to match (deskew).

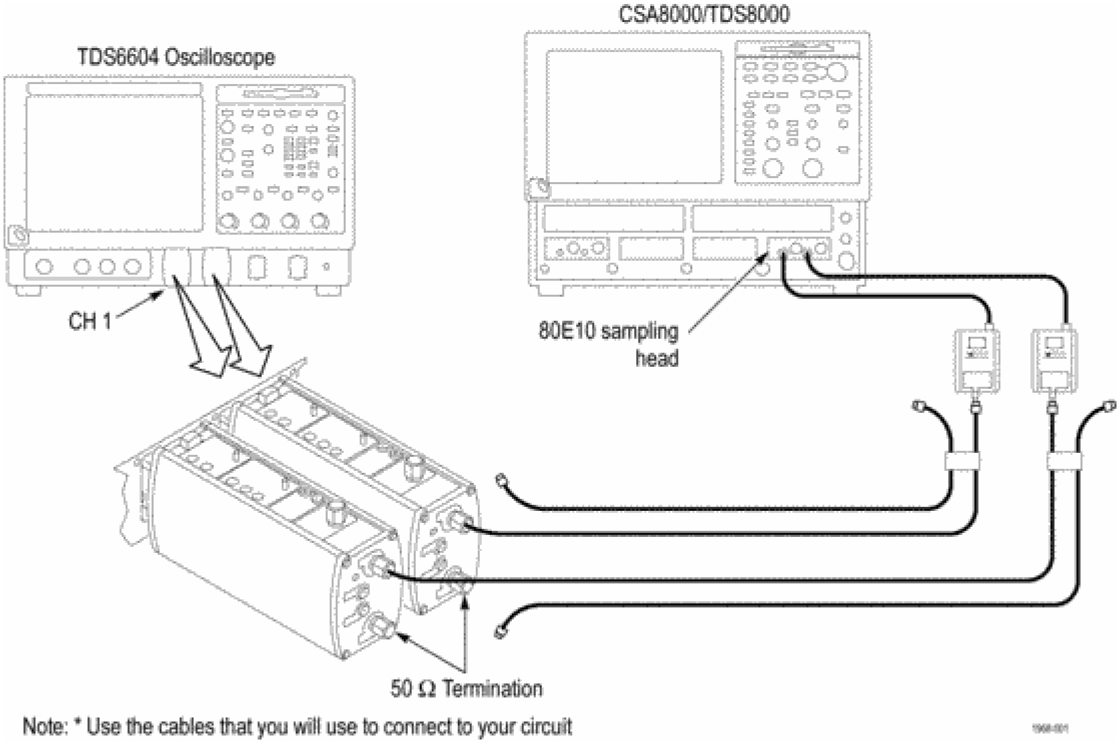
A setup is shown for checking and deskewing two probes. (See Figure 14.) Deskewing aligns the time delay of the signal path through the oscilloscope channel and probe connected to that channel, to the time delay of other channel/probe pairs of the oscilloscope.

If you need to deskew more than two probes, keep one deskewed probe connected to the sampling head as a reference (after deskewing two probes), and deskew additional probes to that probe. In this procedure, Channel 1 is used as the reference channel.

1. Set up the equipment and let it warm up for 20 minutes, but don't make any connections to the TDR outputs yet.
2. Do a system compensation for the TDR module, and then verify the skew of the two outputs with the TDR outputs open, using a common-mode TDR drive.

Skew between the two outputs can be compensated with the deskew control. Refer to your sampling head or oscilloscope manual for instructions.

3. Attach the probes to the TDR outputs. (See Figure 14.)



Note: * Use the cables that you will use to connect to your circuit

Figure 14: Deskewing two P7313SMA probes

4. Display the channel(s) that you want to deskew.
5. Push the **AUTOSET** button on the instrument front panel.

6. Turn averaging on to stabilize the display.
7. Adjust vertical **SCALE**, and **POSITION** (with active probes, adjusting **offset** may be required) for each channel so that the signals overlap and are centered on-screen.
8. Adjust horizontal **POSITION** so that a triggered rising edge is at center screen.
9. Adjust horizontal **SCALE** so that the differences in the channel delays are clearly visible.
10. Adjust horizontal **POSITION** again so that the rising edge of the Channel 1 signal is exactly at center screen. Now, if you want to, you can use the measurement cursors to display the channel-channel skew, and enter this value in step 14.
11. Touch the **VERT** button or use the **Vertical** menu to display the vertical control window.
12. Touch the Probe **Deskew** button to display the channel-deskew control window.
13. In the **Channel** box, select the channel that you want to deskew to Channel 1.

NOTE. *If possible, do the next step at a signal amplitude within the same attenuator range (vertical scale) as your planned signal measurements. Any change to the vertical scale after deskew is complete may introduce a new attenuation level (you can generally hear attenuator settings change) and, therefore, a slightly different signal path. This different path may cause up to a 200 ps variation in timing accuracy between channels.*

---

14. Adjust the deskew time for the signal that you want to deskew so that the signal aligns with the Channel 1 signal. You can do this several ways:

- Click the **Deskew** field and input the time value you measured with the cursors in step 10.
- Use the front-panel controls to position the signal.
- Use the on-screen controls to position the signal.

15. Repeat steps 3 through 14 for each additional channel that you want to deskew.

Reference

This section contains reference information about communication standards and related differential measurements.

Serial Bus Standards

Some popular high-speed data communication standards that can be measured with the P7313SMA differential probe are listed below. (See Table 3.)

Table 3: Serial bus standards with dynamic range requirements

Standard Data Rate	Vdm_max	Vdm_min	Vcm_max	Vcm_min
HDMI 1.65 Gb/s	800 mV	150 mV	3.3 V	2.8 V
InfiniBand TX 2.5 Gb/s	1.6 V	1.0 V	1.0 V	0.5 V
InfiniBand RX 2.5 Gb/s	1.6 V	0.175 V	1.0 V	0.5 V
PCI Express TX 2.5 Gb/s	1.2 V	0.8 V	AC	AC
PCI Express RX 2.5 Gb/s	1.2 V	0.175 V	AC	AC
Serial ATA TX 1.5 Gb/s	0.6 V	0.4 V	0.3 V	0.2 V
Serial ATA RX 1.5 Gb/s	0.6 V	0.325 V	0.3 V	0.2 V
XAUI TX 3.125 Gb/s		0.4 V		
XAUI RX 3.125 Gb/s		0.1 V		
OIF-SxI-5 TX 3.125 Gb/s	1.0 V	0.5 V	1.23 V	0.72 V
OIF-SxI-5 RX 3.125 Gb/s	1.0 V	0.175 V	1.30 V	1.10 V
LV PECL (stdECL) >12GHz	1.66 V (typ)	1.48 V	1.3 V (vt)	0.5 V (vt)
LV PECL (RSECL) >12GHz	1.05 V	0.70 V	1.3 V (vt)	0.5 V (vt)

InfiniBand

A number of high-speed serial data communication standards have been introduced to address the need for next generation I/O connectivity. One of these interface standards, InfiniBand, is briefly discussed here. (See Figure 15.)

An InfiniBand communication lane includes two independent differential signaling paths, one for transmit and one for receive, both operating at a 2.5 Gb/s rate. As shown in the example below, the differential output parameter is specified as a peak-to-peak voltage difference, and thus the signal swing on each pin of the driver is half that value.

The V_{diff} signal shown in (b) is measured with a differential probe connected between the two signals in (a). The V_{diff} signal represents the result of the receiver processing the two complementary input signals from the driver shown in (a), and cannot be measured directly as a single-ended signal.

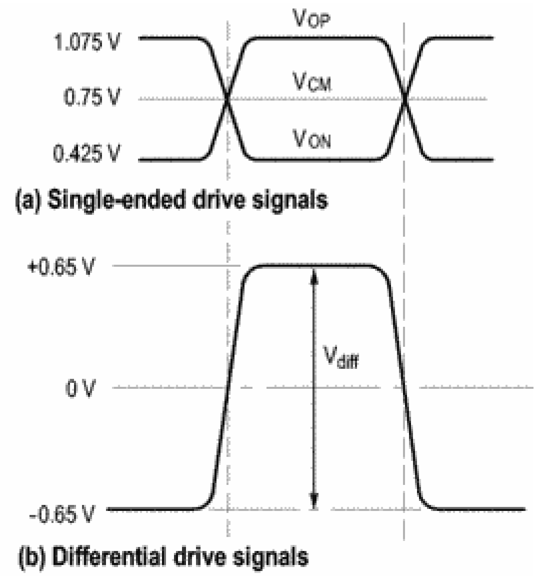


Figure 15: InfiniBand signals

Specifications

The specifications in the following tables apply to a P7313SMA probe installed on a TDS6804 oscilloscope. The probe must have a warm-up period of at least 20 minutes and be in an environment that does not exceed the limits described. (See Table 4.) Specifications for the P7313SMA differential probe fall into three categories: warranted, typical, and nominal characteristics.

Warranted Characteristics

Warranted characteristics describe guaranteed performance within tolerance limits or certain type-tested requirements. (See Table 4.) Warranted characteristics that have checks in the *Performance Verification* section are marked with the ✓ symbol.

Table 4: Warranted electrical characteristics

Characteristic	Description
✓ Differential rise time, 10-90% (probe only) (Main output)	≤40 ps, +20 °C to +30 °C (+68 °F to +86 °F), 100 mV differential step in 2.5X attenuation 500 mV differential step in 12.5X attenuation
Differential signal range	0.800 Vp-p (2.5X attenuation) 3.6 Vp-p (12.5X attenuation)
✓ DC gain (Main output)	0.40 ±2.0% (corresponds to 2.5 X attenuation) 0.08 ±2.0% (corresponds to 12.5 X attenuation)
Termination voltage range	+3.6 V /-2.5 V
✓ Termination voltage accuracy	
(EXT mode)	±(0.2% x V_T +2 mV) over a +3.6 V/–2.5 volt V_T range
(INT mode)	±(0.3% x V_T + 2 mV) over a +3.6 V/–2.5 volt V_T range
(AUTO mode)	±(2.5% x V_{CM} + 20 mV) over a +3.6 V/–2.5 volt V_{CM} range
Linearity	±1% or less of dynamic range
✓ Output offset voltage (Main output) V_{CM} = 0 V, V_{DM} = 0 V, V_T = 0 V	±2.5 mV +20 °C to +30 °C (+68 °F to +86 °F)
✓ Differential-mode input resistance	100 Ω ±2%
Maximum nondestructive input voltage V_T= 0 V, applied <5 minutes	±5 V (DC + peak AC) on either SMA input
Maximum nondestructive external termination input voltage	±15 VDC
Temperature	Operating: 0 to +40 °C (+32 to +104 °F) Nonoperating: -55 to +75 °C (-131 to +167 °F)
Humidity	Operating: 0-90% RH, tested at +30 to +40 °C (+68 to +104 °F) Nonoperating: 0-90% RH, tested at +30 to +60 °C (+68 to +140 °F)

Typical Characteristics

Typical characteristics describe typical but not guaranteed performance. (See Table 5.)

Table 5: Typical electrical characteristics

Characteristic	Description
Differential bandwidth (probe only)	
Main output	DC to 13 GHz (-3 dB)
Aux output	DC to 13 GHz (-6 dB)
Differential rise time, 20-80% (probe only, Main and Aux output)	≤25 ps, +20 °C to +30 °C (+68 °F to +86 °F), 100 mV differential step in 2.5X attenuation 500 mV differential step in 12.5X attenuation
Single-ended rise time, 10-90%, (probe only, Main and Aux output)	≤40 ps, +20 °C to +30 °C (+68 °F to +86 °F), 250 mV step
Differential signal input skew	<1 ps (with matched SMA cable pair)
Differential input return loss	>25 dB @DC to 5 GHz (VSWR <1.12:1) >20 dB @5 GHz to 10 GHz (VSWR <1.22:1) >12 dB @10 GHz to 13 GHz (VSWR <1.67:1)
Termination voltage driver current	±(82.5 mA ±8 mA) overload
Common-mode DC input signal range	+3.6 V/–2.5 V
Common-mode input return loss	>25 dB @DC to 5 GHz (VSWR <1.12:1) >20 dB @5 GHz to 10 GHz (VSWR <1.22:1) >12 dB @10 GHz to 13 GHz (VSWR <1.67:1)
Common-mode rejection ratio (Main output) (See Figure 16 on page 25.)	>45 dB @1 GHz >40 dB @2.5 GHz >30 dB @5 GHz >20 dB @10 GHz >15 dB @13 GHz
Common-mode rejection ratio (Aux output)	>45 dB @1 GHz >40 dB @2.5 GHz >30 dB @5 GHz >20 dB @10 GHz >15 dB @13 GHz
Delay time (includes standard cables)	5.15 ns ±100 ps, relative to a TCA-SMA adapter
Noise, referred to input	13 nV/ √Hz (2.5 X attenuation) 40 nV/ √Hz (12.5 X attenuation)
DC gain (Aux output)	0.40 ±2.5% (corresponds to 2.5 X attenuation) 0.08 ±2.5% (corresponds to 12.5 X attenuation)
Output offset voltage (Aux output)	±15 mV, +20 °C to +30 °C (+68 °F to +86 °F)
Output offset voltage (Main output)	
V_{CM} = 0 V, V_T = ±2.0 V	<±5 mV, +20 °C to +30 °C (+68 °F to +86 °F)
V_{CM} = ±2.5 V, V_T = 0 V	<±5 mV, +20 °C to +30 °C (+68 °F to +86 °F)

Table 5: Typical electrical characteristics (cont.)

Characteristic	Description
DC offset drift	-50 mV/°C or less at output of probe (results in -0.125 mV/°C or less (2.5 X), or -0.625 mV/°C or less (12.5 X) displayed on screen)
DC voltage measurement accuracy (referred to input)	±(2% of input + 8.00 mV + 8.00 mV) (2.5 X) ±(2% of input + 36.00 mV + 36.0 mV) (12.5 X) gain error = ±2% of input voltage output zero offset (referred to input) = ±8.00 mV (2.5 X) ±36.00 mV (12.5 X) linearity error = ±1.0% of: 800 mV dynamic range = 8.00 mV (2.5 X) 3.6 V dynamic range = 36.0 mV (12.5 X)

Typical differential CMRR plot for the probe. (See Figure 16.)

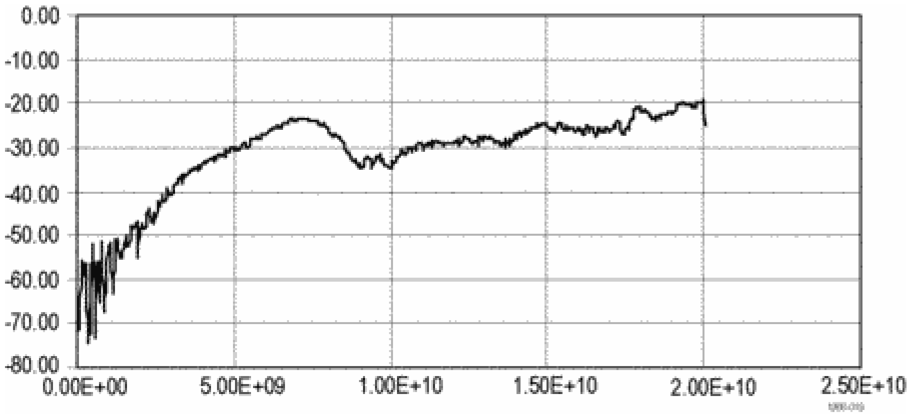


Figure 16: Typical CMRR plot

Typical differential input return loss plot for the probe. (See Figure 17.)

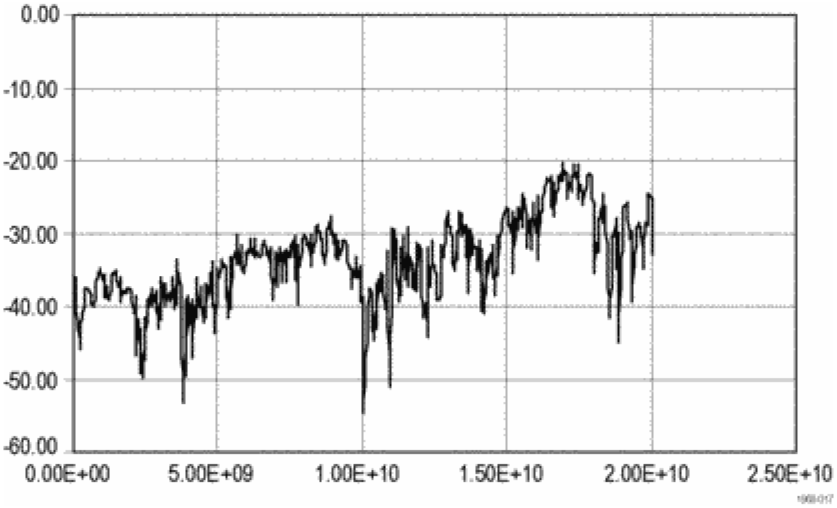


Figure 17: Typical differential input return loss

Typical differential-mode bandwidth plot for the probe. (See Figure 18.)

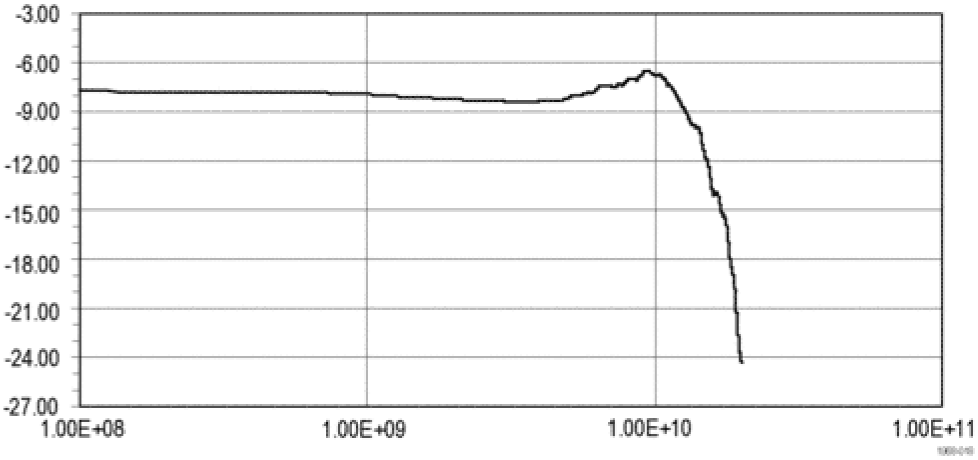
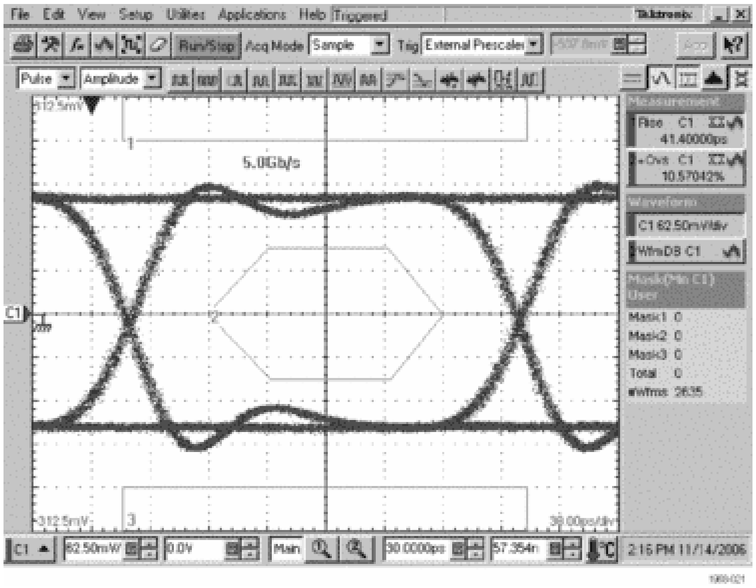


Figure 18: Typical differential-mode bandwidth

Typical eye pattern as measured with the probe. (See Figure 19.)



Acq Mode Sample

Trig External Prescaler

Rise C1 41.40000ps

+Ovs C1 10.57042%

C1 62.50mV/div

WfmDB C1

Mask1 0

Mask2 0

Mask3 0

Total 0

#Wfms 2635

C1 62.50mV/ 0.0V Main 30.0000ps 57.354n

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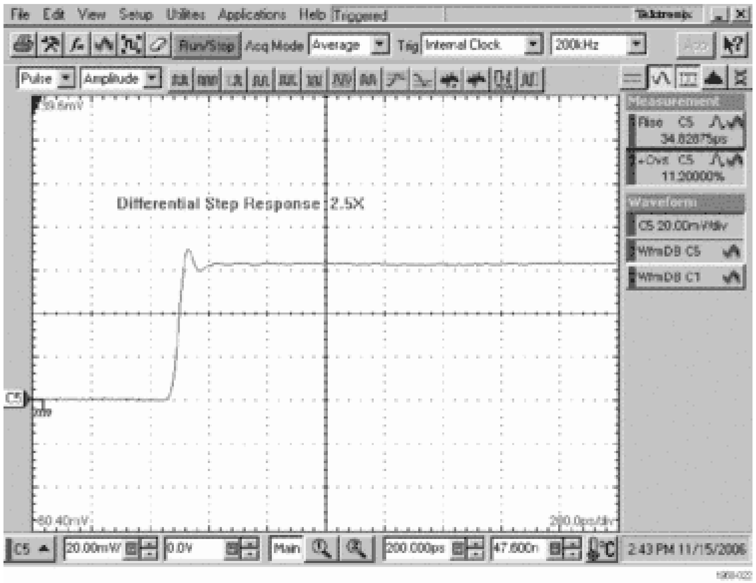
Figure 19: Typical eye pattern

Typical step response as measured with the probe. (See Figure 20.)



Acq Mode Average

Trig Internal Clock

200kHz

Rise C5 34.82875ps

+Ovs C5 11.20000%

C5 20.00mV/div

WfmDB C5

WfmDB C1

C5 20.00mV/ 0.0V Main 200.000ps 47.600n

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Figure 20: Typical differential step response

Nominal Characteristics

Nominal characteristics describe guaranteed traits, but the traits do not have tolerance limits. (See Table 6.)

Table 6: Nominal electrical characteristics

Signal input configuration	Differential (two SMA inputs, + and -)
Input coupling	DC
Attenuation	2.5 X and 12.5 X [1]
Common-mode input resistance	50 Ω ±1% (internally per side)
Termination voltage input configuration	DC (two 0.080 in jacks, + and -)
Termination voltage buffer input resistance	100 KΩ
Termination voltage output monitor	DC (two 0.040 in jacks, + and -)
Termination voltage output monitor resistance	1 KΩ
Output coupling and termination	DC, terminate output into 50 Ω
Auxiliary signal output	SMA output

[1] All TekConnect host instruments recognize this gain setting and adjust the Volts/Div setting to correspond to a normal 1-2-5 sequence of gains.

Mechanical Characteristics

The mechanical characteristics of the probe are listed below. (See Table 7.) The mechanical dimensions are shown. (See Figure 21.)

Table 7: Typical mechanical characteristics

Dimensions	48.0 mm × 31.8 mm ×129.5 mm (1.9 in × 1.3 in × 5.1 in)
Unit weight	230 g (0.51 lb)
Shipping weight (includes shipping materials)	1.38 kg (3.1 lb)
Standard cable assembly length	0.96 m (38 in)

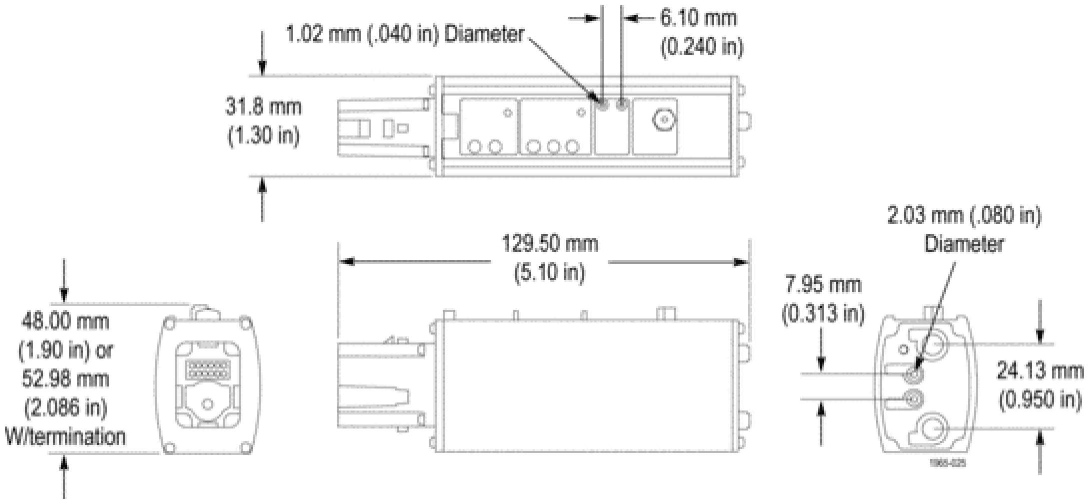


Figure 21: Probe dimensions

Performance Verification

Use the following procedures to verify specifications of the probe. The recommended calibration interval is one year.

These procedures test the following specifications:

- Differential mode input resistance
- Termination voltage accuracy
- Output offset zero
- DC gain accuracy
- Differential mode rise time

Equipment Required

A list of the equipment required to verify the performance of your probe is shown. (See Table 8.)

Table 8: Equipment required for performance verification

Item description	Performance requirement	Recommended example [1]
Oscilloscope	TekConnect interface	Tektronix TDS6804, TDS7704, or DPO70000
Sampling Oscilloscope	Windows 2000 OS, with oscilloscope FW ≥V2.5 (for compatibility with Tektronix 80E08/10 modules)	Tektronix TDS8000
Sampling Module	30 GHz bandwidth	Tektronix 80E08
Sampling Module	20 GHz bandwidth	Tektronix 80E04
TekConnect Probe Interface Module with semi-rigid cable	Firmware version V2.2 or above	Tektronix 80A03, with 174-4857-xx cable
DMM (2), with leads	0.1 mV and 0.01 Ω resolution	Fluke 187 or equivalent
Dual Power Supply	5.0 VDC at 200 mA	B+K Precision 1760A or equivalent
Feedthrough Termination	BNC, 50 Ω ±0.05 Ω	011-0129-00
Attenuators (2)	SMA, 50 Ω, 5X attenuation	015-1002-01
Coaxial cable	Male-to-Male SMA	012-0649-00
Coaxial cable	Dual, matched-delay Male-to-Male SMA	174-4944-00 [2]
Coaxial cable	Male-to-Male BNC, 50 Ω	012-0057-01
Test leads (2)	Banana plug ends, red	012-0031-00
Test leads (2)	Banana plug ends, black	012-0039-00
Test leads	0.080 in pin-to-Banana plug ends, one each color	012-1674-00 (red) [2] 012-1675-00 (black) [2]
Adapter	(See Figure 22 on page 32.)	Tektronix TCA-SMA
Adapters (3)	SMA 50 Ω termination	015-1022-00 [2]
Adapter	SMA Male-to-SMA Male	015-1011-00 [2]
Adapters (2)	0.040 in-to-0.080 in pin jack	012-1676-xx [2]
Adapter	SMA Male-to-BNC Female	015-1018-00
Adapters (2)	BNC Male-to-SMA Female	015-0572-00 [3]
Adapters (3)	BNC Female-to-Dual Banana	103-0090-00
Adapter	BNC T	103-0030-00
Adapter	BNC Female-to-BNC Female	103-0028-00
SMA torque wrench	5/16-in, 7 in-lb.	

[1] Nine-digit part numbers (xxx-xxxx-xx) are Tektronix part numbers.

[2] Standard accessory included with the probe.

[3] One adapter is included with the probe.

Special Adapters Required

Some of the adapters listed in the previous table are available only from Tektronix. These adapters are described on the following pages.

TekConnect-to-SMA Adapter

The TekConnect-to-SMA Adapter, Tektronix part number TCA-SMA, allows signals from an SMA cable or probe to be connected to a TekConnect input. (See Figure 22.) Connect and disconnect the adapter the same way as you do the probe.

This adapter is an oscilloscope accessory that may be used for measurement applications, as well as these performance verification procedures.

Figure 22: TekConnect-to-SMA Adapter

Equipment Setup

The following tests use two oscilloscopes; use this procedure to set up and warm the equipment to test the probe. Wear the antistatic wriststrap when performing these procedures.

1. Connect the 80A03 TekConnect probe interface to channels 3 and 4 of the TDS8000 oscilloscope. (See Figure 23.)
2. Connect the 80E04 module to the 80A03 TekConnect probe interface.
3. Connect the 80E08 module to channels 7 and 8 of the TDS8000 oscilloscope.
4. Connect a 50 Ω termination to the Aux Output connector on the probe, and connect the probe to one of the 80A03 channels.
5. Turn on both oscilloscopes and allow 20 minutes for the equipment to warm up.
6. Photocopy the test record to record the performance test results. (See Table 9 on page 46.)

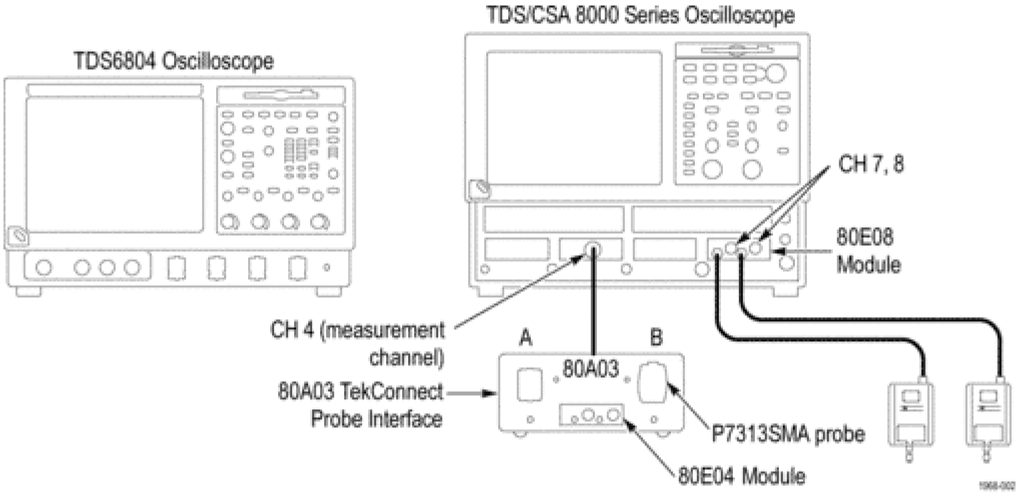


Figure 23: Preliminary test setup

Input Resistance

This test checks the differential mode input resistance (the resistance between each SMA input). The test is performed with the probe disconnected from the oscilloscope.

1. Disconnect the probe from the oscilloscope.
2. Zero the DMM with its measurement leads connected together on the lowest scale that can measure 100 Ω.
3. Remove the SMA terminations from the two probe inputs and gently probe the center contacts of the input connectors. Be careful not to touch the outer edge (ground) of the connector. (See Figure 24.)
4. Measure the resistance and write down the value.
5. Reverse the DMM connections and repeat the measurement. Write down the value.
6. Add the two measurements from steps 4 and 5, and divide the total by two. Record the result in the test record.
7. Connect the probe to the oscilloscope channel that you will use in the next test so that the probe warms up to operating temperature.

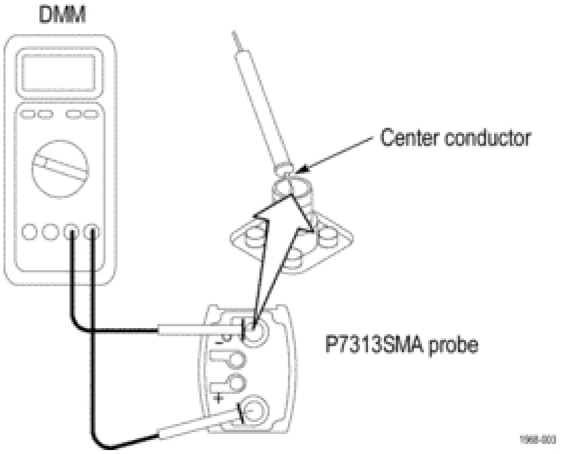


Figure 24: Checking differential mode input resistance

Termination Voltage Accuracy

These tests compare the termination control voltage that you apply (using the adjustment control for that termination voltage mode), to the termination voltage output at the Vterm monitor jacks.

***NOTE.** The Auto mode LED will flash when the probe inputs are open-circuit, or below a 50 mV threshold. If the LED continues to flash after you connect the inputs, cycle the mode SELECT button.*

External (Ext) Mode

The Ext mode test setup is shown. (See Figure 25.)

1. Plug the probe directly into an oscilloscope channel and set the Vterm Source Select to EXT on the probe.

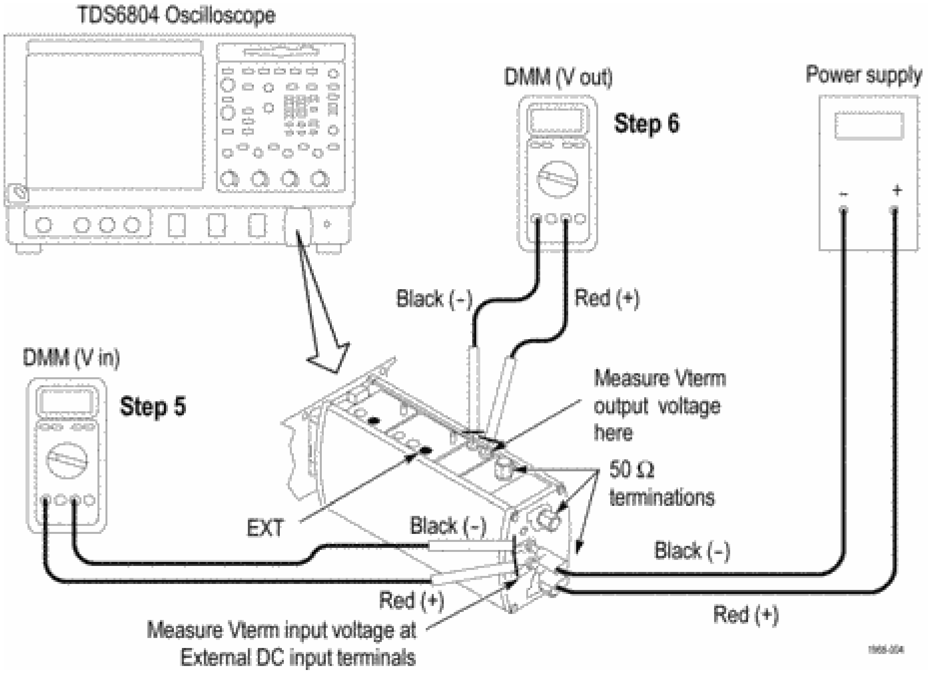


Figure 25: Termination Voltage Accuracy, Ext mode setup

2. Connect the 50 Ω terminations on the three probe SMA connectors. This sets the common mode input voltage to 0.0 V.
3. The probe attenuation can be set to either 2.5X or 12.5X.
4. Using the 0.080 in pin-to-Banana plug cables, connect the power supply to the external DC input jacks on the front of the probe.
5. Set the power supply as close as practical to 0.000 volts, and use the DMM to measure this input voltage at the terminals on the front of the probe. Record this voltage as Vin on the test record.
6. Use the second DMM to measure the output voltage at the termination voltage monitor jacks on the top of the probe. Record this voltage as Vout on the test record, and verify that the Vout voltage is within the specified limits in the min/max columns. For example, within ±2 mV of the actual Vin voltage that you measured in the previous step.

7. Repeat steps 5 and 6 for the +2.500 volt and -2.500 volt input values listed in the test record.

Internal (Int) Mode

If your oscilloscope supports internal mode, use this test to check the accuracy of the internally-generated termination voltages. In Int mode, you use a graphical user interface in the oscilloscope to set the test values to the 0.000, +2.500 and -2.500 volt levels, instead of using external power supplies. You do not need to measure these values in Int mode, as they are digitally set.

See your oscilloscope manual for details on using the interface.

1. Disconnect the power supply from the probe.
2. Set the Vterm Source Select to INT on the probe.
3. Use the graphical user interface in the oscilloscope to set the termination voltage to 0.000 V.
4. Use the DMM to verify that the termination voltage output at the Vterm monitor jacks on the top of the probe is within the limits on the test record. Record this value as Vout on the test record.
5. Repeat steps 3 and 4 for the +2.500 volt and -2.500 volt input values listed in the test record.

Auto Mode

In Auto mode, the probe measures the input signal DC common mode voltage and automatically sets the termination voltage to equal that voltage. In this test, the two signal inputs are connected together and driven by an external power supply to set the common mode voltage to the 0.0, +2.500 and -2.500 volt test values.

1. Connect the test setup as shown. (See Figure 26.)

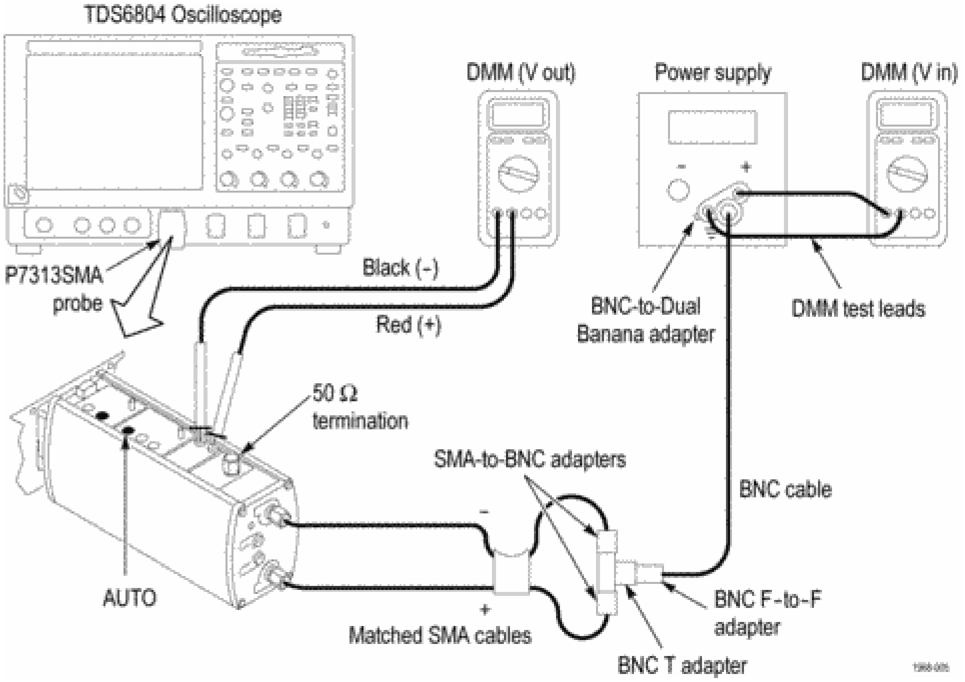


Figure 26: Termination Voltage Accuracy, Auto mode setup

2. Set the Vterm Source Select to Auto on the probe.
3. Set the power supply as close as practical to 0.000 volts, and use the DMM to measure this input voltage at the terminals on the power supply. Record this voltage as Vin on the test record.
4. Use the second DMM to measure the output voltage at the termination voltage monitor jacks on the top of the probe. Record this voltage as Vout on the test record, and verify that the Vout voltage is within the specified limits in the min/max columns.
5. Repeat steps 3 and 4 for the +2.500 volt and -2.500 volt input values listed in the test record.

Output Offset Zero

By terminating the two probe SMA inputs with 50 Ω, this procedure tests the zero output voltage of the probe. The probe output is measured at the SMA connector on the front of the 80A03 interface.

1. Connect the equipment as shown. (See Figure 27.)
2. Connect two 50 Ω terminations to the two probe SMA inputs on the probe, and plug the probe into the 80A03 module.
3. Connect the cable from the DMM to the SMA connector that is located below the 80A03 channel that you plugged the probe into.

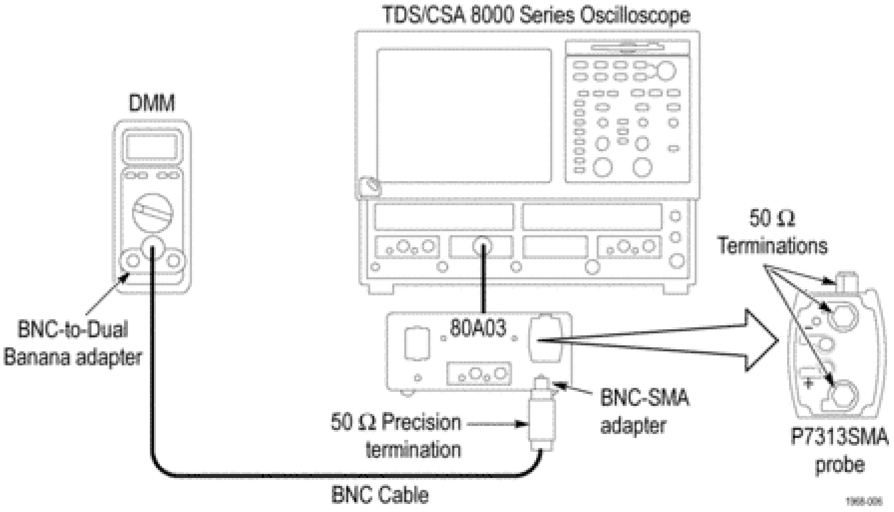


Figure 27: Setup for the output offset zero test

4. Set the Vterm source to Ext on the probe. Leave the external termination control voltage inputs open. This sets the termination voltage to zero.
5. Set the multimeter to read DC volts.
6. Verify that the output voltage is 0 V, ±2.5 mV for both the 2.5X and 12.5X attenuation settings.
7. Record the results on the test record.

DC Gain Accuracy

This test checks the DC gain accuracy of the probe at the two attenuation settings, 2.5X and 12.5X.

Gain Check at 2.5X Attenuation

1. Set the attenuation on the probe to 2.5X, and the termination select to Auto.
2. Connect the probe to the power supplies as shown. (See Figure 28.) Make sure the ground tabs on the BNC-to-dual banana plug adapters are connected to the ground connections on the power supplies. Monitor the source voltage with one of the DMMs.

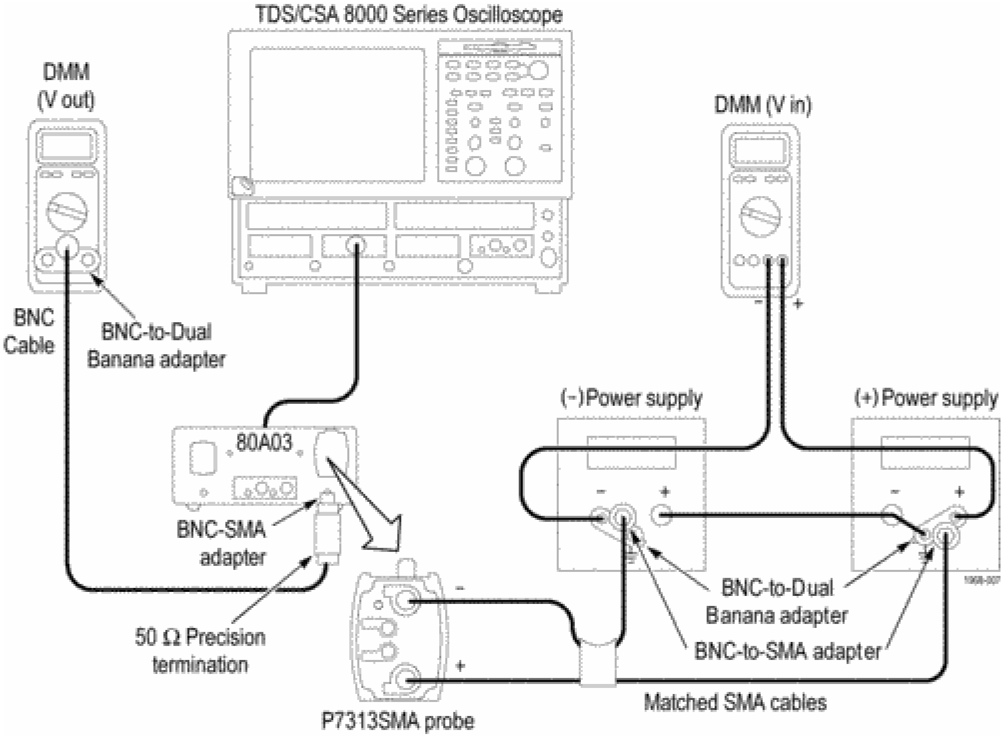


Figure 28: DC Gain Accuracy setup

3. Set the voltage on each power supply to approximately +0.160 V (+0.32 V differential total). This represents 80% of the probe dynamic range in this attenuation setting. Record this source voltage as $V_{in}1$.
4. Record the output voltage (on the second DMM) as $V_{out}1$.
5. Disconnect the BNC-to-dual banana plug adapters from the power supplies. Leave the DMM leads connected to the adapters.
6. Connect the BNC-to-dual banana plug adapters into the opposite power supplies to reverse the voltage polarity to the probe inputs. (See Figure 29 on page 40.)
7. Record the actual source voltage (now a negative value), as $V_{in}2$.

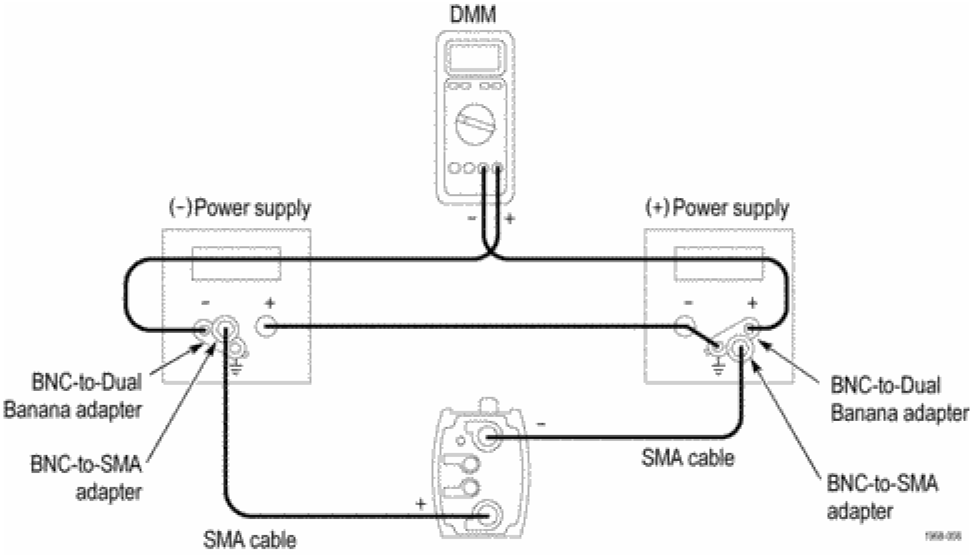


Figure 29: Reverse the power supply polarity on the probe inputs

8. Record the output voltage (on the second DMM) as $V_{out}2$.
9. Calculate the gain as follows: $(V_{out}1 - V_{out}2) \div (V_{in}1 - V_{in}2)$.
10. Verify that the gain is 0.4, ±2.0%.
11. Record the calculated gain for the 2.5X setting on the test record.

Gain Check at 12.5X Attenuation

12. Set the attenuation on the probe to 12.5X.
13. Repeat steps 2 through 9, but in step 3, set each power supply to +0.7 V (+1.4 V differential total).
14. Verify that the gain is 0.08, ±2.0%.
15. Record the calculated gain on the test record.

Rise Time

This procedure verifies that the probe meets the differential rise time specification. Two rise times are measured; the test system alone, and the test system with the probe included. The probe rise time is calculated using the two measurements.

Note: This test uses the TDR function of the 80E08 or 80E10 sampling head as a fast rise time signal source. A second 80E0X sampling head is used to take the measurements, using an 80A03 TekConnect probe interface. Although the following procedure assigns the TDR and measurement functions to specific oscilloscope channels, any valid channel combination can be used. However, the TDR rise times required of the sampling heads in this test are only available on 80E08 and 80E10 sampling heads.

This test checks both of the probe attenuation settings, but due to the differential TDR output amplitude and common mode voltage, inline 5X attenuators must be used when checking the 2.5X attenuation setting on the probe.

Rise Time Check at 12.5X Attenuation

1. Connect the test equipment as shown. (See Figure 30.)

CAUTION. *To prevent mechanical strain on the connectors, use care when working with SMA connectors: support equipment and use a torque wrench to tighten connections to 7 in-lbs.*

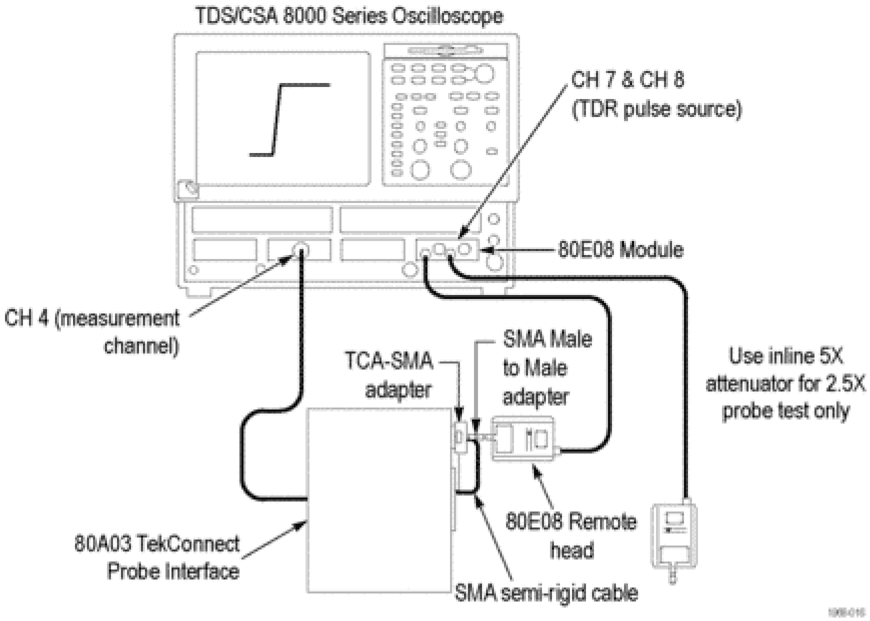
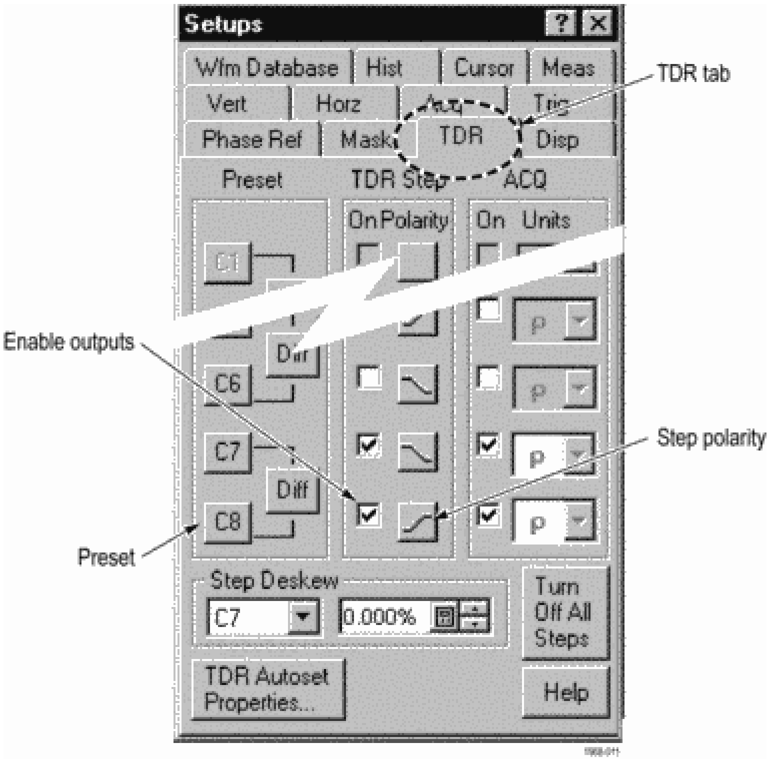


Figure 30: Test system rise time setup

NOTE. *The firmware of the 80A03 TekConnect Probe Interface used to power the probe must be version V2.2 or above.*

2. Turn on Channel 4 and set the vertical scale to 50 mV/div.

3. Set the Channel 7/8 sampling head to TDR mode: Press the SETUP DIALOGS button and select the TDR tab. (See Figure 31.)



TDR tab

Enable outputs

Step polarity

Preset

Figure 31: Setting the TDR parameters

4. Set the Channel 7 (**C7**) **Polarity** to negative (falling).

5. Set the Channel 8 (**C8**) **Polarity** to positive (rising).

6. Set the **Preset** of Channel 7 and 8 on.

TDR Preset sets Internal Clock in the Trigger menu, turns on the TDR Step in the TDR Setups menu, turns on the channel and selects the acquisition Units in the TDR Setups menu, and sets the horizontal scale, position, and reference. The sampling module will turn on a red light next to the SELECT channel button, indicating that TDR is activated for that channel.

Deskew Channel 7 and 8 by doing the following:

7. Check that Ch 7 is set to negative slope and Ch 8 is set to positive slope.

8. Verify/clear all deskew values for Ch 7 and Ch 8 in both the TDR menu and the vertical menu.

9. Turn off the display for Ch 7 and Ch 8 so that only Ch 4 is shown on screen.

10. Set the horizontal scale to 10 ps/div, and the vertical scale to 50 mV/div.

11. Adjust Ch 4 to position the step at 0 V, and then enter –125 mV offset to position the step as shown. (See Figure 32.) Save this waveform to a reference.

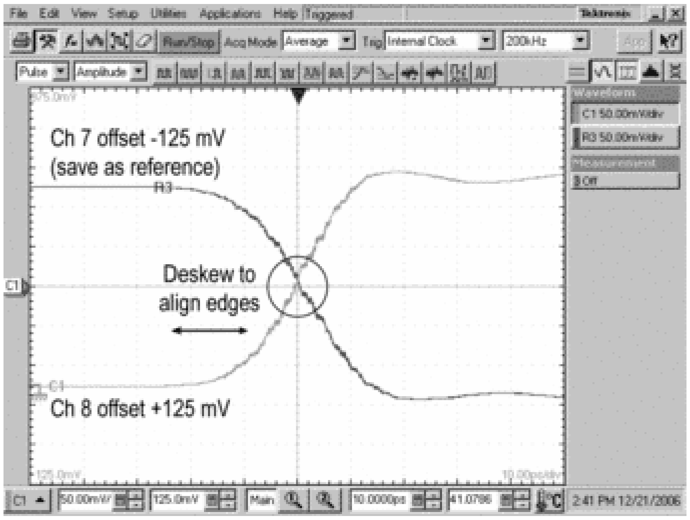


Figure 32: Deskew the TDR steps

12. Remove Ch 7 from the Ch 4 input and connect Ch 8 to the Ch 4 input.

13. Press the Ch button to display Channel 4.

14. Enter 125 mV offset to position the step as shown. (See Figure 32.)

15. From the TDR menu, adjust the deskew on Ch 8 to align the edges with the reference value from step 11.

16. Use the oscilloscope measurement capability to display rise time. Increase the stability of the pulse edge measurement by using averaging, if available. Rise time is measured from the 10% and 90% amplitude points on the waveform. Record the rise time as t_s.

The following steps instruct you to assemble the test setup that includes the probe. (See Figure 33.) The system and probe rise time (t_{s+p}) that you measure in step 24 is used to calculate the probe rise time (t_p) in step 25.

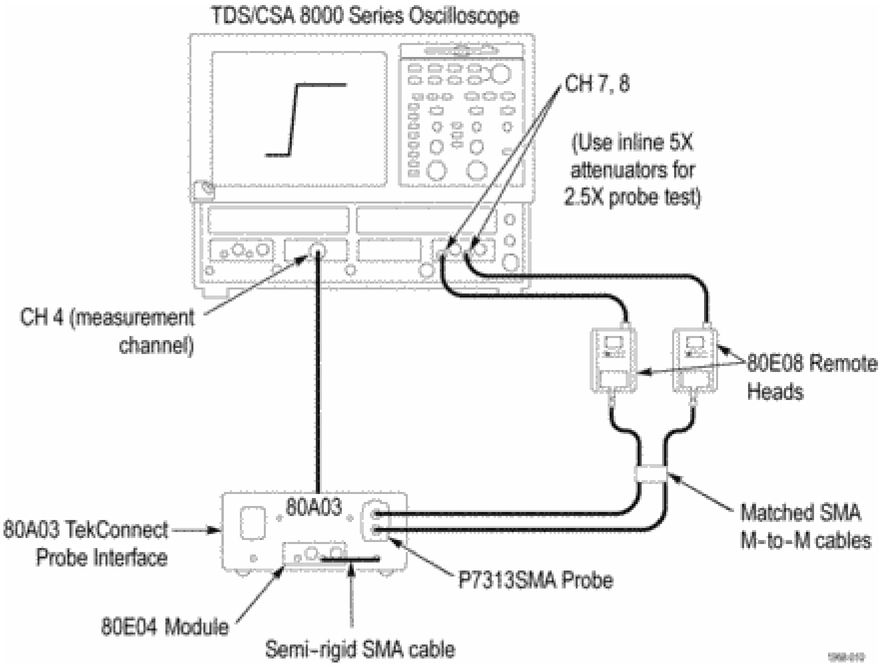


Figure 33: Test system rise time setup with probe

17. Remove the TekConnect-to-SMA adapter from the test setup.
18. Connect the probe to the 80A03 TekConnect probe interface.
19. Connect the matched SMA cables to the probe SMA inputs and the 80E08 sampling head (Channels 7 and 8).
20. Set the attenuation on the probe to 12.5X.

The test setup should now be connected as shown. (See Figure 33.)

21. Expand the horizontal scale to help locate the step edge, and then adjust horizontal range to 50 ps/div while maintaining the edge view. For a more stable measurement display, turn averaging on.
22. Adjust the vertical scale to 100 mV/div, averaging on.
23. Adjust the vertical and horizontal positioning to place the rising edge of the signal on the second vertical and center horizontal graticule lines.
24. Use the oscilloscope measurement capability to display rise time. Rise time is determined from the 10% and 90% amplitude points on the waveform. Record the rise time as $t_{s+p.}$
25. Calculate the probe rise time using the following formula:

$$t_p = \sqrt{t_{(s+p)}^{\,2} - t_s^2}$$

26. Record the calculated probe rise time on the test record.

Rise Time Check at 2.5X Attenuation

The TDR output levels of the 80E08 module must be attenuated when checking the 2.5X attenuation setting on the probe. The attenuators add some delay and a small bandwidth reduction to the test system, so a new system time, t_s , must be measured to accurately calculate the probe rise time.

1. Disconnect the matched SMA cables from the TDR outputs.
2. Install inline 5X attenuators on the TDR outputs. (You will need to set the step offset to 25 mV and vertical scale to 10 mV/div. in the procedure).
3. Measure a new system time by repeating steps 1 through 16 of the 12.5X attenuation check.
4. Remove the TekConnect-to-SMA adapter from the test setup.
5. Connect the probe to the 80A03 TekConnect probe interface.
6. Connect the matched SMA cables to the probe SMA inputs and the inline 5X attenuators on the TDR outputs.
7. Set the attenuation on the probe to 2.5X and set the vertical scale to 20 mV/div, averaging on.
8. Repeat steps 21 through 25 for the 2.5X attenuation setting.
9. Record the calculated probe rise time on the test record.

Table 9: Test Record

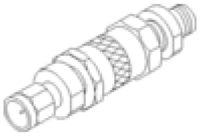
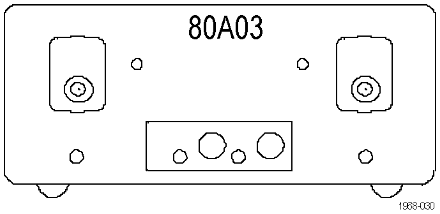
Probe Model:
Serial Number:
Certificate Number:
Temperature:
RH %:
Date of Calibration:
Technician:

Performance test		Minimum	Measured	Maximum
Differential mode input resistance		98 Ω		102 Ω
Termination voltage accuracy				
Ext Mode	Vin @ 0.000 V	Vin - 2 mV	Vin______Vout______	Vin + 2 mV
	Vin @ +2.500 V	Vin - 7 mV	Vin______Vout______	Vin + 7 mV
	Vin @ -2.500 V	Vin - 7 mV	Vin______Vout______	Vin + 7 mV
Int Mode	Vin @ 0.000 V	-0.002 V	Vout	+0.002 V
	Vin @ +2.500 V	+2.4905 V	Vout	+2.5095 V
	Vin @ -2.500 V	-2.4905 V	Vout	-2.5095 V
Auto Mode	Vin @ 0.000 V	Vin - 20 mV	Vin______Vout______	Vin + 20 mV
	Vin @ +2.500 V	Vin - 82 mV	Vin______Vout______	Vin + 82 mV
	Vin @ -2.500 V	Vin - 82 mV	Vin______Vout______	Vin + 82 mV
Output offset zero	2.5X	-2.5 mV		+2.5 mV
	12.5X	-2.5 mV		+2.5 mV
DC gain accuracy	2.5X	0.392		0.408
	12.5X	0.0784		0.0816
Differential rise time	2.5X	NA		40 ps
	12.5X	NA		40 ps

Optional Accessories

The optional accessories that you can order for the P7313SMA differential probe are listed below. (See Table 10.)

Table 10: Optional accessories

Description	Accessory
Phase adjuster. Use two phase adjusters if you need to bring the skew between inputs to 1 ps or less because of skew in the device under test differential signal path. (See page 18, *Adjusting Cable Skew*.)The phase adjuster has a 25 ps adjustment range. The matched-delay SMA cables that come with your probe have a ≤1 ps skew at the cable ends. Tektronix part number: 015-0708-XX (package of 1)	
80A03. The 80A03 TekConnect Probe Interface Module is an adapter that allows you to use TekConnect probes with CSA8000 and TDS8000 Series sampling oscilloscopes and 80E0X sampling modules. The interface contains an enclosure that houses a compartment for one 80E0X electrical sampling module and two TekConnect probe inputs. The interface routes the probe signal outputs through SMA connectors on the front panel. Semi-rigid SMA cables link the probe outputs to the 80E0X module inputs. The 80A03 Interface Module is required to complete a performance verification of the probe.	

Options

These options are available when ordering the P7313SMA probe:

- Option D1-Calibration Data Report
- Option CA1-A single calibration event or coverage for the designated calibration interval, whichever comes first.
- Option D3-Calibration Data Report, 3 years (with Option C3)
- Option C3-Calibration Service 3 years
- Option D5-Calibration Data Report, 5 years (with Option C5)
- Option C5-Calibration Service 5 years
- Option R3-Repair Service 3 years
- Option R5-Repair Service 5 years

Maintenance

This section contains maintenance information for the P7313SMA differential probe.

Inspection and Cleaning

Protect the probe from adverse weather conditions. The probe is not waterproof.

CAUTION. To prevent damage to the probe, do not expose it to sprays, liquids, or solvents. Do not use chemical cleaning agents; they may damage the probe. Avoid using chemicals that contain benzine, benzene, toluene, xylene, acetone, or similar solvents.

Clean the exterior surfaces of the probe with a dry, lint-free cloth or a soft-bristle brush. If dirt remains, use a soft cloth or swab dampened with a 75% isopropyl alcohol solution. A swab is useful for cleaning narrow spaces on the probe. Do not use abrasive compounds on any part of the probe.

CAUTION. To prevent damage to the probe, avoid getting moisture inside the probe during exterior cleaning, and use only enough solution to dampen the swab or cloth. Use a 75% isopropyl alcohol solution as a cleanser, and rinse with deionized water.

Replacement Parts

Due to the sophisticated design of the P7313SMA differential probe, there are no user replaceable parts within the probe. Refer to the *Quick Start User Manual* for a list of replaceable accessories for your probe.

If your probe does not meet the specifications tested in the Performance Verification, you can send the probe to Tektronix for repair. Follow the procedure below to prevent damage to the probe during shipping.

Preparation for Shipment

If the original packaging is unfit for use or not available, use the following packaging guidelines:

1. Use a corrugated cardboard shipping carton having inside dimensions at least one inch greater than the probe dimensions. The box should have a carton test strength of at least 200 pounds.
2. Put the probe into an antistatic bag or wrap to protect it from dampness.
3. Place the probe into the box and stabilize it with light packing material.
4. Seal the carton with shipping tape.
5. Refer to *Contacting Tektronix* on the copyright page for the shipping address.