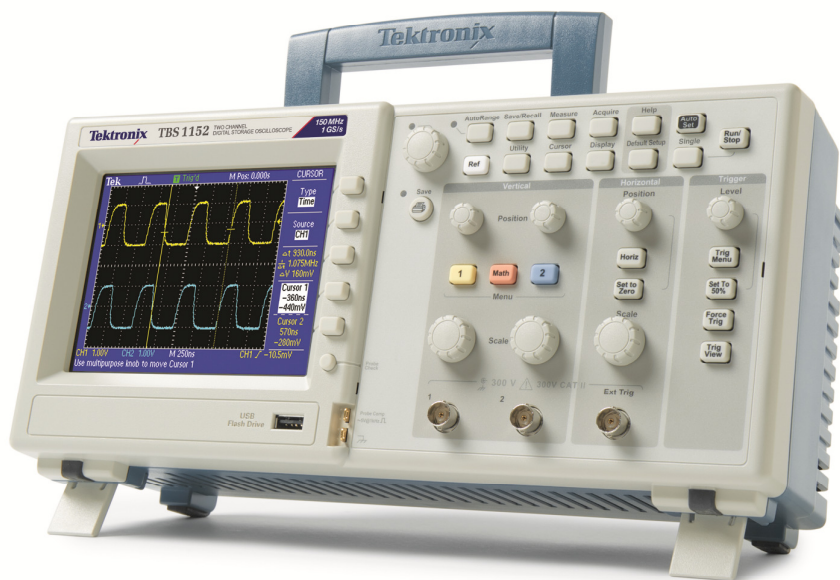


# Oscilloscope Basics Guide



A guide to oscilloscope operation, architecture and common measurements.

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# Overview of an Oscilloscope

## Introduction

An oscilloscope is an electronic test instrument that displays electrical signals graphically, usually as a voltage (vertical or Y axis) versus time (horizontal or X axis) as shown in figure 1. The intensity or brightness of a waveform is sometimes considered the Z axis. There are some applications where other vertical axes such as current may be used, and other horizontal axes such as frequency or another voltage may be used.

Oscilloscopes are also used to measure electrical signals in response to physical stimuli, such as sound, mechanical stress, pressure, light, or heat. For example, a television technician can use an oscilloscope to measure signals from a television circuit board while a medical researcher can use an oscilloscope to measure brain waves.

Oscilloscopes are commonly used for measurement applications such as:

- observing the wave shape of a signal
- measuring the amplitude of a signal
- measuring the frequency of a signal
- measuring the time between two events
- observing whether the signal is direct current (DC) or alternating current (AC)
- observing noise on a signal

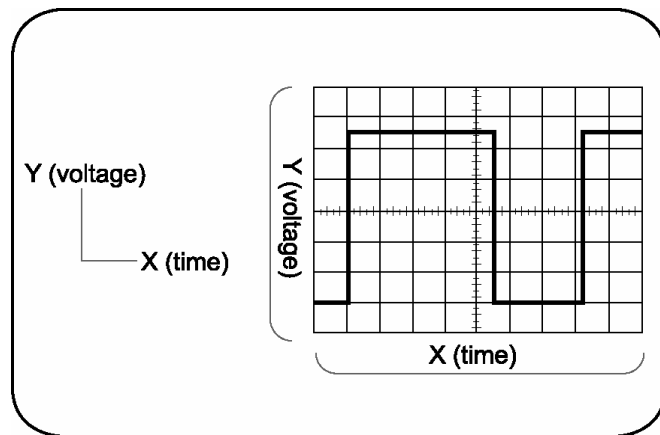


Figure 1: Typical Oscilloscope Display

An oscilloscope contains various controls that assist in the analysis of waveforms displayed on a graphical grid called a graticule. The graticule, as shown in figure 1, is divided into divisions along both the horizontal and vertical axes. These divisions make it easier to determine key parameters about the waveform. In the case of the TBS1000 Series oscilloscope, there are 10 divisions horizontally and 8 divisions vertically.

A digital oscilloscope acquires a waveform by conditioning the input signal in the analog vertical amplifier, sampling the analog input signal, converting the samples to a digital representation with an analog-to-digital converter (ADC or A/D), storing the sampled digital data in its memory, and then reconstructing the waveform for viewing on the display.

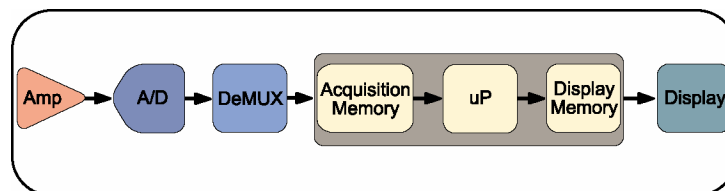


Figure 2: Typical Digital Oscilloscope Block Diagram

## **Performance Terms and Considerations**

There are many ways to specify digital oscilloscope performance, but the most important are bandwidth, rise time, sample rate, and record length.

### **Bandwidth**

Bandwidth is the first specification to consider. Bandwidth is the frequency range of the oscilloscope, usually measured in Megahertz (MHz). It is the frequency at which the amplitude of the displayed sine wave is attenuated to 70.7% of the original signal amplitude.

When measuring high-frequency or fast rise-time signals, oscilloscope bandwidth is especially critical. Without adequate bandwidth, an oscilloscope will not be able to display and measure high-frequency changes. It is generally recommended that the oscilloscope's bandwidth be at least 5 times the highest frequency that needs to be measured. This "5-times rule" allows for the display of the 5<sup>th</sup> harmonic of the signal and assures that measurement errors due to bandwidth are minimized.

$$\text{oscilloscope bandwidth} \geq 5^{\text{th}} \text{ harmonic of signal}$$

*Example: If the signal of interest is 100 MHz, the oscilloscope would need a bandwidth of 500 MHz.*

### **Rise Time**

The edge speed (rise time) of a digital signal can carry more high-frequency content than its repetition rate might imply. An oscilloscope and probe must have a sufficiently fast rise time to capture the higher frequency components, and therefore show signal transitions accurately. Rise time is the time taken by a step or a pulse to rise from 10% to 90% of its amplitude level. There is another "5-times rule" that recommends that the oscilloscope's rise time be at least 5 times faster than the rise time of the signal that needs to be measured.

$$\text{oscilloscope rise time} \leq \frac{\text{signal rise time}}{5}$$

*Example: If the signal of interest has a rise time of 5 μsec, then the oscilloscope rise time should be faster than 1 μsec.*

### **Sample Rate**

Digital oscilloscopes sample the input signals at a frequency called the sample rate, measured in samples / second (S/sec). To properly reconstruct the signals, Nyquist sampling requires that the sample rate be at least twice the highest frequency being measured. That's the theoretical minimum. In practice, sampling at least 5 times as fast is generally desirable.

$$\text{sample rate} \geq 5 * f_{\text{Highest}}$$

*Example: The correct sample rate for a 450 MHz signal would be  $\geq 2.25$  GS/sec.*

### **Record Length**

Digital oscilloscopes capture a specific number of samples or data points, known as the record length, for each acquired waveform. The record length, measured in points or samples, divided by the sample rate (in Samples/second) specifies the total time (in seconds) that is acquired.

$$\text{acquired time} = \frac{\text{record length}}{\text{sample rate}}$$

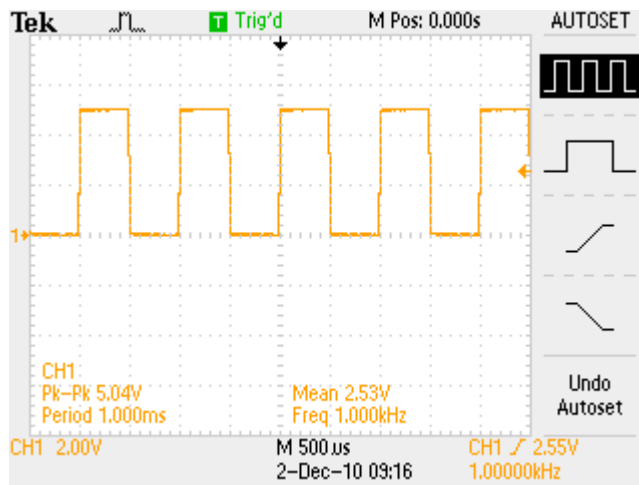
*Example: With a record length of 1 Mpoints and a sample rate of 250 MS/sec, the oscilloscope will capture a signal 4 msec in length.*

## Initial Setup and Screen Explanation

### Creating a Stable Display

1. The following steps will describe how to automatically create a stable oscilloscope display using a 1 kHz, 5 V<sub>pk-pk</sub> square wave.
  - a. Power up the oscilloscope by pushing the power button.
  - b. Push the front-panel **Default Setup** button to set the oscilloscope to a known starting point.
  - c. Connect a passive probe to the channel 1 input. To connect a probe that uses a BNC connector, push and turn the probe connector until it slides on the oscilloscope channel input connector. Then, turn the probe locking ring clockwise to lock the probe connector in place.
  - d. Attach the probe's alligator style ground lead to the ground connector next to the oscilloscope display.
  - e. Attach the probe tip to the **Probe Comp** connector just above the ground lead connector. This connector provides a 1 kHz square wave that this lab will use to demonstrate the operation of an oscilloscope.
  - f. Push the front-panel **AutoSet** button to cause the oscilloscope to automatically set the vertical, horizontal and trigger settings for a stable display of the probe compensation 1 kHz square wave.

**PLEASE NOTE: All screenshots in this Guide were taken in ink-saver mode to allow for better visibility of signal changes in a printed document.**



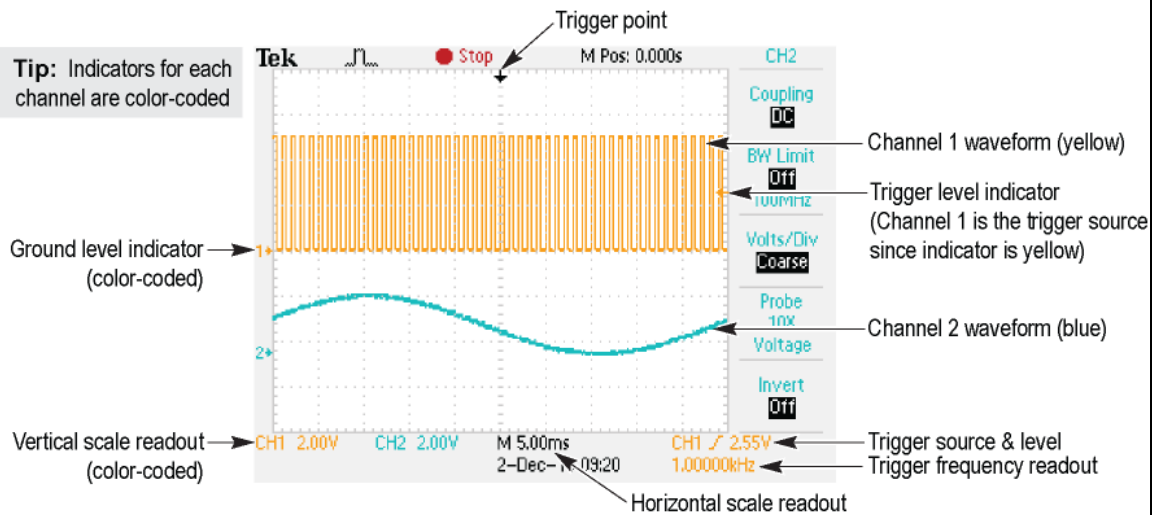
### Key Points to Remember

1. To return the oscilloscope to a known state, push the **Default Setup** button.
2. The **AutoSet** button adjusts the vertical, horizontal and trigger settings such that four or five cycles of the waveform are displayed with the trigger near the middle of the screen.

## Screen Explanation

1. The following is a review of the oscilloscope display.

### Explanation of the oscilloscope display:



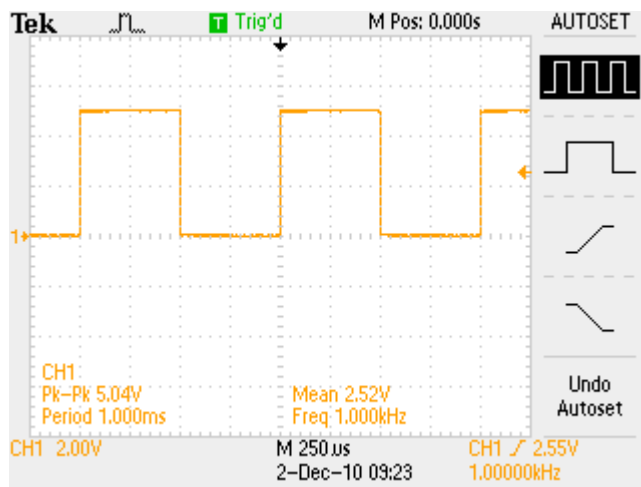
a. The channel 1 vertical axis button is yellow and most of the elements on the screen that relate to the channel 1 signal are yellow in color.

b. On the display, the following items are yellow to indicate they are associated with channel 1:

- waveform
- waveform ground level indicator (center left of screen)
- vertical scale readout (bottom left of screen 2.00 V)

c. The channel 2 vertical axis button is blue. The display uses the color coding of this channel just as it does for the yellow of channel 1.

- d. As can be seen on the oscilloscope screen, the square wave extends up about 2 ½ divisions on the display graticule from the ground level indicator. Since the vertical scale factor is 2 Volts/div, this indicates the signal's positive peak is at about +5 V.



- e. One cycle of the waveform is about 4 divisions wide. The time per horizontal division is indicated by the horizontal scale readout which in this case is 250 μsec/div (bottom center of the display). At 250 μsec/div, the period of the signal is about 1 msec and the frequency is about 1 kHz.

- f. Finally, the trigger frequency readout indicates the channel 1 signal has a frequency of about 1 kHz as shown in the bottom right corner of the display.

### Key Points to Remember

1. The input channels are color coded. Onscreen channel information is in that channel's color, including the waveform, ground indicator, and vertical scale factor (Volts/div).
2. The amplitude of the signal can be determined by multiplying the number of vertical divisions the waveform spans times the vertical scale factor.
3. The signal period can be determined by multiplying the number of horizontal divisions times the horizontal scale factor.
4. Signal frequency is calculated by dividing 1 by the signal period.





# Vertical Controls

## Introduction

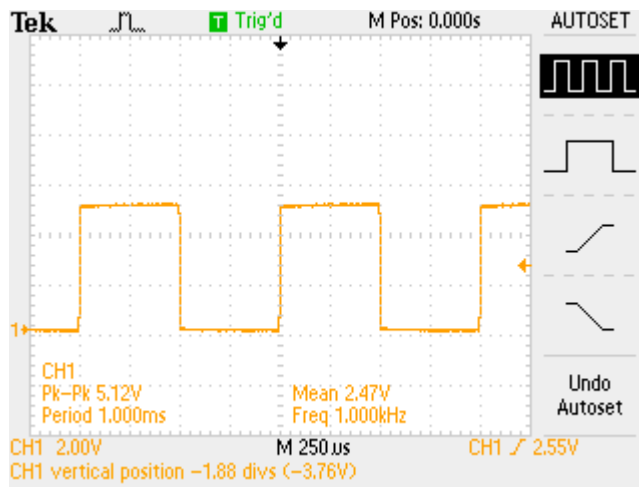
The vertical controls set or modify the vertical scale, position, and other signal conditioning for each of the analog input channels.

There is a set of vertical controls for each input channel. These controls are used to scale, position, and modify that channel's input signal so it can be viewed appropriately on the oscilloscope display. In addition to the dedicated vertical controls for each channel, there are also buttons to access the math menu, reference menu and bus menus.

## Vertical Position/Scale Controls

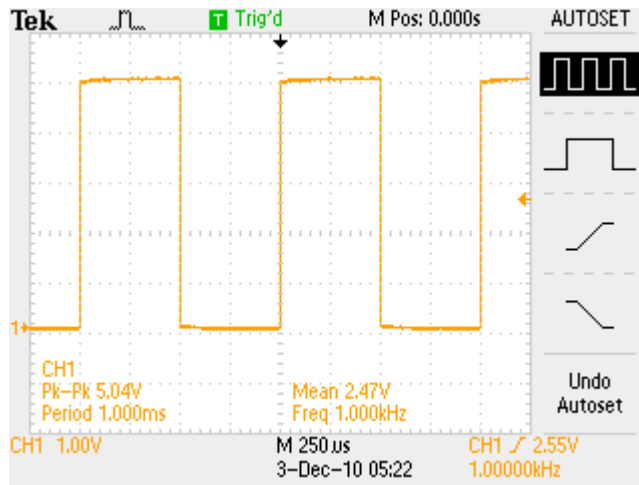
1. The following steps will explore the use of the vertical axis position and scale front-panel controls.

- a. Turn the channel 1 vertical **Position** knob to position the waveform near the bottom of the display and notice the ground level indicator also moves.



The vertical position control moves the waveform up and down. It is generally used to align the waveform with the vertical divisions on the graticule. Position is generally a graphical display function only and does not affect the acquired waveform data.

- b. Turn the channel 1 vertical **Scale** knob to change the vertical scale from 2 V/div to 1 V/div.



The vertical scale (Volts/division) control adjusts the height of the waveform on the display. Generally, the vertical scale control changes the settings of the input amplifier and/or attenuator and does not affect the acquired waveform data. Because the vertical scale controls the amplitude of the signal going into the ADC, the highest-resolution measurements are achieved when the signal almost fills the screen vertically without going off screen.

### Key Points to Remember

1. The vertical position knob controls the position of the waveform on the vertical axis.
2. The vertical scale knob controls the amount of voltage represented by a vertical division on the graticule.

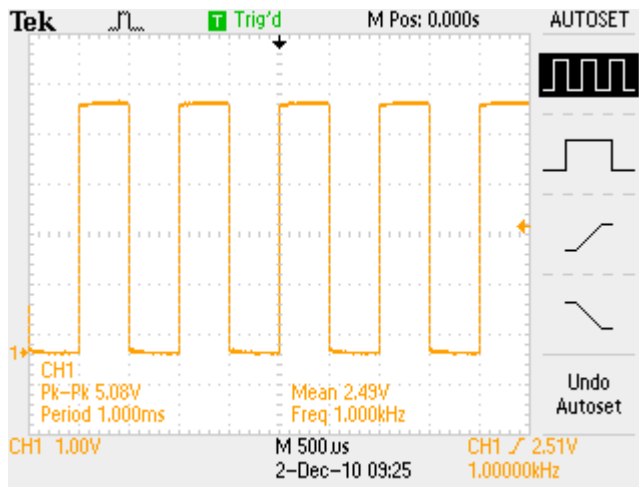
# Horizontal Controls

## Introduction

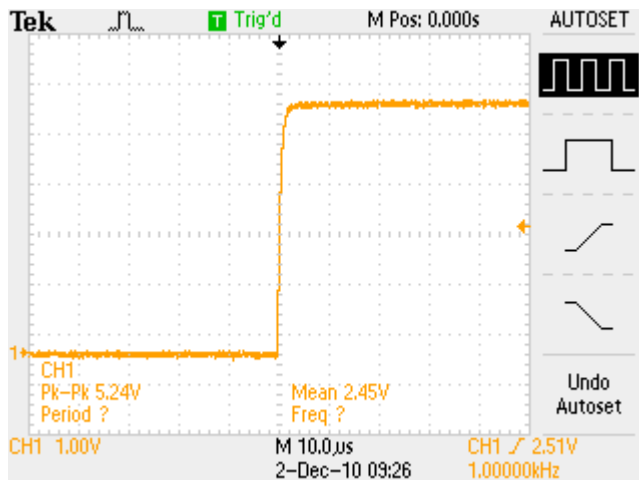
The horizontal controls are used to scale and position the time axis of the oscilloscope display. There is a dedicated front-panel control for setting the horizontal scale (time/division) of the display and another for setting the horizontal position of the displayed signals. The **Horiz** button brings up the horizontal menu with additional options for modifying the waveform display.

## Horizontal Position/Scale Controls

1. The following steps will explore the use of the horizontal axis scale front-panel control. The horizontal scale control (also known as time/division or seconds/division) adjusts the amount of time displayed on the screen.
  - a. Push the front-panel **AutoSet** button to restore the oscilloscope to a known starting point and then set the vertical scale to 1 V/div.
  - b. Turn the vertical **Position** knob to center the waveform on the screen.



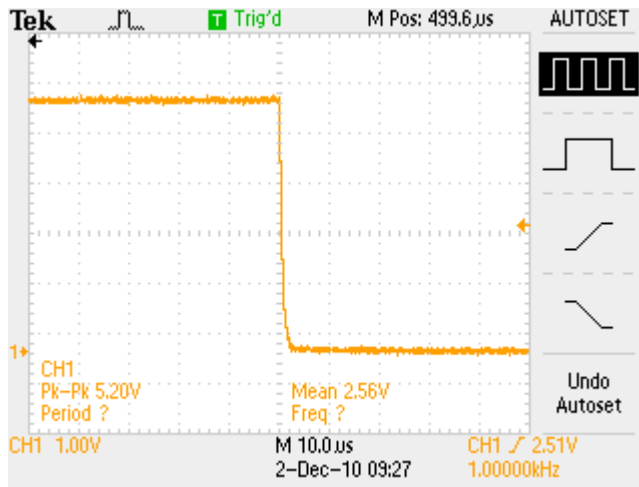
- c. Turn the horizontal **Scale** knob until the horizontal readout indicates 10  $\mu$ s/div (readout is shown in the bottom center of the display.)



Since there are 10 divisions horizontally, a scale factor of 10  $\mu\text{sec}/\text{div}$  yields a 100  $\mu\text{sec}$  time window. This setting shows the actual shape of the rising edge of the square wave.

- The horizontal **Position** control moves the waveform and its horizontal reference or trigger point (indicated by the orange icon at the top of the display) back and forth on the display. This is used to align the displayed waveform with the horizontal divisions on the display graticule.

- Turn the horizontal **Position** knob counter-clockwise to position the waveform's falling edge at the center of the display.



### Key Points to Remember

- The horizontal **Scale** control sets the time window displayed on the oscilloscope screen. Since there are 10 divisions horizontally, the time window is equal to:

$$\text{time window} = \text{horizontal scale factor} * 10 \text{ divisions}$$

- The horizontal **Position** knob allows you to align the displayed waveform with the horizontal divisions of the display graticule or to view a different section of the displayed waveform.

### ***Calculating the Sample Rate***

1. The following steps will investigate the relationship between the oscilloscope's horizontal scale factor, record length and sample rate.

a. Set the horizontal scale to 500  $\mu\text{s}/\text{div}$ .

b. The displayed time window is  $(500 \mu\text{s}/\text{div}) \times (10 \text{ divisions}) = 5 \text{ ms}$ .

c. The record length of the TBS1000 Series is always 2500 points.

d. The sample rate at this horizontal scale setting is  $2500 \text{ points} / 5 \text{ ms} = 500 \text{ kS/s}$ .

### **Key Points to Remember**

1. The sample rate of the oscilloscope is determined by the displayed time window (and therefore, the horizontal scale factor) and the selected record length.

$$\text{sample rate} = \frac{\text{record length}}{\text{time window}}$$

# Trigger Controls

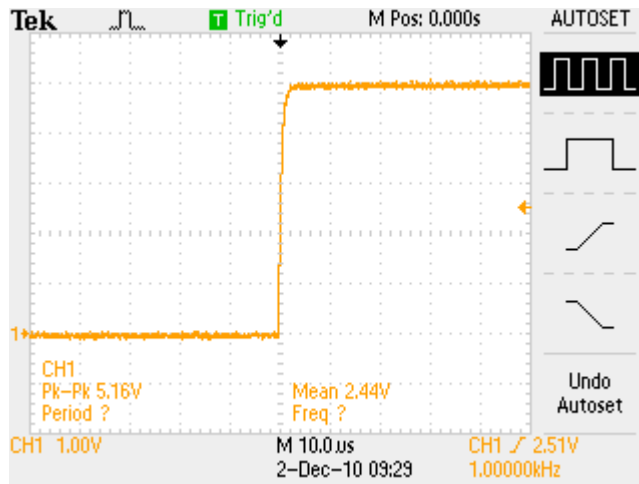
## Introduction

The trigger defines when a signal is acquired and stored in memory. For a repetitive signal, a trigger is required to stabilize the display.

There is a front-panel control to set the trigger level and a button to force the oscilloscope to trigger. The Trigger menu offers different trigger types and allows you to set the conditions of the trigger.

## Trigger Level Control

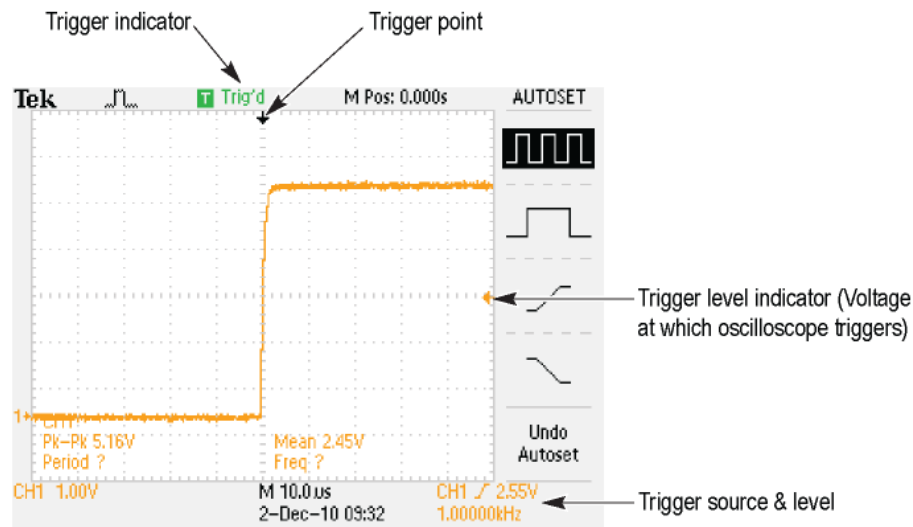
1. The following steps will explore the use of the front-panel trigger level control.
  - a. Use the **Default Setup** and **AutoSet** buttons to set the oscilloscope to a known starting point.
  - b. Set up the oscilloscope to match the display shown here.



- **Adjust the vertical scale factor to 1 V/div using the front-panel vertical scale knob**
- **Position the waveform at the center of the display using the front-panel vertical position knob**
- **Set the horizontal scale factor to 10  $\mu$ sec/div using the front-panel horizontal scale knob**

- In the default trigger setting, the oscilloscope looks for a rising edge on the channel 1 input signal. The trigger level control is used to set the voltage at which the oscilloscope triggers. The waveform is displayed with the rising edge aligned with the trigger point (indicated by the white down arrow icon at the top of the display). The trigger voltage level is shown by a yellow arrow on the right side of the display.

#### Explanation of trigger indicators on oscilloscope display:



- Turn the **Trigger Level** knob until the trigger level, as indicated by the yellow arrow on the right side of the screen, is above the top of the waveform (about 5.5 V) resulting in an un-triggered display.

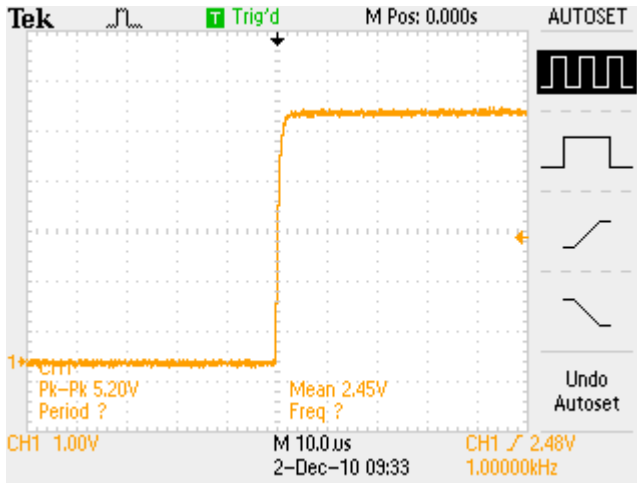
#### Key Points to Remember

- A trigger defines when a signal is acquired and stored in memory.
- The trigger level must be within the signal range to properly trigger the oscilloscope.
- For a repetitive signal, a trigger is necessary to obtain a stable display.

## Trigger Menu

1. During the following steps, a trigger will be set up to create a stable display.

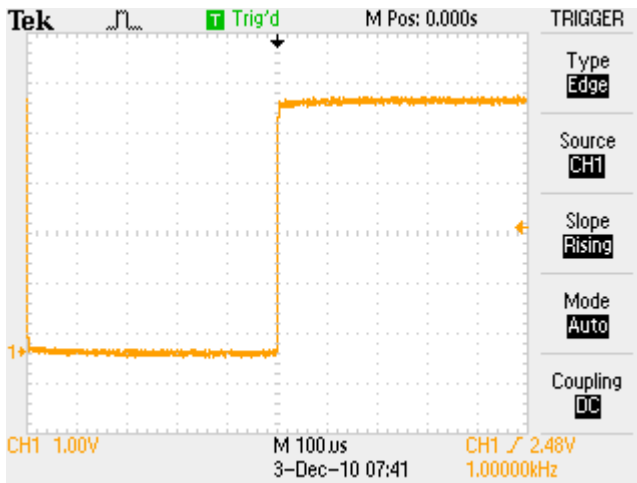
- a. Push the Trigger **Set To 50%** button to force the trigger voltage setting to the 50% point of the signal. The oscilloscope display should now match the figure in step 1b, before you adjusted the **Trigger** level control.



- b. Change the horizontal scale factor to 100 μsec to display one full cycle of the signal.

- c. Push the front-panel **Trig Menu** button.

The Trigger Menu allows you to specify the trigger event used to capture a waveform. Available trigger types include edges, pulse widths, and standard video signals.



- d. Push the **Source** side-bezel button. The source selections allow you to select which signal to monitor for the trigger event.

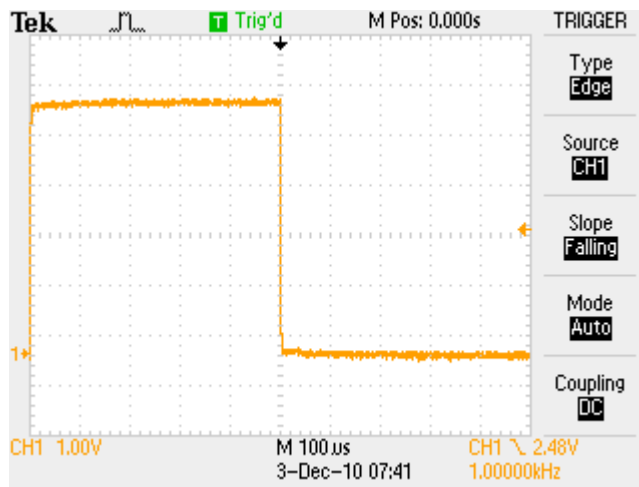


e. Notice that the LED next to the multipurpose control is lit. In this menu, you can turn the multipurpose control to select the channel that will be the source of the trigger. Select channel **2** (and **3** and **4** in sequence if you are using a 4-channel oscilloscope) and note the effect this has on the triggered state of the display. When channel 1 is not selected, the display is not triggered because channel 2 (and 3 and 4 if you are using a 4-channel oscilloscope) do not have an applied signal.

f. Turn the multipurpose control to select channel **1** and ensure the display is triggered.

g. Push the **Slope** side-bezel button to select the falling edge of the signal as the trigger point.

The slope selections control whether the trigger looks for a positive or negative edge on the trigger signal.



2. The edge trigger is used by default. However, because the trigger is a critical element in making a measurement, there are several trigger options to pick from based on your measurement needs. Perform the following steps to see how a few of the other trigger types are used.

a. Push the **Type** side-bezel button for a selection of trigger types.

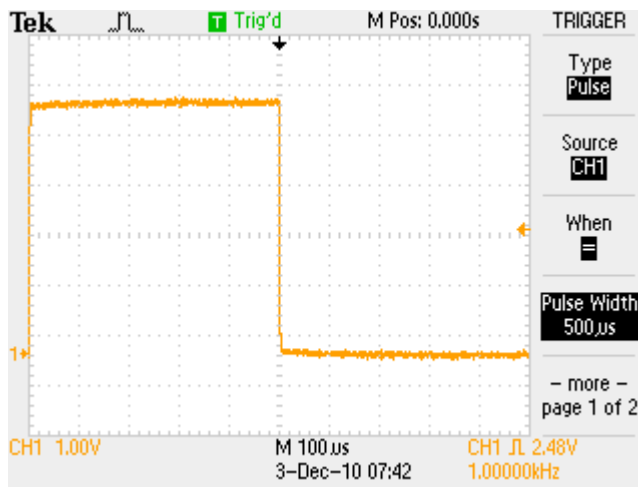
b. Push the **Type** side-bezel button until **Pulse** is selected.

c. Push the **When** side-bezel button to see your choices.

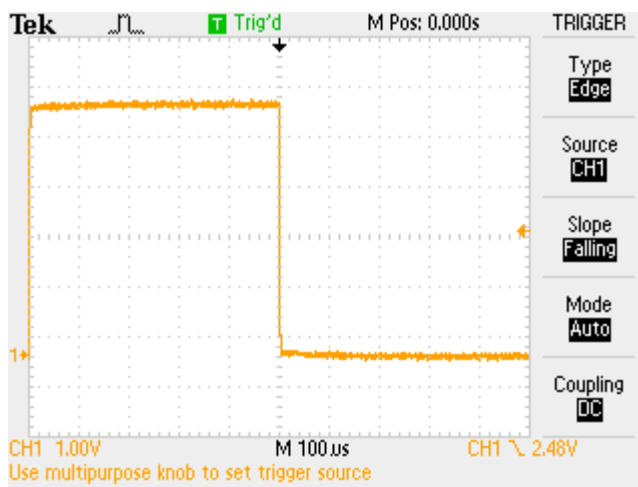
d. Push the **When** button until = is selected.

The pulse width = setting causes the oscilloscope to trigger when the pulse width is within +/-5% of the specified values.

- e. Turn the multipurpose control to set **Pulse Width** to **500  $\mu$ s** and note the oscilloscope triggers on the 500  $\mu$ sec pulse. Remember this signal has a period of 1 msec with a 50% duty cycle. Thus the pulse width is 500 $\mu$ sec.



- f. To return to the default Edge trigger mode, push the **Type** side-bezel button until the **Edge** trigger mode is selected.



### Key Points to Remember

1. Pushing the **Set To 50%** button forces the trigger level to the 50% point of the applied signal.
2. The trigger menu allows you to specify the trigger event used to capture a waveform.
3. Use the trigger source selections to pick which input channel to monitor for the trigger event.
4. Use the trigger slope control to specify which edge (rising or falling) to trigger on.
5. The pulse width trigger can isolate pulses within a signal.

## Oscilloscope Measurements

### *Introduction*

A digital oscilloscope can make a variety of measurements on electrical signals, such as peak-to-peak and RMS amplitude measurements and frequency, period, and pulse width timing measurements. The oscilloscope provides several ways to make these measurements. This section will review the three most common measurement methods:

- Manual measurements
- Cursor measurements
- Automatic measurements

**Manual Measurements.** Manual measurements rely upon the graticule on the display and the vertical and horizontal scale settings to make measurements. A typical graticule has 8 divisions vertically and 10 divisions horizontally. To achieve the highest accuracy, first scale and position the waveform to fill the display vertically and horizontally, and then visually measure the parameter in units of graticule divisions. Then multiply the number of divisions by the scale factor to get the final measurement value.

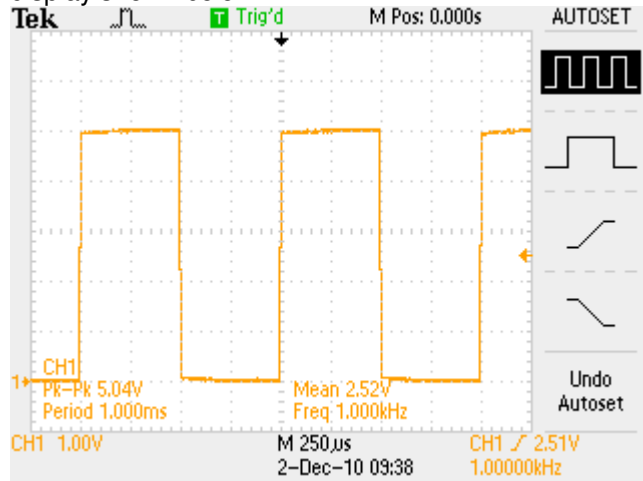
**Cursor Measurements.** Cursor measurements are made by manually aligning a pair of cursors to points on the waveform and then reading the measurement values from the display cursor readouts.

**Automatic Measurements.** Automatic measurements use algorithms stored in the oscilloscope's firmware. These algorithms identify the appropriate waveform characteristics, make the measurements, scale the measurements, apply the appropriate units and display them on the oscilloscope.

## Manual Measurements

The following exercise will explore making manual waveform measurements.

Reset the oscilloscope back to a known starting point and use the front-panel controls to create the display shown below.



Normally, for greatest accuracy, the waveform is adjusted vertically to fill as much of the display as possible. For this exercise, leave the waveform as shown above.

- 1 **Push the Default Setup front-panel button**
- 2 **Push the AutoSet front-panel button**
- 3 **Adjust the vertical scale factor to 1 V/div using the front-panel vertical scale knob**
- 4 **Position the waveform at the bottom of the display using the front-panel vertical position knob**
- 5 **Set the horizontal scale factor to 250 µsec/div using the front-panel horizontal scale knob**

## Cursor Measurements

1. For greater measurement accuracy, the oscilloscope provides cursors that will be used in the next series of steps.

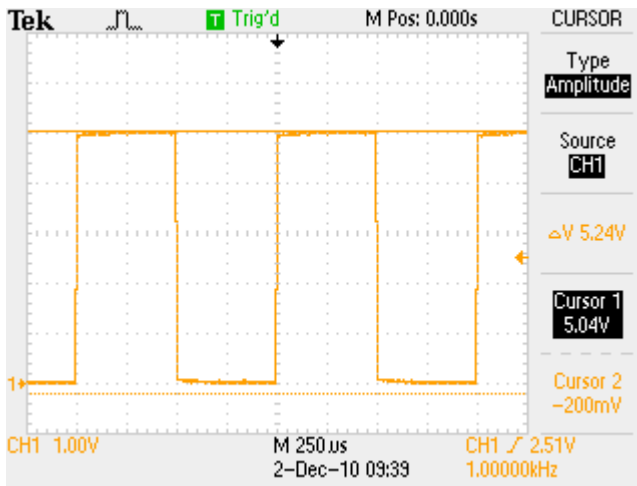
a. Push the front-panel **Cursor** button to display the cursor menu.

b. The **Type** side-bezel button allows you to select either the **Amplitude** or the **Time** cursors.

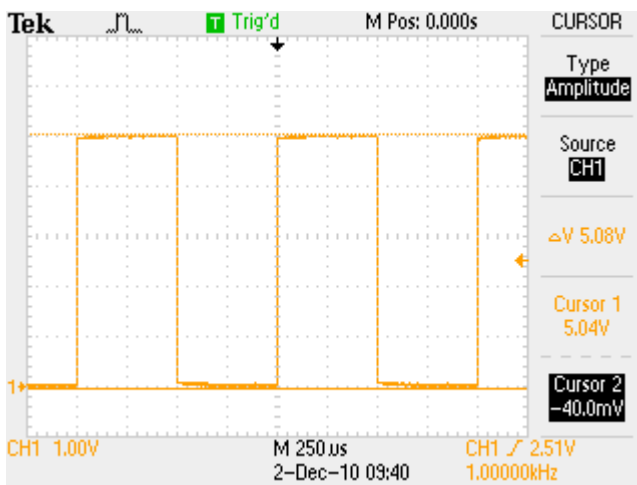
- The amplitude cursors measure voltage along the vertical axis.
- The time cursors measure time along the horizontal axis.
- The active cursor is displayed as a solid line, while the inactive cursor is displayed as a dotted line.

Push the **Type** side-bezel button until **Amplitude** cursors are selected.

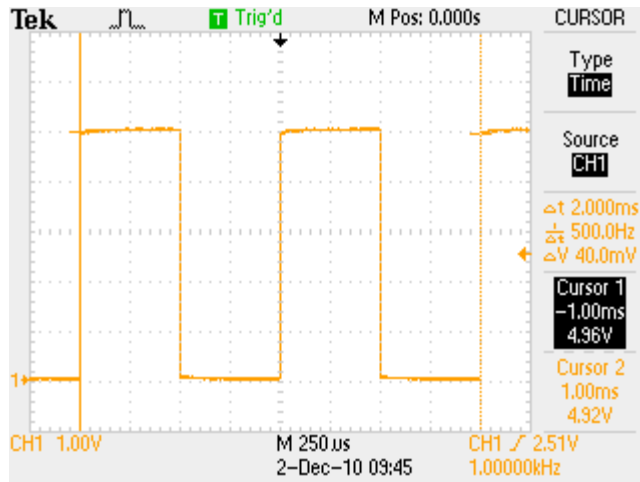
c. Notice that the **Cursor 1** side-bezel readout is highlighted and the LED next to the multipurpose control is lit. Turn the multipurpose control to position the upper horizontal cursor on top of the waveform.



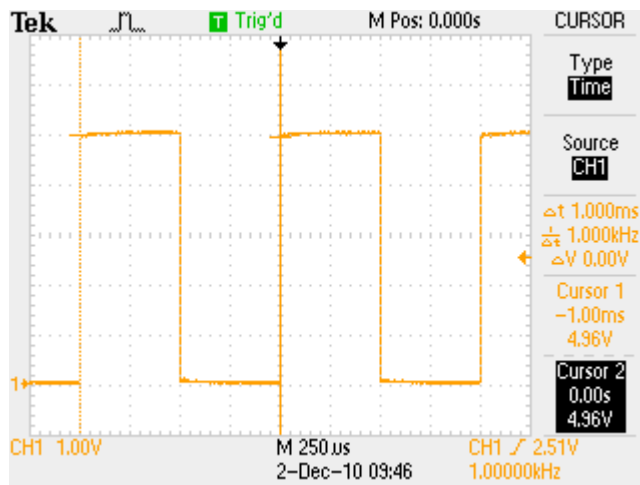
d. Push the **Cursor 2** side-bezel button. Turn the multipurpose control to position the lower horizontal cursor on the bottom of the waveform. Write the signal amplitude from the center right edge of the display in the Exercise section below.



- e. Push the **Type** side-bezel button once to select the Time cursors.
- f. Push the **Cursor 1** side-bezel button.
- g. Turn the multipurpose control to position the cursor at the start of one cycle of the signal (rising edge).



- h. Push the **Cursor 2** side-bezel button.
- i. Turn the multipurpose control to position the cursor at the end of one cycle of the signal (rising edge) and then read out the time on right edge of the display.

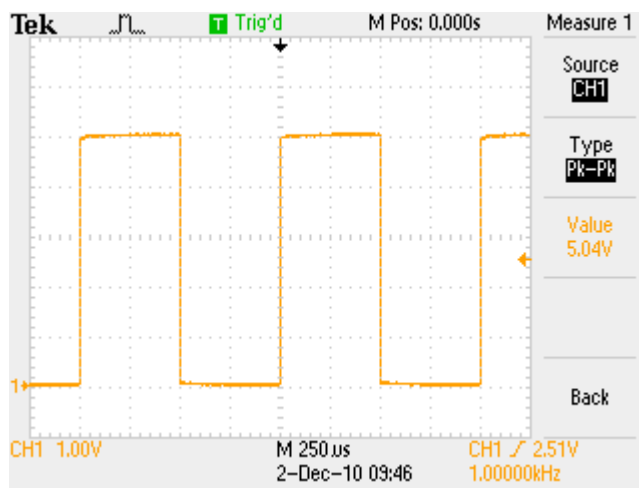


## Automated Measurements

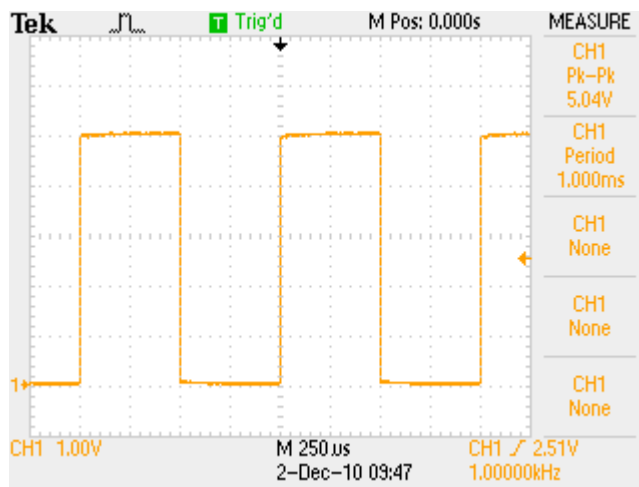
1. The TBS1000 Series oscilloscopes offer 16 automated measurements. To make automated peak-to-peak amplitude, period and frequency measurements, the oscilloscope needs to display at least one full cycle of the waveform and have the waveform fill as much of the vertical axis as possible without the signal going off the top or the bottom of the screen. This ensures the measurement algorithms have a complete description of the waveform in memory upon which to make calculations.

The next steps will use the oscilloscope's automated measurements to analyze the signal.

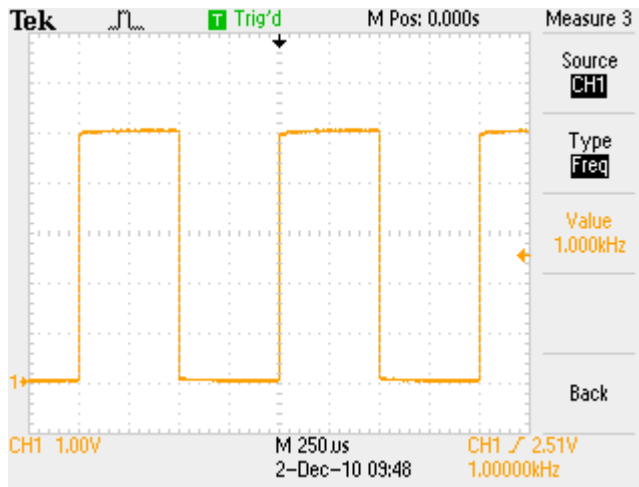
- a. Push the **Type** side-bezel button once to turn off the cursors.
- b. Push the front-panel **Measure** button.
- c. Push the top side-bezel button once.
- d. Push the **Type** side-bezel button until the **Pk-Pk** measurement is selected.



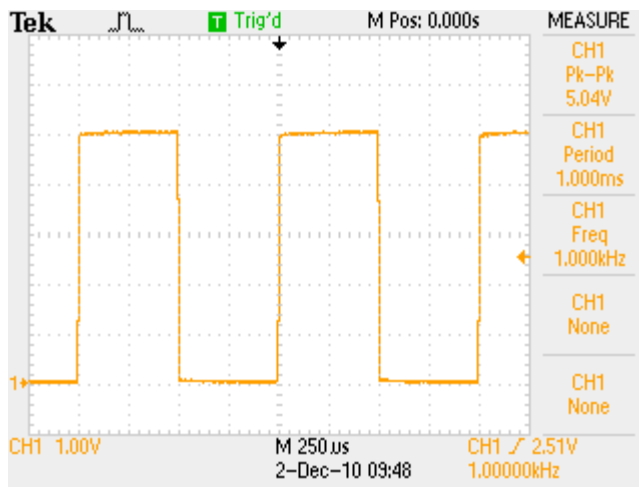
- e. Push the **Back** side-bezel button to return to the main Measure menu.
- f. Push the second-from-the-top side-bezel button once.
- g. Push the **Type** side-bezel button until the **Period** measurement is selected.



- h. Push the **Back** side-bezel button to return to the main Measure menu.
- i. Push the third-from-the-top side-bezel button once.
- j. Push the **Type** side-bezel button until the **Freq** measurement is selected.



- k. Push the **Back** side-bezel button. The Pk-Pk, Period and Freq automated measurements should now be displayed at the side of the screen.



### Key Points to Remember

1. Measurements can be made manually, with cursors or automatically using firmware-based algorithms that process waveform data stored in the oscilloscope's memory.
2. Manual measurements have the lowest accuracy, cursors are typically more accurate than manual measurements and automated measurements are the most accurate of all the techniques.
3. All signal elements pertaining to an automated measurement must be displayed on the oscilloscope's screen.



## Test Your Knowledge

1. The first parameter to consider when choosing an oscilloscope is:

- a. Size
- b. Record Length
- c. Bandwidth
- d. Number of Measurements

**Answer: c**

2. Oscilloscopes usually:

- a. Display amplitudes such as voltages on the vertical axis of the display.
- b. Provide the most-commonly used controls on the front panel.
- c. Provide multiple ways to make waveform parameter measurements.
- d. All the above.

**Answer: d**

3. A typical digital oscilloscope:

- a. Conditions analog input signals with amplification.
- b. Samples the input signals at a high sample rate and converts them to digital format.
- c. Stores the digitized waveform data in memory and displays the waveform on the display.
- d. All the above.

**Answer: d**

4. The three primary sets of oscilloscope controls are:

- a. Vertical, Measurements and Display
- b. Horizontal, Autoset and Measurements
- c. Vertical, Horizontal and Trigger
- d. Trigger, Measurements and Cursors

**Answer: c**

5. Oscilloscopes can make measurements with:

- a. Automated measurements using firmware-based algorithms to process stored waveform data.
- b. Cursor measurements.
- c. Manual measurements based on the graticule of the display.
- d. All the above.

**Answer: d**

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