Collection of slides on laboratory instrumentation

Laboratory instrumentation: quick recap

Warning: this is not the ELECTRONIC INSTRUMENTATION course!

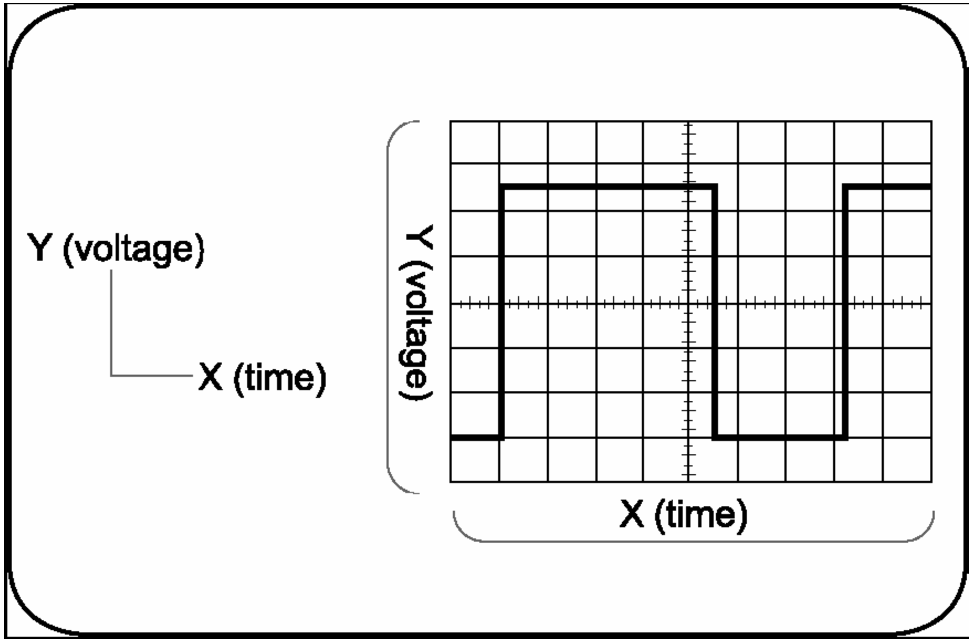
We will explain how to use lab instrumentation (based on a practical approach), but not the related theory!

For a complete reference on this refer to the ELECTRONIC INSTRUMENTATION course

Before you enter the labs, make sure you have passed the exams on safety and risks!!!

The oscilloscope

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



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

An oscilloscope contains various controls that assist in the analysis of waveforms displayed on a graphical grid. The grid is divided into divisions along both the horizontal and vertical axes. These divisions make it easier to determine key parameters about the waveform

The oscilloscope

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

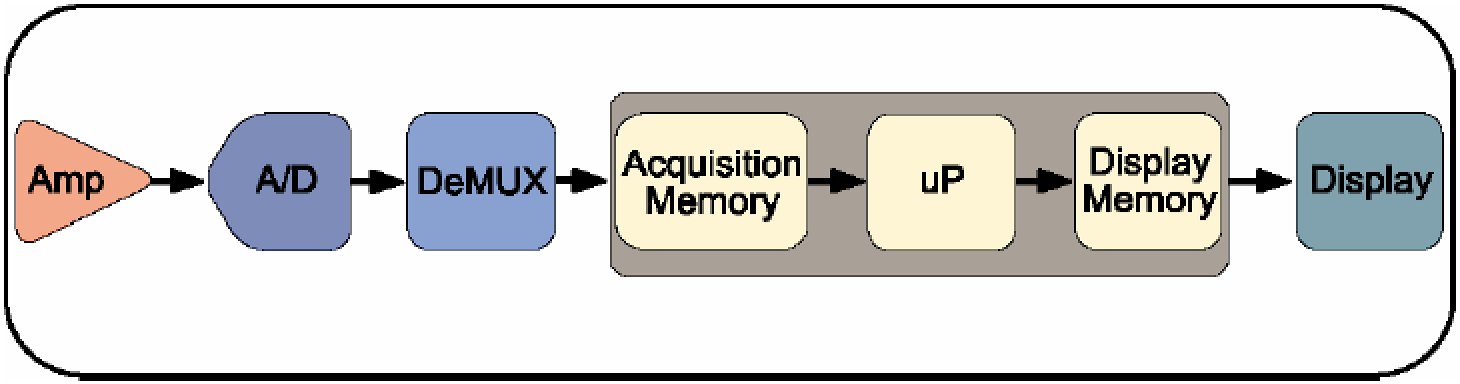
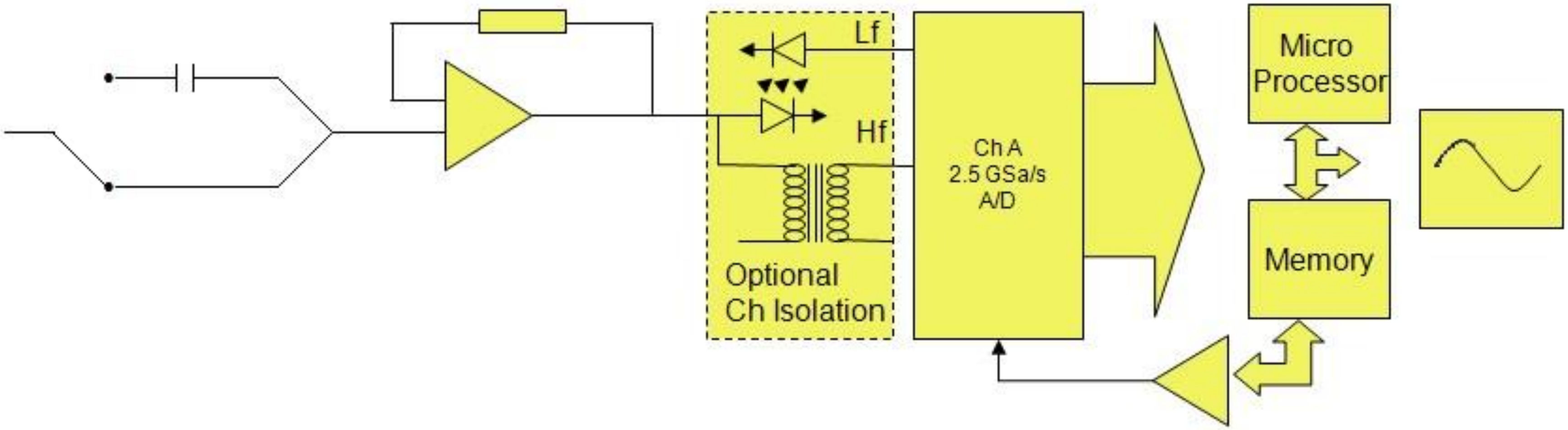


Figure 2: Typical Digital Oscilloscope Block Diagram

Oscilloscope: architecture



<u>Input Coupling</u>
•AC or DC

<u>Amplitude Control</u>
•Attenuation
•Amplification

<u>Channel Isolation</u>
•Up to 1000 Volt isolation
•Available on some scopes

<u>A to D Conversion</u>
•Real time
•Up to 2.5 GSa/s

<u>Triggering</u>
•Edge
•Edge Delay
•Pulse Width
•N-Cycle

<u>System Control</u>
•Sample Storage
•Measure functions
•Graphics processing
•User interface

Oscilloscope: performance

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.

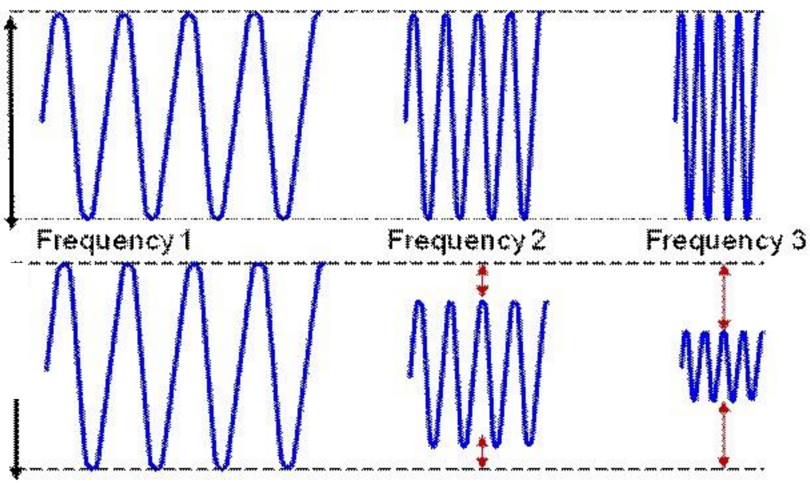
When measuring high-frequency or fast rise-time signals, oscilloscope bandwidth is especially critical. Without adequate bandwidth, an oscilloscope will not be able to display and measure high-frequency changes. It is generally recommended that the oscilloscope's bandwidth be at least 5 times the highest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

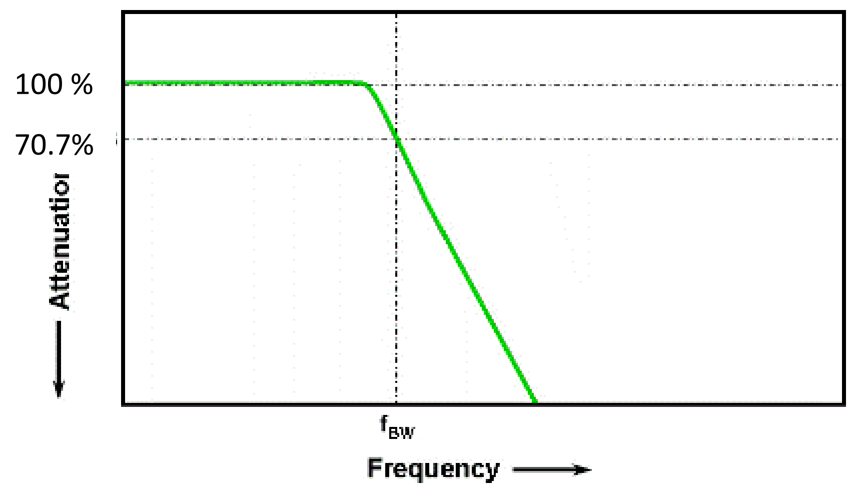
$$\textit{oscilloscope bandwidth} \geq 5^{th} \textit{ harmonic of signal}$$

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

Test signal

Displayed sine wave





Oscilloscope: performance

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.

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

Example: The correct sample rate for a 450 MHz signal would be ≥ 2.25 GS/sec.

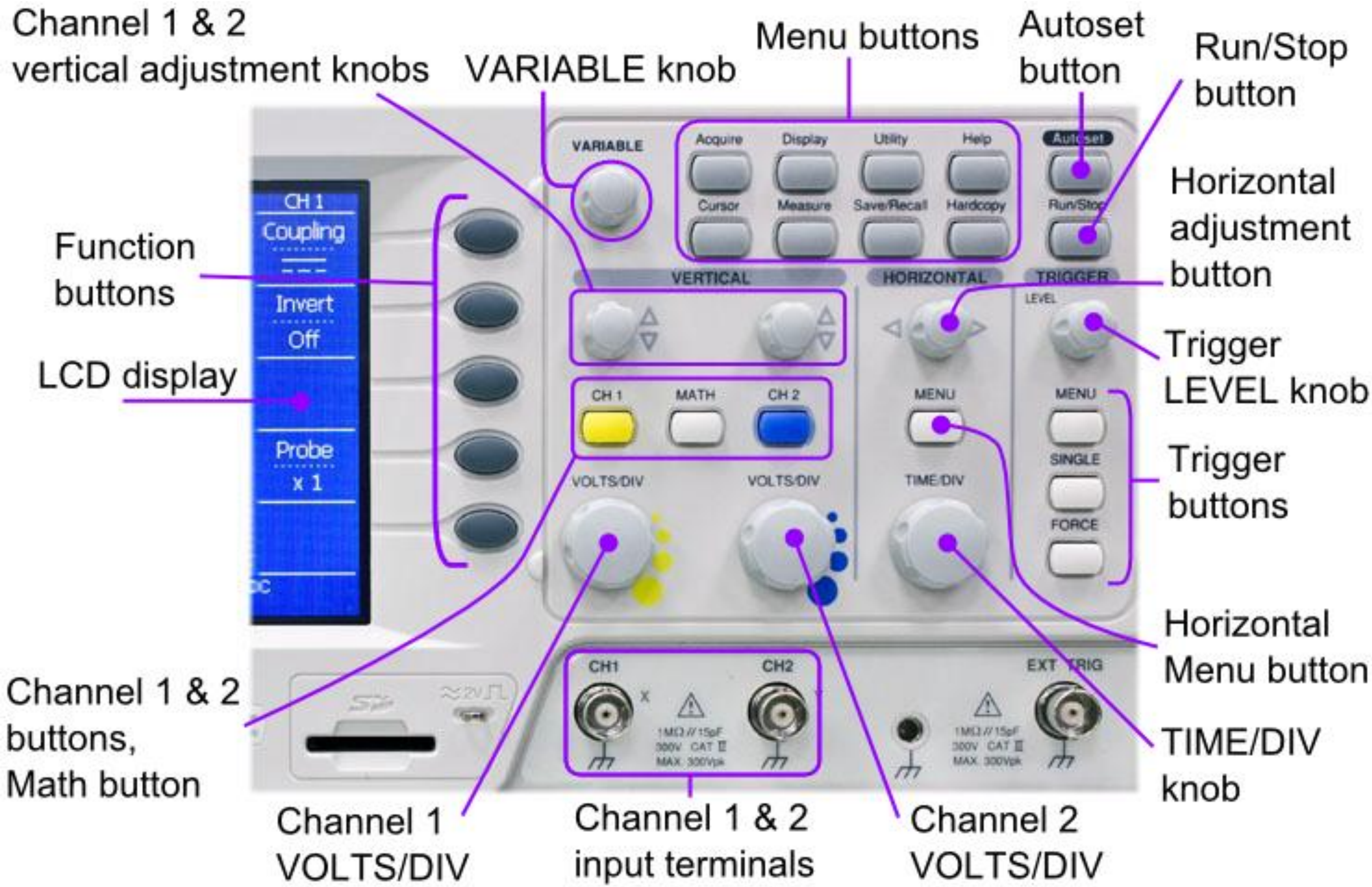
Record Length

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.

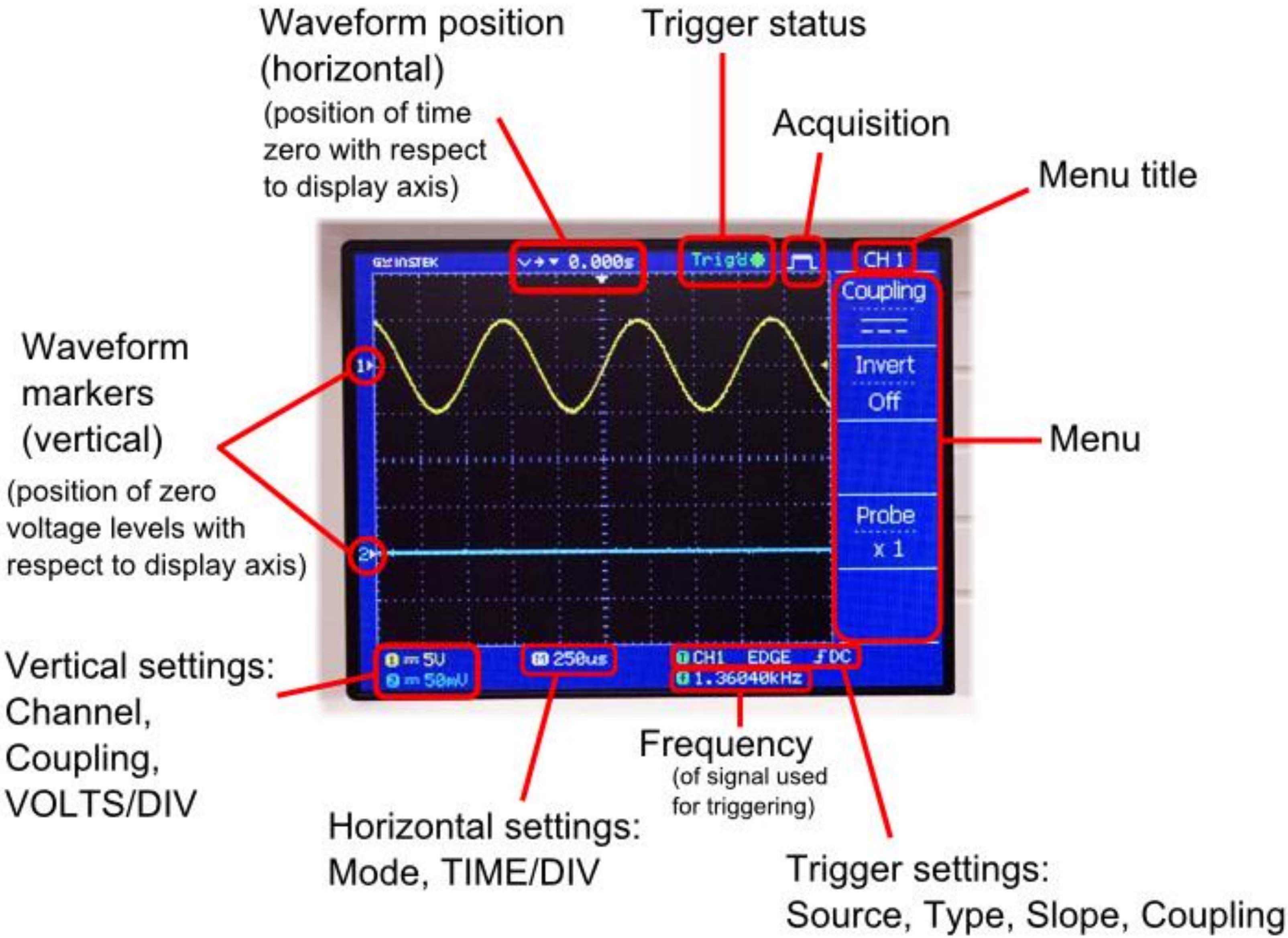
$$acquired\ time = \frac{record\ length}{sample\ rate}$$

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.

Oscilloscope: typical control panel

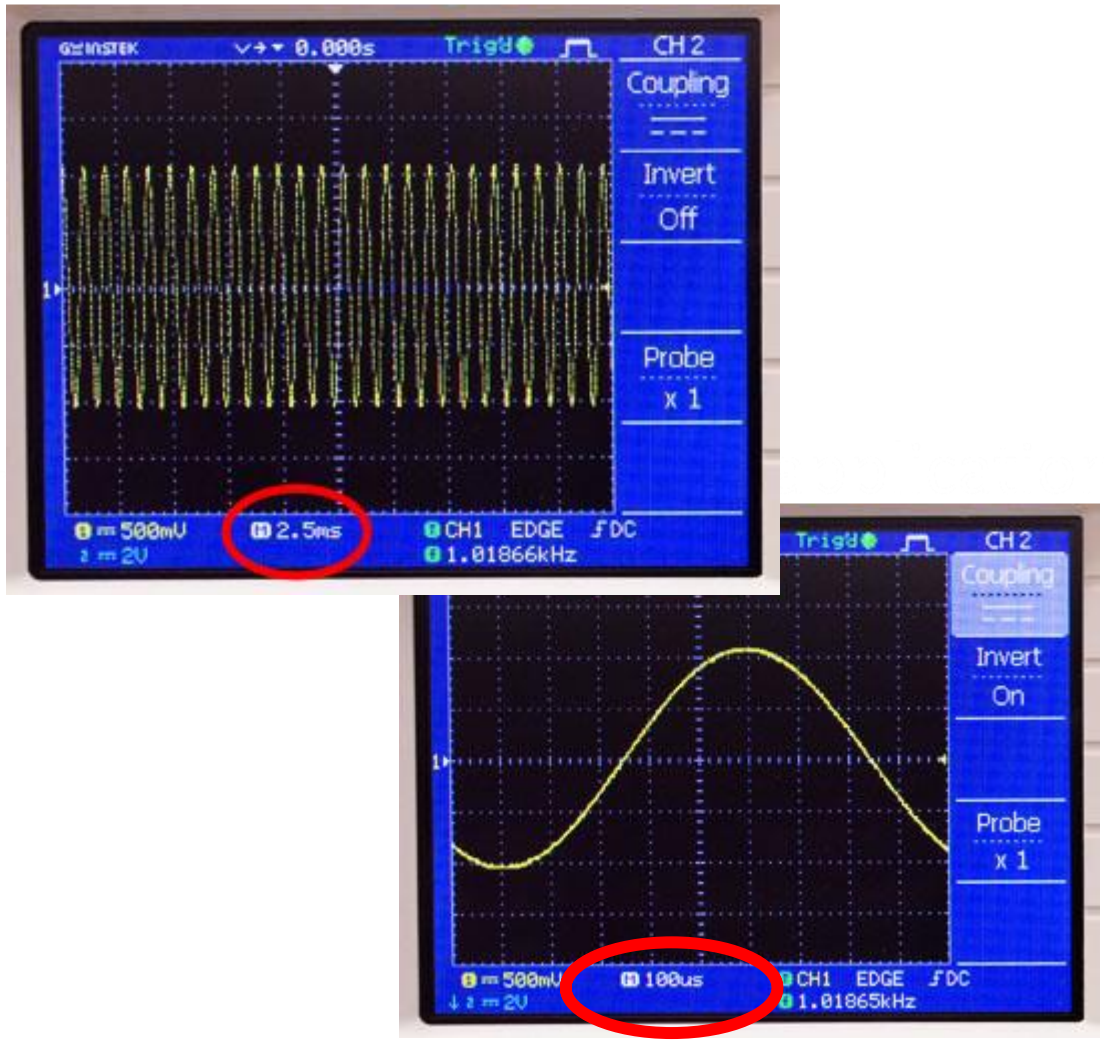


Oscilloscope: typical display



The time/div controls

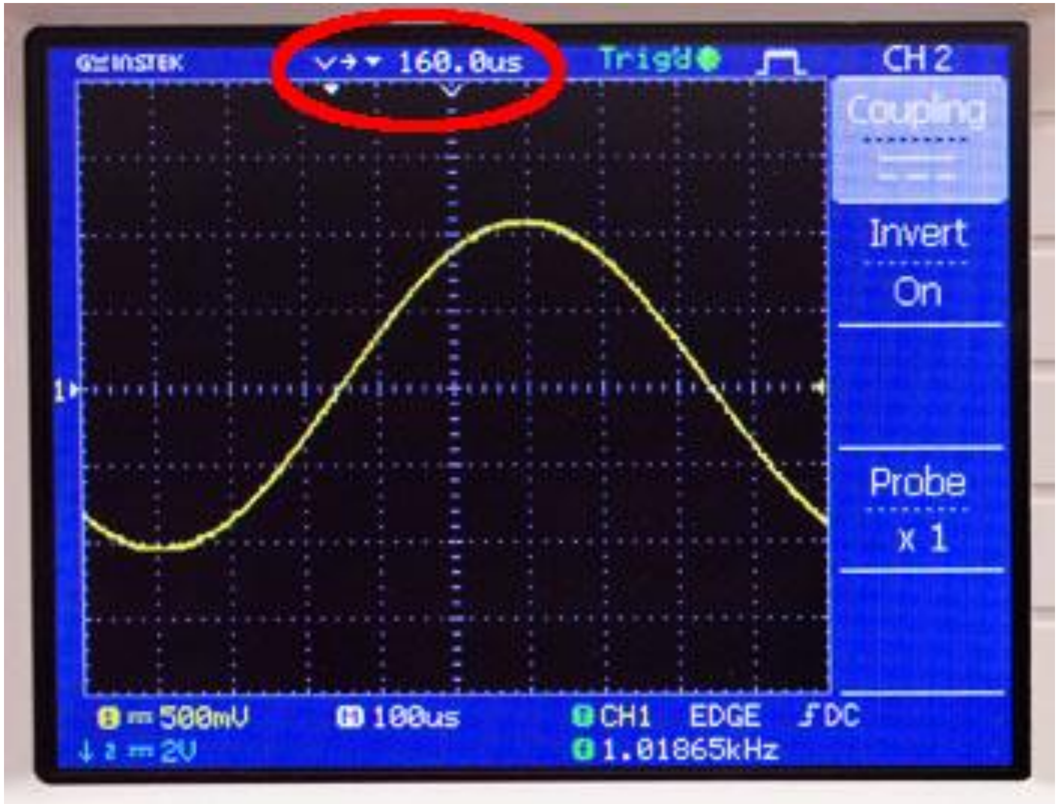
This knob will adjust the horizontal scale of the waveform;
Look carefully at the time/DIV indicator to read the time scale!



The horizontal adjustment controls

This knob will adjust the position of the waveform in the horizontal direction.

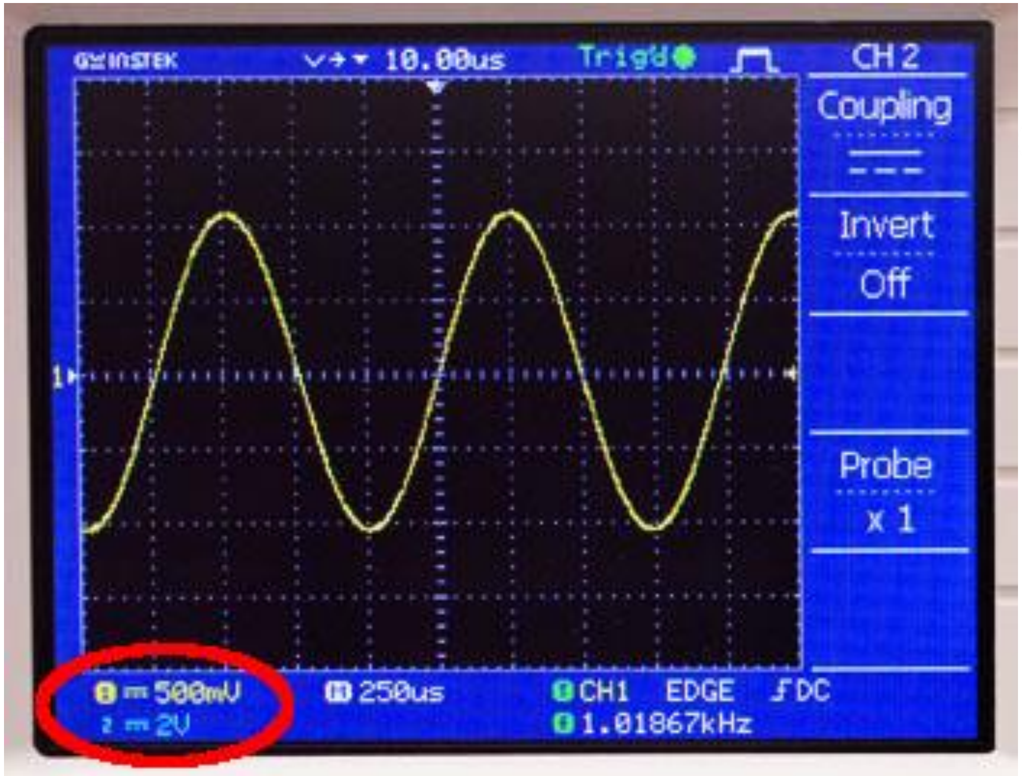
A small arrow at the top of the display will move to the left or right of the central zero position and above this the current displacement from zero is shown in appropriate units of time (circled, right).



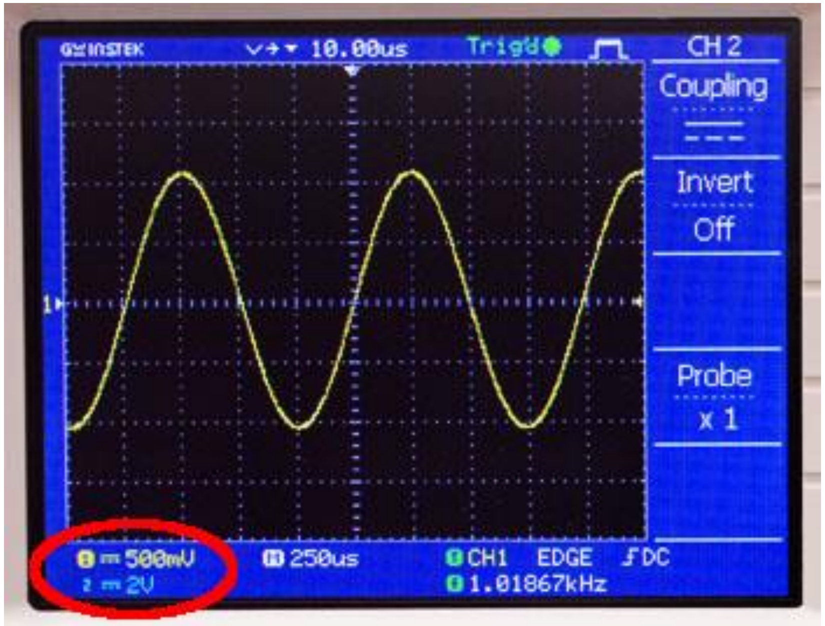
VOLTS/DIV controls

These controls will adjust the vertical scale of the waveforms on channels 1 & 2 independently.

In this scope, the current scale (the Volts / Division) for each channel is shown at the bottom left of the display next to the channel number (circled, right), irrespective of whether the channel is being displayed or not

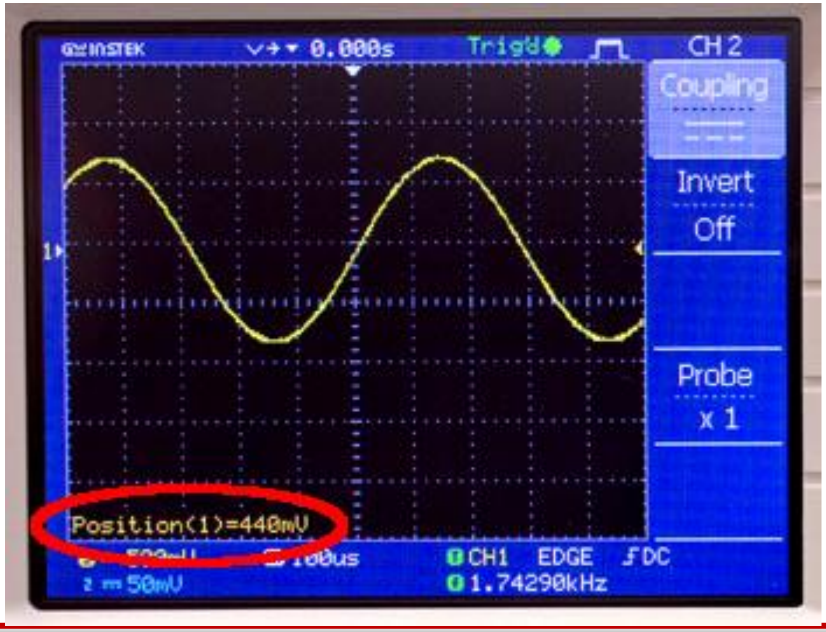


Vertical adjustment controls



These controls will adjust the positions of the waveforms in the vertical direction on channels 1 & 2 independently.

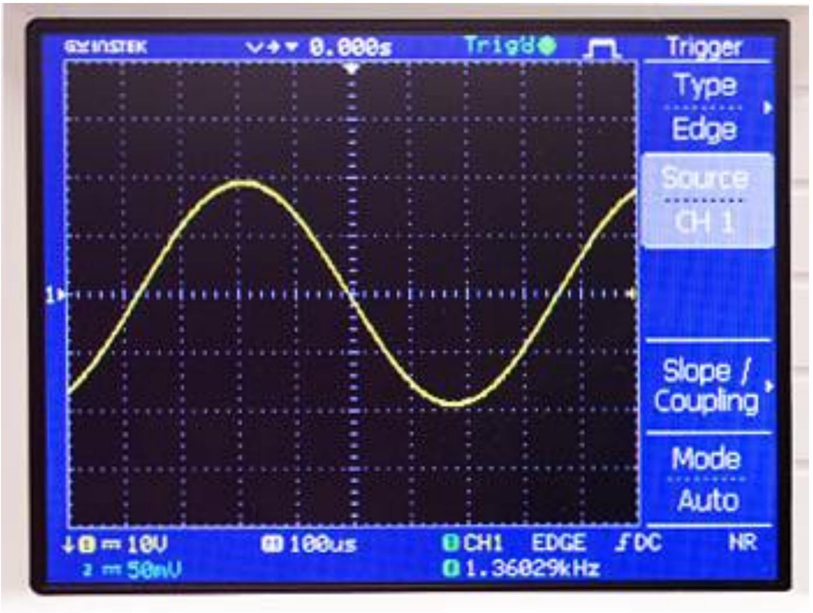
The current displacement of the waveform from the central zero position is shown to the lower left of the display (circled, right) each time the position is adjusted.



Triggering

Often, when looking at signals with an oscilloscope, you're looking at a repeating signal. Triggering allows you to horizontally align repetitions of this signal. When the oscilloscope sees a trigger event, it knows to put a trace onto the screen horizontally aligned with the Trigger Alignment Indicator. A trigger event happens when the voltage goes past the Trigger Level.

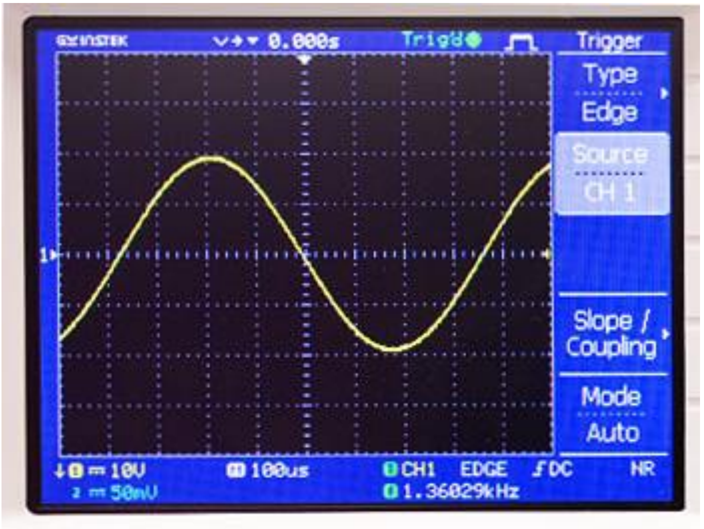
You can best appreciate the trigger by moving the trigger level to a voltage that the trace never reaches. For example, move the trigger level to -2 volts and you should see the trace dance across the screen. Now, move the trigger level back to 0 volts for channel 1 and the trace should stabilize.

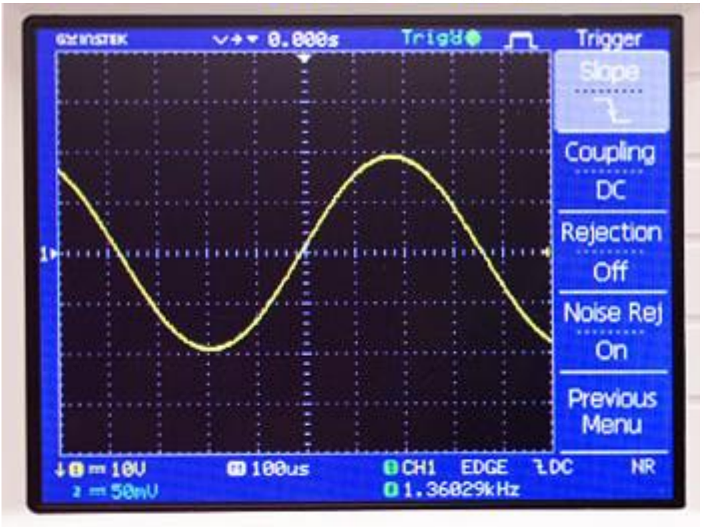


Trigger options

Trigger source

- CH 1: triggering signal on channel one
- CH 2: triggering signal on channel two
- External: triggering off a signal that is carried by an input to the "EXT TRIGGER" terminal on the lower right of the oscilloscope
- Line: triggering off the AC mains signal

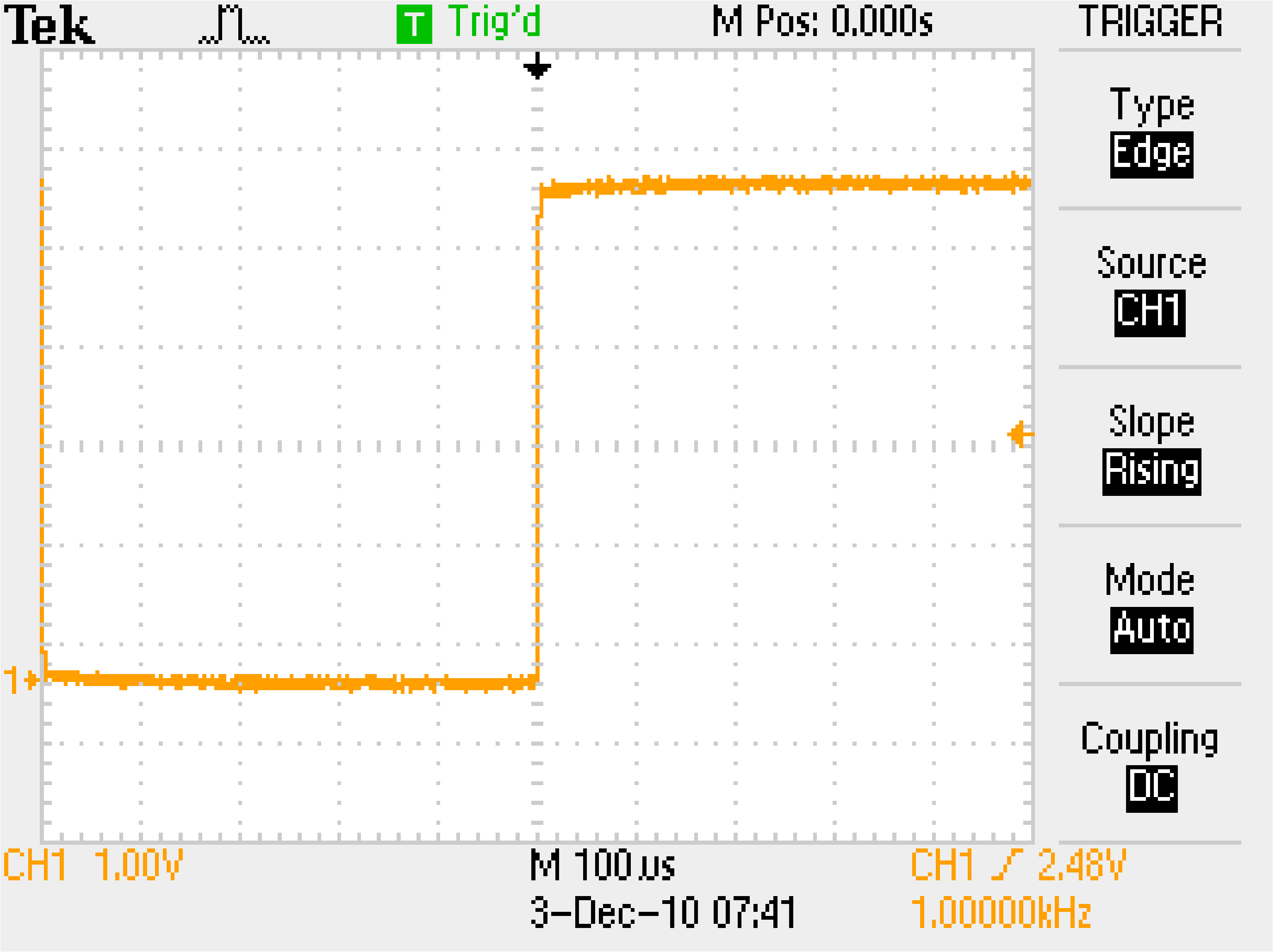




Slope : the oscilloscope can be set to trigger as the signal is rising or falling (i.e. Slope)

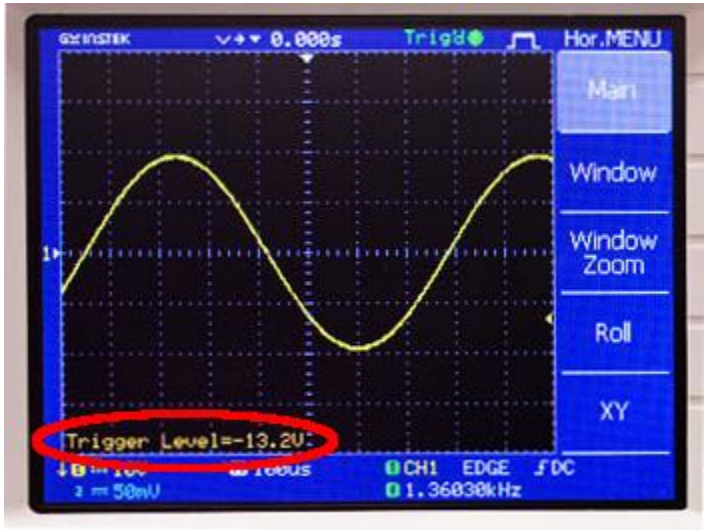
Coupling: whether the Coupling is to the full signal carried by the source (DC Coupling) or just AC portion of it (AC Coupling).

Another screenshot (Tektronix Scope)



Trigger level

Trigger Level: the trigger level is the voltage at which the sinchronization, capture and display of the signal begins

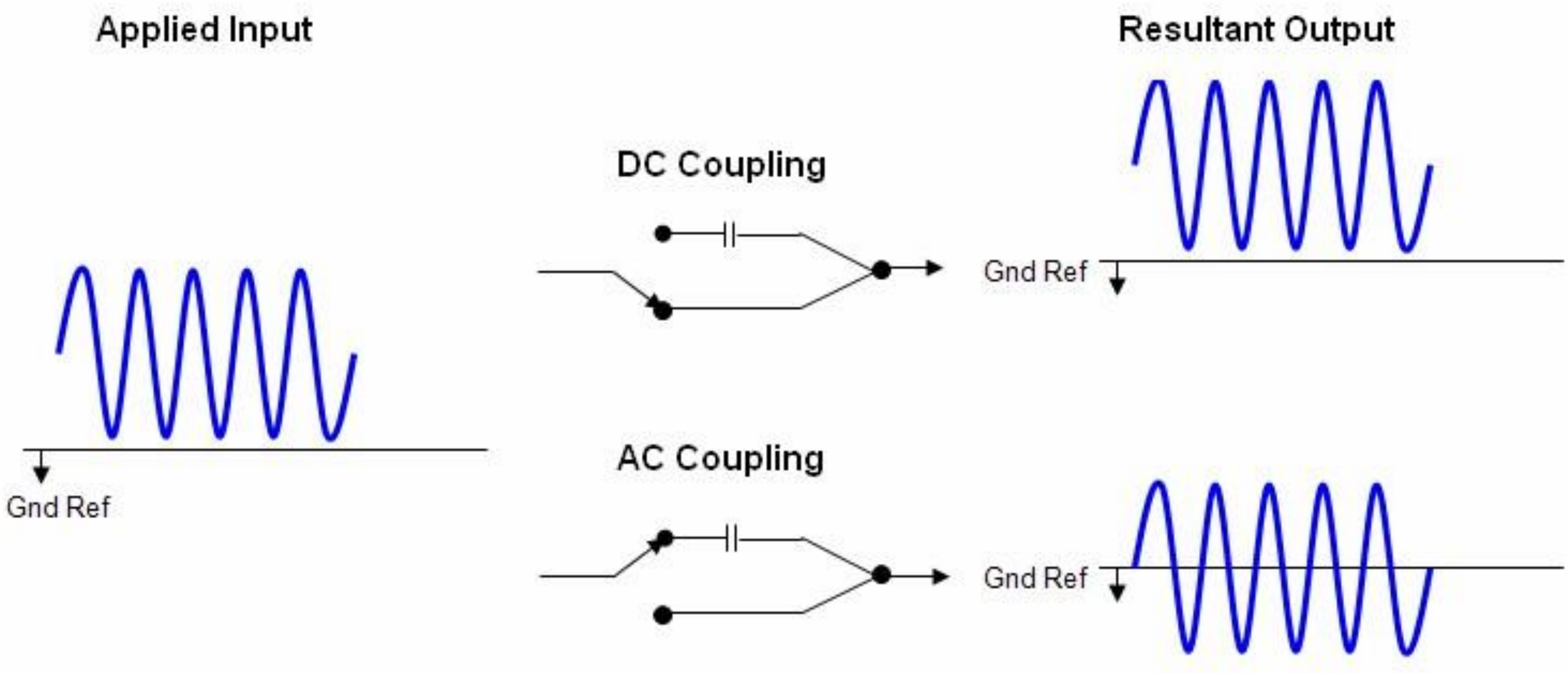


Channel selection: the Channel buttons CH1 and CH2 select and deselect the waveforms carried by inputs 1 & 2.

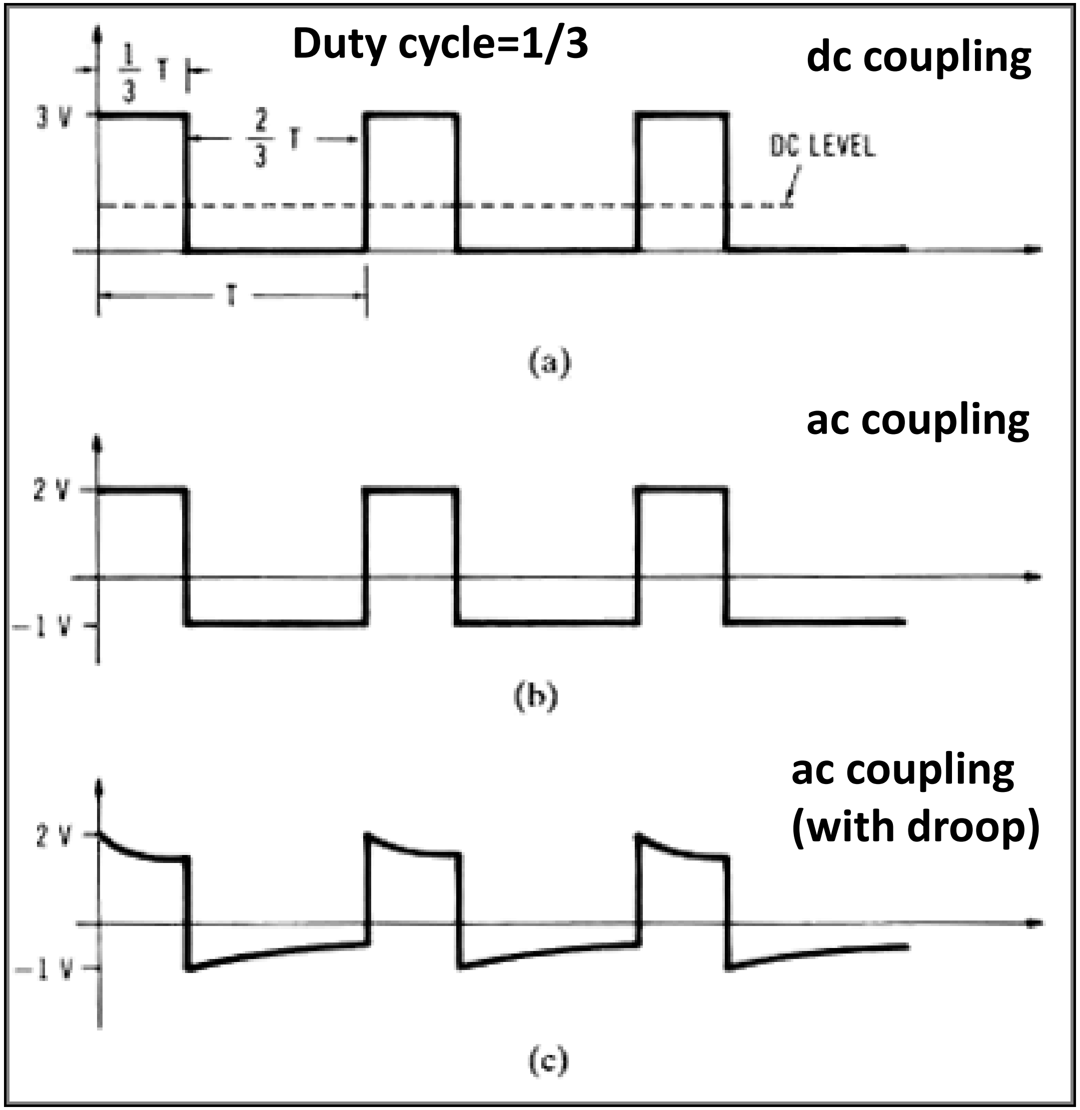
To display a channel that is not currently selected you must press the appropriate channel button. The corresponding number will then be highlighted at the far lower left of the display

Coupling

Each input can be selectively AC or DC coupled. DC coupling allows both DC and AC signals through, while AC coupling accepts only AC signals



Issues related to coupling



Consider the pulse waveform in Figure a, shown as a DC coupled scope would display it.

When the scope is AC coupled, the display changes. The waveform shifts down by about one-third of its original zero-to-peak value (Figure b).

The AC coupling removed the DC, leaving a waveform whose average value is zero. Notice that the waveform is not centered exactly on zero volts, since its duty cycle is 1/3.

AC coupling may also cause voltage "droop" or "sag" in the waveform (Figure c), due to the loss of low frequencies

1 MΩ or 50 Ω of input coupling?

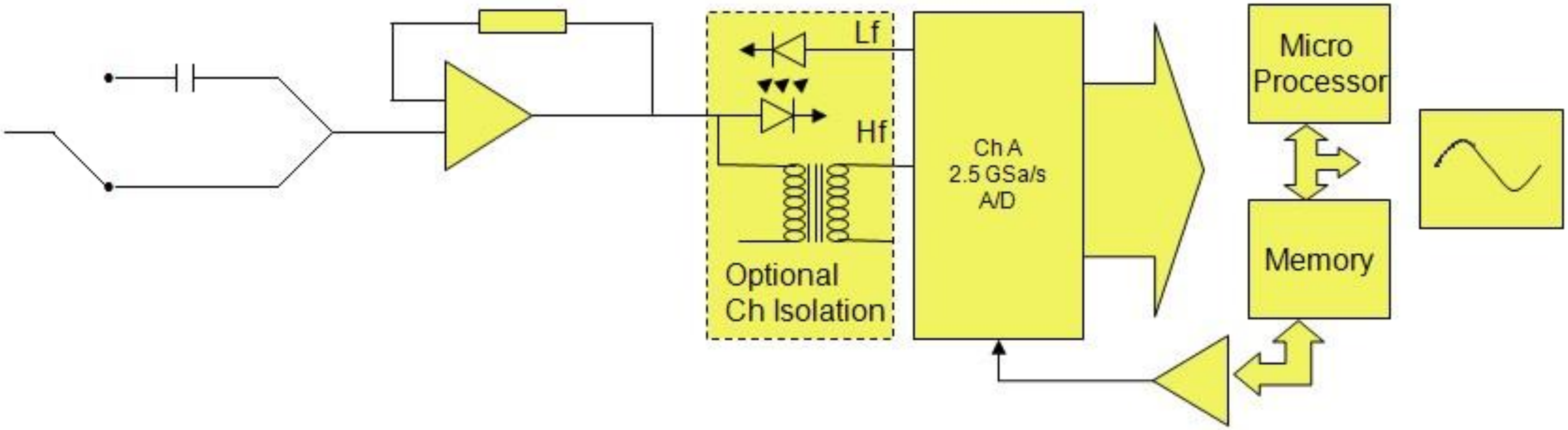
The input signal can be coupled either with 1 MΩ or 50 Ω of input impedance.

If we select 50 Ω of input coupling, we send the input signal directly to the oscilloscope vertical gain amplifier (maximum 5 V!!!)

By selecting 1 MΩ coupling, the oscilloscope places a filter/amplifier in front of the vertical gain amplifier, thus limiting the bandwidth. **The benefit of such approach is inherent protection from high input voltages (e.g. up to 200 V).**

In our labs, you will always have to work with a 1 MΩ coupling (so we can work with high voltages without destroying the oscilloscope)

Oscilloscope: architecture



Input Coupling
- AC or DC

Amplitude Control
- Attenuation
- Amplification

Channel Isolation
- Up to 1000 Volt isolation
- Available on some scopes

A to D Conversion
- Real time
- Up to 2.5 GSa/s

Triggering
- Edge
- Edge Delay
- Pulse Width
- N-Cycle

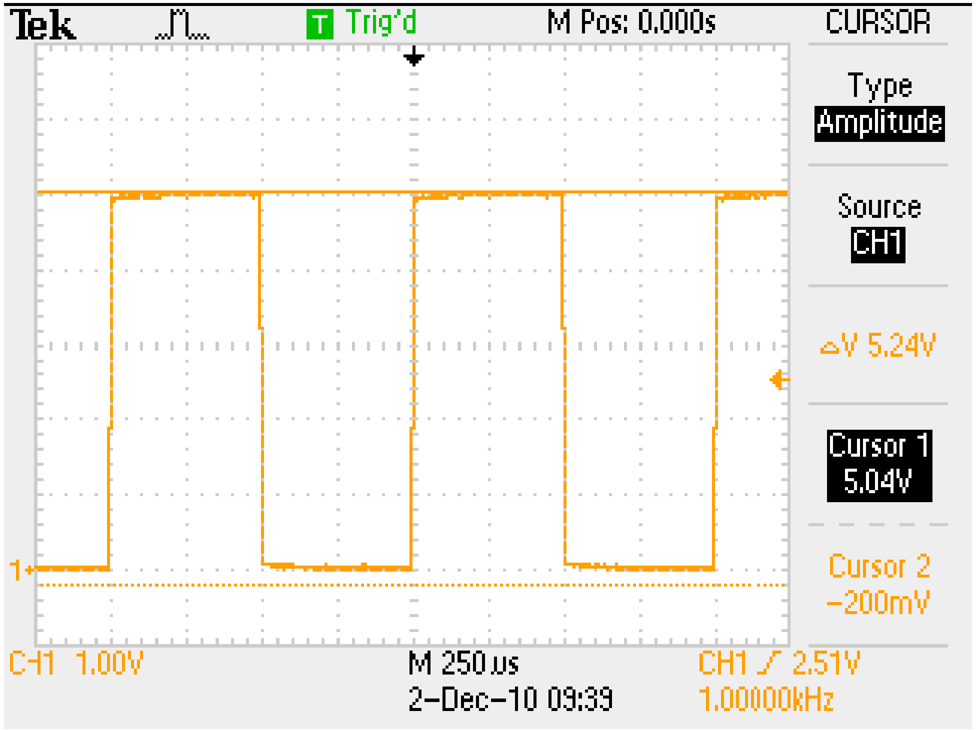
System Control
- Sample Storage
- Measure functions
- Graphics processing
- User interface

Oscilloscope measurements

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

(manual) 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.

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

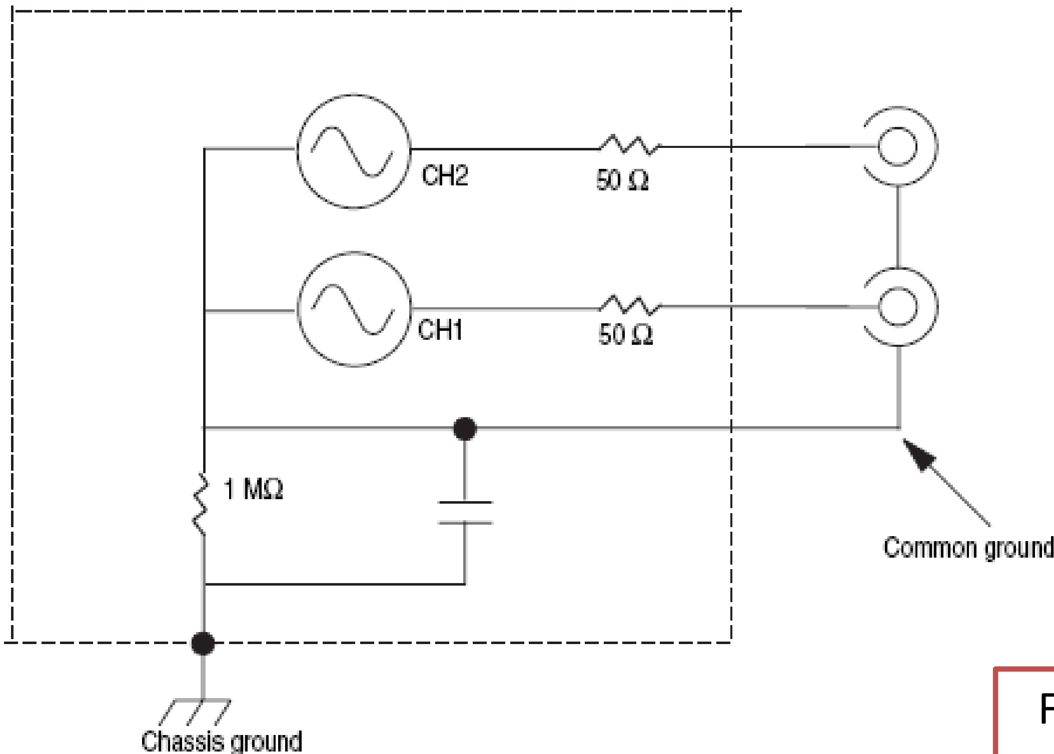


Use the multipurpose controls (knobs) to move the cursors on the screen and read the related voltage/time levels

Get confident with the oscilloscope in the lab!!

The function generator (Keysight 33220A)

50 Ω output coupling



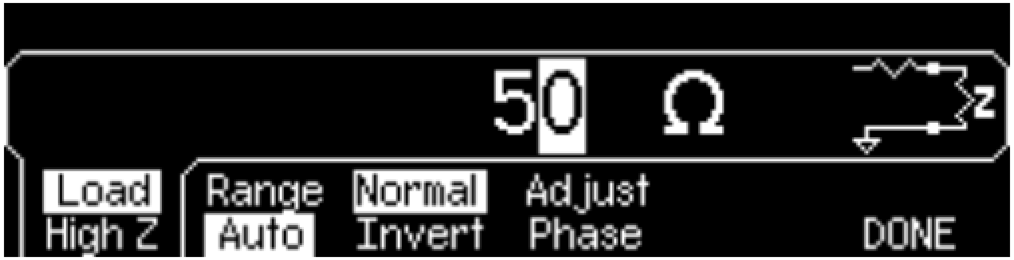
In many cases function generators have an output resistance of 50 Ω

This means that if you set a 1 V output, you'll get:

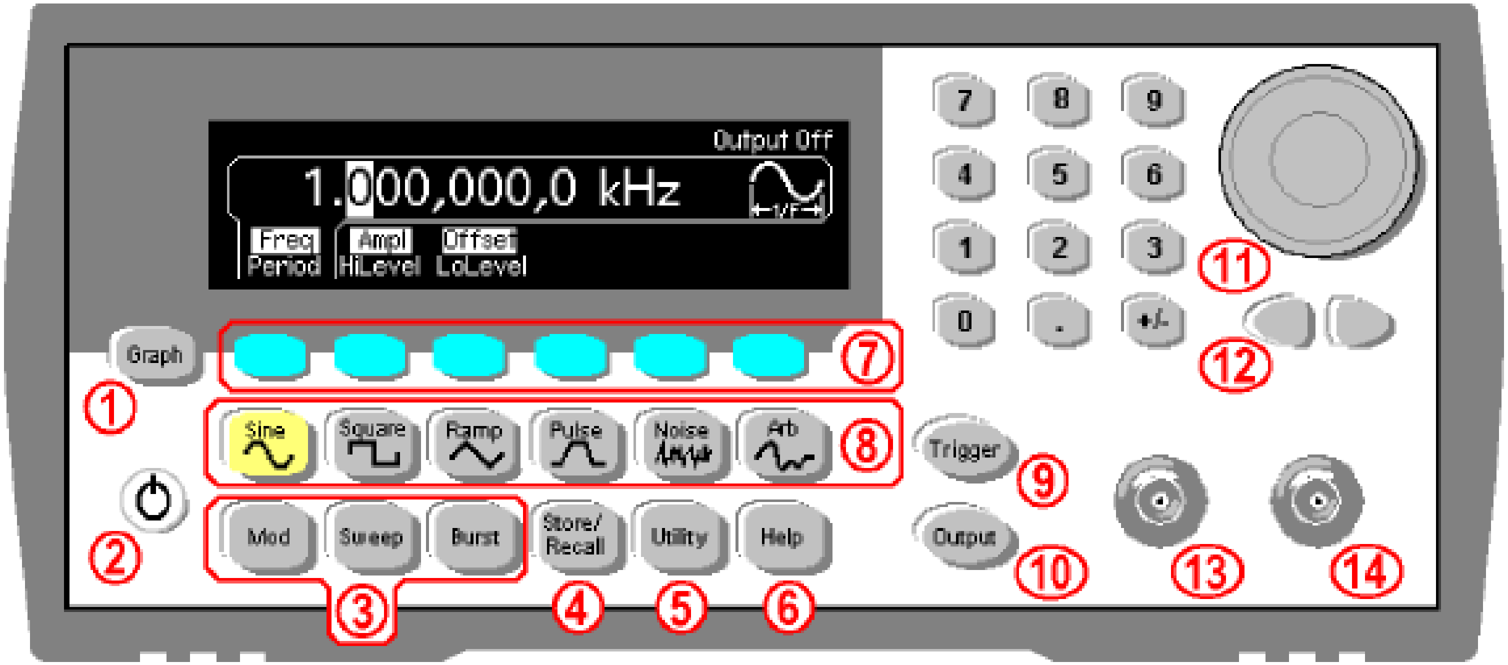
- V_{out}=1 V if the load is 50 Ω
- V_{out}=2 V if the load has high impedance ($R_{IN}=\infty$)

For the experiments, you will always have to use High Impedance coupling!

If the actual load impedance is different than the value specified, the displayed amplitude and offset levels will be incorrect. The output impedance can be adjusted (to visualize correct values), by pressing Utility



The front panel at a glance



Lighted keys indicate active keys and functions (for example Sine above).

The Primary Front Panel Features:

1 Graph Mode Key
2 On/Off Switch
3 Modulation/Sweep/Burst Keys
4 State Storage Menu Key
5 Utility Menu Key
6 Help Menu Key
7 Menu Operation Softkeys

8 Waveform Selection Keys
9 Manual Trigger Key (Sweep and Burst only)
10 Output Enable/Disable Key
11 Knob
12 Cursor Keys
13 Sync Connector
14 Output Connector

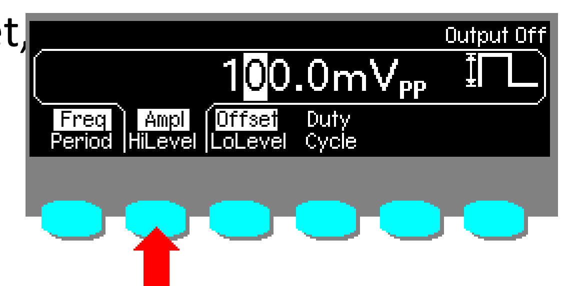
Main Functions

1. Lighted keys indicate active keys or functions → for example the currently active waveform (for example Sine). Most keys toggle on (lighted) or off (not lighted).

2. No signal is output unless the Output key is lighted

3. In Menu Mode, the six softkeys allow you to select parameters and functions as shown in the menu at the bottom of the display. Some softkeys toggle between related parameters. For example, the left softkey toggles between **Freq and Period below:**

4. You can specify a signal by its amplitude and offset, **(maximum) and Lo Level (minimum) values**



Quick start

2. Turn On

Press the On/Off Switch:

The self test takes a few seconds, and then the instrument defaults to Menu Mode with the sine wave function selected:

Note: To protect your equipment, no signal is output until the Output key is pressed (lighted).

3. Select a Waveform

To select a waveform, press the appropriate key. For example, press the Square key to select a square wave. Try it!

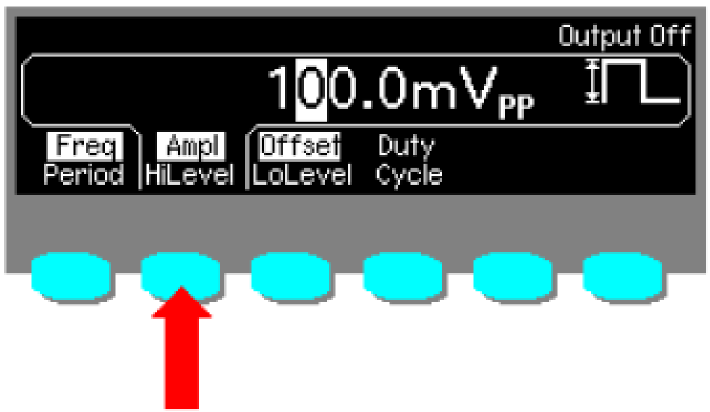
The square wave menu is displayed:

Go to Step 4 at Right

4. Change Waveform Parameters (Knob)

Use the six softkeys to select parameters. Some softkeys toggle between related parameters (for example: **Freq** and **Period**).

For example, press the **Ampl** softkey to select amplitude:



Now let's change the value using the knob.

First, use the cursor keys ( ) to select the first digit. Try it!

Now, use the knob to change the value (turn clockwise to increase). Set it to **500 mVpp**:

Now, press **Offset** to select that parameter:

Use the knob to set the offset to **-1.1 Vdc**:

- Turn left past zero for a negative value.
- Use the cursor keys to select digits.

Tip **Another Way to Set Signal Levels**

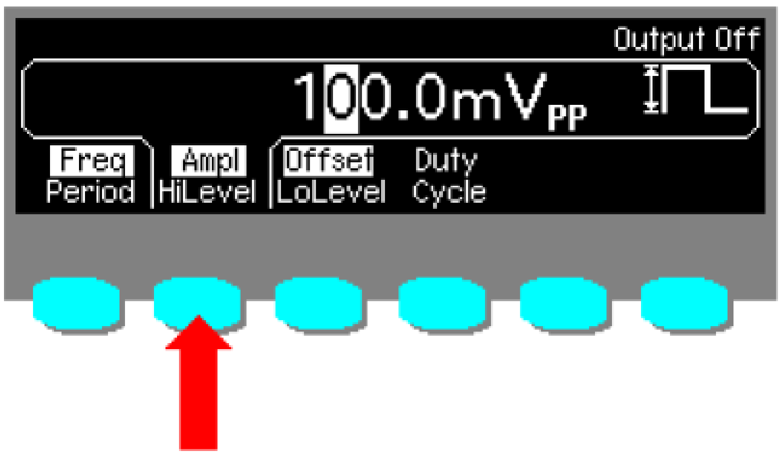
You can also specify a signal by setting its **Hi Level** (maximum) and **Lo Level** (minimum) values. (See Chapter 1 in the *User's Guide*.)

Go to Step 5 at Far Left, Below

4. Change Waveform Parameters (Knob)

Use the six softkeys to select parameters. Some softkeys toggle between related parameters (for example: **Freq** and **Period**).

For example, press the **Ampl** softkey to select amplitude:



Now let's change the value using the knob.

First, use the cursor keys ( ) to select the first digit. Try it!

Now, use the knob to change the value (turn clockwise to increase). Set it to **500 mVpp**:

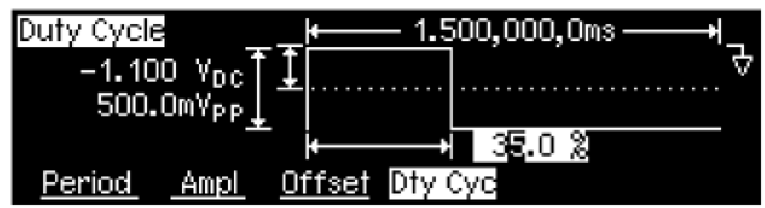
6. Select Graph Mode

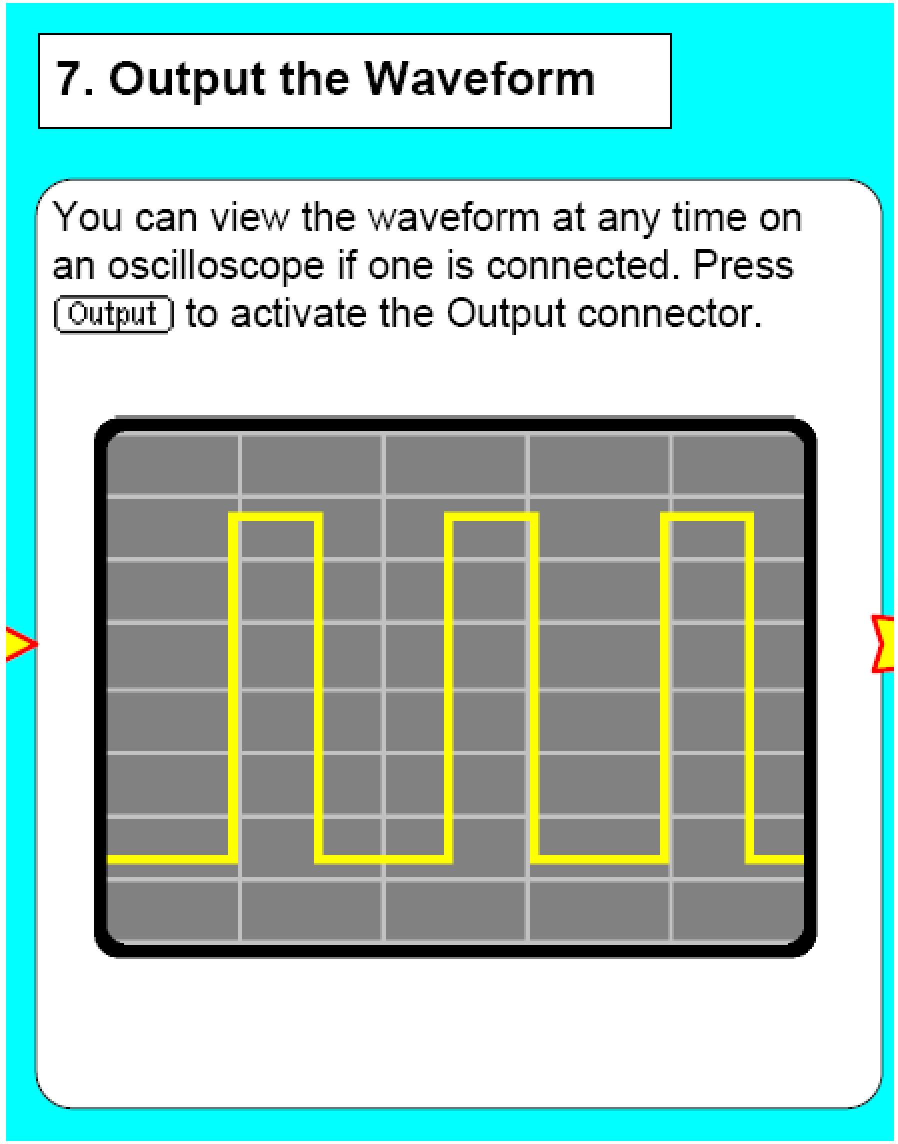
Press Graph (left side of front panel) to select Graph Mode, which displays the waveform:

Note: The Graph key toggles between Graph Mode and Menu Mode. The key is lighted in Graph mode.

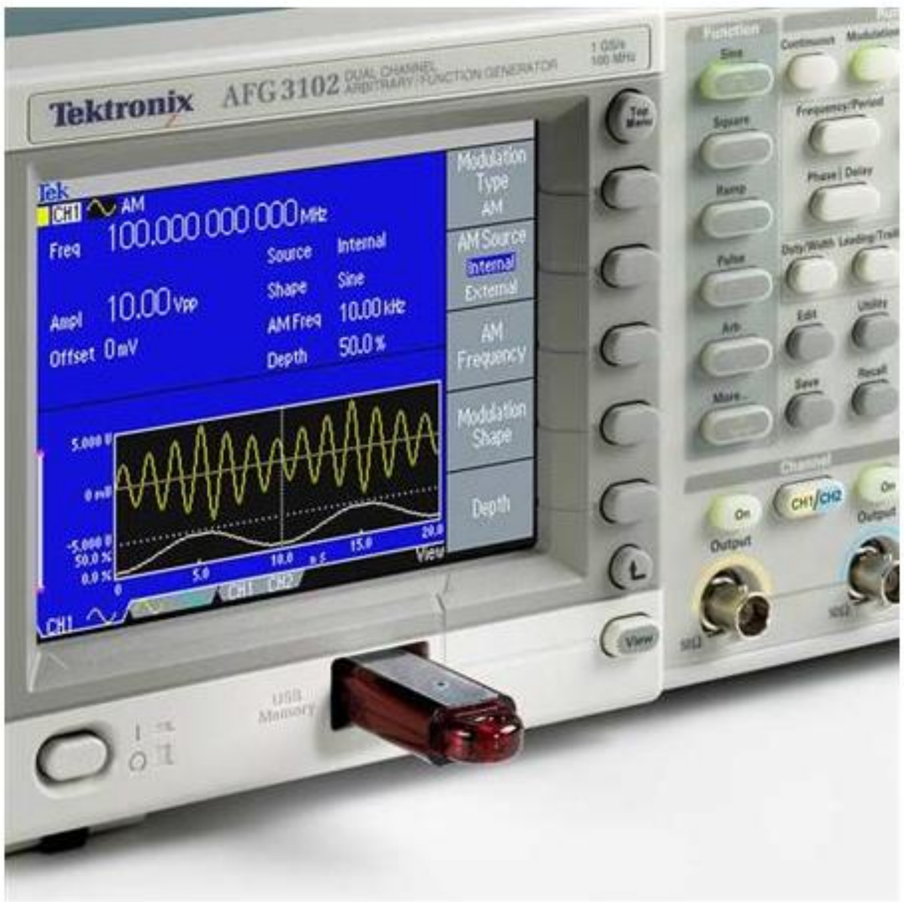
Now let's change the duty cycle. First press the **Dty Cyc** softkey:

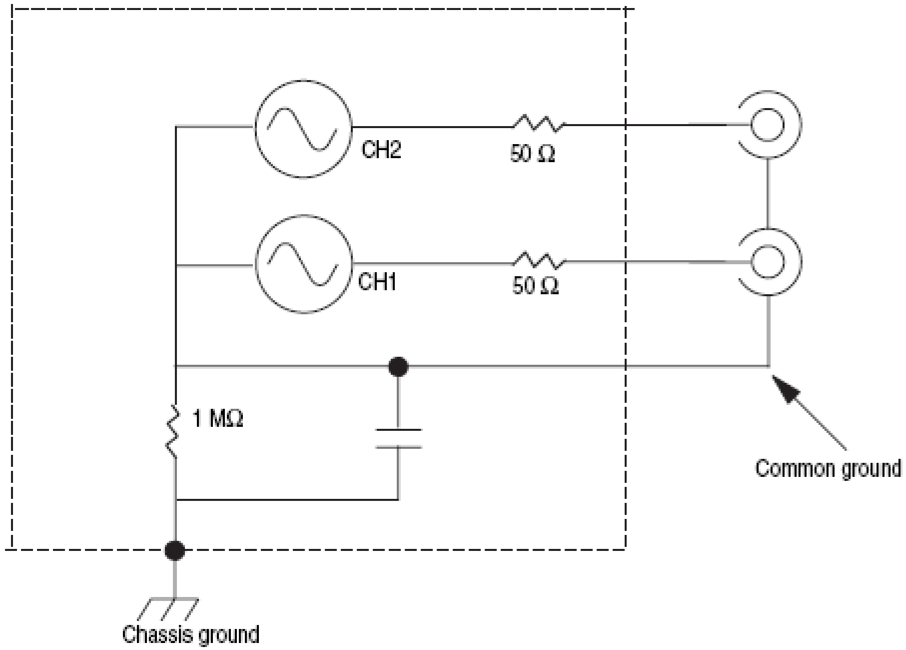
Use either the knob or the keypad to change the value to 35 %:



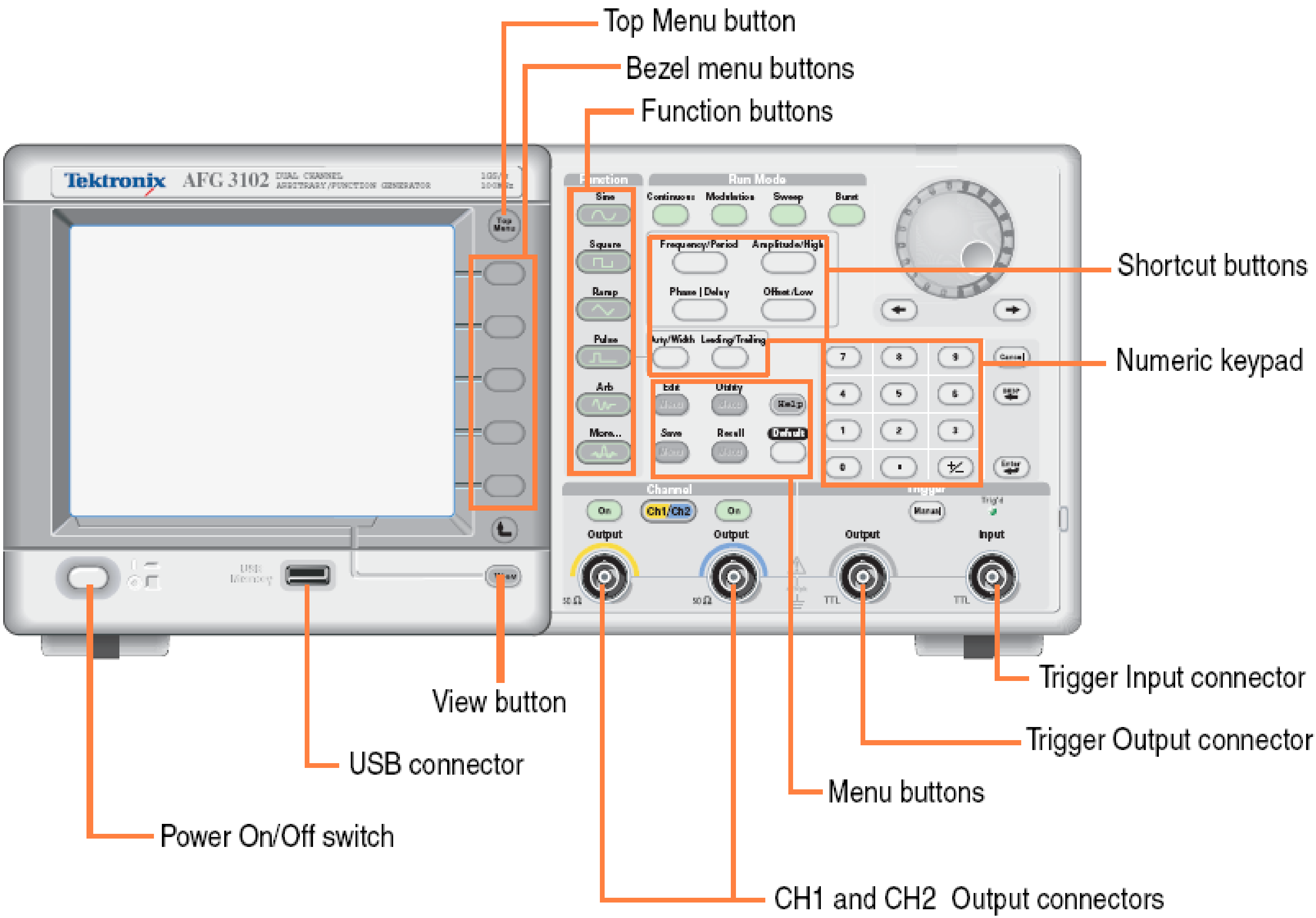

7. Output the Waveform
You can view the waveform at any time on an oscilloscope if one is connected. Press Output to activate the Output connector.

Another (equivalent) function generator: Tek AFG3101

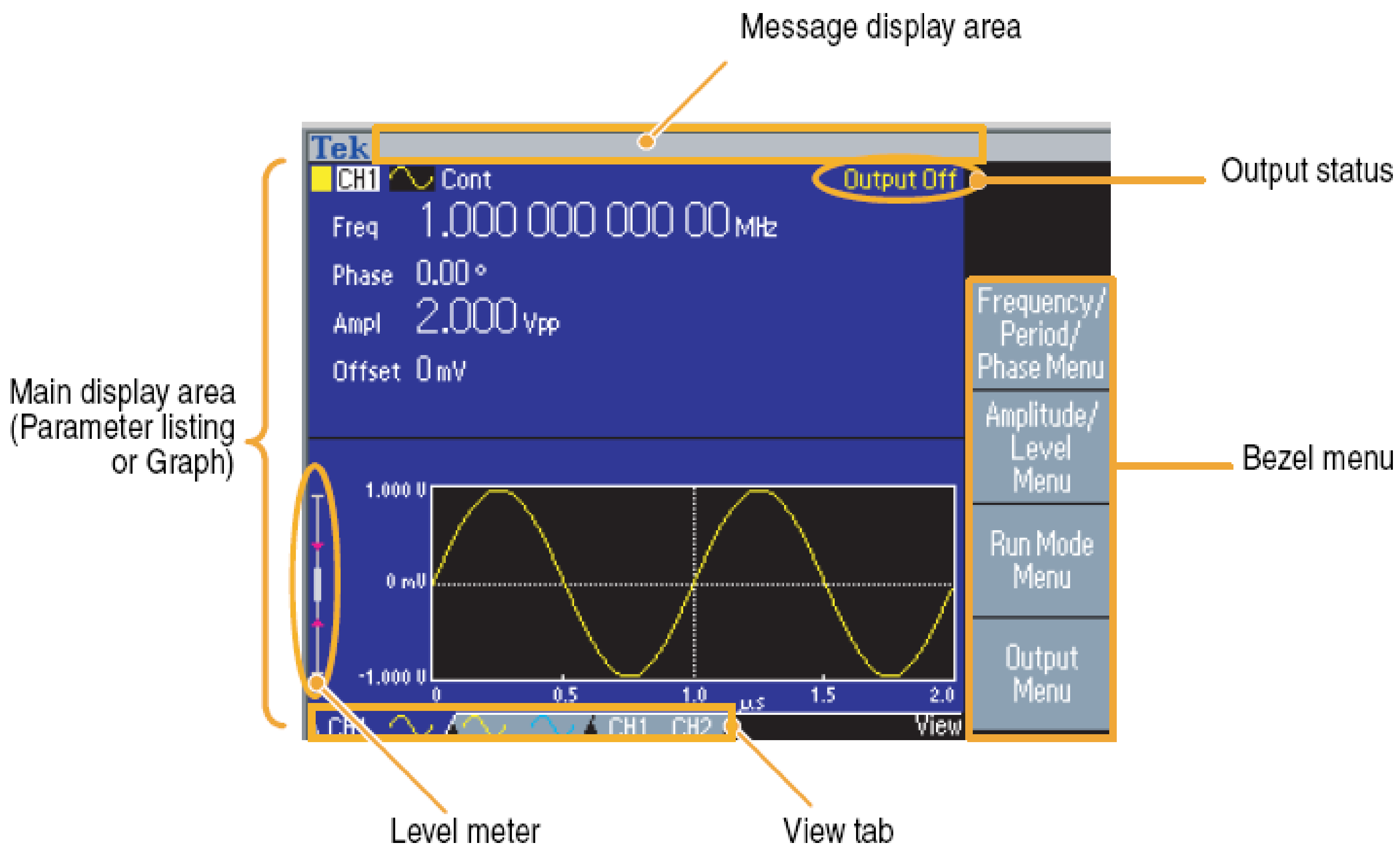




Similar control panel…



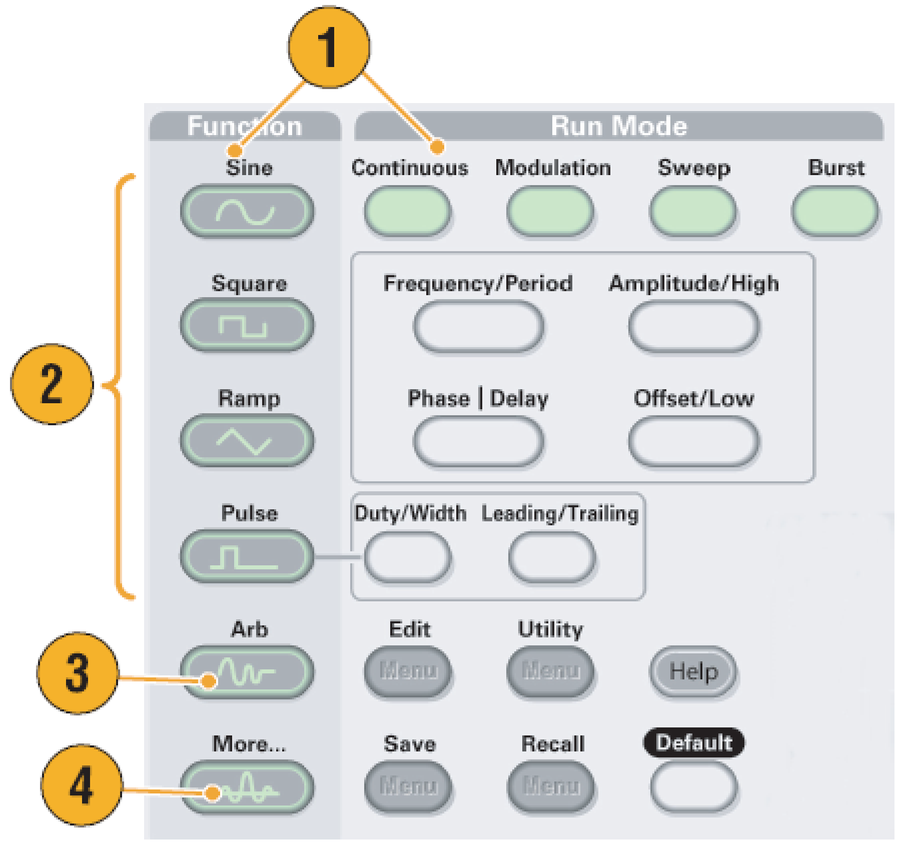
…and similar display/options



How to select an output waveform?

To select an output waveform, follow these steps:

1. To select a continuous sine waveform, push the front-panel **Sine** button and then push the **Continuous** button.
2. You can directly select one of four standard waveforms from the front-panel **Function** buttons.
3. To select an arbitrary waveform, push the **Arb** button. See page 32 for outputting an arbitrary waveform.
4. To select other standard waveforms such as Sin(x)/x, Noise, DC, or Gaussian, push the **More...** button, and then push the top bezel button.

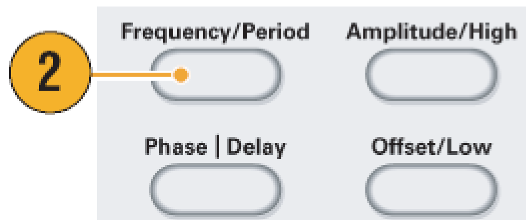


How to set a waveform

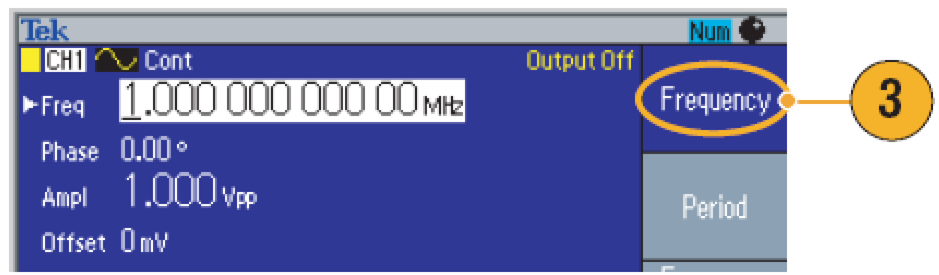
When you turn on your instrument, the default output signal is a 1 MHz sine waveform with an amplitude of 1 $V_{p\text{-}p}$. In the following example, you can change the frequency and amplitude of the original output signal.

1. Push the front-panel **Default** button to display the default output signal.

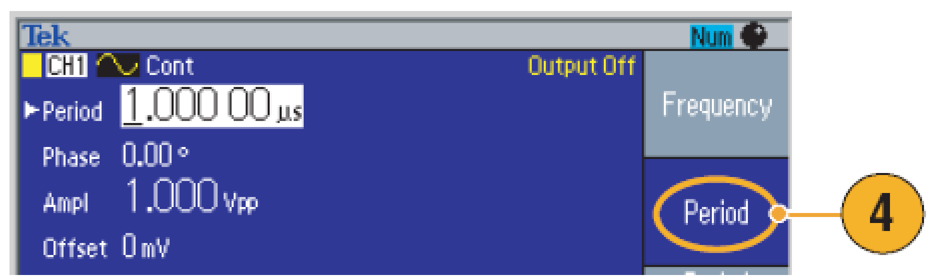
2. To change frequency, push the front-panel **Frequency/Period** short-cut button.



3. **Frequency** is now active. You can change the value using the keypad and Units bezel menu, or you can change the value with the general purpose knob.

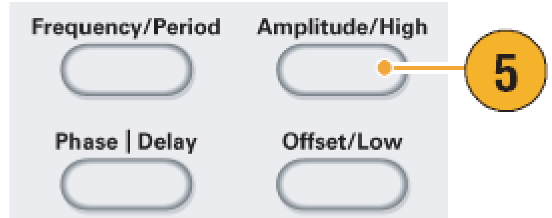


4. Push the **Frequency/Period** shortcut button again to toggle the parameter to **Period**.

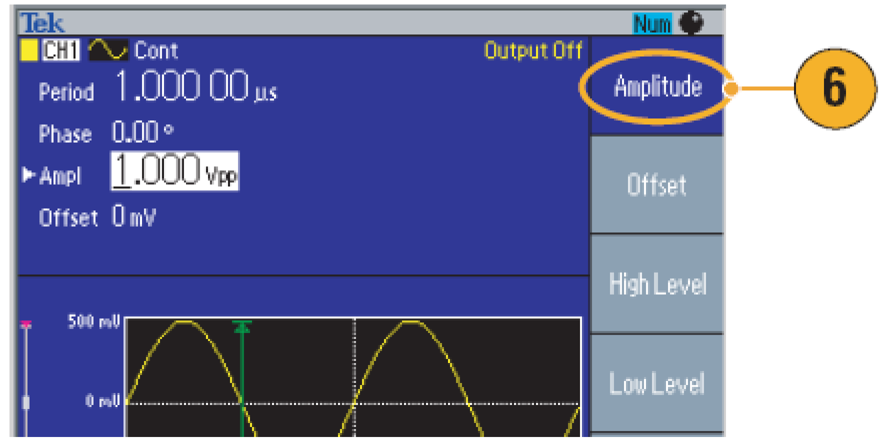


How to set a waveform

5. Next, change amplitude. Push the **Amplitude/High** shortcut button.

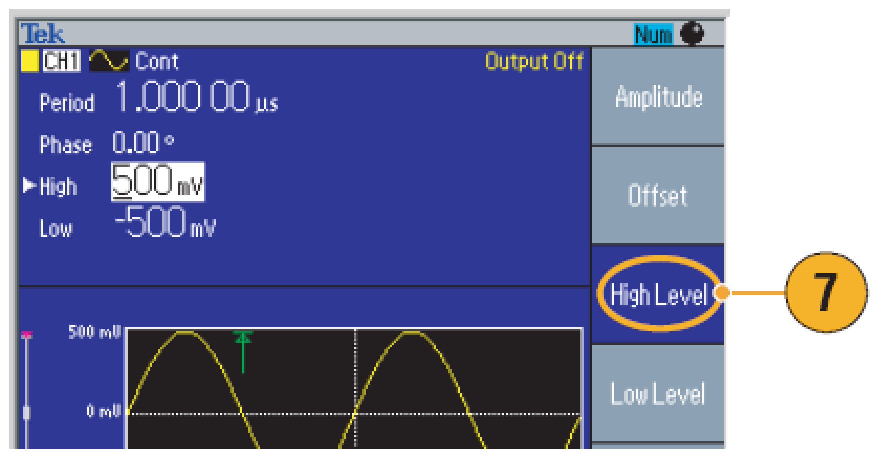


6. **Amplitude** is now active. You can change the value using the keypad and Units bezel menu, or you can change the value using the general purpose knob.



7. Push the **Amplitude/High** shortcut button again to toggle the parameter to **High Level**.

   You can change the values of Phase and Offset in the same way.



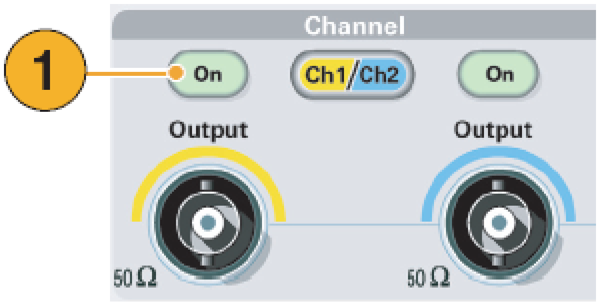
Output ON/OFF

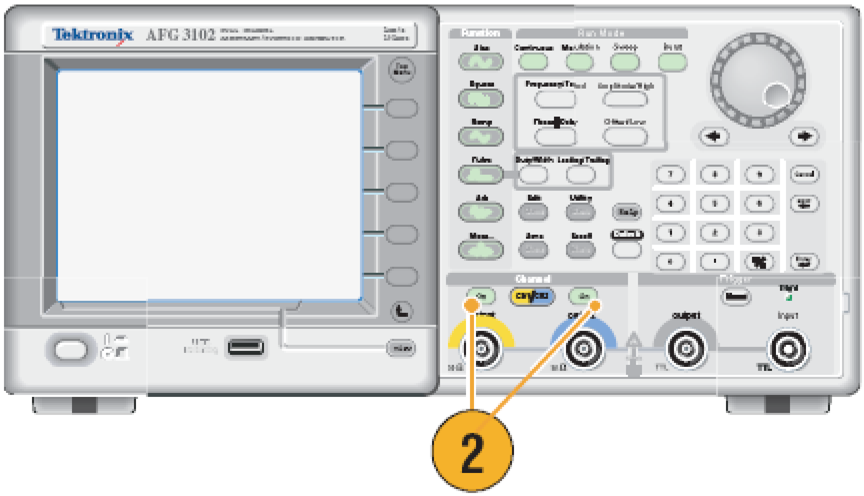
1. To enable signal output, push the front-panel Channel Output **On** button. The button is lit with an LED when it is in the On state.

   You can configure the signal with the outputs off. This will allow you to minimize the chance of sending a problematic signal to a DUT.

2. (Dual-channel model only)
   You can turn on or off the signal output for channel 1 and channel 2 independently.

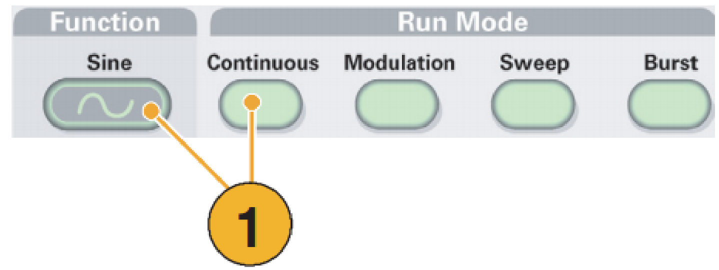
   You can enable one of the two channels or enable both of the two channels at any time.





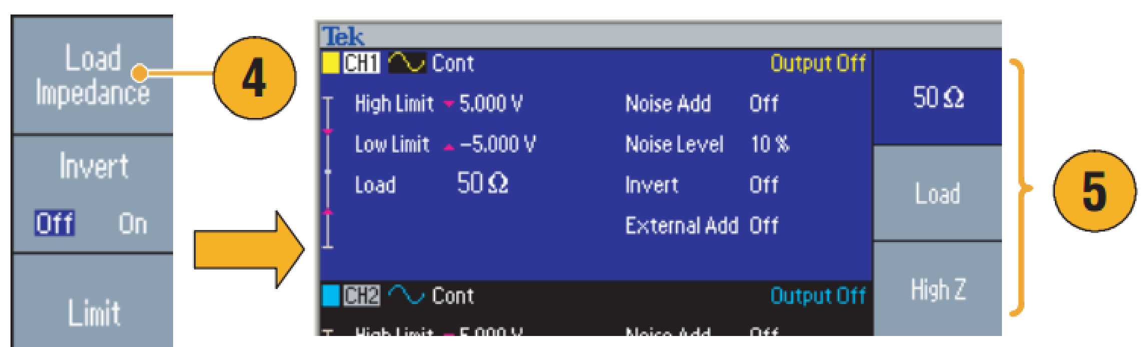
How to change load impedance?

1. Push the front-panel **Sine** > **Continuous** button to display the Sine screen in this example.



2. Push the front-panel Top Menu button, and then push the **Output Menu** bezel button.
3. The Output Menu is displayed.

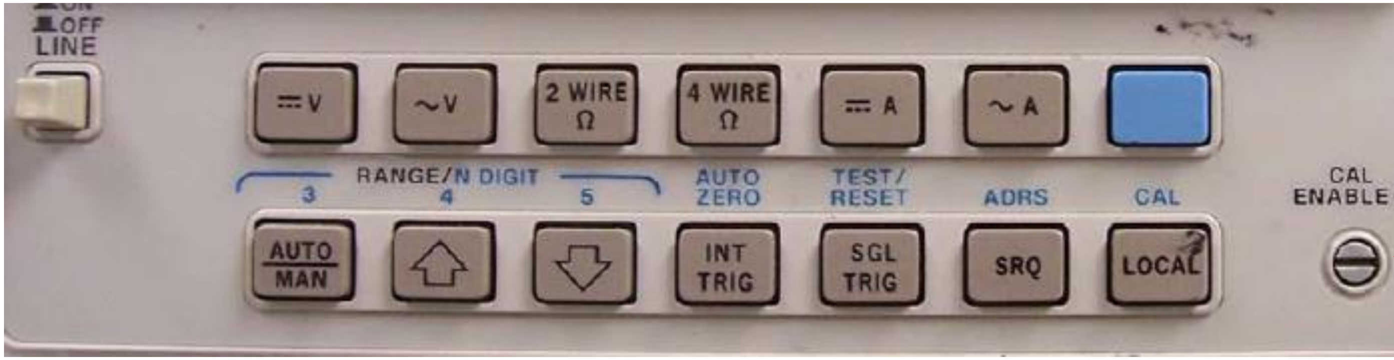
4. To set the load impedance, push **Load Impedance**.
5. The Load Impedance submenu is displayed.



The HP3478A Multimeter

The 3478A is a full 6 digit multimeter capable of reading signals from 0.1µV to 300V peak. The meter is quite flexible in resolution and scaling modes, but also has a lot of advanced features for communications and programming that we will not cover here

Control Buttons

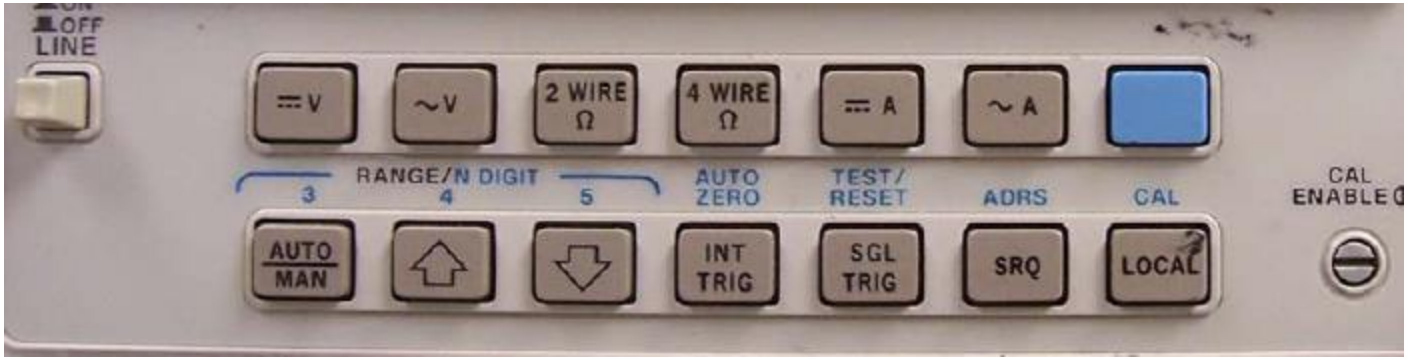


There are two rows of function buttons located under the display. These buttons control what is being measured and how it is measured.

The first control to note is the "cal enable" switch to the right. This should NEVER be turned to the cal position (vertical)

The second thing to note is that some buttons are dual function. Those with dual functions are labeled by **blue lettering above the button**. Pressing the blue button places the keyboard into "shift" mode, indicated by the word 'shift' on the display. In this mode the buttons perform the blue functions.

Control Buttons



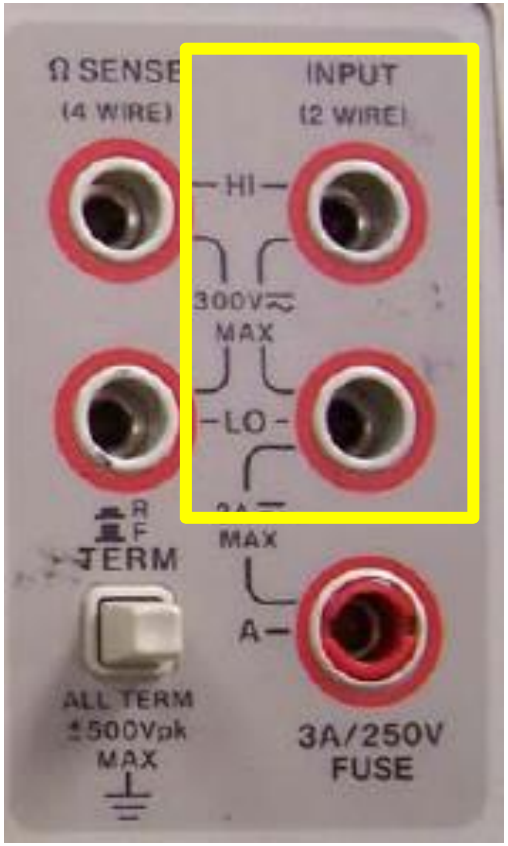
The function selections are controlled from the upper row of buttons and are as follows (left to right)

- DC Volts
- AC volts
- 2 wire resistance
- 4 wire resistance
- DC amps
- AC amps

Under normal circumstances a continuous trigger (INT TRIG) will provide for a continuous update of the current value on the input connections.

Below this row is a second row of buttons. The first is the auto range switch. When the instrument is turned on initially it will be in auto range mode. This will change the measurement range as needed by the incoming signal

Input connections



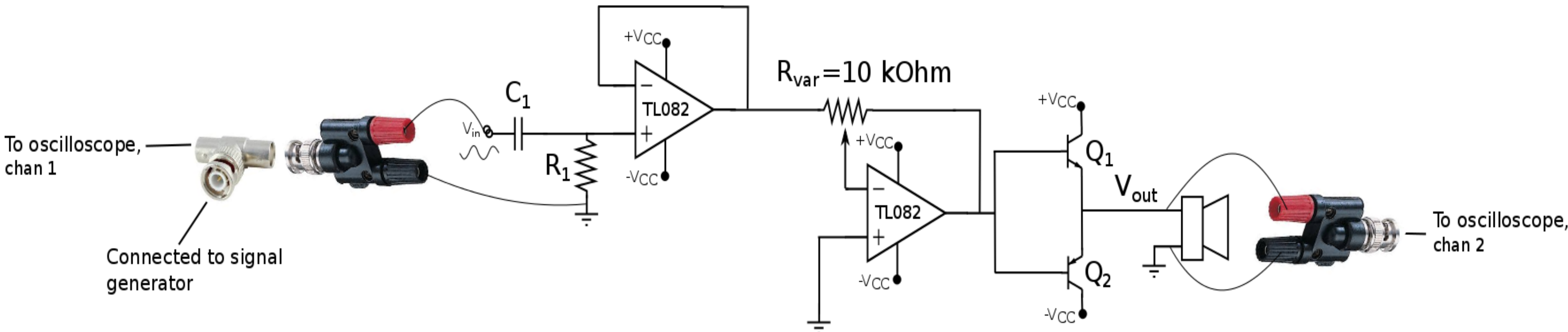
There are 5 connectors used for measurements. The **middle connection on the right** is the normal **common** connection (LOW) for voltage and current readings. The **upper connecton on the right** is the normal **positive connection** (HIGH) for ac and dc readings.

The lower connection on the right side is for current readings. This is the positive connection for all mA and A readings, with the middle (LO) connection being negative.

Resistance readings take two forms, two wire and 4 wire (Kelvin) readings. For normal resistance readings with two probes, use the 2 WIRE Ω mode and the two upper right hand connections. 4 WIRE Ω mode and the two left hand connections should only be used when Kelvin clips are installed. We will only make 2Wire (normal) resistance measurements; for a complete reference on 4Wire measurements refer to the ELECTRONIC INSTRUMENTATION course)

Current measurements will never be done in our experiments: to avoid short-circuiting and damage to the fuse, never connect your probes to the “A” terminal

Typical measurements: in the lab



RG58 cable

BNC T

BNC Cable

BNC female-female

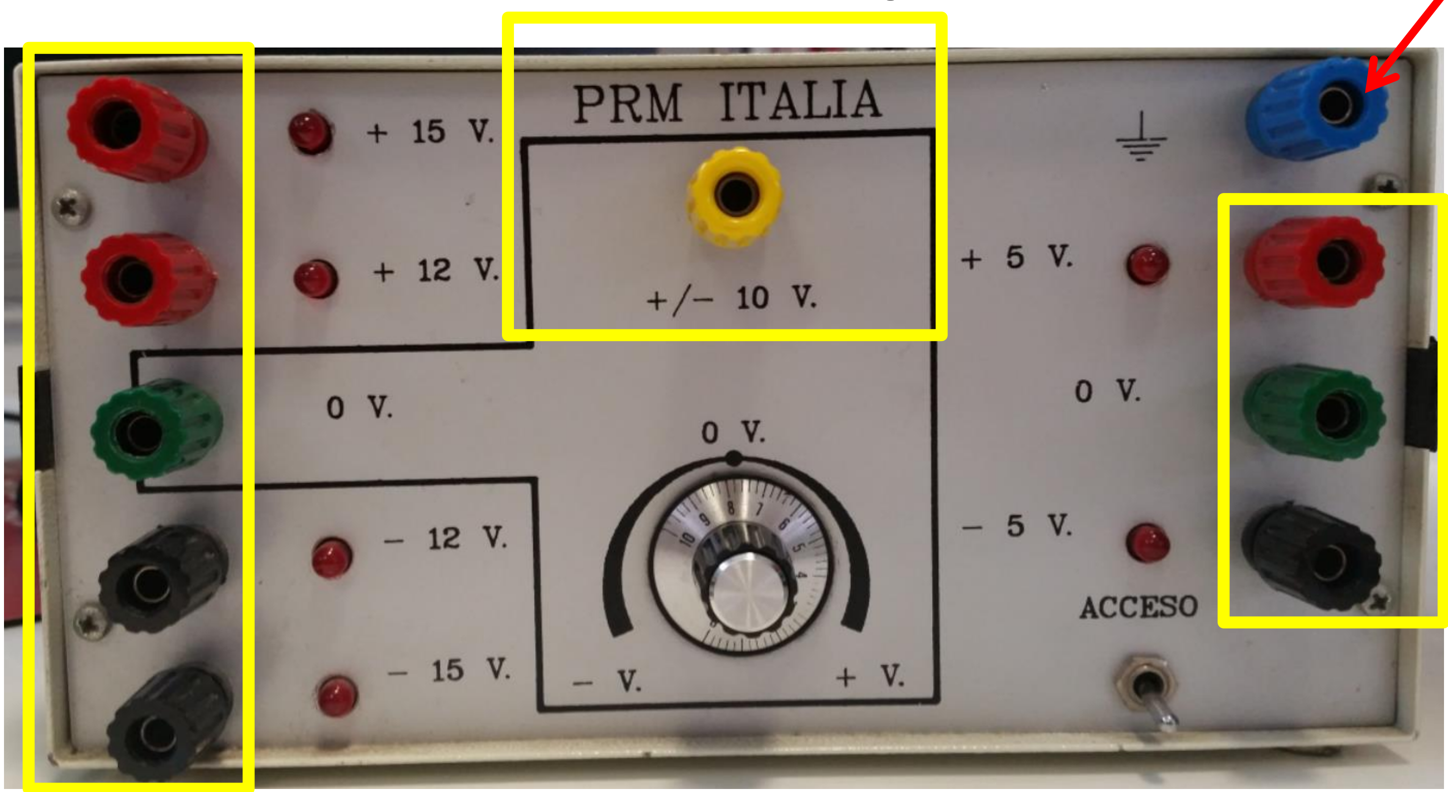
BNC Banana

Power supplies

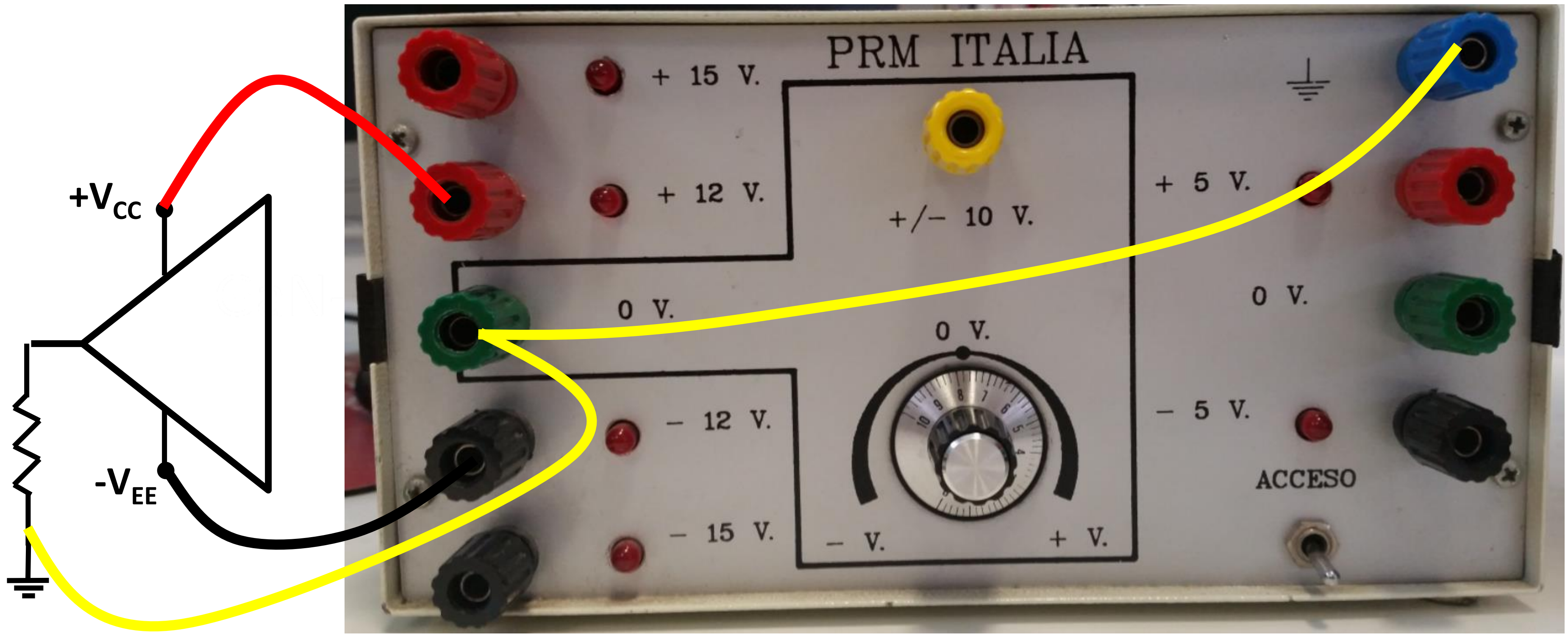
Variable output

GND

Fixed outputs



Fixed outputs


+V_{CC}
-V_{EE}
PRM ITALIA
+ 15 V.
+ 12 V.
0 V.
– 12 V.
– 15 V.
+/– 10 V.
0 V.
– V.
+ V.
+ 5 V.
0 V.
– 5 V.
ACCESO

Another power supply

Sources

Part of the material (figures, text, …) included in these slides originates from the following sources, which were freely accessible on the internet at the time this presentation was created.

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http://www.newark.com/wcsstore/ExtendedSitesCatalogAssetStore/cms/asset/images/americas/common/storefront/tektronix/7136_Oscilloscope-Basics-Guide.pdf
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