**Malta Police Training**

# The Oscilloscope

## What is an Oscilloscope?

An oscilloscope is an electronic instrument used to visualize and measure electrical signals over time. It displays waveforms on a screen, showing how voltage changes in a circuit as a function of time.

## Basic Components of an Oscilloscope:

1. **Display**: Shows the waveform of the signal.
2. **Vertical Controls**: Adjusts the voltage scale (Y-axis).
3. **Horizontal Controls**: Adjusts the time scale (X-axis).
4. **Trigger**: Stabilizes the waveform, ensuring a consistent start point.
5. **Probes**: Used to connect the oscilloscope to the circuit under test.
6. **Time Base**: Determines how much time is represented on the X-axis (e.g., seconds per division).
7. **Voltage Scale**: Determines how much voltage is represented on the Y-axis (e.g., volts per division).

## Getting Started:

1. **Connect the Probe:**
   - Attach the oscilloscope probe to the circuit, usually by connecting the probe's clip to ground and the probe tip to the signal of interest. Typically the probe has a x1 and x10 switch, normally leave it on x1
2. **Adjust the Vertical Scale:**
   - Set the vertical scale (volts/div) to a value that lets you see the full amplitude of the signal.
3. **Adjust the Horizontal Scale:**
   - Set the time/div control so that you can clearly see one or more cycles of the signal. Typically signals in automotive use will be in milli second range. For example the injector pulse will be say 10ms, while a a Pulse Width Modulating (PWM) driver to say a Pressure Control Solenoid will be at around 1 kilo Herz (kHz). 1kHz means 1000 cycles per second , therefore the signal comes On and Off every ms.
4. **Use the Trigger:**
   - The trigger is important for stabilizing the waveform. Set it so that the oscilloscope "captures" the signal at a consistent point each time (e.g., at the rising or falling edge of a waveform).
   - Trigger can be Auto: meaning oscilloscope will show a screen shot of the captured signal but with no defined reference to the signal itself, this may lead to see the signal move horizontally.
   - Trigger can be on Normal: Meaning oscilloscope will show the captured signal keeping a predefined reference point (negative or positive edge slope) in the y axis (vertical) and also a predefined point in the horizontal x axis (time axis). In normal mode the display will be

refreshed repeatedly with new measurements if these are available but will show the last capture if the trigger condition is not satisfied any longer.
    - Trigger can be on Single: Meaning Oscilloscope will capture just one screen shot of the signal that satisfy the trigger condition. This is very helpful in understanding and trouble shooting things that occur once or repeat very slowly. The Oscilloscope will have to be "told" to take a new capture every time a new screenshot is desired. This might be called Run on the push buttons.
    - Trigger can also be External, through a BNC connection on most desktop oscilloscope. However this is rarely used.
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5. **Fine-Tuning:**
    - You can adjust the **Position** knobs to move the waveform on the screen so it's easier to analyse.
    - Play with the **Time Base** and **Voltage Scale** to zoom in or out of the waveform.

## Types of Waveforms:

- **Sine Waves**: Regular, smooth oscillations; common in AC signals.
- **Square Waves**: A wave that switches between high and low states; often used in digital circuits.
- **Triangle Waves**: Linear rise and fall in voltage.
- **Pulse Width Modulating waves**: Similar to square waves but with a varying duty cycle.

## Reading the Oscilloscope:

1. **Amplitude**: The height of the waveform (vertical axis) shows the voltage.
2. **Frequency**: The number of cycles per second (horizontal axis) shows how often the waveform repeats.
3. **Peak-to-Peak Voltage**: The total voltage difference between the highest and lowest points of the waveform.
4. **Period**: The time it takes to complete one full cycle of the waveform.

## Common Tips:

- **Start with Known Signals**: If you're just getting started, practice with a known, simple signal like a sine wave from a signal generator. Actually almost all oscilloscopes have a built in signal generator, typically a 3Volt 1 kilohertz square wave for this purpose to make sure probe and settings are properly set.
- **Be Patient**: It can take some time to get used to how the different settings affect the waveform display. (it took hours for the author of these notes to learn the use of a new oscilloscope)
- **Use the Autoset Function**: Many oscilloscopes have an automatic setting feature that tries to adjust the controls for you, however the undersigned advocates that you should be patient and be able to set up the oscilloscope

yourself based on what you know you expect the signal to be like in voltage magnitude (y axis) and horizontal time x axis.

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## Safety:

- Always ensure that your oscilloscope probe is correctly connected and that the probe's ground is connected to the circuit's ground.
- Never use an oscilloscope on high-voltage circuits unless it's rated for such use.

**Automotive relevance**

The Cam and Crank signals are best analysed by an oscilloscope. Their signal is not sinusoidal but still of an oscillating nature. The amplitude varies with RPM.
The signal should be a hill first followed by a valley. The triggering time is the zero crossing going negative. If the polarity is wrong the ECU will still lock to a zero crossing but it will be offset in crank angle meaning the ECU will not properly know the engine angle. It may also issue a fault if it can check with something else, example cross check between cam and crank sensors.

The function of the crank and cam sensors is to provide knowledge of angular position and speed of the engine to the ECU. The ECU requires knowledge of angular position of the engine crank so that spark and fuel are generated at the desired crank angle.
Usually these sensors are inductive type, two wire (or three wire) and operate on the principle that a voltage is generated in a coil when iron (a tooth) goes past the sensor at some speed. Other types of position sensing is sometimes used such as optical triggering or hall effect (hall effect requires use of magnets).

The two wire sensor gives an output that is AC, that is the voltage goes above and also below zero. The amplitude of the signal depends on the rpm, the gap between sensor and wheel and the sensor itself. The amplitude may be in the range of 0.1V peak to peak at low rpm but will go to a couple of volts at high rpm. If the amplitude needs to be increased, the gap might be reduced, or if lower voltage is desired, gap is increased. The proper connection of the sensor should give the positive voltage hump first, then goes through zero volts and then goes negative see **Figure 1**. The sensor and tooth are aligned perfectly at the zero crossing.

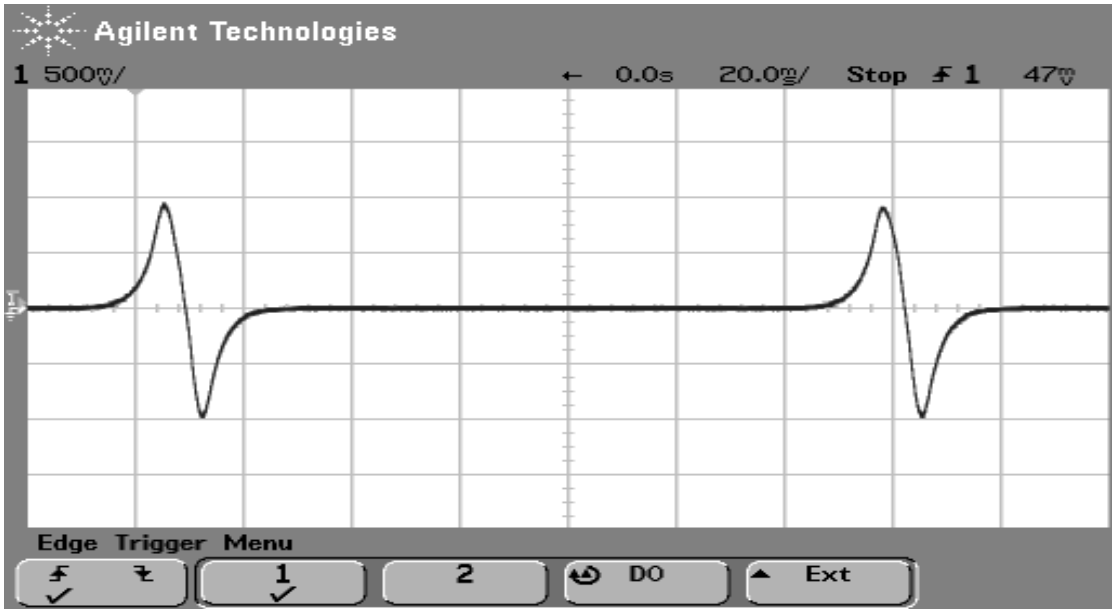



**Figure 1 Signal from a two wire sensor, with proper ground and signal connection**

If the two wires from the sensor are swapped the signal will be upside-down, see **Figure 2**. The position when the sensor is lined up with tooth will correspond to the zero crossing from negative voltage to a positive voltage (which is opposite of the typical). If the ECU internally is looking for strictly a positive to negative zero crossing is will find one which is in the gap between the teeth. However this zero crossing is not very well defined in crank angle (as can be seen in **Figure 2**) and the ECU will not be very accurate in determining angles.

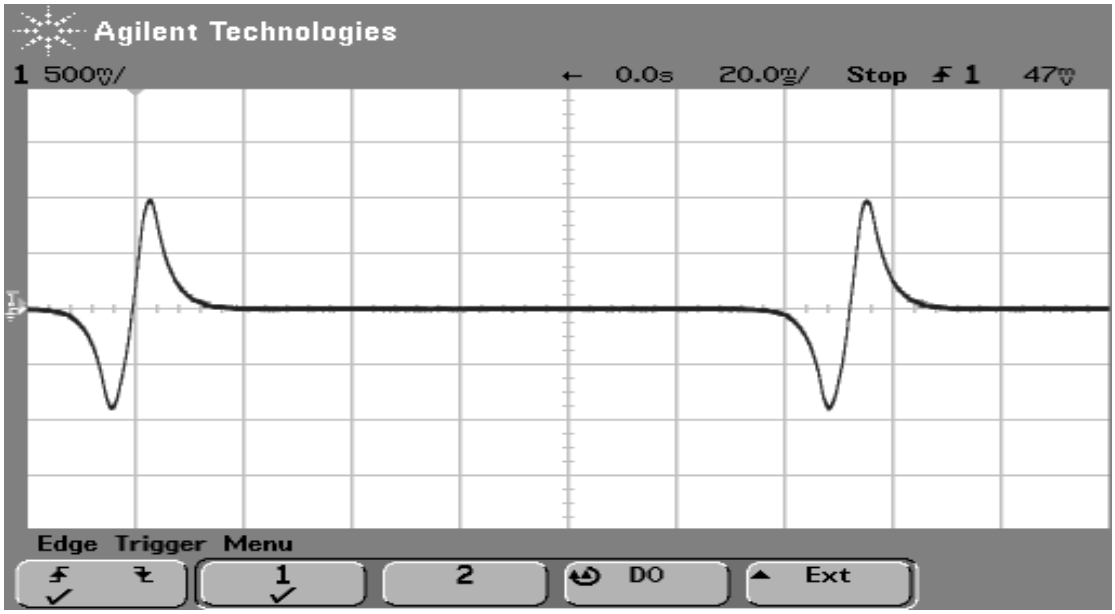



**Figure 2 Signal from a two wire sensor with swapped ground and signal connections**

The cam and crank signals (if both are used) can be seen in **Figure 3**. It is noted here that the positive to negative zero crossing of the cam sensor is located to a gap between the teeth of the crank teeth. This is a good feature to have in the mechanical

orientation between the cam and crank signals and it is advised to implement this if one is setting up the triggering wheels himself.

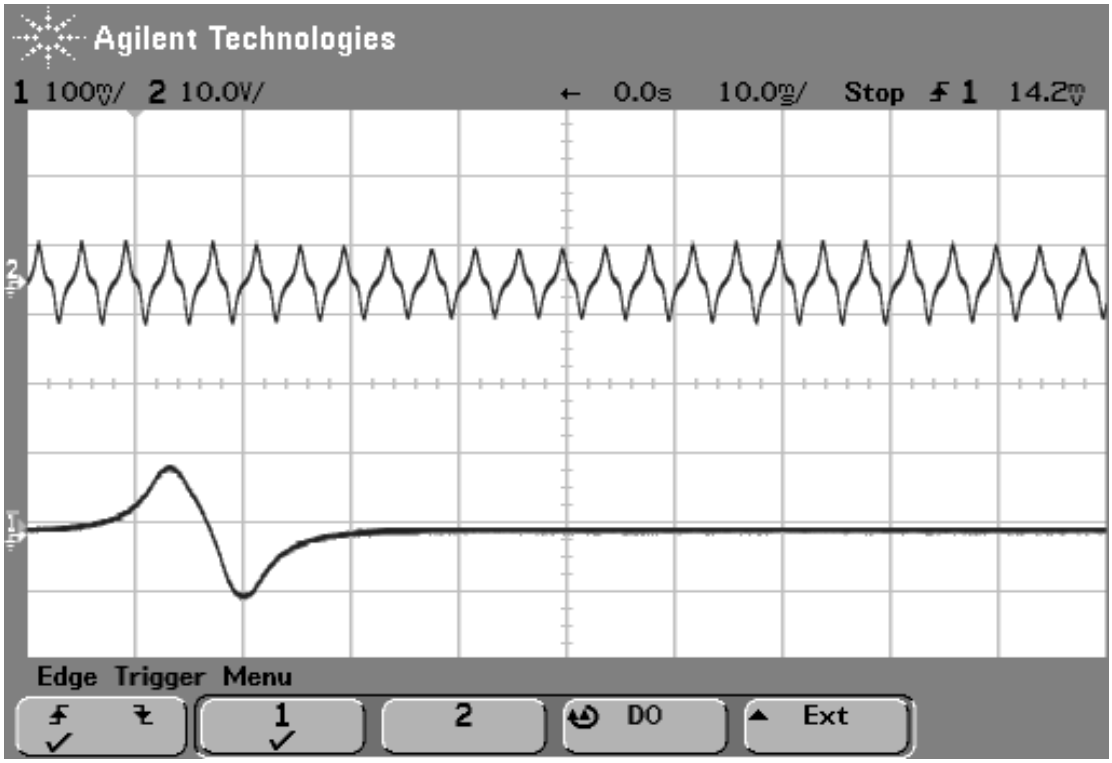



**Figure 3 Signals from Cam and Crank sensors**

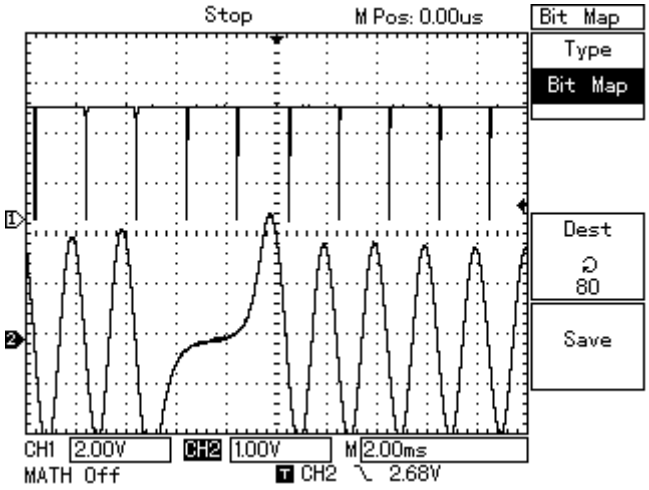
Three wire sensors are typically also inductive type pickups but they also have electronics in them so that the raw signal (which is the same as the two wire described above) is converted into square pulses. The sensor internal electronics will look for the zero crossing and turn on the signal output for a period of time. The "on" time will be calculated on the time interval between the teeth. The three wire sensors will have Ground, Signal and Supply connections. The signal might be having a voltage output on it, or it can be a transistor output which needs to have a load connected to it to have a voltage change (this is technically called "open collector" output and is similar to the transistor used for injector and ignition drivers). One significant difference of the three wire sensor is that it is able to hold the on or off states indefinitely (that is forever). That is the 3 wire will say remain high if the sensor is aligned to the tooth with the engine stopped. On the other hand, the two wire sensor will give zero volts when the engine is stopped regardless of whether the sensor is aligned or not with the tooth.

## Newer Crank Three Wire Sensor

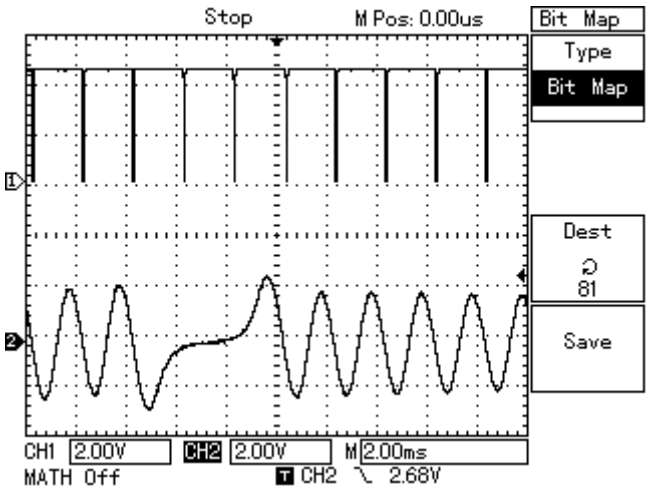
The sensor of a three wire was setup on a trigger wheel and a two wire inductive type was also setup on the same trigger wheel in order to check if the three wire sensor still detected and gave a signal at the centre of the tooth as is the case of the two wire inductive type sensor. Both the three wire and the two wire were mounted to be centred to the respective teeth at the same time. The three wire crank sensor and toothed wheel used were from a Fiat CinqueCento. It is denoted as K 046 on the schematic of the vehicle and the Pinout is : Pin 1 positive supply (which was given 5V

rather than say 12 V decided by the author of these notes because digital signals are typically 5V and it was safer to test with 5V compared to 12V), Pin 2 is signal output, Pin 3 is the ground. The three wire sensor had to be given a pull up to the supply of 5V to see a change in output. That is the three wire sensor is an open collector type. The resistor used was 2700 Ohms (2k7).

The below figure DSO 080.BMP shows a screen shot showing the missing teeth gap on the two wire inductive sensor trace Ch2. This shows that the polarity of the two wire is as expected that is going from positive to negative at the centre of the tooth. DSO 081.BMP shows a zoom into the same picture.
DSO 082.BMP shows that the three wire triggers negative at the zero crossing going down of the two wire, that is the three wire gives the negative going trigger at the centre of the tooth. DSO 083 and 84 show that the trigger is 40 micro second long. The rpm of the wheel was changed considerably and the 40 microsecond remained the same. It can also be noted that the fall is very rapid while the rise is curved which leads to the conclusion that the downstream electronics will be made to work with the fast negative going edge for more precise angular knowledge.



DSO 080.BMP



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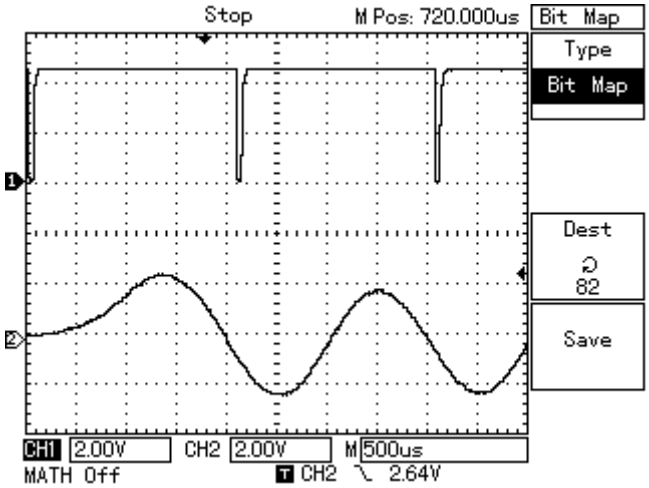

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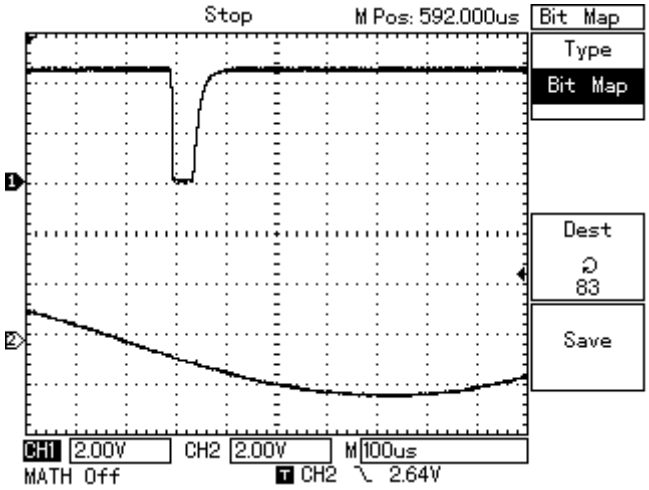

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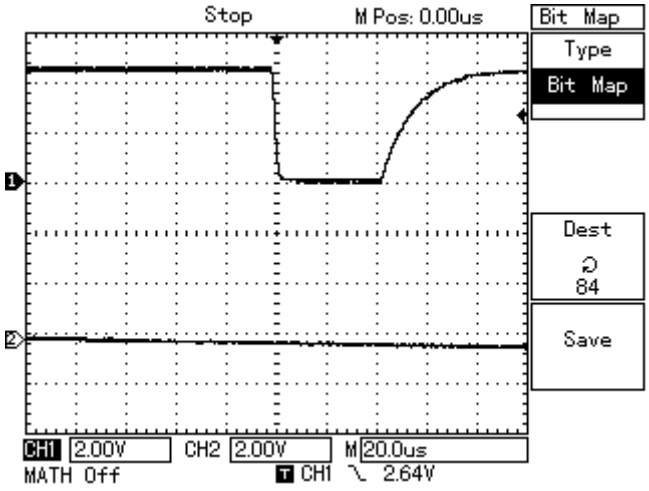
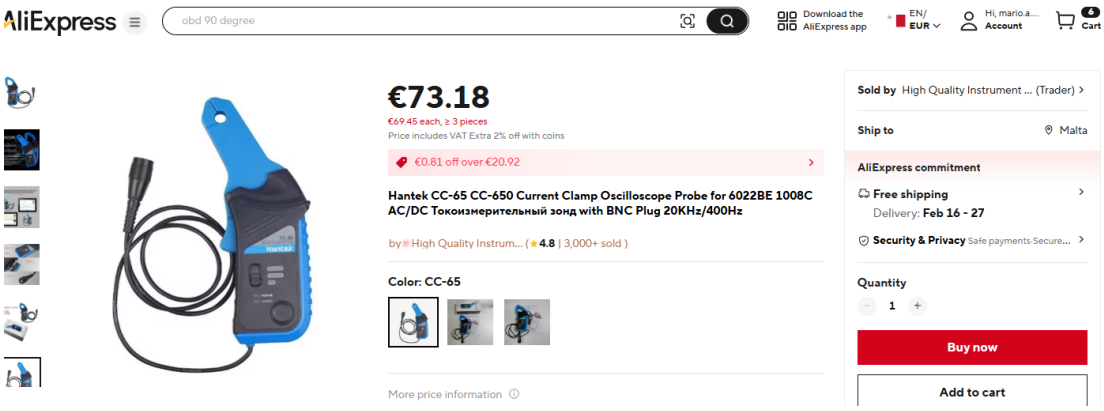


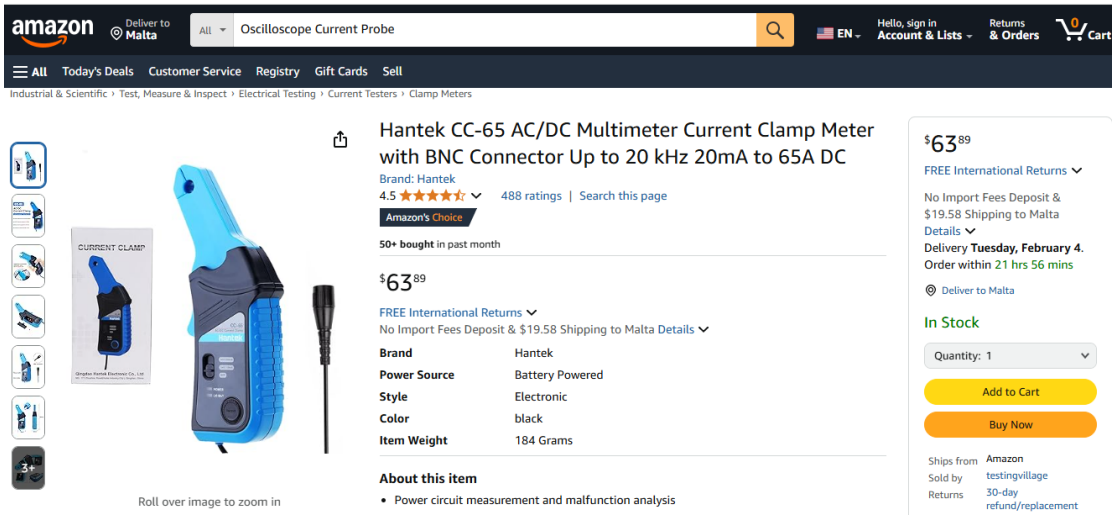
DSO 084.BMP

## The Measurement of Current

Cam and crank voltage signals can be checked by the oscilloscope because they are low voltage. However the signal going to the injectors and coils will have some flyback voltage spike at the opening instance (by opening here is meant transistor opening meaning switch off of current). The low voltage signal going from the ECU to the spark plug coils is better if not read directly by oscilloscope as the low voltage of the could still goes to 300 or 400V which may be beyond the oscilloscope capability. A voltage divider by say connecting 1k and 10 K resistors in series and reading off across the 1k resistor is a good way to read the low voltage side of the coil. However a much safer and more practical way is to use a current clamp connected to the oscilloscope.

Signals operating solenoid valves such as EGR, pressure control solenoid, AdBlue injector, fuel pump, etc can all be monitored safely and without cutting any cables using the current clamp connected to the oscilloscope. The oscilloscope connection is called BNC .



For Automotive use the slow speed and hence cheap oscilloscope is enough.
Two examples from local suppliers are