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Signal spy game

Oscilloscopes as measuring tools
in mechanical engineering

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Image: RS Components

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Oscilloscopes as measuring tools in mechanical engineering

Mechanical engineering is currently shaped by developments that are ultimately led by sensor solutions and actuators, commonly known as the IIoT (Industrial Internet of Things). This technology generates countless different signals that emanate from sensors, bus systems and power supplies. Adequate test instruments are required to untangle this technology. One of the most versatile of these tools – the 'lookout' in the patchwork of signals – is the oscilloscope, which records and analyses these signals.

The oscilloscope is a test instrument used in production, on test and inspection benches, in workshops, labs and in maintenance checks. Depending on the application, the most robust models, handheld devices and those with the broadest analysis functions are particularly in demand. A number of these devices have combined functionalities and 'special talents' for use in any application – from the most basic to the most complex.

An oscilloscope measures changes in the voltage level of electrical signals over time and displays the data on-screen. By way of sensors, it can also convert other signals – such as vibrations and sound – into an electrical signal and display the data. The oscilloscope offers a variety of analysis options, trigger types and digital functions which are used to comprehensively analyse signals. Oscilloscopes are true 'signal spies'.

They also offer memory options for storing the data, communication interfaces for further processing and extensive evaluation software. Graphs and curves are plotted on mostly colour screens, which allow the user a targeted insight into the signal curve. This includes touch controls and split-screen modes. This data can be used, among other things, to find faults in circuits, check the signal quality and detect electromagnetic interference.

Classification by form factor

Regardless of its skillset, an oscilloscope can be designed as a benchtop unit (or a portable device with a battery), as a device without a screen to connect to the PC, or as a handheld.

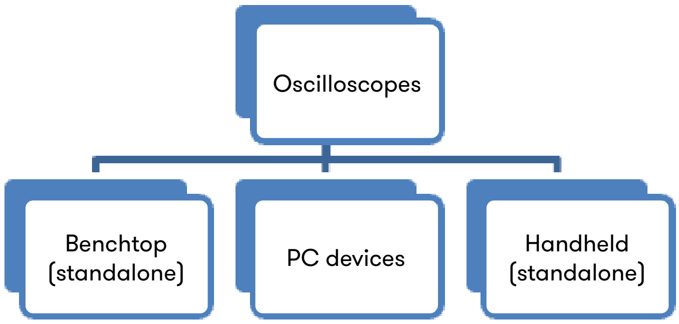

Fig. 1. Oscilloscope types by form factor

Benchtop devices are used in the test lab, testing department, service technician's station or in the development department. They have the largest footprint and can offer extensive functions and signal analyses options. Weight and size are not important selection criteria here, although they are increasingly integrated with smaller devices in this segment.

There are also oscilloscopes that include a battery to make them portable, to enable field assignments or meet special requirements at new test locations.

Benchtop devices have colour screens – e.g 10.1" or 15.6" touchscreens (such as the R&S RTO6 oscilloscope from Rohde & Schwarz), for high-resolution display. There are also devices that have a 15.6" display plus a second 3.5" calibration touchscreen (e.g. Rigol's DS70000-series). You can use any existing cloud connection (e.g. the MSO series 5 B from Tektronix) to store data in the cloud.

Fig. 2. Example of a benchtop device (RS PRO RSDS 1052 DL+; 2-channel digital storage oscilloscope; 50MHz-bandwidth). Slimline and weighs just 2.5kg. Very easy to carry to a test point. (Image: RS Components)

However, they are not ideal as everyday devices for use at the plant. In this case, you would use a digital **handheld oscilloscope**. These are designed to be used anywhere and, being compact and lightweight with a substantial battery life, are ideal for mobile applications. Many come with additional multimeter and recording functions for use in specialist applications.

Fig. 3. Here is a handheld device (RS PRO RSHS806, (2-channel handheld digital oscilloscope 60MHz), which weighs in at a very practical 1.5 kg. (Image: RS Components)

Another type of device is the PC oscilloscope. These are designed to connect to your PC/laptop/notebook, as they do not have a built-in display or a front control panel. They contain only the testing technology itself, while a computer installed with the appropriate software will carry out the data analysis. The range of functions of these devices is tailored to special applications. As such, they are generally considered as 'slimmed-down' oscilloscopes. The computing capacities are hosted by the computer, so these devices can be designed as compact modules and offered at lower prices.

Housed in robust enclosures, these units are also suitable for harsh industrial environments and can even be placed in the control cabinet. In addition to lab use, they are used in the field or with the service laptop in the vehicle, for example. Small and lightweight, these devices have various integrated data interfaces.

The input signals can be pulled up on the PC via a USB interface. The instrument sends data by remote command to the local network or cloud via the LAN network interface. There are also wireless devices available that work on the WiFi (e.g. WiFiScope WS5 from TiePie). Pull up data from the comfort of your desk while the oscilloscope is permanently installed at the test point.

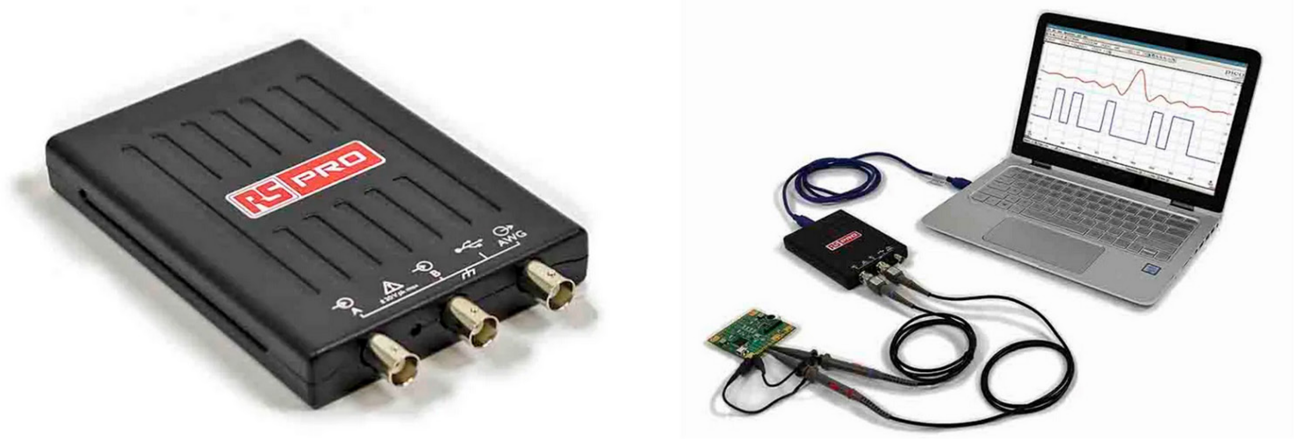

Fig. 4. The PC-based oscilloscope on the left ([RS PRO 2205A](), 2-channel PC oscilloscope with a bandwidth of 20 MHz) can be seen in use on the right. (Image: RS Components)

Instead of enclosed models, some oscilloscopes come in the form of a plug-in card, which you insert directly into a device rack and integrate via bus systems. These include PXI oscilloscopes from National Instruments. While standalone oscilloscopes are made completely to manufacturer specs, modular oscilloscopes can be flexibly programmed by the user to enhance their standard functions.

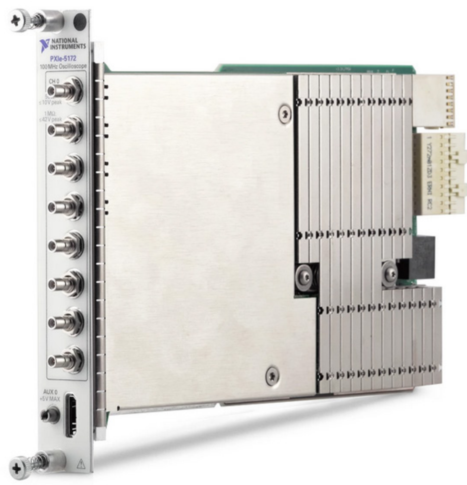

Fig. 5. The National Instruments PXIe-5172 oscilloscope has eight simultaneously sampled channels on which you can set the coupling and voltage range. (Image: National Instruments)

Classification by technology

Much like everything else, the world of oscilloscopes is divided into the analogue and the digital. An analogue device measures the voltage in real-time, while digital models use an analogue-to-digital converter to generate digital data. As a result, the signal is first recorded as a sequence of sampling points, cached, rearranged for display purposes, then output on-screen. The screen is therefore only important for display and analysis purposes; all the 'measurement work' is done by the A/D converter.

Digital oscilloscopes include digital storage oscilloscopes (DSO), digital phosphor oscilloscopes (DPO), mixed-signal and mixed-domain oscilloscopes (MSO/MDO), and digital sampling oscilloscopes.

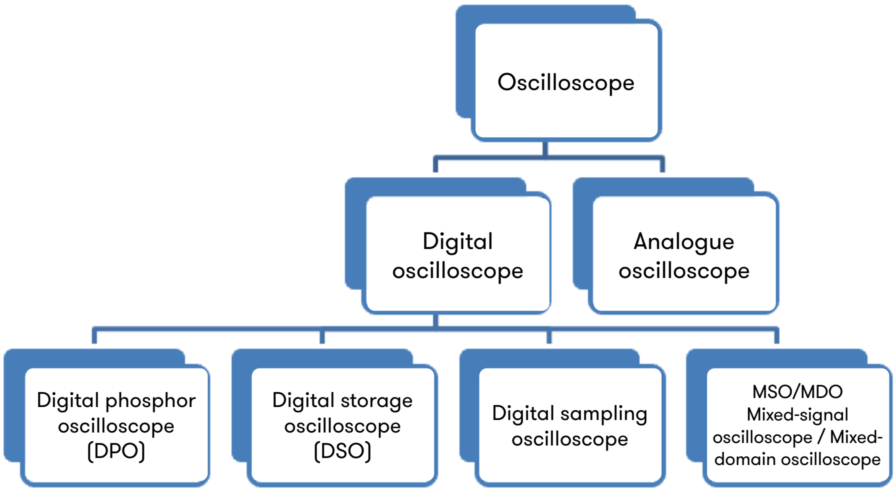

Fig. 6. Classification of oscilloscopes according to type of signal processing

While (older) analogue oscilloscopes (electron beam oscilloscopes) are equipped with a luminous phosphor screen, **digital storage oscilloscopes** (DSO) have a grid screen. They are particularly suitable for detecting and plotting one-off events (transients). The signal is visualised by a sequence of binary values and can be stored and further processed. This means that the signal can be analysed at any time, even if the signal no longer exists in reality; one of the advantages of DSOs.

In addition to monitoring amplitudes and time differences, the system can detect frequency and phase shifting and carry out Fourier analyses (transformation from temporal to frequency range). Oscilloscopes can perform a peak-to-peak voltage measurement, scan serial buses and perform a mixed-signal analysis. They have a very diverse range of possible functions. Probes are an important accessory.

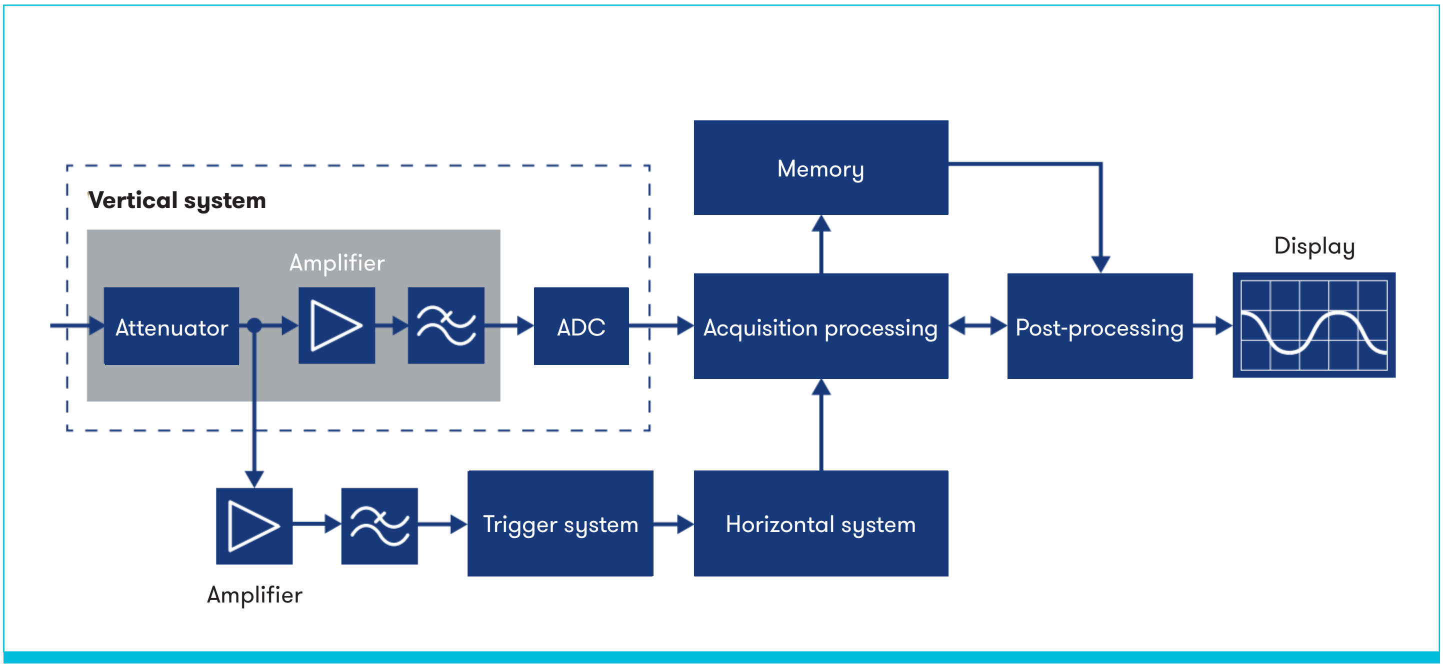

Fig. 7. DSO block diagram with vertical system (image: Rohde & Schwarz)

DSOs cannot output real-time brightness information, which in analogue devices serves as a third dimension (Z-axis) in addition to the voltage (Y-axis) and time (X-axis) when plotting signal data. This variance in the measurement signal over time is expressed here by the colour and intensity of a plotted point.

The Z-data component is further enhanced in the **digital phosphor oscilloscope** (DPO). The number of digital sampling values in certain XY ranges – i.e. pixel intensity – is used to simulate the gauge intensity modulation of phosphor. Over the course of the signal activity, the higher frequency areas become more colour-intensive, to show the frequency of anomalies. Instead of a chemical phosphor layer, this uses a 'digital phosphorus database'. There is an additional data range per pixel in the oscilloscope display, which is fed with this intensity information. The DPO also uses a parallel processing architecture and can capture signal details, intermittent events and dynamic signal characteristics in real-time.

A **mixed-signal oscilloscope** (MSO) is a hybrid device with oscilloscope and e.g. logic/protocol analysis functions. It can analyse both analogue and digital signals. A **mixed-domain oscilloscope** combines oscilloscope and spectrum analyser functions, for example. It provides a simultaneous, time-correlated display of input signals in a recording cycle, in both the frequency and time ranges.

With the **digital sampling oscilloscope**, the input signal is sampled before it can attenuate or amplify. This oscilloscope can be equipped with electrical or optical inputs, capturing just one, highly accurate sample per signal period. This is used to investigate recurrent waveforms that can be around ten times faster than with other oscilloscopes. When sampling happens in real-time, we talk about real-time sampling oscilloscopes.

Fig. 8. Tektronix TEK007 Sampling Oscilloscope; below is the optical module for cycle recovery (press image by Tektronix)

Key technical data of digital oscilloscopes

To find the right device for a specific application, you can refer to the oscilloscope's technical key data specified by the manufacturer. To find out the most important parameters for your planned use, ask for expert advice from the manufacturer or retailer. Below are some of the oscilloscope specifications.

Number of channels

Most oscilloscopes have 2 to 4 analogue input channels that are sampled at the same rate. They can also come with logic channels (e.g. 16 channels). Special models may have 8 channels (e.g. DLM5000 from Yokogawa), which can be extended to 16 channels by synchronisation. The MSOX4154 from Keysight comes with 16 analogue channels. When deciding on the number of channels, check if each channel has its own A/D converter or if switching happens by multiplexer, which reduces the sampling rate per channel by the factor of the channels.

Bandwidth

The bandwidth of an oscilloscope actually results from the difference between the upper and lower key frequency (f1, f2 in Fig. 9). When these frequencies are reached, the amplitude display is distorted by 3dB, which means information is lost. The bandwidth is therefore defined as the frequency at which a sinusoidal input signal is attenuated to 70.7% of the actual signal amplitude. This value is also called the -3-dB-point because of its logarithmic classification.

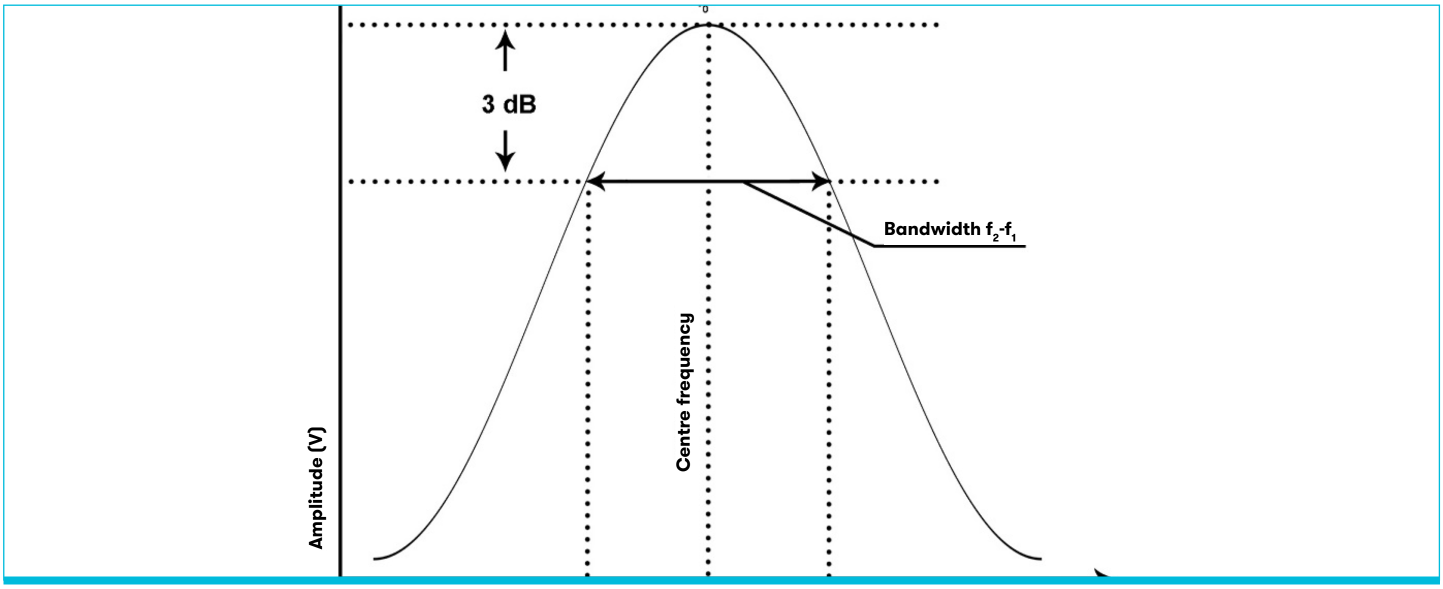

Fig. 9. Relationship between bandwidth, amplitude and frequencies. The bandwidth results from f2 – f1 at the -3-dB-point. (Image: channel-e)

Practical tip: For non-sinusoidal signals, Rohde & Schwarz recommends an oscilloscope bandwidth of at least 3 times the basic clock signal frequency for decoding or fault-finding, and 5 times the clock signal for conformity tests. For non-periodic signals, take into account the rise time t_r of the signal. In this case, you can work with an oscilloscope bandwidth of $f_{BW} = 0.5/f_r$

Sampling rate

The sampling rate is how the analogue input signal is digitised – the number of discrete values that a digital oscilloscope can capture per second. This determines the horizontal resolution of a measurement curve, specified in samples per second (S/s).
The faster an oscilloscope samples, the higher the resolution of the signal curve.

According to the sampling theorem (Nyquist), the sampling rate f_S must be at least twice as large as the highest frequency component to be examined in the measured signal (Nyquist frequency f_N).

So, in theory: $f_S >= 2 \times f_N$

In practice, however, we need a real-time sampling rate that is at least three or four times the bandwidth of the oscilloscope. Sampling rate and bandwidth are not directly related, but should lie in this ratio.

$f_s = 4 \times f_{bandwidth}$

Memory depth

The memory depth indicates the storage capacity available to retain the sampled values. With a deep (large) memory, we can capture long-lasting waveforms in detail, at a continuously high sampling rate and at high resolution. Longer periods of time can then be observed without missing anything. Optional memory expansions are available for some devices. The memory depth can range from 500 KPoints for a digital handheld device up to 2 GSample for a real-time oscilloscope.

Memory depth and sampling rate are related. The more extensive the memory, the longer the observation time can be at a given sampling rate.

Signal capturing rate

This value is the measurement rate in signals per second (wfms/s; waveforms/s). This is the speed at which an oscilloscope can detect signals. For example, with a memory depth of 2000 million points and a signal capturing rate of up to 1 million wfms/s, Rigol's DS70000-series units can capture and play back signals in real-time at up to 2 million frames.

Vertical resolution

Vertical resolution refers to the digital oscilloscope's A/D converter and the accuracy at which input voltages are converted to digital values. The A/D converter divides any measuring range of the input variable into intervals and assigns them to a quantisation stage. This gives us the grid on the display. The more discrete amplitude values it sets apart, the higher its resolution – given in bit units. An 8-bit A/D converter uses 2^8 quantisation stages and can capture 256 discrete amplitude readings. A 10-bit A/D converter allows a resolution of 2^{10} =1024.

Example: an 8-bit oscilloscope divides a 12Vss input range (peak-to-peak) into 2^8 = 256 levels of 47mV and a 12-bit oscilloscope into 2^{12} = 4096 levels of 2.9mV. Incidentally, the best possible resolution is found when the signal is still completely visible on the display.

Triggers

Triggers can be used to determine the parameters or conditions under which the oscilloscope should begin capturing data and displaying signals. You can set a threshold value as a simple trigger. When this is exceeded, the signal recording starts. For this purpose, a comparator checks the input signal against the trigger condition. An oscilloscope can use internal trigger sources (derived from a signal) or external trigger sources (sent from outside). There are also analogue and various digital triggers that work on the basis of the data provided by the A/D converter.

Digital oscilloscopes include the options of setting triggers by edge, glitch and pattern. Mixed-signal oscilloscopes can trigger via logic and/or oscilloscope channels. Serial interface buses can use corresponding trigger protocols for SPI, UART/RS-232, CAN/LIN, USB, I2C, FlexRay and more. There are a variety of simple and complex triggers that can also be used in combination.

At the pulse of the signal

Signals are captured using probe tips, which must be finely adjusted to the oscilloscope to ensure signal integrity and measurement accuracy. Probes have a signal-capturing metal tip, which is connected to the internal BNC connector of the oscilloscope, and a crocodile clip for earthing. Some have a power port.

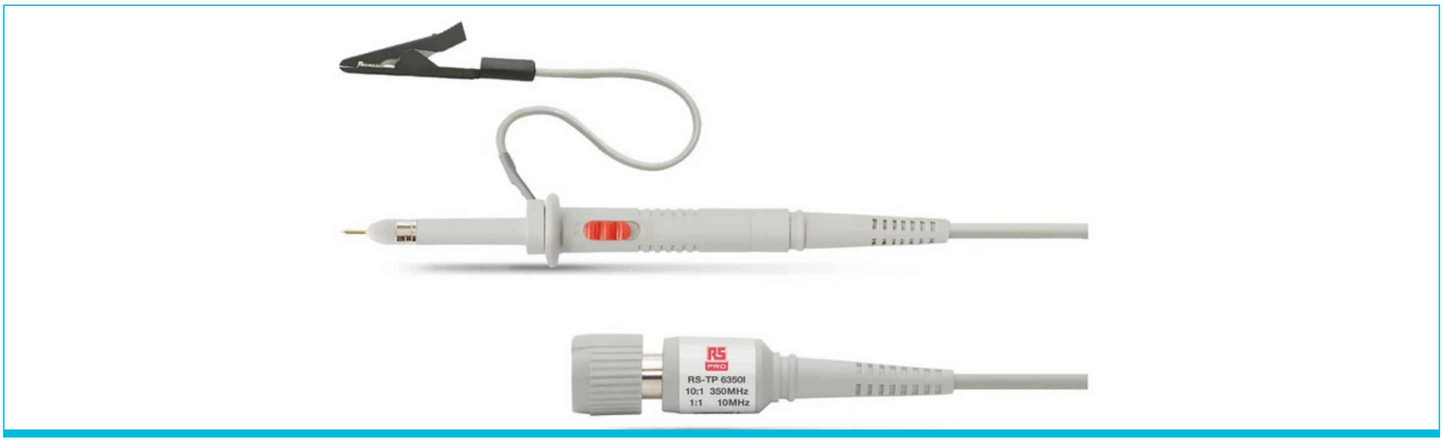

Fig. 10. The passive [RS-TP 6350I oscilloscope probe]() does not require a battery or a power supply, so it has no power port. (Image: RS Components)

Manufacturers recommend using probes with bandwidths that exceed the clock rate by a factor of five. Probes generate unwanted resistive, capacitive and inductive loads, which should be kept as low as possible. Smaller probes are better for use in compact devices. There are passive, active and differential probes, logic probes and customised designs.

Passive probes

Passive probes can be used to measure signal and voltage levels, among other things. As they do not contain any active components, they can be used without a power connection or battery supply. They are also easy to use. Models can come as 1:1 and 10:1 versions. For relatively low measuring frequencies, they can also be combined.

With a 1:1 probe, the oscilloscope is connected to the measuring point without a divider. These probes are very sensitive and can accurately detect low signal levels with precision, the bandwidth is low (<500 MHz) due to the oscilloscope's active input capacitance. 10:1 probes are often supplied as standard accessories for the oscilloscopes. They reduce the signal amplitude by a factor of 10 and are suitable for high-voltage measurements. They have a significantly larger bandwidth than 1:1 models. A capacitance in the probe tip compensates for the input capacitance of the oscilloscope, which helps accurately capture signals with high-frequency components.

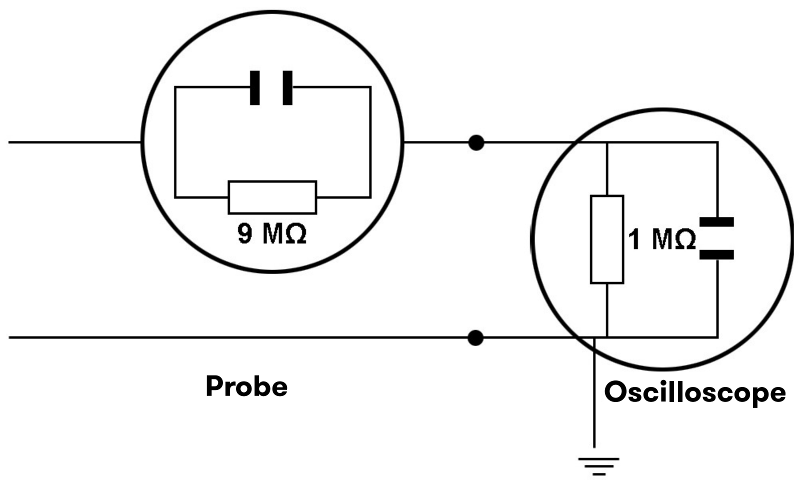

Fig. 11. The input resistance of the probe is 10 MΩ. The resistance of 9 MΩ in series with the 1-megaohm input of the oscilloscope gives a voltage ratio of 10:1 (image: channel-e).

The passive probe comes as a high-impedance or a low-impedance (resistance probe) variant. High-impedance probes are usually designed as 10:1 dividers. The series resistance in the probe tip is 9 MΩ. When plugged into the high-impedance 1-megaohm input of the oscilloscope, the input resistance of the probe is 10 MΩ, giving a voltage ratio of 10:1. As a result, the voltage on the probe appears reduced by a factor of 10 on the oscilloscope. You have to multiply this by 10 again when reading. The divider ratios can vary depending on the resistance or impedance of the probe (e.g. 10:1, 20:1, 100:1). Some oscilloscopes detect the probe design as soon as it is connected.

Active and differential probes

Active and differential probes are used for signals with extremely fast rise times. They have circuits with amplifiers and buffers that ensure signal integrity, with the signal amplified at high bandwidth.

These probes have an additional connection for the power supply. There are also multifunctional probes that allow measurements to be taken in differential mode, asymmetric mode and normal mode, without changing the connectors at the probe tip. Active probes are powered via the connection port or their own power supply. They are designed for a higher bandwidth (>500 MHz), whereby the connected cables can reduce the bandwidth.

Fig. 12. The active probe RT-ZS 6 GHz from Rohde & Schwarz with micro button is used to accurately measure earthed signals. It measures both high-speed and low-frequency signals, in which case it is crucial that the probe impedance places only a minimal load on the test point. (Image: RS Components)

Differential probes are a special type of active probe and are suitable for fast symmetric signals. They have the connections A, B and earth. The A and B connections are connected to the cable pair for the differential measurement, while the earth connection goes to the earth of the circuit. As a result, measurements can be made with just one oscilloscope channel. Differential probes are suitable for monitoring bus systems, for example.

There are still many special variants available – e.g. high-voltage probes and optical designs. Interfaces and earthing cables are optional accessories. Probes need to be calibrated to the varying capacitances in the cable and oscilloscope. For this purpose, probes have a trimmer capacitor, usually at the tip or in the BNC connector.

Verdict

Oscilloscopes are powerful measuring instruments that are useful in a wide variety of areas of mechanical engineering. They have become indispensable tools in servicing and fault-finding tasks, as well as production-related use. It is important to find the best-value device that has the right specifications for your area of application. As the list of specifications is really very extensive and new devices are constantly being developed, we recommend you consult the manufacturer. They can help you select the right 'special agent' for your specific signalling needs.