Get to know your oscilloscope

The oscilloscope is probably the most useful and versatile electronic instrument that you can have on your bench, but its many functions can be a daunting prospect

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The oscilloscope is most simply described as an instrument for displaying voltages and waveforms as they change over time. An oscilloscope screen can be thought of as a piece of graph paper upon which a graph is drawn of input voltage on the Y axis versus time on the X axis. The scale of each axis is under the user's control, with a pair of selectors to set the number of volts per vertical square on the screen, and the number of seconds per horizontal square, referred to as the timebase. Voltages and time intervals can thus be easily measured by counting squares between intervals on the screen, and even though the squares may not be exactly a centimetre in size you will hear them referred to as centimetres. A typical oscilloscope will have a voltage resolution from a fraction of a millivolt to tens of volts per centimetre, and a time resolution from a fraction of a microsecond to a few seconds per centimetre,

Above
A typical CRT oscilloscope screen showing a triangle wave. Voltage is in the vertical axis, and time in the horizontal

PROBES

The input to an oscilloscope is designed to have a high bandwidth: it can accept many frequencies. Physically it will almost always take the form of a BNC socket, into which a coaxial cable can be plugged to feed in whatever signal is to be displayed. You can connect up a lead from a source such as a signal generator and display the waveform, but sometimes you will see distortion on the screen. Waveforms that should be square become rounded, and the instrument does not give a correct picture.

This distortion is due to the capacitance of the cable having a different effect on the different frequencies passing through it, and it must be compensated for before the waveforms displayed can be trusted. The essential companion to an oscilloscope is therefore a dedicated oscilloscope probe containing the required circuitry for this compensation. Oscilloscopes have a calibrated square wave source to which a probe can be connected, and probes have a small variable capacitor which can be adjusted with a screwdriver until the displayed waveform is perfectly square. Many probes will also include an attenuator which reduces the signal level by 10, having the effect of increasing the voltage range of the instrument by a factor of 10.

Above
Two identical waveforms; the top one is displayed through a correctly adjusted probe, while the probe carrying the bottom one needs some attention

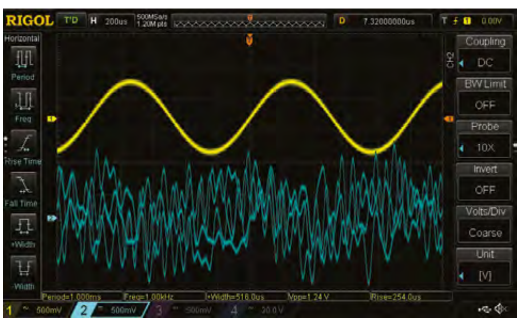
allowing a wide range of voltages and frequencies to be measured.

An oscilloscope will attempt to display any voltage or waveform presented to its input, but is at its most useful when showing cyclical waveforms in which the same pattern is repeated continuously. It works by triggering the start of the waveform it displays at

> A basic oscilloscope can display a single waveform, but a typical real instrument will display **two or even four waveforms at once**

the left-hand side of the screen from the same point in every cycle, such that successive cycles of the waveform simply overlay each other on the screen and appear as a single one. This triggering is governed by a trigger control, which sets a particular voltage point that the waveform passes through as where the leftmost part of the display will be placed. There will be an option to set this either on a falling or a rising voltage, allowing the user to line up a particular point of interest on the screen.

We've described a basic oscilloscope that is able to display a single waveform, but a typical real instrument will have the ability to display two or even four waveforms at once. These so-called dual-trace models have one timebase for all channels, but separate voltage selectors and inputs for all. Modern oscilloscopes are often computerised instruments with many once-unimaginable features governed by software, but a traditional oscilloscope is an analogue device with a CRT screen. Both are →



Above
Two traces on a four-channel digital oscilloscope. The top trace is a sine wave; the bottom one is a complex waveform

FINDING AN OSCILLOSCOPE

When looking for an oscilloscope, it seems that there is an almost infinite array of choices at prices to suit all budgets. Indeed, there seems to be no upper limit to the price of a new oscilloscope; there are specialist models for use with extremely high frequencies that come with six- and even seven-figure price tags. Fortunately, these are the exception rather than the norm, and there are plenty of options for the oscilloscope user on a budget.

When considering a purchase, there are several factors to consider:

- Bandwidth. Quoted in MHz, the maximum frequency you'd expect to use it with.
- Number of channels. The majority of oscilloscopes have two, but you will find models with more, and even also one or two single-channel instruments.
- Digital or analogue? Analogue oscilloscopes use CRT displays, and may be quite bulky. They are, however, simple to use and can be very cheap to buy. Digital models, especially the newer ones, often have LCD displays, are quite compact, and have a lot of features in their software. They are often more expensive, though.
- New or second-hand? After decades of oscilloscope production, there are huge numbers of second-hand instruments to be had, often for very little money indeed. It's worth asking around your hackspace or other community: someone may have an old CRT oscilloscope they are willing to pass on to you. However, an older instrument may lack the features of a new model and, if you have the resources, a wise purchase can provide many years of service.

Below
A large pile of second-hand test equipment for sale at the legendary Black Hole Surplus, Los Alamos. Jeff Keyzer (CC BY-SA 2.0)

> If you were to connect a battery to your oscilloscope, you would see **the flat horizontal line move upwards by an amount equivalent to its voltage**

extremely useful to have on your bench, and for the purposes of this piece we have ensured that we use both types in our examples.

VOLTAGE

Voltages on an oscilloscope are displayed as vertical distances on the screen. If you were to connect a DC source such as a battery to your oscilloscope, you would see the flat horizontal line move upwards by an amount equivalent to its voltage. So for example if the voltage selector is set to 1 volt per centimetre and a 9 V battery is connected, its voltage can be measured through the 9 cm by which the line moves up the screen.

The same voltage measurement can be performed on waveforms. For instance, should you wish to measure the peak-to-peak voltage of a sine wave, you need simply count the squares between the lower edge of the trace and its upper edge. Modern computerised oscilloscopes will often calculate this and other useful figures automatically, but even if you are lucky enough to have one it is still worth knowing how to take measurements without it.

FREQUENCY AND PERIOD

Time periods on an oscilloscope are displayed as distance across the screen from left to right and, just as with a voltage, you can measure a time by measuring the distance between two points on the screen and applying the relevant scale to which the timebase is set.

You can measure the period of a waveform by taking the distance between two adjacent identical points upon it. So, for example, if the measurement is 5 centimetres at 200 microseconds per centimetre then the period is 1 millisecond.

The relationship between period and frequency is as follows: Frequency(Hz) = 1/Period(S). Therefore once you have a reading for the period, it is easy to calculate the frequency. In our example above, 1 millisecond is 0.001 seconds, so the frequency in Hz is 1/0.001, 1000 Hz, or 1 kHz. The probe calibration terminal mentioned above is a 1 kHz square wave on most oscilloscopes, so you can measure this for yourself with relative ease.

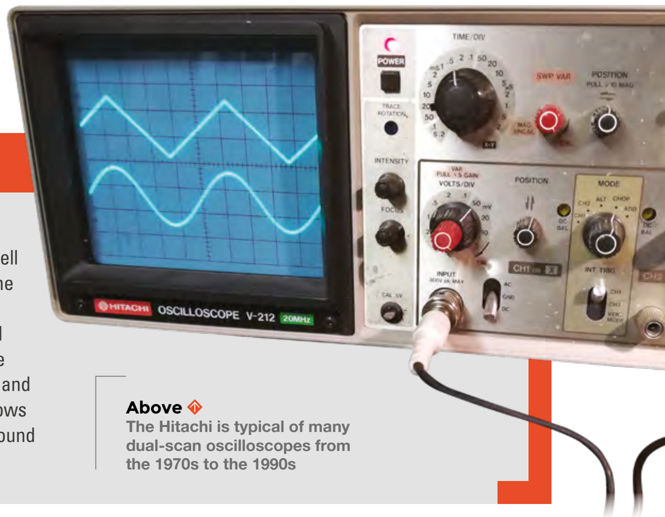
If your oscilloscope has more than one trace, it can be used for measurements involving the comparison of more than one waveform. In digital circuits using a clock, for example, a data line on one trace can be compared with its clock on the other trace to spot timing issues; or in an analogue circuit, the phase difference between two waveforms can be measured by calculating the time difference between them. If you work with video it can be especially useful to have multiple channels, as one can be triggered by the video synchronisation pulses, keeping the others in sync with them for monitoring video waveforms.

The basic functions we have described so far are common to all oscilloscopes, whether digital or

A TYPICAL MODERN BENCH OSCILLOSCOPE: THE RIGOL DS1054Z

The DS1054Z is a four-channel 50 MHz digital storage oscilloscope, from the Chinese manufacturer Rigol, that has become something of a standard in the hobby and professional electronic worlds alike. It has the full range of features you would expect from a modern instrument, as well as a network interface, a USB interface for a computer, and another USB socket on its front for a disk drive. It has emerged as the leader of a crop of superficially similar models from Chinese manufacturers, and is known for being a quality addition to any bench. It is also known for an unauthorised software hack that unlocks some hidden features, including allowing access to the full capabilities of its chipset and turning it from a 50 MHz oscilloscope into a 100 MHz one. Including UK taxes it costs somewhere over £300 so it is hardly an inexpensive purchase, but it provides some of the things you might expect from one costing much more.

Below
The Rigol DS1054Z four-channel digital storage oscilloscope
Dave Jones/EEVBlog (CC BY 2.0)



A TYPICAL ANALOGUE BENCH OSCILLOSCOPE: THE HITACHI V-212

The Hitachi dual-scan oscilloscope used for the purposes of this article was borrowed from the folks at MK Makerspace, and is typical of similar models of its age from multiple manufacturers. It is a 20 MHz instrument manufactured somewhere over two decades ago, and is a very solid and reliable oscilloscope that remains accurate and easy to use. It does not have any of the frills you might expect from a digital model, but it will serve its owners well for many more years. The best thing about the Hitachi, though, was its price: it was bought for £5 at a radio rally, from a vendor who had acquired a significant number of them on the surplus market. If you do not want the latest and greatest in an oscilloscope then this one shows that there are some serious bargains to be found for those prepared to seek them out.

Above
The Hitachi is typical of many dual-scan oscilloscopes from the 1970s to the 1990s

analogue. We have mentioned some of the extra functions a digital instrument may have, such as automatic calculation of voltages or period, but the signature feature of a digital oscilloscope is something beyond the capabilities of its analogue cousins. Because it is at heart a computer, it can store its waveforms in memory for capture and closer examination. It can therefore catch one-off events such as a transient spike from a switching event, making it an even more powerful instrument than you might at first imagine.

We have given you a relatively brief introduction to the oscilloscope in these pages, but of course paper is not the ideal medium for this particular task. The best way to understand one of these instruments is to have one on your bench and put it through its paces, so if you do not possess one we'd like to encourage you to take the plunge. Good luck!

IS IT A TOY OR AN OSCILLOSCOPE? THE JYE TECH DSO 15001 OSCILLOSCOPE KIT

If you take a look on an electronics vendor website that sources its components from China, you will find a variety of oscilloscope soldering kits among the component testers and Arduino clones. They take the form of a fast microcontroller with an analogue input and an LCD screen, along with an input conditioning circuit. Some of them are bare PCB kits while others have laser-cut enclosures bundled, and still more have snap-together plastic cases.

The JYE Tech DSO 15001 is typical among the final group and, after a bit of soldering and assembly, makes a smart little handheld unit.

It requires a separate 9 volt power supply to operate, it only has a meagre 200 kHz bandwidth, and its input voltage range is not as wide as any bench instrument. But it has a perfectly acceptable software interface, it's small enough to hold in your hand, and it cost just under £15 by mail order.

You might be tempted by one of these kits, and should you build one you will find it to be perfectly usable within its specification. It's fair to say, though, that a second-hand CRT instrument will give you a huge performance boost for a similar investment. There are two places in which this kit can shine, though; in the first instance, it's a pocket-sized unit that can be taken almost anywhere that there is a need for a low-bandwidth oscilloscope. In the second instance, it's also a soldering kit that anyone with moderate soldering ability should be able to assemble. So if you have a teenage electronics enthusiast in your life, it might make an excellent project and a first oscilloscope for them.

Left
The JYE kit oscilloscope is tiny, but limited in functionality