

A Shortish Guide to Using an Oscilloscope

An oscilloscope is a test instrument that allows you to “see” how the voltage at a point in a circuit varies with time. A ‘scope’ samples the voltage and displays it on a screen that is marked with a grid in centimetres. From the vertical gain in Volts/cm we can measure the amplitude of the signal in Volts, and from the horizontal scale in sec/cm (the ‘timebase’), we can measure the timing of that signal. Scopes always have two or more channels so that the relative timing or amplitude of two signals can be compared.

Scopes are often a complete mystery to students when they begin a course. Since we expect you to be *proficient* in using a scope, we have written this short note to help you get started. Scopes are actually quite straightforward to use. Regardless of how fancy a scope may appear to be, any scope really has only three controls – vertical, horizontal, and triggering. These are described below.

1 Oscilloscope Controls

Note: The figures show typical controls for both analogue and digital (see section 3) scopes. There will be more control knobs on an analogue scope than on a digital scope. Many of the controls on a digital scope are “soft” controls, where the functions activated by a few push buttons are changed in the instrument’s software.

1.1 Vertical Control (Gain)

The **VERTICAL** control sets the gain (ratio) in Volts/cm between the voltage of the input signal and the vertical deflection of the trace drawn on the screen. There is a separate vertical control for each input channel, similar to those shown in figure 1. Each vertical control is usually a large knob.

CAUTION! There is usually a small knob marked **VAR** (or **VARIABLE**) that allows adjustment between the “clicks” of the **VERTICAL** control knob. When measuring voltages from the screen, ensure that the **VAR** knob is in the **CAL** (or **CALIBRATE**) position!

There are some subsidiary vertical controls that you need to be aware of

- **COUPLING:** The coupling setting determines which part of the signal presented to the input is displayed on the screen. The Coupling control has three settings:
 - **DC:** The full signal voltage, including any DC component that may be present, is displayed. This is the usual setting.
 - **AC:** A coupling capacitor is placed in series with the input, removing any low-frequency component of the signal, including the DC component. The time constant of this high-pass filter is usually about 0.1 sec. AC coupling is useful if you have to look at a small signal sitting on top of a large DC voltage.
 - **GND:** The signal is removed from the input, and the input connected to +0V.
- **POSITION:** This moves the trace vertically on the screen. Use it in conjunction with **COUPLING – GND** to set the zero voltage position of the trace.



Figure 1: Typical vertical gain controls of a two-channel analog (left) and digital oscilloscope (right).

1.2 Horizontal Control (Timebase)

The horizontal control sets the scale in cm/sec at which the trace is drawn on the screen. There is only one horizontal control for all input channels, as shown in Figure 2. There is also a **HORIZONTAL POSITION** control.

CAUTION! There is usually a small knob marked **VAR** (or **VARIABLE**) that allows adjustment between the “clicks” of the **HORIZONTAL** control knob. When measuring times from the screen, ensure that the **VAR** knob is in the **CAL** (or **CALIBRATE**) position!



Figure 2: Typical horizontal (timebase) control of an analog (left) and digital oscilloscope (right).

Note that time on an oscilloscope screen moves from left to right (unlike in a graph), so that older stuff is to the right of the screen.

On some scopes there is also an “XY” setting for displaying two input channels – one channel drives the horizontal display and the other drives the vertical display. This is useful for looking at the phase, frequency or voltage relationships between two signals.

1.3 Triggering Control

This is the tricky bit that no-one understands, so engage your brain...

Imagine that the input signal to an oscilloscope is a sinusoidal voltage. The scope repeatedly¹ draws a trace across the screen that represents the time-varying voltage. The trace is drawn hundreds or thousands of times each second. Now imagine that each time the trace is drawn across the screen, the drawing begins on a different part of the sine wave. The trace of the sine wave will flicker horizontally, backwards and forwards across the screen. I am sure that you have seen something like this. To stop the flickering and “freeze” the trace on the screen, the scope must start to draw the sine wave on *exactly the same part of the wave* every time the wave is drawn. This is what the **TRIGGERING** control lets you do.

Triggering works by setting a reference (DC) voltage level, which the scope compares with the input signal. When the input signal voltage reaches the trigger voltage, the scope begins drawing the trace on the screen. The trace remains rock-solid on the screen, as if by magic! Actually, what is happening is that every time the trace is drawn (thousands of times per second) it is drawn in *exactly the same place*.

Of course, there are a couple of circumstances where this will not give a stable screen trace:

- If the input signal voltage never reaches the trigger voltage, the scope never draws the trace. I am sure that you have (or have not?) seen this, too.
- If the input signal is non-repetitive. For this, you need a storage scope – see later.

Now that you understand the basics, here are descriptions of all the usual trigger controls:

- **LEVEL**: This knob allows the trigger reference voltage to be set;
- **SLOPE**: Sets the slope (+ or –) of the signal that will cause triggering as it crosses the level of the trigger reference voltage;
- **MODE**: Allows selection between
 - **NORMAL**: the trace will be drawn on the screen when the trigger source signal crosses the trigger reference voltage with the correct slope;
 - **AUTO**: the trace “free runs”. This is sometimes useful for looking at signals that have very little AC component, and also for signals that sometimes get very small. Both types of signals can be hard to trigger on;
 - **SINGLE**: Once “armed”, the scope will trigger the next time that the input signal matches the trigger level and slope condition. This triggering option is essential for viewing non-repetitive waveforms, and is most useful when the oscilloscope is a digital storage scope.
- **SOURCE**: Determines which signal is compared to the trigger reference voltage. Usually selectable between
 - **CH1, CH2**, etc: The various input signals;
 - **EXTERNAL**: some other signal that is injected through a dedicated input;
 - **LINE**: the AC power supply for the scope, and maybe some other options.
- **HOLDOFF**: is a time delay before the scope can re-trigger. It is sometimes useful when an input signal is *nearly* repetitive.

Typical triggering controls are shown in Figure 3.

¹ This is a fact, unless it the oscilloscope is a “storage scope” – wait for the explanation later in these notes.



Figure 3: Typical trigger controls of an analog (left) and digital oscilloscope (right).

Fancy scopes often have more, fancy, triggering options. You may come across scopes that trigger when a particular series or parallel pattern appears on one or more inputs, or a scope that triggers when a waveform goes outside of a pre-set voltage-and-time envelope.

2 The Importance of Probes

The function of an oscilloscope is to allow you to “see” a time-varying waveform. The function of a scope probe (see Figure 4) is to transmit the waveform from the circuit node to the scope input *without distortion or added noise*. That is, a scope probe is not just any old bit of wire that happens to be lying around on the lab bench.

WARNING! Scope probes are delicate and expensive. The cheapest scope probe that we can buy costs around \$70 at the moment, and good quality Tektronix probes cost about **\$220 each**. *We will not tolerate anyone misusing scope probes.* You have been warned!



Figure 4: a) A scope probe;



b) Not a scope probe.

The input impedance of a scope is typically around $1\text{M}\Omega$ in parallel with about 100pF . Even this may load the circuit under test too much, with the input capacitance distorting the measured waveform. The usual solution is to use a “10x” passive scope probe which has a resistance of $9\text{M}\Omega$ in parallel with an adjustable capacitor of about 5pF . When the capacitor is adjusted to be $1/9^{\text{th}}$ of the capacitance of the scope input plus probe lead, the probe will have an impedance of $10\text{M}\Omega$ *at all frequencies*. Loading of the circuit under test will have been

reduced by a factor of 10, and waveform distortion eliminated through the process of probe compensation. You should normally use the scope probe in the “10x” mode.

In Figure 4a, the short black lead with the alligator clip is the ground connection, to be clipped to the +0V reference point in the circuit. The probe hook can be seen just above the probe itself. This style of probe hook pulls (*gently!*) off the probe; some styles screw off.

2.1 Probe Compensation

In practice, adjustment of probe capacitance is very easy. All scopes provide a reference output, labelled something like **PROBE ADJ** or **CALIBRATE**, that is typically a 1kHz square wave at 5V peak-to-peak. Just clip the probe onto the reference output, set up the triggering, and adjust the probe capacitance by turning the tiny screw in the probe head. When correctly adjusted, the screen trace should show a crisp, “square” square wave, free of rounded-off corners, overshoot or oscillations.

Do NOT attempt to adjust the probe compensation screw on the Lab scopes – it is fastened with a thread locking compound. The Lab scopes have a feature that allows checking of probe compensation. To use this feature, set the **Probe** entry in the **VERTICAL** menu to match the probe, clip the probe onto the “**PROBE COMP**” output (see Figure 3), and press the “**PROBE CHECK**” button. The message **PASSED** should be displayed on the screen.

3 Digital Scopes

In an analogue scope, the input signal is amplified and used to deflect an electron beam that excites a phosphor to produce the screen trace – like a TV. A digital scope is quite different: it rapidly samples the input signal with an analog to digital converter, then stores the digitised samples in memory. The samples are then retrieved for display. It is clear that a digital scope is intrinsically also a storage scope, capable of capturing and displaying single, non-repetitive events. Digital scopes are therefore very useful for looking at digital signal.

The foregoing has avoided much description of the form of the operator controls, since both analog and digital scopes have essentially the same controls. The only real difference is that an analog scope will have many knobs and push buttons, whereas only the most important controls on a digital scope will have dedicated knobs, and the other controls are usually implemented through screen-based “soft” keys that change in function as the user steps through menus on the screen.

4 Grounds

A scope measures the voltage of the input signal relative to “ground”, the voltage on the outer conductor in the BNC input connector. This ground is usually tied to the oscilloscope chassis for shielding reasons. The protective earth conductor of the AC power supply (the third pin of the power plug) is also connected to the instrument chassis. In other words, one is usually forced to measure the voltage of the input signal relative to the arbitrary ground of the protective earth conductor. If a circuit under test is floating above ground, you cannot connect the probe ground clip to the circuit because this will cause a direct short circuit to protective earth *through the scope*. In this situation, you must make a differential measurement of the voltage between two circuit nodes by using two probes. Invert the input of one probe, then use the oscilloscope’s **ADD** function.

5 Useful Hints

This section provides some hints and suggestions for good practice.

- If *nothing* shows on the screen, follow these steps:
 - Make sure that the scope is powered on.
 - Make sure that at least one input channel (say Ch1) is turned on.
 - Set the VERTICAL gain to 5V/cm. Set the HORIZONTAL time base to 1ms/cm. Set the TRIGGERING to Ch1, Auto, and DC Coupling. Turn the screen brightness up. Ground the probe, and wiggle the VERTICAL POSITION until you see the trace – it will be a horizontal line. You can then slowly adjust the controls, hoping that the beam will not vanish again. If it does, perhaps you should go back to the start of these notes.
 - On an analog scope there may be a button marked Beam Finder. On a digital scope, you can use the Auto Set button. This is about all it is good for!
- The VERTICAL control will always include an **INVERT** setting. In conjunction with the **INPUT MODE** control this allows one input signal to be subtracted from another.

5.1 Whatever Else You Do it is ALWAYS Good Practice to

- Check the input gain and probe attenuation settings by measuring a known voltage, such as a +5V or +12V supply rail.

5.2 and Please, NEVER, EVER

- Use a scope probe for anything other than probing circuits;
- Use anything other than a scope probe for probing circuits;
- Poke the pointed probe tip into anything, including a solderless breadboard. It will get snapped off, ruining the probe and costing you money;
- Twist or kink the scope probe lead – it is a small coaxial cable, and easily damaged. Even slight damage can cause internal reflections of high frequency signals;
- Connect the probe ground clip to a mains voltage (active or neutral) when measuring mains AC circuits. This will short the mains voltage to protective earth through the scope, destroying the scope. In the Mechatronics Lab, you must not do any work with mains AC circuits.
- Use a multimeter in place of a scope unless you are *absolutely certain* that you are measuring a DC voltage. Check the circuit node first with a scope, and then you might as well not bother to get the multimeter out...

Bibliography

Horowitz, P. & Hill, W. *The Art of Electronics*. 2 ed., Cambridge University Press, 1989, Appendix A: The Oscilloscope.

Tektronix. The XYZs of Oscilloscopes. Available 28 July 2002 from http://www.tek.com/Measurement/App_Notes/XYZs/03W_8605_2.pdf

Tektronix. The ABCs of Probes. Available 28 July 2002 from http://www.tek.com/Measurement/App_Notes/ABCsProbes/60W_6053_7.pdf

David Rye, 2002.