

## Mini-Module: Oscilloscope (from Horowitz and Hill, “Art of Electronics” – intended for an analog scope!)

The oscilloscope (scope for short) is the most useful and versatile electronic test instrument. As usually used, it lets you “see” voltages in a circuit as a function of time, triggering on a particular point of the waveform so that a stationary display results. The scope we will describe is usually called a dc coupled dual-trace triggered **analog** scope.

The digital oscilloscopes we’ll use are similar to the other scopes in operation, except that the functions tend to share buttons by using a menu system. (You’ll see what I mean soon.) I will note things that are specific to the digital scope in dark red here.

It usually works out best if you hook up the function generator to the scope and practice working with both together. That way you have something to look at on the scope. There are some suggestions of what to try with the function generator in the applicable mini-module. If you are reading this at home, you may as well stop unless you have your own scope to practice on; this just doesn’t mean much unless you are actually turning the knobs while you read.

### VERTICAL

Beginning with the signal inputs, most scopes have two channels; that’s very useful, since you often need to see the relationship between the signals. Each channel has a calibrated gain switch, which sets the scale of VOLTS/DIVISION *on the screen*. There’s also a VARIABLE gain knob (concentric with the gain switch) in case you want to set a given signal to a certain number of divisions.

The scope is dc-coupled, an essential feature: What you see on the screen is the signal voltage, dc value and all. Sometimes you may want to see a small signal riding on a large dc voltage. In that case you can switch the input to ac coupling, which capacitively couples the input with a time constant of about 0.1 second. **You can check out the difference using the function generator.**

Most scopes also have a grounded input that lets you see where zero volts is on the screen. (In the GND Position, the signal isn’t shorted to ground, just disconnected from the scope, whose input is grounded. Thus this won’t zap your external circuit.) Scope inputs are usually high-impedance (a megaohm in parallel with about 20 pF), as any good voltage measuring instrument should be. They aren’t nearly as high impedance as the DMM, but that is done for a reason which you will understand after Lab 2. The input resistance of 1.0 megaohm for scopes is an accurate and universal value, so that high impedance attenuating probes can be used (as will be described later); unfortunately, the parallel capacitance is not standardized, which is a bit of a nuisance when changing probes. **The digital scope can also be set to have an input resistance of 50 ohms using the channel menu. Do NOT use this setting unless you are sure you need it.** It is used to watch very fast signals, but it significantly degrades the signal for most applications and exposes the scope to damage from overvoltage.

The vertical controls include a vertical POSITION control and a vertical SCALE control. The menu button under the SCALE control accesses a number of other controls and options, some of which we will use this term. The digital scope will let you display both traces simultaneously. The two traces are different colors, which really helps you keep track of them. But the knobs and other controls only operate on one channel at a time – the active channel. Pushing the button for a channel makes it the active one.

## HORIZONTAL

As with the vertical controls, there is a calibrated TIME/DIVISION switch and a VARIABLE knob. Many scopes have a 10 x MAGNIFIER and also allow you to use one of the input channels for horizontal deflection (this lets you generate those beloved but generally useless "Lissajous figures" featured in elementary books and science fiction movies). The digital scope is digitizing the voltage readings as they occur in time and then drawing a picture of the trace on the screen (a true X, Y graph) using the digital data. This means it can show you things that happen (a short time) before the trigger, as well as after it. A nice aspect of the digital scope is that the trace, which is really a bunch of numbers, can be sent via an interface to a computer.

## TRIGGERING

Now comes the trickiest part: triggering. We've got vertical signals and horizontal sweep; that's what's needed for a graph of voltage versus time. But if the horizontal sweep doesn't catch the input signal at the same point in its waveform each time (assuming the signal is repetitive), the display will be a mess - a series of pictures of the input waveform superimposed over each other at different times. You can see this later by looking at the function generator, but triggering off the LINE. You can see from the trigger menu (always near the right side of the scope) that you have a number of choices about trigger sources and mode. First, you can choose to trigger off either of the waveforms (input channels). The trigger circuitry lets you select a LEVEL and SLOPE (+ or -) on the waveform at which to begin the sweep. NORMAL mode produces a sweep only when the source selected crosses through the trigger point you have set, moving in the direction (SLOPE) you have selected. In practice, you adjust the level control for a stable display. Watch how a repetitive waveform moves around as you adjust the trigger level or the DC offset on the signal. Then see how the "starting point" stays constant and the waveforms moves around as you change the fine frequency on the function generator. In AUTO the sweep will "free run" if no signal is present; this is good if the signal sometimes drops to small values, since the display won't disappear and make you think the signal has gone away. AUTO is the best mode to use if you are looking at a bunch of different signals and don't want to bother setting the trigger each time. SINGLE SWEEP is used for non-repetitive signals. LINE causes the sweep to trigger on the ac power line, handy if you're looking at hum or ripple in a circuit or a DC voltage level.

The EXTERNAL trigger inputs are used if you have a clean signal available at the same rate as some "dirty" signal (highly variable) you're trying to see; it's often used in situations where you are driving some circuit with a test signal, or in digital circuits where some "clock" signal synchronizes circuit operations. The various coupling modes are useful when viewing composite signals; for instance, you

may want to look at an audio signal of a few kilohertz that has some spikes on it. The HF REJ position (high-frequency reject) puts a low-pass filter in front of the trigger circuitry, preventing false triggering on the spikes. If the spikes happen to be of interest, you can trigger on them instead in LF REJ position.

## HINTS FOR BEGINNERS

Sometimes it's hard to *get anything to show up on the scope*. The digital scope has an auto setup option under the save/recall button. Otherwise, begin by turning the scope on and set triggering for AUTO and turn both channels on. Set the horizontal scale at 1 ms/div and the magnifier off. If you still don't see anything, ground the inputs and adjust the vertical position control until you see a horizontal line. Now you can apply a signal and fiddle with the trigger. Become familiar with the way things look when the vertical gain is far too high, when the sweep speed is too fast or slow, and when the trigger is adjusted incorrectly. This is a good time to hook up the function generator to the scope if you haven't already done so and practice working with both together.

## PROBES

The oscilloscope input capacitance seen by a circuit under test can be quite high, especially when the necessary shielded connecting cable is included. The resulting input impedance (1 megaohm in parallel with 100 picofarads or so) is often too low for sensitive circuits and loads it by the usual voltage divider action. Worse yet, the capacitance may cause some circuits to misbehave, even to the point of going into oscillation! In such cases the scope obviously is not acting like the "low-profile" measurement instrument we expect; it's more like a bull in a china shop. The usual solution is the use of high impedance "probes." The popular 10X probe will be used most often. At dc it's just a 10X voltage divider. The digital scope has a setting under the channel menu that assumes the 10X and adjusts the readings accordingly – no thinking required! By adjusting a variable capacitor in the probe to 1/9th the parallel capacitance of the cable and the scope input, the circuit becomes a 10X divider at all frequencies, with an input impedance of 10 megaohms in parallel with a few picofarads.

In practice, you adjust the probe by looking at a square wave of about 1 kHz, available on most scopes as CALIB, or PROBE ADJ, by setting the capacitor on the probe for a clean square wave without overshoot. This is also good scope practice, so you may want to ask for help doing this, or just give it a shot on your own. It is also a good idea to tweak your probes up before you start taking measurements with them. Sometimes the adjustment is cleverly hidden; on some probes you twist the body of the probe and lock it by tightening a second threaded part. On most probes, the adjustment is a small recessed screw. One drawback: A 10X probe sometimes makes it difficult to look at signals of only a few millivolts; for these situations use a 1X probe, which is simply a length of low capacitance shielded cable with the usual probe hardware (wire "grabber", ground clip, handsome knurled handle, etc.) The 10X probe should be the standard probe, left connected to the scope, with the 1X probe used when necessary. Our probes feature a convenient choice of 1X or 10X attenuation, switchable at the probe tip.

## GROUND

As with most test instruments, the oscilloscope input is referred to the instrument ground (the outer connection of the input BNC connectors), which is usually tied electrically to the case. That, in turn, connects to the ground lead of the ac power line, via the 3-wire power cord. This means that you cannot measure voltages between the two arbitrary points in a circuit, but are forced to measure signals relative to this universal ground.

**An important caution is in order here: If you try to connect the ground clip of an oscilloscope probe to a point in the circuit that is at some voltage relative to ground, you will end up shorting it (the circuit) to ground.** This can have disastrous consequences to the circuit under test; in addition, it can be downright dangerous with circuits that are "hot to ground" (transformerless consumer electronics like television sets, for example). If it is imperative to look at the signal between two points, you can either "float" the scope by lifting the ground lead (not recommended, unless you know what you're doing) or make a differential measurement by inverting one input channel and switching to ADD (some plug-in modules permit direct differential measurements).