

# The Oscilloscope and the Function Generator:

## Some introductory exercises for students in the advanced labs

### *Introduction*

So many of the experiments in the advanced labs make use of oscilloscopes and function generators that it is useful to learn their general operation. Function generators are *signal sources* which provide a specifiable voltage applied over a specifiable time, such as a “sine wave” or “triangle wave” signal. These signals are used to control other apparatus to, for example, vary a magnetic field (superconductivity and NMR experiments) send a radioactive source back and forth (Mössbauer effect experiment), or act as a timing signal, i.e., “clock” (phase-sensitive detection experiment). Oscilloscopes are a type of *signal analyzer*—they show the experimenter a picture of the signal, usually in the form of a voltage versus time graph. The user can then study this picture to learn the amplitude, frequency, and overall shape of the signal which may depend on the physics being explored in the experiment.

Both function generators and oscilloscopes are highly sophisticated and technologically mature devices. The oldest forms of them date back to the beginnings of electronic engineering, and their modern descendants are often digitally based, multifunction devices costing thousands of dollars. This collection of exercises is intended to get you started on some of the basics of operating ’scopes and generators, but it takes a good deal of experience to learn how to operate them well and take full advantage of their capabilities.

### *Function generator basics*

Function generators, whether the old analog type or the newer digital type, have a few common features:

- A way to select a waveform type: sine, square, and triangle are most common, but some will give ramps, pulses, “noise”, or allow you to program a particular arbitrary shape.
- A way to select the waveform frequency. Typical frequency ranges are from 0.01 Hz to 10 MHz.
- A way to select the waveform amplitude.
- At least two outputs. The “main” output, which is where you find the desired waveform, typically has a maximum voltage of 20 volts peak-to-peak, or  $\pm 10$  volts range. The most common output impedance of the main output is 50 ohms, although lower output impedances can sometimes be found. A second output, sometimes called “sync”, “aux” or “TTL” produces a square wave with standard 0 and 5 volt digital signal levels. It is used for synchronizing another device (such as an oscilloscope) to the possibly variable main output signal.

A wide variety of other features are available on most modern function generators, such as “frequency sweep”—the ability to automatically vary the frequency between a minimum and maximum value, “DC offset”—a knob that adds a specified amount of DC voltage to the time-varying

waveform, and extra inputs or outputs that can be used to control these extra features by other instruments.

## *Oscilloscope basics*

All oscilloscopes share certain basic features. Refer to Fig. 1 to see where typical controls may be found.

- The most recognizable feature: a screen. On older analog scopes this is a cathode-ray tube or CRT; the signal creates a moving dot or “trace” across the screen. On newer digital scopes the screen is a CRT or flat-panel display that operates like a computer monitor. The basic use of the screen is to display the signals in a voltage versus time graph. The screen usually has a graticule on it of about 1 cm squares.
- At least two (maybe more) signal inputs, or “channels”, typically called “CH1”, “CH2”, etc., and one external “trigger” input, typically called “EXT TRIG”.
- A collection of controls related to vertical part of the display associated with the input signals. These control the kind of coupling to the input: direct—“DC”, through a capacitor—“AC”, or disconnected—“GND”. The amount of amplification applied to the signal is controlled by a knob, and is specified in terms of screen units: a “10mV/div” setting means that a 10 millivolt change in the input signal will move the trace vertically by one major division.
- A collection of controls related to the horizontal part of the display. These controls set the time axis and are calibrated in seconds per division, e.g.,  $1\mu\text{s}/\text{div}$  means that one major division corresponds to 1 microsecond. The horizontal controls are sometimes called the “timebase” and the setting is called the “sweep rate”.
- A collection of controls called the “trigger” that are used to synchronize the input signal to the horizontal display. Because there is no fixed relationship between an external signal and the internal timebase, the trigger makes the scope wait until some prescribed level in an input is reached before beginning its display. Triggering controls are discussed in more detail on page 6.

In addition to the above features which are common to both analog and digital varieties, digital oscilloscopes typically come with the ability to save data and control settings to memory, perform mathematical operations on data traces, average many cycles together to reduce the effect of random fluctuations, and carry out automatic measurements of frequency and amplitude of the input signals. One can also make printouts of the display screen to keep a paper record of the measurement. The basic and advanced features of oscilloscopes will be explored in the following exercises.

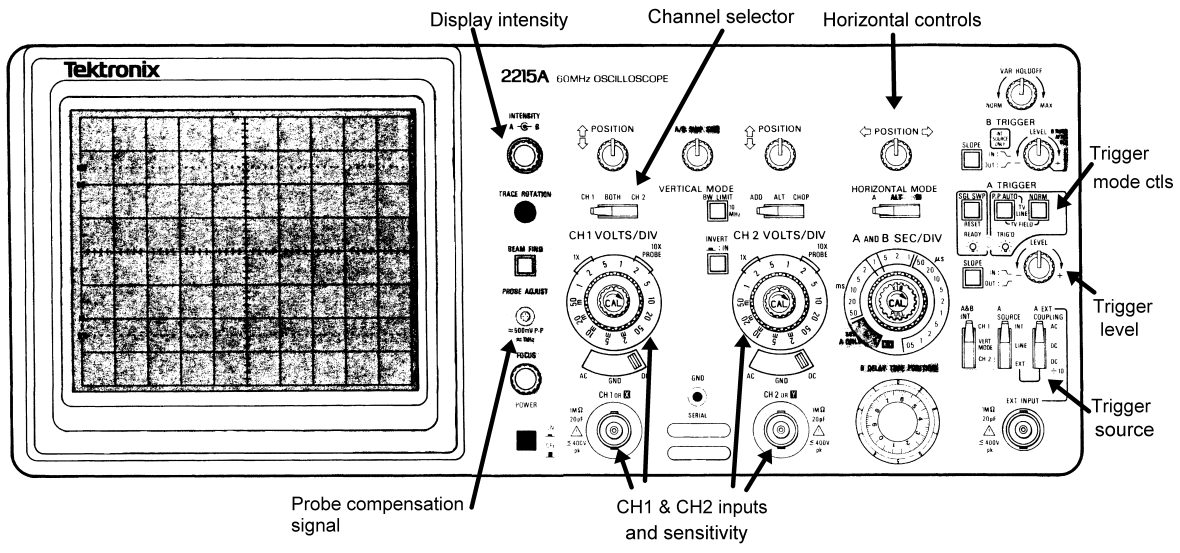
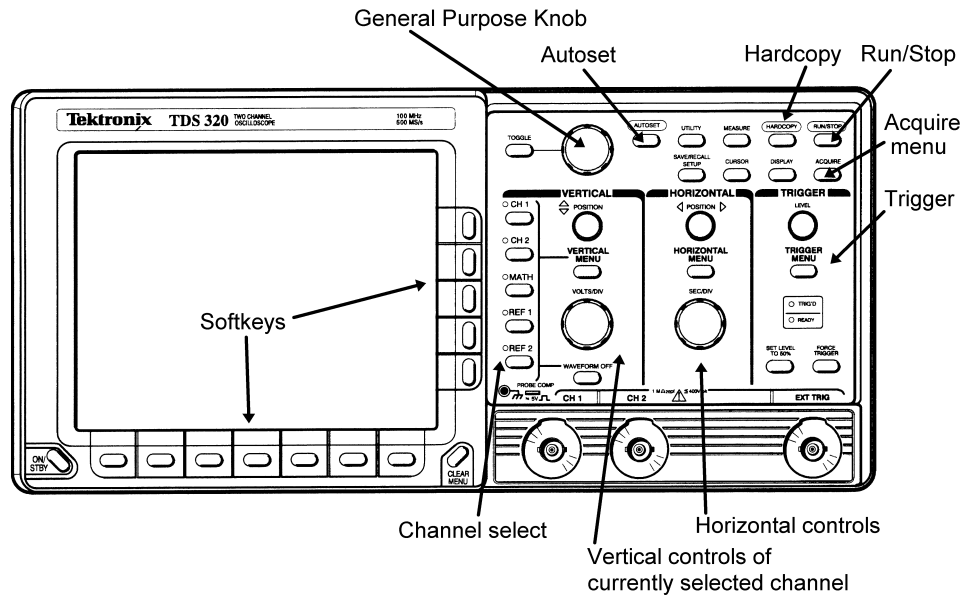


Figure 1: Front panel layouts of the digital scope (top) and the analog scope (bottom).

## *Getting started*

In this exercise you will look at the types of signals available from a generator and explore the basic controls of the generator and digital oscilloscope. First check to see that you have the following equipment at your station:

- One digital oscilloscope. You may have one of the following, all made by Tektronix: TDS320, TDS340, TDS360, TDS620B or TDS3012.
- One analog oscilloscope. These are Tektronix models 2213A, 2215A, or 2235.
- Two function generators. Analog types are made by Krohn-Hite, Wavetek, or Exact and are identifiable by their prominent frequency-adjust knob and fairly simple panel controls. Digital types are made by Wavetek and Stanford Research Systems (SRS) and are identifiable by the digital display and large number of panel buttons.
- An oscilloscope probe. A scope probe is *not just a wire with a clip*, but it has other circuitry in it to modify the signal before it passes to the scope input. In most of the advanced lab experiments, the scope is wired into the setup using BNC cables, so you won't use a probe in these cases, but it is standard equipment when using a scope to study the internals of a circuit.
- A box of small parts, which should have a small screwdriver (possibly made of plastic), a few resistors, a capacitor, some wires and some BNC adaptors.
- A plug-in circuit board ("breadboard") that can be used to wire up test circuits.
- BNC cables. You will need a few of these. There are a variety of lengths available on racks attached to the back side of the mobile whiteboard.

Let's get started by looking at some function generator signals.

1. Turn on a function generator. The digital ones will take a few seconds to complete internal tests, but the analog ones will be ready right away.
2. Turn on the **digital** oscilloscope. After the scope completes its internal tests, press the "Clear menu" button at the lower right hand corner of the display screen.
3. Get a couple of BNC cables from the cable rack; six-foot lengths should be adequate. Use the BNC cables to connect the "main" output of the generator to CH1 of the oscilloscope and the "aux" (or "sync" or "TTL") output to CH2.
4. Set the controls of the function generator to produce a sine wave of about 1000 Hz frequency and a few volts amplitude. Depending on your generator, here's how:

**ANALOG** (Krohn-Hite, Wavetek, Exact) Use the "waveform" or "function" switch to select the sine (curvy-line) waveform type. Use the frequency adjust knob and multiplier button/switch to select the frequency, and then set the amplitude knob ("Ampl" or "Attenuator") at about 12 o'clock, with any attenuator switches set at 0dB.

**DIGITAL** (SRS DS345) Use the  $\Delta$ ,  $\nabla$  buttons under the FUNCTION menu to highlight the sine function symbol. Press the **FREQ** button, and then key in "1" followed by the

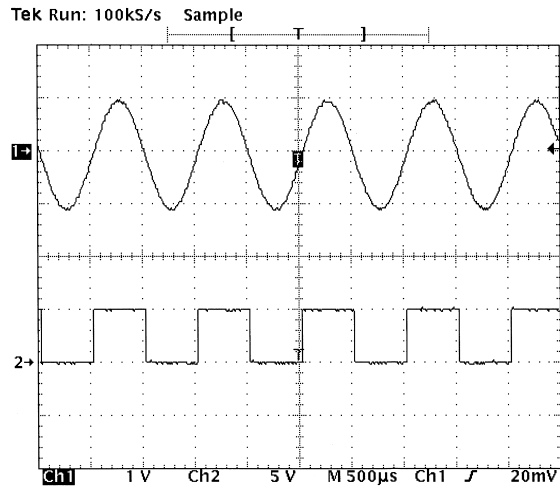


Figure 2: Digital scope display of a 1 kHz sine wave from a function generator and its associated “sync” signal. Note these important features: the channel 0-volt markers (“1→” and “2→”); the trigger indicators: the “T” in the middle of the screen and the small arrow on the right; the channel sensitivities (volts/div), sweep time (sec/div) and trigger settings are shown along the bottom of screen: channel 1 (“Ch1 1V”) is showing a 2 volt peak-to-peak sine wave, and channel 2 (“Ch2 5V”) is showing a 0 to 5 volt square wave. The sweep time is 500  $\mu\text{s}/\text{div}$  (“M 500 $\mu\text{s}$ ”), and the trigger is set for a 20 mV positive-going level in channel 1.

“kHz/Vrms” units button. To set the amplitude, press the AMPL button followed by “2” and the “kHz/Vrms” units button.

DIGITAL (Wavetek 29) Select the “Sine” option under the FUNCTION menu. Press FREQ/PER under the SET menu, followed by “1” and the “kHz us mV” units button. Set the amplitude by pressing AMPL followed by “2” and “MHz ns V”. **IMPORTANT:** the Wavetek 29 will not activate its main output until you press the OUTPUT button at the lower right, above the MAIN OUT connector.

5. In order to start from a uniform setting, reset the oscilloscope to its factory default values by pressing the SAVE/RECALL button, and then using the softkeys to choose the “factory default” setup. Then press the CH1 and CH2 buttons to turn on both of these channels. Finally, press AUTOSET on the oscilloscope panel. Autoset tell the scope to examine the inputs and choose a best guess at reasonable input gain and timebase settings. You should see a display similar to that shown in Fig. 2. If you don’t get this, *ask for help now*.

## Oscilloscope vertical, horizontal and trigger controls

Now that you have a signal, explore the effects of the various scope controls. Refer to Fig. 1 to help you locate the controls on your scope.

### Vertical

1. Press the CH1 button and see what happens when you turn the POSITION and VOLTS/DIV knobs. Pay attention to both the changes in the displayed waveform and the text indicators

at the bottom of the screen. You should be able to deduce the meaning of these indicators.

2. Press the CH2 button and repeat the above step.
3. You can turn a waveform off by first pressing the channel selector button (turning the adjacent green LED on), followed by the WAVEFORM OFF button. Try this, and turn off and then on the waveforms from channel 1 and channel 2.
4. Press the VERTICAL MENU button and study the various options that are controllable by the softkeys.

### *Horizontal*

1. Adjust the POSITION and SEC/DIV knobs and see what happens. Notice that both the sample rate and the sweep rate depend on the setting of the SEC/DIV knob. (The sample rate is the rate at which the waveform is digitized, and it must be notably higher than the sweep rate for the trace to be accurately drawn.) Also notice how the bar indicator and trigger-position indicator at the top of the screen changes as you move the POSITION knob: the bar represents the scope's memory, and the region between the square brackets [ ] represents the amount of the memory shown on the screen. In the TDS300 series, the screen always looks at a portion of the scope's total memory; in the TDS600 series, the amount of memory visible on the screen is adjustable (as an option under the HORIZONTAL MENU); in the TDS3000 series, the screen always looks at all of the scope's memory, but you can zoom in on a small part of it with the "magnify" option (under the button with the magnifying glass symbol).
2. (TDS300 and TDS600 series only) Press the HORIZONTAL MENU button and study the various options. Note in particular the presets for the trigger location on the screen. Other options are used less frequently, so you can ignore them for now.

### *Trigger*

The purpose of a trigger is to synchronize the scope's measurement cycle with an input signal. You can think of triggering as analogous to the following example. Imagine that you want to measure the time duration that a runner takes to run the first 100 meters on an 800 meter track while she runs laps. You would first position yourself so that you could see the runner approach a specific marker and then start your timer as she passed it. After timing the 100-meter stretch, you would wait until the runner made a full lap and returned to the marker again before timing it again. Because the events you are measuring (100-meter time duration over successive laps) take a different amount of time than the duration of a full lap, and may start at different time points from lap to lap, you need to wait for a part of each lap for the runner to reach the marker before starting your timer. The oscilloscope trigger works in a similar way: the scope waits until the input waveform reaches a particular level or produces a particular pattern before starting its "trace" or measurement cycle. Subsequent traces occur after waiting until the level/pattern repeats.

The operation of the oscilloscope trigger is the most difficult skill for the novice to learn. Before we look at the trigger controls, let's review some terms associated with triggering.

**Trace** Jargon term for the visible part of a scope's measurement cycle. The term originates from the older analog scopes in which a moving bright dot is created on a CRT screen by an electron

beam deflected under the influence of the vertical and horizontal amplifiers. In digital scopes the trace is the visual display of the scope's data memory. In general, a proper trigger must occur before a trace is created or updated.

**Trigger Level** The voltage that a trigger signal must cross before the trace will start.

**Slope** The trigger level coupled with the “slope” defines the pattern that must be sensed by the trigger circuit before it will start the trace. A “positive slope” means that the trigger level must be crossed going from a lower to a higher voltage, i.e., “going up”; likewise a “negative slope” means that the trigger level must be crossed going from a higher to a lower voltage: “going down”.

**Source** The signal from which the trigger circuit takes its input. If the trigger comes from one of the channel inputs (CH1 or CH2), the source is “internal” or INT. This is the most common choice. The second most common choice is from a separate signal connected to a special trigger input, called EXT TRIG (or just EXT). The other choices are from the 60Hz power-line signal (LINE) or from an oscillator internal to the scope (AUTO).

**Mode** Refers to additional conditions under which a trace is triggered. The two basic modes are “normal” (NORM) and “automatic” (AUTO). Under the normal triggering mode, no trace will be made until the triggering condition is met. Under automatic triggering, the scope looks for a valid triggering condition within a certain time, but if none is found, it will trigger anyway. Automatic triggering is useful when you are looking for a signal that you do not know much about—you may see some movement in the trace but it won't be stable. Normal triggering gives you more control over when a trace happens, and is the best mode to use when you know that a usable trigger signal exists. With analog scopes the screen will be *blank* under normal triggering unless a valid trigger occurs; with digital scopes the screen will freeze the last trace recorded.

**Coupling** DC coupling means that the trigger signal is passed to the trigger circuit unchanged. AC coupling means that any constant or very slowly varying voltage is blocked from the trigger circuit. Some scopes also have coupling options for low-frequency or high-frequency rejection in order to reduce the effects of noise that may be present in those frequency ranges.

**Holdoff** A time period following a trigger event where subsequent triggers are blocked. The holdoff control can help stabilize traces when looking at more complex waveforms that have many possible trigger points.

**Delay** A waiting time between trigger event and the start of a trace. Trigger delay is used when you want to look at a part of a signal that happens well after the desired trigger point.

**Pretrigger** The time before the trigger event. Digital scopes can show a fairly long pretrigger period. You can use this period to see the signal leading up to the trigger condition. Analog scopes have a very short pretrigger period.

Most of the time you need only worry about four settings: the trigger *level*, the *slope*, the *mode* and the *source*. Let's see how these work.

1. Press AUTOSSET again to reestablish the settings so that the traces are similar to Fig. 2.
2. Press the TRIGGER MENU button.

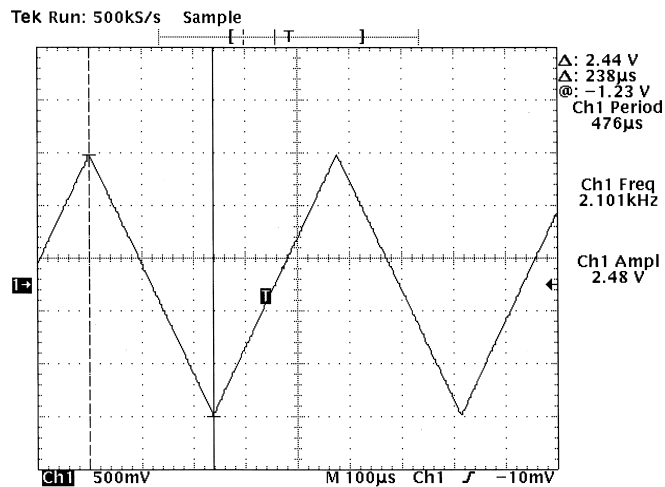


Figure 3: Digital scope measurements of a triangle wave.

3. Look at the softkey selections along the bottom of the display, select the “Level” menu, and turn the LEVEL knob. The source for the trigger should be CH1. Note what happens on the screen. In particular, note how the sine wave shifts horizontally as you change the level.
4. Select the “Slope” menu, and note how the waveform changes when you switch between the positive and negative slope settings (from the softkeys on the side of the display). Pay attention to the shape of the waveform right at the “T” marker.
5. Select the “Mode” menu, and make sure the mode is set to “Auto (Untriggered Roll)”. Turn the LEVEL knob clockwise until the arrow marker denoting the trigger level is well above the sine wave. You should see the trace lose stability and drift horizontally. Now switch the mode to “Normal”. The trace should freeze. When you adjust the level back down, the trace will become active again once the scope senses a valid trigger.
6. Select the “Source” menu, and select “Ch 2”. Notice how the trigger markers change to the second trace. Now disconnect the sync signal going into CH2 and plug it into the EXT TRIG input. You should lose triggering first, but recover it when you select “Ext” from the source menu.

### *Exercise 1: Making measurements with a scope*

Now that we have reviewed the basics, you should be able to make the following setup: Use the generator to create a 2100 Hz triangle wave of approximately 2.4 volts peak-to-peak amplitude. Feed this signal into CH1 of the digital scope and get a stable trace showing this signal. You should see something similar to Fig. 3. When you make this setup, think about what kind of trigger settings you need to make a stable trace.

Now, measure the amplitude and frequency of this signal by three different methods:

- **Use the graticule.** This method works with any oscilloscope. Compare your waveform to the markings on the screen and use them along with the horizontal and vertical settings



to calculate the amplitude and frequency. For example, in Fig. 3 the vertical peak-to-peak extent of the waveform is a little less than 5 large divisions (more accurately, about 4.9 large divisions), and the vertical sensitivity is 500mV/div, so the peak-to-peak amplitude is  $4.9 \times 500\text{mV} = 2.45\text{V}$ . The horizontal extent corresponding to one full period is a bit less than 4.8 large divisions, and the sweep rate is  $100\mu\text{s}/\text{div}$ , so the period is  $4.8 \times 100\mu\text{s} = 480\mu\text{s}$ , which gives a frequency of  $1/(480 \times 10^{-6}\text{s}) = 2080\text{ Hz}$ .

- **Use the cursors.** The digital scopes (and some advanced analog scopes) have cursor markers that can be used to ease the challenge of converting graticule distances to time and voltage units. To access the cursors on our digital scopes, press the CURSOR button near the upper right of the front panel. Notice that you can select either “H bars” (horizontal bars: voltage only), “V bars” (vertical bars: time only) or “Paired” (both time and voltage). The cursor positions are controlled by the unmarked “General Purpose Knob” that is linked to the TOGGLE button; see Fig. 1 to help you locate it. Choose one of the cursor options, and see what happens when you turn the General Purpose Knob and press the TOGGLE button. Notice also the appearance of the  $\Delta$  and @ symbols at the right side of the screen. The  $\Delta$  symbol denotes the difference between the cursors, while the @ symbol denotes the position of the active cursor (denoted by the solid line) relative to the 0 volts indicator for voltage or the trigger point for time.

In the example in Fig. 3, the cursors shown are the “paired” type that are positioned to measure the peak-to-peak voltage and one-half of the period. The  $\Delta$  indicators (at the top right) show a voltage difference of 2.44 V and a time difference of  $238\mu\text{s}$  (which would imply a period of  $476\mu\text{s}$  or frequency of 2100 Hz).

Use the cursors to measure the period and peak-to-peak amplitude of your waveform, and compare these numbers with what you got from the graticule examination method.

- **Use the automated measurement function.** If you are using a digital scope *and* you have a very uniform stable waveform, like a sine, triangle or square wave, you can use the easiest method of all: automated measurements. Press the MEASURE button in the upper part of the scope’s panel (near the CURSOR button). Then press (if not already highlighted) the “Select” softkey. You should see a wide selection of measurement possibilities from the menu at the right side of the screen. By scrolling through this menu, you should be able to select a frequency measurement and an amplitude measurement that will be applied to the active channel. Try it, see what you get, and compare the results with those from the previous two methods.

In the example of Fig. 3, automated measurements of “Ch1 Period”, “Ch1 Freq” and “Ch1 Ampl” have been applied. You can see that the automated measurements give a peak-to-peak amplitude of 2.48 V and frequency of 2.101kHz. These compare well with the cursor results.