ENGR 206

Experiment 6:
Function Generator and Oscilloscope

Objective

To become familiar with the use of the Agilent 33120A Function Generator and the Tektronix TDS2012C Oscilloscope and to use these instruments to measure the properties of simple waveforms.

The Agilent 33120A Function Generator

The Agilent 33120a Function Generator is a versatile piece of equipment that can generate a variety of synthesized periodic electrical waveforms, including sine waves, square waves, triangle waves and even arbitrary user-designed waveforms. The next few paragraphs give a brief overview of the capabilities of this instrument that we will need in our laboratory exercises. The detailed user's guide for this device, which describes all its functions, is found here.

The basic layout of the function generator is shown in Figure 1.

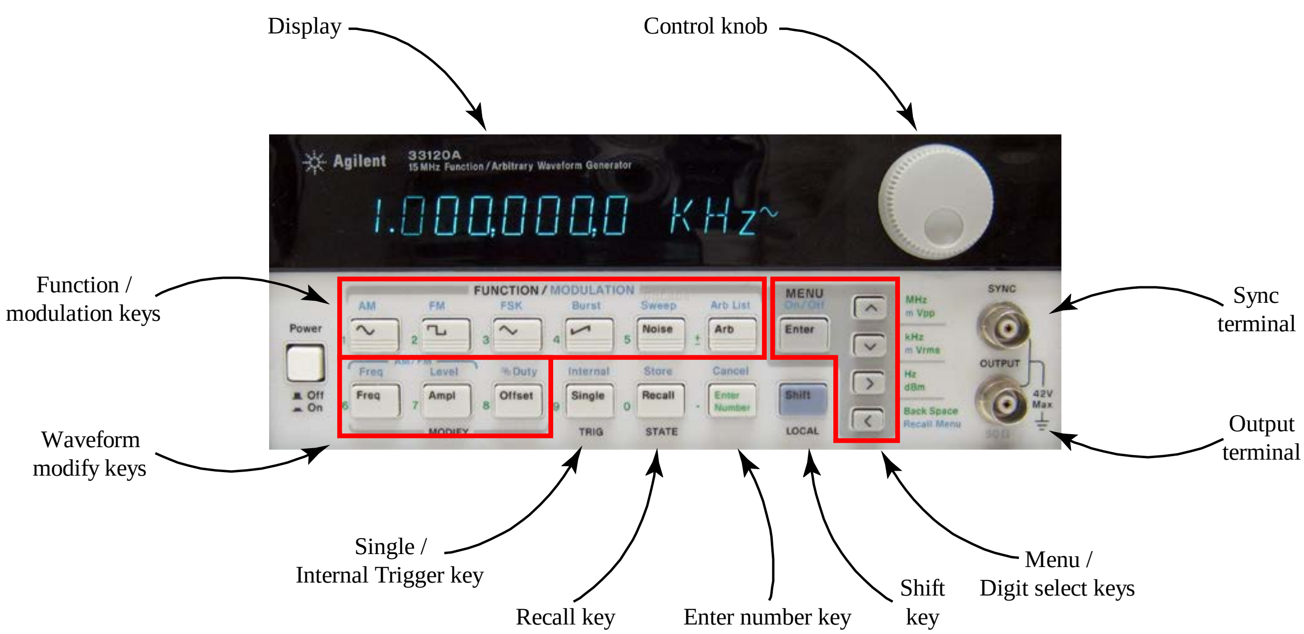


Figure 1: Agilent 33120A function generator controls

The front panel of the function generator comprises a number of functional blocks. The main parts with which we will be concerned are the following:

- The **display** shows frequency, amplitude and other settings.
- The **function/modulation keys** are used to select the type of waveform to be output, such as sine wave, square wave or triangle wave. When use in conjunction with the 'Shift' key, the instrument can also produce AM, FM and other types of swept waveforms, but in this laboratory, we will only need the sine-wave output. When the instrument starts up, it should be set up to generate at 1-kHz sine wave with an amplitude of 100 mV. If not, press the  key.
- The **waveform modification keys** control the frequency, amplitude and offset of the output waveforms. In our laboratory exercises, we will only need to adjust the frequency ('Freq') and amplitude ('Ampl').
- The **menu/digit select keys** and the **control knob** are used to change the frequency, amplitude and other parameters of the output waveform, as described below.

Changing waveform parameters

There are three ways to change a waveform parameter, such as frequency or amplitude.

1. **Use the control knob and arrow keys to modify the displayed number**. When you look at the display, one of the digits will be blinking. The selected digit can be moved to the left or right by using the [<] and [>] digit shift keys, respectively. The value of the digit can be adjusted using the control knob. If you want to get rid of the flashing number, just move the selected digit all the way to the left of the display.
2. **Use the arrow keys to edit individual digits**. The digit to be changed is again chosen using the [<] and [>] digit shift keys. The value of the digit can be incremented or decremented by using the [^] and [v] keys, respectively.
3. **Use the "Enter Number" mode to enter a number directly**. Press the 'Enter Number' key and enter the number by pressing the buttons (0-9 and .) on the keypad. Then press the appropriate digit select key to choose the units. For example, to change the frequency to 2.1 kHz, key in the sequence 'Freq'→'Enter Number'→2.1→[v]. To change the amplitude to 5.5 V, key in the sequence 'Ampl'→'Enter Number'→5.5→[^].

An important note on amplitude

There's one peculiarity of the function generator that can lead to confusion and erroneous measurements. The model of the output of the function generator is shown in Figure 2. The voltage at the output terminals is given by the voltage divider relation:

$$V_{out} = V_S \frac{R_L}{R_S + R_L},$$

where V_S is the internal voltage amplitude of the voltage source, $R_S = 50\,\Omega$ is the output impedance of the generator, and R_L is the resistance of the load that you are connecting to the output. The peak-to-peak amplitude on the function generator's display is only correct if the output is terminated by a load of $R_L = 50\,\Omega$. If the actual load is of high impedance, then the actual value of V_{out} will be higher than the value on the display. For example, if $R_L = \infty$, then the voltage that appears across the load will be *twice* the value shown in the display. In this case, you can interpret the display number as the peak amplitude, rather than the peak-to-peak amplitude. The best advice is not to trust the display, but to measure the amplitude independently, using either the DMM or the oscilloscope.

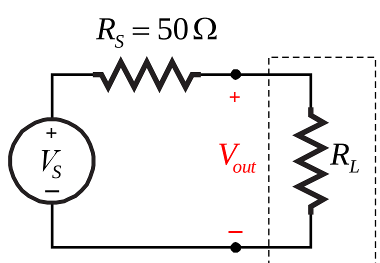


Figure 2: Output of the function generator

The Tektronix TDS2012C Oscilloscope

The oscilloscope is the principal instrument used by electrical engineers to acquire and display electrical signals as a function of time. Modern oscilloscopes in our laboratory provide additional capabilities to store waveforms, and make a variety of measurements on them. The following paragraphs provide a brief overview of the "scopes" in our lab. A complete user's guide is found here.

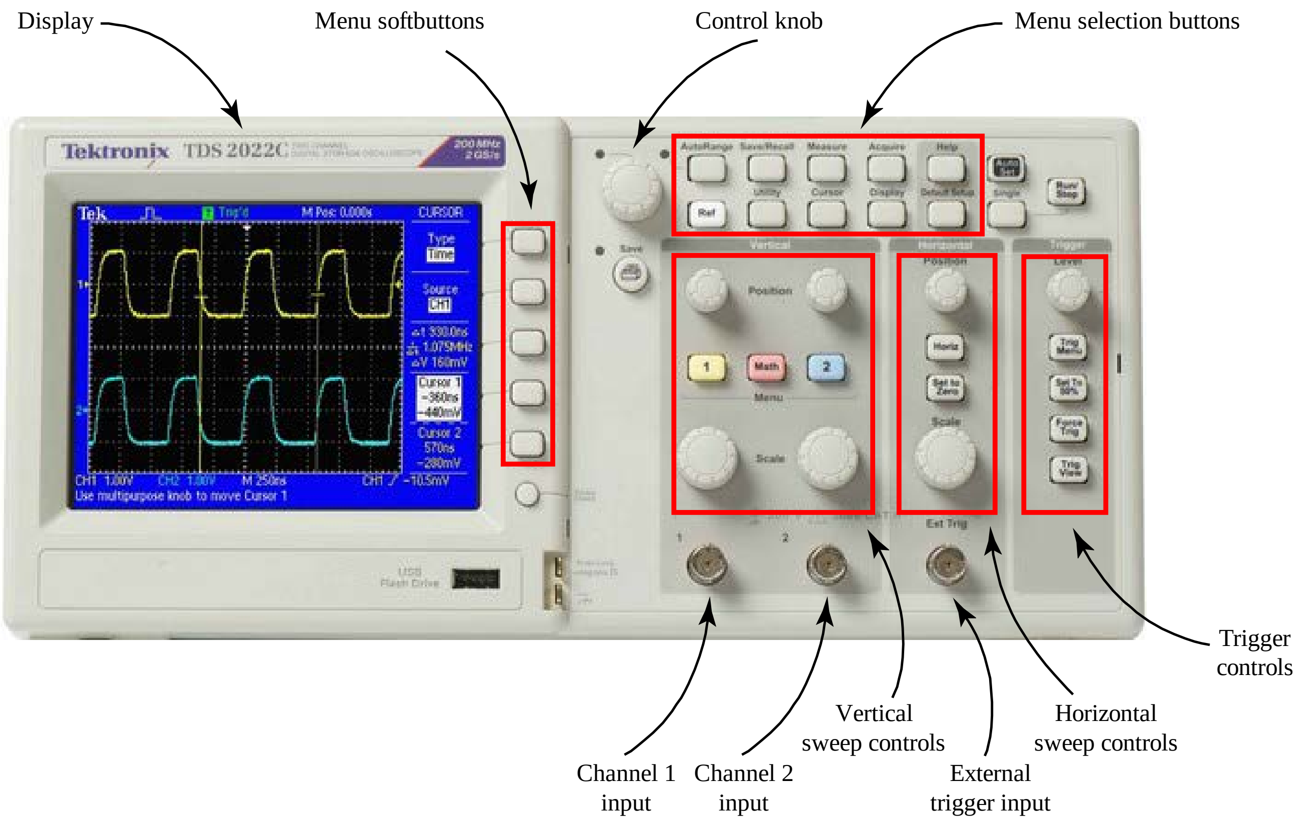


Figure 3: The oscilloscope

The oscilloscope, shown in Figure 3, comprises a display area, menu selection buttons and a control knob, vertical and horizontal sweep control panels and a triggering control panel. There are BNC two input channels and one external trigger input.

Display area

The black display area in Figure 3 displays the actual waveforms being measured, Around the periphery are displayed other information, such as the horizontal and vertical scales of the display, plus the positions and readouts from measurement cursors, if they have been activated. To the right of the waveforms in the blue area are a number of menus to control various functions of the oscilloscope, which can be activated by pushing the five soft menu buttons to the right of the display. A more detailed description of the annotations on the display is given in Figure 4.

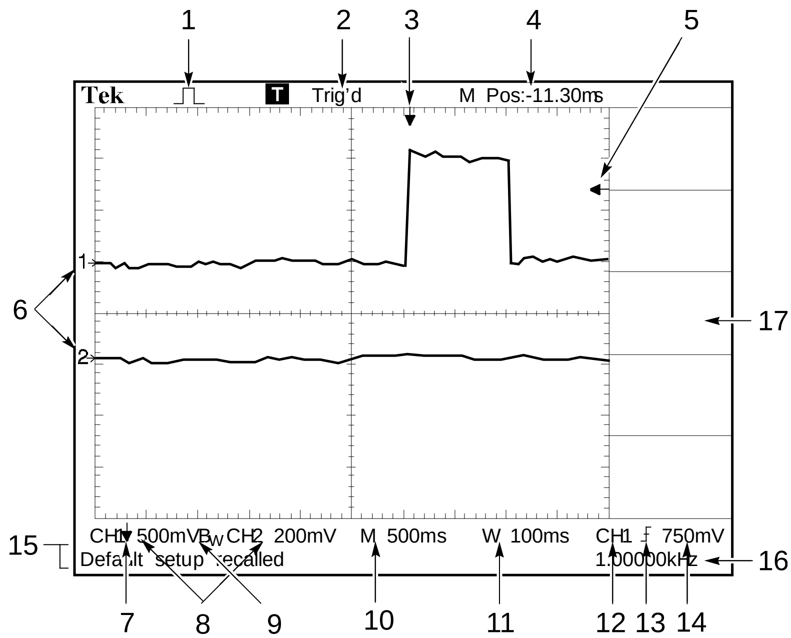


Figure 4: Display annotations

1. Acquisition mode

   Sample mode

   Peak detect mode

   Average mode
2. Trigger status

   Armed. The oscilloscope is acquiring pre-trigger data. Triggers are ignored in this state.

   R Ready.

   T Trig'd. The oscilloscope has seen a trigger and is acquiring post-trigger waveform data.

   Stop. The oscilloscope has stopped acquiring waveform data.
3. Horizontal trigger marker. Turn the 'Horizontal Position' knob to adjust the position of this parker
4. Time of center graticule with respect to the horizontal trigger marker.
5. Trigger level.
6. Ground reference markers for channels 1 and 2. If there is no marker, the channel is not being displayed.
7. An arrow icon indicates that the waveform is inverted.
8. The readouts show the vertical scale factors of the channel(s).
9. A B_w after the scale factor indicates that the channel is bandlimited.
10. Main timebase setting, corresponding to the width of one major division of the abscissa. The horizontal screen is in this example is 10 divisions wide, or 5 seconds.
11. Window timebase (if used). See manual.
12. Trigger source, which could be CH1, CH2, SYNC, or AUTO.
13. Trigger type

   Edge trigger, rising edge.

   Edge trigger, falling edge.

   Video trigger, line sync (see manual).

   Video trigger, field sync (see manual)

   Pulse-width trigger, positive polarity

   Pulse-width trigger, negative polarity
14. Trigger level

15. Message area. Display area shows helpful messages; some messages display for only three seconds. Messages include directions to access another menu, such as when you push the ‘Trig Menu’ button or suggestions of what to do next, such as when you push the ‘Measure’ button.
16. Trigger frequency
17. Soft menu area

Vertical sweep controls

The vertical sweep controls are shown in Figure 5. The oscilloscope is capable of displaying waveforms from two inputs simultaneously. The buttons labeled ‘1 and ‘2’ select which inputs will be displayed. By defaults, both input channels are displayed when the scope is turned on.

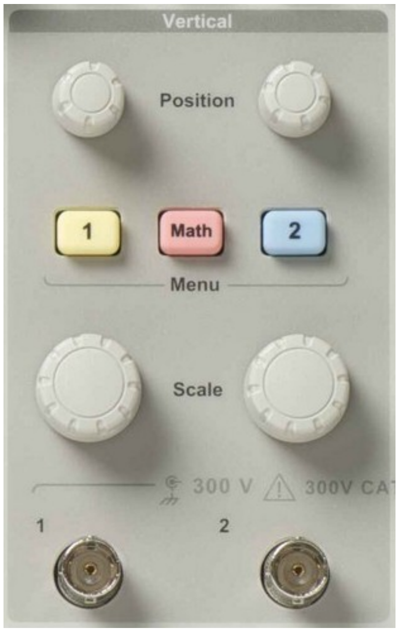


Figure 5: Vertical sweep controls

Turning back to the vertical sweep controls, the ‘Position’ knob is used to adjust the horizontal position of the traces. The voltage value of each channel that corresponds to signal ground is shown by the ‘1’ (and/or ‘2’) markers on the left part of the display (Figure 4, label 6).

The ‘Scale’ knobs allow you to adjust the displayed vertical scale of each waveform separately. The vertical scales are annotated on the display (Figure 4, label 8). The units of the vertical scale are volts/division, where each division is one-eighth of the vertical axis of the display.

The ‘Math’ button toggles the math menu on the display, which allows you to perform various operations on the displayed waveforms, including algebraic operations (‘+’, ‘-‘, ‘*’) and fast Fourier transforms of the data.

Pressing the ‘1’ and/or ‘2’ buttons also brings up menus on the right side of the display, as shown in Figure 6.

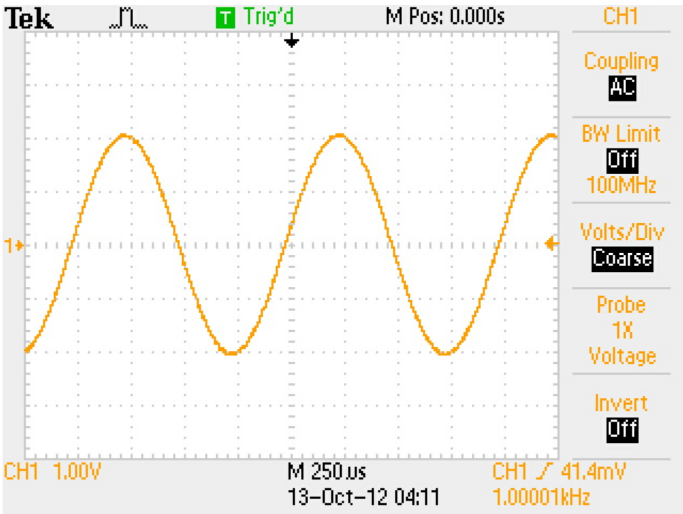


Figure 6: Channel display

The ‘Coupling’ menu item determines whether the oscilloscope filters out the DC component of the waveform by internally placing a large blocking capacitor in series with the input (‘AC’), leaves the input alone (‘DC’) or grounds the input (‘Gnd’). The ‘BW Limit’ item selects whether the input will be lowpass filtered at 100 MHz or not. The ‘Volts/Div’ toggle determines how the ‘Scale’ knob is interpreted. Selecting the ‘Invert’ menu item inverts the displayed waveform. The ‘Probe Voltage’ item is used to scale the display when probes with amplification are used. We don’t use these probes in our experiments, but other classes do, therefore…

In this and all future labs, make sure that the 'ProbeVoltage' of both channels is set to '1X'.

<u>Horizontal sweep controls</u>

The horizontal sweep controls are shown in Figure 7.

The 'Position' knob controls the position of the traces on the screen with respect to the time of occurrence of the trigger. A vertical arrow marker at the top of the display (Figure 4, label 3) shows when trigger occurred and the readout (Figure 4, label 4) indicates the time that corresponds to the center graticule of the display. For example, in Figure 4 the time at the center of the graticule is -11.3 ms before trigger shown by the arrow.

The 'Horiz' button toggles the horizontal menu on the screen.

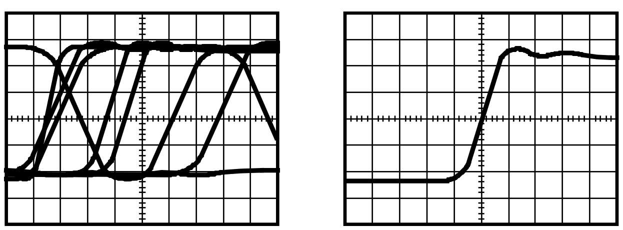
The 'Set to Zero' button sets the horizontal position to zero (i.e. at the position of the center graticule) .

The 'Scale' knob sets the horizontal scale factor of the display.

Figure 7: Horizontal sweep controls

<u>Trigger controls</u>

Triggering determines when waveforms are acquired and displayed on the screen. Figure 8 shows the scope trigger controls. The 'Level' knob controls the voltage trigger level. The oscilloscope constantly compares the incoming waveform with this level. Then the threshold is crossed, the waveform is triggered and displayed so that time at which the trigger occurred corresponds to the center graticule of the display. Triggering allows aperiodic waveforms to be captured when the occur and allows periodic waveforms to be synchronized so that repeated periods of the waveform will be aligned at the identical position of the display. Figure 9 shows what happens when a periodic waveform is untriggered (or has a low trigger level) and then what happens when the triggering level is set to 50% of the peak-to-peak amplitude of the waveform, which is what happens when you push the 'Set to 50%' button on the panel.



Untriggered waveforms Triggered waveform

Figure 9: Untriggered and triggered displays

Figure 8: Scope trigger

The 'Trig Menu' button toggles the trigger menu on the display, which is shown in Figure 10.

The top menu item ('Type') selects the type of triggering: 'Edge', 'Video', or 'Pulse Width'.
We will use 'Edge' triggering almost exclusively in our laboratory experiments. The trigger type is shown on the display (Figure 4, label 13). This triggers the waveform on the rising or falling edge of a waveform, as selected by the 'Slope' menu item. The trigger level is set by the 'Level' knob, and is displayed as an arrow on the right side of the display (Figure 4, label 5). The time at which the trigger occurs is given by the arrow on the top of the display (Figure 4, label 3).

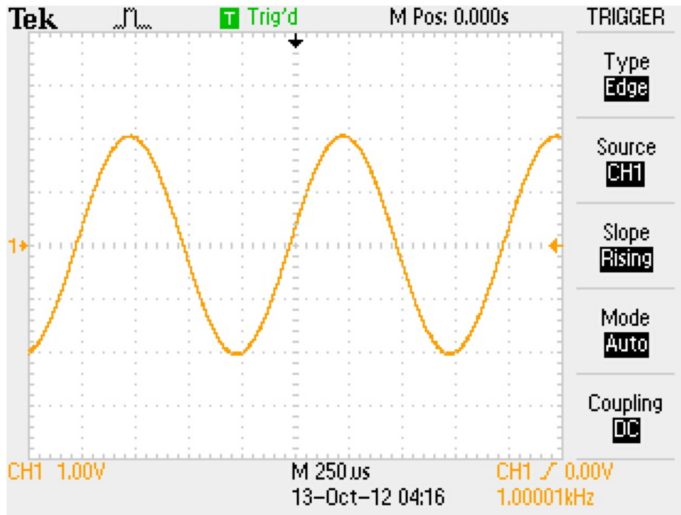


Figure 10: Trigger menu

The 'Source' menu item selects whether the triggering will occur on channel 1, channel 2, or on an external input presented to the 'Ext. Trig' BNC input on the front panel. This is shown on the display (Figure 4, label 12). The 'Mode' ('Auto' or 'Normal') selects how the oscilloscope acquires data when it does not detect a trigger condition. 'Auto', the default setting, will display waveforms even if the scope does not detect a valid trigger event. The 'Coupling' determines how the triggering circuit will filter the signal prior to triggering. The coupling options are shown in Table 1.

Option	Detail
DC	Passes all components of the signal
AC	Blocks DC components and attenuates signals below 10 Hz
Noise Reject	Adds hysteresis to the trigger circuitry, which reduces the chances of false triggering on noise
HF Reject	Attenuates the high-frequency components in the signal above 80 kHz
LF Reject	Blocks the DC component and attenuates low-frequency components below 300 kHz

Table 1: Trigger coupling options

It's important to note that the coupling of the signal displayed on the screen and the signal going to the trigger circuitry are separate. The coupling of the displayed signal is controlled by the top menu item of the channel menu (Figure 6), whereas the coupling of the trigger is controlled by the bottom menu item of the trigger menu (Figure 10).

In practice, you adjust the triggering to stabilize a free-running waveform and, in conjunction with the horizontal position control, to place a portion of the waveform in the center of the screen for better analysis.

<u>Making measurements: the menu selection buttons</u>

There are several ways to take measurements with an oscilloscope. You can simply read values off the graticule to make a quick visual estimate, or you can use several automated features of the oscilloscope to perform various measurements and computations on the displayed signal waveforms automatically. These functions are controlled by the menu selection buttons shown in Figure 11. Here, we'll highlight a few of the measurements you can make.

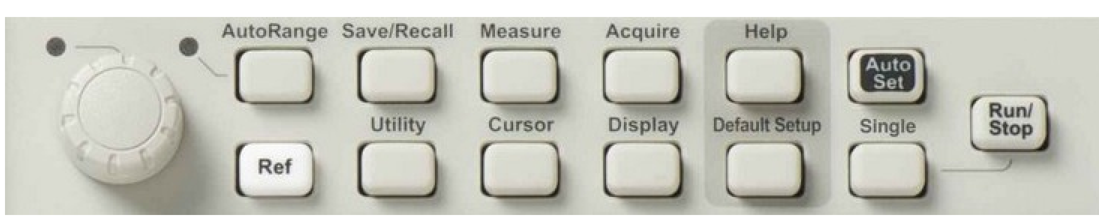


Figure 11: Menu selection buttons

Measure

Pressing the 'Measure' button brings up a set of measurement menu on the right side of the display, as shown in Figure 12. There are five menu items, each of which can display a different measurement of the signal on either Ch1 or Ch2. There are twelve different measurements to choose from, as shown in Table 2. To select a measurement, push the menu soft button of one of the five items and cycle through the eleven choices until you find what you want. Then make the appropriate changes to the parameters that are listed for each measurement. hen you are finished selecting parameters, select 'Back'. In the example below, the first menu item measures the RMS voltage on Ch1, and the third measures the peak-to-peak voltage. The other items have been left in their default state.

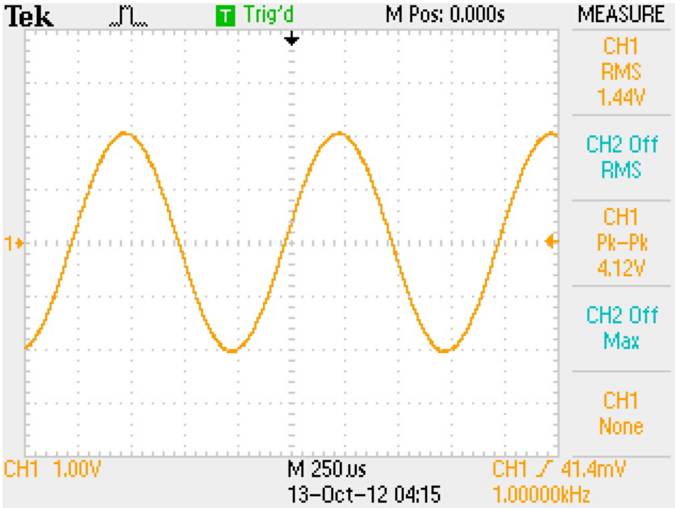


Figure 12: Measure menu

Measurement type	Definition
Freq	Calculates the frequency of the waveform by measuring the first cycle
Period	Calculates the time of the first cycle
Phase	Measures phase difference between waveforms on Ch1 and Ch2
Mean	Calculates the arithmetic mean voltage over the entire record
Pk-Pk	Calculates the absolute difference between the maximum and minimum peaks of the entire waveform
Cyc RMS	Calculates a true RMS measurement of the first complete cycle of the waveform
Min	Examines the entire 2500 point waveform record and displays the minimum value
Max	Examines the entire 2500 point waveform record and displays the maximum value
Rise Time	Measures the time between 10% and 90% of the first rising edge of the waveform.
Fall Time	Measures the time between 90% and 10% of the first falling edge of the waveform.
Pos Width	Measures the time between the first rising edge and the next falling edge at the waveform 50% level.
Neg Width	Measures the time between the first falling edge and the next rising edge at the waveform 50% level.
None	Does not take any measurement

Table 2: Measurement options

It's important to keep in mind that the measurement functions use that portion of the waveform that is being displayed to calculate the requested quantity. For example, if the peak of your waveform is offscreen, the maximum and peak-to-peak values will be incorrect.

Cursor

Pushing the ‘Cursor’ button on the panel brings up a set of menu options on the right side of the display, as shown in Figure 13. The ‘Type’ menu item gives the option of choosing ‘Time’ or ‘Amplitude’. In Figure 13, the ‘Time’ option has been selected. This allows one to measure the time and amplitude of two waveforms between two horizontally spaced cursors. The ‘Source’ item chooses which waveform on which to take the cursor measurements (e.g., ‘CH1 or ‘CH2’). Select ‘Cursor 1’ (the fourth menu item) and turn the control knob on the front panel to move the left cursor to the desired position. As you turn the knob, the menu item reports the time and amplitude corresponding to the cursor’s position. Then, select ‘Cursor 2’ (the bottom menu item) and turn the control knob to move the right cursor. The third menu item displays of measurements of difference of the time (Δt) between the cursor points as well as the equivalent frequency ($1/\Delta t$) and the difference in amplitude (ΔV).

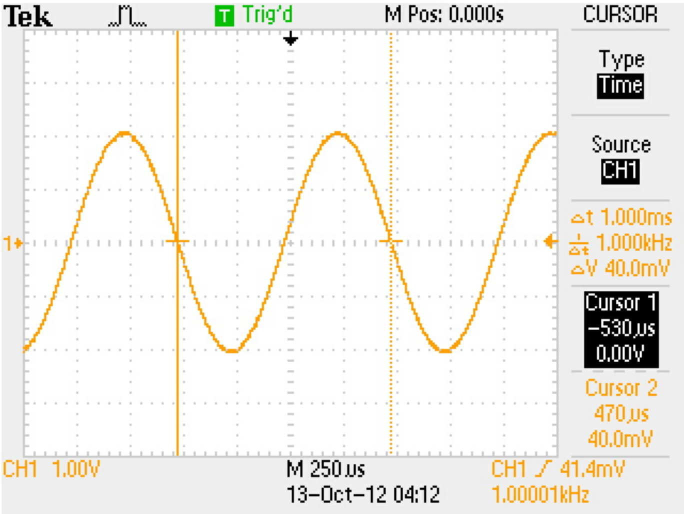


Figure 13: Cursor menu, time display

In Figure 14, the ‘Amplitude’ option has been selected. This allows one to measure the amplitude between two vertically spaced cursors.

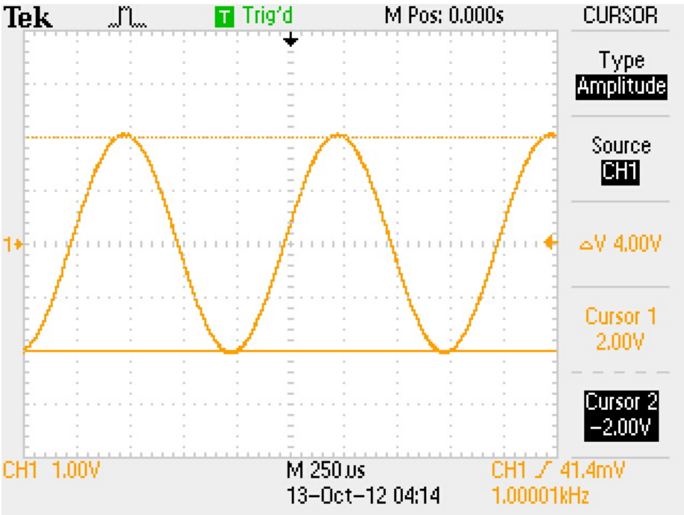


Figure 14: Cursor menu, amplitude display

Autorange

The ‘AutoRange’ button on the panel allows the scope to identify the type of waveform at the input(s) and adjust its controls – including horizontal position, triggering mode, level, source and slope – to produce a usable display.

Acquire

The oscilloscope has the capability of averaging waveforms. This is particularly useful to smooth noisy periodic signals. Figure 15a shows a portion of a relatively noisy periodic waveform measured from two channels in the default ‘Sample’ mode. To display the average of several cycles of the waveform, push the ‘Acquire’ menu button and select the ‘Average’ option. Toggle the ‘Averages’ menu option to change the number of cycles that are averaged. Figure 15a shows the result of averaging 64 cycles.

a) b)

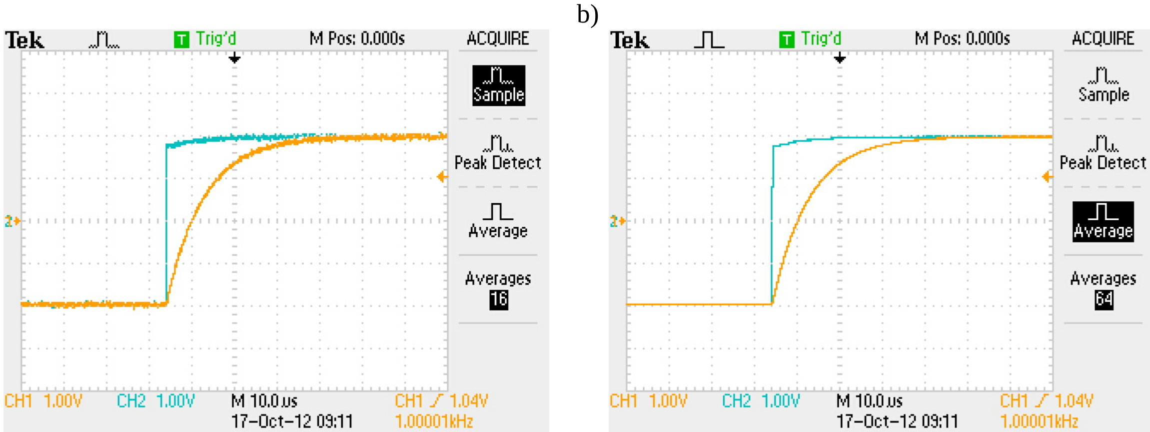


Figure 15: Sampled and averaged waveforms

To return the oscilloscope to its non-averaging mode, click the ‘Sample’ menu item, as in Figure 15a.

Saving information to the USB drive

The oscilloscope can save displayed waveforms and data and all the oscilloscope settings to files on a USB device that is plugged into the slot on the front panel . It appears that the capacity needs of the stick needs to be moderate (<16 GB) and the stick must be formatted with FAT32 file system. In order to save information, press the ‘Save button on the front panel. The scope should be set up to save the screen image onto the USB stick. When you press the button, a little clock icon should show up in the bottom right-hand corner of the screen to indicate that data are being saved. If it takes more than ~30 seconds to save the data, the capacity or format of the USB stick may be wrong. Ask your instructor if you need help.

Pre-laboratory work

In this laboratory, we'll make some simple measurements in order to get acquainted with the function generator and oscilloscope. Figure 16 shows three common waveforms: the sine wave, the triangle wave and the square wave.

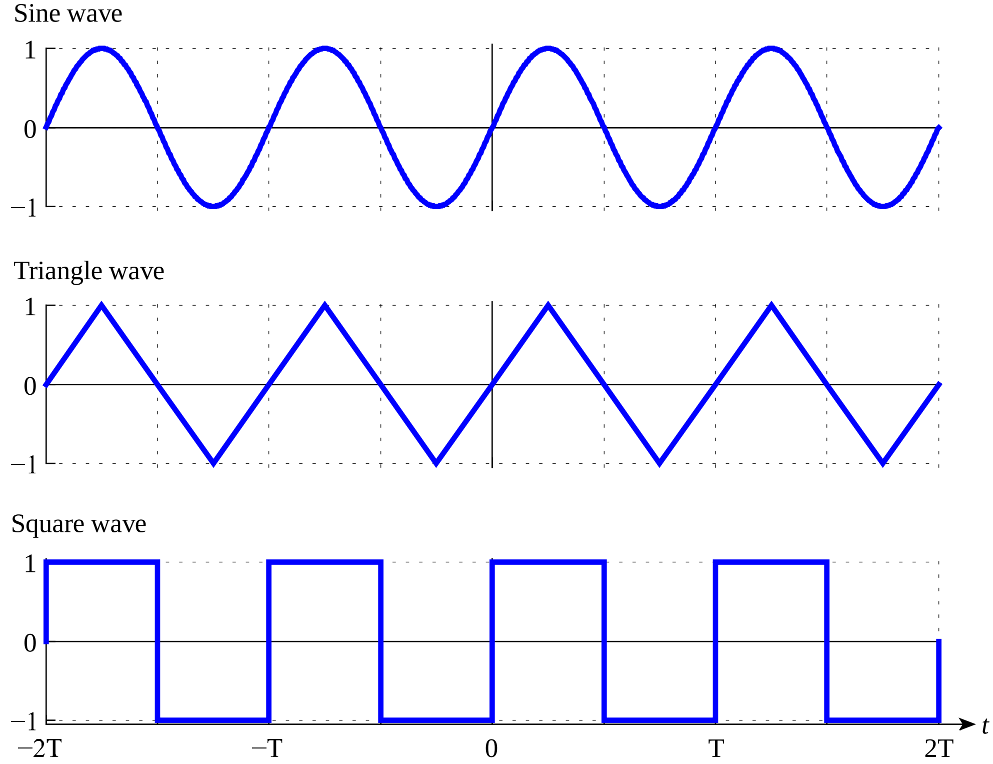


Figure 16

Some definitions

The waveform is *periodic* with a period of T seconds if $x(t) = x(t+T)$ for all t. The frequency of a periodic waveform is $f = 1/T$ Hz. For the sine wave, one period of the waveform corresponds to 2π radians, so in this case we can also define the radial frequency as $\omega = 2\pi f = 2\pi/T$ rad/sec.

The *mean value* of a waveform is defined as

$$\bar{x} = \frac{1}{T}\int_0^T x(t)dt .$$

The *DC offset* of a waveform is defined as

$$V_{off} = \frac{V_{\max} + V_{\min}}{2} .$$

Each of the waveforms in the figure has a DC offset of zero.

The *peak-to-peak amplitude* of a waveform is the difference between the maximum and minimum values. Each waveform in the figure has a peak amplitude of 1V, and a peak-to-peak amplitude of 2V.

The *root-mean-square (RMS)* value of a waveform is defined as

$$V_{RMS} = \frac{1}{T}\int_0^T \left(x(t) - \overline{x}\right)^2 dt \ .$$

The rise time, τ_{rise} , of a waveform is defined as the time it takes for the waveform to rise from 10% to 90% of its peak-to-peak value, as shown in Figure 17. The fall time, τ_{fall} , is similarly defined as the time to fall from 90% to 10%.

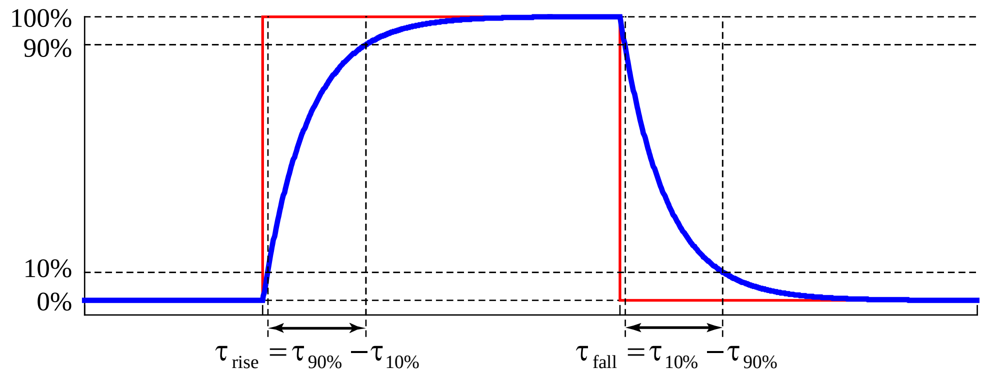


Figure 17: Rise time and fall time

As part of your pre-laboratory work, find the RMS values of the three waveforms in Figure 16.

Laboratory work

1. Set up oscilloscope
    a. Attach a T-splitter to the output terminal of the function generator. Run a BNC cable from one end of the splitter to the DMM and the another cable to the Ch 1 input of the scope.
    b. Create a 1kHz sine wave with the function generator. Set the amplitude to 2V peak-to-peak (2V p-p) with 0 volts DC offset.
    c. Press the 'AutoRange' button on the oscilloscope panel and observe the waveform. If necessary, adjust the time base (horizontal scale) so that two or three cycles of the waveform are visible. The time base setting (Figure 4, label 10) should be about $250\,\mu s$.
2. Vertical position.
    a. Practice adjusting the vertical position knob on the scope and watch what it does to the waveform. Notice that at the ground reference marker on the left side of the display screen (Figure 4, label 6) changes as the control is adjusted.
    b. Adjust the 'Scale' knob and notice the change in the size of the waveform. Also notice the display of the vertical scale factor (Figure 4, label 8).
    c. Investigate the functions of channel display menu items (Figure 6). Press the '1 button if the 'CH1' menu items are not visible on the display. Change the 'Coupling' to 'Gnd' and notice that the wavefrom is replaced by a straight line at the position of the ground reference marker. Note the 'Volts/Div' and 'Invert' menu items.
    d. Return the settings to non-inverted, DC coupled waveform
3. Horizontal position.
    a. Practice adjusting the vertical position knob on the scope and watch what it does to the waveform. Notice that at the ground reference marker on the left side of the display screen (Figure 4, label 6) changes as the control is adjusted.
    b. Practice adjusting the horizontal position knob on the scope and watch what it does to the waveform. Notice that at the arrow and numbers at the top of the display (Figure 4, labels 3 and 4) change as the control is adjusted.
    c. Press the 'Horiz' button and investigate the functions of the menu items on the display.
    d. Press the 'Set to Zero' button and return the horizontal position to zero.
4. Triggering
    a. Notice what happens to the displayed waveform as you adjust the trigger level move the trigger level above the maximum value of the waveform. What happens? Move it below the minimum value. What happens?

   b. Press the ‘Set to 50%’ button to return the triggering to the default value.
5. Measurements
   a. Press the ‘Measure’ button to bring up the measurement menu options on the display, as in Figure 12.
   b. Select the ‘Ch1’ menu item and then the ‘Type’ soft menu button. Cycle through the choices until you find the ‘Freq’ option that allows you to measure the frequency of the waveform. Does it match the frequency on the function generator? Note that the trigger frequency on the oscilloscope display (Figure 4, label 8) of the waveform should also match the frequency.
   c. Measure the mean the waveform. Does it correspond to your expectations?
   d. Measure the peak-to-peak voltage of the waveform. Does it match the value you set on the function generator? If not, why not? Adjust the output voltage of the function generator to have a peak-to-peak of exactly 1V p-p.
   e. Measure the RMS value. Does this correspond to your calculations in the pre-laboratory part of the experiment?
   f. Add a 0.5V offset to the waveform with the function generator. You may wish to check the value of the offset using the DC setting of the DMM. Repeat the measurements of the mean, peak-to-peak and RMS values. How do they differ from the values you got in parts 5c-e? Why?
   g. With the 0.5V offset still on the waveform, press the ‘1 button on the vertical panel and change the ‘Coupling’ to ‘AC’. Repeat the measurements of the mean, peak-to-peak and RMS values. How do they differ from the values you got in parts 5c-e? Why?
   h. Return the offset of the waveform to 0V and the coupling to ‘DC’.
6. Repeat the measurements of Part 5 with a square wave, using offsets of 0 and 0.5V. Do the results match your predictions?
7. Repeat the measurements of Part 5 with a triangle wave, using offsets of 0 and 0.5V. Do the results match your predictions?
8. Measurements using cursors
   a. Press the ‘Cursor’ button to bring up the cursor menu as in Figure 13. Choose the ‘Time’ cursors
   b. Adjust the two cursors to measure the time between two successive positive-going zero-crossings of a sine wave with zero DC offset. Does this time correspond to the period of the waveform that you expect? Save the waveform.
   c. Adjust the horizontal time base, horizontal position and triggering of the display so that exactly one cycle of the waveform covers the entire screen with the positive-going zero-crossing point (i.e., the "starting point") of the waveform coinciding with the center of the graticule.
   d. Since the screen is divided into ten major divisions, each division therefore corresponds to $2\pi/10$ of a cycle of the full-scale waveform. Using one of the cursors, read voltage values at -3, -1, 1 and 3 divisions. Do the measured values they agree with expected values? What can you conclude about the sine wave provided by the function generator? Is it close to an ideal sine wave?
9. Response of an RC circuit
   a. Construct the circuit shown in Figure 18 with $R = 1k\Omega$ and $C = 0.01\mu F$ and V_S being a square wave with a frequency of 1kHz, an amplitude of 1V p-p, and a DC offset of 0V.
   b. Connect the output of the function generator to Ch1 of the scope and the output of the circuit, V_{out} , to Ch2. Adjust the vertical position of the two traces so that they are superimposed.
   c. Adjust the horizontal time base so that one cycle of the waveform are displayed and adjust the triggering and horizontal position so that the rising portion of the waveform is roughly centered on the display.
   d. Measure the rise time and fall time of V_{out} using the ‘Rise-time’ and ‘Fall-time’ options in the ‘Measure’ menu. The rise time is the time it takes for the rising phase of the waveform to go from 10% to 90% of the peak-to-peak value. The fall time is the time it takes the falling phase of the waveform to go from 90% to 10%, as shown in Figure 17.
   e. Measure the rise time and fall time of the waveform manually using the time cursors. Do the results match?

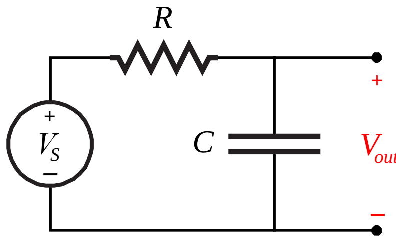


Figure 18: RC circuit

10. LED fun
    a. Construct the circuit shown in Figure 19 with $R = 1k\Omega$ and V_S being a 4Hz (not kHz!), 5V p-p triangle wave.
    b. Connect the output of the function generator to Ch1 of the scope and the voltage across one of the LEDs, V_a, to Ch2. Adjust the vertical position of the two traces so that they are superimposed. Explain what you see the lights doing and explain the waveforms that you see on the display. Specifically, why does the voltage across the diode "flatten out" and how does the timing of that voltage plateau correlate with the diode's illumination?
    c. Repeat part b. with the Ch2 probe attached to V_b. Explain.
    d. Slowly lower the amplitude of the triangle wave to 1V p-p. What happens to the lights and the displayed waveforms and why?

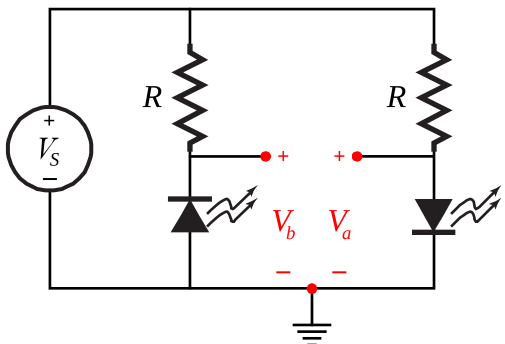


Figure 19: LED fun

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