3. Oscilloscope Measurements

This experiment is designed to familiarize you with the oscilloscope and its use for AC and DC measurements.

3.1. Apparatus

Rigol digital oscilloscope (1054Z), signal generator, rectifier circuit on plexiglass or breadboard, digital multimeter, DC power supply, step down transformer with variable and fixed output (black unit or on breadboard), 1.5k-ohm, 8.2k-ohm, 0.1microfarad capacitor, 10millihenry inductor.

3.2. Introduction and control locations

An analog oscilloscope makes use of cathode ray tube in which a focused beam of electrons strikes the front of the screen producing light. The beam creates a dot on the phosphor screen and the position of the beam is controlled in such a manner that its position traces the input voltage's value as a function of time. By rapidly sweeping the beam horizontally, a continuous trace is produced owing to the persistence of the phosphor material on the inside of the tube/display.

In contrast, a digital oscilloscope uses an analog to digital converter to repeatedly sample the input voltage and then stores the voltage and time values in digital form: a table of numbers. This data is then read out of memory and plotted on an LCD display to produce a plot of the input waveform. Both scopes use the same basic controls, they are each displaying a graph of voltage as a function of time.

The advantage of an oscilloscope over a multimeter is that the voltages being tested can be functions of time. Both repeating and non-repeating components may be captured, displayed and measured. Multimeters have to be designed with certain assumptions (waveform shape and frequency) and consequently can only give general information about a voltage variation with time.

3.3. Controls

The control locations are shown in figures 3.1.

1. the horizontal time-base controls which sets the scale of the horizontal axis in $seconds/cm$ (number 18 in Figure 3.1)
2. the voltage or input controls which set the scale of the vertical axis in $volts/cm$ (number 17)
3. a trigger control to allow manual adjustment of the signal trace's starting position if necessary (number 19)
4. menus and controls to choose which measurement values are displayed (numbers 1 and 5 and more).

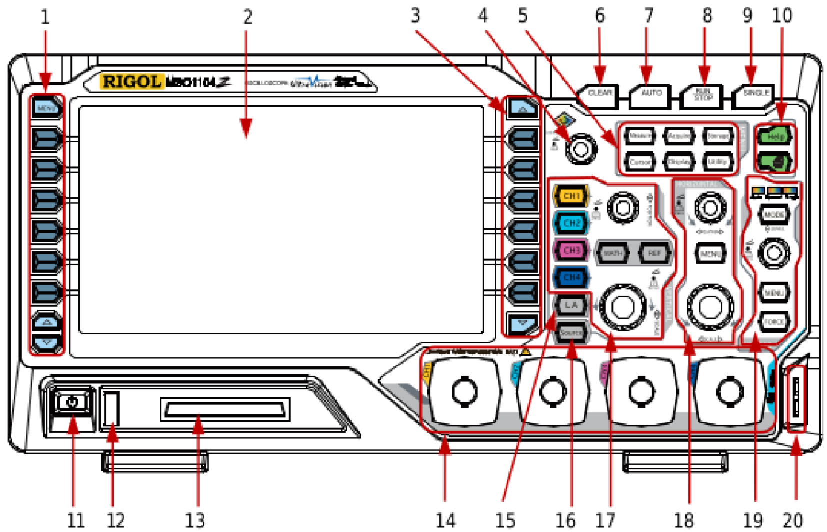


Figure 1-10 Front Panel Overview

Table 1-1 Front Panel Descriptions

No.	Description	No.	Description
1	Measurement Menu Softkeys	11	Power Key
2	LCD	12	USB Host Interface
3	Function Menu Softkeys	13	Digital Channel Input Interface[1]
4	Multifunction Knob	14	Analog Channel Input Interface
5	Common Operation Keys	15	Logic Analyzer Control Key[1]
6	CLEAR	16	Signal Source[2]
7	AUTO	17	VERTICAL Control
8	RUN/STOP	18	HORIZONTAL Control
9	SINGLE	19	TRIGGER Control
10	Help/Print	20	Probe Compensation Signal Output Terminal/Ground Terminal

Note[1]: Only applicable to MSO1000Z and DS1000Z Plus.
Note[2]: Only applicable to digital oscilloscopes with source channels.

Figure 3.1.: Rigol 1054Z front panel controls

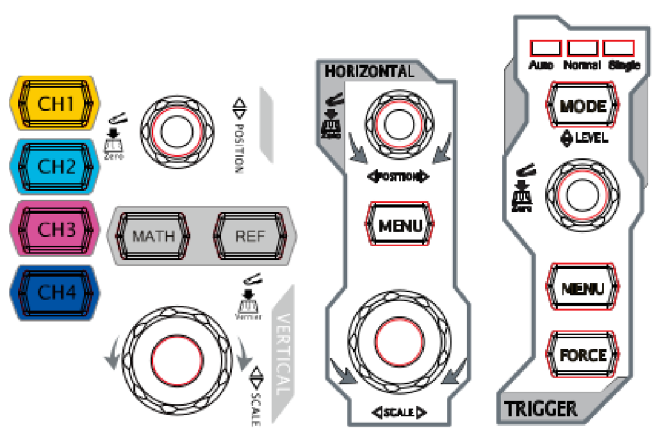


Figure 3.2.: Individual control sections

3.4. General Advice

1. Use the horizontal and vertical scale controls to spread the waveform out as much as possible when making measurements. This will reduce error and provide measurements that are steady.
2. Be aware that your scale controls must be set so that all the waveform fits into the display. This refers mainly to the vertical scale.
3. The input voltage should be checked for any DC offset. You can double check for this using the multimeter.
4. ***Units: When stating the result of the measurement, make sure you put the correct units down***. voltages: V_p, V_{pp}, V_{rms}, V_{DC}, time: s, ms, μs frequency: *Hz, kHz, MHz* etc.

3.5. Review of Waveform Parameters

The parameters which describe a sinusoidal waveform are its:

- amplitude A in $Volts_{peak}$,
- angular frequency ω in $\frac{radians}{second}$ and phase ϕ in *radians* or *degrees*.
- a DC voltage if present and represented by $\mathbf{B}$ in $Volts_{DC}$ if the oscillation has a nonzero average.

Mathematically, the form of the equation is:

$$v(t) = B[V_{DC}] + A[V_p] \cdot \sin(\omega t + \phi) \tag{3.1}$$

These characteristics are measured using the oscilloscope and are shown in Figure 3.3. The Rigol digital scope has a menu on the left side for the user to choose both horizontal and vertical waveform measurements along the bottom of the screen.

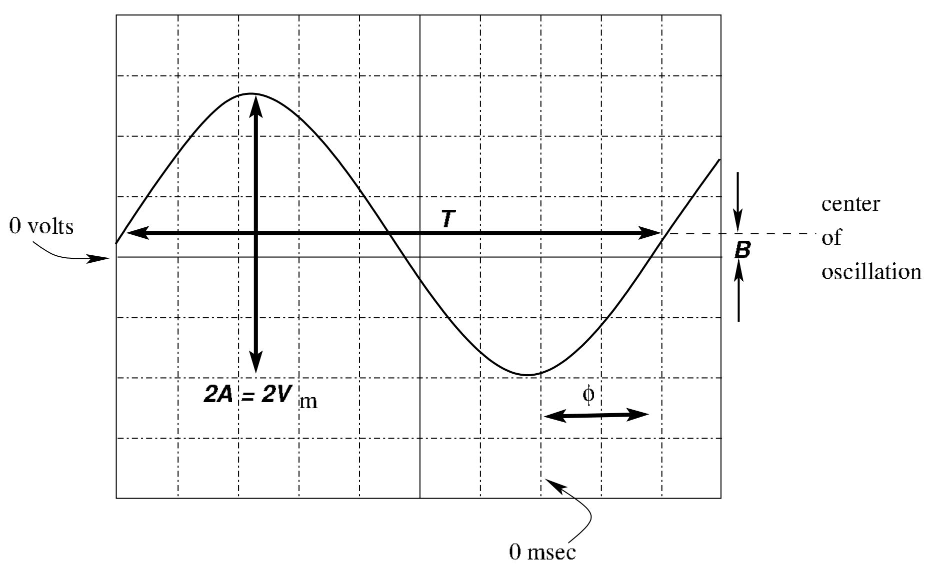


Figure 3.3.: Voltage as a function of time: Sinusoidal waveform.

3.6. Vertical Controls and Coupling

MSO1000Z/DS1000Z provides 4 analog input channels (CH1-CH4). As the setting methods of the vertical systems of the four channels are the same, CH1 is used as an example to illustrate the setting method of the vertical system. Since there is one set of controls for vertical settings, these are reused for every channel displayed. Press the channel button to switch what channel is being controlled. The menu and the highlighted scale will change to indicate the channel under control.

1. Connect a signal to the channel connector of CH1 and then press CH1 in the vertical control area (VERTICAL) at the front panel to enable CH1. At this point, the channel setting menu is displayed at the right side of the screen and the channel status label at the bottom of the screen (as shown in the Figure 3.4) is highlighted.

2. The information displayed in the channel status label is related to the current channel setting. After the channel is turned on, modify the parameters such as the vertical scale, horizontal time base, trigger mode and trigger level according to the input signal for easy observation and measurement of the waveform.

3. **Channel Coupling:** The undesired signals can be filtered out by setting the coupling mode. For example, if the signal under test is a square waveform with DC offset.

   a) When the coupling mode is "DC": the DC and AC components of the signal under test can both be displayed on the channel.

   b) When the coupling mode is "AC": the DC components of the signal under test are blocked.

   c) When the coupling mode is "GND": the DC and AC components of the signal under test are both blocked and the trace indicates where zero volts occurs.

4. Press CH1 Coupling and use to select the desired coupling mode (the default is DC). The current coupling mode is displayed in the channel status label at the bottom of the screen as shown in the figure below. You can also press Coupling continuously to switch the coupling mode.

Figure 3.4.: Coupling Settings

5. **Channel Scaling:** Vertical scale refers to the voltage value per grid in the vertical direction on the screen and is usually expressed as V/div. Rotate SCALE to adjust the vertical scale (clockwise to reduce the scale and counterclockwise to increase). The size of the displayed waveform will be changed accordingly. The scale information (as shown in the figure below) in the channel label at the bottom of the screen will change accordingly during the adjustment. 

[1]

3.7. RMS Voltage

The digital multimeters used in the lab display the root-mean-square (rms) voltage of a sinusoidal waveform when set to AC. The general formula for calculating the rms value of a voltage waveform $v(t)$ is shown in equation 3.2.

$$V_{rms} = \left[\frac{1}{T} \int_0^T v(t)^2 \, dt \right]^{\frac{1}{2}} \tag{3.2}$$

[1] The adjustable range of the vertical scale is related to the probe ratio currently set. 2017: This has been set to 1X.

For a sinusoidal voltage with no DC component, amplitude $V_{maximum} = V_m$ (in $Volts_{peak} = V_P$) and angular frequency ω, $v(t) = V_m \sin(\omega t)$, the relation between the amplitude and the rms voltage simplifies to equation 3.3.

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 \cdot V_m \tag{3.3}$$

Similarly the AC current of $i(t) = I_m \sin(\omega t)$ can be quantified using the rms value:

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 \cdot A_I$$

The rms values of voltage and current are known as the "effective" values. The goal for developing rms values was to quantify an AC voltage/current with one value that could be compared to a DC value and deliver the equivalent power to the load. Comparing the power $P = V \cdot I$ dissipated by

- a DC current of $10A_{DC}$ and
- an AC current of $10A_{rms}$ through the same load,

the heat dissipated by the load is the same amount.

Questions

1. What is the advantage of a "true rms meter"? (Hint: google.com)
2. What is the frequency limits of the Fluke 77 meter for AC measurements and the ProPoint 83444665 meter? (google or hogan53.net)

3.8. EXPERIMENT: Step-Down Transformer Waveform

Figure 3.5 shows the schematic diagram for the step-down transformer connected to a variable resistor. Two output voltages are available. These are a fixed $\sim 3.3V_{rms}$ AC voltage and a variable voltage output with a maximum of $\sim 7.5V_{rms}$.

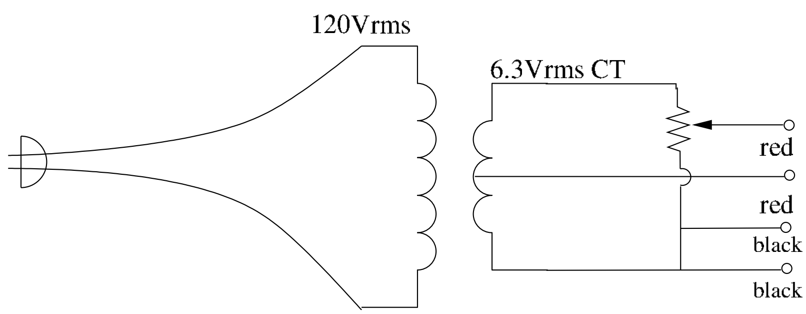


Figure 3.5.: Step-Down transformer

Execute the following measurements:

1. Record the model and make of oscilloscope and DMM you have:

   ____________________________ ________________________________

2. Start with AC coupling. Connect the oscilloscope *CH1* input to the red terminal which has the fixed voltage coming from the secondary center-tap. Adjust the scope's time/div dial to get between one and 6 wavelengths on the screen.

3. Record the peak to peak voltage [V_{pp}] of the waveform. Calculate the amplitude in volts peak [V_p]. Include the proper units.

a)

peak to peak voltage	amplitude

4. Use the digital multimeter (DMM) to measure the same output voltage. State the correct units for this measurement?

a) DMM measurement with error = ___________________________________

5. Measure the period of the output waveform. Calculate the frequency of the waveform.

a)

Period T	Frequency = f

6. Check for and record the *DC* offset using the oscilloscope and the DMM. Include the units.

a)

DC offset (oscilloscope)	DC offset (DMM)

7. Measure and record the maximum and minimum amplitude of the voltage available at the variable output terminals. Use the potentiometer dial to set the minimum and maximum voltages. Include the units.

a)

Maximum	Minimum

Question

1. Show that the scope's peak voltage measurement and the DMM's ac voltage measurement agree.

3.9. EXPERIMENT: Signal Generator Waveforms

1. Connect the output[2] to the *CH1* input of the scope.

2. Set the signal generators controls so that it produces the voltage waveform shown in equation 3.4. Show this waveform to your lab instructor.

$$v(t) = 2.8V_p \sin(2\pi \times 7.2kHz \cdot t) \tag{3.4}$$

a) Calculate the period of the waveform with units:

T = ____

3. Next add a *DC* offset of $-1.7V_{DC}$ and show the instructor. This can be measured by the oscilloscope or the DMM. Verify using one of these means.

[2] 50Ω if stated on generator

Question

1. In terms of frequency content, what is the difference between a sine, a triangle and a square wave, all with the same frequency of $1kHz$?

3.10. Rectifier Circuit

Safety Note: You will make use of a step-down transformer. This device limits the available voltage at the secondary to a safer value compared to the primary's voltage of $120V_{rms}$. However, never short the output of a transformer! Doing so will remove any limit on the current generated. The secondary will generate large current values producing dangerous conditions. Arcing and overheating are two.

3.10.1. Description

Although electrical power is generally delivered as alternating current, the majority of electronic circuits utilize DC voltages for operation. This requires conversion from AC to DC. A rectifier circuit is one which performs all or part of this conversion.[3] The circuit provided[4] is shown in figure 3.6.

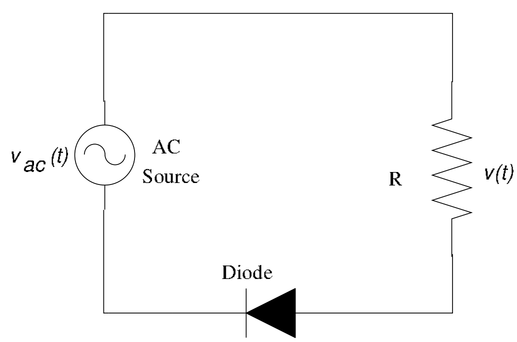


Figure 3.6.: Rectifier circuit schematic

3.10.2. Operation

1. Current can only pass through a diode in one direction and the direction of the arrow shows the direction of conventional current.
2. A voltage will develop across the resistor R only when the diode conducts.
3. No voltage will appear across the resistor when the diode blocks current.

Freezing time at two instances ($t_1$and t_2) during a full cycle of the AC voltage source helps with understanding the output voltage waveform. Consult figure 3.7.

One way of thinking about a diode is to say that it has a small resistance for current in one direction (a few $10's$ of Ω), and a very large resistance ($M\Omega's$) for current in the other direction.

[3]Additional smoothing and filtering may be needed.
[4]built on plexiglass or on a breadboard

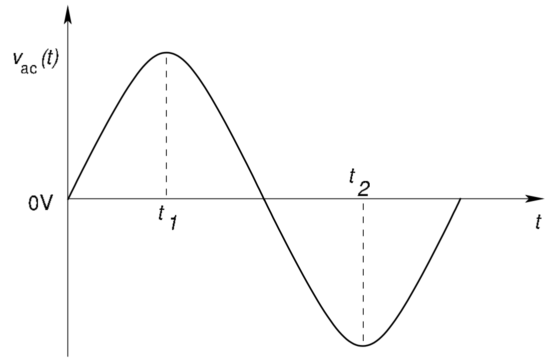


Figure 3.7.: Voltage applied to rectifier circuit.

1. At t_1: Conventional current flows from high potential to low. When the AC voltage is at its most positive voltage on the source's upper terminal (figure 3.7), then a maximum current will flow though the diode. The value of current is determined by Ohm's law using the resistance values of the resistor and conducting diode.

2. At t_2: When the polarity of the AC voltage source reaches its negative peak, then the diode blocks current. This is due to the behavior of the junction of two doped semiconductor materials which make up the diode. Applying a "reverse bias" to a diode only increases the barrier to current flow, and so the voltage drop across the resistor becomes zero.

3.10.3. EXPERIMENT: Rectifier Circuit

NOTE: Use only one channel and one probe for this section.

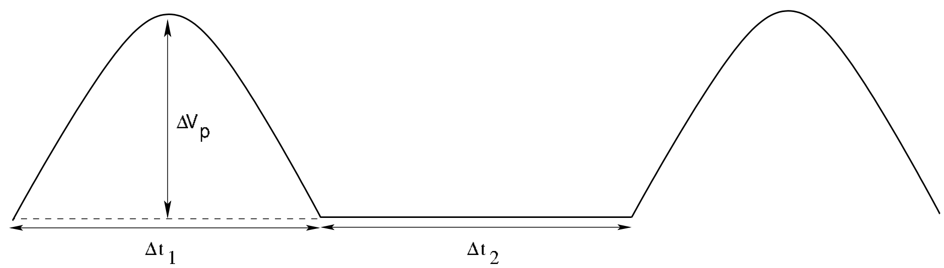
1. Connect the fixed AC output from the step-down transformer to the input terminals of the rectifier circuit. If using a breadboard, build the circuit shown in figure 3.6.

2. Connect the oscilloscope *CH1* to the output terminals to monitor the voltage difference present across the resistor.

3. Use DC coupling on the oscilloscope. Record the values shown in figure 3.8.

4. Indicate in the provided diagram where 0 volts is.

5. Use the DMM to measure the DC voltage and rms voltage across R. Which measurement is correct and which one is not correct? Explain why for both measurements cases.



Measurements:
$\Delta V_P =$______________________
$\Delta t_1 =$______________________
$\Delta t_2 =$______________________
Average Value = ______________________

Figure 3.8.: Rectifier waveform measurements

Question

1. Why is $\Delta t_1 \neq \Delta t_2$?

3.11. Lissajous Figures

Lissajous figures can used to measure phase shift and frequency of a waveform:

- They can yield accurate phase measurements for small phase shifts which are difficult to directly measure as the two traces are nearly on top of each other.
- The advantage in frequency measurements is that a noisy signal's frequency can be accurately determined by comparison to a signal of known frequency.

3.11.1. Horizontal Controls: Time Base Mode

Press MENU for the horizontal control section. Next press Time Base to select the time base mode of the oscilloscope. The default is *YT;* select *XY* mode for Lissajous pattern measurements. Selecting *XY* mode changes the horizontal axis from a time axis to a voltage axis. Check that the *X-Y* setting show *CH1-CH2* as selected in the time-base menu.

CH1's input becomes the voltage that sets the horizontal excursion of the trace. The vertical channel is *CH2* as usual. Use this *XY* mode to measure the frequency of the signal generator at a few different frequencies as instructed below.

3.11.2. EXPERIMENT: Lissajous Figures

In the following, *CH1* will be considered the signal of known frequency f_1. *CH2* will be consider the signal of unknown frequency f_2.

1. Set the scope up for *XY* mode. Put both *CH1* and *CH2* to $2 V/_{division}$. Use *AC* coupling on both channels. Further adjustment of channel scale (V/divison) is usually necessary.
2. Put the time-base scale on 2.00ms. This setting is shown in white numbers and letters along the top of the display.

3. Connect the fixed voltage terminals of the step-down transformer to the *CH1* input. This provides an exact *60Hz* sine wave input for the vertical or Y channel. The amplitude of this waveform cannot be changed. Consider this the known frequency.

4. Check that the DC offset of the signal generator output is off.

5. Set the signal generator to a sine wave output, and the frequency to *approximately* 60Hz (our "unknown"). Connect it to *CH2*.

6. Set the amplitude of the signal generator to give a noticeable vertical deflection *(Y)*. Once the amplitude is about equal to the *CH1's* amplitude, a pattern similar to a rotating ring will be seen. [5]

7. Adjust the signal generator's frequency to stabilize the ring. It is difficult to hold the pattern still due to frequency mismatch. Once this ring pattern is nearly still, you have set the signal generator to a frequency of *60Hz*. This is a *1:1* ratio, *X:Y*.

8. Use the frequency dial to go for a *1:2* ratio (*X:Y*), and then a *2:3* (*X:Y*) ratio. Draw the two different patterns below. Explain how to calculate the "unknown" *CH2* frequency based on the known *CH1* input's frequency of 60Hz.

3.12. Phase Shift of RC and RL Circuits

Both capacitive and inductive circuits introduce a phase shift between applied voltage $v(t)$ and the resulting current $i(t)$. The phase shift is a result of the reactance[6] of the component to voltage and current. The reactance is frequency dependent. Their opposition to flow of charge is still measured in ohms, but the term reactance is used instead of resistance.

Reactance has the symbol X and units of ohms. For inductors, the magnitude of the reactance is

$$X_L = \omega L$$

where ω is the angular frequency in radians per second and L is the inductance in henries, symbol H. ω refers to the applied voltage's or resulting current's frequency of oscillation. For capacitors, the reactance has a magnitude of

$$X_C = {}^1\!/_{\omega C}$$

where C is the capacitance in farads.

Both reactances are vector quantities. The directionality relates to whether the current leads of lags the applied voltage.

[5]Both channels are being driven by sinusoidally varying voltages.

[6]Inductors and capacitors are classified as reactive components as opposed to passive components like resistors.

3.12.1. EXPERIMENT: Measuring phase shift.

For the following measurements, the input voltage $v_i(t)$ is considered the reference voltage. Therefore the phase difference measurements are made with respect to it. For both circuits, the current is in phase with $v_o(t)$ but not necessarily with $v_i(t)$[7].

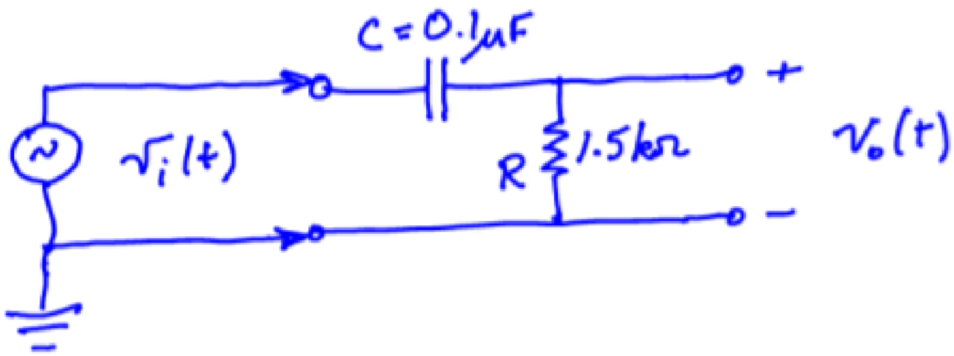


Figure 3.9.: Series RC Circuit

1. Return the oscilloscope to *YT* mode.
2. Construct (breadboard) the RC series circuit shown in Figure 3.9. $v_i(t)$ will be supplied by the signal generator set to generate a sine wave. Use *CH1* to monitor this waveform. Monitor the output voltage with *CH2*.
3. Measure the phase shift at 1kHz, 2kHz, 10kH, 20kHz and 50kHz. Make a table for your values below.
4. Build the RL series circuit shown in Figure 3.10. Measure the phase shift at 1kHz, 2kHz, 10kH, 20kHz.

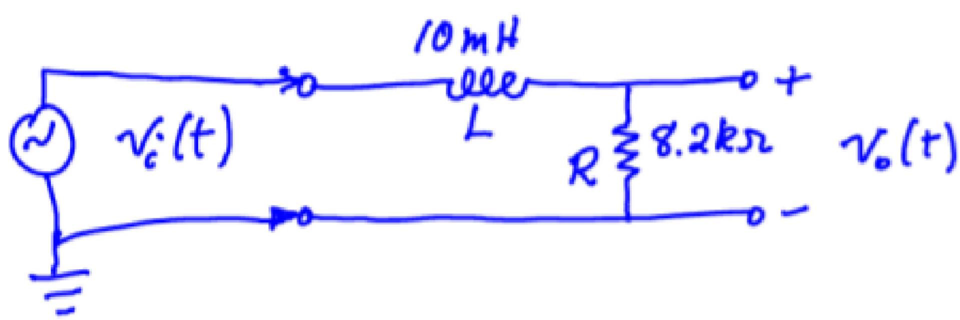


Figure 3.10.: Series RL Circuit

[7] It depends on the frequency.

User Interface

MSO1000Z/DS1000Z provides 7.0 inch WVGA (800*480) TFT LCD.

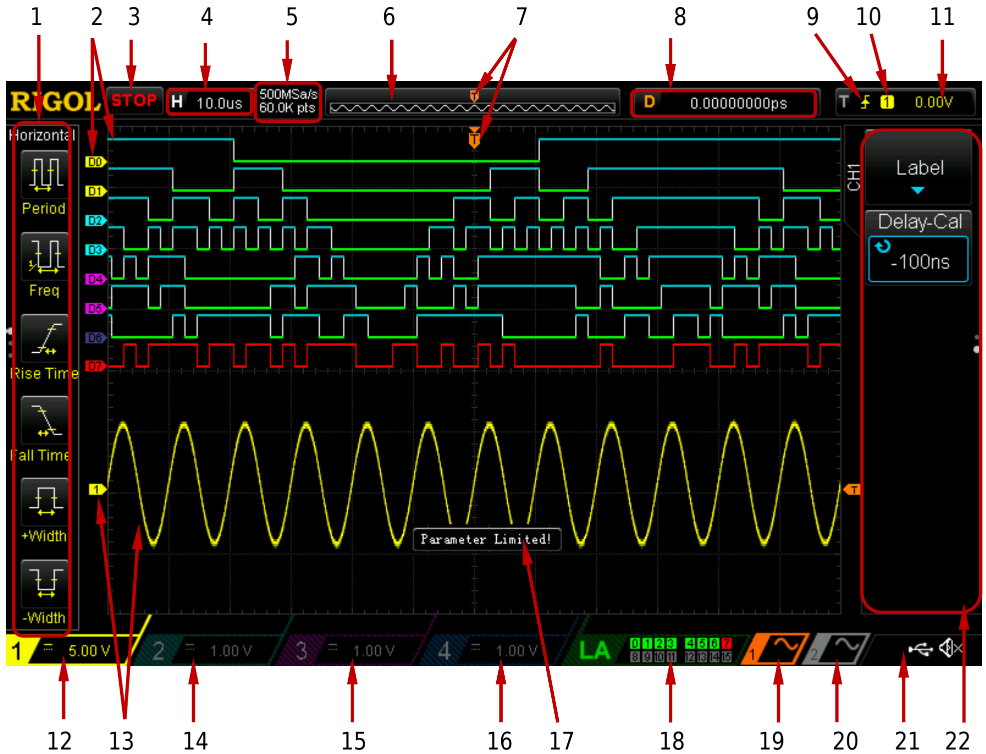


Figure 1-12 User Interface

1. Auto Measurement Items

Provide 20 horizontal (HORIZONTAL) and 17 vertical (VERTICAL) measurement parameters. Press the softkey at the left of the screen to activate the corresponding measurement item. Press **MENU** continuously to switch between the horizontal and vertical parameters.

2. Digital Channel Label/Waveform

The logic high level of the digital waveform is displayed in blue and the logic low level in green. Its edge is displayed in white. The waveform of the digital channel currently selected and the channel label are displayed in red. The digital channels can be divided into 4 channel groups by the grouping setting function of the logic analyzer function menu. The channel labels of the same channel group are displayed in the same color; different channel groups are marked with different colors.

Note: This function is only applicable to MSO1000Z and DS1000Z Plus with the MSO upgrade option.

3. Status

Available states include RUN, STOP, T'D (triggered), WAIT and AUTO.

4. Horizontal Time Base

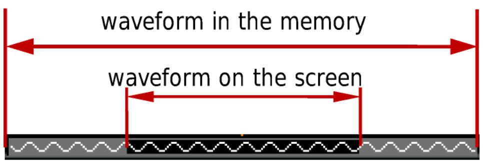
- Represent the time per grid on the horizontal axis on the screen.
- Use **HORIZONTAL** **SCALE** to modify this parameter. The range available is from 5 ns to 50 s.

5. Sample Rate/Memory Depth

- Display the current sample rate and memory depth of the oscilloscope.
- The sample rate and memory depth will change in accordance with the horizontal time base.

6. Waveform Memory

Provide the schematic diagram of the memory position of the waveform currently on the screen.



7. Trigger Position

Display the trigger position of the waveform in the waveform memory and on the screen.

8. Horizontal Position

Use **HORIZONTAL** **POSITION** to modify this parameter. Press down the knob to automatically set the parameter to zero.

9. Trigger Type

Display the currently selected trigger type and trigger condition setting. Different labels are displayed when different trigger types are selected. For example, represents triggering on the rising edge in "Edge" trigger.

10. Trigger Source

Display the trigger source currently selected (CH1-CH4, AC or D0-D15). Different labels are displayed when different trigger sources are selected and the color of the trigger parameter area will change accordingly. For example, 1 denotes that CH1 is selected as the trigger source.

11. Trigger Level

- When an analog channel is selected as the trigger source, you need to set a proper trigger level.
- The trigger level label is displayed at the right of the screen and the trigger level value is displayed at the upper-right corner of the screen.
- When using **TRIGGER** **LEVEL** to modify the trigger level, the trigger level value will change with the up and down of .

Note: In slope trigger, runt trigger and window trigger, two trigger level labels (and) are displayed.

12. CH1 Vertical Scale

- Display the voltage value per grid of CH1 waveform vertically.
- Press **CH1** to select CH1, and use **VERTICAL** **SCALE** to modify this parameter.
- The following labels will be displayed according to the current channel setting: channel coupling (e.g.) and bandwidth limit (e.g.).

13. Analog Channel Label/Waveform

Different channels are marked with different colors and the colors of the channel label and waveform are the same.

14. CH2 Vertical Scale

- Display the voltage value per grid of CH2 waveform vertically.
- Press **CH2** to select CH2, and use **VERTICAL** **SCALE** to modify this parameter.
- The following labels will be displayed according to the current channel setting: channel coupling (e.g.) and bandwidth limit (e.g.).

15. CH3 Vertical Scale

- Display the voltage value per grid of CH3 waveform vertically.
- Press **CH3** to select CH3, and use **VERTICAL** **SCALE** to modify this parameter.
- The following labels will be displayed according to the current channel setting: channel coupling (e.g.) and bandwidth limit (e.g.).

16. CH4 Vertical Scale

- Display the voltage value per grid of CH4 waveform vertically.
- Press **CH4** to select CH4, and use **VERTICAL** **SCALE** to modify this parameter.
- The following labels will be displayed according to the current channel setting: channel coupling (e.g.) and bandwidth limit (e.g.).

17. Message Box

Display the prompt messages.

18. Digital Channel Status Area

Display the current status of the 16 digital channels. The digital channels currently turned on are displayed in green and the digital channel currently selected is displayed in red. The digital channels turned off are displayed in grey.
Note: This function is only applicable to MSO1000Z and DS1000Z Plus with the MSO upgrade option.

19. Source 1 Waveform

- Display the type of waveform currently set for source 1.
- When the modulation of source 1 is enabled, will be displayed below the source 1 waveform.
- When the impedance of source 1 is set to 50 Ω, will be displayed below the source 1 waveform.
- This function is only applicable to digital oscilloscopes with source channels.

20. Source 2 Waveform

- Display the type of waveform currently set for source 2.
- When the modulation of source 2 is enabled, will be displayed below the source 2 waveform.
- When the impedance of source 2 is set to 50 Ω, will be displayed below the source 2 waveform.
- This function is only applicable to digital oscilloscopes with source channels.

21. Notification Area

Display the sound icon and USB storage device icon.

- Sound Icon: Press **Utility** → **Sound** to enable or disable the sound. When the sound is enabled, will be displayed; when the sound is disabled, will be displayed.
- USB Storage Device Icon: when a USB storage device is detected, will be displayed.

22. Operation Menu

Press any softkey to activate the corresponding menu. The following symbols might be displayed in the menu:

Denote that the multifunction knob can be used to modify the parameters. The backlight of turns on in the parameter modification status.

Denote that you can use to select the desired items and the item currently selected is displayed in blue. Press down to enter the menu bar corresponding to the selected item. The backlight of is constant on after menus with this symbol are selected.

Denote that you can press to open the pop-up numeric keyboard and input the desired paramrter values directly. The backlight of is constant on after menus with this symbol are selected.

 Denote that the current menu has several options.

 Denote that the current menu has a lower level menu.

 Press this key to return to the previous menu.

 The number of dots indicates the number of pages of the current menu.