EE283 Lab 5
RL And RC Circuits

Objective:

- To understand the operation of the Tektronix TBS 1064 Oscilloscope and the Tektronix AFG 1022 Function Generator.
- To understand the phase relationship between AC voltages and currents in resistors, capacitors and inductors

Equipment Required:

- Tektronix TBS 1064 Oscilloscope
- Tektronix AFG 1022 Function Generator
- resistors, inductor and capacitor

Theory:

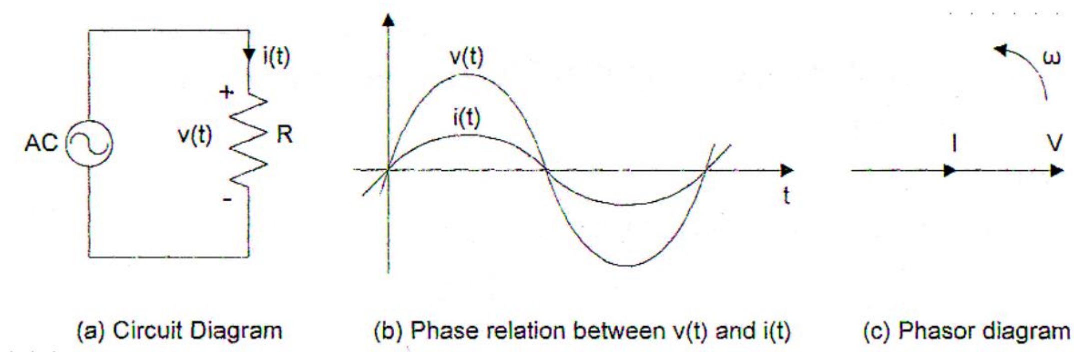
Resistor:

Let the time varying voltage across a resistor, R, as shown in Figure 1a be

$$v(t)=V_{PEAK}\cos(\omega t)$$

Where ω is the angular frequency (radians per second) = 2πf – frequency f is the number of cycles per second (units of Hertz) and t is the time in seconds.

From Ohm's law, the current $i(t) = v(t)/R = V_{PEAK}\cos(\omega t)/R$
Then $i(t) = I_{PEAK}\cos(\omega t)$ where $I_{PEAK} = V_{PEAK}/R$
Therefore i(t) and v(t) are in phase as shown in Figure 1b.
In phasor form, **I**=**V**/R. Therefore phasors **V** and **I** are in phase as shown in Figure 1c (Note **V** and **I** for phasors are in **bold**).



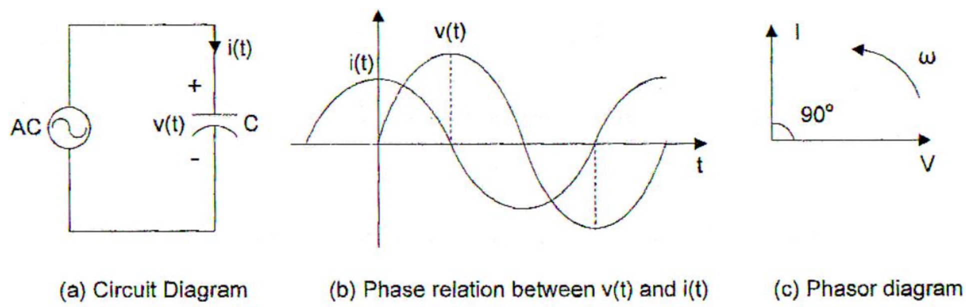
Relationship between voltage and current in a resistor
Figure 1

Capacitor:

Let the time varying voltage across a capacitor, C, as shown in Figure 2a be

$$v(t)=V_{PEAK}\cos(\omega t)$$

Then $i(t) = C\, dv(t)/dt = -\omega C V_{PEAK}\sin(\omega t) = \omega C V_{PEAK}\cos(\omega t+90^o)$
So $i(t) = I_{PEAK}\cos(\omega t+90^o)$ where $I_{PEAK} = \omega C V_{PEAK} = V_{PEAK}/X_C$. $X_C = 1/(\omega C)$ is called the capacitive reactance and is inversely proportional to frequency. The current, i(t) leads the voltage, v(t), by 90° as shown in Figure 2b. In phasor form, $\mathbf{V = IX_C}$ where
$\mathbf{X_C = -j/(\omega C)} = 1/(j\omega C)$. $\mathbf{X_C}$ has the units of ohms. Therefore **I** leads **V** by 90° as shown in Figure 2c.



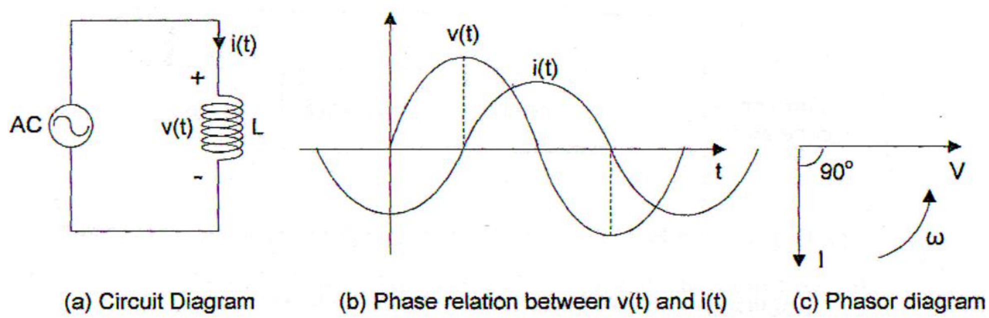
Relationship between voltage and current in a capacitor
Figure 2

Inductor:

Let the time varying voltage across a inductor, L, as shown in Figure 3a be

$$v(t)=V_{PEAK}\cos(\omega t)$$

Then $i(t) = (1/L) \int v(t)/dt = V_{PEAK}\sin(\omega t)/(\omega L) = V_{PEAK}\cos(\omega t-90^o)/(\omega L)$.
So $i(t) = I_{PEAK}\cos(\omega t-90^o)$ where $I_{PEAK} = V_{PEAK}/(\omega L) = V_{PEAK}/X_L$. $X_L = \omega L$ is called the inductive reactance and is directly proportional to frequency. The current, i(t) lags the voltage, v(t), by 90° as shown in Figure 3b. In phasor form, $\mathbf{V = IX_L}$ where $\mathbf{X_L} = j\omega L$. $\mathbf{X_L}$ has the units of ohms. Therefore **I** lags **V** by 90° as shown in Figure 2c.



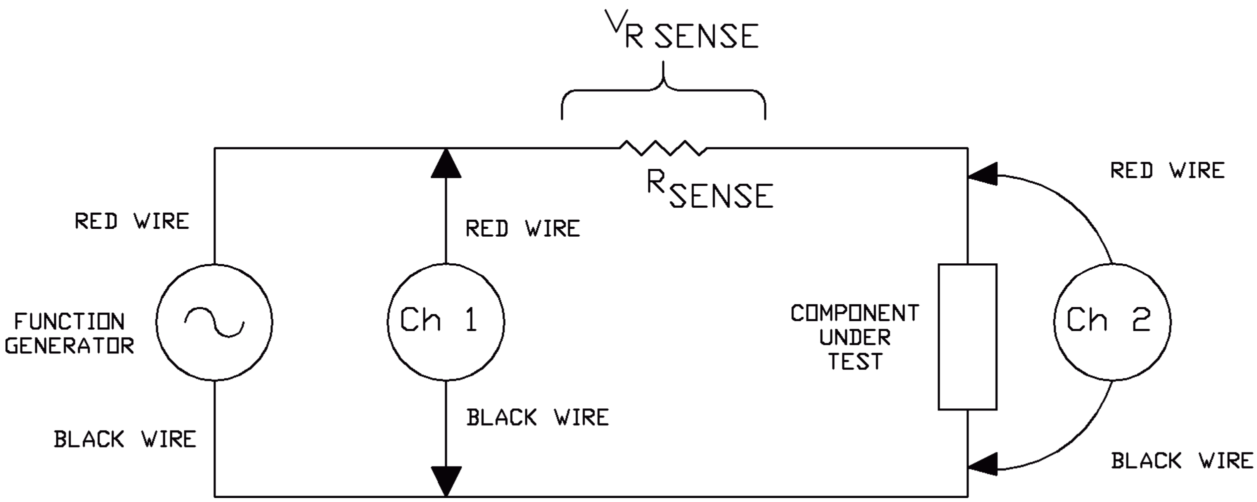
Relationship between voltage and current in an inductor
Figure 3

Basic Setup:

This lab exercise uses the Tektronix AFG 1022 Function Generator to supply an AC voltage source and a Tektronix TBS 1064 Oscilloscope to measure voltages. The oscilloscope input channels (Ch 1 and Ch 2) each have a BNC connector to which we will attach a coax cable that terminates in two leads (one red and the other black). The two black leads are connected together inside of the oscilloscope so the black leads from the oscilloscope must be connected to the same point in the circuit otherwise part of the circuit will be shorted out.

The Tektronix AFG 1022 Function Generator has two output signals (we will only be using one of the output signals) which each have a BNC connector. We will attach a coax cable to one of the BNC connectors with the opposite end of the cable terminated in two leads (one red and the other black). The black lead from the function generator is also connected to the black leads of the oscilloscope - that is they are connected to ground.

The basic setup used to measure the current and voltage in RC and RL circuits is shown in Figure 4. Notice the three black wires from the oscilloscope and the function generator are connected together.



Test Setup
Figure 4

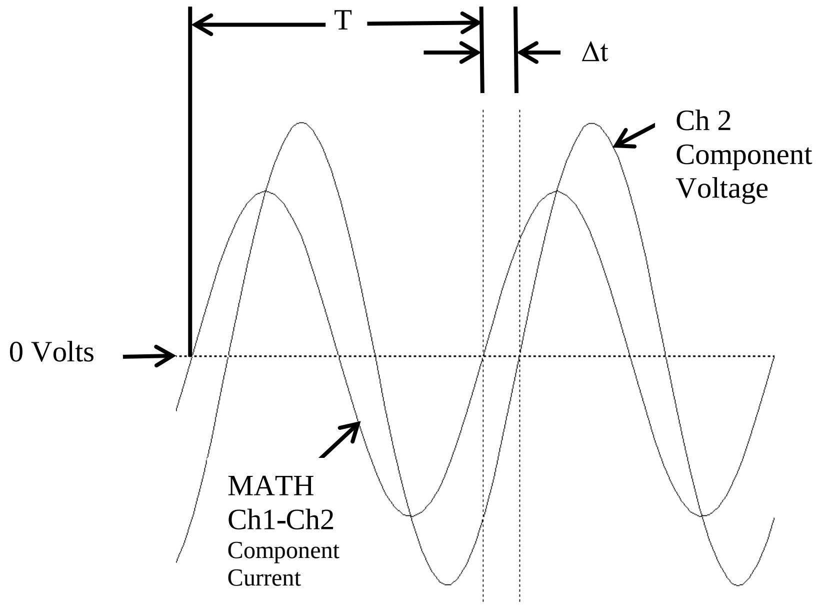
The component under test is either a resistor, capacitor or an inductor. The voltage across the resistor, $V_{R\ SENSE}$, represents the current in the component under test since all of the R_{SENSE} resistor current must flow into the component under test. That is

$$I_{COMPONENT} = \frac{V_{R\ SENSE}}{R_{SENSE}}$$

If the black wire of the oscilloscope Ch1 was connected to the other end of R_{SENSE} the voltage across R_{SENSE} could be measured but this would leave the component under test shorted and no voltage would be seen in Ch2. So how to measure the voltage across R_{SENSE}? We will use the MATH function on the oscilloscope to subtract the Ch2 voltage from the Ch1 voltage. With the oscilloscope connected as shown in Figure 4 push the MATH button and select Ch1-Ch2. Now turn off the Ch1 display by pushing the yellow 1 button. The display should look similar to Figure 5.

Figure 5 shows typical MATH (sense resistor voltage) and channel 2 (component voltage) waveforms. The time, T, represents the time for one complete cycle of the waveform. Both channels will have the same time, T. If the frequency of the signal generator is f Hertz then

T=1/f. The time, Δt, is the difference in time between the MATH and the channel 2 waveforms as these waveforms cross zero volts.



Typical MATH and Ch 2 Waveforms
Figure 5

If time T represents one complete cycle of the AC waveform (360^o) then the phase shift between the MATH and channel 2 waveforms, X^o, can be calculated by the ratios:

$$\frac{360^o}{T} = \frac{X^o}{\Delta t}$$

or

$$X^o = \left(\frac{\Delta t}{T}\right)(360^o)$$

Procedure:
For each component – the resistor, capacitor and the inductor do the following:

Resistor:
- Use a 1K resistor for R_{SENSE} and a 2.2K resistor for the component under test.
- Connect the circuit as shown in Figure 4 using the Tektronix AFG 1022 Function Generator for the signal generator and the Tektronix TBS 1064 Oscilloscope for the channel 1 and channel 2 voltages.
- Set the amplitude of the signal generator to 1 volt peak and set the frequency of the signal generator to 1kHz.
  - Adjust the vertical position controls on the oscillospope so that the little arrows at the left hand side of the screen are centered on the middle graticule line on the oscilloscope screen. Be sure to do this for both channels.
  - Adjust the vertical sensitivity controls (VOLTS/DIV) of both channels so that both waveforms fit on the oscilloscope screen. Turn on the MATH function and select Ch1-Ch2. Turn off Ch1 by pushing the yellow 1 button. Adjust the MATH waveform sensitivity by adjusting the Multipurpose Knob.
  - Adjust the sweep rate control (SEC/DIV) until just two or three cycles are showing on the computer screen. The waveforms should look like those in Figure 5.
  - Your report should include a "screen capture" figure of the oscillosope screen.The waveforms have to be properly annotated (not MATH or Ch 2) using the words "component voltage" and "component current". The figure has to have a title such as "The Voltage and Current in a Resistor". The values for times T and Δt have to be clearly marked on the figure. Both axis must be correctly labeled with the correct units. The sensitivity of the vertical axis must be shown (for example 500mV/DIV). Each channel may have different sensitivity values. The sweep rate must also be shown (for example 250 µS/DIV).
- Calculate the phase shift between the voltage and current in the resistor. Include this calculation and answer in the report.
- Calculate the value of the resistor under test using the peak to peak values of the component voltage and current ($V_{R\ SENSE}/R_{SENSE}$) from your figure. Record the calculation and resistance value in your report.

Capacitor:
- Use a 1K resistor for R_{SENSE} and the capacitor supplied for the component under test.
- Connect the circuit as shown in Figure 4 using the Tektronix AFG 1022 Function Generator for the signal generator and the Tektronix TBS 1064 Oscilloscope for the channel 1 and channel 2 voltages.
- Set the amplitude of the signal generator to 1 volt peak and set the frequency of the signal generator to 700 Hz.
  - Adjust the vertical position controls on the oscillospope so that the little arrows at the left hand side of the screen are centered on the middle graticule line on the oscilloscope screen. Be sure to do this for both channels.
  - Adjust the vertical sensitivity controls (VOLTS/DIV) of both channels so that both waveforms fit on the oscilloscope screen. Turn on the MATH function and select

Ch1-Ch2. Turn off Ch1 by pushing the yellow 1 button. Adjust the MATH waveform sensitivity by adjusting the Multipurpose Knob.
    - Adjust the sweep rate control (SEC/DIV) until just two or three cycles are showing on the computer screen. The waveforms should look like those in Figure 5.
    - Your report should include a "screen capture" figure of the oscillosope screen.The waveforms have to be properly annotated (not MATH or Ch 2) using the words "component voltage" and "component current". The figure has to have a title such as "The Voltage and Current in a Capacitor". The values for times T and Δt have to be clearly marked on the figure. Both axis must be correctly labeled with the correct units. The sensitivity of the vertical axis must be shown (for example 500mV/DIV). Each channel may have different sensitivity values. The horizontial sweep rate must also be shown (for example 250 µS/DIV).
- Calculate the phase shift between the voltage and current in the capacitor. Include this calculation and answer in the report.
- Calculate the value of the capacitor under test using the peak to peak values of the voltage and current ($V_{R\ SENSE}/R_{SENSE}$) from your figure. Record the calculation and capacitance value in your report.

Inductor:

- Use a 1K resistor for R_{SENSE} the inductor supplied for the component under test.
- Connect the circuit as shown in Figure 4 using the Tektronix AFG 1022 Function Generator for the signal generator and the Tektronix TBS 1064 Oscilloscope for the channel 1 and channel 2 voltages.
- Set the amplitude of the signal generator to 1 volt peak and set the frequency of the signal generator to 3kHz.
    - Adjust the vertical position controls on the oscillospope so that the little arrows at the left hand side of the screen are centered on the middle graticule line on the oscilloscope screen. Be sure to do this for both channels.
    - Adjust the vertical sensitivity controls (VOLTS/DIV) of both channels so that both waveforms fit on the oscilloscope screen. Turn on the MATH function and select Ch1-Ch2. Turn off Ch1 by pushing the yellow 1 button. Adjust the MATH waveform sensitivity by adjusting the Multipurpose Knob.
    - Adjust the sweep rate control (SEC/DIV) until just two or three cycles are showing on the computer screen. The waveforms should look like those in Figure 5.
    - Your report should include a "screen capture" figure of the oscillosope screen.The waveforms have to be properly annotated (not MATH or Ch 2) using the words "component voltage" and "component current". The figure has to have a title such as "The Voltage and Current in a Inductor". The values for times T and Δt have to be clearly marked on the figure. Both axis must be correctly labeled with the correct units. The sensitivity of the vertical axis must be shown (for example 500mV/DIV). Each channel may have different sensitivity values. The horizontial sweep rate must also be shown (for example 250 µS/DIV).
- Calculate the phase shift between the voltage and current in the inductor. Include this calculation and answer in the report.
- Calculate the value of the inductor under test using the peak to peak values of the voltage and current ($V_{R\ SENSE}/R_{SENSE}$) from your figure. Record the calculation and inductance value in your report.

Remember: ELI the ICE man!

EE283 Laboratory Exercise 5 Form Report

Name:______________________ Section:_____ Station:_____ Date:___________

Setup figure here

Screen capture for resistor component

Phase shift between the resistor voltage and current:________

Show phase shift calculations here.

Resistance the component resistor:________

Show resistance calculations here.

Screen capture for capacitor component

Phase shift between the capacitor voltage and current:________

Show phase shift calculations here.

Capacitance value of the capacitor:________

Show capacitance value (not the reactance) calculations here.

Screen capture for inductor component

Phase shift between the inductor voltage and current:________

Show phase shift calculations here.

Inductance value of the inductor:________

Show inductor value (not the reactance) calculations here.

Tektronix TBS 1064 Oscilloscope

The function of the oscilloscope is to display a voltage that varys with time (AC voltages). The oscilloscope can also display DC voltages. The front panel of the oscilloscope is shown below in Figure A1. The pushbutton power switch is located on the top of the oscilloscope on the left hand side.

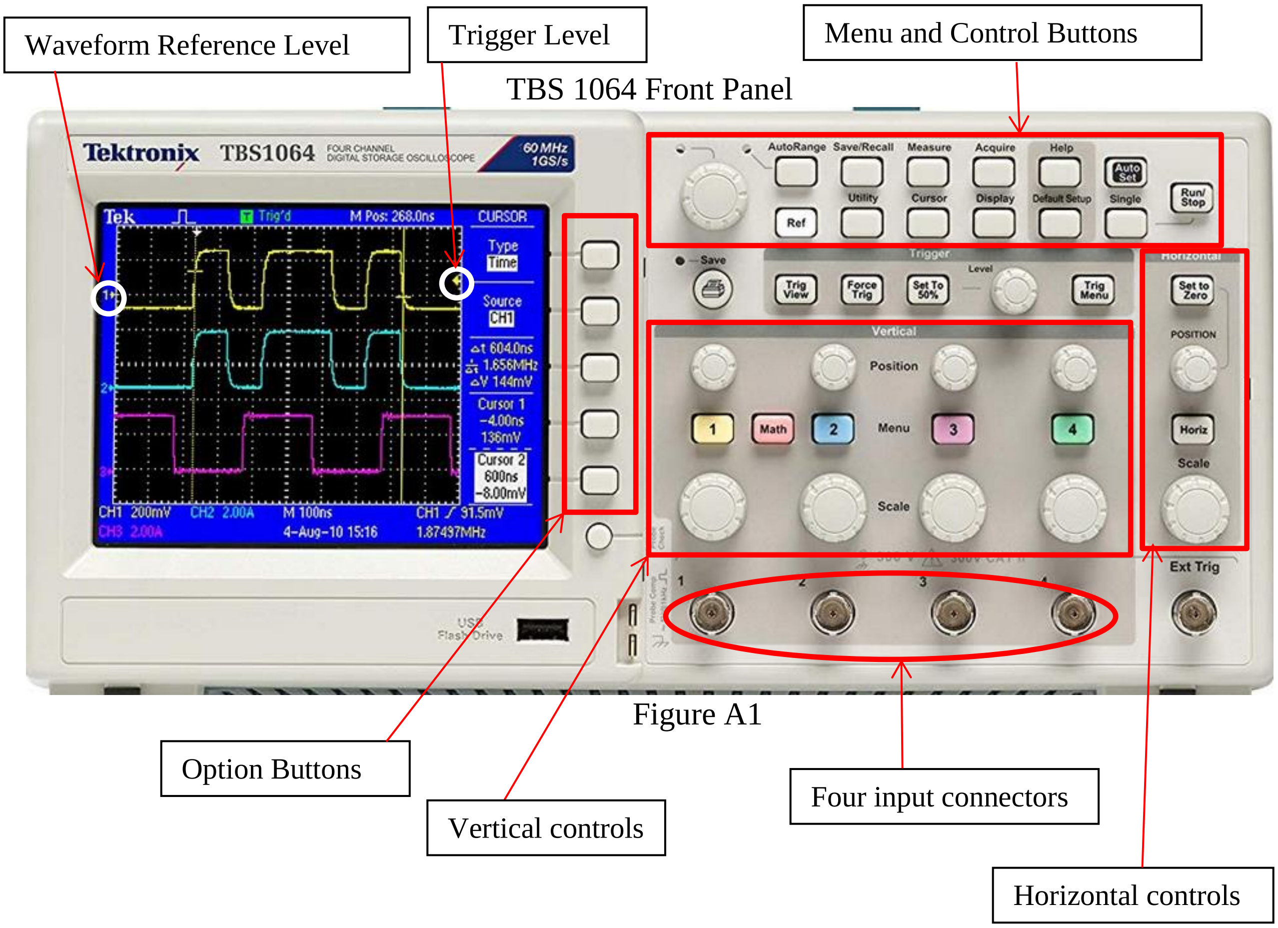
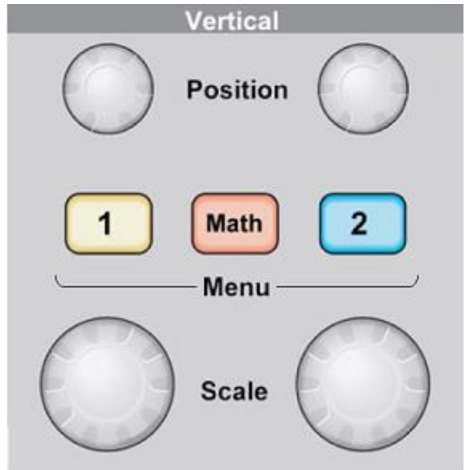


Figure A1

Input Connectors:

There are four input connectors (1, 2, 3 and 4) which are used to measure voltage. The vertical controls associated with each input connector are located directly above the input connector. Each of the input connectors mates with a male BNC connector attached to a coax cable. The other end of the cable terminates in two clips – one red and one black. When the BNC connector is connected to the input connector the black clip is connected to the chassis of the oscilloscope. If more than one input connectors have coax cables the black clips of each cable will be connected together. Therefore the rule is: all black clips must be connected to the same point in the circuit. Failure to follow this rule will result in part of the circuit being shorted out. Do not attempt to connect the AC line voltage (120 VAC) to the input connector.

Vertical Controls:



There are four sets of vertical controls (only two are shown here) which control the vertical portion of the waveform. Each set of controls directly above the input connector controls the display waveform for that input channel.

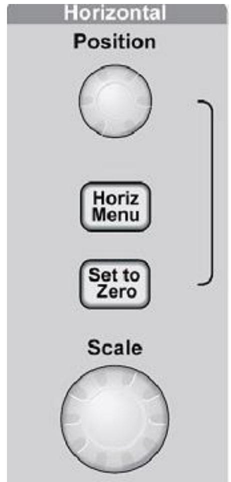
The yellow 1 push button toggles on and off the channel 1 display which will appear in yellow. The blue 2 push button toggles on and off the channel 2 display which will appear in blue. When a display is turned on it’s characteristics are displayed on the right hand side of the screen. The display should read (from top to bottom) Coupling-DC; BW Limit-Off; Volts/Div-Course; Probe-1X Voltage; Invert-Off. If any of the characteristics are not correct you can use the corresponding option buttons to the right of the screen to toggle to the correct characteristic.

The Scale knob controls the sensitivity of the channel (Volts/Div). Turning this knob clockwise increases the channel sensitivity (less Volts/Div) and turning the knob counterclockwise decreases the channel sensitivity (more Volts/Div). The actual sensitivity (Volts/Div) for each channel is displayed in the lower left hand corner of the display.

The Position knob positions the waveform on the screen. We usually (but not always) position all of the waveforms so that they center in the middle of the screen. The small arrow at the left hand side of the screen (in Figure A1 white circle) shows the position of the waveform at zero volts. The color of the arrow and its associated number shows which channel the arrow is associated with.

The red Math push button toggles on and off the math function. The math function allows mathematical operations (+,-, *, /, and many others) between the channels. The resulting waveform appears in red on the display. Use the option buttons to select the channels and operation that are desired. When the math function is active the sensitivity of the function can be controlled using the Multipurpose knob.

Horizontial Controls:

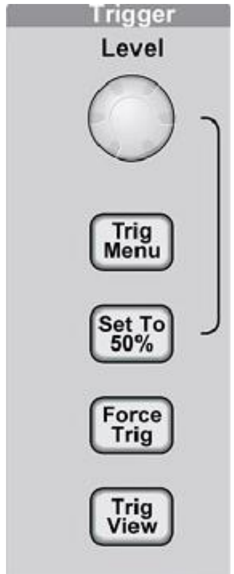


The horizontial controls set the sweep rate and position for all of the input channels. Normally all of the input channels have the same sweep rate and position. The display beam sweeps from left to right across the display but at the sweep rates that we will be using the beam will appear as a single straight line if there are no input signals.

The sweep rate is controlled by the Scale knob. Turning this knob clockwise increases the sweep rate (less Time/Div) and turning this knob counterclockwise decreases the sweep rate (more Time/Div). The actual sweep rate (S/Div or mS/Div or µS/Div) is displayed in the lower middle of the display directly to the right of the M. The M means that the displayed time is for the main time base and the time shown is for one division on the display.

The Position knob just moves the display to the right or left. Use the Position knob to adjust the waveform so that it starts at the left hand side of the screen.

Trigger Controls:

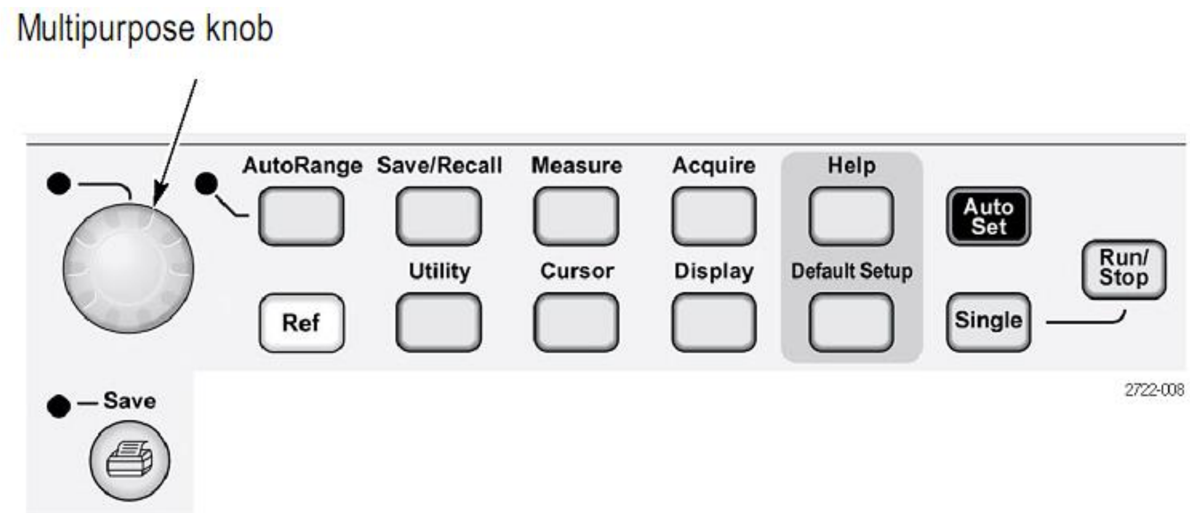


On the TBS 1064 Oscilloscope this set of controls is in a horizontal position not vertical. The trigger level sets the time that the oscilloscope beam starts moving across the display. If the waveform that you are viewing is jumping all over the place the trigger is probably not set properly.

Pushing the Trig Menu button displays the trigger menu on the right hand side of the screen. You can then use the option buttons to select the input channel you want to trigger on and if you want to trigger on the rising edge or trailing edge of the waveform.

The Level knob sets the trigger level. The small arrow at the right hand side of the screen (in Figure A1 white circle) shows the level. The color of the arrow shows which channel the oscilloscope is set to trigger on. Use the Level knob to position the arrow so that it is in the middle of the waveform that corresponds to the color of the arrow.

Menu and Control Buttons:



The Cursor button turns on two kinds of cursors in the display area, Time and Amplitude.

To measure the time difference between two waveforms push the Cursor button and then select Time from the options buttons. Two vertical cursor lines will appear in the display. At the Source button in the options buttons select Ch2. Push the Cursor 1 button in the options buttons and use the Multipurpose knob to position the first cursor at the desired position on the Ch2 waveform (in Lab Exercise 5 this is the rising edge of the Ch2 voltage where it crosses zero volts). Push the Cursor 2 button in the options buttons and use the Multipurpose knob to position the second cursor at the desired position on the second waveform (in Lab Exercise 5 this is the rising edge of the MATH voltage where it crosses zero volts). The time difference between these two cursors, Δt, can now be read from the Cursor menu. In a similar manner the time period of one cycle, T, can be measured.

To measure the peak to peak voltage of a waveform push the Cursor button and then select Amplitude from the options buttons. Two horizontal cursor lines will appear in the display. At the Source button in the options buttons select Ch2. Push the Cursor 1 button in the options buttons and use the Multipurpose knob to position the first cursor at the very top of the Ch2 waveform. Push the Cursor 2 button in the options buttons and use the Multipurpose knob to position the second cursor at the very bottom of the Ch2 waveform. The peak to peak voltage between these two cursors, ΔV, can now be read from the Cursor menu. At the Source button in the options buttons select MATH and repeat the same procedure to measure the peak to peak voltage, $V_{R\ SENSE}$. The peak to peak component current is $V_{R\ SENSE}/R_{SENSE}$.

If you have the function generator turned on and connected to your circuit but you can’t figure out how to set the oscilloscope display just press the black Auto Set button and you will be happy!

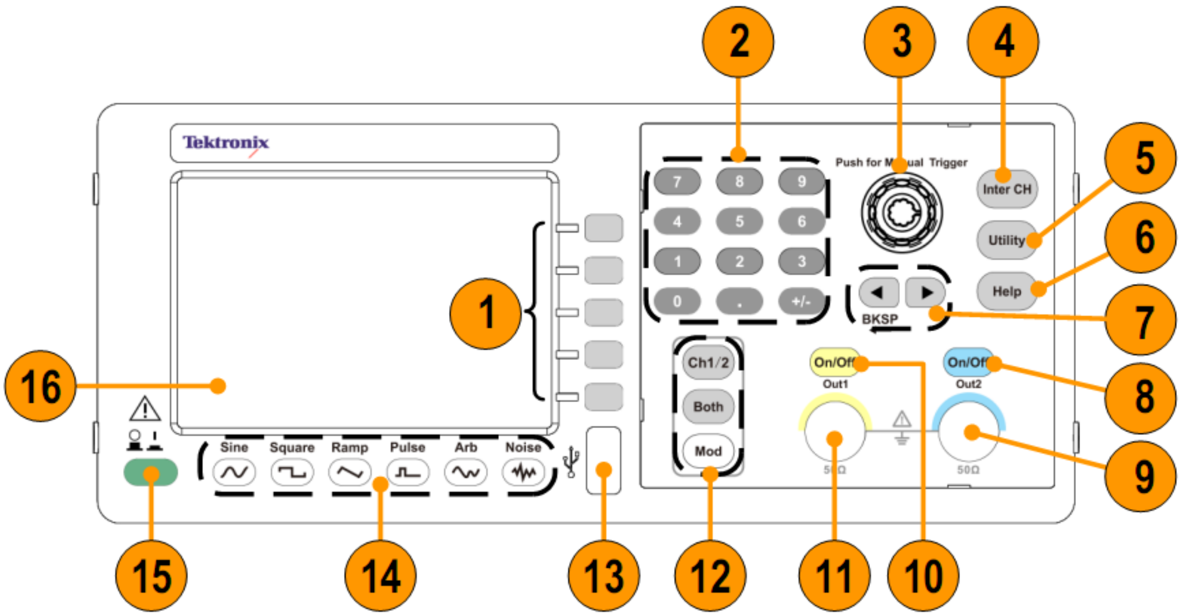
To Copy the Oscilloscope Display to Word

- Left click on the TEK Open Choice icon on the computer desktop
- Left click Select Instrument and select USB in the window that opens
- TBS 1064 should be displayed below Select Instrument
- Left click Screen Capture and then Get Screen
- Left click Copy to Clipboard.
- Paste the clipboard into your Word document

The oscilloscope display must have a white background in your report. If the Word figure has a black background you must turn the Ink Saver function in the oscilloscope on. To turn the ink saver on in the Menu and Control section push the Utility button:

Utility
 Options
  Printer Setup
   Ink Saver
    On

AFG 1022 Function Generator



Item	Description
1	Bezel buttons
2	Numeric keypad, including numeric, point, plus/minus sign
3	General purpose knob
4	Channel copy button
5	Utility button
6	Help button
7	Arrow buttons allow you to select a specific number on the display screen when you are changing amplitude, phase, frequency, or other such values
8	Channel 2 On/Off button
9	Channel 2 output connector
10	Channel 1 On/Off button
11	Channel 1 output connector
12	Ch1/2: Switch channel on the screen Both: Show the parameters of the two channels at the same time Mod: Run modes, including continuous, modulation, sweep and burst, which just apply to Channel 1.
13	USB connector
14	Function buttons
15	Power button
16	Screen

To Use the Function Generator

- Turn the power on by pushing the Power Button (item 15)
- Select a sine wave by pushing the Sine button in item 14
- Select Ch1 by pushing the Ch1/2 button in item 12 until a 1 appears in the upper left hand side of the screen (item 16)
- Select the frequency by pushing the top Bezel button (item 1) until Freq is illuminated in the display next to the Bezel button.
- In the window that opens enter the desired frequency using the keypad (item 2) and then select the units MHz, kHz, Hz or mHz.
- Select the amplitude by pushing the middle Bezel button and enter the desired amplitude in the window that opens using the keypad (item 2). Then select the units mV_{P-P}, V_{P-P}, mV_{RMS}, V_{RMS}.
- Connect a coax cable with a BNC connector to the Out 1 connector (item 11) and turn on the output by pushing the On/Off button (item 10) directly above the Out 1 connector. The On/Off button will illuminate when the generator output is connected to the Out 1 BNC connector.

A note on the function generator output voltage amplitude:

The Lab 5 Exercise requires the amplitude of the function generator output voltage to be set to 1 V_{PEAK} which is 2 $V_{PEAK-PEAK}$. The function generator desired voltage amplitude setting is the voltage seen at the BNC connector when that connector is terminated in a 50 ohm load. The generator internal source impedance is also 50 ohms therefore the oscillator inside the function has to supply twice the desired BNC output voltage. But our circuits have a much higher impedance compared to 50 ohms therefore the output voltage seen at the BNC connector will be very close to twice the desired voltage setting of the function generator. The bottom line is if you want the generator to supply 1 V_{PEAK} to a high impedance circuit set the generator to 1 $V_{PEAK-PEAK}$, which will give almost 2 $V_{PEAK-PEAK}$ at the BNC connector. This will be the required 1 V_{PEAK} funtion generator output voltage.