MS101 Makerspace
2025-26/I Autumn
Expt 1: Familiarization with Basic Measuring Instruments (Ver_Jul19)

Objectives

a) To familiarize with the laboratory measuring instruments and general lab equipment (DMM, DSO, and AFG)
b) To measure the frequency response of an RC high-pass filter

1. Digital Multimeter (DMM)

Digital Multimeter (DMM) is an electronic instrument, used for measuring voltages, currents and resistances. Both desktop and portable versions are available; portable DMMs being more popular because of their low cost, portability and usefulness for most of the general-purpose applications. The front panel of a DMM has mainly three sections, viz. a) push buttons or a rotary switch for selecting DMM functions, b) connector sockets, typically three sockets, and c) an LED/LCD display panel to display the measured parameter (voltage, current, resistance, etc). Portable DMMs are battery operated.

Typical specifications of a medium cost DMM (say, within Rs 1000/-):
DC Voltage ranges: 200 mV/2 V/ 20 V/ 200 V/ 600 V
AC Voltage ranges: 200 V/ 600 V
DC Current ranges: 200 µA/ 2 mA/ 20 mA/ 200 mA/ 10A
Resistance ranges: 200 Ω/ 2 kΩ/ 20 kΩ/ 200 kΩ/ 2 MΩ

Low-to-medium cost DMMs typically have accuracies better than ± 1% for most ranges.
In addition to the above, most DMMs have two useful features:
a) Continuity testing using a buzzer (for say, resistances < 50 Ω)
b) Diode check (for Si or Ge diodes)

DMM Input resistance (typical) for DC voltage measurements : 10 MΩ

Fig.1 shows the front panel of a DMM (Mastech 830L), which is typical of a medium cost DMM.

Fig 1 Front panel of Mastech 830L Digital Multimeter

Note the various parts of your DMM (similar to what is shown in Fig.1 – the rotary switch for selecting different functions, and the DMM terminals (VΩmA, COM, and 10A). For almost all the applications of DMM in the MS101 lab, you will require only the **VΩmA** and the **COM** terminals. The **VΩmA** terminal is where you connect one end of the DMM wire (Red) for measuring a voltage, a resistance or a current within 200 mA. The **COM** terminal is the 'Common' or the reference terminal.

- For example, for measuring a DC voltage in a circuit, say between points A and B, firstly choose the appropriate voltage range on the DMM. Now connect the **COM** terminal to point B, and the **VΩmA** terminal to point A. This would give the voltage V_{AB} on the DMM, i.e. the voltage at point A with respect to point B.

- For measuring an AC voltage, say the secondary output voltage of the transformer, choose the appropriate AC voltage range and connect the secondary output to the **VΩmA** and the **COM** terminals.

- For measuring a resistance, put the DMM into the appropriate resistance range and then touch one end of the resistor to the **COM** terminal and the other end to the **VΩmA** terminal. The following precautions need to be taken:

    - Take care not to touch both ends of the resistor with your hand, which would then cause your body resistance to be in parallel with the resistance you are measuring. This is especially important when you are measuring a large resistance, say any value of 10 kΩ or higher.
    - If you get a display '1' as the display, then the resistance value is greater than the range you chose. Choose a higher range and repeat the measurement.
    - The resistance settings 2M, 200k, 20k, 2k, and 200 shown in Fig 1 indicate the range or the maximum resistance that can be measured in that setting. If the resistance value you are measuring is higher than the chosen setting, the DMM will display '1'.

- For measuring a current within 200 mA, connect the '+' lead of the measuring port of interest to the **VΩmA** terminal and the second lead to the **COM** terminal. Care should be taken not to exceed 200 mA.

In the MS101 laboratory, you will be using the DMM mainly to measure the resistance values and also for measuring DC voltages. DMMs are very seldom used for measuring currents. DC currents up to about 200 mA can be measured by most DMMs. However, it is best to avoid measuring currents; instead estimate the current through voltage and resistance measurements.

<u>Procedure for making DMM measurements</u>:

a) Decide the parameter to be measured (say, voltage or resistance).
b) Choose the Voltage or Resistance function using the rotary switch and also the appropriate setting/range (based on the maximum expected magnitude). Choose the ranges carefully. If unsure, choose the higher range. Most DMMs display '1' to indicate overrange, i.e. the parameter you are measuring is outside the currently selected range.

<u>Note</u>:

a) Resistance mode of the DMM assumes that there is no current flowing in the resistor. Therefore, take extra care when using the resistance mode.
b) In the resistance mode, most DMMs send out a constant dc current, and then measure the voltage across the terminals (i.e. the resistance) to estimate the resistance value. If you try to measure the resistance in a circuit which is powered through a dc power supply, the DMM can get damaged, or its internal fuse (typically rated for 200 mA) might blow. Hence take extra care while measuring resistances.
c) DMM is essentially a voltage measuring instrument. Resistances and currents are first converted into voltages by the DMM circuitry. For ac voltage measurements, most DMMs are calibrated at 50 Hz, for sinusoidal rms voltages. Readings for voltages with other frequencies and/or waveforms may be incorrect.

d) For measuring current, the DMM is set in current mode and connected in series with the current path. The DMM set in current mode must not be connected across a voltage, as it may cause the meter's internal fuse to blow and damage to the circuit.

2. Breadboard

Breadboard is essentially an electronic prototyping board meant for wiring electronic circuits. Fig. 2A shows the breadboard with a circuit connected. The right side shows the internal connections. Note that the central portion is the main area where circuits are wired. Each column has five holes connected together. Each column is isolated from the neighbouring column.

The top two rows and the bottom two rows are commonly used for GROUND and Power supply connections (as these two may require more connections). Most breadboards have the bottom and top rows divided further into two halves.

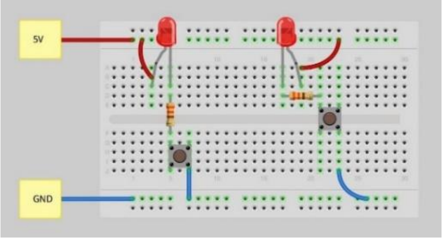

Fig 2A Breadboard with a wired circuit

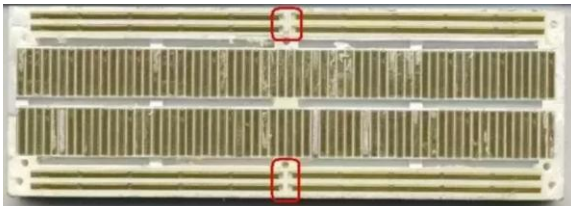

Fig 2B Typical Breadboard internal connections

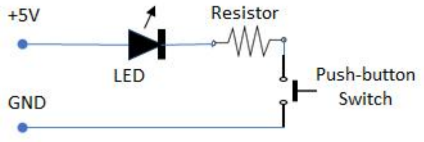

Fig 2C Circuit diagram of the wired circuit

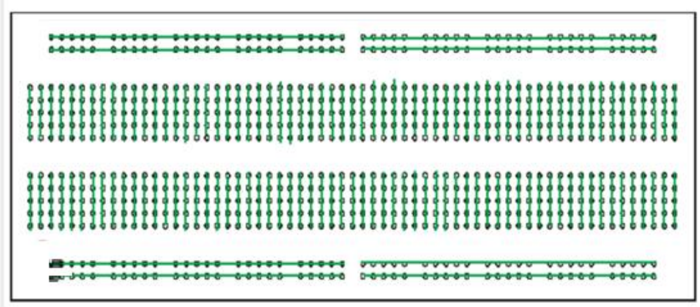

Fig 2D Breadboard internal connections - schematic

Experiment

2.1 Experiment: Part A - Verifying Breadboard Connectivity

- Using the wire stripper, prepare two short wire lengths (of say 15 cm each).
- Using the above wires verify the connectivity of a few points of your breadboard.
- Check whether there is continuity along the top row.
- Check for no connectivity between the top two rows of your breadboard.
- Check at a few random grids at the middle of the breadboard and verify that there is connectivity within various points of a column.
- For a given column, check and verify that there is no connection between the bottom half and the top half.

2.2 Experiment: Part B - Resistances in series and parallel

- Measure the resistance of the two resistances given to you. Measure their individual resistances and note down those values. Please take special care not to touch both ends of the resistor (or the DMM leads) with your hand. This would cause your body resistance to be in parallel with the resistance you are measuring.

- Connect the two resistances in series and measure the value obtained. Note down the value obtained in your Lab notebook. Verify the result.
- Connect the two resistances you measured in parallel. Note down the value obtained in your Lab notebook. Verify the result.

3. Arbitrary Function Generator

Arbitrary Function Generator (AFG) is a special function generator which can generate a variety of waveforms (sine, square, ramp, arbitrary, etc). The parameters of these waveforms, such as amplitude, frequency, offset, can be adjusted through the front panel buttons. Please refer to '**AFG1022-User-Manual.pdf** '

Fig.3 AFG 1022 front panel

AFG 1022 specifications:

- 25 MHz Function Generator
- 12.5 MHz Pulse Generator
- 14-bit Arbitrary Waveform Generator
- 200 MHz Frequency Counter

We will be using the AFG to generate sinusoidal waveforms of different frequencies and amplitudes.

Read the following pages of the AFG user manual to understand how to choose different waveforms, amplitudes and frequencies.

a) Refer to page 34 on how to generate a sine waveform and to adjust its dc offset voltage, amplitude and frequency.
b) By default, the AFG output is set for Hi-Z output. Please do not change this. (In case of a mistake, the output setting can be brought back to Hi-Z by pressing the 'Utility' and then choosing Hi-Z under 'Output Setting')
c) Waveform selection and generation is quite intuitive and menu driven. Choose the values appropriately.

In the MS101 lab, you will use the AFG mainly to generate sinusoidal waveforms of different frequencies. Occasionally you might use it for generating pulse/square waveforms.

4. Digital Storage Oscilloscope (DSO) - Tektronix TBS 1000C series

Oscilloscopes are versatile electronic instruments used for displaying and measuring time varying voltage signals. They are very useful in measuring the amplitude and frequency/time period of a waveform. The oscilloscope most commonly used till about a decade ago was called a 'Cathode Ray Oscilloscope (CRO)'. CROs are now almost obsolete. Today, Digital Storage Oscilloscopes (DSO) are the ones in common use. DSOs have several useful features which make waveform measurements much easier compared to a CRO, which lacked these features.

CROs/DSOs are useful in measuring waveforms up to their rated bandwidths. TBS1000C series DSOs have bandwidths of 70 MHz. Please note that in general for DC voltages, DMMs give better accuracies than DSOs. This is because of the fact that the ADC (analog-to-digital converter) of the DSO vertical waveform is typically 8 bits (as compared to 10 to 12 bits in a DMM).

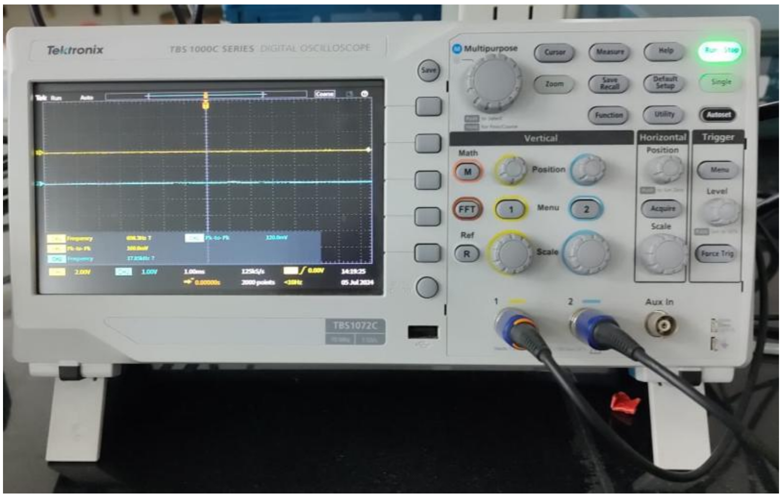

Fig.4 TBS 1000C series (TBS1072C) DSO front panel

Major Front Panel DSO Blocks

1. Display area: waveforms and readouts – yellow for Channel-1 and blue for Channel-2.
2. Vertical section: Channel 1 and Channel 2 scales in volts/div, menu, and position controls.
3. Horizontal section: horizontal scale and position controls.
4. Trigger section: trigger menu and level controls.
5. Measurement and other utility controls.

Basic DSO Operations

Familiarize yourself with the above DSO blocks and basic DSO operations by going through the following sections of the DSO User Manual '**TBS1000B-UserManual.pdf**'

a) Operating Basics (pp. 9-18)
b) Understanding Oscilloscope Functions (pp. 19-28)
c) Application examples (p. 29)
d) Taking simple measurements (p. 30)
e) Taking automatic measurements (p. 31)
f) Measuring two signals (pp. 32-33)

The above reference manual will explain in detail the procedure to be followed in making a variety of measurements.
In the MS101 lab, you will be using the DSO for measuring the amplitudes of the waveforms, viz. at the output of the RC high-pass filter, ripple voltages in a rectifier circuit, output waveform of the inverting amplifier etc.

A brief description of the major DSO blocks is given below.

Display area: In addition to displaying waveforms, the display provides details about the waveform and the oscilloscope control settings.

Menu system: When a front-panel button is pressed, the oscilloscope displays the corresponding menu on the right side of the screen. The menu shows the options that are available when the unlabelled option buttons on the right of the screen are pressed.

Vertical controls:

See Fig. 4(a).
Position (1 and 2) - positions the waveform vertically.
Menu (1 and 2) - displays the vertical menu selections and toggles the display of the channel waveform on and off.
Scale (1 and 2) - selects vertical scale factors.

Horizontal controls

See Fig. 4(b).
Position - adjusts the horizontal position of all channel and math waveforms. The resolution of this control varies with the time base setting.
Acquire - displays the acquisition modes — Sample, Peak Detect, and Average.
Scale - selects the horizontal time/division (scale factor).

Trigger controls

See Fig. 4(c).
Menu - when pressed once, it displays the Trigger Menu.
Level - when an Edge or Pulse trigger is used, the Level knob sets the amplitude level that the signal must cross to acquire a waveform.
Force Trig – used to complete the waveform acquisition whether or not the oscilloscope detects a trigger.

Other Utility Controls

See Fig. 4(d).
Multipurpose knob – for adjusting parameters/settings of the current menu option.
Measure -for choosing automatic measurement of waveform parameters.
Cursor – displays the cursor menu.
Run/Stop - continuously acquires waveforms or stops the acquisition - Run (green); Stop (Red).
Autoset - automatically sets the oscilloscope controls to produce a usable display of the input signals.

(a) Vertical controls (b)Horizontal controls (c) Trigger controls (d) Multipurpose knob, Measure, Run/Stop, Autoset

Fig. 5 Vertical, Horizontal and Trigger controls of the DSO

Steps to Get a Stable (Steady) Waveform Display

The major use of a DSO is to display time varying voltage signals so that their parameters, such as the amplitude and frequency/time period can be measured. In order to do any measurement, a steady waveform of the desired test signal must be displayed. One needs to have a rough estimate of the parameters of the waveform under observation. Based on these estimated appropriate scale settings on the vertical and horizontal controls are chosen, followed by the trigger source and the trigger level controls. The above procedure of choosing the appropriate vertical and horizontal scale settings and the trigger source and level controls is explained below for a test signal.

Let the test signal be $V_{in} = 5\ sin\ \omega t$ V, (frequency = 1 kHz). The DSO display area has 15 horizontal divisions and 10 vertical divisions. Let us assume that we want to display the above waveform on Channel 1.

The following settings can be used to get a stable display.

Horizontal controls: choose 'Scale' as 1 ms/div or 400 µs/div or 200 µs/div. (In most cases there is no need to adjust the 'Acquire' or 'Position' controls).

Vertical controls: Press '1' under 'Menu' to select Channel 1; choose Channel 1 'Scale' as 1 V/div or 2 V/div; adjust Channel 1 'Position' so as to align the display vertically as desired. Note that when the position control is adjusted the reference (zero voltage) level of the channel gets shifted. (In Fig 3 note the reference level indicators on the left-hand side of the Channel 1 and Channel 2 waveforms).

Trigger controls: Press 'Menu' to get the trigger menu; under 'Source' choose CH1. Now adjust the 'Level' to be within +/- 5 V. (When the 'Level' knob is adjusted the display indicates the actual trigger level. Adjust this level to be within the waveform voltage swing).

Some Commonly used Terminologies in the EE Labs

AC and DC*

AC: Alternating Current
DC: Direct Current

The term 'AC voltage' implies that the polarity of the voltage with respect to the reference node may change from time to time.

Similarly, the term 'DC voltage' implies that the polarity of the voltage with respect to the reference node will not change with time.

DSO Input (Vertical) Coupling Modes: DC, AC and GND

DC: Direct Coupling mode – The waveform connected to the DSO channel is displayed as it is with all its voltage contents. This mode is the most commonly used one.

AC: Alternating Coupling mode – This mode is used when one wants to observe only the alternating component of the input voltage, i.e. this mode is used to block the constant voltage component of the input voltage and to display only the alternating voltage components. This mode internally uses a capacitor in series with the input resistance to block the constant voltage component and couple the alternating voltage components of the input voltage. The coupling mode has a cutoff frequency of approximately 10 Hz, and therefore coupling is effective only for the alternating components above about 50 Hz.

GND: Ground mode – the DSO channel is disconnected from the input waveform and connected to the reference ground. This mode is used generally to disconnect the waveform so as to align the reference level to the desired level on the DSO screen.

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*It may be noted that AC and DC have three somewhat related but different meanings.

(i) Alternating current (AC): current that periodically reverses polarity. Direct current (DC): current that has constant polarity (flows only in one direction).

(ii) The abbreviations AC and DC are often used as adjectives to mean alternating and direct, respectively.

AC voltage: voltage with periodically reversing polarity. DC voltage: voltage with constant polarity. AC current: current with periodically reversing polarity. DC current: current with constant polarity. DC motor: motor powered by DC voltage. AC motor: motor powered by AC voltage. DC supply: power supply with DC voltage output. AC supply: power supply with AC voltage output. DC/DC converter: circuit converting a DC voltage to another DC voltage.
(iii) DC (direct coupling) and AC (alternating coupling): DC/AC input coupling modes of a DSO, DC/AC triggering, DC/AC amplifiers.

5. DSO Measurements using CRO Probes

CRO probes are special cables connected to the DSOs with a BNC connector on one end and a probe end with two leads (a black **ground** lead with an alligator clip and a retractable clip for the **signal**). They have a built-in RC/LC network to compensate for the input capacitance of the CRO. For example, the equivalent circuit of the lab DSO input is 1 MΩ in parallel with a 20 pF capacitor. CRO probes have 1X and 10X modes. The 1X mode would display the waveform as it is, whereas the 10X mode would attenuate the input waveform by 10 (i.e. in this mode a network, consisting of a 9 MΩ series resistance and an adjustable capacitor, would appear in series with the input waveform, thereby attenuating the waveform by a factor of 10. This is done to compensate the input capacitance of the DSO by adjusting the adjustable capacitor). Please ensure that DSO channel input parameters are adjusted for the probe setting chosen. See page 33 of the user manual for the procedure to be followed.

For high frequency waveforms, and also for measuring fast rising waveforms, the 10X mode should be used. It is best not to use 1X except for input waveform amplitudes < 50 mV.

6.1 Experiment: Part C - Measuring Parameters of the DSO Front Panel Test Waveform

Procedure:

a) Recommended settings of the DSO:
   - Choose Vertical Channel-1 (press the yellow button marked ‘1’). You should be able to see a yellow line on the DSO screen.
   - Choose Channel-1 voltage setting as 2 V/div by turning the ‘Scale’ knob. Selected scale will be shown in yellow in the DSO screen.
   - Choose Horizontal scale as 200 µs/div.
   - Using the trigger controls choose Channel 1 as the trigger source.

b) Connect the DSO probe of the Channel-1 DSO input (Yellow) to the ‘Probe Comp’ test point, located at the extreme lower RHS.

   Adjust the trigger settings and the ‘Horizontal’ rotary knob (potentiometer) such that the test waveform is displayed clearly. (Use the ‘Trigger Menu’ and the ‘Level’ potentiometer to get a stable waveform on the DSO. If you are unable to do so, then press the ‘Autoset’ button to get a stable waveform).

   The test waveform in the DSO is used to compensate the DSO probe (done by adjusting the probe variable capacitor). It is likely that the displayed square waveform is slightly distorted (due to the uncompensated probe you are using). You need not worry about probe compensation in this experiment.

c) Measure the period, frequency, maximum voltage, minimum voltage, and the Peak-to-peak voltage of the test waveform.

   You can do this by pressing the ‘Measure’ button followed by choosing the ‘Ch1’ option on the menu. Now all the measurement options will be shown. You can choose a maximum of three or four waveform parameters at a time. Choose the parameter of interest by rotating the ‘Multipurpose’ potentiometer or the cursor, and then by pressing it to select the parameter of interest.

Observation and Measurement

- Observe the displayed waveform and sketch the test waveform. Write down the measured parameters in your Lab Notebook.

6.2 Experiment: Part D - Measurements of Sinusoidal Waveform Parameters using the DSO

Procedure

a) Setup the AFG1022 so as to obtain a waveform $V_{wfm} = (3 + 5\ sin\ \omega t)$ V, frequency = 5 kHz.
b) Connect the AFG output through a BNC cable to the Breadboard and then connect it to the CH-1 input of the DSO using the DSO probe.
c) Adjust the DSO trigger and horizontal settings so as to obtain a stable display. (In case you are not able to set the trigger and the horizontal settings properly, you may press the 'Autoset' button to allow the DSO to display through automatic setting).

Observation and Measurement

- Observe the displayed waveform. Verify the displayed voltage levels. Sketch the waveform and write down the measured parameters in your Lab Notebook.

6.3 Experiment: Part E - Measurement of the Frequency Response of an RC High-Pass Filter

6.3.1 Theory

The circuit diagram of an RC high-pass filter is shown in Fig. 5. As seen in the figure, a sinusoidal signal is applied as the input test signal to the RC high-pass circuit.

Knowing that the impedance of the capacitor C at the angular frequency ω is $(1/j\omega C)$, we can write the output voltage V_{out} as the voltage appearing across resistor R.

Hence, we can write, $V_{out}/V_{in} = R / [R + (1/j\omega C)]$

The amplitude of (V_{out}/V_{in}) can be written as $|\ V_{out}/V_{in}\ | = 1/\ \text{sqrt}[1 + (f_c/f)^2]$, where $\omega = 2\pi f$, and $f_c = 1/(2\pi\ RC)$.

The frequency f_c is called the cut-off frequency of the above RC filter. When $f = f_c$, $|\ V_{out}/V_{in}\ | = 1/\text{sqrt}(2) = 0.707$ V/V.

From the above expression for $|\ V_{out}/V_{in}\ |$, we see that its value will be lower than 0.707 for $f < f_c$, and greater than 0.707 for $f > f_c$ and would reach unity asymptotically for $f >> f_c$.

Because of the above behaviour (i.e. passing frequencies above a certain cut-off frequency while attenuating those below it) the circuit in Fig. 5 is called a high-pass filter.

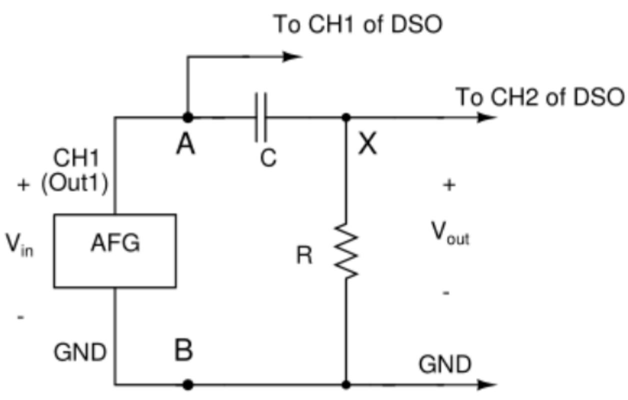

Fig. 5 RC high-pass filter circuit

6.3.2 RC High-pass Filter Frequency Response: Experimental Procedure

a) Wire the circuit of Fig.5 on your bread board with $R = 1$ kΩ and $C = 0.1$ μF. Note that the output of the AFG is connected as input of the circuit (to nodes A and B) as shown. i.e. V_{in} = AFG output. Output of the filter (V_{out}) is taken across the resistor R, i.e. across nodes X and B.

b) Connect DSO probe of Channel-1 (Yellow) to the filter input so as to display V_{in} at all times.

c) Adjust the AFG settings so as to get a sinusoidal waveform $V_{in} = 4 \sin \omega t$ V. Adjust the DC offset of the AFG waveform such that the average voltage of V_{in} is zero.

d) Connect the AFG output to the circuit carefully (i.e. connect the GND wire of the BNC cable to the circuit ground and then connect the DSO probe ground to this common GND.

e) Connect the filter output (V_{out}) to the Channel-2 (Blue) of the DSO.

f) Ensure that the scales of Channel-1 and Channel-2 are chosen properly so as to display both the waveforms clearly (setting both Channel-1 and Channel-2 at 2 V/div may be a good option).

g) Before tabulating your results, do a quick cross-check as to whether your high-pass filter is working or not. You may do this by varying the waveform frequency from about 100 *Hz to* 10 *kHz and verify that the V_{out} amplitude on the DSO is indeed varying as expected. Observe the maximum (V_{out}/V_{in}) value and locate the experimental cut-off frequency (i.e. the* 0.707 [V_{out}/V_{in}] *) point). Compare this with the theoretical cut-off frequency. Once you are sure that the circuit is working as a high-pass filter, you could go ahead with the tabulation of results as detailed below.*

Observation and Measurement

i) Vary the frequency of the input test signal V_{in} from about 100 Hz to about 50 kHz. Using the peak-to-peak measurement option of the DSO, measure the peak-to-peak of V_{in} and V_{out} at each of these frequencies. Altogether, take readings for about 8 to 10 frequency settings (take a few readings around the cut-off frequency).

ii) Observe the V_{in} and V_{out} outputs. Note down the waveform frequency, peak-to-peak of V_{in} and V_{out} values and the V_{out}/V_{in} ratio in a tabular form (*Frequency,* V_{in}*,* V_{out}*,* V_{out}/V_{in}) . Note down your theoretical and experimental cut-off frequencies. Also note down any other special observation.

iii) Using Microsoft Excel, sketch the $|V_{out}/V_{in}|$ as a function of frequency. Use log scale for frequency and linear scale for (V_{out}/V_{in}).

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Pre-Lab Quizzes

1. All students should come to the labs with adequate preparation, by going carefully through the detailed lab handout for the experiment. Without such preparation it will be impossible to perform the experiments properly.
2. In order to check the lab preparation, there will be a Pre-lab Quiz during the first 10 minutes of each lab session. This will be based on the Lab handout and the associated theory.
3. There will be a sample quiz in each experiment handout to familiarize students with the level and scope of the questions.

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