MS101 Makerspace
2022-23/II
Expt 1: Familiarization with Basic Measuring Instruments (Ver 1.1)

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 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 typical 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 B. 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 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.

- 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 the appropriate 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 converted into voltages by the DMM circuitry. For ac voltage measurements, most DMMs are calibrated at 50 Hz, for sinusoidal rms voltages. Hence, do not attempt to measure using a DMM any ac voltages other than 50 Hz sinusoidal voltages.

2. Breadboard

Breadboard is essentially an electronic prototyping board meant for wiring electronic circuits. Fig.1.1A 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.

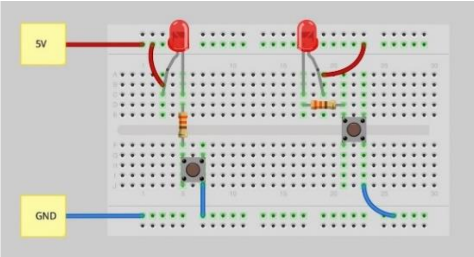

Fig 1.1 A Breadboard with a wired circuit

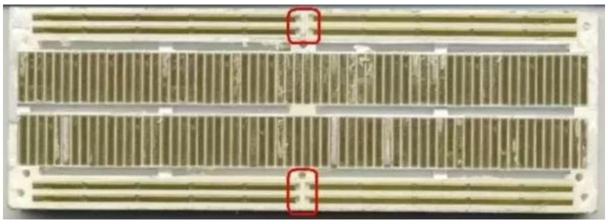

Fig 1.1B Typical Breadboard internal connections

Experiment

2.1 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 Resistances in series

- 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.

2.2 Resistances in Parallel

- 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.2 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 1000B series/TBS1072B-EDU

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. TBS1000B series DSOs/TDS 1072B 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).

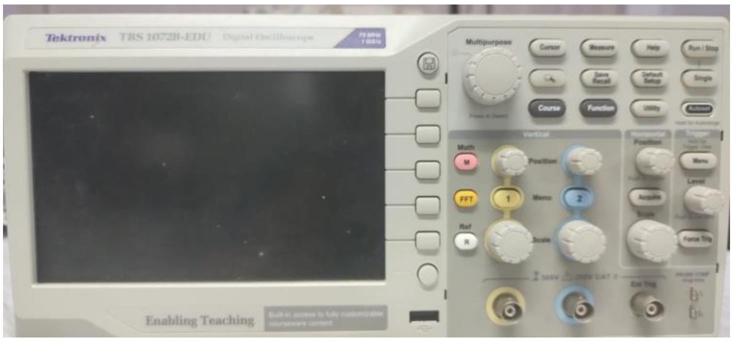

Fig.3 TBS 1072B-EDU DSO front panel

Basic DSO Operations
Familiarize yourself with the DSO 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 would explain the procedure to be followed in making a variety of measurements. Other features are also explained in the user manual which you might like to explore.

In the MS101 lab, you will be using the DSO in 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.

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 when for input waveform amplitudes < 50 mV.

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

Procedure:

a) 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.

b) 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 - 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 - 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. 4. 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. 4 is called a high-pass filter.

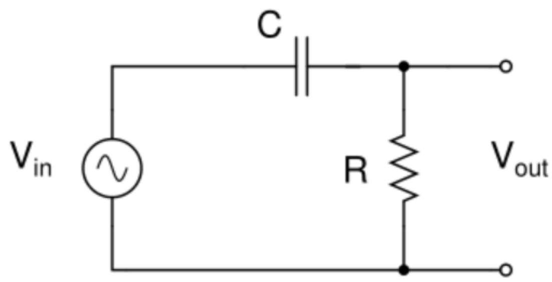

Fig. 4 RC high-pass filter circuit

Experimental Procedure

a) Wire the circuit on your bread board with $R = 1$ kΩ and $C = 0.1$ μF.
b) 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.
c) 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.
d) Connect DSO probe of Channel-1 (Yellow) to the filter input so as to display V_{in} at all times. Verify that the Vin waveform displayed is $4 \sin \omega t$ V.
e) Now, using the DSO probe, 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 10 to 15 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}).