PHYSICS 176

UNIVERSITY PHYSICS LAB II

Experiment 4

Alternating Current Measurement

Equipment: Oscilloscope, Function Generator.

Supplies: Filament Transformer.

A sine wave A.C. signal has three basic properties: amplitude, frequency, and phase. The measurement of amplitude and frequency with an oscilloscope is illustrated below. The vertical and horizontal axes can be set to various voltage/div and time/div scales respectively.

The peak-to-peak amplitude of the sine wave is the voltage $V_{pp}$ between the top of the wave and the bottom. Its value is found from the trace on the oscilloscope screen as follows:

$$V_{pp} = \text{(peak-to-peak amplitude in div)} \times \text{(volts/div)}$$

The period of the sine wave is time $T$ between successive peaks of the wave. Its value is found from the trace on the oscilloscope screen as follows:

$$T = \text{(distance between peaks in div)} \times \text{(time/div)}$$

The frequency of the sine wave signal is the inverse of the period:

$$f = \frac{1}{T} \text{ Hertz} \quad (1 \text{ Hertz} = 1 \text{ second}^{-1})$$

The mathematical expression for the sine wave signal is usually in terms of the peak amplitude $V_p = V_{pp}/2$ and the angular frequency $\omega = 2\pi f$.

$$\text{Signal voltage} = V_p \sin (\omega t + \theta)$$

The phase angle $\theta$ is given in radians (2$\pi$ radians = 360$^\circ$). The phase angle describes how one sine wave signal is shifted relative to another. The dual trace oscilloscope allows two signals to be displayed on the screen simultaneously and this permits a measurement of their relative phases. The measurement of phase will be considered in more detail in Experiment 5.
A. Oscilloscope Operation

The front panel of TDS 1002 oscilloscope is given below. It is divided into easy-to-use functional areas.

Vertical controls:
- Cursor 1 and Cursor 2: Position the waveform vertically.
- Ch1 Menu, Ch2 Menu: Display the vertical menu selections and toggles the display of the channel waveform on/off.
- Math Menu: Displays the waveform math operations menu.

Horizontal controls:
- Position: Adjusts the horizontal position of the waveform.
- Horiz. menu: Displays the Horizontal menu.
- Set to zero: Sets the horizontal position to zero.
- Sec/Div: Selects the horizontal time/div (scale factor) for the window time base.

Trigger controls: Used to set up the trigger level.

Menu and Control buttons:
- Save/Recall: Displays the Save/Recall menu
- Measure: Displays the automated measurements menu
- Acquire: Displays the acquire menu
- Cursor: Displays the cursor menu
- Utility: Displays the utility menu
- Auto Set: Automatically sets the oscilloscope controls to produce a usable display of the input signal.
  *This is your ‘panic’ button. Punch it in anytime something goes wrong and you do not know why...*
- Default set up: Recalls the factory set up.
- Single Seq: Acquires a single waveform and then stops.
- Run/Stop: Continuously acquires waveforms.
- Print: Starts print operations.

The BNC connectors labeled Ch1 and Ch2 are two inputs. Each input is an amplifier which takes the input signal and uses it to drive the electron beam up and down. To use channel 1 only, punch in the button Ch1; similarly for channel 2. Because there are two input channels, the TDS 1002 is called a dual trace oscilloscope. However, there is only one electron beam, which is shared by the two channels.
The electron beam appears on the screen left to the controls. It sweeps across the screen with a speed selected with the Sec/Div control.

Each channel input has AC-GND-DC coupling selected by pushing the Ch1/Ch2 menu buttons:

AC: A blocking capacitor is in series (internally) with the input so that the trace on the screen shows only the A.C. signal part of the input.

GND: The scope trace is a horizontal line which represents the level of zero volts D.C. (ground level).

DC: The trace on the screen is shifted relative to the GND level by an amount equal to any D.C. voltage input. There may be an A.C. voltage (signal) superimposed on the D.C. voltage.

If the input signal is periodic (which is the usual case), you want the horizontal sweep of the electron beam to start at the same point of the signal pattern each time; otherwise the trace of the signal on the screen will not appear stationary. This is accomplished by triggering the sweep of the electron beam with a chosen level of the input signal (Trigger controls).

In order to find the trace initially (when the scope is first turned on), push the AutoSet button. The sweep is then triggered by the power company’s 60 Hz line voltage. In order to trigger on a displayed signal use the Trigger controls.

B. The Filament Transformer

In the days when vacuum tube circuits were common, the tube filament was heated (to boil off electrons from the tube cathode) by passing an A.C. current through it. The A.C. voltage across the filament was derived from the secondary winding of a filament transformer. The A.C. voltage across the primary winding of the transformer was the power company's line voltage.

When an A.C. voltage

\[ v(t) = V_p \sin \omega t \]

is applied to a resistor R, an A.C. current

\[ i(t) = \left( \frac{V_p}{R} \right) \sin \omega t \]

flows through the resistor. The instantaneous heating effect of this current in terms of heat dissipated/second (joules/second) is the instantaneous power

\[ p(t) = i^2(t) R = \left( \frac{V_p^2}{R} \right) \sin^2 \omega t \]

The time average power is

\[ P_{av} = \frac{1}{2} \left( \frac{V_p^2}{R} \right) \]

since the time average of \( \sin^2 \omega t \) is \( \frac{1}{2} \).

A.C. voltages are often referred to by their root-mean-square values

\[ V_{rms} = 0.707 V_p \]

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Then the time average power, in terms of the root-mean-square voltage is

\[ P_{av} = \frac{V_{rms}^2}{R} \]

which has the same form as the power formula for D.C. \((P = I^2R = \frac{V^2}{R})\).

The root-mean-square value of the power company's line voltage is about 110 volts. The root-mean-square value of the filament transformer output is typically 6.3 volts (or sometimes 12.6 volts).

C. The Function Generator

The function generator produces square waves, triangle waves, and sine waves shown below:

![Waveforms](image)

In this Lab you will be using BK PRECISION Model 4017A function generator. The front panel of the generator is given in the next page.

To operate the generator:

Turn on the Power switch.
Select the waveform of the generated signal by pushing the corresponding Function switch.
Push Range Selector switch to select the frequency range at your desire. Adjust the frequency of the signal by turning the Coarse/Fine Frequency Controls.
The amplitude of the output signal is controlled continuously with operating the Output Level Control (use it to generated waveforms with amplitudes from 1 V to 10 V). If the -20 dB Switch is also engaged, the output amplitude is reduced by a factor of \(-20\text{dB}\) (use it to generated waveforms with amplitudes from 100 mV to 1 V)
The DC OFFSET control may be used to offset the waveform above or below ground (0 volts) by a D.C. voltage in the range ±10 volts.
1. **POWER On/OFF Switch.**
2. **RANGE Switch.** Seven ranges from 1 Hz to 10MHz
3. **FUNCTION Switch.** Selects sine, square, or triangle waveforms.
4. **OUTPUT LEVEL Control:** up to ±20 Vpp (open circuit) or ±10 Vpp into 50 Ω.
5. **DC OFFSET Control:** up to ±10 Vpp (open circuit) or ±5 Vpp into 50 Ω.
6. **OUTPUT Jack** – outputs the generated waveform.
7. **TTL/CMOS Jack.** TTL or CMOS square wave, selected by switch (15), is output at this jack.
8. **CMOS LEVEL Control.**
9. **VCG/SWEEP Jack.**
10. **DUTY CYCLE Control.**
11. **-20 dB Switch.** When engaged, the signal at the OUTPUT jack is attenuated by -20dB.
12. **Sweep INT/EXT Switch.**
13. **Sweep LIN/LOG Switch.**
14. **DC OFFSET Switch.** When engaged, enables operation of the DC OFFSET control (5).
15. **CMOS LEVEL Switch.**
16. **Sweep WIDTH Control.**
17. **DUTY CYCLE Switch.**
18. **Sweep TIME Control.**
19. **FINE FREQUENCY Control.**
20. **COARSE FREQUENCY Control.**
21. **COUNTER DISPLAY.** Displays frequency of internally generated waveform.
22. **GATE LED.** Indicates when the frequency counter display is updated.
23. **Hz and KHz LED.** Indicates whether the counter is reading in Hz or kHz
D. **The Circuit Ground**

When you measure signals it is a good practice to have the function generator, the oscilloscope and your circuit at a common ground. It is essential that you identify the ground connections on the oscilloscope and on the function generator output cable.

On one end of the function generator cable there is a silver BNC connector which plugs into the output of the function generator box. The other end of this cable may again be terminated with a BNC connector or have two leads: one with a red collar and one with a black collar. The lead with the red collar carries the signal produced by the function generator, while the lead with the black collar is the ground. When an end with two leads is used connect the ground lead to the ground of the circuit you are building.

The oscilloscope probes also have two leads: one carries the signal and the other (black collar with an alligator–type clip) is the ground. Always connect this end to the ground of the circuit you are building.

The grounds must always be connected to the same point of any circuit. When building circuits it is useful to use a ground bar so that ground is easily identified. The ground bar is a silver metal rod about ten inches long with two brass connectors to fasten it to the pegboard.

The filament transformer also plugs into a wall socket, but the primary winding has no D.C. connection with the secondary winding. Therefore the transformer secondary winding is D.C. isolated from the ground in the primary winding. This is shown by the schematic diagram for the transformer below:

![Schematic diagram of a transformer](image-url)

A voltage is induced in the secondary winding when the current in the primary winding changes (Faraday's law of induced emf).
Setting Up Your Oscilloscope

1. Turn the oscilloscope On.

2. Examine the scope. (You should see a line "trace" in the display window). Locate the controls and examine their function and various menus.

3. Attach function generator coaxial cable (output) to oscilloscope input (Channel 1).

4. Turn on the function generator and set the following:

   Function = \(\frown\frown\) (Square Wave)

   Frequency = x1K
   Amplitude: 2 V
   A thousand \(\frown\frown\)’s are sent out every second

5. To activate the oscilloscope and display the signal push the **AUTOSET** button and select Channel 1.

6. Observe:

   ![Square wave signal](image)

7. Adjust VOLTS/DIV and SEC/DIV knobs so that you understand their effect on the signal.

8. Examine the rising and falling edges of the square wave signal. Push the corresponding menu buttons (just on the right of the display window) to display only the edges on the screen.

9. Measure the rise time and the amplitude of the signal using moving cursors. To activate the cursors push the **CURSOR** button. Push the **TYPE** option button and select **Time/Voltage**. Use the Cursor1 and Cursor 2 knobs to move the cursors (appearing as broken lines). The position of the cursors are displayed/digitized on the screen.

10. Completely disassemble and then begin lab.

   ![Square wave signal](image)
**Procedure - Experiment 4**

### A. First Time Oscilloscope Operation

1. Connect the channel 1 input to Probe COMP (located at the bottom right corner of the oscilloscope). This connection provides a 5 V, 1 kHz square wave which is used to check the oscilloscope probe for capacitive compensation. If the signal which you see is not a clean square wave, the oscilloscope probe needs compensation and you should contact your laboratory instructor.

2. If you do not see any trace on the oscilloscope screen check the following:
   - a) Is the oscilloscope plugged in? Is the scope turned on?
   - b) Is the intensity high enough?
   - c) Are the **Position** controls properly adjusted?
   - d) Is the Triggering Mode set on **Auto**?

3. Position the square wave trace so that it is centered.

4. Adjust the **Volts/Div** and **Sec/Div** controls to give a good picture of the square wave. Set both the probes and the scope to 1X. Keep this setting during all measurements.

5. Measure the peak-to-peak amplitude of the square wave.

6. Measure the period $T$ of the square wave. Compute the frequency $f$.

7. Switch channel 1 to GND. Use the Position control to superimpose the GND line on the central line of the screen mesh. Then switch channel 1 to DC and note the position of the square wave trace relative to the GND line. Does the square wave contain a D.C. component?

### B. The Filament Transformer

1. When the transformer is plugged in, do not allow its secondary leads to touch. Contact of the secondary leads puts a short circuit across the transformer output. Since a short circuit represents effectively zero resistance, a very large current would be drawn and the result would be to overheat the transformer windings.

2. Connect the channel 1 probe across the entire secondary; connect the channel 2 probe across 1/2 the secondary by using the center-tap. **BE SURE THAT THE GROUNDS OF THE TWO PROBES ARE CONNECTED TOGETHER.** If you have any doubts about the ground connections, check with your instructor before you make any connections. A ground on one end of the secondary and another ground on the other end of the secondary represents a short circuit across the secondary and will cause serious overheating of the transformer.

3. Measure the peak-to-peak values of the two sine waves.

4. Compute the peak values of the sine wave amplitudes.

5. Compute the root-mean-square values of the two sine waves.

6. Measure the frequency of the sine wave, that is, measure the period $T$ and then compute the frequency $f$. You should find the frequency to be about 60 Hz.
C. **The Function Generator**

1. Set the function generator for a 1 volt p-p, 1 kHz signal.

2. Connect the function generator cable to the channel 1 oscilloscope probe.

3. With the channel 1 input on AC, measure the peak-to-peak voltage of the 1 kHz signal (nominally 1 volt). Note the following: (a) setting of the Volts/Div control, and (b) number of divisions (centimeters) peak-to-peak.

4. Measure the frequency of the 1 kHz signal. Note the following: (a) setting of the Sec/Div dial, and (b) number of divisions (centimeters) between successive peaks.

5. Switch channel 1 to GND (be sure that the Triggering Mode is Auto) to establish the ground level on the scope screen. Use the Position control to put the ground level in the center of the screen.

6. Switch channel 1 to DC and determine the maximum D.C. offset voltages (both positive and negative) that can be added to the 1 kHz signal voltage.

D. **Oscilloscope Practice**

Your lab partner should adjust every knob on the oscilloscope and function generator. Then you should try to obtain this signal.

\[ V_{pp} \uparrow \uparrow \quad T = 1 \text{ msec} \]

\[ V_{pp} = 5 \text{ volts} \]

Now it is your turn. Adjust all the knobs and ask your partner to find these two signals:

**Signal 1**

\[ T = 500 \text{ usec} \]

\[ V_{pp} = 8 \text{ volts} \]

**Signal 2**

\[ T = 20 \text{ msec} \]

\[ V_{pp} = 10 \text{ volts} \]
A. First Time Oscilloscope Operation

1. Peak-to-peak amplitude of square wave \( V_{pp} = \) ______ mV = ______ volts

2. Period of square wave \( T = \) ______ msec = ______ sec

   Frequency \( f = \) ______ Hz

3. Sketch a picture of the square wave showing the ground level.

B. The Filament Transformer

1. Peak-to-peak amplitudes \( V_{pp}(1) = \) ______ \( V_{pp}(2) = \)

2. Peak amplitudes \( V_p(1) = \) ______ \( V_p(2) = \)

   Root-mean-square amplitudes \( V_{rms}(1) = \) ______ \( V_{rms}(2) = \)

3. Period and frequency \( T = \) ______ sec \( f = \) ______ Hz

C. The Function Generator

1. Peak-to-peak amplitude \( \) VOLTS/DIV setting =

   Number of div. peak-to-peak =

2. Frequency \( \) TIME/DIV setting =

   Number of div. between peaks =

3. Maximum positive D.C. offset voltage = ______ Volts

   Maximum negative D.C. offset voltage = ______ Volts

D. Oscilloscope Practice

   Show the signals to your instructor !