LABORATORY 4

MEASUREMENTS OF AC AND DC COMPONENTS OF A COMPOSITE VOLTAGE

OBJECTIVES

1. To study how electrical measurement equipment measures dc, ac and composite waveforms.
2. To become familiar with concepts relating to average, half-cycle average and root-mean-square values of waveforms.

INFORMATION

Note: *Actual lab procedure follows this information section.*

1. Average and root mean square values

In many measurement applications, we do not deal only with DC (Direct Current) voltages and currents, but also with time varying signals. These can be purely AC (Alternating Current) voltages and currents or these can be composite voltages and currents consisting of AC and DC components. Most time varying signals will be periodic, and the pattern of the waveform will repeat itself over a fixed period of time. If the period of the waveform is *T*, then a periodic waveform *f(t)* can be described by Equation (4.1)

$$f(t) = f(t+T) . \qquad \text{Equation (4.1)}$$

There are several types of measurements that can be considered when measuring a time varying periodic waveform. Two of these are the ***average value*** and the ***root mean square (rms) value*** of the waveform.

The ***average value*** of a periodic waveform is determined by Equation (4.2)

$$f_{avg} = \frac{1}{T}\int_0^T f(t)dt \quad . \qquad \text{Equation (4.2)}$$

For a purely ac waveform (i.e., having no DC component), however, this value will be zero and the half-cycle average value is considered. This value is defined as

$$f_{avg\_half} = \frac{1}{T/2}\int_0^{T/2} f(t)dt \qquad \text{Equation (4.3)}$$

which can be simplified to

$$f_{avg\_half} = \frac{2}{T}\int_0^{T/2} f(t)dt \quad . \qquad \text{Equation (4.4)}$$

The ***rms value*** is related to the effective power dissipated in a resistor by an ac or composite waveform. The rms of any periodic waveform is

$$f_{rms} = \sqrt{\frac{1}{T}\int_0^T [f(t)]^2\,dt} \,. \qquad \text{Equation (4.5)}$$

The mathematical stages required to determine the rms value are expressed by the initials of **R**oot **M**ean **S**quare, i.e. the waveform is first squared, then the average (or mean) value is calculated over the period, and then the square root of the mean value is calculated. It is standard practice to indicate the amplitude of a sinusoidal waveform by its rms value instead of its peak value.

It should be noted that the rms value of a composite waveform consisting of a DC component with a value of DC_0, an AC waveform with an rms value of AC_1, and another AC waveform with a different frequency and with an rms value of AC_2 can be expressed by the Equation (4.6)

$$f_{rms} = \sqrt{DC_0^2 + AC_1^2 + AC_2^2} \,. \qquad \text{Equation (4.6)}$$

2 Oscilloscope voltage measurements

Voltage measurement with a scope is concerned with the vertical deflection of the display, although the settings of some horizontal controls can affect the ease and accuracy of the resulting vertical measurements. Vertical measurements are most often made in units of peak-to-peak volts, and expressed, for example, as 3.0 Vp-p. The measurement is accomplished by measuring the vertical deflection of the waveform from one peak to the other, in units of "divisions peak to peak." This vertical distance is then multiplied by the vertical sensitivity, which is in units of "volts per division." When divisions peak to peak is multiplied by volts per division, the resulting number has units of "volts peak to peak," since the division terms cancel. An example is illustrated in Figure 4.1.

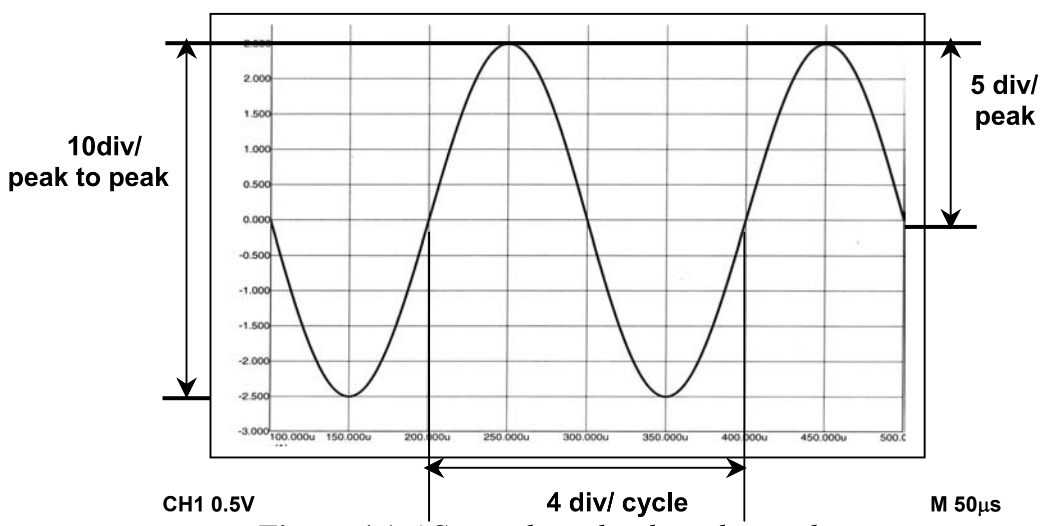

Figure 4.1 *AC signal amplitude and period measuring*

Some users prefer measuring peak voltage. This can be accomplished by measuring the number of peak divisions from the vertical centre of the waveform to either peak, then multiplying by volts per division, resulting in units of volts peak. In the case of Figure 4.1, this would demand that the user position the waveform in the centre of the screen vertically.

In the current example the measured signal has the following parameters:

- 10 Divisions peak to peak x 0.5 Volts/Division = 5.0 Volts peak to peak = 5.0Vp-p
- 5 Divisions peak x 0.5 Volts/Division = 2.5 Volts peak = 2.5Vp
- 4 Divisions/cycle x 50 μs/Division = 200 μs cycle

The peak-to-peak measurement can now be converted into peak volts by dividing by two, therefore 5.0 Vp-p is equal to 2.5 Vp. This peak voltage can be converted to RMS voltage by dividing by √2, or 1.41, which evaluates to 1.77 V_{RMS}. These are all the same voltages, they are expressed differently; thus, 5.0 Vp-p = 2.5 Vp = 1.77 V_{RMS}.

The Tektronix TDS210 oscilloscope, shown in Figure 4.2 has the capability to measure most of the observed signal parameters and shows them directly on the LCD display. By pressing the assigned buttons you could choose to display different signal parameters, such as RMS and Peak-to-Peak voltages, frequency and cyclic period.

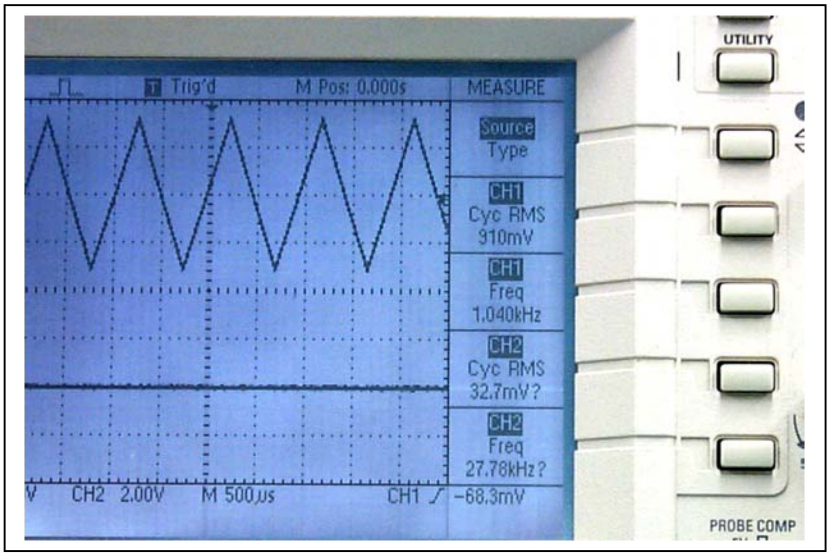

Figure 4.2 *Measuring signal parameters using the Tektronix TDS210.*

DC voltages can also be measured with a scope. A DC voltage appears as a horizontal line on the scope, since the voltage does not vary with time. To measure a DC voltage, first using the CH MENU and COUPLING Button, set the coupling to GROUND. Next, position the trace to a convenient horizontal graticule line as a reference. Then switch the COUPLING to DC, measure the vertical displacement of the line, and multiply by the vertical sensitivity. Combined DC and AC voltages can also be measured in this fashion.

When the VERT MODE is set to BOTH, two waveforms may be measured independently of each other, and their settings of the VOLTS/DIV switches can be different from each other.

EQUIPMENT

1. Digital multimeter (Fluke 8010A, BK PRECISION 2831B or BK PRECISION 2831C)
2. Analog multimeter (Simpson 260/270)
3. DC power Supply
4. PROTO-BOARD PB-503 (breadboard)
5. Function generator Wavetek FG3B
6. Digital Oscilloscope Tektronix TDS-210
7. Resistor 1 kΩ (3)

PRE-LAB PREPARATION

The lab preparation must be completed before coming to the lab. Show it to your TA at the beginning of the lab and get his/her signature in the Signature section of the Lab Measurements Sheet.

1. **[24 MARKS]** Calculate the average value, the half-cycle average value and the RMS values of a sinusoidal waveform and a square waveform (see Figure 4.3), each with a peak value of $V_P = 3$ V and a frequency of 1000 Hz. To do this, you must ***derive*** the answer as opposed to simply plugging numbers into a formula. Record your calculations results in the first three columns of Table 4.1 of the Lab Measurements Sheet section.

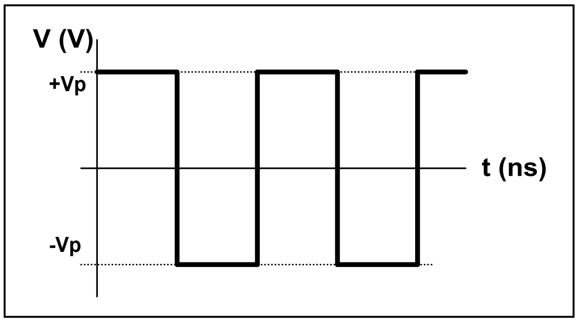

Figure 4.3 *A square waveform*

2. **[8 MARKS]** A composite voltage (AC superimposed on DC) can be created across a fixed resistor using the simple summing circuit shown in Figure 4.4 in which R1 = R2 = R3. Show, either by explanation or by analysis, that

$$Vo = \frac{1}{3}(V_1 + V_2) \qquad \text{Equation (4.7)}$$

or, in other words, that the voltage V_0 is directly proportional to the sum of the voltages V_1 and V_2 and the resultant waveform will consist of an AC voltage superimposed on a DC voltage. Show your calculations as instructed in part 3 of the Lab Measurements Sheet.

3. **[18 MARKS]** For each of the following combinations of V_1 and V_2 in Figure 4.4:

(i)V_1 = 3.0 VDC and V_2 = 3.0 VAC_{PEAK} 1000 Hz sine wave
(ii) V_1 = 3.0 VDC and V_2 = 3.0 VAC_{PEAK} 1000 Hz square wave
sketch the output waveform V_0 in part 4 of your Lab Measurements Sheet. Clearly label both the horizontal and vertical axes, and calculate the average and the RMS values and record the results in Table 4.2 of the Lab Measurements Sheet.

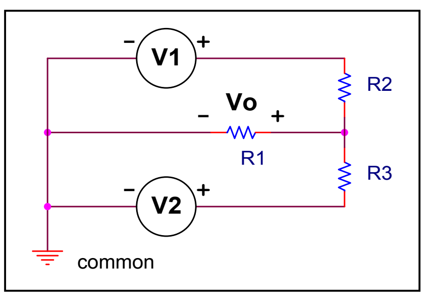

Figure 4.4 *Circuit to obtain a composite voltage.*

V_1 is the DC source, and V_2 is the AC source. The resistors are of equal value (R1 = R2 = R3 = 1 kΩ), and V_0 is the composite output voltage.

PROCEDURE

1. AC voltage measurements

1.1. This exercise will begin by measuring a periodic voltage with the Tektronix TDS210 Digital Oscilloscope, Simpson 260/270 analog multimeter (Va) and FLUKE 8010A Digital multimeter (Vd) on the AC range. Connect the circuit in Figure 4.5. Show the circuit to a teaching assistant (TA) and ***get his/her signature in the Signature section of the Lab Measurements Sheet. You will be penalized marks if your sheet is not initialed.***

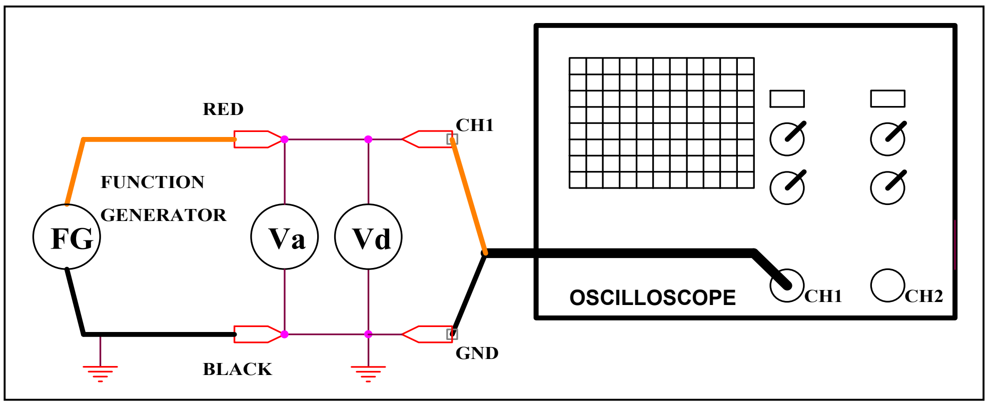

Figure 4.5 *AC periodic voltage measurements*

1.2. Set the function generator (FG) to provide a 1000 Hz sinusoidal signal and adjust the voltage amplitude to 3 volts peak. Use the oscilloscope to help adjust the amplitude of the signal, as shown in Figure 4.1. Use the Fluke 8010A (Vd) and Simpson 260/270 (Va) meters to measure the AC value of this signal. Make the measurements with both instruments connected together in parallel. For more convenience you could use your PROTO-BOARD to connect together all equipment. Record the measured data in columns, marked with (V), in Table 4.1 of the Lab Measurements Sheet.

1.3. Comment on what each instrument is actually measuring and on any discrepancies or anomalies between measured and calculated values in section 2 of the Lab Measurements Sheet.

1.4. For the Simpson meter, also make the AC measurement using the “output” terminal and the “+” terminal with the mode switch in the AC position. Read the AC voltage from the *red* scale of the face plate with the back of the instrument flat down on the bench. Record the measured data in Table 4.1 of the Lab Measurements Sheet.

1.5. Repeat the measurements made in part 1.2 for a 3 volts peak, 1000 Hz square waveform. Record the measured data in Table 4.1 of the Lab Measurements Sheet.

2. Composite voltage measurements

2.1. Set up the circuit shown in Figure 4.6. Note that this is the same circuit as in Figure 4.4 of the pre-lab. Show the circuit to a teaching assistant and ***get his/her signature in the***

Signature section of the Lab Measurements Sheet. You will be penalized marks if your sheet is not initialed.

2.2. For the DC voltage source V1, use the adjustable Power Supply (PS) Unit on your workbench. Connect the POS terminal of the Power Supply to the "+" sign of your circuit, and the COM terminal to the "-" sign of your circuit. The NEG terminal of the Power Supply will not be used. Adjust the output voltage to get the required values.

2.3. For the AC voltage source V2, use the Function Generator (FG) on your workbench. Connect CH1 of the oscilloscope in parallel with the Function Generator to observe and measure the AC input signal V2.

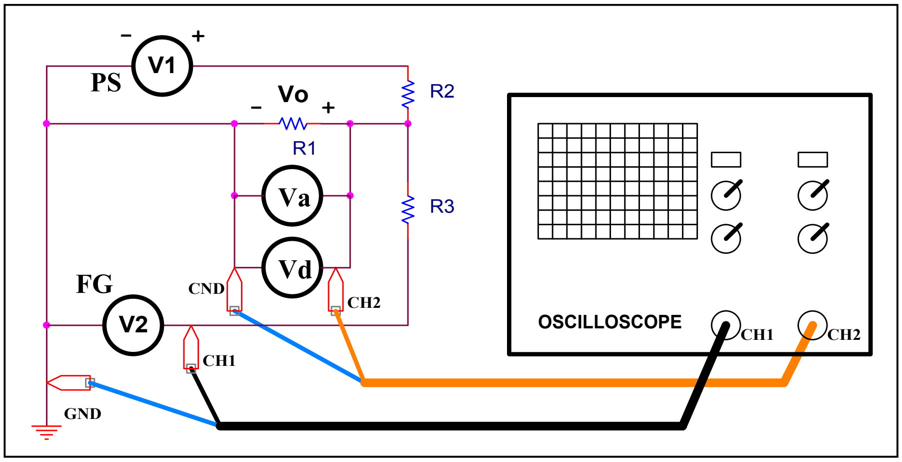

Figure 4.6 *Composite voltage measurements circuit*

2.4. Connect both Simpson (Va) and Fluke (Vd) multimeters in parallel to the resistor R1 to measure the composite voltage Vo. Also connect CH 2 of the oscilloscope in parallel to the voltmeters to observe the composite voltage signal Vo.

2.5. You will be making ***dc*** and ***ac*** measurements of the composite waveform V_O with the Fluke and Simpson meters for the following six combinations of V_1 and V_2:

a) V_1 = 3.0 VDC and V_2 = 3.0 VAC_{PEAK} 1000 Hz sine wave
b) V_1 = 3.0 VDC and V_2 = 3.0 VAC_{PEAK} 1000 Hz square wave
c) V_1 = 3.0 VDC and V_2 = 2.0 VAC_{PEAK} 1000 Hz sine wave
d) V_1 = 3.0 VDC and V_2 = 2.0 VAC_{PEAK} 1000 Hz square wave
e) V_1 = 2.0 VDC and V_2 = 3.0 VAC_{PEAK} 1000 Hz sine wave
f) V_1 = 2.0 VDC and V_2 = 3.0 VAC_{PEAK} 1000 Hz square wave

Use the oscilloscope as a guide to set the V2 voltages.

Note: *The oscilloscope measures Vp-p (peak-to peak voltages). Therefore to obtain 3.0 VAC_{PEAK} signal, as required in exercise 2.5-a, you need to set the Function Generator to 6.0 Vp-p value, measured by the oscilloscope*.

You will need to do the following for each V_O composite waveform:

(i) Measure and record V_O with the Fluke 8010A meter set to measure DC on the 2.0 VDC scale.

(ii) Measure and record V_O with the Simpson 260/270 meter set to measure DC on the 2.5 VDC scale.
(iii) Measure and record V_O with the Fluke 8010A meter set to measure AC on the 2.0 VAC scale.
(iv) Measure and record V_O with the Simpson 260/270 meter set to measure AC using the "output" terminal on the 2.5 VAC scale.
(v) Measure and record V_O with the Simpson 260/270 meter set to measure AC using the "+" terminal on the 2.5 VAC scale.

You will be making a total of 30 measurements for V_O. Record your data for parts (a) and (b) in Table 4.2, for parts (c) and (d) in Table 4.3 and for parts (e) and (f) in Table 4.4 of the Lab Measurements Sheet.

2.6. Examine the results that you have included in your table, and answer the questions in part 6 of the Lab Measurements Sheet.

2.7. **OPTIONAL**

The circuit in Figure 4.6 allows a weighted combination of voltages V1 and V2 to appear across R1. In this case, $Vo = \frac{1}{3}(V_1 + V_2)$, which results in a composite waveform since V1 is purely DC and V2 is purely AC.

Describe how you can use the function generator by itself, i.e., without the circuit in Figure 4.6, to generate a composite waveform at its output terminal with a DC component of 1 V and an AC component with a peak value of 1 V and a frequency of 1000 Hz.

LAB MEASUREMENTS SHEET – LAB 4

Name ________________________

Student No____________________

Workbench No_____

NOTE: Questions are related to observations, and must be answered as a part of the procedure of this experiment.

Sections marked * are pre-lab preparation and must be completed BEFORE coming to the lab.

1. *Average value, the half-cycle average value and the RMS values calculations of periodic signals. **SHOW ALL CALCULATION ON SEPARATE SHEETS, AND FILL IN THE COLUMNS LABELED WITH AN "*" IN TABLE 4.1.**

Table 4.1 *Average, half-cycle average and RMS values of periodic waveforms.*

V_P = 3 V f = 1000 Hz	*Average Value (V)	*Half-Cycle Average (V)	*RMS Value (V)	FLUKE Measured Value (V)	Simpson "+" term Value (V)	Simpson "output" Value (V)
Sine waveform						
Square waveform						

2. Comment on what each instrument is actually measuring for a purely AC waveform and on any discrepancies or anomalies between measured and calculated values.

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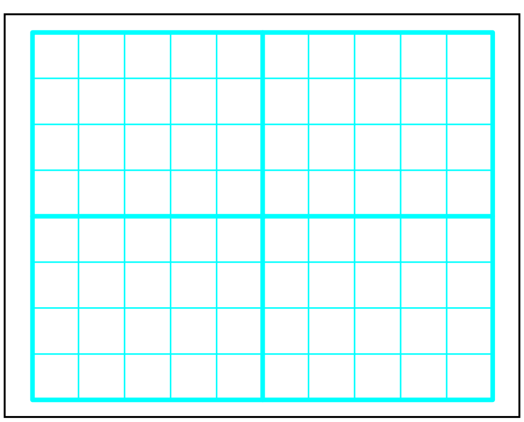
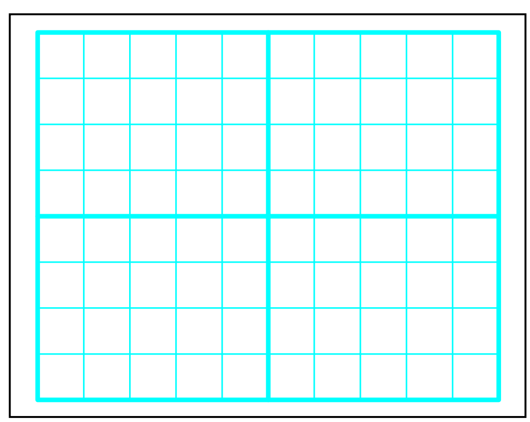
3. Composite voltage calculations. **SHOW ALL CALCULATIONS ON SEPARATE SHEETS.**

4. *Composite voltage output waveforms



a) sine waveform



b) square waveform

5. *Average value, the half-cycle average value and the RMS values calculations of composite waveform signals.

Table 4.2 *Average, half-cycle average and RMS values for composite waveforms.*

V_1 = 3 VDC V_2 = 3 VACp f=1000 Hz	*Average Value (V)	*RMS Value (V)	FLUKE Vo DC (V)	FLUKE Vo AC (V)	Simpson Vo DC (V)	Simpson "+" term Vo AC (V)	Simpson "output" Vo AC (V)
Sine waveform							
Square waveform							

Table 4.3 *Composite waveforms measurements.*

V_1 = 3 VDC V_2 = 2 VACp f=1000 Hz	FLUKE Vo DC (V)	FLUKE Vo AC (V)	Simpson Vo DC (V)	Simpson "+" term Vo AC (V)	Simpson "out" Vo AC(V)
Sine waveform					
Square Waveform					

Table 4.4 *Composite waveforms measurements.*

V_1 = 2 VDC V_2 = 3 VACp f=1000 Hz	FLUKE Vo DC (V)	FLUKE Vo AC (V)	Simpson Vo DC (V)	Simpson "+" term Vo AC (V)	Simpson "out" Vo AC (V)
Sine waveform					
Square Waveform					

6. Examine the results that you have included in your table, and answer the following questions.

   (a) For a composite waveform, what does the Fluke meter measure in DC mode?
   (b) For a composite waveform, what does the Fluke meter measure in AC mode?
   (c) For a composite waveform, what does the Simpson meter measure in DC mode?
   (d) For a composite waveform, what does the Simpson meter measure in AC mode with the probe in the "output" terminal?
   (e) What parts of a composite waveform are processed when using the Simpson with the probe in the "+" terminal? In the "output" terminal?
   (f) For the Sine waveform in Tables 4.3 and 4.4, you should not see a significant change in reading between the tables when the Simpson is used with the probe in the "+" terminal. Explain why this is to be expected. Why is there a change in Table 4.4? It might be helpful to sketch figures to explain this.

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7. OPTIONAL

QUESTIONS

1. **[2 MARKS]** Quantities such as RMS value, Peak-to-Peak value, Frequency and Period can be automatically measured by the oscilloscope and displayed numerically, i.e. you do not have to make manual measurements on the waveform. List the steps you must take to make the oscilloscope display this information.

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2. **[3 MARKS]** When displaying the composite waveform $V(t) = 1.0 + \sin(2000\pi t)$ [volts] what would you see on the oscilloscope screen when coupling is set to:
   a) AC ____
   b) DC ____
   c) GROUND ____

3. **[1 MARK]** What is the use of GROUND coupling on the oscilloscope?

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SIGNATURES **TA name:________________________**

To be completed by TA during the lab session.

Check Boxes				TA Signature	Student's Task
					Pre-lab completed.
					Circuit of Figure 4.5 connected and equipment used correctly
					Circuit of Figure 4.6 connected and equipment used correctly
					Data collected and observations made
					Final questions completed

MARKS

To be completed by TA after the lab session.

Granted Marks	Max. Marks	Student's Task
	50	Pre-lab preparation
	10	Circuit of Figure 4.5 connected and equipment used correctly
	10	Circuit of Figure 4.6 connected and equipment used correctly
	24	Data collected and observations made
	6	Final questions completed
	100	**Total**