Sirindhorn International Institute of Technology

Thammasat University at Rangsit

School of Information, Computer and Communication Technology

COURSE **:** ECS 210 Basic Electrical Engineering Lab

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EXPERIMENT : 04 AC Measurements

I. OBJECTIVES

1. To study how to use a cathode-ray tube oscilloscope and a function generator.
2. To learn and verify the relationship among instantaneous, peak, and rms values of ac voltages and currents.
3. To measure frequency by using a cathode-ray tube oscilloscope.
4. To measure phase shifts and power consumed in ac circuits.

II. BASIC INFORMATION

1. **A cathode-ray oscilloscope (CRO)** is one of the most versatile instruments in electronics. An oscilloscope (abbreviated sometimes as scope or O-scope) displays the **instantaneous amplitude of a voltage waveform versus time** on the screen. A dual-trace oscilloscope makes it possible to observe two time-related waveforms simultaneously at different nodes in a circuit.
2. A **function generator** is also one of the most versatile instruments in electronics. It generates various waveforms of basic signals at various frequencies and amplitudes.
3. The amplitude of dc voltage can be identified by a single value. However, there are many values that can be used to specify ac voltages: the peak, the rms, the average, and the instantaneous values. All of these values are related. **Peak value** means the maximum value of an ac voltage. **Rms value** is the value of the ac voltage that will produce the same power as the equivalent dc level. **Instantaneous value** is the value of voltage at any particular time. Integrating the instantaneous value over the time of one period and

dividing it by the period yields the **average value**. In the design of ac circuits, voltage and current measurements are usually made in rms values.

4. In this experiment, we consider signals of the form $A\cos(2\pi ft+\theta)$.

> For a signal of the form $A\cos(2\pi ft+\theta)$, the ***peak value*** is given by its amplitude *A*. Its ***peak-to-peak (p-p) value*** is $2A$. The ***rms value*** is given by $\frac{A}{\sqrt{2}}$.

Note that $1/\sqrt{2}$ is approximately 0.707.

5. The oscilloscope can measure frequency of periodic signals. If the time base of the scope is calibrated in time units per division, then the horizontal divisions covered by one cycle of any periodic signal will represent the signal period. The **period** T is the reciprocal of the **frequency** f, and can be calculated by using the formula $f = 1/T$.
6. **In resistive circuits, voltages and currents are in phase, while in non-resistive circuits, voltages and currents may not be in phase. For a pure inductor, the current lags the voltage by 90 degrees. For a pure capacitor, the current leads the voltage by 90 degrees.** Using a dual-trace oscilloscope, the phase difference between two waveforms can be calculated.

II.1 The passive circuit elements in the phasor domain

Inductors are circuit elements based on phenomena associated with magnetic fields. The source of the magnetic field is the charge in motion, or current. If the current is varying with time, the magnetic field induces a voltage in any conductor linked by the field.

Capacitors are circuit elements based on phenomena associated with electric fields. The source of the electric field is the separation of charge, or voltage. If the voltage is varying with time, the electric field is also varying with time, and a time-varying electric field produces a displacement current in the space occupied by the field.

When the circuit consists of passive circuit elements such as resistor, inductor, and capacitor, we can change the frequently used formula v = iR to the *phasor form* as

$$\mathbf{V} = Z\mathbf{I},$$

where **V** is the phasor voltage, **I** is the phasor current, and Z represents the ***impedance*** of the circuit elements. The above equation is the **Ohm's law** for ac circuits.

The impedance of a resistor, an inductor, and a capacitor are given by R, *jωL*, and 1/*jωC*, respectively, where R is the resistance of the resistor, L is the inductance of the inductor, and C is the capacitance of the capacitor. The angular frequency ω is $2\pi f$, where f is the frequency, and j = $\sqrt{-1}$. In all cases, the impedance is measured in ohms. The concept of impedance is crucial in sinusoidal steady-state analysis.

II.2 V-I relationship for a resistor

The phasor voltage at the terminals of a resistor is the resistance times the phasor current.

$$\mathbf{V} = R\mathbf{I}$$

Figure 4-1(a) depicts the phase relationship between the current and the voltage of a resistor R. It can be seen from Figure 4-1(a) that there is no phase difference between the current and voltage.

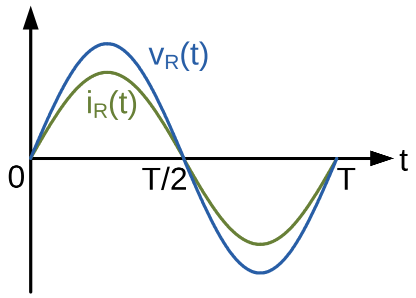


Figure 4-1(a): The voltage and current at the terminals of a resistor are in phase.

II-3 V-I relationship for an inductor

The phasor voltage at the terminals of an inductor (pure inductor) equals $j\omega L$ times the phasor current, i.e.,

$$\mathbf{V} = j\omega L\,\mathbf{I}.$$

In the phasor domain, "j" means $\angle 90°$ shift. Thus, the voltage and current are out of phase by exactly 90°. In particular, the voltage leads the current by 90° or, equivalently, the current lags behind the voltage by 90°, as shown in Figure 4-1(b)

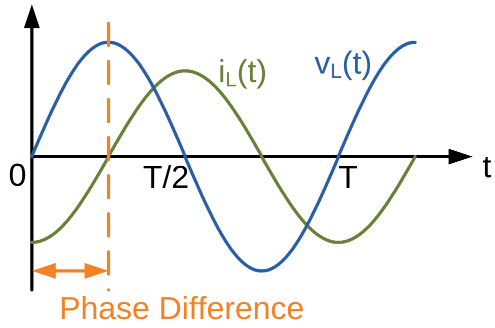


Figure 4-1(b): The voltage leads the current by 90° in the pure inductor circuit.

II.4 V-I relationship for a capacitor

Similar to the inductor circuit, the phasor voltage at the terminals of a capacitor equals $1/j\omega C$ times the phasor current. So,

$$\mathbf{V} = \frac{1}{j\omega C}\,\mathbf{I} = -\frac{j}{\omega C}\mathbf{I},$$

where -j means ∠-90° shift. Therefore, the voltage and current are out of phase by exactly 90°. However, in this case, the voltage lags the current by 90°, or the current leads the voltage by 90° as shown in Figure 4-1(c).

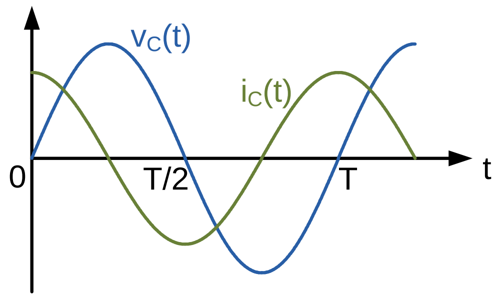


Figure 4-1(c): The voltage lags the current by 90° in the pure capacitor circuit.

III. (DUAL-TRACE) OSCILLOSCOPE

III.1 Front panel

To successfully accomplish this lab, the student has to be able to use an oscilloscope proficiently. Figure 4-2 shows the front panel of the oscilloscope.

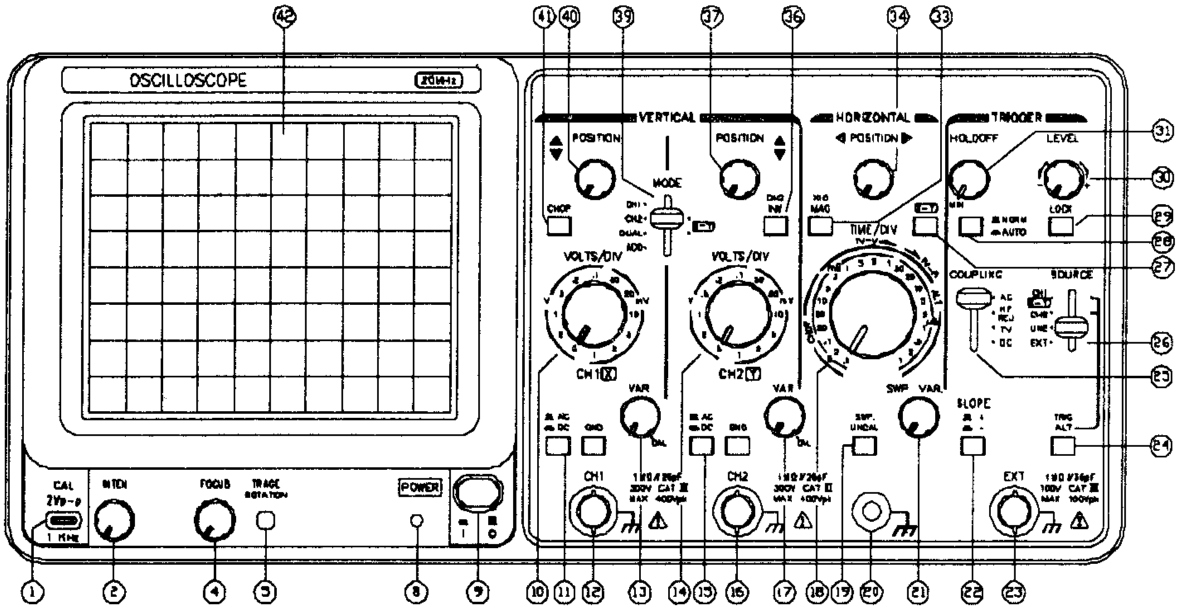


Figure 4-2: An oscilloscope (front panel)

III.1.1 CRT (CATHODE-RAY TUBE)

Controls/Sockets	Functions
POWER (9)	Main power switch of the instrument. When this switch is turned on, the LED (8) is also turned on.
INTEN (2)	Controls the brightness of the spot or trace.
FOCUS (4)	For focusing the trace to the sharpest image.
TRACE ROTATION (5)	Semi-fixed potentiometer for aligning the horizontal trace in parallel with graticule lines.
FILTER (42)	Filter for ease of waveform viewing.

III.1.2 VERTICAL AXIS

Controls/Sockets	Functions
CH 1 (X) input (12)	Vertical input terminal of CH 1. When in X-Y operation, X-axis input terminal.
CH 2 (Y) input (16)	Vertical input terminal of CH 2. When in X-Y operation, Y-axis input terminal.
AC-DC-GND (11)(15)	Switch for selecting connection mode between input signal and vertical amplifier: **AC : AC coupling** (Input signal is coupled via blocking capacitor and DC component is blocked.) **DC : DC coupling** (Input signal is directly coupled.) **GND** : Vertical amplifier input is grounded and input terminal are disconnected.
VOLTS/DIV (10)(14)	Select the vertical axis sensitivity, from 1mV/DIV to 5V/DIV in 12 ranges.
VARIABLE (13)(17)	Fine adjustment of sensitivity, with a factor of ≥ 1/2.5 of the indicated value. When in the CAL position, sensitivity is calibrated to indicated value.
POSITION (40)(37)	Vertical positioning control of trace or spot.
VERTICAL MODE (39)	Select operation modes of CH 1 and CH 2 amplifiers: **CH 1** : The oscilloscope operates as a **single-channe**l instrument and only CH 1 is displayed. **CH 2** : The oscilloscope operates as a **single-channel** instrument and only CH 2 is displayed. **DUAL** : The oscilloscope operates as a **dual-channel** instrument with both CH 1 and CH 2.[1] CHOP/ALT are automatically changed by TIME/DIV switch. When CHOP (41) button is pushed in, the two traces are displayed in the CHOP mode at all ranges. **ADD** : The oscilloscope displays the algebraic sum (CH 1+CH 2) or difference (CH 1-CH 2) of the two signals. The pushed in state of CH 2 INV (36) button is for the difference (CH 1-CH 2).

[1] Most multichannel scopes do not have multiple electron beams. Instead, they display only one trace at a time, but switch the later stages of the vertical amplifier between one channel and the other either on alternate sweeps (ALT mode) or many times per sweep (CHOP mode).

III.1.3 HORIZONTAL AXIS (TIME BASE)

Controls/Sockets	Functions
TIME/DIV (18)	Select the sweep time.
SWP.VAR	Vernier control of sweep time. When SWP.UNCAL (19) button is pushed in, the sweep time can be made slower by a factor ≥ 2.5 of the indicated value. The indicated values are calibrated when this button is not pushed in.
POSITION (34)	Horizontal positioning control of the trace or spot.
× 10 MAG (33)	When the button is pushed in, a magnification of 10 occurs.
X-Y (27)	Press the X-Y button to enable X-Y operation.

III.1.4 TRIGGERING

Controls/Sockets	Functions
EXT TRIG input (23)	Input terminal is used in common for external triggering signal. To use this input, set SOURCE switch (26) to EXT position.
SOURCE (26)	Select the internal and external triggering source signal: CH 1(X-Y) : When the VERT MODE switch (39) is set in the DUAL or ADD state, select CH 1 for the internal triggering source signal. When in the X-Y mode, select CH 1 for the X-axis signal. CH 2 : When the VERT MODE switch (39) is set in the DUAL or ADD state, select CH 2 for the internal triggering source signal. TRIG.ALT (24) : When the VERT MODE switch (39) is set in the DUAL or ADD state, and the SOURCE switch (26) is selected at CH 1 or CH 2, with the engagement of the TRIG.ALT switch (24), it will alternately select CH 1 & CH 2 for the internal triggering source signal. LINE : To select the AC power line frequency signal as the triggering signal. EXT : The external signal applied through EXT TRIG input (23) is used for the external triggering source signal. When in the X-Y mode, the X-axis operates with the external sweep signal.

III.1.4 TRIGGERING (CONTINUED…)

Controls/Sockets	Functions
COUPLING (25)	Select COUPLING mode (25) between triggering source signal and trigger circuit; select connection of TV sync trigger circuit: AC : AC coupling (Trigger signal is coupled via blocking capacitor and DC component is blocked.) DC : DC coupling (All frequency components of applied signal are coupled to the trigger circuitry.) HF REJ : Remove signal components above 50 kHz (-3dB) TV : The trigger circuit is connected to the TV sync separator circuit and the triggered sweeps synchronize with TV-V or TV-H signal at a rate selected by the TIME/DIV switch (18)
SLOPE (22)	Select the trigger slope: + : Triggering occurs when the triggering signal crosses the triggering level in positive-going direction. - : Triggering occurs when the triggering signal crosses the triggering level in negative-going direction.
LEVEL (30)	To display a synchronized stationary waveform and set a start point for the waveform: Toward + : The triggering level moves upward on the display waveform. Toward - : The triggering level moves downward on the display waveform. LOCK (29) : Triggering level is automatically maintained at optimum value irrespective of the signal amplitude (from very small to large amplitudes), requiring no manual adjustment of triggering level.
HOLDOFF (31)	Used when the signal waveform is complex and stable triggering cannot be obtained with the LEVEL knob alone.
TRIGGER MODE (28)	Select the desired trigger modes: AUTO : When no triggering signal is applied or when triggering signal frequency is less than 50 Hz, sweep runs in the free run mode. NORM : When no triggering signal is applied, sweep is in a ready state and the trace is blanked out. Used primarily for observation of signal ≤ 50 Hz.

III.1.5 OTHERS

Controls/Sockets	Functions
CAL (1)	This terminal delivers the calibration voltage of 2 Vp-p, 1kHz, positive square wave.
GND (20)	Ground terminal of oscilloscope mainframe.

III.2 Rear panel

Figure 4-3 shows the rear panel of the oscilloscope.

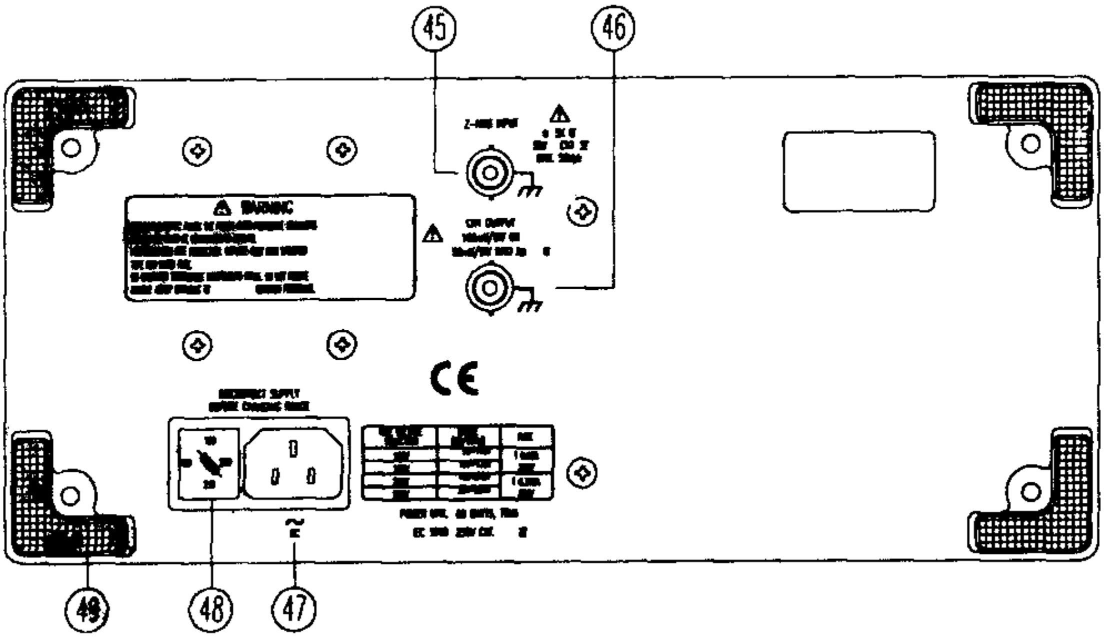


Figure 4-3: An oscilloscope (rear panel)

Sockets	Functions
Z AXIS INPUT (45)	Input terminal for external intensity modulation signal.
CH 1 SIGNAL OUTPUT (46)	Delivers the CH 1 signal with a voltage of approximately 100mV per 1 DIV of graticule. When terminated with 50 ohms, the signal is attenuated to about one half. Suitable for frequency counting, etc.
AC Power input connector (47)	AC Power input socket.
FUSE & line voltage selector (48)	Select power sources.
Studs (49)	For laying the oscilloscope on its back to operate it in the upward posture. Also used to take up the power cord.

III.3 Oscilloscope Preparation

Before powering the oscilloscope, set the switches and controls of the instrument as shown below.

Item	Setting	
INTEN (2)	Clockwise (3-o’clock position)	🖫
FOCUS (4)	Mid-position	🖫
VERT MODE (39)	CH 1	✓
CHOP (41)	Released	🖫
CH2 INV (36)	Released	✓
POSITION (40)(37)	Mid-position	✓
VOLTS/DIV (10)(14)	0.5V/DIV	✓
VARIABLE (13)(17)	CAL (clockwise position)	🖫
AC-DC-GND (11)(15)	GND	✓
SOURCE (26)	Set to CH 1	✓
COUPLING (25)	AC	✓
SLOPE (22)	+	🖫
TRIG ALT (24)	Released	🖫
LEVEL LOCK (29)	Pushed in	🖫
HOLDOFF (31)	MIN (anti-clockwise)	🖫
TRIGGER MODE (28)	AUTO	🖫
TIME/DIV (18)	0.5mSec/DIV	✓
SWP.UNCAL (19)	Released	🖫
POSITION (34)	Mid-position	✓
×10 MAG (33)	Released	🖫
X-Y (27)	Released	🖫

1. Engage the POWER (9) switch and make sure that the power LED is turned on. In about 20 seconds, a trace will appear on the CRT screen. If no trace appears in about 60 seconds, recheck the switch and control setting.
2. Adjust the trace to an ***appropriate*** brightness/sharpness using the INTEN control and FOCUS control, respectively.
3. With the VERTICAL (VERT) MODE set to Channel 1 (CH1), set the AC-DC-GND switch to the GND mode. Notice a green trace on the monitor. Make sure that the NORM

control is not enabled, i.e. the TRIGGER MODE (28) is in the AUTO position, otherwise the trace will not be shown.

4. Adjust the CH1 POSITION control (or (in rare case) the TRACE ROTATION control which is adjustable by a screwdriver), i.e. adjust the Δ∇ POSITION and < > POSITION controls in order to align the trace with the horizontal centre line. Adjust the FOCUS control so that the trace image appears sharply.

III.4 Use of the Calibration Signal

1. Apply the steps given in Section III.3.
2. Connect a probe to the CH 1 INPUT terminal. At the lower left corner of the front panel of the oscilloscope, you will find an outlet of a CALIBRATOR signal which generates a 2-Vp-p square wave. Apply the CALIBRATOR signal to the probe tip of CH1.
3. Set the AC-DC-GND switch to the AC state. The square wave of the calibrator signal will be displayed on the CRT screen.
4. Adjust the FOCUS control so that the trace image appears sharply.
5. For signal viewing, set the VOLTS/DIV switch and TIME/DIV switch in appropriate positions so that signal waveform is displayed clearly.
6. Adjust the Δ∇ POSITION and < > POSITION controls in appropriate positions so that the displayed waveform is aligned with the graticule and voltage (Vp-p) and period (T) can be read conveniently.

The above are the basic operating procedures of the oscilloscope. The above procedures are for **single-channel operation** with CH 1. Single-channel operation with CH 2 can also be achieved in a similar manner.

III.5 Dual-channel operation

1. Switch the VERT MODE to DUAL so that traces in both channel 1 (CH1) and channel 2 (CH2) are displayed simultaneously. At this state, the CH1 trace is the square wave of the calibrator signal (from Section III.4) and the CH2 trace is a straight line since no signal has been applied to the CH2 yet.

STATIONARY DISPLAY OF CH1

2. In the dual channel operation (DUAL or ADD mode), either CH1 or CH2 signal must be selected using the SOURCE switch for the triggering source signal.
   As CH1 is used (to measure the Calibrator Signal), select the SOURCE switch to CH1 in order to make the Calibrator signal stationary in CH1.

NON-STATIONARY DISPLAY OF CH1

3. If CH1 is used (to measure the Calibrator Signal) but the SOURCE switch is not selected to CH1, i.e. being selected to CH2 or others, the signal in CH1 will not be stationary.

STATIONARY DISPLAY OF BOTH CH1 AND CH2

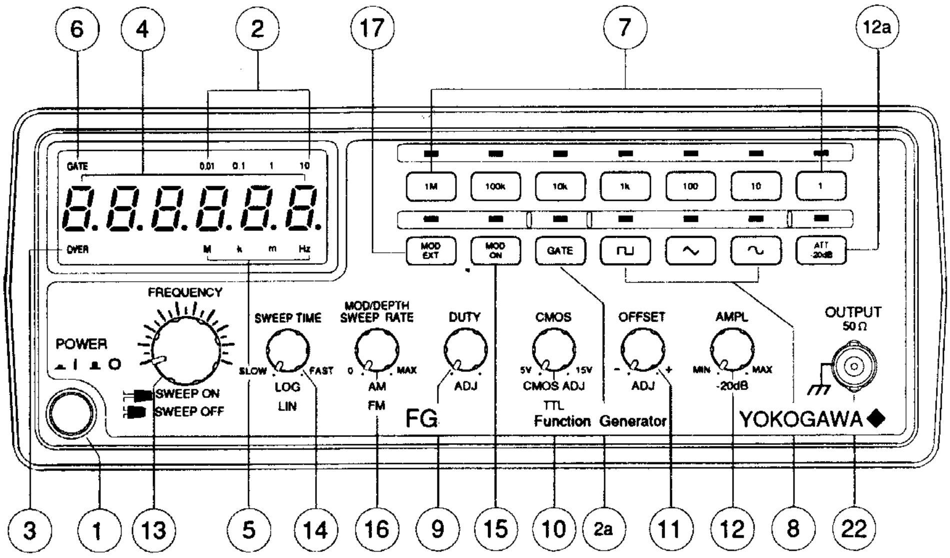
4. Let the CH1 be connected to the Calibrator Signal, and the CH2 be connected to a sinusoidal waveform of 1 kHz (1 volt peak) generated from a signal generator. (Consult Section IV for instructions on using the function generator.) Adjust the vertical POSITION knobs (40) and (37) so that both channel signals are displayed clearly, i.e. the calibrator signal in CH1 is displayed at the top part and the sinusoidal signal in CH2 is display at the lower part of the monitor.
5. In order to enable both signals in CH1 and CH2 stationary, the TRIG.ALT switch is pushed and engaged. Both waveforms can be stationary because they are triggered alternatively (TRIG.ALT) between CH1 and CH2.
   DO NOT enable CHOP and TRIG.ALT switches at the same time, otherwise TRIG.ALT will not work. (When the CHOP push switch is engaged, the two traces are displayed in the CHOP operation at all ranges. The CHOP operation has priority over the ALT operation.
   Selection between CHOP mode and ALT mode is automatically made by the TIME/DIV switch. The 5 mSec/DIV and lower ranges are used in the CHOP mode and the 2 mSec/DIV and higher ranges are used in the ALT mode).

Note: For more advanced operations of the oscilloscope, please consult the instruction manual available from the lab technician.

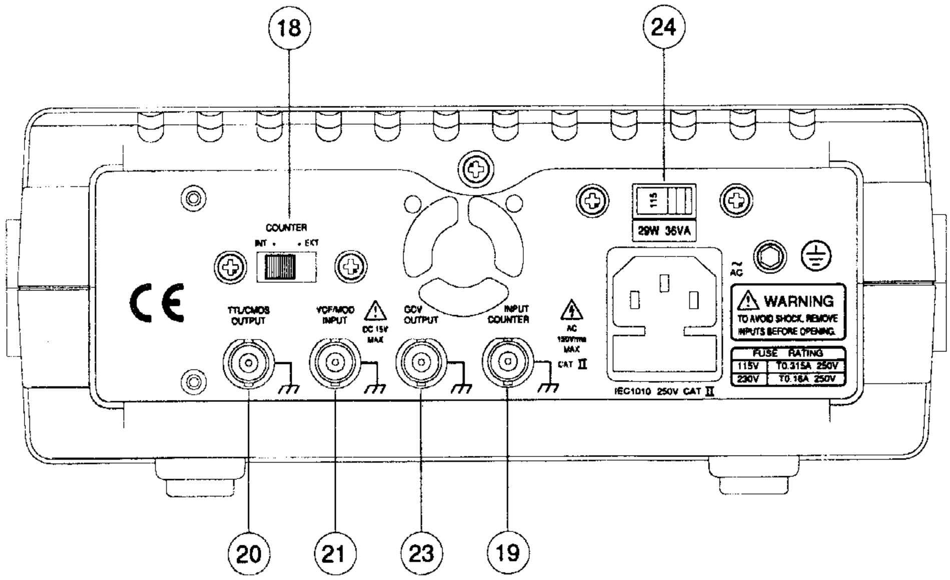
IV. Function generator

IV.1 Front and rear panels

To successfully accomplish this lab, the student has to be able to use a function generator proficiently. Figure 4-4 shows the front and rear panels of the function generator.



(Front panel)



(Rear panel)

Figure 4-4: Front and rear panels of a function generator

IV.2 Function description

<table>
<tr><th>Controls/Sockets</th><th>Functions</th></tr>
<tr><td>Power Switch (1)</td><td>Connect the AC power, then press power switch.</td></tr>
<tr><td>Frequency Indicator (5)</td><td>Indicates the current frequency value.</td></tr>
<tr><td>Gate Time Indicator (6)</td><td>Indicates the current Gate time (external counter mode use only)</td></tr>
<tr><td>Frequency Range Selector (7)</td><td>To select the required frequency range by pressing the relevant push button on the panel as shown in the table below:
<table>
<tr><td>Button</td><td>1</td><td>10</td><td>100</td><td>1k</td><td>10k</td><td>100k</td><td>1M</td></tr>
<tr><td>Freq.</td><td>0.5Hz
|
5Hz</td><td>5Hz
|
50Hz</td><td>50Hz
|
500Hz</td><td>500Hz
|
5kHz</td><td>5kHz
|
50kHz</td><td>50kHz
|
500kHz</td><td>500kHz
|
5MHz</td></tr>
</table></td></tr>
<tr><td>Function Selector (8)</td><td>Press one of the three push buttons to select the desired output waveform.
Caution: Default waveform when the generator starts is triangular which you will never use in any ECS304 experiment. If you turn the generator off and then turn it back on again, do not forget to change it to sinusoidal or rectangular specified in the experiment.</td></tr>
<tr><td>Duty Function (9)</td><td>Pull out and rotate the knob to adjust the duty cycle of the waveform.</td></tr>
<tr><td>DC Offset Control (11)</td><td>Pull out the knob to select any DC level of the waveform between ±10V, turn clockwise to set a positive DC level waveform and invert for a negative DC level waveform.</td></tr>
<tr><td>Output Amplitude Control with Attenuation Operation (12)</td><td>Turn clockwise for MAX output and invert for a -20dB output. Pull the knob out for an additional 20 dB output attenuation.</td></tr>
<tr><td>MANU/SWEEP Selector and Frequency Adjustment [Sweep On/Off] (13)</td><td>Press and turn the knob clockwise for MAX frequency and invert for MIN frequency (keep the pointer within the scale range on the panel). Pull out the knob to start the auto sweep operation; the upper frequency limit is determined by the knob position.</td></tr>
<tr><td>Sweep Time Control and LIN/LOG Selector (14)</td><td>1. Rotate the knob clockwise to adjust sweep time for MAX, or invert for MIN.
2. Select linear sweep mode by pushing in the knob or select LOG sweep mode by pulling out the knob.</td></tr>
<tr><td>Main Output Terminal (22)</td><td>Main signal output.</td></tr>
</table>

IV.3 Use of a Function Generator

The function generator can provide versatile waveforms of high efficiency. **One of the best ways to observe waveforms is to connect the function generator to an oscilloscope**. Watch the effect in different control of waveforms on the oscilloscope carefully while proceeding as follows.

1. Press the PWR switch (1) and **ensure all the rotary controls are pushed in**.
2. Connect the output (22) of the function generator to the CH1 of the oscilloscope.
3. Select Function of desired waveforms (8) , e.g. a sinusoidal wave (or Triangle or Square Waves), and select Range (7). Rotate FREQ (13) to set the desired frequency (determine from display window).
4. Rotate AMPL (12) knob to obtain desired amplitude, e.g. 1 Vp-p.

Note: For more advanced operations of the function generator, please consult the instruction manual available from the lab technician.

V. MATERIALS REQUIRED

- Function generator
- Dual-trace oscilloscope
- Multi-meter
- Resistors (½ W): two 100-Ω, two 3.3-kΩ, and one 4.7-kΩ.
- Inductor: 22-mH
- Capacitor: 0.47-μF

VI. EXPERIMENTS

Part A: The relationships among instantaneous, peak, and rms values

1. **Connect the circuit** of Figure 4-5.

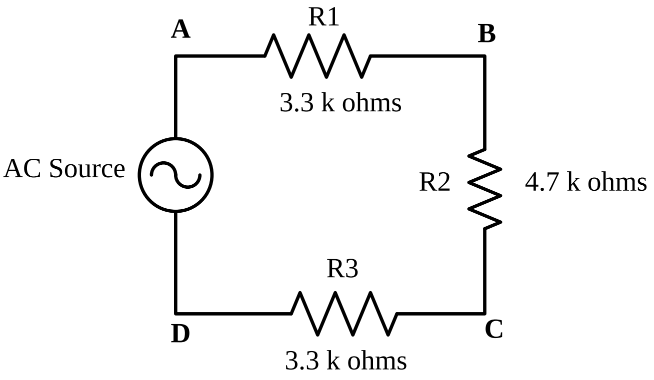


Figure 4-5: A circuit for measuring rms and peak values.

2. Connect the output of the sine-wave generator (AC source in Figure 4-5) to channel 1 of the dual-trace scope.
3. Turn on the generator. (Press the POWER (9) button.) Select sinusoidal waveform. Set the frequency to 1000 Hz. With a DMM (used as an AC voltmeter) connected across its output, adjust the signal generator output to 5 V (rms). Record the value in the "Voltage, rms, measured" column of Table 4-1.

   Caution:

   (i) Make sure that the DMM is in AC mode. In this mode, the value that you get for zero-mean waveform is the rms value.

   (ii) All measurement should be done with the AC generator still connected in the circuit.
4. With the DMM, measure the rms voltage across each resistor, R1, R2, R3. Record the values in the "Voltage, rms, measured" column of Table 4-1.

   Caution: All the grounds (both from the oscillator probes and from the generator) should be connected together at one node.
5. Using the scope, measure the peak voltages across the generator, R1, R2 and R3. Record the values in the "Voltage, peak, measured" column of Table 4-1.
6. Use a DMM (as an AC ammeter) to measure current flowing through R1. Record the ammeter reading in the "current, rms, measured" column.
7. Similarly, measure currents in R2 and R3, and record the values in Table 4-1.

8. From the measured voltage value of the AC source and the measured resistance values, calculate rms currents, rms and peak voltages and record the values in the "calculated" columns of Table 4-1.

Part B: Frequency measurement

1. Set the output of the sine-wave generator to an arbitrary[2] frequency in the range of 1 kHz and 2 kHz. Record the value in Table 4-2.
2. Connect the output of the generator to channel 1 of the oscilloscope. Adjust the scope so that approximately **one cycle** of the waveform is displayed on the screen.
3. Measure the number of divisions spanned by one cycle. Record the value in Table 4-2. Record the Time-base/Div. setting.
4. Calculate the period of waveform, and record your answer in Table 4-2.
5. Calculate the frequency and verify it with the setting value on the generator.

Part C: Phase shifts and power consumed in ac circuits

C.1 RESISTIVE CIRCUIT

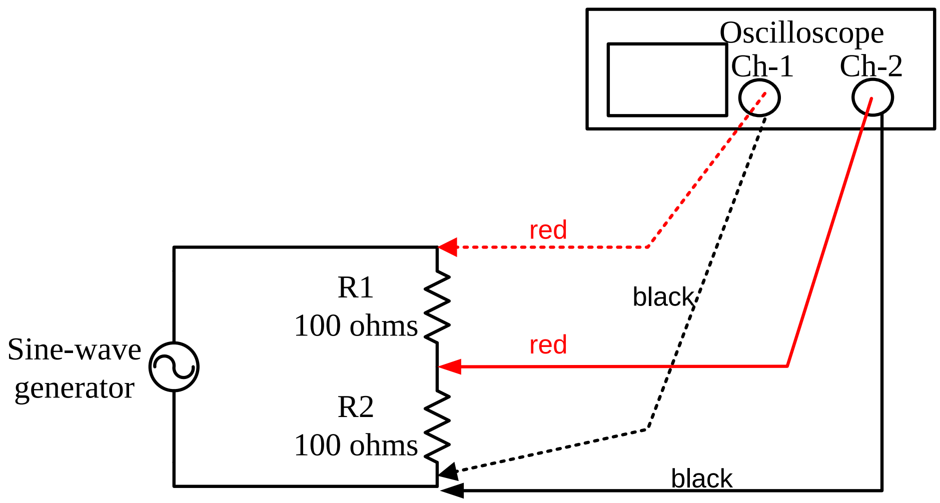


Figure 4-6: A circuit for measuring phase shifts.

1. Make sure that the generator is off. Connect the circuit of Figure 4-6. Channel 1 is connected to the output of the generator. Select channel 1 as the trigger source. Channel 2 is connected across resistor R2.[3]

[2] "Arbitrary" means you choose your own value within the specified range.

2. Turn on and adjust the generator to output 2 kHz ***sinusoid*** with output voltage of 2 V (**rms**).
3. Switch the Vertical Mode to channel 1, this will be the reference signal channel. Adjust scope (Volts/Div. Button) and output level of the generator until a single stationary sine wave is displayed on the screen for the entire width. Center the waveform. (See Figure 4-7)
4. Switch the Vertical Mode to the dual-trace mode to display both signals. Adjust the Volts/Div. Button to obtain the waveforms that are easy to draw. Draw the waveforms in Graph 4-1. Label channel 1 to represent *v* and channel 2 to represent *i*.

   Remark: The waveforms that you get from the scope are voltage waveforms. However, because R2 is a resistor, the voltage v_2 across its terminals and the current i_2 that passes through it are in phase. Therefore, we can tell the phase of the current i_2 from the voltage waveform v_2. Because the whole circuit is a single loop, the current i_2 is the same as the current *i* that passes through all the components.
5. Measure the horizontal distance D (in divisions, see Figure 4-7) for the voltage sine wave labeled *v*. Record the value in Graph 4-1. This is the period of the waveform.
6. Measure the horizontal distance d (in divisions, see Figure 4-7) between the two positive (or negative) peaks of the sine waves. Record the value in Graph 4-1. This is the phase difference between the two waveforms.
7. With reference to Figure 4-7, the phase shift θ (in degrees) is given by

$$\theta = \frac{360}{D} \cdot d$$

   where θ = phase shift

   D = period of the waveform (in divisions)

   d = phase difference (in divisions)

   Calculate the phase shift and record the value in Graph 4-1.
8. Calculate the average power P delivered by the generator.

   Hint: $P = \underbrace{V_{rms} I_{rms}}_{\text{apparent power}} \underbrace{\cos\theta}_{\text{power factor (pf)}}$

[3] Channel 1 is (typically) connected to the input of the circuit. Channel 2 is (typically) connected to the output of the circuit.

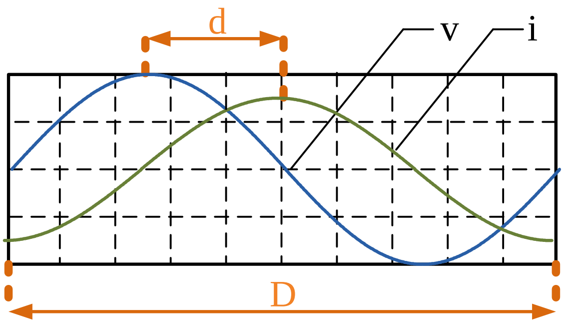


Figure 4-7: Output waveforms.

C.2 INDUCTIVE CIRCUIT

Repeat the steps given in Part C.1 with the following modifications.

1. Replace R1 in Figure 4-6 by a 22-mH inductor.[4]
2. Record the results in Graph 4-2.

C.3 CAPACITIVE CIRCUIT

Repeat the steps given in Part C.1 with the following modifications.

1. Replace R1 in Figure 4-6 by a 0.47-µF capacitor.
2. Record the results in Graph 4-3.

Do not forget to turn off the scope and the generator.

Note: Capacitance can be determined by the following methods:

✓ Measurement: Use the multi-meter in the capacitance measurement mode (-||- mark) with the SELECT button pressed to display the unit F (farad).

✓ Numerical code read from the capacitor body:

For a code *abc*, *a* and *b* give the first two figures of the capacitance while *c* gives the value of multiplier (the number of 0's). The capacitance read from the code is set to have a unit of pF. Thus, 474 is equal to 470000 pF or 470 nF or 0.47 µF.

[4] The inductor used is not a perfect inductor and therefore has an internal resistance (inside the inductor) of approximately 100 Ω.

Table 4-1: The relationship between peak and rms values

	rms voltage, V		peak voltage, V		rms current, mA	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
Sine wave generator output						
R1 = Ω						
R2 = Ω						
R3 = Ω						

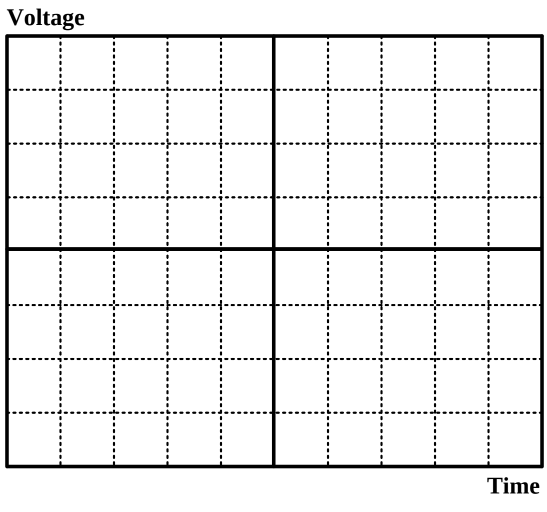
TA Signature:

Table 4-2: Frequency measurement

Frequency of wave (Hz) (Setting value)	Width of one cycle (div.)	Time-base setting (time units/div.)	Period of wave *T* (sec.)	Calculated frequency of wave f (Hz)

TA Signature:

Graph 4-1: Phase relationship in a resistive circuit



Channel 1: volts/div = ______________

Channel 2: volts/div = ______________

Time/div = ______________

Distance D from 0° to 360° for the voltage sine wave, *v* = ______ divisions.

Horizontal distance d between maximum points of *v* and *i* = ______ divisions.

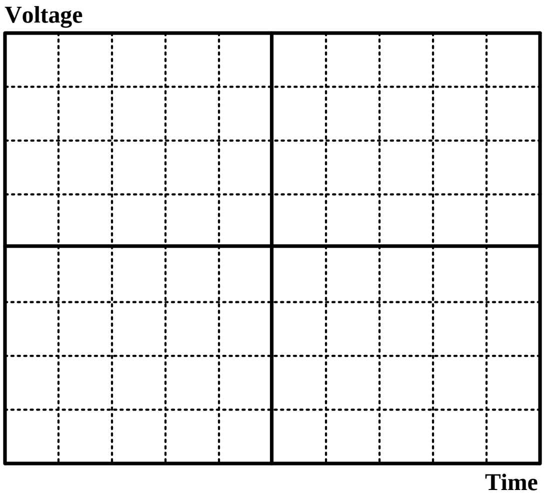
Phase angle θ = (360/D)(d) = _________ degrees.

v leads *i* by __________ degrees. Power factor cos θ = _________ .

Average power delivered by the generator = __________ watts.

TA Signature:

Graph 4-2: Phase relationship in an inductive circuit



Channel 1: volts/div = ______________

Channel 2: volts/div = ______________

Time/div = ______________

Distance D from 0° to 360° for the voltage sine wave, *v* = ______ divisions.

Horizontal distance d between maximum points of *v* and *i* = ______ divisions.

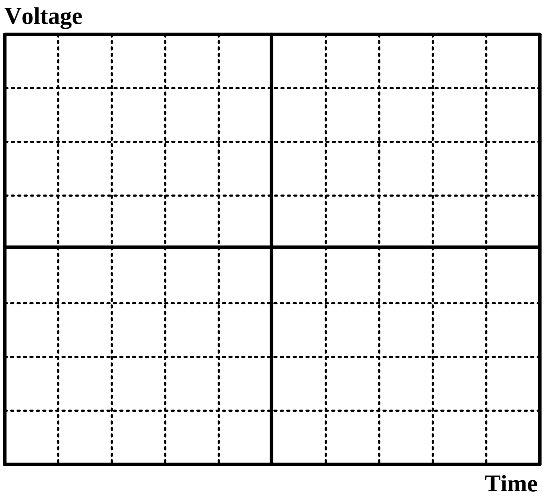
Phase angle θ = (360/D)(d) = _________ degrees.

v leads *i* by __________ degrees. Power factor cos θ = _________ .

Average power delivered by the generator __________ watts.

TA Signature:

Graph 4-3: Phase relationship in a capacitive circuit.



Channel 1: volts/div = ______________

Channel 2: volts/div = ______________

Time/div = ______________

Distance D from 0° to 360° for the voltage sine wave, *v* = ______ divisions.

Horizontal distance d between maximum points of *v* and *i* = ______ divisions.

Phase angle θ = (360/D)(d) = _________ degrees.

v leads *i* by __________ degrees. Power factor cos θ = _________.

Average power delivered by the generator __________ watts.

TA Signature:

VII. QUESTIONS

1. Which controls of the oscilloscope affect the following, and how?

   a. The height of the displayed waveform

   b. The vertical position of the waveform on the screen

   c. The brightness of the waveform

2. From Graphs 4-1, 4-2, and 4-3, what can be concluded about the phase relationship of voltage and current for each case?

Fill in the blanks.

3. The waveforms seen on the screen of a CRO shows the ________________ versus _______________.
4. How rapidly a waveform is produced is determined by the _________________ of the waveform.
5. The _____________ value of a waveform is also known as the effective value.
6. A sine wave has a peak value of 100 V. Its average value is _____________, and the rms value is _____________.
7. The period of a sinusoidal radiation from a station FM100 at 100 MHz is ______________ seconds.
8. The possible maximum value of power factor is _____________, and the minimum value is ______________.
9. The measured average power, current, and voltage in a circuit are 880 W, 5 A_{rms}, and 220 V_{rms}, respectively. Determine the following.

   Phase angle θ = _______________

   Power factor $\cos\theta$ = _______________

True or *False*

10. _______ The trigger circuit can be actuated only by a signal from internal oscilloscope circuits.
11. _______ A dc voltage cannot be measured with an oscilloscope.

VIII Supplementary Exercises

Name			ID	
Section		☐ 9 AM ☐ 1 PM	Group	

Answer the following questions in detail. When possible, use drawing to illustrate your answers.

1. How can you make AC <u>voltage</u> measurement using the DMM?

2. How can you make AC <u>current</u> measurement using the DMM?

3. The DMM gives rms value in AC mode. How can you change the rms value into (i) the peak value and (ii) the p-p value.

4. How can you adjust the frequency of the output from the function generator?

5. How can you adjust the amplitude of the output from the function generator?

6. Why do we need to be careful with the probe grounds?

7. Can the oscilloscope do addition/subtraction? How?