University of Jordan
School of Engineering
Electrical Engineering Department

EE 204
Electrical Engineering Lab

EXPERIMENT 4
SINUSOIDAL SIGNALS

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EXPERIMENT 4
SINUSOIDAL SIGNALS

OBJECTIVE

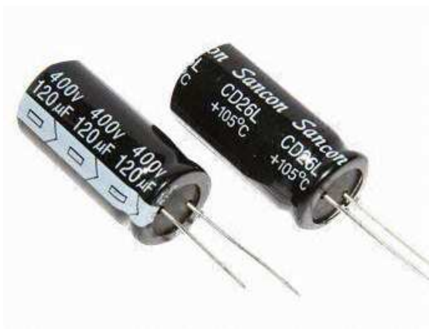
When you complete this experiment, you will have learnt how to read the values of capacitors and inductors from their number or color codes. You will also have investigated the shape and characteristics of a sinusoidal (AC) signal, including the difference between peak-to-peak, average and rms values. In addition, you will have learnt how to use an oscilloscope to display and measure various waveforms, including sinusoids.

DISCUSSION

Capacitors

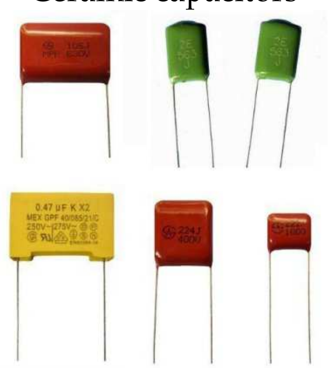
A *capacitor* (also known as a *condenser*) is a passive electrical component that can store energy as an electric field. The forms in which practical capacitors are built vary widely, but all contain at least two electrical conductors (plates) separated by a dielectric (i.e. insulator). The following are some of the most common capacitors used in practice:

Ceramic capacitors



Electrolytic capacitors

Tantalum capacitors



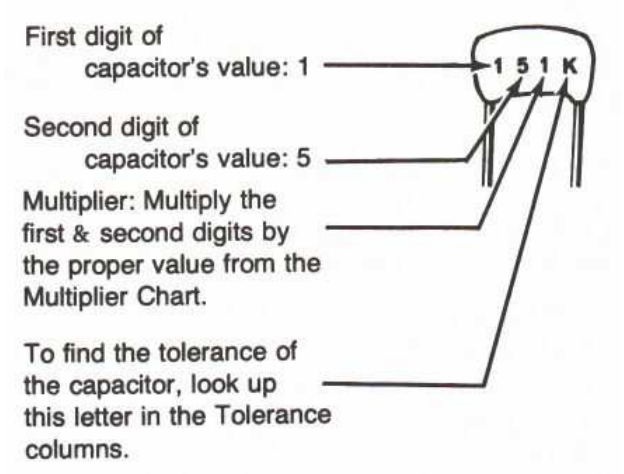
Polyester film capacitors

Variable capacitors (trimmer)

SMT (surface mount technology)

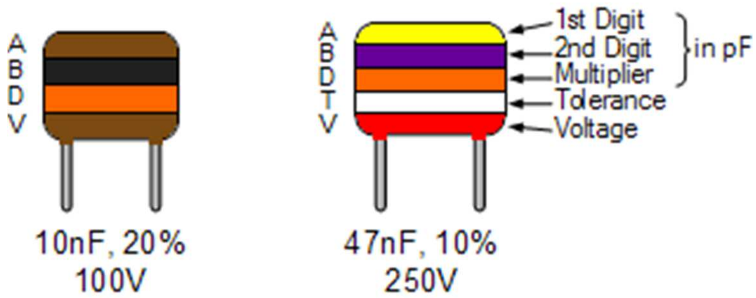
Unlike a resistor, an ideal capacitor does not dissipate energy. Instead, a capacitor stores energy in the form of an electrostatic field between its plates. The capacitance SI unit is the farad (F), which is equal to one coulomb per volt. Typical capacitance values range from about 1 pF (10^{-12} F) to about 1 mF (10^{-3} F). Capacitance values are usually encoded using numbers and letters on the face of the capacitor, but sometimes colors are also used (similar to resistors).

The following shows how to read the capacitance values from both the number/letter code and the color code. Three examples are provided: 150pF, 10 nF and 47 nF. In practice, the dielectric between the plates passes a small amount of leakage current and also has an electric field strength limit, known as the breakdown voltage, which you can also read from the capacitor code.



Values are in pico farad (pF)
Example: **151K** means 150 pF ±10%

For number:	Multiply by:	Letter	Tolerance ≤10pF	Tolerance >10pF
0	1	B	±0.1pF	
1	10	C	±0.25pF	
2	100	D	±0.5pF	
3	1000	F	±1.0pF	±1%
4	10,000	G	±2.0pF	±2%
5	100,000	H		±3%
		J		±5%
8	0.01	K		±10%
9	0.1	M		±20%

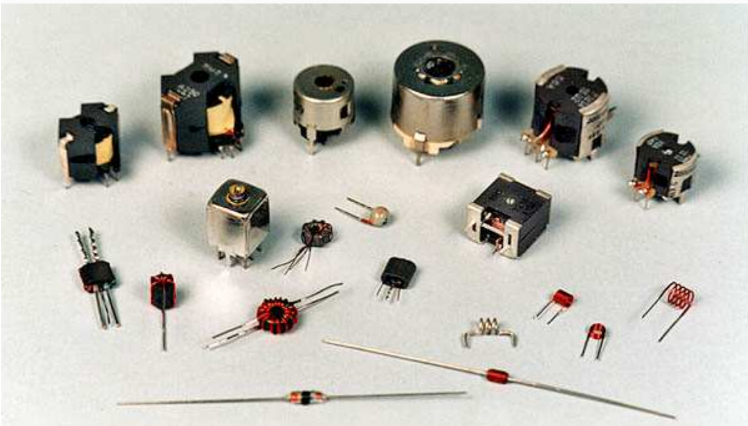


Color		A (1st digit)	B (2nd digit)	D (multiplier)	Tolerance ≤10pF	Tolerance >10pF	V (voltage)
Black		0	0	1	±2pF	±20%	
Brown		1	1	10	±0.1pF	±1%	100V
Red		2	2	100	±0.25pF	±2%	250V
Orange		3	3	1000		±3%	
Yellow		4	4	10,000		±4%	400V
Green		5	5	100,000	±0.5pF	±5%	
Blue		6	6	1,000,000			600V
Violet		7	7				
Grey		8	8	0.01		+80%,-20%	
White		9	9	0.1	±1pF	±10%	
Gold				0.1		±5%	
Silver				0.01		±10%	

Inductors

An inductor (also known as *coil* or *choke*) is a passive electrical component that resists *changes* in electric current passing through it. It consists of a wire wound into a coil. When a current flows through it, energy is stored temporarily as a magnetic field in the coil. When the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor, according to Faraday's law of electromagnetic induction, which opposes the change in current that created it.

The unit for inductance is the Henry (H). Inductors have values that typically range from 1 μH (10^{-6}H) to 1 H. Many inductors have a magnetic core made of iron or ferrite inside the coil, which serves to increase the magnetic field and thus the inductance. The following are some of the most common forms of practical inductors:



Inductance values are usually encoded using numbers and letters on the casing of the inductor, and sometimes using colors. To read this code, follow the same rules for the capacitor, except that you read the inductance value in μH (instead of pF for the capacitor). It is also important to remember that a practical inductor has a small internal resistance, so you have to be careful in experimenting with inductors as you sometimes need to represent an inductor as a series combination of an ideal L element (the inductance) in series with R_{DC} (the internal resistance of the inductor).

Measurement of capacitance and inductance in the laboratory can be performed using an RLC meter. Simply set the test frequency of the RLC meter, its function (L or C), and then connect it in parallel with the component you want to measure.

Sinusoidal Signal Characteristics

Sinusoidal signals are prevalent in our lives, as the electricity grid makes use of them extensively. When dealing with a sinusoidal signal $v(t) = V_p \sin(\omega t) = V_p \sin(2\pi f t)$, we can refere to any of its identifying properties, such as (see also the figure below):

Peak value or **magnitude** or **amplitude**: the maximum possible value attained by the sinusoidal waveform compared to the zero level, which is V_p in the above sinusoidal $v(t)$ signal (see figure).

Peak-to-Peak value: the difference between the signal maximum positive value (positive peak) and the maximum negative value (negative peak). For a sinusoidal signal $v(t)$ with peak value of V_p, the peak-to-peak value is $V_{p-p} = 2V_p$.

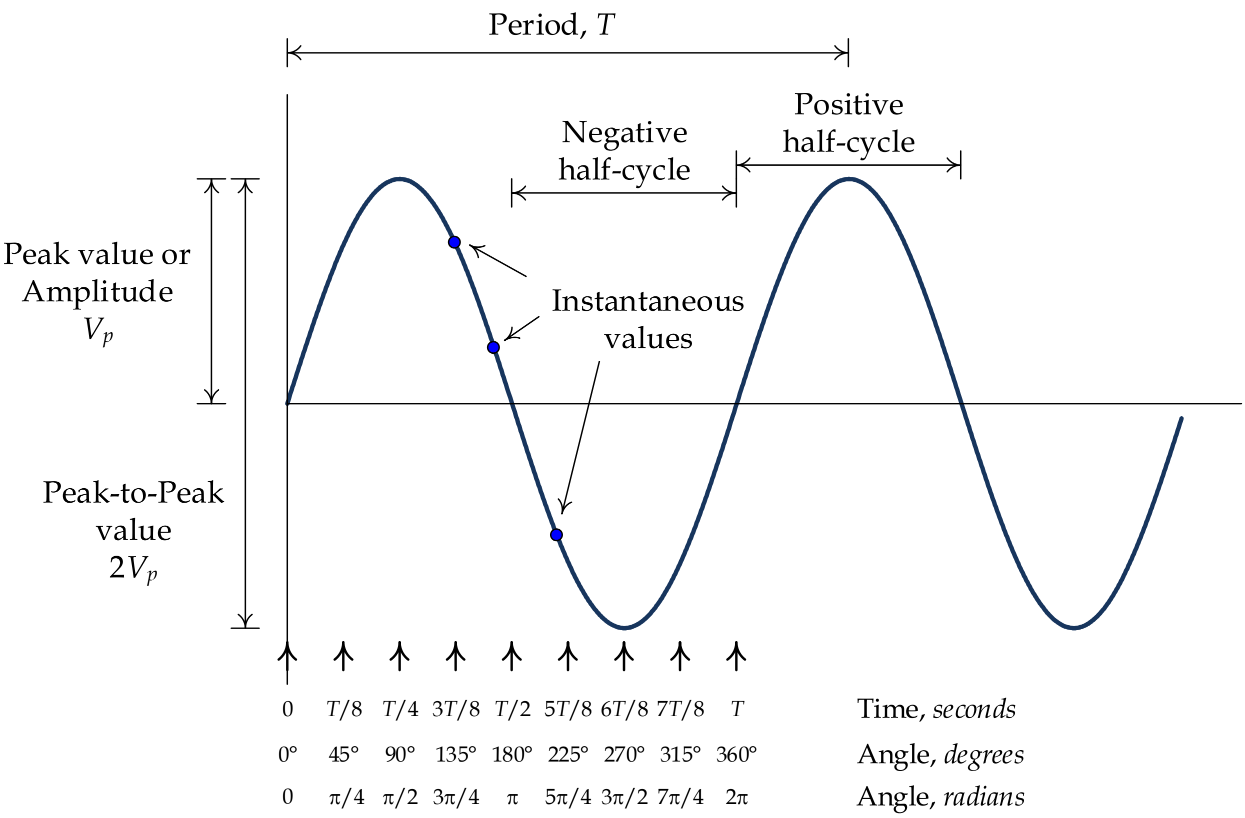
Root mean square value (**RMS** or **R.M.S.** or **rms**) or **effective value**: equal to the square root of the arithmetic mean of the squares of the signal instantaneous values over one cycle. For alternating electric current, the rms value represents the value of the equivalent direct current that would produce the same average power dissipation in a resistive load. For a sinusoidal signal $v(t)$ with peak value of V_p, the rms value is $V_{rms} = V_p/\sqrt{2}$.

Average value or **DC offset** or **DC shift** or **DC value**: the mean of the instantaneous values of the signal over one complete cycle. It represents the amount of shift from the zero level for the horizontal line of symmetry (i.e., the line midway between the positive half-cycle and negative half-cycle) for the sinusoidal signal. For the above AC voltage $v(t)$, the DC offset is zero.

Period or **cycle length**: the smallest value of time T after which the periodic sinusoidal signal repeats itself. The period is measured in units of seconds.

Frequency: the number of complete cycles that exist in the sinusoidal waveform in one second. For a sinusoidal signal with period T, the frequency is $f = 1/T$ in units of Hertz (Hz).

Radial Frequency: measured in radians, and is related to frequency as $\omega = 2\pi f = 2\pi/T$.



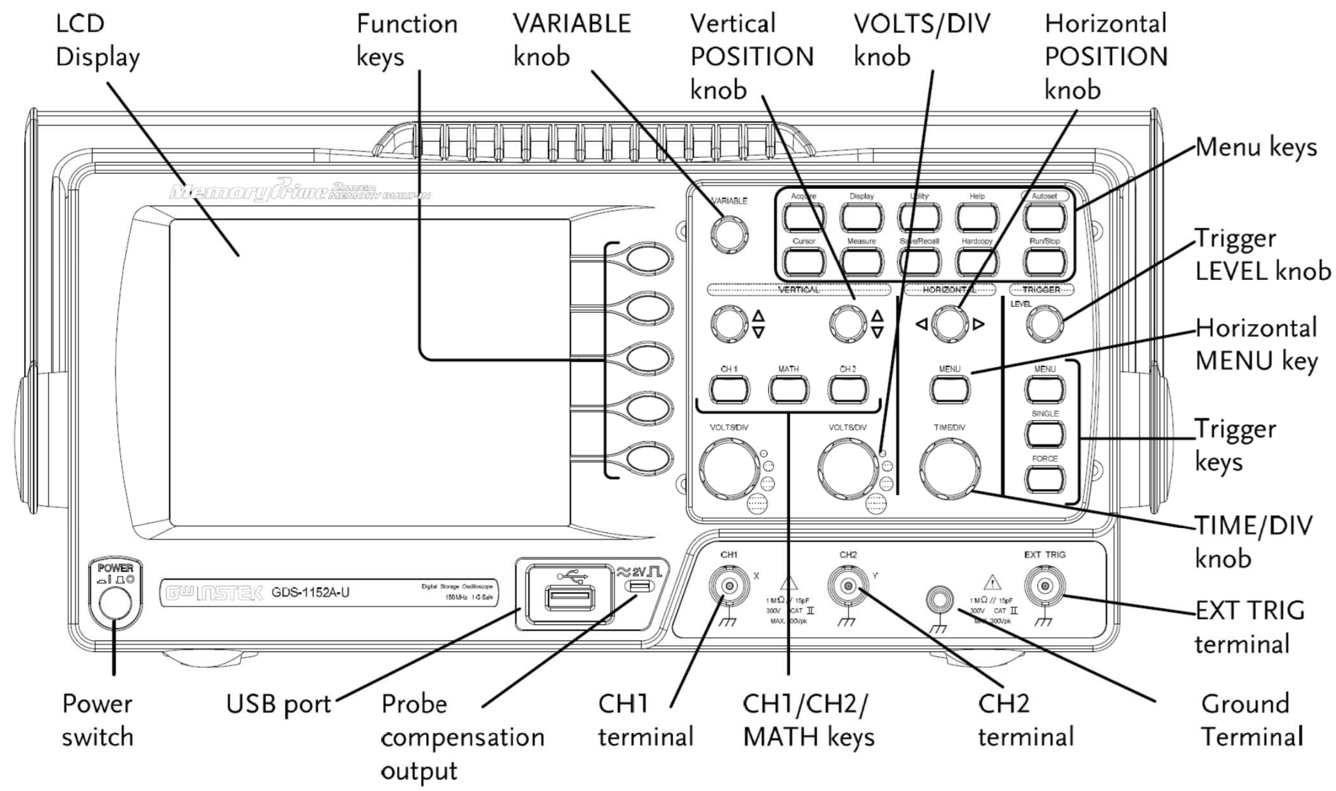
When instantaneous values for a sinusoidal signal are mentioned, they are given for a certain instant of time in seconds (for example, when $t = T/4$ seconds or when $t = T$ seconds), but sometimes instantaneous values are given when the argument (angle) of the sinusoidal waveform is a certain value (for example, when $\omega t = \pi/2$ radians or when $\omega t = 2\pi$ radians). The equivalent of these angle values in degrees is 90° and 360°, repsectively.

It is worth mentioning that oscilloscopes can measure the instantaneous values of a sinusoidal signal, as well as its peak, rms and peak-to-peak values, in addition to its period, frequency and phase shift, while voltmeters and ammeters can only measure rms values for sinusoidal signals.

The Oscilloscope

An oscilloscope is a measurement device designed to measure and display voltages. Unlike a voltmeter, however, an oscilloscope does not display a single number. Instead, it displays signals (waveforms) that are functions of time. Such a signal shape allows you to measure certain signal parameters, such as its frequency, period, peak-to-peak voltage, DC offset value (average value), phase shift, pulse width, rise time, delay time, etc. Notice that the oscilloscope is suitable for displaying signals that are periodic (i.e., repeat themselves in time), such as sinusoidal, triangular and square wave signals. Only new oscilloscope models can display *aperiodic* signals, but not the older models.

The oscilloscope has extremely high input impedance (1 MΩ parallel with 25 pF), which means it will not significantly affect the input signal when connected in parallel with the circuit. The oscilloscope screen almost always has 8 squares (divisions) on the vertical axis (which indicates voltage), and 10 squares (divisions) on the horizontal axis (which indicates time). The oscilloscope consists of **five** subsystems (see below): Horizontal controls, Vertical controls, Trigger controls, Quick measurement controls and Function keys.



The main **Horizontal** controls are:

- **Scale (Time-Per-Division)**: Determines the amount of time displayed.
- **Position**: Moves the waveform left and right (horizontally) on the display.

The main **Vertical** controls are:

- **Scale (Volts-Per-Division)**: Varies the size of the waveform on the screen.
- **Position**: Moves the waveform up and down (vertically) on the display.
- **Input coupling**: Determines which part of the signal is displayed as follows:
  - *DC Coupling*: Shows all of the input signal.
  - *AC Coupling*: Blocks the DC component of the signal, centering the waveform at 0 volts.
  - *Ground Coupling*: Disconnects the input signal to show where 0 volts is on the screen.

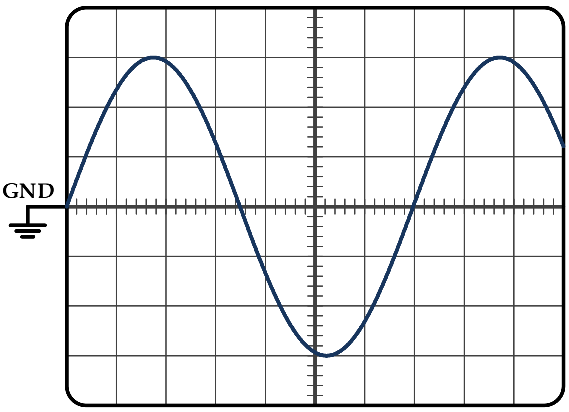
The main **Trigger** controls are:

- **Source**: Determines which signal is used for triggering the sweep.
- **Level**: Determines where on the edge of the source signal the trigger point occurs.
- **Slope**: Determines whether the trigger point is on the rising edge (positive slope) or the falling edge (negative slope) of the source signal.

The main **Quick measurement** controls are:

- **Autoset:** Adjusts horizontal, vertical and trigger settings automatically to display the input signals.
- **Cursor**: Places two horizontal or vertical lines (cursors) on top of the trace so the user can easily read values from the display.
- **Measure**: Automatically measures certain parameters from the screen (see Experiment 6).

An example oscilloscope screen displaying a sinusoidal waveform is shown to the right. You can read the amplitude and frequency of this sinusoidal signal if you are given the vertical scale and horizontal scale of the screen. For example, assume that the vertical scale is 2 Volt/DIV while the time scale is 0.5 msec/DIV, then the peak amplitude of this sinusoidal signal is 3 DIV × 2 Volt/DIV = 6 Volt, while its period is 7 DIV × 0.5 msec/DIV = 3.5 msec. The frequency of the sinusoidal signal is the inverse of period, which is $f = 1/T = 1/3.5$ ms = 285.7 Hz.



PROCEDURE A – CAPACITORS AND INDUCTORS

1. You will be provided with three capacitors C_1, C_2, and C_3 in the Lab. Use their color or number/letter coding to read their nominal values, tolerances and break down voltage. Record that information in Table 1. Also note the type of the capacitor: ceramic, electrolytic, etc in the table.

Table 1

	C_1	C_2	C_3
Code or color on the capacitor			
Nominal Value			
Tolerance (%)			
Breakdown voltage			
Capacitor type			
Measured @ f_1			
Deviation (%)			
Measured @ f_2			
Deviation (%)			

2. Use the RLC meter to measure the actual value for each of the three capacitors. Use the two available frequencies in the RLC meter. Record the results in Table 1. Also record the deviation between the nominal value and the measured value as a percentage, calculated as:

$$Deviation = \frac{Measured - Nominal}{Nominal} \times 100\%$$

3. What are the two frequencies f_1 and f_2 that the RLC meter uses for its measurements?

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4. You will also be provided with two inductors L_1 and L_2 in the Lab. Use their color or number/letter coding to read their nominal values and tolerances. State the code, nominal value and tolerance in Table 2.

5. Use the RLC meter to measure the actual value for the inductor, and then evaluate the deviation from nominal value. Use both available frequencies. Record the measured values and deviations in Table 2.

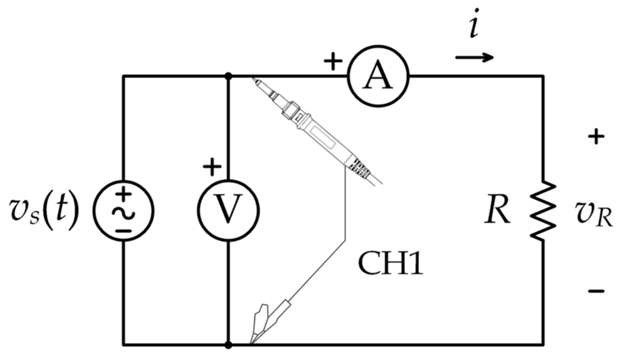
6. Use the RLC meter to measure the internal *series* resistance of each inductor (also known as the inductor DC resistance R_{DC}), which is a property of practical inductors due to the internal resistance of the long wire wound to make up the inductor? Record this resistance value at the two test frequencies in Table 2.

Table 2

	L_1		L_2	
Code or color on the inductor				
Nominal Value				
Tolerance (%)				
Measured @ f_1				
Deviation (%)				
Measured @ f_2				
Deviation (%)				
Internal series resistance R_{DC}	@f_1	@f_2	@f_1	@f_2

PROCEDURE B – OSCILLOSCOPE AND PEAK-TO-PEAK VERSUS RMS VALUES

1. Construct the circuit shown below on the breadboard. Assume that R = 3300 Ω. The AC power supply here is the function generator, not the DC supply you used in earlier parts.



2. Make sure you connect the voltmeter, ammeter and oscilloscope with the correct polarity. Set the voltmeter and ammeter to measure AC (not DC). CH1 indicates channel 1 probe of the **oscilloscope**.

3. Set Channel 1 of the oscilloscope to 0.5 V/DIV and set the sweep to 0.25 ms/DIV. Set the coupling of Channel 1 to DC, and set the Trigger Source to CH1. Switch off Channel 2 of the oscilloscope.

4. Make sure the vertical position of the oscilloscope is set to zero. You can do that by noticing the movement of the small triangle to the left of the oscilloscope screen as you adjust the vertical position knob. Make sure it points exactly to the middle of the screen.

5. Set the function generator to produce a **sinusoidal waveform** (AC) with frequency of 1 kHz, and *peak voltage* of V_p = 1.5 V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift (positive or negative). Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

6. If the vertical position or horizontal position on the oscilloscope is not set in the middle, perform the necessary adjustments. How many cycles of the sinusoidal wave do you see on the oscilloscope screen?

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7. Increase the frequency of the sinusoidal signal using the function generator controls. What do you see on the oscilloscope screen?

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8. Decrease the frequency of the sinusoidal signal using the function generator controls. What do you see on the oscilloscope screen?

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9. How do you increase the voltage level coming out of the function generator?

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10. Now increase the voltage level from the function generator. What do you see on the oscilloscope screen?

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11. If you increased the signal voltage level from the function generator until it exceeds the screen limits of the oscilloscope, what should you do to see the signal again on the oscilloscope screen?

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12. What other signal shapes (other than sinusoidal wave) can the function generator produce? See them on the oscilloscope screen.

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13. Now make sure the vertical position of the oscilloscope is set to zero. You can do that by noticing the movement of the small triangle to the left of the oscilloscope screen as you adjust the vertical position knob. Make sure it points exactly to the middle of the screen.

14. Bring the function generator signal back to 1 kHz frequency sinusoidal wave with *peak voltage* of $V_p = 1.5$ V.

15. What is the period (one cycle) of the above sinusoidal wave signal in units of horizontal screen divisions and also in units of milliseconds?

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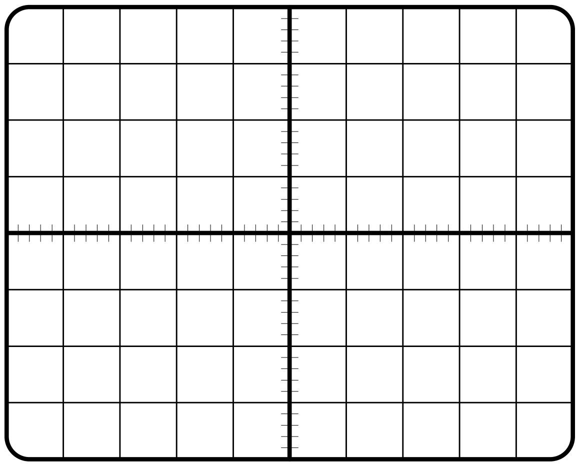
16. Draw what you see on the oscilloscope screen below. Make sure you have Channel 1 of the oscilloscope set to 0.5 V/DIV and the sweep set to 0.25 ms/DIV.



17. Use theoretical analysis to determine the **rms value** of the source voltage $v_S(t)$ and the current in the circuit $i(t)$ at the different frequencies shown in Table 3. Record these values in the table? What equation should you use to calculate the current in rms from the peak source voltage V_p?

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18. *Measure* the peak-to-peak value V_{p-p} of the source voltage using the oscilloscope screen at the different frequencies and record them in the first column of Table 3.

CAUTION: Whenever you change the frequency of the function generator, verify the period of the signal from the oscilloscope. Also re-check the peak-to-peak voltage as the function generator might change the amplitude when you change the frequency.

Table 3

AC Source Frequency (Hz)	**Source V_{p-p} (V) (Oscilloscope)**		**Source V_{rms} (V) (Oscilloscope)**		**Source V_{rms} (V) (Voltmeter)**		**I_{rms} (mA) (Ammeter)**	
	Theory	**Meas.**	**Theory**	**Meas.**	**Theory**	**Meas.**	**Theory**	**Meas.**
100								
1000								
2000								

19. Evaluate the *measured* rms value V_{rms} of the source voltage using the peak-to-peak oscilloscope reading, and record this in the second column of Table 3.

20. Now use the voltmeter to read the *measured* rms value V_{rms} of the source voltage, but record the answer this time in the third column of Table 3. How are the voltmeter and oscilloscope different in reading the AC voltage?

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21. What extra information about the source voltage can the oscilloscope provide, which the voltmeter cannot provide?

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22. Use the ammeter to *measure* the rms value I_{rms} of the current, and record the answer in the last column of Table 3. Are the measurements close to the theoretical answers?

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23. Does the resistor change its impedance $\mathbf{Z_R}$ with frequency?

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24. What if you only had an oscilloscope without an ammeter. How would you be able to measure the current in the circuit in rms? *Explain* clearly.

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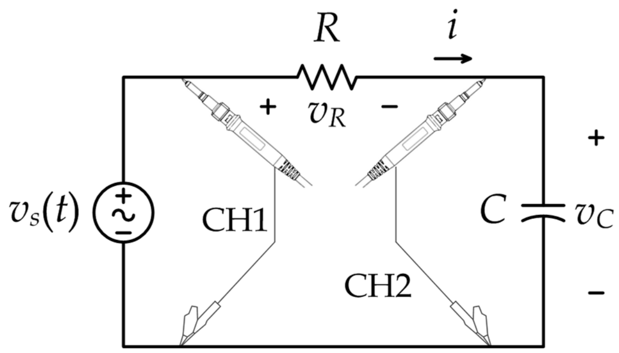
PROCEDURE C – AC-EXCITED CIRCUIT

1. Construct the circuit shown below. Assume that R = 3300 Ω and C = 0.1 μF.



2. Set the function generator to produce a sinusoidal waveform (AC) with frequency of 300 Hz, and *peak voltage* of $V_p = 4$ V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Use theoretical AC steady-state analysis to determine the voltages in the circuit $v_S(t)$ and $v_C(t)$ at the time instances shown in Table 4. Record these values in the table? Also explain below the complex-number equations you used to calculate the complex quantities $\boldsymbol{V_S}$ and $\boldsymbol{V_C}$, and how did you convert the results into $v_S(t)$ and $v_C(t)$.

. . . .

4. Use the oscilloscope screen to measure the actual times (in ms) plus the instantaneous values of the voltages $v_S(t)$ (using channel 1 of the oscilloscope) and $v_C(t)$ (using channel 2 of the oscilloscope). Record these values in Table 4 for all required time instants. Use as your reference (i.e., when $t = 0$) the point in time in which $v_S(t)$ crosses zero from negative to positive value. Remember that you can change the oscilloscope horizontal sweep settings to get more accurate readings. Alternatively, to speed up your work, you can use the cursor feature of the oscilloscope as explained below. Are the measured values close to the theory-based answers?

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Table 4

Time since positive zero crossing for $v_S(t)$	Time t (in ms)		Voltage $v_S(t)$		Voltage $v_C(t)$	
	Theory	**Meas.**	**Theory**	**Meas.**	**Theory**	**Meas.**
$t = 0$	0		0 V			
$t = T/8 \equiv 45°$						
$t = T/4 \equiv 90°$	0.8333		4 V			
$t = 3T/8 \equiv 135°$						
$t = T/2 \equiv 180°$						
$t = 5T/8 \equiv 225°$						
$t = 6T/8 \equiv 270°$						
$t = 7T/8 \equiv 315°$						
$t = T \equiv 180°$	3.3333		0 V			

5. Using the measured values in Table 4, plot (**by hand**) the following figure using the graph paper attached at the end of the report: $v_S(t)$ and $v_C(t)$ on the same plot versus time. Make sure you include one full cycle of $v_S(t)$ in the plot.

<u>USING THE OSCILLOSCOPE CURSOR</u>

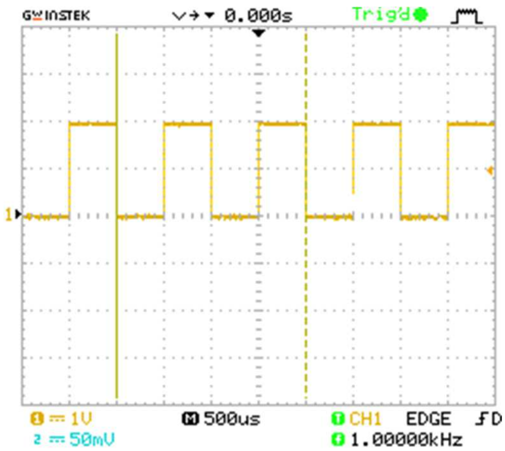
Newer digital oscilloscopes have extra features that can make the life of an engineer easier. For example, if you want to skip the process of converting vertical and horizontal divisions into voltages and seconds, respectively, you can use the cursor feature in the oscilloscope.

For Table 5 measurements in this experiment try the following steps to measure the time difference between two points on the oscilloscope screen.

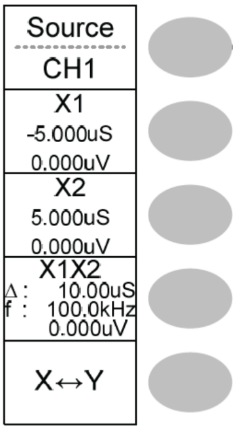
CAUTION: You still need to know how to work with the oscilloscope's vertical and horizontal divisions since this is a skill that will be tested in the exam.

a. On the oscilloscope turn the cursors feature ON by pressing the "Cursor" key.

b. Two vertical cursors will show up on the oscilloscope screen.



c. The function keys next to the oscilloscope screen allow you to control the cursors and will automatically calculate the time difference between such cursor positions.



d. The first function key selects the channel you want to measure. In this case it is CH1 of the oscilloscope.

e. Pressing the second function key allows you to move the X1 cursor by adjusting the VARIABLE knob clockwise and counter-clockwise. The voltage value at the cursor is also displayed.

f. Pressing the third function key allows you to move the X2 cursor by adjusting the VARIABLE knob. The voltage value at the cursor is also displayed.

g. The time difference between X1 and X2 cursors is continuously calculated and displayed next to the fourth function key. This key moves both cursors simultaneously.

h. If you need to measure voltage difference instead of time difference, the fifth function key switches to horizontal cursors instead of vertical ones.

**** End ****