BIRZEIT UNIVERSITY

Faculty Of Engineering and Technology

Electrical and Computer Engineering Department

CIRCUITS AND ELECTRONICS LABORATORY

ENEE 2103

Experiment #: 4

Sinusoidal Steady State Circuit Analysis

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Section: 4

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1.Abstract:
The aim of this experiment is to measure the circuit elements impedances and voltage and current phasor, and to verify the validity of the circuit theorems in the sinusoidal steady state, also to measure the power in sinusoidal steady state circuits, by using the Oscilloscope, the DMM, the Wattmeter for AC electric quantities measurements.

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2.Theory

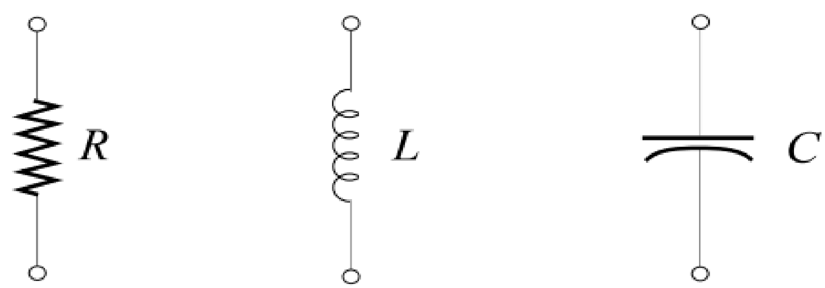
2.1. Impedance

The impedance characteristics of common circuit elements (resistors, capacitors, inductors) utilized in circuit theory are simply low-frequency asymptotes of the overall frequency responses of these components.

Impedance, represented by the symbol Z, is a measure of the opposition to electrical flow. It is measured in ohms.

For DC systems, impedance and resistance are the same, defined as the voltage across an element divided by the current (R = V/I).

In AC systems, the "reactance" enters the equation due to the frequency-dependent contributions of capacitance and inductance. Impedance in an AC system is still measured in ohms and represented by the equation Z = V/I, but V and I are frequency-dependent. [1]



$$\boldsymbol{Z}_R = \boldsymbol{R} \qquad \boldsymbol{Z}_L = j\omega \boldsymbol{L} \qquad \boldsymbol{Z}_C = \frac{1}{j\omega \boldsymbol{C}}$$

2.2.Sinusoidal steady state analysis using phasor

A sinusoidal voltage source (dependent or independent) produces a voltage that varies as a sine wave with time. A sinusoidal current source (dependent or independent) produces a current that varies with time. The sinusoidal varying function can be expressed either with the sine function or cosine function. Either works equally as well; both functional forms cannot be used simultaneously. Using the cosine function throughout this article, the sinusoidal varying voltage can be written as:

$$v = V_m \cos(\omega t + \phi)$$

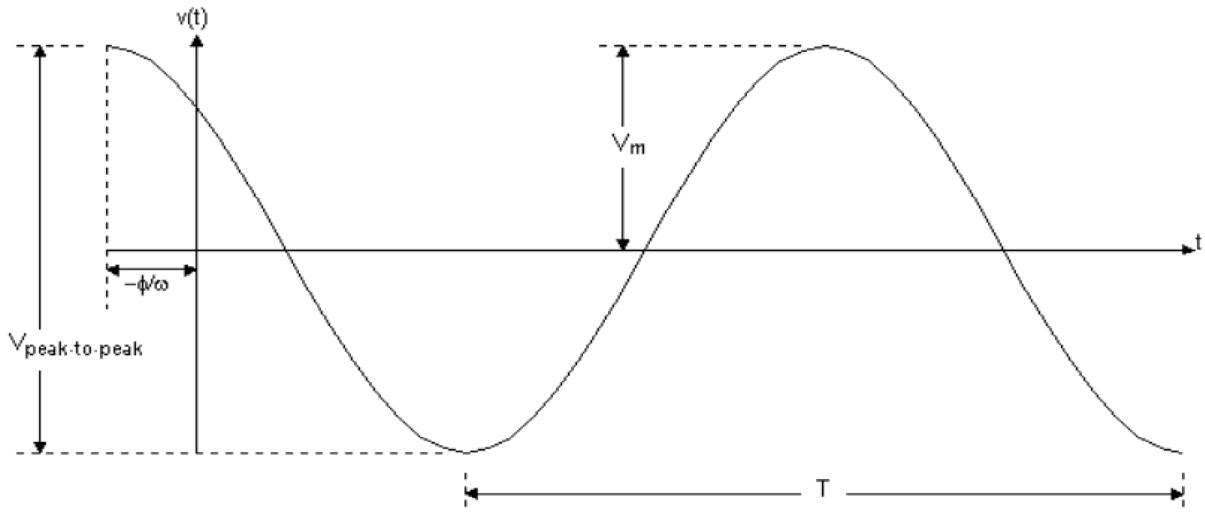


Figure 2.2.1:The voltage versus time plot

this sinusoidal function above repeats continuously on a regular interval. Such a function of regular intervals, is called periodic. One key parameter is the length of time required for the sinusoidal function to pass through all its possible values. The time required to pass through all possible values is known as the period of the function and is denoted as *T*. The period of the sinusoidal function is measured in seconds. Taking the reciprocal of *T* gives the number of cycles per second, or the frequency, of the sine function and is denoted *f*, where $f=1/T$.

A cycle per second is referred to as a hertz, or abbreviated as Hz. In the sinusoidal voltage equation, the coefficient *t*, contains the value of *T* or *f*. Omega (ω) represents the angular frequency of the sinusoidal function, where $\omega=2\pi f=2\pi/T$(radians/second).[2]

2.3. Power in sinusoidal steady state circuits

Power is the rate at which work is done by an electrical component. It tells us how much heat will be produced by an electric furnace, or how much light will be generated by a bank of fluorescent tubes. It is also important to know the power rating of a device so that we can ensure that its rating is not exceeded.[3]

When voltage and current vary with time their product is instantaneous power.

This equation $\mathbf{p(t) = \pm v(t) * i(t)}$ refers to instantaneous power which is positive when power is consumed (load) and is negative when power is produced (source). If we assume that the element is a resistor then voltage and current are in phase:

$V(t) = V_p \cos wt$

$I(t) = I_p \cos wt$

The equation become: $p(t) = (V_p \cos wt) * (I_p \cos wt)$

the power rating on all AC equipment is the average power dissipated over one cycle. From now on the term “power” will mean “average power over one cycle” unless stated otherwise. The most straightforward way to determine the average power dissipated over one cycle is to integrate p(t) over one cycle and divide the result by the periodic time. Once again let us assume that the element is a resistor then this becomes:

$$P = \frac{1}{T}\int_0^T v(t)i(t)dt$$

In sinusoidal steady-state:

$$v(t) = V_P \cos \omega t$$
$$i(t) = I_P \cos \omega t$$
$$T = \frac{2\pi}{\omega}$$

After reduce the equation : P = Vp Ip /2

3.Procedure & Discussion

3.1.Impedance

We first connected the circuits in figure 3.1.1 and sat the signal generator to generate a sinusoidal waveform with amplitude 5 volts and frequencies 1 kHz, 500Hz and 1500Hz. Output measurements are in table1.

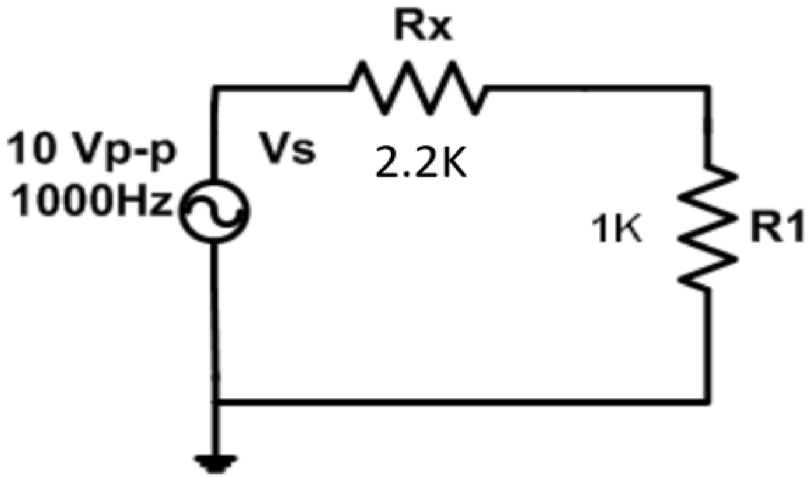


Figure 3.1.1: first circuit with R1

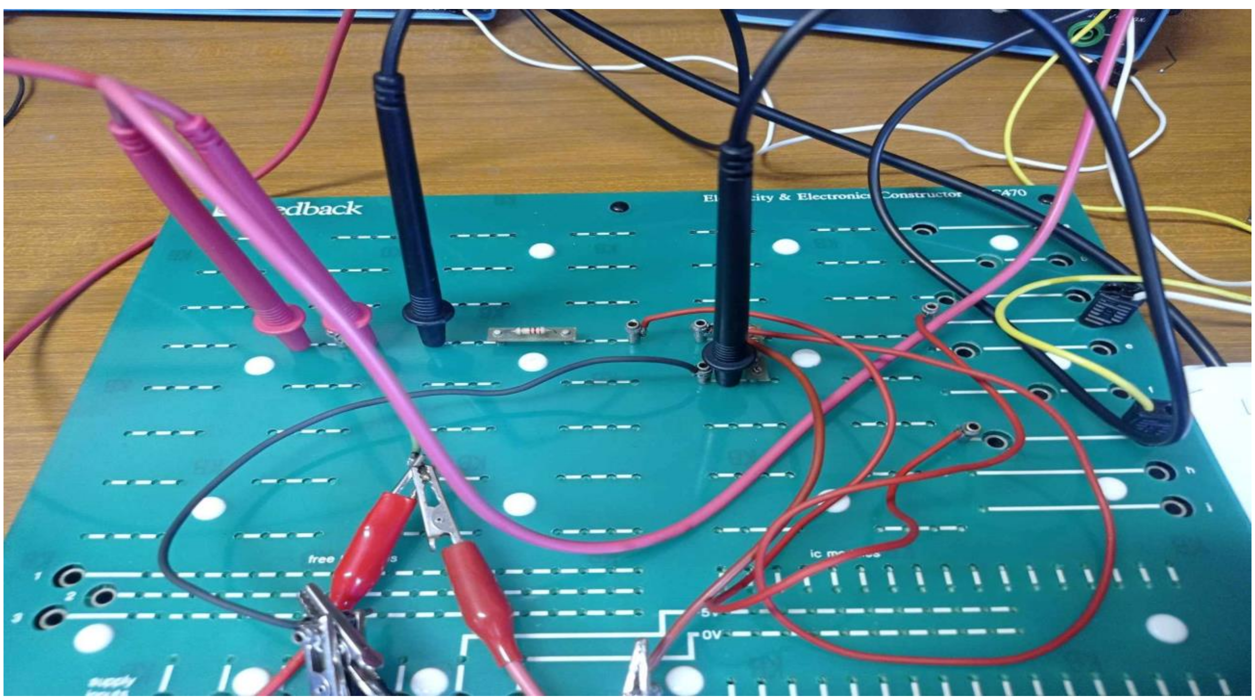


Figure 3.1.2: the first circuit after connected

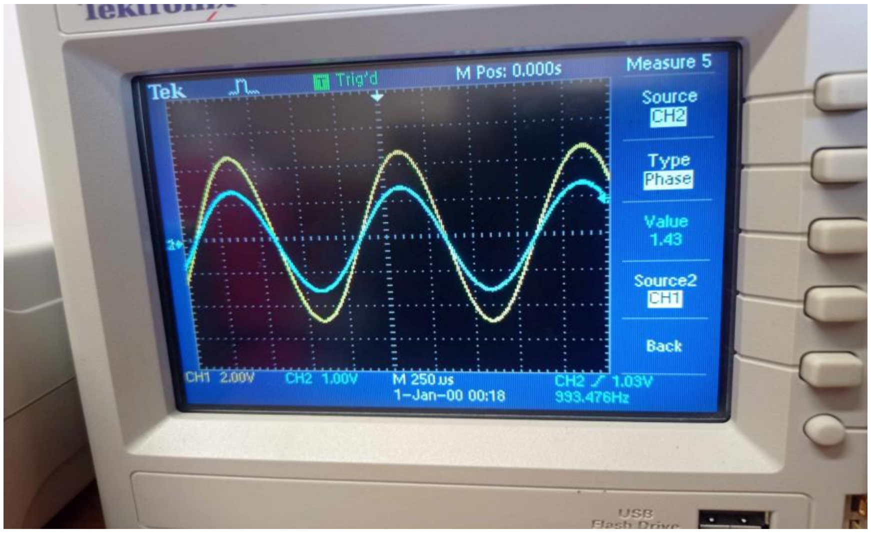


Figure 3.1.3: voltage and current representation for the first circuit

F[Hz]	Vrms	Irms	Phase shift
500	3.35v	1.03mA	0
1k	3.35v	1.03mA	0
1.5k	3.35v	1.03mA	0

Table1: results for first circuit

We have noticed from these results that Phase shift in all three cases after changing the frequency is zero, because the circuit is doesn't have capacitor or inductor.

- Total current = 1.03A

- total voltage = 3.35 V

total impedance = V/I =3.35/1.03 = 3.25 ohm, which approximately equals to the total resistance in the circuit.

The circuit below is RC circuit with 100nf capacitor, and 2.2k, 1k resistor.

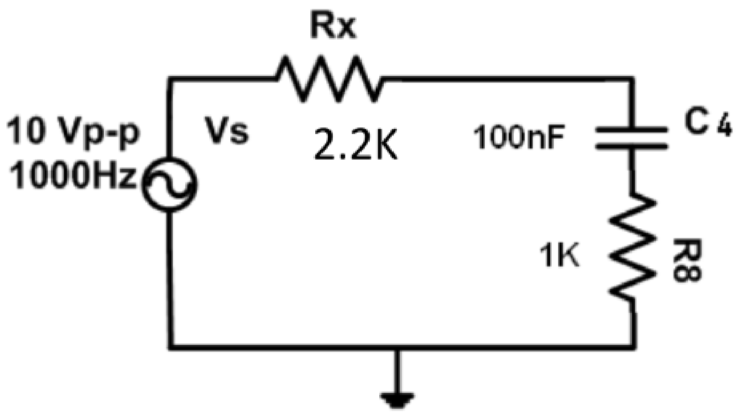


Figure 3.1.4: second circuit with R and C

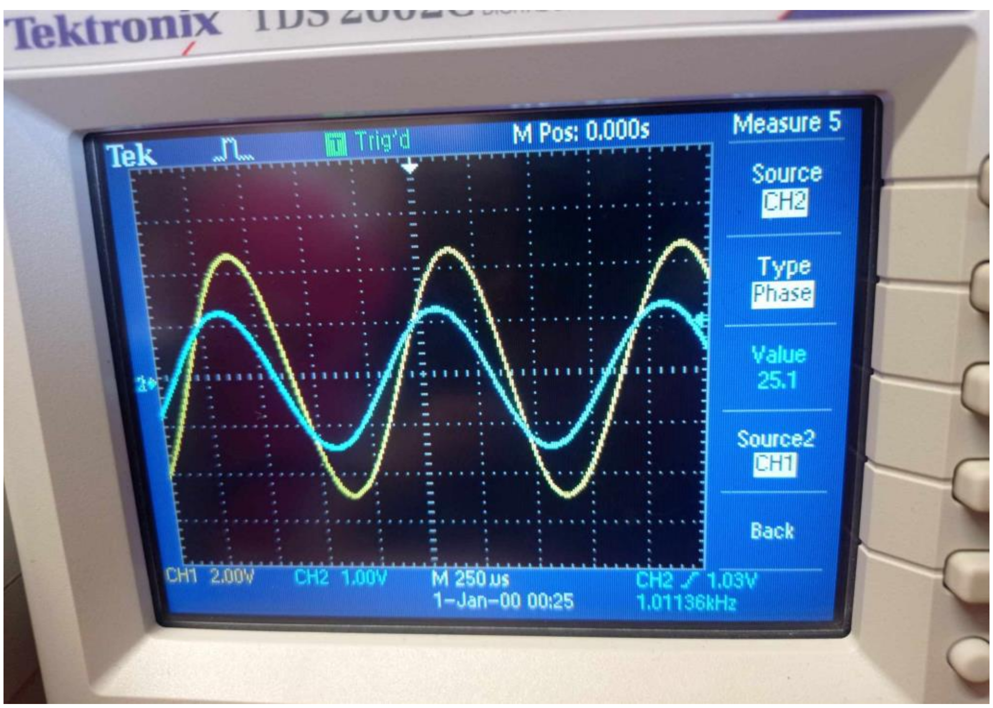


Figure 3.1.5: voltage and current representation when f=1kH

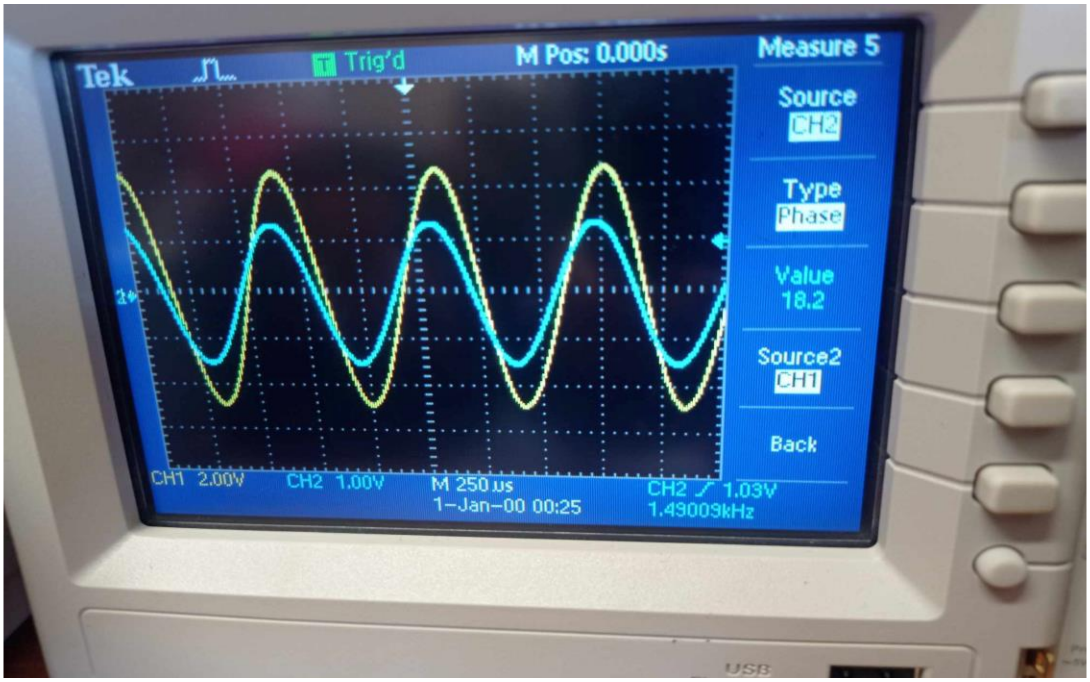


Figure 3.1.6: voltage and current representation when f=1.5kH

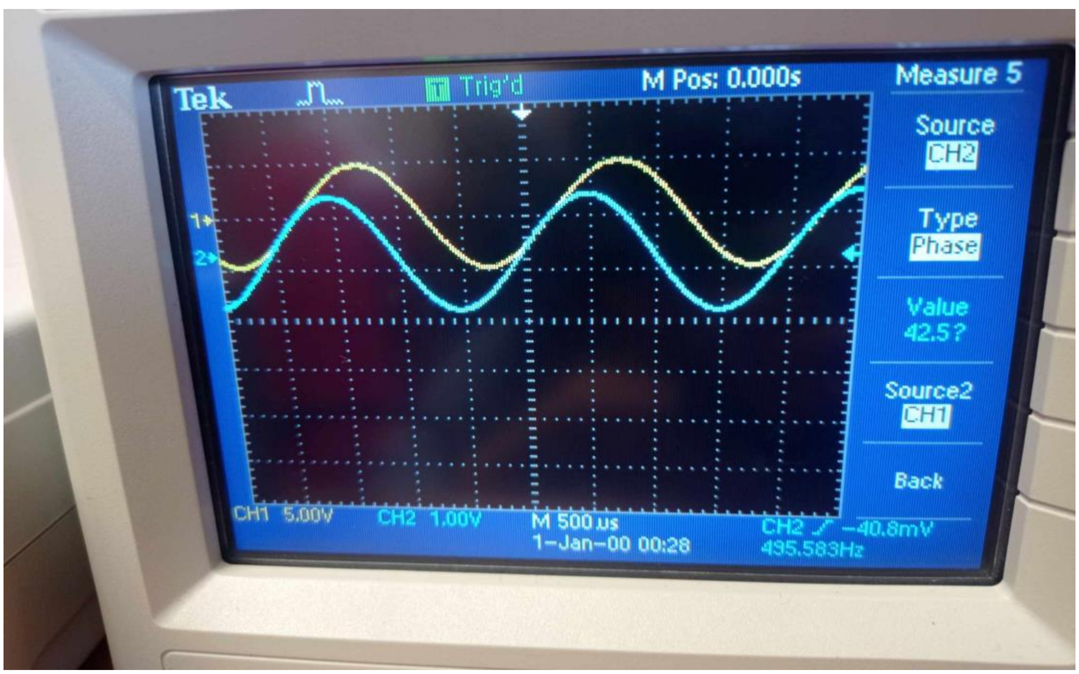


Figure 3.1.7: voltage and current representation when f=500H

F[Hz]	Vrms	Irms	Phase shift
500	3.3	0.95mA	42.1
1k	3.3v	1.769mA	25.5
1.5k	3.3v	1.015mA	18.2

Table2: results for second circuit

We have noticed from these results That the output signal in the three cases has a phase shift, because of the capacitors inherent properties.

- The phase shift decreases with increasing the frequency. This is because the R-C circuit behaves capacitive at low frequencies and resistive at high frequencies.

The circuit below is RL circuit with 400mH inductor and 0.47k,1k resistor.

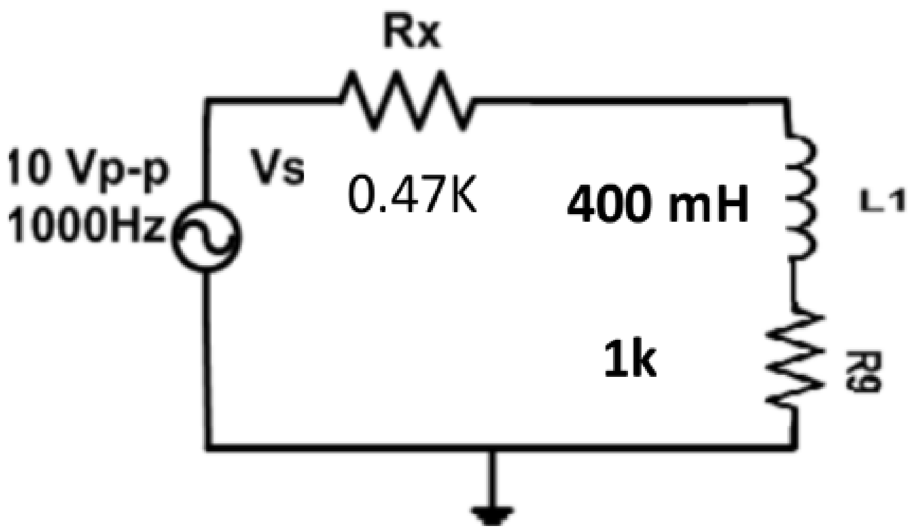


Figure 3.1.8: third circuit with R and L

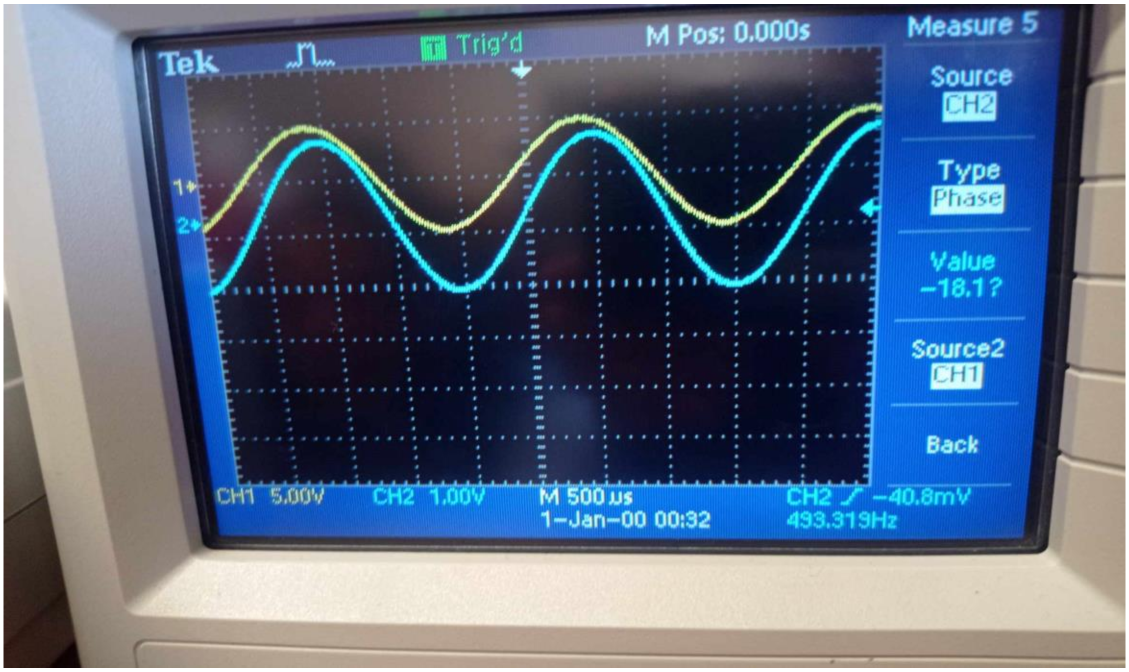


Figure 3.1.9: voltage and current representation when f=500H

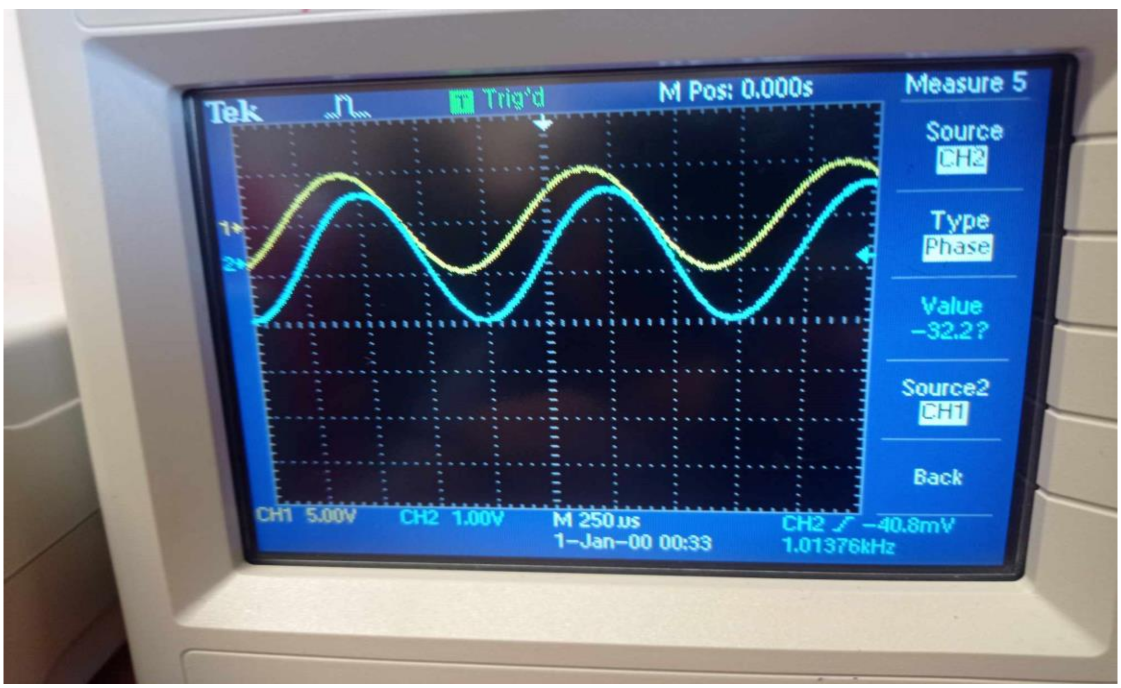


Figure 3.1.10: voltage and current representation when f=1kH

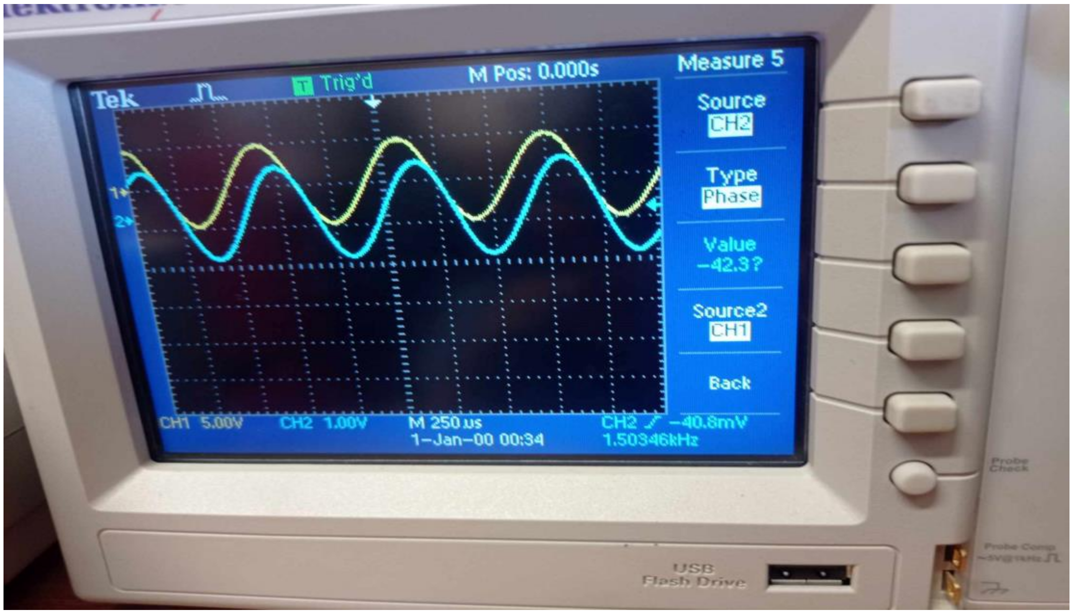


Figure 3.1.11: voltage and current representation when f=1.5kH

F[Hz]	Vrms	Irms	Phase shift
500	3.3	0.978mA	-17.5
1k	3.3v	0.8728mA	-31.4
1.5k	3.3v	0.754mA	-42,2

Table3: results for third circuit

We have noticed from these results That when the frequency increases, phase shift increase.

3.2. Capacitive and inductive behavior

We first connected the circuit in figure 3.2.1, and sat the signal generator to generate a sinusoidal waveform with amplitude 5 volts and frequency 1 kHz, then we measured the phase shift between the total current and the voltage. We repeated the same steps for 2K, 4K, 6K and 8K.

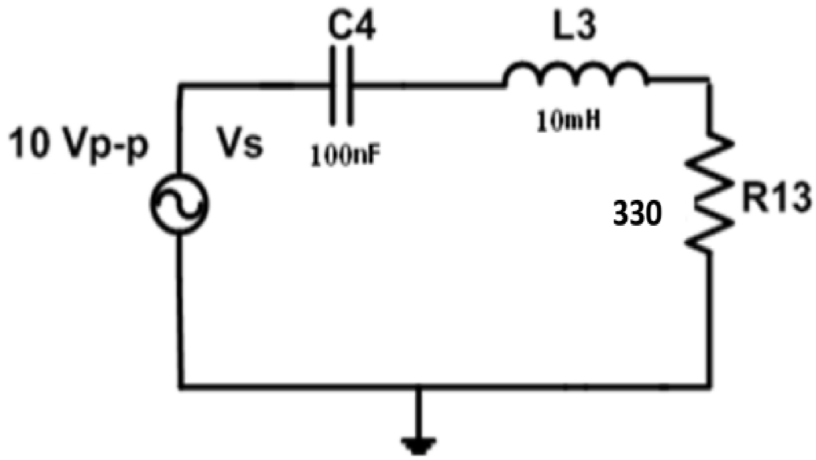


Figure 3.2.1: circuit with R & L & C

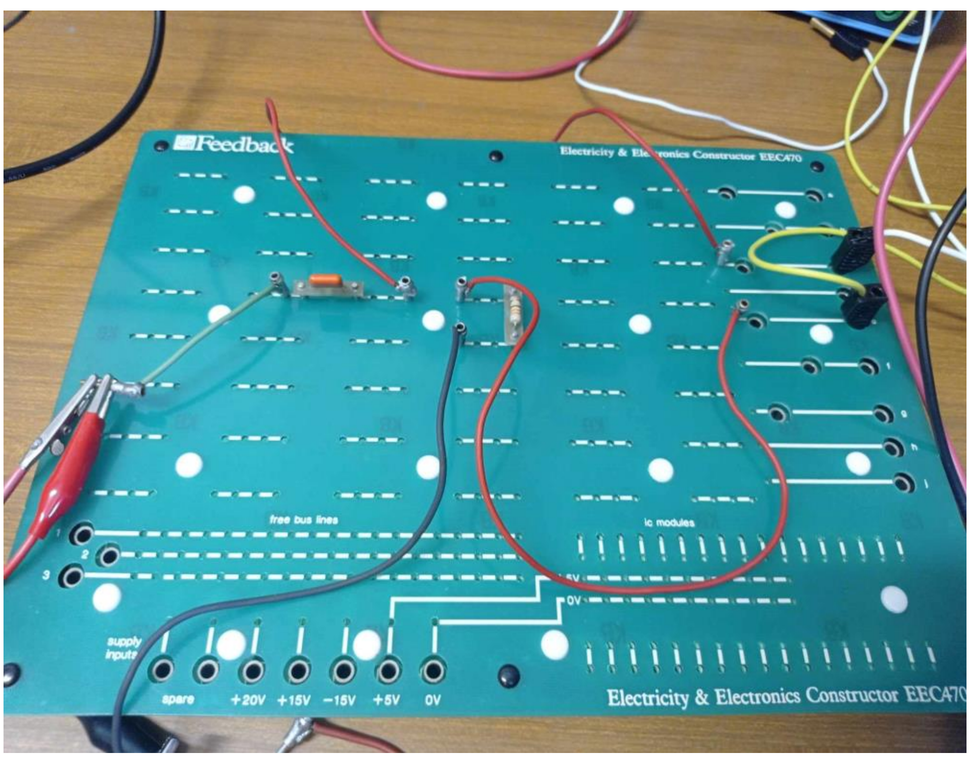


Figure 3.2.2: circuit connected

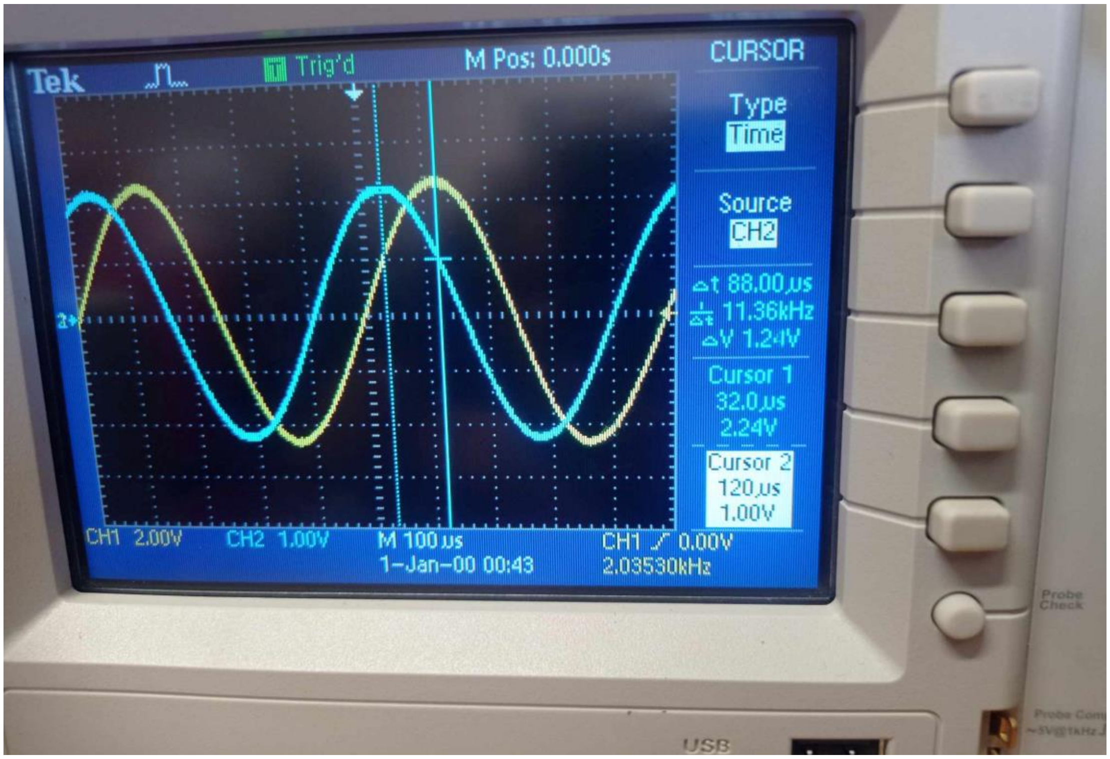


Figure 3.2.3: finding delta t when f=2k

f	1k	2k	4k	6k	8k	fo
Delta t	-	88us	-	-	-	-
Phase shift(vs-is)	77.3	61.4	19.5	-21.7	-44.5	0

Table 4: results of measurements of R & L & C circuit

From figure 3.2.3 we found that delta t when f=2k -> 88us .

We found that resonance frequency fo = 4.8kH we found it from the phase shift, because phase shift equal zero when we reach to resonance frequency that is because the impedance of the inductor equals impedance of capacitor.

As frequency increases the phase shift decreases , then starting to increase as frequency decrease.

After this,we connected another 100nF capacitor in parallel to c2 .

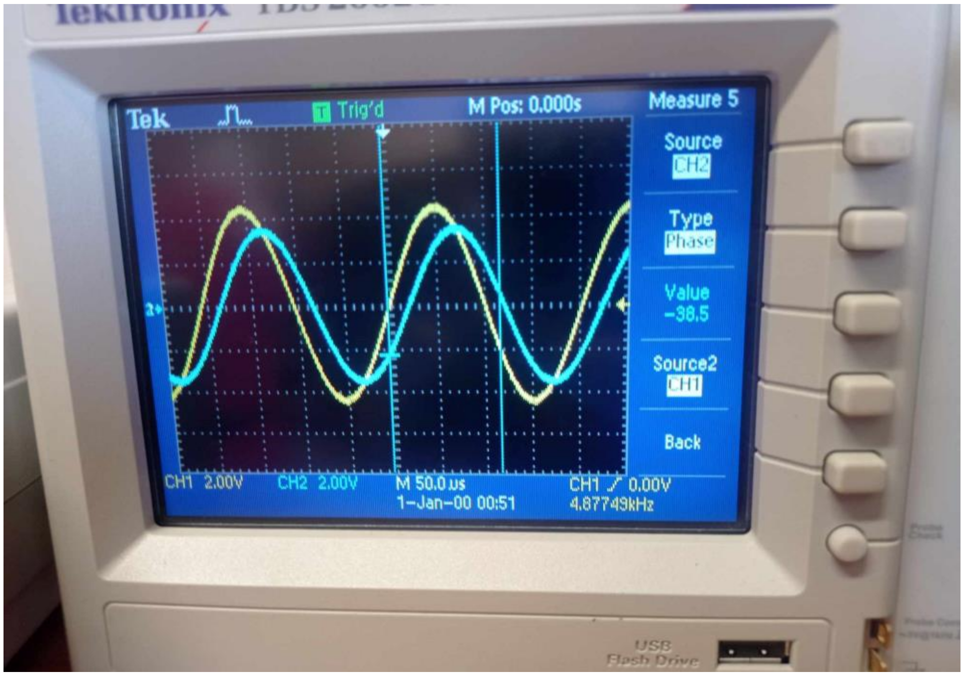


Figure 3.2.4: phase shift when we connect another capacitor

We found that when we added the capacitor ->

Phase shift= -38 and I = 0.26mA and V = 4.95v

After that we disconnect the extra capacitor and double the value of L3

The result ->

Phase shift = 42.3 and I = 0.28mA and V =4.76v

We noticed that adding a capacitor in parallel to the first capacitor will reduce the overall impedance of the capacitor branch. Since the impedance of a capacitor decreases with increasing capacitance, also when we added another capacitor in parallel, the effective capacitance increases, which may shift the resonant frequency of the circuit. The new resonant frequency will be determined by the combined capacitance of the two parallel capacitors.

Also we noticed that when we doubling the value of L3 The impedance of an inductor ***z=j2πfL*** will also double due to the increased inductance. also, doubling the inductance while keeping the capacitance constant will reduce the resonant frequency. This means the circuit will become more resonant at lower frequencies.

3.3. Sinusoidal steady state power

First we connected the circuit in figure 3.3.1, and sat the signal generator to generate a sinusoidal waveform with amplitude 2.5v and frequency 2KH. Output measurement are in Table5.

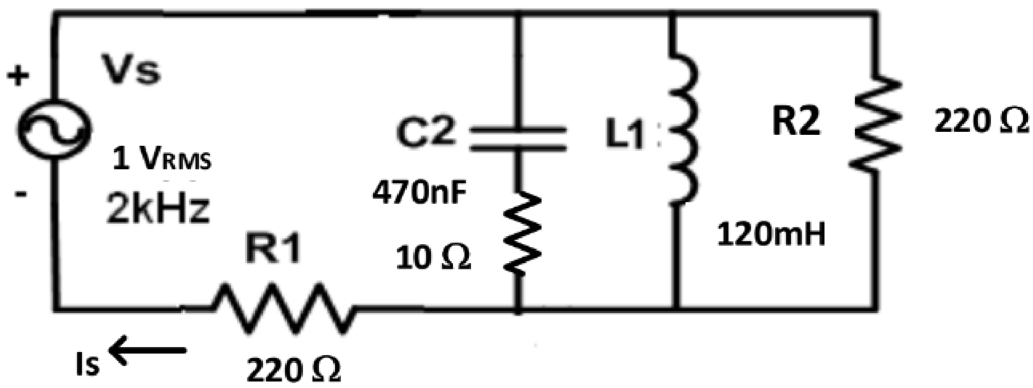


Figure 3.3.1: circuit that connected to find power

V(R1)	VL=V(R2)	IL	I(R2)	Vs	Is	Phase shift between VS & IS	Vc	Ic	Phase shift between Vc & Ic
0.7v	0.42v	0.27mA	1.48mA	1.03v	3.1mA	18.1	0.42v	3.3mA	58.2

Table 5: results of measurements that we found for this circuit

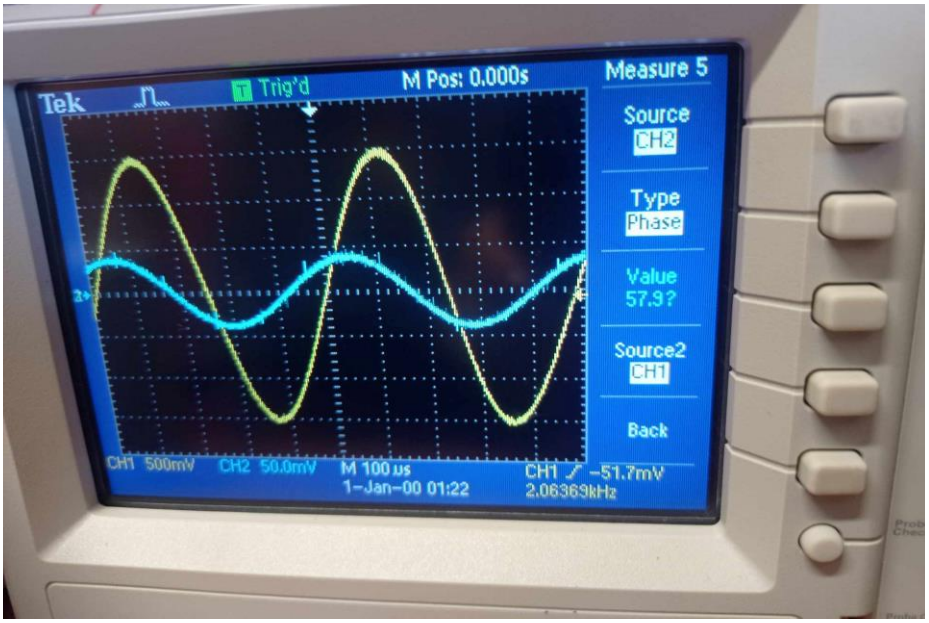


Figure 3.3.2: phase shift between VC & IC

phase shift between VC & IC = 58.2

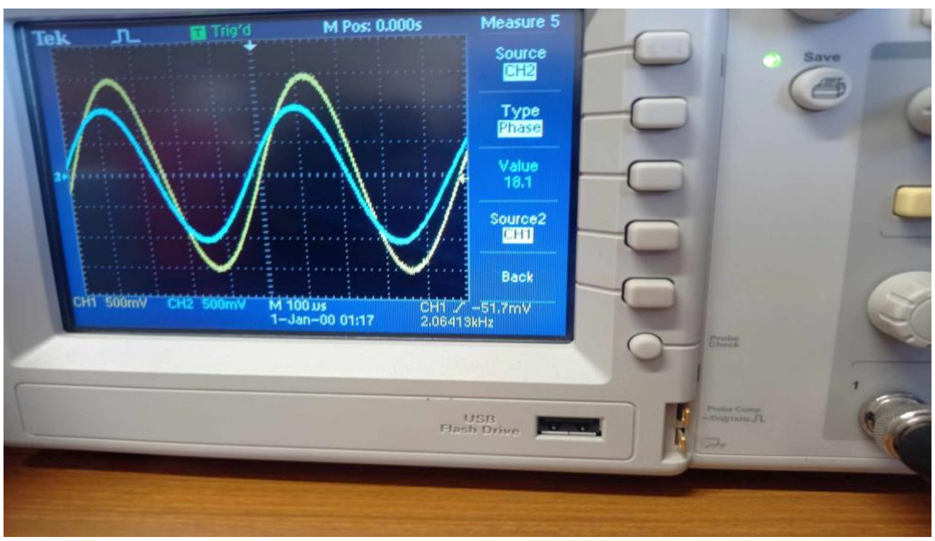


Figure 3.3.3: phase shift between Vs & Is

phase shift between VS & Is = 18.1

For C:

Power Factor = cos (phase shift between VC & IC) = cos (58.2) = 0.526

Active Power = V * I * cos (58.2) =0.72

Reactive power = V * I * sin (58.2) =1.17

For S:

Power Factor = cos (phase shift between VS & IS) = cos (18.1) = 0.95

Active Power = V * I * cos (18.1) =2.8

Reactive power = V * I * sin (18.1) =0.9

The conservation of energy law is a fundamental law of physics that states that energy cannot be destroyed, only transformed from one form to another. In the context of electrical circuits, this principle dictates that the total electrical power entering a circuit must be equal to the total power leaving the circuit**. (sum of input power = sum of output power).**

4.Conclusion

In conclusion, after we finished this experiment we became able to measure the circuit elements impedances and voltage and current phasor, and we became know the validity of the circuit theorems in the sinusoidal steady state, also we measured the power in sinusoidal steady state circuits, by using the Oscilloscope, the DMM, the Wattmeter for AC electric quantities measurements, and we verified the validity of the conversation of energy law.

5.References

[1] https://www.analog.com/en/design-center/glossary/impedance.html
(accessed date 8/13/2023)

[2] https://www.allaboutcircuits.com/technical-articles/sinusoidal-steady-state-power-calculations/ (accessed date 8/13/2023)

[3]https://www.rosehulman.edu/class/ee/HTML/ECE370/PDFs/Review%20of%20Power%20in%20the%20Sinusoidal%20Steady-State.pdf (accessed date 8/13/2023)

6.Appendices

Circuits & Electronics Lab ENEE2103

Experiment#4 ENEE2103

Sinusoidal Steady State Circuit Analysis

Objectives:

1. To use the Oscilloscope, the DMM, the Wattmeter for AC electric quantities measurement..
2. To measure the circuit elements impedances and voltage and current phasors.
3. To verify the validity of the Circuit theorems in the sinusoidal steady state.
4. To measure the power in sinusoidal steady state circuits.

Equipment :

1. Digital Multimeter.
2. Oscilloscope (TDS-2002B).
3. Power supply.
4. Function generator.

$\phi = \Delta t * 360 * f$

$\phi = \frac{\Delta t}{T} * 360$

Pre-lab:

1. Simulate the circuits in the procedure section and determine the required values (set the parameters that must be assigned by the instructor in the procedure to proper values).
2. Verify if Simulation Results match the expected results

Procedure:

A. *Impedance:*

1. Connect the circuit of Fig (4.1)
2. Value of R_x =2.2 kΩ
3. Set the signal generator to generate a sinusoidal waveform with amplitude 5 volts and frequency 1 kHz.
4. Measure the total impedance of the circuit using DMM by measuring the total voltage and current. Find the phase shift between total voltage and current using the oscilloscope cursor menu. $I = 1,0257$ $V = 3,35$
5. Repeat the step (4) with the signal frequencies: 500 Hz , 1500 Hz. Fill in the results in table 4.1
6. Write your conclusions about the variation of the impedance of the resistor with the frequency.
7. Connect the circuit of Fig (4.2).
8. Repeat the steps (2-5) with the signal frequencies: 500Hz , 1500 Hz. Fill in the results in table 4.2
9. Write your conclusions about the variation of the impedance of capacitor with the frequency.
10. Connect the circuit of Fig (4.3)
11. Repeat the steps (2-5) with the signal frequencies: 500Hz , 1500 Hz. Fill in the results in table 4.3
12. Write your conclusions about the variation of the impedance of the inductor with the frequency.

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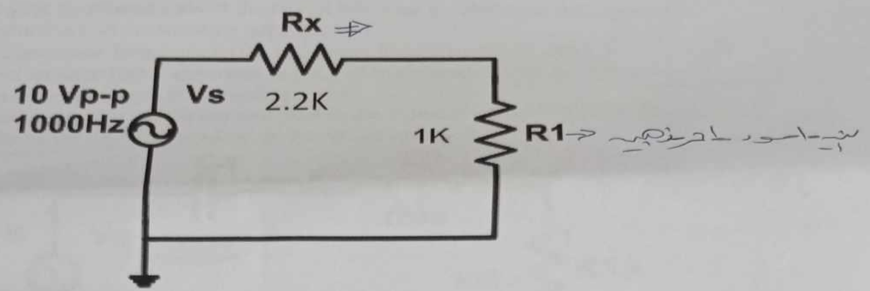

Fig (4.1)

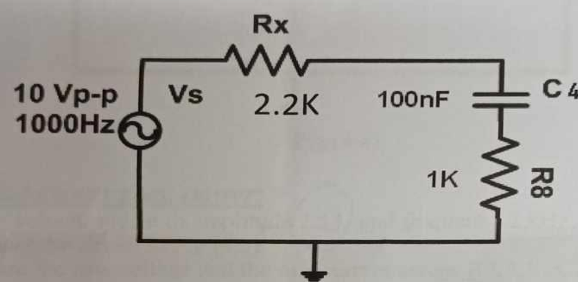

Fig (4.2)

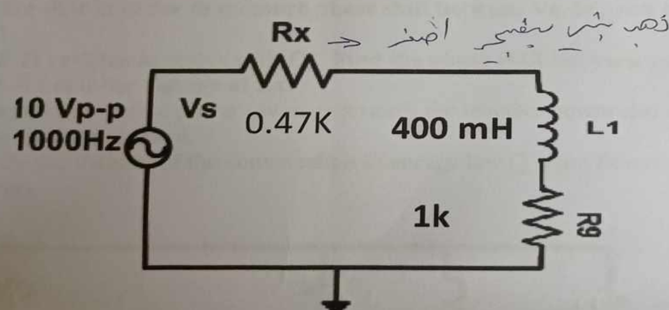

Fig (4.3)

B. Capacitive and inductive behvior:

1. Connect the circuit in Fig (4.4) (note : use table 4.5 to fill in the results)
2. Set the generator to generate a sinusoidal waveform with amplitude 5 volts and frequency 1 kHz.
3. Measure the phase shift between the total current and the voltage.
4. Repeat the step (3) incrementing the frequency 2 kHz, 4 kHz,6 kHz,8 kHz .
5. Determine the resonance frequency fo experimentally ***(note that at fo, both voltage and current will be in phase)***

6. Write your conclusions about the circuit behavior in relation to the capacitive and inductive and the resistive behavior.
7. Set the generator frequency to the resonance frequency found in (3) -38
8. Connect another 100nF capacitor in parallel to C2 and explain the behavior of the circuit according to the circuit response.
9. Disconnect the extra capacitor and double the value of L3 and Explain the behavior of the circuit according to the circuit response.

Φ=42,3
I=0,28mA
V=4,76V

I=0,26
V=4,95

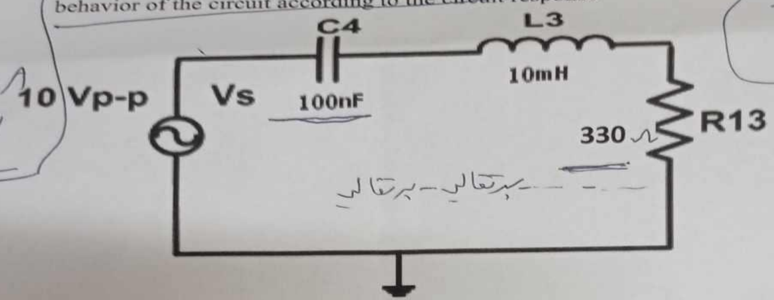

Fig (4.4)

C. Sinosoidal steady state power:

1. Set the voltage source to amplitude 2.5 V and frequency 2 kHz
2. **Connect** the circuit in Fig (4.5)
3. **Measure** the rms voltage and the rms current across R2, L1 , C2 and R1
4. **Measure** the phase shift between Vs and Is; Vc and Ic and fill table 4.5.

Notice that in order to measure phase shift between Vc, Ic , you need to add
a 10 Ω resistor in series with C2. Find the phase shift between voltage of C2+ Rx and the voltage of Rx.

5. **Compute** the active power (average power), the reactive power and the power factor in each element.
6. **Verify** the validity of the conversation of energy law (∑input Power=∑Output Power)

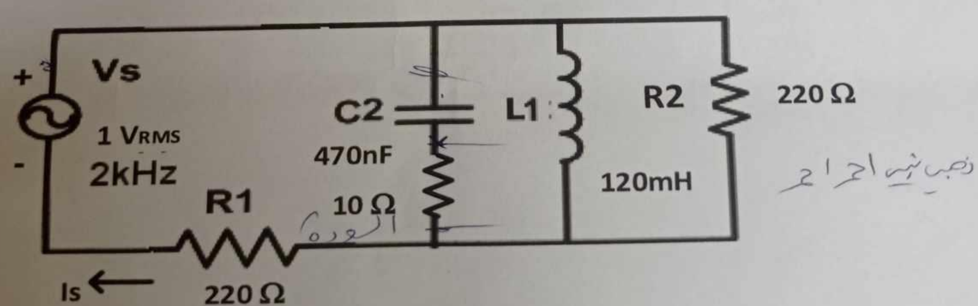

Fig (4.5)

$\frac{V_{p-p}}{2\sqrt{2}} \rightarrow RMS$

Table 4.1

$\frac{V_p}{\sqrt{2}} \rightarrow RMS$

f [Hz]	Vrms	Irms	Δt	Phase shift
500	3,35 V	1,03 mA		0
1k	3.35 V	1.03 mA		0
1.5k	3,35 V	1,03 mA		0

Table 4.2

f [Hz]	Vrms	Irms	Δt	Phase shift
500	3.30	0.95 ~~0.776~~		42,1
1k	3.3	0.769		25,5
1.5k	3.3	1,015		18,2

Table 4.3

f [Hz]	Vrms	Irms	Δt	Phase shift
500	3,3	0,978		−17,5
1k	3,35	0,8728		−31,4
1.5k	3,3	0,754		−42,2

Table 4.4

4.8 KHz

f	1k	2k	4k	6k	8k	fo
Δt	X	88 μs	X	X	X	X
(Θ_{Vs}- Θ_{Is})	77.3	61.4	19.5	−21.7	−44.5	0

Table 4.5

$V_{(R1)}$	$V_L=V_{(R2)}$	I_L	I_{R2}	V_s	I_s	(Θ_{Vs}- Θ_{Is})	V_c	I_c	(Θ_{Vc}- Θ_{Ic})
0,71	0,42	0,27	1,48	1,03V	3,1mA	18.1	0.42V	3.3 mA	58.2

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