Qais Abu El Haija, abuelhaq
400294443

Deliverable / Lab 5 - ENG PHYS 2E04

Qais Abu El Haija, abuelhaq - 400294443

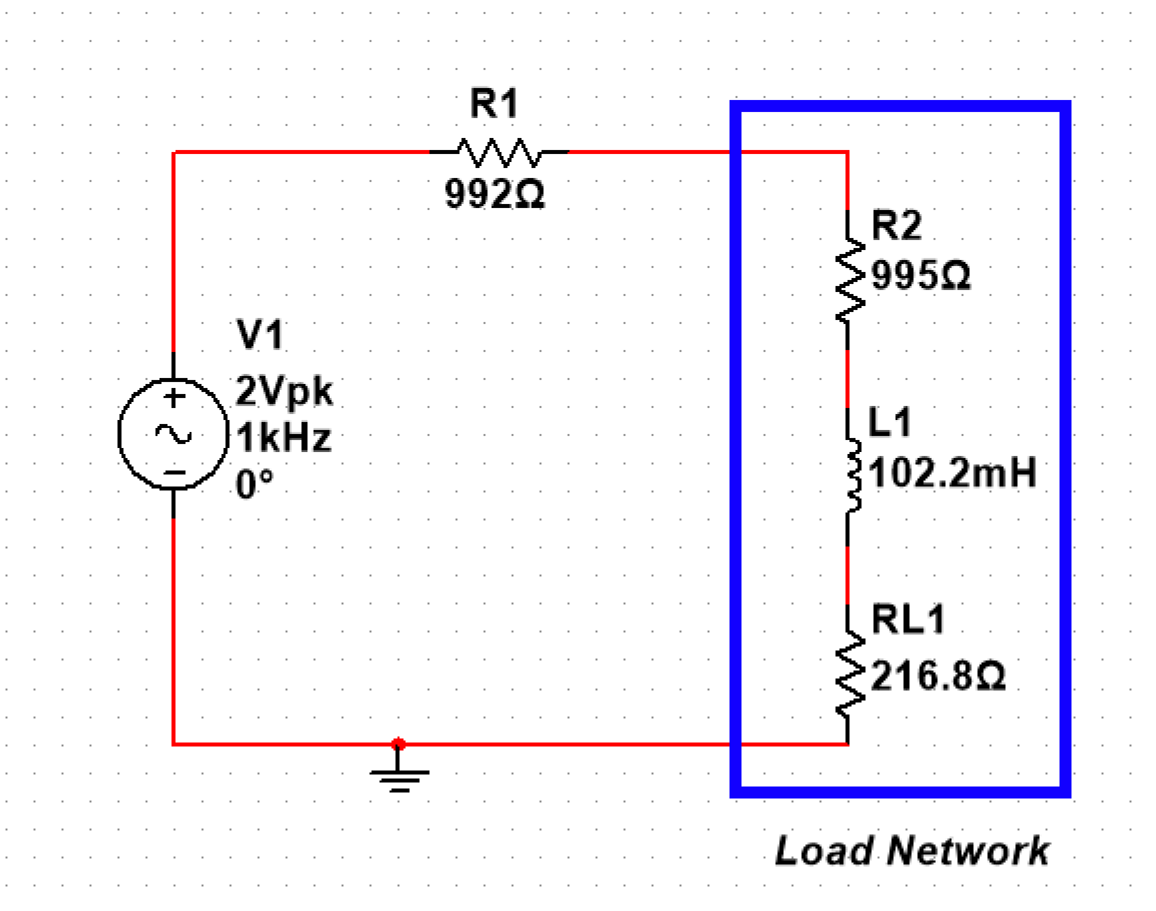

Fig 5.1

Purpose of this lab:

1) Solve for the apparent power, real power and reactive power used by the load network in the circuit in Figure 5.1. Determine the power factor of the load network and state whether it's leading or lagging. Determine the admittance of the load network, and the capacitor necessary to correct the power factor without changing the real power the load is using. Determine the power consumed by R1 before and after the capacitor is added.

2) Simulate the circuit of Figure 1 in Multisim and measure the power consumed in the load and R1 before and after adding the capacitor to correct the load network's power factor. Measure the magnitude and phase (relative to the voltage) of the current supplied by the source before and after adding the capacitor.

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3) Build the circuit in Figure 1 on a breadboard and measure the voltage and current magnitude and relative phase before and after adding the capacitance. Measure the apparent power the source is supplying before and after adding the capacitance, and the change in the power dissipated in R1 and the load network. Do your results from all three steps agree within experimental accuracy?

The values of the resistors and capacitors was measured using the Hantek 2D42. However, the value obtained for the inductor was through averaging inductor values obtained by a VICHY LCR Meter DM4070.

Value	Actual	Measured
R1	1000Ω	992Ω
R2	1000Ω	995Ω
L1	100mH	102.2mH
RL1 (internal inductor resistance)	220Ω	216.8Ω

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Analytical Method

- The load resistor R2 can be combined with the internal resistance of the inductor, RL1 using the series resistor formula which gives a value of **1211.8 Ω**.

$$Reff := R2 + RL1;$$

- The impedance of the inductor L1, ZL1, is calculated using the formula shown below,

$$ZL1 := I \cdot \omega \cdot L1;$$

- The overall impedance of the load network, ZLoad is calculated as follows,

$$ZLoad := ZL1 + R2 + RL1;$$

- Since the current passing through the whole circuit is the same, the voltage divider formula is used to calculate the load network voltage. The formula used was:

$$VLoad := \frac{ZLoad \cdot V1}{ZLoad + R1};$$

This formula was used as the voltage is divided based on the impedances of the components. Therefore, a ratio of the Zload was considered to the total impedance.

The real value of the Vload that was obtained was 1.19V

- The phase difference of the Vload in terms of the source is calculated using the following algebra,

$$\mathrm{abs}(VLoad); \mathrm{argument}(VLoad); DeltaT := \frac{\%}{\omega}$$

a value for the time difference obtained is 31.93 µs.

However, the phase difference for the current was calculated using the similar algebra but a time difference obtained of -**44.20 µs**.

We know,

$$\theta_Z \equiv \theta_V - \theta_I$$

Therefore, Theta$_Z$ = 31.93 – (- 44.20) = 76.13 µs

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- The current of the circuit was found using Ohm's law,

$$ILoad := \frac{V1}{ZLoad + R1};$$

And the <u>real value</u> obtained is <u>0.839 mA</u>.

- The **apparent power** of the load is the absolute value of Sload, which is the sum of the Voltage and Current in rms. Apparent power is considered to be greater than or equal to real power, and only equal to it if the power factor,pf, is 1.

  The voltage and the conjugate of the current in phasors are used to calculate the complex power. It is divided by 2 as the value of the V and I assumed are peak and the formula uses rms values. The following algebra is used to find the **apparent power**.

$$SLoad := \frac{(VLoad \cdot conjugate(ILoad))}{2}; ApparentPower := \mathrm{abs}(SLoad);$$

The value obtained for the apparent power is approximately <u>519.9 µW</u>.

- The real and reactive powers for the load are calculated by finding the real and imaginary part of the SLoad value. The real value obtained using the maple code shown below is denoted by PLoad which is the power that is lost in the R2 and internal resistor, RL1. The imaginary value obtained using the algebra shown below is the reactive power denoted by QLoad and is the power due to the inductor.

$$PLoad := \mathrm{Re}(SLoad);$$
$$QLoad := \mathrm{Im}(SLoad);$$

The values obtained are,
Real Power (Pload) = <u>461.5 µW</u> (rms current used)
Reactive Power / Imaginary Power (Qload) = <u>239.3 µVAR</u> (rms current used)

- The **power factor or pf** for short, is the ratio between the real and the apparent power. It is a value that stands between 0 and 1, relying on the phase difference between the voltage and current of the load. It can be obtained using,

$$pf := \frac{PLoad}{ApparentPower};$$

The pf obtained for the load is approximately <u>0.888</u>.

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As we can see from Maple output, the power factor is approximately 0.888 which is a relatively high value. Since,

$$\theta_Z \equiv \theta_V - \theta_I > 0$$

Then current lags. Also, we only have an inductor at this point, so this is **a lagging power factor**. (Phase difference is +27.4 degrees, cos(27.406) = 0.8877 = pf)

The power factor can be changed by adding either capacitors or inductors in series or parallel. This is called **power factor correction** in which elements are added to change the power factor to unit value or 1. In the case of the circuit above a capacitor can be added in parallel to attain the unit factor. A capacitor is used as the inductor adds positive reactive power to the circuit and the capacitor adds negative reactive power as the impedance is -jC. This makes the reactive power equal to 0.

- The formula to calculate the value of the capacitor needed to make the reactive power equal 0 is,

$$C = \frac{L}{Reff^2 + (\omega L)^2}$$

Using this formula gives the value of the capacitor as <u>53.67nF</u>.

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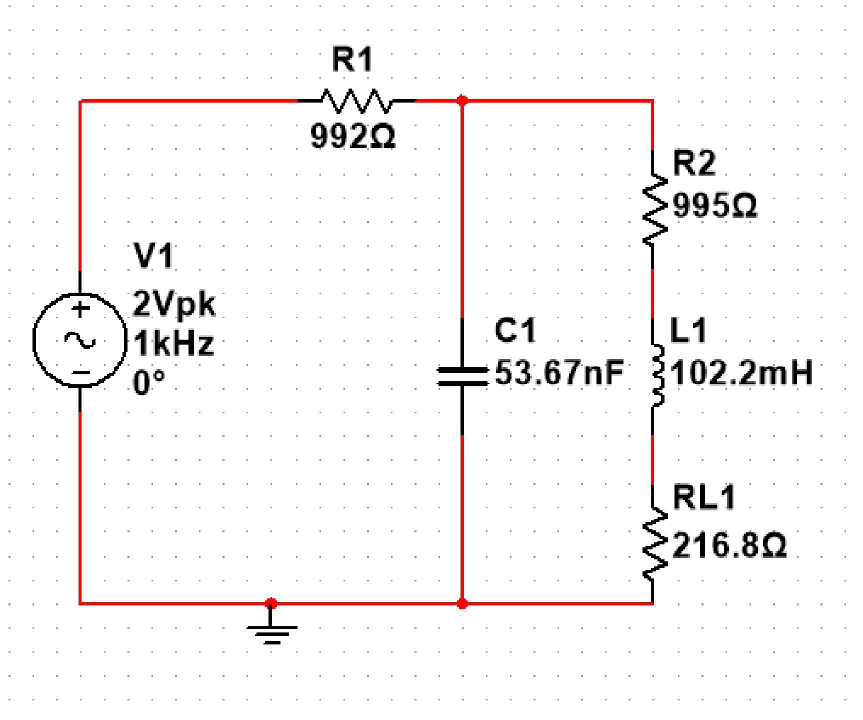

Fig 5.2

After the capacitor is added in parallel the circuit would look like this:

- The impedance of the capacitor, ZC1, needs to be calculated and is calculated using the formula,

$$ZC1 := \frac{1}{I \cdot \omega \cdot C1};$$

- The overall new impedance of the load, ZloadNew, is calculated after adding the capacitor in parallel and the new current of the circuit is found using ohm's law.

$$ZLoadNew := \left(\frac{1}{ZC1} + \frac{1}{ZLoad} \right)^{-1};$$

$$INew := \frac{V1}{ZLoadNew + R1};$$

The value obtained for the new current is <u>0.791 mA</u>.

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- Since R1 is a resistor, all the power consumed by it is real therefore only the current value should be used while calculating the power consumed by the resistance. The formula used is,

$$P = I^2 R$$

And therefore, the power consumed by R1 before and after the capacitor is added, is calculated using the above equation. The INew would represent the current after C1's addition, and ILoad would represent the current before C1's addition.

$$PBeforeC1 := \mathrm{abs}(ILoad)^2 \cdot R1;$$

$$PAfterC1 := \mathrm{abs}(INew)^2 \cdot R1;$$

The power consumed by R1 before the capacitor was added is <u>756 µW</u>
The power consumed by R1 after the capacitor was added is <u>620 µW</u>

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Analysis Of Analytical Solution:

Value	Before pf correction	After pf correction
Zload(Ω)	1211.8 + 628.320*I	1537.580 - 0. *I
Iload(mA)	0.839 - 0.239*I	0.791 + 0. *I
Phase (Degrees)	11.494	0.000
pf	0.888	1.000
Real Power (µW)	461.505	480.586
Apparent Power(µW)	519.852	480.586
Reactive Power(µVAR)	239.290	0.000
P consumed by R1(µW)	755.591	620.120

As we can see from above table, values like real, apparent, and reactive power decreased by adding a capacitor. The power that reduces is the power lost in the transmission line resistance. Moreover, it also reduces because of the pf correction which allows some currents to be supplied by the capacitor rather than the voltage source. Reactive power and phase difference deceases to zero and the power factor goes to 1 as we expected. The new total impedance and new current only represents real values. This indicates that all the power are real, and all energies goes to the load.

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Multisim Method

Circuit before adding a capacitor:

The modified circuit was modelled in Multisim as shown in Fig 5.1 and 5.2. The power consumed in the load and the resistor R1 can be calculated using the formulas listed in the analytical part. Multisim is used to measure the V and I in the load and R1 using the oscilloscope and the current probe as shown below.

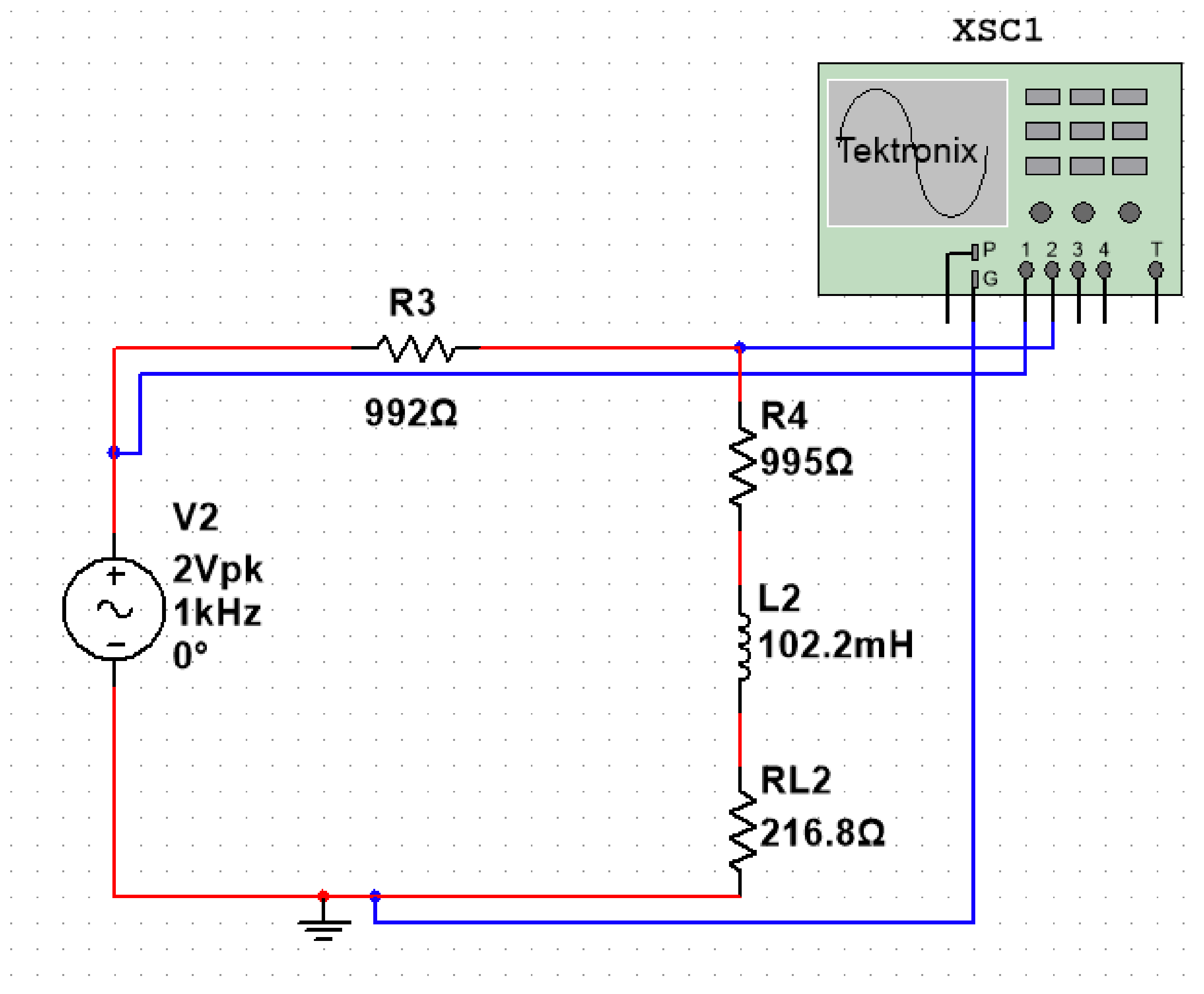

Fig. 5.3

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Using the Oscilloscope to calculate V1, Vload, DeltaT, Phase Angle, and pf:

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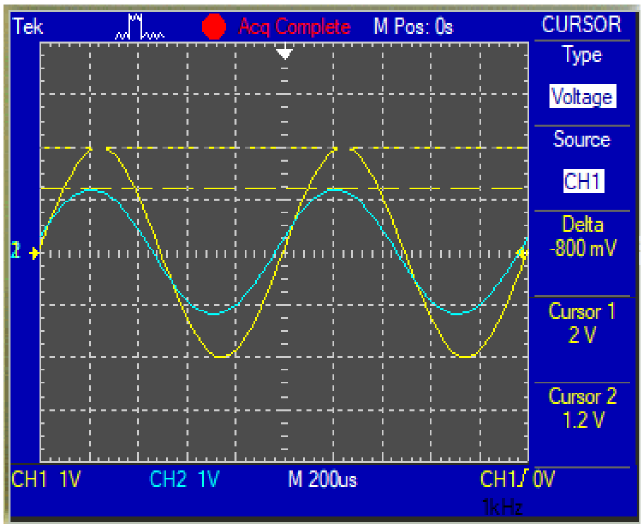

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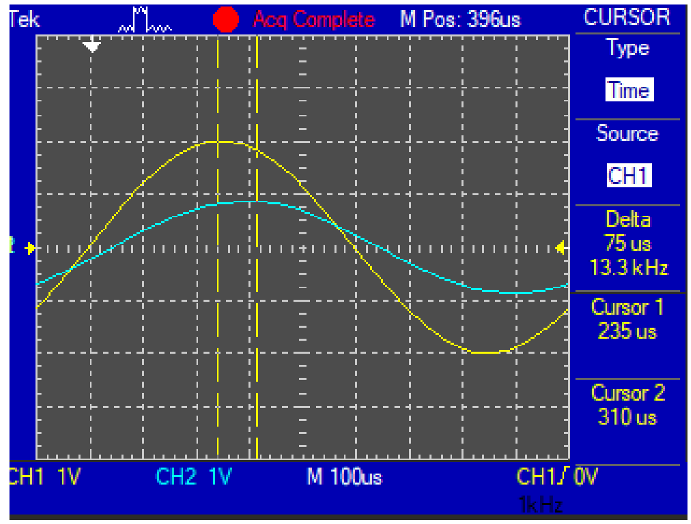

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- The above picture shows how the oscilloscope was used to measure the values of the voltages of the peaks of the source voltage and the load voltage. **The value obtained for the source voltage, V1, is <u>2.00±0.5V</u> and for the load voltage, VLoad, is <u>1.2±0.5V</u>.**

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- The above picture shows the time difference, DeltaT, between the two waves, the time difference is **<u>75±50µs</u>**. The phase angle can be calculated using the formula shown below and
the value obtained is **<u>27±1 degrees</u>**.

$$PhaseAngle := \left(\frac{DeltaT}{\frac{1}{f}}\right) \cdot 360;$$

Then using this phase angle, we can calculate to find pf.

$$pfmultism := \cos\left(PhaseAngle \cdot \left(\frac{\pi}{180}\right)\right);$$

The value obtained for pf is <u>0.891±0.03</u>.

Uncertainty for time (half the smallest increment) ± 50µs

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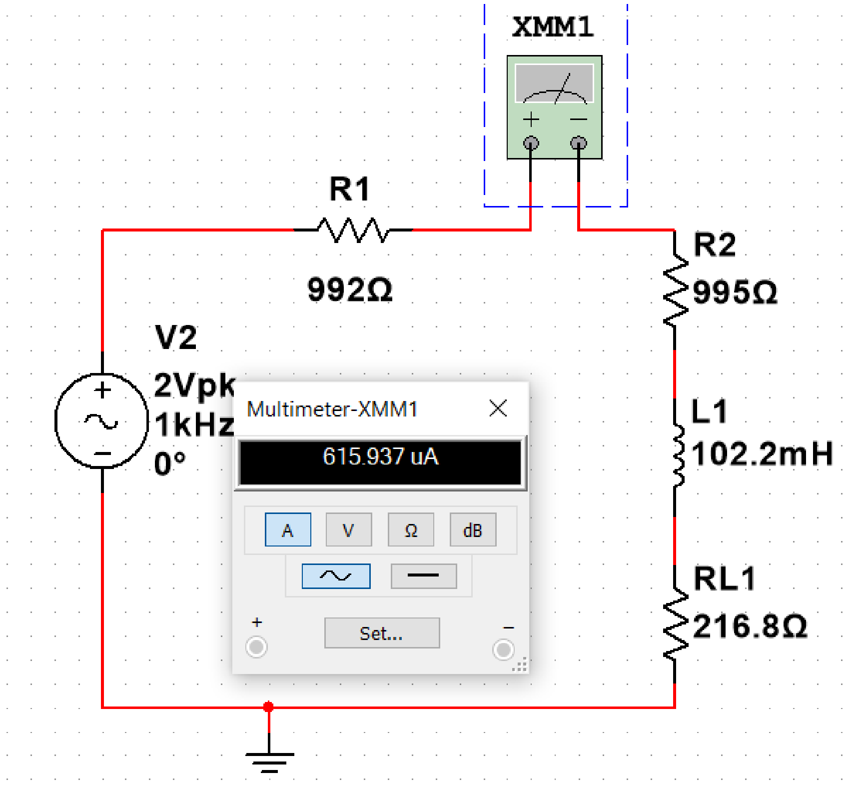
Calculating ILoad at rms and peak value:



The current obtained is **615.937±10 μA in rms**. To find the current at **peak value**, we can use the following formula,

$$I_{Peak\ Value} = I_{rms} * \sqrt{2} = 615.937 \pm 10 * \sqrt{2} = \mathbf{871.066 \pm 10}\ \mu\boldsymbol{A}$$

Using the ILoad at peak value and rms, we can use these values, with the help of Ohm's Law, to find the Power consumed by the load and R1 before the addition of C1.

$$PR1_{Before\ C1} = (I_{Peak\ Value})^2 * R1 = (871.066 \pm 10e-6)^2 * 992 = \mathbf{752.69\ \pm 10}\ \mu\boldsymbol{W}$$

$$PLoad_{Before\ C1} = (I_{rms})^2 * ZLoad = (615.937e-6)^2 * 1211.8\ +\ 628.32 * I$$
$$= \mathbf{0.0004597\ +\ 628.32} * \boldsymbol{I\ \ W}$$

$$\boldsymbol{Using\ only\ the\ real\ portion\ of\ PLoad,} = \mathbf{459.7 \pm 10}\ \mu\boldsymbol{W}$$

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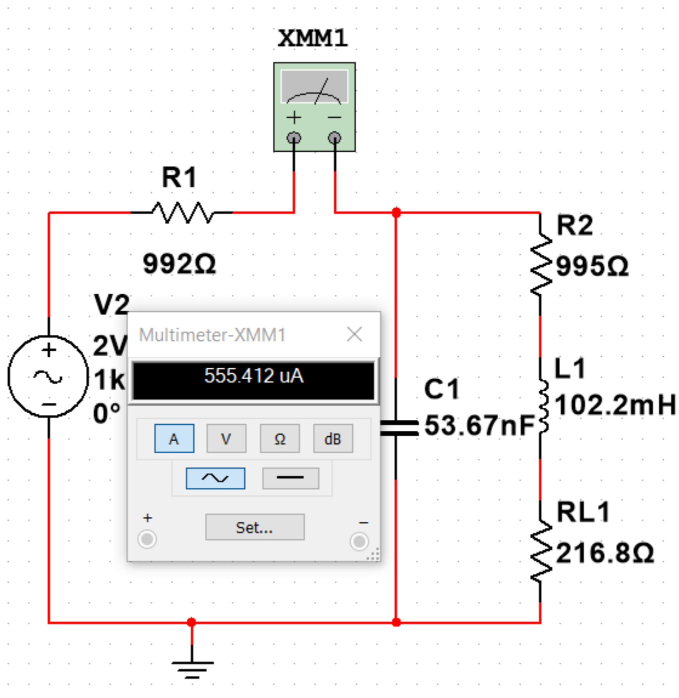
Circuit after adding a capacitor:

According to the analytical calculations, C1 would hold a value of **53.67nF**, which is added in parallel to the circuit to correct the power factor of the circuit. After adding a multimeter, we can obtain a value for Inew.



The current obtained is **555.412±10 μA in rms**. To find the current at **peak value**, we can use the following formula,

$$I_{Peak\ Value} = I_{rms} * \sqrt{2} = 555.412 \pm 10 * \sqrt{2} = \mathbf{785.47 \pm 10}\ \mu\boldsymbol{A}$$

Using the INew at peak value and rms, we can use these values, with the help of Ohm's Law, to find the Power consumed by the load and R1 after the addition of C1.

$$PR1_{After\ C1} = (I_{Peak\ Value})^2 * R1 = (785.47 \pm 10e-6)^2 * 992 = \mathbf{612.03 \pm 10}\ \mu\boldsymbol{W}$$

$$PLoad_{After\ C1} = (I_{rms})^2 * ZLoadNew = (555.412 \pm 10e-6)^2 * 1537.583\ -\ 0.* I$$
$$= \mathbf{0.00047432\ +\ 0 * I\ \ W} = \mathbf{474.32 \pm 10}\ \mu\boldsymbol{W}$$

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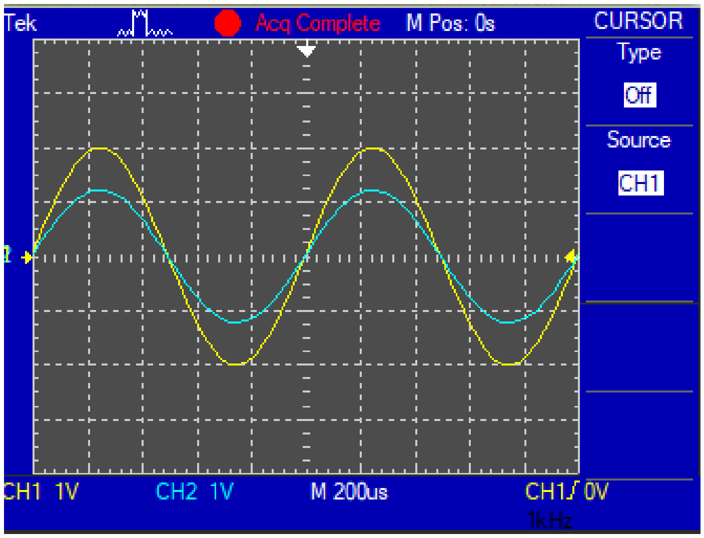
The phase can be calculated and shown using an oscilloscope. It would be shown by using the cursor option. The resultant of both cursors is going to be 0, meaning DeltaT would also be = 0



As it could be seen that there is no time difference in the waves therefore the phase is 0.

The values are compared to the analytical method in the table shown below

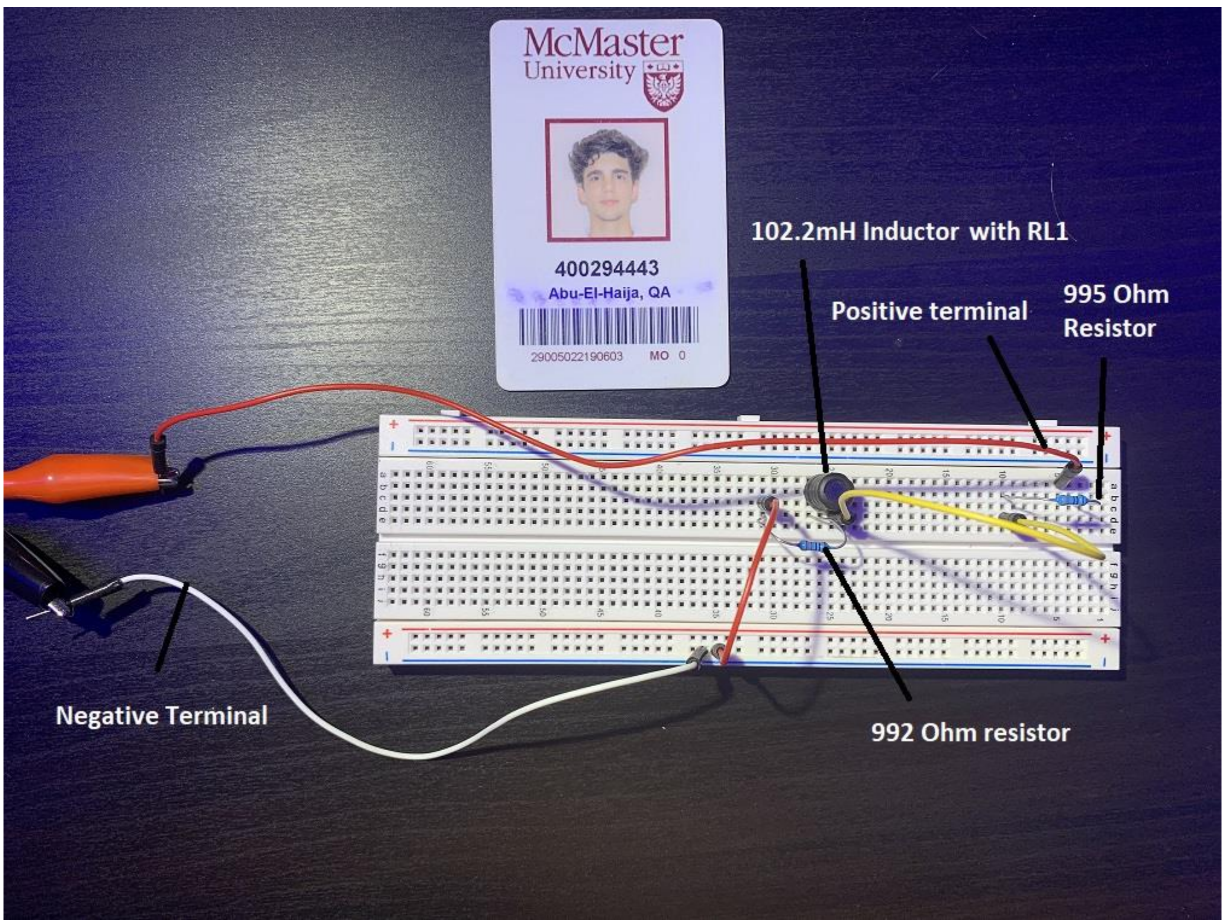
Value	Analytical	Multisim
Vsource (V)	2.00	2.00 ± 0.5
Vload (V)	1.19	1.20 ± 0.5
ILoad (µA)	872.75	871.07 ± 10
Inew (µA)	790.64	785.47 ± 10
DeltaT for Vload and Vsource (µs)	76.13	75.00 ± 50
Power before R1 (µW)	755.59	752.69 ± 10
Power after R1 (µW)	620.12	612.03 ± 10
Pf	0.888	0.891 ± 0.01
Power load before (µW)	461.50	459.70 ± 10
Power load after (µW)	480.59	474.32 ± 10
Phase difference before C1 (Degrees)	27.41	27.00 ± 0.5
Phase difference after C1 (Degrees)	0.00	0.00

From the table above, values obtained by the Multisim and analytical methods all lie within uncertainty and are very close to each other. This suggests that the calculation done is accurate and reliable.

Experimental Method

Circuit before adding C1:

The circuit was set up shown below using the Take-Home kit and using the Hantek as the Power source and the oscilloscope to measure the values.



The circuit consists of a 992-ohm resistor which is in series with the load network. The load network consists of a 102.2mH inductor, which contains an internal resistance of 216.8 ohm, and a 995-ohm resistor.

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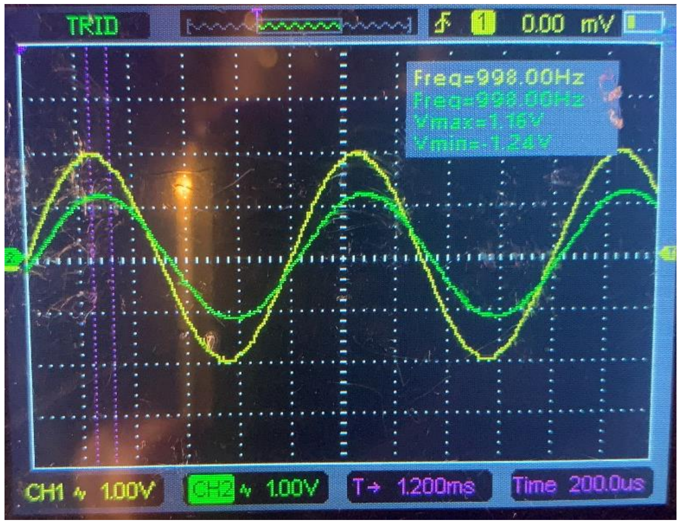
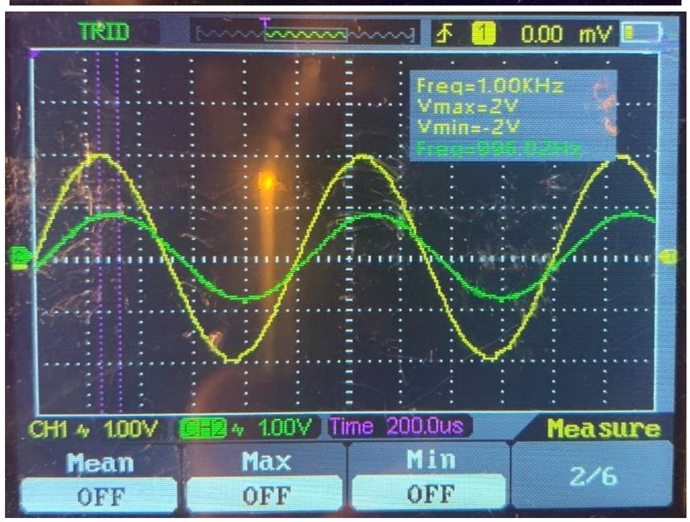
- The current and the voltage was measured using the Hantek and the values are shown below.





The above pictures show the value of the load voltage compared to the value of the source voltage. The **load voltage** has a value of **1.24±0.56V** at the peak and the **source voltage** has a value of **2.0±0.6V** at the peak. The frequency for both waveforms is 1000Hz.

Uncertainty = 5% of reading ±half increment of smallest interval

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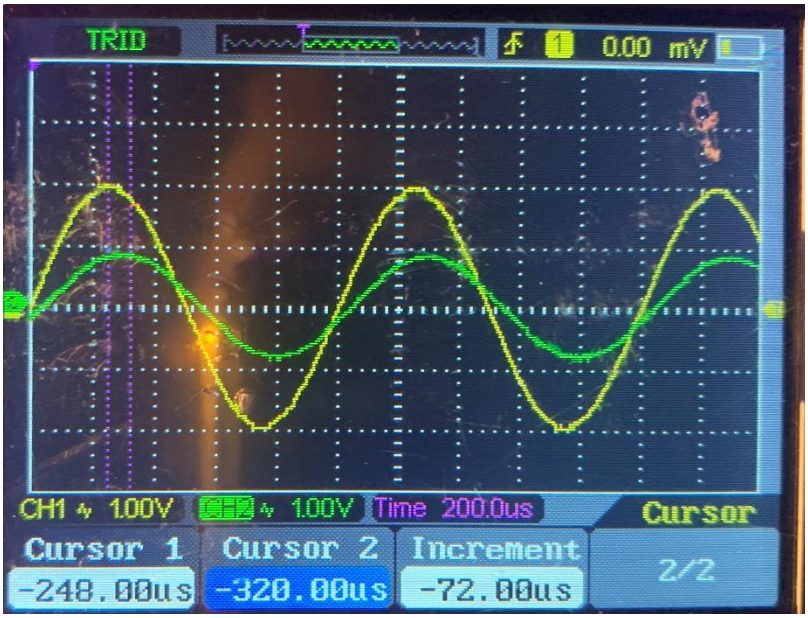

- The above picture shows the time difference between the waveforms. The cursor is used to find the difference and it could be seen as **72±4μs** with the source voltage leading. The time difference can be used to calculate the phase of the voltage and the angle. This could be done using the formula used in the Multism method:

$$PhaseAngle := \left(\frac{DeltaT}{\frac{1}{f}}\right) \cdot 360;$$

Then using this phase angle, we can calculate to find pf.

$$pfmultism := \cos\left(PhaseAngle \cdot \left(\frac{\pi}{180}\right)\right);$$

The value obtained for the phase angle using this time difference is <u>26±(0.15) degrees</u>.

- Then by using the Phase Angle, we can determine the pf obtained during the experiment, using the following maple code.

$$> \quad pfexp := \cos\left(PhaseAngleExp \cdot \left(\frac{\pi}{180}\right)\right);$$

$$pfexp := 0.8994052515$$

Pf or Power factor obtained is <u>0.899±0.01</u>.

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- The figure below shows the rms value of the ILoad that is found. The value obtained is **656 $\pm$20 µA**.

- To find the ILoad at **peak value**, we can use the following formula,

$$I_{Peak\ Value} = I_{rms} * \sqrt{2} = 656 \pm 20 * \sqrt{2} = \mathbf{927.72 \pm 20}\ \mu\boldsymbol{A}$$

- Using the ILoad at peak value and rms, we can use these values, with the help of Ohm's Law, to find the Power consumed by the load and R1 before the addition of C1.

$$PR1_{BeforeC1} = (I_{Peak\ Value})^2 * R1 = (927{,}7 \pm 20e-6)^2 * 992 = \mathbf{853.79 \pm 20}\ \mu\boldsymbol{W}$$

$$PLoad_{Before\ C1} = (I_{rms})^2 * ZLoad = (656e-6)^2 * 1211.8 + 628.32 * I$$
$$= \mathbf{0.00052148 + 628.32} * \boldsymbol{I}\ \boldsymbol{W} = \mathbf{521.48 \pm 20}\ \mu\boldsymbol{W}$$

- To find the apparent power before adding the capacitor to the circuit, we know that,

$$SLoad := \frac{(VLoad \cdot conjugate(ILoad))}{2};\ ApparentPower := \mathrm{abs}(SLoad);$$

Therefore, we know that the Vload has an absolute value of 1.24 V, and ILoad has an absolute value of 927.72 $\mu\boldsymbol{A}$**.**

Apparent Power = (1.24 * 927.72e-6) / 2 = 575.19±20 $\mu\boldsymbol{W}$

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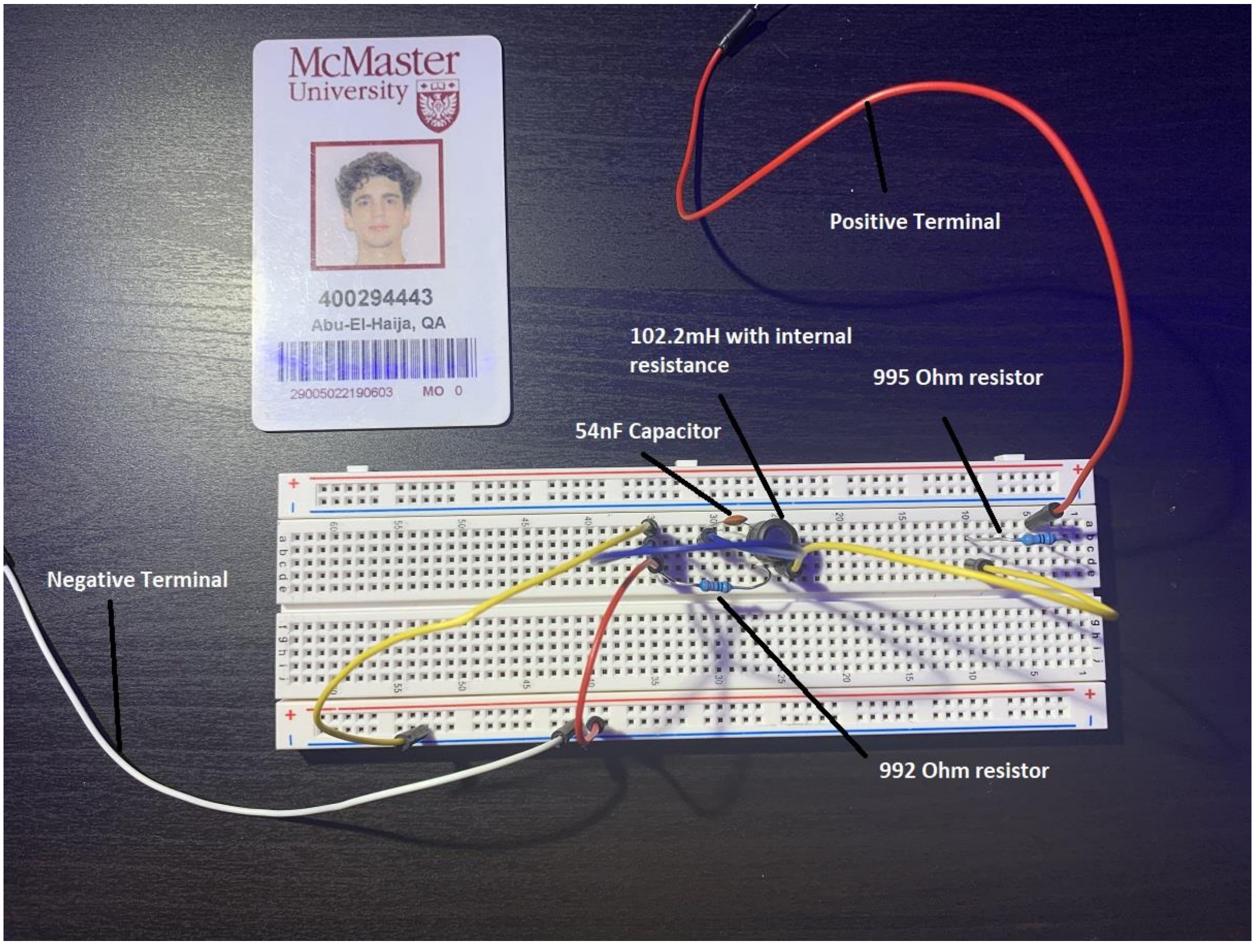
Circuit after adding C1:

- The circuit is then changed by adding a ***55.0nF*** (due to the unavailability of a 53.7nF capacitor) capacitor in parallel to the load as shown below.



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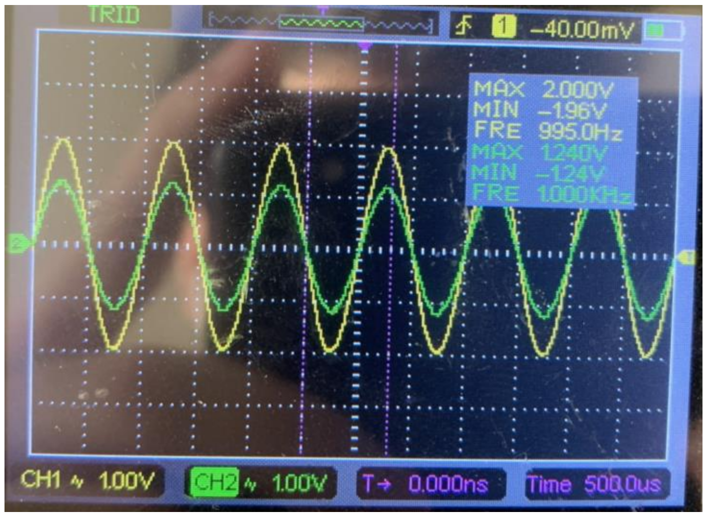
- The values of the current and the load voltage and the time difference for the new circuit were measured using the Hantek.
- The value obtained for the voltage of the load network is **1.24±0.56V,** and the value obtained for the source voltage is **2.0±0.15V** both having a frequency of 1000Hz.



- The value obtained for the time difference for the circuit is 0s. This means that the phase angle is also 0.

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Since,

$$pfexp := \cos\left(PhaseAngleExp\cdot\left(\frac{\pi}{180}\right)\right);$$

- The value of pf is determined using the formula above, and since the phase angle is = 0, **therefore, cos (0) = 1 = pf**

- To find the INew at **peak value**, we can use the following formula,

$$I_{Peak\ Value} = I_{rms} * \sqrt{2} = 541 \pm 20 * \sqrt{2} = \mathbf{765.09 \pm 20}\ \mu\boldsymbol{A}$$

- Using the ILoad at peak value and rms, we can use these values, with the help of Ohm's Law, to find the Power consumed by the load and R1 before the addition of C1.

$$PR1_{AfterC1} = (I_{Peak\ Value})^2 * R1 = (765.09 \pm 20e-6)^2 * 992 = \mathbf{580.68 \pm 20}\ \mu\boldsymbol{W}$$

$$PLoad_{After\ C1} = (I_{rms})^2 * ZLoadNew = (541 \pm 20e-6)^2 * 1537.58\ -\ 0.*I$$
$$= \mathbf{0.0004500\ +\ 0*\boldsymbol{I}\ \boldsymbol{W} = 450.02 \pm 20}\ \mu\boldsymbol{W}$$

- To find the apparent power after adding the capacitor to the circuit, we know that,

$$SNew := \frac{(VNew\cdot conjugate(INew))}{2};\ ApparentPower := \mathrm{abs}(SNew);$$

- Therefore, we know that the VNew has an absolute value of 1.24 V, and INew has an absolute value of $\mathbf{765.09 \pm 20\ \mu A.}$

Apparent Power = (1.24 * 765.09e-6) / 2 = 474.36±20 μW

Analysis of Results

The results from the three solution methods can be compared with each other to determine if the results obtained from the experiment are accurate under limits of experimental accuracy. The results compared are the values of Vsource, Vload, ILoad, INew, Phase before, Phase after, Power change in R1(before and after), Power change in load (before and after), and Apparent Power.

Value	Analytical	Multisim	Experimental
Vsource (V)	2.00	2.00 ± 0.5	2.00±0.6
Vload (V)	1.19	1.20 ± 0.5	1.24±0.56
ILoad (before C1) (µA)	872.75	871.07 ± 10	927.72±28.28 (Using Error propagation)
Inew(After C1) (µA)	790.64	785.47 ± 10	765.09±20
DeltaT for Vload and Vsource (µs)	76.13	75.00 ± 50	72.00±4
Power before R1 (µW)	755.59	752.69 ± 10	853.79±18.4(using error propagation)
Power after R1 (µW)	620.12	612.03 ± 10	580.68±15.18(using error propagation)
Pf before C1	0.888	0.891 ± 0.01	0.899±0.1
Pf after C1	1.00	1.00	1.00
Power load before (µW)	461.50	459.70 ± 10	521.48±15.90(using error propagation)
Power load after (µW)	480.59	474.32 ± 10	450.02±20
Phase difference before C1 (Degrees)	27.41	27.00 ± 0.5	26.00±0.1
Phase difference after C1 (Degrees)	0.00	0.00	0.00

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The values obtained from the Analytical and Multism methods are very similar to each other. However, some values obtained regarding the experimental method where not within the uncertainty error and had to use the error propagation formula to articulate for those values.

The values obtained for Vsource and Vload are almost identical with all of them being 2V and around 1.2V volts respectively. The current values, ILoad for the analytical and the Multisim are similar, but the values obtained in the experimental method were higher by about 11%. The phases are calculated using the time difference as shown above therefore to compare the phases the time differences are compared. It could be seen at the phase before the addition of C1, for all three methods, that values are lie within the uncertainty error where the value for DeltaT for the three methods gave an approximation of 75microseconds. The phase for I after all has a value of 0microseconds indicating there is no phase difference between I and V. This occurs as the capacitor is added to the load in parallel as explained above. The power difference for the load and resistor R1 can be seen to be significantly more in the experimental method and less similar in the Multisim and analytical method. There are several reasons why the values are different.

1) The time difference is hard to measure in the Hantek and the Multisim since the cursors are very small and are prone to human error.
2) The values of the current are different as there is impedance in the jumper cables which reduce the current being transferred in the circuit.
3) The resistors have a tolerance value which means they aren’t exactly the value which has been stated. Even when measured with a Hantek there is still some level of uncertainty. This can be seen in the first table where for eg a 1000 ohm resistor has a value of 992 ohm. This accounts for error.
4) The value of the capacitor needed for the correction needed was 53.7nF but this exact value of capacitor was unavailable and a 55nF capacitor was used which also accounts for the error in the power losses and the current.
5) The Hantek also has impedance which leads to errors in the measurements of the current.

- To increase accuracy of results in the future, the following could improve my results,

    1) If the budget was not a problem, a more accurate and precise oscilloscope could be used to be able to place the cursor in a better position.
    2) If time was not a factor, a trimmer can be used to adjust the resistance and reduce the tolerance in the resistors.
    3) If all resources where accessible, a more accurate and precise Capacitor value could’ve been used to minimize the error.

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400294443

Error Propagation:

Every measurement has a demeanor of uncertainty about it, and not all uncertainties are equal. Therefore, the ability to properly combine uncertainties from different measurements is crucial. Anytime a calculation requires more than one variable to solve, propagation of error is important to appropriately decide the uncertainty.

As seen in the table listed in the analysis, we can see the values highlighted in yellow are not within the error bound. Therefore, using uncertainty rules and some error propagation formulas, a level of uncertainty was redetermined for values like, ILoad, Power consumed by R1 before and after the addition of C1, and finally the power consumed by the load before the addition of C1.

Uncertainty Rules:

Uncertainty = 5% of reading ±half increment of smallest interval (Experimental)
Uncertainty = half the smallest increment (Multism)

Error Propagation Formula used:

Multiplication	$\bar{z} = \bar{x} * \bar{y}$	$\sigma_z = \bar{z} * \sqrt{\left(\frac{\sigma_x}{\bar{x}}\right)^2 + \left(\frac{\sigma_y}{\bar{y}}\right)^2}$

Overall, values obtained by the Analytical and Multsim methods did meet my expectations, however on the other hand, some values obtained by the experimental method did not.

Qais Abu El Haija, abuelhaq
400294443

Reflection

The concept of AC power is important since AC current, and voltage has loads of uses. In this topic I learned about the concept of apparent power which is the sum of the real and reactive power. Real power is the power which is lost in the resistor and is the power supplied by the source and is measured in watts. Reactive power is a complex power which is elements such as capacitors and inductors and is measured in VAR. The concept of AC power is important since AC is used in everyday life. AC current and voltage is the type of current which is generated in the power stations and is the type which is used in transmission lines to transport current from the generator to the public. AC power also contains a topic which is known as power factor which is the ratio of real and apparent power. This is important as it tells us how much of the apparent power is converted into real power and how much is used up as reactive power. Power factor is the cos(theta) = P/S. Another important topic is power factor correction, as the power factor is not always 1 and is usually either lagging or leading based on the components. Power factor correction is when a capacitor is added to make the power factor 1 meaning all the apparent power is converted to real power and in the circuit above it was seen this was done using a capacitor connected in parallel to the load. Power factor correction is used in times of motor failure and when transformers overheat. It is also used in places where there are high energy uses and helps to reduce costs by making the system more efficient.

H5 mini project video

https://mcmasteru365-my.sharepoint.com/:v:/g/personal/hamada11_mcmaster_ca/ESZf_FrRbxFCl6nQdGwlcyEBmakV4Cd7Ueh76OpU8uK9yA

Ps: Video says 6:30 mins but it was less (Time loss between starting and stopping of the recording) It also felt like 3 mins 😉

Qais Abu El Haija, abuelhaq
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Maple code and output:

Qais Abu El Haija, abuelhaq
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$restart;$

$V1 := 2; f := 1000; R1 := 992; R2 := 995; RL1 := 216.8; L1 := 102.2e-3;$
$\omega := 2 \cdot \pi \cdot f;$

$$V1 := 2$$
$$f := 1000$$
$$R1 := 992$$
$$R2 := 995$$
$$RL1 := 216.8$$
$$L1 := 0.1022$$
$$\omega := 2000\,\pi \qquad (1)$$

$ZL1 := I \cdot \omega \cdot L1;$

$$ZL1 := 628.3185308\,\mathrm{I} \qquad (2)$$

$ZLoad := ZL1 + R2 + RL1;$

$$ZLoad := 1211.8 + 628.3185308\,\mathrm{I} \qquad (3)$$

$VLoad := \frac{ZLoad \cdot V1}{ZLoad + R1}; \mathrm{abs}(VLoad);$

$$VLoad := 1.167414320 + 0.2373759015\,\mathrm{I}$$
$$1.191303283 \qquad (4)$$

$ILoad := \frac{V1}{ZLoad + R1};$

$$ILoad := 0.0008393000810 - 0.0002392902232\,\mathrm{I} \qquad (5)$$

$SLoad := \frac{(VLoad \cdot conjugate(ILoad))}{2}; ApparentPower := \mathrm{abs}(SLoad);$

$$SLoad := 0.0004615046004 + 0.0002392902233\,\mathrm{I}$$
$$ApparentPower := 0.0005198521974 \qquad (6)$$

$PLoad := \mathrm{Re}(SLoad);$

$$PLoad := 0.0004615046004 \qquad (7)$$

$QLoad := \mathrm{Im}(SLoad);$

$$QLoad := 0.0002392902233 \qquad (8)$$

$$pf := \frac{PLoad}{ApparentPower};$$

$$pf := 0.8877611804 \tag{9}$$

$$C1 := \frac{L1}{(R2 + RL1)^2 + (\omega \cdot L1)^2};$$

$$C1 := 5.366985287 \times 10^{-8} \tag{10}$$

$$\mathrm{abs}(VLoad); \mathrm{argument}(VLoad); DeltaT := \frac{\%}{\omega};$$

$$1.191303283$$

$$0.2005999864$$

$$DeltaT := 0.00003192647942 \tag{11}$$

$$\mathrm{abs}(ILoad); \mathrm{argument}(ILoad); DeltaT1 := \frac{\%}{\omega};$$

$$0.0008727453448$$

$$-0.2777380005$$

$$DeltaT1 := -0.00004420337564 \tag{12}$$

$$ZC1 := \frac{1}{I \cdot \omega \cdot C1};$$

$$ZC1 := -2965.443998\,\mathrm{I} \tag{13}$$

$$ZLoadNew := \left(\frac{1}{ZC1} + \frac{1}{ZLoad}\right)^{-1};$$

$$ZLoadNew := 1537.583278 - 0.\,\mathrm{I} \tag{14}$$

$$INew := \frac{V1}{ZLoadNew + R1}; \mathrm{abs}(INew);$$

$$INew := 0.0007906440628 + 0.\,\mathrm{I}$$

$$0.0007906440628 \tag{15}$$

$$PBeforeC1 := \mathrm{abs}(ILoad)^2 \cdot R1;$$

$$PBeforeC1 := 0.0007555909614 \tag{16}$$

$$PAfterC1 := \mathrm{abs}(INew)^2 \cdot R1;$$

$$PAfterC1 := 0.0006201170897 \tag{17}$$

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$$Reff := R2 + RL1; \; VNew := \frac{ZLoadNew \cdot V1}{ZLoadNew + R1};$$

$$Reff := 1211.8$$

$$VNew := 1.215681090 + 0.\,I$$

$$SNew := \frac{(VNew \cdot conjugate(INew))}{2}; \; ApparentPower := \operatorname{abs}(SNew);$$

$$SNew := 0.0004805855180 + 0.\,I$$

$$ApparentPower := 0.0004805855180$$

$$PNew := \operatorname{Re}(SNew);$$

$$PNew := 0.0004805855180$$

$$QNew := \operatorname{Im}(SNew);$$

$$QNew := 0.$$

$$PhaseAngle := \left(\frac{75e-6}{\frac{1}{f}}\right) \cdot 360;$$

$$PhaseAngle := 27.000000$$

$$pfmultism := \cos\left(PhaseAngle \cdot \left(\frac{\pi}{180}\right)\right);$$

$$pfmultism := 0.8910065242$$

$$PLoad2 := (615.937e-6)^2 \cdot 1211.8 + 628.3185308\,I; \; \operatorname{Re}(PLoad2)$$

$$PLoad2 := 0.0004597307306 + 628.3185308\,I$$

$$0.0004597307306$$

$$PhaseAngleExp := \left(\frac{72e-6}{\frac{1}{f}}\right) \cdot 360;$$

$$PhaseAngleExp := 25.920000$$

$$pfexp := \cos\left(PhaseAngleExp \cdot \left(\frac{\pi}{180}\right)\right);$$

$$pfexp := 0.8994052515$$