B O Ğ A Z İ Ç İ   U N I V E R S I T Y

E L E C T R I C A L & E L E C T R O N I C   E N G I N E E R I N G   D E P A R T M E N T

E E 3 2 7 - N E T W O R K S   L A B .   R E P O R T

Number of The Experiment : ***7***

Name of The Experiment :***AC power Measurement, Power Compensation and Impedance Matching***

Group No: **Wednesday 1**

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Delay

<u>Do not fill in the grading table. It is for the instructor</u>

Grading

General		/20
Data		/30
Discussion		/20
Answers		/30
Total		/100
Delay		
SCORE		/100

1. THE EQUIPMENT USED IN THE LAB

1. HAMEG HM-203-7 Dual Trace Oscilloscope with x10 probe
2. Escort EDM 168A Digital Multimeter
3. Black Star Jupiter 2000 Signal Generator
4. Resistors, capacitors and inductors of different values (see section 2 for these values)

2. THEORY AND METHOD

Theory:

If a network includes reactive components, i.e. capacitive and/or inductive components, the power delivered to a load is not simply the product of the voltage across and the current through it. The instantaneous power to a load can, generally, be defined as

$$p(t) = v(t) * i(t)$$

However, the effective power, i.e. the power delivered to the load if the voltage and current were constant, is given by

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

If the voltage and the current are sinusoidal functions with a phase difference, the constant part of this equation survives the integral over one period

$$P = V * I * \cos\phi ,$$

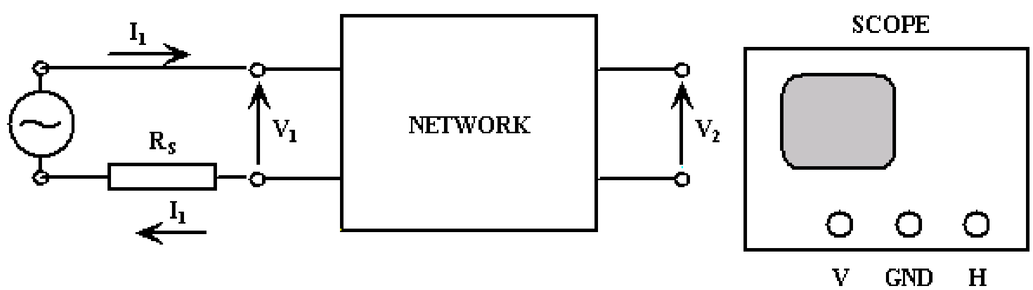
where V and I are the rms (root mean square) values of the voltage and current respectively. ϕ is the phase difference between the voltage and the current. This equation is also called the active power, i.e. the power that is actually dissipated. A general power equation is

$$P = P_A + jP_R = V * I * \cos\phi + jV * I * \sin\phi ,$$

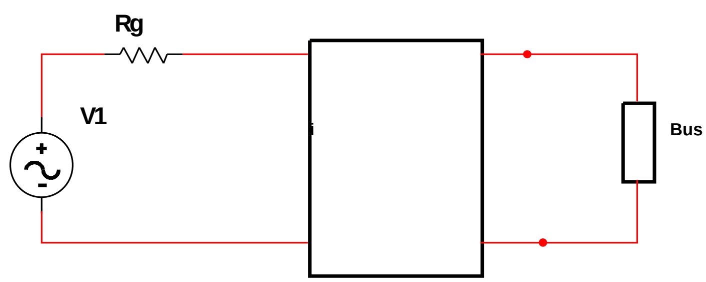
where P_A is the active and P_R is the reactive power. The magnitude of P is the apparent power

$$P_{app} = \sqrt{{P_A}^2 + {P_R}^2} = V * I$$

So, P_{av}, the average power, is $P_A = P_{app} * \cos\phi$, whereas $P_R = P_{app} * \sin\phi$.
In this experiment, the phase difference is determined using the method in the previous experiment, in which an additional resistor is connected to the network as shown in the figure below. The voltage across this resistor is a measure for the current through it when the Lissajou curve with another input signal representing the voltage across another component is observed to determine the phase difference between these two signals.(Figure is obtained from laboratory report of Onur Derin for the Experiment 6: Two Port Parameters and Equivalent Circuits)



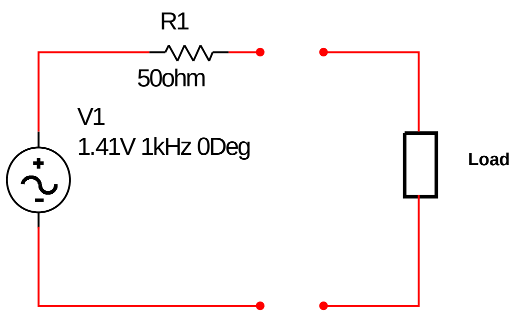
The effect of the reactive components is not dissipating energy but introducing phase shifts due to storing and delivering energy. However, this mechanism results in an increased average current in the transmission lines, causing loss of some power delivered by the power plant, considering within the context of power delivered to a household, factory, etc from a power plant. This loss can be minimized, if the impedance of the load is corrected to obtain a purely resistive load seen from the power source, i.e. a purely resistive load. This process is called impedance matching, and can be achieved by introducing an impedance matching network between the source and the load



Source Impedance Matching Network Load

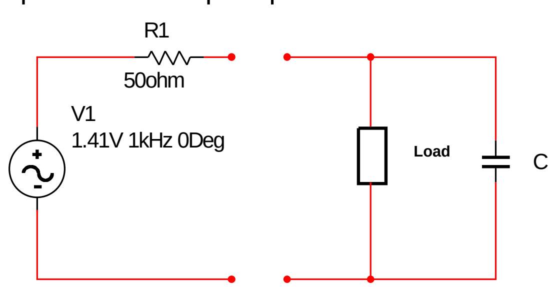
Experimetal Setups:

Experimental Setup for parts 1 & 2:



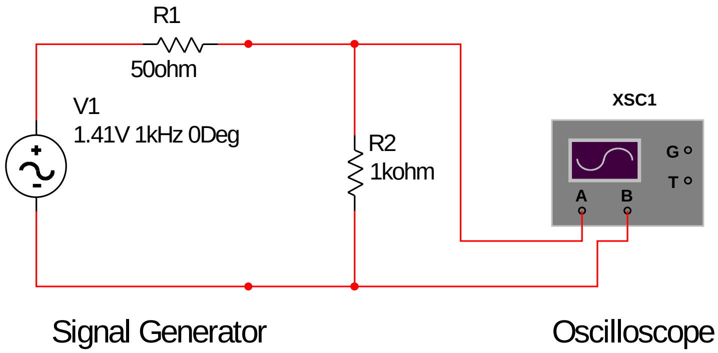
Signal Generator

Experimental Setup for part 4:

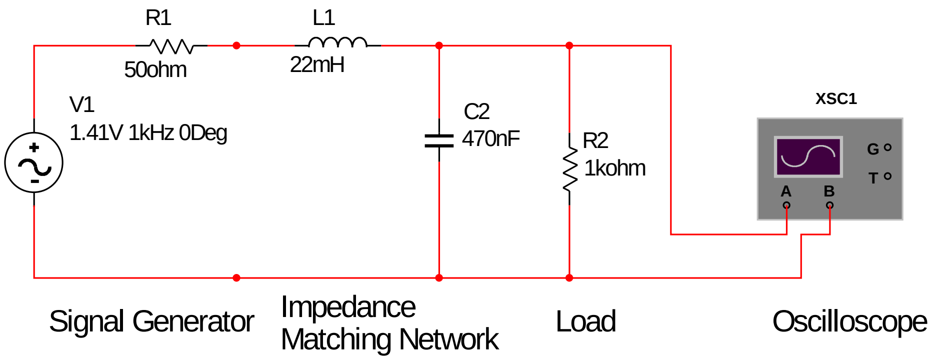


Signal Generator

Experimental Setup for part 7:



Experimental Setup for part 9:



3. DATA

Part 2:

I= 21 mA V= 0.99 V P_W= 20 mW ϕ= 0°

Part 3:

I=8.7 mA V=2.63 V P_W=0.01 W ϕ=64°

Part 4:

a- C=470 nF I= 3.61 mA V= 0.81 V P_W=2.94 mW ϕ=4°
b- C=47 nF I= 4.05 mA V= 0.81 V P_W=2.94 mW ϕ=25°
c- C=100 nF I= 3.94 mA V= 0.81 V P_W=2.94 mW ϕ=21°

Part 5:

	P_A=VI cos(f) [W]	P_R=VI sin(f) [VAr]	P_{app}=P_T=VI [VA]
Resistive Load	0.02	0	0.02
Inductive Load	0.01	0.021	0.023
a	2.94 mW	0.20 mW	2.95 mW
b	2.94 mW	1.37 mW	3.24 mW
c	2.94 mW	1.14 mW	3.15 mW

Part 6:

Maximum power signal generator can supply: $P_{max}=V^2/R=1/50=0.02$ W. This the power dissipated by the output resistance of the signal generator. For maximum power transfer, a load of 50 Ω should be connected. To such a load, the maximum power delivered would be 0.01 W.

Part 7:

V= 0.950 V, I= 0.960 mA, P=VI=0.912 mW

Part 8:

L=22 mH, $C=L/(R_G R_L)$=440 nF. However, a capacitor C=470 nF has ben used.
V= 1.29 V, I= 1.3 mA, $P=V^2/R$=1.66 mW.

Part 9:

f (Hz)	V (V)	f (Hz)	V (V)
500	1.00	1100	1.370
600	1.038	1200	1.466
700	1.085	1300	1.540
800	1.140	1400	1.575
900	1.210	1500	1.563
1000	1.290	1600	1.490

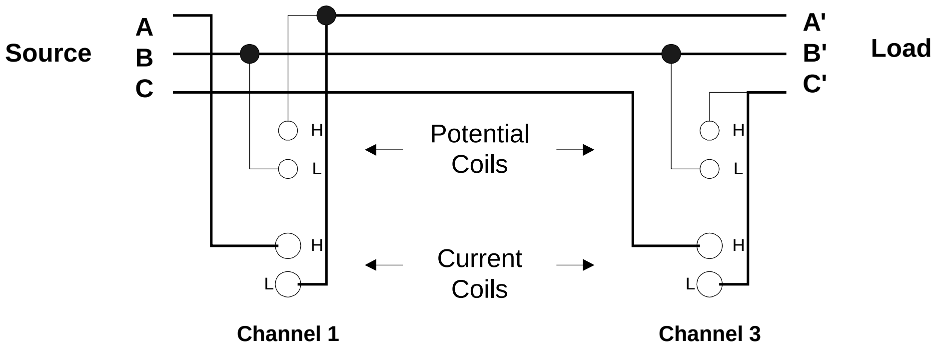
4. ANALYSIS AND DISCUSSION

Determining the phase angels were particularly difficult due to the low quality Lissajou curve images. Moreover, internal resistance of the inductors used caused in phase shifts deviating from the expected theoretical values. However, the part of the experiment realized with capacitors resulted in very consistent results. The introduction of capacitors only introduced phase shifts and didn't change the active power.
Although the capacitor that had to be used to match the impedance properly was 440 nF , a capacitor of 470 nF was used. This changed the frequency for maximum power transfer. Therefore an additional measurement was done to show the decrease in the voltage clearly.

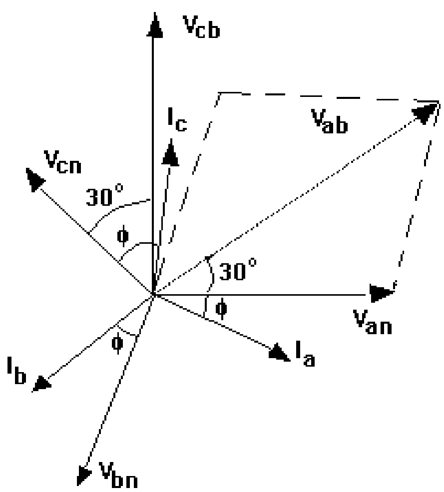
5. ANSWERS TO THE QUESTIONS

1. Consider the circuit of Part 9 without the impedance matching network. Then the current through the load resistor is simply the quotient of source voltage and the total resistance. If constant voltage is required as it is the case in power delivery to households and other consumers, then the reactive loading would result in an increased average current:
Let $P=V*I*\cos\phi$ denote the active power dissipated by the resistive load. Without reactive loading, $\cos\phi=\cos 0=1$ and I=P/V is maximum for P and V required by a consumer. However, due to reactive loading, the line current is $I=P/(V*\cos\phi)$ which increases with increasing ϕ. This increase in the line current , in return, increases the power dissipated by the line impedance. So some power is "lost" due to reactive loading.

2.The connection of the voltage and current coils of 2 wattmeters and the phasor relationships of phase voltages and line currents are shown below. The line voltages V_{ab} and V_{cb} are shown as well. The power readings of wattmeters are calculated according to this phasor diagram.



Three-Phase Connection



$$P_1 = V_{ab} I_a \cos(\angle V_{ab} - \angle I_a)$$

$$P_1 = V_{ab} I_a \cos(30° + \phi)$$

$$= V_L I_L \cos(30° + \phi) \text{ (Wattmeter 1)}$$

$$P_3 = V_{cb} I_c \cos(\angle V_{cb} - \angle I_c)$$

$$P_3 = V_{cb} I_c \cos(90° - 90° + f - 30°)$$

$$P_3 = V_{cb} I_c \cos(f - 30°)$$

$$= V_L I_L \cos(f - 30°) \text{ (Wattmeter 2)}$$

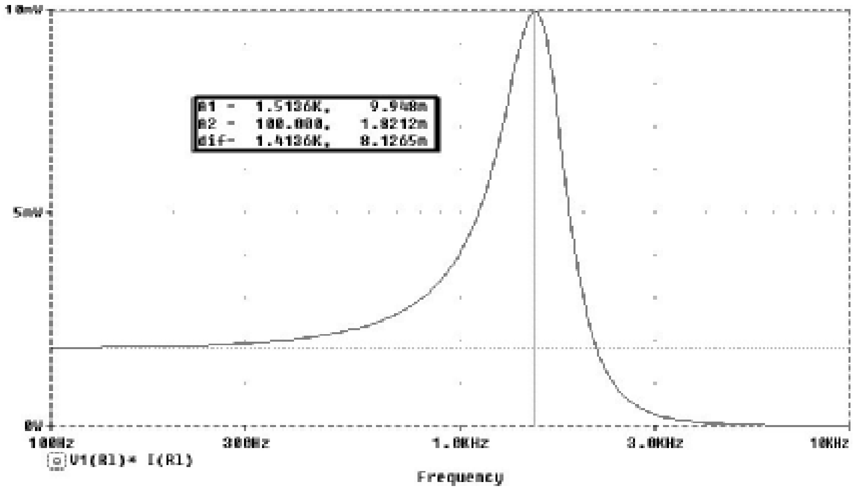
$$P_{tot} = P_1 + P_3 = \sqrt{3} V_L I_L \cos f$$

$$\tan f = \sqrt{3} \frac{P_3 - P_1}{P_3 + P_1}$$

P_{tot} is the average total power of the three-phase circuit. f is the phase difference between line voltage and current. (References: Dorf, R. C., Svoboda, J. A. *Introduction to Electric Circuits*, John Wiley & Sons, New York, 2001; http://www.ee.calpoly.edu/~ashaban/ee365.html)

3.

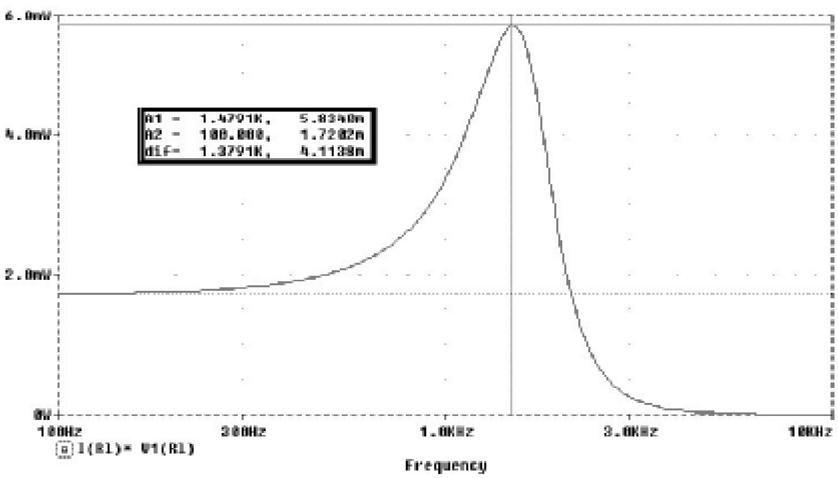
For low frequencies, the capacitor behaves like a open circuit and the inductor like a short circuit, and the circuit becomes a voltage divider. For large frequencies, the inductor behaves like an open circuit so no power transferred to the load. However between these two extreme case there is a frequency at which the impedance matching network equals the source output and load impedances, so that maximum power is transferred to the load. Since, theoretically, the inductive components do not dissipate energy, load resistor dissipates the highest possible power in this circuit configuration.



The SPICE code for this analysis:

```
imp
Vac 1 0 ac 1.412 (1 Vrms corresponds to 1.412 Vpeak)
Rg 1 2 50
L1 2 3 22m
C1 3 0 470n
Rl 3 0 1k
.ac dec 100 100 10000
.op
.probe
.end
```

As shown in the figure, the maximum power transfer occurs at f=1514 Hz, however adding the internal resistance of the inductor changes this frequency The following plot is obtained by adding an extra resistor of 30Ω in series with the inductor:



In this configuration, accounting for the internal resistance of the inductor, the max. power transfer frequency is below 1.5 kHz which is consistent with the experimental data given in section 3 under Part 9.

4.For maximum power transfer:

$$R_G - j\omega L = [1/(j\omega C)]//R_L$$

$$R_G - j\omega L = R_L\ (1 - j\omega R_L C)/(1+\omega^2 R_L^2 C^2)$$

i) $R_G = R_L\ /(1+\omega^2 R_L^2 C^2)$ and ii) $L = R_L^2 C/(1+\omega^2 R_L^2 C^2)$

from i) $C = \dfrac{1}{\omega R_L}\sqrt{\dfrac{R_L}{R_G} - 1}$

if R_G is substituted into ii), then $L = R_G R_L C$ or $C = L/(R_G R_L)$.