

Experiment # 14

R L C - Resonance

Principles

Definition

When connected in *series* and fed by an AC supply V_s (*rms*), of variable frequency ($\omega = 2\pi f$), a resistor R , a capacitor C , and an inductor L together produce a state of minimum impedance, Z , at a certain frequency $\omega_o = 2\pi f_o$. This causes the circuit current I_s *rms*, (the only current in a series circuit,) to rise to a maximum value: $I_{s,max}$. This is known as the phenomenon of resonance or just *Resonance*. The sum of the individual *rms* voltages across the three components, at this time, is several times larger than the supply voltage.

The circuit and its frequency response waveform are shown in Fig (1)

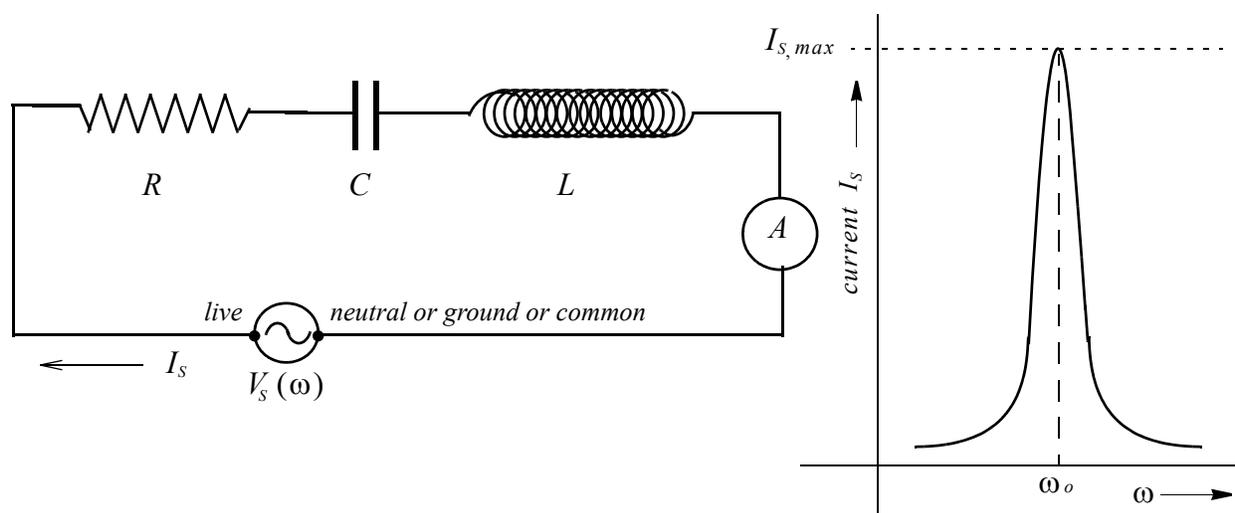


Fig (1) RLC Series Circuit and Resonance

The “V-I” Characteristics of R, L, & C in a DC circuit

The characteristics of R , L and C in DC circuits have been experimentally studied in earlier experiments. We shall now summarize them in a table:

Table 1: R, L & C in a DC Circuit

R	L	C
$V_R = RI_R$	$V_L = R_L I_L$	$Q_C = CV_C$

Please note that R_L is the resistance of the wire of which the inductor is made.

The “V-I” Characteristics of R, L, & C in an AC circuit

The characteristics of R, L and C in AC circuits, have also been experimentally studied in earlier experiments. We shall now summarize them in a table.

Table 2: R, L & C in an AC Circuit

R	L	C
$V_R = RI_R$	$V_L = R_L I_L$ & $V_L = \chi_L I_L$ or $V_L = Z I_L$	$V_C = \chi_C I_C$

Here:

$$Z = \sqrt{R^2 + \chi_L^2} \text{ and } \chi_L = 2\pi fL \text{ and } \chi_C = \frac{1}{2\pi fC} \dots\dots(1)$$

The V-I Phase Relationships in AC Circuits

We shall next consider the phase relationships between voltages and currents for each of R, L and C when placed in an AC circuit. These relationships are found directly from their respective V-I characteristics for AC electricity. (Table 2).

(a) The Resistor

From Ohm’s law for resistors in AC from Table (2), we may write by rearranging:

$$I_R = V_R / R$$

Since the resistance of a given resistor R is always constant, we may write:

$$I_R \propto V_R \dots\dots(2)$$

For a given resistor, the resistor current I_R is directly proportional to the resistor voltage V_R . Thus when voltage rises, current rises, when voltage drops, current drops accordingly and when voltage is zero, current is zero. Thus current follows voltage faithfully. And for sinusoidal voltage of AC electricity, current will also be sinusoidal. The two will rise and fall synchronously, and will pass through their nodes and antinodes, also synchronously.

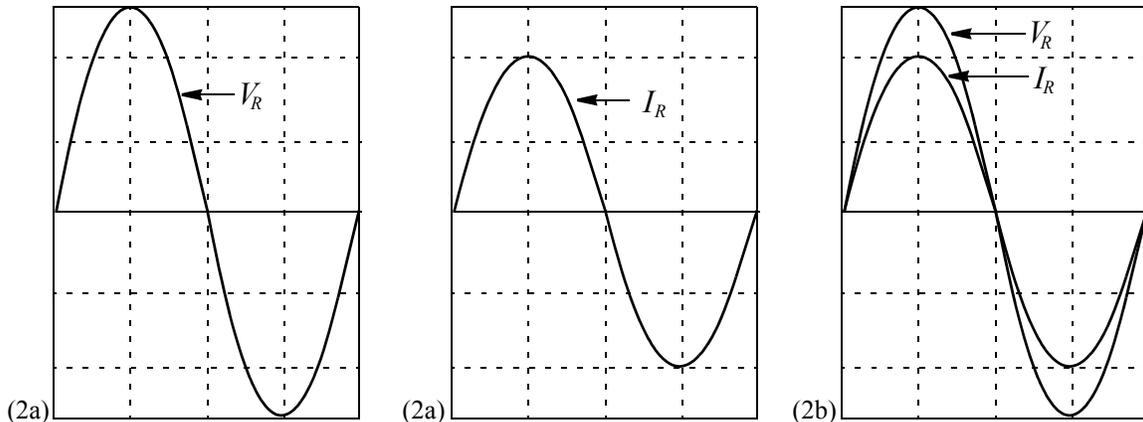


Fig (2) Voltage & Current Relationships For Resistors

The waveforms of AC voltage and AC current for a resistor are shown individually, in Fig (2a), and superimposed on one another, in Fig (2b).

We state that for resistors, their voltages and currents are always **in phase**.

(b) The Capacitor

We have an interesting scenario here. In a DC circuit, a capacitor stores energy but in an AC circuit the capacitor pseudo-conducts electricity and a so-called capacitor current I_C flows in the circuit (but not through the capacitor). An equation for this current was developed in the experiment on *Capacitors*. It reads:

$$I_C = C \frac{\Delta V_C}{\Delta t}$$

And since the capacitance C of a given capacitor is always constant, we may write:

$$I_C \propto \frac{\Delta V_C}{\Delta t} \quad \dots\dots\dots(3)$$

This is an interesting result. We find that, unlike a resistor where the current was proportional to the voltage (or vice versa), here the current is proportional to the *change* in voltage and not to the voltage itself! Thus current is maximum when the *change* in voltage is maximum and is minimum when the *change* in voltage is minimum.

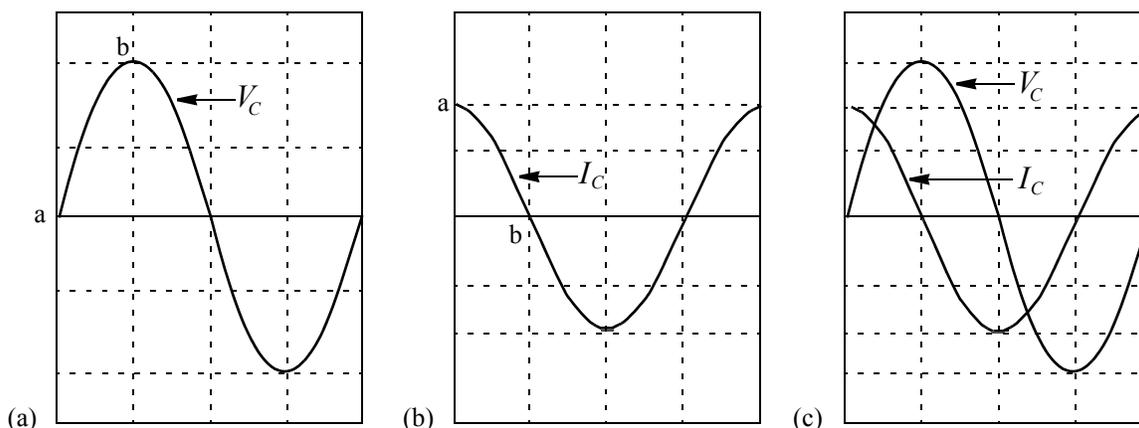


Fig (3) Voltage & Current Relationships For Capacitors

Looking at the sinusoidal waveforms for the AC voltage in Fig (3a), we find that change in voltage is maximum at point a (maximum slope of the curve). Hence current is maximum here, as shown in Fig (3b). At point b , the voltage has reached its maximum value and will shortly begin to decrease in magnitude. The voltage is momentarily constant and hence the rate of change (or the slope) is zero. Correspondingly, the capacitor current is zero at b . Carrying out this analysis for an entire waveform, we find that the sinusoidal waveform for the current is displaced with respect to that for the voltage by one quarter of a cycle or by 90° . Because current is already at its maximum level while the voltage is at its zero level, it is in order to say that current leads voltage by 90° . The waveforms of voltage and current are shown superimposed on each other in Fig (3c).

We state that for capacitors, their voltages and currents are **out of phase**, and that capacitor current I_C leads capacitor voltage V_C by 90° .

(c) The Inductor

When an inductor is placed in an AC circuit, a counter emf, ε_L is induced in the inductor, as described in the experiment on *Inductors*. The value of ε_L is given by:

$$\varepsilon_L = -L \frac{\Delta I}{\Delta t} \quad \dots\dots(4)$$

Since the inductance L of a given inductor is always constant, we may write:

$$\varepsilon_L \propto \frac{\Delta I}{\Delta t}$$

The negative sign has been omitted as it is only symbolic. It is this induced voltage ε_L which is shown as inductor voltage V_L in Table (2). Writing V_L for ε_L , we get:

$$V_L \propto \frac{\Delta I}{\Delta t} \quad \dots\dots(5)$$

This is another very interesting result. We find that unlike the capacitor where the current was proportional to the change in voltage, here voltage is proportional to the change in current. Eqn. (5) shows that the inductor voltage is proportional to the *change* in the inductor current and not to the current itself. Thus voltage is maximum when the *change* in current is maximum and is minimum when the *change* in current is minimum.

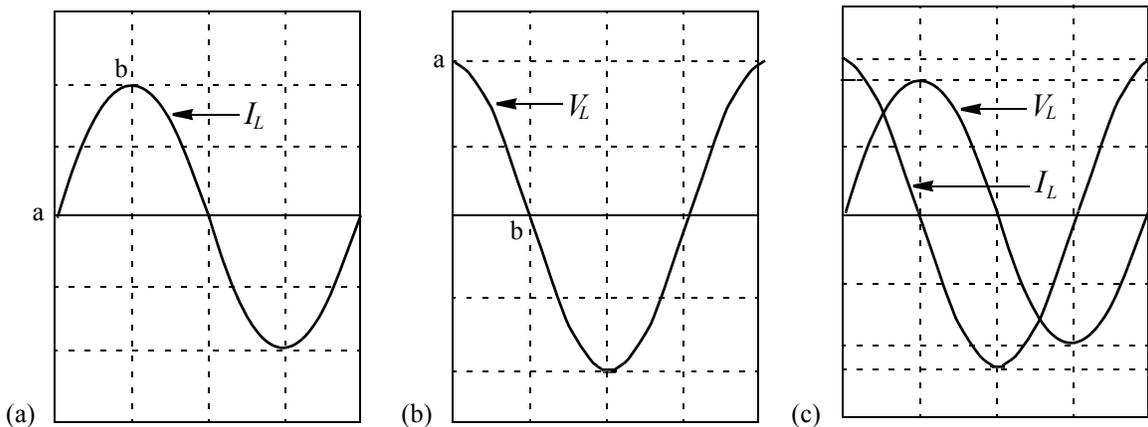


Fig (4) Voltage & Current Relationships For Inductors

Looking at the sinusoidal waveforms for the current in Fig (4a), we find that change in current is maximum at point a (maximum slope of the curve). Hence voltage is maximum here, as shown in Fig (4b). At point b , the current has reached its maximum value and will shortly begin to decrease in magnitude. The current is momentarily constant and hence the rate of change (or the slope) is zero. Correspondingly, the inductor voltage is zero at b . Carrying out this analysis for an entire waveform, we find that the sinusoidal waveform for the voltage is displaced with respect to that for the current by one quarter of a cycle or by 90° . Because voltage is already at its maximum level while the current is at its zero level, it is in order to say that inductor voltage V_L leads inductor current I_L by 90° . In an inductor, therefore, voltage leads current by 90° . The waveforms of voltage and current are shown superimposed on each other in Fig (4c).

We state that for inductors, their voltages and currents are **out of phase**; and that inductor voltage V_L leads inductor current I_L by 90° .

The Collective Phase Relations of R, L, & C

We now consider R , L and C in a series circuit, fed by AC electricity. Being in a series circuit, R , L and C will share a common current. Thus

$$I_R = I_L = I_C = I_S$$

where I_S is the source current. It is natural, therefore, to choose I_S as the reference variable for the study of the relative phases of the three voltages. The resistor voltage V_R is in phase with the current, the inductor voltage V_L leads the common current by one quarter of a cycle or by 90° , and the capacitor voltage V_C lags behind the common current by one quarter of a cycle or by 90° . One way of representing the situation will be to superpose all waveforms on one another, in accordance with the above criteria. This is shown in Fig (5a). For a quantitative analysis, however, we shall use the vector technology and plot the voltages and their common current on an x-y reference frame. Thus if I_S were to be plotted on the x-axis, then V_R (for reasons of being in the same phase) should also be plotted on the x-axis. Being ahead of common-current by 90° , V_L should be plotted along the positive y-axis and for similar reasons, V_C will find its place along the negative y-axis. Such a plot is shown in Fig (5b).

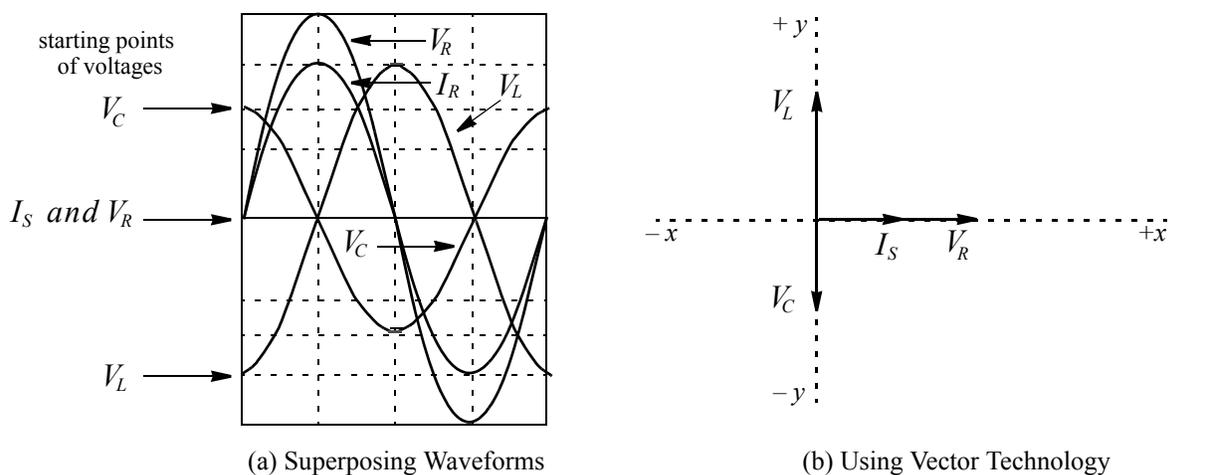


Fig (5) Combining the Three Voltages (a) Superposing Waveforms (b) Using Vector Technology

The inductor and the capacitor voltages being 180° out of phase, get subtracted and the absolute difference $(V_L - V_C)$ is plotted on the y-axis (positive or negative). We are now left with

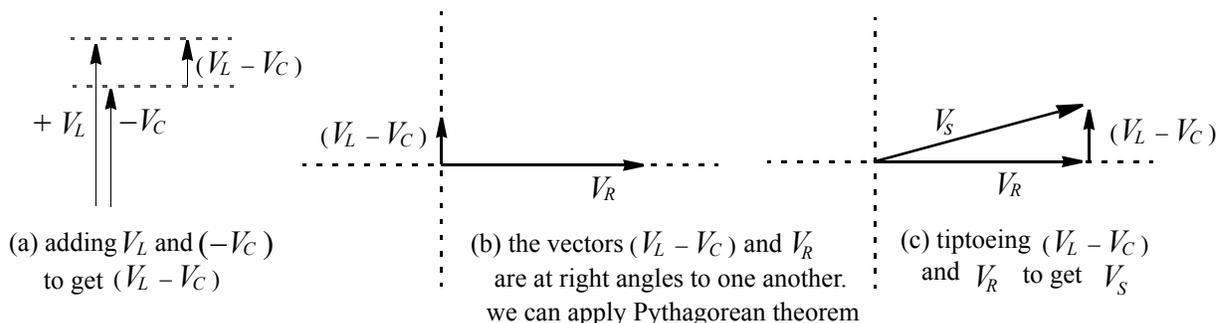


Fig (6) Combining Voltages Vectorially

two mutually perpendicular vectors that may now be combined using the Pythagorean theorem. This procedure is shown in a sequence in Fig (6a) to (6c), for the case $V_L > V_C$. It is easy to see that the source voltage V_s is given by the equation:

$$V_s = \sqrt{V_R^2 + (V_L - V_C)^2} \quad \text{.....(6)}$$

As the next step, we replace voltages by their respective resistances or reactances, as given by the applicable Ohm's law. These are also combined in a similar manner. The sequence of this operation is shown in Fig (7a) to (7c), for the case $\chi_L > \chi_C$.

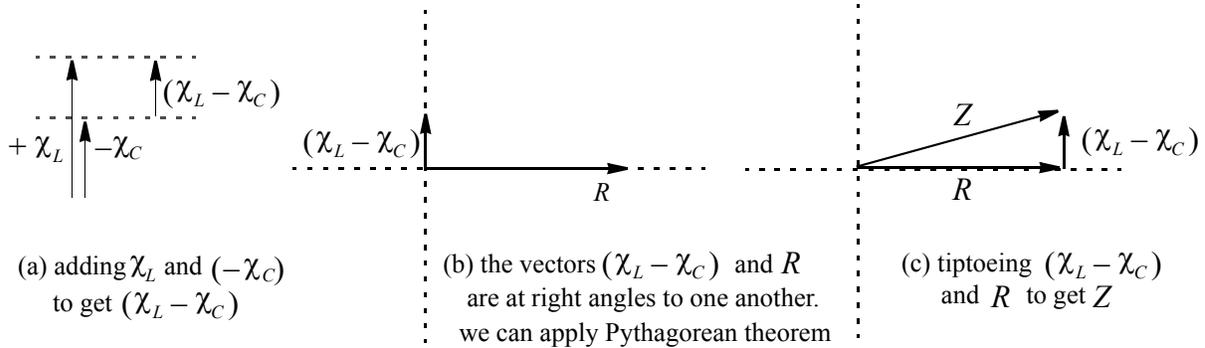


Fig (7) Combining Reactances and the Resistance

The use of Pythagorean theorem, here, leads to the impedance Z , of the series R , L and C circuit. It should be noted that in the above analysis, we have neglected the effect of the resistance R_L of the inductor in AC circuit. The inductor is, therefore, assumed to be an ideal inductor. The above treatment leads to the following mathematical expression for the total circuit impedance Z :

$$Z = \sqrt{R^2 + (\chi_L - \chi_C)^2} \quad \text{.....(7)}$$

The Ohm's Law for the circuit may be written down as:

$$V_s = Z I_s \quad \text{.....(8)}$$

Resonance

From Eqn. (1) we find that each of the two reactances χ_L and χ_C , depends on the circular frequency ω of the AC source voltage V_s . The mode of their dependence is however, different. One of the two χ_L , depends on the circular frequency directly. Thus if ω were to increase, χ_L will also increase. On the other hand, χ_C depends inversely on the circular frequency. Thus if ω were to increase, χ_C will decrease. This *opposite* reaction to a change in frequency, leads to a very interesting phenomenon. Starting from a situation where χ_C is greater than χ_L , if ω were to increase, the inductive reactance will grow but the capacitive reactance will diminish. It is possible to reach a frequency where the two will become equal in magnitude and the vector $(\chi_L - \chi_C)$ will become zero. Eqn. (7) then leads us to:

$$Z = R \quad \text{.....(9)}$$

When $(\chi_L - \chi_C) = 0$ then $(V_L - V_C)$ must also be zero. This leads to:

$$V_s = V_R \quad \text{.....(10)}$$

The minimal impedance of the circuit components has led to the maximum current in the circuit, **provided of course that V_s remains constant**. This is **Resonance**. If a series R , L and C circuit with arbitrary values of inductor and capacitor, be connected to an AC source of variable frequency, the circuit will resonate at some frequency $\omega_o = 2\pi f_o$.

If $(\chi_L - \chi_C) = 0$, then χ_L must be equal to χ_C . Replacing them by their respective expressions developed in experiments on *Inductors* and *Capacitors*, we get:

$$2\pi f_o L = \frac{1}{2\pi f_o C}$$

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad \dots\dots(11)$$

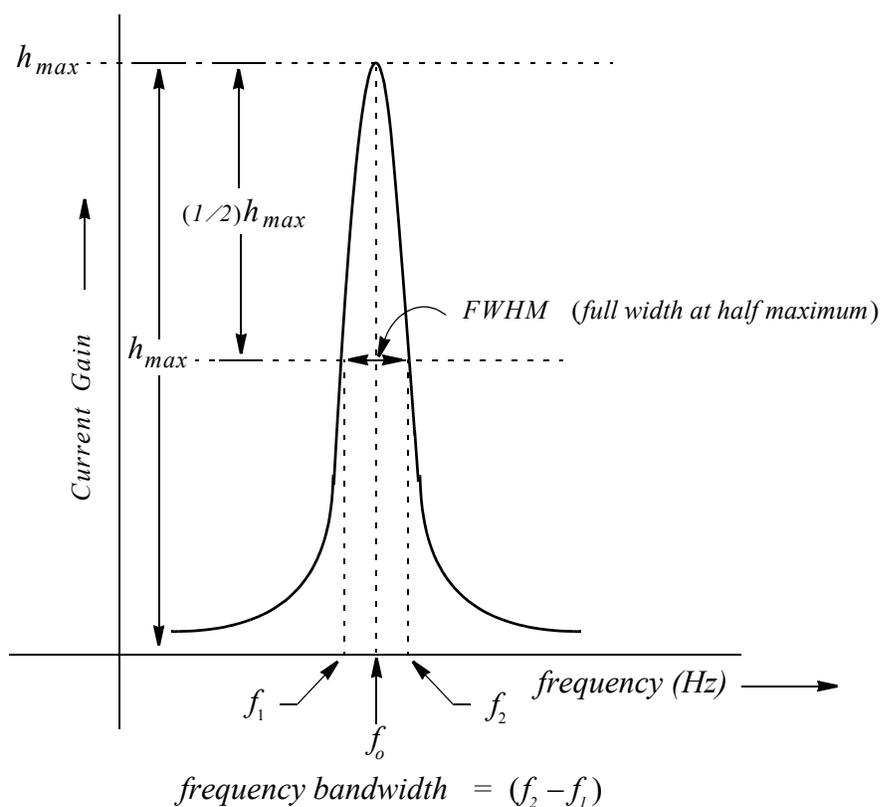


Fig (8) The Resonance & its Characteristics

This result shows that f_o exists for all combinations of R , L and C . At resonance, the current in the circuit will be maximum and the circuit impedance will change to pure resistance. A frequency response plot of a series R , L and C circuit is shown in Fig. (8). As frequency increases towards an anticipated resonance, the reactances shrink and the output current increases. It is maximum at the resonant frequency where the reactances have totally cancelled out. The output current then falls sharply as a result of the reemergence of reactances. The sharpness of the peak depends on the resistance R of the circuit. For modest values of R , resonance peak will be slim and sharp. For larger resistances, the peak will be short and fat.

Objectives of the Experiment

- (a) To draw a frequency response waveform for the given series R , L and C circuit, to find the resonant frequency f_o experimentally and compare it with its expected value. Deduce a value of the inductance L of the inductor used.
- (b) To use the resonance phenomenon to determine the inductance of the inductor used in (a) above. Compare with the value obtained in (a) above.

Setting Up

(a) Even though it is the circuit current that gets maximized at resonance, it is customary to study the voltage gain of the circuit, rather than its current gain. This is because voltages can be measured directly on an oscilloscope. The voltage gain is measured across the capacitor. We shall, therefore, be measuring the voltage output at the capacitor terminals of our series R , L C circuit.

The first part of the objective is straightforward. After connecting the given components in series with a function generator, one would monitor the voltage amplitude (using an oscilloscope) for different frequencies. A graph of voltage gain G against f will yield a typical frequency response curve, as shown in Fig (1) and Fig (8). From the peak of the waveform, one can find f_o . The value of f_o , in turn, may be plugged in Eqn (11) to calculate the inductance L of the inductor used, provided of course that the capacity of the capacitor is known.

(b) For determining the inductance L , using the resonance technique, one would re-arrange Eqn (11) to read:

$$4\pi^2 f_o^2 = \frac{1}{LC} \quad \text{.....(12)}$$

Writing $\omega_o = 2\pi f_o$, we get:

$$\omega_o^2 = \frac{1}{LC}$$

Taking reciprocals on both sides:

$$(1/\omega_o^2) = LC \quad \text{.....(13)}$$

This conforms to the equation of a straight line. Plotting $(1/\omega_o^2)$ against capacitor values C , one should get a straight line of slope L . Thus L can be determined.

Procedure

(a) Plotting the Resonance Curve

- (1) Select $R = 100 \Omega$ on the resistance substitution box and check the value with an ohm-meter. Select $C = 0.0005 \mu F$ or $500 pF$ on the capacitor substitution box. Check the value with an LCR meter. As for the inductor, use the one on your table. Check the value with an LCR meter. Enter all values in your data sheet
- (2) Set up a series R , L and C circuit using the digital function generator (with amplifier) as the AC source. When the series circuit is assembled, connect channel (1) of the oscilloscope across the function generator and channel (2) across the capacitor, as shown in Fig (9).

- (3) Set the *frequency range selector* knob to $1\text{ kHz} - 10\text{ kHz}$ range. Make sure the generator is set to *sine wave* waveform. Use the frequency control knob to select 5 kHz frequency as displayed on the digital display. The frequency need not be exactly 5000 Hz . Few cycles per second, either way would be unimportant. Record the actual frequency in the *actual frequency* column in the data sheet.
- (4) Select *channel 1* on the oscilloscope. Select 0.2 volts/div setting for channel 1's *vertical amplifier*. Using the *amplitude control* knob of the function generator, adjust the input voltage V_{in} , to 1 volt peak-to-peak. The *total* height of the waveform (peak to peak) on the screen will be 5 divisions vertically. It is very important to keep V_{in} precisely at 1 volt peak-to-peak. Check the setting often and adjust precisely to the above, as and when necessary.

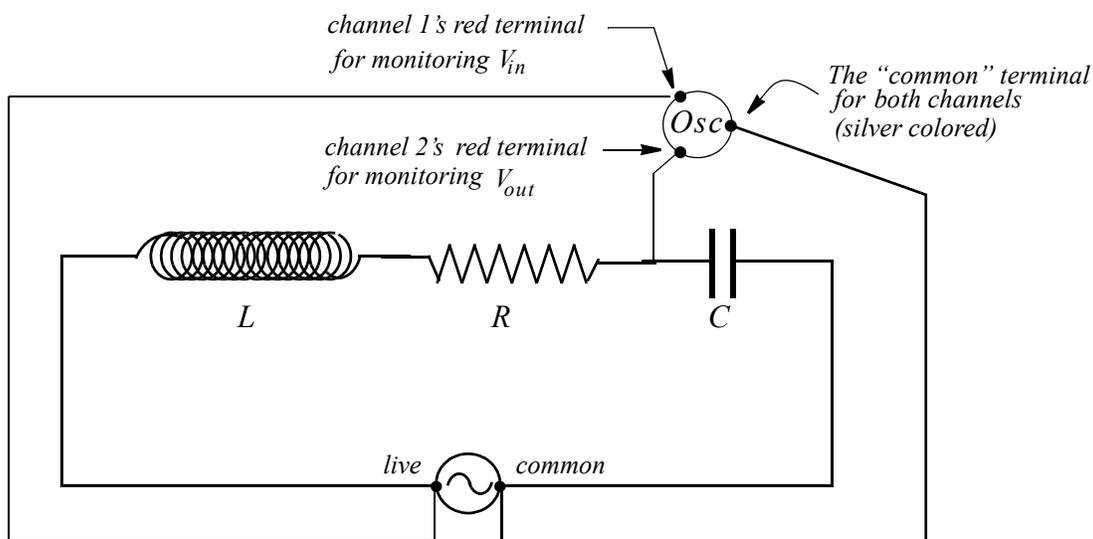


Fig (9) The Series R , L and C Circuit for the Experiment

- (5) The philosophy of reading and recording V_{out} :

To read the amplitude of V_{out} , we shall select *Channel 2* on the oscilloscope. The *volts/div* setting of Channel 2's *vertical amplifier* will be adjusted so as to have a large enough amplitude on the screen. By *large enough* we understand that the height of V_{out} on the screen should be 4 divisions (vertically) or more. Depending on the magnitude of V_{out} , we may set the *volts/div* setting of Channel 2's vertical amplifier to anywhere from less than a volt per division to several volts per division. You will notice that we have 12 settings to choose from; ranging from 5 mV/div to 5 volt/div . When the amplitude of V_{out} is small, we shall choose settings with fractional voltages per division. As the amplitude grows, we shall select settings with increasingly larger *volts/div* settings.

To compute V_{out} , multiply the height of the output voltage (measured in terms of the *number of divisions* vertically, on Channel 2) with the *volts/div* setting of Channel 2's vertical amplifier.

- (6) To read V_{out} for the 5 kHz frequency that we set up in step (3), select Channel 2. Set the *volts/div* knob to 0.2 *volt/div*. The amplitude should be 5 or about 5 vertical divisions; indicating that the output voltage, at this frequency is about 1-V peak to peak. The circuit gain will be just about 1. Record the exact number of vertical divisions and the value of *volts/div* setting, in the data sheet. Note that the vertical divisions can be read to one-tenth of one division.
- (7) Second trial's frequency is 10 kHz. Set the *frequency range selector* knob to 10 kHz - 100 kHz range. Use the frequency control knob to select 10 kHz. This frequency will be shown on the digital display. The frequency need not be exactly 10 kHz. Record the actual frequency in the data sheet.
- For V_{out} proceed as in step 6 and record (i) the magnitude of vertical divisions, peak-to-peak (amplitude of V_{out}) and the value of *volts/div* setting in the data table. The amplitude of V_{out} will most likely be between 5 and 6 divisions on the 0.2 *volts/div* setting.
- (8) The 3rd trial. Making sure that V_{in} is still 1-V peak to peak, increase the frequency until V_{out} is exactly 6 divisions vertically, on the 0.2 *volts/div* setting, on Channel 2. Record the actual frequency, as shown on the digital display, in the data sheet, for trial #3.
- (9) The 4th trial. Proceed as in step (8) but increase frequency until V_{out} is exactly 7 divisions on the 0.2 *volts/div* setting, on Channel 2.
- (10) Before the 5th trial, switch to 0.5 *volts/div* setting. The amplitude of V_{out} from the 4th trial will shrink and be between 2 and 3 divisions vertically. Increase the frequency until V_{out} is 3 divisions exactly. Read and record the frequency in your data sheet.
- (11) For the 6th and subsequent trials, increase the frequency until the amplitude of V_{out} rises to 4,... 7 divisions respectively. Record corresponding frequencies, as they appear in the digital display. This should take you to 9 trials.
- (12) Before the 10th trial, switch to 1 *volt/div* setting. The amplitude of V_{out} from the 9th trial will shrink and be between 3 and 4 divisions. For the tenth trial, increase the frequency until the amplitude of V_{out} rises to 4 divisions. Then, for the 11th and subsequent trials, increase the frequency for the amplitude of V_{out} to rise to 5,... 7 divisions. This will take you to 13 trials.
- (13) Before the 14th trial, switch to 2 *volt/div* setting. The amplitude of V_{out} from the 13th trial will shrink and be between 3 and 4 divisions. For the 14th trial, increase the frequency until the amplitude of V_{out} rises to 4 divisions.
- (14) You may have noticed that the amplitude is now increasing at a faster rate. This requires that we record the frequencies for a rise of amplitude of one-half of one division for better resolution. For 15th and subsequent trials, therefore, increase frequency until the amplitude of V_{out} rises to 4.5, 5.0, 5.5,... 7 divisions. Read and record the frequency in your data sheet. This will take you to trial #20.
- (15) Before the 21st trial, switch to 5 *volt/div* setting. The amplitude of V_{out} from the 20th trial will shrink to between 2 and 3 divisions. For the 21st trial, let the amplitude of V_{out} grow to 3 divisions. Record the frequency. For the 22nd and subsequent trials, increase the frequency until the amplitude of V_{out} rises to 3.5, 4.0, 4.5,...until you hit the resonance. Very carefully adjust for the resonance and then read the frequency and enter in

the row that is labeled “R”. Also carefully read the total number of vertical (peak to peak) divisions, to one decimal place and enter in the appropriate space (provided in that row). This corresponds to trial #31 but it may not really be your trial #31. Suppose (as an example) that this is your trial #28. You would have completed trial #27. Leave the next 3 rows blank and enter the resonance data in row marked “R”.

The frequency entered in this row is the *experimental* values of f_o .

- (16) Having reached the resonance peak, we shall be *climbing down the peak*. Retrace the path by going backward. As a first step in this direction, cross out as many rows below “R”, as you had to leave blank, above “R”. Suppose (as in the above example), your resonance occurred at trial #28 and you had to leave out 3 rows: #s 28, 29 and 30. Now you cross out row #s 32, 33 and 34 and start with trial number 35.
- (17) Increase frequency until the amplitude of V_{out} has decreased by one-half of one division. Record the actual frequency in the appropriate row. Other data is already present and you do not need to bother.
- (18) Now that understand the philosophy of collecting data, it will perhaps be easier to follow the data table, and if need be, refer to the above steps for general guidance. Keep two things in mind.
 - (i) the (vertical) amplitude is always *decreasing*.
 - (ii) we are always *increasing* the frequency.
- (19) This part of the experiment ends.

b) Determining the Inductance L

- (20) For the same circuit and for the same resistor and inductor, we shall now select different values of capacitor C . The input voltage V_{in} of the function generator will also be left unchanged. For each capacitor, we shall scan the frequency range (using frequency control knob) to obtain resonance, i.e. the frequency for maximum voltage amplitude (vertically of course). We shall, however, not be measuring these voltage amplitudes. We shall simply be recording the actual frequency in the data sheet.
- (21) Select $C = 100 \text{ pF}, 200 \text{ pF}, 300 \text{ pF}, 400 \text{ pF}, 500 \text{ pF}, 700 \text{ pF}, 900 \text{ pF} \dots\dots 1700 \text{ pF}, 2000 \text{ pF}, 2500 \text{ pF}, 3000 \text{ pF} \dots\dots 5000 \text{ pF}$. For each capacitor setting, scan the frequency range, locate the resonance frequency, and enter in the data sheet.
- (22) The experiment ends. Disconnect the circuit and arrange all wires, components neatly as instructed. Make sure that the function generator is switched off.

Calculations & Graphs

(a) The Resonance Curve

- (1) For each trial, calculate the circuit gain: $G = V_{out} / V_{in}$. However, as V_{in} is just 1 volt, V_{out} itself is your gain. No calculations will be needed.

- (2) Plot a graph of frequency f (in Hz) on the x-axis and the circuit gain G on the y-axis. After punching the data, ask the computer to fit a line in the *interpolate* mode. It will then draw a smooth line through all the data points. If you successfully retraced your path, the peak of the bell shaped curve will be the true peak, otherwise it may be an approximate peak and we shall have to accept it. *This graph is part of your "Results"*.
- (3) Calculate f_o by inserting the values of L and C (as determined using the LCR meter) in Eqn (11). This is the *expected* value of f_o .
- (4) The resonance frequency, as found in step (15) of procedure, is the *experimental* value of f_o . Compare with the *expected* value and calculate percent error.
- (5) Using the value of f_o from step (15) of Procedure, and the value of capacitor C used in the experiment, calculate the inductance L of the inductor of your circuit. Do not forget to convert μF or pF to F .

(b) Determining the Inductance, L

- (6) Multiply each resonance frequency f_o (in Hz , and not in kHz) by 2π to convert it to ω . Then calculate $1/\omega^2$.
- (7) Plot $1/\omega^2$ on y-axis and the corresponding values of capacitor C (in farads and not in μF or nF or pF) on the x-axis. The slope of this line will directly be the value of the inductance L of the inductor (in henries) used in the experiment.
A minimum of four significant decimal places are required.
- (10) We have two experimentally obtained values of L for our inductor from this experiment. Find the average of these 2 values and declare it as the *experimentally determined* value of L . Find percent error with respect to the *given* value (as entered in the data sheet).

In the *Discussion* part of the report you should discuss the relative merits of the two determinations and point out the one you think is the *preferred* value. These investigations will not be part of the *Results* of the experiment.
- (11) Compile the *Results* of the experiment.

Conclusions and Discussions

Write your conclusions from the experiment and discuss them.

What Did You Learn in this Experiment?

A hearty and thoughtful account of what you learned in this experiment by way of the principle and the techniques of experimentation, should be given

Data & Data Tables

Name.....

Date.....

Instructor.....

Lab Section.....

Partner.....

Table #.....

(a) Plotting the Resonance Curve

Table 3: The Resonance

#	Actual Frequency (Hz)	V_{out} (volts)		#	Actual Frequency (Hz)	V_{out} (volts)		#	Actual Frequency (Hz)	V_{out} (volts)	
		# of Div	Volts/Div			# of Div	Volts/Div			# of Div	Volts/Div
1	5000	5	0.2	23		4	5	45		5.5	2
2	10,000		0.2	24		4.5	5	46		5	2
3		6	0.2	25		5	5	47		4.5	2
4		7	0.2	26		5.5	5	48		4	2
5		3	0.5	27		6	5	49		7	1
6		4	0.5	28		6.5	5	50		6	1
7		5	0.5	29		7	5	51		5	1
8		6	0.5	30		7.5	5	52		4	1
9		7	0.5	R			5	53		7	0.5
10		4	1	32		7.5	5	54		6	0.5
11		5	1	33		7	5	55		5	0.5
12		6	1	34		6.5	5	56		4	0.5
13		7	1	35		6	5	57		3	0.5
14		4	2	36		5.5	5	58		7	0.2
15		4.5	2	37		5	5	59		6	0.2
16		5	2	38		4.5	5	60		5	0.2
17		5.5	2	39		4	5	61		4	0.2
18		6	2	40		3.5	5	62		3	0.2
19		6.5	2	41		3	5	63		2	0.2
20		7	2	42		7	2	64		1	0.2
21		3	5	43		6.5	2				
22		3.5	5	44		6	2				

Inductance of the given inductor: (mH)
 Function Generator Amplitude set to: 1 volt, p-p
 Resistance R : Nominal Value: 100.0Ω Actual Value: Ω
 Capacitance C : Nominal Value: $500 pF$ Actual Value: pF

(b) Determining the Inductance L

Table 4: The Inductance

#	Capacitor C (pF)	Resonance Frequency (Hz)	#	Capacitor C (pF)	Resonance Frequency (Hz)
1	100		9	1300	
2	200		10	1500	
3	300		11	1700	
4	400		12	2000	
5	500		13	2500	
6	700		14	3000	
7	900		15	4000	
8	1100		16	5000	

Additional information or data (if any):