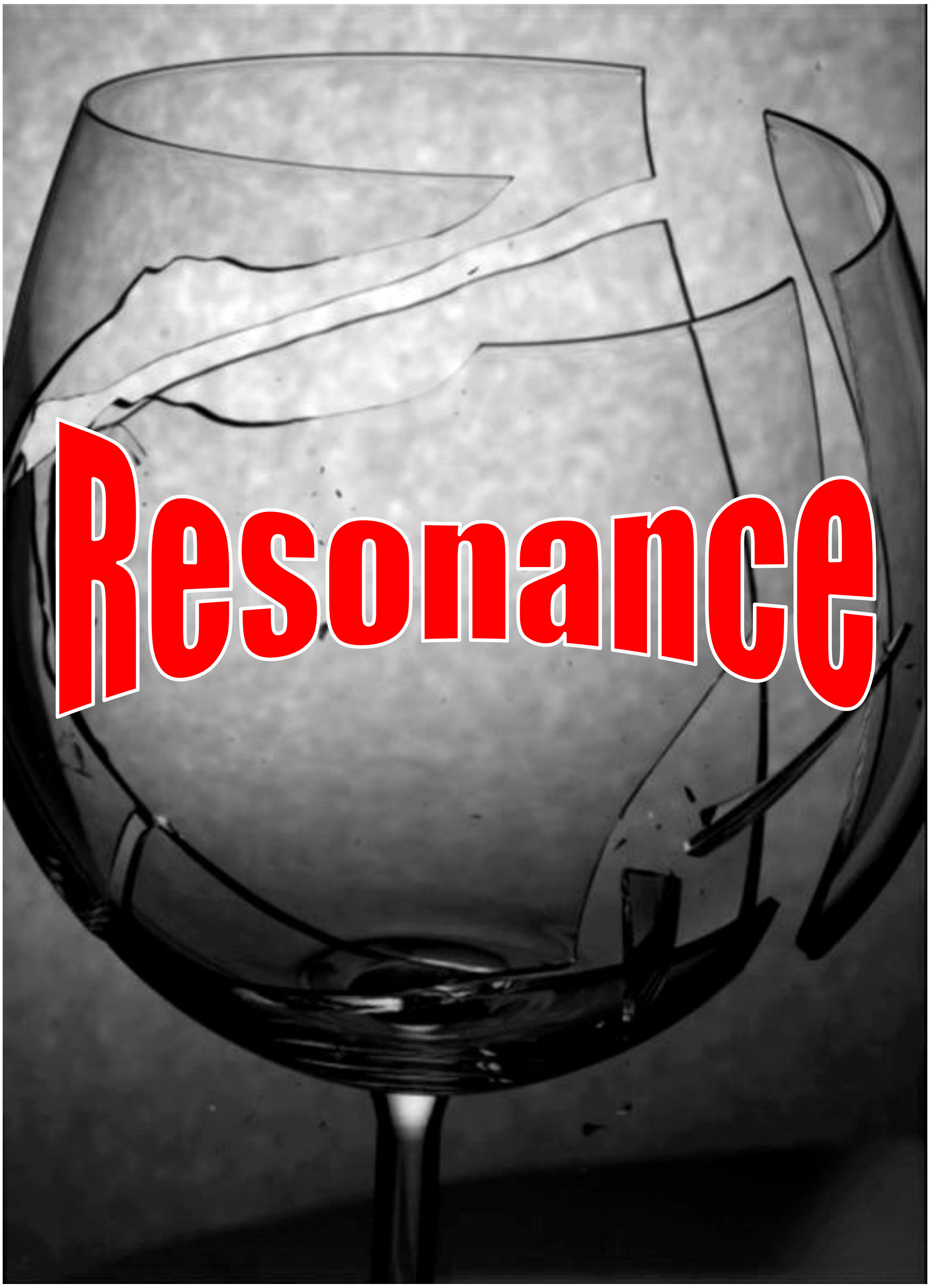
Physics and Astronomy

UNIVERSITY OF LEICESTER

Resonance



FACILITATOR NOTES

PA1140

Contents

Introduction

‘Resonance’ is a first year Core Group Research Project (Core GReP) to be undertaken by small groups of 4 or 5 students, working as teams to perform a variety of experiments on LCR (inductance, capacitance, resistance) electrical circuits. This project corresponds to the PA1720 AC Theory course, although much of the required supporting information and theory is contained in the PA1140 and PA1130 courses. The theory required for this project is given in the course books (Tipler and Mathematical Physics Vol.2), although some thinking may be required to extend this knowledge or apply it to an area that has not been directly covered in the courses.

Students will have four laboratory sessions to perform their experiments, as well as two workshop sessions with facilitators. For each of the workshops, students should supply answers to set questions, which will then be checked and corrected if they need to be. The questions are designed to underscore concepts useful for understanding the laboratory work being undertaken.

Problem Statement

Resonance is a phenomenon that occurs in many diverse physical systems. These include: time-keeping devices such as the pendula of mechanical clocks and the quartz tuning forks of digital watches; nuclear magnetic resonance, as exploited in medical NMR scanners; the creation of coherent light in a laser cavity; acoustic resonances of musical instruments (and shattering wine glasses); resonant tidal systems producing extreme sea level variations; tidal locking of the moon; orbital resonances as shown by some gas-giant moons; the electrical resonance of tuned circuits, as found in radio and TV receivers. It is the latter form of resonance that will be explored in this GReP.

Although the detailed physics of the systems listed above are all different, they display common features: an oscillatory behaviour with a characteristic (or natural) frequency, and a periodic "driving" force which pushes the system at or near its natural frequency: for instance, the child's swing and the parent's push once every oscillation. In the real world, all systems suffer from some form of energy dissipation or loss, for instance, air resistance in the case of the swing. Hence, we expect resonance to occur in systems which can be described as "forced (or driven), damped, simple harmonic oscillators".

Although the detailed physics differs from system to system, the mathematical description of resonance is very similar in each, and understanding resonance in LCR (induction, capacitance, resistance) circuits will shed light on all the other phenomena.

Staff

Prof Richard Alexander

Prof Nial Tanvir

Dr Eloise Marais

Learning Objectives

You are required to recall and use theoretical knowledge from the PA1130 and PA1140 courses (from Tipler) regarding:

- Capacitance (and the effect of capacitors in series and parallel)
- Parallel plate capacitors
- Dielectrics
- Inductance in a solenoid
- LCR circuits

You will also require theoretical knowledge from the AC Theory course documentation (Mathematical Physics Vol.2) regarding:

- LCR circuits and their mechanical analogue
- LCR circuits with a sinusoidal driving voltage
- Resonance in AC series circuits
- The ‘Q’ (quality) factor

You will use the following skills:

- Set-up of electronic equipment
- Use of computer software to generate and evaluate electronic signals
- Analysis of experimental data using corresponding theory
- Making precise measurements of useful sets of parameters
- Managing the team’s use of time
- Report writing

You are also expected to:

- Analyse sources and magnitudes of error
- Assess if your results fit the error estimates made
- Consider possible dangers or safety hazards associated with the experiment

Time-Table

It is important that the introductory material is read **prior to the first laboratory session**, and that relevant theory has been revised.

Session	Dates
1: Laboratory Session 1	**Block 1: Thursday 27th February** **Block 2: Friday 28th March**
2: Workshop 1	**Block 1: Monday 2nd March** **Block 2: Tuesday 3rd March**
3: Laboratory Session 2	**Block 1: Thursday 5th March** **Block 2: Friday 6th March**
4. Workshop 2	**Block 1: Monday 9th March** **Block 2: Tuesday 10th March**
5: Laboratory Session 3	**Block 1: Thursday 12th March** **Block 2: Friday 13th March**
6: Laboratory Session 4	**Block 1: Monday 16th March** **Block 2: Tuesday 17th March**

Please note that the student year is split into TWO BLOCKS – Block 1 and Block 2.

Block 1: consists of student groups A1, A3, B1, B3, C1, C3, D1, D3, E1, E3, F1, F3,

Block 2: consists of student groups A2, A4, B2, B4, C2, C4, D2, D4, E2, E4, F2, F4,

All Sessions take place in Room F

Workshops: 14:00 – 16:00

Laboratory Sessions: 14:00 – 17:00

Deliverables

Group Report: **Submission deadline 2pm, Thursday March 27 2020**

Submit on Blackboard > PA1900: Experimental Physics 1 2019-20 Y > Assessment and Feedback > PA1900 GReP Report 2019-20

The **file name** should be: 114GReP_Group Letter_UserName_Report.pdf
e.g. 114GReP_Group A1_zyx_Report.pdf

Please ensure that you keep an electronic copy of your report.

Reflective Account: **Include as part of group report. See next section for details.**

Project Plan (in Laboratory Note-Book)

Reflective Account – Reminder!

We would like to gently remind you that, as part of the PA1900 Experimental Physics module, you are asked to submit a **personal (i.e. individual) reflective account.**

Reflective Account: **Submission deadline 2pm, Thursday March 27 2020**

Please submit on Blackboard > PA1900: Experimental Physics 1 2019-20 Y > Assessment and Feedback > PA1900 - Reflective Account 2019-20

The **file name** should be: PA1900_First Name_Surname_Reflective_Account.pdf
e.g. PA1900_Dave_Smith_ Reflective_Account.pdf

Reminder: both PA1900 **reflective account guidelines** and **marking criteria** can be found on Blackboard at: Blackboard > PA1900: Experimental Physics 1 2019-20 Y > Learning Materials > PA1900 Reflective Account Guidelines and Marking Criteria

The PA1900 Reflective Account Guidelines are also provided in the following section of this document for your convenience.

Reflective Account Guidelines

This should comment on how your skills have developed over the whole laboratory module during the year. Why is this useful?

- Good professional practice
- Allows you to make connections between different areas of physics
- Helps identify areas of excellence
- Helps identify areas where improvement is required

Reflecting on the skills you have gained, and recognising where they might be useful in future careers, is also an important step in enhancing your CV.

Specifically, please think about your experiences in the lab module, and write a **single short paragraph, of no more than 150 words, in answer to each of the three questions below**. Your account should be written in 11 point Calibri font.

Reminder: your reflective account is worth 5% of the 114 GReP report mark.

Question 1. Reflecting on your experience over the whole of the laboratory module, comment on how your technical skills have developed this year.

You could give an example or comment on your experience with the practical elements or report-writing elements of laboratory activities you have undertaken this year (for example, data-recording, analysis, drawing scientific conclusions etc.) Comment on how your strengths have developed and focus on a specific example with evidence.

Question 2. Reflecting on your experience over the whole of the laboratory module, comment on how your transferrable skills have developed this year.

You could give an example or comment on your communication and report writing, time-management, or team-working experiences. Comment on how your strengths have developed and focus on a specific example with evidence.

Question 3. Which skill have you most enjoyed developing this year, and why?

Think about times when you felt particularly motivated or confident in your ability. This should give you an insight into your personal strengths and motivations. Link your answer to types of career in which you may be interested, or how your skills will be of use to your future academic career.

Laboratory Equipment Provided

Throughout the stages of this experiment you will require a:

- Pair of induction coils (one wider than the other)
- Computer-based signal generator (or) modular signal generator box and variable signal generator.
- Computer-based oscilloscope
- Fixed-value capacitor
- Variable capacitor (consisting of a Perspex strip and two lengths of sheet metal)
- Parallel plate capacitor which can house sugar
- Quantity of sugar
- Pair of small plastic clamps

Students should have access to:

- Wayne Kerr Component meter
- Length of wire to use for connections
- A selection of resistors
- A micrometer or Vernier-calliper

WORKSHOP 1

1. Derive an approximate formula for the inductance of a coil in terms of its physical dimensions, stating your assumptions. How does the inductance depend on the area of the coil and the number of turns? Explain this dependence in physical terms

2. Derive a formula for the capacitance of a parallel plate capacitor in terms of its physical dimensions. How does the capacitance depend on (a) the dielectric (b) the plate area (c) the plate separation? Explain this dependence in physical terms.

3. The differential equation for a driven LCR circuit is

$$L\frac{d^2Q}{dt^2}+R\frac{dQ}{dt}+\frac{1}{C}Q=V_0\cos\omega t$$

   By analogy with a forced oscillation of a mass on a spring, what are the equivalents of mass, damping and resonant frequency? Explain the analogy in physical terms.

4. What is the natural frequency ω_0 of an LC circuit? How do you expect the amplitude of the variations in charge (Q) to change as the driving frequency is varied slowly from $\omega < \omega_0$ to $\omega > \omega_0$?

WORKSHOP 2

1. Define the Q-value of an oscillator and explain how this relates to variations in current in an oscillating LC circuit.

2. How would you increase the Q-value of a circuit without changing its resonant frequency?

3. How does the rate of power dissipation change as the Q-value is increased for (*a*) a damped SHO, (*b*) a forced, damped SHO, (*c*) your LCR circuit?

4. The width of the resonance curve $\Delta\omega$ at resonant frequency ω_0 in a circuit with quality factor Q is given by

   (a) ω_0 (b) $Q\omega_0$ (c) ω_0/Q ?

   How can you explain this result?

5. Two capacitors C_1 and C_2 are connected in series. What is the overall capacitance? What is the capacitance if instead they are connected in parallel?

Lab Sessions

The work throughout these lab sessions is designed to steadily progress towards an understanding of LCR circuits and resonance. The timetable should be considered flexible, if you wish to progress quicker or slower than at the suggested rate. However, all tasks for each session must be completed before moving onto the next.

The following tasks have been grouped in a way that should roughly correspond to three lab sessions. These sessions will be much easier to undertake in a timely manner if you have researched the relevant theory in advance, and perform some analysis of results after the lab sessions.

Facilitators:

Session 1 involves most of the theoretical learning which is relevant to AC theory. If they do not complete the tasks they should continue them in the beginning of the second lab session, as they will need to understand resonant frequencies and the relation to capacitance to perform any of the other experiments.

Some sessions, particularly 2 and 3, have very similar tasks. In this way, if a group has not completed session 2 they should have a chance to complete it in the following session without too great a difficulty to stay on schedule.

Lab Session 1

Session aims

In this session you are asked to research, understand and build an LCR circuit. Several points have been given to you in the introductory lecture which should guide you to some particular points you will have to understand:

1. Measure the self-inductance of a coil, L
2. Compare with a calculated theoretical value
3. Find a formula for the resonant frequency of an LCR circuit
4. Build an LCR circuit, and note the values of components used
5. Find and evaluate the Q (quality) factor
6. Sweep through the frequency range of the input, and record the output voltage
7. Plot the results
8. Repeat the above steps (6 and 7) using a different resistor value
9. Compare your experimental results to the theoretical values

Relevant Theory

To understand how to approach this experiment, it may be helpful to refresh your understanding of:

- Inductance in a solenoid
- Construction and behaviour of a driven, damped LCR circuit
- Resonant frequencies of an LCR circuit
- The quality factor of a driven LCR circuit

Facilitator:

Self-Inductance:

A changing magnetic field over a length of wire, or wire moving in a constant magnetic field, generates an electric current. This is known as ‘inductance’.

If a wire is carrying an changing current (such as an alternating one) then the magnetic field generated will be continuously changing, and the wire will generate an electric potential to ‘counteract’ the applied voltage. This is known as ‘self-inductance’.

We define the self inductance of a coil of wire carrying a current, I, as being:

$$\phi_m = LI \qquad \textit{Equation 1.1}$$

This equation can be applied to a solenoid (this derivation is already done in Tipler) to give the self-inductance of a solenoid:

$$L = \frac{\phi_m}{I} = \mu_0 n^2 A l \qquad \textit{Equation 1.2}$$

Where n is the number of turns of the solenoid per unit length

Driven LCR Circuits:

Students will only have to know that if a driving voltage (for example, a sinusoidal one) is applied to an LCR circuit, it will have a certain reaction to the applied voltage (the transient response) which diminishes with time, and a steady state response (See the diagram in point 4 of Math. Phys. Vol.2). We will be observing the steady state response.

Resonance:

Due to the way the complex impedances behave in an LCR circuit, there will be a certain frequency of driving voltage at which the current that flows to become maximal (as the resistance becomes minimal). This can be seen in the diagram in point 17 of Math.Phys.Vol.2.

The resonant frequency, ω_0, is given by:

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad \textit{Equation 1.3}$$

The resonant frequency describes a peak in the current flowing in the circuit, which has several properties:

- It becomes sharper for lower resistances

- It is roughly symmetric about ω_0
- It has a width $\Delta\omega$ at a height of $I_{max}/\sqrt{2}$

Note: The definition of the angular frequency is as normal, so to compare to the frequency that you would measure on an oscilloscope we have to use:

$$\omega = 2\pi f \qquad \textit{Equation 1.4}$$

Quality Factor:

This can be used to describe any damped oscillating system. Students may be most familiar with a damped oscillator such as a spring in the PA 1110 course. It is defined as:

$$Q = 2\pi \frac{(TotalEnergyStoredinTheSystem)}{(EnergyLostperPeriod, T)} \qquad \textit{Equation 1.5}$$

When we apply this definition to an LCR circuit we get:

$$Q_{res} = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR} \qquad \textit{Equation 1.6}$$

The Q-factor describes the width of the resonance peak in LCR circuits. If we were to plot a graph of output voltage against driving frequencies, we get a peak (the resonance peak). The Q-factor describes the width of this peak. If I_{max} is the maximum height of the resonance peak then the width $\Delta\omega$ at the height of $I_{max}/\sqrt{2}$ is given by:

$$\Delta\omega = \frac{\omega_0}{Q_{res}} \qquad \textit{Equation 1.7}$$

Suggested Experimental Method

It should be possible to measure the inductance of the coils you have by using the Component Meter, which you should have access to. (See the ‘How to use Equipment’ section in ‘Additional Information’)

The theoretical value for the coil can be calculated using a formula which you may remember, or can research in *Tipler*.

The information regarding the resonant frequency and Q-factor of an LCR circuit is given in the ‘Mathematical Physics Vol.2’ booklet. It is possible to understand the circuit in enough depth to perform this experiment without knowing exactly how these circuits behave (for example the complex impedances and their effects) but only considering the mechanical analogy. However, it is strongly recommended that the whole chapter is read, as this may help you significantly.

Once the circuit is set up, you can sweep through a range of frequencies of the driving voltage and measure the output for each. Plotting the results should let you see a resonance peak. Doing this for all possible input frequencies would however take a long time, as the peak may be very small. What would you need to know to estimate the position of the peak before beginning the experiment, thus reducing the range you have to ‘sweep’ over?

Note: Contrary to what you may expect, we do not put the capacitor, inductor and (if used) resistor all in series with the signal generator. The signal generator has been made to output a constant voltage, and the method by which it does this may create anomalies with the circuit you will make. Therefore we use the signal generator connected to one induction coil, and have our LCR circuit connected to the signal generator by having the two induction coils one inside the other. (See ‘Induction Coils’ section in ‘Additional Information’)

Facilitator: Suggested Experimental Methods:

Self Inductance of Coil:
The self inductance of the coil is to be measured using the ‘Wayne Kerr Component meter’. If students are to compare this to a theoretical value, they will need to measure the number of coils on the inductor, so will have to use the inductor where the coils are visible (the thin one). The number of coils per unit length is to be measured, as well as its length and cross sectional area. Then the measured value can be compared to the one using Equation 1.2.

Resonant Frequency/Q-factor:
The theoretical value for the resonant frequency of the coil is given by Equation 1.3 (taking into account equation 1.4 to give the observed value):

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \textit{Equation 1.8}$$

The inductance and capacitance of the components used can be measured using the component meter.
It is also a good idea (although not strictly necessary) to measure the internal resistance of the inductor, as this allows us to calculate a theoretical value of the width of the resonance peak later. This is necessary in determining the Q-factor.

Students should then construct the circuit as shown in Figure 1:

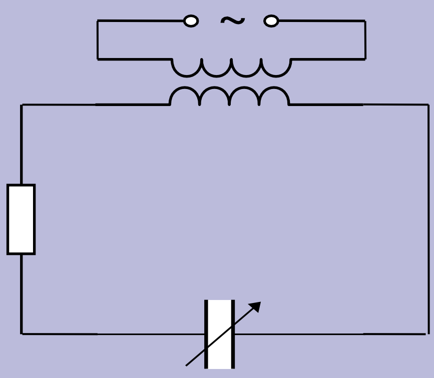


Figure 1 Basic Circuit Diagram

Once students have familiarised themselves with the computer software, it should be relatively simple to plot either the peak of RMS output from the oscilloscope at a range of different driving frequencies (which should be roughly centred around the calculated value of the resonant frequency).

These results should then be plotted. In order to measure the Q-value, results will have to be taken at very small steps from the resonant frequency. The width of the peak at 1/√2 of the peak intensity is measured, and the Q value calculated from Equation 1.6.

Q-factor note:
If no resistor has been added to the circuit yet, students should have realised that the coil has an internal resistance. If not, ask them why the peak is not infinitely thin, and suggest that there are always sources of resistance in the circuit.
A different resistance should then be used in the circuit, and the same process undergone. The plots of the different results should be combined to see the effects of resistance.
Note: The resonant frequency should not change when a resistor is added.

Facilitator: Expected Results:

The inductance of the long, thin coil should be in the region of 0.8mH. This should be close to the value which students calculate for themselves (within 0.05mH).
Example figures: l = 20.1 cm, r = 2.1 cm, n = 100 coils in 6.7 cm, gives L = 0.78 mH
The coil has an internal resistance of approximately 3.3 Ω.

The theoretical value of the resonant frequency should be relatively easy to calculate. The results depend on the capacitor used. Use equation 1.8 to check their results.
Example figures: if L = 0.8 mH, C = 100 nF, then f = 18 kHz (see the left hand side diagram in Figure 2)

When the frequency has been swept across the resonant region, students should produce a plot similar to those shown in Figure 2.

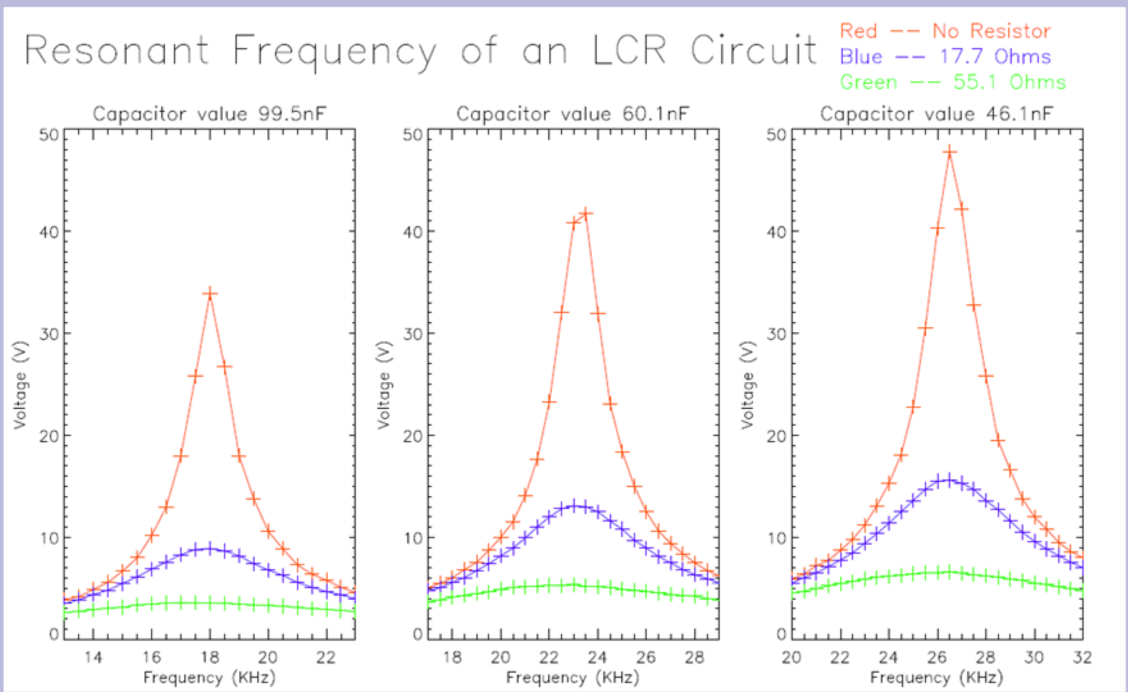


Figure 2 Example results showing resonant frequencies for three different resistor values for each of three capacitors

The peak should be approximately at the calculated value of resonant frequency.

The Q-value is simple to calculate using Equation 1.6. It is, however, much more difficult to compare to actual results, as it requires that the increments in frequency are very small. When calculating the Q-value, measurements should be made of the resistance and inductance of the coils. Results should be close to:
R = 3.26 Ω, L = 0.8 mH, $\omega_0 \sim 10^5$ so Q ~ 25.

For measurements of the Q value from the graph, we can see from Figure 2 that the frequencies the peak has diminished to 1/√2 are approximately 17.4 and 18.6 kHz. Using Equation 1.7 this gives a Q-value of 15. Whilst this is not the same as the theoretically calculated value, it is close enough given that the peak in the diagram is not too well defined.
They should roughly agree.

Facilitator: Common Problems

The construction of the LCR circuit may prove difficult for some students, as they may expect the power source and components to be in series with the signal generator. This should be checked before the group spends time trying to find the resonance peak. (See 'Additional Information' section)

Also, groups may forget that ω must be multiplied by 2π to get f.

When sweeping the frequencies to find when the output increases sharply, if no resistor is in the circuit the peak can be very small. If a digital signal generator is used each step must be individually chosen, so it is quite easy to miss the resonance point. Theory should fit the results well, so make sure they find out where the resonance point should be first.

Lab Session 2

Session aims

In this session you are asked to investigate the effect that changing capacitance has on an LCR circuit. Once you have an understanding of this, you are to use the resonant frequency of the circuit and a signal generator to measure the capacitance of a parallel plate capacitor given to you.

If the relationship between capacitance and resonant frequency is fully understood, you can use the same method to investigate the dielectric properties of a sheet of Perspex.

Relevant Theory

In order to perform this experiment, you will need all of the theory used in the previous lab session.

You will also require a good understanding of parallel plate capacitors and dielectrics.

Facilitator:

The capacitance of a parallel plate capacitor is given by:

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d} \qquad \textit{Equation 2.1}$$

Where A is the area of, and d is the separation between, the two plates.

This amount is changed when a dielectric is present in between the plates. This is according to:

$$C = \kappa C_0 \qquad \textit{Equation 2.2}$$

Where C is the modified capacitance, C_0 is the original capacitance and κ is the dielectric constant.

When the students come to measure the dielectric constant of the parallel plate capacitor, they may choose to move the Perspex sheet so than the amount inside the parallel plate varies. In this case, we consider the section with, and the section without, Perspex as two separate capacitors in parallel:

$$C_{total} = C_1 + C_2 + \ldots + C_N \qquad \textit{Equation 2.3}$$

Other than these capacitance equations, we again require the resonant frequency equation:

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \textit{Equation 1.8}$$

As we wish to use the resonant frequency to find the capacitance, we need to rearrange Equation 1.8 to:

$$C = \frac{1}{4\pi^2 L f^2} \qquad \textit{Equation 1.9}$$

Suggested Experimental Method

You will use largely the same methods as you used in the previous lab session, as you still have to drive the LCR circuit at a range of frequencies in order to find the resonant frequency.

You need to consider how the capacitance of the parallel plate capacitor can be modified using the dielectric, and attempt to determine the dielectric constant of the Perspex.

Facilitator: Suggested Experimental Method

The internal resistance of the inductor is quite small (~3.3 Ω), which means that the resonance peak will be very sharp. This may (although not certainly) mean that students find it difficult to find the peak when altering the input frequencies. Considering this was a task in the last session, this should suggest to them that they can attach a small resistor to the circuit to make the peak easier to find.

A theoretical relation between the value of the capacitance and the dielectric constant of Perspex can be made by measuring the dimensions of the metal and Perspex sheets, as given by Equation 2.1.

The capacitance of the parallel plate capacitor is measured by placing it into the LCR circuit and measuring the resonant frequency, relating the two using equation 1.9. This can be fairly difficult to do, as we do not know the approximate capacitance of the capacitor, so do not know where to beginning the sweep of frequencies.
This can be done easily if the Component meter is still available to students, when the capacitance can be directly measured. However, this takes away all the learning theory which the students are supposed to use, so should really be avoided! (The 'Component Meter' should really only be available for tasks from Lab Session 1)

Now that the capacitance has been measured, we can use our theoretically calculated result to find the dielectric constant of Perspex. We can use Equations 2.1 and 2.2 to arrive at the results.

At alternative method which doesn't involve simply measuring the dimensions of the plates and Perspex would be as follows:

The simplest idea would be to have a capacitor without the dielectric and one with. However, the separation between plates must remain constant, which requires the presence of the Perspex sheet. Therefore we cannot simply remove the Perspex.

We can, however, slide the Perspex sheet out of the plates gradually, and record the capacitance and length of Perspex in between the plates at each stage. We can then use Equations 2.1-2.3 on a couple of measurements to calculate the value of the dielectric.

Facilitator: Expected Results:

If the students decide to measure the dimensions of the Perspex and metal to find the capacitance, they should have approximately:
Length and width: 33.3 cm x 3.6 cm
Depth of Perspex: 2.00 mm

This gives: $C = \kappa \frac{\varepsilon_0 A}{d} \approx \kappa(5\times10^{-11})$ F

The resonant frequency when the Perspex sheet is fully enclosed by the metal sheets should be in the region of 380kHz (Although this varies a lot depending on how well clamped the apparatus is). Using Equation 1.8 this gives us a capacitance of approximately: $C = \frac{1}{4\pi^2 L f^2} = 2.2 \times 10^{-10}$ F

From $C = \kappa C_0$ we can then compare the two results above, and would arrive at the dielectric constant as approximately 4. Anywhere in the region of 3 to 5 should be acceptable.

For the alternate method, students should have measured the resonance frequency under several given conditions (lengths of Perspex), and used Equation 1.9 to calculate the capacitance of each. They can then observe the changes to calculate the dielectric constant.

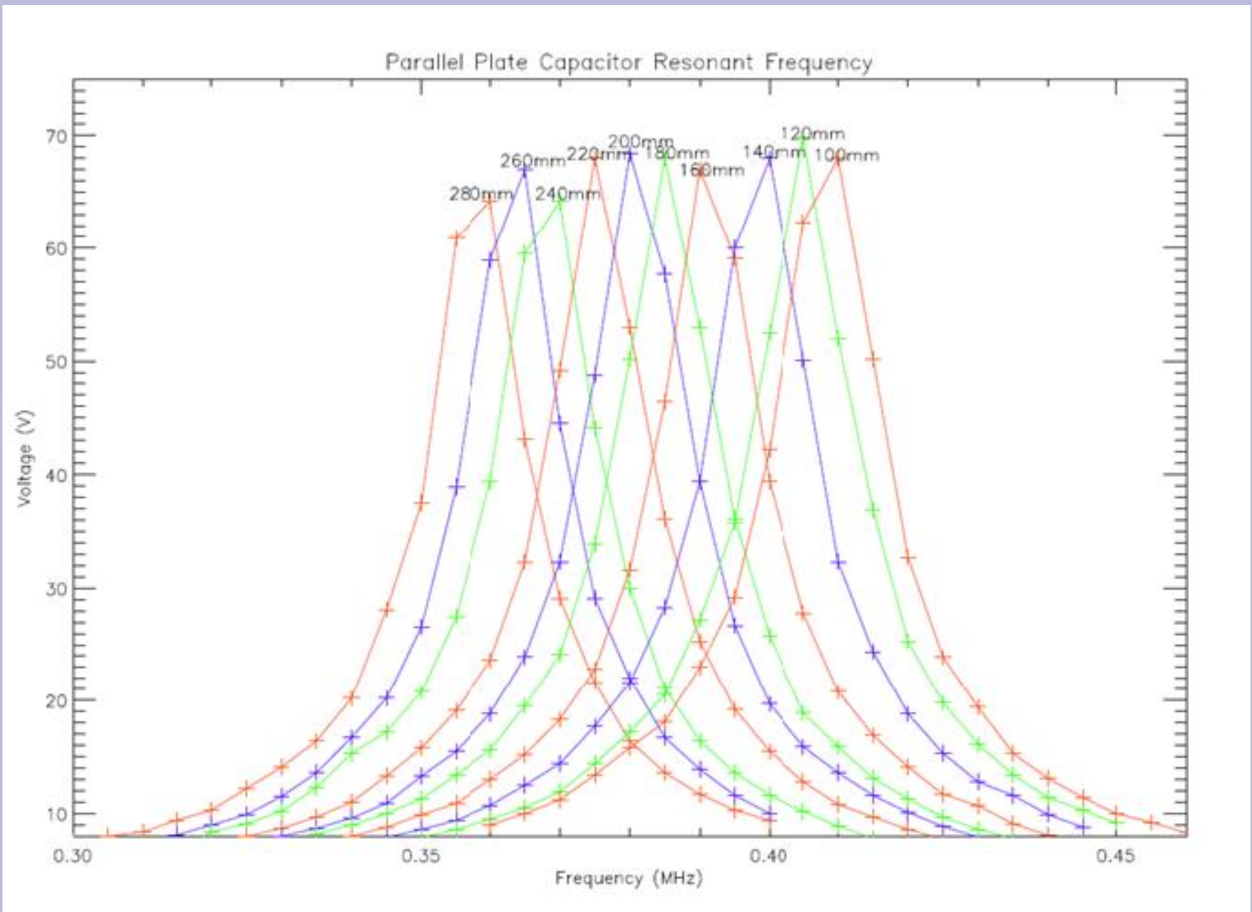


Figure 3 Parallel plate capacitor resonance with changing quantities of Perspex in between the plates.

Note: We do not expect students to perform enough measurements to make a plot like in Figure 3. It is simply here to show how the resonance peak increases as the length of Perspex inside the capacitor decreases.

With the alternate method, the dielectric constant of the Perspex sheet is difficult to accurately measure, as it is difficult to keep the plates equally separated and parallel, which can affect results significantly. Also, the dielectric constant depends on the frequency of field applied. Anywhere in the range of 2 – 4.5 should be acceptable.

Facilitator: Common Problems:

Note the difficulty in finding the peak it only the internal resistance of the inductor is present. If students cannot find the peak, make sure they have calculated a theoretical value correctly, and are sweeping about this point. Then also make sure a resistor has been placed in the circuit so the peak is wider.

One common difficulty which leads to inaccurate results is correct placement of the capacitor plates. In order to keep them in roughly the same place, small clamps can be used. However, if the Perspex sheet is moved out any length, there is nothing to keep the metal separated and the plates can bend towards or away from each other. The use of another piece of Perspex of the same thickness would allow this problem to be minimised, but this may not be available. In this case, the group should simply take care when performing this experiment, and shown that they have considered how a small difference in separation can lead to a big change in capacitance.

Lab Session 3

Session aims

Now that you have a working LCR circuit, it should be possible to substitute the sugar container for the previously used parallel plate capacitor, and start using sugar as the dielectric. In this way the dielectric constant of sugar can be found.

Facilitators:

This experiment is almost identical to that in the previous lab session. For this reason, it shouldn't take too long to perform. If students did not complete the last lab session, they may try to complete it now. However, as the circuit is essentially the same, they should not spend a significant amount of time trying to catch up. Simply give them the circuit that they should use, and proceed with the tasks given here.

Relevant Theory

The theory you require should be exactly the same as the last lab session. All that has changed is that you now use a specially modified parallel plate capacitor which you can fill with sugar, instead of the two strips of metal you used before.

Suggested Experimental Method

It is possible to approximate the capacitance by measuring the dimensions of the capacitor. However, unless a micrometer is used, the result will not be very accurate. It can, however, be used to give you a good idea of what range to sweep the frequency over.

Then sugar can be added placed inside the capacitor, and the change in the capacitance measured.

Facilitator: Suggested Experimental Method

As described in the previous section. Note that the students should be using a resistor in the circuit, as it makes finding the resonance peak repeatedly much quicker.

If students have completed this task, it may be worth discussing the tasks presented in the next lab session now. A good topic to introduce would be the design of a warning system. Students should think about how a resonant frequency can be used to make a signal. Hopefully, they will come to the next session with some idea of what to do.

Facilitator: Expected Results:

If students have measured the dimensions of the capacitor, they should have:
Length and depth: 30.0 cm x 20.0 cm
Width (between plates): 0.50 cm

This leads to: $C = \kappa \frac{\varepsilon_0 A}{d} \approx \kappa (1 \times 10^{-10})$ F

The resonant peak when the capacitor is full should be in the region of:

310 kHz – 360 kHz

Which gives a capacitance of:

$3.3\text{x}10^{-10}$ – $2.4\text{x}10^{-10}$ F

By comparing this to the theoretical result from measuring the dimensions above, the dielectric constant can be seen to be in the region:

2.5 - 3.5

If students have taken several measurements at different heights, they should have a plot as follows:

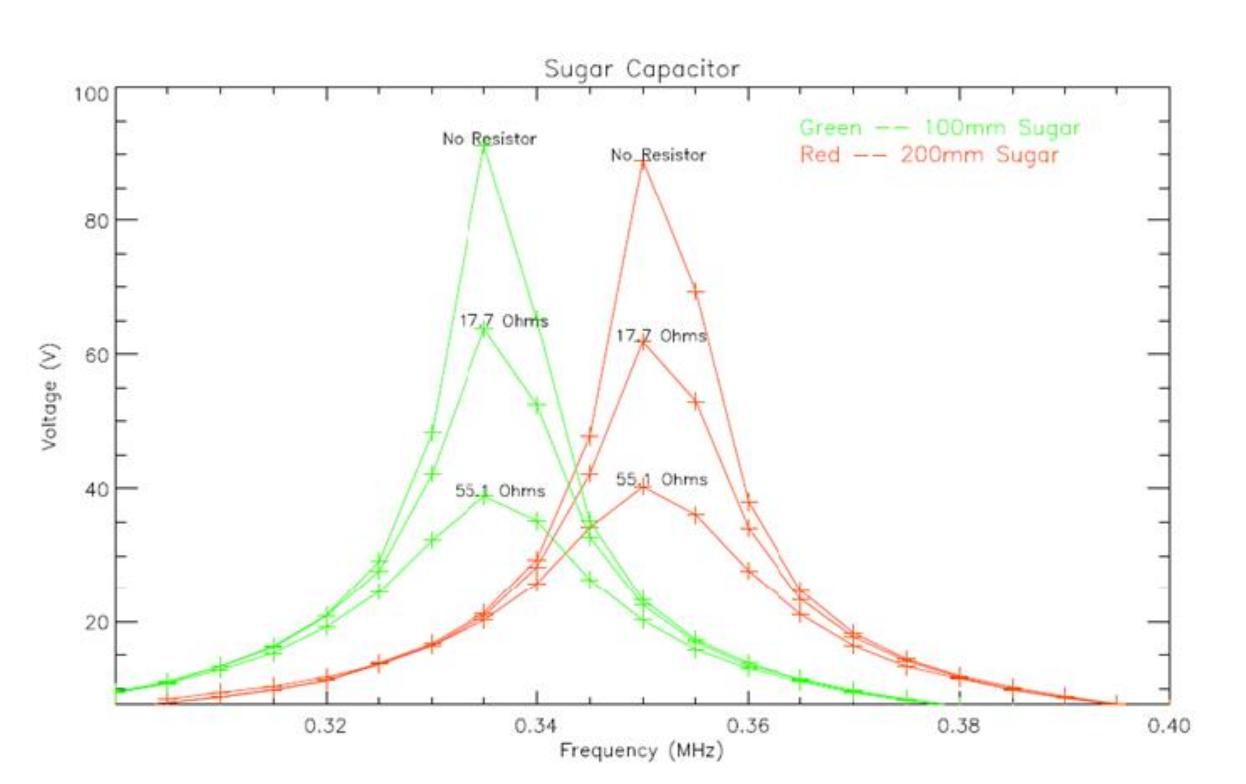


Figure 4 Resonant frequency as the level of sugar inside the parallel plate capacitor changes, with a selection of resistors attached.

Note: We don't expect students to make plots such as this. They are only required to find the peak for a given level, and then adjust the level and find the peak again (hence finding the effect of sugar level on capacitance)

The dielectric constant of sugar is in the region of 3. However, the packing of sugar crystals inside the parallel plates is not perfect: we do get gaps of air. This reduces the measured dielectric constant.
Measurements should be between 1.5 and 3.

Facilitator: Common Problems

Students should consider the Q-factor of their circuit, and if they think it may be difficult to find the resonance peak, a small resistor can be added to the circuit.

It is difficult to accurately judge the sugar level inside the capacitor, as only the edge can be seen, and the sugar may heap in the centre. Some consideration of this should be made by students, although it is not a very pronounced effect. Gently tapping the capacitor may help this, although too much movement will let sugar leak out the bottom.

The groups should also be mindful of the method by which the capacitor is held. Clamp stands are the obvious answer, but if they are made of metal, will short the capacitor. Therefore some kind of extra layer should be added to prevent this effect. Also, if the funnel used to pour in the sugar is not removed, we will have the same problem.

Lab Session 4

Repeat or extend measurements, catch-up, finish off.

Additional Information

Computer Software

Set-up:

1. Start/ Programs/ Pc-lab2000se/ Pc_Lab2000Se
2. Turn on all devices at the plugs
3. Check USB devices present. You will need:

   LPT device: PCS500 (PC scope)

   Or USB Device: PSCU1000 (Function Generator)
4. Press OK.

The main window should now be displayed, showing an oscilloscope screen (with nothing on it yet), time divide buttons on the right hand side, voltage divides along the bottom for each channel, and a few buttons (such as Oscilloscope, Spectrum Analyser, Transient response and Function generator) along the top.

5. Click on the ‘Function Generator’ button. A new window should open.

Function Generator:

Here you can select the form, frequency and output of the signal generated. The form is displayed in the right-hand side box. Exactly what is in this box may be confusing. If you select one of the three standard forms (Sine, Digital and Sawtooth) it shows two wavelengths in the box. However if a specified other waveform is loaded, then the entire box represents one ‘wavelength’.

For an example, click on the sinusoidal pattern at the bottom left. Two wavelengths should be present in the box. This may seem trivial with something such as a sine wave. However, you may want to have a more complicated function, such as a modulated sine wave with a carrier frequency and modulation frequency. In this case, you will need to know that the computer means when it says it's driving the circuit at a given frequency. Knowing that the box shows a single wavelength can help you in this situation.

Preliminary Exercise:

Try connecting both the function generator and oscilloscope to the same points in a circuit (or just connect them together). Set the function generator to a Sine wave at a frequency of 10 kHz. Click on 'AUTOSET' in the oscilloscope window just under the main screen. You should be able to see the function generated on the main window (if the 'Oscilloscope’ button at the top of the screen has been depressed). Clicking on the 'AUTOSET' button will make the computer decide what voltage and time divide to use. Bear in mind that its choice is often wrong, and that setting it yourself can often be a better idea.

If you want to measure a wavelength, you can select the 'Single' (rather than 'Run') option on the oscilloscope (Right hand side centre) to take a single frame. The wavelength can then be observed.

Try selecting the sawtooth or digital waves. You should see that the forms seen in the oscilloscope window are wrong (if not, excellent. The drivers may have been updated!). Some waveforms are not produced properly by the signal generator at certain frequencies.

For most of your experiment, you should be able to use the sine form. If you want to load a different form (such as a modulated Sine wave) you can click on 'MORE FUNCT.', select 'Library waveforms' and then select the form you wish to use.

Helpful Options:

In the oscilloscope window, under the 'View' tab, you can select the option to see the waveform parameters. In here is the RMS voltage. You may want to be able to quickly compare the output voltage at two different frequencies, so the option to see the RMS output, as well as the fundamental frequency, can be very useful.

Facilitator:

If a modulated wave is selected, the ‘Autoset’ option focuses on the carrier frequency. If this is done, the modulation can only be observed as a slight increase and decrease of RMS voltage. It is often better to choose the time divide yourself for this reason.

How to use equipment

Wayne Kerr Component Meter:

This allows you to measure the resistance, capacitance and inductance of a component, and is therefore very useful when dealing with LCR circuits.

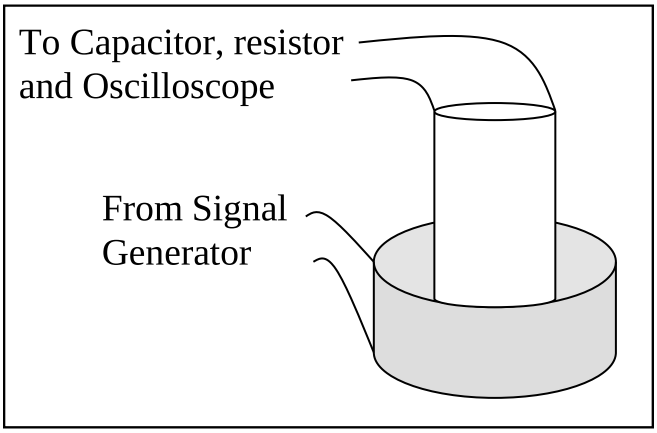
The object to be measured should be connected to both of the ‘measure’ sockets, and the property to be measured selected using the buttons labelled ‘R’, ‘C’ and ‘L’.

The range of the meter does not automatically adjust for whatever component is connected. Therefore you must manually alter the knob on the right to select the magnitude. If an incorrect magnitude is selected, a small arrow will flash (either ‘up’ or ‘down’) at the right of the display. Adjust the dial in the direction stated, one step at a time, until no arrow is present.

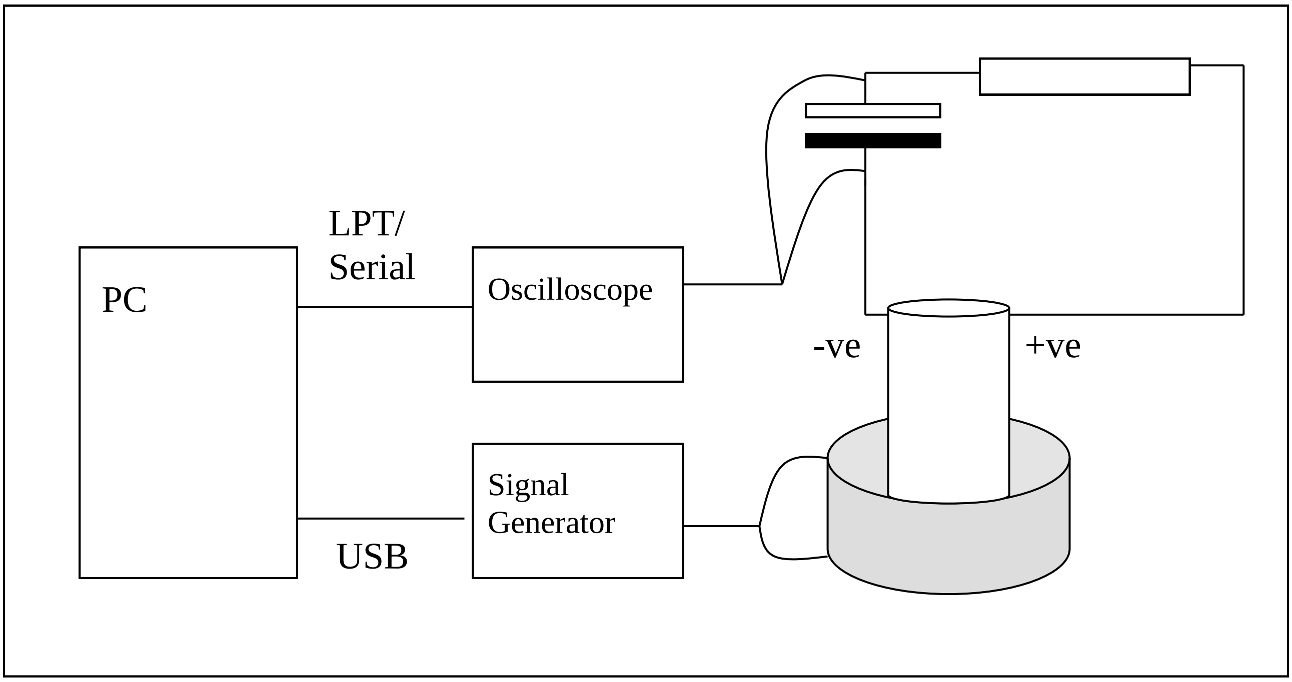
You can then take the reading.

Induction coils:

The signal from some generators will be adjusted so that it has a continuous voltage or wave parameters depending on the components it’s connected to. As we are using an LCR circuit, this may interfere with our results. For this reason, we will not directly connect the signal generator to the circuit. Instead, we will place two coils one inside the other and power one, taking readings from the other (like a transformer).



Circuit Connections:



where:

‘Oscilloscope’ is the Velleman PCS500 PC-Scope

‘Signal Generator’ is the Pc-Function Generator PCSU1000

These components must be specified to PC-lab in order for them to work. This should be done on the startup screen.