Electronics – First year physics course Jan 2005

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Introduction

The first year course in Electronics comprises 12 lectures at the beginning of term 2, with 4 additional classworks and problems sheets. Along with the 20 lecture course on Electricity and Magnetism given later in the term by Prof. Bell, this course forms the basis for the Electricity and Magnetism paper in your summer exams.

The title Electronics is in many respects a misnomer and the material we will cover would much better be described as Electrical Circuits. The course covers material from the basics of Ohm's law and the fundamental physical concepts of charge, voltage and current, to the analysis of circuits involving capacitors, inductors and resistors with sinusoidal voltages and currents. In the main we will stick to analyzing passive circuit components and will not be dealing with transistors or other active semiconductor devices. Our only consideration in the direction of active electronic components will be to look at simple operational amplifier circuits that you may already have seen in first year Lab.

You may also be somewhat alarmed at the fact that you have signed up for a Physics degree and suddenly seem to be studying engineering! "Why, as a physicist", you might ask, "do I need to know anything about electronics?" Well it would be true to say that the two disciplines are inextricably linked. Many significant developments in electronics have been made by physicists or on the basis of knowledge developed by physicists and likewise many significant findings in physics would not have been made without electronics or electronic instrumentation. But just in case you are still not convinced then consider the following:

1) Understanding the operation of and uses to which electronics is put will put into context your study in other areas of physics such as solid state physics, quantum mechanics, electromagnetism and of course mathematical methods.
2) Studying effects and analyses in electronics will help you to understand material you encounter elsewhere in the course, ranging from complex numbers and differential equations to oscillatory systems.
3) As an experimental physicist you will undoubtedly have to use electronic instrumentation in some form or other in order to make measurements. Understanding the operation of the instrumentation will enable you to make better a judgment of the accuracy of the measurements it reports or of any limitations the instrumentation might have in its ability to report the measurements you would like it to.
4) The basic physics behind this course can be summed up as Ohm's law, and the principles of conservation of energy and charge. Of course if it were as simple as that then we would be over and done with in one lecture! The real skill comes in being able to apply those basic principles to solving real problems – and this is what the bulk of the course covers. Problem solving in general is a key skill of the physicist and one, which will be tested, thoroughly in your third year comprehensive papers.

Aims and Outcomes

Aims

To introduce the fundamental concepts of charge, current, voltage, electrical circuits, and circuit analysis, including passive circuit elements such as resistors, capacitors and inductors.

In the context of electronics to reinforce understanding and application of fundamental conservation laws, linear superposition, the use of sinusoidal signals, complex numbers and simple differential equations.

Outcomes

On completing the course the students will:

- Be able to define charge, current, current density, drift velocity potential difference power and electromotive force (EMF) and use suitable units to represent these terms.
- Know and be able to use the linear, differential and integral relationships between charge, current and voltage for resistors, capacitors and inductors and to be able to describe the energy storage and/or dissipation in these devices.
- Be able to describe arbitrary sinusoidal signals in terms of complex numbers and understand the nature of phase, phase lead, lag and delay.
- Be able to convert between complex vector representations of sinusoidal signals and their time domain amplitude peak-to-peak amplitude or root mean square equivalent.
- Be able to describe the operation of simple circuit elements such as conductors, resistors, capacitors and inductors in isolation and be able to write down suitable complex equations and phasor diagrams relating voltage and current using the concept of complex impedance in each case.
- Be able to calculate the complex impedance of combinations of passive circuit elements.
- Be aware of the physical construction of simple passive electronic devices and how this can have implications on real world performance.
- Know the symbols used to describe simple electronic components, voltage and current sources, and switches and be able to formulate a mathematical description of a circuit based on a circuit diagram.
- Know and understand the basis of Kirchhoff's laws.
- Be able to use Kirchhoff's laws in the form of node-voltage and mesh-current analysis with complex impedances to calculate the currents and voltages in simple circuits driven by AC or DC current and/or voltage sources
- To be able to find Norton and Thevenin equivalent circuits for arbitrary meshes of passive circuit elements, voltage and/or current sources.
- To be able to analyse simple circuits containing operational amplifiers using the virtual earth approximation.
- To be able to describe or understand the behaviour of circuits over a range of frequencies using Bode plots.
- Be able to relate the transient operation of DC circuits containing switches to suitable zero, first and second order differential equations, find explicit solutions for zero and first order systems and know special case solutions for second order systems.
- Be aware of the equivalence of electrical circuits to other physical systems such as damped spring balances described by the same differential equations.
- Be able to derive the centre frequency and Q value of and LCR resonant circuit and be able to give example uses for such a circuit.
- Be able to analyse or design simple high, low, notch and band pass filters using complex circuit analysis.

Lecture course

The lectures will be based around the following structure:

Lecture 1 - Ohm's law, voltage, current and resistance

Ohms law and the physical nature of charge, current, voltage and resistance. Conservation of energy and charge. Simple combinations of resistances.

Lecture 2 - Simple electrical circuits, Norton and Thevenin equivalents

The treatment of 2 terminal circuits as black boxes and their reduction to their simplest forms – the Thevenin and Norton equivalent circuits. Potential dividers and impedance matching.

Lecture 3 - Kirchhoff's laws, Nodal analysis

Kirchhoff's laws governing the currents and voltages in a circuit and their relationship to energy and charge conservation. Application of Kirchhoff's laws to circuit analysis by Node voltage analysis.

Lecture 4 - Mesh analysis, principle of superposition

Application of Kirchhoff's laws to analyzing circuits by mesh current analysis. Principles of superposition in linear systems and the analysis of complex circuits with multiple sources.

Lecture 5 - Op-amp circuits

Op-amps as simple circuit elements and the virtual earth approximation. Analysing circuits containing op-amps.

Lecture 6 - Capacitors

Principles, construction and operation of capacitors. Ohm's law for capacitors in differential and integral forms. Simple RC circuits - charging and discharging a capacitor. Energy storage in a capacitor.

Lecture 7 - Inductors

Principles, construction and operation of inductors. Ohm's law for inductors in differential and integral forms. Simple RL circuits charging and discharging an inductor. Energy storage in an inductor.

Lecture 8 - AC signals - complex impedance

Sinusoidal currents and voltages and their interaction with resistors, capacitors and inductors. Complex number representation of sinusoidal signals and the concept of complex impedance as a means of dealing with capacitors and inductors.

Lecture 9 - Bode plots

Representing the behaviour of a circuit over a range of frequencies with Bode (Log-Log) plots. Constructing Bode plots for simple circuits.

Lecture 10 - LCR circuits

Series and parallel resonant circuits containing inductors, capacitors and resistors. Resonant frequency, bandwidth and Q factor. Drawing Bode plots for a resonant circuit.

Lecture 11 - LCR circuits and parallels to other damped oscillating systems

Analysing LCR circuits with differential equations. Equivalence to other damped oscillatory systems. The damping factor zeta and its relationship to Q.

Lecture 12 - Op-amps with capacitors (and inductors)

Op-amp circuits with inductors and capacitors. Differentiation, integration, filters and oscillators.

Classworks and problem sheets

In addition to the lectures there will also be 4 classes after lectures 1, 5, 8 and 11. Here we will build on the material presented in the lectures. In addition to questions in two of this term's assessed problem sheets there will also be additional problem sheets distributed that can be used as the basis for discussion with your academic tutors. You are strongly encouraged to complete all of these problem sheets, as they will contain material that is typical of the sort you will see in this summer's exams.

Recommended reading

The bulk of the information required for the course is contained in the lectures, handouts and problem sheets. You are also encouraged to read around the subject, but be warned that there are not only several ways to describe a method but that the notation used by different authors can vary markedly. You should also expect to refer to other courses that you have already received or will shortly be receiving. In particular material on complex numbers and differential equations from your maths courses will be essential. Other places you will find useful material are your electronics practical course, the electricity and magnetism and the vibrations and waves lecture courses.

Particular textbooks where there is a substantial amount of relevant information are:

Young and Freedman, "University Physics" Tenth Edition, Addison Wesley. The recommended general physics text for first year. Contains much insightful information and explanation of the basic principles although is somewhat light on complex impedances.

Horowitz and Hill, "The art of Electronics", Second Edition, Cambridge University Press. While not the first book to turn to for in depth analysis of circuits or the underlying physics, it certainly is the first book you should look at if you want to actually *build* some electronics. It is also good at pointing out why things are done as they are in terms of the end application of electronics.

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