X4

Analysis and Interpretation

This laboratory involves two activities, one of which you will need to complete as preparation. Each exercise involves a very simple circuit, and the challenge is for you to make the correct measurements such that you are able to draw meaningful conclusions. As preparation, you study the current-voltage characteristics of a diode; in the laboratory session you will, again, examine the behaviour of a diode/inductor circuit that exhibits chaotic behaviour.

Schedule

Preparation time	:	3 hours
Lab time	:	3 hours

Items provided

Tools	:	n/a
Components	:	Inductor (~10 mH), diode
Equipment	:	Function generator, oscilloscope
Software	:	n/a

Items to bring

Essentials. A full list is available on the Laboratory website at https://secure.ecs.soton.ac.uk/notes/ellabs/databook/essentials/

Before you come to the lab, it is essential that you read through this document and complete ***all*** of the preparation work in section 2. If possible, prepare for the lab with your usual lab partner. Only preparation which is recorded in your laboratory logbook will contribute towards your mark for this exercise. There is no objection to several students working together on preparation, as long as all understand the results of that work. Before starting your preparation, read through all sections of these notes so that you are fully aware of what you will have to do in the lab.

> **Academic Integrity** – *If you undertake the preparation jointly with other students, it is important that you acknowledge this fact in your logbook. Similarly, you may want to use sources from the internet or books to help answer some of the questions. Again, record any sources in your logbook.*

Revision History

September 04, 2013	Geoff Merrett (gvm)	Minor updates
February 26, 2013	Alun Vaughan (asv)	First version of this lab created

1 Aims, Learning Outcomes and Outline

This laboratory exercise aims to:

- Provide further experience of designing experimental procedures
- Provide further experience of recording and analysing measurements and observations

Having successfully completed the lab, you will be able to:

- Develop efficient and effective experimental designs to meet defined objectives
- Evaluate the uncertainties associated with practical procedures
- Record in detail processes and events that occur during laboratory experiments

The two exercises that make up this laboratory both involve very simple circuits containing at most two electronic components.

In the first exercise (preparation) you will determine the current-voltage characteristics of a diode, determine the ideality factor, and hence use the diode as a temperature measuring device. You will do this exercise as preparation using a virtual experiment (VE) – this is not a computer simulation but represents a very large number of real measurements rendered into a virtual form.

In the second exercise (laboratory session) you will repeat the analysis of the chaotic behaviour exhibited by an inductor connected in series with a diode.

The associated procedures are deliberately not described in detail, since a key feature of working with such simple systems is to provide you with “space” to decide how you want to approach the problem. A key challenge for professional engineers involves devising ingenious solutions to problems: The real world is not ideal, as will be seen, and it does not come with a manual!

---

2 Preparation

Read through the course handbook statement on safety and safe working practices, and your copy of the standard operating procedure. Make sure that you understand how to work safely. Read through this document so you are aware of what you will be expected to do in the lab.

2.1 Electrons and Semiconductors Virtual Experiment

In this Virtual Experiment (VE), you have a power supply connected to a diode; the voltmeter measures the voltage drop across the diode and the AVOmeter measures the current flowing through the circuit, as shown below. Despite the simplicity of this circuit, this experiment involves a number of complex concepts and you will need to consider in detail what each element of the experiment *really* means. It is very easy to make invalid measurements or to interpret your data incorrectly. However, by doing this in a virtual environment you can always go back and repeat any element of the work, having reflected on what you have done.

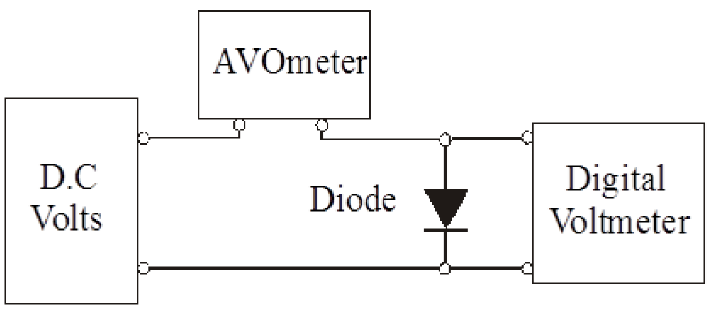

FIGURE 1: Circuit diagram for VE exercise

Many of the electronic components that you have encountered obey Ohm's Law. That is, the current, i, that flows in the device is proportional to the voltage drop across it, V:

$$i \propto V$$

Examples of so-called linear devices are resistors, capacitors and inductors; a diode is a device which will only conduct electricity to a significant degree in one direction and even in this, the forward direction, the current is not proportional to the voltage. A diode is therefore a non-linear electronic device.

2.2 The Diode Equation

Diodes contain a junction between two dissimilar materials, such as a p-type and an n-type semiconductor and, while a number of processes may be involved at the junction, the net result is that the behaviour of such a device is characterised by:

$$i = i_s[\exp(\frac{eV}{nkT}) - 1]$$

In this equation, V is the voltage across the device, i is the current that flows through it at a temperature T, and e, k, i_s, and n are constants; e is the charge on an electron, k is the Boltzmann constant, i_s is the saturation current and n is an ideality factor that equals one for an ideal diode but which, in practice, is somewhat higher.

- *Sketch the current flowing through a diode as a function of V; what quantity is indicated by the gradient of such a plot?*
- *Can you rearrange the diode equation shown above into a form in which i and V can be related to one another in the form of a linear plot?*
- *Can you rearrange the diode equation shown above into a form in which (i + is) and V can be related to one another in the form of a linear plot?*
- *As the reverse bias voltage is increased, what is the limiting value of i as $V \rightarrow -\infty$?*

2.3 Preliminary Experiments

The VE can be accessed at https://www.hestem.soton.ac.uk/ecsdiode/

To start the experiment, first click on the PLAY button at the bottom left of the image, which will provide you with a guide to using the VE.

Because of the non-linear behaviour of this device, before taking any detailed measurements, take a few minutes to familiarise yourself with the experiment and to explore the way in which the current varies with the applied voltage in the forward direction.

Repeat the above with the diode connected in the reverse direction.

- *What is the maximum current that you can observe **in reverse bias** with the given power supply?*

Repeat the above with the diode connected in the reverse direction but now with the voltmeter disconnected.

- *What is the maximum current that you can now observe with the given power supply?*
- *Why does disconnecting the voltmeter affect the current flowing through the circuit?*

- *What is the physical meaning of i_s and can you estimate its value? If not, why not?*
- *Can you rearrange the diode equation shown above into **an approximate form** in which i and V can be related to one another in the form of a linear plot?*

2.4 Forward Bias Current/Voltage Characteristics: Room Temperature

Now, returning to the forward direction, take measurements of *i* as a function of *V*. You will now need to plot a suitable *linear* graph(s) to enable you to evaluate *n* and i_s.

- *How does the value of the resistance of the diode vary with V? What determines the current that flows through the circuit?*
- *Is you graph linear across the complete range of V values? If not, why not?*
- *How does your derived value compare of n compare with expectations?*
- *How does your derived value of i_s compare with your previous estimate?*
- *Is your previous use of an approximate form of the diode equation justified?*

2.5 Forward Bias Current/Voltage Characteristics: Liquid Nitrogen

You are now in a position to use the diode to measure temperature, since you can measure *i* as a function of *V*, and you know *e*, *n* and *k*. Take measurements of *i* as a function of *V* and, once again, plot a suitable graph on log-linear graph paper.

- *What is your experimental temperature for boiling liquid nitrogen and does it agree within your derived uncertainties with the accepted value?*

From this you can evaluate the temperature of the diode, which will be very close to that of the liquid nitrogen.

2.6 The Chaotic Oscillator

You have already met this X3 so not only should you be familiar with the basic principles but you should also have reflected on this and now be much more aware of the issues. As indicated previously, this exercise is all about making detailed and precise observations – sufficiently detailed that, at a future date, you will be able to describe in detail what you did. The circuit you will study is simple but exhibits deterministic chaos. Deterministic chaos applies to highly non-linear systems where the future is strongly dependent upon the initial state of the system. Before starting this laboratory you should undertake some background reading and ensure you have a good understanding of the following terms, as they apply to a chaotic system:

- *What is meant by "period doubling"?*
- *What is meant by "bifurcation" and a "bifurcation diagram"?*
- *What is meant by a "fractal" and "self-similarity"?*
- *What is a "Feigenbaum number"?*

3 Laboratory Work

3.1 Chaotic Oscillator

You will again explore the behaviour of the circuit shown below, using what you have learnt through the lab programme to improve on your previous efforts.

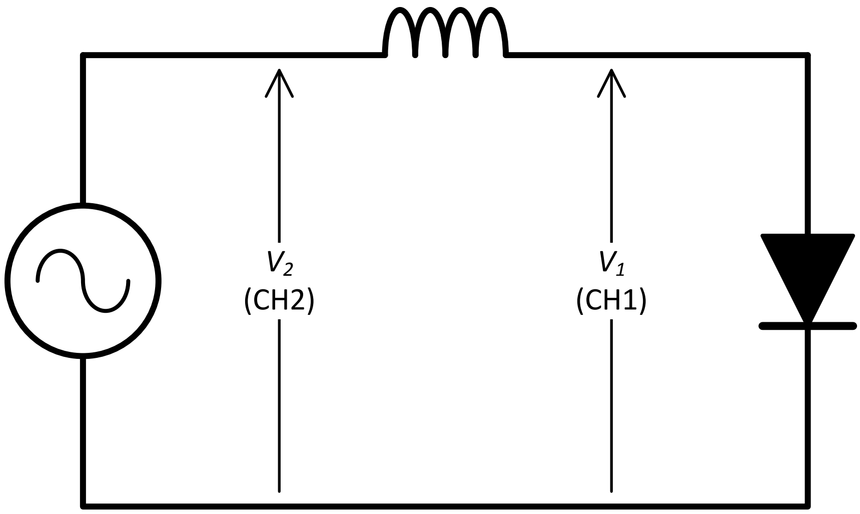

FIGURE 2: Circuit diagram for the chaotic oscillator exercise

Having assembled this circuit, the first objective is to find the resonant circuit. To do this, you should set the function generator to provide a sinusoidal output of ~200 kHz and a peak-to-peak voltage of ~200 mV at v_2, as seen using channel 2 of the oscilloscope. Vary the frequency and note the variation in output voltage (i.e. the voltage across the diode).

Hint: the resonant frequency will depend upon the precise component values but, in most instances, seems to fall below 200 kHz.

? *What is the frequency corresponding to the maximum output voltage?*

Now chose a frequency close to but not at resonance and explore the effect of increasing the amplitude of the input signal. You need to record your observations in detail.

Specifically, you are looking for input voltages at which the output signal bifurcates – that is, the period of the output waveform doubles.

? *How do the precise points of period doubling relate to the bifurcation diagram?*

The amplitudes of the input signal at which period doubling takes place follow a universal law for chaotic behaviour. If you can identify the amplitude at which the period doubles from 1→2 (A_1), from 2→4 (A_2) and 4→8 (A_3), you can estimate the Feigenbaum number, δ, where:

$$\delta = \frac{A_2 - A_1}{A_3 - A_2}$$

? *Based upon your measurements, what is the value of the Feigenbaum number?*

It is not easy to determine the bifurcation points accurately and therefore the amplitude values you used to estimate δ are likely to be quite unreliable. By repeating these measurements determine the uncertainty in each of the above amplitude values.

What is the uncertainty in your estimate of the Feigenbaum number?

Are your data consistent with the accepted value of the Feigenbaum number? There are only two possible answers to this question: definitely yes or definitely no. The two values are close is not an acceptable answer.

4 Optional Additional Work

Marks will only be awarded for this section if you have already completed all of Section 3 to an excellent standard and with excellent understanding.

There is no specified additional work for this lab. 'Outstanding' marks will be awarded for students which can demonstrate outstanding understanding and have performed outstanding experimental investigation that has gone well beyond that specified in section 3.