

## Virtual Laboratory for Measurements in Electromagnetics

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**Abstract** – The main objective of this paper is to detail the development of a computer assisted virtual laboratory which has been put in place to teach the theoretical and practical aspects of Electromagnetics, without physically using the necessary instruments and doing measurements. The virtual laboratory has allowed us to teach Electromagnetics in a new and effective way, helping our students master this difficult subject. In particular, virtual experiments have been designed which the students perform before attempting to do the corresponding real experiments. These virtual experiments help the students to appreciate the essential features of an experiment without being confused or distracted by the complications of the real experimental procedures. We believe excellence in teaching can be achieved by developing this innovative way of teaching the laboratory material through a computer based flexible and interactive environment of virtual experiments.

**Keywords** – Electromagnetics, Ferromagnetism, Virtual Laboratory, B-H Characteristics Measurement

### I. INTRODUCTION

Electromagnetics is a demanding subject both to teach and to learn. A student has to comprehend difficult physical concepts and apply advanced mathematical techniques. Even though Electromagnetics is the very basis of our modern life, the material may seem esoteric and divorced from the real world. Student interest must be stimulated so that adequate learning can take place and the use of virtual experiments is one way of doing this. Virtual experiments can introduce students to a wide range of electromagnetic experiences and methods without requiring them to spend inordinate amounts of time, thereby freeing learning time for other rewarding activities. Also, Electromagnetics is such a rapidly evolving subject, that equipment and instrumentation, and experiments can become outdated very fast. It is possible to maintain the experiment up-to-date in the virtual laboratory environment.

This paper describes the development of virtual laboratory experiments for the subject 143.352 Electromagnetics, a core subject for the Bachelor of Information and Telecommunication Engineering degree program at Massey University, New Zealand.

### II. BACKGROUND OF THE COURSE

The development of virtual laboratory reported in this paper is a part of the subject 143.352 Electromagnetics in the course curriculum of Information and Telecommunication Engineering. Electromagnetics theory is a key to understanding and modeling antenna and radio frequency propagation. The course 143.352 Electromagnetics has been introduced as a core subject since 2002. It is a single semester course taught in the second semester starting from mid-July and continuing till the middle of October. The semester spans a thirteen week period, so there are effectively 39 hours of lecture, 13 hours of tutorials and 13 two-hour laboratory classes available. Since the Institute of Information Sciences and Technology, Massey University does not have the necessary resources for conducting the practical experiments, the course is combined together with another course 124.328 Applied Electromagnetism, offered by the Physics department. The laboratory experiments are conducted in the Physics department for the joint courses.

### III. STUDENTS' OPINION

SECAT (Student Evaluation on Composition, Administration and Teaching) was done in the year 2002. The students expressed grave concerns about the laboratory experiments. Two of the comments centered on -

- i) Learnt the theory after the laboratory.
- ii) Did laboratory experiments on unfamiliar topics that were not covered in the class.

In essence, it was difficult for the students to grasp the laboratory as they were often not familiar with the theory. Developing an infrastructure for multiple experimental setups puts a heavy financial burden on the university. Thus the development of virtual experiments was explored with an added intention to make the laboratory experiments much more interesting,

#### IV. TEACHING WITH LABORATORY EXPERIMENTS

Real practical experiments are conducted to increase the students' practical skills and knowledge, and to give them the opportunity to become acquainted with many instruments and experimental procedures. The students are required to conduct the experiments in pairs and laboratory support is provided. At the completion of an experiment, the students are allowed one week to complete their analysis and submit a report using the computers provided.

In the first year, i.e. in 2002, five experiments were conducted. Since we had only one experimental set-up for each experiment, the students were divided into groups and asked to do one experiment each week. So effectively all the experiments were conducted on the same day, albeit by different student groups.

Fig. 1 shows the photograph of the bound region, a part of the experimental set-up (necessary instruments are not shown) to verify Laplace's equation. The experiment involves determining the electrical potential in a region of interest confined within known boundary conditions. The apparatus is rectangular-trough whose bottom is lined with conductive paper overlaid by a clear plastic sheet with a rectangular grid of 21 by 14 of holes punched in it at 1 cm spacing. The students are required to measure the electric potential at each grid point with a voltmeter and a sharp probe. One side of the trough is held at 25 V while the remaining 3 sides are held at 0 V. The students measure the electric potential and plot the potential distribution. The large grid spacing of 1 cm is to allow the students sufficient time to collect data, but the spacing is too large for the students to be able to use the electric potential to calculate the electric field distribution with precision. Fig. 2 shows the distribution of electric potential obtained from the measured data.

Fig. 3 shows the experimental set-up for another practical experiment on B-H characteristics of ferromagnetic material.

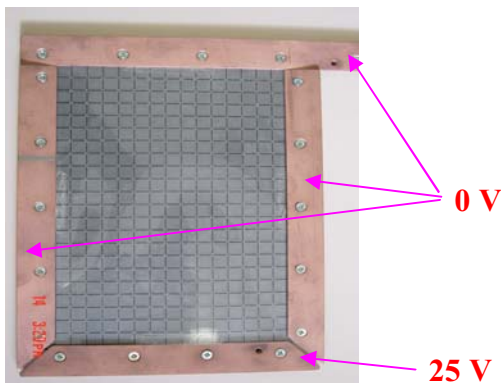


Fig. 1. Experimental apparatus for the solution of Laplace's equation

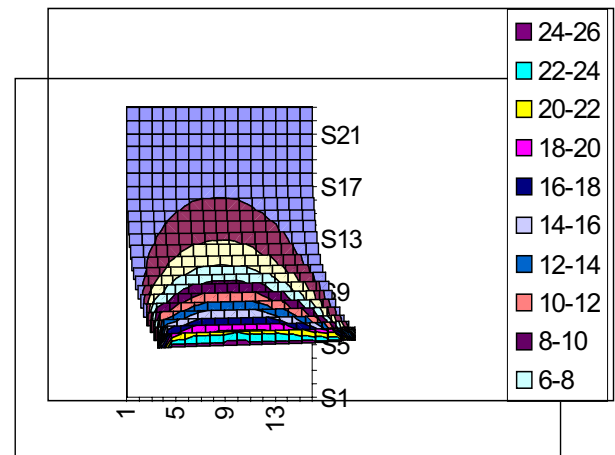


Fig. 2. Potential distribution obtained from measured data

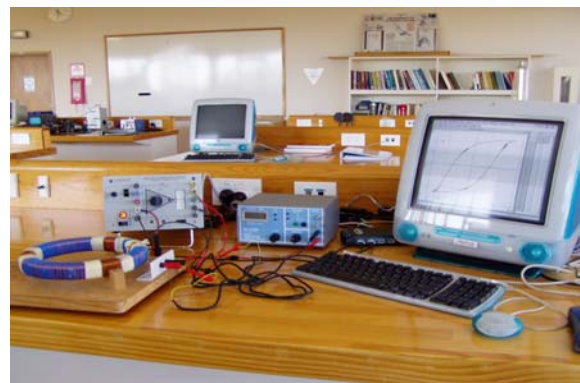


Fig. 3. Experimental set-up for ferromagnetism experiment

#### V. DEVELOPMENT OF VIRTUAL EXPERIMENTS

The development of a Virtual Experimental Platform, to study Electromagnetics experiments, started in the year 2002 with the support of a FIET (Funds for Innovation and Excellence in Teaching) grant and assistance from IIST (Institute of Information Science and Technology) and IFS (Institute of Fundamental Sciences). FEMLAB, a finite element software package for Electromagnetics modeling, was purchased and some development work was carried out [1,2, 3]. The laboratory accounts for 25% of the course marks, out of which half accounts for practical laboratory and another half for the virtual laboratory. Virtual experiments can be readily altered to illustrate new techniques and to demonstrate genuinely interesting phenomena. The other advantages of virtual experiments are-

1. Observation of phenomena not directly observable by human senses (e.g. flux lines).
2. Observation of transient processes [4].
3. Observation of processes which are either very large or very small.
4. Regulation of complexity to suit different educational levels.

- The experiments are safe and accessible through internet. This is particularly important for multiple campus universities like Massey University.

So far six virtual experiments are conducted-

- Solution of Laplace's equation
- The magnetic field in a solenoid
- Impedance characteristics of a planar coil
- B-H characteristics of ferromagnetic materials
- Magnetic dipole antenna
- Helmholtz Coil

Each of these virtual experiments has been developed around a real experiment. The students perform the virtual experiment before they attempt the corresponding real experiment. Hence the students are able to appreciate and investigate the phenomenon to be studied without the distraction of the real experimental environment. Subsequently when they fully appreciate the purpose of the investigation they perform the real experiment.

The development of virtual experiments has been centered on visual basic [5] and FEMLAB software [6, 7]. The students were given a brief introduction to virtual experiments, and instructed how to conduct a virtual experiment. An instruction sheet accompanied each virtual experiment, and the students had 2 hours to complete it. The exercises are given and they are asked to submit the report at the end of the experiment.

A brief description of a few virtual experiments is given here.

In the experiment on solution of Laplace's equation, the practical laboratory involves determining electrical potential in the region of interest with given boundary conditions as shown in Fig. 1. They measure the electric potential and the data is used to plot the potential distribution. The same experiment has been developed for the virtual laboratory.

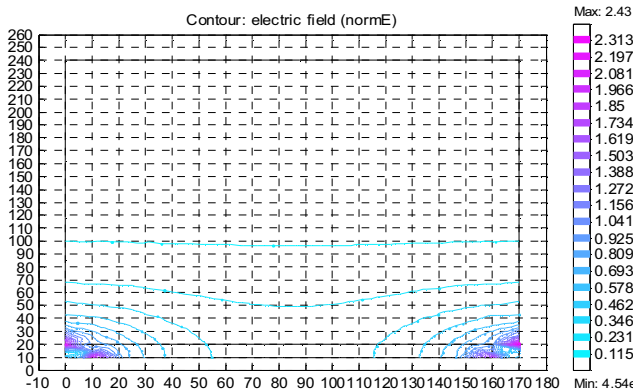


Fig. 4. Potential distribution

The students follow the method of conducting the virtual experiment which has been explained in the lab-sheet. Once the solution is obtained they can do post-processing and see the desired waveform. Fig. 4 shows the electric potential distribution for the problem. It is really cumbersome to do many things during the actual experiment, which are very easily done with the virtual set-up. Fig. 5 shows the distribution of the electrical field intensity (norm) for the problem.

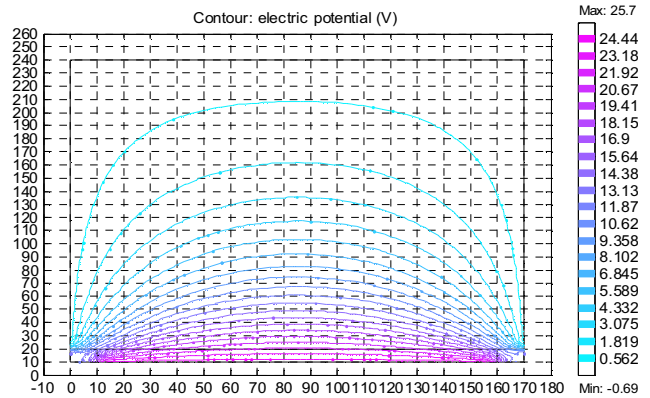


Fig. 5. Plot of electric field intensity (norm)

In the virtual experiment, it is very simple to change different parameters and see their effect on the response.

The virtual experiment on the solution of Laplace's equation has been configured around FEMLAB. On the other hand the experiments on ferromagnetism and the B-H characteristics of magnetic material have been configured around Visual Basic. Fig. 6 shows the output on the screen when the experiment is invoked. Fig. 7 shows the output B-H characteristics when proper inputs and parameters have been chosen. For off-line analysis a lot of data needs to be stored in a file and it is not possible to investigate anything other than the stored parameters. Due to this reason the students do not appreciate much the virtual experiment configured around Visual Basic of this form.

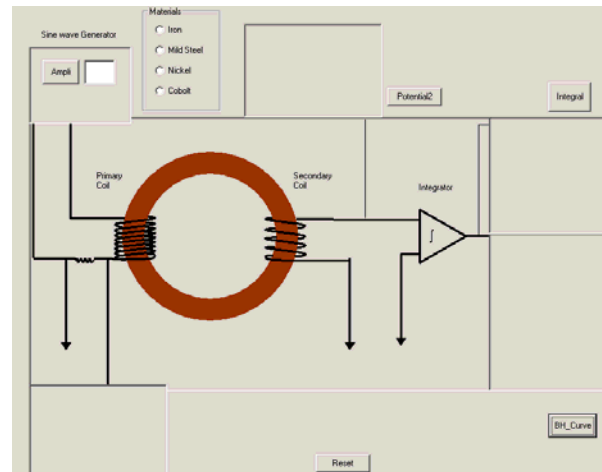


Fig. 6. Virtual experiment on ferromagnetism

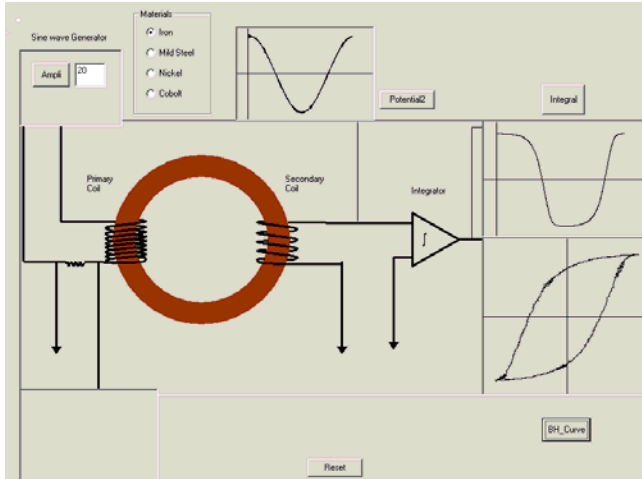


Fig. 7. B-H curve on virtual experiment

## VI. ASSESSMENT AND STUDENT EVALUATION OF VIRTUAL EXPERIMENTS

The assessment part of virtual experiment can be looked at from two different aspects. First these virtual experiments give the students an opportunity to assess the theory of the subject which they learn through lectures. In a practical experiment it is not possible to observe the effect of changing a parameter on the system performance very quickly which can be done with the virtual experiments with ease. The students are asked to explain the reason for those changes and this ignites their thinking process and reinforces the learning.

Each laboratory is worth 2.5% of the final grade for the course. The students are asked to answer a few questions which are described in the instruction sheet. The exercises form step by step process of the learning cycle and the backbone of the continual assessment. At each stage during the laboratory the students are provided necessary guidance to conduct the experiment. The students are asked to show the results during the laboratory when they are ready and they are assessed for their grading. They submit the final report at the end of the laboratory. The reports are assessed and marked and handed back to the students before the next laboratory so that they get immediate feedback. The student attitudes to virtual experiments and assessment were surveyed so that their usefulness in enhancing student learning and appropriateness of the assessment could be assessed. The students were divided about whether sufficient time was allocated to virtual experiments but the majority believed virtual experiments had enhanced their understanding and learning. There was unanimous agreement that virtual experiments were worthwhile and should continue to be offered, though the students also believed that they could not replace real experiments. They are very happy with the mode of assessment used for this part.

## VII. CONCLUSIONS

In this paper we have presented the development work of conducting virtual laboratories for Electromagnetics, a 3<sup>rd</sup> year core subject for the Bachelor of Information and Telecommunication Engineering degree and Physics specialization offered at Massey University and the assessment part of the laboratory. With the help of FIET (Fund for Innovation and Excellence in Teaching), the development work for an innovative way of teaching laboratory experiments have been started. This is part of the development of a comprehensive method for teaching electromagnetism at undergraduate level. The main purpose has been to use a computer assisted teaching environment to make the complex, abstract subject as simple as possible without compromising the subject's integrity, so that the students can learn more effectively with enthusiasm and interest. The questionnaires have shown that the development so far has enhanced the student learning and increased their interest of the subject.

The development work is being continued to make the experiments more interactive so that students can obtain immediate and more constructive feedback. It is also being extended to being available on the web so that it can be accessed anytime from anywhere at the convenience of the student. The development thus far has helped us to teach the subject with more satisfaction and our students have enjoyed this subject in the computer assisted learning environment. The method of assessment for the laboratory part is very effective and students appreciate it.

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