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Article

Electromagnetic theory: Electromagnetic pulse in the laboratory

Teoría electromagnética: Pulso electromagnético en el laboratorio

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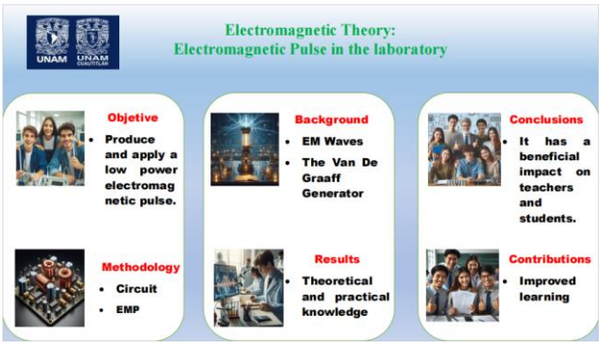
Abstract

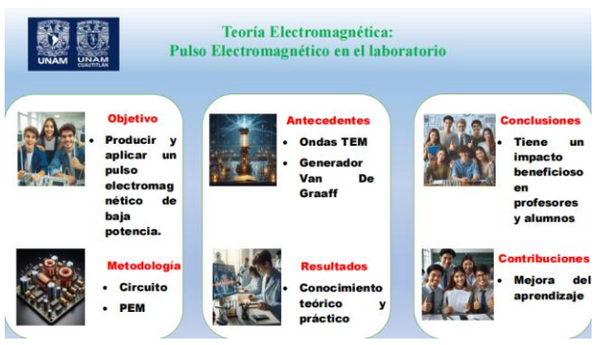
This article shows the process in the development of a laboratory practice of Electromagnetic Theory, applied to the Telecommunications, Systems and Electronics Engineering Career, of the Facultad de Estudios Superiores Cuautitlán (FESC) belonging to the Universidad Nacional Autónoma de México (UNAM). The objective for future engineers is to learn about the impact of an electromagnetic pulse on electronic equipment. It begins with the theoretical background of the electromagnetic pulse, then basic oscillator circuits are addressed and an experiment with a low-power electromagnetic pulse is developed. The impact of the practice on the students is measured and with it, conclusions are drawn, indicating the importance of this knowledge for future engineers in telecommunications systems and electronics.



Telecommunications, Laboratory, Pulse

Resumen

En este artículo se muestra el proceso en el desarrollo de una práctica de laboratorio de Teoría Electromagnética, aplicado a la Carrera de Ingeniero en Telecomunicaciones Sistemas y Electrónica, de la Facultad de Estudios Superiores Cuautitlán (FESC) perteneciente a la Universidad Nacional Autónoma de México (UNAM). El objetivo para los futuros ingenieros es conocer el impacto de un pulso electromagnético en los equipos electrónicos. Se comienza por los antecedentes teóricos del pulso electromagnético, posteriormente se abordan los circuitos osciladores básicos y se desarrolla un experimento con un pulso electromagnético de baja potencia. Se mide el impacto de la práctica en los alumnos y con ello, se establecen las conclusiones, indicando la importancia de este conocimiento para los futuros ingenieros en telecomunicaciones sistemas y electrónica.



Telecomunicaciones, Laboratorio, Pulso

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Introducción

The Facultad de Estudios Superiores Cuautitlán (FESC), part of the Universidad Nacional Autónoma de México (UNAM), is an important academic center located in the municipality of Cuautitlán Izcalli, State of Mexico. It was inaugurated on April 22, 1974, and has been in existence for more than 50 years. It now has 17 degree programs and has approximately 18,000 students enrolled.

In the curriculum of the Telecommunications Systems and Electronics Engineer (ITSE), taught at the FESC of the UNAM is the subject of Electromagnetic Theory, located in the fifth semester of the career and marked as a theoretical and practical subject (therefore includes a laboratory), has 10 mandatory credits, so it is of great importance in the training of future engineers.

According to Yeang (2024), Electromagnetism and electrodynamics, central to classical physics, began with Ampère's electrodynamics and Faraday's electromagnetic induction. By the mid-19th century, Neumann and Weber developed a unified electrical theory, while Faraday and Thomson explored the electromagnetic field. Maxwell expanded this theory, introducing the displacement current and predicting electromagnetic waves, which Helmholtz further developed, leading to Hertz's 1887 discovery of electric waves.

In the internal structure of the Electromagnetic theory subject, the topic of "Fundamentals of Electrodynamics" is located, and within it, subtopics such as Maxwell's Equations, electric potential and Gauss's Law among others. Source: FESC (2024).

Within the Electromagnetic Theory, the Electromagnetic Pulse, also referred to in the literature as EMP, is a phenomenon that has gained increasing relevance, due to its high impact on electronic devices and communication systems, increasingly used by our students in Universities.

The EMP is defined as a rapid release of electromagnetic energy, generating waves that can affect electronic systems through the induction of currents and voltages.

Its importance lies in the vulnerability of modern infrastructure to these pulses, since critical devices, such as power and communication systems, may suffer irreparable damage.

According to Mendieta (2008), in the 1940s, after experimenting with the first Atomic Bomb, very destructive effects were observed in electrical and electronic devices on the Island of Hawaii, and as tests continued and the destructive effect of these was observed, the "Comprehensive Nuclear Test Ban Treaty" (CTBT) was proposed.

For the scope of this article, we will focus on Electromagnetic Pulses generated in the laboratory through voltage variations such as those produced by the Van De Graaff Generator.

The problem we wanted to attack was the general ignorance of our students to the EMP phenomenon and the importance that it has in the proper functioning of electronic devices today.

The contribution of this experiment is the realization of a controlled EMP, as well as the design and measurement of the basic circuit to raise the voltage, all this is visually attractive to students and motivates them the deepen of the subject.

For all of the above, we developed a laboratory practice called: "Passive circuits and electromagnetic pulse", which has already been included in the manual of laboratory practices of the Physics Department of the FESC UNAM.

The results were encouraging, especially improving the interest of our students in Electromagnetic Theory. It should be noted that these young people will be the future engineers in telecommunications, systems, and electronics of the Universidad Nacional Autónoma de México (UNAM).

Methodology

For the elaboration of this work, first a theoretical research was carried out that included basic elements of the Electromagnetic Theory subject, the programmatic contents approved by the H. Technical Council of the Faculty, and the quality guidelines according to the ISO 9001:2015 standard were considered.

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We worked with several academics belonging to the Electromagnetic Theory faculty to distribute the work equitably.

Considering that Maxwell's equations refer to the conversion of electric and magnetic fields, we decided to include an experiment that had the necessary characteristics to make it attractive to students and at the same time demonstrate the relationship between the mentioned fields.

All the topics of the theoretical course were covered and several practices were developed, all of which resulted in the laboratory practices manual.

For this article, only practice 3, called Passive Circuits and Electromagnetic Pulse, was considered. This practice was first applied in a pilot test to teachers and students, with the feedback obtained, modifications were made and the final product was obtained, which was integrated to the Laboratory Manual and sent to the Physics Department for its electronic publication.

Van De Graaff Generator and Electromagnetic Theory

Within the theoretical analysis, a review of Maxwell's equations, RC (Resistive-Capacitive), RL (Resistive-Inductive), CL (Capacitive-Inductive), and RCL (Resistive-Capacitive-Inductive) circuits, as well as a historical review of the PEM starting with Robert J. Van de Graaff were considered.

According to Open AI (2022), in 1929, Robert J. Van de Graaff, a graduate student at the Massachusetts Institute of Technology (MIT), decided to build what would become the first Van de Graaff generator.

The original Van de Graaff Generator is a device that, through a moving conveyor belt, accumulates electric charge in a hollow metal sphere. Its primary purpose was to generate exceptionally high electrical voltages to undertake research into the dispersion of charged particles.

Over the years Van de Graaf's initial design has been modified to the equipment we have in our laboratories.

Where not all the bands (made of latex) present friction with the hull of the Generator, instead they induce the charges on it. There are even some generators where the mechanical movement has been replaced by a voltage booster circuit, also known as boost converter.

Development of the Experiment

For this project we used the Van De Graaff Generator of the Physics Laboratory, FESC, which works with the friction of the band on a roller and the induction of charges to the generator shell, see Figure 1, to produce a controlled EMP that allowed the students enrolled in the Electromagnetic Theory course to observe the effect of the same on electronic devices.

Box 1

Figure 1
Van De Graff generator
Source: Own Elaboration

Compared to other techniques (such as nuclear), the PEM generated by the Van De Graaff Generator is of low power, which allows students to understand and measure it more safely.

We also built a passive oscillator circuit with laboratory elements (Capacitive-Inductive circuit) and accompanied it with a Diode to produce the effect of voltage growth in the capacitor. See Figure 2

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Box 2

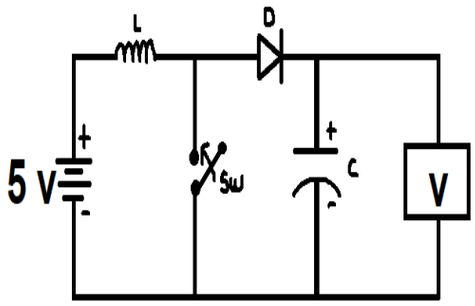


Figure 2
Wiring diagram
Source: Own Elaboration

We consider it important to mention that, although we could have worked with a power transistor, to make the experiment more didactic we used a basic button switch.

By using the basic switch, we were able to allow the students to interact with the circuit and demonstrate the relevance of the operating frequency in a practical and didactic way.

Elaboration of the laboratory practice

The Laboratory of the Physics Department of the FESC is certified under the ISO 9001-2015 standard, which is why when introducing a new practice it was necessary to comply with certain organizational guidelines.

According to Departamento de Física (2024), the structure of each of the practices of the manual for the Electromagnetic Theory laboratory, consists of 8 main elements, see Table 1.

Box 3

Table 1
Structure of the practice

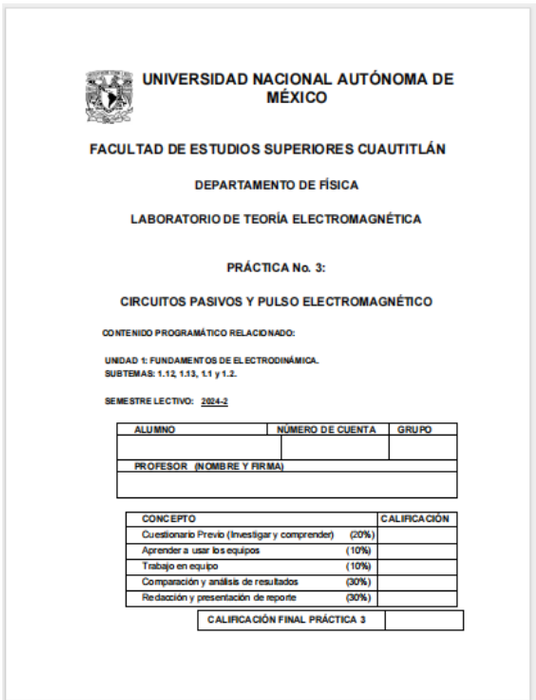
1.	Home page
2.	Previous knowledge
3.	Objectives
4.	Theoretical foundations
5.	Previous questionnaire
6.	Materials and equipment
7.	Development
8.	Conclusions

Source: Own Elaboration

The proposed practice complied with these guidelines and additionally, being a product of a collegiate work, it could be integrated to a UNAM program called: Program of Support to Projects for the Innovation and Improvement of Teaching (PAPIME for its acronym in Spanish), which indicated additional elements to be considered, which was fulfilled in the drafting determining the final structure of the document.

The final work consisted of 15 pages, including the cover page. Its name was: Practice 3. Passive circuits and electromagnetic pulse. It was presented to a pilot group of teachers for their observations and later to a pilot group of students to evaluate its impact.

Box 4



UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

FACULTAD DE ESTUDIOS SUPERIORES CUAUTITLÁN

DEPARTAMENTO DE FÍSICA

LABORATORIO DE TEORÍA ELECTROMAGNÉTICA

PRÁCTICA No. 3:

CIRCUITOS PASIVOS Y PULSO ELECTROMAGNÉTICO

CONTENIDO PROGRAMÁTICO RELACIONADO:

UNIDAD 1: FUNDAMENTOS DE ELECTRODINÁMICA.
SUBTEMAS: 1.12, 1.13, 1.1 y 1.2.

SEMESTRE LECTIVO: 2024-2

ALUMNO	NÚMERO DE CUENTA	GRUPO
PROFESOR (NOMBRE Y FIRMA)		

CONCEPTO		CALIFICACIÓN
Cuestionario Previo (Investigar y comprender)	(20%)	
Aprender a usar los equipos	(10%)	
Trabajo en equipo	(10%)	
Comparación y análisis de resultados	(30%)	
Redacción y presentación de reporte	(30%)	
CALIFICACIÓN FINAL PRÁCTICA 3		

Figure 3
Cover page of the practice
Source: Own Elaboration

For the electromagnetic pulse part, the Van de Graff and a basic calculator were added, the students were asked to place a certain level of band velocity to generate sufficient charge and then at different distances to measure the impact of the electric field on the electronic device. As can be seen in Figure 4.

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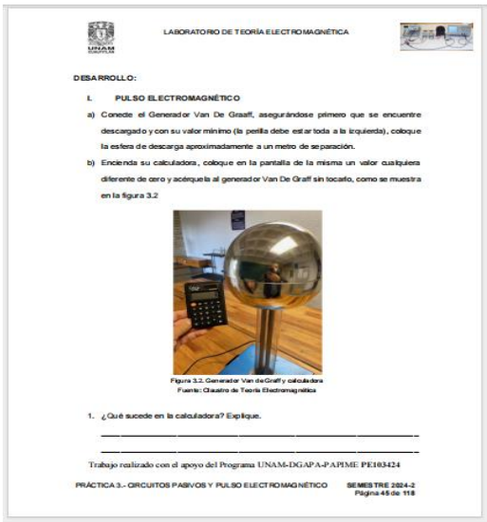
Box 5


LABORATORIO DE TEORÍA ELECTROMAGNÉTICA

DESARROLLO:

I. PULSO ELECTROMAGNÉTICO

a) Conecte el Generador Van De Graaff, asegurándose primero que se encuentre descargado y con su valor mínimo (la perilla debe estar toda a la izquierda), coloque la esfera de descarga aproximadamente a un metro de separación.

b) Encienda su calculadora, coloque en la pantalla de la misma un valor cualquiera diferente de cero y acérquela al generador Van De Graff sin tocarlo, como se muestra en la figura 3.2

Figura 3.2. Generador Van de Graff y calculadora
Fuente: Cuaderno de Teoría Electromagnética

1. ¿Qué sucede en la calculadora? Explique.

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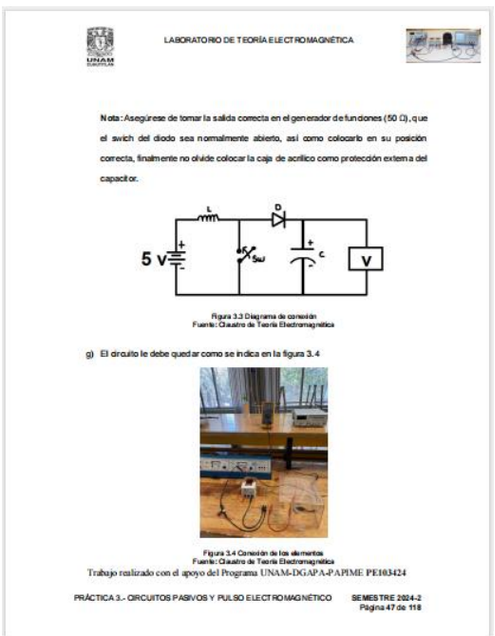
Figure 4

Electromagnetic Pulse Experiment

Source: Own Elaboration

The experiment with the voltage booster circuit was also developed with safety measures in mind, including the use of an acrylic enclosure to prevent incidents with the capacitor and to protect the students. See Figure 5.

Box 6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Nota: Asegúrese de tomar la salida correcta en el generador de funciones (50 Ω), que el swich del diodo sea normalmente abierto, así como colocarlo en su posición correcta, finalmente no olvide colocar la caja de acrílico como protección extema del capacitor.

Figura 3.3 Diagrama de conexión
Fuente: Cuaderno de Teoría Electromagnética

g) El circuito le debe quedar como se indica en la figura 3.4

Figura 3.4 Conexión de los elementos
Fuente: Cuaderno de Teoría Electromagnética

Trabajo realizado con el apoyo del Programa UNAM-DGAPA-PAPIME PE103424

PRÁCTICA 3.- CIRCUITOS PASIVOS Y PULSO ELECTROMAGNÉTICO SEMESTRE 2024-2
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Figure 5

Experiment developing the circuit

Source: Own Elaboration

Students were asked to take different readings and interact with the switch at various speeds to observe the effect of frequency on these circuits.

Results

During the development of the study, a significant understanding on the part of the students concerning the concept of electromagnetic pulse was observed.

This finding suggests a deep understanding on the part of the students about this phenomenon, which indicates remarkable progress in their learning.

In addition, the teachers participating in the study were able to develop and strengthen their didactic skills by incorporating new tools and strategies to improve the teaching of the Electromagnetic Theory course.

This pedagogical adaptation can be considered an important achievement for the teaching team, as it allows them to offer a more enriching and effective educational experience to their students.

Regarding the students' understanding of the operation of a voltage booster circuit, the results showed a satisfactory level of comprehension. This ability acquired by the students suggests an improvement in their knowledge and skills in the field of electronics and telecommunications engineering.

In general, the objectives set for the practical were achieved, which included:

- To observe phenomena related to electric charges in motion, interacting with electric and magnetic fields, through passive circuits.

- To produce and apply a low-power electromagnetic pulse.

These results confirm the effectiveness of the methodological approach used in practice, as well as the students' ability to assimilate and apply the theoretical concepts learned in a practical context.

Conclusions

The results obtained in this study provide a clear view of the positive impact that the lab session had on students' learning and the professional development of teachers. From these findings, several important conclusions can be drawn:

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Effectiveness of the pedagogical approach: The lab session was effective in enhancing students' understanding of fundamental electromagnetics and electrical circuit concepts. The integration of theory with hands-on practice enabled a deeper and more meaningful comprehension of the studied phenomena.

Teacher development: The results indicate that the participating teachers were able to strengthen their didactic skills and adapt their pedagogical approach to offer a more enriching learning experience. This aspect is crucial to improve the quality of teaching and learning in the classroom.

Practical application of knowledge: Practice allowed students not only to understand theoretical concepts, but also to apply them in practical situations. This is essential for developing practical skills and fostering critical and creative thinking in students.

Fulfillment of objectives: It was confirmed that the objectives set for the practicum were satisfactorily achieved. Students were able to observe and apply electromagnetic phenomena, while teachers were able to strengthen their course with new tools and approaches.

In summary, the results highlight the importance of educational practices based on experience and active interaction with content, both for students' learning and for teachers' professional development. These findings can serve as a basis for future research and the continuous improvement of academic programs and teaching in general.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Guzmán-Tinajero, Pedro: Contributed to the project idea, research method, and technique. He supported the design of the field instrument. He carried out the data analysis and systematization of results, as well as writing the article.

Hernández-Gómez, Víctor Hugo: Carried out the systematisation of the background for the state of the art. She supported the design of the field instrument. She also contributed to the writing of the article.

Castro-Fuentes, Aide: contributed to the research design, the type of research, the approach, the method, and the writing of the article.

Availability of data and materials

The images were obtained from photographs taken at the physics laboratory of the Facultad de Estudios Superiores Cuautitlán, UNAM.

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Funding

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Abbreviations

CTBT	Comprehensive Nuclear Test Ban Treaty
EMP	Electromagnetic Pulse
FESC	Eaculty of Higher Studies Cuautitlán
ISO	Internacional Organization for Standardization
ITSE	Telecommunications Engineering Systems and Electronics
MIT	Massachusetts Institute of Technology

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PAPIME	Program of Support to Projects for the Innovation and Improvement of Teaching
RC	Resistive Capacitive
RCL	Resistive Capacitive Inductive
RL	Resistive Inductive

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