AC 2008-1407: LEARNING ANALOG ELECTRONICS THROUGH PROJECT-BASED INVESTIGATION OF FM COMMUNICATION CIRCUITS

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LEARNING ANALOG ELECTRONICS THROUGH PROJECT-BASED INVESTIGATION OF FM COMMUNICATION CIRCUITS

Abstract

Since historically much of the early development of analog electronics took place in the communication field present, day students' understanding of electronics can be enhanced by working with FM communication circuits. Students majoring in the electrical and computer engineering concentrations at our university are required during their junior year to take a three-hour lecture course and a two-credit-hour lab course in analog electronics. By the end of the courses, students learn the theory and application of such components as diodes, Zener diodes, NPN and PNP transistors, MOSFETs, SCR's Diacs, Triacs, and optoelectronic devices.

New experiments have been added to the electronics lab to enhance understanding of basic analog components. This project investigated the effects on the students' learning of analog electronics by having them develop an FM transmitter and an FM receiver circuit much earlier than they are prepared to handle them. Electronic communication circuits are studied in detail a semester later in the second electronic course and RF theory is introduced a year later in the communication courses. The objective for the student was to discover how the electronic components studied in class can be placed together in an FM transmitter to work as: a signal amplifier, local oscillator, FM modulator, frequency multiplier, and power amplifier at the final output stage. In an FM receiver they see the components working as: an RF amplifier, local oscillator, FM mixer, IF amplifier, FM detector, output audio amplifier and automatic frequency control circuit. Students also learned to appreciate the modular nature of complex designs.

At the end of the semester, a survey was given to determine the results on student learning concerning the concepts and applications of electronics. The results of this project may prompt the implementation of other projects that may include multidisciplinary collaboration, integration of projects between classes, projects across concentrations, and integration of a single project from the freshman to the senior year.

Introduction

Lecture-based training is known to address only certain learning styles. The use of design projects provides the students with a broader context to the material learned in class. With project-based learning students shift from a passive to an active learning pattern that is likely to improve knowledge retention as well as the ability to integrate material from different courses [1]

Like many undergraduate engineering schools in the nation, our university emphasizes a hands-on approach in engineering education. From the beginning of the freshman year to the senior year, students participate in different levels of engineering projects, from LEGO Mindstorms designs, to conducting a research project. Each project provides the students with the opportunity to apply the knowledge they learned in classes, and each problem they face in the project inspires them to explore more deeply in future study [2].

Project-based learning develops the ability of the students to work in interdisciplinary teams. Projects carried out by interdisciplinary teams are not only an expectation of industry but also have become a required outcome of the ABET engineering criteria. Many obstacles may arise when working in interdisciplinary teams, but a series of curriculum tools have been initiated at our school to insure that students will have a measure of success in project teamwork [3]. Project-based learning is an instructional method that demands from the student acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills [4]

In the fall semester of 2006, a new project experience was introduced into the 2 credit hour Electronics I lab [5]. This project had the following objectives:

1. Provide students with the opportunity to apply the concepts learned from the lectures and the instructor's predefined labs.
2. Allow students to work on projects that motivate them.
3. Provide a fun and enjoyable problem solving real life learning experience
4. Engage the students in the analysis, synthesis and evaluation process to generate a working solution for their projects

In this exercise the students were given the opportunity to propose and work on projects of their personal interest while the instructor observed the students applying higher order thinking skills to formulate, analyze, and generate a working solution for their projects [6, 7].

In the fall semester of 2007, a second project experience was introduced into the 2 hour credit Electronics lab. This project had the following objectives:

Provide students with the opportunity to:

a) Apply the concepts learned from previous courses, especially Circuits I and II,
b) Apply the concepts learned from their concurrent Electronics lectures and predefined lab experiments, and
c) Challenge them to research, study and apply concepts from future course such as electronic communication circuits and RF theory.
d) Allow student to work in teams.

In this opportunity the students were not given the opportunity to propose the topic of the project. An FM transmitter and an FM receiver were chosen by the instructor. These new labs were designed to prepare the stage for the student to discover how the electronic components studied in class, can be placed together in an FM circuit to work as a signal amplifier, local oscillator, FM modulator, FM demodulator, frequency multiplier, FM mixer, FM detector, and audio power amplifier. This paper presents the results of our 2007 FM transmitter/receiver project.

Background

To be able to enroll in the analog electronic course, students majoring in electrical and computer engineering are required during their sophomore year to take two electric circuit courses. The first electric circuits course “Circuits I” is a three-hour lecture course with a one-credit-hour lab. In this course the following topics are covered: basic electric circuit components, Kirchoff’s voltage and currents laws, nodal and mesh analysis, linearity, source transformations and superposition, Thevenin and Norton equivalent circuits, RL and RC circuits, sinusoidal steady-state analysis, phasor circuit analysis, impedance, admittance, A.C. analysis of power, and three-phase systems.

The second course, Circuits II is a 3 credit hour lecture course without a lab and is organized to cover the following topics: Series and parallel RLC circuits, frequency response, series and parallel resonance, mutual inductance, ideal transformers, Z, Y, H and T parameters, Fourier series, Fourier and LaPlace transforms.

At their junior year, or after completing both circuits I and II, students can enroll in analog electronics, EEGR 3113, a three-hour lecture course. The content of the course is organized in six to seven topics that cover the following subjects:

1. Diodes and Rectifiers.
2. Semiconductor Physics.
3. Two-Ports, Load Lines and Biasing.
4. Piecewise-Linear Models.
5. Q-Point Stabilization, Thermal and Environmental Considerations.
6. Emitter Follower, Common Base and Common Emitter, Coupling and Loading.
7. Power Amplifier, Transformer Coupling.
8. Operational Amplifiers.
9. N and P channel depletion and enhancement mode MOSFETs.

To provide a hands-on experience to the electronic lectures a set of learning oriented, pre-defined labs are incorporated in a two-hour lab course: EEGR 3112 Electronic Lab. This lab is designed to cover the following topics:

1. Introduction to diode circuits.
2. I-V curves of diodes.
3. Diode circuit applications in clippers, clampers, and regulator circuits.
4. Passive and active, low pass and high pass filters.
5. RLC resonant circuit response.
6. Terminal characteristic of BJT transistors (DC load lines and Q points).
7. BJT transistors and small signal amplification (DC and AC load lines).
8. BJT transistor thermal stability and frequency response.
9. Operation of BJT Transistors: LC oscillator and frequency multiplier.
10. Applications of Operational Amplifiers.
11. Characteristic of MOSFETs (DC and AC analysis).

By the end of the semester, after taking both the electronics lecture and the lab, students are expected to have theoretical knowledge of, and application experience with such components as diodes, Zener diodes, NPN and PNP transistors, operational amplifiers, low pass, high pass and band pass filters, MOSFETs, SCR's Diacs, Triacs, and optoelectronic devices.

To further enhance the student's understanding of the basic analog electronic components and to allow the integration of knowledge from previous courses, as well as to incorporate the research of topics from future courses, two new experiments in the form of short term projects, have been added to the electronic labs. Through these projects the students will develop an FM transmitter and an FM receiver circuit much earlier than they are prepared to handle them; since electronic communication circuits are studied in detail a semester later in the second electronic course and RF theory is introduced a year later in the communication courses.

Methodology

The project schedule was:

- First week:
    - Initial presentation of the FM project to the students by the instructor.
    - Organized students in four groups: two groups to work on two FM transmitter projects and the other two to work on two FM receiver projects.
- Second to third week:
    - Homework assignment: to study FM communication theory
    - Researched assignment: to look for FM transmitter and receiver circuits and their implementations.
- Fourth week:
    - Selection of FM electronic kits: Fully transistorized electronic kits were selected (a three transistor transmitter and a six transistor FM receiver).
    - The FM transmitter and receiver kits were purchased
- Fifth week:
    - Students were given free access to work in the university's electronic labs at their own pace. Only one lab period from the scheduled labs was assigned for the FM projects.
- Sixth to seventh week
    - Students soldered and tested the FM electronic kits
- Eight to tenth week
    - To study and analyze the FM transmitter circuit, the students sub-divided it into the following stages: input microphone, first amplification stage, local oscillator stage, second amplification stage, antenna coupling stage.
    - To study and analyze the FM receiver circuit, the students sub-divided it into the following stages: RF amplifier stage, FM mixer and oscillator stage, 1st and 2nd IF amplifier stages, FM detection stage and audio amplifier stage.
    - All teams performed a system functional analysis, and a mathematical input/ output gain analysis and presented a report of their findings and calculations.
    - Students prepared a power point presentation.

- Tenth week
    - Project demo and presentation

The Electronic FM transmitter kit

When researching for FM transmitters, students were looking for circuits in which they could easily trace and recognized the following functional stages: input signal amplifier, local oscillator, FM modulator, frequency multiplier, output power amplifier and antenna and transmission coupling stage. It turns out that most of the FM electronic kits are now reduced to single-chip circuits and we could not find a transmitter built with more than three transistors due to the FCC transmission output power limitations. An electronic kit that did meet must of our requirements was the CANCK108 Universal FM transmitter (Figure 1), with Mic and line inputs (solder kit), and it was purchased at a price of US$ 19.95.

Figure 1: FM transmitter electronic kit

The Electronic FM Receiver kit

When searching for FM Receivers, students were looking for circuits which they could easily trace and recognized the following functional stages: antenna and transmission coupling stage, input RF amplifier, local oscillator, FM mixer, IF amplifier, FM detector, output audio amplifier. Students were able to find an FM receiver using six transistors that met must of our requirements. The FM transmitter kit was the model AM/FM-108k radio kit (Figure 2), by Elenco Electronics, Inc. The unit price of the kit was US$ 27.95.

Figure 2: FM receiver electronic kit

Results

Assessment of the learning objectives was done through the traditional tools such as quizzes, lab reports, exams plus an anonymous survey that the students completed at the end of the semester. A copy of the survey is attached as the appendix. The Two the FM Transmitter and receiver circuits are shown by their team leaders in figures 3 and 4.

Figure 3: Team Leader and his FM Transmitter project

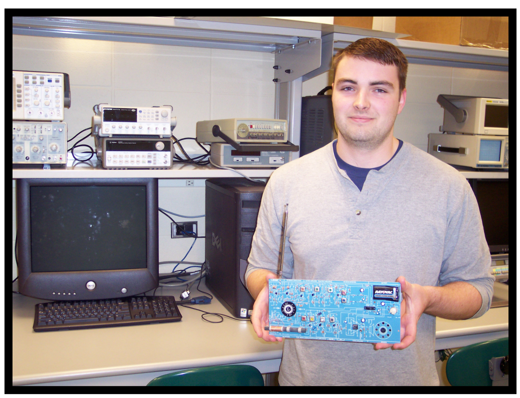


Figure 4: Team Leader and his FM Receiver project

To have an idea on how project-based learning had influence the grades of the students that took both the electronics and the Lab sessions, grades from the years 2005, 2006 and 2007 were used. During the year 2005 the students were enrolled in regular three hour lectures and the two hour hands on labs, no project was introduced this year. During 2005, the students were enrolled in both the lecture and the regular lab, and the first project was introduced. The students were given the opportunity to propose and work on projects of their personal interest. During 2006, the students again were enrolled in both lecture and regular lab and a second project was introduced, but this time a more complex and multi-faced project was chosen.

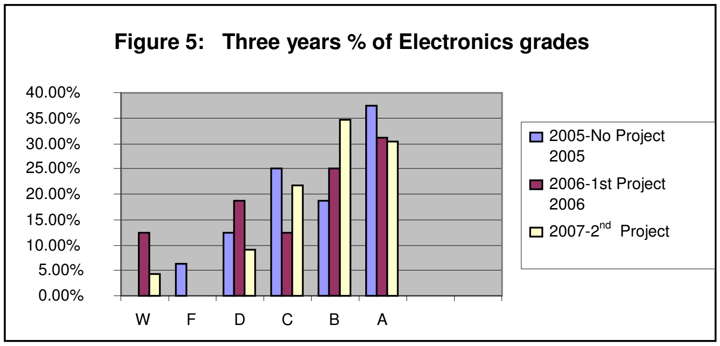


Figure 5 represents the student's grades in electronics. The first column corresponds to the 2005 students grades without the PROJECT-BASED LEARNING project, 2nd column represents the 2006 student's grades with the introduction of the 1st project and the 3rd column represents the 2007 grades with the 2nd project. The grade letters represents W= withdraw, and the letters grade A=(90-100), B=(80-89.9), C=(70 to 79.9) and D=(60-69.9). From year 2005 to the year 2006, little change is noticed, but we can see significant improvement in the grades obtained in 2007.

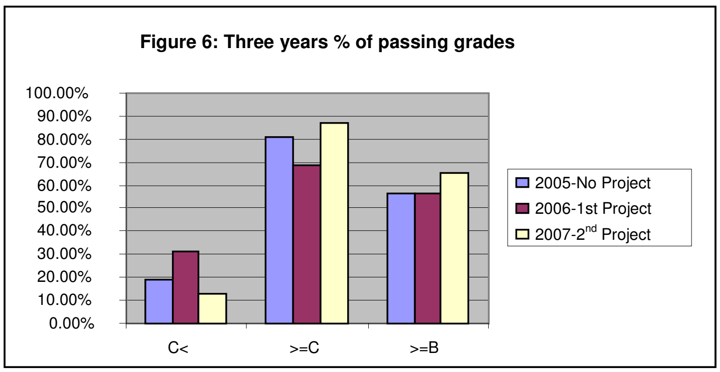
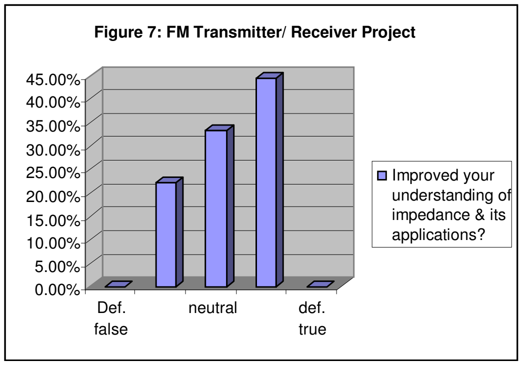
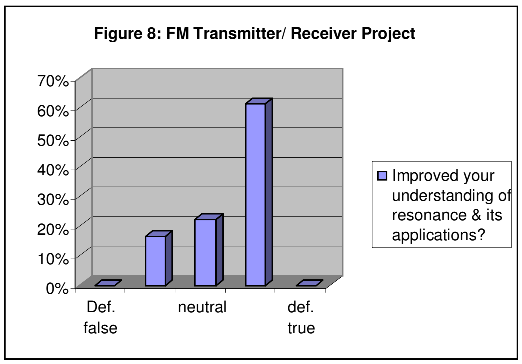


Figure 6 represents the same students grades for the years 2005, 2006, and 2007, but in this graph column number one represents the percentage of students that obtained a grade lower the "C", column number 2 represents the percentage of students that obtained a passing grade C or better, and the last column represents all the students that obtained a grade equal or better than B. The results of the 2006 project don't seem to improve the passing grade of the students, but we can definitely see an improvement in the results of the 2007 project.

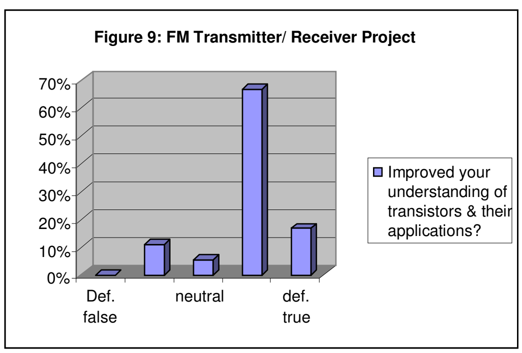
A survey was given to the students to gauge their opinion about this project. The survey asked students to rate how helpful the regular labs and the FM project have been in understanding the analog electronic components studied. Twelve (12) questions asked them to indicate their degree of agreement with (1=definitively false, 2= false, 3=neutral, 4= true, and 5= definitively true). Figures # 7, 8, 9, and 10 show the results of the questions asking specifically about how the FM transmitter and receiver project had helped them understand the concepts and applications of impedance, resonance, transistors and communication circuits.



From the results in Figure 7 we can see that even though impedance is a concept the students learn in Circuits I and II the Project helped the students to increase their understanding of it.



From the results in Figure 8 we can see that the FM transmitter and receiver circuit had a positive result in the understanding of resonance.



The results of Figure 9 shows that working and analyzing the FM circuits strongly increased their knowledge of transistors and its applications

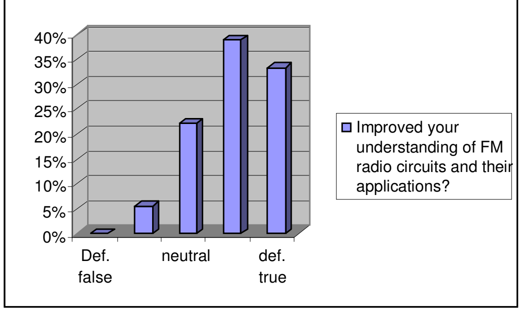


Figure 10: FM Transmitter/ Receiver Project

The results of Figure 10 were expected, since FM circuits were new to all of them and are topics of future lectures.

The last question of the survey was: In a short sentence, tell us what you think about the FM transmitter/receiver project? Here are some of the student's answers:

- ~ It was a good project to learn about the uses of transistors.
- ~ I believe it is a good project, but I would enjoy if some lectures could be given about the project.
- ~ I think the FM transmitter/receiver project was an interesting project, although not all the knowledge was readily available for the students.
- ~ I think the project needs to be evaluated for effectiveness. I do not feel I learned a large amount from the project.
- ~ It was a good way to integrate class topics, but the expectations were vague.
- ~ Already had some radio experience, but was somewhat helpful still. Some what unrealistic to calculate everything in some one else design when not all components values are given/ explained.
- ~ Some of what we were trying to do seemed very far above our heads.
- ~ I think that it is a good project, but it will be helpful if the theory was covered more in class.

Conclusions

The students' performance in the course, and the results of the survey, support the conclusion that the project was considerably successful. The objective of the project were met in the sense that students were able to: 1) apply their previous knowledge from Circuit I & II courses, 2) apply the concepts learned from their concurrent Electronics lectures and predefined lab experiments, 3) respond to the challenge to research, study and apply concepts from future Electronic Communication and RF theory courses, and to work in teams to complete tasks, meet deadlines, and deliver a working final product.

One lesson that we learned from the first project-based learning experience in 2006, was that when the students are given the opportunity to propose and select the project to work on, they will usually select a project that is within their current knowledge level, one that they think the can easily do. This produced negative results as one can see from the data presented from 2006.

As a result of this experience, we assigned a project that we believed was at the proper level and adequately challenging to generate positive results.

The results of this experiment can not be considered as final, since there many other variables that can affect student learning, but they provide us with a sense of satisfaction and with a refreshed desire to generate new projects to continue to use project-based learning at our institution.

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APPENDIX

	STUDENT EVALUATION OF ELECTRONIC PROJECT EFFECTIVENESS “Participation in this survey is voluntary. The results of the survey will be accumulated and shared with ASEE members only. No individual results will be reported on or connected to any faculty, staff or student respondent. **Do not sign your name**.”									
1	Did the introductory diode’s lab improve your understanding of diodes?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
2	Did the diode’s IV curves lab improve your understanding of diodes?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
3	Did the diode clippers and clampers lab improve your understanding of diodes and their applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
4	Did the use of zener diodes improve your understanding of voltage regulation?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
5	Did the RC and RLC frequency response labs improve your understanding of how electronic components react to changes in frequencies and can be used as filters?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
6	Did the transistor’s labs experiments improve your understanding of transistors and their applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
7	Did the Op-Amp’s labs experiments improve your understanding of Op-Amps and their applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
8	Did the MOSFET’s lab experiment improve your understanding of MOSFETS and their applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
9	Did the FM transmitter/receiver project improve your understanding of impedance & its applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
10	Did the FM transmitter/receiver project improve your understanding of resonance & its applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
11	Did the FM transmitter/receiver project improve your understanding of transistors & their applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
12	Did the FM transmitter/receiver project improve your understanding of FM radio circuits and their applications?									
		Definitely False		Mostly False		Neutral		Mostly True		Definitely true
13	In a short sentence, tell us what do you think about the FM transmitter/receiver project?									

Study and research assignment for members of the Transmitter group

The following are the basic stages for the FM transmitter:

1_ The microphone and input signal amplification
2_ The oscillator
3_ The Fm Modulator
4_ Frequency multiplier stage (check if your kit perform freq multiplication to obtain the final transmitting signal)
5_ Power output amplification
6_ Antenna and impedance matching

I am attaching the ck207.pdf file with the technical information about your transmitter.

You need to research and study how the transistor(s) or diode(s) used perform the particular function of each stage. Perform a system functional analysis, and a mathematical input/ output gain analysis at each state, and then write a formal report and a prepare power point presentation.

(Remember that for the report and Power point presentation you will need to describe how the transmitter work as a whole, and how the transistor(s) or diode(s) combined with other circuit elements perform the functions of each stage.

Study and research assignment for members of the Receiver group

The following are the basic stages for the FM receiver:

1_ FM RF amplifier
2_ The oscillator
3_ The Fm Mixer
4_ Intermediate frequency "IF" amplifier stage
5_ FM detector
6_ Automatic frequency control
6_ Audio amplifier

I am attaching the amfm108K.pdf file with information about your receiver.

You need to research and study how the transistor(s) or diode(s) used in your electronic kit, perform the particular function of each stage. Perform a system functional analysis, and a mathematical input/ output gain analysis at each state, and then write a formal report and a prepare power point presentation.

(Remember that for the report and Power point presentation you will need to describe how the transmitter work as a whole, and how the transistor(s) or diode(s) combined with other circuit elements perform the functions of each stage.