The Construction of an Analog Vocoder as a Hands-on Introductory Course in Electrical Engineering

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Abstract

This paper describes the Tallerine-Vocoder; a hands-on course for Electrical Engineering (EE) freshman students. This course aims to motivate students and stimulate their creativity meanwhile the objects, topics, methodologies and actors of the EE program are also introduced. Throughout the course, students build and test all the necessary modules to assembly an analog Vocoder. The Vocoder modules are briefly explained and the course methodology exposed. Finally, the main goals of the course are objectively evaluated by a student survey and discussed in the results.

Keywords: active learning methodologies; hands-on; electronics and music; Vocoder.

1 Introduction

The Electrical Engineering program of Universidad de la República, Uruguay lasts five years, and is structured in three vast consecutive blocks: (1) the basic skills in Mathematics and Physics are concentrated in the first two years, (2) the basic technological skills are concentrated in the third year, (3) the specific technological contents are in the two final years. With the syllabus organized in this way, the students have their first approach to more tangible topics related to electrical engineering only from the third year onwards. Furthermore, technical subjects are generally taught with strong emphasis on theoretical aspects. All this has a high contrast with the students' expectations, who frequently expect to have direct contact with practical tasks since the beginning of the career. In this context, it is usual to have students reaching the end of their undergraduate education without a basic notion of practical issues such as circuits designing, soldering, testing, etc. Therefore the EE program faces some difficulties:

1. A scarce freshmen visibility of the EE program among all the Engineering programs (mechanical, civil, chemical, computer science, etc.).
2. Serious difficulties with student motivation, social integration and evasion.
3. The number of freshmen EE students descending from 240 to 120 in seven years.

To overcome this, the EE program offers the Tallerine course since year 2013. The main goals of Tallerine are: to motivate the students, stimulate their creativity, integrate them socially, that the students identify themselves with the University and the program, and to introduce the objects, topics, methodologies and actors of the EE program (Giusto, 2014). Each edition of Tallerine consists in various EE projects among which the students can choose according to their interests and preferences. Projects must meet the following requirements: the students have to build a prototype; are representative of EE applications and have ludic and motivating aspects.

In this context, members of the Open Electronic Workshop[3] (TEL) and the Audio Processing Group[4] (GPA) propose EE projects with musical applications. In the first two editions of Tallerine, one of those projects was an analogue synthesizer (Tarragona, Davoine, & Eirea, 2014). This experience yield good results and showed various advantages when using audio applications:

- The modular synthesizer enables students to build, understand and test the modules by stages.

[3] http://iie.fing.edu.uy/tel/

[4] http://iie.fing.edu.uy/investigacion/grupos/gpa/

- The skills and tools needed for building each module are very basic and do not require previous experience.
- Only standard electronic components and tools are needed and these are low in budget.
- No special workspace is required: students can even work in their own homes.
- The synthesizer is a musical instrument that can be played by controlling electrical signals, enabling students to link electronic operation with sounds; they can also demonstrate it to non-technical public such as their friends and families, rising their motivation.
- The students can link engineering and musical concepts. For instance, the link between amplitude and frequency modulation with tremolo and vibrato.

2 Vocoder

In the first semester of 2015 the audio related project was the Tallerine-Vocoder, which involved the building of an analog Vocoder. The Vocoder was original developed as a speech coder for audio data compression, and then utilized during the WWII as part of the SIGSALY encryption system (Boone, & Peterson, 2000). In the sixties and seventies the Vocoder was applied in artistic contexts, and was widely utilized by musicians such as Wendy Carlos, Kraftwerk, and Laurie Anderson (McClary, 1989). The Vocoder is also used today in movies and music, such as in the voice of the robot "EVE" in the movie "WALL-E" (Rowe, 2010) or by musician from Phil Collins to Daft Punk.

The Vocoder (Dudley, 1936) has two inputs: namely program and carrier, and one main output. The spectral envelope of the program is extracted and then applied to the carrier. The block diagram of Figure 1 depicts the process. Both input signals are filtered to perform a sub-band processing. In each sub-band, an envelope-follower estimates the amplitude of the filtered program signal. Then, each carrier sub-band is amplified by a Voltage Controlled Amplifier (VCA) with gain given by the previously estimated amplitude. Finally, all the sub-bands are recombined by a summing amplifier.

For example, when the program signal is speech and the carrier a keyboard, this results in a talking keyboard effect. This allows the expansion of the expressive possibilities of an instrument with some voice characteristics. To efficiently capture the voice formants at least 10 bands are needed. In short, each band process has four modules: two pass-band filters, an envelope follower and a voltage controlled amplifier.

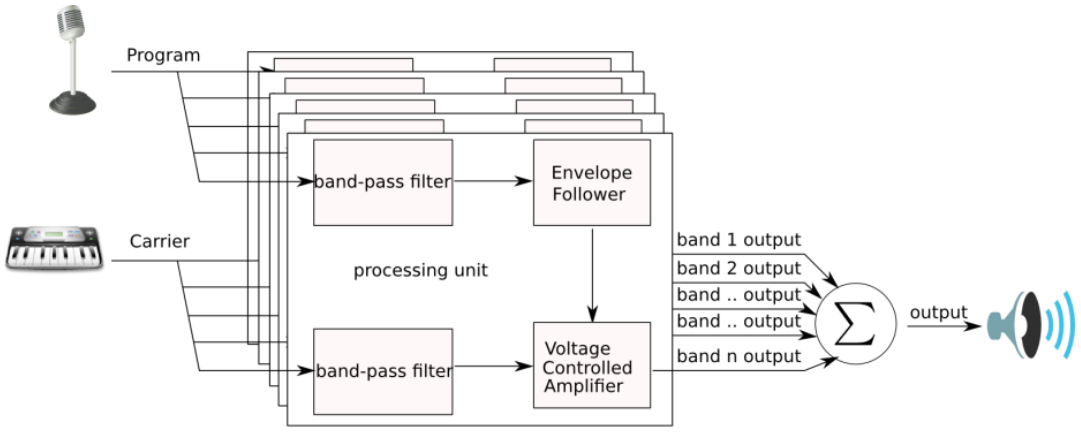


Figure 1. Vocoder block diagram.

Band-Pass Filter (BPF)

As previously mentioned, the band-pass filter modules allows the sub-band processing. The filters are standard 4-pole active Butterworth band-pass filter with constant quality factor Q. Two matched filters are needed per band. Filtering, invariant linear systems, and frequency response are the topics introduced in this module.

Envelope Follower (EF)

The Envelope Follower consists in a half-wave rectifier that drains current into a capacitor. Then, the capacitor voltage follows the signal peaks. This voltage results in an estimation of the program sub-band amplitude. Amplitude dynamics varies with frequency, so the capacitance value has to be adjusted for each band. Non-linear elements (diodes), rectifiers, capacitor natural response, and amplitude modulation are presented in this module.

Voltage Controlled Amplifier (VCA)

This module has two inputs, the signal and the control voltage. The VCA amplifies the carrier filtered signal (input signal) with gain given by the EF output (control voltage). As a result, the amplitude of the carrier in this band is determined by the amplitude of the program signal in the same band. The spectral envelope of the processed carrier approximately matches the spectral envelope of the program when all the sub-bands are processed. Transistors and the differential pair are introduced in this module.

Main Board (MB)

The four modules of each sub-band are interconnected via a predefined pinout, forming a processing unit as depicted in Figure 2. The main board accomplish different tasks: distribute the input signals across the processing units, sums all the processing units outputs, dispatches the power supply, act as mechanical holder for the units and interconnects the front panel with the modules adjustable controls.

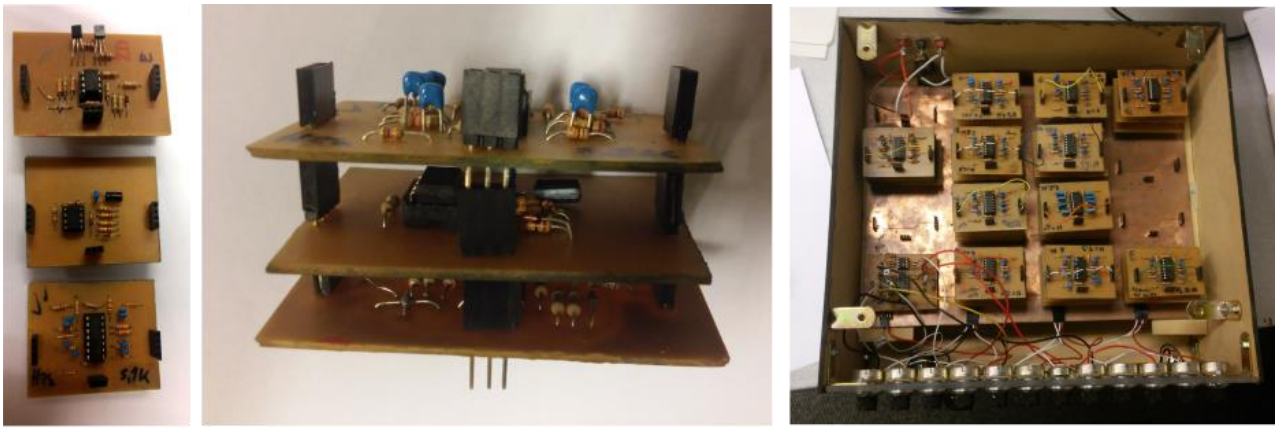


Figure 2. a) From top to bottom: VCA, EF and BPFs modules. b) Assembled processing unit. c) Main board with processing units.

3 Methodology

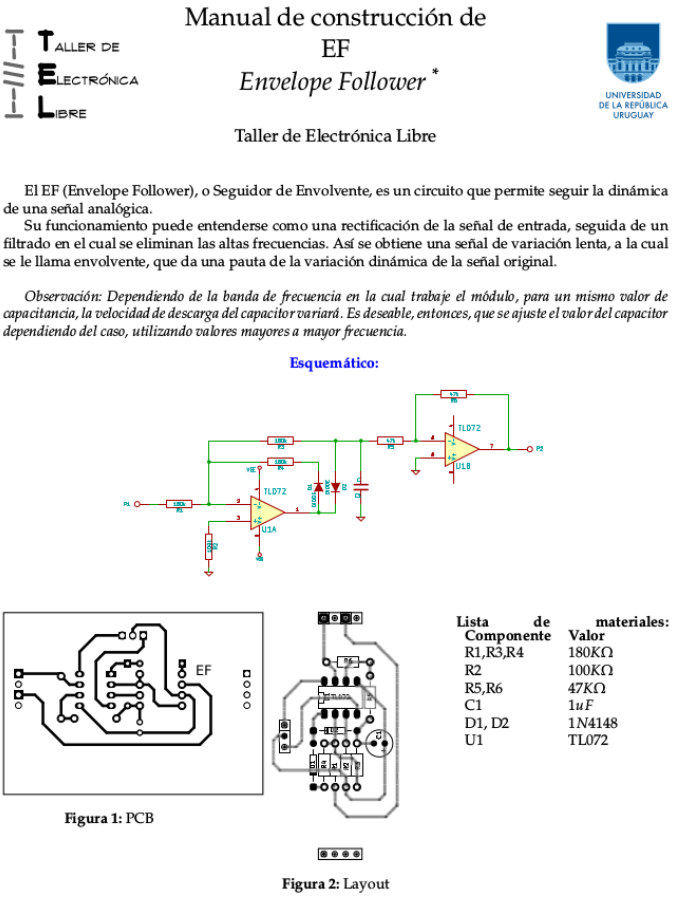
The first half of the course deals with the introduction of basic aspects of electronics, electrical components, signal processing and circuit theory. As a general rule of the course, from the beginning the students are divided in groups of six, in order to enable reasonable task divisions as well as for integration purposes (Giusto, 2014). The teachers calibrate the scope of the topics to be understandable for first grade student. The modules of the Vocoder are then presented, emphasizing the related concepts of electrical engineering. After that, the student assemble the modules on protoboard and evaluate them with a testing and debugging procedure. Laboratory devices such as multimeters, oscilloscopes, signal generators and power supplies are introduced at this stage. All of these activities are done by each group promoting peer learning and the increase of motivation. The first part ends with a written report and a presentation. This is the first time the students face this kinds of evaluations at the University. Corrections and comments are made to improve their skills in this area.

The next stage consists in a lecture about the Vocoder, including general subjects such as: operating principles, historical perspective and different applications. This lecture attempts to bring an integral approach of the project, showing the relation between Engineering and other disciplines.

Finally, the groups build the processing units of the Vocoder. This consists in making the Printed Circuit Board (PCB), mounting and soldering the different components and testing the modules. Once the building process is explained, the students receive a chart (see Figure 3) with the necessary information summarized. It consists in a brief description, circuit schematic, layout, footprint and bill of material.

The evaluation process is done taking into account several inputs collected all along the course:

1. Written reports. This reports show the team involvement in the course and serve as a practice of writing technical reports.
2. Oral presentations. Each group choose a specific topic related to the Vocoder and make an oral presentation to teachers and classmates.
3. Class observation. Group work, equal participation and solidarity between team members are evaluated by the teachers.
4. Co-evaluation. Each student has to evaluate the others group members in punctuality, complying with stipulated deadlines, quality of work, proposing ideas and compliance with group agreements. Then, each student receives the average result of his evaluation. This tool is very helpful to prevent an unfair distribution of tasks and responsibilities inside the student teams. This coevaluation is inspired in (Alonso, 2001; Míguez & Loureiro, 2012).



Manual de construcción de
EF
Envelope Follower *

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El EF (Envelope Follower), o Seguidor de Envolvente, es un circuito que permite seguir la dinámica de una señal analógica.
Su funcionamiento puede entenderse como una rectificación de la señal de entrada, seguida de un filtrado en el cual se eliminan las altas frecuencias. Así se obtiene una señal de variación lenta, a la cual se le llama envolvente, que da una pauta de la variación dinámica de la señal original.

Observación: Dependiendo de la banda de frecuencia en la cual trabaje el módulo, para un mismo valor de capacitancia, la velocidad de descarga del capacitor variará. Es deseable, entonces, que se ajuste el valor del capacitor dependiendo del caso, utilizando valores mayores a mayor frecuencia.

Esquemático:

Figura 1: PCB

Figura 2: Layout

Lista de materiales:

Componente	Valor
R1,R3,R4	180KΩ
R2	100KΩ
R5,R6	47KΩ
C1	1uF
D1, D2	1N4148
U1	TL072

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Figure 3.Chart of the Envelope Follower given to the students.

4 Results

At the end of the semester the Vocoder was assembled, tested (Figure 3) and used in a music live performance at the Tallerine final fair (Figure 4). Input instrument is an electric guitar which is modulated by the singing voice[5].

The course was evaluated by the students through a final survey. The results of the final survey shows that the main goals of the course were achieved. In brief:

- 90,5% of the students answered affirmatively to the question "Did you participate with enthusiasm?"
- 81% of the students answered affirmatively to the question "Did you find the methodology appropriate?"
- 71,4% of the students answered affirmatively to the question "Did the Course improve your initial perception of the methods and contents of the program?" .

The survey was completed by 21 students at the end of the semester and presents comparable results to the others projects involved in Tallerine course.

All the supplies generated in this course are available as an open educational resource with a creative commons license. This includes the modules schematics, layouts, course slides and charts. The material is available at the TEL webpage (http://iie.fing.edu.uy/tel).

Figure 4.Vocoder assembled and tested.

Figure 5. Vocoder at live performance.

5 Conclusions and future work

Active Learning and hands-on methodologies showed that can be effective to motivate the freshman students and introduce some of the main topics of the EE program. The Vocoder proved to be a good tool to introduce various EE topics. Also, their units and module structure brings the possibility to keep the complexity level bounded.

Electronic musical instruments can be used as an active learning tool. Students experiment with practical electronics meanwhile the theoretical background is presented. This process includes the development of transversal skills like project management, teamwork, and creativity. Working with music and engineering is very motivating and allows the students to find links between them.

[5] This performance is available at: https://www.youtube.com/watch?v=2a7Ey2_1Mlg

A textbook as an educative resource was elaborated collecting the experience generated in all the audio related projects. This book is in review process and its release is planned to the end of this year. It contains audio applications projects with their links to the different EE courses. This book could be useful for EE students of all degrees.

Finally, the GPA and the TEL are generating educative resources for a new course intended to third year students. It is planned for the second semester of this year and to build a Theremin (Moog, 1996) is the proposed project. Students of the third year have already acquired a theoretical background that allows a more in-depth analysis of some of the topics covered by the course. Our expectation is that students work independently and pro-active searching solutions for problems that arising from the project.

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