Innovative Engineering Education in Circuits & Systems

Abstract—**Nowadays, the field of microelectronics has become the drive for the advancement of the times, which promotes new demands on the cultivation of the students in colleges and universities. In order to keep up with the trend of the global engineering educational reform, three important reforms in education have been in progress step by step, including classroom teaching, innovative training and virtual laboratories. At first, for enhancing and integrating the existing courses related to the circuit, so that the students can comprehend the existing knowledge much more effectively, an important and effective curriculum reform has been performed by combining "Circuit Analysis" and "Analog Circuit Foundation" into one course; Then, innovative training has been carried out to cultivate the team skills among the students; Finally, in consideration of the rapid development of the electrical and electronic experiment, the conventional laboratory equipment may not satisfy the demand of every student due to financial constraints, therefore, the construction of virtual simulation experiment center is an efficient way to break this bottleneck. As a result, the atmosphere of academic innovation of the pursuit of truth, advocacy of science, brave exploration, dare to practice have been formed in colleges and universities through the above innovative engineering education reform.**

Index Terms—**Circuit Analysis; Analog Circuit Foundation; Engineering Education; Curriculum Reform**

I. Introduction

In the 21^{st} century, in the tide of the new informatization around the world, the vigorous development of cloud computing, big data, internet of things (IoT), robotics, mobile communications, virtual reality and other fields has made people dazzled and overwhelmed. So far, no discipline has been able to follow the fast growth of the information technology field, it is so colourful and ever-changing. Human beings have entered into the era of information technology represented by the high-tech comprehensive innovation. The development of such a field is extremely rapid and, time to time, unforeseeable. The Moore's law (the number of transistors that can be fit on a computer chip will double every 18 months), the Metcalfe's law (the effect of a telecommunications network is proportional to the square of the number of connected users of the system (n^2)) and the new Moore's law (internet is improved double in bandwidth but the cost is also reduced by half every 9 months) and others have played roles all the time. As some economists have said: "The expansion and penetration of information technology in the whole society is tantamount to the second industrial revolution, even more profound than the impact of the first industrial revolution." Therefore, the modern engineering education faces enormous challenges. For example, the topics regarding the design of integrated analog circuits are very important yet very difficult. Indeed, analog circuits can be found everywhere in modern electronic devices, but, at the same time, their performance is often a bottleneck for practical applications [1]–[7].

On February 18, 2017, the Ministry of Education held a seminar on the development strategy of higher engineering education, and reached a consensus on the construction of the "new engineering". With the flourishing development of the new economy characterized by new technologies, new formats, new industries and new models, it is urgent to cultivate a large number of emerging engineering innovation talents. Compared with the traditional engineering education, "new engineering" talents should be the elites who have basic knowledge, strong professional ability, high comprehensive quality, and international competitiveness. They should be able to adapt to the age of informatization, facilitate interdisciplinary researches and integrate cross-border innovation abilities.

In order to adhere as much as possible to the above inspirations and guidelines, crucial tasks are: to develop the core competencies of students, to nurture the ability to learn and master new knowledge quickly, and to train the students to contribute to cross-disciplinary researches. The changes of the age urge our university to carry out teaching reforms, together with adopting innovative training programs and stimulating the use of virtual laboratories in order to let the students easier verify their idea and progresses [8]–[10]. The following Sections of this paper will elaborate on these key topics.

II. Reform of Classroom Teaching of "Circuit Analysis" and "Analog Circuit Foundation"

In our university and in many universities of several countries, the traditional teaching consists of taking "Circuit Analysis" [11], [12] and "Analog Circuit Foundation" [13], [14] as two separate courses. In our university, the "Circuit Analysis" course takes 64 hours, and is offered in the second semester of the freshman year. The "Analog Circuit Foundation" course also takes 64 hours, and is offered in the first semester of the sophomore year, that is to say, the "Circuit Analysis" is the pre-requisite course of "Analog Circuit Foundation".

The disadvantages of delivering the two courses of "Circuit Analysis" and "Analog Circuit Foundation" in two different semesters lie in the fact that most of the students have become unfamiliar with the key knowledge of "Circuit Analysis" when they start following "Analog Circuit Foundation", and, therefore, they can not integrate the knowledge effectively. This teaching model creates a barrier for students to recognize and apply relevant knowledge. Therefore, two independent courses are not conducive to the integration of the originally

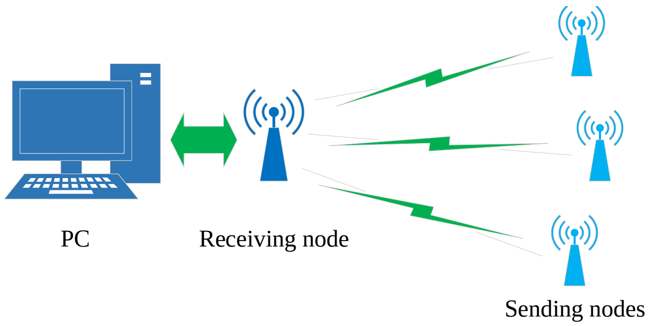

Fig. 1. System network topology.

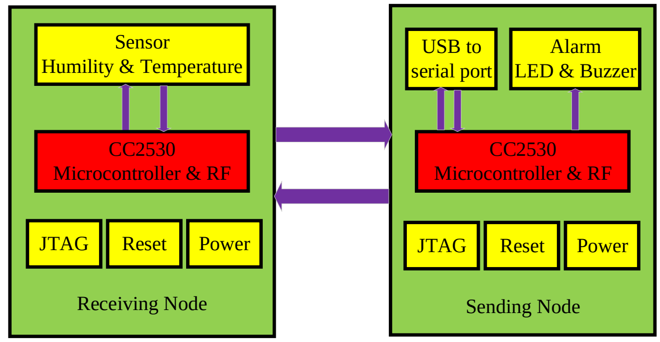

Fig. 2. Block diagram of the sending and receiving nodes.

interlinked knowledge system: the integration of the two courses "Circuit Analysis" and "Analog Circuit Foundation" was necessary and urgent.

Therefore, our university has integrated "Analog Circuit Foundation" and "Circuit Analysis" into one course: "Electronic Circuit Foundation", 82 hours, corresponding to 5 credits, offered in the second semester of freshman. In this way, the key knowledge points of "Circuit Analysis" are reasonably interspersed into the "Analog Circuit Foundation", and has been granted as one of the major course reform projects of our university in 2017.

For example, after learning the two chapters "circuit and circuit model" and "circuit analysis method" in "Circuit Analysis", students are ready to learn the "semiconductor device" and " amplifier circuit by using single transistor" in the "Analog Circuit Foundation". This is because, once the students establish the basic concepts of the circuit models and grasp the superposition theorem, the Thevenin theorem, and the Norton theorem, they can use these theorems to flexibly analyze dual-port network AC small signal equivalent amplification circuits composed of bipolar or field effect transistors.

III. Innovative Training

At present, electronic designers cannot work alone. There are so many demanding requirements and tasks to be fulfilled, and various sources of information required to be accomplished by a single player. We have all learned at home and at school to compete as individuals for awards, attention, and prizes. But the reality is that the teamwork obtains optimal performance. Team skills are quite different from those of competing individuals. They involve cooperation, mutual support, and accountability to the team. An individual alone has a limited perception of the range of possibilities in a situation. A team develops a variety of abilities and so widens the scope of available information, options and ideas. As a result, the quality and effectiveness of individuals is enhanced because a team can help to explore hidden factors, [15]. Therefore, it is crucial for students to learn together in order to acquire the skill of developing new ideas and new methods of working together.

The team skills of students in our university are cultivated by some innovative and comprehensive training programs, introduced over the last few years. For example, students are required to complete the experiment of "The design of wireless temperature and humidity measurement system" through group cooperation. Students must master extracurricular knowledge related to system communication by self-study. In addition, they need to learn how to implement wireless communication and wired communication between the devices, or between a device and a computer. The network topology of the system that the students have to deal with is shown in Fig. 1. In this system, data of temperature and humidity are detected by multiple measurement nodes and transmitted to the receiving node through the ZigBee wireless network protocol. The receiving node sends the data to the PC for display and storage. The implementation of the sending nodes and of the receiving node include both hardware design and software design. At first, the students need to carry out task decomposition and module decomposition, and then design the modules in a cooperative manner.

Fig. 2 shows the block diagram of each sending node and of the receiving node. Each sending node consists of five modules: a micro-controller together with an RF module, the temperature and the humidity sensors, the JTAG debug module, the power-on reset and the power management modules. The receiving node consists of six modules: a micro-controller together with an RF module, a sound and light alarm module, an USB to serial port, the JTAG debug module, the power-on reset and the power management modules. Although the designs of the receiving and the sending nodes are different, the micro-controller and RF module, the JTAG debug module, the power-on reset and the power management block can use the same module. The students are, then, encouraged to design the sending module and the receiving module in a unified manner. Students can use the integrated ZigBee and MCU SOC chip of CC2530 provided by Texas Instruments, the digital temperature and humidity sensors of DHT22 provided by Aosong (Guangzhou) Electronics CO.,Ltd, the power management chip AMS1117-3.3, the USB transfer Serial chip of CH340T and sound-light alarm device buzzer and LED to complete the design. The software environment includes Altium Designer and the embedded program development software (IAR). In the design of the Zigbee wireless network, students are required to master the wireless transmission and

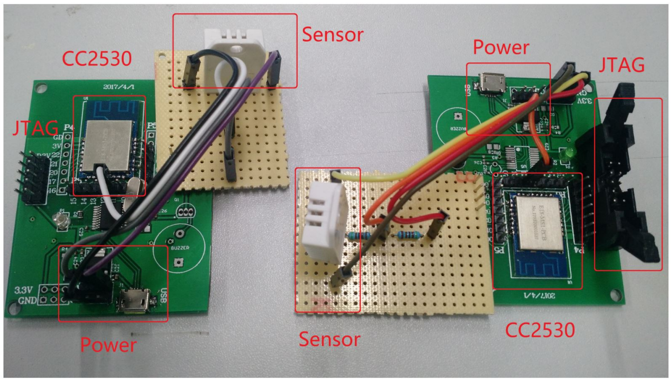

Fig. 3. Implementation of sending nodes.

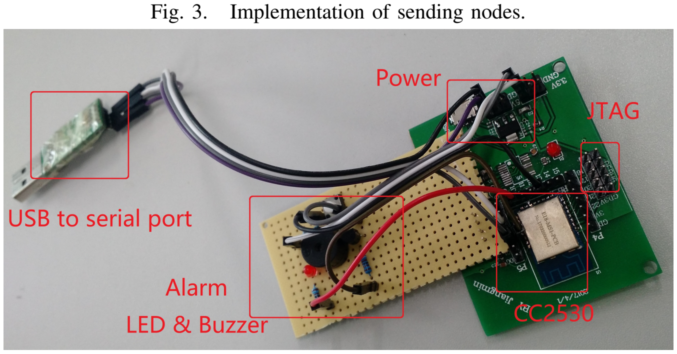

Fig. 4. Implementation of the receiving node.

reception basis, but they are not forced to go deep into the complex protocol layer, leaving the students interested in the communication protocol to experiment on their own. At the same time, students are required to use USB to serial chip CH340T to realize the communication between the receiving node and the PC. Fig. 3 and Fig. 4 depict the sending and the receiving nodes, respectively, implemented during the last semester in our university.

IV. Virtual Laboratories

Our university has recently started using the teaching simulation software ElvisLab (Electronic Virtual Student Lab), available online and free of charge. The tool has been conceived and developed by Prof. Franco Maloberti at the University of Pavia (Italy) few years back. ElvisLab is an online teaching software that does not need to be downloaded and installed on the computer of the user. It only requires the student to reach out the URL *http://ims.unipv.it/~ElvisLab/ElvisLite/ElvisLite.html*. The advantage of ElvisLab over other circuit simulation softwares is that it is more suitable for teaching as it has been conceived to complement a textbook, [11]. The advantage of a simulation software over actual circuits is obviously that the virtual circuit will never explode and that the virtual instruments will never be damaged. From a teaching perspective, this means that the students can confidently and boldly adjust device parameters and input signals. Students can, therefore, verify their ideas and designs much easier.

Once loaded the home page at the above mentioned URL,

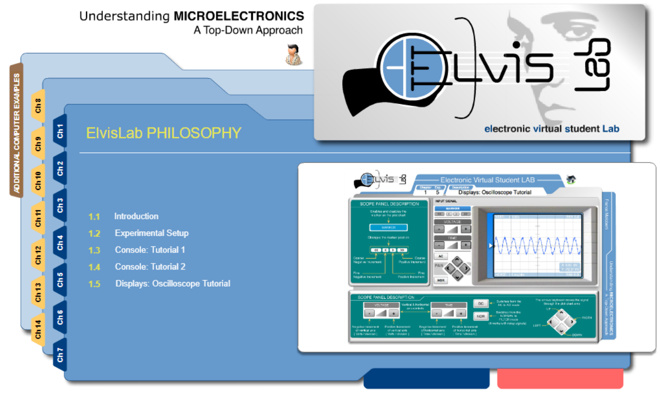

Fig. 5. ElvisLab user interface.

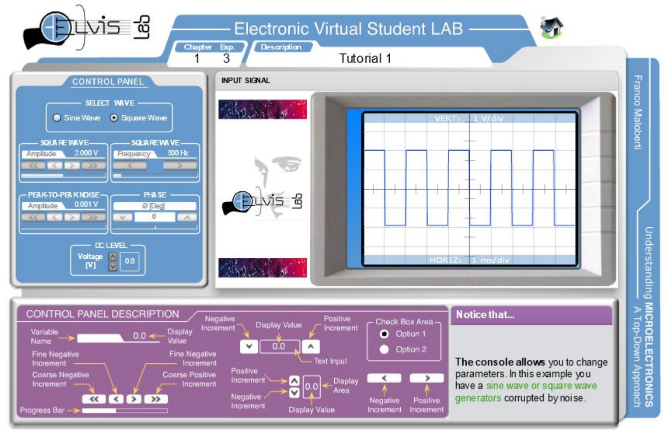

Fig. 6. ElvisLab waveform generators example.

the user can enjoy an introduction and few tutorials before getting started with actual examples and exercises. The interface is depicted in Fig. 5: on the left there is, chapter by chapter, the possibility to browse among different topics, while the right part of the page contains thumbnails corresponding to the left section. As an example, Fig. 6 shows the console related to the Course 1.3, a tutorial on how to change parameters of a sine wave or square wave generators corrupted by noise. The student can change parameters with the two or four buttons and see what happens. In the phase control the user can write a number or change the value using the arrows.

Fig. 7 shows a second type of generators and console (Course 1.4). The student can see a digital signal made by word of 12 bits. The console allows the user to set 16 different words and to see their representation on the display. An additional feature is the possibility to change the amplitude of the logic ones.

Fig. 8 shows the console related to the tutorial about the usage of an oscilloscope (Course 1.5). The student can change both the voltage and the time scale, place or remove markers, switch from DC to AC coupling, apply or not a filter to the displayed waveform, and move the signal through the plot chart area.

As a last example, Fig. 9 shows how the student can figure out which is the behaviour of a real battery, by visualising

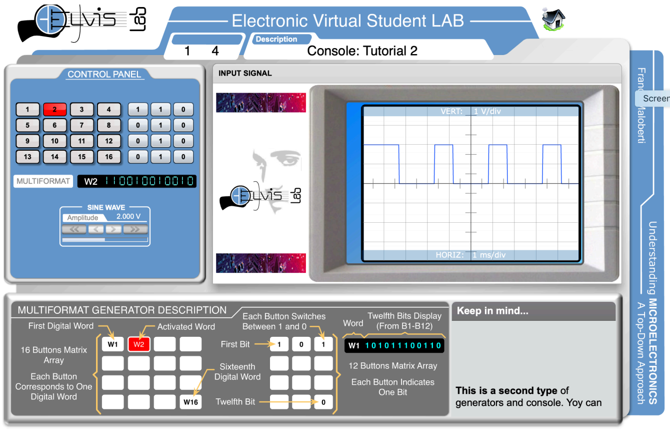

Fig. 7. Digital signal generation.

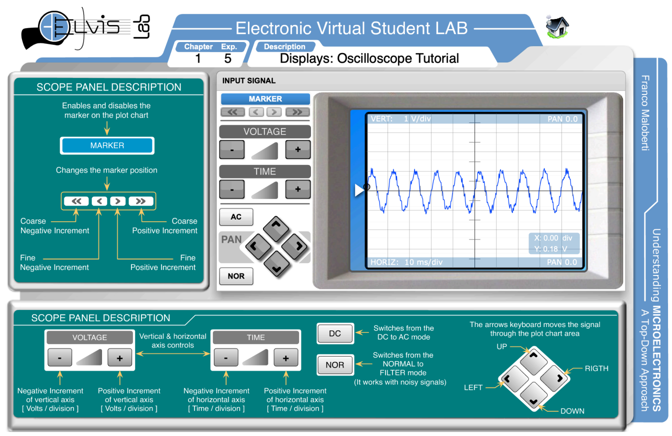

Fig. 8. Learning how an oscilloscope works by using ElvisLab.

on an oscilloscope with three channels the cumulated and individual contributions of random noise and glitches over a given voltage value. The user can change the peak-to-peak amplitude of the random noise, the amplitude and frequency of the glitches, the charge/discharge rate of the battery, and, obviously, its value.

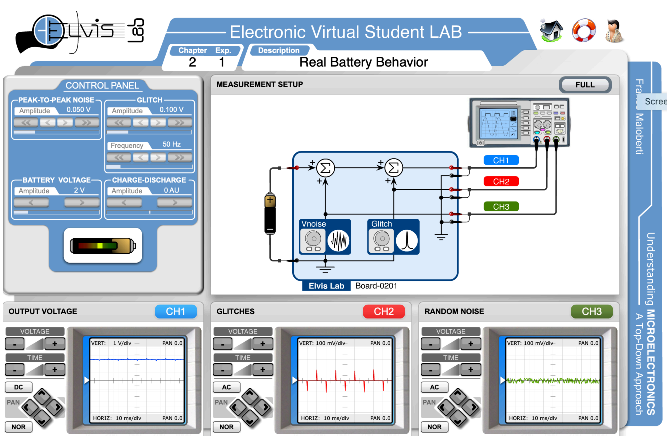

Fig. 9. Experiencing the behaviour of a real battery by using ElvisLab.

V. Conclusion

In order to deepen the reform of engineering education in colleges, our university has launched a special education reform project: the combination of electronic circuit courses. The teaching reform is based on breaking the original segmented teaching mode, realizing the internal and smooth transition of the curriculum knowledge system, promoting the organic integration of curriculum content, cultivating students' innovative thinking and engineering practice ability and decision-making power to solve complex problems and decision-making power to solve complex problems and the ability of independent learning and lifelong learning.

References

[1] M. Božanić and S. Sinha, "A Survey of Current Trends in Masters Programs in Microelectronics," *IEEE Transactions on Education*, vol. 61, no. 2, pp. 151–157, 2018.

[2] P. Prevedello and A. L. Aita, "Virtual Collaborative Environment for Support of Teamwork-based Education of Analog IC Design," in *2018 IEEE International Symposium on Circuits and Systems (ISCAS)*. IEEE, 2018, pp. 1–4.

[3] A. Garbaya, M. Kotti, N. Drira, M. Fakhfakh, E. Tlelo-Cuautle, and P. Siarry, "An RBF-PSO technique for the rapid optimization of (CMOS) analog circuits," in *2018 7th International Conference on Modern Circuits and Systems Technologies (MOCAST)*. IEEE, 2018, pp. 1–4.

[4] M. Turkanović, M. Hölbl, K. Košič, M. Heričko, and A. Kamišalić, "EduCTX: A blockchain-based higher education credit platform," *IEEE Access*, vol. 6, pp. 5112–5127, 2018.

[5] Y. Zhao, X. He, T. Huang, and Q. Han, "Analog circuits for solving a class of variational inequality problems," *Neurocomputing*, vol. 295, pp. 142–152, 2018.

[6] P. C. Kotsampopoulos, V. A. Kleftakis, and N. D. Hatziargyriou, "Laboratory education of modern power systems using PHIL simulation," *IEEE Transactions on Power Systems*, vol. 32, no. 5, pp. 3992–4001, 2017.

[7] P. Shekhar and M. Borrego, "After the Workshop: A Case Study of Post-Workshop Implementation of Active Learning in an Electrical Engineering Course," *IEEE Transactions on Education*, vol. 60, no. 1, pp. 1–7, 2017.

[8] H. Fan, W. Chen, Y. Li, J. Zhang, X. Ye, and Q. Feng, "Promoting engineering education by scientific research," in *2018 IEEE Global Engineering Education Conference (EDUCON)*. IEEE, 2018, pp. 60–64.

[9] J. L. M. Núñez, E. T. Caro, and J. R. H. González, "From Higher Education to Open Education: Challenges in the Transformation of an Online Traditional Course," *IEEE Transactions on Education*, vol. 60, no. 2, pp. 134–142, 2017.

[10] J. Garcia-Zubia, J. Cuadros, S. Romero, U. Hernandez-Jayo, P. Orduña, M. Guenaga, L. Gonzalez-Sabate, and I. Gustavsson, "Empirical analysis of the use of the VISIR remote lab in teaching analog electronics," *IEEE Transactions on Education*, vol. 60, no. 2, pp. 149–156, 2017.

[11] G. Qiu and X. Luo, *Circuit(Fourth edition)*. Higher Eduction Press, 1999.

[12] W. Zhang, Z. Tan, L. Li, and C. Fan, "A Trial of Reform in Teaching of Electric Circuit," *Journal of Electrical and Electronic Education*, pp. 65–67, 2008.

[13] P. E. Allen and D. R. Holberg, *CMOS analog circuit design*. Oxford university press, 1987.

[14] S. Tong and C. Hua, *Analog Electronics*. Beijing: Higher Education Press, 2001.

[15] F. Maloberti, *Understanding microelectronics: a top-down approach*. John Wiley & Sons, 2011.