Received July 1, 2019, accepted July 17, 2019, date of publication July 26, 2019, date of current version August 9, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2931343

Cultivating Intellectual Property Education in the Electronics Engineering Curriculum: A Case Study in Integrated Circuit Design

WEN-QI LIU[1] AND XIAO-PENG YU[2], (Member, IEEE)
[1]School of Law, Zhejiang Gongshang University, Hangzhou 310018, China
[2]Institute of VLSI Design, Zhejiang University, Hangzhou 310027, China

Corresponding author: Wen-Qi Liu (liuwenqi@zjgsu.edu.cn)

This work was supported in part by the NSFC-Zhejiang Joint Fund for the Integration of Industrialization and Informatization under Grant U1709221, and in part by the Innovative Teaching Project, College of Electrical Engineering, Zhejiang University.

ABSTRACT A survey on engineering students' attitude toward intellectual property (IP) education has been conducted in several China's universities, revealing the need for more effective teaching and learning methods. To improve the students' IP awareness and the capability of innovative learning, a small module of patent and circuit design case study has been included in an engineering course, namely, radio-frequency integrated circuit (IC) design, which is offered to senior undergraduate or postgraduate students in a top engineering university in China. Along with the instruction of the RFIC design techniques, the concepts of the IP for the ICs are presented, followed by the analysis of innovative circuits to explore potential legal issues. The feedback of the students suggests that the curriculum is considerably helpful to enrich the knowledge of engineering students in both the design technique and IP awareness.

INDEX TERMS Engineering ethics, integrated circuits, intellectual property, innovation, project learning, learner centered, adult learning.

I. INTRODUCTION

With the tremendous development of technology in recent decades, the engineering education has become an interdisciplinary problem of education, innovation, engineering practice and law, etc., which calls for more innovative teaching and learning methods [1]–[7]. In the area of electrical engineering, e.g., the traditional teaching methods in higher education are currently facing emerging challenges including the effectiveness of learning to meet the desires in the students' engineering career, and the gap between the teaching content in the universities and future engineering practices. The engineering students are expected to be productive individuals of the innovation economy and their training in the university is playing a key role in developing student's capabilities of research and innovation [6]–[10]. The learning of intellectual property (IP) is of course an important part of engineering education. The students need not to be the specialists, but they should have some basic concepts and the ethics in dealing with IP issues and thereby they are capable of carrying out technical innovation without the risks of infringement or being infringed. This leads to interesting questions. What are the key knowledge and skills essential to the engineering students and who are the right instructors of the IP courses [10]–[13]. Due to the diversity of the areas of expertise, it's impossible to provide a unified solution for the students, especially in the area of electrical engineering (EE), which is closely related with other disciplines such as computer science, mechanical engineering, materials science and engineering, and system engineering, etc. It is necessary to cultivate the students' awareness and ethics of IP based on their majorities. As for the instructor, the professors in IP law are undoubtedly the right instructors to build the background of IP laws, but they are not able to forecast the potential legal issues in the students' industrial career due to their lack of knowledge in special engineering areas. In a nutshell, a gap exists between the desires of the students and the available IP education. As a popular solution, the introduction of IP law is arranged at the early stage of the undergraduate program, from which the students acquire general IP knowledge such

The associate editor coordinating the review of this manuscript and approving it for publication was Chin-Feng Lai.

as patent and copyright. After that, they are trained with more detailed applications such as patent searching and writing in subsequent IP courses organized by the colleges. Unfortunately, due to the gap between the content of specialized engineering courses and IP, the students are quite confused about the key features of the innovation of technology even the tools or database of IP management are widely accessible, hence they are not able to effectively perform IP analysis and consequently build up a comprehensive knowledge for their future career in R&D. Some of the recent work has been reported to cultivate the IP awareness of engineering student, such as self-learning support system and special IP modules [4], [5]. In [4], the learning of IP is implemented as logical structures while special IP modules have been proposed for engineering students in [5]. However, due to the lack of innovative learning experience, the gap between general and specialized IP education still exist. To solve this dilemma, a new concept of embedding IP module for engineering curriculum is proposed. This paper is organized as follows. Section II provides the theoretical background of the innovative course, followed by the survey of state-of-the-art in Section III. The proposed course is detailed in Section IV and the evaluation of this course is addressed in Section V.

II. THEORETICAL UNDERPINNING AND PEDAGOGICAL BASIS

The engineers are the leaders of technological development, and they should be trained with innovative ideas and entrepreneurial spirit. With the enormous emphasis on ''innovation'', engineering education in the university needs to incorporate the spirit of innovation and entrepreneurship into existing curriculum, which is preferably design-oriented courses emphasizing on multi-disciplinary concepts [3], [8]. These courses should therefore be designed considering the pedagogical basis as well as engineering practice.

In the Internet era, students have increasingly lost interest in traditional lectures since these contents can be easily found online. The instructors are expected to deliver the knowledge in more interesting and engaging ways. In the engineering education, especially electronics engineering and computer science, it's a big challenge since the technology is developing faster than ever. Pedagogical beliefs are generally categorized as either being teacher-centered or student-centered [14]. Education systems around the world have increasingly sought to move from conventional teacher-centered towards learner-centered education (LCE) [15]. Within limited classroom time, instructors have to employ all possible means to make full use of every minute of teaching so that students can engage in learning [16]. Review and analysis of related studies suggest that learner-centered teaching approaches stimulate student interest, curiosity, and intrinsic motivation to learn, thus improving the student achievements and satisfaction [17]. LCE has been an important aspect of engineering education since the goal of education has shifted from memorizing facts to building competences, working effectively in teams, promoting creativity, etc, which are critical to the career development of engineering students [18]. The implementation of learner centered engineering education, however, is not so straightforward. The curriculum and the way of instruction should be carefully designed accordingly to promote active and inquiry-based learning, hence helping develop positive attitudes towards flipped learning in general [19].

In many studies reported in literatures, flipped classroom, project learning, puzzle-based quizzes, peer instruction, etc [20]–[25], have been used to improve the learning effectiveness. However, the problem is that what is the key desire of these learners. In the technology-intensive engineering, the content of the lectures will be outdated soon, hence the key desire of the students is to cultivate the capability in learning skills such as analysis, synthesis, and development of certain designs. In their future career, the students are still able to study as life-long learning (or adult learning), which is common in these areas [26], [27]. The knowledge and innovation are increasingly important to them. In this regard, the designs involving IP rights are good examples of how innovative designs are developed. For example, patent files have been used as the learning materials in many engineering courses so that the students know how to protect their own ideas and legitimately use existing IP rules besides the way of innovation [2]. Indeed, the instructors need to have pedagogical content knowledge of IP rules if they are to incorporate them into their learning programs [12]. Offering the list of related patents to the students is not enough since the students are unable to gain the historical perspective on how designs have developed in this particular technical field. The instructor should address the existing literature, and teach the students how to perform innovative improvement based on the state-of-the-art. This requires more detail work on novelty retrieval as well as evolution of certain technology [2].

III. SURVERY OF IP EDUCATION

The state-of-art of IP education in China has been investigated by conducting a questionnaire survey, which has been widely used in empirical study. The questionnaire is ''primarily a collection of questions that fit the research themes and its objectives, and the answers to which will provide the necessary data for testing hypothesis/propositions formulated for the study'' [28]. The survey was conducted in China's five famous universities. It focuses mainly on three aspects, namely, the students' general knowledge and awareness concerning IP protection for industrial products or methods, as well as the educational resource of IP knowledge and students' attitude toward the offered resources by the college. In total, there are 249 engineering students, who are senior undergraduate and graduate students, aged between 19 and 24, participated in the survey. As shown in Appendix, this questionnaire form includes 17 items, for each of which the students are required to choose the best answer from the given choices.

The questions 1 to 4 examine the students' knowledge of the creation of IP rights, which focuses on how an exclusive

IP right can be produced and recognized by an IP legal system. A vast majority of students give correct answers in the questions 2 (83%) and 3 (84%), but a small number of students get correct answers in the questions 1 (30%) and 4 (16%), suggesting that the students know much about the patents and trademarks but less about the copyright. The questions 5 to 8 are designed to evaluate whether students can identify IP infringement and non-infringement. As for questions 5 and 7, 78% and 80% of the students show correct options respectively. However, only 55% and 52% of the students choose right answers in questions 6 and 8, indicating that the participants have not developed a sufficient and correct understanding of legal or illegal industrial designs. In particular, nearly half of the participants lack the knowledge of reverse engineering. Fig. 1 shows the percentage of undergraduate/postgraduate students who give correct answers in questions 1 to 8, which suggesting that the postgraduate students generally know more about IP knowledge than undergraduate students, especially in questions 5 to 8 which are more likely to occur in the industrial field. It also implies that the postgraduate students might benefit from their industry experience.

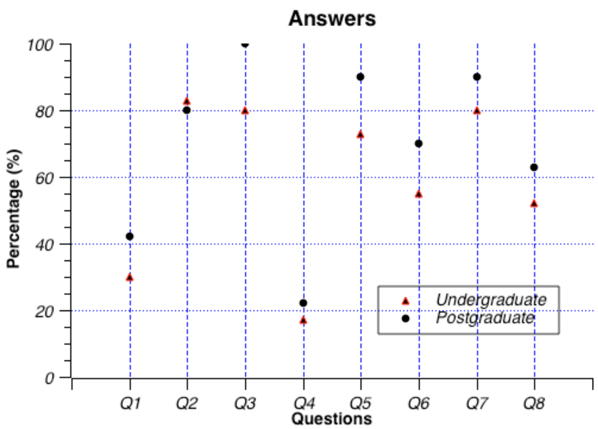


FIGURE 1. The percentage of correct answers of question 1 to 8.

The questions 9, 10 and 11 are designed to find the students' intention and basic capability of circumventing IP infringement before launching the innovative work. An overwhelming majority of students (86%) have the intention of novelty retrieval, but only 41% of the students have the capability of carrying it out independently. Moreover, only 36% of the students often care about the information with respect to IP protection. The results show that the participants have not sufficient awareness or basic capability of circumventing IP infringement in pre-innovation work. Furthermore, as shown in Fig. 2, the responses to the questions 10 and 11 given by the postgraduate students and undergraduate students exhibit significant difference. Although the answers to the question 9 demonstrate that the postgraduate students' intend to make novelty retrieval is roughly the same as the one of the undergraduate students, the answers to the question 10 show that the majority of the postgraduate students have capability to

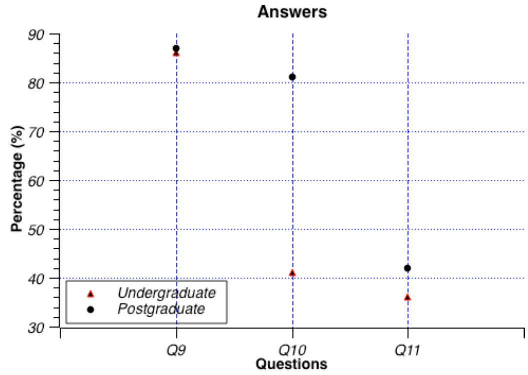


FIGURE 2. The percentage of positive answers of question 9 to 11.

make it independently but the majority of the undergraduate students have not. In addition, the responses to the question 11 also suggest that the postgraduate students have more interests in IP issues than the undergraduate students.

The questions 12 to 17 are to investigate the educational resource for developing the IP awareness of the students. 35% of the participants express that their universities are providing IP courses particularly for engineering students and 45% of them state that their universities offer general IP courses for all college students. When the participants are asked about their favorite teaching mode of IP courses, approximately half of them prefer the way of face-to-face teaching, while the rest prefer online teaching. Moreover, 67% of the participants have recognized the necessity and benefits of offering particular IP curriculums for engineering students. This means that a plenty of students have clear intention of receiving IP education whatever the online or face-to-face teaching. When being asked about their desired content of IP courses, the majority of the students show their interests to learn the knowledge of novelty retrieval, non-infringement design and protecting intellectual creation, suggesting that the students are interested in how to achieve and protect innovation rather than how to implement innovation in business. This is also helpful to design the content of curriculums. In addition, it merits noting that only 40% of the participants believe that college students applied for patents based on their innovative intention, while more impetus originate from getting good scores in the study. It seems that some students' original intention of making innovation are quite different from the objective of the IP system.

Further factor analysis can be performed to gain deeper understanding of the questionnaire, about the relationship between the IP education and IP awareness as well as innovation based on the theory of factor analysis. From the question 12, there are 29 postgraduate (Group A) and 59 undergraduate students (Group B) received specialized IP courses. As shown in Fig. 3, these students exhibit significant advantages on the awareness of IP protection, inclination and capability of innovation. For instance, in the question 2 regarding the origination of IP rights, the correct rate of

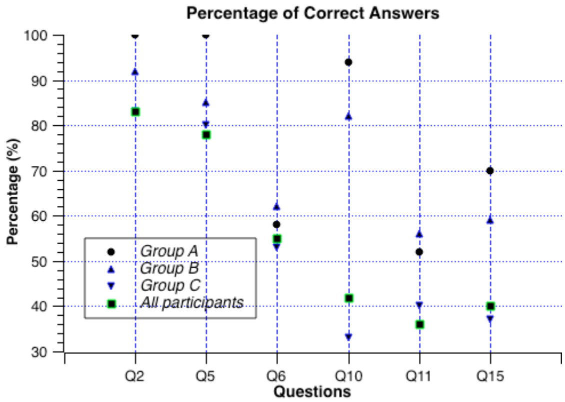


FIGURE 3. The percentage of positive answers of question 2, 5, 6, 10, 11 and 15.

the students of Group A and Group B are 100% and 85% respectively, which are much higher than the rate 78% of the total participants. Similarly, in the questions 5, 6, 10, 11 and15, the students received IP education previously show much stronger motivation and capability in innovation as well as the awareness of IP protection. Also, in the questionnaire, there are 38 students (Group C) who attend general IP education (the question 14) but not the specialized IP course (the question 12). The rate of positive answers in the aforementioned questions 2, 5, 6,10,11 and 15 are 83%, 80%, 53%, 33%, 40% and 37%. It can be concluded that general IP education is somehow insufficiently to build a solid background for the engineering students working in the area of advanced technology.

The quantitatively survey demonstrates the necessity of innovative curriculum. Moreover, qualitative studies are conducted to finalize detail strategies in designing the proposed course. Several students in the small groups have been invited to attend a volunteering interview to learn what are their key desires if IP education is incorporated in current courses. These desires mainly about the new way of learning that can bridge the gap between the learning of IP and specialized engineering courses as well as the opportunity to perform innovative engineering practice. Even there is plenty of resource provided by the universities, they are not able to effectively learn IP related knowledge without guide of experienced instructors, which means a learner-centered experience emphasizing engineering practice considering the innovative design perspective is strongly desired.

IV. DESIGN OF THE PROPOSED COURSE

Based on this survey and the interview, it is possible to design the course to enhance IP education in engineering practices. The key problem is that the students have difficulties in conducting engineering designs based on general IP rules. Actually, in some research-oriented industry, the goal of IP protection is somehow in accordance with the way of innovation. Taking the circuit design as an example, the major content of the course is to address the design techniques, which is, to some extent, the base for novelty retrieval and subsequent innovations. Understanding of design techniques means the students will be able to distinguish innovative industrial solutions from conventional designs. This might shed some light on how to integrate IP education into the courses regarding design techniques.

A. WHY IC DESIGN

Semiconductor is celebrated as the heart of all modern-day electronics and the integrated circuit (IC) industry has been a key momentum of nowadays information technology and IC design has been a very hot topic in engineering education [29], [30]. Complex design specifications related with multidisciplinary knowledge are the key challenges in teaching. In addition, obtaining patents and licensing patents in ICs, and fighting against infringing competitors are the crucial consideration of the engineering practices [31]. It is therefore of a great interest to study the general IP rules and methods of novelty retrieval in learning of design techniques in the current curriculum. There are various types of IP for ICs, such as patent, copyright as well as layout. ''Unlike conventional industrial produce, there is a need for a Sui Generis Protection for IC Layout since the ICs these works are exceptionally susceptible to easy, rapid, and competitive misappropriation by technological means, which often require only a tiny proportion of the developers' cost'' [32]. Of course, the laws regarding protecting patents and layouts of ICs are the major base for IC design protecting. For example, the reverse engineering is a controversial design strategy in the IC design field, but it can be a legal strategy when certain conditions are met. [32]. The novelty of circuits usually can be protected by patent, while the standards to determine the patentability include novelty, inventive step and industrial applicability. Similarly, an IC layout refers to the predetermined design of three-dimensional, layered pattern of elements and interconnections of an IC, making the chip unique in fabrications.

B. COURSE OVERVIEW

Based on this concept, a module of IP education is designed to embedded into the course ''Radio-Frequency Integrated Circuit (RFIC) Design'' in Zhejiang University. The course has been offered to undergraduate and postgraduate students separately once in an academic year. When designing the course, we were mindful of our particular audience. Considering the very focused industrial applications, the course is only offered to senior undergraduate and post-graduate students with a solid engineering and technical background, most of whom are full-time students. The class size is less than 30 students to ensure necessary facilities and supervision on the project. The topics of the course include the fundamental theories of radio-frequency system and the key building blocks in the form of ICs. The instructor of the course is required to present the detail topologies of the circuits. The proposed course aims to develop both students' design techniques as well as IP awareness that may benefit them in industrial practices. The key features and novelty of the topologies or architectures of the circuit and system are addressed in this course, hence to further strengthen the IP awareness. In order to improve students' design techniques, the target design and Electronic Design Automation (EDA) tools are identical to the ones in industry. As an engineering course, the teaching method is to some extent similar to the conventional courses. Considering the industrial application, the major focus is the project learning, which offers students opportunities of team working, novelty retrieval and conducting industrial designs.

C. PEDAGOGICAL MODEL

The pedagogical models in this course includes the student-centered learning environment, problem solving, project learning and case study, as illustrated in Fig. 4.

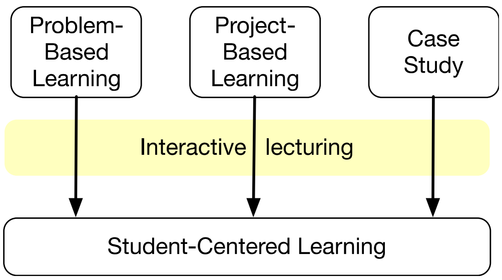


FIGURE 4. The pedagogical model in the proposed course.

The course is designed with student-centered learning environments, where students are active and independent and the teacher plays a guiding or coaching role. Even the circuits addressed in this course are more like engineering practices, knowledge is viewed as tool instead of a goal. Students are actively involved rather than passive receivers of information.

This student-centered learning environment is created by using different instructional methods, including interactive lecturing, problem-based learning, project-based learning and case-based learning.

The interactive lecturing has been used as the main way of instruction in design techniques. The teacher is trying to turn the lecture into an interactive form by encouraging discussions. Students are stimulated to be engaged in the learning, and problem-based learning, project-based learning and case-based learning are used to enhance the learning experiences of the fundamental theory, circuit design and patents respectively. The course includes several key building blocks after the instruction of fundamental theories. During the learning of theoretical work, the students are required to work collaboratively in small groups on theoretical problems under the guidance of the instructor, who guides the discussion rather than merely providing information to students. The problem forms the starting point of the learning process. Followed by the discussion of the problem based on common knowledge and their own experiences and self-study, the students are able to gain a deep understanding of the fundamental theories.

The difference between the project-based learning methods and problem-based learning is that the vehicle is a project rather than a problem. Students need to accomplish a well-defined end product (building blocks or system in the course) and to solve the problem when achieving the project. Teachers will give expert guidance and suggestions for improvements.

Likewise, the case study is be introduced to explore the way of innovation. In this course, several key building blocks, mainly in the form of patent are introduced. How the circuit has been designed and improved, and eventually patented will be addressed in a very detailed form. This provide the opportunity to learn the way of innovation and improve the awareness of IP.

D. SYLLABUS AND LECTURE ORGANIZATION

The outline of the course includes several key building blocks in the radio frequency system considering the needs of IP education. The design of RFIC has been a very popular topic in recent years and many open courses can be found online, such as MIT, UCLA, UC Berkeley. These courses are excellent examples of engineering education, which include the instruction of state-of-the-art and project learning concepts [33], [34]. For the EE142 in UC Berkeley, e.g., it includes 16 weeks of lectures (several lecture hours for labs) covering all the basic concept of radio frequency ICs, including the amplifier, mixer, and oscillator, etc. The course is featured with several key labs to exhibit the design methodology in the area [35]. In the proposed work, besides the circuits and system addressed in these courses, several IP topics highlighted are included as shown in Table I. The basic theoretical work offered to the undergraduate and postgraduate students are roughly the same. Several advanced topics, which are marked with 'p' in Table 1, are offered to the postgraduate students only. The one term course uses following materials of the textbooks and reading materials from the professors in MIT, UCLA, Stanford University, and TU Dresden. Besides the learning of fundamental theory and circuit topology, the students are encouraged to investigate the innovative work reported recently in academic papers from IEEE trans. Microwave Theory and Techniques, Journal of Solid-State Circuits, Circuits and Systems, IEEE International Solid-State Circuits Conference, RFIC symposium, Custom ICs Conference as well as the patents in China and US. Part of these reading materials are listed in Appendix, which will be updated annually.

The main object of the course is the design technique of RFICs along with related IP knowledge. Actually, the implementation of the IC is a comprehensive subject which includes several legal issues. Taking the design flow as an example, since the circuit implementation heavily depends on the layouts, it is essential to clearly address the way to design a real chip from the very first idea to a real product. Certainly, IP protection is one of the key considerations in this procedure. Fig. 4 shows a typical design flow of a RF oscillator from the circuit's schematic and layout to fabrication. The schematic is the skeleton outline of the design in the forms of circuit topologies, which should be consequently implemented with certain layouts using a certain technology.

TABLE 1. Course outline.

Course Module	Technique content	IP issues and examples
Communication system	Different communication standards	Patents in communication CDMA as an example
Transceivers	Architectures of receiver and Transmitter	The example of a patent transmitter
Passive component	The on-chip inductor, capacitor for ICs	patterned ground shield spiral inductor
Low noise amplifier	Different topologies	Noise cancelling LNA
Mixer	Passive and active mixers	Design case
Oscillator	LC oscillators for communications Low power design p Low noise design [p]	Design case
Power amplifier	Power amplifiers for communications, Class A B C E F amplifiers Linearization techniques [p]	Design case
EDA tools	Cadence and ADS Advance EDA techniques [p]	PSS, HB (Periodic Steady-State and Harmonic Balance Simulation)
Design Project I	Receiver design CMOS receiver review Sub-GHz Receiver simulation, measurement of chip [p]	Design case DC offset cancelling Super regeneration receiver design case [p]
Design Project II	Transmitter design CMOS transmitter review EM Co-simulation, Grounding [p]	Design case LO pulling Grounding techniques [p]
Oral Presentation	Presentation of projects	Analysis of novelty

[p] postgraduate only

Though the major innovation lies in the topology (schematic), optimized layouts are quite important to achieve desired performances followed by the fabrication of the layout that provides the information of physical implementation in a foundry. Through this course, the students are expected to be able to answer the following problems. How can a schematic be transformed into a layout? What is the key consideration in layout design? What makes the layout unique? How will the parasitic in the layout impact the performance of the circuits? How to design layout with the best performances? How should the measurement be performed after fabrication? These topics are addressed together with the instruction of circuit design, the lecture hour of these examples is not strictly defined.

E. EXAMPLES OF IP MODULES

In the course, IP analysis is addressed together with the instruction of circuit design. It merits noting that all the materials involving IP analysis are prepared through full discussion with IP experts, including the professor in IP laws, IP lawyer and patent agency. This work gains strong support from Zhejiang INPRO Law Firm, which is a famous law firm specialized in IP business. The instruction given by IP experts mainly focuses on IP issues related to the circumventing design and reverse engineering. As for the different designs given in the lectures, they also give their suggestions on strategies of seeking for IP protection at different levels. Thus, professional opinions in IP analysis are well integrated into the teaching of design techniques. These topics include the major concerns in the general survey of IP awareness, which mainly about the lack of capability to connect the general concepts of IP to the design of circuits. The teaching of these IP topics is embedded in the instruction of circuit design (roughly half an hour for one lecture, and literature review after the lectures). The teaching method is slightly different since the teaching contents involve the novelty retrieval for patents and layouts of the IC. Some examples of IP analysis in this course are detailed as follows [36], [37]. The first example pertains to the patentability of the architecture of RF transceiver. As shown in Fig. 5.a, in the RF transceiver,

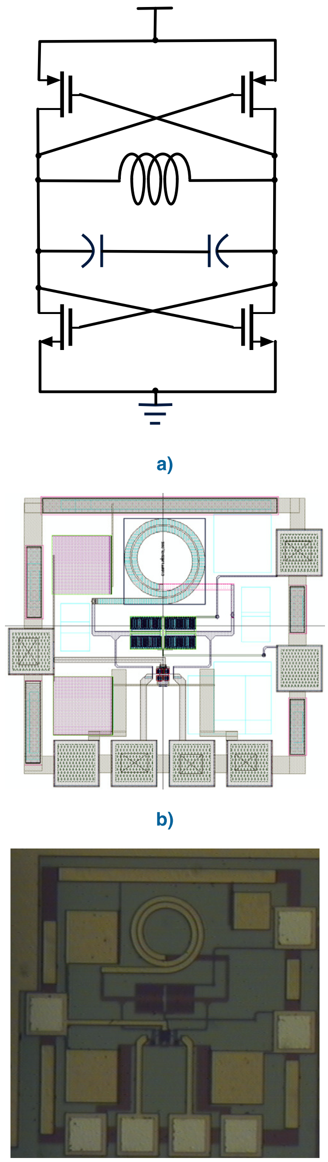


FIGURE 5. The oscillator a) schematic b) layout c) chip.

the local oscillator (LO) pulling has been a major issue in designing the transceiver with a fully integrated power amplifier (PA). In the system where the LO works at the same frequency as the carrier, it is likely that the output of the LO will be seriously deteriorated by the strong output signal of the PA, which will consequently impact the performance of the transceiver. This issue has been widely discussed in the textbooks. For example, in the book ''RF microelectronics'', several possible solutions are addressed [36]. A simple and popular solution is to use a local oscillator working at two times of the carrier frequency. The second harmonic of the PA still interferes the carrier frequency but the amplitude is reduced by tens of dB. In this course, the students are encouraged to solve this issue by proposing new architectures. The instructor presents the patent invented by former students engaged in this course as shown in Fig. 5.b. It can be easily observed that the novelty of the proposed patent is merely the increase of division ratio of the LO, which is working at three times of the carrier frequency. This is quite impressive to the students that a simple change of operating frequency is patentable while the two architectures are so similar. The instructor then addresses the key difference between circuits in the two architectures as shown in Fig. 5.c. The change of division ratios inevitably leads to different circuits schematic and layouts. In the circuit design, the 3rd harmonics will be much weaker than the 2nd one, therefore, the inferences of LO pulling can be reduced significantly. This is the key reason why the architecture has been successfully granted with Chinese patent. This design, despites its simplicity, is a typical example to demonstrate the merits of design techniques and IP awareness. The students will therefore be able to acquire a deep understanding of the key design issues in the RF transceiver as well as the analysis of the novelty in the system architecture.

Besides the examples of system design, innovations are addressed in terms of the circuits designs. In the lecture of the low noise amplifier, e.g., the design techniques regarding low noise, high frequency, high gain and low power are addressed. As a popular technique in low noise design, the noise cancelling topology is presented as illustrated in Fig. 6, where the input signal is amplified by two separate paths with the same gain but in the opposite phases. At the output stage, the two signals are then configured as a differential output, hence to sum up the desired signal while cancelling the noise [36], [37]. In this course, the key features of the noise cancelling path are analyzed to enlighten the innovation, while a circuit invented by a postgraduate student in the EE department of Zhejiang University is addressed as shown in Fig. 6.b. In addition, the design is simulated with EDA tools to demonstrate the advantages over conventional noise cancelling techniques. Hence, the way of innovation as well as design techniques are fully demonstrated in this lecture.

Certainly, as an engineering course, the principle aim of the course is to teach design techniques. Therefore, the proposed course provides students with opportunities of engaging in designing practice rather than merely listening to the lecture (passive learning). After several lectures focusing on the instruction of design techniques and innovation, all the students are required to undertake one design project related to the design of circuits or system. There is no strict requirement time for the project, but it usually takes more than 20 hours for each project. They are assigned into several groups with maximum three members and they meet the instructor on a weekly basis after independently completing circuit simulations. The groups have to present their work to fellow students and instructors. The activities are presented in a competitive format and the winning group gets entered into a chip fabrication subject to justification of the novelty in the design. A final technical report is submitted by each design team, which includes schematic and layouts of the finished design and the final peer evaluation is directly incorporated into the students' marks.

In summary, the proposed course is to some extent similar to the conventional courses/programs in the technical content and the way of instruction, which have been widely reported in world famous universities. However, the key innovation in this project is to incorporate the knowledge of IP rules and methods of novelty retrieval in the design. The teaching samples come both from the latest designs in the industry, and from the patents and layouts held or designed by ZJU students. In such a way, the students may achieve a proper understanding of legally conducting innovative.

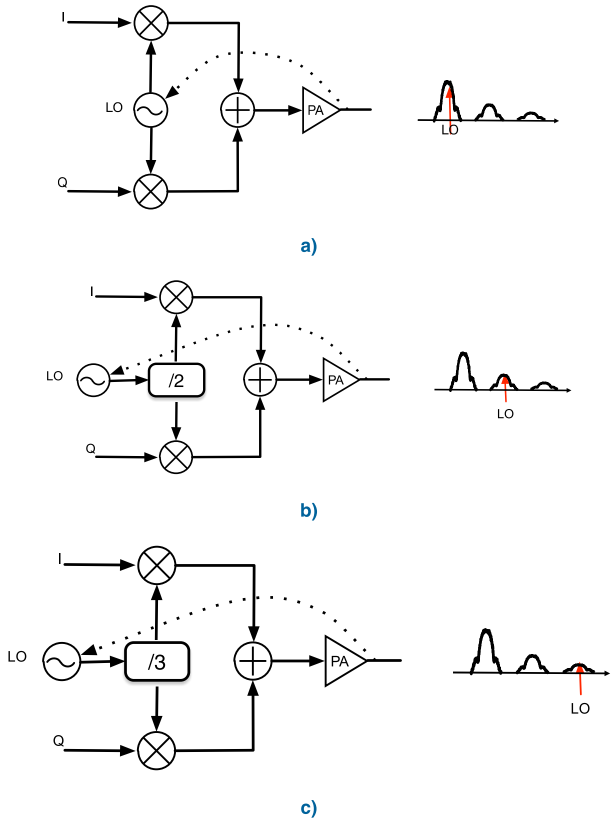


FIGURE 6. The problem of LO pulling a) X1 frequency b) X2 frequency c) X3 frequency [36].

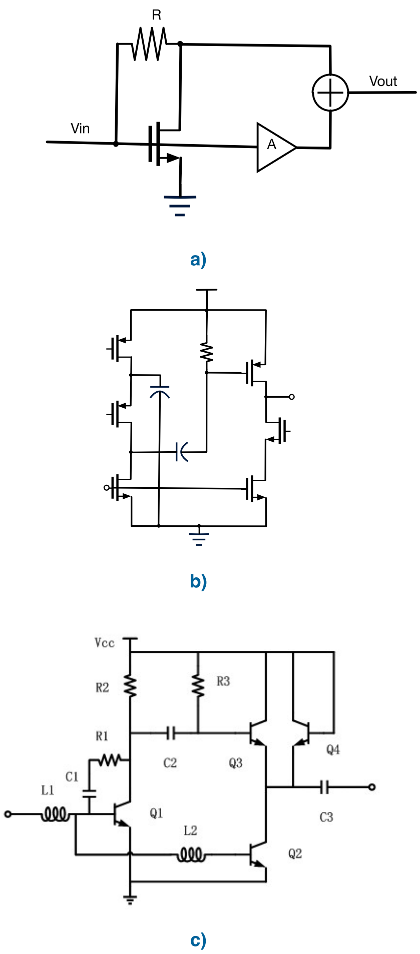


FIGURE 7. Noise cancelling Technique a) architecture b) topology c) proposed design [37].

V. RESULTS AND DISCUSSION

The courses have been offered to undergraduate and postgraduate students in the College of EE, Zhejiang University since 2015. In total, there are 187 students engaged in this course. The course and teaching shall be evaluated to analyze the effect of the new teaching design.

Teaching evaluation is widely implemented in higher education, because it provides instructors with the opportunity to consider teaching processes and assess teaching effectiveness. The system of teaching evaluation shall be established on the principle of validity and reliability.

Student evaluation is generally used in the teaching evolution. Its popularity may be attributed to the following reasons: (1) Students are the main body of learning, and under the learner-centered principle, instructors merely co-learners and contributors to students' academic and social development [38]; therefore, their perception of teaching is more immediate than other evaluators; (2) it is convenient, feasible, and inexpensive for administration and decision making; (3) it gives an impression of objectivity compared with any other alternative alone [39].

Despite these, the disadvantages of are obvious as well. Some factors outside the control of instructors are not considered in this procedure, such as class size [40], course content [41], gender of instructor [42], diversity of student characters, students' motivation towards teaching evaluation, and so on. Sometimes they tend to be more positive to the teachers and give a higher grade.

Considering the disadvantages of students' evaluation, researchers propose the use of supplemental methods to evaluate teaching. Some studies find that both instructors and evaluators have similar perceptions of the peer review system [43]. In order to achieve a more realistic picture of teacher performance, the 360 degree feedback system and other similar evaluation methods have been developed to use multiple data sources for teaching evaluation, including student ratings, peer ratings, self-evaluation, videos, student interviews, alumni ratings, employer ratings, administrator ratings, teaching scholarship, teaching awards, learning outcome measures, teaching portfolios, and so on [44]–[46].

In this study, multiple data sources are used for the effectiveness of the course. It is performed by a mixed-method using triangulation of quantitative data to confirm our qualitative assessment approach [47]–[49] as shown in Fig. 8. The evaluation indicators include interviews face to face (qualitative method and some quantitative results), the academic outcomes, feedback of the students as well as experts' rating (quantitative method), which are carried out from both the qualitative and quantitative aspects.

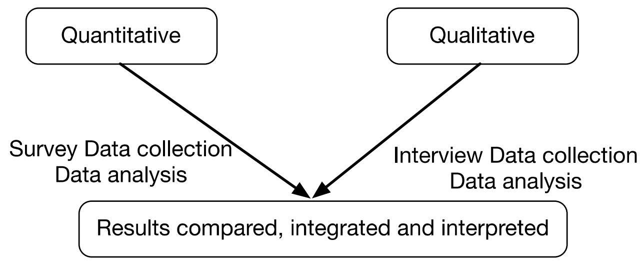


FIGURE 8. Triangulation mixed methods used in this evaluation.

The first observation herein is the outcome of the courses. The students' scores of the examination, the student academic outcomes, including academic papers, patents, layout, as well as novel designs are taken into consideration. In the practice of the courses since 2015, it is observed that all the group of students (100%) can finish their projects and submit the final reports. However, no undergraduate student can produce real innovative circuit (from the instructor's viewpoint) with physical verification due to their limitation in academic capability, and they are not able to publish academic paper but to propose some simple ideas of innovative circuits that may not be realized in practice. Excitingly, in the course offered to postgraduate students, two academic papers and one patent (in three years), which are rarely achieved in conventional courses, have been published or granted. Meanwhile, the students have recognized that the valuable industrial innovation should be based on due respect for laws, which is the best way to protect the legal rights and avoid disputes or loss.

Many students concern about how to develop a new design that is substantially different from the existing designs and does not infringe IP rights. In order to understand these issues, quite a few students show a strong motivation of learning how to make novelty retrieval and lawful reverse engineering, as well as other relevant technological and legal knowledge. In comparison with the traditional work, this new teaching method is helpful in cultivating engineering professionals with innovative capability and IP awareness.

The other aspect of this mixed method evaluation is the teaching rating. Like many universities in China, in Zhejiang University, a compensative evaluation system, which includes the feedback of students and the review of external experts, has been established at the university level for many years [50]–[52]. At the end of each semester, the rating will be given by the students anonymously. As shown in Table 2 and 3, students' questionnaire and rating have been conducted after each semester. The rating forms for graduate students and undergraduate students are different, which are designed by the teaching administrative apartment of Zhejiang University. The indicators for graduate students' teaching rating are divided into three levels. The first level is the final index of evaluating the course suitability. Then, four level indicators are set: teaching attitude, teaching content, teaching method, and teaching effectiveness. Each of them has a 25 percent weighting in rating. Each indicator at the second level is sub-divided into several indicators at the third level, as shown in Table 2. The indicators for undergraduate students' teaching rating is simpler, which only have ten indicators at the second level as shown in Table 3 and each of them has a 10 percent weighting in rating.

The results of the evaluations are released by the university after the lectures. The overall ratings of the undergraduate and postgraduate students of the latest five years (2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018 and 2018-2019), are summarized in Fig. 9. The gradually increased average scores suggest that the students are generally satisfied with the course, even after the modification of syllabus.

TABLE 2. Teaching evaluation form: Part I postgraduate.

Item	Detail content	Rate (highest to lowest)
1.Teaching attitude	1.1. Lectures prepared well 1.2 Timely feedback 1.3 On time	
2.Teaching content	2.1 Clearly presented 2.2 Easy to follow 2.3 With well-prepared lab	
3.Teaching method	3.1 Suitable textbook 3.2 Effective teaching 3.3 Interactive and feedback 3.4 After course learning	5 4 3 2 1
4.Teaching effectiveness	4.1 Innovation skill 4.2 Analysis and problem solving	

TABLE 3. Teaching evaluation form: Part II undergraduate.

Detail content	Rate (highest to lowest)
1. The teacher knows my progress very well	
2. The lectures are well prepared	
3. The teacher is willing to answer my questions	
4. Inaction in the course is suitable	
5. The lecture benefits me much	
6. My overall evaluation on the lecturer	5 4 3 2 1
7. Teaching content is well organized and abundant	
8. Rationally teaching is suitable	
9. Teaching materials are resourceful	
10. Lecturer is abided by professional ethics	

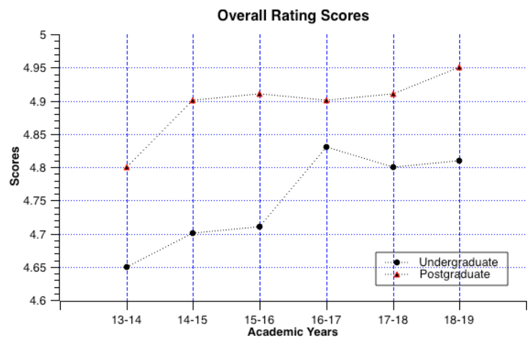


FIGURE 9. Overall rating scores of the undergraduate and postgraduate courses.

In the postgraduate courses, e.g., the average scores of the item 3 and 4 of the years from 2013 to 2018 are shown in Fig. 9. The results are quite encouraging since it shows an increasing level of satisfaction on the effectiveness of teaching and learning as indicated in item 3 and 4, which are summarized in Fig. 10.

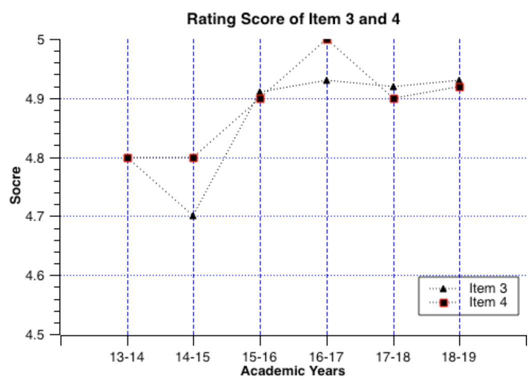


FIGURE 10. Rating scores of items 3 and 4 of the postgraduate course.

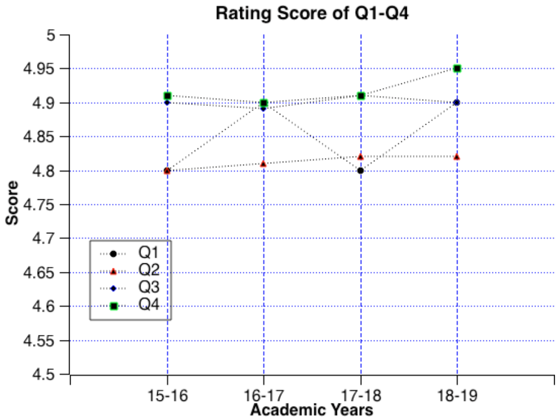


FIGURE 11. Rating scores of Q1-Q4.

Considering that the students' feedback is somehow a limited indicator as aforementioned, the external auditors, retired professors with more than 30 years teaching experience as the expert auditors are invited to supervise and evaluate the quality of teaching. These experts can establish credibility because of their outstanding achievements. They randomly attend the courses 2-3 times every semester without notice in advance. They mainly consider the following indicators: achievement of teaching objectives, content and techniques of teaching, organization, presentation, and final results of teaching. After scoring each item, the experts give a total score and comments, which are used to evaluate the effectiveness of teaching and learning as shown in Fig. 11. In this study, the experts give very positive assessment on the course and the instructor and several questions related with this research are listed as follows.

Q1: the objective of teaching is well achieved and students' self-directive capabilities are developed in teaching;

Q2: teaching is well organized, and exploration and innovation of teaching techniques are fully reflected;

Q3: the instructor has an ability of constructing teaching and new teaching design;

Q4: the overall teaching results of the students' engagement in leaning

The comments related with the IP education are only available after 2015 as shown in Fig. 11. The experts' comments are quite positive suggesting the effectiveness of teaching.

Apart from the aforementioned quantitative methods, the qualitative method, namely interviews face to face, is introduced to offer students opportunities of detailing their perception and observation. This approach aims to get more information about students' perception of this course. In previous study [35], the course of RFIC design flow has been offered to engineering students; however, it is hard to know how much students benefit from the course after their graduation. Therefore, interview face to face after the end of the course, can help the instructor learn more about the effectiveness of the course.

In the study, the students are randomly interviewed face to face every year since the total number of students are quite limited (below 30 students). For the students attended the initial survey of IP awareness, they are all invited to give their feedback on the changes of the course. In the interview, the students are able to address the detail of their rating. Several questions are summarized as follows.

Q1: Why the way of teaching is effective?

Q2: What is the key difference of this IP module?

Q3: Do you have any comments for further improvement?

Q4: This course makes me be interested in this research area

Q5: This course is helpful for my research work

Q6: The percentage of completing project in the final grade is appropriate, and extra lab time is worthy

Q7: The project improves my learning capability and innovative skills

Q8: The project improves my research capability

Q9: Have you improved the awareness of IP

Q10: Can you perform IP investigation independently now

These comments are used as qualitative and quantitative data to support the rating of the students as well as the experts. Since the number of interviewed students are relatively small, the quantitative data is summarized in the percentage of total student in the five years and the answers are summarized in Fig. 12. Quantitatively, the students have positive comments on these questions in the interview. Both the surveys and interviews clearly indicate the students' enthusiasm for learning design techniques as well as their satisfaction with the course. Over 90% students express their satisfaction because the course is well balanced between the theoretical delivery and design practice, and 95% students agree with the effectiveness of improving IP awareness.

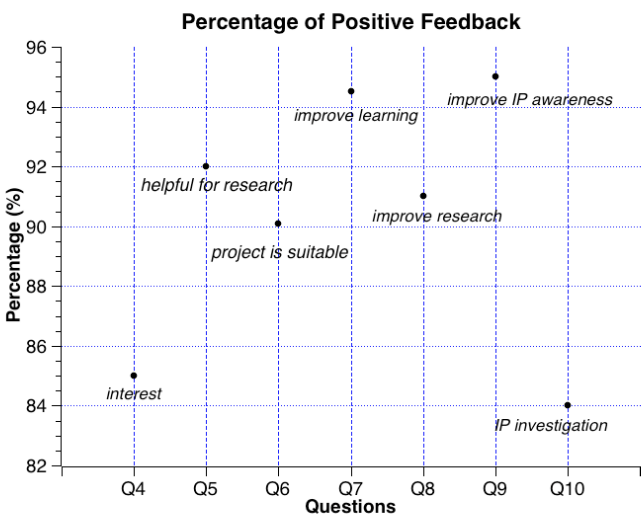


FIGURE 12. Percentage of positive feedback of Q4-Q10.

The students' feedback can be summarized qualitatively as follows. First, although the task of the project is quite time-consuming, they regarded this course as a wonderful opportunity in learning design techniques and IP knowledge. Students have gradually recognized that the crucial considerations in IC design include not only technical problems but also legal issues. Through the course, the students improved their capabilities of independent analyzing, designing and circumventing IP infringement have been substantially developed. Second, the students have been encouraged by their own (or fellow students') academic results. Their new circuit designs, patents and academic papers demonstrate their potential capability in industrial innovation. Many students expressed their interests in participating future industrial projects if they have such opportunities. Third, the students showed great interests in this course also because they can acquire IP knowledge specialized in the engineering design area. As aforesaid discussion, mere a professor in engineering or law seems to be insufficient to serve the objective of this course. Therefore, in some lectures, some legal professionals are invited to give opinions on innovative designs from the view of IP protection, which is helpful to improve the students' understanding of relevant IP issues.

In summary, the concept of embedding IP education into the design-oriented course is a way to actively improve the innovation capability of engineering students. It requires some additional work to prepare the materials. In this study, the instructor who is a senior researcher in this area, successfully incorporates the content of conducting technological innovation in a legal way in teaching. The positive and effective results are observed from the complex evaluation system.

Certainly, the proposed course does have limitations. As an enrichment course, it is impossible to have too many lectures for discussing fundamental theories. In this regard, the course is only suitable to the students who already of a solid background in the area of circuit design and it should be only offered to the senior undergraduate students or postgraduate students in this very specific area. This suggesting that the proposed course cannot be widely adopted in other engineering course if the area is not heavily project-based with a lot of IP issues. Moreover, as indicated from the results of survey, the level of satisfaction of undergraduate students is lower than that of the postgraduate students since they face more difficulties in the projects assigned, suggesting that the course more suitable for senior students capable of independent researching. Also, due to the limited lecture hours up to 40 (with about 32 hours project), the content instructed should be very focused, which makes the target of the course very limited within a certain area. Nevertheless, from a global view, this course is suitable for all kinds of research-oriented universities where the innovation of high technology is emphasized.

VI. CONCLUSION

With the rapid progress of technological innovation, it is essential to include the cutting-edge technology into modern engineering education. Along with design techniques, it is necessary to divert considerable attention to improve students' IP awareness. In this study, IP education has been partially embedded into the instruction of design techniques. Through the survey of IP awareness of college engineering students, it is possible to identify the most important issues and thereby design a suitable teaching method to satisfy academic needs of senior undergraduate students and postgraduate students. By offering a new curriculum in a project-learning course in Zhejiang University, it's observed that IP knowledge can be conveyed with the instruction of design techniques. The instruction of laws actually plays an important role on the education relating to innovation. The educational practice since 2015 demonstrates the effectiveness of this curriculum in the terms of academic results as well as the level of the students' satisfaction. It has been offered to senior undergraduate and postgraduate students, and it is highly appreciated by the students. Compared with undergraduate students, the postgraduate students are more active in learning of the IP issues and demonstrate higher potential in creative work. This kind of practice can be further extended to other courses, which are highly industrial based.

RESEARCH ETHICS

This study was carried out under the innovative project of ''New Engineering Education Program'' of the school of electrical engineering. All the innovative circuits addressed in the courses are from the groups' work, which are supported by the National Natural Science Foundation under grant No. U1709221. All the participants provide written informed consent. The survey of IP awareness is conducted anonymously and the interview is voluntarily based. The use of the data is approved by the college, while the sharing of innovative teaching method is encouraged.

APPENDIX

A. QUESTIONNAIRE

1 When does the copyright establish?

(A) Once the work has been finished, copyright automatically establishes.

(B) Copyright establishes on condition that right holder applies for copyright and this application is approved by the eligible governmental agency.

(C) Copyright establishes on condition that the work has been registered in the eligible governmental agency.

2 When does the patent establish?

(A) Once a new method or product has been invented, patent automatically establishes.

(B) Patent establishes on condition that the right holder applies for a patent and this application is approved by the eligible governmental agency.

(C) Patent establishes on condition that the work has been registered in the eligible governmental agency.

3 When does the trademark establish?

(A) Once the design of a trade sign has been finished, the exclusive right over a trademark automatically establishes.

(B) Once a trademark has been used in trade, the exclusive right over a trademark automatically establishes.

(C) The exclusive right over a trademark establishes on condition that right holder applies for trademark and this application is approved by the eligible governmental agency.

4 When does the copyright over computer program establish?

(A) Once the computer program has been developed, the copyright over computer program automatically establishes.

(B) Copyright over computer program establishes on condition that right holder applies for copyright and this application is approved by the eligible governmental agency.

(C) Copyright over computer program establishes on condition that the computer program has been registered in the eligible governmental agency.

5 Whether does the behavior of downloading pirated computer software and installing it on a local computer establish infringement?

(A) Yes (B) No (C) Have no idea

6 Whether does the behavior of making an innovative design based on reverse engineering establish infringement?

(A) Yes (B) No (C) Have no idea

7 Whether does the behavior of copying the "Black Cat Sheriff" cartoon image as a three-dimensional shape of a humidifier products without the permission of copyright holder establish infringement?

(A)Yes (B) No (C) Have no idea

8 Whether does the behavior of copying the shape of a bird nest as a three-dimensional shape of a kid toy establish infringement?

(A) Yes (B) No (C) Have no idea

9 Whether do you intend to make novelty retrieval before starting to invent a new technology?

(A) Yes (B) No

10 Do you have capability of independently making novelty retrieval?

(A)Yes (B) No

11 Do you often keep a close eye on information of intellectual property protection or infringement?

(A)Yes (B) No

12 Has your university offered intellectual property courses particularly for your majority?

(A)Yes (B) No

13 If your university opens particular intellectual property curriculums for your engineering students, which mode of teaching do you like?

(A) Online teaching, because of its flexible-time study arrangements

(B) Online teaching, because the examination of online courses is generally easy

(C) Face-to-face teaching, because this mode benefits students to understand the knowledge delivered in the course

(D) Face-to-face teaching, because students have more opportunities to inquire instructors about their interested questions

14 Has your university offered general intellectual property curriculums for students?

(A)Yes (B) No

15 Do you know what is the main impetus for your university students to applying patents?

(A) Innovative intention (B) To obtain good scores in certain subjects

(C) Get bonus points in the appraisal

16 What is your attitude toward offering particular intellectual property curriculums for your engineering students?

(A) Like such courses because the knowledge may benefit students

(B) Be indifferent to it.

17 If your university offers particular intellectual property curriculums for your engineering students, what would you like to learn?

(A) How to make novelty retrieval

(B) How to design a product or method and circumvent infringement

(C) How to protect intellectual creation

(D) How to increase the value of intellectual creation by using intellectual property system

(E) How do advanced international technological companies make intellectual property strategies

B. TEXT BOOKS

B. Razavi, RF Microelectronics, 2nd, Prentice-Hall, 2011.

T. H. Lee, The Design of CMOS Radio-Frequency Integrated Circuits, Cambridge University Press, 2nd, 2003

F. Ellinger, Radio Frequency Integrated Circuits and Technologies, 2nd Edition, Springer, 2009.

C. SELECTED READING MATERIALS

W. Chen, S. Member, G. Liu, B. Zdravko, A. M. Niknejad, and A. Abstract, "A Highly Linear Broadband CMOS LNA Employing Noise and Distortion Cancellation," *IEEE Journal of Solid-State Circuits*, 43(5), pp. 1164–1176, 2008.

S. Joo, S., T. Y. Choi, B. Jung, "A 2.4-GHz Resistive Feedback LNA in 0.13-um CMOS", *IEEE Journal of Solid-State Circuits*, 44(11), pp. 3019-3029, 2009.

S. Shekhar, S. Member, J. S. Walling, S. Aniruddhan, D. J. Allstot, and A. A. Tito, "CMOS VCO and LNA Using Tuned-Input Tuned-Output Circuits," *IEEE Journal of Solid-State Circuits*, 43(5), pp. 1177–1186, 2008.

A. Mazzanti, P. Andreani, and S. Member, "Class-C Harmonic CMOS VCOs, With a General Result on Phase Noise," *IEEE Journal of Solid-State Circuits*, 43(12), pp. 2716–2729, 2008.

W. Laflere, M. S. J. Steyaert, and J. Craninckx, "A Polar Modulator Using Self-Oscillating Amplifiers and an Injection-Locked Upconversion Mixer," *IEEE Journal of Solid-State Circuits*, 43(2), pp. 460–467, 2008.

S. C. Blaakmeer, E. A. M. Klumperink, S. Member, D. M. W. Leenaerts, and B. Nauta, "The B LIXER, a Wideband Balun-LNA-I / Q-Mixer Topology," *IEEE Journal of Solid-State Circuits*, 43(12), pp. 2706–2715,

D. Chowdhury, S. Member, C. D. Hull, O. B. Degani, Y. Wang, and A. M. Niknejad, "A Fully Integrated Dual-Mode Highly Linear 2.4 GHz CMOS Power Amplifier for 4G WiMax Applications," *IEEE Journal of Solid-State Circuits*, 44(12), pp. 3393–3402, 2009.

B. G. Perumana, S. Member, R. Mukhopadhyay, S. Chakraborty, S. Member, C. Lee, and J. Laskar, "A Low-Power Fully Monolithic Subthreshold CMOS Receiver with Integrated LO Generation for 2.4 GHz Wireless PAN Applications," *IEEE Journal of Solid-State Circuit*, 43(10), pp. 2229–2238, 2008.

Z. Ru, N. A. Moseley, E. A. M. Klumperink, S. Member, and B. Nauta, "Digitally Enhanced Software-Defined Radio Receiver Robust to Out-of-Band Interference," *IEEE Journal of Solid-State Circuit*, 44(12), pp. 3359–3375, 2009.

M. Demirkan and R. R. Spencer, "A Pulse-Based Ultra-Wideband Transmitter in 90-nm CMOS for WPANs," *IEEE Journal of Solid-State Circuit*, 43(12), pp. 2820–2828, 2008.

S. Kaeriyama, Y. Amamiya, H. Noguchi, Z. Yamazaki, et. Al., "A 40 Gb/s Multi-Data-Rate CMOS Transmitter and Receiver Chipset With SFI-5 Interface for Optical Transmission Systems," *IEEE Journal of Solid-State Circuit*, 44(12), pp. 3568–3579, 2009.

D. DESIGN TOOLS AND DOCUMENTS

Cadence IC, with Spectre RF design manual Keysight Advanced Design System, with Design manual

E. DESIGN KITS

Grace Semiconductor Manufacturing Corporation

F. PATENTS EXAMPLES

X. P. Yu, C. Z. Nan, M. N. Jia, A noise cancelling technique and circuits for low noise amplifier, Chinese Patent, No. 201210071642.1, 2015 (granted).

X. P. Yu, C. H. Hu, N. Tan, A transceiver with LO pulling suppression circuits, Chinese Patent, No. 201410104005.9, 2016 (granted).

REFERENCES

[1] C. J. Finelli, S. R. Daly, and K. M. Richardson, "Bridging the research-to-practice gap: Designing an institutional change plan using local evidence," *J. Eng. Educ.*, vol. 103, no. 2, pp. 331–361, Apr. 2014.

[2] C. A. Garris, Jr., "The United States patent system: An essential role in engineering design education," *J. Eng. Educ.*, vol. 90, no. 2, pp. 239–246, Apr. 2001.

[3] B. K. Jesiek and L. H. Jamieson, "The expansive (Dis)integration of electrical engineering education," *IEEE Access*, pp. 4561–4573, 2017.

[4] T. Akakura and T. Ishii, "Development and evaluation of a self-learning support system for patent act suited to the current state of intellectual property education in engineering departments," in *Proc. IEEE Int. Conf. Teach., Assessment, Learn. Eng. (TALE)*, Dec. 2016, pp. 122–127.

[5] V. Raës, P.-L. P. Rau, X. Ji, and C. Chen, "Promoting intellectual property education for engineers in China," *Int. J. Technol. Learn., Innov. Develop.*, vol. 8, no. 1, pp. 57–69, 2016.

[6] L. Liebenberg and E. H. Mathews, "Integrating innovation skills in an introductory engineering design-build course," *Int. J. Technol. Des. Educ.*, vol. 22, no. 1, pp. 93–113, Feb. 2012.

[7] E. A. Fishman, "The role of intellectual property management education in a technology management curriculum," *J. Technol. Transf.*, vol. 35, no. 4, pp. 432–444, Aug. 2001.

[8] T. Ozkul, "Using patents as a tool for reinforcing constructivist learning environment in engineering education," *Int. J. Educ. Inf. Technol.*, vol. 2, no. 2, pp. 157–166, 2008.

[9] J. Roach and R. Soetendorp, "Intellectual property in the engineering syllabus: A model for integrating key but not core concepts across the disciplines," Eng. Subject Centre, The UK Centre Legal Educ., Bournemouth Univ., Poole, U.K., Tech. Rep., 2008.

[10] H. B. Rockman, *Intellectual Property Law for Engineers and Scientists*. Hoboken, NJ, USA: Wiley, 2004.

[11] A. Silva, E. Henriques, and A. Carvalho, "Creativity enhancement in a product development course through entrepreneurship learning and intellectual property awareness," *Eur. J. Eng. Educ.*, vol. 34, no. 1, pp. 63–75, 2009.

[12] L. Starkey, S. Corbett, A. Bondy, and S. Davidson, "Intellectual property: What do teachers and students know," *Int. J. Technol. Des. Educ.*, vol. 20, no. 3, pp. 333–344, Aug. 2010.

[13] K. L. Wood, D. Jensen, J. Bezdek, and K. N. Otto, "Reverse engineering and redesign: Courses to incrementally and systematically teach design," *J. Eng. Educ.*, vol. 90, no. 3, pp. 363–374, Jul. 2001.

[14] A. du Plessis, "Student-teachers'pedagogical beliefs: Learner-centred or teacher-centred when using ICT in the science classroom," *J. Baltic Sci. Educ.*, vol. 15, no. 2, pp. 1–19, Mar. 2016.

[15] S. Brinkmann, "Teachers' beliefs and educational reform in India: From 'learner-centred' to 'learning-centred' education," *Comparative Educ.*, vol. 55, no. 1, pp. 9–29, 2019.

[16] Q. Wen, "The production-oriented approach to teaching university students english in China," *Lang. Teach.*, vol. 51, no. 4, pp. 526–540, Oct. 2018.

[17] P. Dębiec, "Effective learner-centered approach for teaching an introductory digital systems course," *IEEE Trans. Educ.*, vol. 61, no. 1, pp. 38–45, Feb. 2018.

[18] R. Motschnig, M. Sedlmair, S. Schröder, and T. Möller, "A team-approach to putting learner-centered principles to practice in a large course on human-computer interaction," in *Proc. Frontiers Educ. Conf. (FIE)*, Erie, PA, USA, Oct. 2016, pp. 1–9.

[19] A. Bakla, "Learner-generated materials in a flipped pronunciation class: A sequential explanatory mixed-methods study," *Comput. Educ.*, vol. 125, pp. 14–38, Oct. 2018.

[20] H. Lattimer, "Translating theory into practice: Making meaning of learner centered education frameworks for classroom-based practitioners," *Int. J. Educ. Develop.*, vol. 45, pp. 65–76, Nov. 2015.

[21] S. Aslan and C. M. Reigeluth, "Investigating 'the coolest school in america': How technology is used in a learner-centered school," *Educ. Technol. Res. Develop.*, vol. 64, no. 6, pp. 1107–1133, Dec. 2016.

[22] S. Yehia and C. Gunn, "Enriching the learning experience for civil engineering students through learner-centered teaching," *J. Prof. Issues Eng. Educ. Pract.*, vol. 144, no. 4, Jul. 2018, Art. no. 05018013.

[23] Y.-T. Lin, "Impacts of a flipped classroom with a smart learning diagnosis system on students' learning performance, perception, and problem solving ability in a software engineering course," *Comput. Hum. Behav.*, vol. 95, pp. 187–196, Jun. 2018.

[24] S. Luo and M. Kalman, "Using summary videos in online classes for nursing students: A mixed methods study," *Nurse Educ. Today*, vol. 71, pp. 211–219, Dec. 2018.

[25] D. Lee, Y. Huh, C.-Y. Lin, and C. M. Reigeluth, "Technology functions for personalized learning in learner-centered schools," *Educ. Technol. Res. Develop.*, vol. 66, no. 5, pp. 1269–1302, Oct. 2018.

[26] Y. Owusu-Agyeman and M. Fourie-Malherbe, "Learning conceptions and priorities of adult engineering students in higher education," *Cogent Educ.*, vol. 5, no. 1, Jan. 2018, Art. no. 1528700.

[27] J. E. Lord, "Adapting lifelong learning to adults: Principles and practice," *Proc. IEEE*, vol. 66, no. 8, pp. 911–917, Aug. 1978.

[28] C. R. Kothari, *Research Methodology: Methods and Techniques*. Chennai, India: New Age International, 2004.

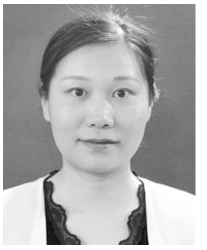
[29] V. Barzdenas, G. Grazulevicius, and A. Vasjanov, "A new approach for the successful team building in vls idesign projects," *Int. J. Eng. Educ.*, vol. 33, no. 5, pp. 1618–1626, 2017.

[30] L. Albasha and O. Hammi, "Introducing industrial design flow of an RFIC chip to a graduate course: Building the ecosystem and bridging the gap between industry and academia," *IET Circuits, Devices Syst.*, vol. 11, no. 4, pp. 299–303, Jul. 2017.

[31] Y.-J. Han, "Analysis of essential patent portfolios via bibliometric mapping: An illustration of leading firms in the 4G era," *Technol. Anal. Strategic Manage.*, vol. 27, no. 7, pp. 809–839, 2015.

[32] K. S. Yeo, K. T. Ng, Z. H. Kong, and T. B. Y. Dang, *Intellectual Property for Integrated Circuits*. Plantation, FL, USA: J. Ross Publishing, 2010.

[33] Y. Xu and W. Liu, "A project-based learning approach: A case study in China," *Asia Pacific Educ. Rev.*, vol. 11, no. 3, pp. 363–370, Sep. 2010.
[34] D. E. Kanter, "Doing the project and learning the content: Designing project-based science curricula for meaningful understanding," *Sci. Educ.*, vol. 94, no. 3, pp. 525–551, May 2010.
[35] *Integrated Circuits for Communications, EECS 142*. Accessed: Jun. 30, 2019. [Online]. Available: http://rfic.eecs.berkeley.edu/142/
[36] B. Razavi, *RF Microelectronics*, 2nd ed. Upper Saddle River, NJ, USA: Prentice-Hall, 2011.
[37] F. Bruccoleri, E. A. M. Klumperink, and B. Nauta, "Wide-band CMOS low-noise amplifier exploiting thermal noise canceling," *IEEE J. Solid-State Circuits*, vol. 39, no. 2, pp. 275–282, Feb. 2004.
[38] Y. Xu, "Developing a comprehensive teaching evaluation system for foundation courses with enhanced validity and reliability," *Educ. Technol. Res. Develop.*, vol. 60, no. 5, pp. 821–837, Oct. 2012.
[39] S. M. Cahn, *Saints and Scamps: Ethics in Academia*. Totowa, NJ, USA: Rowman Littlefield, 1986.
[40] G. S. Hanna, D. P. Hoyt, and J. D. Aubrecht, "Identify and adjusting for biases in student evaluations of instruction: Implication for validity," *Educ. Psychol. Meas.*, vol. 43, no. 4, pp. 1175–1185, 1983.
[41] W. E. Cashin, "Students do rate different academic fields differently," *New Directions Teach. Learn.*, pp. 113–132, Sep. 1990.
[42] K. Anderson and E. D. Miller, "Gender and student evaluations of teaching," *Political Sci. Politics*, vol. 30, no. 2, pp. 216–219, Jun. 1997.
[43] L. B. Hansen, M. McCollum, S. M. Paulsen, S. M. Paulsen, T. Cyr, C. L. Jarvis, G. Tate, and R. J. Altiere, "Evaluation of an evidence-based peer teaching assessment program," *Amer. J. Pharmaceutical Educ.*, vol. 71, no. 3, pp. 45–68, Sep. 2007.
[44] K. M. Dyers, "The power of 360-degree feedback," *Educ. Leadership*, vol. 58, no. 2, pp. 35–38, 2001.
[45] S. Ortega, L. Baptiste, and A. Beauchemin, "A model for 360 teacher evaluation in the context of the CSME," in *Proc. Biennial Cross-campus Conf. Educ.*, Apr. 2007, pp. 581–586.
[46] R. A. Berk, "Survey of 12 strategies to measure teaching effectiveness," *Int. J. Teach. Learn. Higher Educ.*, vol. 17, no. 1, pp. 48–62, 2005.
[47] M. J. Peeters and V. A. Vaidya, "A mixed-methods analysis in assessing students' professional development by applying an assessment for learning approach," *Amer. J. Pharmaceutical Educ.*, vol. 80, no. 5, p. 77, Jun. 2016.
[48] J. W. Creswell and V. L. P. Clark, *Designing and Conducting Mixed Methods Research*. Thousand Oaks, CA, USA: Sage, 2017.
[49] J. Branney and J. Priego-Hernández, "A mixed methods evaluation of team-based learning for applied pathophysiology in undergraduate nursing education," *Nurse Educ. Today*, vol. 61, pp. 127–133, Feb. 2018.
[50] Y. W. Dong, L. Hongling, and X. Lin, "Research on the method for comprehensive evaluation on the colleges and universities course," in *Proc. 7th Int. Conf. Comput. Sci. Educ. (ICCSE)*, Jul. 2012, pp. 1838–1841.
[51] Y. Li, "Quality assurance in chinese higher education," in *The Rise of Quality Assurance in Asian Higher Education*. Sawston, U.K.: Chandos Publishing, 2017, pp. 15–33.



WEN-QI LIU received the L.L.B. degree from the Department of International Law, Zhejiang University, China, in 1999, the L.L.M. degree from the School of Law, National University of Singapore, Singapore, in 2003, and the Ph.D. degree in law from the School of Law, Erasmus University Rotterdam, The Netherlands, in 2014. She is currently an Associate Professor with the School of Law, Zhejiang Gongshang University. Her research interests include intellectual property law and international business law.

XIAO-PENG YU (M'06) received the B.Eng. degree from the Department of Optical Engineering, Zhejiang University, Hangzhou, China, in 1998, and the Ph.D. degree from the School of Electrical and Electronic Engineering, Nanyang Technological University (NTU), Singapore, in 2006.

He was an Engineer with the MOTOROLA Global Telecom Solution Sector, Hangzhou, from 2000 to 2002, and a Research Staff with NTU, from 2005 to 2006. Since 2006, he has been with the Institute of VLSI Design, Zhejiang University, where he is currently a Full Professor. He was with the Eindhoven University of Technology (TU/e), Eindhoven, The Netherlands, as a Visiting Scholar, from 2008 to 2010, and a Marie Curie Fellow with the Mixed Signal Microelectronics Group, TU/e (co-hosted with Philips Research, Eindhoven). His current research interests include radio frequency, millimeter-wave integrated circuits, and clock circuits for communication using CMOS technology.