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The Open Experiment: An Experimental Graduate Course in Electronics Communications Engineering*

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This paper mainly discussed the novel open experiment graduate course in electronic information and engineering. The course is designed to teach postgraduates how to design, test, and simulate some basic experiments related to wireless communication systems and microwave transmission systems using modern instruments and computer-aided design (CAD) software. One of the objectives of the course is to assist postgraduates to understand the theoretical concepts of wireless systems, parallel DSP, embedded systems, electromagnetic waves, electromagnetic compatibility and optical communication systems through hands-on experiments and to make them more confident both in system design and analysis. The course also aims at increasing the interest of postgraduates in engineering and technology. Therefore, laboratory experiments that are complementary to the materials discussed in the theoretical part of the course are designed specifically to incorporate the use of several common instruments that students probably use extensively in their research fields. Complementing and expanding upon the materials covered in six basic courses is another merit of this laboratory-based course. Meeting the course requirements also helps students improve their oral presentation and report preparation abilities. The laboratory has provided more than 2000 postgraduates during the past ten years with the opportunity to acquire both in-depth theoretical understanding and hands-on experience in this rapidly growing discipline. The evaluation of the course indicates that most of the objectives are achieved.

Keywords: laboratory courses; open experiment; innovation

1. Introduction

Beihang University is a top-ranked research university in China leading in communication and information engineering, electronic science and technology. By evaluating the present technological development and foreseeing the future development in the field of electronic and information engineering, Beihang University has effectively developed the syllabus for postgraduate courses with comprehensive laboratory course. Beihang has established an experimental center named as 'The Center for Experimental and Practice Teaching' for the purpose of the course**.** The Center for Experimental and Practice Teaching was established with the help of "985" projects fund and laboratory improvement grant to make the graduates of Beihang more capable and confident in the field of communication and information engineering, electronic science and technology. In the past ten years, more than 2000 postgraduate students have had the opportunity to get profound practical knowledge and hands on working experience in this center. Upon completion of these curricula, many students have formed a major working force for many local high-tech industries at home and abroad who have been provided with training in the Beihang's center.

A review of the published literature over the past decade reveals that a number of other schools also offer separate laboratory courses relating to wireless communications, DSP, MCU and microwave engineering. Among these are University of Colorado (Boulder) [1, 2], the University of Utah [3], Virginia Polytechnic Institute and State University [4, 5], Carnegie Mellon [6], UCLA [7], the University of Southern California (USC) [8], Illinois Institute of Technology [9] and University Technology Malaysia [10]. And in China they are Tsinghua University [11], Beijing Jiaotong University [12], Xidian University [13], Southeast University [14], Harbin Institute of Technology [15], and Beijing University of Posts and Telecommunications [16]. Some laboratories are about DSP experiments [17, 18]; Others focus on wireless networks [19–25], radio-frequency (RF)/microwaves [26–28], antennas [29], radar [30] and so on. Some are hands-on hardware-related laboratories, while others emphasize modeling and MATLAB simulations [17]. From the literature, it is also found that these experiments are offered as a part of a course for the undergraduate students in many universities, and none of the universities have a separate comprehensive laboratory course for postgraduate students as Beihang University. Beihang's Centre for Experimental and Practice Teaching provides a hands-on learning experience at the physical layer of wireless communication systems, signal and information processing, embedded system, electromagnetic waves, electromagnetic compatibility and optical communication. In addition to the formal laboratory

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experiments, it includes lectures on each experiment to develop the theoretical concepts and the project-oriented work.

One of the objectives of Beihang's Centre is to provide the students with a hands-on laboratory experience that includes an in-depth theoretical understanding of this rapidly growing discipline. The laboratory experience can play an important role in motivating students and stimulating their interest in a specific discipline, such as wireless communication systems, signal and information processing, embedded system, electromagnetic waves, electromagnetic compatibility and optical communication. Reading about DBPSK modulation/demodulation in a textbook and actually observing DBPSK modulation/demodulation on the laboratory oscilloscope can be two very different experiences for many students. The witnessing frame shape and the transmission experiment in the digital transmission system is an example of how the laboratory experience both complements and supplements the other theoretical courses taken by the students.

The open experiment is one of the special courses in Beihang's Centre. The open experiment categories are divided into communication, microwave, signal processing, electromagnetic compatibility and so on, which could offer the students a wide field and guarantee the students to have a proper topic. And they could choose their topics from scientific research projects so as to combine the open experiment with the scientific research together. By designing the whole open experiment procedure, the postgraduates of electronic engineering information could integrate and apply many of the basic and widely used techniques and skills learned in other engineering courses (e.g., physics; electromagnetic field; signals and systems; and analog and digital communication systems) and mathematical techniques learned in calculus, differential equations, and probability courses. Above all, the purpose of the open experiment is to help the students to get access to the basic theoretical knowledge, the design method and the experiment knowledge, while foster their innovation ability, the analysis ability, the module design ability, the testing ability and the ability of solving resulting problems and so on. The required project reports, and oral presentations are all designed to help develop their communication skills. In addition, the open experiment experience could also help students learn how to work in team.

This paper is divided into five parts. Section I introduces the situation of various schools offering separate laboratory courses relating to electronic and information engineering. Then Beihang university laboratory center and its open experiment are briefly introduced. Section II describes the education curriculum system for the master of engineering, which includes the laboratory public experiment and open experiment. Then the open experiment is thoroughly described in section III. And section IV demonstrates the assessment methods of the open experiment. Section V is the conclusion of the paper. The open experiment system is encouraged to set up a similar laboratory and curricula in other universities.

2. Education curriculum system for master of engineering

2.1 Construction contents

Table 1 shows the postgraduate courses system composition. The courses are divided in to two parts: degree courses and comprehensive practice. The experimental course belongs to the comprehensive practice, and occupies at least 3 credits, which is very important in the comprehensive practice category. In Beihang University, the experimental course is consisted of public experiment (2 credits) and open experiment (1 credit). And the description of the public experiment and open experiment is described in the following part.

2.2 Description of the public experiment

2.2.1 Platform introduction

The comprehensive experiments of postgraduates are required experiments with 2 credits which required 36 hours, including six platforms: wireless

Table 1. The postgraduate courses system composition

Academic master's knowledge, ability structure and credit requirements								
Course nature	**Degree Courses**				**Comprehensive Practice**			
	Common-required Courses	**Mathematics Course**	**Cross Subject Courses**	**Elective Courses**	**Experimental Course**	**Teaching Practice**	**Academic Activities**	**Literature survey and Thesis Proposal Report**
Credit Requirement	≥ 6	≥ 14	≥ 2	≥ 0	≥ 3	1	1	1
Total Credit Requirement	≥ 30 (To simultaneously meet all kinds of credit subtotal and total credit requirements)							

communications test platform, signal and information processing experimental platform, embedded systems experimental platform, electromagnetic wave experimental platform, EMC experiment platform, optical communication and information experimental platform technologies and systems. The six laboratory platforms cover the core courses and basic knowledge of information and communication engineering, electronic science and technology, traffic engineering, optics engineering and biomedical engineering, which are the main directions of our school.

The experiment contents on the six laboratory platforms can make students feel the cross merging of knowledge, develop their new interest, stimulate their innovative inspiration, make up their one-sided knowledge which they have learned unilaterally. Comprehensive experiments can expand the students' knowledge, and this is very important for cultivating innovative talents. We make the experiment courses as a required training procedure for all the postgraduates. The experiment results indicate that the students observed many of the problems through the experiments which were not previously been aware of.

2.2.2 Teaching methods of laboratory courses

Postgraduates can reserve the experiments in specified time according to their study situations. There are three processes to complete their experiments.

The first process is the examination before doing the experiment. Students must participate in the examination of the experiments before they do the experiment in the lab. They become qualified to do the experiment after they pass the exam. The examinations related to the experiments make students preview the correlating knowledge, master the basic processes of the experiment, and avoid doing experiment blindly and resulting in a superficial understanding of the experimental contents and finally having little harvest.

The second process is to complete the whole process of experiments under the teachers' guidance.

The third process is to write a summary report after doing experiments to enhance the students' experience and understanding of experimental content. Experimental teachers give the result of each experimental platform based on the student's test scores, experimental process and summary report. Finally, they give the comprehensive results of the experiments according to the results of six experimental platform classes.

Practice shows that the experimental center has an effective measure in the management process of experimental courses, not only to ensure the experimental quality, but also enhance the efficiency of the experiments.

2.2.3 Evaluation methods of laboratory courses

The result of each experimental platform will be input into the computer system, and the computer system will synthesize the results of the laboratory course based on the six platforms' results. The result is divided into four levels: "excellent (5 point)", "good (4 point)", "qualified (3 point)" and "not qualified (2 point or less)". Only when the results of all six platforms are given, the results of the laboratory course can be synthesized. The results of the laboratory courses cannot be given if it lacks the score of any platform. The method to synthesize the results of the laboratory course according to the results of six platforms is: if 4 or more experimental platforms are excellent, the student will get "excellent", and 4 or more laboratory platforms are good, the student will get "good". Other conditions are qualified. If any laboratory platform is not qualified, the whole laboratory course is not passed. 1 "excellent" + 1 "qualified" = 2 "good", Etc.

2.3 Description of the open experiment

The open experiment can make the postgraduates improve their innovation ability while finishing an innovation experiment design in free-time and free-space.

To improve the innovation ability of the postgraduate students and achieve the opening and innovative goal of the open experiment, the postgraduate students in the open experiment of communication and information technology will be asked to finish an experiment module design or software/hardware design under the background of their teachers' research project individually or in a team of 2$\sim$5 persons. The open experiment will be finished within 1 year. And in the end of next semester, the research products (hardware/software products and the test results report) will be handed in. Finally, the grades are given by defense of each team. The defense grades are divided into 4 levels: "excellent", "good", "qualified" and "not qualified", and only the students whose grades are no less than "qualified" could obtain 1 credit successfully.

To unify the difficulty of the topic and grade evaluation standard, the topic requirements of the "open experiment of postgraduate design" are as follows:

1. The difficulty of hardware/software is proper, and the experiment can be finished in about 6 months.
2. The number of projects handed by a same research team has no limit, and it is determined by the number of students' teams. The total number of students in one team is no more than 5 persons. And the topics between each team should be different.

3. The final hardware/software products and test result report should be handed to the teacher, and make sure the results are reproducible. And the grade is obtained by defense.
4. The materials needed in the hardware design is afforded by their research teams, thus the topic should not be too difficult and complex.
5. The existed research result shouldn't be taken as the open experiment result.
6. The hardware results could be tested in their own lab or the experimental center.

3. Projects design of open experiments

Despite the laboratory experiment courses, there are also open experiments for students to choose. The students may form teams to conduct a scientific research relative to the project they are occupied with in their master period. The open experiment is another important aspect to improve the students' research ability in many aspects.

During the open experiment, students firstly need to form a team less than 5 persons, and then choose a project to study. Next, they need to make a proposal presentation, after which they will find ways to do the project and find out innovation ideas, solve problems, analyze phenomenon, validate the method and finally obtain conclusions. At last they will make the defense presentation. The teachers will give scores according to their works and presentations. Table 2 shows the available topics of open experiment module.

Open experiment project is designed for postgraduate students as an innovative pilot project with one credit, and students choose any one from 20 modules of two systems—digital voice recorder systems and microwave communication systems. The project of the laboratory runs throughout the second term. This project of the laboratory operates as an "open lab," where students are permitted to work in the laboratory during certain scheduled hours. Projects must be approved by the course instructor. Many of the modules selected build upon the formal laboratory experiments. Examples include microstrip antennas, microwave amplifiers, microwave band-pass filter, microwave up frequency converter, microwave power divider, microwave phase-locked source, audio and video IF modulator, microwave directional coupler, microwave power attenuators, microwave low-noise amplifier, microwave down frequency converter, microwave impedance filters, microwave voltage-controlled oscillator, DAC, ADC, FPGA, etc. Students are allowed to complete the work in the lab, and students can also complete the work in a formal professional lab. A written report and a 20-minute formal oral presentation using PowerPoint are required at the end of second semester by each student. The result of each student's achievement is given according to their report. Students enrolled in the laboratory are required to attend all project presentations, and interested faculty is also invited to attend.

4. Assessment

4.1 Defense (evaluation methods)

There are many ways to evaluate the innovation ability of a student, such as observation evaluation, evaluation by investigative study, science and technology works analysis, rating scale evaluation method and so on. In observation evaluation, the teacher can get access to observe and understand the students in experiment procedure during a long-time interaction between teacher and students. Through the observation, the teachers can make an impression and preliminary evaluation of the students' innovation consciousness, innovation spirit and innovation ability. The whole procedure that students complete the opening experiment is also a research and study procedure. The experiment is conducted according to the sequence of topic choosing and proposal stage (the circumstances of questioning), actual research stage and summary exchange stage. Therefore, the teacher can make analyses and judgments on the students about their sensitivity of problems, the innovation consciousness and spirit, the profundity of the understanding and analysis on problems, practical ability, the idea that can form conclusions and achievements, and the innovation level in the whole period. The application of science and technology work analysis method can have the omni-bearing evaluation and analysis about the opening-experiment achievements that students provide, and make analysis and evaluation on the students' knowledge, imagination, innovative ideas, innovate thinking quality, innovative ability, comprehensive or integrated ability and originality, the innovation level of the experiment works and the social value and economic value of the experiment works, etc. The rating scale evaluation method, often based on the connotation of innovation and the psychological and behavioral characteristics of the innovation process, can design a series of projects, and form the "innovation ability evaluation sheet" for the evaluation of students' innovation ability. The proposed "master of engineering opening experiment evaluation method" in this paper needs to combine the evaluation methods above together. The score evaluation is conducted by the following method:

Make the evaluation on the topic, project, the whole process of project implementation and project summary of the innovative experiment. The

Table 2. Available Topics of Open Experiment Module

Number	Topic	Experiment Content
1	EBG structure design of power integrity	Design a simple EBG structure. The suppression bandwidth is 0.8MHz∼5GHz. The suppression depth is –30dB. A VNA is used to measure the S21 for validation.
2	Mobile communication network coverage testing experiment	Choose an area to collect the signal in this area with the test terminal, and map the distribution of the signal.
3	Microwave frequency-sweep source structure design	Design a microwave frequency-sweep source with the output frequency of 10GHz∼12GHz and an amplitude above 0dBm. A spectrum analyzer is used to validate the design.
4	The signal input processing and output circuit based FPGA minimum system	1. The design of FPGA minimum system. 2. Use 12-bit serial AD converter AD7476 to sample the analog signal and put it into FPGA. 3. The digital signal from FPGA is input to 12-bit serial DA converter AD5621 to obtain an analog circuit. 4. Extension Design: After the design above, signals with variable frequencies will be sent into AD converter. A filter is designed in FPGA. And after DA converting, we can evaluate whether the design of filter satisfies the requirements by observing the waveform.
5	Design of wireless transmission based on USB	1. The USB transmission protocol. 2. USB interface chip. 3. Links and control of MCU and USB. 4. nRF2401 single-chip radio frequency transceiver. 5. MCU+USB interface chip+nRF2401 single-chip radio frequency transceiver.
6	Laser velocimeter	1. Design of laser Doppler principle and speedometer structure. 2. Design and implementation of laser and the driving circuit. 3. Design and implementation of laser detector and the subsequent driving circuit. 4. The driving software and circuits connecting RS232, RS422, RS485 and the upper computer to transport the measured information.
7	Practical adjustable current-limited regulated power supply	1. Design a regulated power supply with a regulation voltage of 0∼24V and a current of 0.002∼3A. 2. Design a regulated power supply programmed by a certain MCU, with a limited output current and an adjustable limited value.
8	Digital baseband signal transmission pattern generator design	1. Based on the VHDL language description system, convert the input binary data as follows: (1) alternating polarity code (AMI); (2) bipolar NRZ (SRN); (3) unipolar NRZ (DRZ); (4) unipolar NRZ (NRZ); (5) Manchester code (FXM); (6) differential codebook (CFM); (7) coded mark inversion code (CMI) and other baseband signal. 2. Compile and simulate the waveform in quartus II.
9	Free-space Laser voice communication system Design	1. Laser voice communication system structure design. 2. Design and implementation of lasers, modulators and driver circuit. 3. Design and implementation of the laser detector and follow-up circuit. 4. Signal amplification, demodulation circuit design and implementation.
10	Microwave up-converter module design	The parameters are as follows: IF frequency: 20MHz; Local oscillator frequency: 2190MHz
11	Microwave band-pass filter module design	The parameters are as follows: f: 2000MHz–2020MHz; ATT@2190MHz≥35dB, IL≤6dB
12	Microwave power amplifier module design	The parameters are as follows: Operating Frequency: 1900MHz–2020MHz; Gain: ≥18dB
13	Microwave power splitter module design	The parameters are as follows: f: 2000MHz—2020MHz; IL≤3.5dB, Isolation ≥23dB
14	Microwave directional coupler module design	The parameters are as follows: f:2000MHz-2020MHz; Coupling=20±1dB, IL≤0.5dB, Directivity≥20dB
15	Microwave power attenuator module design	The parameters are as follows: f: 2000MHz–2020MHz; ATT=4dB±0.3dB, VSWR≤1.2, TYPE: T, Π
16	Microwave impedance matching module design (50Ω->75Ω)	The parameters are as follows: f: 2000MHz–2020MHz; TYPE: T
17	Microwave down frequency-converter module design	The parameters are as follows: IF frequency: 20MHz; Local oscillator frequency: 2190MHz
18	Micro-strip antenna module design	The parameters are as follows: f: 2000MHz–2020MHz; Gain>5dB; Input impedance: 50Ω

overall evaluation score of the project is according to the cumulative score, consisting of three parts: the basic ability evaluation (20%), formative assessment (50%) and the summative assessment (30%).

The basic ability evaluation: Evaluate the basic ability the students need before the innovative experiment, which consists 20% of the total score. The evaluation forms are shown in Table 3.

Formative assessment: Used for the management of the innovation experiment process. Teachers are mainly the evaluation subjects. And they guide students to obtain information, find out new problems, grasp the innovation points, strengthen the team cooperation consciousness, overcome various difficulties and improve the innovation ability. The formative assessment consists 50% of the total grades. The concrete evaluation questionnaire is shown in Table 4.

The achievement evaluation index is used to evaluate the quality of the creative learning. The evaluation subject is the students, teachers and experts, combined with the process evaluation, showing the process elements in the achievements evaluation, and overcoming the disadvantage of

Table 3. The basic evaluation targets

	Study points	**Weights**	**Contents**	**Score**
Basic ability assessment	Theoretic basis	5	The related mathematic, physics and natural science needed to do the electronic information engineering jobs.	
		5	Master the basic knowledge of electronic information engineering	
	Practical ability	5	Be familiar with the common electronic instruments and the related software.	
		5	Have the basic ability to design and conduct experiments and analyze the results.	

Table 4. Formative assessment index

	Evaluation index	**Assessment factor**	**Weights**	**Main contents**	**Score**
Formative assessment	Innovation knowledge	Investigation and argumentation	5	Have the ability to actively collect the materials in the investigating and demonstration stage, and the ability to process information and obtain new knowledge.	
		Project design	7	Design the reasonable experiment plan on the basis of the investigation and argumentation.	
		Stage check	10	Have the ability to perform the experiment independently in the process of the plan implementation and organize the monthly check to assess the project progress.	
		Experimental diary	3	Record the experiment process accurately, real-timely and in detail, then make the summary.	
	Innovative ability	Ability level	5	Have the ability to apply the learned knowledge and skills to discover, analyze and solve the practical problems, and can correctly process the experimental data and carry out the theoretical analysis on the project, then obtain the valuable conclusions.	
		Team cooperation	5	Be good at adopting others' advise, communicating with team members and completing tasks in cooperation with others actively.	
		Innovative awareness	5	Have innovative awareness, have improvements or breakthroughs on the previous work or have unique insights.	
	Innovative thinking	Thinking	3	Have deep, agile thinking, and original creation.	
	Innovative personality	Work attitude	2	Have full and difficult workload and rigorous work style with a hardworking attitude.	
		Personality characteristics	5	Have curiosity, imagination, interest, persistence, self-confidence and criticism.	

Table 5. Summative evaluation index

		Investigated points	Weights	Main contents	Score
Summative evaluation	Written reviews	Logicality	2	The research report has strong logic and bright ideas.	
		Clarity	2	The research report is rigorous and clear expressed.	
		Theoretical reliability	4	The specification of technical language, figures, charts and writings and reliable and accurate data is needed.	
		Words level	2	Good organization and written expression ability of the research report is needed.	
	Defense and review	Innovation	5	Have innovation and certain technical difficulty in knowledge, technology or research method. The overall level main and technical index should reach or be near to the advanced level of the project of the same kind. And analysis the case that hasn't reached the expected objective of experiment	
		Practical object or achievements	7	Have the research achievements, including software and hardware achievements, or patent application acceptance notice, academic papers published.	
		Independence	3	The work must be finished independently by students of the research team, without relying on teachers and doctoral research data and results.	
		Defense performance	5	The situation of the defense, demonstration and answering questions.	

overweighing the outcome and underestimating the process. It weighs 30% of the total grade. The concrete evaluation questionnaire is shown in Table 5.

As to the score distribution in the assessment of the open experiments, there is a common standard. The scores of all teams must follow the lognormal distribution. The number of the teams which have scores above 90 occupies 15% of the total team numbers. And the number of the teams which have scores below 60 occupies 15% of the total team numbers. While the number of the teams which have scores between 60 and 90 occupies 70% of the total team numbers.

4.2 *Satisfaction investigation*

The experimental courses are required as compulsory courses in new revised postgraduate training plan since 2005. The total credit is 3, in which the comprehensive experiment is two credits and the opening experiment is one credits. Over the past ten years, more than 2000 graduate students have completed the experiment in this experimental platform, and a fairly good effect is achieved. All graduate students are required to complete the survey and provide feedback to the instructor. The questionnaire is extensive and includes 72 questions covering the areas of procedures and policies (course syllabus, grading policy, office hours, etc.), instructor (prepared for lectures, knew material thoroughly, spoke clearly, organized lectures, etc.), graded assignments and exams, overall rating for the course, and an overall rating for the instructor.

The statistical results of "do you think if the experiments are helpful to understand and learn the related knowledge?" and "your comprehensive evaluation to the experiments" are shown in Table 6 and Table 7 respectively. From the table, we can see

Table 6. The questionnaire results 1

	Do you think if the experiments are helpful to understand and learn the related knowledge?
Very helpful	31%
Helpful	51%
Certain helpful	18%
Not helpful	0%

Table 7. The questionnaire results 2

	Your comprehensive evaluation to the experiments
Excellent	68%
Good	30%
Qualified	2%
Not qualified	0%

that most postgraduates are satisfied with the arrangement of experiment types and experiment contents. They think the experiments are helpful to their research. The experiment courses expand their thoughts, exercise their practical ability and achieve the expected results.

Students were also given the opportunity to make specific comments regarding the course and/or instructor. The comments collected in recent semesters include the following:

> "This is a course from which I learned a great deal."
>
> "I thoroughly enjoyed the course."
>
> "This is very useful and comprehensive laboratory course. I did learn a considerable amount about the project that I undertook. I feel that the experiments of six platforms done in the Beihang Experiment Centre would have trained me better for the engineering challenges I will surely face."

5. Conclusion

The course is designed to teach postgraduates how to design, test, and simulate some basic experiments related to wireless communication systems and microwave transmission systems using modern instruments and computer-aided design (CAD) software. One of the objectives of the course is to assist postgraduates to understand the theoretical concepts of wireless systems, parallel DSP, embedded systems, electromagnetic waves, electromagnetic compatibility and optical communication systems through hands-on experiments and to make them more confident both in system design and analysis. The course also aims at increasing the interest of postgraduates in engineering and technology. Therefore, laboratory experiments that are complementary to the materials discussed in the theoretical part of the course are designed specifically to incorporate the use of several common instruments that students probably use extensively in their research fields. Complementing and expanding upon the materials covered in six basic courses is another merit of this laboratory-based course. Meeting the course requirements also helps students improve their oral presentation and report preparation abilities. During the past ten years, over 2000 students have enrolled. The laboratory experience clearly motivated the students, stimulated their interest, and complemented the theoretical topics they studied in their other communication and microwave courses. The students had the opportunity not only to achieve in-depth theoretical understanding but also to acquire an excellent hands-on learning experience. The hands-on learning environment proved invaluable to the students in preparing them for a career in the communications/ computer/ consumer electronics industries. Many graduating students commented that they received employment opportunities in industry and credit the practical experience they acquired at Beihang's Center with helping them obtain the job offers and preparing them well for their professional career in the field of electronic and information engineering. The evaluation of the course indicates that most of the objectives are achieved. China Electronics Education Society provided an opportunity to bring this laboratory experience to a national audience.

To achieve these experiments must have good test equipment, platforms and the environment, in addition to the postgraduate students have the relevant theoretical basis and experimental skills, or it is very difficult to complete such an experiment.

The author would be pleased to share the laboratory notes with anyone interested in them. He can be contacted at yanzhaowen@buaa.edu.cn.

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References

1. T. X. Brown, University of Colorado, TLEN 5320 Wireless Lab. [Online]. Available: http://ece-www.Colorado.edu/~timxb/
2. T. X. Brown, O. Notaros and N. Jadav, Agilent Technologies Educator's Corner. Wireless Systems Lab. [Online]. Available: http://www.educatorscorner.com/index.cgi?CONTENT_ID=2448
3. C. Furse, Agilent Technologies Educator's Corner. Utah State Univ., Wireless LAN Lab. [Online]. Available: http://www.educatorscorner. com /index.cgi?CONTENT_ID=2454.
4. L. DaSilva, S. Midkiff and I.-R. Chen, A Laboratory Course in Wireless and Mobile Systems Design. [Online]. Available: http: www.lan.ece.vt.edu/Presentations/dasilva_midkiff_chen.pdf
5. Virginia Polytechnic Institute and State University, New Course Gives Students Hands-On Experience with Network Interface, Wireless Networking. Virginia Tech ECE Annu. Rep.[Online]. Available: http:// www.ecpe.vt.edu/news/ar03/newcourse.html
6. R. Negi, Carnegie Mellon University, Wireless Lab. [Online]. Available: http://www.ece.cmu.edu/~negi/courses/wireless_lab.html
7. H. Fetterman, EEM 171L Data Communication Systems Laboratory. [Online]. Available: http://www/eeweb/ee.ucla.edu/course_objectives.php?class=eeM171L & squarter=20052&grad=0
8. A. Helmy, EE-599 Wireless and Mobile Networks Design and Laboratory. [Online]. Available: http://nile.usc.edu/~helmy/ee599
9. Jafar Saniie, Erdal Oruklu, Richard Hanley, Vijay Anand and Tricha Anjali, Transforming Computer Engineering Laboratory Courses for Distance Learning and Collaboration, *International Journal of Engineering Education*, **31**(1)(A), 2015, pp. 106–120.
10. Nur Ayuni Shamsul Bahri, Naziha Ahmad Azli and Narina Abu Samah, Determining the Elements of Problem Solving Strategies in Project-Based Laboratory (PB Lab) Course, *International Journal of Engineering Education*, **32**(1)(B), 2016, pp. 409–423.
11. Introduction to the Electrical and Electronic Lab Center of Tsinghua University, Tsinghua University, Electrical and Electronic Lab Center [Online]. Available: http://dgdz.cic.tsinghua.edu.cn/dgdz/detail_wh.jsp?boardid=27&pageno=1

12. Beijing Jiaotong University, Electrical & Electronic Experimental Center [Online]. Available: http://ee.bjtu.edu.cn/labcenter/lab/lab.htm
13. Xidian University, Electrical & Electronic Experimental Center [Online]. Available: http://eelab.xidian.edu.cn/ survey.htm
14. Southeast University, Electrical & Electronic Experimental Center [Online]. Available: http://eae.seu.edu.cn/LimsCMS/
15. Harbin Institute of Technology, Electrical & Electronic Experimental Center [Online]. Available: http://eelab.hit.edu.cn/
16. Beijing University of Posts and Telecommunications, Central Laboratory for Electronics and Information Technology, [Online]. Available: http://eilab.jwc.bupt.cn/
17. P. I. Muoka, M. E. Haque, A. Gargoom and M. Negnevitsky, DSP-Based Hands-On Laboratory Experiments for Photovoltaic Power Systems, *IEEE Transactions on Education*, **58**(1), Feb, 2015, pp. 39–47.
18. H. Kwon, V. Berisha, V. Atti and A. Spanias, Experiments with Sensor Motes and Java-DSP, *IEEE Transactions on Education*, **52**(2), May 2009, pp. 257–262.
19. D. R. Thompson, Jia Di and M. K. Daugherty, Teaching RFID Information Systems Security, *IEEE Transactions on Education*, **57**(1), Feb, 2014, pp. 42–47.
20. T. D. J. Mateo Sanguino, C. Serrano López and F. A. Márquez Hernández, WiFiSiM: An Educational Tool for the Study and Design of Wireless Networks, *IEEE Transactions on Education*, **56**(2), May 2013, pp. 149–155.
21. Z. Dawy, A. Husseini, E. Yaacoub and L. Al-Kanj, A Wireless Communications Laboratory on Cellular Network Planning, *IEEE Transactions on Education*, **53**(4), 2010, pp. 653–661.
22. S. Güzelgöz and H. Arslan, A Wireless Communications Systems Laboratory Course, *IEEE Transactions on Education*, **53**(4), 2010, pp. 532–541.
23. J. S. Chenard, Z. Zilic and M. Prokic, A Laboratory Setup and Teaching Methodology for Wireless and Mobile Embedded Systems, *IEEE Transactions on Education*, **51**(3), Aug, 2008, pp. 378–384.
24. J. Frolik, Implementation of Handheld, RF Test Equipment in the Classroom and the Field, *IEEE Transactions on Education*, **50**(3), 2007, pp. 182–187.
25. W. T. Padgett, B. A. Black and B. A. Ferguson, Low-frequency wireless communications System-infrared laboratory experiments, *IEEE Transactions on Education*, **49**(1), Feb, 2006, pp. 49–57.
26. L. Zhou, S. Zhang; W. Y. Yin and J. F. Mao, Investigating a Thermal Breakdown Model and Experiments on a Silicon-Based Low-Noise Amplifier Under High-Power Microwave Pulses, *IEEE Transactions on Electromagnetic Compatibility*, **58**(2), 2016, pp. 487–493.
27. M. M. Potrebic, D. V. Tosic and P. V. Pejovic, Understanding Computation of Impulse Response in Microwave Software Tools, *IEEE Transactions on Education*, **53**(4), 2010, pp. 547–555.
28. N. E. Cagiltay, E. Aydin, R. Oktem, A. Kara, M. Alexandru and B. Reiner, Requirements for Remote RF Laboratory Applications: An Educators' Perspective, *IEEE Transactions on Education*, **52**(1), 2009, pp. 75–81.
29. E. Taslidere, F. S. Cohen and F. K. Reisman, Wireless Sensor Networks—A Hands-On Modular Experiments Platform for Enhanced Pedagogical Learning, *IEEE Transactions on Education*, **54**(1), 2011, pp. 24–33.
30. U. Hernandez-Jayo, J. M. Lopez-Garde and J. E. Rodriguez-Seco, Addressing Electronic Communications System Learning Through a Radar-Based Active Learning Project, *IEEE Transactions on Education*, **58**(4), 2015, pp. 269–275.

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