On Developing a Software Defined Radio Laboratory Course for Undergraduate Wireless Engineering Curriculum

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Abstract – A software defined radio (SDR) is a modern radio communication system that can be reconfigured on-the-fly. In this paper, we describe a project on introducing SDR to the Bachelor of Wireless Engineering (BWE) curriculum at Auburn University. In particular, we focus on developing an SDR laboratory course based on the GNU Radio and Universal Software Radio Peripheral (USRP) platform. We describe the detailed lab course structure, compare it with existing approaches, and present sample labs and results. A small scale assessment was conducted for the Spring 2013 offering with positive student response observed.

Keywords: Software defined radio, situated learning, undergraduate curriculum, laboratory course, wireless engineering.

INTRODUCTION

Software Defined Radio (SDR) represents a modern approach to radio engineering[11]. In traditional wireless systems, multiple chipsets that each implements a different wireless standard are required in a wireless device to enable communications between heterogeneous devices. With SDR, there is a single piece of programmable hardware (with field programmable gate arrays (FPGA) on board); wireless communications waveforms and protocols are implemented in software, which can be uploaded to the FPGAs on-demand. As a result, SDR enables flexible reconfiguration of wireless communication systems, more efficient access to the spectrum, coexistence, and great inter-operability among heterogeneous wireless systems[10].

SDR has great potential for both military and civilian applications, with far-reaching impact in our society. It is important to expose our undergraduate students to this advanced technology. In addition, the SDR platforms provide easy access to all the layers in a wireless network system, which was not possible with traditional wireless systems. Usually MATLAB simulation projects are used in our communication system course due to the lack of access to the physical layer (PHY), and sometimes device drivers are used to modify certain parts of the MAC layer in research projects[2]. With SDR, students can easily access both the PHY and MAC and build and experiment with real wireless waveforms and applications.

In this paper, we report our experience on the development of an SDR laboratory course at the undergraduate level to enhance the Bachelor of Wireless Engineering (BWE) curriculum at Auburn University, an ABET-accredited program and first-of-its-kind in the US. With the

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“learning by doing” approach[1], we aim to enhance teaching and student learning of communications theory and wireless networking. We adopted an open-source platform consisting of GNU Radio and Universal Software Radio Peripheral (USRP), which could be helpful for dissemination and adoption at other schools[3]. The lab experiments are organized into 10 labs, covering preliminaries, analog communications, digital communications, wireless local area networks (WLAN), and cellular networks. These labs are complementary to the existing SDR lab at the graduate level[4].

We have developed detailed lab instructions for the nine experiments in this lab course. The last lab is an open project to allow students to explore their creativity to build their own communication systems with help from the instructor and graduate teaching assistants (GTA). The lab course was test offered in Spring 2013 as ELEC 4970—Special Topics in Electrical Engineering: Software Defined Radio Lab. The Student Assessment of their Learning Gains (SALG) web tool was used to create a survey to collect feedback from students[12].

In the remainder of this paper, we first introduce the preliminaries of SDR and its advantages for undergraduate wireless engineering education. We then review the current wireless engineering course structure at Auburn University and report our experience on developing the SDR lab course, including the lab platform, the lab structure, sample lab results, and assessment results. This paper is concluded with a discussion of future work.

SOFTWARE DEFINED RADIO IN A NUTSHELL

An SDR is a wireless communication system, within which components that have been implemented in hardware in traditional radio systems, such as mixers, filters, amplifiers, modulators, demodulators, and detectors, are actually implemented in software. As a result, such radios can provide flexible control of various modulation techniques, operations on different spectrum bands, security schemes, and waveforms for the current and evolving wireless standards[10,11]. A comparison of SDR and the traditional hardware radio (HDR) is illustrated in Fig. 1.

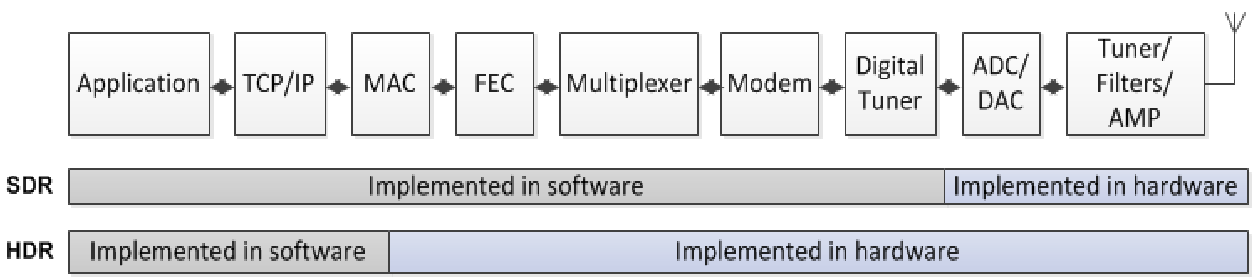


Fig. 1 Comparison of SDR with traditional hardware radios (HDR).

The SDR concept was first proposed by Joe Mitola III in the early 1990s[10]. With traditional HDR radios, waveforms and standards are typically implemented in application-specific integrated circuits (ASIC), and a wireless device needs to have multiple chip-sets (one for each standard) in order to communicate with heterogeneous devices. With the SDR radios, there is a single hardware platform consisting of FPGA, Digital Signal Processor (DSP), and General-Purpose Process (GPP), while each standard is implemented in software that can be dynamically loaded and executed in the common platform. Usually the general components are implemented as generic functions maintained in a library that can be called to implement various radios. Such an SDR platform is illustrated with National Instruments' USRP, as shown in Fig. 2.

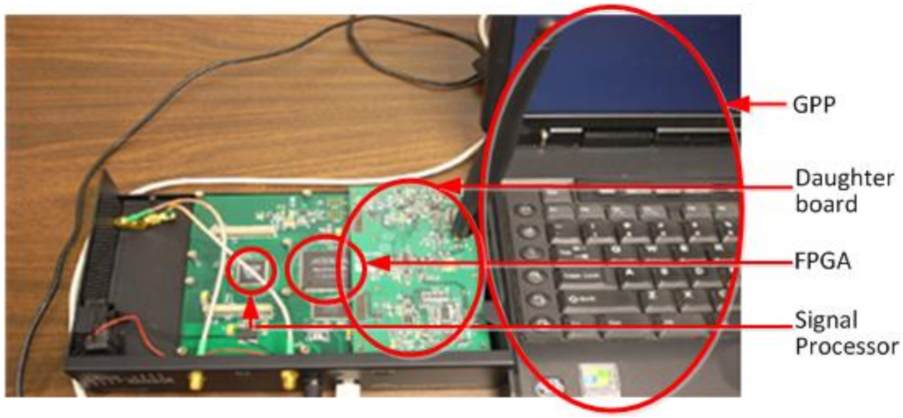


Fig. 2 SDR platform illustrated with National Instruments' USRP.

SDR can enable seamless wireless interoperability among heterogeneous wireless systems, where wireless terminals can support multiple protocols. Upgrading an existing infrastructure could be as easy as uploading the software code for the new standard/system, and the evolution of wireless protocols can be easily supported. It can also greatly reduce the time to market for new wireless technologies. However, SDR also brings about substantially increased computation at the common platform, as well as greatly increased power consumption at the mobile device. In SDR, the received analog signals are sampled and digitized at the analog-to-digital converter (ADC), leading to high data volume to be transmitted and processed. For example, an IEEE 802.11 channel is 20 MHz. To assure the full channel is accurately captured, the ADC usually digitizes about 40 MHz analog signals, which leads to 80 M samples/sec. The existing SDR platforms are usually expensive with a large form factor. Considerable research is needed to make SDR suitable for handheld devices.

In recent years, there are several SDR hardware platforms that are available, such as National Instruments' USRP, Rice University's Wireless Open-Access Radio Platform (WARP), Kansas University's Agile Radio, Microsoft Research Software Radio (Sora), and Adafruit's SDR Receiver USB Stick (a low-cost SDR that operates in 24MHz ~ 1850MHz). Usually the hardware platforms should work with a software platform for building SDR systems. Such SDR software platforms include National Instruments' LabView, Mathworks' Simulink, Virginia Tech's Open Source SCA Implementation for Embedded-Systems (OSSIE), and GNU Radio (which is an open-source software development kit of DSP and SDR). In this project, we adopt the GNU Radio/USRP platform after a comparison study of the available platforms. The open-source nature of GNU Radio makes it appealing for promoting adoption of the lab at other institutions[3].

SDR has found wide adoption in education, research, and military and commercial applications, such as the DoD's Joint Tactical Radio Systems (JTRS), SDR base stations, and wireless terminals. We find SDR a particularly powerful tool for wireless engineering education. In this project, we aim to develop wireless communications experiments and projects, by exploiting the full access to the PHY and MAC as enabled by the programmable wireless platforms. We also aim to expose undergraduate students to the advanced SDR technology with a hands-on approach and to train the future wireless workforce with the much needed SDR expertise. We have made effort to integrate the SDR experiments and projects with traditional wireless communications courses to enhance teaching and student learning and to offer senior design projects for students with different expertise to work together[9]. In this paper, we focus on reporting our work on developing a new SDR laboratory course for junior and senior level wireless engineering students.

CURRENT COURSE STRUCTURE AT AUBURN

Auburn University offers a Bachelor of Wireless Engineering program, which is ABET-accredited and first-of-its-kind in the nation. The BWE curriculum has two formal options: (i) wireless engineering-hardware (WIRE), emphasizing a hardware design-oriented approach to wireless engineering, and (ii) wireless engineering-software (WIRS), emphasizing a software-oriented approach. The communications/networking courses in the BWE curriculum are illustrated in Fig. 3, including four theoretical courses ranging from communications to networks, and two lab courses focusing on analog and digital communications, respectively. We briefly discuss the most related courses in the following, including ELEC 3400, ELEC 5110, ELEC 3030 and ELEC 3060.

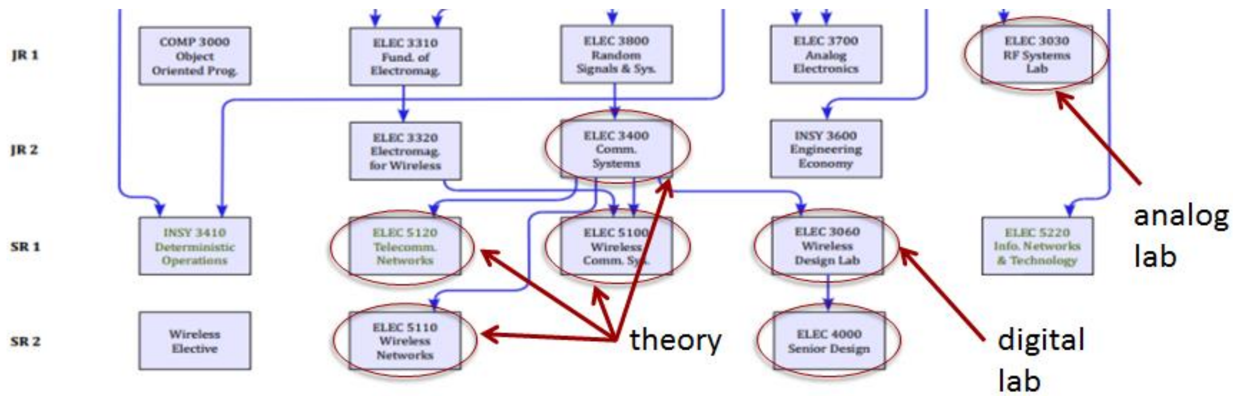


Fig. 3 Auburn wireless engineering courses at junior and senior levels.

ELEC 3400 – Communication Systems: This is an introductory course in communications. It covers mainly the traditional analog communication techniques, such as amplitude modulation (AM) and frequency modulation (FM), digitalizing analog signals, and digital communication techniques, such as baseband transmission and modulated transmission. The course can be very theoretical since a thorough understanding of these systems requires familiarity with Fourier analysis, probability and stochastic processes. Students need to be very proficient with the conversion between time- and frequency-domain representations of signals. When talking about the spectra of different modulated signals, the most frequently asked question by the students is how the abstract mathematical equations look like in real life. In addition, the students have a strong curiosity on how the modulation/demodulation process really works. To address this problem, optional MATLAB exercises are assigned for the students to plot various signals.

Although the MATLAB exercises are helpful, an important component the course is lacking is an accompanying lab course through which students can systematically obtain hands-on experience and in-depth understanding of the theory. To make up for this disadvantage, the course can be enhanced to incorporate several projects involving analysis and construction of transmitters and receivers, making use of the SDR lab environment. Upon completion of these projects, students can improve their hands-on experience with practical communication systems and see for themselves how the signals are modulated and demodulated, and what happens in the time and frequency domain at different stages of the process. Using the SDR lab, students will also be able to build the components of a digital communication system, observe the signal waveforms and constellations at different stages, and study the effect of noise and interference on the waveforms and the overall system performance. Through these projects, students will gain first-hand knowledge and practical skills on digital communication systems. Consequently, their understanding of the theory and practice of telecommunications will also be greatly enhanced.

ELEC 5110 – Wireless Networks: The material in this course is beyond the scope of what is typically presented in undergraduate electrical and computer engineering programs, and is a senior-level required course in the specialized BWE program. It covers a wide range of different wireless networking techniques such as cellular networks, wireless local area networks (WLAN), mobile ad hoc networks, Bluetooth, and wireless sensor networks, among others. The proposed SDR lab provides an excellent platform for term projects for investigating the interoperability of heterogeneous wireless networks, the performance of various medium access control (MAC) protocols, and for a study of the emerging cognitive radio networks (e.g., implementing a spectrum sensing or a dynamic spectrum access scheme)[13].

ELEC 3030 – RF Systems Laboratory: This is a lab course where students assemble, test and analyze AM and FM radios, by integrating basic concepts of electronics, electromagnetics, and signals and systems. The objectives include: (i) to understand the overall operation of an AM radio; (ii) to be able to analyze circuits with LTspice; (iii) to be able to design and implement a circuit that will enhance radio operation; and (iv) to develop capability in written and oral technical communications. Students are divided into lab sections and all lab sections meet together for a one-hour weekly lecture along with each section's two-hour laboratory session.

ELEC 3060 – Wireless Design Laboratory: This is also a lab course with experiments geared towards understanding the implementation and testing of components used in wireless communication systems. The objectives include: (i) to understand the key components of analog and digital wireless voice transmission; (ii) to understand key components of wireless digital data transmissions; (iii) to be able to design key components of a wireless transceiver; and (iv) to be able to communicate experimental results orally and in writing. Students will implement various digital modulations and line coding schemes and measure bit error rates when transmitting digital waveforms through a noisy channel.

The proposed SDR lab is developed in parallel to the above theoretical and laboratory courses. The goal is to enhance the theoretical courses with a hands-on approach, while providing a more flexible and modern alternative to the two laboratory courses. The coverage of each of the courses is illustrated in Fig. 4.

SDR Lab Development

In this section, we introduce the SDR lab in more detail. We first introduce the software and hardware platforms used in the lab. We then review the SDR lab structure and introduce the 10 lab experiments in detail. We also provide a comparison of the proposed SDR lab with two existing approaches widely adopted in teaching wireless engineering courses: a MATLAB based simulation approach and the hardware radio lab approach.

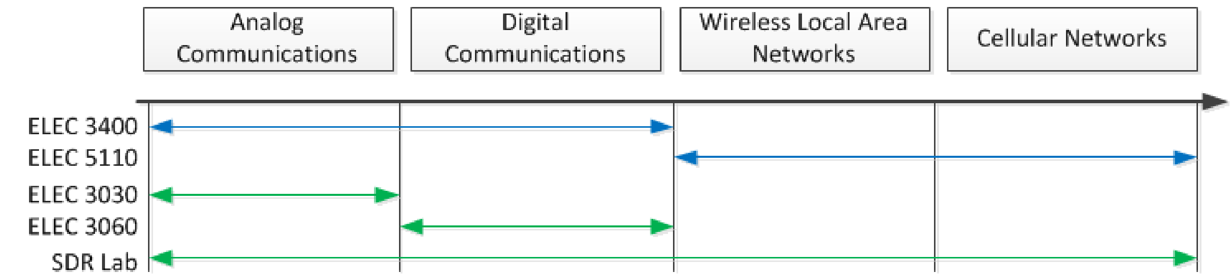


Fig. 4 Coverage of related wireless engineering courses and the proposed SDR Lab

Software/Hardware Platform

The proposed SDR lab will be based on the GNU Radio/USRP platform. USRP is a popular SDR platform developed by Ettus Research, which was acquired by National Instruments a few years ago. The USRP platform can provide the flexibility of modifying and optimizing the PHY layer and integration with the MAC and higher layers, where FPGAs are used for handling the high data rates from the analog-to-digital (A/D) and digital-to-analog (D/A) converters and for symbol rate processing.

GNU Radio is an open-source software toolkit for building software radios, generally independent of the hardware. GNU Radio was started in 1998 by Eric Blossom based on the MIT Pspectra SDR design. GNU radio consists of Python and C++ codes. To build a radio is equivalent to “gluing” together a series of C++ blocks with Python to form a data processing pipeline. GNU Radio Companion (GRC) is a graphical user interface (GUI) tool for creating the data processing pipelines. Programming with GNU Radio/USRP is relatively easy since minimal programming skill is required. The open-source nature also makes it suitable for classroom use.

We have acquired 12 USRP kits, including six latest models (i.e., N210) and six older models, along with various daughter boards, antennas, computers, etc. The SDR lab was first hosted in Broun Hall 352 in the Auburn University main campus and then moved to Broun Hall 314, a 372 square feet lab as shown in Fig. 5 below.

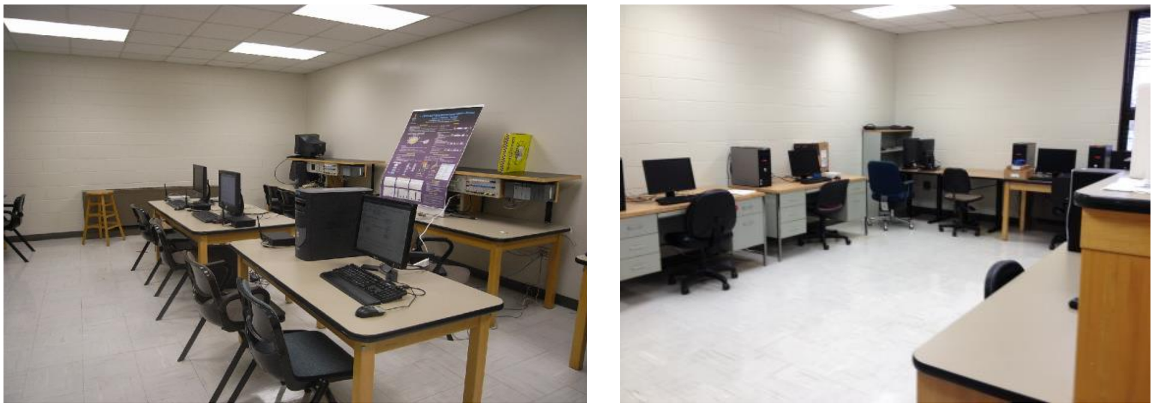


Fig. 5 The SDR Lab was firstly hosted in Broun Hall 352 and now in Broun Hall 314.

SDR Lab Structure

The proposed SDR lab consists of 10 lab experiments that are organized into six parts, covering the core topics introduced in ELEC 3400—Communication Systems and ELEC 5110—Wireless Networks. The structure of the lab is shown in Fig. 6.

- Preliminaries, including introduction to Linux, Gnu Radio, and the USRP platform.
- Analog communications, including AM and angle modulation.
- Digital communications, including binary phase-shift keying (BPSK), quadrature phase shift keying (QPSK), intersymbol interference and eye diagram.
- WLAN: including various WLAN protocols such as ALOHA, CSMA, CSMA/CA (802.11DCF) and a polling service based MAC (PSMAC)[8].
- Cellular network: students will use OpenBTS to build a Global System for Mobile communications (GSM) base station to support cellphone calls in the lab.
- Suggested SDR projects for more involved students.

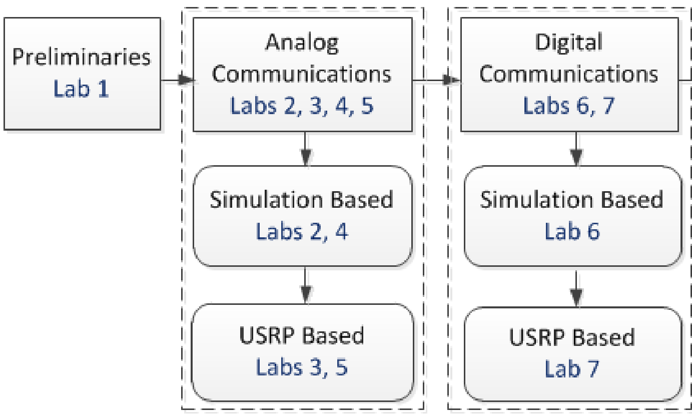


Fig. 6 Structure of the SDR lab course.

The ten lab experiments are presented in the following.

- Lab 1: An introduction to SDR, Linux, GNU Radio and USRP, and demonstration. The objective is to acquire the basic knowledge on Linux, GNU Radio, USRP, and GNU Radio Companion (GRC), which are generally lacking among our students, but will be essential for the future SDR experiments.
- Lab 2: Amplitude modulation/demodulation techniques. The objective is to implement and experiment with AM using GNU Radio. This lab is based on GRC and simulation, and no USRP is required.
- Lab 3: Build an AM transmitter and an AM receiver using USRP. Students will first implement an AM receiver using GNU Radio and USRP, to receive from broadcast AM radio stations and to play out the received program via the sound card and speaker in the computer. Then students will implement an AM transmitter with GNU Radio and USRP. They will transmit a single-tone single with AM modulation from one USRP and receive it from another USRP with the AM receiver they just built.

- Lab 4: Angle modulation/demodulation techniques. This lab is to implement Phase Modulation (PM) and Frequency Modulation (FM), and FM Demodulation in GNU Radio. Like Lab 2, these are simulation based experiments with GNC, and the USRP hardware is required.
- Lab 5: Build an FM transmitter and FM receiver using USRP. This lab is to first implement an FM receiver using GNU Radio and USRP, to receive FM radio station programs from the air and then play out with the sound card in the computer. The students will then implement an FM transmitter using GNU Radio and USRP. They will transmit a tone with FM modulation from one USRP and receive it with the FM receiver they just built from another USRP.
- Lab 6: Digital modulation techniques. This lab is to implement digital modulation and demodulation schemes with GNU Radio. The objective is to understand digital modulation and demodulation through constellation diagram. Students also learn how to plot eye diagrams and evaluate the impact of channel bandwidth and Signal to Noise Ratio (SNR) on received signal quality.
- Lab 7: Build a digital transmitter and receiver using USRP. This lab is to implement a digital modulation transmitter and receiver with GNU Radio and USPR. This lab is an extension from Lab 6 with real wireless transmission and reception. Students will observe the different modulation under real channel propagation effect.
- Lab 8: Experiments with Wi-Fi based WLAN MAC protocols. The objective of this lab is performance analysis of various MAC protocols. Students will investigate several distributed random access MACs: ALOHA, carrier sense multiple access (CSMA), CSMA/Collision Avoidance (CSMA/CA, i.e., 802.11DCF), and PSMAC[8]. Different from the point-to-point communication scenario in previous labs, this lab uses multiple USRPs to build various network topologies. Multiple data traffic flows will be generated to drive the wireless network. The throughput, delay and fairness performance of the MAC protocols will be measured in the real radio propagation/interference scenario.
- Lab 9: Experiments with a cellular network emulator. The objective of this lab is a demonstration of the GSM network. Students will take advantage of the flexibility offered by SDR to configure a GSM network in the Lab. The OpenBTS software running on the machine with USRP and GNU Radio will serve as base transceiver station (BTS) for the GSM network, to provide connection service for two unlocked GSM cellphones.
- Lab 10: Recommended SDR projects. This is an optional lab for more involved students, to provide them the opportunities to work on more advanced projects. A list of recommended projects will be offered, and students are also strongly encouraged to come up with their own ideas on how to exploit the power of SDR.

SDR versus MATLAB Simulations and Hardware Radio Lab

We next provide a comparison of the SDR lab with two widely adopted approaches in teaching wireless engineering courses, i.e., MATLAB simulations and hardware radio lab. The three approaches are illustrated in Fig. 7.

When teaching ELEC 3400—Communication Systems, we assign a MATLAB project along with each homework assignment. Usually the MATLAB code is provided in the textbook. The student needs to enter the code, debug it, and execute it to plot the waveforms. A certain amount of MATLAB programming skills is required and the student needs to have access to MATLAB, a commercial tool. Although it helps to visualize abstract transforms and modulations, it does not feel like “real” radios since most of the MATLAB projects are simulation based and static.

In ELEC 3030—RF Systems Laboratory, students conduct LTspice computer simulations on every stage of their radio design except for the antenna; MATLAB is used for antenna design. They then build a real radio using a breadboard to implement the validated design. They may also implement the design by soldering devices on a printed circuit board (PCB).

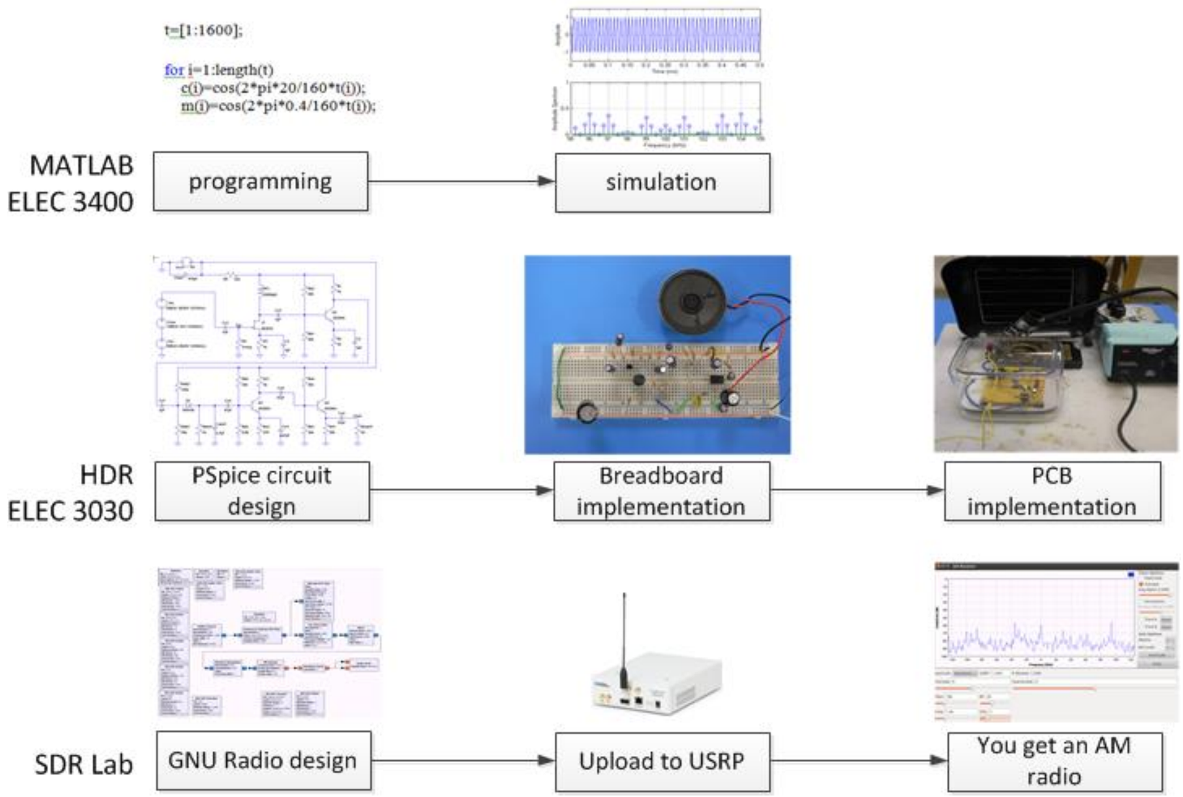


Fig. 7 Comparison of MATLAB, hardware radio, and SDR for building an AM radio.

With the SDR lab, students first use the GRC graphical tool to create signal flow graphs and generate flow-graph source code. Then the code can be loaded to the USRP to make it function as the radio as designed. Due to the GRC (a free, open-source tool), there is no need for programming. While the radio is working, e.g., receiving from a broadcast radio station, various parameters can be tuned on-the-fly and the effect can be instantaneously observed. If the student does not have access to a USRP (e.g., in the dormitory), she/he can still work with the radio implementation by building transmitters and receivers and connecting them internally in the same computer.

Comparing to the two existing approaches, the amount of effort is minimum and the flexibility is tremendous with the SDR lab. The platform also allows projects on more up-to-date technologies (rather than just the basic AM radio receiver) and fancy applications (such as recoding and analyzing the remote car key signal), making the lab more interesting to students.

SAMPLE LABS AND RESULTS

In this section, we present two sample labs, i.e., Lab 3—Building an AM Radio and Lab 8—WLAN MAC Protocols. Selected results are provided to demonstrate the procedure and goals.

Lab 3: Build an AM Radio

In this lab, students implement an AM receiver using GNU Radio and USRP to receive from broadcast AM radio stations and to play out the received program via the sound card and speaker in the computer. The core of this AM receiver is the AM demodulator built in Lab 2.

The full AM radio diagram is shown in Fig. 8. The main blocks of the AM receiver include the USRP, Frequency Translation Filter, Automatic Gain Control, AM Demodulator, and Audio Output Control. The USRP is used for receiving AM signals broadcast from AM radio stations. The Frequency Translation Filter efficiently combines a frequency translation (typically, a "down conversion") with a finite impulse response (FIR) filter (typically, a "low-pass filter") and decimation. It is ideally suited for a "channel selection filter" and can be effectively used to select and decimate a narrow band signal out of the wideband input. Simply speaking, it moves the AM channel down to the base band. The Automatic Gain Control block is used for controlling the signal strength to the demodulator. It automatically increases or decreases the gains to keep the strength of the demodulated signal at the same level, since the strength of demodulated signal is dependent on the received signal in AM systems. The AM Demodulator is the same as that built in Lab 2. Finally, the Audio Output Control block configures the sound card hardware and plays back the AM radio programs.

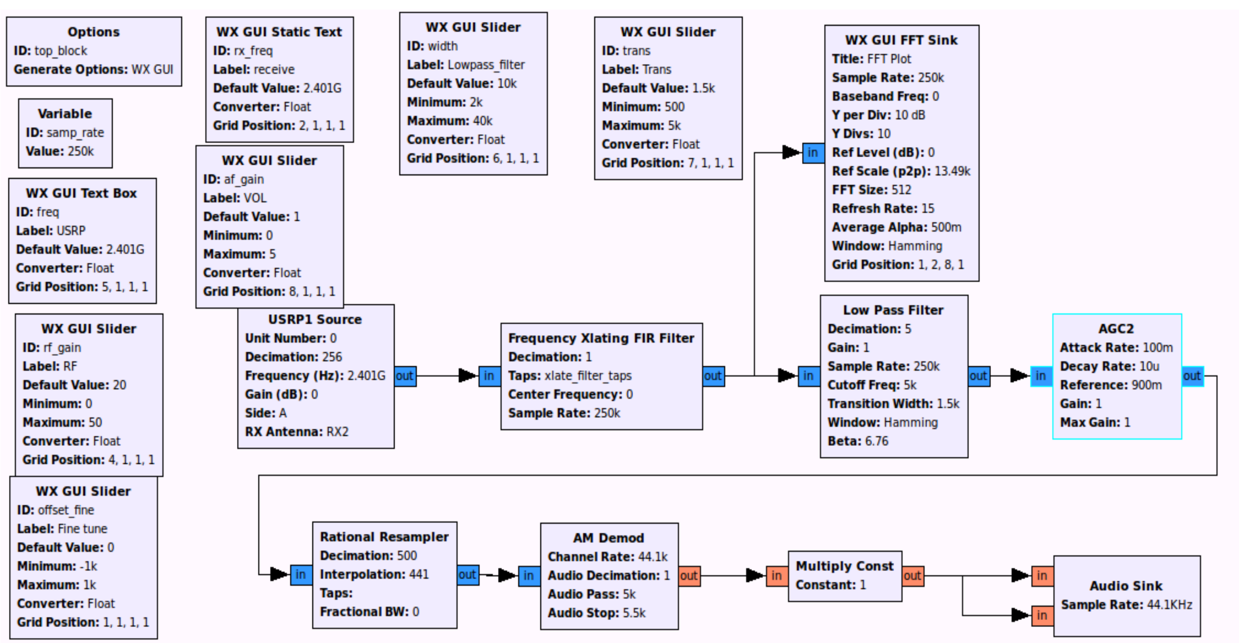


Fig. 8 The complete design of the AM radio receiver in GNU Radio Companion (GRC).

Attach the antenna to the USRP and execute the code. The screenshot of the FFT Plot is shown in Fig. 9. Students can adjust Coarse Tune and Fine Tune to search for radio stations. They can also change the spectrum settings to show the baseband or the RF band signals.

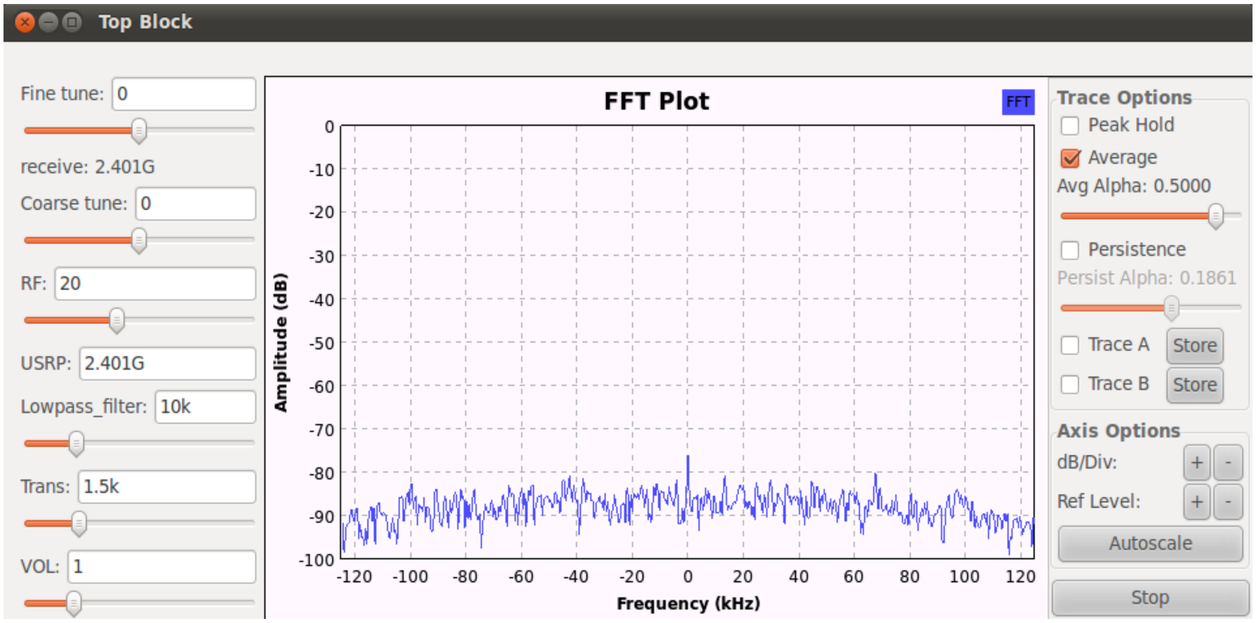
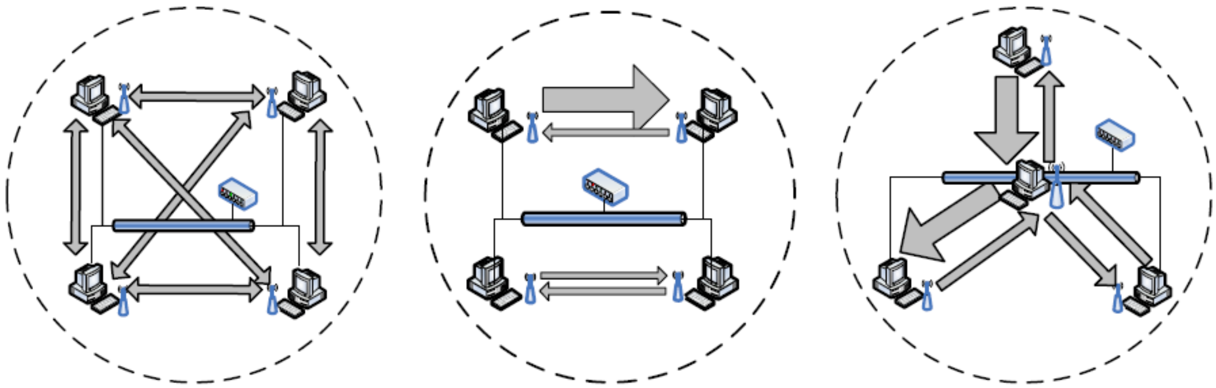


Fig. 9 The FFT Plot of the AM radio receiver.

Lab 8: Build and Experiment with WLANs

In this lab, students study the performance of four types of random access MACs: ALOHA, CSMA, CSMA/CA and PSMAC. Different from the point to point communication in previous labs, this lab uses multiple USRPs to build a wireless network. The MAC protocol implementations are developed from an earlier research project and reused for education purpose[5,6,7]. Students first configure the USRPs to form various network topologies. They then learn how to synchronize the USRPs, generate multiple data traffic flows to drive the network, collect packet level performance statistics, plot, and analyze experimental results. The throughput, delay, and fairness of different MACs are measured in the real radio propagation scenario.

The three types of network topologies used in the lab are shown in Fig. 10, including a single-hop ad hoc network under a uniform traffic pattern (i.e., each node is equally loaded), a single-hop ad hoc network under a non-uniform traffic pattern (i.e., one link has a heavier traffic load), and an infrastructure-based network under non-uniform traffic pattern. For each topology, students will start the transmissions for a sufficiently long period, and packet level statistics are collected for each packet transmitted and received. When the transmission is over, the student can compute the throughput of the network, the average delay of all the received packets, and fairness indices of the nodes with respect to delay. The sample experiment results with the ad hoc network topology under a uniform traffic pattern are presented in Fig. 11, with respect to the network-wide throughput, average packet delay, and fairness. Two MAC protocols are evaluated in these results, including CSMA/CA and PSMAC. In Fig. 11, PSMAC achieves significant gains over CSMA/CA, illustrating the high efficiency of gated-service based polling.



(a) Ad hoc mode with a uniform traffic pattern

(b) Ad hoc mode with a non-uniform traffic pattern

(c) AP mode with a non-uniform traffic pattern

Fig. 10 Various topologies for the testing medium access control protocols[5,6,7].

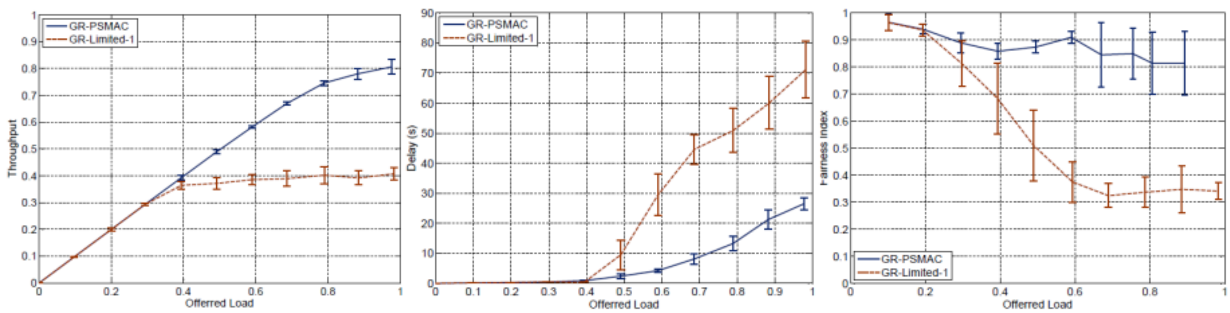


Fig. 11 Experiment results with the ad hoc network topology and uniform traffic pattern. Left: total network throughput. Middle: average packet delay. Right: fairness index[5,6,7].

ASSESSMENT

The SDR lab was test offered in Spring 2013 as ELEC 4970—Special Topics in Electrical Engineering: Software Defined Radio Lab, with five undergraduate students and one graduate student enrolled. We employed the Student Assessment of Learning Gains (SALG) web tool[12] to collect feedback from the undergraduate students. SALG is an on-line survey tool recommended by the NSF that measures student perceptions of their learning gains due to any components within a course. We modified the standard template provided at SALG to match the unique features of the SDR term projects, and had our students take the survey by the end of the semester. When the data was returned, we analyzed the raw data to reveal the effectiveness of our effort and to identify potential problems for further improvement.

The anonymous survey consists of 10 sets of questions (totally, 63 questions and comments). We find the SDR term projects well received by the students, although the sample pool is small. Some sample student comments are given below:

> "*By actually practicing the theory from Communication Systems, I am confident that I can apply this theory in practical radio design*."
>
> "*I have realized and found what I want to do for my Masters!!*"

> "*This confirmed what I learned in Communication Systems. Could be very beneficial to have this as a lab for Communication Systems.*"

Selected student survey scores for the effectiveness of the SDR lab from the Spring 2013 ELEC 4970 class are plotted in Fig. 12. The survey questions are:

> *As a result of your work in this project, what gains did you make in your understanding of each of the following?*
>
> *(1.1) The main concepts explored in this class.*
>
> *(1.2) The relationships between the main concepts.*
>
> *(1.3) The following concept that has been explored in this class: Modulation of analog signals.*
>
> *(1.4) The following concept that has been explored in this class: Transforming an analog signal to digital.*
>
> *(1.5) The following concept that has been explored in this class: Modulation/transmission of digital signals.*
>
> *(1.6) How studying this subject area helps people address real world issues.*

The optional scores for each problem and the corresponding meanings are:

No gains	*A little gain*	*Moderate gain*	*Good gain*	*Great gain*	*Not applicable*
1	2	3	4	5	0

The average score for the five undergraduate students in the class are plotted in Fig. 12. It can be seen that the average scores are all between 3 and 4 (i.e., moderate to good gain). The highest average score is 4.0 for Question 1.4; the lowest average score is 3.2 for Questions 1.1, 1.3, 1.5 and 1.6. Since the number of samples is small, we also plotted the standard deviations for each survey question, which are all around 1.0. From the survey, we found the SDR term projects did help to enhance classroom teaching and student learning of the abstract communications theory, although there was still room for improvement.

CONCLUSIONS AND FUTURE WORK

In this paper, we introduce the development of an SDR laboratory course for Auburn University's undergraduate wireless engineering curriculum. The SDR lab is based on the GNU Radio/USRP platform and covers the core topics in analog communications, digital communications, WLANs and cellular networks. In the near future, we will further improve the lab exercises and the lab manual, by incorporating more interesting materials and providing sufficient background materials, in particular, in digital signal processing. We will also offer the lab again and conduct more thorough surveys for further improvements. Once the lab is fully developed, we will work on promoting adoption of the SDR lab at other institutions.

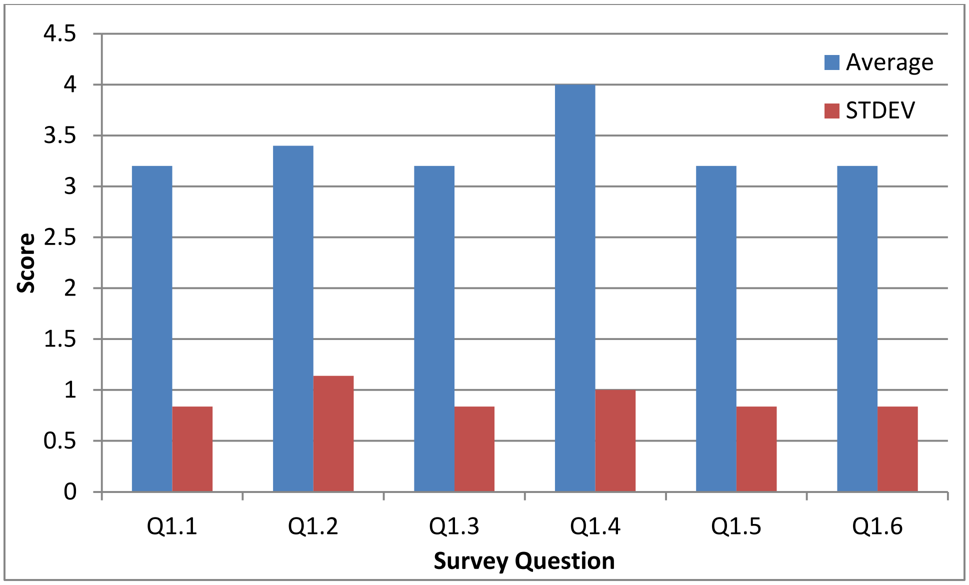


Fig. 12 Selected student survey statistics about the effectiveness of the SDR Lab for the Spring 2013 ELEC4970— Special Topics in Electrical Engineering: Software Defined Radio Lab class.

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