USING SOFTWARE DEFINED RADIO IN MULTIDISCIPLINARY SENIOR DESIGN PROJECTS AT CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

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ABSTRACT

In this year's senior design program at California State University Northridge (CSUN), faculty assigned two six-person teams with year-long design projects utilizing software defined radio (SDR). Students gained invaluable and in-demand expertise in this emerging technology, while fulfilling the criteria required by the Accreditation Board for Engineering and Technology (ABET). This paper focuses on the advantages to both faculty and students particular to using SDR in a senior design program.

Over the last three years the authors have been developing expertise and supervising student projects in SDR. While many schools offer study in SDR for graduate students, the authors felt that SDR was coming into such widespread use that undergraduates would benefit from exposure to the technology. In addition, upper division communications theory courses combined with the required foundations in programming, made the transition to SDR a logical and inevitable step in undergraduate electrical engineering education.

1. INTRODUCTION

Most electrical engineering programs require a culminating senior design project to demonstrate a student's mastery of engineering concepts and electrical theory. Furthermore, these projects are essential in fulfilling the required engineering program accreditation criteria. Colleges and universities use a variety of approaches to assign projects to students. At California State University, Northridge (CSUN), faculty often sponsor projects in their own field of expertise.

This year's senior design program incorporated SDR into projects assigned to two teams. The first project was the design of a data link capable of transferring images and telemetry from an unmanned air vehicle (UAV) to a ground station with SDR being used both aboard the aircraft and on the ground. The link was to be semi-intelligent and adaptive to changing propagation and noise. The UAV and project funding were provided by Edwards Air Force Base. The second project was the design of an amateur radio high frequency transceiver. The transceiver was to include state of the art features found on high end non-SDR models.

In addition to their design work, students were required to report to faculty sponsors acting as the "customer", giving students additional exposure to real world engineering tasks such as writing specifications, documentation, written and oral presentations, team design and management. This experience parallels the Accreditation Board for Engineering and Technology (ABET) requirements that engineering programs demonstrate that their students attain outcomes, including: designing a system or process within realistic constraints, functioning on multidisciplinary teams, communicating effectively, and identifying, formulating and solving engineering problems.[1]

Multidisciplinary projects are often difficult to develop. SDR has proven to be an excellent basis for projects because of the wide spectrum of areas it encompasses. SDR provided the students the flexibility to rapidly explore different designs and features while challenging their mastery of concepts in communications, electronics and programming.

2. SENIOR DESIGN AT CSUN

At California State University (CSUN), the senior design project is implemented as a one year course in which students are assigned to work on a group project with three to five other students. This group project is to be completed in two semesters. Additionally, each student enrolled in senior design is assigned an individual project. This paper focuses on the group project.

Engineering programs are designed to demonstrate the outcomes required by ABET, the accrediting agency for engineering and other technology programs in the U.S. While many of the required outcomes are demonstrated in the course of standard engineering coursework, the following outcomes are best demonstrated in the context of a culminating experience such as the senior design project:

- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

- an ability to function on multidisciplinary teams
- an understanding of professional and ethical responsibility
- an ability to communicate effectively

3. ADVANTAGES OF SDR IN EDUCATION

Many of the aspects that make SDR attractive to the military and industry also make it ideal as a learning and teaching tool. Recently, the authors experimented with using SDR in classroom demonstrations for an upper division communications course. It is widely known that communications theory can be especially abstract and math intensive.[2,3] The authors felt that students would be motivated and their learning would be enhanced by relating abstract communications concepts to tangible examples students were already familiar with. Using SDR, the authors developed a series of demonstrations centering on the basic principles of the time domain – frequency domain relationship, filtering, AM and SSB modulation and demodulation, and FM modulation and demodulation.[4] The use of real world signals, such as AM/FM broadcast and SSB communications, made these demonstrations particularly effective in motivating students to continue study in communications.

One advantage of using SDR in this way stood out almost immediately: SDR allows the rapid implementation of even complex receiver or transmitter systems. Using such readily available tools as GNU Radio and GNU Radio Companion (GRC), a complete SSB receiver can be programmed in less than an hour.[5] Similarly, AM and FM receivers and transmitters for all modes can be created in a single sitting. Modification and improvement are equally easy.

Another advantage of SDR is its inherent ability to transfer a theoretical principle or equation directly into a working system. GNU Radio and GRC include a number of basic math blocks, including adders, multipliers, dividers and delay stages. With them, the designer can go directly from a formula to a functioning unit in short order. A good example of this is FM detection, i.e. finding the instantaneous frequency of a signal. The equations for a complex (I and Q) signal are outlined below:

$$f = \frac{d\phi}{dt}$$

$$\phi = \tan^{-1}\frac{Q}{I} \Rightarrow \frac{d\phi}{dt} = \frac{d}{dt}\tan^{-1}\frac{Q}{I}$$

which can be approximated in a complex sampled system as:

$$f = \frac{d\phi}{dt} = \frac{I_n Q_{(n+1)} - Q_n I_{(n+1)}}{I_n^2 + Q_n^2}$$

This is implemented in GRC as shown in figure 1, below.

Perhaps as obvious as it is important is the fact that using SDR in senior design, either as a centerpiece of the project or simply as an implementation tool, exposes the students to an emerging technology that will have an increasing role in communications and signal processing.

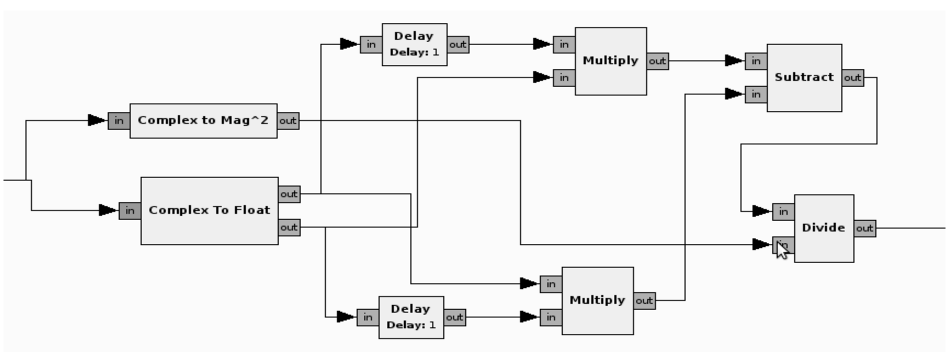

Figure 1. FM Demodulator

Finally, using SDR brings together students from various disciplines, including electronics, radio frequency design, computer engineering, and computer science. This allows students to work in a multidisciplinary team.

As mentioned above, previous senior design projects had difficulty moving from concept to design to implementation in the two semester time limit. Senior students, already strapped for time with course work, find it difficult to even prototype a complex system, much less go through design iterations and improvements. SDR speeds this process by an order of magnitude. This will be discussed later in this paper.

4. UAV SENIOR DESIGN PROJECT

A team of six students was given the task of designing and implementing a telemetry link with a small unmanned air vehicle (UAV) that was provided by Edwards Air Force Base, who funded the project. The constraints on the implementation were that the link had to be in the 70 cm UHF Amateur Radio Band, comply with FCC regulations for a data link in that band, be under three pounds in weight, fit inside the UAV (which has a wingspan over slightly more than 9 feet), and use SDR with the Ettus USRP.[6] The system was required to downlink, on command, image data from an on board camera, GPS data, battery voltage, vehicle temperature and a snap shot of the received radio spectrum as seen from the vehicle.

This last feature was included to deal with potential interference problems and lay the groundwork for future work in cognitive radio. A further foundation for this work was the requirement that the system be agile in frequency, mode and data rate. Additionally, the link health would be measured and the results presented to the ground controller. For this year, decisions on the link parameters would be made by the ground controller and the vehicle would change them only on command. However, the vehicle would automatically return to a default "phone home" frequency and mode in the event of loss of link.

The overall system would be controlled from a GUI at the ground station which would display all data and images, while allowing the input and queuing of commands to the vehicle. A screenshot of the ground control screen is in figure 2.

The students began their work with GNU Radio and GRC as a basis for their initial experiments with the data link. While the GNU Radio software worked well initially, the UAV team rapidly found it to be limiting and are creating their own blocks as of this writing. They have used the GNU Radio blocks as a starting point and are integrating them into a master controller process both for the UAV and the ground station.

5. AMATEUR RADIO DESIGN PROJECT

The second group of six students was given the task of designing an all mode high frequency amateur radio transceiver. The requirements were that the transceiver operate on the amateur bands from 1.8 to 30 MHz in the CW (Morse Code), SSB, AM, FM and two digital modes. The transceiver would use SDR and the Ettus USRP, but interface with a receive pre-amp and a 100 watt transmitting amplifier provided by the senior design faculty. The project was constrained mainly by the Part 97 FCC rules for bandwidth, spectral purity and mode parameters.

One of the chief requirements for this project was that the end product be a radio which would be familiar to most

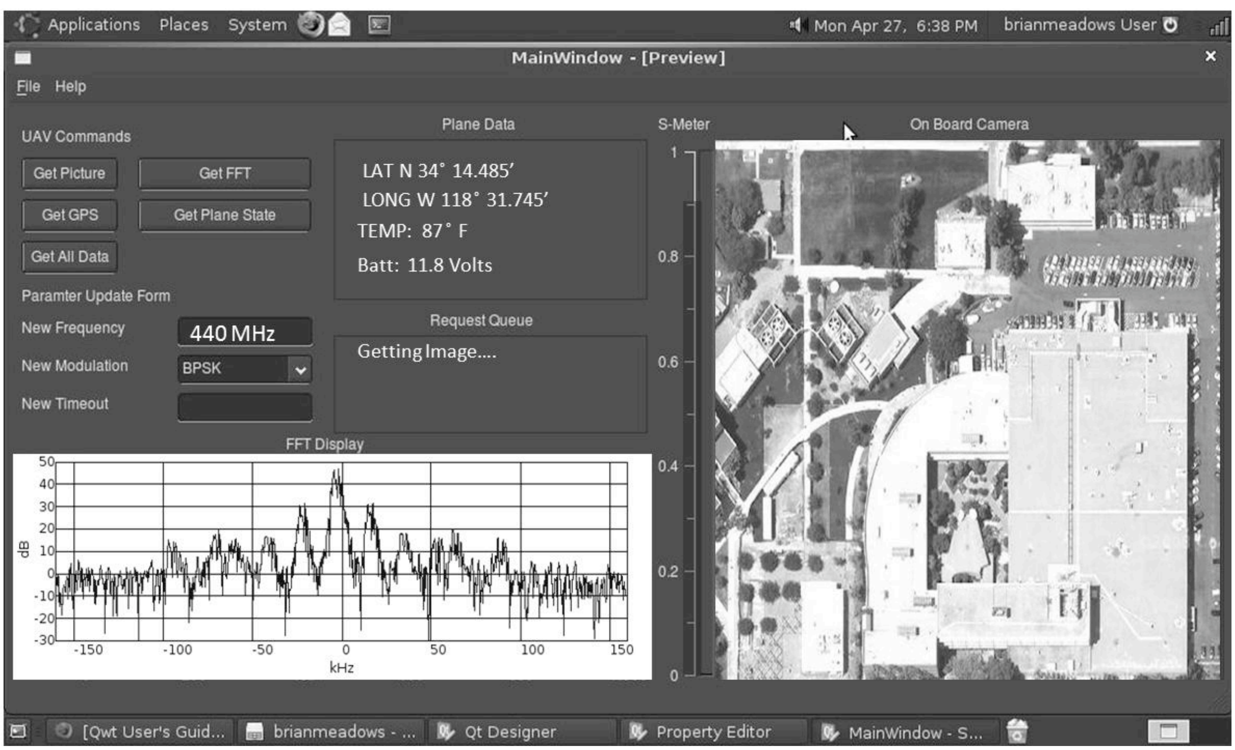

Figure 2. UAV Ground Control GUI

radio amateurs and easy to use by someone with limited technical experience. The transceiver would incorporate displays and controls found on most high end hardware transceivers, such as signal strength meter, large frequency display, spectral display of the band in use, variable bandwidth filters, squelch and half-duplex operation. The group was challenged to make the operation of the radio as intuitive as possible.

As with the UAV group, the Amateur Radio group used GNU Radio and GRC as the basis for their work in developing modulators and demodulators for various modes. While the existing software provides a modulator and demodulator for FM, the group was required to develop their own FM system. They tried various methods for modulation, including indirect FM (Armstrong's method). These did not provide satisfactory results. They settled on a CORDIC modulator which was simple to implement. For detection, they developed the instantaneous frequency detector outlined earlier in this paper. Both schemes are similar to the existing blocks in GNU Radio. For SSB and CW, they designed a system using Weaver's method for reception. For transmission, the USRP's frequency shifting function makes the operation trivial. AM was a direct implementation of the AM equation for transmit and a magnitude detector for receive.

Again, like the UAV group, the Amateur Radio team faces a number of problems with integration, including managing processor load and the more mundane issue of interface with the receive and transmit amplifiers. A screen shot of their GUI is in figure 3.

6. INCORPORATING REAL WORLD SKILLS

One of the key goals of Senior Design at CSUN is to begin the transition from students as learners to productive engineers. Real world skills are often overlooked in courses concentrating on theory. Crucial among these skills is design experience. This creative aspect of engineering is personal and experiential; something a student must practice to learn. SDR offers an essential vehicle for design practice. With SDR, senior design students can rapidly create and test various approaches to solving the problem and receive feedback from faculty and peers. Allowing them to focus on the design process enables students to develop and refine their creative skills within the time constraints of the senior design course.

In addition to design skills, Senior Design requires students to develop oral and written communication skills. Students must present oral weekly status reports and document their work. Both teams presented their status reports at the same session and this had the benefit of the teams sharing information and discoveries. This occurred often enough that it greatly accelerated development on both projects, with teams avoiding mistakes already made and dead ends already explored.

Finally, it should not be overlooked that SDR itself is a real world skill. The students put directly into practice theories encountered in class. They also developed a vital, new mind set for communications, not based on compromise and bound in hardware, but adaptive to conditions at the time a message is sent or the immediate user requirements.

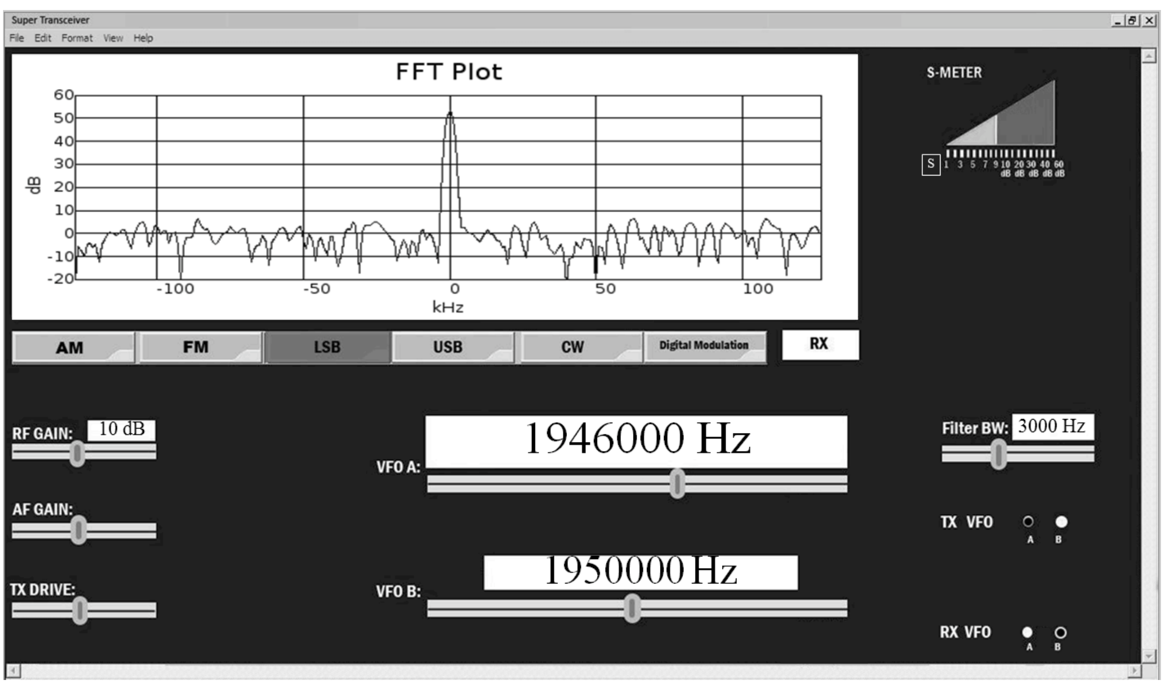

Figure 3. Amateur Radio GUI

7. RESULTS OF THE PROJECTS

At the end of the Spring 2009 semester, both projects have completed their basic design and implementation phases. Both teams presented their work in progress to faculty and representatives from industry, including Edwards Air Force Base. Each team presented their design goals and the challenges they still face. Based on the comments from the industry representatives, the Senior Design Project is accomplishing its goals of improving the communications skills, team work and multidisciplinary design capabilities of students.

The UAV Team has perfected a communications link using the USRP and their own software based on the GNU Radio code. They have demonstrated reliable data communications with images and test data being sent a distance of a quarter mile using the 20 milliwatt output of the USRP to a quarter wave antenna. The mode is BPSK at a data rate of 90 Kbits per second. The vehicle system has successfully downloaded images on command from the ground station. The UAV Team has developed their ground station GUI and is in the process of integrating all the command and receive tasks. Some of the challenges they face include the integration of the USRP and computer into the UAV with its attendant weight and power restraints. The test phase of the project is being planned and should be completed during the Fall 2009 semester.

The Amateur Radio Team has successfully demonstrated transmit and receive capabilities on AM and SSB. During Summer 2009, FM is being finalized as other team members are exploring the digital modes of FSK (radio teletype) and BPSK31. CW (Morse code) transmit will be addressed before the beginning of the Fall 2009 semester. The team has developed their user GUI as shown above. Their main challenges will be to integrate all the software into a functioning system and interface with the transmit and receive amplifiers. During Summer 2009, they are working on improving the throughput efficiency of their software to minimize the processor load on integration.

8. FUTURE WORK

The use of SDR in Senior Design at CSUN is part of an overall effort to introduce SDR into the graduate and undergraduate courses of study. The authors intend to expand the use of SDR as a teaching tool and a subject of study. This work is primarily focused on increasing the exposure of SDR to undergraduates.

In a course in analog communications, the authors have already conducted and reported on preliminary trials of using SDR to demonstrate complex communications theory, using real signals in the classroom to motivate students. With promising results, the authors are seeking to expand the use of the demonstrations to include courses in digital communications.

Immediate plans for the study of SDR itself are centered on the Senior Design Program. Many of the requirements for the UAV telemetry link were created with an eye toward building on these features with future teams. Most of the operation of the ground control and vehicle SDRs are currently directly controlled by the ground controller. However, these same features, such as frequency and mode agility, can be implemented automatically, moving the project toward cognitive radio.

In addition, both projects currently use a PC or an embedded PC to perform most of the signal processing functions. The authors intend to continue using PC based SDR as a development tool, but then carry the design into a more practical implementation using field programmable gate arrays (FPGAs). The goal is to complete the design cycle with a usable system or device that could actually be manufactured in quantity. This phase would expose students to all aspects of design engineering and greatly expand the possible applications that could be tackled in Senior Design.

The authors plan to expand on their success in achieving the goals of giving students communications and multidisciplinary design skills; outcomes demanded by accreditation and prized by industry. The authors will widen their partnership with local companies and provide employers with engineering graduates experienced in the emerging technology of SDR.

9. REFERENCES

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