SOFTWARE DEFINED RADIO (SDR) ON RADIOCOMMUNICATIONS TEACHING

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Abstract

The recent outbreak of Software Defined Radios (SDR), where traditionally hardware components are substituted by software, have revolutionized the way we understand and manage radiocommunications. The current state of technology allows low cost SDR receivers to tune emissions in a simple way with almost no experience and little effort. The great flexibility of this equipment allows a perfect adaptation of the practice part of the subject to the theory objectives and makes possible to learn outside the classroom, something unthinkable until now. To achieve this, the student only needs a low-cost SDR receiver, a computer and some free software. This paper presents a new teaching methodology for practicing radiocommunications subject using a workstation based on a SDR device that can receive, display and analyze radio transmissions. Subject learning outcomes and skills are acquired and strengthened through experimentation with this new kind of devices. This platform also represents a significant saving because avoids our university to buy expensive and closed "training kits".

Keywords: classroom demonstration, radicommunications education, signal processing, software defined radio.

1 INTRODUCTION

The recent outbreak of Software Defined Radios (SDR), where traditionally radio hardware components are substituted by software, have revolutionized the way we understand and manage radiocommunications. Radio equipment and solutions based on SDR devices are a fact in a commercial and industrial level as they are present in many communications equipment: mobile phones, radio equipment for defense and security, etc. However, the educational use of the SDR equipment is almost non-existent.

This paper presents a new teaching tool for practicing radiocommunications where subject learning outcomes and skills are acquired and strengthened through experimentation with a software defined radio (SDR) device.

A SDR device can receive, display and analyze radio transmissions in different spectrum bands and of different nature with all its associated parameters. By using SDR in the classroom, communication systems are demonstrated to students with no practical experience with communications systems, using real and very familiar radio signals like FM radio, TV or radio-teletype.

The students can learn the use and operation of these devices through a number of practices that have been defined, putting into practice what they have learned in the theoretical study of analog and digital modulations, and in the understanding of certain concepts of a radio receiver chain.

The next section of this paper provides a background on some of the issues that our university currently face when practicing radio communications and explains the need for a new tool in the course. This section is followed by an overview of the SDR technologies and the features that make it a great platform for classroom practices. The implementation section describes the particular SDR platform (hardware and software) used by the authors and the demonstration section presents a practice created for the students. Finally, the results section describes the benefits of using these demonstrations in a classroom and presents the conclusions.

2 BACKGROUND

In the University Center of Defense (CUD) of the Spanish Naval Academy (ENM) a degree in Mechanical Engineering is taught from 2010-2011. The study plan includes basic subjects common to industrial engineering, specific subjects on mechanical technologies and intensification subjects on naval technologies. These last ones arise due to the dual nature of the studies that enables graduates to obtain in parallel a double degree after graduation: Degree in Mechanical Engineering and Officer of the Spanish Navy. The compulsory subjects of naval intensification, placed in the 4th and 5th year, allow students to supplement their knowledge in the naval world, which is where they will play its professional activity.

The subject of "Radiocommunications Systems" (SRCOM), whose teaching is taught in the first semester of the 4th year with an intensity of six credits in the European Credit Transfer and Accumulation System (ECTS), is one intensification subject with a clear orientation towards naval technologies but certainly far away from the mechanical engineering. Nevertheless, this subject is needed in the curriculum, as it is essential for the future of a Navy Officer.

The aim of SRCOM subject is to provide students, which have no practical experience with communications systems, with a basic knowledge, both theoretical and practical, on the principles of radio communications. The practice part of the course (with a weight of 1 ECTS) is composed of several experiments related to analog and digital modulation, antennas and radiowave propagation, that allow students to put into practice various concepts learned in theory.

Since the beginning of this subject during the academic year 2012/2013, various training kits of a reputable german brand of training equipment solutions for education have been used. Nevertheless, these experiments are predefined and do not perfectly suit to the subject. The experiments are focused on students with deeper knowledge in telecommunications topics and are too specific, leading to a difficulty on the adjustment of practices to the theoretical contents of the subject. These experiments are based on very closed kits that do not allow to experiment with new radio technologies.

Furthermore, the learning kits work with simple or simulated data or signals, so sometimes students lose the perception of reality of what they are doing. To work with real signals, more complex and expensive equipment is needed with a steep learning curve and the application of these tools may not be possible for a typical undergraduate student. In addition, system development would require a significant amount of time, several hours, if not weeks, to achieve a functioning prototype.

One of the most important tasks set out in the Bologna process is "learning to learn". To achieve this task, students must build their knowledge from their own learning and experience. In many cases, students (and especially inside the ENM) do not have enough time to acquire this knowledge through experimentation or may not have access to facilities and the aforementioned kits when they want. In addition, radio receivers are generally expensive for the CUD and unaffordable for students, so their experience outside the laboratory becomes impossible.

Taking into account the previous experiences from [1] and [2], a new workstation based on a very low cost software-defined radio (SDR) device that can interface with free software is presented, allowing our students to experiment with real radio-signals and systems from the desktop.

3 THE SOFTWARE DEFINED RADIO

A software-defined radio (SDR) is a radio communication system where components that have been typically implemented in hardware are instead implemented by means of software or programmable hardware on a personal computer. Because a software-defined radio has a significant portion of the system defined in software, it has several advantages: ease of development, flexibility in reconfiguration, and cost effectiveness.

SDRs typically consist of an RF front end (transmitter or receiver) with an analog-to-digital or digital-to-analog converter. In its purest form, and SDR receiver might consist simply of an analog-to-digital convert chip connected to an antenna.

Figure 1 shows a block diagram of a software SDR receiver [3]. The RF (radio frequency) tuner converts analog RF signals received by the antenna to analog IF (intermediate frequency). The A/D (analog to digital) converter that follows, digitizes the IF signal thereby converting it into digital samples. These samples are fed to the next stage which is the digital downconverter (DDC) shown within the dotted lines. The digital downconverter is typically a single monolithic chip, and it is a key part of the SDR system. A DDC translates the digital IF samples down to baseband, filtering and limiting the signal bandwidth. The digital baseband samples are then fed to a block labelled “digital processor” which performs tasks such as demodulation, decoding and other processing tasks. From the A/D stage, most of the digital signal processing is done by software.

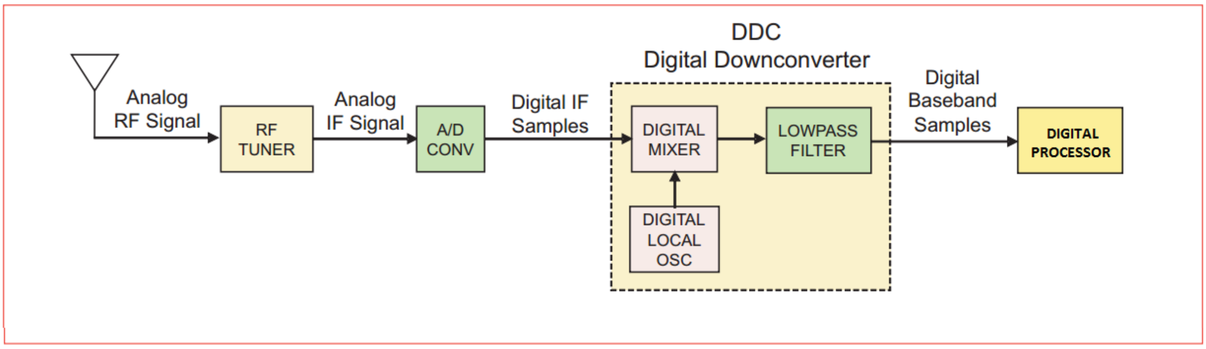

Fig. 1 SDR receiver block diagram.

4 IMPLEMENTATION OF SDR

For the purpose of our course each student working station is equipped with a SDR device including a little antenna and a laptop or tower computer running Windows supporting various software packages. This equipment (Figure 2) allows students display, record, analyze, and process a wide range of radio signals.

Fig. 2 Student workstations used in the CUD Labs with SDR software running.

4.1 SDR Hardware

The high cost of equipment traditionally used to execute a radiocommunications laboratory might be prohibitive to universities that have low budget, even the new SDR devices may have a high cost depending on the models used.

It was recently discovered that small, compact, and easy-to-use USB sticks devices, originally meant for digital television (DVB-T) reception, are capable of receiving RF radio signals acting as software-defined radio receivers. These devices based on the Realtek RTL2832U demodulator and thus called RTL-SDR devices, are capable of streaming 8-bit samples through a USB interface at a maximum rate of 3.2MS/s. A variety of RTL-SDR variants based on this demodulator are currently available on the market. The major difference between them concerns to the specific RF tuner used with the RTL2832U. Figure 3 below shows one of such variant used in our classrooms based on the Rafael Micro R820T tuner, which is capable of tuning between 24-1766 MHz. This particular USB-stick is widely available at a cost of 30 €.

Fig. 3 RTL-SDR device used in the classroom and a simple antenna (comes with the SDR)

In addition to the existing equipment in the laboratory, students can acquire these ultra-low cost RTL-SDR devices and process actual real-world signals using their own hardware at home, which we believe particularly impactful for many of our students. Due to the relatively large tuneable bandwidth, students can explore a large range of the RF spectrum and "see" signals such as AM/FM radio, digital television, amateur radio, GPS, and repeat the exercises done at the laboratory.

4.2 SDR Software

There are a number of software packages that can be used to process the real-time radio signals received from the RTL-SDR. Very popular and known packages as GNU-Radio [4], LabVIEW [5], MATLAB [6], all of them with RTL-SDR support, have been tested for our objective, but we finally propose to use PothoSDR [7] and SDR# [8], which is what the authors are using in the classroom. Alternatives like MATLAB or LabVIEW were discarded due high licensing cost and GNU-Radio was dropped because it needs a working Linux platform.

4.3 Pothos-SDR

The Pothos project [7] is a complete data-flow framework for creating topologies of interconnected processing blocks. Topologies can be designed and tested graphically using a GUI (Graphical User Interface) design tool that accompanies the library. Some prominent features of the GUI are live evaluation, live topology reconfiguration, support for networked topologies, and embedded widgets and plotters.

The project also has a diverse set of processing and hardware support toolkits. Software defined radio (SDR) is one of the major use-cases for Pothos. To support SDR, Pothos has a toolkit for interfacing with SDR hardware, and contains graphical design tools with live signal-analysis plotters, GNU Radio signal processing blocks, and various drivers for hardware support (including RTL-SDR). New processing blocks created by users in C++ or Phyton can be easily added.

Figure 4 shows a typical GUI developed in Pothos which depicts a "spectrogram", a visual representation of the spectrum of frequencies in a signal as they vary with time, using a RTL-SDR device as a radio signal source.

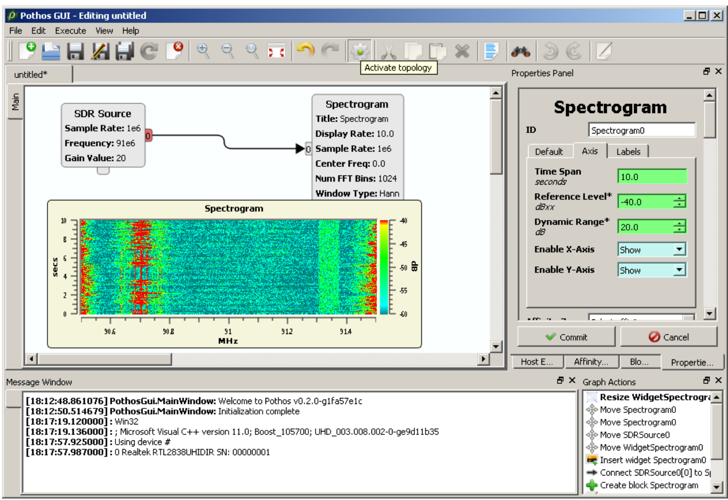

Fig. 4 Pothos GUI representing a spectrogram

4.4 SDR-Sharp

SDR# (pronounced "SDR Sharp") is the most popular free RTL-SDR compatible software in use at the moment running under Windows. It is relatively simple to use compared to other SDR software and has some advanced features. It has a useful modular plugin type architecture, and many plugins have already been developed by third party developers. The basic SDR# download without any third party plugins includes a standard FFT display and waterfall, a frequency manager, recording plugin and a digital noise reduction plugin. SDR# also decodes RDS signals from broadcast FM. Figure 5 shows the typical SDR# user interface with a waterfall wideband spectrum display.

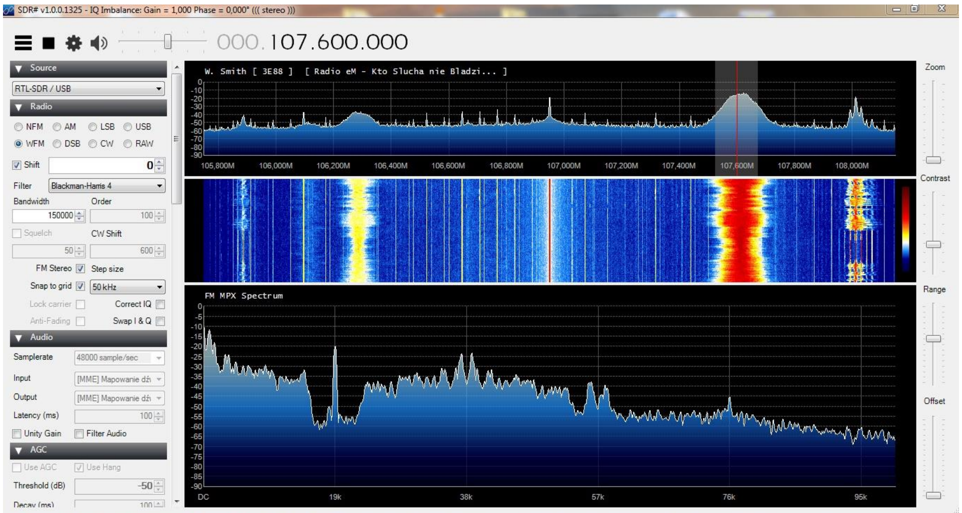

Fig. 5 SDR# GUI representing a FM band reception

5 DEMONSTRATION: AN FM RADIO DEMODULATOR

In this section, we present a practice created for the students that has been developed for use in our course. For this practice we utilize the abovementioned SDR workstation for data collection and for development, implementation, and testing of the digital signal processing algorithms

This practice demodulates a live audio signal from a RTL-SDR source. Real FM broadcast signals are available essentially everywhere, at all times. The practice project has been structured to guide students through a series of activities, ultimately leading to a complete, real-time implementation of an FM receiver. Figure 6 shows the control panel consisting of a real-time FFT (waterfall) that shows a portion of radio spectrum and an audio waveform display.

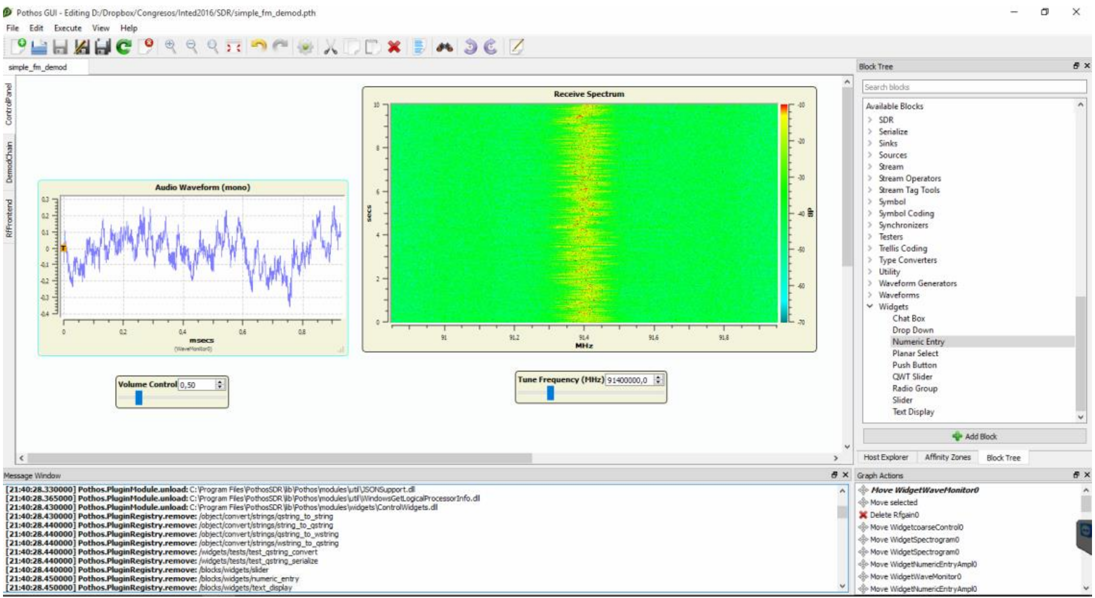

Fig. 6 FM Radio Demodulator build using Pothos-SDR (control panel)

Flowgraph shown in Figure 7 consists of just a few blocks: a quadrature demodulator followed by a low-pass filter that is used to extract the audio signal. This audio signal allows the student to listen to live FM radio.

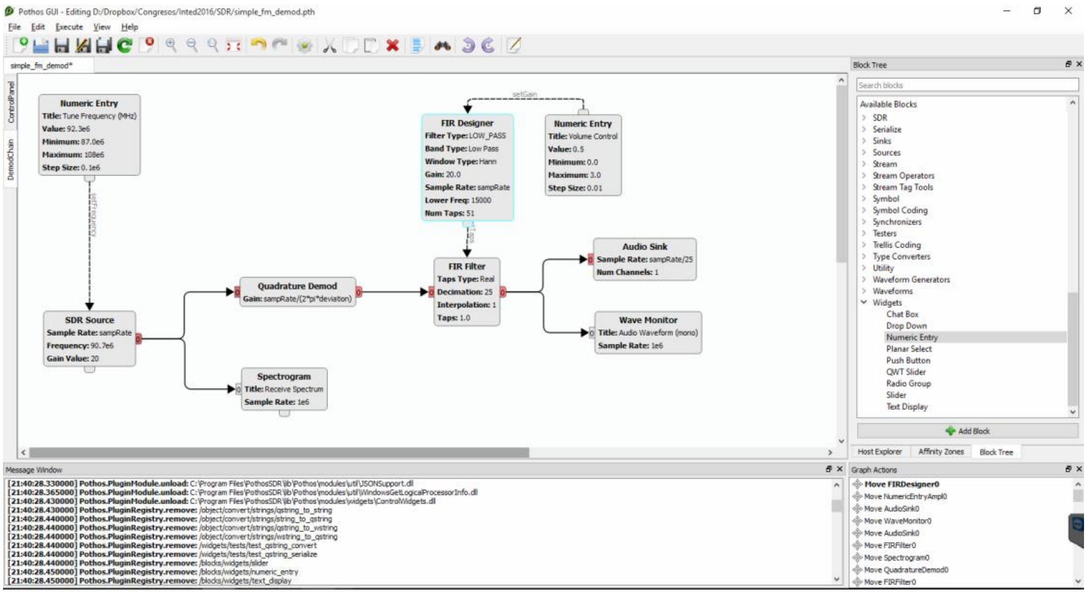

Fig. 7 Building blocks of the FM Radio Demodulator using Pothos-SDR

6 RESULTS AND DISCUSSION

A very flexible tool has been discovered, adaptable to the radiocommunication subject in any related university degree. The great flexibility of this equipment allows a perfectly adaptation of the practice part of the subject to the theory objectives and also represents a significant saving because avoids our university to buy expensive and closed "training kits".

This new tool enables the student to continue learning at home, facilitating the realization of those practices outside school hours, something unthinkable until now. To achieve this, the student only needs a low-cost SDR receiver, a computer and some free software tools.

The inherent flexibility of SDR, coupled with the ability to capture, visualize, and process real-world signals, provides numerous benefits in classroom and laboratory settings. Experimentation with radio transmissions of the "real world" allows the students to assimilate concepts better and definitely motivates the alumni achieving surprising results. Furthermore, first contact to SDR is increasingly important for students wishing to pursue a specialization course in the telecommunications, networking, and radar fields.

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