Final Report - "SDR-Powered Education" Project

Abstract

It all began when I first saw ARDC's ad at GNU Radio Conference 2021 held both in-person and virtual. I was one of the virtual attendees of the conference. It was the conference that I had been following for some years and that I had been looking forward to travelling to sometime. Later I decided to write to ARDC grant team about our educational project that we newly initiated. Having received positive feedback, I applied for educational grant. After our proposal got accepted and funded, we embarked on a journey for reaching our goals. Since the beginning, our main goal has been to to provide our students with resources that will assist them in learning communication systems with hands-on experimentation using Software Defined Radio (SDR), to establish a regional SDR center for radio science research, to become a model for other universities that plan to take a similar approach, and to serve broader community through educational outreach programs. We have made a big progress towards our goals. This report summarizes what we have achieved so far and where we failed during our journey. The first section outlines enhancements we have made in the current laboratory course. Section II provides information on research projects that we have been conducting. Conferences and outreach activities are detailed in the third section. And, we discuss our results, challenges we have faced, and suggestions in the last section.

Section I - Course Enhancements

At [TOBB ETU](), the course "[ELE361L]()", titled "Introduction to Telecommunication Systems Laboratory" is a required course for 3rd or 4th year undergraduate students. This course had been offered two times before ARDC grant got received. New Fall 2023 term started in September and our first laboratory session was held on 29th September 2023. The program is 10-week long in total and it all went well as scheduled. I have been receiving very good feedback. According to the surveys students tell they **"grow interest in communication systems"** and they **"learn tools that are helpful in their future careers"**.

Thanks to the support of ARDC, the enhancements in the program are outlined in this section.

Update of Course Website

We had a single-page, text-based, unfriendly course website before. [Our course website]() got updated, and gained its modern appearance. Main page outlines key aspects of the course which are
- Openness
- Modularity
- Real-world signals
- Professional development
- Mobility/Remote opportunity
- Software-based
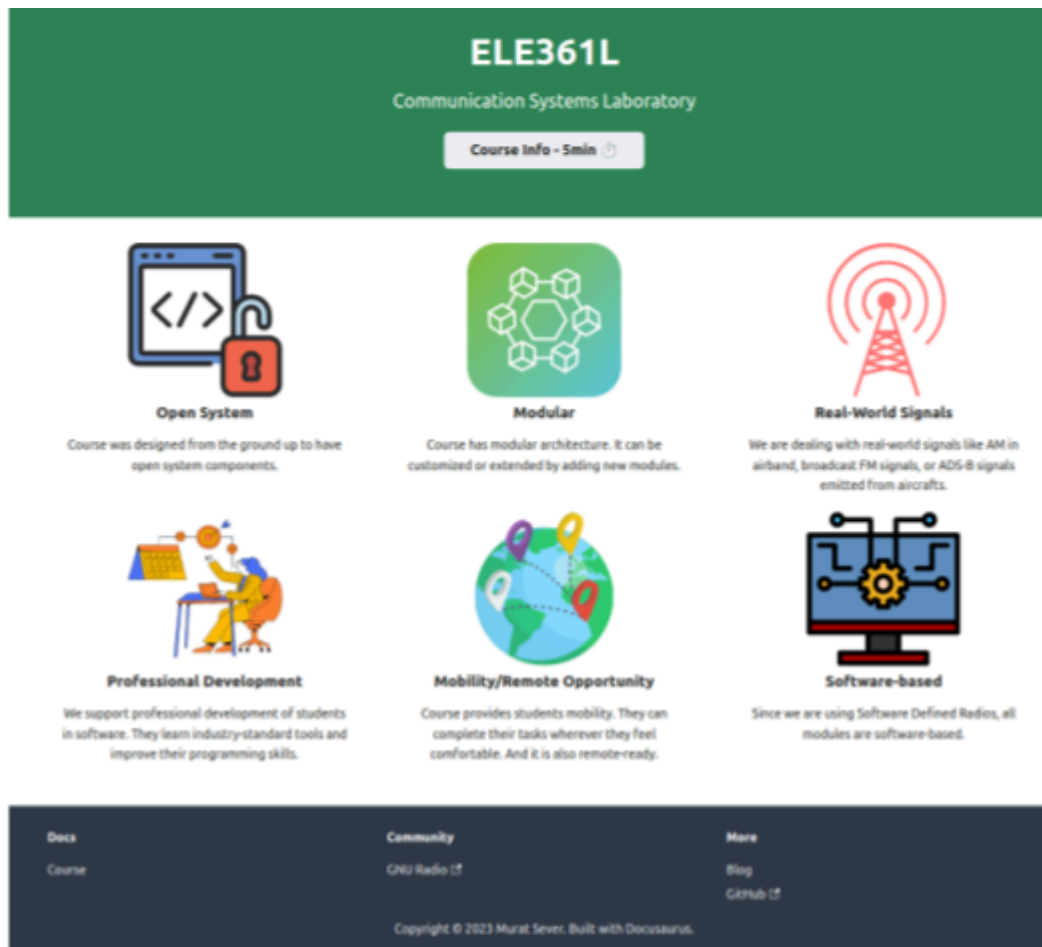
Our renewed course website

The new website contains
- **course**,
- **blog** and
- **outreach** pages.

The **course** page gives information about laboratory course. All research activities get reported under the **blog** page. And you can find all outreach educational events under the **outreach** page.

Website has a link to GitHub page that contains our public repositories.

New term, SDR Kits and Team Forming

We had insufficient number of SDR kits before the grant. This forced us to create a team of 3-4 students to experiment together. To increase the availability of equipment required for experimentation, we purchased additional SDR kits, so that we have enough number of SDR kits available for lab work. Our SDR kits were ready-to-use before the start of the course. I managed to design a "box" and a sticker for the kits. The sticker has a qr code that points to the course webpage. I used FM broadcast spectrogram record from IQ Engine as

background image. The box includes RTL-SDR Dongle, Dipole Antenna Base, 2x Telescopic Antennas, Extension Cable, Flexible Tripod Mount, Suction Cup Mount.


SDR Kit boxes with sticker

The course was taken by more than 70 students. We had teams named after by AR phonetic alphabet. We were also able to supply the SDR kits for students who want to perform lab work individually. There were 31 teams of two and 6 individuals in total. So, we used Turkish AR phonetic alphabet in addition to international phonetic alphabet for the team names.

Snapshot of team list on GitHub

Capture-the-Signal (CTS) Activities and Generating Over-the-Air Signals for Educational Purposes

I added some CTS activities to engage students more into lab. Students grow more interest through these CTS activities. It works like this: I give little clue about what I am going to transmit like frequency band at the beginning of the activity. Then the students use general purpose SDR applications (SDR#, gqrx) on their laptops with their SDR kits to scan and catch the signal. I was able to broadcast in the class in AR/ISM bands, and students were able to catch, record, and demodulate over-the-air signal. These activities included **spectrum painting, AM, and FM broadcast**. Since we were celebrating the 100th anniversary of the proclamation of the Republic of Turkey on 29 October 1923, I transmitted specially designed logo over the ISM band using GNU Radio OOT module "Spectrum Painter".
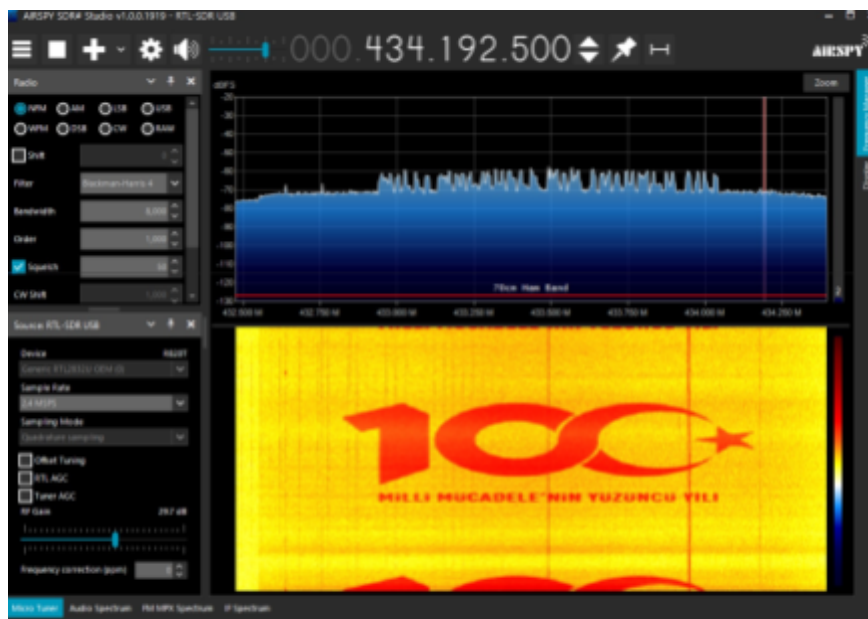
Spectrum painting CTS activity: 100th year anniversary of Turkish Republic

Students enjoyed the CTS events, below is a photo taken in the class.

Students working hard to catch the signal in the class!

Amateur Radio Introduction

I have given some information to students on amateur radio. I talked about what the hobby is about, what its benefits are and how to obtain a license. One of the modules contains a record from a repeater. So, they learn what a repeater is, how to communicate over a repeater, what CTCSS tone is in the module.

Adding Python and C/C++ Language Support

MATLAB was used as programming language for the assignments. But survey results show that students prefer using Python over MATLAB. So we decided to port notebooks from MATLAB to Python. We also added a Python module for students who are new to it. There is also request for C/C++ language support but we couldn't meet this request because most of the students chose Python as the primary language in the surveys.

Real-time DSP on Embedded Device

We designed a standalone system what we called "Communication Educational Kit (HaKi)" in order to apply RF signal processing on an embedded device. Simply the kit is a low-cost integrated development environment that includes open-architecture hardware and software and it can be utilized to visualize and process RF signals. We later also developed a simple GUI that easily launches the installed software with just one click making it easier to use for ones with little knowledge on devices or tools. Left image below shows the main window and when Wide Band Frequency Modulation radio button is clicked gqrx application is launched as shown in the right image all configured to run with Wide Band FM modulation and use RTL-SDR. This way the user can easily watch most common signals like Narrow Band Frequency Modulation signals by clicking mobile radio button; Industrial, Scientific and Medical or (ISM) band signals by clicking on remote control button and ADS-B signals by clicking on the plane button. They can also start an IQ record with their last tuned frequency.
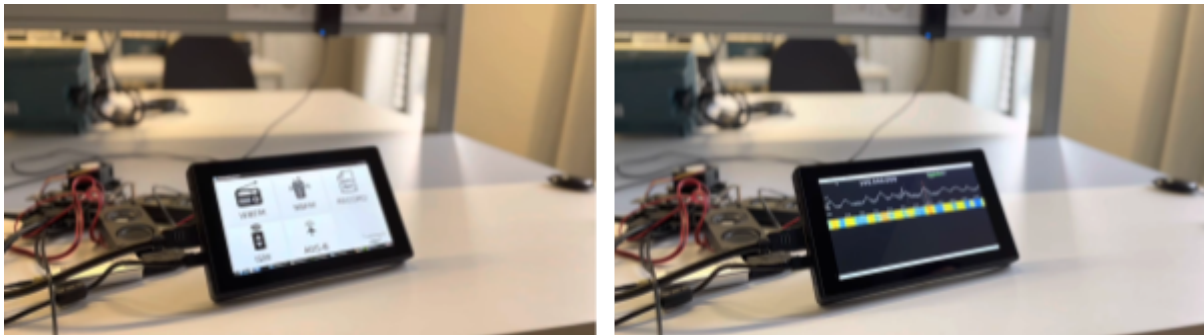
HaKi GUI main window (to the left) and gqrx running (to the right)

Adding Autograding to Lab Assignments

As part of their assignments, students have to capture the signal of interest first by tuning to correct frequency. They prove this task by taking a screenshot. Having captured the signal, they record it for a few seconds, save it as an IQ file in their homework. After that they test their algorithm on the record and put the resulting speech in a sound file. Clearly, this

produces a lot of lab artifacts to be checked for correctness. We were not able to check all the artifacts for their correctness since this requires applying some AI to the files. We will be continuing to work on this item for the next term.

Section II - Research Projects

Our blog page on the website contains information about some interesting projects we have been conducting. So far, we have posted about
- Vessel Tracking using AIS
- End-to-end 5G Test Network Creation
- NOAA Satellite Image Reception with RTL-SDR
- LoRa Signal Analysis of RAKWireless Earthquake Sensor Kit
- Direction/Location Finding Project using KrakenSDR

Since there is already detailed information on our website, we will not replicate the data here.

Section III - Conferences and Outreach Programs

I had the opportunity to travel to three prestigious conferences across the globe. All of the three conferences are on the top of SDR conferences. I actively participated in **SDR Academy** with my paper and presentation. I also attended **GNU Radio Conference** with my workshop and talk. Lastly, I had the chance to attend **FOSDEM'24** SDR and AR devroom. Conferences provided us to build a network of radio enthusiasts.

We offered various **educational outreach events** like school visits and public workshops. I had to chance to meet with students from high schools and universities in cities of **Ankara and İstanbul**.

Software Defined Radio Academy (SDRA) 2023

SDRA takes place as a sub-conference to HAM RADIO 2023 Expo, the greatest Amateur Radio vention in Europe with 18000 visitors from all over the world. I had the opportunity to share our experience with global community of radio amateurs, Software Defined Radio researchers and developers. I presented the **HaKi Project**, a kit to introduce communication systems to everybody, and also our **SDR-powered laboratory work** at TOBB ETÜ for undergraduate electrical engineering students. I also had the chance to meet and talk to Phil there.

Presenting "HaKi" at SDRA

GNU Radio Conference (GRC) 2023

It was my first time to join GRC, I both delivered a workshop and gave a short talk at the GRCon23. It was an honor to speak in front of such a great community. I had the opportunity to meet the people behind the big GNU Radio Project, hear the future directions and join Capture The Flag (CTF) activity. I collected many stickers for my students :) I also met Jon, Technical Director at ARDC.

While presenting at GRCon

# Free and Open Source Software Developers Meeting (FOSDEM) 2023

I attended FOSDEM 2024, held in Brussels between 4-5 February. Believing in the power of #FOSS, the event was full of success with its developer rooms, great talks, stands and demonstrations. I was able to catch up with SDR enthusiasts and hamradio experts on wide range of topics from satellites to 5G, GPU processing and of course GNU Radio. The radio devroom was full all day long like other devrooms.

Visiting GR stand at FOSDEM

Public Workshops

Introductory Workshop for SDR and GNU Radio Beginners at GNU Radio Conference 2023

I gave a workshop that aims to introduce fundamental DSP concepts and GNU Radio to new users at the [GRCon'23](). The workshop actually contains some modules from our university laboratory course curriculum. All of the workshop materials are available on [GitHub]().
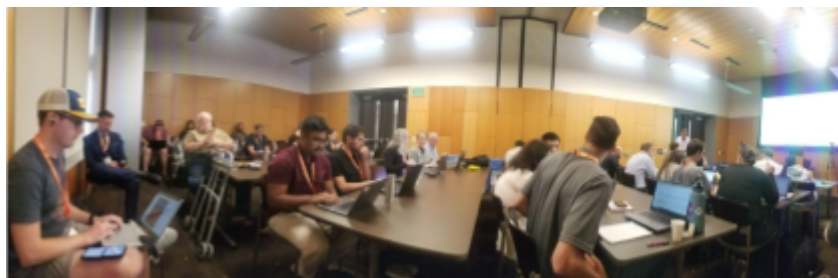
The room was full with GNU Radio new beginners

Hands-on Communications Workshop at Başakşehir Living Lab

I delivered a hands-on workshop held by Başaksehir Living Lab. I got the chance to meet many students from high-school, university and professionals from industry. The participants were able to experience over-the-air signals on their own.

Attendees experiencing with SDR kits

Public Talks

"Wireless Signal Processing Education" Talk at GNU Radio Conference 2023

I gave a short 15-minute talk on our newly developed laboratory coursework. My presentation includes details of the course like its modules, its mixed-methodology, and the survey results we received.

"Wireless Communications" Seminars

I gave a talk on Wireless Communications which outlines fundamental telecommunication concepts like spectrum, frequency bands, analog/digital modulation schemes, modern communication systems like cellular technology, WiFi, BT, and ameteur radio hobby. Along with my presentation, I made demonstrations using RTL-SDR and HackRF, too. The students showed great interest in the topics. They also have desire to perform ameteur radio activities. I repeated the seminar three times for high-school students, grades 9-12 from
- [Başakşehir Living Lab](#) (BLL) - Virtual
- [Keçiören Fen Lisesi](#) (Keçiören Science High School) - Ankara
- [Kadıköy Anadolu Lisesi](#) (Kadıköy Anatolian High School) - İstanbul
- [Ankara Fen Lisesi](#) (Ankara Science High School) - Ankara
- [Ankara Yıldırım Beyazıt Üniversitesi](#) (Ankara Yıldırım Beyazıt University) - Ankara
- [İstanbul Atatürk Fen Lisesi](#) (İstanbul Atatürk Science School) - İstanbul

I reached to the most brilliant minds of Turkey since these high schools select their students through national exam. The students are selected from the top %1 percentile. My talk aims to spark their curiosity at communications and radio science.

Photos of youth removed for privacy by ARDC.

Keçiören Science High School (top left), Kadıköy Anatolian High School (top right)
Ankara Science High School (bottom left), İstanbul Atatürk Science High School (bottom right)

Linux Camps

On our project proposal, we stated our intention to participate in Linux Camps (Fall and Summer). But we couldn't make it. I was too late to apply for the Fall Camp because we had not received the funds before application time window. The Summer Camp was held at the same time GNU Radio Conference. Because I already applied to give a workshop and a talk at the GRCon'23, I couldn't participate in the Linux Summer Camp, either. But we hope to participate in Linux camps in the near future.

Final Remarks

All the things presented in this report wouldn't have been possible without support of **ARDC**. We are so thankful for ARDC regarding their grant on our education project. We have made a big change with SDR-powered education. Our students directly benefited from this change. TOBB ETU has become a model for other higher education institutions that want to make the same change. We also reached to hundreds to let them know what we have done. We offered public workshops both online and in-person, made several school visits, gave talks through our outreach events.

Our initial assumption on indirect costs was wrong. We faced very high indirect costs like tax and customs while buying a product. When we want to buy a product for the project, I supposed that I would send my request to university's procurement and financial affairs office so they will handle the rest. In Turkey customs is a big problem. And I supposed they would handle customs for us. But they said we should better find a company for that purpose. This caused delays and increased our indirect costs. Giving some funds to individuals directly may help in this regard.

I added a traceability table below for quick reference to our goals written in our proposal. This table will give you a quick overview about our project results, what worked well and what did not work well.

Goal Description	Result/Outcome	Notes
Current Course Enhancements		
Amateur Radio (AR) Introduction	Partially done	Curriculum contains AR concepts. Also, purchased two amateur radios
Adding Python and C/C++ Language Support	Partially done	Only Python support added
Real-time DSP on Embedded Device	Done	Standalone kit presented at SDRA
Generating Over-the-Air Signals for Educational Purposes	Done	Now, able to transmit a signal with a known modulation at the lab
Adding Autograding to Lab Assignments	Failed	Some artifacts to be assessed require AI to grade correctly.
New web page	Done	https://ele361l.github.io/ Contains info on course, research projects, and outreach events
New Course & Research Areas		
Advanced Telecommunications Course Curriculum	Partially done	Equipment is ready, and some initial work has been done
Radiosonde Tracking	Pending	We are waiting to collaborate with Turkish State Meteorological Services
HF Band Monitoring	Done	We are able receive better with newly acquired SDRs
Direction Finding and Localization	Done	https://ele361l.github.io/blog/

		[KrakenSDR2](#)
Open Air Interface (OAI) 5G New Radio (NR) Stack	Done	https://ele361l.github.io/blog/5GsrsRAN
Conferences		
SDR Academy & Ham Fest	Jun 23-25, 2023	Paper & Talk (100 people)
GNU Radio Conference 2023	Sep 5-9, 2023	Workshop (50 people) & Talk (300 people)
FOSDEM 2024	Feb 2-3, 2024	Attended SDR Devroom
Linux Camps	Failed	Could not meet the dates
Educational Outreach		
Keçiören Science High School Seminar	Dec 11, 2023	40-50 students, grades 10-11 [Post on school's website](#)
Başakşehir Living Lab Workshop	Jan 28, 2024	10 people
Kadıköy Anatolian High School Seminar	Feb 08, 2024	20-30 students, grades 9-10-11
Ankara Science High School Seminar	Feb 29, 2024	50 students, grade 10
Ankara Yıldırım Beyazıt University Seminar	Mar 8, 2024	30 Senior, master and PhD students from EE Department
İstanbul Atatürk Science School	Mar 11, 2024	60 students, all grades
Kadıköy Anatolian High School Seminar (second time)	Mar 11, 2024	50 students, grades 11-12 [Post on school's website](#)
Traceability table		

We hope to collaborate with ARDC further, so we will apply for fund to continue our work, and to reach out to more people with your help. You can reach out to me directly for anything not clear enough or for more information.

Best regards,
Murat Sever
TOBB ETU Communication Systems Laboratory Coordinator