Preliminary Evaluation of RHL-RELIA Post-Development

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Abstract. Leveraging the Remote Hub Lab (RHL/RHLab) research group's work on democratizing educational access, RHLab, in partnership with LabsLand, has developed the Remote Engineering Lab for Inclusive Access (RELIA/RHL-RELIA). This initiative introduces an educational tool specifically designed for communication courses, aiming to promote learning experiences in technical education. RHL-RELIA, built upon Software Defined Radio (SDR) technology, offers a novel approach to manipulating radio-frequency (RF) hardware through programming, aiming to promote the learning experience in wireless communication. This study presents an initial evaluation of RHL-RELIA post its development, focusing on its usability and educational impact, particularly for students with limited experience in RF technology. The assessment involved three engineering students testing the system, providing feedback on its interface design and effectiveness in facilitating remote experimentation. The preliminary findings suggest that RHL-RELIA is successful in improving the efficiency of completing assignments and making complex wireless concepts more accessible. Future work will include a comprehensive evaluation of RHL-RELIA within a classroom environment, involving a more diverse student population to assess its adaptability and overall educational impact. Future studies will employ mixed methods, including surveys and interviews, to gain a deeper understanding of RHL-RELIA's role in enhancing engineering education.

Keywords: GNU Radio, Software Defined Radio, remote laboratory, embedded systems, wireless communication

1 Introduction

Remote laboratories are gaining popularity in higher education due to their flexibility, allowing students to access them anytime and from anywhere. Furthermore, the challenges associated with ensuring reliable access to hardware in traditional hands-on labs make remote labs an attractive alternative for educational institutions [1–5]. At the same time, remote labs contribute to equitable access, expanding opportunities for students from lower-income and underrepresented minority backgrounds, especially through community colleges [6–8].

Building on the Remote Hub Lab (RHL/RHLab) [9] research group's efforts in democratizing educational access, the group continues to contribute to remote labs development, harnessing technologies like Software Defined Radio (SDR). With the aim of making advanced engineering education more universally accessible, RHLab, in collaboration with LabsLand [10], introduced the Remote Engineering Lab for Inclusive Access (RELIA) for telecommunication courses that uses SDR technology. RHL-RELIA is characterized by its affordable hardware, use of an open-source framework, and a user-friendly web interface[9, 11, 12]. These features are central to ensuring that diverse student populations have the opportunity to engage in advanced technical learning.

RHL-RELIA is a remote laboratory that employs SDR devices for wireless signal transmission. The primary advantage of SDR technology is its capability to facilitate various forms of wireless communication (Analog, Digital, Cellular, etc.) using a single hardware platform, which can be modified exclusively through code. ADALM-PLUTO was selected as the SDR for RHL-RELIA due to its cost-effectiveness, robust hardware, and strong community support. Additionally, RHL-RELIA provides students with the convenience of remote access through a standard web browser, eliminating the need for specialized software and reducing barriers related to prior knowledge. In this paper we present a preliminary evaluation of RHL-RELIA through the perspective of a three undergraduate students who embarked on this task as an independent study, possessing no prior knowledge in the topic area.

2 Background

In Engineering courses, having a laboratory section for practical application of learned concepts is a common practice. These labs are traditionally designed to be solved with physical hardware, often requiring significant financial resources to provide materials for all students. However, financial constraints may lead to a shortage of equipment if funds are insufficient. In addressing this challenge, remote laboratories aim to provide a solution while enhancing accessibility for users [13].

SDR educational labs effectively address many of the challenges associated with traditional labs. The SDR community consistently enhances both hardware devices and software tools, emphasizing their relevance and potential impact across various disciplines. The transition from the complexity of setting up SDR devices in the past to the current user-friendly interfaces reflects a notable trend in the ongoing efforts of the SDR community. A prominent example is the open-source graphical user interface, GNU Radio Companion (GRC), which functions as a graphical layer on the standard GNU Radio programming environment implemented in Python [14]. This interface offers an intuitive user experience comparable to Matlab's Simulink [12]. In the realm of RF education based on GRC, there are illustrative developments. For instance, Emona TIMS project offers a comprehensive package that includes hardware, software solutions, and modular experiments [15]. However, its reliance on specific EMONA hardware may limit scalability for providing flexible laboratory access to a larger student body. Another notable project is the FORGE initiative, employing 16 SDR devices for heightened flexibility and scalability [16]. Nonetheless, none of these labs currently allow students to access the hardware remotely [17], establishing the RHL-RELIA project as a pioneering initiative in this aspect. Evaluation of remote labs in the literature has included many efforts and different methodologies [1, 13, 18–21]. These diverse evaluation methods will collectively guide the interpretation of initial results and subsequent findings from RHL-RELIA.

In the field of engineering, especially in ECE, communication emerges as a noteworthy subject for the application of remote labs. Given the pervasive impact of modern communication systems in our daily lives, the effective instruction of communication to engineering students becomes crucial to meet industry demands [22]. The efficacy of Software-Defined Radio (SDR) in education has witnessed a significant surge in affordability and performance since the early 2000s [23]. For the successful integration of SDR into the design of communication systems, certain prerequisites must be met, including affordable SDR hardware, availability of SDR software, compatibility between SDR hardware and robust technical computing software, and established SDR-based engineering undergraduate curricula [24]. The successful realization of these crucial points, facilitated by advancements in SDR technology and the utilization of tools such as the Universal Software Radio Platform (USRP) hardware with the GNU Radio software framework in undergraduate courses, has proven effective for various radio engineering assignments [22]. The ongoing evolution of SDR tools remains pivotal in shaping the future trajectory of SDR in engineering education.

The preliminary study we are presenting in this paper is anchored in the perspective of students, examining their experiences as they undertake assignments aligned with the traditional Communication curriculum and reference conventional lab materials. In this study the RHL-RELIA lab is assessed based on its technological attributes and the perceived educational benefits from students. It is noteworthy that this study represents an initial exploration, and future publications are planned to conduct a more comprehensive investigation. Subsequent studies will employ mixed methods, pre and post surveys, and interviews for a larger student cohort.

3 RHL-RELIA Remote Laboratory

RHL-RELIA comprises components that enable users to remotely access and configure any SDR station located within an educational institution. As an implementation of the MELODY model [17], RHL-RELIA serves as an agnostic technological framework, offering design considerations for educational remote labs that control SDR devices. The block diagram illustrating the structure of RHL-RELIA is depicted in Figure 1. Key features of RHL-RELIA include:

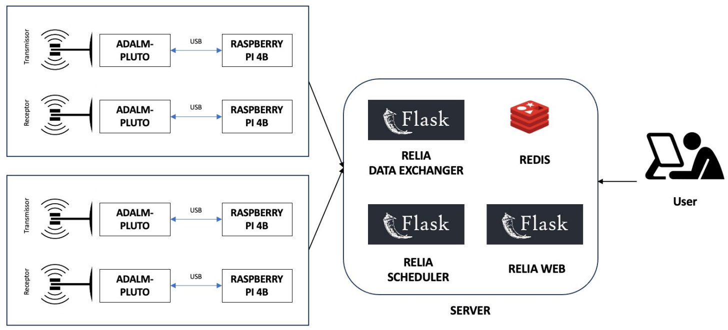

Fig. 1: RHL-RELIA block diagram

- Open source: The development code is accessible for installation by any collaborator or developer.
- Scalability: Due to its architecture and cost-effectiveness, leveraging the ADALM-PLUTO priced at $400 per unit—significantly lower than the USRP devices commonly used in literature—RHL-RELIA demonstrates flexibility in scaling the number of remote units. This scalability not only enhances accessibility but also allows for the accommodation of a greater number of units.
- Web access: RHL-RELIA can be accessed through any web browser, streamlining its usability, reducing the learning curve, and ensuring compatibility with various operating systems.

The features of RHL-RELIA suggest its potential as a useful tool for educational institutions requiring remote access and configuration of SDR stations. With its technology-agnostic framework and notable capabilities, RHL-RELIA could serve as a foundational resource for the integration into communication courses. This perspective is based on its current functionalities and observed benefits, positioning it as a candidate for consideration in future educational applications.

4 Assessment Methodology

Examining both the operational intricacies of the system and its educational implications, the methodology in this study aimed to uncover essential insights. Feedback for the evaluation was collected from three undergraduate students who served as early testers, lacking prior experience in RF topics. From an accessibility standpoint, our decision was to allow students with or without education in communication theory. We aimed to ensure that students testing the lab have a comparable level to those who will eventually use it, thereby democratizing access to this lab.

For the initial assignment, students acquaint themselves with the lab environment. They follow guidance to install the necessary software and engage in two exercises. The first exercise involves verifying correct system installation through simulation, followed by remote transmission and reception using Amplitude Modulation (AM) with the ADALM-PLUTO. Moving on to the second assignment, students undertake two experiments. The initial experiment focuses on calibrating the ADALM-PLUTO by adjusting the frequency values of the transmitter or receiver. The second experiment involves executing digital transmission using Binary Phase Shift Keying (BPSK). These assignments necessitate students to quantitatively analyze signal quality and transmission efficiency, offering a practical complement to theoretical coursework. To ensure a comprehensive comparison, the testers completed both assignments using RHL-RELIA, accessing ADALM-PLUTO remotely in one scenario and physically accessing ADALM-PLUTO in another.

Regarding the operational intricacies, we gathered feedback from students on the following:

- User interface: The user interface ensures that students can easily navigate and interact with the lab platform, enhancing the efficiency of conducting experiments.
- Technology dependence: Understanding the degree of dependence on technology helps assess the accessibility of the remote lab. Additionally, compatibility with various devices and operating systems is crucial.
- Lab availability: Lab availability refers to the accessibility of the remote lab at different times and from various locations. Moreover, assessing lab availability involves understanding how resources, such as equipment and simulation tools, are managed.

Regarding educational implications, students provided their impressions on the following:

- Time Efficiency: Explores the time-related aspects of using RHL-RELIA, focusing on efficiency and the learning curve. Understanding how long students take to complete assignments and become comfortable with the system is crucial in evaluating its practicality in an educational setting.
- Learning Independence: Assesses the level of autonomy students experienced while working with RHL-RELIA. Measuring the degree of independent work versus the need for external help provides insight into the user-friendliness and intuitiveness of the lab system.
- Interest in subject matter and overall satisfaction: Focuses on assessing students' interest in wireless communication, a field in which they were initially novices, following their use of RHL-RELIA. Additionally, it seeks to gauge their overall satisfaction with the learning experience provided by the lab.

5 Results

In this section, we present the findings from our preliminary evaluation of the RHL-RELIA as experienced by three engineering students. These students, who were novices in the field of wireless communication prior to using RHL-RELIA, provided insights into the lab's usability, access, and its educational implications.

User Interface The user interface (UI) of RHL-RELIA presents noticeable differences when compared to traditional lab systems. RHL-RELIA is built with web-specific libraries, providing a distinct user experience from the Graphic User Interface (GUI) used with ADALM-PLUTO, which is derived from the broader SDR community. Illustrations of both interfaces are showcased in Figures 2 and 3. Our findings indicate diverse preferences among students for the RHL-RELIA's UI versus that of conventional labs. Notably, several students highlighted a unique feature of RHL-RELIA: the system allows a 20-second window of access for each student. This functionality is particularly beneficial in situations where the demand for resources exceeds the available units, thereby demonstrating RHL-RELIA's ability to cater to a larger group of users efficiently. Table 1 summarizes students' answers.

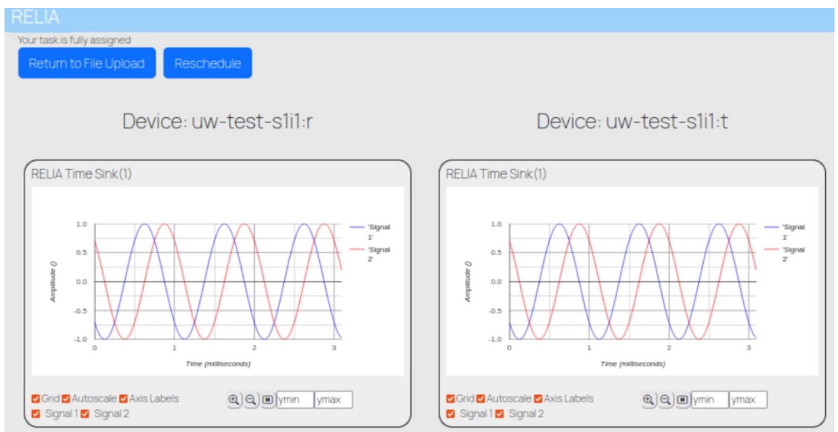

Fig. 2: RHL-RELIA web user interface

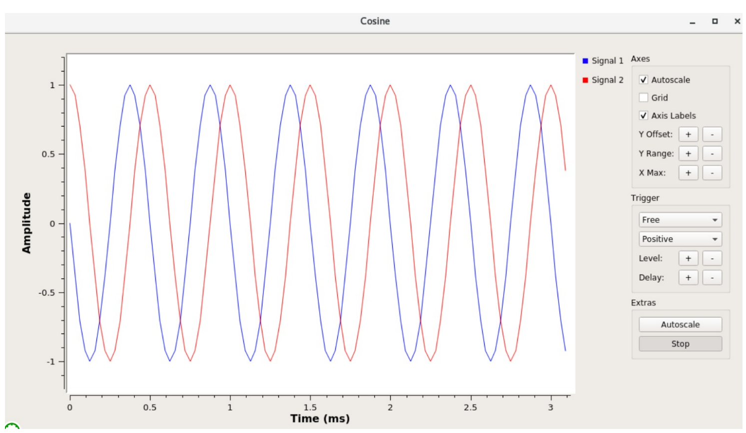

Fig. 3: GRC user interface

Table 1: Students' Impression Over the User Interface

	RHL-RELIA	Traditional
Student 1	*"The interface is friendly, but it would be more effective with prolonged use for manipulating signal graphs".*	*"The configuration process was complex, and it doesn't function on certain operating systems".*
Student 2	*"A timer of how long it is used will be helpful".*	*"Access to a more robust user interface for signal analysis and readability".*
Student 3	*"It simplifies the process but is difficult handle long period results".*	*"I can use it for as long as I need".*

Technology Dependence We analyzed the technological components and tools necessary for configuring both RHL-RELIA and ADALM-PLUTO in a traditional lab setting. The emphasis is on familiarizing students with the requisite technology for effective engagement in these lab environments. RHL-RELIA has been designed to minimize the need for specialized components, thus prioritizing equitable access [19]. This design contrasts traditional labs, which often demand the installation of specific software on the user's computer. By reducing these technological barriers, RHL-RELIA aims to offer a more streamlined and accessible user experience, catering to a broader student base. The outcomes of the students' responses are depicted in Table 2.

Table 2: Students' Impression on the Technology Dependence

	RHL-RELIA	Traditional
Student 1	*"Requires only a device compatible with GNURadio and later any device with internet access can be used".*	*"A computer that has USB ports is needed".*
Student 2	*"Operates through the web, eliminating the need for expensive devices and dealing with varying connections to different computers. It is straightforward and accessible on all devices".*	*"GNURadio poses a challenge in terms of usage across different devices. Traditional labs, with actual hardware, add an extra layer of work".*
Student 3	*"Requires only a device compatible with GNURadio and internet access".*	*"A device with USB support is needed, and modern devices often lack USB ports, necessitating extensions".*

Availability and Accessibility Students shared their insights regarding the accessibility of both RHL-RELIA and traditional lab setups. RHL-RELIA stands out for its 24/7 availability, albeit with a limited duration for each user to accommodate more students and reduce waiting times. In contrast, traditional labs provide complete and unrestricted access for individual students, as they have direct and personal access to the hardware. The students' responses to this aspect are presented in Table 3.

Table 3: Students' Impression Over the Availability and Accessibility

	RHL-RELIA	Traditional
Student 1	*"Accessible from anywhere once configured".*	*"Allows playing, pausing, and taking one's time but requires carrying hardware at all times".*
Student 2	*"Accessible from any device, ability to save and load previous files".*	*"Lack of features like saving files, requires connection to specific devices".*
Student 3	*"No need to carry devices, access anytime but 30-second limit can be pressuring for analysis".*	*"Allows taking time, despite the burden of carrying devices".*

Educational Implications: We gauged the potential educational impact of the lab through questions on time efficiency, learning independence, interest in subject matter and overall satisfaction. Table 4 summarizes student's input. Together, these categories offer a holistic view of RHL-RELIA's effectiveness in not only educating students but also in fostering an engaging and autonomous learning environment, thereby enhancing their interest and satisfaction in the subject matter. This multi-faceted approach underscores the lab's potential in revolutionizing educational experiences in engineering disciplines.

Table 4: Students' Educational implications

Question	Student 1	Student 2	Student 3
How long did it take you to complete the lab assignment using RHL-RELIA?	2 hours	1 hour	4 hours
How much time did you spend learning to use the RHL-RELIA system before you felt comfortable with it?	20 minutes	1 hour	2 hours
What percentage of the lab were you able to complete independently, without external help?	75%	100%	80%
Has your experience with RHL-RELIA increased your interest in the field of wireless communication?	Somewhat	Yes	Yes
Overall, how satisfied are you with your learning experience using the RHL-RELIA lab?	Overall satisfied	8 [on a scale 1-10]	Very satisfied
Would you recommend the RHL-RELIA lab to other students learning about wireless communication?	Yes	Yes	Yes

The collective feedback from students shows a promising picture of the lab's efficacy. Completion times for lab assignments, ranging from 1 to 4 hours, alongside the learning curve of 20 minutes to 2 hours, indicate a flexible system that accommodates varying student abilities and learning speeds. The high degree of independence in lab completion, with 75% to 100% of tasks done without external help, reflects RHL-RELIA's success in fostering self-sufficiency and intuitive learning. Additionally, the increase in students' interest in wireless communication and the high levels of overall satisfaction, with scores as high as 8 out of 10 and strong endorsements for recommending the lab to peers, underscore the system's ability to engage students effectively and enhance their educational experience. These findings, albeit from a limited sample, suggest that RHL-RELIA is a valuable tool, capable of not only imparting technical knowledge but also stimulating interest and ensuring student satisfaction in the learning process.

While the scope of our data is limited in quantity, the insights gathered from the responses of the three students provide a meaningful glimpse into the effectiveness of the RHL-RELIA. Despite the small sample size, the qualitative nature of this preliminary feedback is valuable, offering a foundational understanding of how RHL-RELIA impacts student interest in wireless communication and their satisfaction with the learning experience. These initial findings, though not extensive, are instrumental in guiding future research directions and in making incremental improvements to the RHL-RELIA system. They serve as an encouraging indication of the potential benefits and educational contributions of RHL-RELIA, setting the stage for more comprehensive studies in the future.

6 Conclusions and Future Work

This initial assessment of the RHL-RELIA remote lab system has provided promising insights, particularly in its potential to enhance engineering education methodologies. The system underwent testing by three engineering students with no prior experience in software-defined radio. This deliberate choice of novice testers aimed to collect preliminary feedback before the system undergoes a more comprehensive evaluation in a classroom setting. The observed interface improvements and technology-agnostic features highlight RHL-RELIA's potential to make complex wireless communication concepts more accessible. Despite being tested in a lab setting and not yet in a classroom environment, the feedback from these students indicates a notable improvement in the efficiency and ease of completing assignments.

Building upon these preliminary findings, the next phase for RHL-RELIA entails a thorough assessment within a classroom environment. Engaging a broader and more diverse student population in this context will facilitate a more comprehensive evaluation of the system's adaptability and educational impact. This pivotal phase will specifically address the assessment of the system's user-friendliness and scalability for larger student groups, generating valuable insights for further refinements. Subsequent publications will delve into a more extensive study, employing mixed methods, pre and post surveys, and interviews conducted for a larger student cohort, providing a deeper understanding of RHL-RELIA's impact on engineering education.

Acknowledgements

This work was supported by the National Science Foundation's Division of Undergraduate Education under Grant #2141798.

References

1. Garcia-Zubia, J., Cuadros, J., Romero, S., Hernandez-Jayo, U., Orduna, P., Guenaga, M., Gonzalez-Sabate, L., Gustavsson, I.: Empirical analysis of the use of the visir remote lab in teaching analog electronics. IEEE transactions on education 60(2), 149–156 (2016)
2. Li, S., Wang, H., Rodriguez-Gil, L., Orduña, P., Hussein, R.: Fpga meets breadboard: Integrating a virtual breadboard with real fpga boards for remote access in digital design courses. In: Online Engineering and Society 4.0: Proceedings of the 18th International Conference on Remote Engineering and Virtual Instrumentation. pp. 144–151. Springer (2021)
3. Orduña, P.: Transitive and Scalable Federation Model for Remote Laboratories. Ph.D. thesis, Universidad de Deusto, Bilbao, Spain (May 2013), https://morelab.deusto.es/people/members/pablo-orduna/phd_dissertation/
4. Orduña, P., Irurzun, J., Rodriguez-Gil, L., Garcia-Zubia, J., Gazzola, F., López-de Ipiña, D.: Adding new features to new and existing remote experiments through their integration in weblab-deusto. International Journal of Online Engineering (iJOE) 7(S2), pp–33 (2011)
5. Bose, R.: Virtual labs project: A paradigm shift in internet-based remote experimentation. IEEE access 1, 718–725 (2013)
6. Atienza, F., Hussein, R.: Student perspectives on remote hardware labs and equitable access in a post-pandemic era. In: 2022 IEEE Frontiers in Education Conference (FIE). pp. 1–8. IEEE (2022)
7. Hussein, R., Maloney, R.C., Rodriguez-Gil, L., Beroz, J.A., Orduna, P.: Rhl-beadle: Bringing equitable access to digital logic design in engineering education. In: 2023 ASEE Annual Conference & Exposition (2023)
8. Inonan, M., Orduña, P., Hussein, R.: Adapting a remote sdr lab to analyze digital inequalities in radiofrequency education in latin america. Revista Innovaciones Educativas (2023), in press
9. Hussein, R., Chap, B., Inonan, M., Guo, M., Monroy, F., Maloney, R., Alves, S., Kalisi, S.: Remote hub lab – rhl: Broadly accessible technologies for education and telehealth. 20th annual International conference on Remote Engineering and Virtual Instrumentation REV 2023 (2023)
10. Orduña, P., Rodriguez-Gil, L., Garcia-Zubia, J., Angulo, I., Hernandez, U., Azcuenaga, E.: Labsland: A sharing economy platform to promote educational remote laboratories maintainability, sustainability and adoption. In: 2016 IEEE Frontiers in Education Conference (FIE). pp. 1–6. IEEE (2016)

11. Zhang, Z., Inoñan, M., Orduña, P., Hussein, R., Arabshahi, P.: Rhlab interoperable software-defined radio (sdr) remote laboratory. In: Proceedings of the 21st International Conference on Smart Technologies & Education (STE). Helsinki, Finland (March 6–8 2024), paper accepted for presentation
12. Inonan, M., Chap, B., Orduña, P., Hussein, R., Arabshahi, P.: Rhlab scalable software defined radio (sdr) remote laboratory. 20th annual International conference on Remote Engineering and Virtual Instrumentation REV 2023 (2023)
13. Hussein, R., Wilson, D.: Remote versus in-hand hardware laboratory in digital circuits courses. In: 2021 ASEE Virtual Annual Conference Content Access (2021)
14. Guided Tutorial GRC. https://wiki.gnuradio.org/index.php, accessed on June 05, 2023
15. May, D., Morkos, B., Jackson, A., Hunsu, N.J., Ingalls, A., Beyette, F.: Rapid transition of traditionally hands-on labs to online instruction in engineering courses. European Journal of Engineering Education pp. 1–19 (2022)
16. Abreu, P., Barbosa, M.R., Lopes, A.M.: Robotics virtual lab based on off-line robot programming software. In: 2013 2nd Experiment@ International Conference (exp. at'13). pp. 109–113. IEEE (2013)
17. Inonan, M., Hussein, R.: Melody: A platform-agnostic model for building and evaluating remote labs of software-defined radio technology. IEEE Access 11, 127550–127566 (2023), doi: 10.1109/ACCESS.2023.3331399
18. Paul, A., Inoñan, M., Hussein, R., May, D.: Exploring diversity, equity, and inclusion in remote laboratories. In: 2023 ASEE Annual Conference & Exposition (2023)
19. Inonan, M., Paul, A., May, D., Hussein, R.: Rhlab: Digital inequalities and equitable access in remote laboratories. In: 2023 ASEE Annual Conference & Exposition (2023)
20. Hussein, R., Guo, M., Amarante, P., RodriguezGil, L., Orduña, P.: Digital twinning and remote engineering for immersive embedded systems education. In: Frontiers in Education (FIE) Conference. IEEE, USA (2023)
21. Gustavsson, I., Zackrisson, J., Håkansson, L., Claesson, I., Lagö, T.: The visir project–an open source software initiative for distributed online laboratories. In: Proceedings of the REV 2007 Conference, Porto, Portugal (2007)
22. Petrova, M., Achtzehn, A., Mähönen, P.: System-oriented communications engineering curriculum: teaching design concepts with sdr platforms. IEEE Communications Magazine 52(5), 202–209 (2014)
23. Tuttlebee, W.H.: Software defined radio: enabling technologies. John Wiley & Sons (2002)
24. Wyglinski, A.M., Orofino, D.P., Ettus, M.N., Rondeau, T.W.: Revolutionizing software defined radio: case studies in hardware, software, and education. IEEE Communications magazine 54(1), 68–75 (2016)