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Portable SDR Kit Designed for Student Learning in Radio Operations

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Abstract: Hands-on learning in radio communications remains limited in various engineering institutions in the Philippines due to outdated laboratory tools, bulky equipment, and the high cost of modern RF instrumentation. To address this gap, this study developed a Portable Software-Defined Radio (SDR) Kit designed to provide Electronics Engineering students with an accessible, low-cost platform for practical experimentation in radio operations. The kit integrates an SDR module, Raspberry Pi 4B, TinySA, mini oscilloscope, signal generator, Wi-Fi modem, antennas, and essential electronic components, all supported by a custom web-based application for real-time spectrum visualization, demodulation, and frequency tuning. The prototype was evaluated through technical performance tests, including software responsiveness, antenna reception capability, and signal strength precision, as well as pre- and post-assessment of student learning. Results showed that the SDR kit performed reliably in receiving and demodulating AM and FM signals, demonstrated stable single-band reception using basic antennas, and yielded signal strength readings consistent with a standard spectrum analyzer. Moreover, students exhibited improved cognitive understanding of key RF concepts, supported by positive usability and functionality ratings. The findings confirm that the portable SDR kit provides an effective, user-friendly alternative to traditional laboratory setups. Its affordability, compact design, and real-time visualization capabilities make it a practical tool for bridging theoretical instruction and real-world radio communication applications within engineering education.

Keywords: *SDR, Web-Application, Radio, Spectrum, Signal, RPi, Learning.*

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I. INTRODUCTION

The rapid advancement of wireless communication systems has increased the demand for practical and accessible training tools in communication engineering education, as many institutions continue to rely on outdated and costly laboratory equipment [1]. Software-Defined Radio (SDR) provides a flexible platform that enables students to analyze real radio signals and understand modulation, spectrum behavior, and signal processing through software-based implementations, thereby bridging the gap between theory and practice [1], [2]. However, the adoption of SDR in academic environments remains limited due to technical difficulties, budget constraints, and insufficient instructor and student training [3], [4]. To address these challenges, this study focuses on developing a low-cost, portable, and user-friendly SDR kit that supports hands-on learning, enhances student competencies, and assists instructors in delivering effective laboratory instruction. This research contributes to the modernization of engineering education by promoting experiential learning and technical skill development. The scope of the study is limited to instructional use, basic analog modulation techniques, and selected performance parameters, excluding advanced communication standards and long-range applications due to hardware, environmental, and regulatory constraints.

II. RESEARCH METHODOLOGY

This study employed a developmental research design to systematically design, construct, implement, and evaluate a portable Software-Defined Radio (SDR) kit intended to enhance student learning in radio operations. Developmental research is appropriate for studies focused on producing and assessing instructional tools, prototypes, and educational

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systems through structured development, testing, and refinement processes [1]. In this research, the portable SDR kit was developed not only as a functional communication device but also as an instructional platform that supports experiential learning through real-time signal reception, spectrum visualization, and modulation analysis.

The study was conducted at San Sebastian College–Recoletos de Cavite, where Electronics and Computer Engineering students enrolled in communication-related subjects served as the primary respondents. The research locale was selected due to its relevance to engineering education and the institutional need for accessible laboratory tools that can modernize instruction in radio communication and spectrum analysis. The controlled academic environment provided an appropriate setting for implementing laboratory demonstrations and evaluating the effectiveness of the developed SDR kit as a learning tool.

A random sampling technique was applied in selecting participants. This method ensure that respondents possessed adequate academic background in communication concepts, basic modulation techniques, and signal processing principles.

To ensure a comprehensive evaluation, multiple research instruments were utilized to address both the technical performance and educational impact of the SDR kit. Standardized technical performance testing tools were employed, including spectrum analyzers, signal generators, and monitoring software. These instruments validated the operational reliability of the kit in terms of signal reception, demodulation accuracy, spectrum visualization, tuning responsiveness, and stability during real-time laboratory experiments. SDR-based learning platforms such as GNU Radio and RTL-SDR have been recognized for their ability to bridge theoretical knowledge and practical signal experimentation, making them valuable tools in communication engineering education [5], [6].

In addition, validated pre-test and post-test questionnaires were administered to measure the cognitive competency of students before and after using the SDR kit. Pre-assessment instruments established the baseline knowledge of respondents regarding radio spectrum behavior, modulation and demodulation principles, antenna reception, and spectrum interpretation. After system exposure, post-assessments evaluated the knowledge gained through hands-on interaction with real radio signals. The use of pretest and post-test comparison is widely accepted for determining learning improvement in instructional technology research [1].

A structured user acceptance and usability survey was also conducted to evaluate student perceptions of the SDR kit's functionality, ease of use, portability, and overall satisfaction. User acceptance evaluation is essential in prototype-based educational research, as the effectiveness of learning tools depends not only on technical performance but also on usability and accessibility for students [7]. Participant feedback provided insights into the practicality of integrating the SDR kit into communication engineering laboratory courses.

The data gathering procedure began with the systematic assembly, installation, and configuration of the SDR hardware components and the supporting web-based application. Once operational, supervised laboratory sessions were conducted where students performed activities such as signal reception, frequency tuning, demodulation, and spectrum analysis. These experiments allowed respondents to directly observe real RF signals, reinforcing theoretical lessons with real-world applications. Practical exposure to radio operations is critical in engineering education, especially in institutions where access to modern RF instrumentation is limited [8], [9].

All gathered data were organized, tabulated, and analyzed using descriptive statistical techniques, particularly the computation of the mean. Descriptive analysis determined the average level of system performance, user satisfaction ratings, and overall learning improvement among respondents.

Overall, this methodology ensured an objective and comprehensive assessment of the portable SDR kit's educational value. By integrating technical performance testing, cognitive competency evaluation, and usability assessment, the study provided a reliable basis for determining the effectiveness of the developed SDR prototype in enhancing student learning in radio operations. Furthermore, the methodology considered institutional limitations, laboratory constraints, and the controlled academic environment in which the system was implemented, ensuring that the evaluation remained both practical and academically grounded [1].

III. RESULTS AND DISCUSSION

This section presents and discusses the results obtained from the technical performance evaluation, user acceptance assessment, and learning improvement analysis of the developed portable Software-Defined Radio (SDR) kit.

A. Software Responsiveness Test

Table 1 Software Responsive Test

Trial	Time Recorded	Scale Value
1	1sec.	4
2	1sec.	4
3	1sec.	4
4	1sec.	4
5	1sec.	4
Average	1sec.	4

Table 1 presents the results of the software responsiveness test, which measured the system's response time when users

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changed frequencies or refreshed the display. Five trials were conducted, and all recorded a consistent delay of one second.

Based on the Software Responsiveness Scale, a one-second delay falls under the category "Responded Immediately (1–2 seconds)" with a scale value of 4, corresponding to Excellent Responsiveness and a Passed rating. This indicates that the SDR system responds quickly and reliably without noticeable lag. The results confirm that the developed kit meets the required performance standards for real-time signal tuning and visualization.

B. Antenna Performance Comparison

Table 2. Antenna Comparison Test

Trials	Types of Antenna Used	Timed Results	Scale Value
	Telescopic Whip (Monopole)	1min.	4
1	Collapsible Dipole	1min.	4
	Mini Magnetic Loop	1min.	4
	Telescopic Whip (Monopole)	2min.	4
2	Collapsible Dipole	2min.	4
	Mini Magnetic Loop	2min.	4
	Telescopic Whip (Monopole)	3min.	3
3	Collapsible Dipole	3min.	4
	Mini Magnetic Loop	3min.	4
	Telescopic Whip (Monopole)	4min.	3
4	Collapsible Dipole	4min.	4
	Mini Magnetic Loop	4min.	4
	Telescopic Whip (Monopole)	5min.	3
5	Collapsible Dipole	5min.	4
	Mini Magnetic Loop	5min.	4
Average			

Table 2 presents the results of the antenna comparison test, which evaluated the speed and stability of signal detection using three basic antennas. Each antenna was tested five times under identical conditions and rated using a four-point scale.

The monopole antenna obtained mostly ratings of 4, with slight decreases to 3 in the final two trials due to minor detection delays. Both the collapsible dipole and mini magnetic loop antennas consistently achieved ratings of 4 in all trials, indicating immediate and stable signal detection.

The overall weighted mean of 3.8 indicates optimal antenna performance. These findings demonstrate that the SDR module can efficiently receive signals using commonly available antennas, making it suitable for instructional laboratory use.

C. Signal Stability and SNR Analysis

Table 3. Signal Stability Test

Trial	Time Recorded	Scale Value
1	1min. 23dB	3
2	3min. 23dB	3
3	5 min. 23dB	3
4	8 min. 23dB	3
5	10 min. 23dB	3
Average		

Table 3 shows the results of the signal stability test conducted at 1, 3, 5, 8, and 10 minutes of continuous operation. The Signal-to-Noise Ratio (SNR) remained constant at 23 dB throughout all trials.

According to the evaluation criteria, an SNR value of 23 dB falls under the category "fairly stable signal (20–29 dB)" with a scale value of 3 and a Passed rating. This indicates that the SDR kit is capable of maintaining stable signal quality during prolonged operation, even when using basic antennas. The results confirm the system's reliability for continuous classroom and laboratory demonstrations.

D. Signal Detection and RSSI Evaluation

Table 4. Signal Strength Test

Trial	Frequency Signal & RSSI Level	Scale Value
1	89.6 MHz Level 5	3
2	60.5 MHz Level 5	3
3	70.2 MHz Level 5	3
4	75 MHz Level 4	3
5	101.7 MHz Level 2	3
Average		

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Table 4 presents the signal detection and Received Signal Strength Indicator (RSSI) test results. The SDR successfully detected signals at 89.6 MHz, 60.5 MHz, 70.2 MHz, 75.0 MHz, and 101.7 MHz, with corresponding RSSI levels of 5, 5, 5, 4, and 2.

The system correctly tuned to these frequencies and identified AM and FM signal presence when compared with measurements from a physical spectrum analyzer. Based on the evaluation criteria, the SDR achieved a Scale Level of 3, corresponding to Acceptable Performance. Minor deviations were observed due to the limited resolution of the low-cost hardware.

These findings are consistent with the study of Freitas et al. [10], which reported that SDR platforms are effective for signal detection despite small variations in amplitude and frequency. Overall, the portable SDR kit is reliable for general signal monitoring, although it is not intended for precision measurement applications.

E. User Acceptance and Usability Assessment

Table 5. User Acceptance Test

	Mean	Standard Deviation	Interpretation
Functionality	3.79	0.41	Strongly Acceptable
Usability	3.73	0.44	Strongly Acceptable
Ease of Use	3.78	0.41	Strongly Acceptable

Table 5 summarizes the results of the user acceptance and usability evaluation. Functionality obtained the highest mean rating of 3.79, while usability and ease of use scored 3.73 and 3.78, respectively. All indicators were interpreted as "strongly acceptable."

The low standard deviation values indicate consistent agreement among respondents. These results suggest that the SDR kit is user-friendly, portable, and effective for classroom and laboratory instruction. The positive feedback supports the practicality of integrating the developed system into communication engineering courses.

F. Learning Improvement Analysis

Table 6. Pre-Test and Post-Test

	Pre-Test	Post-Test
Mean	16.3	18.1
Variance	10.23683234	3.092427263
Observation	100	100
Pearson Correlation	-0.370623442	
Hypothesized Main Difference	0	
df	99	
t Stat	-9.404612399	
P(T<=t) One-Tail	0.001123387	
t Critical One-Tail	1.709342512	
P(T<=t) Two-Tail	0.002472574	
t Critical Two-Tail	2.033204124	

Table 6 presents the results of the pre-test and post-test comparison. The decrease in variance from 10.24 to 3.09 indicates that students' post-test scores became more consistent after using the SDR kit.

The negative Pearson correlation coefficient (–0.3706) suggests that students with lower pre-test scores experienced greater improvement. Furthermore, the t-test result (t = –9.4046, p = 0.0024) confirms a statistically significant difference between pre-test and post-test scores.

These findings indicate that the observed improvement in student performance was not due to chance. The results demonstrate that the SDR kit effectively enhanced cognitive competency and reduced learning gaps, consistent with the findings of Inthama et al. [11]

IV. CONCLUSION AND RECOMMENDATION

➢ *Conclusion*

The findings of the study confirm that the Portable SDR Kit successfully addressed the limitations of conventional radio learning environments by providing a practical and user-friendly platform for real-time signal analysis. Technical evaluations demonstrated reliable performance, including consistent signal stability with an average SNR of 23 dB, optimal antenna reception with a weighted mean of 3.8, and responsive waveform visualization with an average response

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time of one second. Although the system is intended primarily for relative signal measurements, the Signal Strength Test showed sufficient accuracy for instructional purposes. The integration of the TEA5767 and TA7642 modules with a Raspberry Pi and ESP32 enabled effective reception and visualization of RF signals through a responsive web interface. Despite being limited to receive-only operation and being influenced by environmental factors, the kit proved suitable for classroom instruction, laboratory exercises, and independent learning. Overall, the Portable SDR Kit enhanced students' academic performance, reduced learning gaps, and successfully bridged theoretical concepts with practical radio communication applications.

➢ *Recommendation*

To further improve the educational and technical value of the Portable SDR Kit, several enhancements are recommended. The conversion of dBFS readings to dBm should be implemented to enable absolute and calibrated signal power measurements for more accurate RF analysis. The integration of digital modulation techniques such as ASK, FSK, PSK, and BPSK is also suggested to expand learning beyond analog modulation. Implementing IQ data logging would allow continuous storage and retrieval of signal data for advanced analysis and extended experimentation. In addition, incorporating assessment features such as pre-tests and post-tests into the web application would strengthen the evaluation of student learning outcomes. Finally, periodic upgrading of external devices is recommended to ensure that the kit remains relevant, functional, and aligned with evolving communication technologies.

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