A Modern, Two-Course Undergraduate Communications Sequence

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***Abstract*—Software Defined Radios (SDR) present a unique opportunity for undergraduate communications courses, as they are low-cost and easily obtained. In addition, the recent momentum of the GNURadio project has significantly lowered the barrier to entry for implementing SDR applications. GNURadio is an open source project designed to provide a simple, intuitive interface for processing data from SDRs. Some universities have integrated GNURadio into their Undergraduate communications courses as a motivation to further study of the theory [1]. Additionally, other resources are publicly available, such as the excellent website PySDR.org and open source textbooks (e.g., [2]). However, it can be difficult to build a meaningful, cohesive curriculum that covers traditional communications theory while providing exposure to modern SDR applications. This paper presents a two-course sequence that utilizes a variety of traditional and non-traditional resources to expose undergraduate students to both theoretical and applied concepts, which the authors taught in its entirety during the 2023-2024 academic year. It contains a full outline, explanation of pedagogical methodology, and links to lesson plans and resources.**
***Keywords*—SDR, Education, Communications**

I. Background & Motivation

Traditional first undergraduate courses in Communications systems focus exclusively on the theoretical aspects of the fundamental concepts of the field: signals and linear analysis; digital and analog amplitude modulation; digital and analog angle modulation; random noise; and channel capacity. These concepts are crucial to enable a proper handling of modern communications systems and signals. At the United States Air Force Academy (USAFA), we followed a similar structure for many years and we included only two hands-on exercises to reinforce the classroom concepts. In this implementation of the course, we utilized traditional lab equipment. While it is important for students to gain familiarity with this equipment, there are several drawbacks. First of all, the equipment can be difficult to use and obscures the bigger picture of the lab. Secondly, not all students will have access to such equipment when they graduate. Finally, students are not aware of an entire class of hardware designed to make communications more accessible and widely available. Therefore, it seems important to merge the traditional approach to this sequence with a more modern approach which includes SDRs and the associated software. A large number of software tools exist for working with SDRs, such as GNURadio, Python, GQRX, Universal Radio Hacker, SCEPTRE, SigDigger, SDRSharp, SDR Angel, and MATLAB®. This course utilizes open source tools as much as possible, in order to maximize the current momentum in the community and provide an common, broadly accessible toolkit for the students. However, we also seek to provide exposure to licensed tools, as cost and availability allow.

In addition to modernizing the curriculum, A cursory literature review reveals overwhelming evidence for various implementations of active learning [3], regardless of the discipline. In [4], the authors suggest a number of activities to support active learning, including:

- Problem/project/case-based learning
- Discovery learning
- Technology-enhanced learning

Many courses in USAFA's curriculum implement these strategies, but the communications sequence utilized a more lecture-based approach. Therefore, our goal is to reinvigorate the communications sequence by ensuring our curriculum provides exposure to modern technology, communications, and pedagogical approaches. Students who complete the first course and are interested in more practical applications of communications systems may proceed to the second course. Historically, enrollment is typically 15-20 in the first course and 6-15 in the second course.

II. Previous Sequence

Semesters at USAFA consist of 40 lessons of 53 minute duration, for a 3 credit hour class. The previous sequence consisted of two entirely separate 3 credit hour courses, ECE 447 (Theory of Communications) and ECE 448 (Applications of SDRs). Both are electives, but ECE 447 is a directed elective, meaning cadets must choose between this course which provides depth in the EE

1. Signals	
	Power/Energy
	Fourier Series/Transform
	Spectral Density
	Convolution & Correlation
	Complex Sampling
2. Analog Amplitude Modulation	
	AM theory
	DSB-LC
	SSB
	Mixing
	Pulse Modulation
	Analog AM/FM Lab
3. Analog Angle Modulation	
	FM
	FM demodulation
4. Noise	
	Random Signals
	Noise in Digital Systems
	Probability of Error
5. Digital Modulation	
	ASK, FSK, PSK
	Digital Modulation Lab
6. System Design	
	Link Budgets
	Channel Capacity & Noise Figure
7. Final Exam	
	Comprehensive

TABLE I: Previous ECE 447 Sequence. Red text indicates hands-on or lab topics.

1. SDR Intro	
	Course intro & Motivation
	SDR overview & Market Intro
	Link budgets, Comms overview
2. Basic GNURadio	
	GNURadio Install
	GRC: Data types, Sampling, Flow
	GRC: Basic Blocks
	GRC: AM Simulation
	GRC: AM receiver
	GRC: File Recording & Playback
	ZMQ
3. FSK	
	FSK Overview
	FSK Project
	Hier blocks
4. PAM	
	ASCII PAM
	Matched Filters
5. RF Remote Hacking	
	URH Intro
	PPM
	RF Remote Reverse Engineering
	RF Remote Project
6. Custom Blocks	
	API Overview
	Custom Block Project
7. mPSK	
	mPSK Overview
	mPSK in GRC
8. Final Project	
	Comprehensive
	Starts at midterm
	Replaces final exam

TABLE II: Previous ECE 448 (Applications of SDRs) Sequence. Red text indicates hands-on lab topics.

area, and two other courses providing depth in Computer Engineering. This equates to a typical enrollment of 15-20 students each Fall semester. The course topics are summarized in tables I and II.

This two-course sequence suffers from a few significant shortfalls, both in the categories of student engagement and pedagogical approach.

First, we note ECE 447 was primarily conducted as a lecture course from an academic textbook, and coursework largely consisted of homework problems, two in-class labs, a midterm exam, and a final exam. While this is useful pedagogy, the course presentation lacked a concrete applicability to modern systems. Furthermore, observations and student feedback reinforced this intuition, as it was not always clear to students how to connect the theory to some meaningful application. Finally, it is difficult to motivate cadets to pursue a deeper study in the area of communications without a tangible sense of the possibilities for building useful, modern communications systems. Mathys [1] provides an excellent description of this problem and his sequence on Pulse Amplitude Modulation serves as the functional catalyst of our course reorganization.

In contrast, ECE 448 is largely hands-on and project based, combining materials from many outstanding sources [5], [6], [1], along with curriculum developed in-house. This class is based on exploratory learning, where students are given foundational information and encouraged to develop their own novel applications and uses. Each topic typically concludes with a loosely-structured project and the course culminates with a final project. The final project provides an opportunity for students to define their own problem and develop an appropriate solution from start to finish.

In addition to the different approaches of the two courses, the opportunities for students to explore more advanced topics and more specific signals is limited by the number of lessons available. It can be difficult to introduce the appropriate software while also developing intuition regarding the connection between theory and application – both are necessary when troubleshooting basic flowgraphs and when approaching more advanced applications, such as mPSK modulation, tactical communication links, and spread spectrum techniques.

1. Signals
Power/Energy
Fourier Series/Transform
Spectral Density
Convolution & Correlation
Complex Sampling
2. Intro to SDRs
SDR hardware & Software
IQ Sampling & Data
Intro to GNURadio (GR)
GR Data Types, Sampling, & Filters
ZMQ, raw data files
3. Analog Amplitude Modulation
AM theory
DSB-LC
SSB
Mixing
Pulse Modulation
Analog AM Lab*
4. Analog AM in GR
AM Simulation
AM Receiver
5. Analog Angle Modulation
FM
FM demodulation
FM Lab*
6. FM in GR
FM Receiver
Dual FM Receiver
7. Noise
Random Signals
Noise in Digital Systems
Probability of Error
8. Digital Modulation
ASK, FSK, PSK
Digital Modulation Lab*
9. FSK in GR
FSK Tutorial
FSK Project

TABLE III: New ECE 447 Sequence. Red courses indicate hands-on or lab topics.

1. Adv Comms Theory
Course intro & Motivation
Link budgets, Comms overview
Signal Space (constellations)
2. GR PAM
PAM Tutorial
Hier blocks
PAM project (matched filter)
3. GR OOT Modules
OOT Module Usage
Common OOT Modules
Custom Blocks (Python/C++)
Custom Block Project
4. Common Signals
CW
HD WBFM Radio
ADS-B
AIS
DTMF
5. mPSK
mPSK Overview
mPSK in GRC
6. FHSS
FHSS Overview
FHSS Project
7. RF Remote Hacking
URH Intro
PPM
Remote Reverse Engineering
Remote Project
8. Special Topics
FMCW RADAR?
GRCon fun?
9. Final Project
Comprehensive
Starts at midterm
Replaces final exam

TABLE IV: New ECE 448 (Applications of SDRs) Sequence.

III. New Curriculum Description

The overall goal of the reorganization is to provide a foundational introduction to SDRs in the first course (ECE 447) alongside the theory. This provides two significant benefits in addition to the rigorous theoretical instruction of a traditional communications course: they are able to learn the capabilities of SDRs alongside those of traditional lab equipment (such as a pristine spectrum analyzer); and this insight provides an on-ramp to more intermediate and advanced communications topics during the second course (ECE 448). Although we are still fine-tuning the presentation, we are interweaving the material in such a way that students will learn theory, practice lab techniques, and apply the concepts using SDRs. This allows for the most natural connection between theory and practice, while allowing students to more fully explore the trade space of capability, precision, and cost.

IV. Course Implementation

Tables III and IV capture the updated course flows, which consist of an increased number of hands-on or lab topics (indicated by red text) and the shift of introductory SDR lessons. This improves the the approachability of the course and equips students for more in-depth exploration of intermediate and advanced communications systems in the second course. Additionally, ECE 448 has become a more in-depth exploration of modern modulation and encoding schemes such as: CW, HD WBFM, FHSS, and custom GNURadio applications. Under this new organization, even though the courses are now aligned, each course takes a slightly different pedagogical approach, and it is valuable to consider those now.

A. ECE 447 (Theory of Communications)

ECE 447 is based on a more balanced combination of theory and application. Therefore, the students attend lecture periods and are assigned traditional calculation-based homework problems to build confidence with the mathematical underpinnings of communication signals. The course previously used the canonical book by Ziemer [7], but is now using the freely available electronic book from Cooklev and Yagle [8]. We chose this book in order to facilitate a more accessible experience for the students and one that may be updated more frequently than a traditional publishing cycle allows, to maintain currency in the ever-evolving technology. Additionally, the course makes frequent use of the following additional materials:

- PySDR [6]
- GNURadio Wiki/Tutorials [5]
- Custom built course materials

In contrast to the customary lecture method, lessons incorporating GNURadio follow a less structured, exploratory approach. Although a presentation or supplementary information is used to guide student efforts and provide some minimal information, students follow instructors as they build their flowgraphs in real time, and lessons are recorded for future reference. This approach facilitates an inclusive, engaged environment and allows students the opportunity to implement evidence-based practices such as dual coding [9] in a controlled environment. In this course, the primary SDR tools are GNURadio and GQRX, which are conveniently packaged in distributions for all major computer operating systems.

Assignments in the first course are evenly mixed between traditional formats (i.e., homework, exam, lab, etc.) and exploratory methods (research report, GNURadio flowgraph development, projects). Our institution requires a midterm and a final exam (or comprehensive final project) to comprise a significant portion of student grades which imposes a non-trivial constraint on the course format. The hard-copy exams consist of the usual calculation-based questions followed by conceptual and applied questions regarding GNURadio and SDR operation. The latter often cover common GNURadio mistakes and oversights, trusting the dynamic evaluation of SDR applications to projects.

The traditional hands-on labs (denoted by a * in the course sequence) are designed to be used in conjunction with Keysight N9000B series Spectrum Analyzers, tabletop function generators, and signal generators. It is useful for students to gain some familiarity with conventional lab-grade equipment, as it still pervades research labs globally and allows a level of precision not typically found in SDRs. Furthermore, we strongly believe in the principle of corroborating data by means of multiple methods and sources, and this approach affords students a practical way to develop best engineering practices.

1) Course Topic Descriptions:

- **Signals:** The course begins with a review of signal theory and the usual treatment of power and energy signal theory. This includes Fourier series and transforms, Parseval's theorem, the Wiener-Khinchin theorem, and power/energy spectral density. We cover convolution and complex sampling to prepare students for their study of filters and IQ data manipulation and treatment.
- **Intro to SDRs:** In this portion of the class, we introduce the superheterodyne architecture, principles of IQ sampling and IQ data. We also expose students to the wide variety of SDRs available on the open market, to include their strengths and limitations. Next, we expose the students to GNURadio starting with installation and basic operation, then progressing to data types, sample rates, and filter types. Finally, students learn how data flows through GNURadio and how to work with complex data outside of GNURadio.
- **Analog Amplitude Modulation:** We begin with a review of modulation theory, including the Hilbert transform and then discuss DSB-LC and SSB signals, along with pulse modulation. This section contains the first of the traditional labs, Analog AM, which requires students to generate AM signals with various modulation depths and to measure the power efficiency of the resulting modulated waveforms.
- **Analog AM in GNURadio:** This section begins with straightforward DSB-LC and SSB simulations, then progresses to an end-to-end example demonstrating modulation and demodulation. The GNURadio AM Lab closely follows the form of the traditional Analog AM lab, in that we generate simulated AM signals with varying modulation depths and measure the resulting efficiencies. By essentially reproducing the results of the Analog AM lab, students generate a link between lab equipment and SDR software. Furthermore, this provides a relatively low barrier of entry activity for students to learn the nuances of GNURadio and common pitfalls novices experience when developing their own flowgraphs.
- **Analog Angle Modulation:** We start by laying a theoretical foundation for frequency modulation, then discussing power and bandwidth considerations. The second traditional lab, FM Modulation,

requires students to generate FM signals at various bandwidths and measure the resulting power distributions and modulation indices.

- **FM in GNURadio:** Michael Ossmann describes the FM receiver as the "hello world" program of GNURadio [10]. And, while this may be true, we delay any real study of the FM receiver until after the traditional FM lab. This allows us to more thoroughly investigate and understand the received WBFM signal. Additionally, cadets gain familiarity with some of the filtering, frequency shifting, and demodulation capabilities of GNURadio. The Dual FM Receiver is a "homework assignment" Ossmann provides through his excellent video series and allows students a sandbox in which to investigate those concepts and synthesize their first novel GNURadio application.
- **Noise:** Since ECE 447 satisfies an ABET requirement for applications of probability and statistics, and noise/random signals are a key consideration for any communications system, we dedicate several lessons to this area. Our focus is on how noise affects probability of error and the associated bit error rates.
- **Digital Modulation:** Following the theoretical foundation laid in the angle modulation section, we extend the students understanding to ASK, FSK, and PSK. Our focus is on the modulation techniques and the associated bandwidth, SNR, and probability of error considerations. The third lab, Digital Modulation, requires students to generate various ASK and FSK signals modulated by a pseudo-random bit sequence and explore the bandwidth and power efficiencies of each modulation scheme.
- **FSK in GNURadio:** The first course culminates in an exploration of FSK signals, largely modeled after the FSK tutorial found on the GNURadio wiki [5]. In this case, though, the students are required to develop a script to receive a demodulated signal from GNURadio and reconstruct the signal into ASCII characters. This requires the cadets to familiarize themselves with data flow formats and constructs within GNURadio, as well as off-board data handling techniques and data decoding.

B. ECE 448 (Applications of SDRs)

ECE 448 takes a much different pedagogical approach, utilizing fewer slides and lectures in preference of an exploratory approach which asks questions and requires students to answer those questions through both independent and collaborative research. In many cases, instructors and students are learning together – which, anecdotally, significantly improves the commitment to learning. When students recognize firsthand that faculty also have much to learn, many of the typical barriers vanish, including imposter syndrome and the perception of faculty infallibility.

Note almost all the course activities are highlighted in red – *nearly every* lesson is hands-on. The students come to class with their SDRs in hand and laptops open, fully prepared for an engaging 53-minute, bidirectional learning adventure.

The course is organized topically, beginning with generalized modulation and encoding schemes and progressing to specific signals they are likely to encounter as engineers in the USAF. The chosen signals are specifically relevant to their job domain; regardless of whether students become pilots or developmental engineers, they are likely to see ADS-B, AIS, HD Radio, and CW. Each topic is covered in 3-5 lessons and includes a mini-project. The mini-projects are designed to allow students to extend the concepts covered in class. Taking the FM receiver from ECE 447 as an example, students learn the basics of the single channel FM receiver, then extend the concept to receive two stations simultaneously. This requires them to learn many new concepts: handling hardware limitations (such as bandwidth), interacting with GUI elements, separate a single IQ stream into multiple channels, shift each channel independently, demodulate, and recombine to an audio output. The "make it better" approach is at the core of our department's approach as we strive to build the next generation of leaders with strong critical thinking skills. This course is a perfect proving ground for building this kind of critical thinking. Furthermore, each project requires a technical report deliverable, which enables a long-term evolution of students' technical writing – a critical yet often overlooked skill for modern engineers.

Additionally, the course makes frequent use of the following hardware and software tools:

- Nooelec RTL-SDR v5, HackRF, Pluto SDR
- GNURadio
- GQRX
- `rtl_433`
- Universal Radio Hacker (URH)
- SDR Angel
- SDR Sharp

1) Course Topic Descriptions:

- **Syllabus:** From the first lesson, students are expected to continue where the previous course concluded. In fact, their syllabus is encoded using one of the modulation techniques learned in the first course and, even to see the schedule, they are required to build a flowgraph to demodulate and decode it.
- **Advanced Communications Theory:** This is the only traditional portion of the course; we chose to

move this to the beginning of the course to discuss concepts without which a student's understanding of the signals and systems we cover would be incomplete. The material derives from the 447 textbook. This topic concludes with a realistic analysis of a communications system, where students conduct research to present a technical description of a relevant system that is not explicitly covered in the syllabus.

- **GR Pulse Amplitude Modulation (PAM):** Although Mathys [1] intended this as a set of introductory lessons for a first undergraduate course in communications, it serves as a perfect launching point for our second course; it just as easily summarizes many concepts from the first course and provides additional exposure to GNURadio usage.
- **GR Out-of-Tree Modules:** Students learn the basics of building Python/C++ blocks using the GNURadio wiki tutorials. We challenge the students to then develop their own custom block and are encouraged to think creatively – grades are contingent on a novel application.
- **Common Signals:** At this point in the semester, students are comfortable enough with the hardware and software to begin analyzing common signals, such as Morse Code (CW), HD WBFM Radio, ADS-B, AIS, DTMF, etc. This series of lessons provides the students with a short background of signal and its specifications, then are required to work collaboratively to demonstrate reception (and sometimes transmission, in a controlled environment) of the signals, using any available tool.
- **Midterm Exam:** The midterm exam is an institutional requirement and represents a sizable portion of their midterm grade. It is given as a "take-home" exam and is often structured very similarly to GRCon CTF events. The deliverable in this case is a technical report/writeup of their journey and is usually 10-15 pages long (including graphics).
- **Phase Shift Keying:** Here we return to the GNURadio Wiki, where Barry Duggan and company have outdone themselves in refining the previous iteration of tutorials. The mPSK tutorial is particularly thorough and provides a fantastically detailed background on many aspects of transmission and reception specific to PSK. Students also learn many of the peculiar nuances of GNURadio, which prepares them well for development of their final projects. The project for this section of the course is to team up with a partner and demonstrate either over-the-air or over-the-wire transmission and reception of a small chunk of data.
- **Frequency Hopping Spread Spectrum:** Although frequency hopping is common in modern electronics, it can be difficult to recreate in the context of an SDR. [11] is perhaps one of the best introductory tutorials to this commonly used technique. Additionally, Sandia National Labs [12] has developed a more rigorous set of tools for use in this context, but students usually wait until their final project to approach this more complex set of tools. Here again, the project is a distributed transmit-receive scenario, where students are forced to deal with the complexities of real, non-trivial communications channels.
- **RF Remote Hacking:** In this portion of the class, we reverse engineer an RF remote in the lower ISM band, such as a Hunter fan remote, commonly available at Lowe's. These fans typically use a simple modulation, such as On-Off-Keying (OOK). In the course of these lessons, we teach reverse engineering strategies (following guides such as the excellent [13]) and journey through many software options, such as URH, `rtl_433`, GNURadio, etc. Once we uncover the modulation and encoding scheme as a class, students build their own remote transmitter to operate the fan.
- **Special Topics:** Finally, time-permitting, we will investigate special topics, such as FMCW [14], GNURadio CTF challenges [15], [16], Electronic Warfare (EW), and any other topics students indicate interest in. This is a good time to investigate ongoing departmental research and encourage students to engage in those efforts.
- **Final Project:** The culmination of the class is a final project, in which the students are expected to choose a challenging communications problem, then build and test a solution. They produce a comprehensive technical report as their final deliverable. The course establishes regular milestones to develop familiarity with a rigorous, systematic approach to research. Furthermore, the documentation accompanying each milestone assembles into their final technical report, which *could* be appropriate for publication. These milestones are, in order:
  - **Project proposal:** Students provide a description of what they want to build, why they consider it important and/or novel, and describe what constitutes success (which determines their final grade). We review their proposal, modify it if necessary to appropriately set the difficulty level, and approve the project.
  - **Background research:** Students are required to perform a literature review similar to an annotated bibliography. They must review at least three reputable sources and discuss why these sources are relevant to their project and how it impacts their approach.

- **Design Description:** After reviewing the literature, students should have an idea of what they want to build and perhaps even be conducting small-scale tests for feasibility. The design description documents their process up to this point.
- **Prototype Description:** At this point, students describe the progress they have made in assembling their prototype and the work left to complete their project.
- **Final report, presentation, and demonstrate:** We reserve the final in-class lesson for a short presentation which includes a demonstration (or video, when appropriate) of their system capability. Students combine previous milestone documentation into a final project report. Their grades depend on the level of completion of the technical aspect of their project, along with the quality of their presentation and report.

Although we are consistently impressed with the quality of the final projects, here are a few of the more notable achievements:

- **First Person View (FPV) Detector:** A student extended gr-NTSC and developed a flowgraph to detect and demodulate FPV video in both NTSC and PAL formats.
- **GNURadio-Powered Remote Control:** The student replicated an RC car remote by interfacing an Xbox controller with GNURadio, which then modulates the signal onto the appropriate carrier and transmits it.
- **NOAA Satellite Image Decoding:** A student successfully received and decoded images from a NOAA satellite. In addition to properly addressing the signal SDR and processing aspects, the student designed their own antenna array for the effort.

V. Generic Feedback & Instructor Observations

As of this writing, it is too early for a formal assessment of the efficacy of this sequence, but course feedback has been stellar – some students refer to the assignments as some of the best they've completed during their time at USAFA. Additionally, students expressed great interest in the topics and enrollment in the second course has doubled for the next offering. Finally, we recently received an email from a graduate who had taken the sequence and their supervisor was very happy with his level of proficiency in modern communications systems – this is truly some of the best and most consistent course feedback of our courses.

From the instructor perspective, the course has been fun and rewarding to teach. We consistently learn new uses of SDRs as we teach the course. It is challenging to stay at the cutting edge of the SDR world and remain engaged with the GNURadio community (among others).

VI. Ongoing Challenges

Although we deem the reorganization a success, some challenges remain. First and foremost, student laptop configurations vary significantly, as does the serviceability of each computer. Most student laptops utilize Windows OS, while in many cases, Linux remains a more attractive OS for SDR development. Although we are investigating building an SDR laboratory, the portability of laptops and SDRs is a powerful combination. We currently rely on Radioconda [17], which meets approximately 90% of our needs. However, compiling OOT blocks that are not included is difficult on Windows. Furthermore, specifying editors for custom blocks can be a challenge. We have previously investigated Virtual Machines, Docker, and dual boot systems, but each approach introduces additional complexity and its own unique challenges. Additionally, DragonOS is an excellent turnkey solution and contains many of the required tools. However, we prefer students start with a clean image – this allows students to wrestle with some of the difficulties of installing open source software and the associated dependencies. We find this approach beneficial in that students will learn how to set up an environment from scratch in future jobs. Given these constraints, we are currently hoping to use a USB-C connected solid state drive (SSD) to live boot into an Ubuntu environment with persistent data storage, but the efficacy of the approach is not yet clear.

Secondly, ECE 447 (the first course in the sequence) fulfills one of our main ABET requirements, applications of probability and statistics. Therefore, in reorganizing the sequence, we must take care to keep the random signals and noise portions of the course, to ensure our accreditation remains valid.

Thirdly, multipath and electromagnetic interference (EMI) remains a significant issue in our facility. Many of the lower cost radios struggle with sending and receiving signals in this context. For this reason and for legal reasons, we often restrict our students to receive only.

VII. Future Work

While the initial work on the two course sequence is complete, the lesson organization requires some fine-tuning to best align the topics and tell the most coherent story. For example, in the first course, the interweaving of Signals and Systems with SDR topics may cause confusion among students. Therefore, we may consider a different lesson order.

Furthermore, we will begin collecting data from student feedback in order to quantify the efficacy of this approach. This data will include student assessments, "customer" surveys, and instructor observations. This data will allow us to further fine-tune the course and identify strengths, weakness, and opportunities for improvement.

VIII. Conclusion

In this paper, we detailed our modern, two-course Communications sequence that we believe will be instrumental in generating renewed interest in the communications field amongst our students, while also providing rigorous education to the next generation of engineers. The course sequence implements a logical progression of theory, lab practice, and SDR applications, while integrating evidence-based pedagogical practices. Informal feedback from our initial run of the sequence is promising, as is the increased enrollment for future offerings.

IX. Acknowledgments

We would like to thank those who have worked so hard to build the content we reference throughout the paper and the entire GNURadio community for welcoming us into their midst. This organization is experiencing a true renaissance, which will benefit seasoned engineers and future generations alike. Finally, we acknowledge our department leadership, who have graciously allowed us the flexibility to attempt bold projects like this. We also thank Dr. Kaitlin Fair for her thorough review and excellent suggestions regarding the paper and our methodology.

X. Disclaimer

The views expressed in this article, book, or presentation are those of the author and do not necessarily reflect the official policy or position of the United States Air Force Academy, the Air Force, the Department of Defense, or the U.S. Government. Approved for public release: distribution unlimited. PA#: USAFA-DF-2024-491.

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