

GRCon '24

A Modern,
Two-Course
Undergraduate
Communications
Sequence



UNITED STATES
AIR FORCE
ACADEMY

DISCLAIMER

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START WITH WHY

Make Undergrad Comms Great Again

START WITH WHY

Build Spectrum-Aware Tech Leaders

START WITH WHY

Generate Renewed
Interest

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START WITH WHY

Generate Renewed
Interest

Modernize Course
Curriculum

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Build Spectrum-Aware Tech Leaders

Improve Course
Pedagogy

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Theoretical Foundation

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Hands-On Learning

A HUGE CAVEAT



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A LITTLE BIT ABOUT USAFA

- Not a typical 4-year school
- Cadet academics
- Military training
- Athletics
- Semesters consist of 40 lessons
- 53-minute lessons
- Block schedule
- Two Comms Courses



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	MON	TUE	WED	THU	FRI	A/SAT	S/SAT	B/SAT	SUN
0515 0625	RELEASE FROM QUARTERS - Personal Time 0515 - 0625 No duties/activities/training Personal Time 0515 - 0515 No duties/activities/training (mornings w/ PC)								
0628-0646	Military Call to Quarters					0910 Academic Saturday	Silver Saturday 0700 - 0900	Blue Saturday	
0630-0723	Common Graded Review Period					0930 Follow regular MT Day schedule as applicable	See OPORD for scheduled training, home football games and meals	0900 Branch Buffet	0700 Reveille Personal Time
0730 0823	1 st Pd	1 st Pd	1 st Pd	1 st Pd	1 st Pd	0745 PHY ED 0900			0900
0830 0923	2 nd Pd	2 nd Pd	2 nd Pd	2 nd Pd	2 nd Pd				
0930 1023	3 rd Pd	3 rd Pd	3 rd Pd	3 rd Pd	3 rd Pd	0945 PHY ED 1100			
1030 1123	4 th Pd	4 th Pd	4 th Pd	4 th Pd	4 th Pd		Lunch 1100 - 1300		
1130-1223	Noon Meal Formation / Lunch								
1223-1238	Military Call to Quarters								
1245 1338	5 th Pd	5 th Pd	5 th Pd	5 th Pd	5 th Pd	M-5 CW T-5 DF		1300	1400
1345 1438	6 th Pd	6 th Pd	6 th Pd	6 th Pd	6 th Pd				
1445 1538	7 th Pd	7 th Pd	7 th Pd	7 th Pd	7 th Pd	1400 PHY ED 1515			
1550	Directed Development Time Or Intramurals/Personal Development Time (Alternate MIT Days)				Shift to Friday Training	Personal Development Time 1515-1645 Intercollegiate (M-F 1500-1645)			
1745	Personal Development Time (PDT) 1745-1945				Personal Time			1700 Dinner Buffet	
1945							1930		
1950	Academic Call To Quarters				Personal Time			Dinner To-Go Available 1930 - 1950	Roll Call 1915 - 1945
2300									1950 ACQ
2300 2400	TAPS/NCQ 2300 before class days - 2400 before training days Lights Out 2400 before class days								2300 TAPS
2400 0130	LIGHTS OUT							0130 TAPS	LIGHTS OUT

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ECE 447: Comms Systems

An **introduction to modern electrical communications**. The performance of various modulation and detection methods for both **analog and digital systems** are analyzed. **Software Defined Radios (SDRs) are introduced** as a practical application of communications systems. Coverage includes theory of operation, effects of random noise, bandwidth and other communication design constraints.

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ECE 448: Applied SDRs

A course in **practical telecommunications using software-defined radios (SDRs)**.

Building on the introduction to SDRs provided in ECE 447, students will gain familiarity with applications of **modern communications techniques**, including topics such as: modulation, filtering, encoding/decoding, sampling, analog-to-digital conversion, multipath, channel noise, and antenna selection. Students will use contemporary software tools, such as **Python and GNU Radio Companion** to implement complete transmitting and receiving systems using SDRs.

PREVIOUS SITUATION

ECE 447: Theory of Comms

1. Signals
2. Analog AM
3. Analog Angle Mod
4. Noise
5. Digital Modulation
6. System Design
7. Final Exam

ECE 448: SDR Applications

1. SDR Intro
2. GNURadio Intro
3. FSK
4. PAM
5. RF Remote Hacking
6. Custom Blocks
7. mPSK
8. Final Project

Note: Red text indicates a hands-on component.

ISSUES

ECE 447: Theory of Comms

1. Signals
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- Only 2 hands-on activities
- Very few applications
- Minimal connection w/ ECE 448
- Little interest in further study

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End result: graduates with gaps in education & experience

ISSUES

- Majority of the time = introducing HW/SW
- Little time to study real-world signals
- Students struggle w/ final projects

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End result: graduates with gaps in education & experience

ADDRESSING THE ISSUES

Generate Renewed
Interest

SDRs earlier in sequence

Modernize Course
Curriculum

Make Undergrad Comms Great Again

Improve Course
Pedagogy

Maintain Strong
Theoretical Foundation

Hands-On Learning:

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Hands-On Learning:

Every class interactive

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LET'S MAKE IT BETTER...

ECE 447: Theory of Comms

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ECE 448: SDR Applications

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THAT'S **BETTER...**

ECE 447: Theory of Comms

1. Signals
2. **Intro to SDRs**
3. Analog AM
4. **Analog AM in GR**
5. Analog Angle Modulation
6. **FM in GR**
7. Noise
8. Digital Modulation
9. **FSK in GNURadio**
10. Final Exam

ECE 448: SDR Applications

1. Advanced Comms Theory
2. **GR PAM**
3. **GR OOT Modules**
4. **Common Signals**
5. mPSK
6. **FHSS**
7. RF Remote Hacking
8. **Special Topics**
9. **Final Project**

Note: **Red** text indicates a hands-on component.

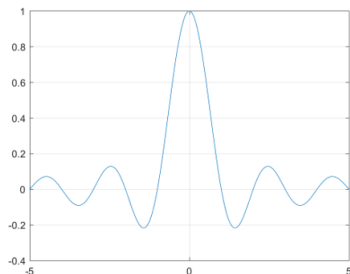
Bold text indicates reorg'd/new material.

ECE 447 TOPIC DETAILS

ECE 447: Theory of Comms

1. Signals
2. Intro to SDRs
3. Analog AM
4. Analog AM in GR
5. Analog Angle Modulation
6. FM in GR
7. Noise
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- Power & Energy
- Fourier Analysis
- Convolution & Correlation



ECE 447 TOPIC DETAILS

ECE 447: Theory of Comms

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- SDR hardware/software
- IQ Sampling & Data
- Intro to GR
- GR Data types, sampling rate, filters
- ZMQ, data files

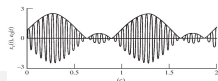
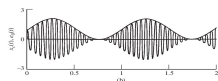
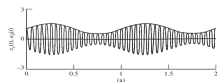


ECE 447 TOPIC DETAILS

ECE 447: Theory of Comms

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10. Final Exam

- AM Theory & Mixing
- DSB-LC
- SSB
- Pulse Modulation
- Analog AM Lab*

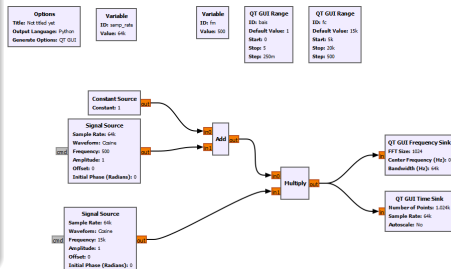


ECE 447 TOPIC DETAILS

ECE 447: Theory of Comms

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- AM Simulation
- AM Receiver



ECE 447 TOPIC DETAILS

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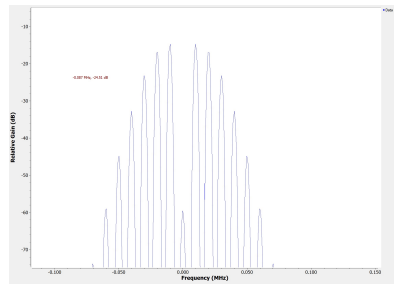
- FM Modulation
- FM Demodulation
- FM Lab*

ECE 447 TOPIC DETAILS

ECE 447: Theory of Comms

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- FM Receiver
- Dual FM Receiver



ECE 447 TOPIC DETAILS

ECE 447: Theory of Comms

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- Random Signals
- Noise in Digital Systems
- Probability of Error

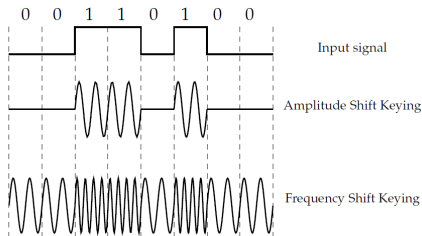


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- ASK
- FSK
- PSK
- Digital Modulation Lab*



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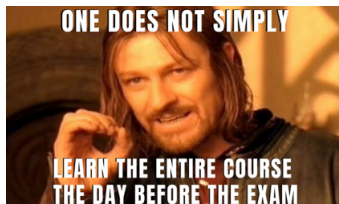
- FSK Tutorial
- **FSK Project**
 - End-to-end tutorial from Wiki
 - Students provided modulated file data
 - Must build decoder
 - Must be resilient to (low) sample errors

ECE 447 TOPIC DETAILS

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- Institutionally required
- Comprehensive
- Includes sample flowgraphs w/ errors
- Includes questions to test GR literacy



ECE 448: PICK UP WHERE WE LEFT OFF...

- Can't start the course without the syllabus...
- `syllabus.sigmf` → `syllabus.pdf`
- Provided Modulated data of PDF bytes
- Must demodulate to PDF document



DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 448 Syllabus - Spring 2023

Course description

Have you ever thought about the sheer number of wireless signals surrounding you in the modern world? From cell phones to WiFi to bluetooth - wireless communications enable just about everything you do! In this course, we will take a look at these signals - how they're generated, transmitted, and received! ECE 447 Communications Theory covers many of the fundamental principles of many methods of communication. This course will focus on the applied aspects wireless communications, specifically using Software Defined Radios (SDRs). This course will introduce SDRs, familiarize the student with the benefits and limitations of various SDRs and, more importantly, the various software packages used to interact with them.

Instructors

Lt Col Rogers (Course Director) 2E38 neil.rogers@afacademy.edu

Course Goals

Cadets enrolled in the course shall develop the ability to interact with SDRs, select the best SDR and software package for a certain application, and develop software to transmit/receive wireless signals. Cadets will also

Course Objectives

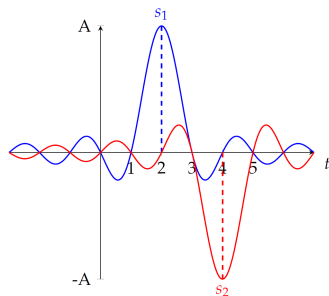
- Make use of modern software applications to simulate, receive, and transmit signals using modern modulation and encoding techniques.
- Describe the principles of basic signal processing techniques, such as filtering, interpolation, decimation, and matched filtering.
- Implement basic signal processing techniques, such as filtering, interpolation, decimation, and matched filtering in the presence of noise and other non-idealities.

Course Prerequisites by Topic

- ECE 215/315: Modulation and demodulation techniques for analog and digital systems.
- CompSci 206/210/211/212: Basic programming skills.

ECE 448 TOPIC DETAILS

- Course Intro & Motivation
- Link Budgets & Comms Systems
- Signal Space

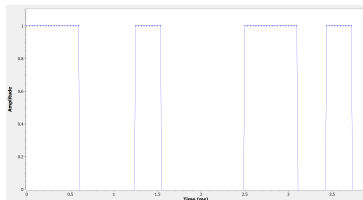


ECE 448: SDR Applications

1. Advanced Comms Theory
2. GR PAM
3. GR OOT Modules
4. Common Signals
5. mPSK
6. FHSS
7. RF Remote Hacking
8. Special Topics
9. Final Project

ECE 448 TOPIC DETAILS

- PAM Tutorial (Mathys, 2016)
- Hier blocks
- Matched filter project
 - Build new MF hier block
 - Must incorporate multiple pulse shapes



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ECE 448 TOPIC DETAILS

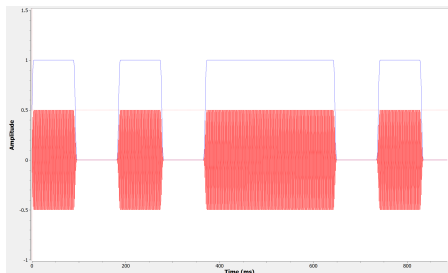
- OOT Module Usage
- Common OOT Modules
- Custom blocks
- Custom block project
 - Build non-trivial block
 - C++ or Python

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ECE 448 TOPIC DETAILS

- CW generator (@duggabe)
- Build CW decoder

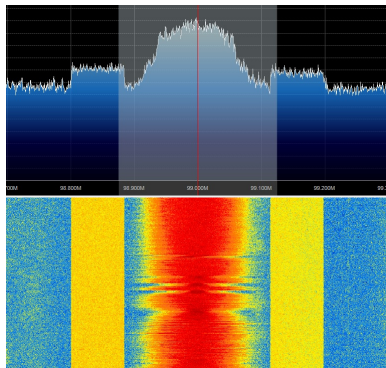


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ECE 448 TOPIC DETAILS

- HD Radio (thanks @Vlad!)



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ECE 448 TOPIC DETAILS

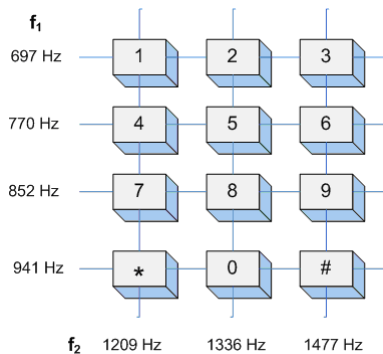
- ADS-B
 - Mode S message breakdown
 - Pymodes, gr-air-modes
 - Mobile device receiving
- AIS
 - NMEA Message structure
 - AIVDM generator, NRZI encoding, GMSK mod
 - AIS Simulator
 - @vtmichael?!

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ECE 448 TOPIC DETAILS

- DTMF generator
- DTMF receiver

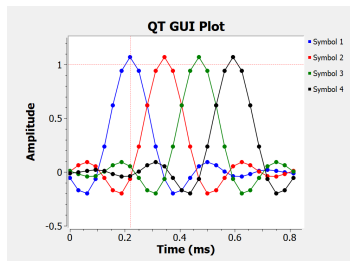


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ECE 448 TOPIC DETAILS

- mPSK Overview
- mPSK Tutorial

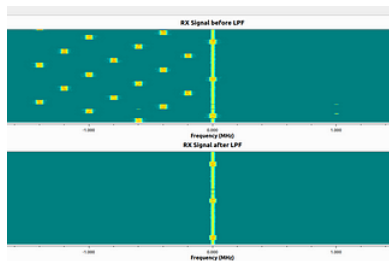


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ECE 448 TOPIC DETAILS

- FHSS (Medium @Solomon)
- Modify FHSS generator to be random



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ECE 448 TOPIC DETAILS

- URH Intro
- PPM
- Remote Reverse Engineering
- Build flowgraph to Tx remote signal



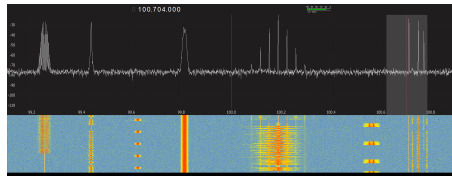
Rogers and Dudevoir

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ECE 448 TOPIC DETAILS

- FMCW
- GRCon CTF fun
- Other interesting topics



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ECE 448 FINAL PROJECT

- Starts around midterm
- Milestones drive work
- FPV Decoder (mod gr-ntsc)
- GR RC Control
- NOAA Image Decoding

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- FPV Decoder (mod gr-ntsc)
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Project Proposal

Background Research

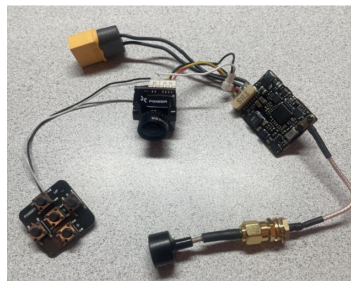
Design Description

Prototype Description

Final report & demo

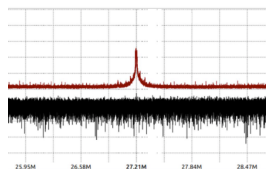
ECE 448 FINAL PROJECT

- Starts around midterm
- Milestones drive work
- FPV Decoder (mod gr-ntsc)
- GR RC Control
- NOAA Image Decoding



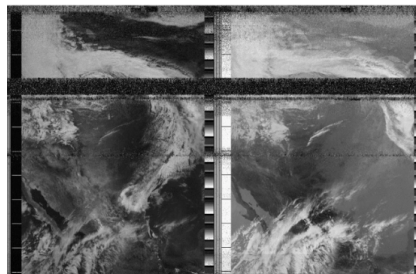
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- Instructor perception is good
- Observed high levels of engagement
- Observed high level of effort on final projects

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“The best assignment I've done at USAFA” - After 448 midterm

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- OS trouble
- Organization
- Accreditation



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0x54 0x68 0x61 0x6E 0x6B 0x73 0x21

Any Questions?