Course Syll

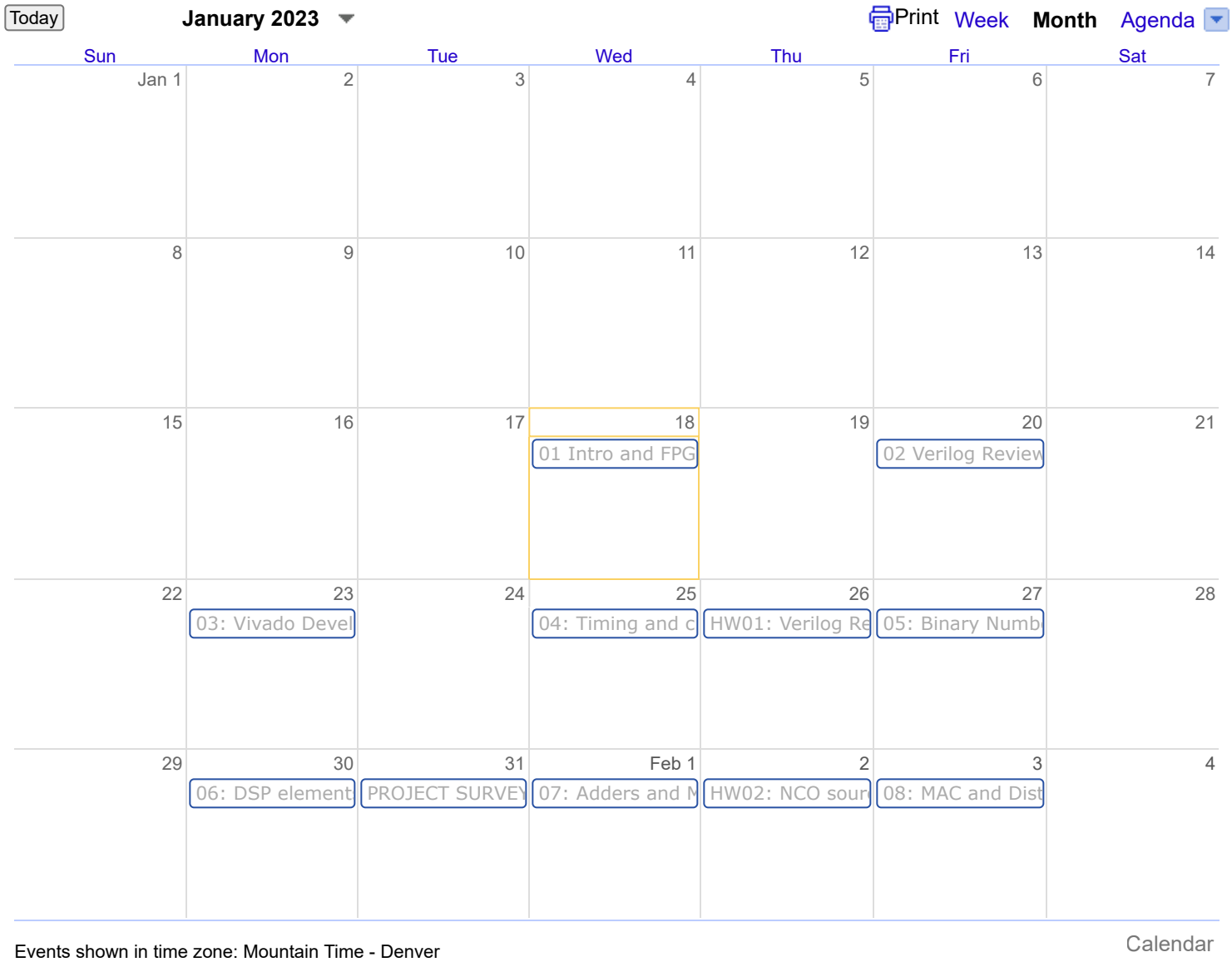
ECE545 FPGA Signal Processing and Software-Defined Radio

Spring 2023
Lectures: 10:00 AM -- 10:50 AM Mountain Time, Mon/Wed/Fri, ENGR B2
Instructor: Jesse Wilson
Email: **jesse.wilson@colostate.edu** (mailto:jesse.wilson@colostate.edu)
MS Teams Messaging: Wilson,Jesse
Phone: 970-491-3706
Office Hours: TBD (Please fill out **https://www.when2meet.com/?18174457-Oyu28** (https://www.when2meet.com/?18174457-Oyu28) as soon as you can).

Attendance policy: Attendance of every lecture *in person* is expected of students in the in-person (001) section. Online section (801) students are expected to view recorded lectures within 24hrs of posting.

Google calendar link (https://calendar.google.com/calendar/embed?src=1cd3aauei6d4hmbkc0l8vsfaak%40group.calendar.google.com&ctz=America%2FDenver) .

ECE545 SP2023



COURSE OBJECTIVES:

The student successfully completing this course will be able to:

- Distinguish FPGA vs microprocessor-based DSP implementation, explain tradeoffs between them, and select an architecture by weighing power consumption, bandwidth, and development effort considerations.
- Identify and explain consequences of analog/digital conversion of radio-frequency signals, such as aliasing and effective bit gain from oversampling.
- Distinguish and select between and fixed-point and floating-point arithmetic, depending on design objectives, and utilize IEEE math libraries to implement basic operations in either format.
- Construct and test in Verilog or VHDL the basic signal processing components: Numerically-controlled oscillator (NCO), mixers, finite- and infinite-impulse response filters (FIR, IIR), adaptive filters, and cascaded integrator-comb downsampling and upsampling (CIC) filters.
- Explain the Fast-Fourier Transform, identify how its implementations on an FPGA differs from on a DSP microprocessor, and construct it in Verilog or VHDL.

- Configure and make use of commercially-available intellectual property (IP) blocks to speed up DSP implementation.
- Configure and integrate on-chip soft CPU to reduce development time of functionality better suited to microprocessors (e.g. configuration, control, serial communications)
- Design and build all the digital elements of a basic communications system, including amplitude modulation of an NCO-generated carrier, transmission through a simulated channel, and demodulation with a digital downconverter (DDC).
- Engage in continued learning beyond this course, to be able to design and implement FPGA-based DSP systems with more sophisticated components (e.g. wavelets, spread-spectrum coding, real-time video processing)

PREREQUISITES: ECE311, ECE312, ECE451

REQUIRED BACKGROUND KNOWLEDGE:

- VHDL or Verilog experience
- Binary arithmetic and computer number systems
- Linear systems concepts, e.g. convolution, Fourier series, ...
- Digital filters, z transform, etc.

REQUIRED MATERIALS:

- *Digital Signal Processing with Field Programmable Gate Arrays,*4th ed. by Uwe Meyer-Baese. Springer, 2014. **Hardcopy recommended**. PDF can be downloaded from on-campus computers at **https://link.springer.com/book/10.1007%2F978-3-642-45309-0 (https://link.springer.com/book/10.1007%2F978-3-642-45309-0)** or off-campus through the **CSU Library Proxy (https://lib2.colostate.edu/help/plugins/proxy-url-converter.html)** .
- Introduction to Logic Circuits & Logic Design with Verilog, 2nd ed. by Brock J. LaMeres. Springer, 2019. PDF can be downloaded from on-campus computers at **https://link.springer.com/book/10.1007/978-3-030-13605-5 (https://link.springer.com/book/10.1007/978-3-030-13605-5)** or off-campus through the **CSU Library Proxy (https://lib2.colostate.edu/help/plugins/proxy-url-converter.html)** . **(https://link.springer.com/book/10.1007/978-3-030-13605-5)**
- MATLAB software.
- Xilinx Vivado ML edition. Free download at https://www.xilinx.com/products/design-tools/vivado.html. Recommend installing on your own machine, but it will also be installed on ETS machines, accessible in engineering labs or via remote desktop to vcl.engr.colostate.edu (VPN required off-campus).

Canvas : canvas.colostate.edu will have the syllabus, links, homework, course grades and other postings. It is your responsibility to check the calendar under the Index tab each week for new postings.

COURSE TOPICS: The planned topics for this course are:

Weeks 1-3	**Introduction**: FPGA technology, VHDL/Verilog review, FPGA vs DSP processors, Digital logic timing, Binary arithmetic	**Exam 1** on 2/8/2023
Week 4-6	**Finite impulse response filters**: Theory, z-transforms, FPGA implementation, Reduced adder graph, IP core usage	**Exam 2** on 2/24/2023
Weeks 7-9	**Infinite impulse response filters and feedback**: Theory, VHDL/Verilog implementation, finite wordlength effects (roundoff and saturation), timing, speedups, adaptive filtering	**Exam 3** on 3/22/2023
Week 10-11	**Communications systems and multirate signal processing:** modulation, demodulation, digital downconverter architecture, Polyphase FIR, CIC filters decimation, interpolation, CIC passband structure aliasing and distortion, compensation filters, analog/digital conversion	**Exam 4** on 4/10/2023
Weeks 12-13	**Fast Fourier Transforms**: Discrete Fourier transform review, Cooley-Tukey algorithm, Verilog/VHDL implementation	**Exam 5** on 4/24/2021
Week 14—15	**Machine learning and High-level synthesis:** neural nets, HLS motivation, design space exploration, C language constructs and datatypes, example with speed-area tradeoffs	bonus topic; no exam
Week 16	Finals week (group project presentations)	

GRADING:

ding quizzes (Canvas): 10%. Due every MWF before lectures. Lowest 2 scores dropped.
Participation / peer review of assignments: 10%. Lowest score dropped.
Homework and Verilog coding assignments: 40%. Lowest score dropped.
Exams: 20%. Lowest score dropped.
Final Project: 20%

A+	100%	to 96.67%
A	< 96.67%	to 93.33%

A- < 93.33% to 90%

B+ < 90% to 86.67%

B < 86.67% to 83.33%

B- < 83.33% to 80%

C+ < 80% to 76.67%

C < 76.67% to 70%

D < 70% to 60%

F < 60% to 0%

HOMEWORK:

All submitted homework and code must be your own individual work. Since a large portion of the work will be writing code, students are expected to adhere to the Academic Integrity Policies found on the Computer Science Department website:
http://www.cs.colostate.edu/cstop/csacademics/student_info.php (http://www.cs.colostate.edu/cstop/csacademics/student_info.php) (http://www.cs.colostate.edu/cstop/csacademics/student_info.php)

Each coding assignment must be submitted with a written report, describing the background/motivation for the problem, your approach (including relevant highlights from your code), obstacles and pitfalls encountered, and results.

ACADEMIC INTEGRITY: Students are expected to adhere to the Academic Integrity Policy of Colorado State University, outlined in the CSU General Catalog. Students are also expected to follow the Student Conduct Code which can be found at www.conflictresolution.colostate.edu. Academic dishonesty is not accepted in this course, and any form of cheating (including plagiarism) will be reported. Penalties may include a lowered course grade, loss of course credit, and expulsion from the university. **Assignments with plagiarized content will receive a negative grade.**

If you have any doubts about what constitutes plagiarism, please read:
https://writingcenter.unc.edu/tips-and-tools/plagiarism/ (https://writingcenter.unc.edu/tips-and-tools/plagiarism/)

Course Summary:

Date	Details	Due
Wed Jan 18, 2023	Reading for Lecture 01 (Intro) (https://colostate.instructure.com/courses/161835/assignments/1996364)	due by 11:59pm
Fri Jan 20, 2023	Reading for Lecture 2 (Verilog Primer) (https://colostate.instructure.com/courses/161835/assignments/1996391)	due by 9:50am
Mon Jan 23, 2023	Reading for Lecture 03 (NCO) (https://colostate.instructure.com/courses/161835/assignments/1996365)	due by 9:50am
Wed Jan 25, 2023	Reading for Lecture 04 (Timing) (https://colostate.instructure.com/courses/161835/assignments/1996366)	due by 9:50am
Thu Jan 26, 2023	HW01 Verilog review (https://colostate.instructure.com/courses/161835/assignments/1996335)	due by 11:59pm
Fri Jan 27, 2023	Reading for Lecture 05 (Binary Number Representations) (https://colostate.instructure.com/courses/161835/assignments/1996367)	due by 9:50am
	HW01 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996333)	due by 11:59pm
Mon Jan 30, 2023	Reading for Lecture 06 (DSP elements) (https://colostate.instructure.com/courses/161835/assignments/1996368)	due by 9:50am
Tue Jan 31, 2023	Project interest survey (https://colostate.instructure.com/courses/161835/assignments/1996359)	due by 11:59pm
Wed Feb 1, 2023	Reading for Lecture 07 (Binary Arithmetic) (https://colostate.instructure.com/courses/161835/assignments/1996369)	due by 9:50am
Thu Feb 2, 2023	HW02 NCO (https://colostate.instructure.com/courses/161835/assignments/2000373)	due by 11:59pm

Date	Details	Due
Fri Feb 3, 2023	Reading for Lecture 08 (Multiply-and-ACcumulate) (https://colostate.instructure.com/courses/161835/assignments/1996370)	due by 9:50am
	HW02 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996334)	due by 11:59pm
Wed Feb 8, 2023	Exam 1 (in-person sections) (https://colostate.instructure.com/courses/161835/assignments/1996324)	due by 10:50am
	Exam 1 (online section) (https://colostate.instructure.com/courses/161835/assignments/1996321)	due by 11:59pm
Thu Feb 9, 2023	Reading for Lecture 09 (FIR Review) (https://colostate.instructure.com/courses/161835/assignments/1996371)	due by 9:50am
Fri Feb 10, 2023	HW06 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996342)	due by 11:59pm
Mon Feb 13, 2023	Reading for Lecture 10 (FIR Implementation) (https://colostate.instructure.com/courses/161835/assignments/1996372)	due by 9:50am
Tue Feb 14, 2023	Project Proposal (https://colostate.instructure.com/courses/161835/assignments/1996360)	due by 11:59pm
Wed Feb 15, 2023	Reading for Lecture 11 (FIR Optimizations) (https://colostate.instructure.com/courses/161835/assignments/1996373)	due by 9:50am
Thu Feb 16, 2023	HW03 FIR filter and testbench (https://colostate.instructure.com/courses/161835/assignments/1996340)	due by 11:59pm
	Project proposal peer reviews (https://colostate.instructure.com/courses/161835/assignments/1996361)	due by 11:59pm
Fri Feb 17, 2023	Reading for Lecture 12 (Reduced Adder Graph) (https://colostate.instructure.com/courses/161835/assignments/1996374)	due by 9:50am

Date	Details	Due
	HW03 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996336)	due by 11:59pm
Mon Feb 20, 2023	Reading for Lecture 13 (Pipelined Reduced Adder Graph) (https://colostate.instructure.com/courses/161835/assignments/1996375)	due by 9:50am
Wed Feb 22, 2023	Exam 3 (online section) (https://colostate.instructure.com/courses/161835/assignments/1996320)	due by 11:59pm
Thu Feb 23, 2023	HW04 RAG filter design (https://colostate.instructure.com/courses/161835/assignments/1996343)	due by 11:59pm
Fri Feb 24, 2023	Exam 2 (in-person section) (https://colostate.instructure.com/courses/161835/assignments/1996325)	due by 10:50am
	Exam 2 (online section) (https://colostate.instructure.com/courses/161835/assignments/1996317)	due by 11:59pm
	HW04 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996338)	due by 11:59pm
Mon Feb 27, 2023	Reading for Lecture 14 (IIR Review) (https://colostate.instructure.com/courses/161835/assignments/1996377)	due by 9:50am
Wed Mar 1, 2023	Reading for Lecture 15 (IIR Challenges) (https://colostate.instructure.com/courses/161835/assignments/1996378)	due by 9:50am
▸ Mar 2, 2023	HW05 RAG filter implementation (https://colostate.instructure.com/courses/161835/assignments/1996345)	due by 11:59pm
Fri Mar 3, 2023	Reading for Lecture 16 (Time-domain interleaving) (https://colostate.instructure.com/courses/161835/assignments/1996379)	due by 9:50am
	HW05 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996341)	due by 11:59pm

Date	Details	Due
Mon Mar 6, 2023	Reading for Lecture 17 (Cluster/Scatter lookahead) (https://colostate.instructure.com/courses/161835/assignments/1996380)	due by 9:50am
Tue Mar 7, 2023	Project update 1 (https://colostate.instructure.com/courses/161835/assignments/1996362)	due by 11:59pm
Thu Mar 9, 2023	HW06 IIR Filter Design and Timing (https://colostate.instructure.com/courses/161835/assignments/1996346)	due by 11:59pm
	Project update peer reviews (https://colostate.instructure.com/courses/161835/assignments/1996363)	due by 11:59pm
Wed Mar 22, 2023	Exam 3 (in-person section) (https://colostate.instructure.com/courses/161835/assignments/1996326)	due by 10:50am
Fri Mar 24, 2023	Reading for Lecture 18 (Communications systems intro) (https://colostate.instructure.com/courses/161835/assignments/1996383)	due by 9:50am
Mon Mar 27, 2023	Reading for Lecture 19(Multirate systems intro) (https://colostate.instructure.com/courses/161835/assignments/1996384)	due by 9:50am
Wed Mar 29, 2023	Reading for Lecture 20 (Cascaded integrator-comb filters) (https://colostate.instructure.com/courses/161835/assignments/1996386)	due by 9:50am
Thu Mar 30, 2023	HW07 IIR Lookahead (https://colostate.instructure.com/courses/161835/assignments/1996348)	due by 11:59pm
Fri Mar 31, 2023	Reading for Lecture 21(Carrier recovery) (https://colostate.instructure.com/courses/161835/assignments/1996387)	due by 9:50am
	HW07 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996344)	due by 11:59pm
Mon Apr 3, 2023	Reading for Lecture 22 (IQ Demodulation) (https://colostate.instructure.com/courses/161835/assignments/1996388)	due by 9:50am

Date	Details	Due
Wed Apr 5, 2023	Reading for Lecture 23 (Fourier review) (https://colostate.instructure.com/courses/161835/assignments/1996389)	due by 9:50am
Thu Apr 6, 2023	HW08 CIC Filtering (https://colostate.instructure.com/courses/161835/assignments/1996352)	due by 11:59pm
Fri Apr 7, 2023	HW08 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996347)	due by 11:59pm
Mon Apr 10, 2023	Exam 4 (in-person section) (https://colostate.instructure.com/courses/161835/assignments/1996327)	due by 10:50am
	Exam 4 (online section) (https://colostate.instructure.com/courses/161835/assignments/1996318)	due by 11:59pm
Wed Apr 12, 2023	Reading for Lectures 24 and 25 (FFT theory) (https://colostate.instructure.com/courses/161835/assignments/1996397)	due by 9:50am
Mon Apr 17, 2023	Reading for Lecture 26 (FFT implementation) (https://colostate.instructure.com/courses/161835/assignments/1996392)	due by 9:50am
Tue Apr 18, 2023	Project update 2 (https://colostate.instructure.com/courses/161835/assignments/2035307)	due by 11:59pm
Thu Apr 20, 2023	HW09 FFT 2-point Butterfly (https://colostate.instructure.com/courses/161835/assignments/1996354)	due by 11:59pm
Fri Apr 21, 2023	HW09 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996349)	due by 11:59pm
	Project update 2 peer reviews (https://colostate.instructure.com/courses/161835/assignments/2035311)	due by 11:59pm
Mon Apr 24, 2023	Exam 5 (in-person section) (https://colostate.instructure.com/courses/161835/assignments/1996328)	due by 10:50am
	Exam 5 (online section) (https://colostate.instructure.com/courses/161835/assignments/1996319)	due by 11:59pm

Date	Details	Due
Wed Apr 26, 2023	Reading for Lectures 27-28 (Artificial Neural Networks) (https://colostate.instructure.com/courses/161835/assignments/2031925)	due by 9:50am
Thu Apr 27, 2023	HW10 4-point FFT (https://colostate.instructure.com/courses/161835/assignments/1996356)	due by 11:59pm
Fri Apr 28, 2023	Reading for Lecture 29 (Intro to HLS) (https://colostate.instructure.com/courses/161835/assignments/1996394)	due by 9:50am
	HW10 Peer Review (https://colostate.instructure.com/courses/161835/assignments/1996351)	due by 11:59pm
Mon May 1, 2023	Reading for Lecture 30 (HLS datatypes and ports) (https://colostate.instructure.com/courses/161835/assignments/1996395)	due by 9:50am
Wed May 3, 2023	Reading for Lecture 31 (AXI Protocol) (https://colostate.instructure.com/courses/161835/assignments/2032127)	due by 9:50am
Fri May 5, 2023	Reading for Lecture 32 (HLS example) (https://colostate.instructure.com/courses/161835/assignments/1996396)	due by 9:50am
Thu May 11, 2023	Final Presentation (https://colostate.instructure.com/courses/161835/assignments/1996329)	due by 11:59pm
May 12, 2023	Final project peer reviews (https://colostate.instructure.com/courses/161835/assignments/1996330)	due by 11:59pm
	Final project team evaluations (https://colostate.instructure.com/courses/161835/assignments/1996331)	due by 11:59pm
	Roll Call Attendance (https://colostate.instructure.com/courses/161835/assignments/1996399)	