Syllabus for Computer Logic and Circuit Design: PHYS306/COSC330

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Abstract

The core concepts of digital logic and digital circuit design are presented in this course, augmented with laboratory exercises. The course begins with binary mathematics and floating point representation. The concepts of Boolean logic and logic gates, truth tables, combinatorial logic and Karnaugh maps follow. These core concepts prove useful in a wide range of engineering, business, and scientific situations. Laboratory exercises are designed to emphasize hands-on experience with digital logic in firmware. Following an understanding of core modules, more complex digital elements are introduced. Examples include flip-flops (memory elements), counters, registers and shift registers. The course concludes with examples of digital systems useful for science and engineering, including binary adders (ALUs), analog-to-digital converters (ADCs), and digital-to-analog converters (DACs). Time permitting, the subject of digital signal processing (DSP) is introduced. Students will create and present final projects that integrate programmable logic and peripheral devices, to enrich the learning experience.

Pre-requisites*: PHYS180, COSC120. Pre-requisites may be waived at instructor discretion.*
Course credits, Liberal Arts Categorization*: 3 Credits, None*
Regular course hours*: Tuesdays and Thursdays from 13:30 - 14:50 in SLC 104. Laboratory exercises: SLC 102.*
Instructor contact information*: jhanson2@whittier.edu, tel. 562.907.5130*
Office hours*: Monday 8:00-12:00 in SLC 212*
Attendance/Absence*: Students needing to reschedule midterms and exams should notify the professor.*
Late work policy*: Late work is generally not accepted, but is left to the discretion of the instructor.*
Text*: Digital Fundamentals, 11th ed., by Thomas L. Floyd (Pearson). This is a widely adopted text with a variety of online features, online chapters, code examples, and excellent homework sets*[1].
Grading*: The assignment weighting for this course: two midterms worth 15% each, laboratory exercises worth 15%, homework exercises worth 25%, a final project design and presentation worth 15%, and a final exam worth 15%. The final exam will be held on May 8th, from 15:30 - 17:30.*
Grade Settings*:* $< 60\%$ *= F,* $> 60\%, \leq 70\%$ *= D,* $> 70\%, \leq 80\%$ *= C,* $> 80\%, \leq 90\%$ *= B,* $< 90\%, \leq 100\%$ *= A. Pluses and minuses: 0-3% minus, 3%-6% straight, 6%-10% plus (e.g. 79% = C+, 91% = A-)*
Homework Sets*: Due weekly on Thursdays, including textbook problems, subitted code, and digital designs.*
ADA Statement on Disability Services*: The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation, please contact Disability Services: disabilityservices@whittier.edu, tel. 562.907.4825.*
Academic Honesty Policy*:* `http://www.whittier.edu/academics/academichonesty`
Course Objectives:

- To master the binary and hexadecimal number systems, fluency with various binary codes and checksums.
- To master Boolean logic and logic gates, Boolean algebra and logical simplification through Karnaugh maps.
- To practice the application of Boolean logic to scientific, engineering, and business scenarios.
- To train in the art of transforming a diagram into a working prototype.
- To train in the art of troubleshooting a digital design and remedy bugs and errors.
- To develop confidence in building digital prototypes that accomplish design goals.
- To learn how to control programmable logic firmware with computer code.

[1] As a general rule, Prof. Hanson does not require students to purchase expensive texts. However, it is generally recommended to have this book as a reference if you are planning on a a degree in engineering or science. Please make arrangements with Prof. Hanson if you need assistance acquiring the book.

Course Outline:

1. Week 0 - **Reading: Chapter 1 of Digital Fundamentals.**
   (a) First meeting - Thursday, January 30th, 2020.
      i. Course introduction, syllabus distribution
      ii. *Laboratory tour and introductory laboratory exercises*
         A. The PYNQ-Z1 System on a Chip (SoC) and Jupyter Notebooks
         B. Breadboards, digital voltmeters, DC power supplies
         C. Oscilloscopes and signal generation
2. Week 1 - **Reading: Chapters 1-2 of Digital Fundamentals.**
   (a) First meeting - Tuesday, February 4th, 2020. *Reading: Chapter 1.*
      i. Logic functions: basic, combinatorial, and serial and parallel
      ii. Programmable logic and fixed IC logic
      iii. Test and measurement instruments
      iv. *Laboratory exercise, part I*
         A. Logic signal creation and measurement with oscilloscope
         B. Capturing digital signals from PYNQ-Z1: the PL layer and logictools library
   (b) Second meeting - Thursday, February 6th, 2020. *Reading: Chapters 2-1 through 2-7*
      i. Decimal and binary numbers, conversions and arithmetic, signed numbers
      ii. *Laboratory exercise, part II*
         A. Representing a binary number with LEDs
         B. PYNQ-Z1 and logictools: boolean generator, simple version.
3. Week 2 - **Reading: Chapter 2 of Digital Fundamentals.**
   (a) First meeting - Tuesday, February 11th, 2020. *Reading: Chapter 2-1 through 2-7.*
      i. Binary arithmetic, signed numbers
      ii. *Laboratory exercise, part I*
         A. Representing a binary number with LEDs, part II
         B. PYNQ-Z1 and logictools: boolean generator, with multiple logic functions (python dictionaries)
   (b) Second meeting - Thursday, February 13th, 2020. *Reading: Chapters 2-8, 2-10 through 2-12*
      i. Hexadecimal numbers
      ii. BCD, gray codes, and the parity and CRC error codes
      iii. *Laboratory exercise, part II*
         A. Breadboard prototyping
         B. Digital voltmeters, DC power supplies
4. Week 3 - **Reading: Chapters 3 of Digital Fundamentals.**
   (a) First meeting - Tuesday, February 18th, 2020. *Reading: Chapters 3-1 through 3-3*
      i. Hexadecimal numbers
      ii. BCD, gray codes, and the parity and CRC error codes
      iii. *Laboratory exercise, part I*
         A. Decimal, binary, and hexadecimal conversion
         B. Python programming, random number generation, and matplotlib
   (b) Second meeting - Thursday, February 20th, 2020. *Reading: Chapters 3-4 through 3-6*
      i. Logic gates: NOT, AND, OR, NAND, NOR, XOR, XNOR
      ii. *Laboratory exercise, part II*
         A. PYNQ-Z1 and logictools: finite state machine (FSM) generator, gray code counter
5. Week 4 - **Reading: Chapters 3-4 of Digital Fundamentals.**
   (a) First meeting - Tuesday, February 25th, 2020. *Reading: Chapters 3-8 and 3-9, 4-1 and 4-2*
      i. Programmable logic with gates
      ii. Boolean algebra, with applications and examples in business and engineering
      iii. *Laboratory exercise, part 1*
         A. Complex boolean functions, simulation, programmable logic, verification, part I

(b) Second meeting - Thursday, February 27th, 2020. *Reading: Chapters 4-3 through 4-10*
   i. DeMorgan's Theorems; further abstract examples in business and engineering
   ii. Boolean analysis of logic circuits, simplification
   iii. Truth tables, Karnaugh maps and SOP/POS minimization
   iv. *Laboratory exercise, part II*
      A. Complex boolean functions, simulation, programmable logic, verification, part II

6. Week 5 - **Reading: Chapter 5 of Digital Fundamentals**
   (a) First meeting - Tuesday, March 3rd, 2020. *Reading: Chapters 5-1 through 5-3*
      i. Combinatorial systems of logic gates
      ii. Universal NAND and NOR gates
      iii. *Laboratory exercise, part I*
         A. PYNQ-Z1 logictools: trace analyzer and pattern generator
         B. Use PYNQ-Z1 and pattern generator to multi-pin digital patterns, view with trace analyzer
         C. Plot the trace of combinatorial logic, part I
   (b) Second meeting - Thursday, March 5th, 2020. *Reading: Chapters 5-4 through 5-7*
      i. *Laboratory exercise, part II*
         A. Introduction to pynq logictools control module, stepping through code
         B. Plot the trace of combinatorial logic, part II
         C. System simplification and plot trace to show equivalency

7. Week 6 - **Reading: Review chapters 1-5 of Digital Fundamentals**
   (a) First meeting - Tuesday, March 10th, 2020.
      i. Review material, collection of example problems
      ii. Catch-up on laboratory exercises and troubleshooting
   (b) Second meeting - Thursday, March 12th, 2020.
      i. **First midterm exam**
         A. Covers material from chapters 1-5
         B. Emphasis on binary operations, boolean algebra, and simple collections of gates

8. Week 7 - **Spring Break: March 16th through 20th, 2020.**

9. Week 8 - **Reading: Chapter 6 of Digital Fundamentals**
   (a) First meeting - Tuesday, March 24th, 2020. *Reading: Chapters 6-1 through 6-6*
      i. Adders, comparators, and encoders
      ii. *Laboratory exercise, part I*
         A. Testing fixed IC adders with scope, LEDs
         B. Testing fixed IC comparators with scope, LEDs
   (b) Second meeting - Thursday, March 26th, 2020. *Reading: Chapters 6-7 through 6-11*
      i. Multiplexers and Demultiplexers
      ii. *Laboratory exercise, part II*
         A. Adders in programmable logic with gates
         B. Comparators in programmable logic with gates

10. Week 9 - **Reading: Chapters 7 and 8**
   (a) First meeting - Tuesday, March 31st, 2020. *Reading: Chapters 7-1 through 7-4, 7-5*
      i. S-R latches, flip-flops, and applications
      ii. Timers and pulse generation
      iii. *Laboratory exercise, part I*
         A. Demonstration of fast pulse generation
         B. Measurements of RF pulses, digital signal processing with NumPy/Octave
   (b) Second meeting - Thursday, April 2nd, 2020. *Reading: Chapters 7-5, and 8-1 through 8-4*
      i. One-shots (timers)
      ii. Shift registers
      iii. *Laboratory exercise, part II*

         A. Formation of final project teams. *Project proposals due one week later.*

11. Week 10 - **Reading: Chapters 8 and 9**
    (a) First meeting - Tuesday, April 7th, 2020. *Reading: Chapters 8-5, 9-1 through 9-5*
        i. Shift register applications
        ii. Finite state machines (FSMs)
        iii. Asynchronous and synchronous counters
        iv. *Laboratory exercise, part I*
            A. Testing fixed IC counters with scope
            B. Simple FSM and counter example with PYNQ-Z1
    (b) Second meeting - Thursday, April 9th, 2020. *Reading: 9-6 through 9-8*
        i. Cascaded counters and applications of counters
        ii. *Laboratory exercise, part II*
            A. Pattern generator counting and combination with boolean generator via pynq logictools control
            B. FSM counter generation and combination with boolean generator via pynq logictools control
12. Week 11 - **Reading: Review chapters 6-9**
    (a) First meeting - Tuesday, April 14th, 2020.
        i. Review material, collection of example problems
        ii. Catch-up on laboratory exercises and troubleshooting
    (b) Second meeting - Thursday, April 16th, 2020.
        i. **Second midterm exam**
            A. Covers material from chapters 6-9
            B. Emphasis on adders, timers and pulse generation, shift register applications, FSMs and counters
13. Week 12 - **Reading: Chapter 12**
    (a) First meeting - Tuesday, April 21st, 2020. **Reading: Chapters 12-1 through 12-3**
        i. Analog-to-Digital Conversion (ADC)
        ii. Digital-to-Analog Conversion (DAC)
        iii. *Laboratory exercise, part I*
            A. PYNQ-Z1 PMOD (peripheral modules) ports
            B. ADC PMOD - read in a voltage and plot it
    (b) Second meeting - Thursday, April 23rd, 2020. **Reading: Chapters 12-4 through 12-5**
        i. Digital Signal Processing (DSP) - an introduction to sampling and digitization
        ii. *Laboratory exercise, part II*
            A. PYNQ-Z1 PMOD (peripheral modules) ports
            B. DAC PMOD - produce a voltage and plot it on oscilloscope
14. Week 13 - **Reading: Chapters 2 and 3 of The Scientist and Engineer's Guide to DSP**
    (a) First meeting - Tuesday, April 28th, 2020. *Reading: Chapters 2 of DSP Guide*
        i. Selected topics in statistics and probability
        ii. Mathematics of sampling and digitization
        iii. *Laboratory exercise, part I*
            A. Audio signal acquisition with PYNQ-Z1
            B. Processing of audio data in GNU Octave
    (b) Second meeting - Thursday, April 30th, 2020. *Reading: Chapters 3 of DSP Guide*
        i. The sampling theorem
        ii. Aliasing and anti-aliasing
        iii. *Laboratory exercise, part II*
            A. More with GNU Octave
            B. Aliasing in time-series (audio) data
15. *Optional extra topics*- **Reading: Chapters 30 and 31 of The Scientist and Engineer's Guide to DSP**
    (a) First meeting: *Reading: Chapter 30 of DSP Guide*

            i. Complex numbers and the usage of complex numbers in DSP
            ii. *Laboratory exercise, part I*
                A. Exploring the Fourier transform, part I
                B. Power spectra and spectrograms
    (b) Second meeting: *Reading: Chapter 31 of DSP Guide*
            i. Complex numbers and the FFT, filters
            ii. *Laboratory exercise, part II*
                A. Exploring the Fourier transform, part II
                B. Filters and filtering data

16. Week 14 - **Group presentations and Final Exam**
    (a) First meeting - Tuesday, May 5th, 2020.
            i. *Group presentations: max. 15 minutes each, two students per group*

17. Final Exam: Friday, May 8th, 2020.