EE3220: SYSTEM-ON-CHIP DESIGN

Effective Term
Semester B 2022/23

Part I Course Overview

Course Title
System-on-Chip Design

Subject Code
EE - Electrical Engineering
Course Number
3220

Academic Unit
Electrical Engineering (EE)

College/School
College of Engineering (EG)

Course Duration
One Semester

Credit Units
3

Level
B1, B2, B3, B4 - Bachelor's Degree

Medium of Instruction
English

Medium of Assessment
English

Prerequisites
EE2004 Microcomputer Systems

Precursors
Nil

Equivalent Courses
Nil

Exclusive Courses
Nil

Part II Course Details

Abstract
This course aims to introduce the building components, fundamental concepts, and design considerations of System-on-Chip (SoC) for up-to-date embedded microcontroller MCU design with Hardware Description Language (HDL) and

ARM instruction set architecture (ISA). The course covers complete design flow from initial specifications down to final implementations with ARM processor board and FPGA for rapid prototyping. Students will learn microcontroller concepts, Software design basics, processor core architecture and interrupt system, C as implemented in assembly language, embedded memory mapping and system, peripherals and standard I/O interfacing, embedded ARM processor on System-on-Chip, such as Field-Programmable Gate Array (FPGA). The course emphasizes hands-on exercises of using Electronic Design Automation (EDA) tools, including ARM Development Studio, ARM mbed, Xilinx Vivado, and Xilinx Vitis, to the design of System-on-Chip (SoC) implemented on FPGA chip.

Course Intended Learning Outcomes (CILOs)

	CILOs	Weighting (if app.)	DEC-A1	DEC-A2	DEC-A3
1	Describe the functional components and architecture of an System-on-Chip (SoC)		x	x	
2	Use assembly language and HDL to programme an System-on-Chip (SoC)		x	x	
3	Design the memory system, standard I/O, interrupt for an System-on-Chip (SoC)		x	x	x
4	Implement System-on-Chip (SoC) by integrating processing system (ARM processor), programmable logic and standard AMBA bus architecture.		x	x	x

A1: Attitude
Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.

A2: Ability
Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines or applying academic knowledge to real-life problems.

A3: Accomplishments
Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.

Teaching and Learning Activities (TLAs)

	TLAs	Brief Description	CILO No.	Hours/week (if applicable)
1	Lectures	Key concepts of design are described and illustrated	1, 2, 3, 4	3 hrs/wk
2	Tutorials	Key concepts in designing System-on-Chip are practiced through different problems	1, 2, 3, 4	1 hr/wk
3	Laboratory	Key concepts learnt are applied to system implementation	3, 4	3 hrs/wk (5 weeks)

Assessment Tasks / Activities (ATs)

	ATs	CILO No.	Weighting (%)	Remarks (e.g. Parameter for GenAI use)
1	Tests (min.: 2)	1, 2, 3, 4	30	
2	#Assignments (min.: 3)	1, 2, 3, 4	10	
3	Lab Exercises/Reports	3, 4	10	

Continuous Assessment (%)

50

Examination (%)

50

Examination Duration (Hours)

2

Additional Information for ATs

Remark:
To pass the course, students are required to achieve at least 30% in coursework and 30% in the examination. Also, 75% laboratory attendance rate must be obtained.

may include homework, tutorial exercise, project/mini-project, presentation

Assessment Rubrics (AR)

Assessment Task

Examination

Criterion

Achievements in CILOs

Excellent (A+, A, A-)

High

Good (B+, B, B-)

Significant

Fair (C+, C, C-)

Moderate

Marginal (D)

Basic

Failure (F)

Not even reaching marginal levels

Assessment Task

Coursework

Criterion

Achievements in CILOs

Excellent (A+, A, A-)
High

Good (B+, B, B-)
Significant

Fair (C+, C, C-)
Moderate

Marginal (D)
Basic

Failure (F)
Not even reaching marginal levels

Part III Other Information

Keyword Syllabus

Introduction to System-on-Chip and Internet of Things (IoT)
System-on-Chip organization, design consideration, system requirement, Describe the functional components and architecture of an embedded system

Introduction to Microprocessor, Microcontroller
Building an Embedded System with an Microcontroller Unit (MCU), Microcontroller concepts, Review of Microprocessor Architecture, Arithmetic and Logic Unit (ALU), Concept of Computation, Microcontroller vs. Microprocessor, Stored Program Concept, Reduced Instruction Set Computer (RISC) Philosophy, Instruction Set Architecture, Pipelined Instruction Execution, Compilation and Assembling, ARM Processor Family

Embedded Software Design Basics
Concurrency, Interrupt Service Routine (ISR), Software Engineering for Embedded Systems, Preemptive vs. Non-preemptive Scheduling, Real-Time Operating System (OS), Peer Code Review

ARM Cortex M4 Processor Architecture
ARM Architectures and Processors, Cortex A/R/M Series, ARM Processor vs. ARM Architectures, Cortex M4 Registers, Thumb-1 and Thumb-2 Instruction Set, Nested Vectored Interrupt Controller (NVIC), Wakeup Interrupt Controller (WIC), Advanced Microcontroller Bus Architecture (AMBA)

ARM Instruction Set
Cortex M4 Memory Map, Bit band Operations, Program Image and Endianness,
ARM Cortex M4 Processor Instruction Set, Cortex M4 Instruction Set, Multiple Register Transfer Addressing Mode

C as Implemented in Assembly Language
ARM Programmer Model, Disassembled Program, Code Optimizations, ARM Architecture Procedure Call Standard (AAPCS), Linker Map File, Addressing Automatic and Static Variables, Function Call, Function Prolog and Epilog in C and Assembly.

Exceptions and Interrupts
Entering an exception handler, Push context to the current stack, Examine current vector table, Exiting an exception handler, Pop from the stack, Processor core interrupt, Nested Vectored Interrupt Controller (NVIC) registers and states, Timing analysis, Interrupt response latency

General Purpose I/O, and Peripherals and interfacing
General Purpose Input/Output (GPIO), Basic Concepts, Port Circuitry, Peripheral Access In C, Circuit Interfacing, Digital vs. Analog IO

FPGA & ARM & RISC-V Processor
FPGA Overview, FPGA + ARM Processor, Multi processor System-on-Chip (MPSoC), Building Blocks of a Generic Microcontroller, PicoBlaze vs. MicroBlaze, RISC-V Architecture, Zynq SoC (AP SoC), Processing System (PS), Processor Peripherals, AXI Interfaces

Timer & Serial Communications

Clock, Reset, and Debug Features, Interrupt Timer, Pulse-width modulation (PWM) Module, Serial communications, Full Duplex / Half Duplex, Software structure, Universal asynchronous receiver-transmitter (UART), Inter-Integrated Circuit (I2C), Serial Peripheral Interface (SPI)

Tutorial Schedule:
1. ARM Development Studion Installation
2. Hello World running on ARM
3. ARM Assembly Programming
4. Embedded Software Scheduling
5. Blinky C Program on ARM
6. ARM Instruction Set Architecture
7. Blinky Assembly Program on ARM
8. Timer Assembly Program on ARM
9. System-on-Chip Design Flow
10. Highl-level Synthesis (HLS) for System-on-Chip
11. Using Vivado and Vitis to Design SoC
12. System-on-Chip Numerical Acceleration

Laboratory Experiment:
The five lab exercises are design to enable students to gain hands-on experience using both ARM-based system, and FPGA-based System-on-Chip system:
1. Designing Embedded System with STM32F401RE ARM Board
2. Interrupt Programming and Debugging with Nucleo-F401RE Board and ARM mbed Platform
3. Designing System-on-Chip with MicroBlaze on FPGA
4. Creating custom IP for MicroBlaze and PWM on FPGA
5. Using Seven Segment Display and Pmod with MicroBlaze on FPGA

Reading List

Compulsory Readings

	Title
1	Nil

Additional Readings

	Title
1	Steve Furber, ARM System-on-Chip Architecture, Addison Wesley, ISBN 0-201-67519-6
2	Krzysztof Iniewski, Embedded Systems: Hardware, Design and Implementation, Wiley, ISBN: 978-1-118-35215-1.
3	ARM Cortex-M4 Processor Technical Reference Manual, https://developer.arm.com/
4	ARM Architecture Reference Manual ARMv8, https://developer.arm.com/
5	Steve Heath, Embedded Systems Design, (2nd Edition), Newnes, ISBN 0-7506-5546-1
6	Dr. Mark Fisher, ARM Cortex M4 Cookbook, Packt Publishing, ISBN 978-1-78217-650-3
7	Xilinx, Microblaze Soft Processor Core, https://www.xilinx.com/products/design-tools/microblaze.html