ECE9047B/ECE9407B: Final Exam

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2021 04 17

Honour Pledge: I will neither give nor receive aid on this assessment.

Instructions

- The final examination is **take-home** and **open-book**. You may use any printed or electronic resources to complete this exam.
- The entire exam is out of **100 marks**
- You should **not** collaborate with other students in this class or ask for help from other people (including online tutorial websites). **Doing so constitutes an scholastic offence!**
- You should **not** distribute any of your exam papers after the exam, or upload questions to any website including online tutorial sites.
- The final examination is available from 9:00 EST, Saturday April 17$^{\text{th}}$ until 21:00 EST Saturday, April 24$^{\text{th}}$. You must complete the exam within a **6 hour window** of your choosing during this time.
- The **first time you access the examination paper** "starts the clock", so don't do it until you are ready to finish the exam.
- You should upload your answer paper to the Final Examination *Tests & Quizzes* module on OWL within the 6 hour time limit.
- For uploading your written answers to OWL, either scan or photograph your hand written answers, or do it all electronically with a word processor or touch screen. However you do it, please ensure you upload only **one** document that contains all your work.
- It is each student's responsibility to ensure they can submit their complete answers within the time limit provided. Late submission is **not** accepted.
- University policy states that cheating, including plagiarism, on an examination is a scholastic offence. The commission of a scholastic offence is attended by academic penalties which might include expulsion from the program. If you are caught cheating, there will be no second warning.

This exam is available starting at
9:00 EST, Saturday, April 17$^{\text{th}}$ 2021
This exam will be removed at
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You have a **6 hour time limit** to
complete the exam within this time period.

1 Short Answer Questions

Answer the following questions as clearly as possible. You may use paragraph or point form.

(a). In the context of this course, what is the best definition of a **chip select logic**? [**3 marks**]

(b). What must the status flags be for a mnemonic to execute if it has the `lo` condition code? [**3 marks**]

(c). A UART peripheral is configured to `9-1-2`. What does this mean? [**3 marks**]

(d). In the context of this course, what is the best definition of full coverage? [**3 marks**]

(e). Draw the relay ladder logic (RLL) program to implement the following in one rung. Here A, B, C, D are the inputs. [**3 marks**]

$$f(A, B, C, D) = A\left(\overline{B} + C\right) + B\left(\overline{C} + D\right)$$

2 Memory Mapping

Design a memory map for a system with $64\,\mathrm{K}$ of memory space, a 16-bit address bus, and a 8-bit data bus. The system needs to meet the following design requirements:

- The system needs 20 K of RAM, organized in a contiguous block starting at the bottom of the memory range.
- The system needs 8 K of ROM, organized in a contiguous block ending at the top of the memory range.
- The system additionally needs a block of ROM situated between 0xB000 and 0xCFFF in memory (inclusive).

Your design must be subject to the following constraints in terms of access to memory chips:

- You can use a maximum of two (2) $8\,\mathrm{K}\times 8$ ROM chips.
- You can use a maximum of two (2) $4\,\mathrm{K}\times 8$ ROM chips.
- You can use a maximum of two (2) $8\,\mathrm{K}\times 8$ RAM chips.
- You can use a maximum of two (2) $4\,\mathrm{K}\times 4$ RAM chips.

There may be more chips here than are needed. You do not need to use all of them. Answer the following questions.

(a). Identify the beginning and end addresses (inclusive) for each memory chip used in your map. A diagram or a table may be useful here. Please write the addresses **in hexadecimal**. **[4 marks]**

(b). Design the chip select logic. Use any standard notation, or if you are using your own notation please add an explanation of how to read it. [**4 marks**]

(c). Describe how the address and data bus are connected to each chip: which of the 16 address bus lines (numbered 0 to 15) and which of the 8 data bus lines (numbered 0 to 7) are connected to each chip. **[2 marks]**

3 Assembly Language

Consider an ARM-type microcontroller.

(a). Select registers and memory cells are initialized with the following contents:

Register	Value	Memory Address	Value
r0	0x00000000	0x00001000	0x000000DD
r1	0x00000000	0x00001004	0x00000062
r2	0x00001000	0x00001008	0x00000081
r3	0x00000000	0x0000100C	0x0000005A
r4	0x00000000	0x00001010	0x0000005B

The following code is executed:

```
mov r4, #188
ldr r3, [r2]
ldr r0, [r2,#4]!
ldr r1, [r2], #4
str r4, [r2]
str r3, [r2,#8]
```

After the code has executed, what are the contents of the registers and memory cells? Please provide the contents as **hexadecimal numbers**. [**5 marks**]

(b). Select registers and memory cells are initialized with the following contents:

Register	Value	Memory Address	Value
r0	0x00000080	0xAA002000	0x00000D08
r1	0xAA002000	0xAA002004	0x000003D7
r2	0x00000085	0xAA002008	0x000004C3

The following code is executed:

```
  ldr r0, [r1]
lbl_1:
  cmp r2, r0
  addlo r2, #215
  blo lbl_1
  bl lbl_3
  str r2, [r1,#4]
lbl_2:
  b lbl_2
lbl_3:
  ldr r0, [r1,#4]
lbl_4:
  adds r2, r0
  bpl lbl_4
  bx lr
```

Answer the following questions. [**5 marks**]

- Which line of code is the start of a subroutine?
- How many times does the code on line 4 execute?
- What is the final value in memory address `0xAA002004`?

4 Peripherals

Consider a microcontroller with 16-bit registers, and a 16-pin GPIO port memory mapped to base address `0xE000`. The structure of the GPIO port registers is similar to an ARM-type system. You may also use ARMv7 Assembly code when answering this question.

(a). How can you tell which pins are set to output and which are set to input for this GPIO port? Either provide the assembly language code, pseudocode, or a clear written explanation. Be as specific as possible. **[2 marks]**

(b). Explain how to set pins `2` and `5` on the GPIO port to input. Make no assumptions regarding the initial configuration of the port, and do not modify any other pins. You may provide assembly language code, pseudocode, or a clear written explanation. Be as specific as possible. **[2 marks]**

(c). Explain how to set pins `10` and `12` on the GPIO port to output. Make no assumptions regarding the initial configuration of the port, and do not modify any other pins. You may provide assembly language code, pseudocode, or a clear written explanation. Be as specific as possible. **[2 marks]**

(d). Explain how to read from pins `2` and `5` on the GPIO port, and adds the values from those pins together as single bits (i.e., the result will be `0b00`, `0b01` or `0b10`). You may provide assembly language code, pseudocode, or a clear written explanation. Be as specific as possible. **[2 marks]**

(e). Explain how to write to pins `10` and `12` on the GPIO port. Assume that bits 0 and 1 in `r0` contain the values that should be written to pins `10` and `12`, respectively. You may provide assembly language code, pseudocode, or a clear written explanation. Be as specific as possible. **[2 marks]**

5 Embedded System Design

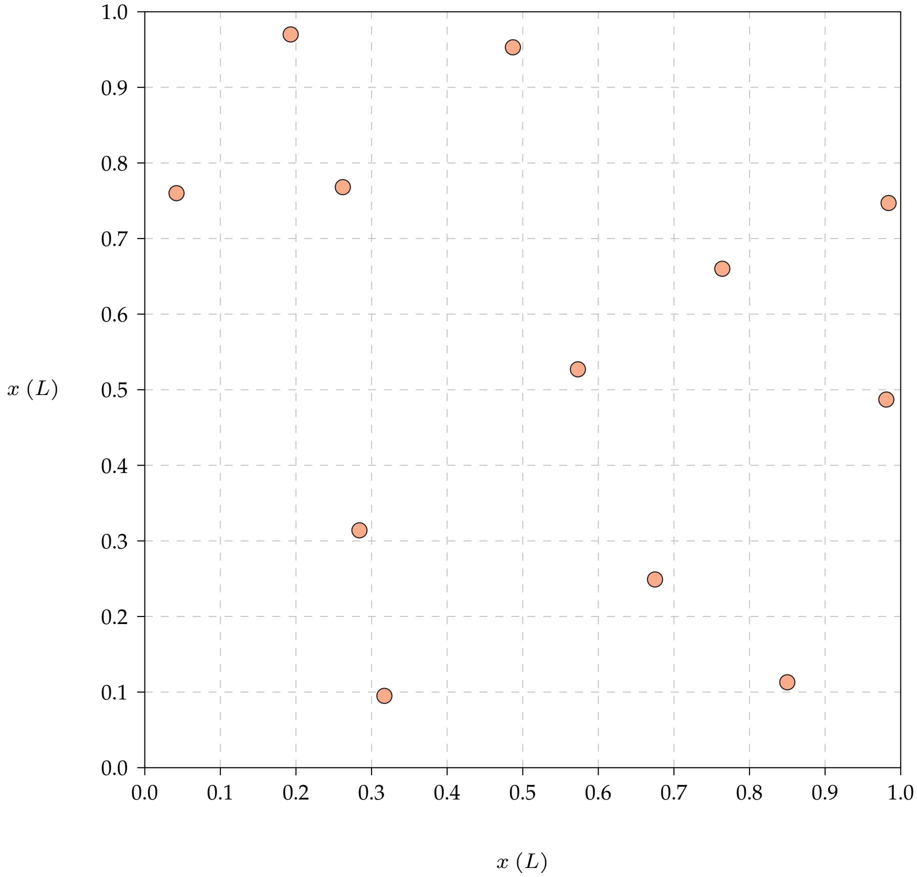
Write a program for the DE1-SoC to do the following:

- Set one of the interval timers for a count time of $10\,\mathrm{s}$.
- Start the timer counting down when push button 0 is pressed.
- Pause the timer when push button 1 is pressed, resume counting down when push button 1 is pressed a second time.
- Stop the timer and reset the timer interval to $10\,\mathrm{s}$ when push button 2 is pressed.

You may provide assembly language code, pseudocode, or a clear written explanation. Be as specific and as complete as possible. The program should run continuously. [**15 marks**]

6 Wireless Sensor Network Analysis

Consider the following WSN with 12 nodes. Here $R_C = R_S = 0.3L$. This diagram is drawn to scale.



The accurate coordinates for this WSN are given below.

Point	x (L)	y (L)	Point	x (L)	y (L)
1	0.317	0.095	7	0.284	0.314
2	0.675	0.249	8	0.042	0.76
3	0.85	0.113	9	0.262	0.768
4	0.487	0.953	10	0.193	0.97
5	0.981	0.487	11	0.984	0.747
6	0.764	0.66	12	0.573	0.527

Please complete the following:

(a). What is the k-connectivity of this network? Indicate (write the node number or label a diagram) which node(s) have the lowest connectivity. [**3 marks**]

(b). What is the k-coverage of this network? Indicate a spot which has the lowest coverage (give coordinates for one spot or mark a point on a diagram). [**4 marks**]

(c). Draw the maximal breach path passing through the area from left-to-right. You are welcome to prepare an accurate plot, but this is not necessary — a reasonably accurate sketch is sufficient. You don't have to draw the full Voronoi tessellation either (although you are welcome to do so), just use the rules for constructing the lines in the Voronoi tessellation along the maximal breach path. [**4 marks**]

(d). Draw the maximal support path passing through the area from left-to-right. You are welcome to prepare an accurate plot, but this is not necessary — a reasonably accurate sketch is sufficient. You don't have to draw the full Delaunay triangulation either (although you are welcome to do so). [**4 marks**]

7 Wireless Sensor Network Design

Since the start of the pandemic, the washroom facilities in public parks have been closed. Consequently, there has been a 5000% increase in public urination. The City Council of London has asked the ECE department at Western to develop WSNs for public parks to monitor for miscreants abandoning all sense of social responsibility and pissing in the parks. As a pilot project, you need to develop a WSN for Ruskin Park — a small park on Sarnia Road between Western Road and Wonderland Road.

Design nodes using equipment from the list given below. The only sensor needed is a urea detector, which senses aerosol urea (chemical compound $CO(NH_2)_2$). This sensor was custom-built by the ECE department and has an effective sensing radius of $5\,\mathrm{m}$. Otherwise all the equipment in this list is the same as the equipment available for Lab 4, and is described in the Appendix at the end of this exam paper.

Category	Description	Cost
Base	Microcontroller	\$10
Sensor	Urea Detector	\$3
Power Source	Low-Capacity Battery	\$5
	Medium-Capacity Battery	\$15
	High-Capacity Battery	\$25
	Power Converter	\$5
Communications	Zigbee Controller (ZC)	\$25
	Zigbee Router (ZR)	\$10
	Zigbee End Device (ZED)	\$5
	Z-Wave Transmitter	\$20
	DSL Modem	\$20

There are five utility poles near the park. Nodes can be wired to these poles to use the power grid instead of batteries. At least one node must be equipped with a DSL modem and attached to any of the utility poles so it can connect to the internet. You can only connect nodes to the utility poles if the node is placed right beside the pole. We cannot run long extension cords into the park — it is a tripping hazard for the children who attend St. Thomas More Catholic Elementary School right beside the park. A scale drawing of the park is provided below and also separately in SVG, PDF, and PNG form.

Please complete the following: [**15 marks**]

(a). Design a WSN to monitor the park with a budget of $5000.

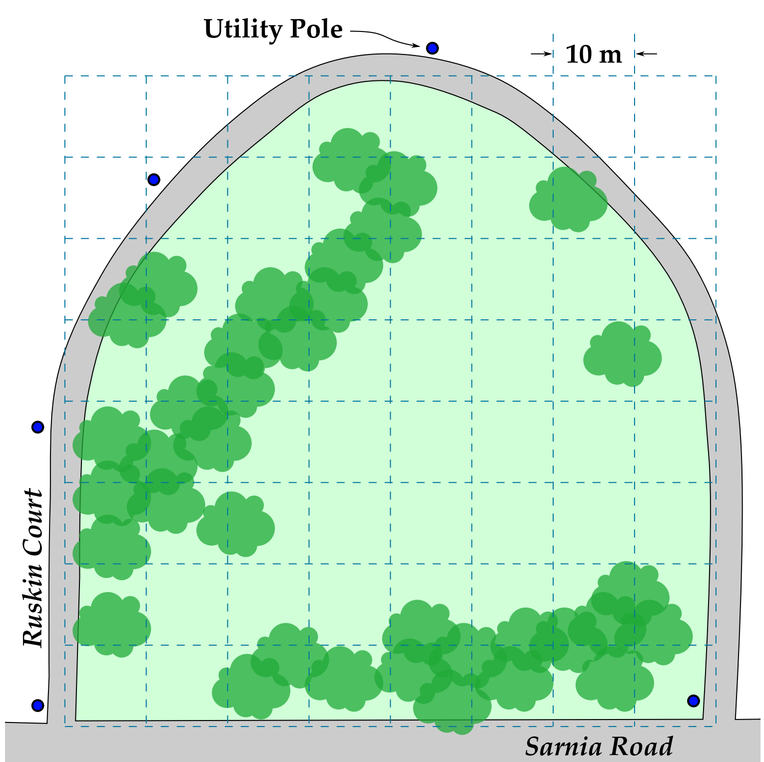
- This is a public project: while it is preferred to be under-budget, it is ok to go over-budget.
- All nodes in the WSN must be connected. At least one node with a DSL modem must be connected to one of the utility poles to connect the WSN to the internet. Nodes without modems may be connected to the other utility poles to use the power grid.
- Draw a reasonably accurate diagram of the WSN. If you have more than one kind of node in your network, make sure it is clear which ones go where. It is not necessary to show communication lines or circles for sensor coverage, but you are welcome to do so. (Drawing communication lines and sensor coverage will make it easier to describe the network.)

(b). Provide a description (point form and/or a diagrams are fine) of the node(s) you will use.

(c). Briefly describe the strengths and weaknesses of your network in terms of cost effectiveness, connectivity, sensor coverage, reliability and lifespan. Point form is acceptable.

- For cost effectiveness, you should discuss how the cost of the WSN falls within the given budget.
- For connectivity, mention the k-connectivity and identify if there are any regions that are only connected through a single node.
- For sensor coverage, identify if there are areas without any sensor coverage and if there are areas with increased sensor coverage, and briefly explain why. It is not necessary for the entire park to be in sensor coverage, but it is desired. The priority areas for sensor coverage are the areas with trees.
- For reliability, you should discuss whether there are any essential nodes that will cause parts of the network to go dark if they fail.
- For lifespan, you should discuss this qualitatively: short, medium, or long lifespan based on using low, medium, or high capacity batteries.

A scale drawing of the park (the green area) showing trees/bushes and utility poles is given below. A grid is superimposed with cells $10\,\mathrm{m} \times 10\,\mathrm{m}$.



8 Relay Ladder Logic Design

A "smart house" has temperature sensors in the living room, dining room, and master bedroom. However there is only one air conditioner for the house. The temperature sensors open (break the flow of electricity) when the temperature goes above 25 °C. The system should have the following operation:

- If all three rooms have temperatures above 25 °C the air conditioner is turned on to the "high" setting.
- If any two rooms have temperatures above 25 °C the air conditioner is turned on to the "medium" setting.
- If any rooms has a temperature above 25 °C the air conditioner is turned on to the "low" setting.
- There is also a master on/off switch for the system.

This question is vague on how to implement the air conditioner settings. One valid approach is to use a different output for each setting — but if you use this method make sure that your design will only ever try to use one setting at a time.

Draw the relay ladder logic diagram that implements this system, and explain how it works (point form is acceptable). Use only the four basic RLL elements discussed in class. If you choose to use your own special symbols instead of the standard symbols given in the notes, please provide a legend so I know what I am looking at. [**10 marks**]

Appendix: Equipment for WSN Nodes

The rules for constructing WSN nodes are the same as those used for Lab 4, except with a different sensor. Most of the information below is the same as was provided in the manual for Lab 4, repeated here for your convenience.

Base: All nodes must use a generic microcontroller as their basic component. This microcontroller has a few timers, a 4-channel analog-to-digital converter, and a few general purpose input/output ports. The microcontroller has enough memory for programs and some data storage, but not enough to store all the collected sensor data collected over an extended period of time (a few days, say). Communicating collected sensor data outside the WSN is a priority.

Urea Detector: A photonic cavity that uses infrared light to detect urea molecules in the air. This detector is appropriately sensitive that it can detect someone taking a leak up to $5\,\mathrm{m}$ away, perhaps even further if they had previously consumed an excessive quantity of beer.

You may assume the power consumed by the sensor is negligible. The major use of power by these nodes will be transmitting data wirelessly, so we will consider that as the only significant use of power.

All available batteries are listed based on the approximate number of transmission packets (assuming each packet is only a few bytes in size) that can be sent before the battery is depleted.

Low-Capacity Battery: The available low-capacity battery can provide an estimate of 2000 short-range wireless transmissions.

Medium-Capacity Battery: The available low-capacity battery can provide an estimate of 10 000 short-range wireless transmissions.

High-Capacity Battery: The available high-capacity battery can provide an estimate of 50 000 short-range wireless transmissions.

Power Converter: An AC/DC power converter brick is needed if the node will be wired into a utility pole. The utility grid provides essentially unlimited power.

Each node uses a wireless transmission to send sensor measurements to a connected node in the network, and *also* must use a wireless transmission to relay another node's transmission. Which nodes need to relay the most information is probably the key aspect to consider when deciding which power supply to use.

We have access to two types of wireless hardware: Zigbee and Z-wave. You may combine both protocols into your network if you wish, but of course Zigbee can only communicate with other Zigbee nodes, and Z-wave can only communicate with other Z-wave nodes. You can put both Zigbee and Z-wave hardware on a single microcontroller if you want a node to be able to use both protocols.

- For simplicity, we will assume both protocols use the same power consumption for a short-range wireless transmission.
- Both wireless signals can pass through trees without any issue.

It is also possible to make sub-networks using either or both protocols — if you wish, your WSN can consist of three independent Zigbee networks — as long as there is a communications path from every node to the DSL-enabled node that connects to the outside world. If you use multiple independent networks, this means that at least one node must have multiple transmission chips so it can communicate on multiple networks.

DSL Modem: At least one node in your network needs a DSL modem to connect to the internet.

Zigbee short-range wireless transmission is limited to $10\,\mathrm{m}$. A power-boosted long-range wireless transmission can reach $90\,\mathrm{m}$, but this uses $20\times$ the normal power consumption.

Zigbee Coordinator: Each Zigbee network must have one node with the Zigbee Coordinator (ZC) chip. A ZC node can communicate directly with other nodes, and can also relay information.

Zigbee Router: A Zigbee router (ZR) can communicate directly with other nodes, and can also relay information.

Zigbee End Device: A Zigbee end device (ZED) can only communicate with other nodes directly. It cannot relay information.

There is no limit to the number of hops in a Zigbee network.

Z-wave short-wave wireless transmission is limited to $30\,\mathrm{m}$ A power-boosted long-range wireless transmission can reach $90\,\mathrm{m}$, but this uses $20\times$ the normal power consumption.

Z-wave Transmitter: All nodes in a Z-wave network use the same hardware. This can communicate directly with other nodes, and also relay information. However the relay path is limited to a maximum of 4 hops.

A Z-wave network requires a control node, but that is software configured and assigned during network deployment — all nodes use the same hardware.