SENIOR DESIGN PROJECT FINAL REPORT
EE/CpE 4097 – Spring 2019

Project title: Educational 8-Bit Computer

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Customer(s): High School Teachers, Students & Hobbyists

Advisor(s): Dr. Joe Stanley (Associate Professor, MST)

Estimated cost:

$ 75.00 (curriculum only)
$ 150.00 (kit only)
$ 225.00 (total cost)

Instructor: **Dr. Robert Woodley**

Presented to the
Electrical & Computer Engineering Faculty of
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In partial fulfillment of the requirements for
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1 Introduction

1.1 Executive Summary

Together, we aim to create a product that creates and draws attention to the need of a fundamental curriculum to educates hobbyists and students the basics of computer architecture. Currently, there are very few CPU kits, if any, that provides all the necessary components and a curriculum in one package at a lower cost. Our biggest goal is to allow others to learn hands-on with information that follows in order to gain interest in the field of computer architecture.

1.2 Background and Problem Statement

There are few 8-bit CPU kits on the market that focuses on how basic computer architecture works using transistor-transistor logic in a piece by piece fashion. Based on interviewing various people, we now know what others expect out of our product. First and probably the most important is that our product is to be simple, but still have enough content for students to use and learn from. Even though the main person that we'd be selling the product to is the educators themselves, a big focus will have to be enjoyment. The product can't just be another tool that the students just quickly complete and lose interest in. If they aren't willing to use it, then nobody will buy it. The goal would be to keep them engaged and wanting to dive deeper into what our product has to offer. Our product must also be more than just a board with stuff stuck attached to it. We need to have lights and a display that people can interact with. Implementing these items should make it more enjoyable for end users. Seeing as they probably aren't interested in something like putting various voltages through their board and taking readings. In the end educators, students, and hobbyists should will benefit from our project.

1.2.1 Existing Works

- **Kano Computer Kit:** A kit costing $150 or $280 depending on the features, to build a computer given a set of instructions using Raspberry Pi 3 and their own OS. Compared to this, our design is focused on using an 8-bit microprocessor to make a computer instead of a Raspberry Pi which is a 64-bit already built computer. Our product also plans to cut the cost by about 65% when compared to the basic $150 computer kit. It is also seen that Kano is more focused towards knowledge of peripherals and using a computer whereas we will educate showing basic architecture with steps getting to the computer portion.
- **Gigatron TTL:** This product provides a kit to build a transistor level computer. The kit can be bought to assemble to play games on. This however, does not show others how each component works or communicate with other components but rather focused on assembling.

1.2.2 Global and Societal Context and Motivation

By introducing users to this knowledge we are expecting to provide motivation and inspiration. We expect users further seek information related to computer architecture after using our kit. Reducing cost of knowledge and access to these kits allows for those who want to to better themselves and possibly others with electrical equipment.

2 Design And Methods

2.1 Goals and Tasks

2.1.1 Goal 1: Creating a Curriculum

1) **Task 1.1: Curriculum Research**

   Description: In order to make our curriculum the best it can be, we have begun looking at our competitors ideas and expanding upon them. There are a lot of straight up sets of instructions which are a big help in creating our own product. We of course our just using their ideas to expand upon our own. Ideally this will allow us to make a curriculum that is better than anything that we are using for reference.

   Challenges: A big challenge with researching our competitors is that we don't want to take their ideas or copy what they are doing. There is also a lot to do to market to schools and whatnot. As in there are a lot of standards and regulations we must uphold in our product.

2) **Task 1.2: Writing the Curriculum**

   Description: This is the biggest part of our project. We have to create easy to understand instructions that allow a user to follow along while actually getting a feel for what they are doing. We would like it to be more than just step by step lego instructions. Seeing as anyone could follow along and not understand what they are doing. This needs to be at least most of the way done before hardware design can be fully completed. Seeing as this is what will be followed while using the hardware.

   Challenges: Explaining a pretty detailed topic in a way that is easy to follow and understand. It is also difficult to do this while following along standards that are set in place for something used for education. There is a lot to think about while writing this.

2.1.2 Goal 2: Hardware Design

1) **Task 2.1: Creation of Kit**

   Description: Choosing Parts and how they will be laid out. After having the curriculum completed, this will be a collection of parts that we can consider our "kit". This is the collection of various parts including our PCB, buttons, switches, LED's, and gates for control logic. In the end we should have a system for the user to build so that they can view what is going on with LED's throughout what they're building. If we can get far enough, we would like to implement something like a game for the user to play in the end.

   Challenges: The biggest challenge for this is having to come up with this at about the same time as the curriculum. Other than that, we have to worry about what pieces we are using. Taking our product to market, which is made up of a lot of little components, could require a lot of jumping around copyrights and patents. Seeing as each component is its own product already.

2.2 Deliverable(s)

Our product is a kit that includes a curriculum to help the user understand basic computer architecture. It will provide step by step instructions that are engaging to the user. Engaging the user in this manner should help them stay focused and want to continue learning. In the end the user should have a much better understanding of computer architecture. This will give them a solid building block for further learning into the subject.

2.3 Specifications and Requirements

Ref Number	Requirement	Description	Measurement
1	Curriculum	Detailed but simplistic booklet for educators to use as a teaching aid/guide to teach a class about the design and purpose of each 8-bit cpu part. This class should be able to be taught in one semester	10-20 page booklet
2	Hardware Kit	Purchasable product that contains every part and pcb necessary in order to build from the designs outlined in the curriculum. This also includes pre programmed memory modules	Every part included
3	Weight	All parts included within a kit must be under 1 pound for cheaper shipping	Weight of product is < 1 lb
4	Software	Software provided via a website where code can be ran from either a downloaded and uploadable file or a standalone client	Accessible website for product
5	Price	Software + hardware must stay below 75 USD. This does not include pricing of the curriculum	software+hardware < $75

3 Technical Approach

3.1 Overview

Creating the 8-bit cpu kit takes a lot of work. In order to complete this product we have employed many different techniques to keep engaged and design a product that futhers educational needs. Starting out the team will use a variety of computer aided designing softwares. After the various components have been modeled they will then be sent off to another CAD program for printed circuit board design assembly. Lastly those designs will be shipped and once received from the distributor, assembled and tested. This cycle will then continue until the prototyping process is complete for a revision.

Concurrently as the models are being made of the circuitry, a curriculum will be designed as well. This curriculum is designed in order to meet strict national guidelines and requirements. The curriculum provided will be instructional in nature and easy to follow alongside. It is to be designed in order to be taught as the user pieces the kit together. Each page of the curriculum is wrote and styled in order to provide an ease of learning while still conveying and covering important information regarding basic computer architecture.

3.2 Development Process

In development of the 8-bit cpu kit we have employed a twelve step design process taught by the PLTW brand. This process described in base functionality as defining a problem, brainstorming and researching ideas, exploring possibilities, designing a proposal, prototyping, refining, and communicating results.[3] Intermittent steps are left out as only the base functionality is described here. Each step in the design process allows for clear cut communication in order to deliver the product and stay on schedule.

3.3 Tools Used

Our team uses various tools to design, create, and develop the 8-bit cpu kit. These tools include use of CAD such as Solidworks, ModelSim, and Altium. These tools relate to the hardware side only. Software comes from using atom with assembly integration and the Arduino ide. In order to create the curriculum our team uses various documentation tools. The tools we use are Microsoft word, Microsoft powerpoint.

3.3.1 Software

Solidworks is used in order to design a connection joints for the pcbs so that we may use 3d printing technology. These connections allow for data to flow and need to be robust enough to withstand everyday use while not compromising product integrity. A suitable alternative is that of Autodesk Inventor. Eric and Tyler have had many hours of experience throughout solar car and first robotics in modeling and designing using cad

ModelSim is used in order to test each component before heading off to Altium. ModelSim is a designing software used to simulate how each cpu component will behave. These pieces will then be joined together to form the 8-bit cpu kit.A suitable alternative is that of Quartus. Tyler, Justin, and Jeremy have taken multiple courses in their pursuit of computer engineering degrees. These courses include CpE 3150

After ModelSim results have been processed the designs are then sent to Altium. Altium allows for rendering and pcb layout. Both of these design needs are crucial as the curriculum needs reliable visuals and the pcb is what is used to establish electrical connection between components. An alternative is kicad or eagle cad. Eric is working on this portion as he has been working with this throughout work at the emclab and from his experience on solar car.

The Arduino ide is used in order to provide a stable platform that’s already existing. This platform allows for cheaper programming of the EEPROM modules. If this wasn’t used we would have to think about a different software solution to programming the EEPROM modules. No real need for an alternative as Arduino are cheap and efficient. Tyler will be working with this as he has many years in programming arduinos and writing software.

Word allow for the curriculum to be designed and rewrote, showing different revisions. This is incredibly important as the curriculum is very fluid before release. An alternative is google docs. Google docs allows for real-time edits with multiple people. All team members will participate in this to provide critical input as to meet requirements and keep it light but educational.

PowerPoint is useful in providing an initial presentation for the teachers to present. Doing this allows for anyone to provide useful information in the form of a presentation. All team members will work on this as well for the same reasons as on Word. Google slides is a suitable alternative.

3.3.2 Hardware

Various tools useful in aiding in the assembly and prototyping are a Soldering Iron, an Oscilloscope, Arduino. These tools are extremely useful as they allow for various debugging and assembly. The soldering iron is for assembly and disassembly of soldered components. The Oscilloscope is useful in debugging. The Oscilloscope allows our team members to see the data traveling and switching of components. Finally the Arduino allows for instance changes where the design would need adjusting before release.

3.4 Hardware Components

The 8-bit cpu runs from 7 main components tied in through a main bus.

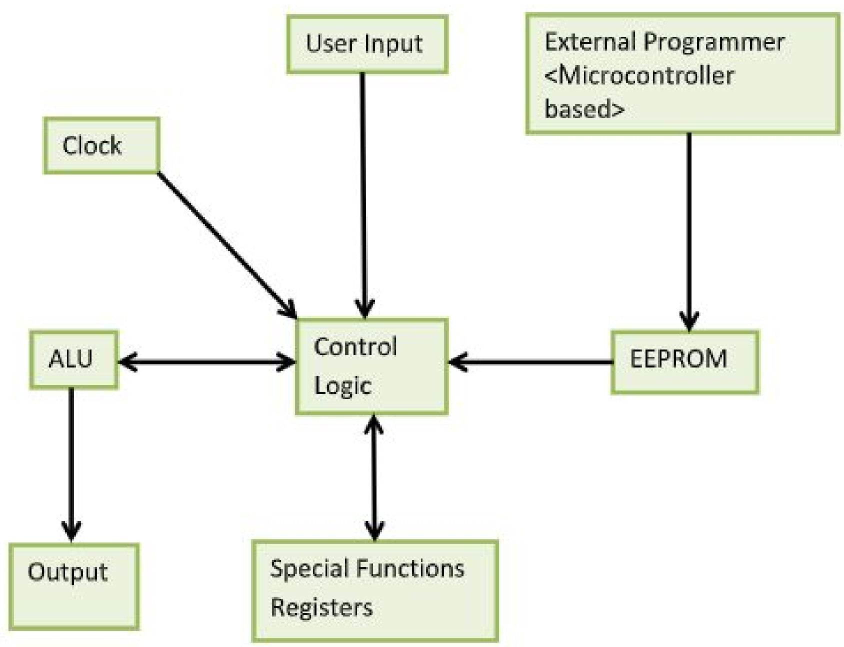

Figure 1: 8-bit cpu block diagram

3.4.1 The Clock:

A 555 timer will be used in conjunction with push buttons and a variable resistor. These components were chosen as they provide reliable and documented performance in similar applications. The pushbutton is used as a step mechanic to trigger one clock cycle at time. A variable resistor was chosen as it would allow the clock to be sped up or slowed down so the user might be able to see what happens in real time.

3.4.2 User Input

For user input the decision was made to use an eight pin dip switch. The reason this was made was that only 8 bits of information will flow through the 8-bit cpu at any given time. Using the switch the user will be able to allow different opcodes to be run at any given time. This also allows the user to see how each bit is critical in overall performance of the device.

3.4.3 Control Logic

Control logic for the 8-bit cpu kit is still will still need to be finalized at a later state. In the current form the control logic provides a means of reading and writing to the various other components. The control logic determines what is happening at each and every state in the cpu.

3.4.4 Special Function Registers

Special function registers haven't been implemented yet but will when load, store, and jump opcodes are in through their final round of testing. The reasons these registers are needed is so that the control logic doesn't need to be unnecessarily large and to keep the diversity of the cpu intact.

3.4.5 EEPROM

Electrical erasable programmable read-only memory is the memory of the cpu. This single chip will store all the opcodes and data for the cpu to be made usable. Programming of the chip will be done externally and loaded in initially.

3.4.6 Arithmetic Logic Unit

The ALU is the largest component of the cpu. This will be comprised of two to four registers for multiple eight bit operations at a time. Final design of the ALU will be added at a later date. This component is a critical part in the cpu as without it no mathematical calculations could be performed.

3.4.7 Output

Lastly the output is what the user sees. This is not just the multiple seven segment displays but also the leds on the input and output of critical components. All of these flashing leds will serve one purpose all together, to provide critical information for the user to follow along with. The information conveyed by the output will detail all the operations of each component and will be neatly arranged in the curriculum.

3.5 Software design

Software developments for the 8-bit cpu kit is aimed at providing more then what is expected. With the kit we have an EEPROM module. This module will hold all the information necessary to communicate what functionality this kit provides. Coding for the EEPROM is done via an external devices. The external device we have chosen is that of the Arduino. Specifically the Arduino will run a simple double for loop to change the EEPROM's storage. The data to be embedded is that of the opcodes that we have been finalized.

The opcodes that will be added to the EEPROM's storage is that of Add, Subtract, Store, Load, Move, and Jump. We know that these opcodes will give the product a great feel for the first time users. Using these instructions allows the user to perform a variety of simple but intriguing designs.

We plan on adding an additional 3 opcodes to be decided at a later time as well as finalizing the arduino code so that it will perform the writes to the EEPROM.

3.6 Final Schematics

3.6.1 Clock

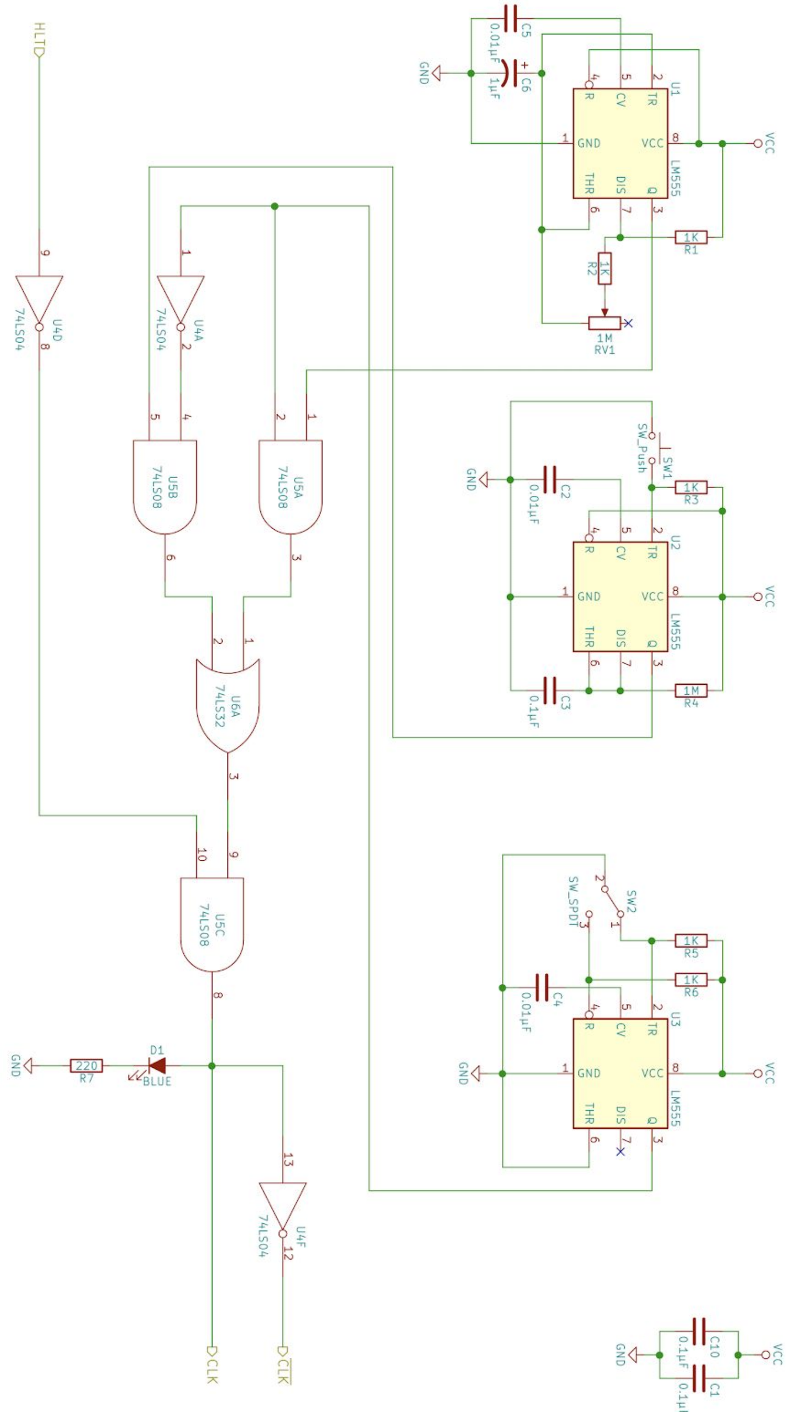

Figure 2: Clock Schematic

3.6.2 A Register

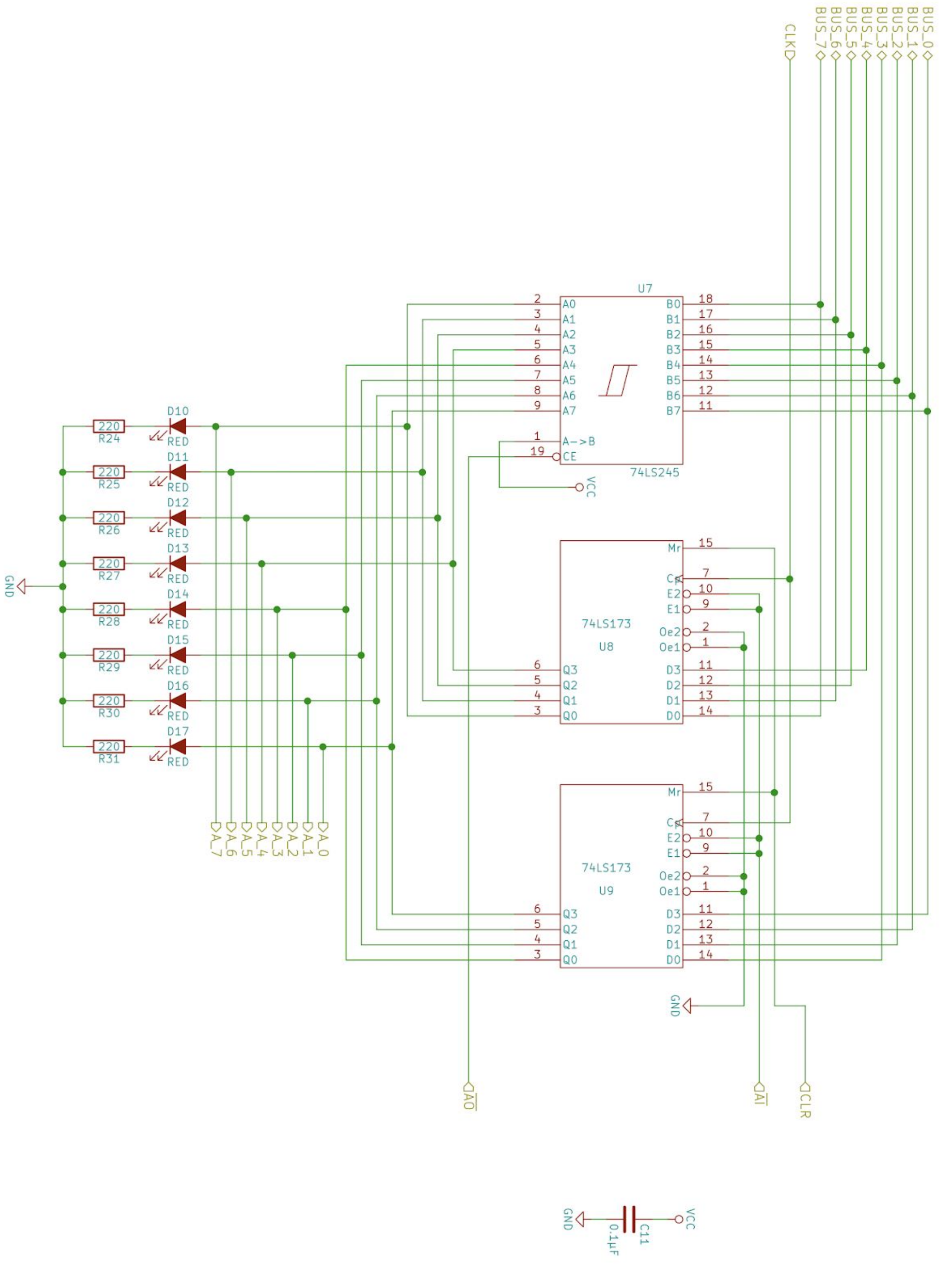

Figure 3: A Register Schematic

3.6.3 B Register

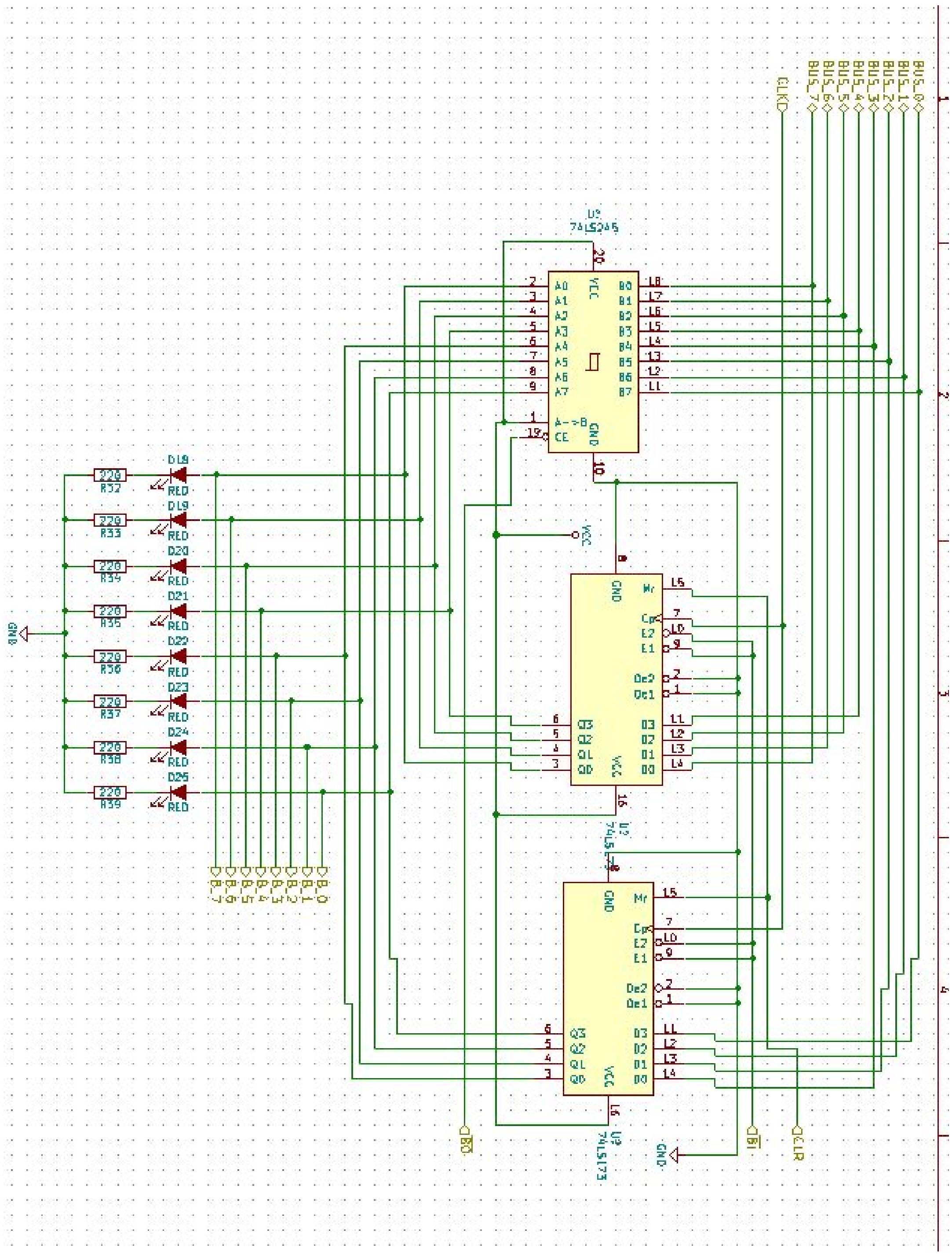

Figure 4: B Register Schematic

3.6.4 Instruction Register

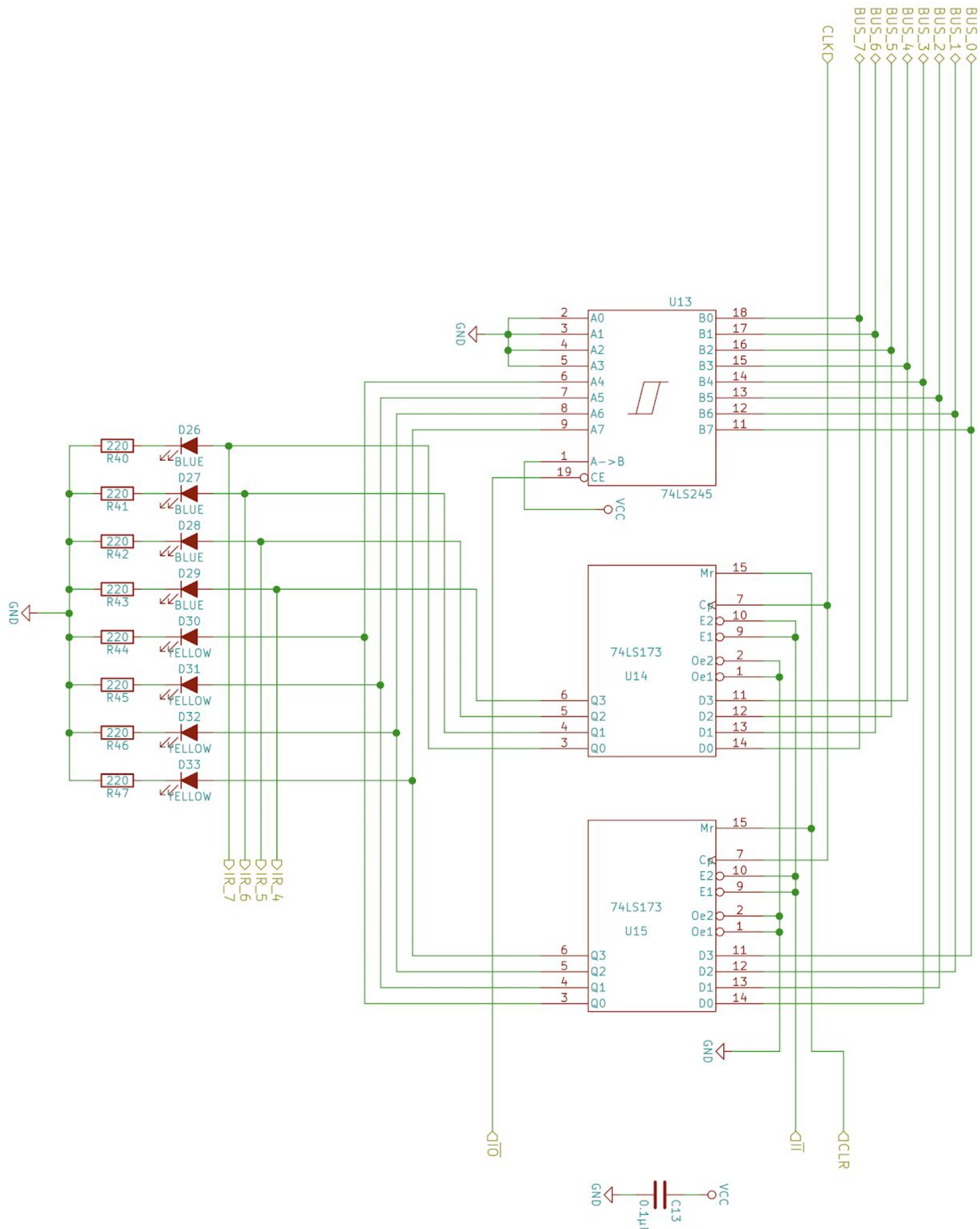

Figure 5: Instruction Register Schematic

3.6.5 Arithmetic Logic Unit

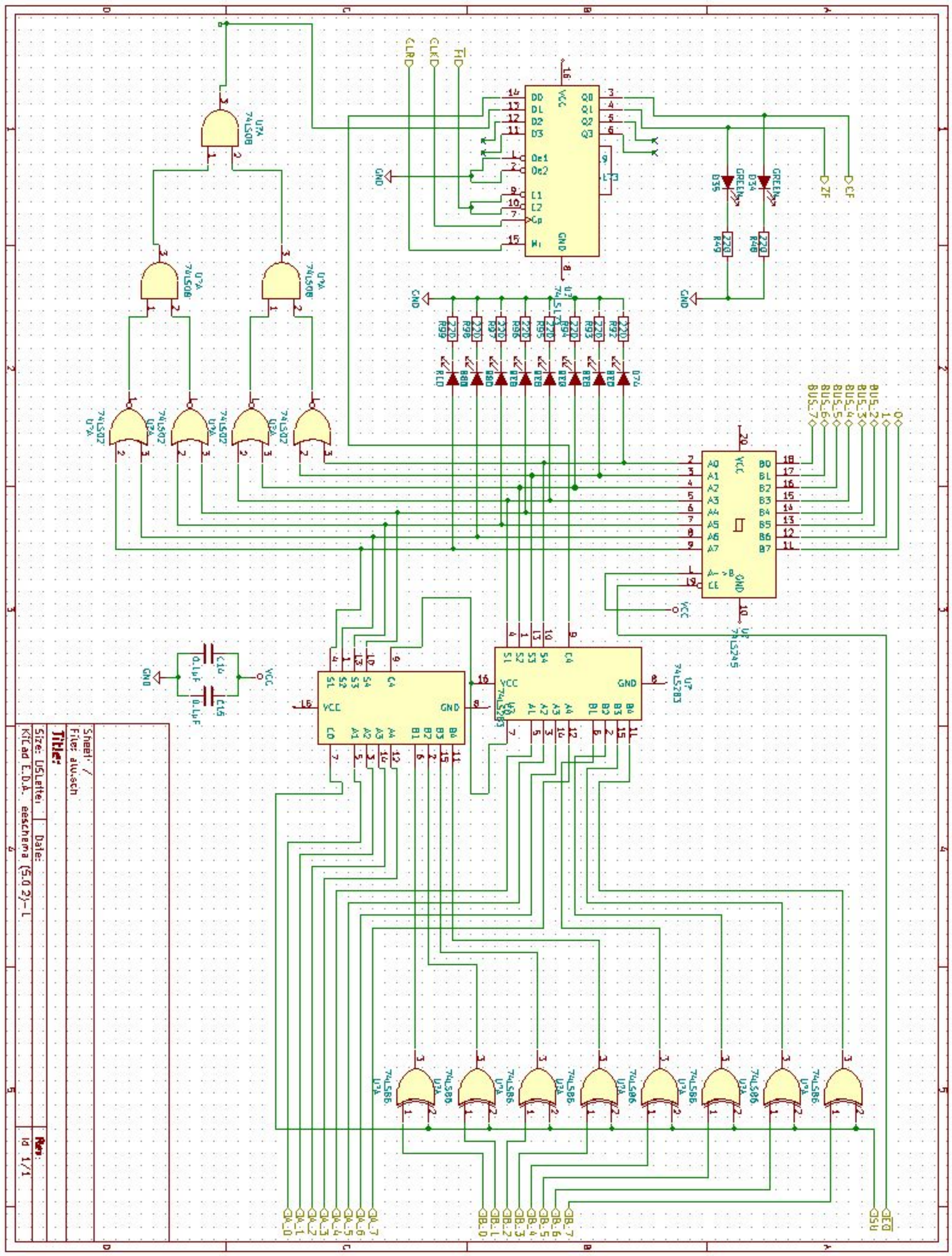

Figure 6: ALU Schematic

3.6.6 Control Logic

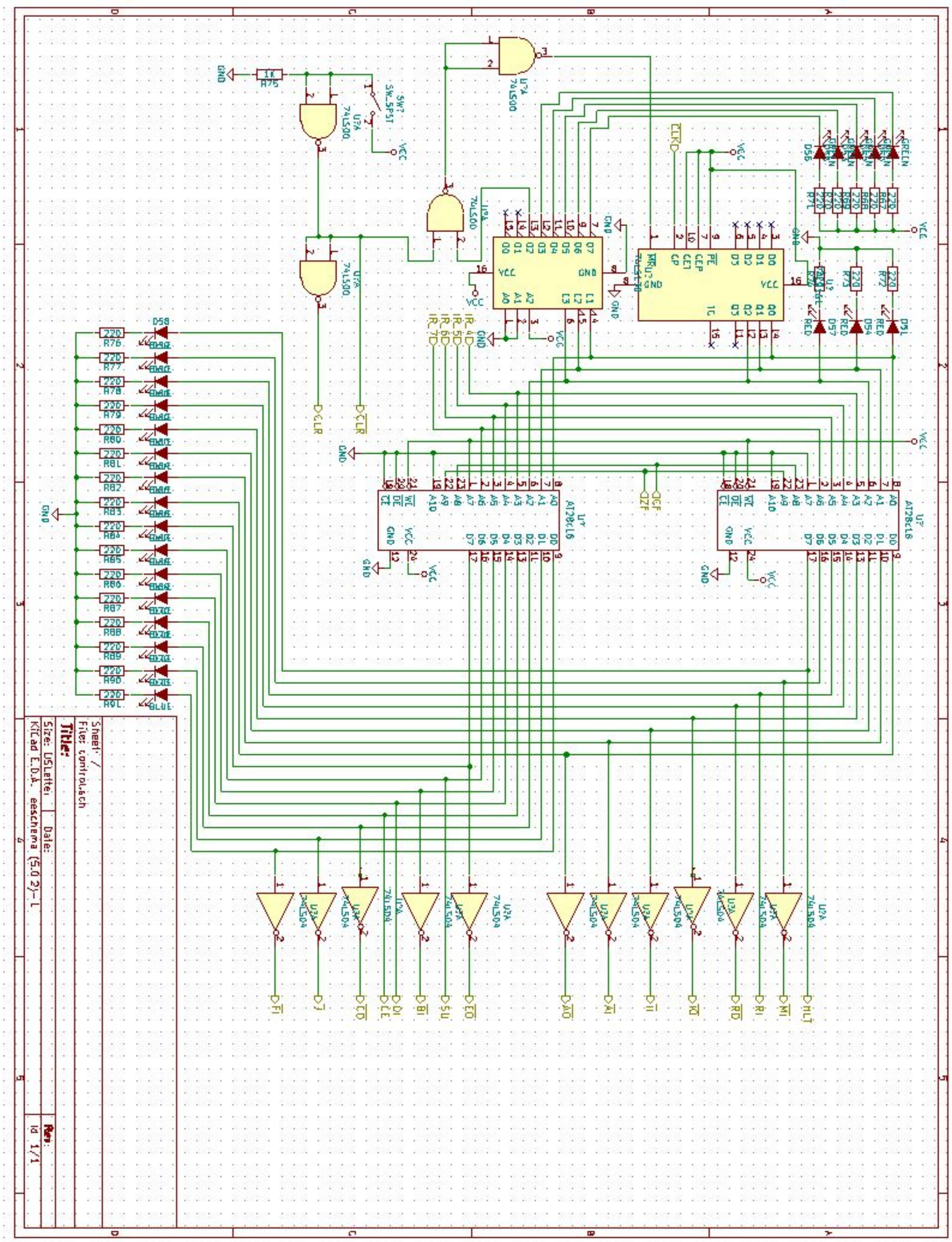

Figure 7: Control Logic Schematic

3.6.7 Memory Address Register

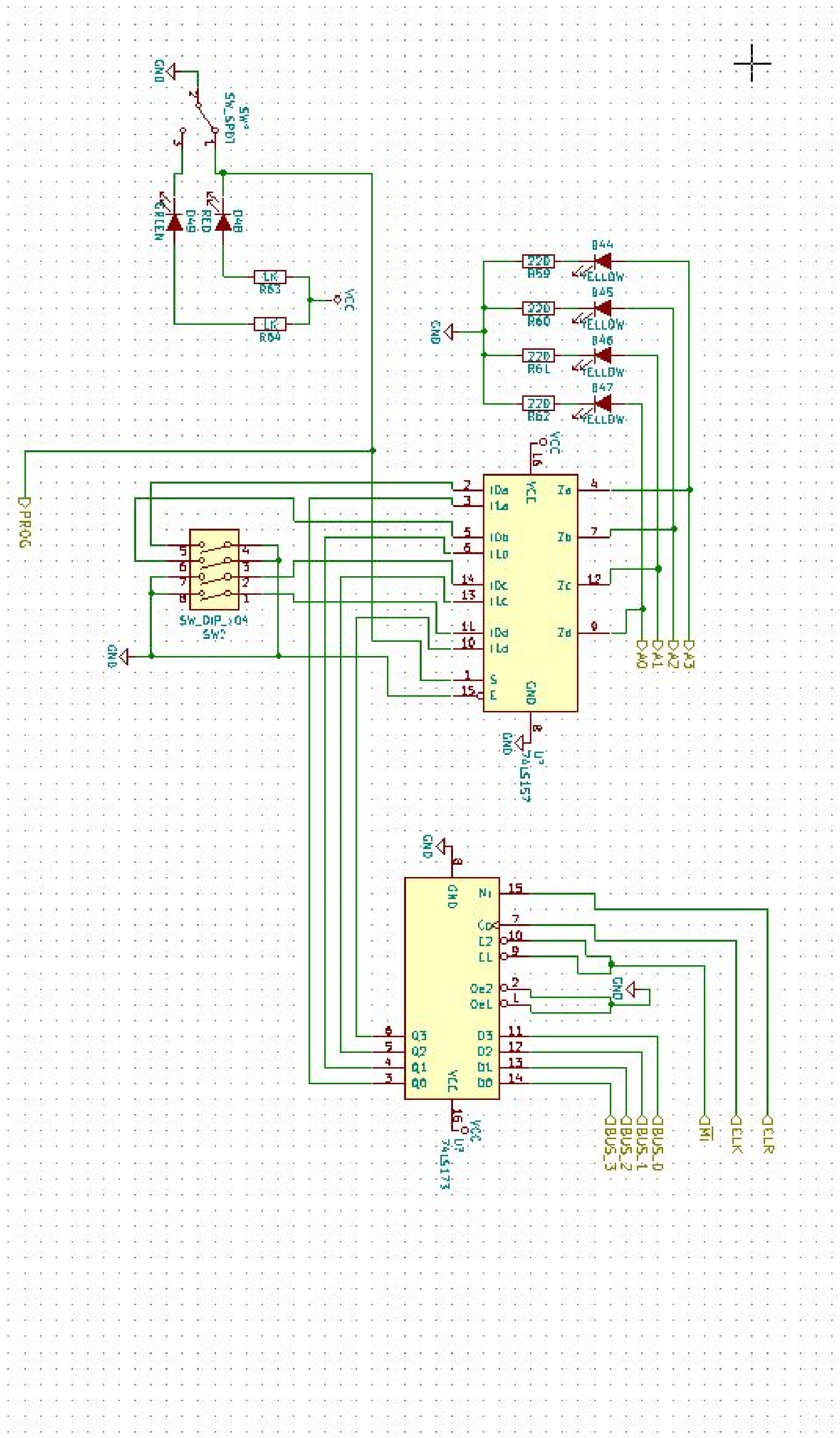

Figure 8: Memory Address Register Schematic

3.6.8 Random Access Memory

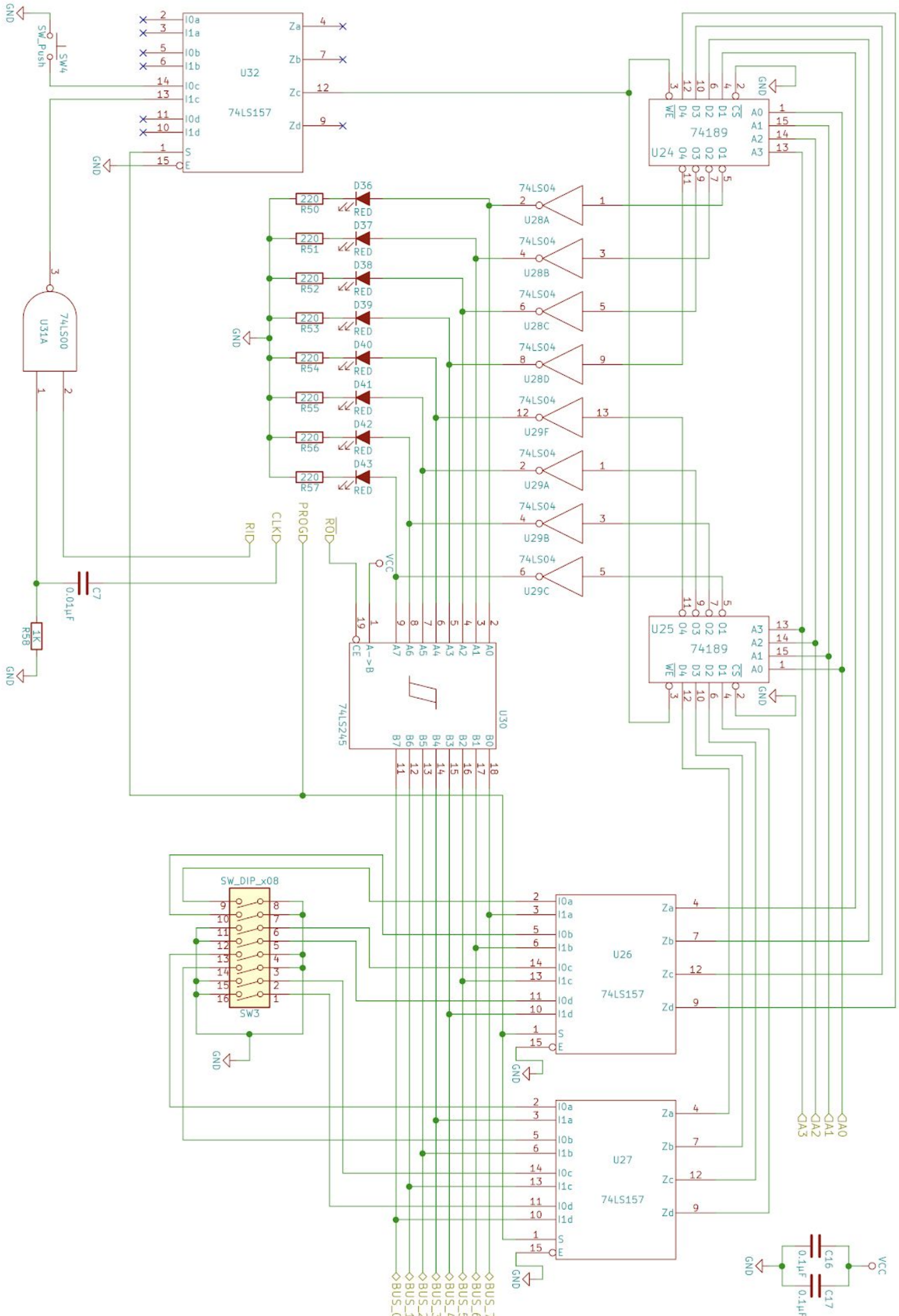

Figure 9: RAM Schematic

3.6.9 Program Counter

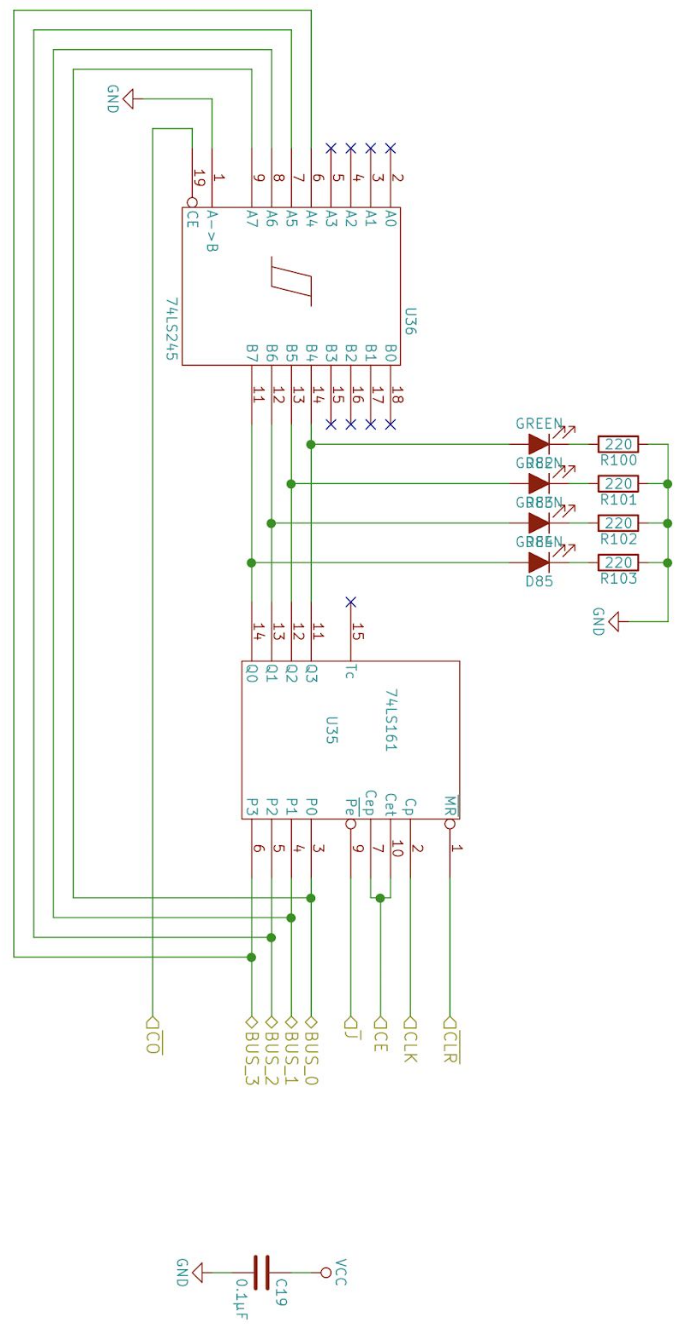

Figure 10: Program Counter Schematic

3.6.10 Output Register

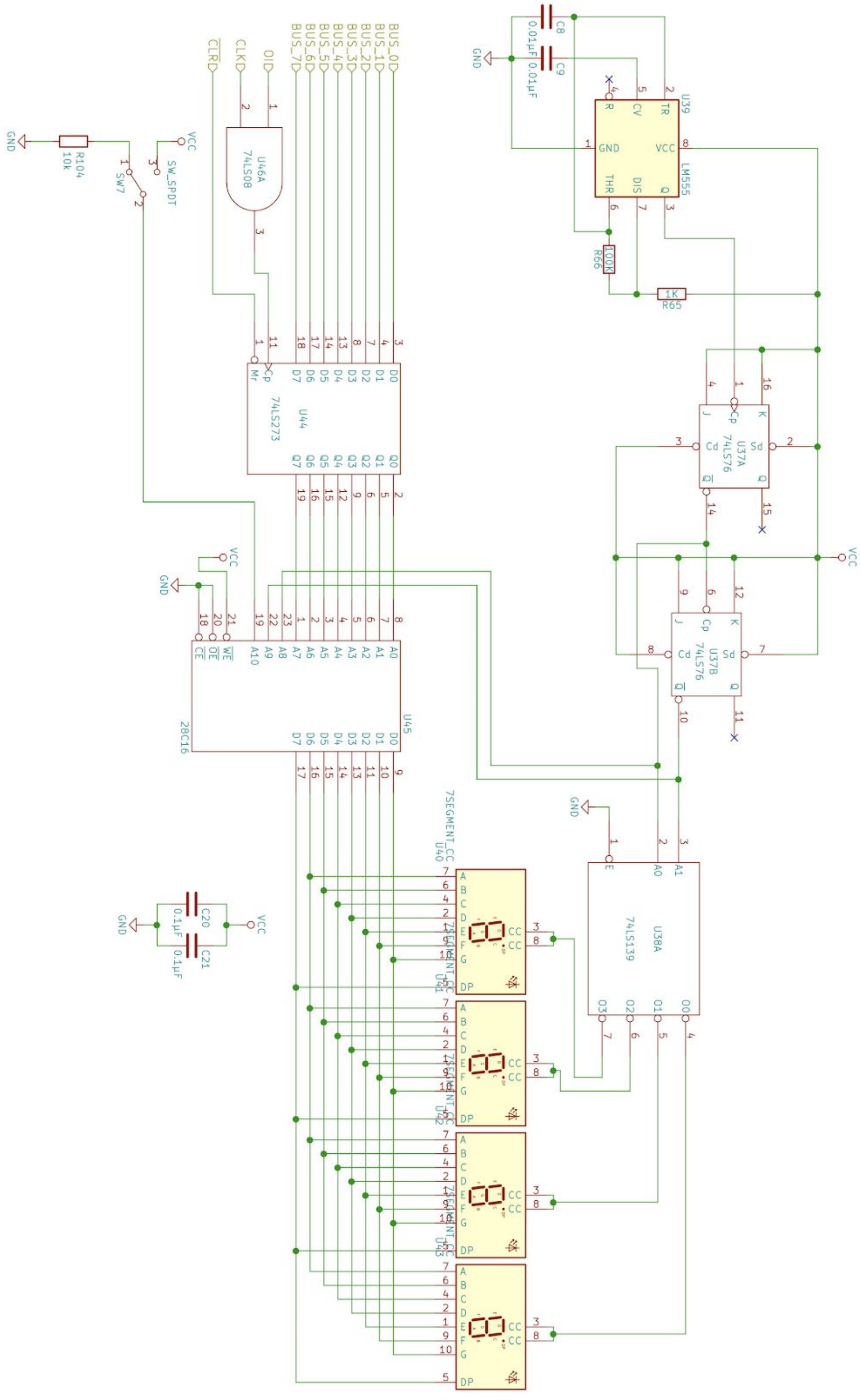

Figure 11: Output Register Schematic

3.7 Results

Utilizing the schematics we created PCB designs but ran out of time to get them printed at a low enough cost. Since the PCBs were no longer an option a pivot had to be made. We decided to breadboard and proto board the circuits. In the end we scrapped the protoboard idea as it was taking too much time. Instead we just went with breadboarding the schematics above. This proved challenging though as we didn't buy pre-made wires and the cutting and stripping of individual wires took too much time.

Overall we did not accomplish what we had intended. The project was too ambitious for us and the time table we had set out. Instead we created multiple breadboarded cpu modules and wrote a curriculum.

4 Management

4.1 Project Milestones

	Task	January					February					March					April					May				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	design circuit boards						X																			
2	pick put components			X																						
3	order components						X																			
4	3D print enclosures for boards								X																	
5	design curriculum																		X							
6	assemble prototype												X													
7	review prototype/ make revisions															X										

4.2 Budget

For our prototype, we ended up spending about $185 for all of the protoboards, wires, ICs, LEDs, and resistors.

Description	Qty.	Approx. cost each	Approx. cost total
Breadboard	3	9	27
22 AWG Solid Tinned-Copper Hook-Up Wire	1	16	16
1kΩ resistor	10	0.06	0.6
10kΩ resistor	9	0.06	0.6
100kΩ resistor	1	0.06	0.6
470Ω resistor	24	0.06	1.8
1MΩ resistor	1	0.06	0.6
1MΩ potentiometer	1	1.39	1.39
0.01µF capacitor	6	0.12	1.2
0.1µF capacitor	16	0.15	3
1µF capacitor	1	0.15	0.15
555 timer IC	4	0.35	1.4
74LS00 (Quad NAND gate)	2	0.79	1.58
74LS02 (Quad NOR gate)	1	0.55	0.55
74LS04 (Hex inverter)	5	0.59	2.95
74LS08 (Quad AND gate)	3	0.69	2.07
74LS32 (Quad OR gate)	1	0.49	0.49

74LS107 (Dual JK flip-flop)	1	1.75	1.75
74LS86 (Quad XOR gate)	2	0.55	1.1
74LS138 (3-to-8 line decoder)	1	0.69	0.69
74LS139 (Dual 2-line to 4-line decoder)	1	0.69	0.69
74LS157 (Quad 2-to-1 line data selector)	4	0.69	2.76
74LS161 (4-bit synchronous binary counter)	2	0.79	1.58
74LS173 (4-bit D-type register)	8	1.39	11.12
74189 (64-bit random access memory)	2	4.95	9.9
74LS245 (Octal bus transceiver)	6	0.79	4.74
74LS273 (Octal D flip-flop)	1	0.75	0.75
74LS283 (4-bit binary full adder)	2	1.49	2.98
28C16 EEPROM	3	3.95	11.85
Double-throw toggle switch	3	0.99	2.97
Momentary 6mm tact switch	3	0.35	1.05
8-position DIP switch	1	0.79	0.79
4-position DIP switch	1	0.89	0.89
Red LED	44	0.12	6
Yellow LED	8	0.09	0.9

Green LED	12	0.1	2
Blue LED	21	0.59	12.39
Common cathode 7-segment display	4	1.09	4.36
Proto board	1	40	40
Total	220		183.24

4.3 Funding Source

Our groups funding source came via the department. We won the senior project 1 poster competition and then Tyler participated with an open house tour.

4.4 Human Safety Assessment

	level of risk	effects	severity if occurance
misuse of soldering iron to assemble kit	low	burns on skin	increases as exposure prelongs
the solder used to assemble	low	contace with harmful chemicals	minor health issues
risk of electrical shock	low	our circuit runs on 5 volts	mild tingle in affected area
choking hazard for small parts	low	people will choke if parts are consumed	potential for the inability to breath
fire hazard	low	5 volts wont arc enough to cause a fire	potential for fire

4.5 Risks Assessment

	probibility	effects	how to mitigate
delay part shipment	high	push back the time schedule	order a single, full parts order
delay pcb shipment	medium	push back the time schedule	place order sooner
errors in code	high	push back the time schedule	plan for this and make sure there is plenty of time for troubleshooting
cost of obtaining matterials	low	push back the time schedule	budget, budget, budget
not being able to obtain a 3D printer or find one to use	medium	have to rethink the enclosure and the merrits of having one	try to obtain a personal 3D printer in time

4.6 Member Credentials, Responsibilities, and Career Plans

Tyler (Team Leader): Throughout the project so far I have been the team's leader. I have helped in facilitating meeting within the team as well as role assignment. Most of what has been done and of what will be done is highly group focused. Multiple if not all of us will be working on the same parts together. As of now my time has been invested in a lot of research into what is currently out there and why it isn't mainstream. Next semester a lot of time will be on the prototyping stage where the researching will come in crucially

Eric: Up to this point, my contributions to this project were mostly logistical, Helping fill out reports and make block diagrams. When our team was making the final commercial, I was the videographer and editor. As the groups only EE, the majority of my contributions will come next semester when we fully design the PCB layouts using Altium and start the assembly process. I will also troubleshoot the circuits and make any necessary revisions to the PCBS.

Justin: So far, as a whole, most of our project has been coming up with how everything will work together and a lot of research towards what our project is meaning to accomplish that others don’t. Most of my duties have been related to typing up and formatting information. Our project doesn’t seem to be focused on dedicating one person on one task. Instead we’re tackling a lot of them all together. Since we have 3 Computer Engineers and an Electrical, i believe that all of us are more than prepared for any task relating to our product.

Jeremy: In this project, I have done a lot of research regarding both the hardware and educational standards. As a team, we wrote down notes and help document our information and required assignments. I also helped brainstorm ideas and plan tasks with the team with a common end goal in mind. Our group dynamic is that of all of us are working in tandem with each other so we are always helping each other out on a set task.

4.6.1 Teamwork

With three Computer Engineers, we are able to understand and give a perspective on how we are able to understand computer architecture and how it should be taught. We are required to take courses such as CpE 3110 and 3150 that aids us in understanding. The expertise needed is the understanding of computer architecture or we will not be able to create a curriculum that we planned to do. Eric, our electrical engineer, is able to create our circuit and hardware design with us going more in detail for creating the curriculum.

4.6.2 Tyler Tetens (tntmm7@mst.edu, CpE major):

Member profile: Tyler will serve as our **team leader** and arrange our regular team meeting to discuss our progress. Tyler has taken multiple courses such as CpE 3150 and CpE 3110. These courses have given him a great understanding about microcontroller and how they benefit every day society. Using this information and other knowledge gained he will be involved in aiding in the understanding of the project to others.

4.6.3 Jeremy Ho (jnhkb4@mst.edu, CpE major):

Member profile: Jeremy has experience in microcontrollers, taking CpE 3150/51 Intro. to Microcontrollers and CpE 5160, Embedded Systems. He helped create a curriculum and hardware together with other members.

4.6.4 Justin Merila (jtm7dd@mst.edu, CpE major):

Member profile: Justin has experience in using digital logic and electrical components that would use them, from classes such as CpE 3150, CpE 3110, and CpE 5160. He will be involved in the creation of the curriculum and layout of hardware components.

4.6.5 Eric Walter (ewv7f@mst.edu, EE major):

Member profile: Eric has experience in altium, eagle cad, and kiCad. He will help in the cad work of the PCB layouts, troubleshooting of the circuits, as well as assist in the creation of the curriculum.

5 Conclusion and Future Works

5.1 Problems Encountered and Lessons Learned

The challenges we as a team faced was scheduling, time management, and our main value proposition. Each member had different schedules making it difficult to plan meetings and work together on a set time. The pros of our project and teamwork was marketing ourselves. We were able to present what we wanted to do and clearly explain how we planned to do so. Regarding our teamwork, we are all able to work well together, however, we need to start sooner rather than later for each task given to us. We are also able to realize our own faults and work together to fix them. Additionally we have never made never made a curriculum that meets national standards. To remedy this we have sought out Dr. Stanley for his expertise in teaching particularly in the STEM field. Design flaws were also problems faced and needed to be revised multiple times to ensure proper communication between each components. We can't always be sure that our original idea will work the first time. Another problem we had was dealing with logistics so that we can get our components in time to start building the prototype. We should have understood the time it takes to start shipping and when it finally gets into our hand in advance.

5.2 Suggested Improvement

With this project, we ended up being strapped for time, mainly because of logistics of ordering and shipping components needed to build the prototype. We should have finished designing everything earlier so that we can order the components sooner. if we had more time, we would have been able to actually connect everything together so that it'll be working properly.

5.3 Conclusion

We believe that our 8-bit cpu kit will expand on the current user base for computer architecture. Our aim is to take this knowledge to those who are seeking it and those too intimidated to learn about how the devices they use each and every day function at a basic level. Doing this we believe that we are creating a more knowledgeable population and bringing to light a product that hasn't been done at the same level before.

This project helped us understand a development's full cycle or close enough to it. We ended up making multiple mistakes and learned from them. Everything does not happen as you would expect it too and there are many factors to take into consideration such as logistics and design errors that tends to be overlooked. The experience we gain is invaluable as we head forwards in our future.

6 References

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