Final Project: Vending Machine Control Unit

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ECE 3130-30: Digital Electronics and Design

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December 9, 2012

1. Objectives

The goal of this final project was to design, build, and simulate a fully functional vending machine control unit in Tanner Tools. The vending machine needed to be capable of taking in quarters, dimes, and nickels as well a choice of drink selection from two separate options. The machine also was designed to have a coin return button that would return all change that was input to the machine before pressing the button. The vending machine would then be able to dispense the correct drink type depending on which was selected as well as the proper amount of change back to the user. The entire control unit was designed, implemented, and simulated using Tanner Tools to verify that it functioned properly.

2. Design Procedure

The design procedure for the vending machine was fairly straightforward, although it did require a bit of thought and planning. Student's took the guidelines directly from the given documentation and first needed to decide the best way to go about pinpointing the basic functions of the vending machine. Students examined the specifications for the machine and began to plan and build from that foundation as follows.

Specifications:

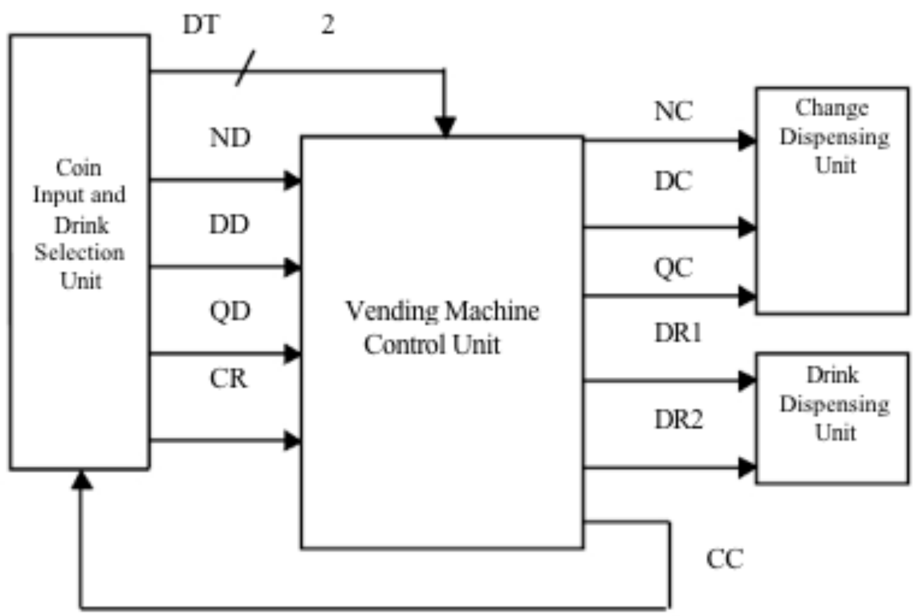

Figure 2.1 – Simple Design Overview of Vending Machine

Inputs & Outputs:

Inputs to Control Unit	Outputs From Control Unit
ND = Nickel Deposited	CC = Collect Coins
DD = Dime Deposited	NC = Nickel Change
QD = Quarter Deposited	DC = Dime Change
CR = Coin Return	QC = Quarter Change
DT1 = Drink Type 1	DR1 = Dispense Drink Type 1
DT2 = Drink Type 2	DR2 = Dispense Drink Type 2

Table 2.1 – Necessary Inputs and Outputs for the Vending Machine Control Unit

***Additional Specifications*:**

Value	Specification
Drink Type 1 Cost	$0.60
Drink Type 2 Cost	$0.85
Maximum Change Allowed to be Deposited	$1.05
Clock	200ns
ND, DD, QD	200ns Pulse with 500ns Between Pulses
CR, DT1, DT2	200ns Input Pulse
DR1, DR2	200ns Output Pulse
NC, DC, QC	Output Pulse of at Least 200ns

Table 2.2 – Additional Specifications for the Vending Machine

***Further Design Considerations*:**

With the list of necessary inputs and outputs, requirements and specifications, the student was able to begin designing the vending machine control unit. One of the primary design features in this project was that the monetary values were converted by binary after having first been divided by 5. Therefore, a quarter, $0.25, was represented as 101, for 5 nickels. The student also had to decide how to handle some of the different inputs and outputs. They decided that pressing the coin return button would need to return all of the change input by the user back out to them. They also determined that since going over $1.05 was pointless and the device needed some maximum threshold anyways, to output all of the users change back to them in the event that they go over $1.05.

They then determined the necessary components and set out to design each component to meet the required specifications, particularly focusing on ensuring the pulse widths for all inputs and outputs were nice 200ns pulses that could be properly read by the other modules attached to the control unit. The varying components consist of the input, memory, an adder/subtractor module, comparators, pulse generators, and a change module.

Input:

The input section needed to consist of three separate inputs: ND, DD, and QD. When a nickel was deposited, the input value should be 00001, 00010 for a dime, and 00101 for a quarter. The dime input was fed directly to the second bit of the next module and the quarter input was connected as the third bit of the next module. The nickel input was OR'ed with the quarter input so that the first bit would be a 1 when either a nickel or quarter was put in the machine. This can be seen in more detail in **Figure 3.13**.

Memory:

In order to store the value of the coins currently in the machine, it was necessary to have some form of memory element. The student decided on using D flip-flops, which would hold the current value of money in the machine at any given time. In order to account for both drink types and the highest amount allowed in the machine, $1.05, the use of five flip-flops, one for each bit, was ultimately decided on. This is shown clearly in **Figure 3.16**.

Adder/Subtractor Module:

The adder-subtractor works off of a regular 5-bit full adder that has another input named Subtraction that would perform the two's complement on the 2nd input in order to have it subtracted from the first. This design was fairly simple because the nature of the machine eliminates the necessity for taking any negative answers into account because they should never happen. The adder-subtracor is shown in detail in **Figures 3.5-3.8**.

Comparators:

Throughout the design, it is necessary to have a variety of 5-bit comparators checking whether or not the amount of money stored in the flip-flops is greater than or equal to certain values. The internal design of the comparator is very similar to that of the 4-bit comparator. It is shown in **Figures 3.3-3.4**.

Pulse Generators:

The pulse generators were necessary to stabilize a short pulse and ensure it lasted the necessary 200ns outlined by the project specifications. The short pulse came when a drink was selected and the value was compared to the price of the drink. That signal was then fed through the pulse generators shown in **Figure 3.15**.

Change Module:

The change module is possibly the most intricate piece of circuitry in the entire vending machine control unit. The change unit in this design uses various multiplexers and comparators to determine whether the vending machine is adding or subtracting change and also what change to subtract if it is indeed subtracting. It is fed by the same Subtraction input that was sent to the adder-subtractor and either feeds through the input signals for ND, DD, and QD, or chooses a value to subtract from what is left stored in the D flip-flops. The subtraction value is stored in a D flip-flop once the circuit senses that subtraction is necessary (ie., when the coin return button is pressed, a drink is dispensed, or the user puts in more than $1.05). It is only then cleared when the values in all of the flip-flops are back at 0.

3. Schematic Drawings

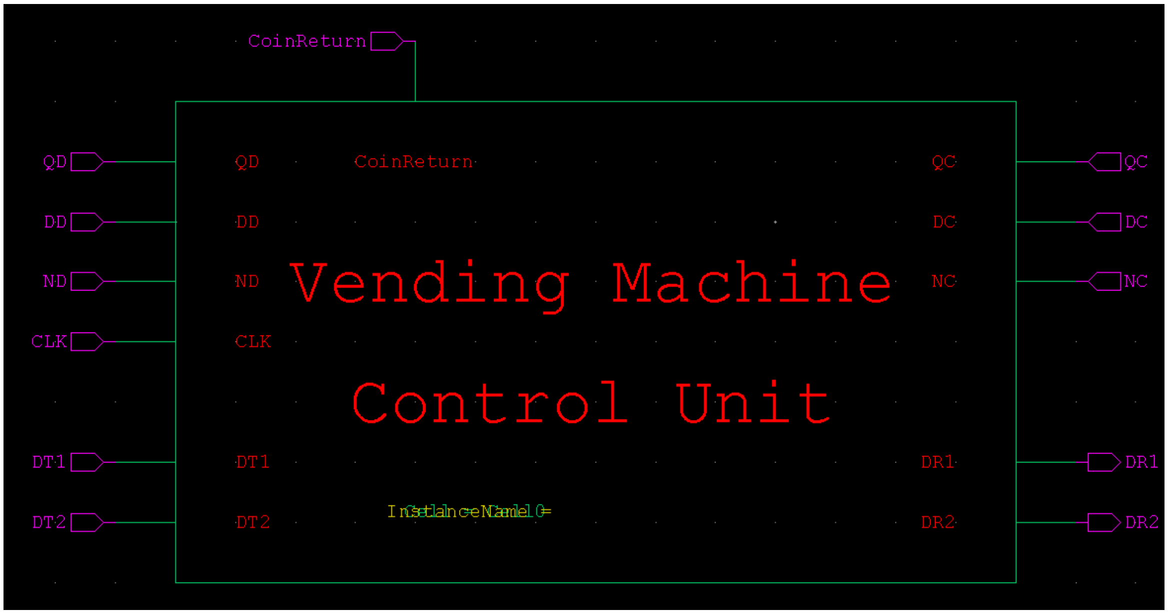

Figure 3.1 – Vending Machine Control Unit Symbol View

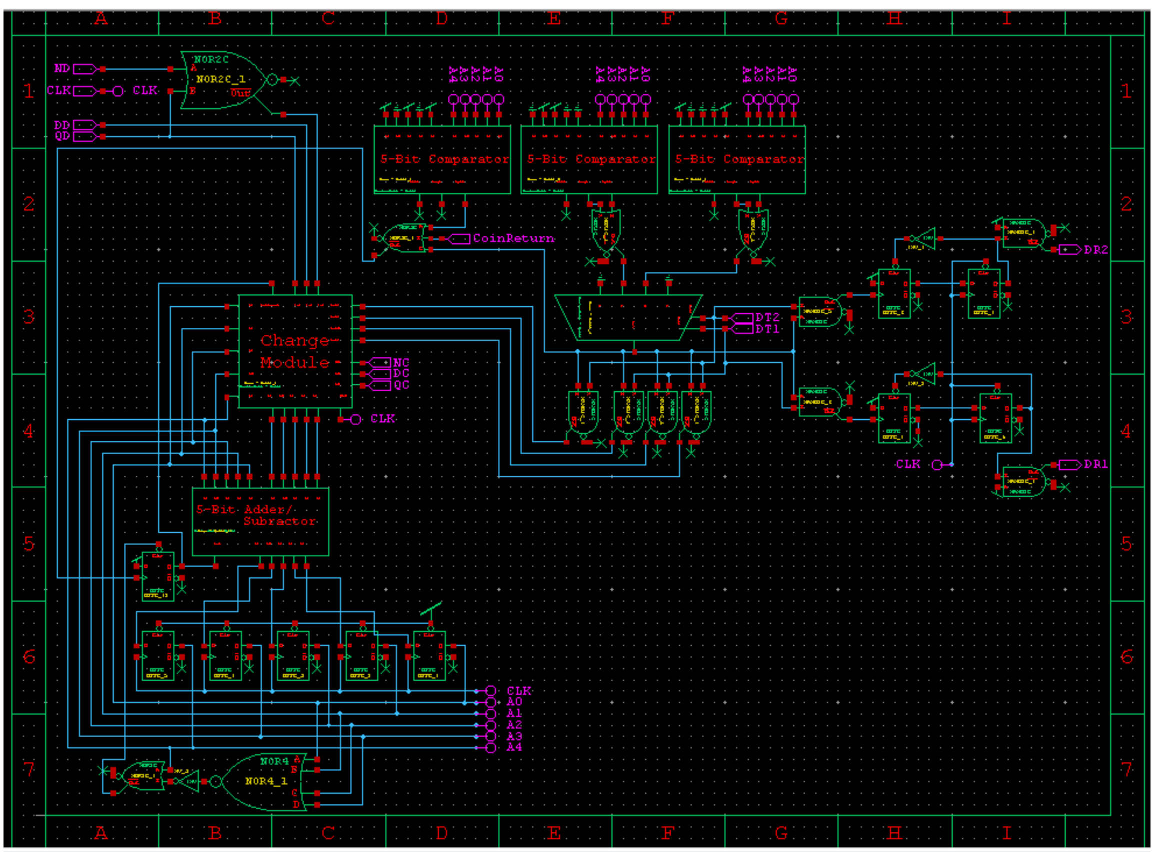

Figure 3.2 – Full Vending Machine Schematic

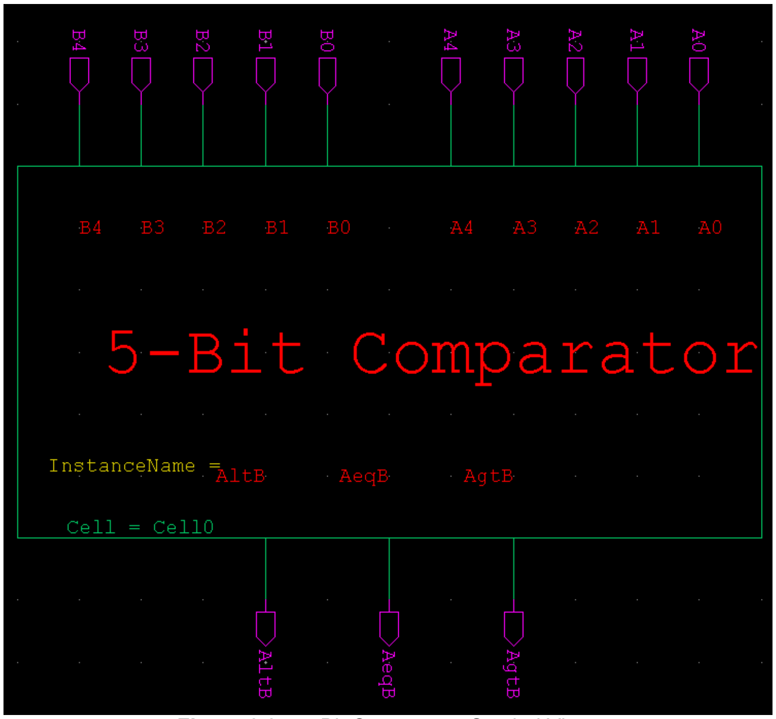

Figure 3.3 – 5-Bit Comparator Symbol View

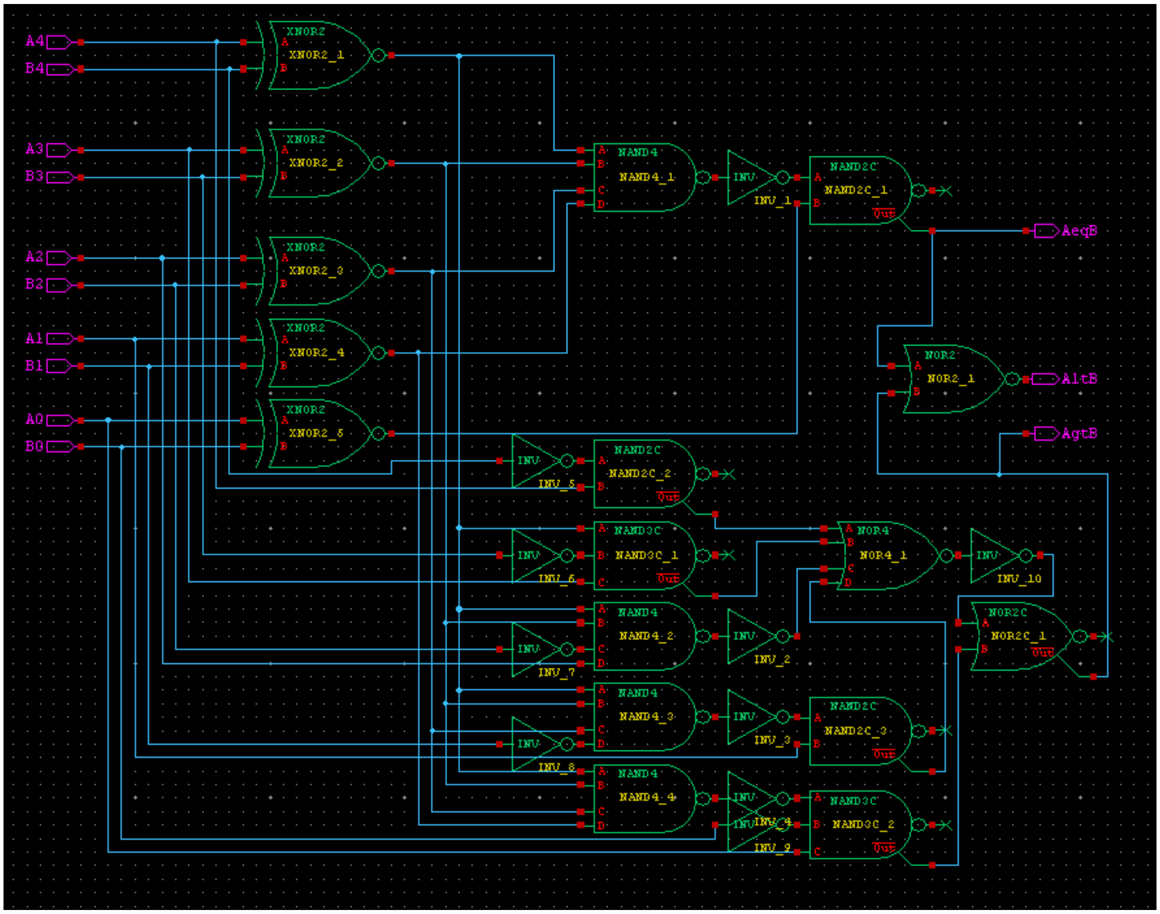

Figure 3.4 – Entire 5-Bit Comparator Schematic

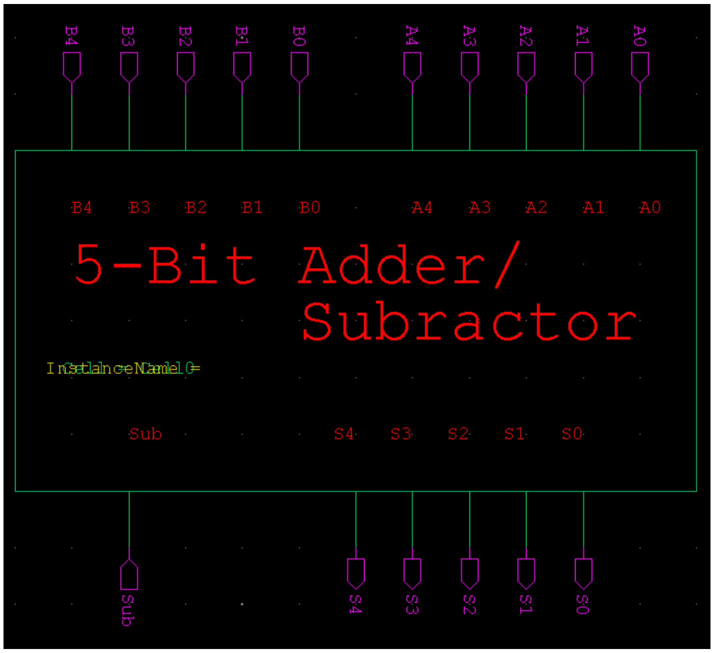

Figure 3.5 – 5-Bit Combined Adder/Subtractor Symbol View

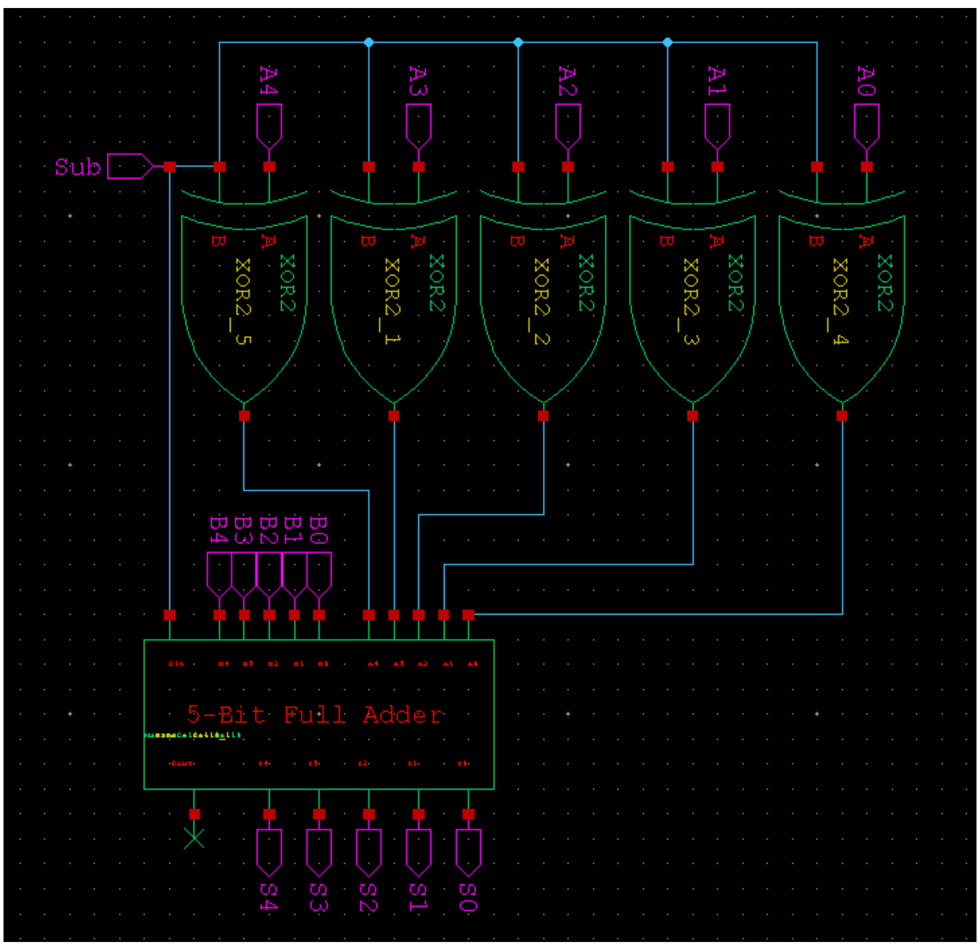

Figure 3.6 – Full 5-bit Combined Adder/Subtractor Schematic

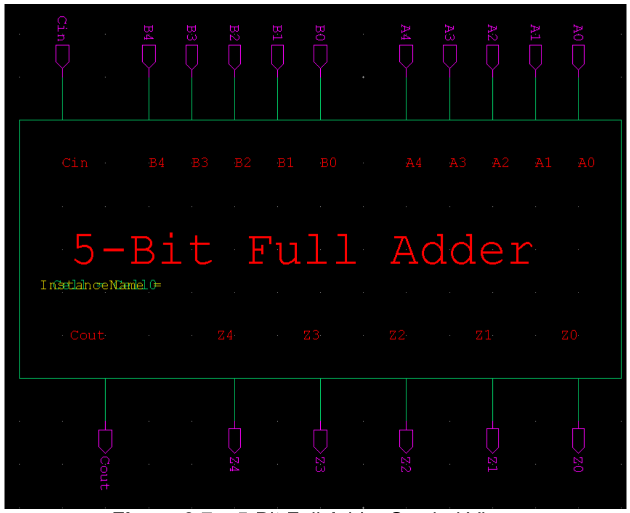

Figure 3.7 – 5-Bit Full Adder Symbol View

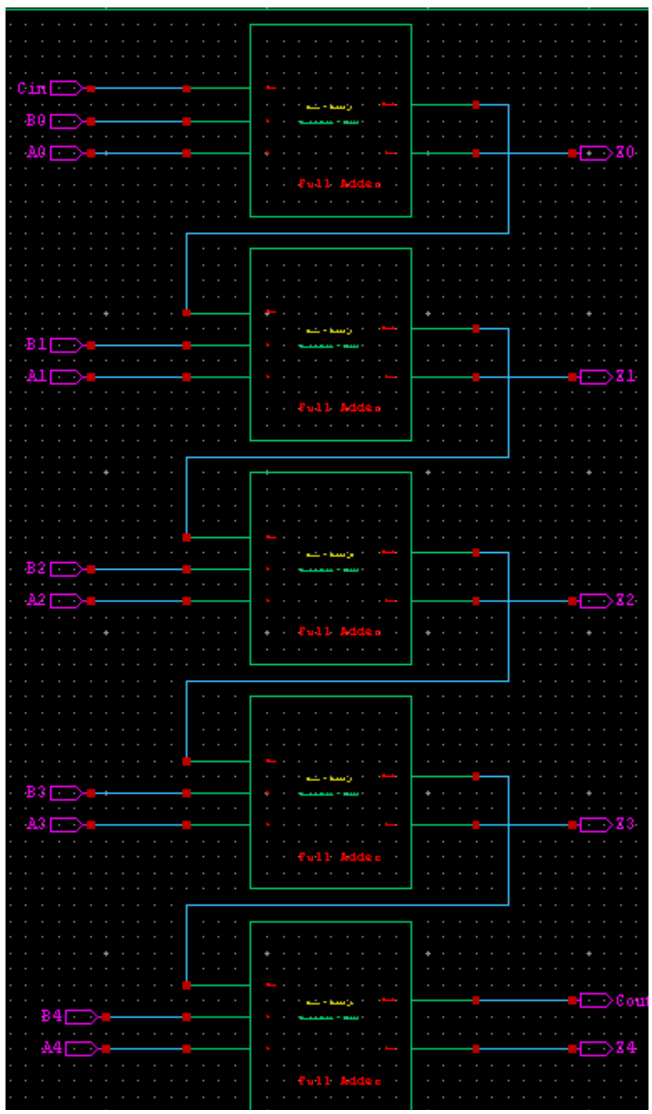

Figure 3.8 – Full 5-Bit Full Adder Schematic

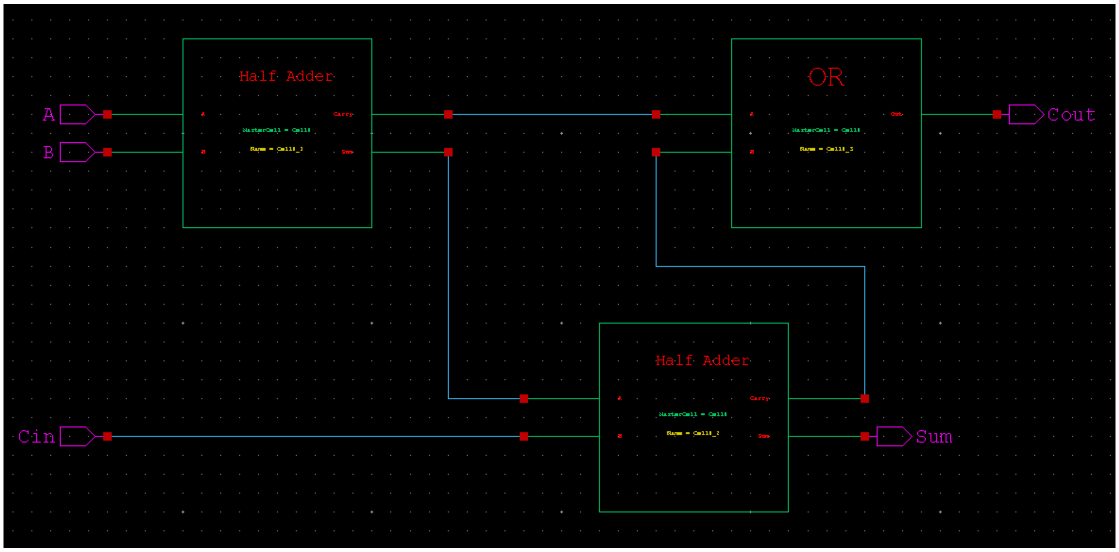

Figure 3.9 – Full Adder Schematic

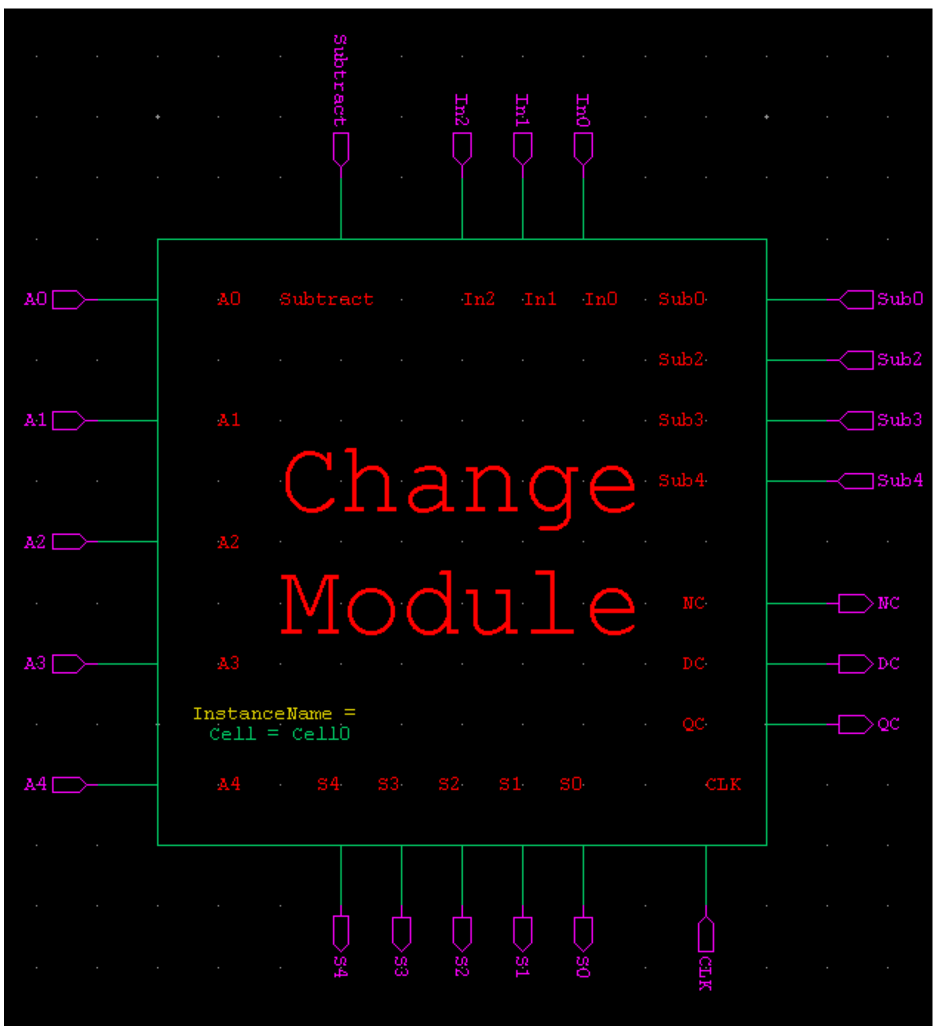

Figure 3.10 – Change Module Symbol View

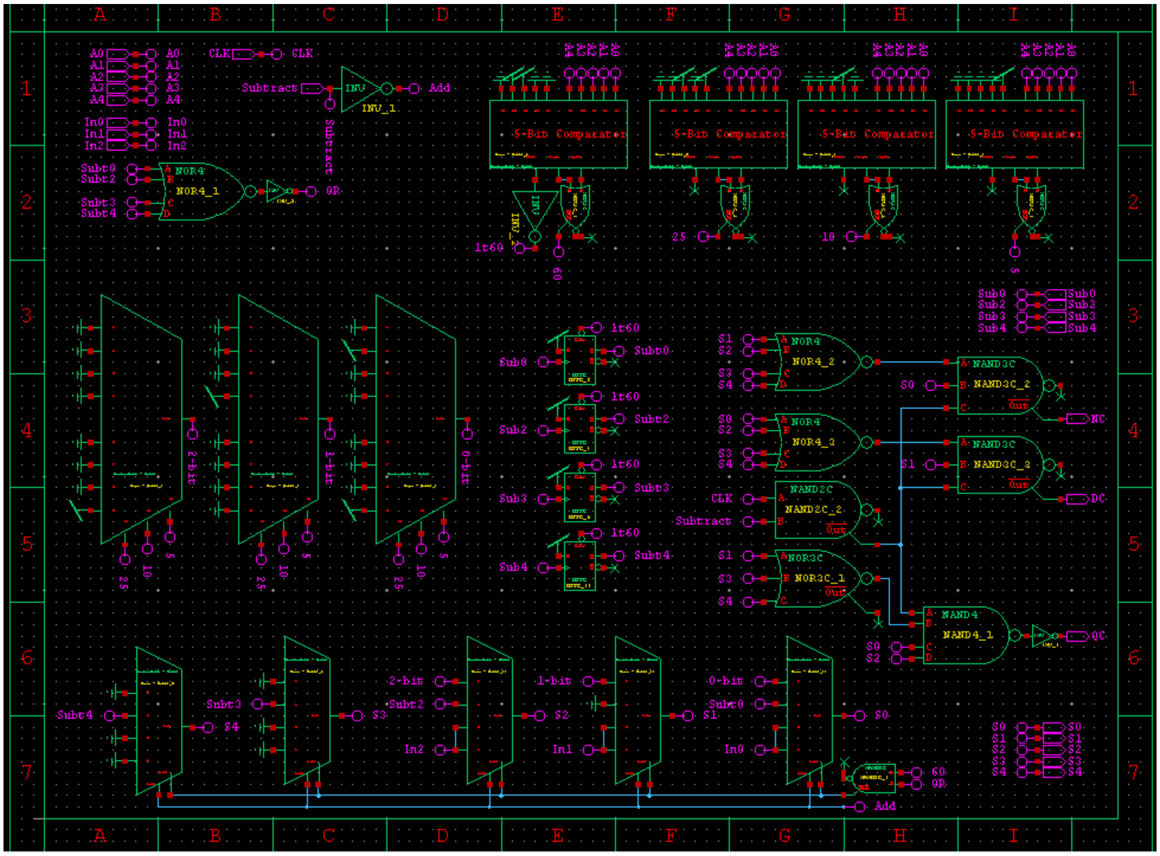

Figure 3.11 – Full Change Module Schematic

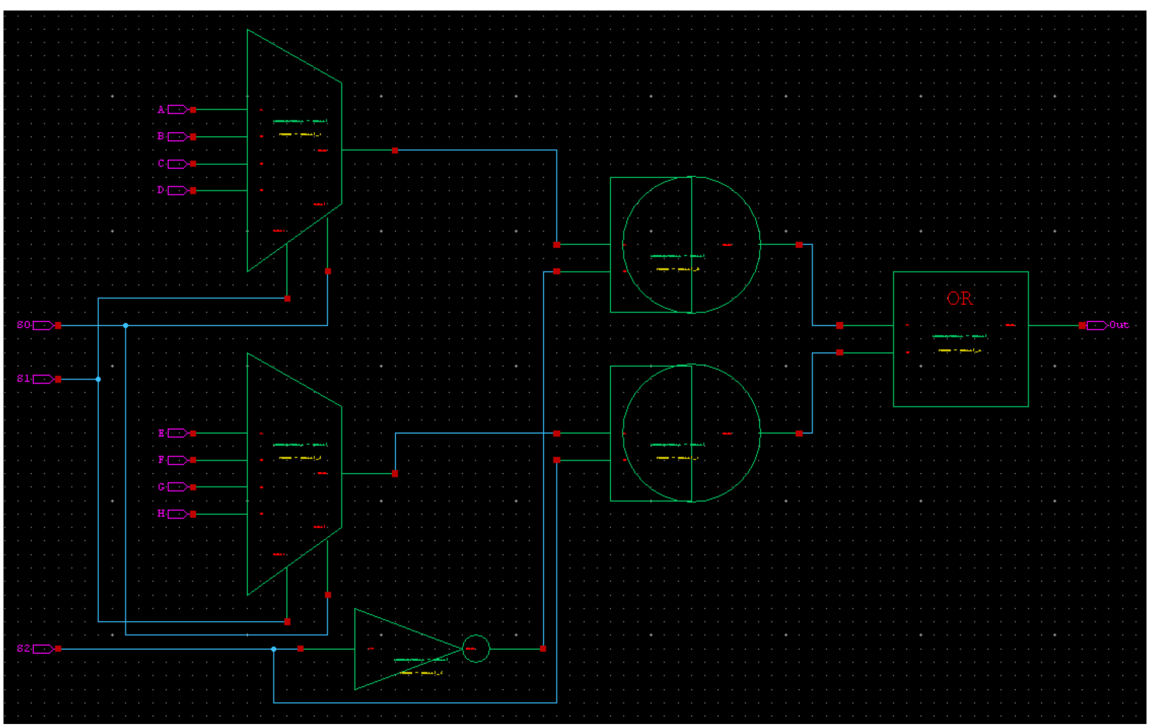

Figure 3.12 – 8:1 Multiplexer Schematic

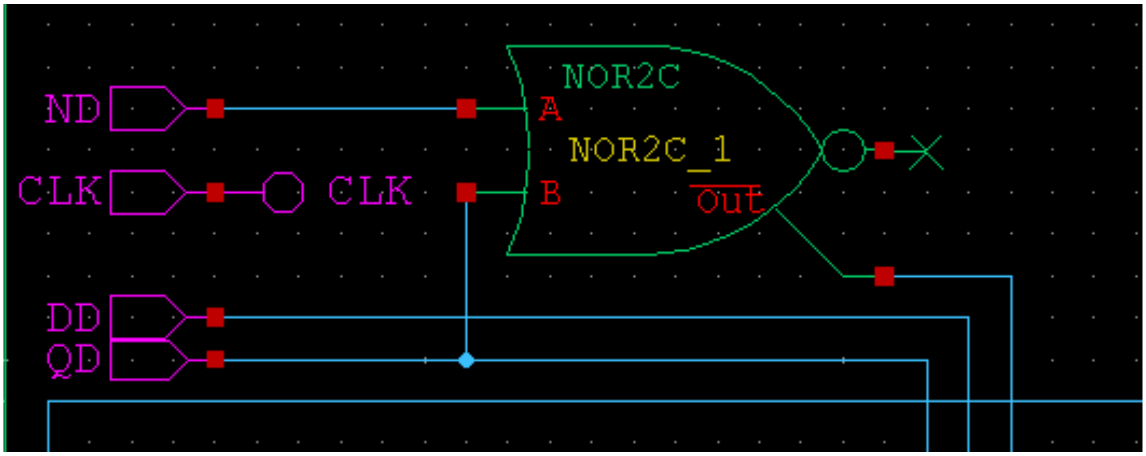

Figure 3.13 – Input Section of Vending Machine

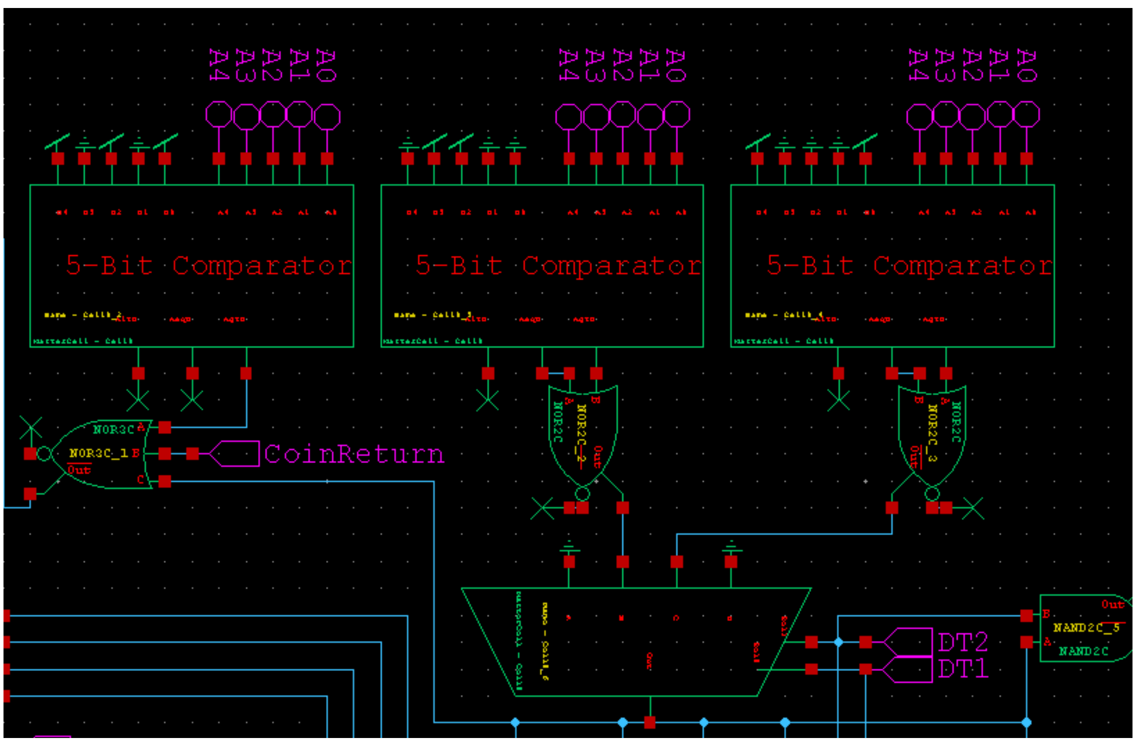

Figure 3.14 – Comparators Section of Vending Machine

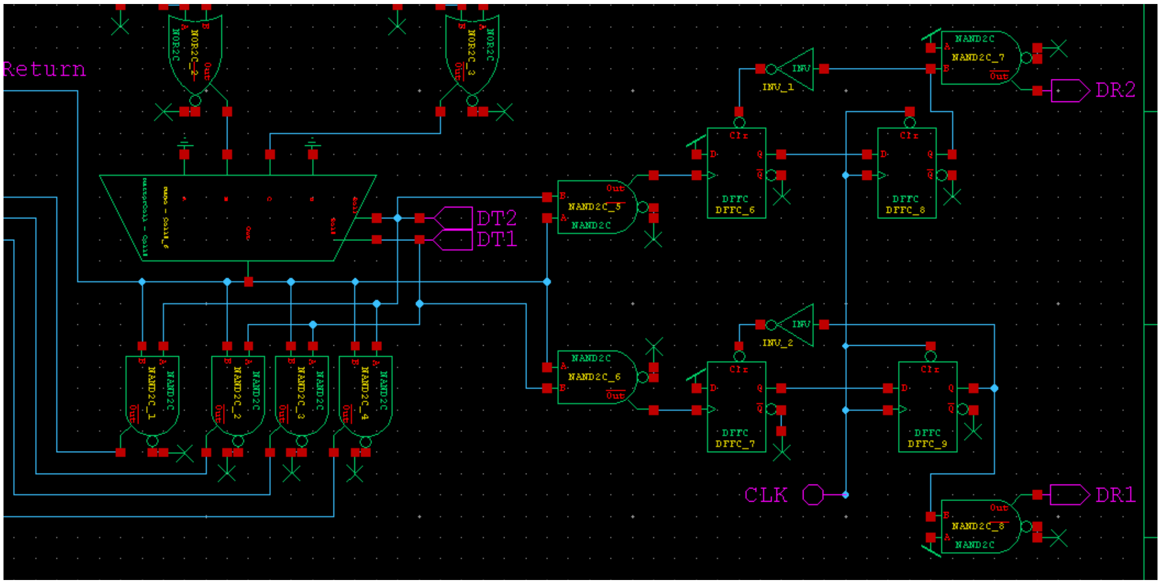

Figure 3.15 – Pulse Generation Section for Drink Dispense Outputs

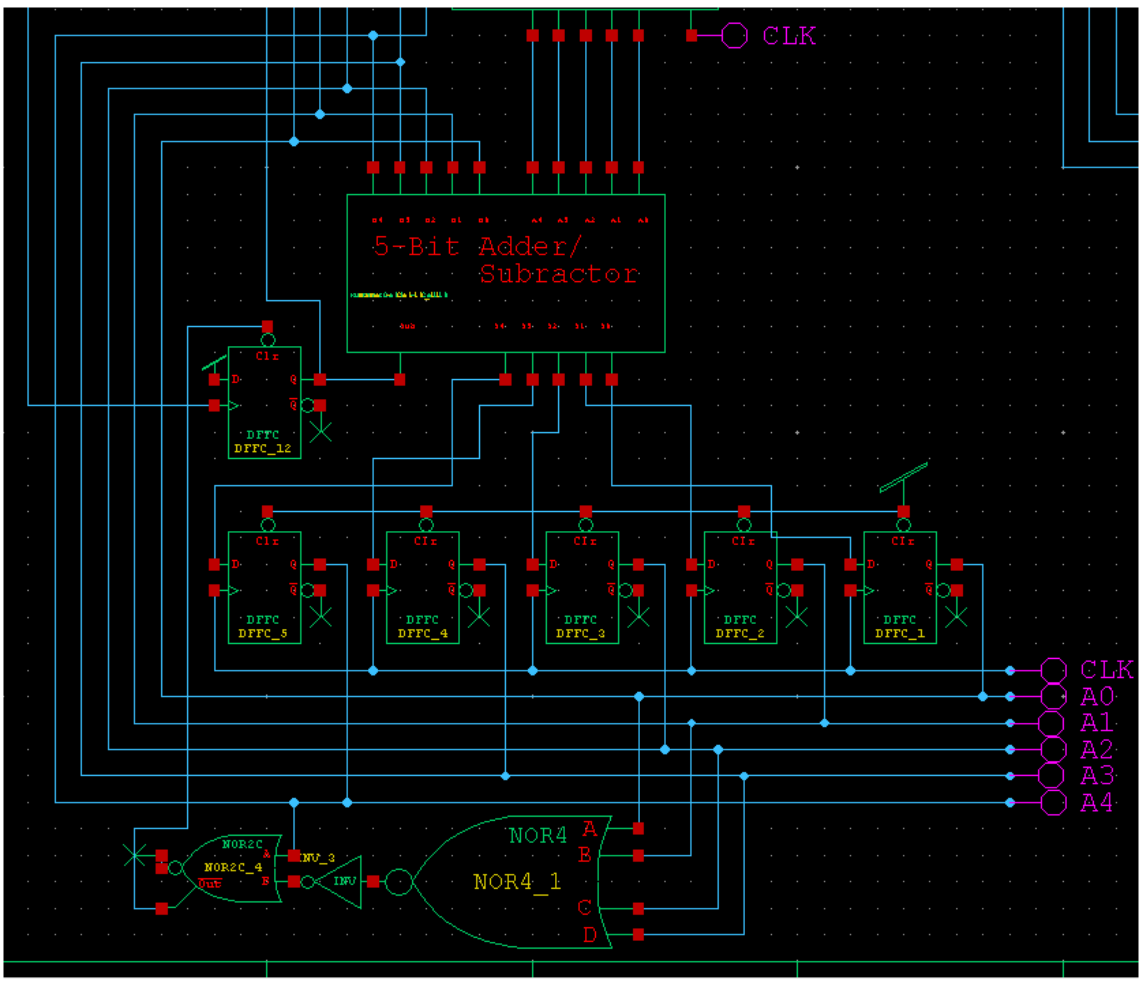

Figure 3.16 – D Flip-Flops Section to Hold Memory

4. Verification

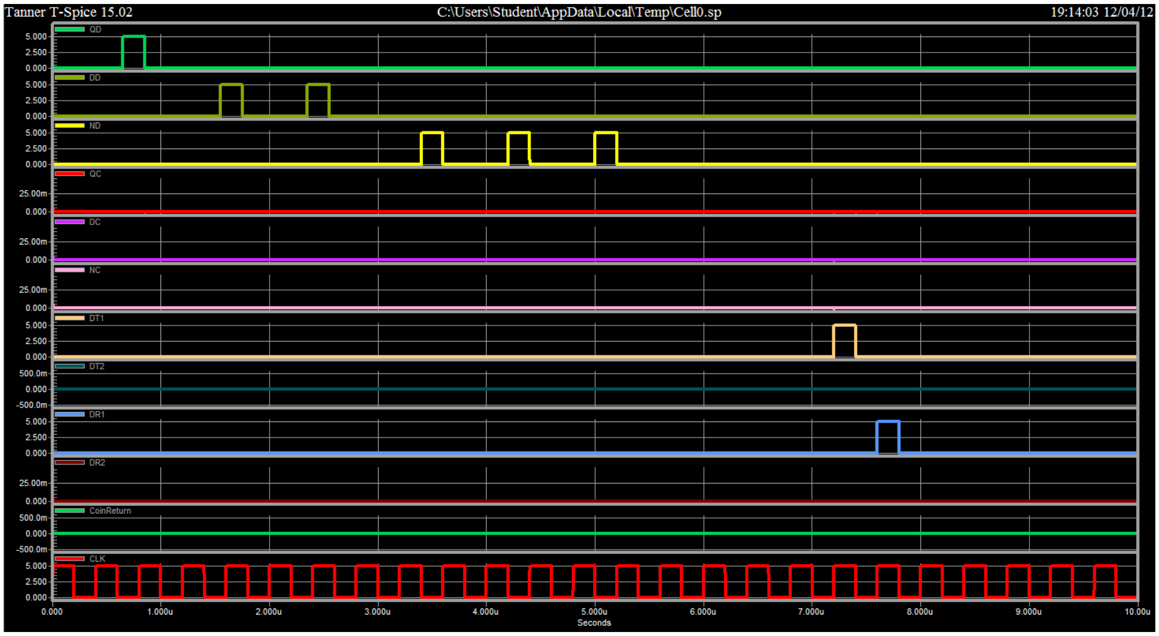

Figure 4.1 – Exact Change Deposited for Drink 1
(Input: Q,D,D,N,N,N for DT1; Output: DR1 and No Change)

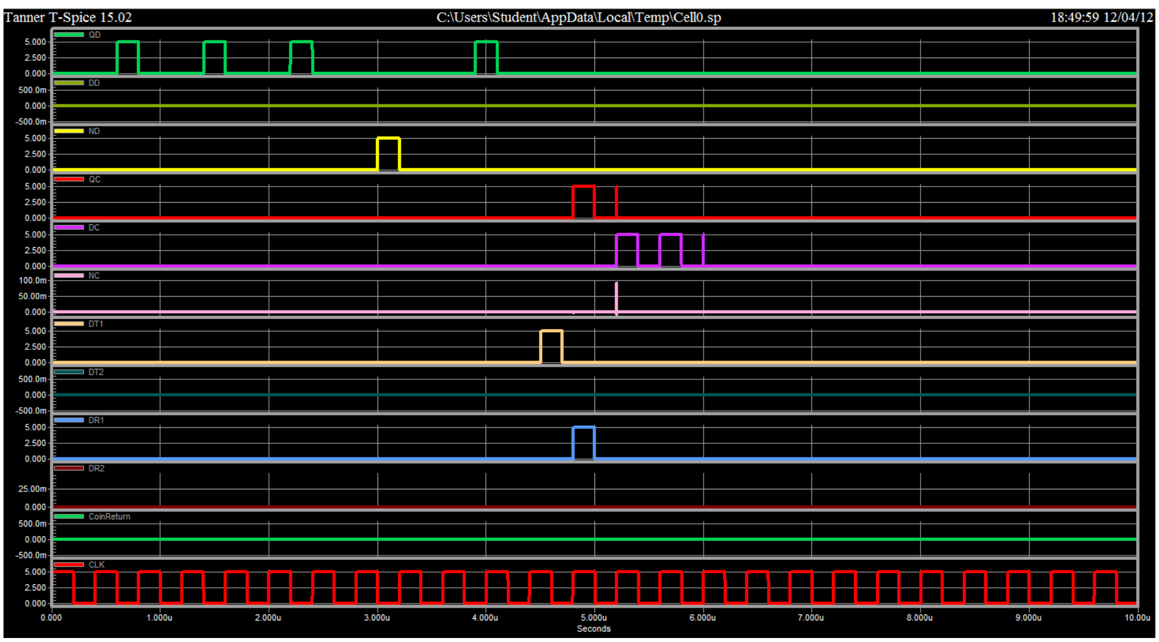

Figure 4.2 – $0.45 Change Dispensed with Drink 1
(Input: Q,Q,Q,N,Q for DT1; Output: DR1 and Q,D,D in Change)

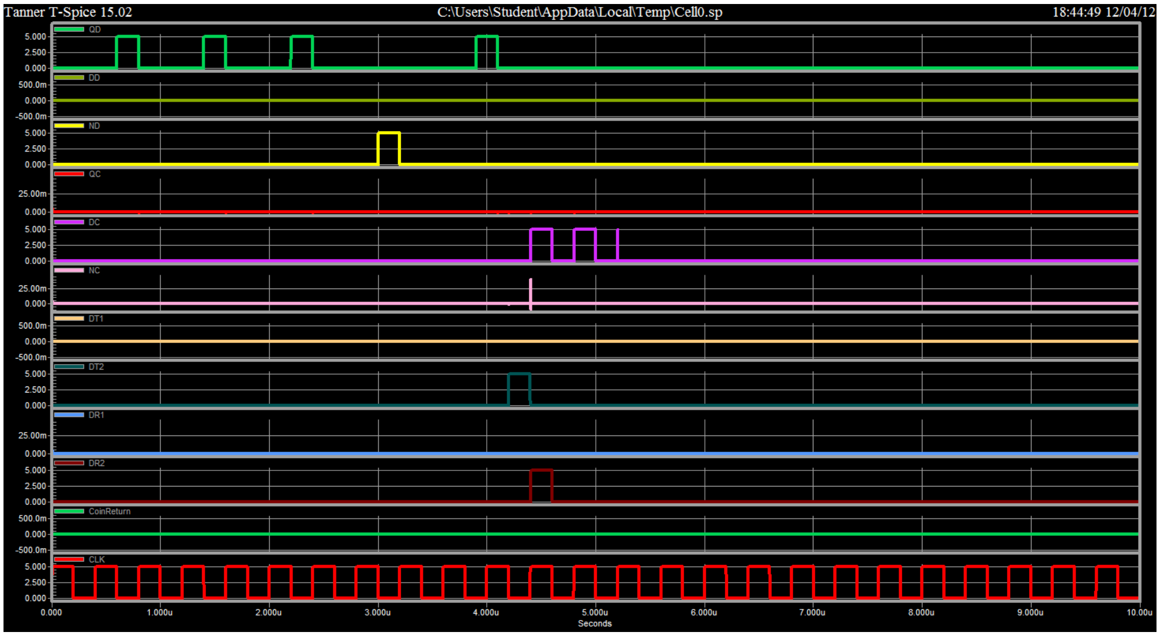

Figure 4.3 – $0.20 Change Dispensed with Drink 2
(Input: Q,Q,Q,N,Q for DT2; Output: DR2 and D,D in Change)

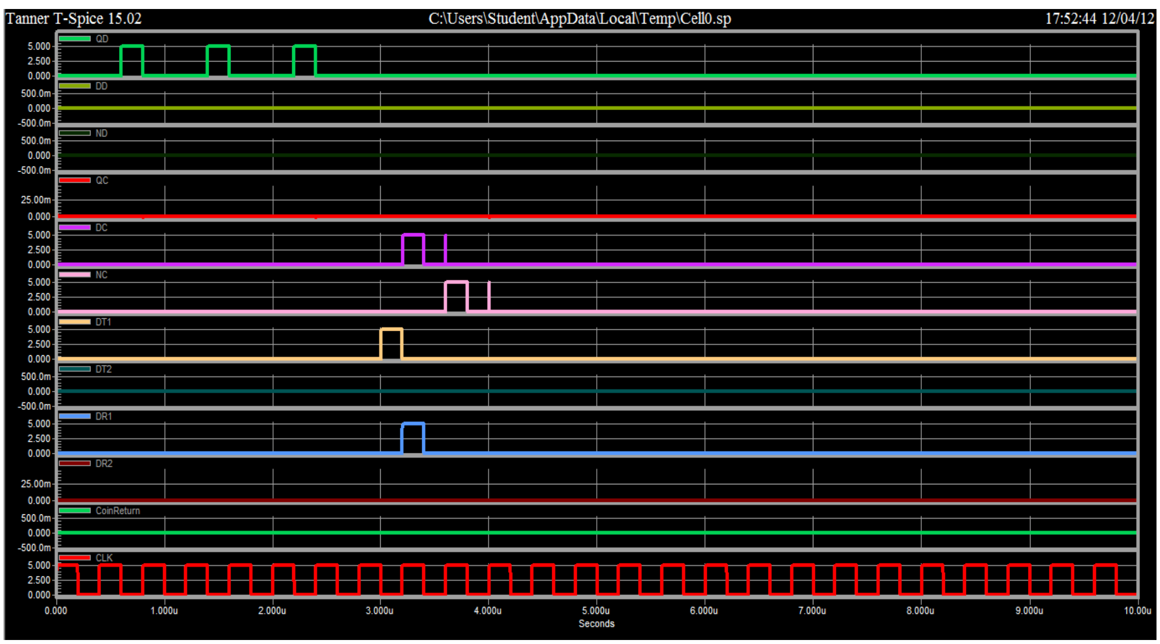

Figure 4.4 – $0.15 Change Dispensed with Drink 1
(Input: Q,Q,Q for DT1; Output: DR1 and D,N in Change)

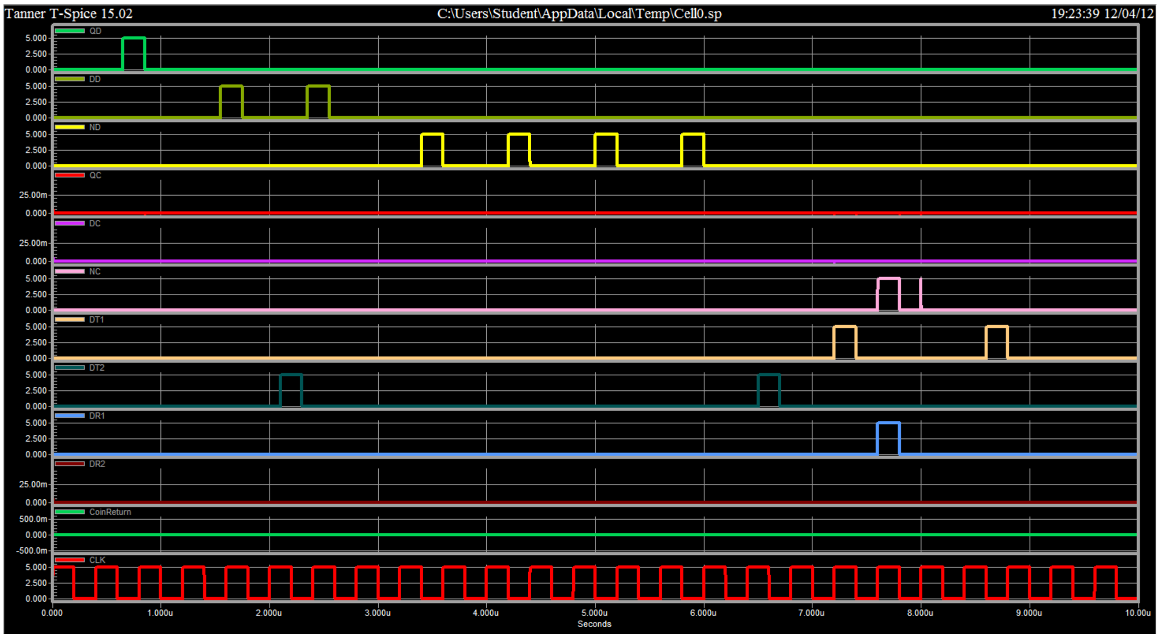

Figure 4.5 – $0.05 Change Dispensed with Drink 1 at Appropriate Time
(Input: Q,D,D,N,N,N,N for DT1; Output: DR1 and N in Change)
(Drink dispenses only once enough money is present when button is pressed, no sooner or after)

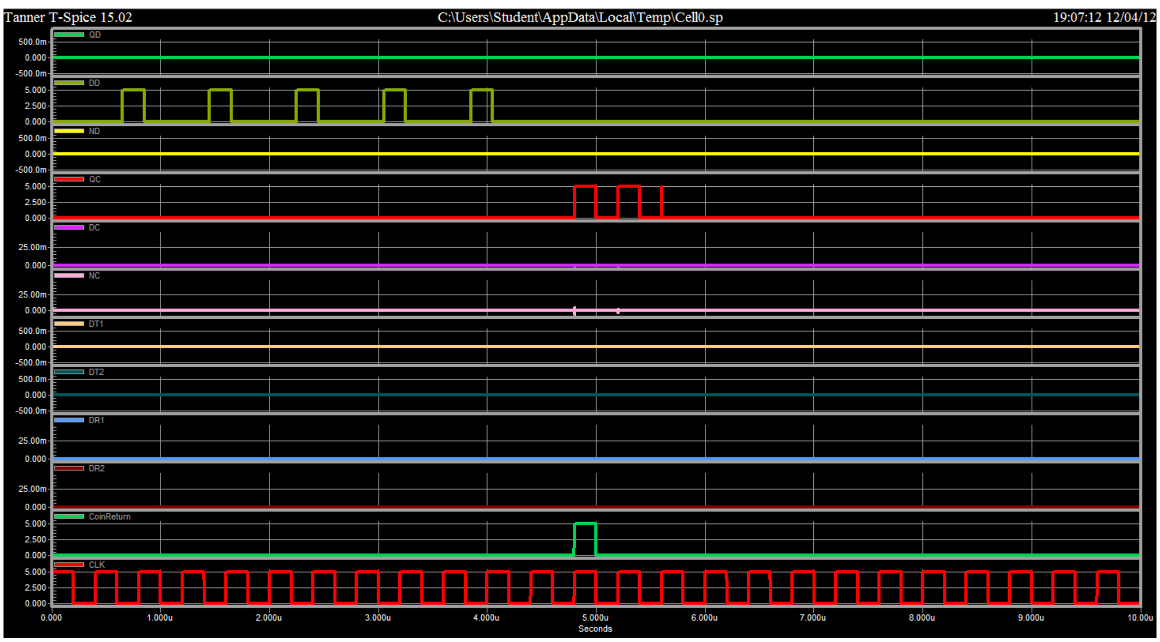

Figure 4.6 – Example of Coin Return Button
(Input: $0.50 as D,D,D,D,D; Output: $0.50 as Q,Q)
(Coin Return will always return same amount of money put into machine in highest possible coinage)

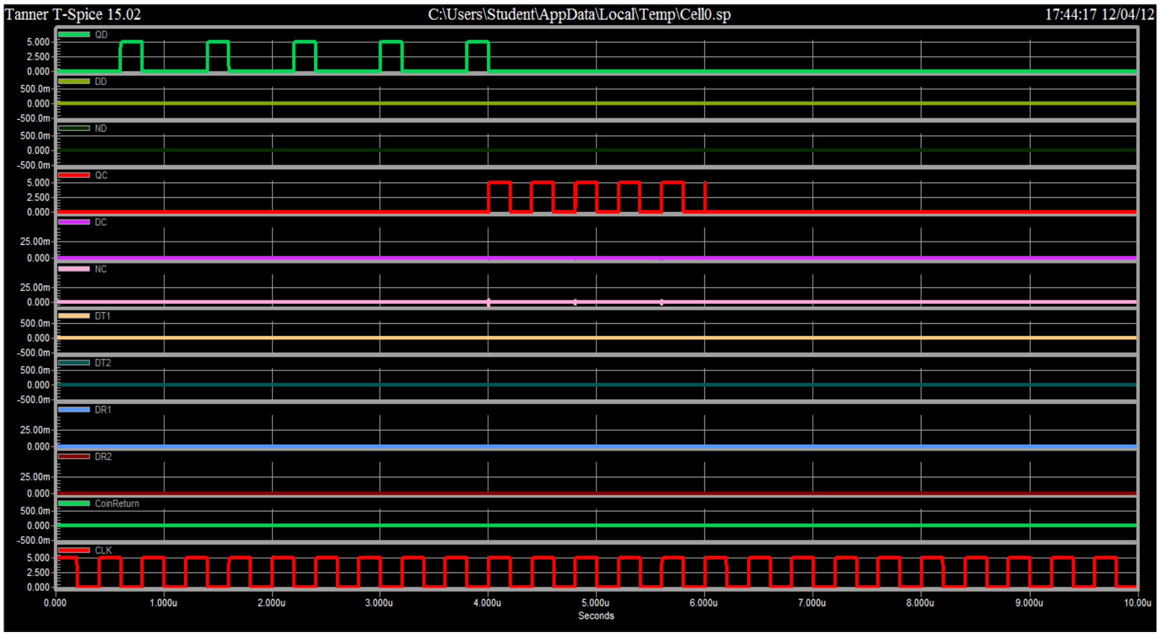

Figure 4.7 – Example of Going Over $1.05 Maximum Threshold
(Change is returned to the user to start over)

5. Discussion

While the design process of the vending machine control unit has already been described, a few of the necessary functions and their implementation require some further explanation. Looking at the main circuit in **Figure 3.2**, the main parts of the entire control unit are the input, memory, adder/subtractor, comparators, pulse generators, and the change module. While many of these pieces have already been thoroughly described in the design section, it is beneficial to take a closer look at a few of them.

The 5-bit combined adder and subtractor shown in **Figure 3.6** uses a subtraction input to determine whether or not it should be subtracting or adding the input value. This subtraction input is stored in a D flip-flop when either a change return is triggered, a drink is dispensed, or when the user inserts more than $1.05. When the subtraction input is high, the two’s complement of the input is taken so that it is subtracted from the values in the D flip-flops which are looped back into the adder/subtractor. The subtraction bit is cleared when all of the values in the D flip-flops go back to 0, meaning there is nothing more to subtract.

The set of comparators in **Figure 3.14** constantly monitors whether the user has input more than $1.05, or enough for either of the two drink types, $0.60 or $0.85.

The pulse generators for the outputs DR1 and DR2 shown in **Figure 3.15** take in a short pulse when a drink is selected AND’ed with the value of whether or not there is enough money to buy that drink. Because this pulse is very short and needs to be a nice 200ns pulse for the next module to properly dispense the correct change and drink, it is sent through two D flip-flops to stabilize the pulse. The first flip-flop stores the value quickly, then the second creates a pulse the length of the clock pulse.

The change module is the most complex of all of the modules. Shown in **Figure 3.11**, it uses a series of comparators and multiplexers to decide which values to pass on to the output and feed into the combined adder/subtractor. It also takes in the subtraction bit to determine whether or not to supply values to subtract, or pass through the values from the input module to add with those looped back from the D flip-flops. Within the change module, there are predetermined values and comparators, so that anytime the machine is dispensing, it subtracts the maximum value possible. On the initial drink dispense, it subtracts either

$0.60 or $0.85, then on the next loop back, it will determine the highest possible coin it can output as change. It continues to do this until all change is dispensed. This allows the machine to produce accurate 200ns pulses to the change dispensing unit. One important thing to note is the small hazard in these output pulses. Because the D flip-flops do not update until the next clock pulse, after the last change coin is dispensed, there is about a 3ns pulse because the comparators still believe the value in the flip-flops is the same as it previously was. Once they update, however, the pulse disappears. This is okay because the change dispensing module is designed to only output a coin for each pulse supplied to it of greater than or equal to 200ns. Therefore, it would not read these very short 3ns pulses as another coin to return and would ignore them.

In general, the output tests and simulations shown in **Figure 4.1-4.7** accurately show that the vending machine operates as expected and to the specifications outlined in the project description as well as within this project report.

6. Conclusions

This project challenged students to design and build a fully functional vending machine control unit. While students were familiar with the concept of a vending machine, it was a much more difficult challenge to design one at the gate level. It required a lot of thought and planning before ever beginning to lay out the first logic gates in Tanner Tools. This project forced students to approach the task at hand and tackle it with a well-designed plan.

There were a variety of obstacles to overcome in order to complete this project. First, students needed to think about and figure out how exactly to implement the necessary functions of a vending machine. While generally simple in concept, implementing a form of memory in the system as well as having everything happen with a clock to synchronize the behavior was more challenging than originally expected. One of the biggest challenges was being able to meet the desired specifications to ensure the control unit produced uniform output pulses. There were plenty of errors and warnings in Tanner Tools, and the project forced us to figure them out on our own and attempt to get the complete circuit to work in the end.

Overall, students were greatly challenged by this project, but the results were extremely fulfilling. Seeing the design and implementation of a common device, a vending machine, come to fruition showed the usefulness of digital electronics and the logic involved in their design.

7. References

[1] GWU SEAS ECE Department, "Vending Machine," The ECE 3130 Course Website, Fall 2012. <www.seas.gwu.edu/~ece122/fall12/projects/ece122_vending_machine.doc>

[2] A.S. Sedra and K.C. Smith, “Microelectronic Circuits, 5th Edition,” Oxford University Press, 2007.