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ECSE 323: Digital System Design

Lab #5: Card Game System Integration

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# Introduction

The purpose of this lab was to complete the design of a Blackjack card game by integrating various components which were designed during the last four labs. This includes the stack, the rules modules, as well as smaller components like the 7-segment decoder. This left two components to design: the controller FSM, and the data path which includes the user interface. Both components were successfully tested directly on the Altera DE1 board.

The design was completed using the FPGA design software Quartus. This design was part of the project file *g21\_lab5.QPF*.

Deal\_FSM

## **Circuit Function**

The Deal\_FSM circuit is a finite state machine with 14 inputs and 12 outputs defined below. The inputs are used to determine the next state, while the outputs are used as control signals for the rest of the circuit.

Table Deal\_FSM inputs and outputs

|  |  |  |  |
| --- | --- | --- | --- |
| **Type** | **Name** | **Length (bit)** | **Purpose** |
| Input | Request\_Deal | 1 | Button press – indicates player wants another card. |
| Input | Stop | 1 | Button press – indicates player has finished playing. |
| Input | INIT | 1 | Button press – indicates start of a new hand. |
| Input | reset | 1 | Button press – indicates player want to reset game. |
| Input | Clock | 1 | Clock signal |
| Input | Dealer\_legal | 1 | True if current dealer total is less than 21. |
| Input | Player\_legal | 1 | True if current player total is less than 21. |
| Input | Dealer\_total | 5 | Current dealer sum. |
| Input | Player\_total | 5 | Current player sum. |
| Input | Dealer\_high | 1 | True when dealer sum is greater than player sum. |
| Input | Player\_high | 1 | True when player sum is greater than dealer sum. |
| Input | Game\_over | 1 | True if game is over (one player has won 3 out of 5 games). |
| Input | score\_dealer | 2 | Number of hands won by dealer in current game. |
| Input | score\_player | 2 | Number of hands won by player in current game. |
| Output | rand\_seed | 1 | Starts the random address generator. |
| Output | Clear\_count | 1 | Clears the counters for the number of hands won. |
| Output | Dealer\_Enable | 1 | Enables card to be dealt to the dealer. |
| Output | Player\_Enable | 1 | Enables card to be dealt to the player. |
| Output | player\_turn | 1 | Lights an LED to indicate player turn. |
| Output | Compare\_enable | 1 | Enables the comparison of the dealer and player sums. |
| Output | Count\_dealer | 1 | Increment the hands won by dealer in current game. |
| Output | Count\_player | 1 | Increment the hands won by player in current game. |
| Output | Count\_gd | 1 | Increment games won by dealer. |
| Output | Count\_gp | 1 | Increment games won by player. |

The circuit has twenty states which enable and disable different output signals that control the data path circuit. Please see the design file *Deal\_FSM.vhd* for the details of the state transitions conditions.

## **Circuit Design**

The circuit is described in VHDL design file *Deal\_FSM.vhd*. Although the instructions [1] recommended the use of a second FSM to control the computer player, a design decision was made to integrate both in one FSM. This had the advantage of simplifying its implementation. This FSM can be broken up into five distinct operations, although each of these is composed of several states: start of hand, initial card deal, player play, dealer play, and winner determination.

### Start

The start operation initializes the circuit and waits for the user to start the game. During this operation, the random address generator is started with a seed, and the deck of cards is initialized. This operation also handles the total game count. Three states make up the start operation.

Table Start operation states and signal assigments

|  |  |  |
| --- | --- | --- |
| State | Function | Signal Assignments |
| rand\_seed | Initialize the random address generator | Rand\_seed <= ‘1’; |
| waiting | Wait for user to press start button. Reset signals to ‘0’. | Dealer\_Enable <= '0';  Player\_Enable <= '0';  count\_dealer <= '0';  count\_player <= '0';  Compare\_enable <= '0'; player\_turn <= '0'; count\_gp <= '0';  count\_gd <= '0';  rand\_seed <= '0'; |
| ready | Check if game is over and increment dealer or player game totals. | if(game\_over = ‘1’ and player\_score = ‘11’) then count\_gp <= ‘1’;  if(game\_over = ‘1’ and dealer\_score = ‘11’) then count\_gd <= ‘1’; |

### Initial Card Deal

This operation consists of dealing out two cards to both the dealer and the player and checking if either has already reached 21. If either player reaches 21, the hand terminates. Note that the dealer’s first comparison occurs before the players, as the dealer wins if there is ever a tie. Six states make up the initial card deal operation.

Table Initial card deal operation states and signal assigments

|  |  |  |
| --- | --- | --- |
| State | Function | Signal Assignments |
| dealer\_card1 | Deal first card to dealer. Clears hand totals if game was over. Disables game count signals. | Dealer\_enable <= ‘1’;  count\_gp <= ‘0’;  count\_gd <= ‘0’;  if(game\_over = ‘1’) then Clear\_count <= ‘1’; |
| player\_card1 | Deal first card to player. Disables clear hand signal. | Player\_enable <= ‘1’;  Dealer\_enable <= ‘0’;  Clear\_count <= ‘0’; |
| dealer\_card2 | Deal second card to dealer. | Dealer\_enable <= ‘1’;  Player\_enable <= ‘0’; |
| player\_card2 | Deal second card to player. | Player\_enable <= ‘1’;  Dealer\_enable <= ‘0’; |
| dealer\_fc | Verify if dealer has reached 21. | Player\_enable <= ‘0’;  Dealer\_enable <= ‘0’; |
| player\_fc | Verify if player has reached 21. | Player\_enable <= ‘0’;  Dealer\_enable <= ‘0’; |

### Player Play

This operation allows the player to request additional cards. If the player reaches 21, he wins. If the player exceeds 21, the dealer wins. Four states make up the player play operation.

Table Player play operation states and signal assigments

|  |  |  |
| --- | --- | --- |
| State | Function | Signal Assignments |
| player\_wait | Wait for player to ask for a card or indicate he is finished. | player\_turn <= ‘1’; |
| player\_play | Enable card deal to the player. | Player\_enable <= ‘1’;  player\_turn <= ‘0’; |
| player\_en | Disable the card deal so only one card is dealt. | Player\_enable <= ‘0’; |
| player\_test | Verify if player has reached or exceeded 21. | Player\_enable <= ‘0’; |

### Dealer Play

The play of the dealer replaces the Computer\_FSM specified by the instructions [1]. The operation requests cards until the dealer total has exceeded 16. Four states make up the dealer play operation.

Table Dealer play operation states and signal assigments

|  |  |  |
| --- | --- | --- |
| State | Function | Signal Assignments |
| dealer\_wait | Check if dealer has exceeded 16 or reached 21. | player\_turn <= ‘0’; |
| dealer\_play | Enable card deal to the dealer. | Dealer\_enable <= ‘1’; |
| dealer\_en | Disable the card deal so only one card is dealt. | Dealer\_enable <= ‘0’; |
| dealer\_test | Verify is dealer has exceeded 21. | Dealer\_enable <= ‘0’; |

### Winner Determination

The winner is determined by comparing the totals of the dealer and player if neither has gone bust or reached 21. Note that the dealer breaks any ties. This operation handles the hands won count. Three states make up the winner determination operation.

Table Winner determination operation states and signal assigments

|  |  |  |
| --- | --- | --- |
| State | Function | Signal Assignments |
| compare | Enable external comparator module. | Compare\_enable <= ‘1’; |
| dealer\_win | Increment dealer hands won count. | count\_dealer <= ‘1’; |
| player\_win | Increment player hands won count. | count\_player <= ‘1’; |

## **Schematic**

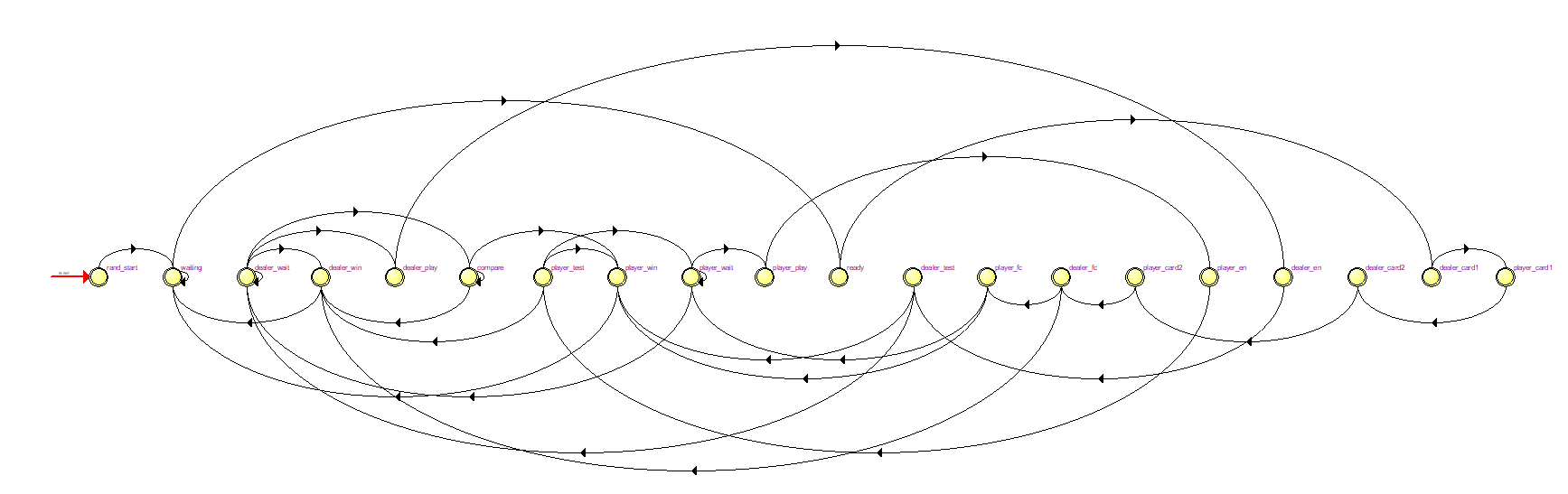


Figure Deal\_FSM generated State Machine diagram

## **Discussion**

No simulations were completed for the FSM because of the sheer quantity of states. It was found to be simpler to integrate the FSM into the datapath and test it directly on the Altera DE1 board.

The most important design decision made here was to integrate the Computer\_FSM as a part of this controller. This had the advantage of simplifying the implementation of FSMs in the overall circuit. With a single controller, the control signals would all come from the same module as opposed to two different ones, as would be the case with a separate FSM for the computer player. The limitation lies in further implementations of the FSM. As the dealer’s play is effectively hard-coded to be controlled by the computer, it would be far more complex to exchange the role of the computer. This would useful if the game were expanded to more players and the computer would play for a different player. However, because this was the final lab of the current project, it was decided that this simplification of the controllers was acceptable.

# Data Path Circuit

## **Circuit Function**

The data path circuit has 5 inputs and 7 outputs. It is the final circuit which incorporates modules created over the course of the semester to play Blackjack on the physical Altera DE1 board.

Table Data path circuit input and outputs

|  |  |  |  |
| --- | --- | --- | --- |
| **Type** | **Name** | **Length (bit)** | **Purpose** |
| Input | CLK | 1 | Clock Signal |
| Input | butt\_INIT | 1 | Input mapped to a button on the board and triggers the start of a hand. |
| Input | butt\_reset | 1 | Input mapped to a button on the board and triggers the reset of the games. |
| Input | butt\_Stop | 1 | Input mapped to a button on the board that indicates player has finished playing. |
| Input | butt\_Play | 1 | Input mapped to a button on the board that indicates player has requested a card. |
| Input | sel\_0 | 1 | Input mapped to 1 switches on the board and designates the display of the 7-segment LEDs. |
| Output | 7\_dealer\_dec | 7 | Output mapped to 7-segment LED and displays the dealer’s total decimal position, or the previous card played. |
| Output | 7\_dealer\_un | 7 | Output mapped to 7-segment LED and displays the dealer’s total unit position. |
| Output | 7\_player\_dec | 7 | Output mapped to 7-segment LED and displays the player’s total decimal position, or the dealer’s games won. |
| Output | 7\_dealer\_un | 7 | Output mapped to 7-segment LED and displays the player’s total unit position, or the players games won. |
| Output | player\_turn\_led | 1 | Output mapped to a green LED on the board and triggers when it is the player’s turn to play. |
| Output | score\_player | 3 | Output mapped to 3 green LEDs on the board which indicate the number of hands won by the player. |
| Output | score\_dealer | 3 | Output mapped to 3 red LEDs on the board which indicate the number of hands won by the dealer. |

The data path circuit incorporates the user interface with the circuit functionality. User inputs are control signals for the rest of the circuit. The outputs of the circuit are in turned translated to the user so that the user can continue to communicate with the board.

## **Circuit Design**

The data path circuit is defined in the block diagram *g21\_lab5\_testbed.bdf*. To facilitate its design, several components were written to interface the output signals of the functional circuitry into LED patterns the user would be able to interpret. Within the functional circuitry, circuits which perform tasks which are related to the function of the circuit, not the UI, additional modules were also created to simplify the assembly of the data path. The following provides descriptions of the design of these components.

### User Interface

The user interface is composed of push buttons, dipswitches, 7-segments LEDs and red/green LEDs. It was decided to use the red/green LEDs to display the hand score of the player and dealer as opposed to displaying them in decimal on the 7-segment LEDs so that a single dipswitch so that there would only be 2 different 7-segment LED displays to toggle between. Although it has the advantage of being simpler visually for the user, it is limiting as if the rules were to change, if a game were to become best out of 7, significant changes would need to be made to the circuit.

#### Single Pulse Generators

There are four single pulse generators present in the data path circuit, one for each of the push buttons which are used as inputs. The circuit was defined in Lab #3 in the design file *g21\_SPG.bdf*. It ensures a single pulse is generated on the signal when the button is pressed by setting a minimum number of clock cycles between when the signal can be high. This can also be called a “debouncer” circuit as it mitigates the effect of the mechanical switch bouncing when it is pressed.

#### Show Totals

The show\_totals circuit is used to translate the two binary values of the player and dealer totals into decimal values that could be displayed on the 7-segment LEDs. This circuit is defined in Lab #5 as *show\_totals.vhd*. It separates the binary value of each total into its decimal and unit position value using the divide and mod functions. It incorporates the *g21\_7\_segment\_decoder* defined in Lab #2 to translate each of the 4 values into the correct segments to be properly displayed to the user.

#### Show score

The show\_scores circuit is used to translate the hand score which is a 2-bit value into a 3-bit vector corresponding to each LED to light up depending on the score. It is defined in Lab #5 as *show\_score.vhd*. Two instances of the circuit are used to display the hand score of the dealer and the player. Its output is wired to the LEDs directly.

#### g21\_7\_segment\_decoder

Defined in the Lab #2 as *g21\_7\_segment\_decoder.vhd*, this circuit is used whenever a value needs to be displayed on the 7-segment LEDs. On top of being used in the show\_totals circuit, it also used on its own to display the game scores of the dealer and player, as well as the previous card played from the stack.

### Functional Circuitry

The functional circuit is composed of modules which complete tasks in conjunction with several registers and counters.

#### Controller

The Deal\_FSM circuit functions as the controller for the data path circuit. By enabling and disabling various control signals, it ensures all the operations are occurring at the right time in the right order.

#### Card Deck

The deck of cards is an instance of the g21\_stack52 circuit which was developed in Lab #3 (*g21\_stack52.bdf*). It is initialized at the start of the of each hand. Cards are popped from random address to simulate shuffling of the deck. The module can be enabled by either the INIT button being pressed or by the FSM when it requests a card.

#### Random Address Generator

The random address generator was developed during Lab #4, but the actual design entity was only created in Lab #5 under *random\_address\_gen.bdf*. It uses the *g21\_RANDU.bdf* circuit from Lab #2 and a mod function to generate random addresses when the module is enabled. It is initialized after a reset by asynchronously setting a seed value.

#### Determine Winner

The g21\_determine\_win circuit was developed in Lab #5 and is described in *g21\_determine\_win.vhd*. It is enabled by the compare signal from the FSM. It compares the totals values of the dealer and player to determine which wins. Note that the dealer breaks any ties.

#### Game Over

The g21\_game\_over circuit determines if a game is over. This occurs when either the dealer or player gets to 3 hands won. It is described in *g21\_game\_over.vhd* as a part of Lab #5.

#### Registers

Three LPM\_FF registers are used in the data path to hold the values of the totals of the dealer and player, as well as the last card taken from the stack. The registers are useful for the totals as the values are used in a feedback loop. For the last card dealt, the registers are necessary to ensure only cards dealt are shown to the user. Since the random number generator is continually outputting random addresses, the stack output value will continually change unless the value is stored in a register at the right moment.

#### Counters

Four lpm\_counters are used in the circuit to keep track of the game and hand scores of the player and the dealer. These components are useful as they are very easy to increment scores, and reset when a game finishes or a reset occurs.

## **Schematic**

The following are some of the more important parts of the datapath schematic. Please refer to the block diagram *g21\_lab5\_testbed.bdf* for the full schematic.

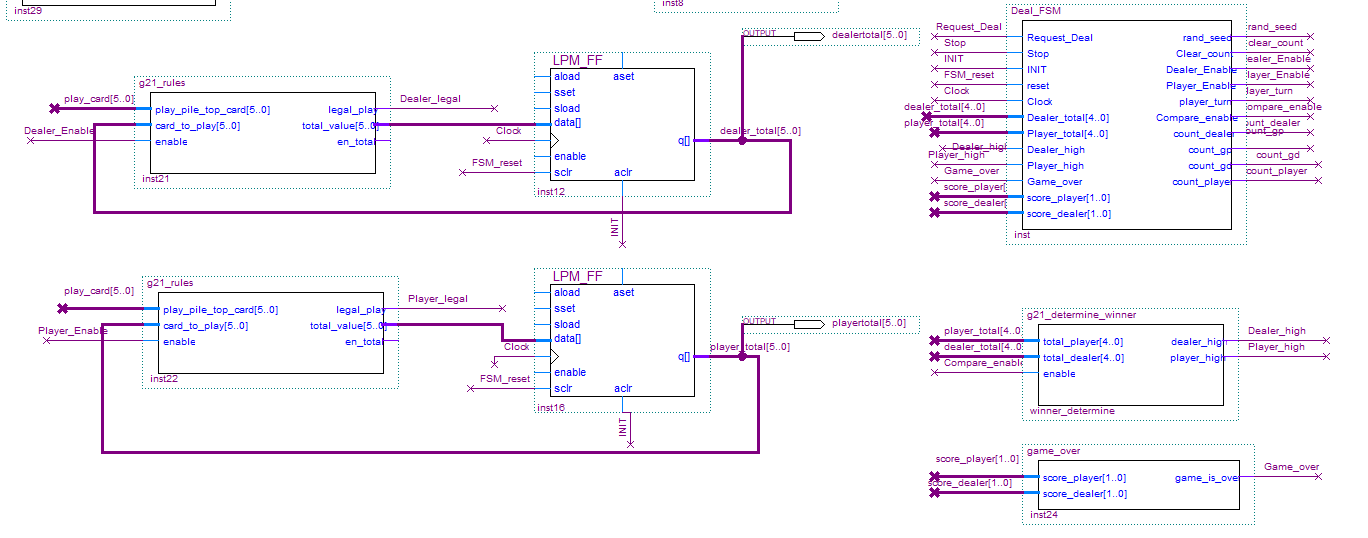


Figure Schematic of Deal\_FSM, rules, determine\_winner and game\_over

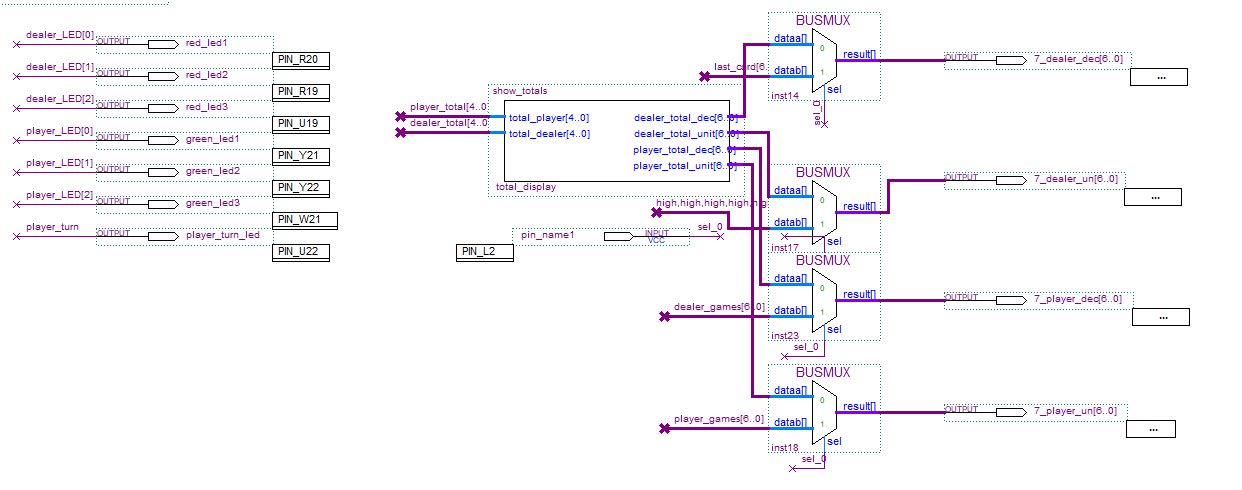


Figure Schematic of LED and 7-segment display output assignments

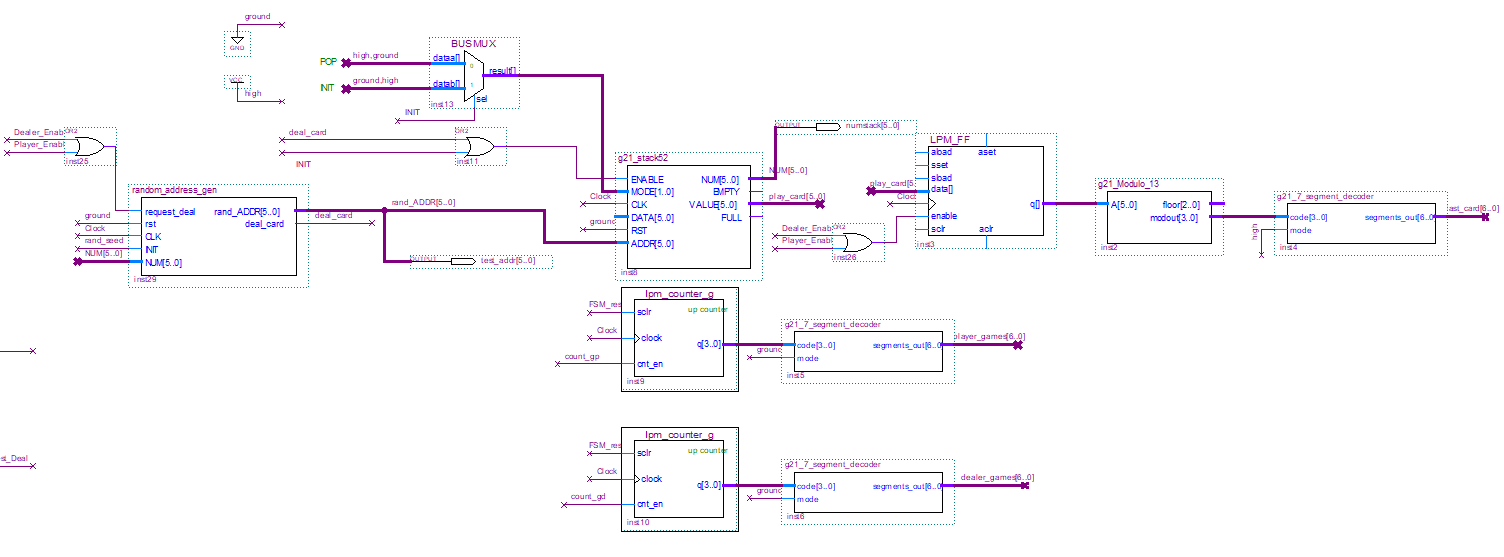


Figure Schematic of random\_address\_gen, stack52, game counters and last card

## **Discussion**

As with the Deal\_FSM circuit, no simulations were conducted on the data path circuit. To be debugged, the circuit was loaded to the Altera DE1 board after every modification was made to the code or design file. The circuit was ultimately successfully functional.

Although the circuit functions for this specific application, several components are “hard coded” and thus to extend the functionality of this circuit, significant modifications would need to be applied. This is a definite limitation of the circuit.

Furthermore, the data path consists of several interconnected modules which increases the possibility of errors. For every extra module, more control signals are needed, but this makes debugging more tedious and challenging. The circuit is highly sensitive to timing issues as several operations need to occur in synchronized fashion.

In such situations, race conditions are likely to develop. It was attempted to limit such conditions by using more control signals and slowing down the operation. For example, the final comparison between the totals of the player and dealer is enabled, even though it is only combination logic. This was put in place to avoid that the comparison between the totals would occur before one of the totals had time to propagate to the comparator circuit. Therefore, upon completion of play, an entire clock cycle is dedicated to enabling this circuit. This ensures the comparison only occurs after both totals have been updated. In this case, efficiency was sacrificed for protection against race conditions.

It should be noted that a small percentage of the board is in use as per the Figure 2 g21\_lab5\_testbed Compilation Flow summary.

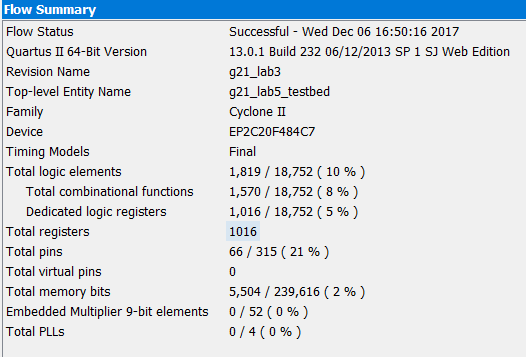


Figure g21\_lab5\_testbed Compilation Flow summary

# Conclusion

The game of Blackjack was successfully implemented on the Altera DE1 Cyclone II boards. The circuit used various components which were developed in the labs which occurred over the course of the semester. Although the final product is functional and meets all requirements, some components were designed with this specific implementation and with the specific instructions and thus are not easily extendable to other applications. This should be considered if the circuit, or its associated modules were to be used in other contexts.

# References

[1] Prof. J. Clark, Lab Instructions, “ECSE-323 Digital Systems Design: Lab #5 – System Integration for the Card Game”, Department of Electrical and Computer Engineering, McGill University, Nov. 2017.